Fundamentals of Electrical & Electronics Engineering

(with Lab Manual)

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Contents

1 Overview of Electronic Components and Signals

UNIT SPECIFICS

This unit discusses the following topics:

- Passive and active components
- Resistors, capacitors and inductors
- Diodes and their applications
- Bipolar Junction Transistors and their applications
- Field Effect Transistors, MOS and CMOS and their applications
- Signals: DC/AC, voltage/current, periodic/non-periodic signals
- Average, rms, peak values of signals
- Different types of signal waveforms
- Voltage and current sources

The practical applications of the topics are discussed for generating further curiosity as well as improving problem solving capacity. Besides giving a number of multiple choice questions as well as questions of short and long answer types belonging to different categories following lower and higher order of Bloom's taxonomy, number of numerical problems are provided for practice.

The related practicals are provided based on the content of Unit 1, followed up by a "Know More" section. This section mainly contains "micro project and activities" that highlights the practical activity, examples of some interesting applications focusing on self-learning, creativity and developing outcomes in all the domains of learning. This has been incorporated so that the supplementary information provided through this part, becomes beneficial for the users of the book. It is important to note that for getting more information on various topics of interest, QR code of videos and websites have been provided that can be scanned and viewed for relevant supportive knowledge in between as well as in the "Know More" section. In the end, list of references and suggested readings are given in the unit so that one can go through them for further reading and practice.

RATIONALE

The wired world and human beings are dependent on electricity to perform many activities. Number of applications are controlled by electrical and electronic circuits, from miniature ones in integrated circuits in mobile phones and music players, to the computers and TV sets, to massive ones that carry power to the homes.

This unit is a basic theme in the study of fundamentals of electrical and electronics engineering. In this unit, working of components like resistors, capacitors, inductors, diodes, BJT, FET that are basic constituents of any circuit are described. Signals that aids in analyzing, processing and validating the circuits and an overview of active sources which can deliver or absorb energy continuously are also explained in this unit.

PRE-REQUISITE

1. Science: Effects of Current , Chemical Substances-Nature and Behaviour (Class X)
2. Applied Chemistry: Atomic Structure, Engineering Materials (Semester I)
3. Applied Physics-I: Physical world, Units and Measurements (Semester I)
4. Mathematics-1: Trigonometry, Algebra (Semester I)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U1-O1: Classify electronic and electrical components.
U1-O2: Suggest suitable discrete components for a given application.
U1-O3: Describe the construction and working principle of a given semiconductor devices.
U1-O4: Interpret parameters of continuous electrical signals.
U1-O5: Compare ideal and practical active sources.

Unit-1 Outcomes	**EXPECTED MAPPING WITH COURSE OUTCOMES** (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**
U1-O1	3	-	-	-	-	-
U1-O2	3	-	-	-	-	-
U1-O3	3	-	-	-	-	-
U1-O4	-	-	-	-	-	-
U1-O5	-	-	-	-	-	-

Georg Simon Ohm (1789-1854) began his research with the electrochemical cell, invented by Italian scientist Alessandro Volta. His practical experiments showed the mathematical links and he found that there is a direct proportionality between the potential differences (voltage) applied across a conductor and the resultant electric current, provided the temperature does not change. This relationship is known as Ohm's law and is now a cornerstone of electrical circuit design.

1.1 PASSIVE COMPONENTS

1.1.1 Introduction

Teenagers as well as children love to play jig saw puzzles. Number of discrete parts have to be properly placed together in the puzzle to develop a complete picture. Each part has a specific role in the developed picture. Similarly, for any electrical or electronics application, circuits or systems are developed in which each component has a specific meaningful role for the application to become operational. In fact, it is possible to assemble a circuit without really understanding the different parts involved. One can just connect components together like jigsaw puzzle to match an electronic schematic. That said, in order to debug an existing circuit or design one, it is important to actually understand how the individual electrical components work and how to use them together. In this topic working of components like resistors, capacitors, and inductors that are basic constituents of any circuit will be described.

1.1.2 Types of Circuit Elements

Electronic elements also known as components that make up a circuit are connected together by conductors to form a complete circuit. They can be classified into two main categories depending on whether they deliver or absorb energy from the circuit:

a. Passive components
b. Active components

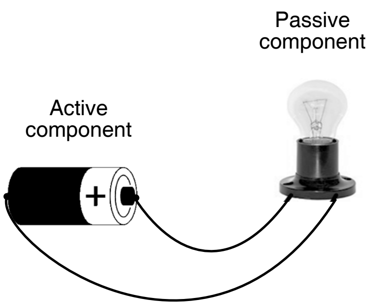


Fig. 1.1: A basic circuit

A passive component can only receive energy, which it can either dissipate or absorb. An active component supplies energy to an electric circuit, and hence has the ability to electrically control the flow of charge. An example of a basic circuit made up of two electronic elements, a cell and a bulb has been illustrated in Fig.1.1.

Discrete components

The components, which are discrete in nature i.e. with just one circuit element, are called discrete components. These components may be active or passive in nature. They are widely used in electrical and electronic circuits. Some of the discrete components are Resistors, Capacitors, Inductors, Semiconductor diodes, Transistors. The term discrete component should be understood as it is used to differentiate discrete components from integrated circuits (ICs) which contain multiple different circuit elements.

Resistor

Definition of a passive component

A passive component is an electronic component when connected in a circuit can only receive energy, which it can either dissipate, absorb or store it in an electric field or a magnetic field. Passive elements do not need any form of electrical power to operate. As the name 'passive' suggests – passive devices do not provide gain or amplification. Common examples of passive components include Resistors, Inductors, Capacitors.

1.1.3 Resistance

Resistance is the opposition to current flow in an electrical circuit. It is described as the property of a substance due to which it opposes the flow of current through it. Resistance is not same for all materials. Conductors like copper, aluminum etc. offer small resistances whereas insulating materials like Bakelite, glass, rubber, mica, dry wood, p.v.c. (polyvinyl chloride), etc. offer high resistance.

The higher the resistance provided by a material, the lower the flow of electrons or current through the material. The property of resistance is used in a wide variety of applications and appliances such as computer mother board, televisions and incandescent lamps. The SI unit for resistance is the ohm, symbolized by the Greek letter Ω (omega) and also represented by letter R. Resistance of a material is one ohm when a current of one ampere passes through a material with a voltage of one volt. The current is proportional to the voltage across the terminal ends. This ratio is represented by Ohms law:

$$R = \frac{V}{I} \qquad \text{...(1.1)}$$

The resistance R offered by a conductor depends on the following four factors:

a. It varies directly as its length, 'l'.

b. It varies inversely as the cross-section area 'A' of the conductor.

c. It is dependent upon the nature of the material.

d. It also depends on the temperature of the conductor.

Neglecting the last factor for the present,

$$R \,\alpha\, \frac{l}{A} \;\; or \;\; R = \frac{\rho\, l}{A} \qquad \text{...(1.2)}$$

Where ρ is a constant depending on the nature of the material and is known as its specific resistance or resistivity. The unit of specific resistance is ohm-meter.

Resistors

The resistor is an electrical component with two terminals. It is one of the most important components in a circuit as it allows the user to precisely control the amount of current and voltage in the circuit.

Resistors can be divided in terms of construction type as well as resistance material. A resistor though very small, is often made up of copper wires coiled around a ceramic rod and an outer coating of insulating paint. This is called a wire-wound resistor, and the number of turns and the size of the wire determine the precise amount of resistance. Smaller resistors, those that are designed and used for low-power circuits, are often made out of carbon film, which replaces the wound of copper wire that can be bulky. Fig. 1.3 shows Colour Coding of carbon film resistors, which is described in

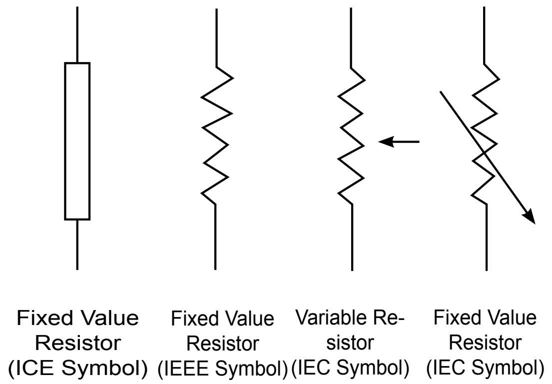


Fig. 1.2: Symbol of Resistors

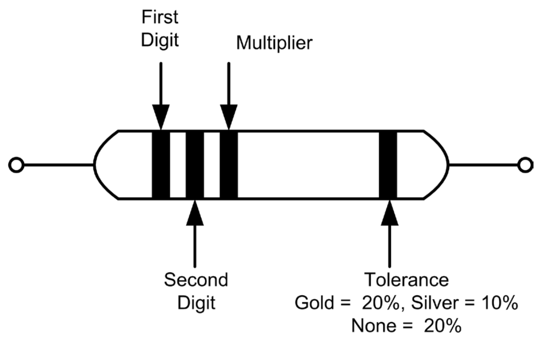


Fig. 1.3: Colour Coding of Resistors

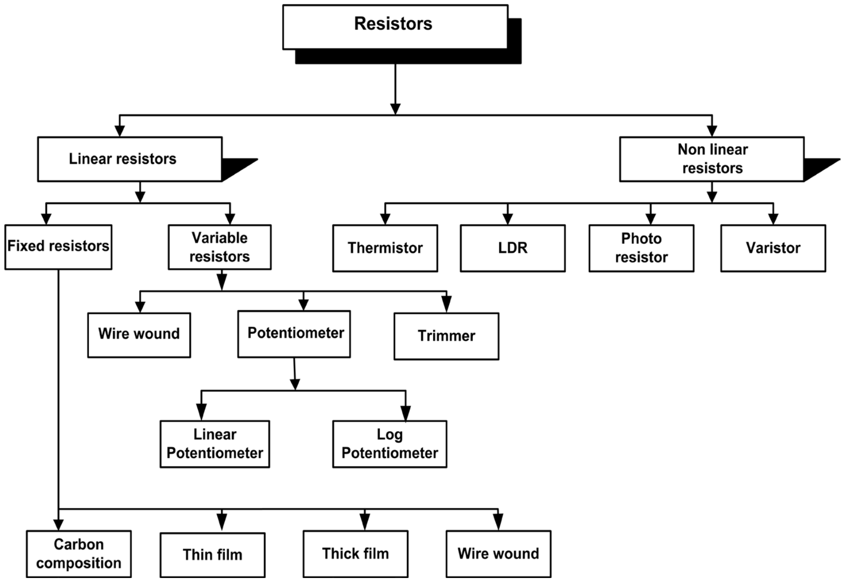


Fig. 1.4: Classification of Resistors

Power rating or wattage

- The maximum amount of heat dissipated by a resistor at maximum specified temperature without damage to resistor is called power rating of a resistor.
- It is expressed in watt (W) at specified temperature.
- When resistor is used at higher temperature, power rating will be decreased.
- The normal available resistors have power ratings of 1/8 W, 1/4 W, 1/2 W, 1 W, 2 W.
- The size of a resistor depends on its power handling capacity. Small resistors are designed to handle low powers,as size of resistor increases power handling capacity also increases.

Conductance and conductivity

The reciprocal of resistance is called as Conductance, represented by letter *'G'*. Whereas resistance of a conductor measures the opposition which it offers to the flow of current, the conductance measures the inducement which it offers to its flow. From Eq. 1.2

$$R = \rho \frac{l}{A} \qquad G = \frac{1}{\rho} \frac{l}{A}$$

$$G = \sigma \frac{A}{l} \qquad \text{...(1.3)}$$

where σ is called the conductivity or specific conductance of a conductor. The unit of conductance is Siemens (S). The unit of conductivity is Siemens/metre (S/m).

Effect of temperature on resistance

One of the factors that effects resistance of any material is temperature.The effect of rise in temperature is:

a. to increase the resistance of pure metals.

b. to decrease the resistance of carbon, electrolytes, and insulators.

c. to increase the resistance of alloys, though in their case, the increase is relatively small.

Temperature coefficient of resistance

Let a metallic conductor having a resistance of R_0 at 0°C be heated of t°C and let its resistance at this temperature be R_t. Then, considering normal ranges of temperature, it is found that the increase in resistance, $R_t - R_0$ depends

a. directly on its initial resistance

b. directly on the rise in temperature

c. on the nature of the material of the conductor.

$$\text{or } R_t - R_0 \propto R_0 \times t \text{ or}$$

$$R_t - R_0 = \alpha R_0 t \qquad ...(1.4)$$

where α (alpha) is a constant and is known as the temperature coefficient of resistance of the conductor. Rearranging Eq. (1.4) results in

$$R_t = R_0 + \alpha R_0 t = R_0 (1 + \alpha t) \qquad ...(1.5)$$

1.1.4 Inductors

Inductor is a two-terminal component that temporarily stores energy in the form of a magnetic field. It is usually called as a coil. The main property of an inductor is that it opposes any change in current. An inductor is also considered as passive element of circuit, because it can store energy in it as a magnetic field, and can deliver that energy to the circuit, but not in continuous basis. The energy absorbing and delivering capacity of an inductor is limited..

According to the Faraday's law of Electromagnetic induction, when the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor. According to Len's law, the direction of induced EMF opposes the change in current that created it. Hence, induced EMF is opposite to the voltage applied across the coil. This is the property of an inductor.

An inductor blocks any AC component present in a DC signal. The inductor is sometimes wrapped upon a core, for example a ferrite core. Fig.1.5 shows an inductor with various parts labelled.

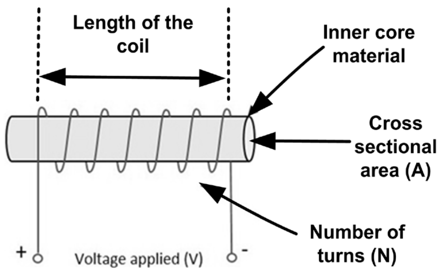


Fig.1.5: Parts of an inductor

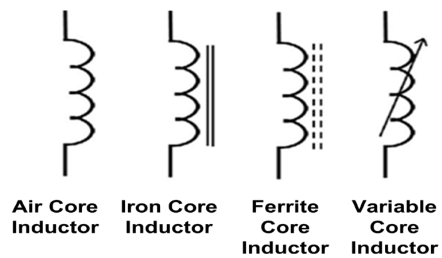


Fig.1.6: Symbol of inductors

Symbol and units

The symbols of various types of inductors are as given in Fig.1.6. The unit of inductance is Henry i.e. H. In actual practice, Henry is an extremely large unit. Therefore, much smaller units are used like millihenry (mH) or microhenry (μH). 1 mH = 1×10^{-3} H and 1μH = 1×10^{-6} H.

Factors affecting inductance

The inductance of a coil depends upon the following parameters:

1. Number of turns, N   2. Core material

3. Length of winding   4. Dimension of coil former

Storage of energy in inductor

One of the basic properties of electromagnetism is that the current when flows through an inductor, a magnetic field gets created perpendicular to the current flow. This keeps on building up. It gets stabilized at some point, which means that the inductance won't build up after that. When the current stops flowing, the magnetic field gets decreased. This magnetic energy gets turned into electrical energy. Hence energy gets stored in this temporarily in the form of magnetic field.

Coil Tutorial

Q Factor of an inductor

- The ability of an inductor to store energy as compared to the dissipation of energy within the inductor is called Quality (or Q) factor. It is also known as figure of merit.
  The Q factor is given by,

$$Q = \frac{Energy\ Stored}{Energy\ Dissipated} \qquad ...(1.6)$$

- A high Q factor means little energy dissipation with respect to energy storage, while a low Q factor means energy dissipation as large as energy storage.
- The value of Q factor for coils may range between 5 to 100.
- It may be noted that smaller the value of DC resistance of a coil, higher is the value of Q factor. The high Q coils are preferred in tuning circuits, because it makes the circuit more selective and sensitive

1.1.5 Capacitors

A capacitor is a passive component that has the ability to store the energy in the form of potential difference between its plates. It resists a sudden change in voltage. The charge is stored in the form of potential difference between two plates, which form to be positive and negative depending upon the direction of charge storage.

A non-conducting region is present between these two plates which is called as dielectric. This dielectric can be vacuum, air, mica, paper, ceramic, aluminium etc. The name of the capacitor is given as per the dielectric used.

Symbol and units

The standard units for capacitance is Farads. Generally, the values of capacitors available will be in the order of micro-farads, pico-farads and nano-farads.

The symbol of a capacitor is as shown in Fig.1.7.

The capacitance of a capacitor is proportional to the distance between the plates and is inversely proportional to the area of the plates. Also, the higher the permittivity of a material, the higher will be the capacitance. The permittivity of a medium describes how much electric flux is being generated per unit charge in that medium.

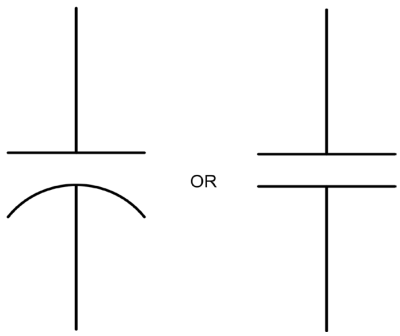


Fig.1.7: Symbol of a Capacitor

Dielectric materials used in a capacitor

The dielectric materials used in manufacturing of capacitor are as under:

1. Air	2. Mica
3. Glass	4. Ceramic
5. Porcelain	6. Polystyrene
7. Fibre	8. Bakelite
9. Waxed paper	10. Electrolyte

Functions of a capacitor

The important functions of a capacitor in the electric circuit are as given below :

1. It opposes the flow of direct current (D.C.) through it.
2. It bypasses the alternating current (A.C.) through it very easily.
3. It stores the electric energy in it.
4. It removes the ripple from D.C. power supply.
5. It opposes any change of voltage in the circuit.

Capacitor Types

1.1.6 Series and Parallel Circuits

Resistors connected in such a way that current from one flow only into another are said to be connected in series. The series combination of two resistors as shown in Fig.1.1.8 acts, as far as the voltage source is concerned, as a single resistor having a value equal to the sum of the two resistances.

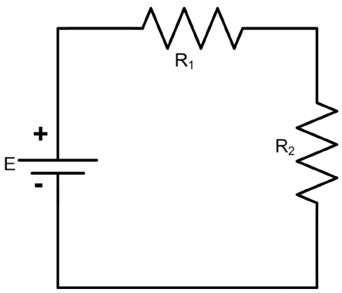


Fig. 1.8: Series circuit

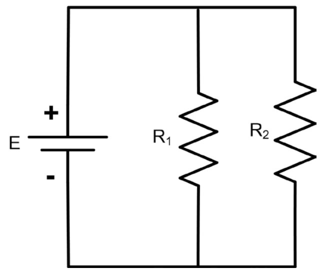


Fig. 1.9: Parallel circuit

For circuits having resistances connected in parallel as shown in Fig. 1.9 Similar to resistance, when capacitance and inductances are connected in series and parallel in circuits, Table 1.1 shows the formula for equivalent value.

Table 1.1: Formulas for Parallel and Series connection of elements

Type of Connection	Resistor	Inductor	Capacitor
Series	$R = R_1 + R_2$	$L = L_1 + L_2$	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$
Parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$	$C = C_1 + C_2$

Applications of passive components in Real life

Passive components are used in number of devices. Some of the uses will be explained in later units.

Resistors

Following are the applications of resistors:

1. Potential dividers
2. Current control
3. D.C. power supplies
4. Filter circuit networks
5. Amplifier circuits
6. Heating element

Some other applications include

- For protection purposes, e.g. fusible resistors.
- Wire wound resistors find application where balanced current control, high sensitivity, and accurate measurement are required like in shunt with ampere meter.
- Photo resistors find application in flame detectors, burglar alarm, in photographic devices, etc.

Capacitors

The important applications of capacitor in electronic circuits are as given below :

1. It is used for the storage of energy.
2. It is used in the filter circuits to minimize the ripple voltage.
3. It is used in the tuning circuits for selection of frequency.
5. It is used for starting the motor, for running the motor
6. It is used for equipment like SMPS, Modem.

Inductors

The important applications of inductors are as given below:

1. It is used to minimize the ripples alternating current in a circuit.
2. It is used for allowing the flow of direct current.
3. It is used in filter circuits to minimize the ripple voltage or ripple factor.
4. It is used in tuning circuits of radio transmitters and receivers to select the frequency.
5. It is used in devices like Relays, Electric Motors, Transformers, Sensors

Solved Problems

Example 1.1.1: Five resistors with resistances of 2.2 Meg ohms, 470 KΩ, 220 KΩ, 55 KΩ, and 1.6 Mega ohms are connected in series. Calculate the total or equivalent resistance of this series combination?

Solution: For series combination of resistances, the equation is

$$Req = R_1 + R_2 + R_3 + R_4 + R_5$$

However, there is a note of caution that all the resistances must be expressed in terms of the same unit. In terms of kilo ohms we have

Req = 2200 + 470 + 220 + 55 + 1600

Req = 4545 kΩ

Req = 4.545 Mega ohms

Example 1.1.2: Four resistors with resistances of 1 kΩ, 2 kΩ, 4 kΩ, and 8 kΩ are connected in parallel. Calculate the equivalent resistance of this combination?

Solution: For parallel combination of resistances, the equation is

$$\frac{1}{\text{Req}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\frac{1}{\text{Req}} = \frac{1}{1} + \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

$$= 0.125 + 0.250 + 0.500 + 1.000$$

$$= 1.875$$

Then

$$\text{Req} = \frac{1}{1.875} = 0.53\text{k}\Omega$$

1.2 ACTIVE COMPONENTS

1.2.1 Introduction

Automation, Digitization and Smart system requires use of active components. Active components play a vital role in all engineering disciplines and engineering application ranging from domestic to industrial, space, defense, agriculture, medical, transportation, education and entertainment. All electronic products are based on functioning of active components.

The components which operation changes as per external energy are termed as active components. Active components performance relies on external energy. Active components are suitable for rectifying, amplifying and switching applications. Two main types of active components are: 1) Tube devices 2) Semiconductor devices.

Now a days tube devices are not commonly used as they exhibits many drawbacks such as low speed of operation, larger size, difficult for mounting and expensive than semiconductor components. Semiconductor active components are also called as solid state components. These are made up of semiconductor materials. Active semiconductor components have many advantages such as: high speed of operation ,compactness, easy for mounting and cheaper than tube devices. Commonly used active components are diode, BJTs (Bipolar Junction Transistors) , FET (Field Effect Transistor), MOSFET (Metal Oxide Semiconductor FET), SCR (Silicon controlled Rectifier), DIAC, UJT (Uni Junction Transistor), TRIAC , IGBT, PUT and Integrated circuits.

Semiconductor material has electrical conductivity less than conductor and more than insulator. Its conductivity changes as per application of external energy. Pure semiconductor materials are called as intrinsic semiconductor. Commonly used pure semiconductor materials are Silicon (Si) and Germanium (Ge). To improve conductivity i.e. free charge carriers, impurity is added to intrinsic semiconductor. The process of addition of impurity to intrinsic semiconductor is called as doping. Due to doping process intrinsic semiconductor is converted into impure semiconductor. This impure semiconductor material is called as extrinsic semiconductor. Depend on type of impurity material added to intrinsic semiconductor, two types of extrinsic semiconductor are obtained such as P type and N type material. By using these two extrinsic semiconductor active components are constructed. To obtain P type extrinsic semiconductor trivalent material and to obtain N type extrinsic semiconductor pentavalent impurity material is added. In P type material positive charge carrier Holes are majority charge carrier while in N type.

1.2.2 P N Junction Diode

A P-N junction diode is formed by connecting P and N type semiconductors. As soon as the P-N junction is formed, it results in the following processes:

1. Holes from P region near the junction diffuse into N region and combine with free electrons. Similarly, free electrons from N region and near the junction enter P region to recombine with holes.
2. These re-combinations near the junction do not continue for a long because electrons trying to diffuse into P region are now repelled by the negative immobile ions and the holes from P region are repelled by positive immobile ions in the N region. So total recombination of holes and electrons cannot occur.
3. Due to few re-combinations near the junction, a region is formed on both sides with no charge carriers. It contains only negative and positive immobile ions. This region is called depletion region or space-charge region Fig.1.10 shows P N junction with depletion region.

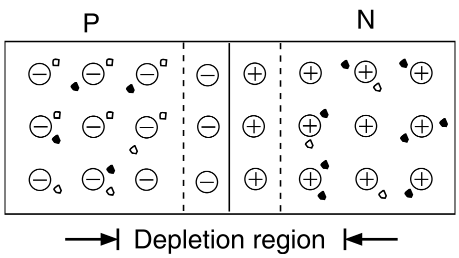


Fig. 1.10: P N Junction

The electric field between the acceptor and donor ions is called barrier. The potential difference between the two sides of barrier, i.e., barrier potential is about 0.7 V for Si and 0.3 V for Ge P-N junction. P-N junction diode is a two terminal device. The terminal connected to the P region is called anode. The terminal connected to N region is called cathode. There are two electrodes, hence the name diode (DI + electrode).The symbol of a P-N junction diode is as shown in Fig. 1.11.

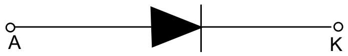


Fig. 1.11: P N junction Diode symbol

1.2.2.1 Operation of P-N junction diode

The P N junction diode can be operated in two states or conditions namely forward bias state and reverse bias state. When anode is at higher potential with respect to cathode, the diode is said to be in forward bias, i.e., connecting positive terminal of the external battery to anode and negative terminal to the cathode. Fig. 1.12 shows diode forward bias connection. Holes from the P region are repelled by the positive terminal of the battery and move towards the junction. Similarly electrons from N region move towards the junction. So the width of depletion region decreases.

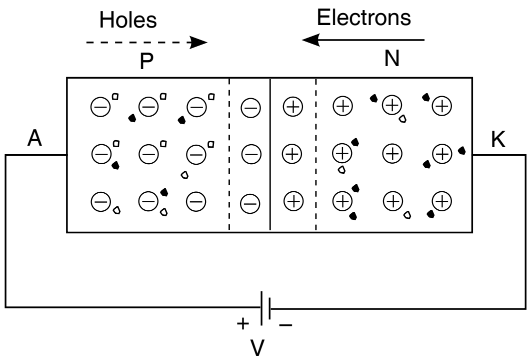


Fig. 1.12: Diode-Forward bias

The direction of conventional current is the direction of movement of holes, i.e., from anode to cathode. If the battery voltage is increased, the current also increases. Very little current flows due to minority carriers in opposite direction.

When the anode is at lower potential with respect to cathode (negative w.r.t. cathode), the P-N junction is said to be reverse biased, i.e. negative terminal of the external battery is connected to the anode and positive terminal to the cathode. Holes from P region are attracted towards the negative terminal of the battery and the electrons from N region move towards the positive terminal of the battery. Since the carriers move away from the junction, the width of depletion region increases. Thus there is no current due to majority carriers. But there is very small current from cathode to anode due to minority carriers. These are very less in number so the current is also very small.

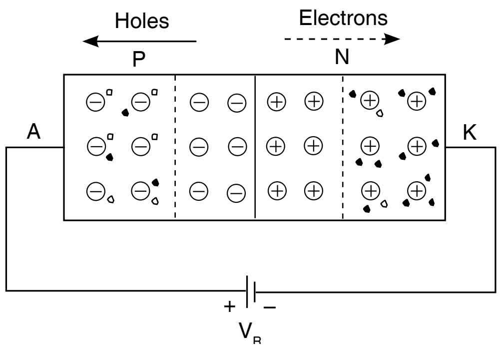


Fig. 1.13: Diode-Reverse bias

1.2.2.2 Characteristics of a diode

V I Characteristics of a device shows device operation for various applied input voltages. The forward and reverse characteristics of diode is as shown in Fig. 1.14.

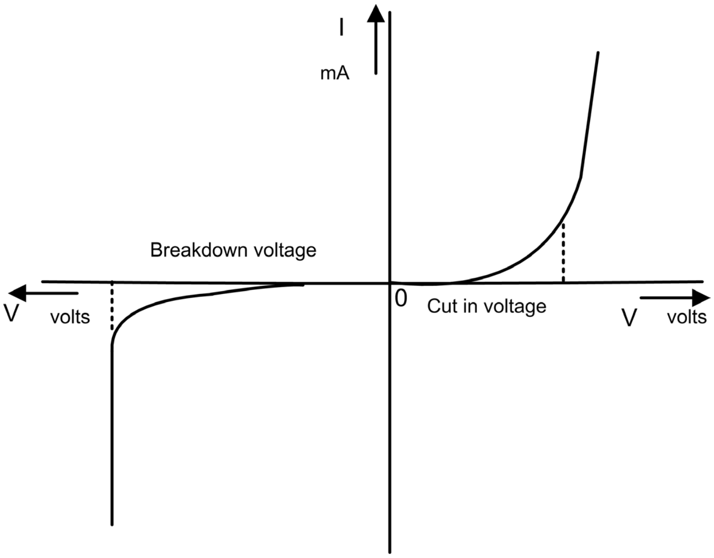


Fig. 1.14: Diode V–I characteristics

The diode connected in a DC circuit offers a definite resistance which is called DC resistance or static resistance. It is the ratio of DC voltage across the diode to the DC current through the diode (Eq. 1.10).

$$R_F = \frac{V}{I} \qquad ...(1.7)$$

As seen from the forward characteristics nature, the static resistance is small in few ohms in forward bias condition. Also it is clearly seen from the reverse characteristics that the current is very small so the static resistance is high in mega ohms.

1.2.2.3 Diode parameters

Following parameters are specified by the manufacturers:

a. The Maximum Forward Current (I_{Fmax}): The maximum current in the forward bias which the diode can withstand safely. Beyond this, the diode will be damaged.
b. Inverse Voltage (PIV): The maximum reverse voltage that can be applied safely to a diode.
c. Forward and reverse static and dynamic resistance
d. Junction capacitance

V-I Characteristics of Junction Diode

1.2.2.4 Diode applications

PN junction diode is a basic semiconductor component used in variety of electronic circuits. These electronics circuits are used in various engineering applications. Major applications of PN junction diode are

1 Diodes are used to construct rectifier circuits to convert A signals to DC signals.
2 In wave shaping circuit diode is used to clip or clamp input signal.
3 Diodes are used in digital circuits as a switching element.
4 To construct all types of DC power supply, battery charger, voltage multiplier and eliminator diode plays important role.

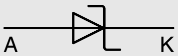
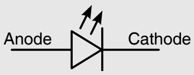
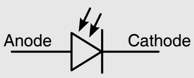
5 In communication systems, for signal demodulation i.e. detection of information signal and in computers for reset circuits diodes are used.

6 To avoid D.C. saturation of inductive relay or motor, diode is connected across it.

1.2.2.5 Types of diodes

PN junction diode operation, VI characteristics and applications are depends on material used doping construction and physical dimensions. Table 1.2 shows basic three types of diodes their features and applications.

Table 1.2: Types of Diodes

Sr. No	Diode with symbol	Features	Applications
1	Zener Diode 	1 Doping concentration is very high than normal P N junction diode. 2 Normally operated in reverse biased. 3 It exhibits zener breakdown in reversed biased condition. 4 It is made up of silicon.	Zener diode is used for 1 Voltage regulation in regulated D C power supply. 2 Meter protection circuits 3 Spike guard circuits.
2	Light Emitted Diode (LED) 	1 Special semiconductor materials are used such as GaAs, GaAsP, GaP, SiC. 2 When this diode is forward biased then it emits light. Wavelength i.e. color of emitted light depends on doping material. 3 Emission of light energy due to injection of charge carrier is a basic working principle of LED 4 It is available in various sizes. 5 Emitted light intensity is proportional to current flowing through it.	LED is used for 1 Power indicator for various electrical and electronics appliances. 2 In electronic appliances as a display device. 3 Constructing seven segment and matrix display. 4 Opto coupler, remote control 5 Light sources for distance measurement and other similar instruments. 6 Optical switching and communication systems.
3	Photo Diode 	1 Special semiconductor material is used. 2 It covert light intensity into current. 3 It is normally operated in reverse biased.	Photo diode is used for 1 Light sensing. 2 Burglar alarm. 3 Opto coupler. 4 Auto flash camera.

1.2.3 Transistors

A bipolar junction transistor (BJT) is basically a silicon or germanium crystal having two P-N junctions formed by sandwiching either P-type or N-type semiconductor between a pair of opposite types. BJT is normally called a transistor. It is capable of amplifying weak signals. Thus the current in transistor (or BJT) flows due to positive as well as negative polarity charge carriers. Therefore, a transistor (BJT) is called a bipolar device.

1.2.3.1 Construction of Transistor

Transistor is a solid state semiconductor two junction, three region and three terminal device. Three terminals are emitter, base and collector. From constructional details, two types of transistors are PNP transistor and NPN transistor. When a thin layer of a P-type semiconductor is sandwiched between two layers of an N-type semiconductor, it is known as an NPN transistor. Fig.1.15 shows constructional details of NPN transistor. In BJT emitter region is heavily doped as compare to collector region. Collector region has large physical area where as base region is having lower doping concentration as compare to collector region. So always emitter current is largest in BJT. In NPN BJT emitter current is base to emitter (outward direction) the emitter current is the sum total of the collector and base currents.

i.e. $I_E = I_B + I_C$ ...(1.8)

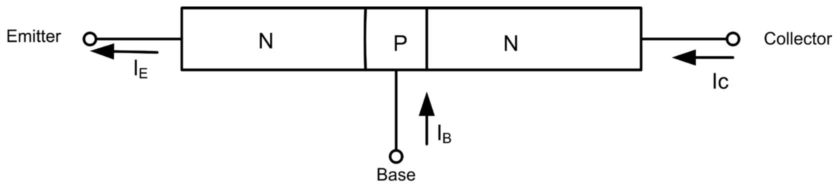


Fig. 1.15: Structural diagram of NPN BJT

Fig. 1.16 shows schematic symbol of NPN and PNP BJT.

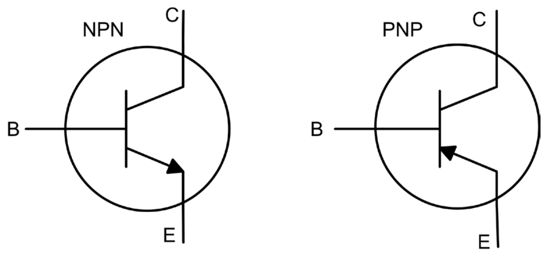


Fig. 1.16: Schematic symbol of NPN and PNP BJT

1.2.3.2 Configuration of transistor

BJT can be operated in any one of three configurations. Three configurations for BJT are 1) Common Base (CB) configuration 2) Common Emitter (CE) configuration 3) Common Collector (CC) configuration. Table 1.2. shows comparison of three configurations. For any configuration, the input is not applied to collector terminal and in any configuration, output is taken from base terminal.

Table 1.3: Comparision of Transistor Configuration

Sr. No.	Parameters	Common Base	Common Emitter	Common Collector
1	Input terminal	Emitter	Base	Base
2	Output terminal	Collector	Collector	Emitter
3	Input impedance	Low	Medium	High
4	Output impedance	Very high	Medium	Low
5	Current gain	Nearly one	High	Very high
6	Voltage gain	High	Higher than CB	Nearly one

7	Power gain	Medium	High	Low
8	Thermal stability	High	Low	High
9	Applications	Low noise preamplifier (wide band)	AF voltage amplifier	Impedance matching, buffer

$$\alpha_{dc} = I_c / I_E \qquad ...(1.9)$$

Current gain beta (β):The ratio of collector current I_C to base current IB for a constant collector to emitter voltage V_{CE} in the CE configuration is called current gain beta(β).It is given by a relation as shown in eq.1.2.4 The value of beta (β) ranges from 20 to 250.

$$\beta_{dc} = I_C / I_B \qquad ...(1.10)$$

From eq. 1.11, 1.12 and 1.13 relation between α and β can be obtained as

$$\alpha = \beta /(1+\beta) \qquad ...(1.11)$$

$$\beta = \alpha / (1- \alpha) \qquad ...(1.12)$$

Specifications for transistor:

1. Maximum collector-to-emitter voltage, $V_{CE(max).}$
2. Maximum collector current, $I_{C(max).}$
3. Collector-to-emitter cut-off voltage, $V_{CEO.}$
4. Collector cut-off current, $I_{CEO.}$
5. Collector-to-emitter break down voltage, $BV_{CBO.}$
6. Maximum collector dissipation, $P_{D.}$
7. Collector saturation voltage, $V_{CE(sat).}$
8. DC current gain (h_{FE})

1.2.3.3 Applications of transistors

Transistor can be operated in any one of the three operating mode. Three operating modes for BJT are 1) Cutoff state 2) Active state 3) Saturation state. Table 1.4 summarizes the junction biasing required to operate transistor in one of three operating states.

Table 1.4: Operating State and Junction Biasing

Sr. No.	Operating State	Base Emitter Junction	Base Collector Junction	Application
1.	Cut off state	Reverse Biased	Reversed Biased	--
2.	Active State	Forward Bias	Reverse Bias	Amplifier
3.	Saturation State	Forward Bias	Forward Bias	Switching

Transistor are having wide applications in all fields of electronics. It is most commonly used for amplifier circuit. Amplifier increases amplitude of input signal.

1. Amplifier
2. Timers and time delay circuits
3. Switching circuits
4. Oscillator
5. Multivibrator
6 Electronic switch
7. Wave shaping in clipping circuits
8. Modulator
9. Detector (or demodulator)
10. Logic circuits

1.2.4 FET

The FIELD EFFECT TRANSISTOR (FET) is a semiconductor solid state active device. Field effect transistor is an example of a uni-polar transistor. In FET output current is either due to electrons or due to holes. As the input applied electrical field i.e. voltage controls the output current so it is called as field effect transistor.

1.2.4.1 FET construction

There are mainly two types of field effect transistors, the Junction Field Effect Transistor (JFET) and the Metal Oxide Semiconductor Field Effect Transistor (MOSFET). JFET's may be made with either an N channel or P channel. In the construction of the N-channel FET, gate is made up of P type semiconductor and for P Channel FET, N type semiconductor material is used. Fig.1.17 shows schematic symbols for FETs. FET has three terminals: 1) Source 2) Drain 3) Gate. Source and drain terminals are connected to channel. Channel is unevenly doped. In a channel source area is having higher doping as compare to drain area.

(a) N-channel JFET (b) P-channel JFET

Fig. 1.17: FET Symbols

The important feature of the FET is that it is often simpler to fabricate and occupies less space on a chip than BJT. Voltage applied on gate V_{GS} control channel current. For this purpose gate source is reversed bias. So depletion layer width extends in channel area. Drain is also reversed bias with respect to source. Charge carriers pushed from source area and move towards drain. This forms the channel current. The V_{GS} at which channel current becomes zero is called as pinch off voltage. When V_{GS} is zero the current flowing through the channel is maximum. It is called as saturation state drain current I_{DSS}.

1.2.4.2 Comparison between BJT and FET

Transistor and uni-polar transistor(FET) can be compared as given in Table 1.5, on the basis of operation, construction, characteristics and their advantages.

Table 1.5: Comparison between BJT and FET

Sr. No.	Bi-polar Junction Transistor	Field Effect Transistor
1.	It is a semiconductor device consisting of three terminals known as Base, Emitter and Collector.	FET is a semiconductor device having three terminals as Gate, Source and Drain.
2.	Conduction is due to holes and electrons. Hence, it is a bipolar device.	Conduction is due to either holes or electrons. Hence, FET is a unipolar transistor.

3.	BJT is a current controlled device.	FET is a voltage controlled device.
4.	Its operation depends upon the flow of majority as well as minority carriers.	Its operation depends upon the flow of majority carriers only.
5.	The input impedance of BJT is low.	The input impedance of FET is high.
6.	The device is noisy.	It is less noisy than bipolar transistor.
7.	There are two types of BJT's N-P-N and P-N-P.	There are two types of FETs N-channel and P-channel.
8.	BJT is difficult to construct and occupies more space.	FET is simpler to fabricate and occupies less space.
9.	BJT circuits give high gain band width product.	Relatively gives low gain band width product.
10.	Emitter-base junction is forward biased and collector-base is reverse biased.	Gate to source as well as drain to source are both reverse biased. Effectively source area is forward biased
11.	It has poor thermal stability.	It has thermal stability.
12.	BJT cannot be used as a voltage variable resistor.	FET can be easily used as voltage variable resistor.

1.2.4.3 Applications of FET

FET is operated in the constant current region of its output characteristics for the linear applications. The FET is useful as a voltage variable resistor (VVR) or Voltage Dependent resistor. It is called as active load. FET is used in many electronic circuits application such as:

1. RF and AF Amplifier
2. Oscillator
3. Switching circuits
4. Buffer in measuring instruments
5. Communication receivers
6. Signal mixer circuits of TV
7. Memory devices
8. Digital circuits

1.2.5 MOS devices

Insulated gate field effect transistor is called as metal oxide semiconductor field effect transistor. MOSFET. It has insulation layer of SiO_2 between gate and channel. So it offers very high input impedance than FET.

1.2.5.1 Types of MOSFET

From constructional details two types of MOSFETs are 1) Depletion type MOSFET 2) Enhancement type MOSFET. Depletion type MOSFET has a physical channel , insulated gate and substrate. It has four terminals Source , Drain, Gate and substrate. Substrate is connected to device body. According to channel type two type of depletion MOSFETs are 1) N channel Depletion MOSFET 2) P channel Depletion MOSFET. Depletion type MOSFET are also called as Normally ON MOSFET. Two operating modes of depletion type MOSFETs are 1) Depletion Mode 2) Enhancement mode. In depletion mode gate is maintained at negative potential. To operate Depletion type MOSFET in enhancement mode, gate is maintained at positive potential. Fig. 1.18 shows circuit symbols of depletion type MOSFETs.

Fig. 1.18: Depletion type MOSFET

Enhancement type MOSFET has no depletion mode of operation and it operate only in enhancement mode. N channel MOSFET and P channel MOSFETs are also known as NMOS and PMOS devices. Fig. 1.19 shows circuit symbols of enhancement type MOSFETs.

Fig. 1.19: Enhancement type MOSFETs

1.2.5.2 MOSFET applications

Some of the applications of MOSFET are as follows:

1. Suitable for high current and voltage switching applications
2. Traction system
3. AC drives
4. Multiphase inverters

1.2.6 CMOS

P Channel MOSFET and N Channel MOSFETs are used together to form Complementary Metal Oxide Semiconductor device (CMOS). These devices are commonly used for digital circuits fabrications. Logic gates, counters, microcontroller and memories are constructed using CMOS devices. CMOS devices offers features such as low power consumption and compact. Integrated circuits are constructed using these devices. Fig. 1.20 shows construction of CMOS device.

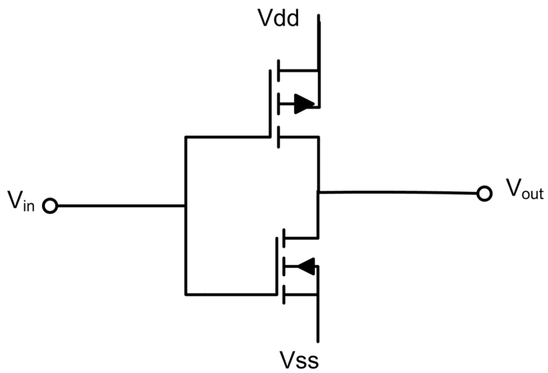


Fig. 1.20: CMOS device

1.2.7 Comparison between Passive and Active Components

Table 1.6 Represents the comparison in brief between passive and active components on major aspects.

Table 1.6: Comparison between passive and active components

Sr. No.	Criteria	Passive Components	Active Components
1.	Nature of source	Passive components utilize power or energy from the circuit.	Active components deliver or control power or energy to the circuit.
2.	Examples	Resistor, Capacitor, Inductor etc.	Diodes, BJT, FET, Integrated circuits etc.
3.	Power Gain	They are incapable of providing power gain.	They are capable of providing power gain.
4.	Flow of current	Passive components cannot control the flow of the current.	Active components can control the flow of current.
5.	Requirement of external source	They do not require any external source for the operations.	They require an external source for the operations.
6.	Nature of energy	Passive components are energy acceptor.	Active components are energy donor.

Activities

1. After learning Topic No. 1.1 and 1.2 of this unit, student should try to identify and prepare list on various gadgets available at home using active and passive components.
2. Student shall refer data book to know about active and passive components with their major specifications and prepare a presentation with two components each of different varieties.

Classifications of Electronic Components

Solved Problems

Example 1.2.1: In BJT three terminals currents are I_1 = 100 mA. I_2 = 93 mA and I_3 = 7 mA. Identify terminal names.

Solution: BJT has three terminals: 1) Emitter 2) Base 3) Collector. Out of the three terminal currents, emitter current is always largest.

As in given data, I_1 is largest so it current flowing through Emitter terminal.

$$I_E = I_C + I_B$$
$$100 \text{ mA} = 93 \text{ mA} + 7 \text{ mA}$$

In BJT, base current is smallest. So I_3 current is flowing through Base terminal.

Therefore I_2 current is flowing through Collector.

Example 1.2.2: Justify that current gain α in CB transistor configuration is less than and nearly equal to 1.
Solution: The current gain of a BJT in CB configuration is given by, Current gain.

$$\alpha = I_C/I_E$$
$$I_E = I_C + I_B$$

Since I_B is very small as compared to I_E, the term I_B/I_E will be very small as compared to 1.
So ,the value of current gain α will be less than 1.

Example 1.2.3: If α of a transistor is 0.9, calculate β.
Solution: Given: $\alpha = 0.9$

$$\beta = \alpha /(1-\alpha)$$
$$= (0.9) /(1-0.9) = 9$$

Example 1.2.4: If β is 100, calculate alpha.
Solution: Given : $\beta = 100$
Current gain $\alpha = \beta / (1+ \beta)$

$$= 100 /101 = 0.99$$

1.3 SIGNALS AND ACTIVE SOURCES

1.3.1 Introduction

The signals can be in different forms like audio, visual which convey information, mechanical signals for physical activities and electrical signals for power delivery. The classification of signals helps in analyzing, processing and validating the circuits. Signals can be classified by any of their physical characteristics, their mathematical representation or on their use. The underlying topic gives a brief overview on the type of signals with special focus on understanding the basic concepts of alternating current and direct current signals.

1.3.2 Classification of Signals

Signals are broadly classified as continuous time signals and discrete time signals. A continuous time signal is one whose mathematical function is defined continuously in the time domain, where as a discrete time signal is defined at specific time instants. Fig. 1.21 and 1.22 shows typical continuous and discrete time signals.

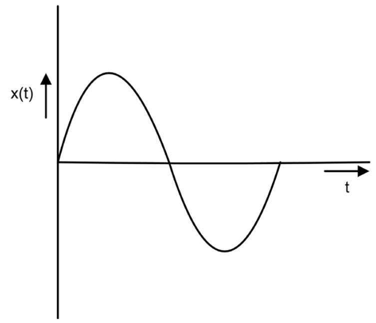


Fig. 1.21: Continuous time signal

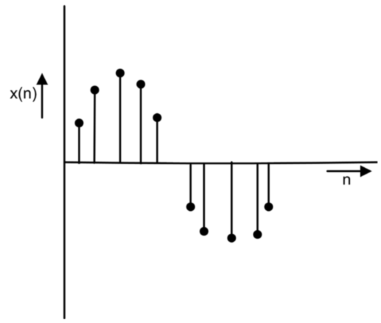


Fig. 1.22: Discrete time signal

The above signals are further classified as

i. Deterministic and Non-deterministic signals
ii. Periodic and Non-periodic signals

1.3.3 Deterministic and Non-Deterministic Signals

Deterministic signals are those signals whose nature and amplitude can be predicted at any instant of time. The mathematical function of a deterministic continuous time signal and that of a discrete time signal is given as

$$x(t) = A \sin\omega t \qquad ...(1.13)$$

$$x(n) = \begin{cases} 1, & n \geq 0 \\ 0, & otherwise \end{cases} \qquad ...(1.14)$$

Eq.1.21 as represented above is a sine function with maximum amplitude is A and is varying sinusoidally with time whereas equation 1.22 represents a discrete time signal with amplitude equals to one for the sampling instants n and zero for all other sampling instants.

Non deterministic signals also known as random signals are not predictive in nature. The pattern of such signals are irregular and cannot be defined by simple mathematical function. For example, the thermal noise created due to the movement of electrons in a semiconductor material. Fig.1.23 and 1.24 shows a deterministic time and a non-deterministic signal.

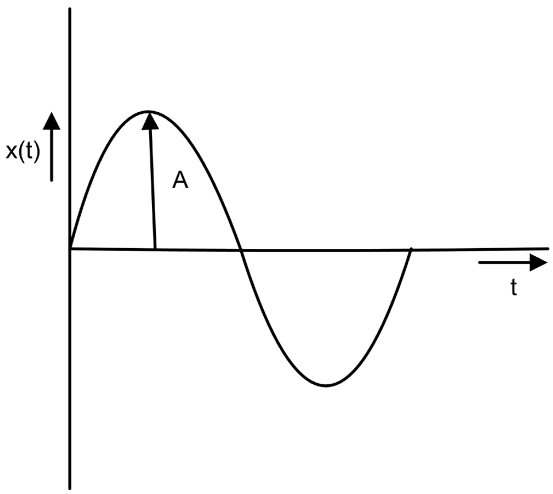


Fig. 1.23: Deterministic Signal

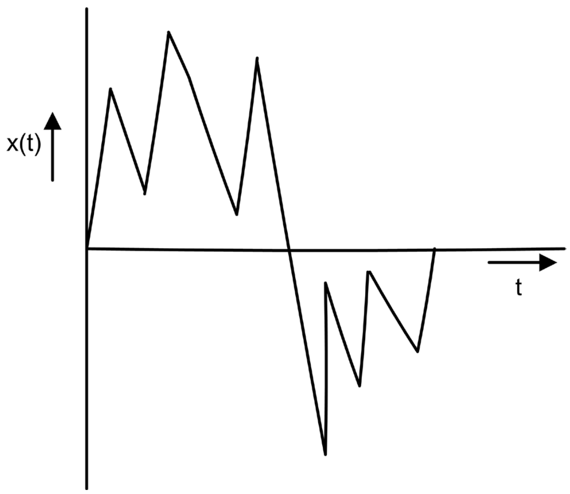


Fig. 1.24: Non-deterministic Signal

1.3.4 Periodic and Non-periodic Signals

A continuous time signal is said to be periodic if it repeats itself after a specific interval of time. The mathematical equation of a periodic signal is represented as

$$x(t) = x(t + T), -\infty < t < \infty \qquad ...(1.15)$$

Where T is the period of the signal. The smallest value of T that satisfies the given equation 1.23 is called the fundamental time period T_O of the signal.

A signal which does not repeat itself after specific interval of time or signals that do not satisfy equation 1.23 are known as non-periodic or aperiodic signals. For example, the signals created by a microphone or signals generated from a radio station.

1.3.5 Electrical Signals

There are two electrical signals in use today, for powering equipments of industries and for appliance used either in offices or houses. The most common electrical signal used is the Alternating current (AC) signal. The major advantage being the relative ease by which it can be generated and amplified, low cost of transmission of the signal from the generating station to the end consumers and the most important it is easier to interrupt an AC signal if any fault occurs in the electrical system. Almost all the major heavy duty equipment's used in industries and the domestic appliances used in household

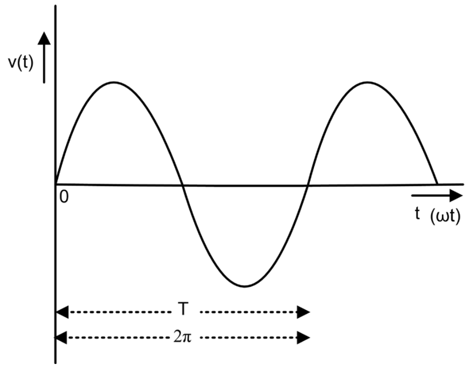


Fig. 1.25: Alternating Current signal

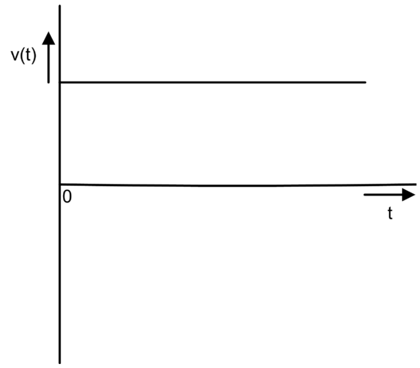


Fig. 1.26: Direct Current signal

are powered by AC signal. In recent years with the advances made in the development of discrete active components the increased use of DC signals for powering equipment's and appliance is going to be a reality Fig. 1.25 and 1.26 shows an AC and DC signal.

The Alternating Current (AC) is a sinusoidal time-varying signal. As the name suggests it goes through a series of different values both positive and negative in a time period T, after which it is continuously repeats the same series in a cyclic manner. It is generated by generators at power plants. The generated voltage is then stepped up using transformers and is then delivered through transmission and distribution networks to factories and residential houses where the voltage is stepped down as per requirement. For a residential household the voltage requirement is 230 V at 50 Hz. To understand an AC signal, the following terms are important.

AC vs. DC

1.3.5.1 Period and cycle

The period of an alternating current or voltage is the smallest value of time which separates the recurring value of the alternating quantity. The period of time which separates this recurring value is denoted by T as shown as in Fig. 1.27. The complete set of one positive and negative values of an alternating current or voltage signal is called a cycle. A cycle is also referred in terms of angular velocity ω as shown in equation 1.24 where one cycle is said to be 360° or 2π radian of angular measure.

$$\omega = \frac{2\pi}{T} \qquad ...(1.16)$$

1.3.5.2 Frequency

Frequency is the number of cycles per second. In rotating machine, one complete cycle is produced when the conductors placed on the stator are cut by the flux from the pair of poles fixed to the rotor of the machine during one complete revolution of the rotor. For a *p* pole machine the number of cycles per second is P/2, and if the speed of rotor rotation is in revolutions per second (rps), the equation for frequency in cycles per second or Hertz is

$$f = \frac{np}{2} \qquad ...(1.17)$$

Since T expressed in seconds is the time period for one cycle, the frequency term can also be expressed as

$$f = \frac{1}{T} \qquad ...(1.18)$$

The most common power plant frequencies in use are the 50 Hz and 60 Hz. In India the frequency of the generating voltage is 50 Hz, whereas in North America, Europe and in many countries of other continents, the frequency of generation is 60 Hz.

1.3.5.3 Waveform

The shape of the curve on a x- y plane resulting from a plot of the instantaneous voltage or current on the y-axis against the time on the x-axis is its waveform or wave shape. The x-axis expressed in terms of time in seconds can be also expressed in terms of radians or degrees.

In practice the Alternating voltage (AC) and current generated approximates a sine wave very closely. Therefore, the calculation of the AC voltage and current are based on sine waves. A true sine wave is shown in Fig.1.29 and is represented as.

$$v(t)=V_m \sin \omega t \qquad ...(1.19)$$

where ωt also known as the time angle is expressed in radians, v is the instantaneous value of the voltage and V_m, the maximum /peak value of the sinusoidal voltage variation.

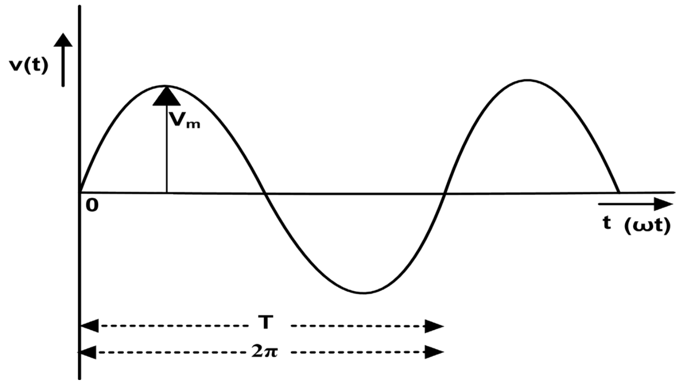


Fig. 1.27: AC Voltage sine waveform

1.3.6 Voltage and Current Sources

In topic 1.1 of this unit, three passive elements were discussed, namely the resistor which absorbs energy and the other two i.e. the inductor and capacitor that can store energy from an active source and deliver it back to the same source. Sources of electrical energy which can deliver or absorb energy continuously are called active sources. The active sources are further classified as voltage source and current source according to their voltage–current characteristics.

1.3.7 Ideal and Non-Ideal Sources

The voltage and current sources are further classified as ideal and non-ideal/practical voltage and current source according to the voltage-current (V-I) characteristics.

1.3.7.1 Ideal voltage source

An ideal voltage source delivers energy with a voltage across its output terminal and is independent of the current from the source. The circuit representation of an ideal sinusoidal voltage source given by $v(t)= V_m \sin \sin \omega t$ and its V-I characteristics are shown Fig.1.28 and 1.29 respectively. The reference polarity at the voltage source terminals labelled with + and - sign as shown in Fig.1.28 is during the positive half cycle when the voltage *v(t)* is positive. The actual polarities at the voltage source terminal change in sign once during each cycle.

From the V-I characteristics of an ideal voltage source it is observed that the voltage represented as v_T is independent of the current *i(t)* flowing out from the source, where v_T is the value of source voltage *v(t)* at any given time instant.

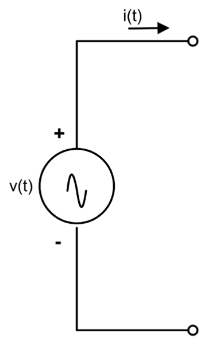


Fig. 1.28: Circuit representation of ideal voltage source

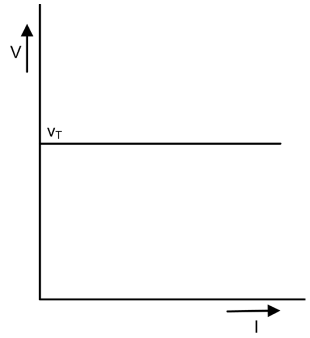


Fig. 1.29: V-I characteristic of ideal voltage source

1.3.7.2 Ideal current source

An ideal current source delivers energy with a current through the output terminals that is independent of the voltage across the terminals of the current source. The circuit representation of an ideal sinusoidal current source given by $i(t)= I_m \sin \sin \omega t$ and its V-I characteristics are shown in Fig. 1.30 and 1.31 respectively. From Fig. 1.31, it is observed that the current i_T being the value of source current *i(t)* at a given time instant is independent of the voltage across the terminals of the current source.

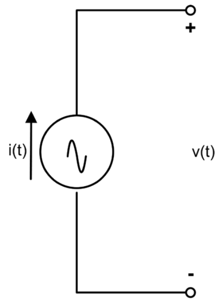


Fig. 1.30: Circuit representation of ideal current source

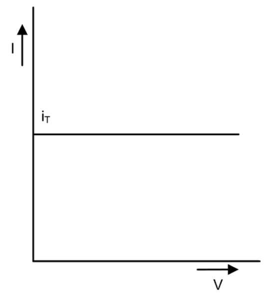


Fig. 1.31: V-I characteristic ideal current source

1.3.7.3 Non-ideal or practical voltage source

In a practical voltage source, energy is obtained by a conversion process. For example, in a voltage source generator, the conversion is from mechanical to electrical energy. Similarly, for a battery source, the chemical energy is converted to electrical energy. Conversion of energy results in losses and this is taken care of by connecting an internal resistance R_{in} in series with the voltage source generator . The circuit representation of a practical voltage source is shown in Fig.1.32 and its V-I characteristics in Fig.1.33. It can be seen from the V-I characteristics that the terminal voltage v_T decreases with increase in the current *i*. The terminal voltage equation is given by

$$v_T = v - iR_{in} \quad \text{...(1.20)}$$

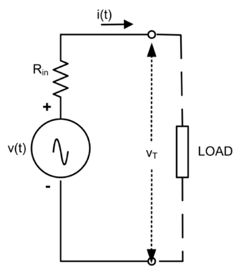


Fig. 1.32: Circuit representation of a practical voltage source

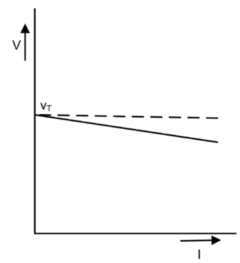


Fig. 1.33: V-I characteristics of practical voltage source

1.3.7.4 Non-ideal or practical current source

In a practical current source, the loss is represented by connecting an internal resistance R_{in} parallel with the current source. The circuit representation and the V-I characteristics of a practical current source is shown in Fig.1.34 and Fig.1.35 respectively. It can be seen from the V-I characteristics that the terminal current i_T decreases with increase in the terminal voltage *v*. The equation of the terminal current is given by

$$i_T = i - \frac{v}{R_{in}} \quad \text{...(1.21)}$$

Electronic circuit using bipolar junction transistors and circuits using photovoltaic cells are often explained by using current sources in their equivalent circuit.

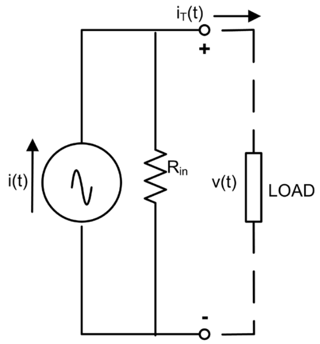


Fig. 1.34: Circuit representation of current source

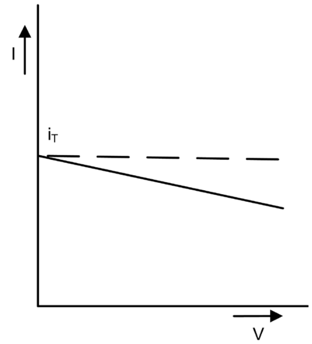


Fig. 1.35: V-I characteristic of current source

1.3.8 Dependent Voltage and Current Source

The independent voltage and current sources are independent of any other current or voltage existing in the circuit to which it is connected. In dependent sources, the voltage across or current through the terminals of a voltage/ current dependent sources are determined either by the voltage/ current existing somewhere else in the circuit. Accordingly, the dependent sources are classified as (i) Voltage dependent voltage source (ii) Current dependent voltage source (iii) Current dependent current source (iv) Voltage dependent current source. The symbols for the dependent sources are shown in Fig. 1.36 and 1.37. k_V, k_r, k_C and k_I are real numbers, where k_r, k_C are trans-resistance and trans-conductance respectively and k_V, k_I are dimensionless

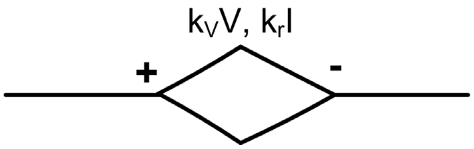


Fig. 1.36: Symbol of dependent voltage source

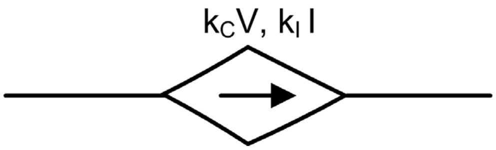


Fig. 1.37: Symbol of dependent current source

Applications

Discrete signals are used for processing the analog signals obtained from sensors, like observing the temperature of a person using Digital thermometer, mobile communication, video streaming, smart watches etc. The active sources are part of our daily life. For example, the 1.5 V cell used to power the wall clock, remote control unit of TV, Air conditioners, 12V battery for ignition and lighting system of vehicles etc. are all active DC source. Similarly, the domestic appliances used in our homes like Refrigerator, washing machine, fluorescent tube lights, ceiling fan etc. use single phase AC source.

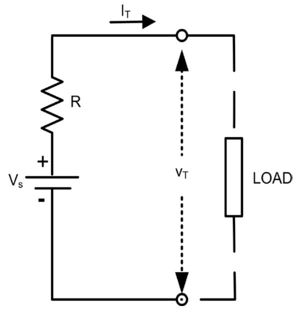
Activities

The students will

1. List the applications of continuous and discrete signals.
2. Prepare a list of gadgets which uses continuous and discrete signals.

Solved Problems

Example 1.3.1 A battery source as an ideal voltage source in series with a resistor is feeding a load connected to the terminals as shown. The voltage V_T at the terminal is 130 V and the current I_T drawn is 10 A. The load at the terminals is now changed and accordingly the voltage at the terminal is 100 V and the current drawn is 25 A. Calculate the raring of voltage Source V_s and the resistor R. Draw the VI characteristic.



raring of voltage Source V_s and the resistor R. Draw the V-I characteristic

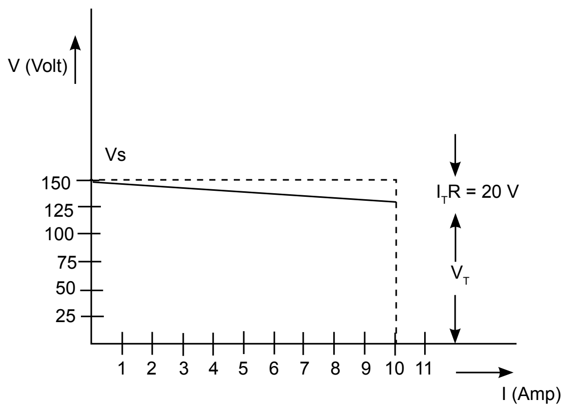
Solution: The terminal voltage in terms of source voltage, terminal current and series resistor is given by

$$V_T = V_s - I_T R \quad ...(1)$$

Using equation (1), the terminal voltage for two different load conditions are as under

$$130 = V_S - 10R \quad ...(2)$$
$$100 = V_S - 25R \quad ...(3)$$

Substituting V_S from equation (2) in (3), the value of series resistor R = 30/(15) = 2 Ω
Substituting the value of R in equation (2), we get the value of V_S = 150 Volt



Example 1.3.2 A practical current source consists of a 3 milliamp ideal current source which has an internal resistance of 1000 ohm. Calculate the open circuit terminal voltage and the power dissipated in internal resistor.

Solution: The equation of a practical current source is given as

$$i_T = i - v/R_{in} \quad ...(4)$$

For the given problem as no load is connected to the terminals of the current source, the current i_T = 0. Therefore (iv) modifies to $v = iR_{in}$, where v is the terminal voltage. Putting the value of i and R_{in}, v = 3 Volt

UNIT SUMMARY

Point-wise summary to be provided at the end of each unit.

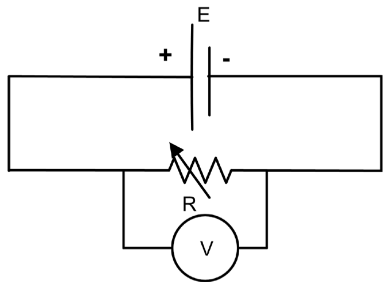
- Passive and active components form the two main types of circuit elements.
- Electrical symbols are used to represent both active and passive components.
- Resistance (R) is a property of a material used for describing the opposition provided to the flow of current.
- A capacitor stores energy in the form of electric charges.
- An inductor is a passive component that is used to store energy in the form of magnetic energy when electricity is applied to it.
- Semiconductor components are active solid state components.
- Diode, BJT and FET are basic discrete active components.
- Diode is a unidirectional device used mainly for rectification.
- BJT is a current operating three terminal device mainly used for amplification and switching operation.
- FET is a voltage operating device having high input impedance. PMOS and NMOS are combined together to construct CMOS.
- Signals are classified broadly as continuous time signals and discrete signals.
- The Electrical Signal used for domestic and Industrial application are classified as AC signals and DC signals.
- The AC and DC signal sources are classified as Ideal and Practical source according to their voltage-current characteristics
- The dependent voltage and current source are used for analysis of circuits containing active components like BJT, JFET.

EXERCISES

A- Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
1.1	With rise in temperature the resisteance of pure metal a. Increases b. Decreases c. Remains constant d. First increases and then decreases	1.7	For opto-coupler, the pair of diodes that is used is a. Zener diode and PN junction diode b. Zener and LED c. Zener diode and Photo diode d. LED and Photodiode
1.2	The insulating medium between the two plates of capacitor is known as a. electrode b. capacitive medium c. conducting medium d. dielectric	1.8	A length of wire having a resistance of 1.0 Ω is cut into four equal parts. These four parts are bunded together side by side to form a thicker wire. The resistance of thicker wire will be a. 4 Ω b. 1/16 Ω c. 1/4 Ω d. 16 Ω
1.3	The most common used semiconductor is a. Carbon b. Silicon c. Germanium d. Gallium	1.9	In BJT, terminal currents are I_1 = 5mA, I_2 = 95 mA and I_3 = 100 mA, then the appropriate option is a. $I_1 = I_B$, $I_2 = I_C$, $I_3 = I_E$ b. $I_1 = I_B$, $I_2 = I_E$, $I_3 = I_C$ c. $I_1 = I_C$, $I_2 = I_B$, $I_3 = I_E$ d. $I_1 = I_E$, $I_2 = I_C$, $I_3 = I_E$

<table>
<tr><td>1.4</td><td>For voltage regulation, the diode that is suitable is
a. P N junction
b. Light emitting
c. Photo
d. Zener</td><td rowspan="3">1.10</td><td rowspan="3">In the circuit diagram shown, if the battery with E volt has some finite internal resistance and if the resistance R is decreased the voltmeter reading will


a. Remain constant
b. Increase
c. Decrease
d. Will be equal to E</td></tr>
<tr><td>1.5</td><td>The signal x (t) is said to be non-periodic signal if
a. the equation x (t) = x (t + T) is satisfied for all values of T
b. the equation x (t) = x (t + T) is satisfied for only one value of T
c. the equation x (t) = x (t + T) is satisfied for no values of T
d. the equation x (t) = x (t + T) is satisfied for only odd values of T</td></tr>
<tr><td>1.6</td><td>In an ideal voltage source the source voltage and terminal voltage can be related as
a. terminal voltage is higher than the source voltage
b. terminal voltage is equal to the source voltage
c. terminal voltage is always lower than source voltage
d. terminal voltage cannot exceed source voltage</td></tr>
</table>

B- Subjective Questions

1. A very long string of 500 multi-colored outdoor lights is installed on a house. After applying power, the home owner notices two bulbs are burnt out. Are the lights connected in series or parallel?
2. There capacitors of 5 F, 10 F and 15 F are connected in series across a 100 V supply. Determine the equivalent capacitance.
3. List out two applications each of inductor photodiode, MOSEFT and active DC source.
4. Compare BJT with FET on the basis of power requirement, input impedance, thermal stability and compactness.
5. Two light bulbs are used for lightening the kitchen and store room. One light bulb draws 300 mA when the voltage across it is 240 V. Another light bulb in the store room draws 240 mA when the voltage across it is 240 V. Calculate the total resistance of the light bulbs?
6. Suggest type of diode suitable to detect light abstraction in burglar alarm.
7. Justify 'In BJT, emitter terminal current is maximum current'.
8. Calculate value of β, if value of α is 0.92.
9. A practical source of a Bipolar Junction Transistors consists of 3 Amp ideal current source with an internal resistance of 500 ohms. To the terminals of the practical current source a load resistor of 250 ohms is connected. Find the voltage across the load terminal and the power absorbed by the load resistor.
10. List the differences between ideal and practical sources.

PRACTICALS

I. P7- ES110: PASSIVE COMPONENTS

P7.1 Practical Statement

Identify various passive electronic components in the given circuit.

P7.2 Practical Significance

Any circuit is composed of various types of components. This experiment is aimed at development of identification skills of passive electronic components. Passive components like resistors, inductor and capacitors dissipates or stores energy. This experiments will help in developing identification skills which is very essential for the troubleshooting of any circuit or device.

P7.3 Relevant Theory

For passive electronic components, please refer section 1.1 of this unit.

P7.4 Practical Outcomes (PrO)

PrO1: Identify various types of resistors in the given circuit.
PrO2: Identify various types of inductors in the given circuit.
PrO3: Identify various types of capacitors in the given circuit.

P7.5 Practical Setup (Work Situation)

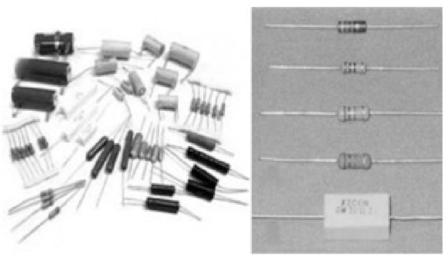


Fig. P7.1: Image showing various types of resistors

Fig. P7.2: Image showing various types of variable resistors (Courtesy:Technicalegg)

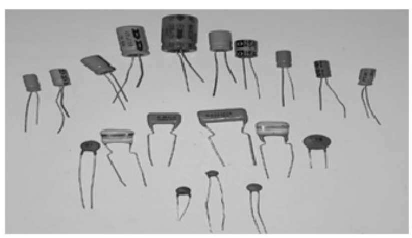


Fig. P7.3: Image showing various types of capacitors

Fig. P7.4: Image showing various types of inductors

Potentiometers: Potentiometers or pots in short form are variable resistors. They normally have their value marked with the maximum value in ohms. Smaller trim pots may use a 3-digit code where the first 2 digits are significant, and the 3rd is the multiplier (basically the number of 0's after the first 2 digits).

For example, code 104 = 10 followed by four 0's = 100000 Ohms = 100K Ohms. They may also have a letter code on them indicating the taper (which is how resistance changes in relation to how far the potentiometer is turned). Potentiometers with Linear (Lin) or Logarithmic (Log) tracks are there. With linear potentiometers, the resistance between one end of the track and the wiper varies at a constant rate as the slider is moved along the track. In logarithmic types, the change in resistance is much less at one end of the track to the other. They are typically marked with an “VR” on a circuit board.

Capacitors : The forms of practical capacitors vary widely, but all contain at least two electrical conductors separated by a dielectric (insulator). A lot have their values printed on them, some are marked with 3-digit codes, and a few are color coded. They are typically marked with an “C” on a circuit board.

Inductors: An inductor, also called a coil or reactor, consists of a conductor such as a wire, usually wound into a coil. It can be a bit harder to figure out their values. Some of them are colour coded, otherwise a good measuring instrument like LCR meter, which can measure inductance will be needed. They are typically marked with an “L” on a circuit board.

P7.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1	Sample circuits containing different components	2			
2	Various types of resistors, pots, inductors and capacitors	Assorted			

P7.7 Precautions

1. Ensure that any passive component taken for identification is put back at the right place.
2. Maintain neatness on the working table.
3. Handle the components properly.

P7.8 Suggested Procedure

1. Observe carefully the various components.
2. Identify value and type of resistors, inductor and capacitors in the given two circuits and note them down in the observation table.

P7.9 Observations

Circuit 1						
Sr. No.	Resistors		Inductors		Capacitors	
	Types	Values	Types	Values	Types	Values

Circuit 2						
Sr. No.	**Resistors**		**Inductors**		**Capacitors**	
	Types	Values	Types	Values	Types	Values

P7.10 Results and Interpretation

P7.11 Conclusions

……..……

……..……

P7.12 Practical related Questions

(Use separate sheet for answer)

Note:Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. If no fourth colour is indicated on the body of a resistor, state its tolerance value.
2. List the passive components that are used in conventional tube lights.

P7.13 Suggested Learning Resources

Familiarisation with Resistor

Familiarisation with Capacitor

Familiarisation with Inductor

II. P8- ES110: RESISTOR IN SERIES AND PARALLEL

P8.1 Practical Statement

Connect resistor in series and parallel combination on breadboard and measure its value using multimeter.

P8.2 Practical Significance

Series and parallel circuit connections are very common in electric equipment. Fuses, automatic house heating equipment and safety cutouts are connected in series with the source. Majority of the equipment are connected in parallel with the voltage source. This experiment aims to develop skill of using measuring instruments and analysing series and parallel circuits.

P8.3 Relevant Theory

For series and parallel circuit, refer section 1.1.6 of this unit.

P8.4 Practical Outcomes (PrO)

PrO1: Use multimeter to measure resistance.

PrO2: Measure equivalent resistance when resistors are connected in series.

PrO3: Measure equivalent resistance when resistors are connected in parallel.

PrO4: Determine whether the error is within acceptable limits.

P8.5 Practical Setup (Circuit Diagram)

Fig. P8.1: Digital multimeter

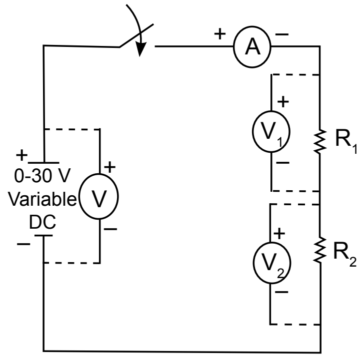


Fig. P8.2: Series Circuit

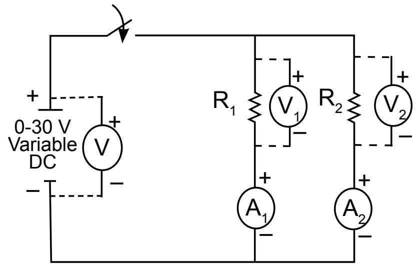


Fig. P8.3: Parallel Circuit

P8.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specifications (to be filled by the student)		Remarks (If any)
1.	Digital Multimeter: 3 1/2 digit display with probes	2			
2.	Variable DC power supply: 0- 30V, 2A	1			
3.	Resistances of two different values R_1 and R_2	2			
4.	Breadboard: 5 cm X 17 cm	1			
5.	Connecting wires: Single strand Teflon coating (0.5 mm diameter)	L.S.			

P8.7 Precautions

1. Ensure that the connections should be as per the experimental setup.
2. While doing the experiment select proper function of multi-meter.
3. Do not switch ON the multi-meter unless you have checked the circuit connections.
4. Connect voltmeter and ammeter in correct polarities as shown in the circuit diagram.
5. Multimeter when used for measuring voltage across resistor should be connected in parallel with it.

P8.8 Suggested Procedure

1. Connect the circuit on the breadboard as shown in Fig. P8.1.
2. Connect the unknown resistor R_1 in the circuit.
3. Connect the black lead to the COM terminal on the multi-meter.
4. Connect the red lead to the Ω terminal on the multi-meter.

5. Turn the multi-meter on. The display window should indicate either 0L or OPEN.
6. Vary the voltage in the circuit using variable voltage supply
7. Record the reading of voltage and current using the multimeter.
8. Calculate the resistance using ohms law.
9. Calculate the average value of resistance.
10. Repeat steps 6 to 9 to calculate unknown resistance R_2.
11. Connect the two resistances R_1 and R_2 in series combination.
12. Repeat steps 6 to 9 to find out resistance by experiment
13. Calculate equivalent resistance theoretically.
14. Connect the two resistances R_1 and R_2 in parallel combination.
15. Repeat steps 6 to 9 to find out resistance by experiment
16. Calculate equivalent resistance theoretically.

P8.9 Observations

Sr. No.	Voltage across Resistor R_1	Current flowing with R_1 in circuit	Voltage across Resistor R_2	Current flowing with R_2 in circuit	Voltage across R_1 and R_2 in series	Current flowing with R_1 and R_2 in series	Voltage across R_1 and R_2 in parallel	Current flowing with R_1 and R_2 in parallel

Calculations:

Average value of R_1 =

Average Value of R_2 =

Average value of equivalent resistance when R_1 and R_2 are in series =

Average value of equivalent resistance when R_1 and R_2 are in parallel =

P8.10 Results and Interpretation

Value of R_1	Value of R_2	Equivalent resistance of series combination of resistances, Rs		Equivalent resistance of parallel combination of resistances, Rp	
Experimentally	Experimentally	Theoretically	Experimentally	Theoretically	Experimentally

P8.11 Conclusions and/or Validation

………………………………………………………………………………………………………

………………………………………………………………………………………………………

P8.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. If the voltage across the resistance is increased three times, how the current will be affected?
2. How should the resistor be connected so that the resultant resistance is decreased?

P8.13 Suggested Learning Resources

Ohms Law

Equiv-alent Resistance

III. P8- ES110: RESISTORS IN SERIES AND PARALLEL

P9.1 Practical Statement

Connect capacitors in series and parallel combination on bread board and measure its value using multimeter.

P9.2 Practical Significance

In industries and domestic applications, measurement of equivalent capacitance with accuracy is very important. Such measurements can be done by multimeter or LCR meter.

P9.3 Relevant Theory

For capacitance, refer section 1.1.1 of this unit.

P9.4 Practical Outcomes (PrO)

PrO1: Use multimeter to measure capacitance.

PrO2: Measure equivalent capacitance when capacitances are connected in series.

PrO3: Measure equivalent capacitance when capacitances are connected in parallel.

P9.5 Practical Setup (Circuit Diagram)

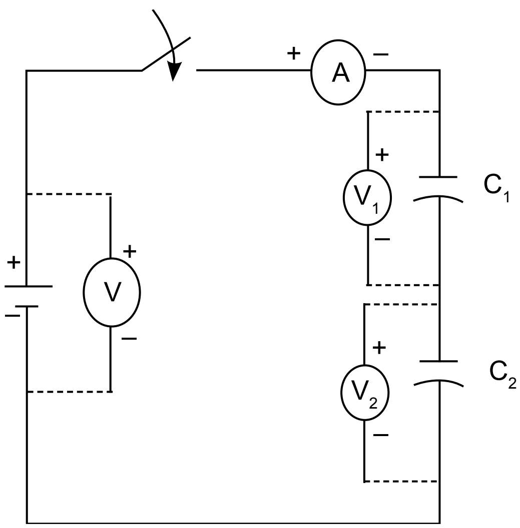


Fig. P9.1: Series combination of capacitors

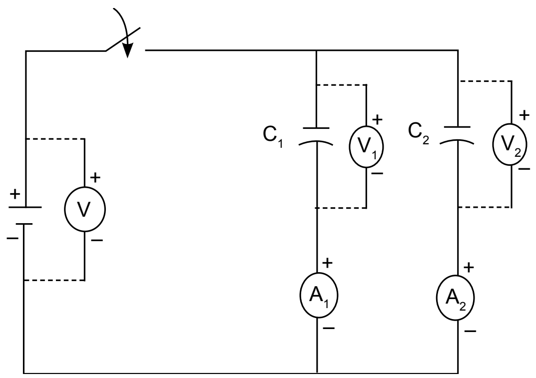


Fig. P9.2: Parallel combination of capacitors

P9.6 Resources Required

Sr. No.	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital Multimeter: 1/2 digit display with probes	3			
2.	DC power supply: 0- 30 V, 2A, SC protection, display for voltage and current.	1	1		
3.	EMF source: Voltage=0-20 V, Ampere=0-1 A	1			
4.	Ammeter: 0-5 Amps	2			
5.	Suitable capacitors in micro farads	2			
6.	Connecting wires: Single strand Teflon coating (0.6 mm diameter)	L.S.			

P9.7 Precautions

1. Do not switch ON the multi-meter unless you have checked the circuit connections.
2. While doing the experiment select proper function of multi-meter.
3. Ensure that all capacitors are discharged completely before connecting in the circuit.
4. Ensure that your hands are not wet while touching the circuit.

P9.8 Suggested Procedure

1. Connect the black lead to the COM terminal on the multi-meter.
2. Connect the red lead to the Ω terminal on the multi-meter.
3. Make sure that each capacitor is discharged (V = 0) by connecting a wire lead across the capacitor for about 30 seconds.
4. Note down the value of capacitors before connecting them in circuit.
5. Connect the capacitors in series on the bread board along with meters as given the circuit diagram, Fig.P9.2.
6. Switch on the supply and note down the readings of ammeter and multimeters used as voltmeter and measure voltage across each capacitor and the supply voltage.
7. Switch off the supply.
8. Find out the series equivalent capacitance.
9. Connect the capacitors in parallel along with meters as given the circuit diagram, Fig 9.3.
10. Switch on the supply and note down the readings of multimeters used as voltmeter and ammeter.
11. Switch off the supply.
12. Find out the parallel equivalent capacitance.
13. Change the value of C_1 to C_1' and C_2 to C_2' and repeat steps 3 to 12 and find series equivalent capacitance CTS_2 and parallel equivalent capacitance CTP_2.

P9.9 Observations

1. C_1 = ______________________________; C_2 = ______________________________
2. C_1' = ______________________________; C_2' = ______________________________

Series connection

Sr. No.	V	V_1	V_2	I

Theoretically, for series connection

$V = V_1 + V_2$

$Q/C = Q/C_1 + Q/C_2$ i.e. $1/C = 1/C_1 + 1/C_2$

$$C_{TS1} = \frac{C_1 \times C_2}{C_1 + C_2} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$C_{TS2} = \frac{C_1' \times C_2'}{C_1' + C_2'} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Parallel connection

Sr. No.	V	V_1	V_1	I_1	I_2

Theoretically, for parallel connection

$V = V_1 = V_2$

$Q = C(V_1 + V_2)$

$C_{TP1} = C_1 + C_2 =$ ______________

$C_{TP2} = C_1' + C_2' =$ ______________

P9.10 Results and Interpretation

P9.11 Conclusions and/or Validation

…...

…...

P9.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Give the reason for discharging each capacitor at the start.
2. There are two capacitors of 2 micro farads and 5 micro farads. Compare the equivalent capacitance, if they are connected in series and then in parallel.
3. If you wish to store a large amount of charge is to be stored in a capacitor bank, the capacitors should be connected in series or in parallel?

IV. P10- ES110: ACTIVE ELECTRONIC COMPONENTS

P10.1 Practical Statement

Identify various active electronic components in the given circuit.

P10.2 Practical Significance

Any circuit is composed of various types of components. Active components supplies energy to the electric circuit .This experiment is aimed at identification of active components, which is very essential for developing skills of designing basic circuits or troubleshooting of any circuit or device.

P10.3 Relevant Theory

For active electronic components, refer section 1.2 of this unit.

P10.4 Practical Outcomes (PrO)

PrO1: Identify various types of diodes in the given circuit.

PrO2: Identify various types of transistors in the given circuit

P10.5 Practical Setup (Work Situation)

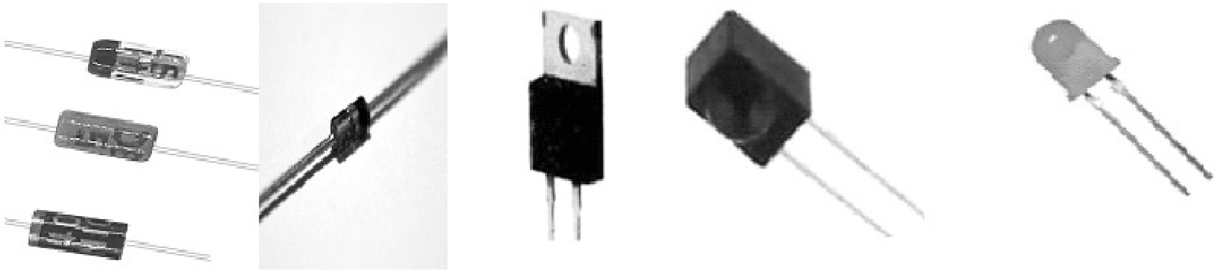


Fig.P10.1: Image showing various types of Diodes like PN Junction Diode, Photodiode, Zener Diode, LED.

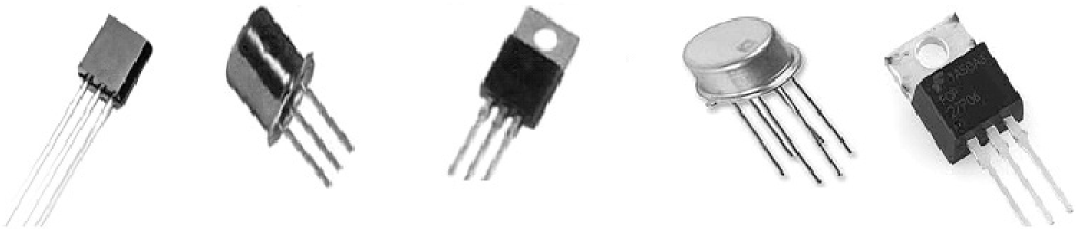


Fig.P10.2: Image showing various types of Transistors like BJT, Power Transistor, JFET, MOSFET

P10.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Sample circuits containing different active components	2			
2.	Diodes: Semiconductor diode, Zener diode, LED, Photo diode, etc.	Assorted			
3.	Transistors: BTL, JFET, MOSFET, etc.	Assorted			

P10.7 Precautions

1. Ensure that any active component taken for identification is put back at the right place.
2. Maintain neatness on the working table.
3. Handle the components properly.

P10.8 Suggested Procedure

1. Observe carefully the various components.
2. Identify Component No. and type of diodes and transistors in the given two circuits and note them down in the observation table.

P10.9 Observations

Circuit 1				
Sr. No.	**Diodes**		**Transistors**	
	Component No.	Values	Component No.	Values
Circuit 2				

P10.10 Results and Interpretation

P10.11 Conclusions

……..………

……..………

P10.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Describe how it can be identified whether the given diode is germanium diode or silicon diode.
2. For a given transistor, describe how can the emitter, base and collector terminal can be identified.
3. Draw the electrical symbols of various active components observed during the practical.

P10.13 Suggested Learning Resources

1. "Diode, Transistor & FET Circuits Manual", Editor(s): R.M. Marston, Circuits Manual Series, Newnes, 1991, ISBN 9780750602280, https://www.sciencedirect.com/science/article/pii/B9780750602280500065

Electronics Devices and Circuits

V. P11- ES110: MEASUREMENT USING LCR METER

P11.1 Practical Statement

Use LCR meter to measure the value of inductance and resistance.

P11.2 Practical Significance

In industries and domestic applications, inductors and resistors are used in circuits. For designing a circuit as well as trouble shooting the circuit, the value of the inductance and resistance should confirmed. This practical will introduce to the front panel controls of an LCR meter and its use to measure the value of inductance and resistance.

P11.3 Relevant Theory

For inductance and resistance, please refer 1.1.1 of Chapter 1 of this unit. An LCR meter is a type of electronic test equipment that is used to measure the inductance (L), capacitance (C), and resistance (R) of an electronic component. It measures the current (I) flowing through a device under test, the voltage (V) across the device, and the phase angle between the measured V and I. From these three measurements, all impedance parameters are calculated by LCR meter.

11.4 Practical Outcomes (PrO)

PrO1: Handle LCR meter to understand various settings.

PrO2: Measure the value of given resistor using LCR meter.

PrO3: Test the resistance value with a digital multimeter and perform error analysis assuming LCR meter as standard meter.

11.5 Practical Setup (Circuit Diagram)

Fig. P11.1: A sample Digital LCR meter Courtesy: Proster for BM 4070

Fig. P11.2: Inductors and Resistors

11.6 Resources Required

Sr. No.	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital LCR meter: 3 ½ - digit LCD display with probes; Resistance: 20Ω-200MΩ; Capacitance: 2000PF-200uF; Inductance: 20mH-20H or LCR meter with similar ranges	1			
2.	Inductor: Various types like air wound, ferrite core toroidal inductor of different values	Maximum 3			
3.	Resistors: Various types like Wire wound, carbonfilm, cermet film of different values	Maximum 5			
4.	Burnout resistor	1			
5.	Connecting wires : Single strand, Teflon coated (0.5 mm diameter)	L.S.			

P11.7 Precautions

1. As soon as it is switched ON, the LCR meter must be allowed to get self-calibrated for about 2 minutes (self-calibration).
2. While doing the experiment, adjust the knob and select proper function of LCR meter.

P11.8 Suggested Procedure

1. Identify the different controls on the panel and try tounderstand their function through the instrument manual.
2. Switch on the LCR meter.
3. Insert the inductor of unknown value in the sockets. Select inductance by adjusting the knob.
4. Observe and note down the value of inductance from digital LCR meter.
5. Similarly, insert other resistors and note down their values.
6. Now measure the resistance value of same resistance using the multimeter.
7. Calculate the percentage of error in measurement of resistance in the step 8, assuming LCR meter as standard.
8. Repeat steps 3 to 7 for different types and values of inductors and resistors and note them down in observation and calculation table.
9. At the end, take one 'burnt out' resistor and insert it and measure the resistance and note down the reading as 'A'.
10. Now simply short the terminals using a wire. Note down the observation as 'B'.

P11.9 Observations and Calculations

Sr. No.	Inductance value 'L' (LCR meter)	Resistance value 'R' (LCR meter)	Resistance value 'R' (Multimeter)	Percentage of error in measurement of resistance
1.				
2.				
3.				

A=...........

B=...........

Calculation:

Percentage of error in measurement of resistance

$$= \frac{(\text{'R' value using LCR meter - 'R'value using Multimeter})}{(\text{'R' value using LCR meter})} \times 100$$

P11.10 Results and Interpretation

(Comment on the values obtained, tolerance, error; result obtained when 'burnt out' resistor is connected; result obtained when a short circuit is made)

....

....

P11.11 Conclusions and/or Validation

....

....

P11.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Describe how the value of a passive component can be measured, which is connected in the circuit?
2. If passive component's value lies outside the range of provided LCR meter, state the effect on measurement.

VI. P12- ES110: CAPACITOR MEASUREMENT USING LCR-Q METER

P12.1 Practical Statement

Use LCR-Q meter to measure the value of given capacitor.

P12.2 Practical Significance

AThe utility of an auto computed digital LCR-Q meter, also called as LCR _Q tester that directly measures value of components like capacitance along with other vital parameters like inductance, capacitance , resistance and other values like Q factor, are useful during developing and troubleshooting electronic circuits. This practical aims at understanding of front panel controls of an LCR-Q meter and its applications in measurement.

P12.3 Relevant Theory

FAn LCR- Q meter is a type of electronic test equipment which used to measure the inductance (L), capacitance (C), resistance (R) and Q factor. If a capacitor is being charged from a known voltage source and through known resistor, then time required for capacitor voltage to reach a certain specified value (say 63% of battery voltage) will directly depend upon the value of 'C'. Lager the value of 'C', more the time LCR meter takes to measure time using counter technique. The digital voltmeter technique can convert 'time' into voltage, so finally the value of C and/or of L and /or R for that matter can be obtained. However, this is an oversimplified description of how measurement is done. The auto compute meters are microprocessor based instrument that facilitates measurement. Please refer the manual for learning more about digital LCR -Q meter.

P12.4 Practical Outcomes (PrO)

PrO1: Set and Handle LCR – Q meter.

PrO2: Use LCR – Q meter to measure capacitance.

PrO3: Compare results obtained through meter with the inscribed value on the component.

P12.5 Practical Setup (Work Situation)

Fig. P12.1: A sample Auto compute LCR-Q meter.

P12.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Auto compute digital LCR-Q meter: 4 digit display; Auto ranging with Self-Test facility	1			
2.	Capacitors for testing	Assorted			

P12.7 Precautions

1. Handle LCR Q meter carefully.
2. While doing the experiment, select proper function of LCR-Q meter.
3. Ensure that the capacitors to be tested are in discharged condition.
4. Connect capacitor in correct polarities as shown in the circuit diagram.

P12.8 Suggested Procedure

1. Identify the main controls available on the panel of LCR-Q meter and try to understand their function.
2. Switch on the instrument.
3. Wait for certain time for about two minutes so that LCR-Q meter is self-calibrated and ready to be used.
4. Insert the capacitor of unknown value in the sockets taking care of the polarities. Press 'R /L/C' switch so that LED under 'C' glows indicating that the instrument is in capacitance measurement mode. The meter being fully automatic, no range setting is required . An LED under appropriate suffix will glow.
5. Similarly, insert other capacitors and note down their values.
6. Compare results obtained through LCR-Q meter with the inscribed value on the capacitor, taking LCR- Q Meter as standard meter and calculate percentage of error.
7. Repeat steps 2 to 5 for different capacitors andnote them down in observation and calculation table.

P12.9 Observations and Calculations

Sr. No.	Capacitance value 'C' (LCR meter)	Capacitance value 'C' (Inscribed value)	Percentage of error in measurement of resistance
1.			
2.			
3.			

Calculation:

Percentage of error in measurement of capacitance =

$$\frac{(\text{`C' value using LCR-Q Meter - `C' (Inscribed value)})}{(\text{`C' value using LCR meter})} \times 100$$

P12.10 Results and Interpretation

……

……

P12.11 Conclusions

……..……

……..……

P12.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. State the reason for the requirement of warm up time for the LCR Q meter.
2. Explain why it is not advised to test the charged capacitor.

P12.13 Suggested Learning Resources

Q meter Experiment

VII. P13- ES110: RESISTOR MEASUREMENT USING COLOR CODE AND CONFIRMING USING MULTIMETER

P13.1 Practical Statement

Determine the value of given resistor using digital multimeter to confirm with colour code.

P13.2 Practical Significance

This experiment aims at finding the value of carbon resister using colour coding. Resistors are used in majority of electronic circuits. For developing and troubleshooting of circuits it is necessary to develop the skills of confirming the values using a measuring instrument like multimeter.

P13.3 Relevant Theory

A carbon resistor's outside is marked by three bands of different colours equidistant to each other and a fourth band slightly farther from the third compared to previous spacing as shown in Fig 13.1. The combination of the colours represents the value of the resistor in ohms. The bands are read from left to right, with the first two colour bands representing the base value as individual digits, while the third is a power multiplier and the last is a tolerance indicator because manufacturing process limits the preciseness of the value. If there are five bands, then the first three represent the base value, whereas the last two still represent the multiplier and tolerance, respectively.

Colour value representation:

0 = Black; 1 = Brown; 2 = Red; 3 = Orange; 4 = Yellow;
5 = Green; 6 = Blue; 7 = Violet; 8 = Grey; 9 = White

Tolerance:

Brown = +/- 1%; Red = +/- 2%; Gold = +/- 5%; Silver = +/- 10%

The power rating of a resistor is given in wattage. The normal available resistors have power ratings of 1/8 W, 1/4 W, 1/2 W, 1 W, 2 W.

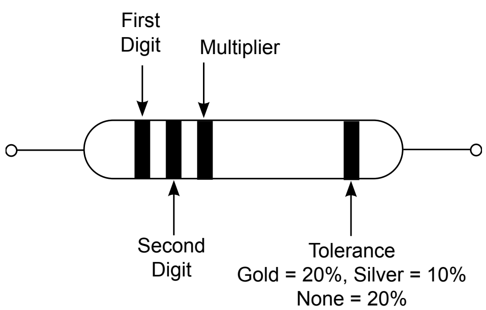


Fig. P13.1: Colour Coding of Resistors

Fig. P13.2: Resistance Measurement using Digital multimeter

P13.4 Practical Outcomes (PrO)

PrO1: Identify the value of resistors by colour coding.

PrO2: Use multimeter to measure resistance.

PrO3: Determine whether the error is within acceptable limits.

P13.5 Practical Setup (Work Situation)

Fig P13.2 shows the work situation of using a digital multi-meter for measurement to confirm the value of resistance.

P13.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital Multi meter 3 1/2 digit LCD display with probes	1			
2.	Carbon resistors of different values and wattages	Assorted (Minimun 5)			

P13.7 Precautions

1. Ensure that both resistor leads are untouched while making the measurement, otherwise DMM will measure the body resistance as well as the resistor.
2. While doing the experiment select proper function of multi-meter.

P13.8 Suggested Procedure

1. Insert the red lead plug into the "V" socket of the digital multimeter and the black lead plug into the "COM" socket.
2. Set function to resistance measurement.
3. Set to the appropriate range.
4. Connect the two probes' crocodile clips to the resistor (or to the resistor circuit via jumper wires to make measurement.
5. Note the reading, adjust range if necessary.
6. Determine the resistance value of various resistors using colour code and DMM .
7. Measure the resistance of each resistor and note the value in the observation table.
8. Compare the colour coded resistance value with measured value.
9. The measured resistance and the colour coded resistance should agree with in the tolerance range of the resistor.

P13.9 Observations and Calculations

Sr. No.	Resistance Value using Colour Code	Colour Coded Tolerance	Colour Coded Tolerance	Percentage Error
1.				

Calculation:

$$\text{Percentage Error} = \frac{\text{Measured value of resistance} - \text{Resistance value using colour code}}{\text{Measured value of resistance}} \times 100$$

P13.10 Results and Interpretation

…….………

…….………

P13.11 Conclusions

…….………

…….………

P13.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. If the color band of a given resistance is brown, green and grey; what is the value of resistance, and tolerance.
2. Can you measure the value of a carboneresitor which is connected in the circiuit. Justify your answer.

P13.13 Suggested Learning Resources

Measure-ment of Resistance

VIII. P14- ES110: TESTING OF PN JUNCTION DIODE

P14.1 Practical Statement

Test PN Junction Diode using digital multimeter.

P14.2 Practical Significance

PN Junction diode is a two terminal semiconductor device . As per application requirement diode is selected. To test diode, it's resistance is measured. Few digital multi-meter and CRO are having direct diode testing facility. This practical aims at developing skills of testing diode using both methods.

P14.3 Relevant Theory

For P N junction diode theory, please refer topic 1.2.2 unit.

P14.4 Practical Outcomes (PrO)

PrO1: Use digital multimeter for diode testing.

PrO2: Measure resistance of diode.

P14.5 Practical Setup (Work Situation)

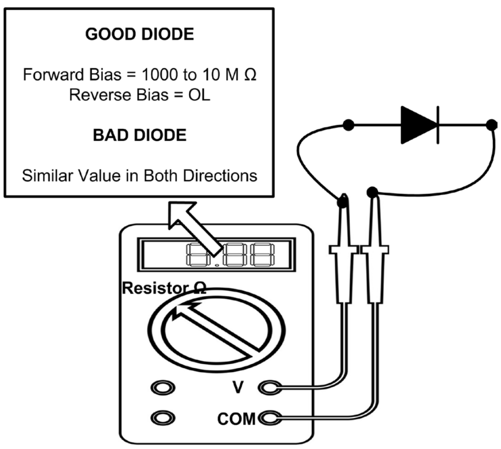


Fig. P14.1: Diode testing using digital multimeter

P14.6 Resources Required

Sr. No	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital multi meter :1/2 digit display with probes	1			
2.	Diode IN4007 (or any other equivalent diode)	1			

P14.7 Precautions

1. Make sure all power to the circuit is OFF.
2. No voltage exists at the diode.

P14.8 Suggested Procedure

A. Direct diode test using digital multimeter:

1. Turn the dial (rotary switch) to Diode Test mode.
2. Connect the test leads to the diode. Record the measurement displayed.
3. Reverse the test leads. Record the measurement displayed.

B. Diode testing using resistance measurement mode:

1. Turn the dial to Resistance mode (Ω).
2. Connect the test leads to the diode after it has been removed from the circuit. Record the measurement displayed.
3. Reverse the test leads. Record the measurement displayed.
4. For best results when using the Resistance mode to test diodes, compare the readings taken with a known good diode.

P14.9 Observations and Calculation

A. Direct diode test

1. Multimeter display during forward biased condition _______ volt.
2. Multimeter display during reverse biased condition _______ volt.

B. Resistance Measurement test

1. Multimeter display during forward biased condition _______ ohms.
2. Multimeter display during reverse biased condition _______ ohms.

P14.10 Results and Interpretation

P14.11 Conclusions and/or Validation

……..………

……..………

P14.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Identify terminals of 1N series diode.
2. Test the given diode using CRO.
3. Select the diode from data sheet for given load current requirement.

IX. P15- ES110: PN JUNCTION DIODE

P15.1 Practical Statement

Test the performance of PN junction diode.

P15.2 Practical Significance

PN Junction diode is used in industries as well as in domestic applications such as detector circuits, wave shaping circuits and in rectifier of DC Power Supplies. For these applications, in order to select an appropriate diode, it is necessary to know the performance of the diode. In this practical, the student will draw VI characteristics of the given diode to understand diode behavior with respect to change in voltage, which in turn will help in selection of relevant electronic devices to be used in circuits.

P15.3 Relevant Theory

For P N junction diode theory, please refer topic 1.2.2 of this unit.

P15.4 Practical Outcomes (PrO)

PrO1: Draw V-I characteristics of PN Junction diode.
PrO2: Measure static resistance of a given diode.
PrO3: Measure dynamic resistance of a given diode.
PrO4: Determine knee voltage of a given diode.

P15.5 Practical Setup (Circuit Diagram)

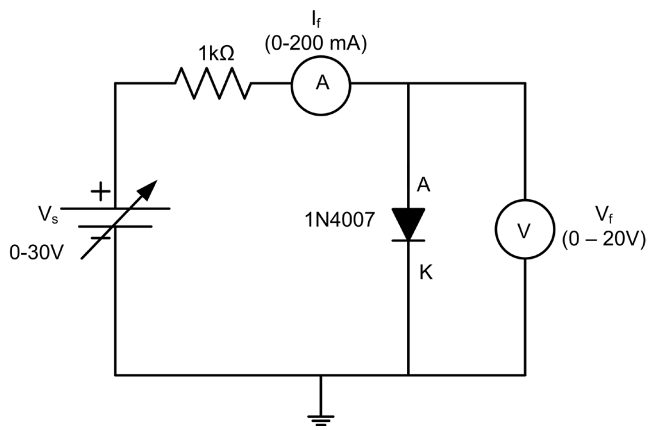


Fig. P15.1: Circuit diagram of diode in forward bias

P15.6 Resources Required

Sr.No	Suggested Resources required with vital specification	Quality	Actual Resources required with broad specifications (to be filled by the student)		Remarks (If any)
1.	Digital Multimeter: 1/2 digit display	3			
2.	DC regulated power supply: Variable DC power supply 0-30 V, 2A, SC protection, display for voltage and current	1			
3.	Voltmeter: 0-20 V	1			
4.	Ammeter: 0 - 200 mA, 0 - 200 μA	2			
5.	Breadboard: 5.5 cm × 17 cm	1			
6.	Diode: IN4007 (or any other equivalent diode)	1			

7.	Resistor: 1 KΩ (0.5 watts/0.25 watts)	1			
8.	Connecting wires: Single strand Teflon coating (0.6 mm diameter)	L.S.			

P15.7 Precautions

1. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.
2. Ensure that voltmeter and ammeter are connected in correct polarities as shown in the circuit diagram.
3. Ensure that the load resistance is of correct value and wattage.
4. While doing the experiment do not exceed the input voltage of the diode beyond the rated voltage of diode. This may lead to damaging of the diode.
5. Ensure that the meter is in off condition before changing any range.

P15.8 Suggested Procedure

1. Connect the electrical circuit as in Fig. P15.1.
2. Switch ON the power supply.
3. Record the voltage V_F and current I_F in the observation table.
4. Increase the input voltage in step of 0.1 V.
5. Record the voltage V_F and current I_F in the observation table
6. Repeat steps 4 to 5, till 1 V is reached.
7. Plot the graph for the forward bias characteristics of diode by taking V_F on X- axis and I_F on Y- axis.
8. Calculate the static resistance at a particular point.
9. Considering two points on the plotted graph, calculate dynamic resistance.

P15.9 Observations and Calculations

Table 1: Measurement of V_F and I_F

Sr.No	V_F (volts)	I_F (mA)
1.		
2.		
3.		

Calculations:

Static resistance at a particular point

$$R_{static} = V_F/I_F$$

Dynamic resistance

$$R_{dynamic} = \Delta V_F/\Delta I_F$$

P15.10 Results and Interpretation

1. Static resistance of given diode = …………………
2. Dynamic resistance of given diode = …………………
3. Knee voltage of given diode = ………………….

P15.11 Conclusions and/or Validation

……..………………………………………………………………………………………………………

……..………………………………………………………………………………………………………

P15.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Identify terminals of BY series diode from data sheet.
2. Describe what will happen if load resistor is removed from the circuit.
3. State what will happen if the value of load resistor is changed to 5 ,1/4W.

Charac-
teristics
of Diode

P15.13 Suggested Learning Resources

X. P16- ES110: TEST THE PERFORMANCE OF ZENER DIODE

P16.1 Practical Statement

Test the performance of zener diode.

P16.2 Practical Significance

In industries, zener diodes are widely used as voltage references and as shunt regulators to regulate the voltage across small circuits, in over voltage protection circuits, in switching applications. Zener diodes are also used in clipping and clamping circuits especially peak clippers as well as in surge suppression circuitry for device protection. To choose appropriate zener diode, it is necessary to understand the performance of zener diode.

P16.3 Relevant Theory

For zener diode theory, please refer topic 1.2.1 of this unit.

P16.4 Practical Outcomes (PrO)

PrO1: Identify zener diode in a circuit.
PrO2: Plot the v/i characteristics of zener diode.
PrO2: Determine the zener breakdown voltage.
PrO4: Use digital multimeter to measure the voltage and current.

P16.5 Practical Setup (Circuit Diagram)

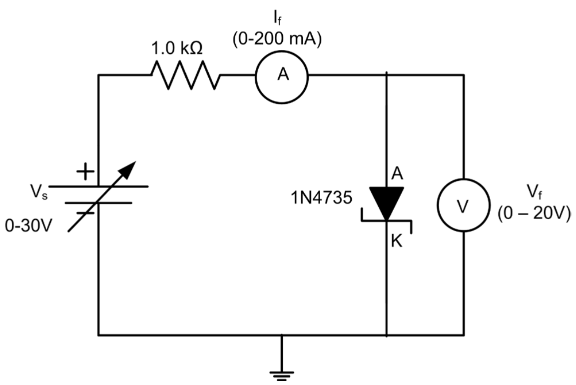


Fig. P16.1: zener diode in forward bias

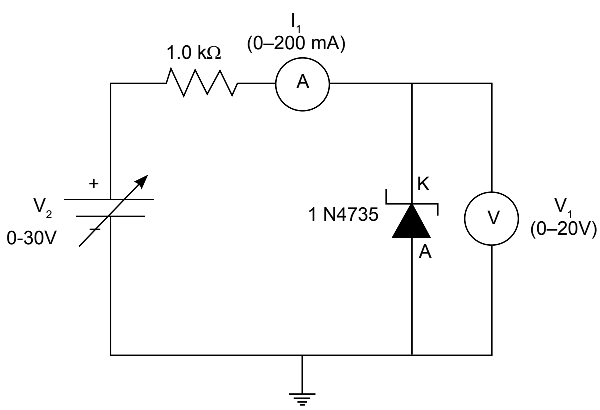


Fig. P16.2: zener diode in reverse bias

P16.6 Resources Required

Sr.No.	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specifications (to be filled by the student)		Remarks (If any)
1.	Digital Multimeter: 1/2 digit display	3			
2.	Variable DC Regulated Power Supply: 0- 30 V, 2 A, SC protection, display for voltage and current	1			
3.	Voltmeter: 0-20 V	1			

4.	Ammeter: 0 - 200 mA, 0 - 200 μA	2			
5.	Breadboard: 5.5 cm X 17 cm	1			
6.	Zener Diode IN4735 (or any other equivalent zener diode)	1			
7.	Resistor: 1KΩ (0.5 watts/0.25 watts)	1			
8.	Connecting wires: Single strand Teflon coating (0.6 mm diameter)	L.S.			

P16.7 Precautions

1. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.
2. Connect voltmeter and ammeter in correct polarities as shown in the circuit diagram.
3. Ensure that the meter is in off condition while changing the range or settings.
4. Check for circuit continuity.

P16.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P16.1.
2. Switch ON the power supply.
3. Record the voltage V_F and current I_F in the observation table P16.1.
4. Increase the input voltage in step of 0.1 V.
5. Record the voltage V_F and current I_F in the observation table P16.1.
6. Repeat steps 4 to 5, till 1 V is reached.
7. Plot the graph for the forward bias characteristics of zener diode by taking V_F on X- axis and I_F on Y- axis.
8. Connect the circuit as shown in Fig. P16.2.
9. Vary input voltage gradually in steps of 1 V up to 12 V.
10. Record the corresponding readings of V_R and I_R. in the observation Table P16.2.
11. Plot the graph for the reverse bias characteristics of Zener diode by taking V_R on X- axis and I_R on Y-axis.

P16.9 Observations and Calculations

Table P16.1: Measurement of V_F and I_F

Sr.No.	V_F (volts)	I_F (mA)
1.		
2.		
3.		

Table P16.2: Measurement of V_R and I_R

Sr. No.	V_R (volts)	I_R (mA)
1		
2		
3		
4		
5		

Calculations:

Forward resistance at a zener diode

$$R_{static} = V_F/I_F$$

Dynamic resistance of zener diode in breakdown region at I = _________mA

$$R_{ZD} = V_R/I_R$$

P16.10 Results and Interpretation

1. Zener breakdown voltage = ………………….
2. Forward resistance of zener diode = ………………….

P16.11 Conclusions and/or Validation

……

……

P16.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Find out the value of zener voltage for any two zener diodes from data manual.
2. State the maximum value of reverse current for the given zener diode.
3. State the effect on voltage across zener diode and current flowing through it, when reverse voltage across it is more than breakdown voltage.

XI. P17- ES110: LIGHT EMITTING DIODE

P17.1 Practical Statement

Test the performance of LED.

P17.2 Practical Significance

In industries and domestic applications, LEDs are widely used as display device and indicators. LED is a two terminal semiconductor light emitting active display device. LED can be tested using multimeter. This practical will help to develop component identification skills and testing skills.

P17.3 Relevant Theory

For Light Emitting Diode features, applications and symbol ref table 1.2 of this unit.

P17.4 Practical Outcomes (PrO)

PrO1: Identify Light Emitting Diode.
PrO2: Follow standard test procedure.
PrO3: Handle DC Power supply and multimeter.

P17.5 Practical Setup (Circuit Diagram)

Fig. P17.1: Digital multimeter

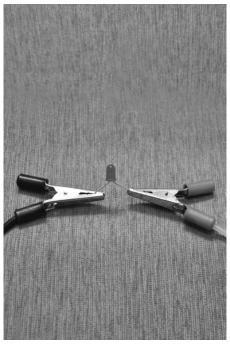


Fig. P17.2: Image showing crocodile probes connected to LED

P17.6 Resources Required

Sr.No	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital Multi meter 1/2 digit display with probes	2			
2.	DC Regulated power supply Variable DC power supply 0- 30 V, 2 A, SC protection, display for voltage and current.	1			
3.	LED for testing	1			
4.	Connecting wires Single strand Teflon coating (0.6 mm diameter)	L.S.			

P17.7 Precautions

1. Do not switch ON the multi-meter unless you have checked the circuit connections.
2. While doing the experiment select proper function of multimeter.
3. Connect voltmeter and ammeter in correct polarities as shown in the circuit diagram.

P17.8 Suggested Procedure

1. Connect the black lead to the COM terminal on the multimeter.
2. Connect the red lead to the Ω terminalon the multimeter.
3. Turn the dial to the diode symbol on the multimeter. This allows for electric current to flow in one direction and not the other.
4. Turn the multi-meter on. The display window should indicate either OL or OPEN.
5. Take a regular LED for testing.
6. Connect the black probe to the cathode end of the LED, which usually is the shorter end Connect the red probe to the anode end of the LED.
7. Observe the status of LED.
8. Read the forward voltage drop displayed on multimeter.
9. LED can be tested using D C power supply by connecting LED across positive and negative terminal of power supply.
10. Observe the status of LED and then repeat step 9 by reversing LED's terminals.

P17.9 Observations

LED is ________ . (glowing /not glowing)

P17.10 Results and Interpretation

P17.11 Conclusions and/or Validation

....

....

P17.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Find out the terminals of given LED.
2. State the procedure to test bicolor LED.
3. State the effect of change in current flowing through LED on its brightness.

XII. P18- ES110: IDENTIFY THREE TERMINALS OF TRANSISTOR USING DIGITAL MULTIMETER

P18.1 Practical Statement

Identify three terminals of transistor using digital multimeter.

P18.2 Practical Significance

Transistor has wide range of applications in industry. Transistors are semiconductor devices used for applications like amplification of voltages, current and are also used in switches and oscillator circuits. In digital circuits they are used as switches. It is used in electronic and telecommunication equipment, computers, televisions, mobile phones, audio amplifiers, and industrial control.

P18.3 Relevant Theory

For theory on transistor, refer sub topic 1.2.3.1 of this unit.

Identifying Transistor Terminals:

Identifying Transistor Terminals:

The transistors are available with various packages in the market. Consider about the TO-92 package shown in Fig. P18.1. Keep the transistor such that the flat surface facing upwards .

Fundamentals of Electrical and Electronics Engineering | 48

1. Internally the transistor has two diodes (NPN ≡ N - P - N ≡ NP Junction + PN Junction and PNP ≡ P - N - P ≡ PN Junction + NP Junction) i.e. emitter to base is one PN junction (diode) and base to collector is another PN junction (diode).
2. In the diode mode, the multimeter will show the voltage, when the positive probe of the multimeter is connected to the anode of the diode and negative probe to the cathode.
3. If the multimeter positive probe is connected to the cathode of the diode and the negative probe to the anode, then it will not give any voltage (showing zero).

P18.4 Practical Outcomes (PrO)

PrO1: Perform testing of a given transistor using a multimeter.

PrO2: Measure the resistance between base and emitter; between base and collector; and between emitter and collector.

PrO3: Identify the terminals of BJT.

P18.5 Practical Setup (Circuit Diagram)

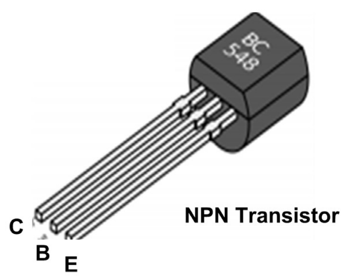


Fig. P18.1: TO-92 package of transistor

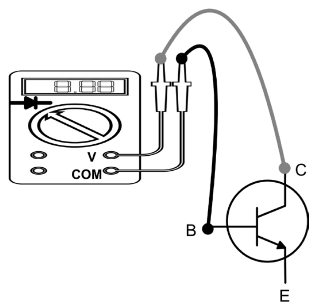


Fig. P18.2: NPN transistor meter check

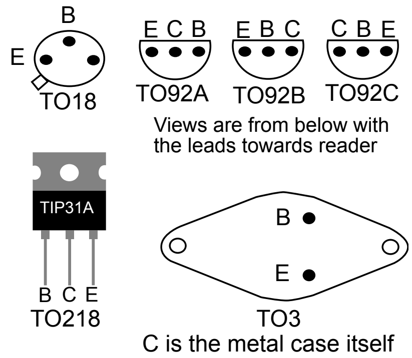


Fig. P18.3: Emitter, base and collector leads for some case styles

P18.6 Resources Required

Sr.No	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Single phase AC source 230 V, 50 Hz	1			
2.	Connecting wires, Multistrand Cu wire, 1.5 mm^2	L.S.			
3.	Digital Multimeter: 3 1/2 digit display	1			
4.	Transistors Small Signal Transitor (TO-92 Package) BC547(NPN), BC557(PNP)	1 of each type			
5.	Power Transistors 2N2955(NPN), 2N3055(PNP)	1 of each type			
6.	CRO: 20 MHz with component testing facility	1			

P18.7 Precautions

1. Select proper type and of range of Digital Multimeter.
2. Connect the circuit as shown in the circuit diagram.
3. Switch OFF the power supply after conduction of experiment.

P18.8 Suggested Procedure

1. Set the multimeter to its ohms range.
2. Connect the multimeter as shown in Fig. P18.1.
3. Measured the resistance between base and emitter.
4. Measured the resistance between base and collector.
5. Measured the resistance between emitter and collector.
6. Verify the above steps with following chart.
7. Change the transistor and repeat steps 2 to 6.

Between Transistor Terminals		PNP	NPN
Collector	Emitter	R_{HIGH}	R_{HIGH}
Collector	Base	R_{LOW}	R_{HIGH}

Emitter	Collector	R_{HIGH}	R_{HIGH}
Emitter	Base	R_{LOW}	R_{HIGH}
Base	Collector	R_{HIGH}	R_{LOW}
Base	Emitter	R_{HIGH}	R_{LOW}

P18.9 Observations

Sr.No.	Transistor No.	Resistance between Emitter and Base, R_{BE}	Resistance between Collector and Base, R_{CB}	Resistance between Collector and Emitter, R_{CE}

P18.10 Results

P18.11 Conclusions and/or Validation

……..………

……..………

P18.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Explain why transistor is called bipolar device?
2. Give the reason for some transistors requiring heat sink?

P18.13 Suggested Learning Resources

Identify npn and pnp transistor

XIII. P19- ES110: PERFORMANCE OF BJT

P19.1 Practical Statement

Test the performance of NPN Transistor.

P19.2 Practical Significance

BJT is a three terminal active discrete component. BJT is available in two types NPN and PNP. BJT can be operated in any one of three configuration namely CE ,CB and CC. BJT performance can be tested by plotting its input and output characteristics Common Emitter (CE) mode is the universal mode of operation for a BJT. All types of amplifications can be performed using CE mode with suitable biasing. Common-emitter amplifiers are also used in radio frequency circuits. This practical is useful to test performance of NPN transistor in common emitter (CE) configuration.

P19.3 Relevant Theory

Common emitter is the most frequently used configuration in practical amplifier circuits, since it provides good voltage, current, and power gain. The input is applied across the base-emitter circuit and the output is taken from the collector-emitter circuit, making the emitter "common" to both input and output. CE configuration provides a phase reversal between input and output signals. For BJT configuration ref 1.2.3.2

P19.4 Practical Outcomes (PrO)

PrO1: Measure input and output currents and voltages.

PrO2: Sketch graph for voltage versus current.

PrO3: Test performance of NPN Transistor.

P19.5 Practical Setup (Circuit Diagram)

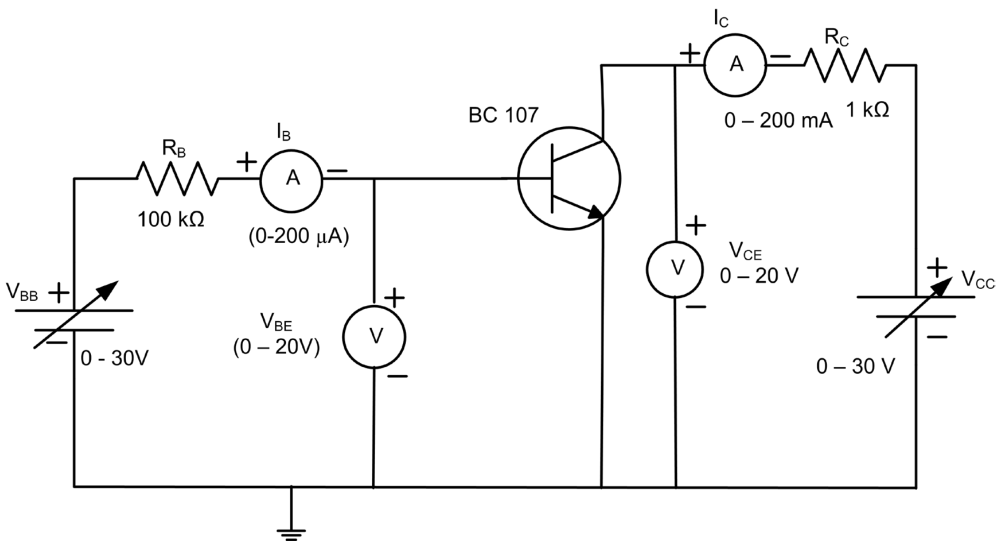


Fig. P19.1: Circuit diagram of BJT in CE mode

P19.6 Resources Required

Sr.No	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital Multi meter : 1/2 digit display with probes	2			
2.	DC Regulated power supply : Variable DC power supply 0- 30 V, 2 A, SC protection, display for voltage and current.	1			
3.	Voltmeter: (0 - 20 V), (0-2 V)	1 Each			
4.	Ammeter : (0 - 200 mA), (0 - 200 μA)	1 Each			
5.	Transistor : BC107 or any other equivalent	1			
6.	Resistor : 1 KΩ (0.5 watts/0.25 watts)	1			
7.	Breadboard : 15 cm X 17 cm	1			

P19.7 Precautions

1. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.
2. While doing the experiment do not exceed the input voltage of the transistor beyond its rated voltage. This may lead to damage of the transistor.
3. Connect voltmeter and ammeter with correct polarities as shown in the circuit diagram.

P19.8 Suggested Procedure

Part I

Input characteristics:

1. Connect the circuit as shown in Fig. P19.1.
2. Set VCE at constant voltage (2 V) by varying VCC.
3. Vary the input voltage VBE in steps of 0.1 V from 0 V up to 1V and record the corresponding value of I_B in observation table.
4. Repeat the above steps 2 and 3 by keeping V_{CE} at 5 V, and 10 V.
5. Sketch the characteristics from the recorded readings.
6. At suitable operating point calculate input resistance (ri).

Part II

Output characteristics:

1. Connect the circuit as shown in Fig. P19.1.
2. Set I_B constant at 10μA by varying V_{BB}
3. Vary the output voltage V_{CC} in steps of 1 V from 0 V upto 10 V and record the corresponding value of V_{CE} and I_C in observation table.
4. Repeat the above steps 2 and 3 by keeping I_B at 20 μA and 30 μA.
5. Sketch the characteristics from the recorded readings.
6. At suitable operating point calculate output resistance (r_o).

P19.9 Observations

Sr. No.	V_{CE} = 2V		V_{CE} = 5V		V_{CE} = 10V	
	V_{BE}(V)	I_B(μA)	V_{BE}(V)	I_B(μA)	V_{BE}(V)	I_B(μA)
1.						
2.						
3.						

Table P19.1: Input Characteristics

Sr. No.	I_B = 10μA		I_B = 20μA		I_B = 30μA	
	V_{CE}(V)	I_C(mA)	V_{CE} (V)	I_C(mA)	V_{CE} (V)	I_C(mA)
1.						
2.						

Table P19.2: Output Characteristics

Calculations: (from graph)

Input resistance R_i:

Output resistance R_o:

Current amplification factor α:

P19.10 Results and Interpretation

1. Input resistance R_i = Ω
2. Output resistance R_o = Ω
3. Current amplification factor β =……..…..

P19.11 Conclusions and/or Validation

……...……

……...……

P19.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference.Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Repeat the same experiment using PNP transistor.
2. Find out thedynamic input resistance of given BJT.
3. State the procedure to measure current gain in CC configuration..

P19.13 Suggested Learning Resources

BJT common emitter

XIV. P20 - ES110: CURRENT GAIN OF BJT

P20.1 Practical Statement

Determine current gain of Common Emitter transistor configuration.

P20.2 Practical Significance

BJT is a current operating ,bi-junction active semiconductor component. BJT can be operated in any one of three configuration namely C_E,C_B and C_C. Current gain of BJT is one of the important performance factor. This practical is useful to determine current gain of BJT .

P20.3 Relevant Theory

Common emitter is the most frequently used configuration in practical amplifier circuits, since it provides good voltage, current, and power gain. The input is applied across the base-emitter circuit and the output is taken from the collector-emitter circuit, making the emitter "common" to both input and output. In C_E configuration current gain is a ratio of output current I_c to input current I_b For BJT configuration, ref 1.2.3.2 of this unit.

P20.4 Practical Outcomes (PrO)

PrO1: Measure input and output currents.

PrO2: Use multi meter for direct current measurement.

PrO3: Determine current gain of CE configuration transistor.

P20.5 Practical Setup (Circuit Diagram)

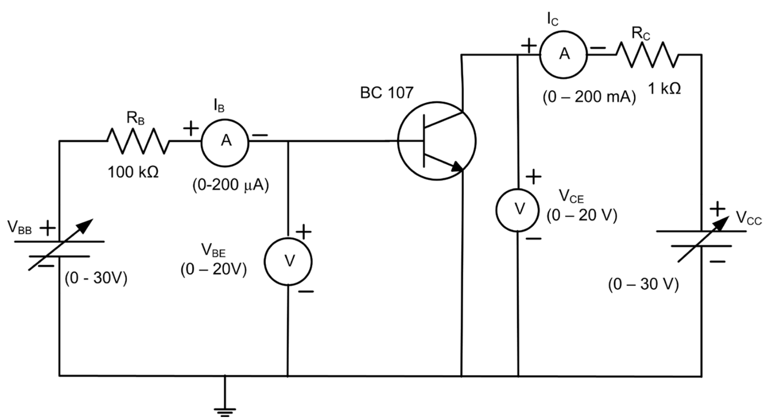


Fig. P20.1: Circuit diagram of BJT in CE mode

P20.6 Resources Required

Sr.No	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Digital Multimeter: 1/2 digit display with probes	2			
2.	Variable DC power supply: 0- 30 V, 2 A, SC protection, display for voltage and current.	1			
3.	Voltmeter: (0 - 20 V), (0-2 V),	1 Each			
4.	Ammeter: (0 - 200 mA, (0 - 200 μA)	1 Each			
5.	Transistor: BC107 or any other equivalent	1			
6.	Resistor: 1 KΩ (0.5 watts/0.25 watts)	1			
7.	Breadboard: 5 CM X 17 CM	1			

P20.7 Precautions

1. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.
2. While doing the experiment do not exceed the input voltage of the transistor beyond its rated voltage. This may lead to damaging of the transistor.
3. Connect voltmeter and ammeter in correct polarities as shown in the circuit diagram.

P20.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P20.1.
2. Set VCE at constant voltage (2V) by varying V_{CC}
3. Apply the input voltage V_{BE} as 0.8 V and record the corresponding value of I_B in observation table.
4. Apply biasing voltage V_{CC} = 7 V and record the corresponding value I_C in observation table.

P20.9 Observations

1. Input Current I_B =
2. Output Current I_C =

Calculations:

Current amplification factor or Current gain = I_C / I_B

P20.10 Results and Interpretation

Current gain in CE configuration is _______ .

P20.11 Conclusions and/or Validation

……...

……...

P20.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. Repeat the same experiment using direct muli-meter method.
2. Find out the current gain for different input and biasing voltages.
3. From data sheet find out value of current gain of a given transistor.

XV. P21- ES110: TRANSISTOR SWITCH CIRCUIT

P21.1 Practical Statement

Test the performance of transistor switch circuit.

P21.2 Practical Significance

One of the most basic applications of a transistor is using it to control the flow of power to another part of the circuit or in other words using it as a simple electric switch. Driving it in either cut-off or saturation mode, the transistor can create the binary on/off effect of a switch. Transistor switches are critical circuit-building blocks; they're used to interface circuits and also to make logic gates, which go on to create microprocessors, microcontrollers, and other integrated circuits that are useful in many applications. Thus through this experiment student will be able to appreciate the performance of a transistor working as a switch that can be made on or off by an external input.

P21.3 Relevant Theory

For theory refer sub topic 1.2.3.3 on 'Applications of Transistor' of this unit. The transistor are current regulating devices that control the amount of current flowing through them from the Emitter to the Collector terminals in proportion to the amount of biasing voltage applied to their base terminal, thus acting like a current-controlled switch. It works in three different regions: Active, Cut-off and Saturation according to applied biasing condition. a square wave input is applied in this circuit. When input is high, the transistor is turned on and works in saturation region. So maximum current IC flows through transistor as well as LED. Hence LED emits the light. When input is low (low means not enough to turn on the transistor), the transistor remains in cut off. So current IC is zero and therefore LED does not emit the light. As the input is square wave, the LED will turn on and off alternately.

P21.4 Practical Outcomes (PrO)

PrO1: Connect the circuit properly.
PrO2: Test the performance of transistor switch circuit.
PrO3: Use transistor as a switch to control an LED.

P21.5 Practical Setup (Circuit Diagram)

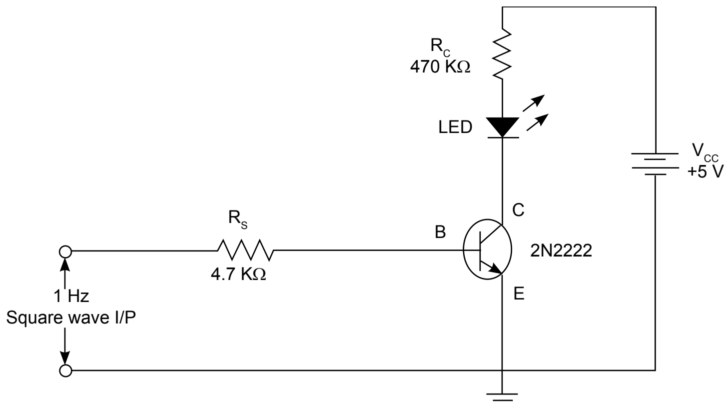


Fig. P21.1: shows the work situation of testing the performance of transistor switch circuit.

P21.6 Resources Required

Sr. No.	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	DC Power supply 0-30V	1			
2.	Breadboard: 5.5 cm X 17 cm	1			
3.	Function Generator: 1Hz- 1MHz	1			
4.	Resistors	1			
5.	Transistors: NPN, 2N2222 (or BC547 or any other equivalent transistor)	1			
6.	Light Emitting Diode				
7.	Connecting wires, Single strand Teflon coating (0.5 mm diameter)	L.S.			

P21.7 Precautions

1. Ensure that all corrections are correct and neat.
2. While doing the experiment select proper function of multi-meter.

P21.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P21.1.
2. Obtain a constant amplitude 1 Hz square wave from function generator of 5V p-p.
3. Apply square wave signal to the base and ground in the circuit from function generator.
4. Apply 5V V_{CC} to collector and ground.
5. Observe the indication of LED.

P21.9 Observations

LED is _______ . (glowing /not glowing)

P21.10 Results and Interpretation

P21.11 Conclusions and/or Validation

……..……………………………………………………………………………………………………

……..……………………………………………………………………………………………………

P21.12 Practical related Questions

1. Explain the advantages of an electronic switch over a mechanical or electro mechanical switch.
2. Explain the term switching circuit.
3. Describe when does the transistor acts as (a) a closed switch (b) an open switch.

BJT: Common Emitter Configura-tion

P21.13 Suggested Learning Resources

XVI. P22: ES110- PERFORMANCE OF TRANSISTOR AMPLIFIER CIRCUIT

P22.1 Practical Statement

Test the performance of transistor amplifier circuit.

P22.2 Practical Significance

Single stage low power amplifiers are generally used for small signal amplification in the electronic circuit. Low power amplifier is used in various electronic appliances and electronic communication. This practical will help the students to develop skills to build and test single stage low power common emitter amplifier.

P22.3 Relevant Theory

Low power amplifier is an electronic device that can increase the power of a signal. An amplifier uses electric power from a power supply to increase the amplitude of a signal by an amplifier but not all amplifiers are the same as they are classified according to their circuit configurations and methods of operation. There are many forms of electronic circuits classed as amplifiers, from operational amplifiers and small signal amplifiers up to large signal and power amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal, that is the relationship between input signal and current flowing in the load. There are three different kinds of amplifier gain which can be measured and these are: Voltage Gain (A_v), Current Gain (A_i) and Power Gain (A_p) depending upon the quantity being measured.

P22.4 Practical Outcomes (PrO)

This practical is expected to develop the following skills

Test the performance of transistor amplifier circuit:

PrO1: Select relevant electronic active and passive components.

PrO2: Test BJT, resistors and capacitor.

PrO3: Mount the electronic component on breadboard as per circuit diagram.

P22.5 Practical Setup (Circuit Diagram)

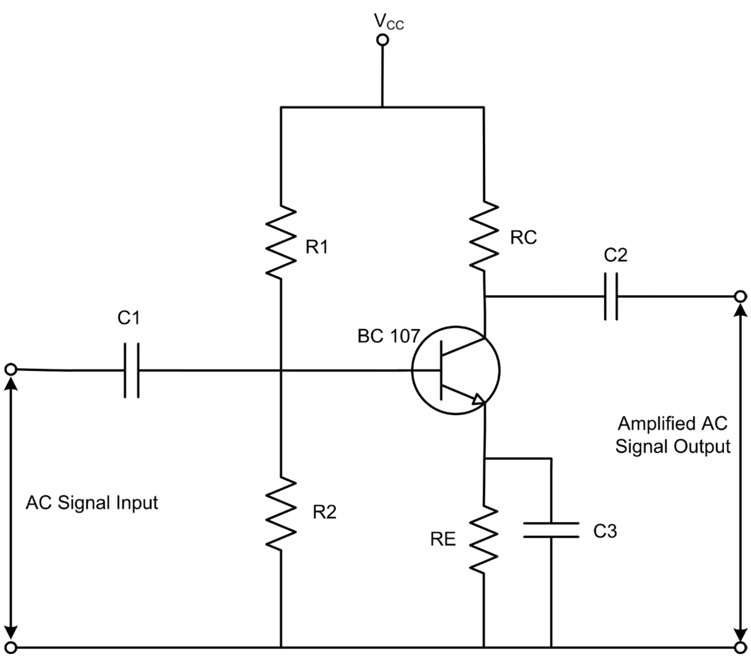


Fig. P22.1: Transistor amplifier circuit

P22.6 Resources Required

Sr. No	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Cathode Ray Oscilloscope: (Analog type) 30/100 MHz Frequency	1 No.			
2.	Function Generator: 0-2 MHz with sine, square and triangular output with variable frequency and amplitude	1 No.			
3.	Regulated DC Power Supply: 0-30 V, 2 Amp SC protection	1 No.			
4.	Transistor: BC 547 or equivalent Transistor	1 No.			
5.	Resistors: R_1 = 33 KΩ, R_2 = 3.3 KΩ, RC = 1.5 KΩ, RE = 470 Ω	1 No.			
6.	Capacitors: C_1 = 0.1 μf, C_2 = 0.1 μf, C_3 = 10 μf	1 each			
7.	Breadboard: 5.5 cm × 17 cm	1 No.			
8.	Connecting wires: Single strand Teflon coating (0.6 mm diameter)	As per requirement			

P22.7 Precautions

1. Ensure proper connections are made to the equipment.
2. Ensure the power switch is in 'off' condition initially.
3. Ensure the use of proper settings of function generator and CRO.

P22.8 Suggested Procedure

1. Build circuit on breadboard as per diagram.
2. Connect function generator output to CRO and observe input signal on CRO.
3. Select appropriate amplitude of A C signal (10 mV to 20 mV) and frequency (1 KHz) on function generator.
4. Connect Function generator at input terminals and CRO at output terminals of circuit.
5. Switch on DC Power Supply.
6. Observe output waveform on CRO.
7. Vary input frequency (100 Hz to 2 MHz) and note down output voltage from CRO.
8. Calculate Gain. Repeat step 7 for twenty readings by varying the function generator frequency.
9. Plot frequency response on semi-log paper.

P22.9 Observations

Input Voltage in mV (To be kept Constant), V_i = ---------

Table P22.1: Observation Table

Sr. No.	Input Frequency (Hz)	Output Voltage, V_o (Volts)	Voltage Gain ($A = V_o/V_i$)	Gain in dB $20 \log(V_o/V_i)$
1.				
2.				

Calculations:

Voltage Gain : V_o/V_i

Voltage Gain at 1 KHz : V_o/V_i

3 dB Bandwidth, B/W = F_H-F_L

P22.10 Results and Interpretation

1. Mid Frequency Region =…………………..
2. Bandwidth =……………………

P22.11 Conclusions and/or Validation

……..……

……..……

P22.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined courseoutcomes.

1. Identify type of biasing used in circuit.
2. Suggest the changes required in circuit if PNP transistor is used.
3. Suggest equivalent transistor using datasheet.

22.13 Suggested Learning Resources

1. "Data Sheet of BC547", https://www.alldatasheet.com/datasheet-pdf/pdf/11551/ONSEMI/BC547.html

KNOW MORE

Micro-project(s) /Activities

Undertake one or two micro project(s) /activity(ies) in a group of 5 - 6 students under the guidance of faculty and present it as group with individual participation as well. A sample list is given below:

a. Prepare a chart of electric circuit elements and their relevant industrial applications.

b. Collect datasheets of different types of resistors, capacitors, inductors and diodes.

c. Collect information and prepare a report on surface mount devices i.e. lead less devices.

d. Measure the voltage using Digital Multimeter at the following terminal points.

Step 1: Choose the appropriate measuring range. Place the selector knob to AC voltage measurement.

Measure the voltage at the 5 Amp switch socket outlet. Observe and note the voltage reading displayed. Now change the selector knob to DC voltage measurement and again measure the voltage at the socket outlet. Note the reading displayed.

Step 2: Repeat Step 1 for measurement of voltage at the terminals of a given Lead-Acid battery.

Comment and infer on the reading observed and noted at Steps 1 and 2.

Video Resources

Passive compo-nents

Use of ICT

Basic Electrical

Note for Resistor Combinations

REFERENCES AND SUGGESTED READINGS

1. Ritu Sahdev, *Basic Electrical Engineering*, New Delhi: Khanna Publishing House, 2018.
2. V.N. Mittle, and A. Mittal, *Basic Electrical Engineering*, McGraw Education, 2017.
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4. B. L. Theraja, *Electrical Technology*, Vol. - I, New Delhi: S. Chand and Company, 2015.
5. V.K. Mehta and Rohit Mehta, *Principles of Electronics,* S. Chand and Company, New Delhi, 2014.
6. David A. Bell, *Electronic Devices and Circuits,* New Delhi: Oxford University Press, 2011.

2 Overview of Analog Circuits

UNIT SPECIFICS

This unit discusses the following topics:

- Basics of Op Amp IC 741
- Op Amp parameters
- Ideal Op Amp characteristics
- Op Amp open loop configuration
- Op Amp close loop configuration
- Op Amp Inverting mode amplifier
- Op Amp Non-inverting mode amplifier
- Op Amp as an adder
- Op Amp as a differentiator
- Op Amp as an integrator

The practical applications of the topics are discussed. Multiple choice questions as well as subjective questions and number of numerical problems are provided for practice. Related practical, followed up by a "Know More" section containing micro projects and activities, video resources along with ICT are given. A list of references and suggested readings are given in the unit so that one can go through them for further practice and enhancement of learning.

RATIONALE

Operational Amplifier (Op-Amp) is the most versatile and Integrated Circuit (IC). An IC is a small semiconductor based electronic device or a microchip on which thousands and hundreds of discrete electrical components, such as resistors, capacitors and transistors, are fabricated. Op Amp is used to develop various applications of analog electronic circuits and is highly popular. This unit is intended to develop the skills to build, test, and diagnose the Op Amp based electronic circuits. This unit deals with various aspects of analog circuits based on Op Amp that are used in various industrial , consumer and domestic applications.

PRE-REQUISITE

1. Science: Effects of Current (Class X)
2. Applied Physics-I: Physical world, Units and Measurements (Semester I)
3. Mathematics-1: Algebra (Semester I)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U2-O1: Describe Op Amp parameters.

U2-O2: Explain Op Amp configurations.

U2-O3: Describe Op Amp as an inverting and non-inverting amplifier.

U2-O4: Use Op Amp for basic applications.

Unit-2 Outcomes	Expected Mapping with Course Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U2-O1	1	3	-	-	-	-
U2-O2	1	3	-	-	-	-
U2-O3	1	3	-	-	-	-
U2-O4	2	3	-	-	-	-

Robert John Widlar (1937-1991)
known as a legendary chip designer was instrumental for the design of first mass-produced operational amplifier ICs. A self-taught radio engineer, Walter Widlar worked for the WGAR (1220 AM) radio station and designed pioneering ultra-high frequency transmitters. The world of electronics surrounded him since birth. Widlar invented the basic building blocks of linear integrated circuits including the Widlar current source, the Widlar band gap voltage reference[] and the Widlar output stage. Widlar, together with David Talbert in 1964 created the first mass- produced operational amplifier ICs . This led to Fairchild Semiconductor and National Semiconductor, becoming the leaders in linear integrated circuits. National Semiconductor where he worked as a contractor produced a series of advanced linear ICs including the first ultra-low-voltage operational amplifier (LM10).

2.1 FUNDAMENTALS OF OPERATIONAL AMPLIFIERS

2.1.1 Introduction

Now a days electronic circuits plays a vital role in all engineering field application. Two main types of electronic circuits are analog electronic circuit and digital electronic circuit. Rectifier, amplifier and oscillator are most commonly used analog electronic circuits. These circuits can process continuous signals i.e. linear or analog signals. Therefore analog circuits are also called as linear electronics circuits. Rectifier circuit is used to convert A.C. signals in to D.C. signals. Diodes are used for rectifier circuits. Amplifier is used to increase amplitude of input signals. Amplifier can be constructed using discrete components such as BJT or FET. Analog circuits constructed using discrete components shows many drawbacks such larger size, more power consumption and less reliability. To overcome these drawbacks integrated circuits (IC) are used. Operational amplifiers known commonly as Op Amps are very popular building blocks in electronic circuits. Op-amps are used for a variety of applications such as AC and DC signal amplification, filters, oscillators, voltage regulators, comparators and in most of the consumer and industrial applications.

2.1.2 Basics of Op Amp

Operational amplifiers are a direct coupled high gain amplifier usually consisting of one or more differential amplifier followed by level shifter and output stage. The term "operational" is used in the name because these amplifiers were initially used in mathematical operations.

An operational amplifier is represented by the symbol given in Fig. 2.1. The most commonly used Op Amp IC is μA 741, which is manufactured by many manufacturers. Two prefix characters in IC number indicates manufacturer. Table 2.1 shows prefix and manufacturer names. Fig. 2.2 shows pin configuration of IC 741. Table 2.2 shows pin functions for IC 741.

Table 2.1: Prefix Characters and Manufacturer names for IC 741

Prefix Characters	Name of Manufacturer
AD	Analog Devices
LM	National Semiconductor
MC	Motorola
NE/ SE	Signetics
OP	Precision Monolithic
TI	Texas Instruments
μA	Fairchild

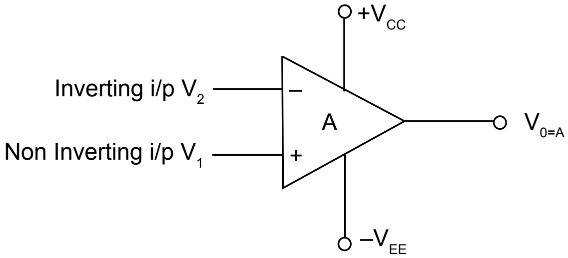


Fig. 2.1: Symbol of Op Amp

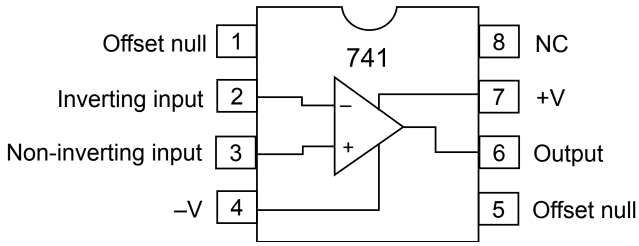


Fig. 2.2: Pin out diagram of IC 741 (μA 741)

Table 2.2: Pin Functions of IC 741

Pin No.	Pin Label	Pin Function
1	Offset Null	It is used to remove or minimize offset voltage. It is used along with Pin No. 5.
2	Inverting Input	This is denoted by minus (–) sign on symbol. A signal applied to this input appears as an amplified but phase inverted signal at the output.
3	Non-Inverting Input	This is denoted by plus (+) sign symbol. A signal applied to this terminal appears at the output as an amplified signal which has the same phase as that of input signal.
4	$-V_{CC}$	Biasing power supply pin for negative supply Normally - 15 V is applied.
5	Offset Null	It is used to remove or minimize offset voltage. It is used along with Pin No. 1.
6	Output	Single ended output from Op Amp is available from this pin.
7	+VCC	Biasing Power supply pin for positive supply Normally + 15 V is applied.
8	NC	Not connected.

2.1.2.1 Packages

Three popular packages that are available are as follows:

1. The dual-in-line package (DIP)
2. The metal can (TO) package
3. The flat package or flat pack

Op Amp packages may contain single, two (dual) or four (quad) op-amps in a single IC. Typical package has 8 terminals, 10 terminals and 14 terminals. The widely used very popular type, μA741 is a single Op Amp IC and it is available in various packages as shown in Fig.2.3. The μA747 is a dual 741 and comes in either a 10-pin can or a 14-pin DIP.

a. Dual-in-line plastic (DIP) package

b. TO-5 style package with straight leads

c. Flat pack

Fig. 2.3: Various IC packages of 741 Op Amp

2.1.2.2 Op Amp parameters

The operational amplifier is simply a high gain, direct coupled amplifier. It is usually designed to amplify the signals extending over a wide frequency range and is normally used with external feedback networks. There are various parameters of Op Amp, which are necessary for faithful amplification. Op Amp has different electrical parameters like differential input resistance, input offset voltage, output offset voltage and common mode rejection ratio. As the operational amplifier has become an universal building block for circuit and system design, a number of widely accepted design terms have involved, which describe the comparative merits of various Op Amp circuits. In this section, the parameters commonly used to characterize operational amplifier performance are explained.

Op-Amp

Input offset current (I_{io}): The input offset current is the difference between the separate currents entering the input terminals of a balanced amplifier. Referring to Fig.2.4

$$I_{io} = I_{B1} - I_{B2}, \text{ when } V_o = 0 \qquad \ldots(2.1)$$

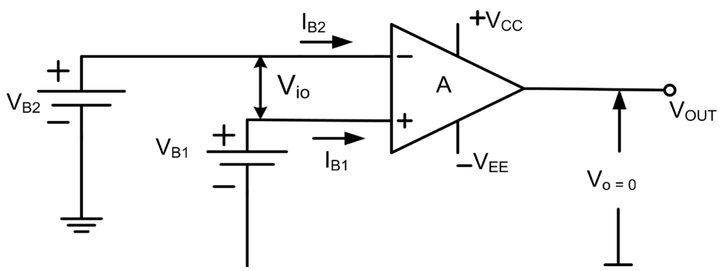


Fig. 2.4: Input bias currents I_{B1} and I_{B2}; and offset voltage V_{io}

Input bias current (I_B): The input bias current I_B is the average value of the current flowing into input terminals with the output at zero volt. From Fig. 2.4,

$$I_B = (I_{B1} + IB_2) / 2, \text{ when } V_o = 0 \quad \ldots(2.2)$$

Input offset current drift: It is defined as the ratio of the change of input offset current to the change of temperature.

$$\textit{Input offset current drift} = \Delta Iio / \Delta T \quad \ldots(2.3)$$

Input offset voltage (V_{io}): It is that voltage required to apply between the input terminals to get output voltage zero, with no input signal.

Input offset voltage drift : It is defined as the ratio of the change of input offset voltage to the change in temperature.

$$\textit{Input offset voltage drift} = \Delta Vio / \Delta T \quad \ldots(2.4)$$

Output offset voltage: It is the output voltage of the Op Amp when the input terminals are grounded. For ideal Op Amp this parameter, it is 0V. For practical Op Amp this parameter value must have very low value. To minimize it offset null pins are used.

Common mode range: It is the maximum range of input voltage that can be simultaneously applied to both inputs without causing cut-off or saturation of amplifier stages.

Input differential range: It is the maximum difference signal that can be applied safely to the Op Amp input terminals.

Output voltage range: It is the maximum output swing that can be obtained without significant distortion.

Full power bandwidth: It is the maximum frequency range over that the full output voltage swing can be obtained.

Power Supply Rejection Ratio (P.S.R.R.): The power supply rejection ratio is the ratio of the change in input offset voltage to the corresponding change in one power supply voltage, with other power supply voltages held constant.

Slew rate (Sr): This is the maximum rate of change of output voltage. It is also defined as the rate of change of the closed loop amplifier's output voltage. It is expressed in V/μS unit. Maximum operating frequency of Op Amp depends on slew rate.

$$Fmax = \textit{slew rate} / (2\pi V_P) \quad \ldots(2.5)$$

Unity gain bandwidth: This is the frequency range from direct current i.e. 0 Hz to that frequency at which the open-loop gain crosses unity.

Input impedance (Z_i): It is defined as the ratio of input voltage Vi to the input current Ii.

$$\textit{Input impedance } Z_i = V_i / I_i \quad \ldots(2.6)$$

Output voltage swing: The AC output is the maximum unclipped peak to peak output voltage that an Op Amp can produce. Since the quiescent output is ideally zero, the AC output voltage can swing positive or negative. This also indicates the values of positive and negative saturation voltages of the OPAMP. The output voltage never exceeds these limits for a given supply voltages $+V_{CC}$ and $-V_{EE}$. For 741 IC, it is ± 13 V.

Common mode rejection ratio (CMRR): The ability of differential amplifier to reject a common mode signal is expressed by its common mode rejection ratio. It is the ratio of differential mode gain Ad to the common mode A_{cm}. It is usually expressed in decibel (db).

$$CMRR = A_d / A_{cm} \quad \ldots(2.7)$$

To calculate CMRR in dB

$$CMRR \ in \ dB = 20 \ log_{10} \ (A_d / A_c) \qquad \ldots(2.8)$$

Differential input resistance (Ri): It is equivalent resistance measured at either input terminal with other terminal grounded.

2.1.3 Ideal Op Amp

The ideal Op Amp has the following properties:

1. Its input impedance is infinite ($Z_i = \infty$).
2. Its output impedance is zero ($Z_o = 0$).
3. It has infinite voltage gain ($A_V = \infty$).
4. It has infinite bandwidth i.e. its open-loop gain tends to infinity. i.e. it provides a constant gain for all frequency ranges.
5. Common Mode Rejection Ratio (CMRR) is infinite.
6. It produces zero output voltage when $V_1 = V_2$.
7. Characteristics do not drift (swing) with temperature.

Ideal Op Amp

The ideal operational amplifier is shown in Fig. 2.5. A signal appearing at the negative terminal (V_2) is inverted at the output, a signal appearing at the positive terminal (V_1) appears at the output with no change in sign. Hence, the negative terminal is called the "inverting" terminal and the positive terminal the "non-inverting" terminal. In general, the output voltage is directly proportional to $V_d = V_1 - V_2$. The constant of proportionality (A_V) is called the voltage gain of the amplifier.

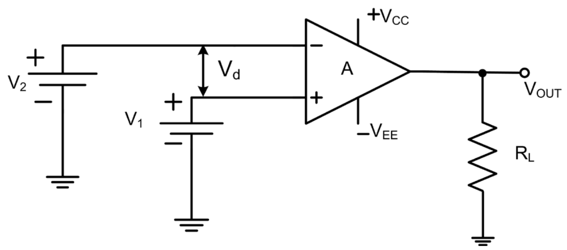


Fig. 2.5: Ideal op-amp

In practice, when Op Amp is selected for some specified application then its parameters are observed from data sheets. Table 2.3 shows some essential parameter values for IC741.

Table 2.3: IC741 parameters

Sr. No.	Parameter	Typical Value (at 25^0 C)
1.	Input impedance	2 MΩ
2.	Output impedance	75 Ω
3.	CMRR	90 dB
4.	Supply Voltage	+/- 18 V
5.	Input offset voltage	1mV
6.	Input offset current	20 mA
7.	Input bias Current	80 mA
8.	Differential Input Voltage	+/- 15 V
9.	Bandwidth	1 MH_Z
10.	Slew Rate	0.5 V $/_{\mu}S$

2.1.4 Op Amp Configurations

Op Amp can be operated in any one of two configurations. Two configurations are: Open loop configuration and close loop configuration.

2.1.4.1 Op Amp Open loop configuration

The Op Amp without feedback is known as open loop configuration of Op Amp.

Open-loop gain (A_{OL}): If 'V_d' is the differential input voltage of an Op Amp, it is very small and V_o is the output voltage, then open-loop gain can be defined as the ratio of the output voltage V_o to the differential input voltage V_d. It is termed as open-loop gain because possible feedback connection between output and input terminals are absent.

The open-loop gain, $A_{OL} = Vo / Vd.$ …(2.9)

In open loop as feedback is absent ,so gain is infinite and non-controllable. To control gain and operate Op Amp as per requirement feedback is essential. Feeding some part or complete output signal to input is called as feedback.

2.1.4.2 Op Amp Close loop configuration

The Op Amp without feedback is not very useful device, since the extremely small voltage at the input will cause it to go into saturation at the output. Hence, it is necessary to apply feedback to get finite voltage gain. When feedback is applied, the characteristics of the Op Amp are determined largely by the feedback network Amp with feedback is called as close loop configuration.

Closed-loop gain (ACL): The gain of the amplifier is called closed-loop gain because the feedback resistor closes a loop from the Op Amp output terminal to the inverting input terminal i.e. negative terminal.

Closed-loop gain, $A_{CL} = Vo / Vi$ …(2.10)

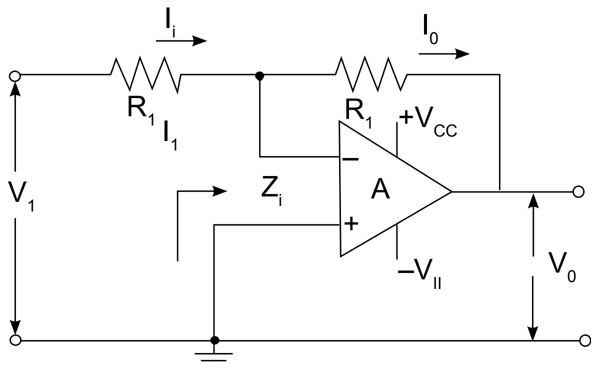


Fig. 2.6: Op-amp close-loop configuration

It is found that the closed-loop gain for inverting amplifier shown in Fig.2.6 which is called as inverting amplifier is equal to – (R_f/R_1).

Output impedance (Zo): The closed-loop output impedance $Z_{o(CL)}$ of an O_p Ampis defined as the ratio of the open-loop output impedance Zo(OL) to the loop gain. Thus,

$$Z_o(CL) = Z_o(OL)/Loop\ gain \quad ...(2.11)$$

where, *Loop gain = Open-loop gain – Closed-loop gain.*

The virtual ground: To illustrate the features of an operational amplifier, consider the feedback circuit, Fig. 2.7 in which negative voltage feedback is produced by the resistor R_f connected between the input and output. Note that the feedback is negative because of phase inversion in the amplifier. The feedback ratio in operational feedback can vary from unity for a high impedance source to R/(R + R_f) for a low impedance source since, the feedback voltage is sufficiently connected in parallel with the input signal source. It is convenient to analyse the operational feedback circuit by applying Kirchhoff's current law to the branch point S. Since, the amplifier input impedance is large, the current in this branch is negligible, which means the current in R equals the current in R_f.

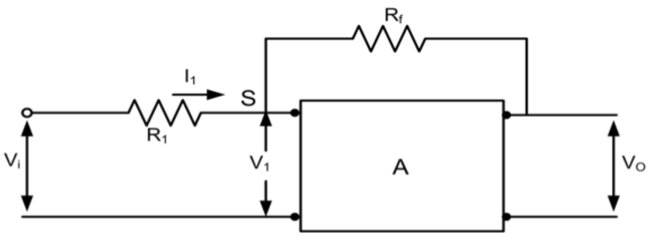


Fig. 2.7: Block diagram of Op Amp with feedback

$$\frac{V_i - V_1}{R} = \frac{V_1 - V_o}{R_f}$$

Introducing $V_1 = \frac{-V_O}{A}$ and rearranging, $V_o\left(1 + \frac{1}{A} + \frac{Rf}{A}\right) = -\frac{R_f}{R} \cdot V_i$

Since, the gain is very large, $V_o = -\frac{Rf}{R} . V_i$

which means that the output voltage is just the input voltage multiplied by the constant factor – (R_f / R). If precision resistors are used for R_f and R, the accuracy of this multiplication operation is quite good.

The branch point 'S' has a special significance in op-amps. This may be illustrated by determining the effective impedance between S and ground, which is given by the ratio V_1 to the input current I_1.

$$Zs = \frac{V_I}{l_i} = \frac{V_I R_f}{V_I - V_o} = \frac{R_f}{1 - \frac{V_o}{V_1}} = \frac{R_f}{1 + A} \quad \text{...(2.13)}$$

where, the right hand side of equation has been inserted for the input current. According to equation 2.1.13, the impedance of S to ground is very low if the gain is large. The typical values are $R_f = 10^5$ ohms and $A = 10^4$ so that the impedance is 10 ohms. The low impedance results from the negative feedback voltage, which cancels the input signal at 'S' and tends to keep the branch point at ground potential. For this reason, the point 'S' is called virtual ground. Although 'S' is kept at ground potential by feedback action, no current to ground exists at this point.

2.1.5 Op Amp operating modes

The Op Amp can be effectively utilized in linear application by providing feedback from the output to the input. If the signal fed back is out of phase by 180^0 with respect to the input, then feedback is called as negative feedback or degenerative feedback. The commonly used closed loop operating modes are

a. Inverting amplifier
b. Non-inverting amplifier

2.1.5.1 Op Amp Inverting mode amplifier

The inverting operational amplifier configuration is one of the simplest and most commonly used op amp operating mode. In inverting mode amplifier, the output is exactly 180^0 out of phase with respect to input (i.e. if a positive voltage is applied, output will be negative). Output is an inverted (in terms of phase) amplified version of input. The inverting operational amplifier configuration is a closed loop mode application of Op Amp. It uses negative feedback, which means that the feedback signal opposes input signal.

$$V_O = -(R_f/R_1)*V_i \quad \text{...(2.14)}$$

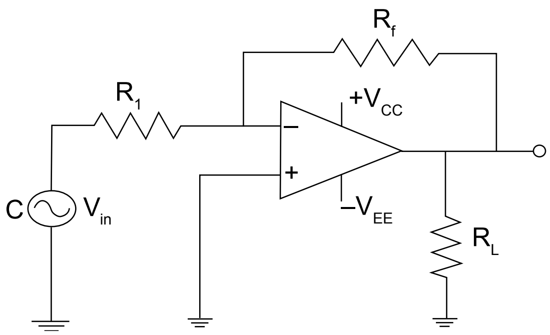


Fig. 2.8: Inverting Amplifier

The circuit diagram shown in Fig. 2.8 is the operational amplifier used in inverted mode. In this mode of operation, the positive input terminal of the amplifier is grounded and the input signal e1 is applied to the negative input terminal through resistor R_1. The feedback applied through R_f from the output to the input terminal is negative. The inverting operation performed by circuit is determined by the feedback resistor R_f and the input resistor R_1.

Considering that the Op Amp is ideal meaning thereby that it has infinite gain. With infinite voltage gain, the potential difference between the input terminals must be zero. In the circuit the voltage between input terminals is forced to zero by the negative feedback around the amplifier. As the input impedance of the amplifier is infinite, the input current to the amplifier is zero. Hence for ideal op-amp, following two conditions must be satisfied:

i. The potential difference between the amplifier terminals is zero.

ii. The current into each input terminal is zero.

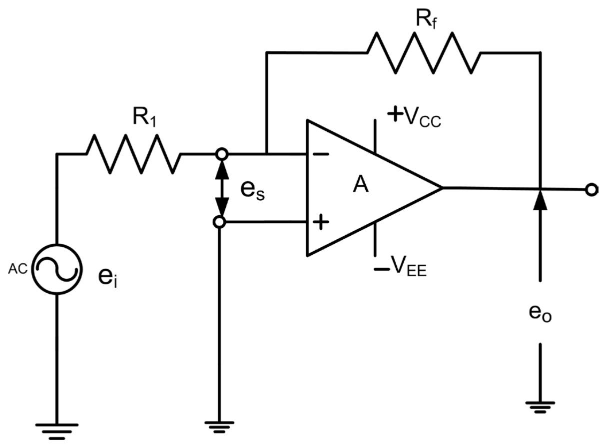


Fig. 2.9: Operational amplifier in inverting mode

Note that the first condition will follow on the assumption that the input voltage of the amplifier is infinite. Thus, a finite output divided by zero input gives infinite gain which is nothing but the characteristic of an op-amp. The voltage $e_s = 0$ implies that the terminal (1) has same potential as that of terminal (2). But terminal (2) is grounded, hence terminal (1) is also virtually grounded. Hence, there is a virtual ground at negative terminal.

Thus, the current 'i_1' flowing through R_1 also flows through R_f. Since the input current is very small, it can be approximated to zero. For any input voltage applied at the inverting input, the input differential voltage is negligible and input current is zero. Hence the inverting input appears to be a ground. The term virtual ground signifies a point which voltage with respect to ground is zero and yet no current can flow into the point.

Therefore, $i_1 = i_f$, …(2.15)

$$\frac{e_I - e_s}{R_I} = \frac{e_s - e_o}{R_f}$$

As, $e_s = 0$,

$$\frac{e_I - o}{R_I} = -\frac{o - e_o}{R_f}$$

$$\frac{e_I}{R_I} = \frac{-e_o}{R_f}$$

$$\frac{e_o}{e_I} = -\frac{R_f}{R_I} \quad \text{...(2.16)}$$

Here, (e_o/ e_i) ratio is termed as closed-loop gain ACL of the inverting amplifier. It is a negative quantity because the closed-loop amplifier reverses the sign of the input signal, i.e. the output is out of phase with input. The gain depends on the ratio of R_f/R_i.

It shows that the input impedance depends only on the external resistor R1. The output impedance is defined as the impedance seen at the output of the Op Amp, when the input terminal is set equal to zero. The ratio of feedback resistance and input resistance can be set to any value, even to less than 1. Because of this property Op Amp is popular in majority of applications.

1 It give phase difference of 180^0 between input and output.

2 Input impedance is lower.

3 Smaller bandwidth as compared to non-inverting amplifier.

2.1.5.2 Op Amp Non-inverting mode amplifier

The non-inverting amplifier configuration is one of the most popular and widely used forms of operational amplifier circuit. The op amp non-inverting amplifier circuit provides a high input impedance along with all the advantages gained from using an operational amplifier.

Non-inverting amplifier is one in which the output is in phase with respect to input(i.e. if input is positive voltage, output will be positive). Output is a Non inverted(in terms of phase) amplified version of input.

$$V_o = (1+(R_f/ R_1))*V_i \quad \text{…(2.17)}$$

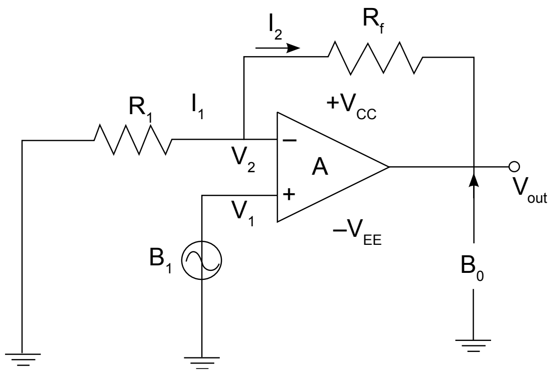


Fig. 2.10: Non-inverting Amplifier

The circuit diagram of an ideal Op Amp in the non-inverting mode is shown in Fig.2.10. In this case, the input signal is applied directly to the non–inverting (positive) input terminal of the amplifier and the feedback resistor R_f is connected between the output terminal and negative input terminal.

The R_1 is connected between the inverting terminal and ground, similar to previous case, $e_s = 0$. Therefore, voltage e_1 from the negative terminal to ground is equal to the input voltage e_2. Note that e_1 is not equal to zero in this case, meaning that non-inverting circuit has no virtual ground at either one of its input terminals.

Since, $e_1 = e_2$ $\quad e_1 = i_1$ $\quad R_1 = e_o \dfrac{R_1}{R_1 + R_f} = e_2$

Thus,
$$\frac{e_0}{e_2} = \frac{R_f + R_1}{R_1}$$

Or
$$\frac{e_0}{e_1} = \frac{R_f + R_1}{R_1}$$

But $\dfrac{e_0}{e_2}$ is closed-loop gain.

Thus,
$$A_{CL} = \frac{R_f + R_1}{R_1} = \frac{R_f}{R_1} + \frac{R_1}{R_1} = \frac{R_f}{R_1} + 1$$

$$A_{CL} = \frac{e_0}{e_2} = \left(1 + \frac{R_f}{R_1}\right) \quad \ldots(2.18)$$

Thus, the closed-loop gain of a non-inverting amplifier is always greater than or equal to unity and is determined by R_1 and R_f. If $R_f = 0$ and $R_1 = \infty$, then the gain is exactly equal to one and the amplifier acts as a voltage follower i.e. the output voltage follows the input voltage exactly. The advantage of such a voltage follower and of non-inverting circuits in general is impedance buffering. Such amplifier circuits are widely used to provide isolation of signal source and load thus, preventing undesired interactions or loading effects.

Advantages of Non-inverting Amplifier

1. There is no phase shift between input and output.
2. The input impedance is higher than inverting configuration.
3. Larger bandwidth as compared to inverting amplifier.
4. Circuit uses negative feedback.

Solved Problems

Example 2.1.1: The output voltage of Op Amp changes by 40 V in 8μS. Calculate slew rate of Op Amp.

Solution:

Slew Rate = dV/dt
= 40V/8 μS
= 5 V/μS

Example 2.1.2: For the inverting amplifier mode of Op Amp R_f = 10 KΩ and R_i = 2 KΩ .Calculate close loop voltage gain A_{CL}.

Solution: The close loop voltage gain in inverting mode = – R_f / R_1
= – (10 KΩ /2 KΩ)
= – 5

Example 2.1.3: For the non-inverting amplifier mode of Op Amp R_f = 10 KΩ and R_i = 1 KΩ .Calculate close loop voltage gain A_{CL} and feedback factor.

Solution:

The close loop voltage gain in non-inverting mode = 1+ (R_f / R_1)
= 1 +(10 KΩ /1 KΩ)
= 11

Feedback factor β = R_1 /(R_1 + R_f)
= 1 KΩ /(1 KΩ +10 KΩ)
= 0.09

Example 2.1.4: Calculate the CMRR of Op Amp that has a differential gain of 300000 and common mode gain is 12.66.

Solution:

CMRR is the ratio of differential mode gain to common mode gain.

$$\text{CMRR} = A_d / A_C$$
$$= 300000/12.66$$
$$= 13850.41$$
$$\text{CMRR in dB} = 20 \log_{10}(A_d/A_C)$$
$$= 82.82 \text{ dB}$$

Example 2.1.5: Calculate the feedback resistor value if in Non-inverting Op Amp amplifier input resistor is of 4 KOhm and required gain for specific application is 13.

Solution:

Given that Op Amp operating mode is Non-inverting amplifier mode.

Input resistance value R_{in} = 4 KOhm

$$\text{Gain} = 13$$
$$\text{Gain} = 1+(R_f/R_{in})$$
$$13 = 1+ (R_f/4 \text{ KOhm})$$
$$13 - 1 = R_f/4 \text{ KOhm}$$
$$12 = R_f/4 \text{ KOhm}$$
$$R_f = 48 \text{ KOhm}$$

2.2 Applications of Operational Amplifiers

The Op Amp was originally developed for requirement of analog computer. As Op Amp is a high gain direct coupled amplifier with feature of externally voltage gain controlled, it finds many applications in signal processing and conditioning applications. Due to its low cost, high performance and versatile nature, it is used in many analog electronics circuits.

It is always used in close loop mode with negative feedback and the voltage gain is controlled by external component Ri and Rf .When the power supply is connected there is output even when the two inputs are grounded this is called offset. It can be made zero by connecting 10 KΩ POT between pin 1 and 5 and connecting wiper to Pin 4.

2.2.1 Op Amp as an Adder

Adder and substractor circuit using Op Amp is used to perform arithmetic operations like addition, subtraction etc Op Amp adder is also called as summing amplifier In adder and subtractor circuit the input signal can be added and subtracted to the desire value by selecting appropriate values for the external resisters. These arithmetic functions employed in analog circuits. This circuit can be used to add AC or DC signals. This circuit provides an output voltage proportional to or equal to the algebraic sum of two or more input voltage each multiplied by a constant gain factor. In inverting configuration of an OP Amp if more than one input is given to inverting terminal then resultant circuits work as summing amplifier or adder.

The Op Amp

$$V_o = -(R_f / R_i) * (V_1 + V_2) \quad \text{...(2.19)}$$

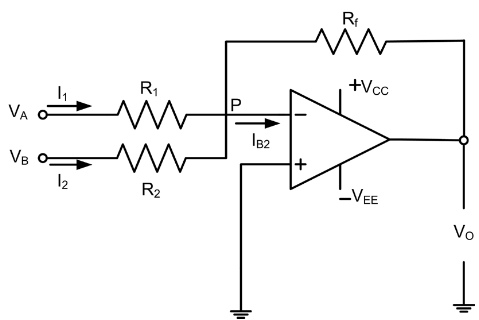


Fig. 2.11: Op Amp as an Adder circuit

Here, the voltages are amplified and then added.

Applying KCL at inverting input node,

$$i_1 + i_2 = i_f + I_{B_2}$$

As Op Amp is ideal, $I_{B_2} = 0$

$$i_1 + i_2 = i_f$$

$$\frac{V_A - V_P}{R_1} + \frac{V_B - V_P}{R_2} = \frac{V_P - V_o}{R_f}$$

Due to virtual ground, $V_p = 0$.

$$\frac{V_A}{R_1} + \frac{V_B}{R_2} = \frac{V_o}{R_f}$$

$$V_0 = -R_f\left(\frac{V_A}{R_1} + \frac{V_B}{R_2}\right)$$

$$V_0 = -\left(\frac{R_f}{R_1}V_A + \frac{R_f}{R_2}V_B\right)$$

If $R_1 = R_2 = R$

$$V_0 = -\frac{R_f}{R}[V_A + V_B] \quad \text{...Summing amplifier (2-20)}$$

If $R_1 = R_2 = R_f = R$

$$V_o = -(V_A + V_B)$$

If $R_1 = R_2 = 2R_f$

If $R_1 = R_2 = 2R_f$, the circuit behaves as an averaging circuit. Then the output voltage is

$$V_0 = -\frac{V_1 + V_2}{2} \quad \text{....(2-21)}$$

2.2.2 Op Amp as a differentiator

In differentiator circuit, the reactance, X_C is connected to the input terminal of the inverting amplifier while the resistor, R_f forms the negative feedback element across the operational amplifier. The differentiator circuit performs the mathematical operation of differentiation and "produces a output voltage which is directly proportional to the input voltages rate-of-change with respect to time". The faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change becoming more of a "spike" in shape. The input signal to the differentiator is applied to the capacitor. The capacitor blocks DC content so there is no current flow to the amplifier summing point. Resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependent on the rate of change of the input signal.

The differentiator circuit performs the mathematical operation of differentiation i.e. the output waveform is the derivative of the input waveform. The differentiator may be constructed from a basic inverting amplifier if an input resistor R_1 is replaced by a capacitor C_{in}.

The expression for the output voltage can be obtained as the output V_o is equal to R_f C_{in} times the negative rate of change of the input voltage V_{in} with time. The (–) sign indicates a 180^0 phase shift of the output waveform V_O with respect to the input signal. Since the differentiator performs the reverse of the integrator function.

The circuit in which the output voltage waveform is derivative of the input waveform is called as a differentiator. The output voltage is given by equation

$$V_O = -R_F C_1 \frac{dV_{in}}{dt} \quad \text{...(2.22)}$$

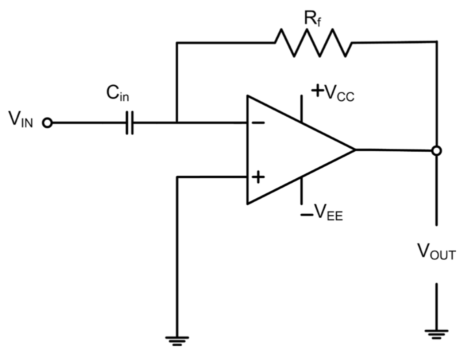


Fig. 2.12: Op Amp Integrator circuit

Fig. 2.13 shows output voltage waveform of an Op Amp differentiator circuit for a square and sinusoidal voltage input waveform.

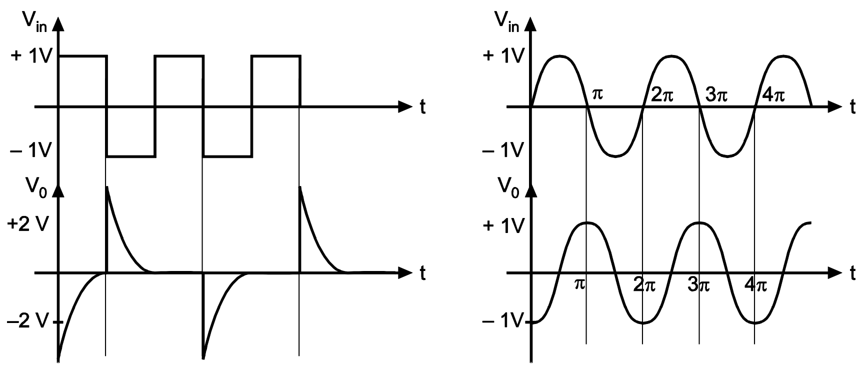


Fig. 2.13: Ideal output waveforms using square and sine waves respectively

If the input is a sine wave the output will be a cosine wave or if the input is a square wave, the output will be trigger pulses as shown.

Applications: The differentiator is used in wave shaping circuits to detect the high frequency components in an input signal and also as a rate of change of detector in FM modulators. The differentiator acts as high pass filter.

2.2.3 Op Amp as an integrator

The circuit in which the output voltage waveform is the integral of the input voltage waveform is called as integrator or integration amplifier. Integrator circuit is obtained by using a basic inverting amplifier. If the feedback resistor R_F is replaced by a capacitor C_F as shown in Fig.2.14, then the circuit acts as integrator. In integrator circuit the position of the capacitor and resistor have been reversed as that of differentiator circuit. Operational amplifier can be configured as analog integration. In an integrating circuit, the output is the integration of the input voltage with respect to time. An integrator circuit which consists of active devices is called an Active integrator. An active integrator provides a much lower output resistance and higher output voltage than is possible with a simple RC circuit. Integrator circuits are usually designed to produce a triangular wave output from a square wave input. Integrating circuits have frequency limitations while operating on sine wave input signals.

Integration is a process of continues additions. The most popular application of an integrator is to produce a ramp of output voltage which is linearly increasing or decreasing voltage. If the input voltage is step voltage, then output voltage will be ramp or linearly changing voltage. Integrators are widely used in ramp or sweep generator, in filter, analog computer etc.

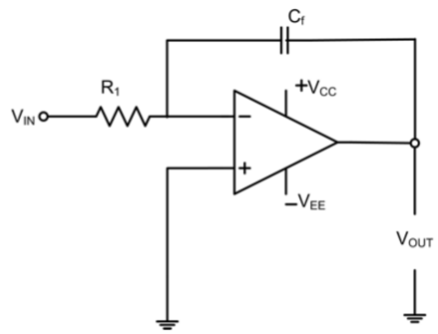


Fig. 2.14: Op Amp Integrator circuit

The output voltage is given by equation $$V_o = \frac{1}{R_1 C_F}\int_0^t V_{in}dt + C$$ ...(2.23)

From above equation the output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant R_1C_F.

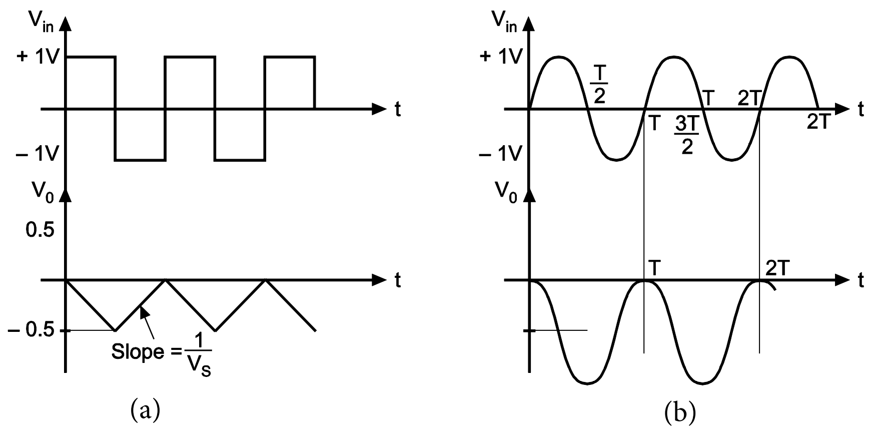


Fig. 2.15: Ideal output waveforms using square and sine wave respectively

If the input is a sine wave, the output will be a cosine wave or if the input is a square wave, the output will be the triangular wave as shown with $R_1C_F = 1$. When $V_{in} = 0$, the integrator work as an open-loop amplifier as C_F acts as an open circuit, $C_F = \infty$. The input offset voltage V_{i0} and the input current charging capacitor C_F produce the error voltage at the output of the integrator. Therefore, to reduce the error voltage at the output, a resistor R_F is connected across the feedback capacitor C_F.

The integrator is most commonly used in analog computers and analog to digital converter (ADC) and signal-wave shaping circuits. The integrator act as a low pass filter. The cut off frequency is inversely proportional to feedback components resistor R_f and capacitor C_f.

Cutoff frequency for integrator i.e. low pass filter is given by equation 2.24.

$$F_1 = 1/(2\pi R_1 C_f)$$ …(2.24)

Applications

Analog circuits are build using Op Amp. Op Amp has wide range of applications in domestic and industrial applications. In various automation, entertainment appliances analog circuits are used. Following type of Op Amp based analog circuits are used in many electronic devices.

- Precision Rectifier
- Zero Crossing Detector
- Frequency to Voltage Converter
- Signal Processing
- Active Filter
- Sample and Hold Circuit
- Instrumentation Amplifier
- Log and antilog Amplifier
- Voltage to Current Converter
- Voltage to Frequency Converter
- Analog to Digital converter
- Signal Conditioning
- Peak Detector
- Computational Building Blocks
- Analog Multiplier and Divisor
- Current to voltage Converter
- Linear and Switching Regulators
- Digital to Analog Converter
- Biomedical Instrumentation
- Oscillators
- Analog Computer

Activity for inquisitiveness and curiosity

Student shall form a group of 5 - 6 students and undertake activity(ies) for developing inquisitiveness and curiosity under the guidance of faculty. A sample is given below:

1. Select a small application circuit of Op Amp. One of the circuit given under Applications in this unit can be selected.
2. Choose an appropriate Op Amp IC with the help of data sheet.
3. Select the electronic component of proper value as per the requirement of circuit.
4. Test the IC and other components needed for the application.
5. Mount the electronic component on breadboard as per circuit diagram.
6. Test the circuit for the given application.
7. Compare the observed output with the expected output.

Solved Problems

Example 2.2.1: For an Op Amp integrator, if cut off frequency is 159 Hz, R_{in} = 1 KΩ and R_f = 100 KΩ, Calculate the value of feedback capacitance.

Solution:

Given $R_{in} = 1\ K\Omega,\ R_f = 100\ K\Omega$ and Fc = 159 Hz

$$F_1 = 1/(2\pi R_f C_f)$$

$$159 = 1/2\pi R_{in} C_f$$

$$159 = 1/2 \times 3.14 \times 100 \times 10^3 \times C_f$$

$$C_f = 1/2 \times 3.14 \times 100 \times 159 \times 10^3$$

$$= 1.0 \times 10^{-8}$$

$$= 0.01\mu F$$

Example 2.2.2: A differentiator has feedback resistor of 10 KΩ and input capacitor value is 0.01 μF Calculate the cut off frequency.

Solution:

Given for differentiator circuit R_f = 10 KΩ and input capacitor C_{in} = 0.01 μF

Cut off frequency of differentiator is given by $f_1 = 1/\ 2\pi R_f\ C_{in}$

$$f_1 = 1/2 \times 3.14 \times 10 \times 10^3 \times 0.01 \times 10^{-6}$$

$$= 1.59\ KHz$$

Example 2.2.3: Calculate output of two input inverting summing amplifier with feedback resistor of 4 KΩ and two inputs are V_1 = 3V and V_2 = 4V Two input resistors are R_1= 4KΩ and R_2 = 8KΩ

Solution: Given that the Op Amp operating mode is inverting configuration

$$R_f = 4\ \text{K}\Omega$$
$$R_1 = 4\text{K}\Omega$$
$$R_2 = 8\ \text{K}\Omega$$
$$V_1 = 3\ \text{V and } V_2 = 4\ \text{V}$$
$$\text{V}_o = -\left[\frac{R_f}{R_1}V_A + \frac{R_f}{R_2}V_B\right]$$
$$= -\ [(4/4) \times 3 + (4/8) \times 4] = -\ [3 + 2]$$
$$\text{V}_o = -\ 5\ \text{V}$$

SUMMARY

- The operational amplifier, more commonly known as Op Amp, is an analog circuit.
- Op Amps perform many arithmetic functions, linear and nonlinear operations in the analog or continuous domain.
- Op Amps are also used in several kinds of analog amplifiers and active filters.
- Op Amp with close configuration having negative feedback can be used in inverting and non – inverting amplifier mode.
- In inverting and non–inverting amplifier mode, close loop gain of amplifier depends on feedback resistor and input resistor.
- Non-inverting amplifier with unity gain is used as an analog buffer.

EXERCISES

A. Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
2.1	The feedback path of Op Amp integrator consists of a. Resistor b. Capacitor c. Inductor d. Diode	2.4	For biasing, Op Amp IC 741 requires a. single power supply b. two power supplies c. four power supplies d. no power supply
2.2	If input signal is fed to inverting input through capacitor and feedback path consists of resistor, then that Op Amp circuit is called as a. Adder circuit b. Integrator circuit c. Differentiator circuit d. Non-inverting amplifier	2.5	For the differentiator circuit to operate as high pass filter, time constant of circuit must be a. High b. Very high in comparison to the time period of input signal c. Small d. Very small in comparison to the time period of inpput signal
2.3	Two input terminals of Op Amp are known as a. High and low b. Inverting and Non-inverting c. Phase and neutral d. Integrator and differentiator	2.6	For inputs averaging circuit, a. R_{in} = Rf /4 b. R_{in} = Rf + 4 c. R_{in} = Rf d. R_{in} = Rf X 16

B. Subjective Questions

1. List six characteristics of an ideal Op Amp.
2. State the various operational amplifier parameters.
3. Explain the non-inverting operational amplifier with neat circuit diagram.
4. Explain Op Amp as a buffer circuit
5. Explain the significance of slew rate parameter in communication circuits.
6. Compare integrator and differentiator circuit on the basis of component used , output equation , required time constant and application.
7. Calculate output of three input inverting summing amplifier with feedback resistor of 2 KΩ and three inputs are $V_1 = 2V$, $V_2 = 4V$ and $V_3 = 6V$. Three input resistors are $R_1 = 2K\Omega$, $R_2 = 4K\Omega$ and $R_3 = 6K\Omega$.
8. State effect of variable resistor connected in feedback path of inverting configuration of OP Amp.
9. Explain construction of Op Amp based subtractor using adder circuit.
10. A differentiator has feedback resistor of 20 KΩ and cut off frequency is 1.5 KHz Calculate input capacitor value.

PRACTICAL

I. P23- ES110: TEST OP AMP AS AMPLIFIER AND INTEGRATOR

P23.1 Practical Statement

Test Op Amp as amplifier and integrator.

P23.2 Practical Significance

Op-amps are among the most widely used electronic devices today, being used in a vast array of consumer, industrial, and scientific devices. Op-amps may be packaged as components or used as elements of more complex integrated circuits. The inverting operational amplifier configuration is one of the simplest and most commonly used op amp topologies. The non-inverting amplifier configuration is one of the most popular and widely used forms of operational amplifier circuit. The op amp non-inverting amplifier circuit provides a high input impedance along with all the advantages gained from using an operational amplifier. Operational amplifier can be configured as integration. In an integrating circuit,the output is the integration of the input voltage with respect to time. An integrator circuit which consists of active devices is called an Active integrator. An active integrator provides a much lower output resistance and higher output voltage than is possible with a simple RC circuit. Integrator circuits are usually designed to produce a triangular wave output from a square wave input. Integrating circuits have frequency limitations while operating on sine wave input signals. This practical will enable student to convert the square wave to triangular waveusing IC 741. This practical will enables student to use Op Amp as inverting amplifier, non inverting amplifier and integrator.

P23.3 Relevant Theory

For Op Amp as an amplifier, refer topic 2.1.5 and for Op Amp as an integrator, refer topic 2.2.3 of this unit.

P23.4 Practical Outcomes (PrO)

PrO1: Use relevant instruments to determine gain of the operational amplifier.

PrO2: Build and test integrator circuit consist of IC741.

P23.5 Practical Setup (Circuit Diagram)

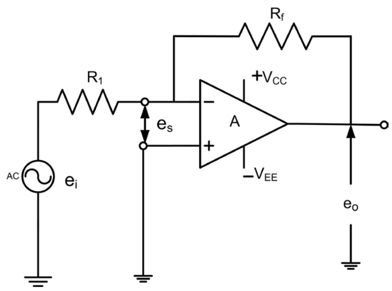


Fig. P23.1 Inverting Amplifier

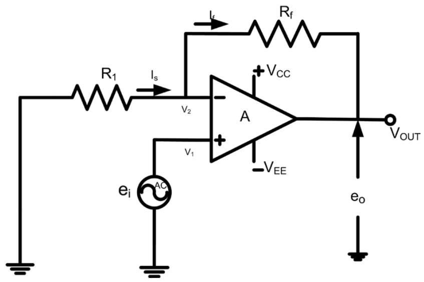


Fig. P23.2 Non Inverting Amplifier

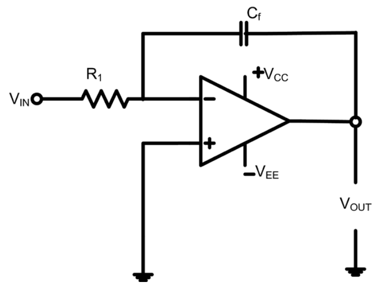


Fig. P23.3 OP AMP Integrator

P23.6 Resources Required

Sr. No	Suggested Resources required with vital specification	Quantity	Actual Resources required with broad specification (to be filled by the student)		Remarks (If any)
1.	Dual Power supply: 0- 30 V, 2 A	1 No.			
2.	IC 741C	1 No.			
3.	Resistors R_1-1 KΩ, R_f-10 KΩ	2 No.			
4.	Capacitor CF 0.01μF	1 No.			
5.	Function Generator 20 MHz	2 No.			
6.	Analog IC tester: Suitable to test analog ICs	1 No.			
7.	CRO: 20 MHz Dual Trace Oscilloscope	2 No.			
8.	Breadboard: 5.5 cm X 17cm	2 No.			
9.	Connecting wires: Single strand Teflon coating (0.6 mm diameter)	L.S.			

P23.7 Precautions

1. Ensure proper mounting of IC 741 and resistor on Breadboard.
2. Ensure proper connection of circuit.
3. Ensure proper input voltage and supply voltage to the circuit.

P23.8 Suggested Procedure

Inverting amplifier

1. Test IC741 with analog IC tester.
2. Make the point of supply voltage +15 V, -15 V and Ground on the Breadboard.
3. Connect Pin No. 7 to +15V and Pin No. 4 to -15 V and Pin No. 3 to Ground.
4. Connect R_1 and R_f as shown in Fig. P23.1.
5. Select Sine wave V_{in} of (1V, 500 Hz) from Function generator, Check the wave on CRO.
6. Apply the selected Sine wave input to Pin No. 2.
7. Keep the amplitude constant and change input frequency from 100 Hz to 1 MHz.
8. Measure V_{Out} on CRO from Pin No.6 and note down the reading.
9. Plot graph of frequency versus gain on semi log.
10. Find out band width and cut off frequency from semi log.

Non Inverting amplifier

1. Test IC741 with analog IC tester.
2. Make the point of supply voltage +15 V, -15 V and Ground on the Breadboard.
3. Connect Pin No. 7 to +15V and Pin No. 4 to -15 V and Pin No. 2 to Ground.
4. Connect R_1 and R_f as shown in Fig. P23.2.
5. Select Sine wave Vin of (1 V, 500 Hz) from Function generator, Check the wave on CRO.
6. Apply the selected Sine wave input to Pin No. 3.
7. Keep the amplitude constant and change input frequency from 100 Hz to 1 MHz.
8. Measure V_{out} on CRO from Pin No. 6 and note down the reading.
9. Plot graph of frequency versus gain on semi log.
10. Find out band width and cut off frequency from semi log.

Integrator Circuit

1. Assemble the circuit on breadboard as per circuit diagram.
2. Connect dual power supply to Pins No. 7 (+Vcc) and pin No. 4 (-VEE) of IC 741.
3. Set the function generator to produce a sine waveform of 1Vpp amplitude at 1KHz to Pin No. 2
4. Check the waveform on CRO before applying it as input.
5. Observe input and output (Pin No. 6) waveforms on CRO for 1 KHz frequency and check the phase shift for the given input from function generator and CRO.
6. Vary the input frequency from 100 Hz to 10 KHz keeping input voltage 1 V.
7. Measure the output voltage for each frequency and note the output voltage in observation table.
8. Plot the graph gain vs. frequency on semi log paper. Calculate gain for different input frequency in decibels.

P23.9 Observations and Calculations

Table No: P23.1 Observation Table For inverting amplifier V_i = 1V pp

Sr. No.	Input Frequency (Hz)	Output Voltage, V_{out} (Volts)	Voltage Gain ($A = V_{out}/V_i$)	Gain in dB 20 $\log(V_{out}/V_i)$
1.	100 Hz			
2.	500 Hz			
3.	1 KHz			

Table No: P23.2 Observation Table for Integrator Input Voltage V_i = 1 V pp

Sr. No.	Input Frequency (Hz)	Output Voltage, V_o (Volts)	Gain in dB 20 $\log 10(V_o/V_i)$
1.	100 Hz		
2.	50 Hz		

Calculations:

i. Voltage Gain: V_o/V_i =

ii. Voltage Gain in dB : 20log (V_o/V_i) =

P23.10 Results and Interpretation

……….....……………………………………………………………………………………………………

……….....……………………………………………………………………………………………………

P23.11 Conclusions and/or Validation

……….....……………………………………………………………………………………………………

……….....……………………………………………………………………………………………………

P23.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achieve pre-defined course outcomes.

1. State the effect of negative feedback in inverting amplifier.
2. State the maximum input signal voltage that can be applied in experimental circuit for linear operation.

3 Can integrator act as low pass filter? Justify your answer with the help of frequency response.

P23.13 Suggested Learning Resources

Ex-perimet: To study op-amp

KNOW MORE

Micro-Projects

Undertake one or two micro project(s) /activity(ies) in a group of 5 - 6 students under the guidance of faculty and present it as group with individual participation as well. Two sample micro-project problems are given below:

1. Build and Test adder and subtractor circuit using IC 741.
2. Build and Test differentiator circuit using IC 741.

Activities

1. Prepare a small presentation based on Library/ Internet survey of Op Amp based linear circuits and their applications.
2. Prepare power point presentation or animation for understanding different Op Amp based circuit behavior.

Video Resource

Integrated Circuits, MOSFETS, Op Amps and their Applications

REFERENCES AND SUGGESTED READINGS

1. Ramakant A. Gayakwad, *Op-Amps and Linear Integrated Circuits*, New Delhi: PHI Learning, 2011.
2. David A. Bell, *Operational Amplifiers and Linear ICs*, New Delhi: Oxford University Press, 2011.
3. William D. Stanley, *Operation Amplifier with Linear Integrated Circuit*, New Delhi: Pearson Education, 2002.
4. Senthil M. Sivakumar, *Linear Integrated Circuits* , New Delhi: S. Chand Publishing, New Delhi, 2014.
5. S. Salivahanan , *Linear Integrated Circuits*, McGraw Hill, New Delhi, 2008.

3 Overview of Digital Electronics

UNIT SPECIFICS

This unit discusses the following topics:

- Number system and conversions
- Boolean laws and theorem
- Logic gates
- Flip flops and its types
- Use of flip flops as counter
- Introduction to Integrated Circuits

The student self-learning activities at the end of each topic along with problem solving examples and ICT references are created for generating further curiosity and creativity as well as improving problem solving capacity. A number of multiple choice questions as well as subjective questions following increased levels of Bloom's taxonomy, assignments through a number of problems provided in the books listed under references and suggested readings are given in the unit so that one can go through them for practice.

A "Know More" section has been introduced, so that the supplementary information provided becomes beneficial for the users of the book. In this section, based on the unit content, "Micro Project" activity and QR code of video resources are provided to learn more about some of the sub-topics covered.

RATIONALE

Digital systems are extensively used for computation, data processing, communication and in measurement and control. The main reason being Digital systems are more reliable, less affected by noise, easier to design and fabricated on IC chips. The unit will aid to understand the fundamental concepts of digital systems and their application in digital devices and integrated circuits.

PRE-REQUISITE

1. Mathematics: Set, Real Numbers, Proofs in Mathematics (Class X)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U3-O1: Simplify the given expression using Boolean laws and theorem.

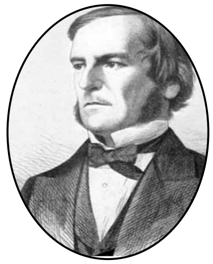
U3-O2: Explain the various types of logic gates.

U3-O3: Use the given flip-flop to construct the specific type of counter.

U3-O4: Suggest appropriate TTL digital IC for gates.

Unit 3 Outcomes	Expected Mapping with Course Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U3-O1	-	-	3	-	-	-
U3-O2	2	-	3	-	-	-
U3-O3	2	-	3	-	-	-
U3-O4	3	-	3	-	-	-

George Boole (1815-1864)
Boolean algebra was introduced by George Boole, Professor of Mathematics at University College, Cork, Ireland in his first book 'The Mathematical Analysis of Logic' in 1847. Boolean algebra is the branch of algebra in which the values of the variables are the truth values 'true' and 'false', usually denoted as '1' and '0', respectively. In elementary algebra, where the values of the variables are numbers and the prime operations are addition and multiplication, the main operations of Boolean algebra are the AND, OR and NOT. Boolean logic is credited with laying the foundations for all modern electronic digital computers.



3.1 BOOLEAN OPERATION AND BOOLEAN ALGEBRA

3.1.1 Introduction

Electronic circuits and systems are of two types, Analog and Digital. Analog circuits are those in which the voltage and current vary continuously between a maximum and minimum value. Digital circuits are those where the voltage level assume a finite value. In all modern digital systems ,there are just two distinct voltage levels. Each voltage level however is a narrow band of finite voltage value. The digital systems use the binary system, where the binary digit 1 used to represent a high voltage level and binary digit 0 is used to represent low voltage level. The digital system is then called a positive logic system. Digital systems are also called as switching circuits or logic circuits. The circuits use Boolean algebra. The Boolean algebra is a system of mathematical logic consisting of a set of elements and operators for analysis and synthesis of logic circuits. The algebra differs from both the decimal and the binary number system algebra and is evaluated by a set of rules and laws.

3.1.2 Number System and Conversions

Number system relates quantities and symbols. The number system represents a value of a given number with respect to its given base. Human beings use the decimal number system for their everyday activities whether counting or measurement. The digital system uses the binary number system. The base value determines the unique representation of a given number and therefore different number system has different representation of the same number.

3.1.2.1 Decimal Number System

The Decimal number system has a base 10 as it uses ten independent symbols i.e. symbols 0, 1, 2, 3, 4, 5, 6, 7, 8 to 9 to represent a number in decimal system. For example, the number 10 is represented by the symbols 0 and 1, where symbol 0 is the least significant digit (right most digit) and symbol 1 is the most significant digit (left most digit). In decimal system each digit position represents a specific power of base 10. For example, the decimal number

$$(3456)_{10} = 3 \times 10^3 + 4 \times 10^2 + 5 \times 10^1 + 6 \times 10^0$$

The right most digit is of the order of 10^0 (unit or ones), the second right most digit is of the order of 10^1 (tens), the third right most bit is of the order of 10^2 (hundreds) , the fourth right most bit (thousands) and so on. In general, a decimal number system with decimal point is represented as

$$D_3D_2D_1D_0.D_{-1}D_{-2}$$

The decimal digit represented by coefficient D_k represents any of the decimal digits from 0 to 9 and the subscript k indicates the position value and hence the power of base i.e. base 10 to which the coefficient must be applied. For the decimal number as shown above, it will be as follows

$$D_3 \times 10^3 + D_2 \times 10^2 + D_1 \times 10^1 + D_0 \times 10^0 + D_{-1} \times 10^{-1} + D_{-2} \times 10^{-2}$$

3.1.2.2 Binary Number System

The binary system has two independent symbols namely 0 and 1. The base of this number system is therefore 2. The decimal number $(2)_{10}$ in binary system is represented as $(10)_2$. A binary digit is called a bit. Like decimal number system the binary system is a positional weight system, where each bit represents a specific power of base 2. The right most bit of a binary system is called the Least Significant Bit (LSB) and the left most bit is called the Most Significant Bit (MSB). In general, a binary number system with binary point is represented as

$$b_3\ b_2\ b_1b_0.b_{-1}b_{-2}$$

The binary bit represented by coefficient b_k represents either bit 0 or bit 1 and the subscript k indicates the position value and hence the power of base i.e. base 2 to which the coefficient must be applied. For the binary number as shown above it will be as follows

$$b_3 \times 2^3 + b_2 \times 2^2 + b_1 \times 2^1 + b_0 \times 2^0 + b_{-1} \times 2^{-1} + b_{-2} \times 2^{-2}$$

3.1.2.3 Octal and Hexadecimal Number System

Octal number system

The octal number system was used by early microcomputers. In octal number system there are eight independent symbols 0, 1, 2, 3, 4, 5, 6 and 7. Therefore the base is 8. The octal number system is also a positional number system, wherein each digit of the octal system represents a specific power of base 8.

Hexadecimal number system

The digital computer system uses binary number system. Although it is easier for machines to process data in binary system, the binary numbers are long and are too lengthy to be handled by human beings. To overcome this problem, the hexadecimal number system was developed and it has become the most popular number system for data processing in digital systems. The independent symbols used are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F. Therefore, the base is 16. It is also a positional number system.

3.1.3 Number Conversion

Number System Conversions

3.1.3.1 Binary to Decimal Conversion

Binary numbers are converted to decimal numbers by their positional weight system. In this method each binary bit is multiplied by the corresponding position weight and thereafter the result of each product terms are added to obtain the decimal number. For example convert 1101.11_2 to decimal

$$1101.11 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2}$$

$$= 8 + 4 + 0 + 1 + 0.5 + 0.25 = 13.75_{10}$$

3.1.3.2 Decimal to Binary Conversion

The integer part of the decimal number system is successively divided by 2 till the quotient is zero to get the binary integer. The last reminder is the MSB. Similarly, the fractional part is successively multiplied by 2 till the product is zero or till the desired accuracy is obtained. For example convert 35.875_{10} to binary. The integer part is first successively divided by 2 as shown.

2	35	Reminder
2	17	1
	8	1
2	4	0
2	2	0
2	1	0
	0	1 (**MSB**)

The answer is 100011, obtained by reading the reminders from bottom to top as shown by arrow. Now convert the fraction part by successively multiplying it by 2 and keep noting the integer part as shown.

$0.875 \times 2 = 1.75$, Integer =1

$0.750 \times 2 = 1.50$, Integer =1

$0.500 \times 2 = 1.00$, Integer =1

Now reading the integers in the forward direction we get (.111). Combining the integer and fractional part, the binary equivalent of 38.875_{10} results as 100011.111_2.

3.1.4 Binary Arithmetic

3.1.4.1 Binary Addition

The addition of two binary bits follow the following rules:

0 + 0 = 0; 0 + 1 = 1; 1 + 0 = 0; 1 + 1 = 0 and carry 1

Add the following binary numbers 1011.011 and 111.010

```
  1 0 1 1 . 0 1 1
  + 1 1 1 . 0 1 0
1 0 0 1 0 . 1 0 1
```

The addition of carry ahead is done in a manner similar to decimal addition

3.1.4.2 Binary Subtraction

The binary subtraction follows the following rules:

0 – 0 = 0; 1 – 0 = 1; 1 – 1 = 0; 0 – 1 = 1 with a borrow of 1 i.e. equivalent to 10 – 1

Subtract the binary number 111.111 from 1010.010

```
1 0 1 0 . 0 1 0
- 1 1 1 . 1 1 0
0 0 1 0 . 0 1 1
```

In digital computers for simplifying the subtraction operation complements are used. There are two types of complement for each number system. For a base b system the complements are the (b-1)'s complement and the b's complement . For a binary number system, the two types are the 1's and 2's complement.

3.1.5 Boolean Laws and Theorems

3.1.5.1 Boolean Algebra

The Boolean algebra is an algebraic system developed for systematic treatment of logic. It is defined with a set of elements, a set of operators and a number of postulates. Unlike ordinary algebra negative number and fraction do not exist. No subtraction or division operations are there in Boolean Algebra. The basic laws of Boolean algebra are

Commutative law: A binary operator plus (+) or dot (.) on a set S is said to be commutative if

1. A+B = B + A
2. A.B = B.A

where A and B are elements of S

Associative law: A binary operator plus (+) or dot (.) on a set S is said to be associative if

1. (A + B) +C = A + (B + C)
2. (A.B).C = A. (B.C)

where A, B and C are elements of S

Distributive law:

1. (A + B).C = A.B + B.C
2. A+ (B.C) = (A + B). (A + C)

AND, OR and NOT law : The table 3.1 shows the basic Boolean laws.
where A= {0,1} and the complement of A is represented as A'

Sr.No.	OR law	AND law	NOT (Complement) law
1	A + 0 = A	A . 0 = 0	A'' = A
2	A + 1 = 1	A . 1 = A	If A = 0, then A' = 1
3	A + A = A	A . A = A	If A = 1, then A' = 0
4	A + A' = 1	A . A' = 0	

De Morgan's Theorem: The theorem represents two laws
Law 1: (A + B)' = A'. B'
The law states that complement of a sum of two variables is equal to the product of the individual complements.
Law 2: (A.B)' = A' + B'
The law states that the complement of the product of two variables is equal to the sum of the individual complements,

Activity

Prepare a presentation on the digital codes used for information processing by digital circuits

Solved Problems

Example 3.1.1: Convert the following decimal number 452_{10} to binary.
Solution:

		Reminder
2	450	
2	225	0
2	112	1
2	56	0
2	28	0
2	14	0
2	7	0
2	3	1
2	1	1
	0	1

452_{10} = **$(111000010)_2$**

Example 3.1.2: Write the first ten decimal digits to base 3.
Solution:
For a base 3 system the symbols are 0, 1 and 2. The remaining decimal numbers are obtained by successively dividing the decimal number by base 3. Decimal digit 3 is written as 10_3 and similarly decimal digit 4 to 9 is written as:

Decimal number	Equivalent in base 3	Decimal number	Equivalent in base 3	Decimal number	Equivalent in base 3
4	11	5	12	6	20
7	21	8	22	9	23

3.2 LOGIC GATES

A Boolean function is an expression formed with binary variables using the binary operators AND, OR, NOT, parentheses and equal sign. A binary variable can take the value 0 or 1. For example a Boolean function F = x + y is equal to 1, if either variable x, y or both are equal to 1, otherwise F = 0. A Boolean function may be represented by a truth table. The truth table of a n variable Boolean function F consists of a column listing the 2^n combinations of the n variables and a column showing the value of F either 0 or 1 for each of the 2^n combinations.

3.2.1 Positive and Negative Logic

Logic Gate Simulator

The voltage level which represents a binary variable equal to logic-1 or logic-0. When the higher voltage represents logic-1 and lower voltage as logic-0, then the logic system is termed as positive logic. For example, a digital system may define logic-1 if the variable voltage level is equal to its nominal value say + 5.0 V. Similarly, logic-0 will be defined if the voltage level of the variable has a nominal value equal to 0 V. On the other hand, the logic system is termed as negative logic, when the higher voltage i.e. + 5 V represents logic-0 and the lower voltage i.e. 0 V represents logic-1. In general, all digital circuits accept binary signals with in the allowable tolerance level. A voltage between 0 V and 0.8 V represents logic - 0 and voltage between 3V to 5V represents logic-1.

Positive Logic   Negative Logic

Fig. 3.1: Logic signal

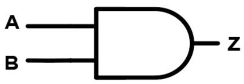
3.2.2 Types of Logic Gates

Boolean Expressions using Logic

The fundamental building block of any digital system are the logic gates. The name logic gates imply that the output of the gate is based on the ability of the device to make decisions, according to its present input. The three types of basic gates are the AND, OR and NOT. The inputs and outputs of logic gates can occur only in two level. These two level are logic-1, termed as HIGH/TRUE and logic-0 termed as LOW/FALSE.

3.2.2.1 AND GATE

An AND gate is a logic circuit whose output assumes logic-1 when each one of its input are at logic-1. Even if one of the inputs is at logic-0, the output assumes logic-0. The AND gate has two or more inputs, but only one output. The logic symbol, Boolean expression and truth table of an AND gate is shown in Fig. 3.2.



Logic Symbol

Z = A . B

Boolean Expression

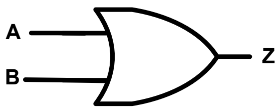
A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

Truth table

Fig. 3.2: AND Gate

3.2.2.2 OR GATE

An OR gate is a logic circuit in which the gate output assumes logic-0 when each one of its input are at logic-0. Even if one of the inputs is at logic-1, the output assumes logic-1. The OR gate has two or more inputs, but only one output. The logic symbol, Boolean expression and truth table of an OR gate is shown Fig, 3.3.



Logic Symbol

Z = A + B

Boolean Expression

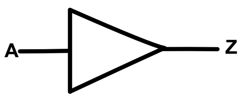
A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

Truth table

Fig. 3.3: OR Gate

3.2.2.3 NOT GATE

The NOT gate, also known as INVERTER gate has only one input and one output. The output of a NOT gate will always be the complement of its input. The logic symbol, Boolean expression and truth table of a NOT gate is shown in Fig. 3.4.



Logic Symbol

Z = A’

Boolean Expression

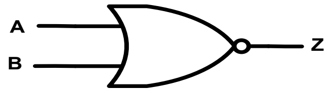
A	Z
0	1
1	0

Truth table

Fig. 3.4: NOT Gate

3.2.2.4 UNIVERSAL GATES

The NAND and NOR gates can realize the logic function of all the three basic gates i.e. AND, OR and NOT. Therefore, these gates are called as Universal gates. Fig. 3.5 shows below the logic symbol, Boolean expression and truth table.



Logic Symbol

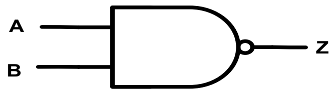
Z = (A + B)’

Boolean Expression

A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

Truth table

NOR Gate



Logic Symbol

Z = (A . B)’

Boolean Expression

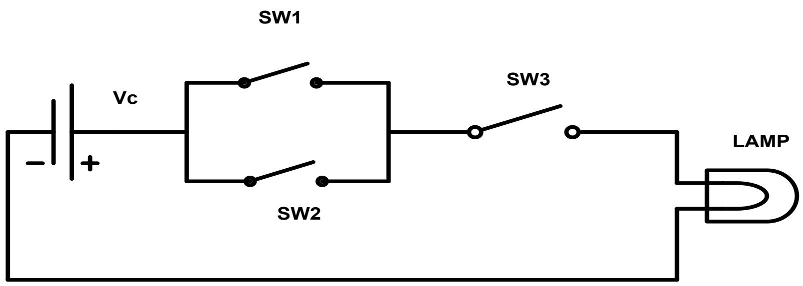
A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

Truth table

Fig. 3.5: NOR and NAND Gate

Activity:

Implement the circuit shown below using logic gates

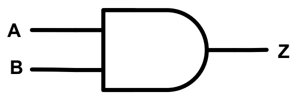


Solved Problems

Example 3.2.1: Which of the logic gate is represented by the expression Z = (A’ + B’)’

Solution: Using DeMorgans theorem first law the above expression (A’ + B’)’ = A’’. B’’ = A.B

The above Boolean expression can be implemented by using AND gate.

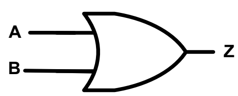


Example 3.2.2: Implement the Boolean expression Z = A + A’B using OR gate.

Solution: Applying Distributive law, the Boolean Expression Z can be rewritten as

Z = (A+A’). (A + B), As per OR law, A + A’ =1

Therefore, Z = 1. (A + B) = A + B



3.3 FLIP FLOPS AND COUNTERS

Digital circuits are broadly classified as combinational circuits and sequential circuits. In combinational circuits the output at any instant of time depends on the inputs present at that time. Examples of combinational circuit are Adders, Subtractors, Encoders, Decoders, Comparators, Multiplexers etc. In sequential circuit the output not only depend on the present input, but also on the past state stored in the memory element. The examples are Flip flops, Registers, Counters etc. The sequential circuits are of two types, Synchronous and Asynchronous. In synchronous sequential circuit, the circuit behaviour can be defined from the knowledge of its signals at discrete instant of time. The discrete instant of time is defined by the clock signal. In asynchronous sequential circuit, the circuit behaviour depends upon the order at which the change in the logic level of the input signal takes place. Table 3.2 shows the comparison between an asynchronous and synchronous sequential circuit.

Table 3.2: Comparison between Synchronous and Asynchronous sequential circuits

Sr.No.	Asynchronous sequential circuits	Synchronous sequential circuit
1.	Memory elements are unclocked flip-flops.	Memory elements are clocked flip-flops.
2.	Change in input signals can affect memory elements at any instant of time.	Change in input signals can affect the memory elements only when the clock signal is present.
3.	Absence of clock signal makes operation of asynchronous circuits faster.	The operating speed depends on the frequency of the clock signal.

3.3.1 Types of Flip-Flops

The most important memory element and the basic building block of a sequential circuit is the flip-flop. A flip-flop has got two stable states and can remain in that state indefinitely. Its state can be changed only by applying the proper input signals. The flip-flop is also called a one-bit memory element.

The flip flops are made of using two cross coupled NAND or NOR gates. There are several different arrangements for making flip-flops. Each type of flip-flop has different characteristics so as to implement a particular application.

3.3.1.1 Basic Flip-flop (S-R Latch)

The simplest type of flip-flop is called an S-R latch. It has two inputs labelled as S (SET) and R (RESET) and two outputs Q and its complement Q'. The state of the latch corresponds to the value of Q either 1 or 0. The analysis of the S-R latch as shown in Fig. 3.6 using NAND gates can be summarized as follows

When the input S = 0 and input R = 1, it will SET the flip-flop i.e. Q = 1 and will remain in the SET state even after S returns to zero.

When the input R = 0 and S = 1, it will RESET the flip-flop i.e. Q = 0 and will remain in the RESET state even after R returns to zero.

When the input S = 1 and R = 1, the flip-flop state will remain as it is i.e. if Q = 1, it will remain as Q = 1 (SET condition) and if Q = 0 it will remain as Q = 0 (RESET condition).

When the inputs S = 0 and R = 0, the output state becomes undefined as both Q and its complement i.e. Q = Q'= 1. This input condition is invalid and should not be used.

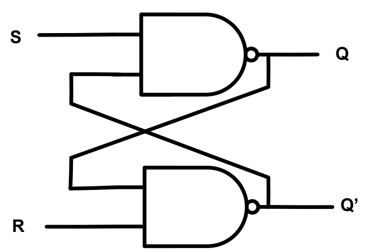
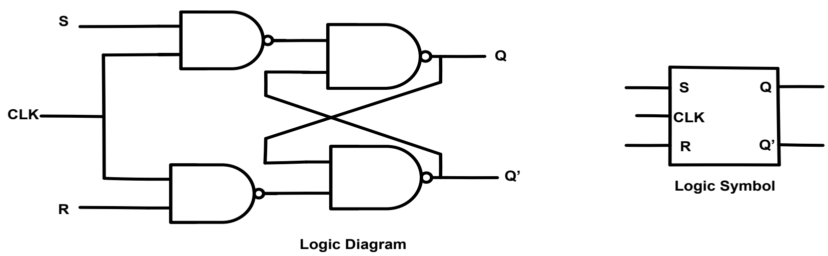


Fig. 3.6: S-R latch using NAND gates

3.3.1.2 Clocked S-R flip flop

The basic S-R latch discussed above is also called as an asynchronous S-R flip-flop, the reason being the output state changes at any time, the input signal condition changes. A clocked flip-flop requires clock signal and will change the state of the flip-flop only when the clocked signal is HIGH (logic-1). These type of flip flops are called level triggered flip flops. A clocked flip-flop is also called as a synchronous sequential circuit. Fig. 3.7 shows the logic diagram, logic symbol and truth table of a clocked S-R flip-flop using NAND gates. From the logic diagram shown, it is seen that when the clock signal is LOW (logic-0), the output of both the input NAND gates is HIGH. In this case, the flip-flop state will remain unchanged. When the clock signal becomes HIGH (logic-1), the S and R input will be passed through the NAND gates and the final output of the flip-flop Q will change according to the input signals S and R.



CLK	S	R	Q_t	Q_{t+1}	State
1	0	0	0	0	No Change
	0	0	1	1	
	0	1	0	1	RESET
	0	1	1	1	
	1	0	0	0	SET
	1	0	1	0	
	1	1	0	X	Undefined
	1	1	1	X	

Truth table

Fig. 3.7: Clocked S-R flip-flop

3.3.1.3 D Flip Flop

From the truth table it is seen that when input S and R = 1, the output state is undefined. To avoid this condition a single input clocked flip-flop as shown in Fig. 3.8 where the R input is obtained by complementing the S input. This single input flip-flop is called as D flip flop or delay/data flip-flop. When D = 1, S = 1 and R = 0, causing the flip-flop to SET, with clock signal HIGH. Similarly, when D = 0, S = 0 and R = 1, causing the flip-flop to RESET.

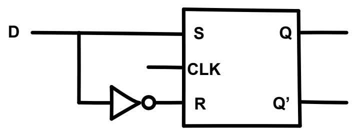
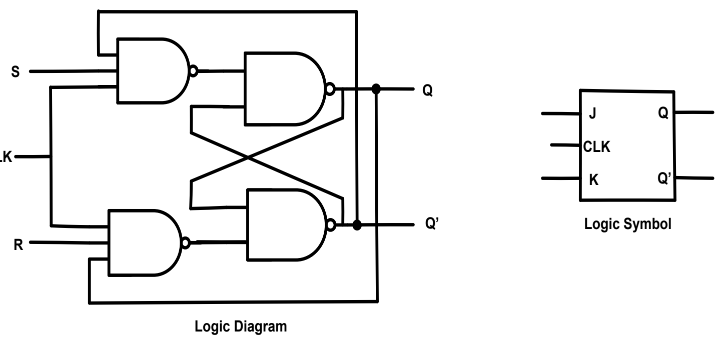


Fig. 3.8: D – flip flop

3.3.1.4 J-K Flip-flop

The most popular and widely used flip-flop. The working of the J-K flip-flop is identical to that of a clocked S-R flip flop as shown in Fig. 3.7. The only difference is that it has no undefined states like that of an S-R flip-flop. Fig. 3.9 shows the logic diagram, logic symbol and truth table of a J-K flip-flop. When J = K = 1, the flip-flop toggles it changes its present state i.e. if Q = 1 it will change to 0 and if Q = 1 then the state will change to 0.



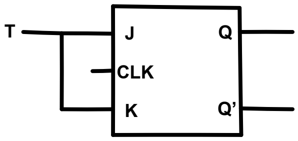
CLK	J	K	Q_t	Q_{t+1}	State
1	0	0	0	0	No Change
	0	0	1	1	
	0	1	0	1	RESET
	0	1	1	1	
	1	0	0	0	SET
	1	0	1	0	
	1	1	0	1	Toggle
	1	1	1	0	

Truth table

Fig. 3.9: J-K Flip-Flop

3.3.1.5 T flip-flop

When both the inputs of a J- K are connected together as shown in Fig. 3.10 and labelling the common terminal as T, the flip-flop is known as T flip-flop. When T=0, both J = K = 0 and the flip flop state remains unchanged. When T = 1, both J = K =1 and the flip-flop toggles its states. The T flip flop is also known as Toggle flip-flop.



Logic Symbol

Fig. 3.10: T flip flop

3.3.2 Counters

Counter is a sequential circuit which is used to count the clock pulse. A digital counter consists of a set of flip-flop whose state changes in response to the clock pulse applied at the input of the counter. Each of the counts of a counter is called the states. The number of states depend on the number of flip-flops used for the counter and the sequence of the states depends on the interconnection between the flip-flops. For example, a 2-bit counter requires two flip-flops and the number of states are 4. The sequence of states for an up-counter and down-counter is shown in Fig. 3.11 (a) and (b) respectively. A 2-bit counter is also called a modulus or mod-4 counter as the number of states which the counter passes before reaching the original state is also called the modulus of the counter. The modulus of an N bit counter is 2^N .

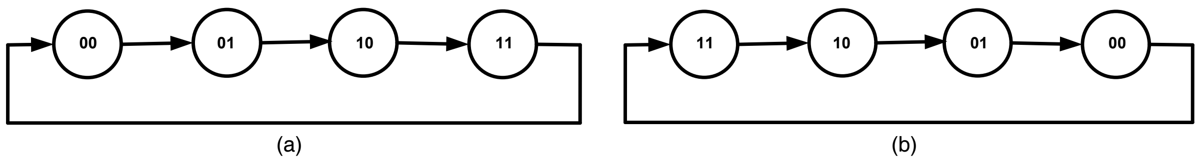


Fig. 3.11: State Diagram of (a) 2-bit UP counter (b) 2-bit DOWN counter

Counters are divided into asynchronous counters and synchronous counters.

1. In asynchronous counters also known as ripple counters, the flip-flops are connected in such a way that the output of the first FF becomes the clock pulse for the second FF and so on. The main drawback of these counters is their low speed.
2. In synchronous counters all the flip-flops are clocked by the same clock pulse simultaneously. The synchronous counters also known as parallel counters are faster than asynchronous counters.

3.3.2.1 Asynchronous Counter

A 2-bit up counter is shown in Fig. 3.12. As shown there are two J-K flips flops with their inputs J = K = 1. From the truth table of Fig. 3.9, it is seen that the flip flops will toggle their present states whenever their clock pulse are HIGH i.e. at logic -1. The counter starts counting from 00 (State 0) to 11 (State 3) as shown in state diagram, Fig. 3.11(a). The output Q_1 represents the MSB and Q_0 the LSB. Fig. 3.13 shows a 2-bit down counter.

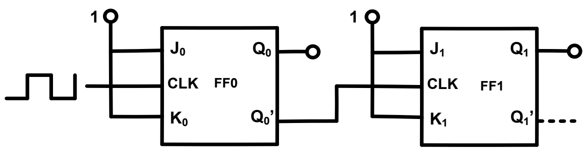


Fig.3.12: 2-bit UP Asynchronous counter

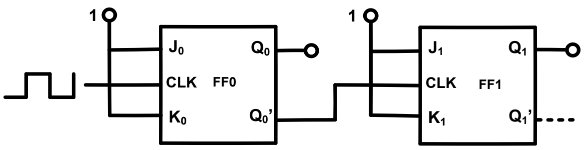


Fig.3.13: 2-bit DOWN Asynchronous counter

3.3.2.2 Mod-10 Asynchronous Counter

The Mod-10 counter is also called decade counter. The number of flip flops required is 4. With 4 flip-flops there are sixteen states, count value sequence starting from $(0000)_2$ to $(1111)_2$. A decade counter has only 10 valid states i.e. count value from $(0000)_2$ to $(1001)_2$. The remaining states are invalid i.e. count value from $(1010)_2$ to $(1111)_2$. For this a feedback logic circuit has to be provided which will clear or reset all the flip-flops as soon as the count value reaches $(1010)_2$. Fig. 3.14 shows a decade counter with the feedback circuit, where output Q_3 is the MSB and Q_0 is the LSB.

Resisters and Counters

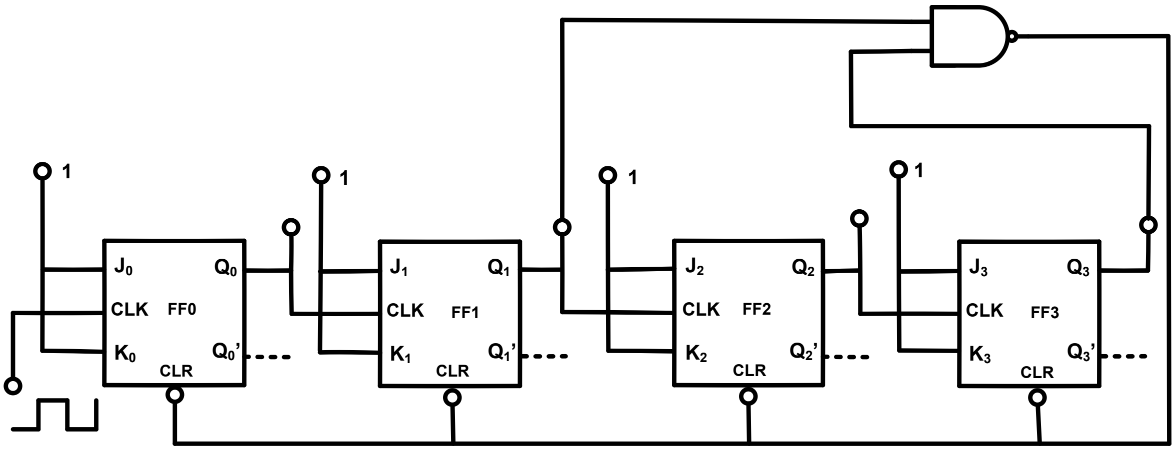


Fig.3.14: 4-bit Decade counter

Activities

1. Find out the applications of D and T flip-flop.
2. Prepare a presentation on the application of counters in our day to day life.

Solved Problems

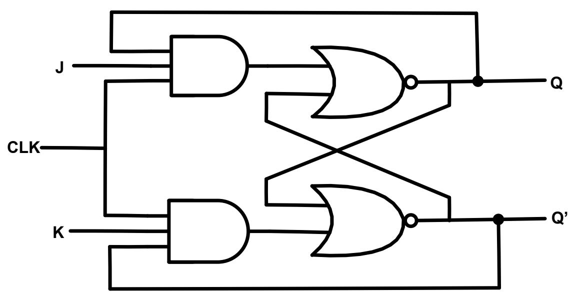
Example 3.3.1: State number of flip-flops required to make a MOD-16 counter?

Solution: The general expression of the number of flip-flops is given as $2^n = N$, where n is the number of flip-flops used for realizing the given count and N is the number of states or the modulus, N = 16 given

$2^n = 16$ or n = 4. The number of flip-flops required = 4

Example 3.3.2: Draw the logic diagram of a J-K flip-flop using NOR gates.

Solution



Logic Diagram

3.4 DIGITAL IC'S

3.4.1 Introduction to Integrated Circuits

Integrated circuits

The Integrated Circuits (IC's) are small silicon semiconductor crystal having components like resistors, diodes, capacitors, transistors, FET's. The components are interconnected to form an electronic circuit. The semiconductor crystal called a chip is mounted on a metal, plastic or ceramic package and the terminal points of the electronic circuit are made available to the external pins to form the IC. The main advantage of an IC is its small size, reduced power consumption, high reliability, high speed of operation and the most important low cost. Integrated circuits come in two types of package, the flat pin and the dual in line (DIP) package. Integrated circuits are classified as Linear and Digital. Linear IC's operate with continuous signals and are widely used as amplifiers, filters, comparators and converters etc., Digital IC's operate with binary signals and are made up of interconnected digital gates. Digital IC's are classified not only by their logic operation, but by the logic circuit family to which it belongs. The IC's include flip-flops, logic gates, counters, memory chips, microcontrollers etc. The different logic circuit family of Digital IC's are

- Transistor-transistor logic (TTL)
- Diode transistor logic (DTL)
- Resistor transistor logic (RTL)
- Emitter coupled logic (ECL)
- Metal Oxide Semiconductor (MOS)
- Complementary metal oxide semiconductor (CMOS)
- Integrated injection logic (I^2L)

3.4.2 Digital IC Specification Terminology

The most useful specification terms of a Digital IC's are as under

Threshold Voltage: The voltage level at the input of the logic gate that causes a change in the output voltage level i.e. from one logic level to the other.

Power Dissipation: The power required by the gate to operate at a specified frequency and is given in milliwatts.

Propagation Delay: The time taken by the input signal to propagate from the gate input to the output.

Fan-in: It is defined as the number of inputs that the gate is designed to handle

Fan-out: It is defined as the maximum number of loads (inputs of other gates) which the output of a gate can handle without overloading it.

Noise Margin: The ability of a logic circuit to tolerate noise voltage at its input terminals and thus avoiding circuit malfunction is known as noise immunity. The measure of the noise immunity in terms of voltage level is called noise margin.

Operating temperature: The IC's contain electronic components and are temperature sensitive. A temperature range is specified between which the IC operate satisfactorily. For a commercial digital IC, it is between 0 to 70° C.

3.4.3 Transistor Transistor Logic (TTL)

The Transistor Transistor Logic (TTL) family is most popular among the logic family. The basic logic operation in TTL family is performed by transistors. The TTL use transistors either in the cut off region or in the saturation region. The advantages of TTL logic families are its low cost and good speed. The major disadvantages are high power dissipation and low noise immunity. The basic TTL logic circuit is the NAND gate. Fig. 3.15 shows the circuit diagram of a two input NAND gate.

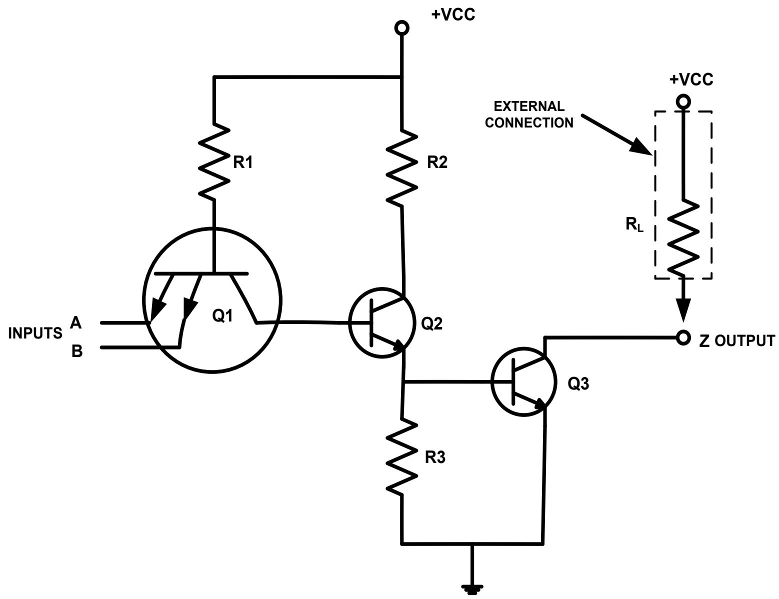


Fig. 3.15: A two input TTL logic NAND gate

3.4.4 TTL Sub families

The TTL subfamilies are classified as (1) Standard TTL, 74 series, (2) Low power TTL, 74L series, (3) High speed TTL, 74H series, (4) Schottky TTL, 74S series, (5) Low power Schottky TTL, 74LS series, (6) Fast TTL, 74F series. Table 3.2 shows the comparison of subfamilies in terms of IC performance specification. Table 3.3 shows some of the most commonly used IC's under TTL subfamilies for realization of basic digital circuits.

Character-ization of digital logic families

Table 3.2: Comparison of TTL subfamilies

Sr. No	Performance Specification	74	74L	74H	74S	74LS	74 F
1.	Propagation delay (ns)	9	33	6	3	9.5	4
2.	Power dissipation (milliWatt)	10	1	23	20	2	1.2
3.	Maximum clock frequency (MHz)	35	3	50	125	45	70
4.	Fan out	10	20	10	20	20	20
5.	Noise margin (V)	0.4	0.4	0.4	0.7	0.5	0.5

Table 3.3: Popular Digital TTL IC's

Sr. No	IC Description	Sr. No	IC Description
1.	7402 Quad 2-Input NOR gate	6.	74LS83, 4-bit full adder
2.	74F00 Quad 2-Input NAND gate	7.	74LS138, 3-8-bit binary decoder
3.	74LS08 Quad 2-Input AND gate	8.	74F74, D type flip-flop
4.	74LS32 Quad 2-Input OR gate	9.	7473, Dual J-K flip-flop
5.	7404 Hex Inverter	10.	7490, Decade counter

3.4.5 Digital IC's application

Digital IC's are mostly used in computers. The reason being the input and output signals are fixed at two levels as in a binary system. They include

- Flip flops
- Multiplexers
- Programmable logic devices
- Timers
- Clock chips
- Microprocessors
- Counters
- Memory Chips
- Microcontrollers

Activities

1. Use datasheets of logic gate ICs and note down the specification terminology.
2. Identify the application of the following IC's: 555, 741, 7445, 7404, 7473, 7490

Solved Problems

Example 3.4.1: Describe in brief the evolution of IC's from SSI to VLSI.

Solution: Digital IC's are categorized according to the number of logic gates on the silicon substrate. According to the level of complexity they are classified as:

- **Small Scale Integration (SSI)** - IC's with less than 12 gate circuits. Examples are flip-flops.
- **Medium Scale Integration (MSI)** - IC's with logic gate circuits between 12 to 100. Examples are counters, registers etc.
- **Large Scale Integration (LSI)** - IC's with gate circuit between 100 to 9999 on a single crystal. Example memory like RAM, ROM etc.
- **Very Large Scale Integration (VLSI)** - IC's with gate circuit between 10,000 to 99,999 on a single crystal. Example microprocessor.

UNIT SUMMARY

Digital systems are more reliable, less affected by noise, easier to design and fabricated on IC chips.

- The digital system uses binary number system.
- The Boolean algebra is an algebraic system developed for systematic treatment of logic with a set of elements, a set of operators and a number of postulates.
- The fundamental building block of any digital system are the logic gates.
- The three types of basic logic gates are the AND, OR and NOT.
- The inputs and outputs of logic gates occur in two levels, logic-1, termed as HIGH/TRUE and logic-0 termed as LOW/FALSE.
- NAND and NOR gates are called as Universal gates as they can realize the logic function of all the three basic gates i.e. AND, OR and NOT.
- Digital circuits are broadly classified as combinational circuits and sequential circuits.
- In combinational circuits, the output at any instant of time depends on the inputs present at that instant of time.
- Sequential circuits are of two types, Synchronous and Asynchronous.
- The basic building block of a sequential circuit is the flip-flop, which is also called a one-bit memory element.
- A flip-flop has got two stable states and can remain in that state indefinitely. Its state can be changed only by applying the proper input signals.
- The simplest type of flip-flop is called an S-R latch, which has two inputs labelled as S (SET) and R (RESET) and two outputs Q and its complement Q'.
- A digital counter is a sequential circuit, consisting of flip-flops whose state changes in response to the clock pulse applied at the input of the counter.

- Counters used to count the clock pulse, are divided into asynchronous counters and synchronous counters.
- In asynchronous counters also known as ripple counters, the flip-flops are connected in such a way that the output of the first FF becomes the clock pulse for the second FF and so on.
- In synchronous counters, also known as parallel counters all the flip-flops are clocked by the same clock pulse simultaneously.
- Digital IC's operate with binary signals and are made up of interconnected digital gates.
- Transistor Transistor Logic (TTL) in which basic logic operation is performed by transistors is most popular among the logic family.

EXERCISES

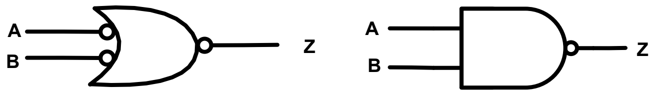
A. Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
3.1	The longest out of the following is a. Byte b. Nibble c. Word d. bit	3.4	SR flip-flop using NAND gates cannot accept following inputs: a. S = R =0 b. S=1, R=0 c. S = R = 1 d. S=0, R = 1
3.2	Identify the gate for which "Z is FALSE only if "A" is TRUE and "B" is TRUE" is applicable. a. NAND b. NOR c. AND d. OR	3.5	Counter is used to count the number of a. Flip flops b. Registers c. bits d. pulse
3.3	Flip flops are a. Chip b. Memory element c. Adders d. Comparators	3.6	The IC's used in watch and calculators are a. TTL b. ECL c. MOS d. CMOS

B. Subjective Questions

1. State why binary number system are used in digital systems.
2. What procedures are adopted in converting a decimal number into a number whose number system is with base b.
3. Perform the arithmetic operation on the binary numbers given below:
   (a)10111.101 + 110111.01 (b) 10001.01-1111.11
4. Verify by truth table method the Boolean expression: A + A'B + AB = A + B
5. Demonstrate by truth table the validity of the following Boolean laws
   (a) Associative law (b) Distributive law
6. Explain positive logic and negative logic in digital circuits.
7. Verify by truth table that the output of the gates shown in Fig. (a) & (b) are same.



(a) (b)

8. Draw logic diagram and truth table for a D and T type flip-flop.
9. Draw the circuit diagram for a 3-bit ripple counter using T flip flop.
10. State the differences between a linear IC and digital IC.

KNOW MORE

Micro-Project

Undertake one or two micro project(s) /activit(ies) in a group of 5 - 6 students under the guidance of faculty and present it as group with individual participation as well. A sample micro-project problem is given below:

a. A cooling unit is controlled by three variables: temperature (T), humidity (H) and the time of the day (T). The cooling unit is turned ON under the following conditions:
   i. The temperature exceeds 78° F and the time of the day is between 8.00 AM and 5.00 PM.
   ii. The humidity exceeds 85%, the temperature exceeds 78° F and the time of the day is between 8.00 AM and 5.00 PM.
   iii. The humidity exceeds 85% and the time of the day is between 8.00 AM and 5.00 PM.

b. Develop a circuit using logic gates using digital IC's to turn ON the cooling unit.
   Note: The cooling unit to be considered as Switching 'ON' an incandescent lamp.

Video Resources

Digital Electronics Circuits

Digital Circuits

Use of ICT

Course on Electronics and Communi-cation Engineering

REFERENCES AND SUGGESTED READINGS

1 Anand A. Kumar, *Fundamentals of Digital Electronics*, PHI Publisher, 2016.

2 R. P. Jain, *Modern Digital Electronics*, New Delhi: Tata McGraw Hill Publishing Company Limited, 2012.

3 S. Salivahnan and S. Pravin Kumar, *Digital Electronics*, Noida: Vikas Publishing House Pvt. Ltd., 2011.

4 A.P. Malvino, D.P. Leach and G. Saha, *Digital Principles and Applications*, Mcgraw Hill Educations, 2017.

4 Electric and Magnetic Circuits

UNIT SPECIFICS

This unit discusses the following topics:

- Definition of current, voltage, power and energy
- Electric circuit parameters and laws
- Parameters of a magnetic circuit
- Comparison between electric and magnetic circuits

The student self-learning activities at the end of each topic along with problem solving examples and ICT references are created for generating further curiosity and creativity as well as improving problem solving capacity. A number of multiple choice questions as well as subjective questions following increased levels of Bloom's taxonomy, assignments through a number of problems provided in the books listed under references and suggested readings are given in the unit so that one can go through them for practice.

The related practical is followed up by a "Know More" section containing micro projects and activities, QR code for video resources along with ICT links are given. A list of references and suggested readings are given in the unit so that one can go through them for further practice and enhancement of learning.

RATIONALE

The phenomena of electricity and magnetism are interconnected. Scientific experiments have proved that electric field produces magnetic effect and vice versa magnetic field can generate electric field. The magnetic field forms a necessary connection between electrical and mechanical energy. All electromechanical devices depend on the magnetic field for interchange of energy in either direction between electrical and mechanical device. The unit deals with the law governing the magnetic field, magnetization characteristic, emf induction and correlation between simple magnetic and electrical circuit.

PRE-REQUISITE

1. Science: Electricity, Magnetic Effects of Electric Current (Class X)
2. Mathematics: Pair of Linear Equation in Two Variables, Quadratic Equations (Class X)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U4-O1: Explain the basic parameters of an electrical circuit.

U4-O2: Describe the basic parameters of a magnetic circuit.

U4-O3: Explain laws of electromagnetic induction.

U4-O4: Interpret electric and magnetic circuits.

Unit 4 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U4-O1	2	-	-	3	2	2
U4-O2	1	-	-	3	1	2
U4-O3	1	-	-	3	1	3
U4-O4	1	-	-	3	1	1

Michael Faraday (1791-1867)

the most influential scientist in history contributed to the study of electromagnetism and electrochemistry. He received very little formal education, but was an excellent experimentalist and his research on the magnetic field around a conductor carrying a direct current established the basis for the concept on electromagnetic field. The breakthrough came when Faraday from his experiments found that a changing magnetic field produces an electric field. This relation was later modeled mathematically by James Maxwell and is known as the Faradays law. Using the above principal led Faraday to the discovery of electric dynamo. The SI unit of capacitance is named as farad in his honor.

4.1:PARAMETERS OF AN ELECTRIC CIRCUIT

4.1.1 Introduction

Fundamentals of different passive circuit elements, active elements, their types i.e. independent and dependent voltage/ current source and the types of signals were introduced in chapter 1. This topic deals with the concept of electric charge, current, voltage and the different electric circuit terminologies and laws for basic analysis of electric circuits.

4.1.2 Current /Voltage and Power/Energy

Current

The fundamental electrical quantity is charge. Its unit is Coulomb and the smallest amount of charge that exists is the negative charge carried by an electron that equals -1.602×10^{-19}C. The other charge carrying particle in an atom is the proton which is positively charged, with magnitude same as that of an electron. The charge of a proton is given as $+1.602\times10^{-19}$C. The electric current consists of the flow of a very large number of these charged particles. The electric current is defined as the time rate of change of the charged particles flowing through a predetermined area. In mathematical form, the current

$$i=\frac{\Delta Q}{\Delta t}$$

where ΔQ is the unit of charge flowing through the predetermined cross sectional area in time Δt. The units of current are called amperes, where 1ampere (A) = 1 *Coulomb/1sec*

Voltage (Potential Difference)

The charge moving in an electric circuit give rise to current. For a charge to be moved say from point **a** to point **b** in a circuit, some work or energy has to be expended. The work done in moving a unit charge from point **a** to **b** is called voltage or potential difference. The unit of voltage is called volt, where 1volt (V) = 1 Joule/1 Coulomb. As in gravitational field the potential difference between two points is independent of the path chosen. As shown in Fig. 4.1 (a), if the voltage of point a is higher than b as indicated as V_{ab} work must be done in moving the charge from point b to a, i.e. energy input to the charge. Similarly if the charge moves from point a back to b , energy is output with $V_{ba}= -V_{ab}$ i.e. voltage drop in going from **a** to **b**. Fig. 4.1 (b) shows the alternate way of representation of voltage difference.

Fig. 4.1: (a) Representation of voltage difference (b) Alternate representation of voltage difference

Power and Energy

Power is defined as the work done per unit time. The power either generated or dissipated by a passive element can be represented by the following equation.

$$Power = \frac{Work}{time} = \frac{Work}{charge} \times \frac{charge}{time} = voltage \times current \text{ or } P = VI$$

The unit of power is joules per second or watts. If both voltage and current remain constant over time t, the energy E transferred is V*I*t joules. Power is also a signed quantity like voltage and current. Power is put in if the current I flow into the positive terminal of V across an element as shown in Fig. 4.2 (a). As per passive sign convention the power dissipated is positive or in other words the element absorb power. In Fig. 4.2 (b) the power is put out if the current I flow out from the positive terminal V of an element, then as per convention the power dissipated is negative i.e. the element delivers power.

Fig. 4.2: (a) Passive sign convention of power dissipated (b) Passive sign convention of power generated

4.1.3 Electric Circuit Terminology

The interconnection of circuit elements is known as electric circuit. The following definition introduces some important parameters of an electric circuit.

Branch

A branch is any portion of a circuit with two terminals connected to it. A branch may consist of more than one circuit elements.

Node

A node is a junction of two or more branches. In practice any connection of two or branch terminals together forms a node. Nodes are very important parameter for circuit analysis. Fig. 4.3 shows a branch and interconnection of branch terminals to form a node.

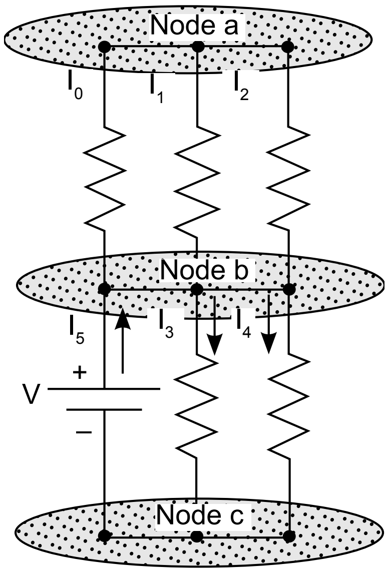


Fig. 4.3: Definition of node

Loop and Meshes

A loop is a closed connection of branches. A mesh is a loop that does not contain any other loop with in it as shown in Fig. 4.4 Meshes are an important aid for analysis of electric circuits.

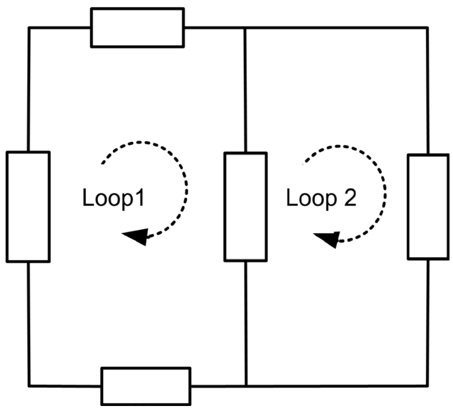


Fig. 4.4: Definition of mesh

4.1.4 Circuit Analysis

The analysis of an electric circuit consists of determining the unknown branch currents and node voltages. For this a set of variables has to identified and after which a set of equations using these variables has to be constructed. The set of equations are constructed by using the two important fundamental laws of circuit analysis namely the Kirchoff's current law and Kirchoff's voltage law.

Kirchoff's Current Law (KCL)

Kirchoff's current law states that since charge cannot be created but must be conserved, the sum of the currents at a node must be zero.

$$\sum_{k=1}^{k=N} i_k = 0 \qquad \text{... (4.1)}$$

where, i_k is the individual current flowing through the branches. Consider the node shown in Fig. 4.5 with the current directions. The current entering a node is assumed negative and that leaving a node as positive. Applying KCL law, the resulting equation at node A is given as

$$i_1 + i_2 + (-i_3) + (-i_4) = 0 \qquad \text{... (4.2)}$$

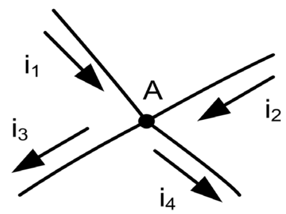


Fig. 4.5: Illustration of KCL

Kirchoff's Voltage Law (KVL)

Kirchoff's voltage law states that no energy is lost or created in an electric circuit. Or in other words, in a closed circuit the sum of all voltages associated with the sources must equal the sum of the load voltages, so that the net voltage around the circuit is zero.

$$\sum_{k=1}^{N} V_k = 0 \qquad \text{... (4.3)}$$

where, V_k are the individual voltages across the passive and active elements of the closed loop circuit. To understand the KVL law further, the concept of reference voltage must be understood. Fig. 4.6 shows a circuit with nodes marked as 1 and 2. The corresponding node voltages are V_1 and V_2 respectively. Any one node either node 1 or 2 can be chosen as reference node and the associated node voltage as the reference voltage. For example in the above figure, if node 2 is chosen as the reference node, connected to the negative terminal of the voltage source, then the node1 voltage V_1 is V_s volts above the reference node voltage V_2 . In practice for ease of calculation, the reference voltage is assigned zero volt.

Introduction: KVL, KCL and Power Balance

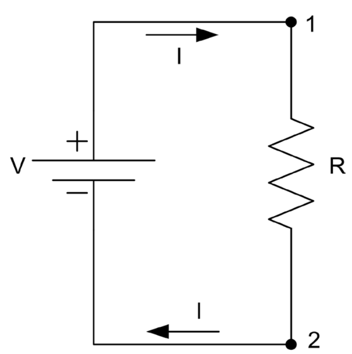


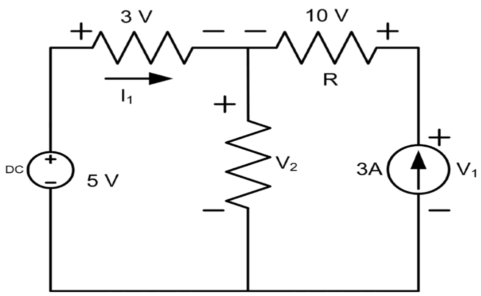
Fig. 4.6: Illustration of reference node

Activity

Prepare a circuit by connecting two bulbs in parallel across a given cell acting as voltage source. Measure the current $\boldsymbol{i}$ drawn from the voltage source and the current $\boldsymbol{i}_1$ and $\boldsymbol{i}_2$ drawn by the two lamps. Verify KCL.

Solved Problems

Example 4.1.1: For the circuit shown determine the power absorbed by the resistor R and the power delivered by the current source



Solution: Applying KVL in mesh-1, the KVL equation is
$5 - 3 - V_2 = 0$, Solving $V_2 = 2$ V.
Now applying KVL in mesh-2, the KVL equation is
$V_2 + 10 - V_1 = 0$.
Putting the value of V_2, the voltage V_1 across the current source of 3A = 12 V
As per passive power sign convention, the power delivered by current source =12× 3= 36 Watt
The power absorbed or dissipated by the resistor R = Voltage drop across R × current flowing through
R= 10×3 =30 Watt

4.2 PARAMETERS OF A MAGNETIC CIRCUIT

4.2.1 Magnetic Effect of Electric Current

To understand the magnetic field created by a current carrying conductor, consider the case of a long straight conductor carrying current as shown in Fig 4.7. The bold dot shows the current is flowing out of the plane of paper. The current causes a magnetic field to be established in the space surrounding the conductor. The magnetic field force can be felt on a north pole at any point on the magnetic field. The circular closed path around the conductor are known as the line of flux and the magnetic force is tangential to it all points around the line. The direction of flux is given by the right hand rule which states that if the conductor is gripped by the right hand with the thumb point in the direction of current, the direction of flux is towards which the other four fingers would encircle it. The flux lines are denser near the conductor and becomes less dense as we move away from it.

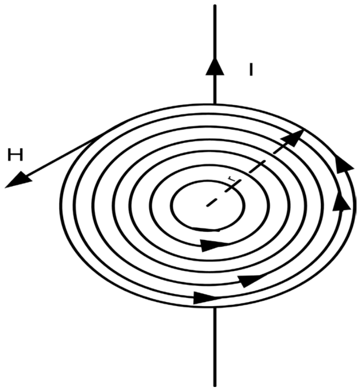


Fig. 4.7: Flux lines surrounding current

Magnetizing force

The magnetizing force or magnetic field intensity 'H' is defined as the current flowing through a conductor per unit length of flux line enclosing the conductor. For a circular flux line with radius 'r' the magnetic field intensity,

$$H = \frac{i}{2\pi r} \frac{A}{m} \qquad \ldots (4.4)$$

From equation it is seen that the magnetic field intensity is unaffected by the material surrounding the conductor or in other words it is independent of the properties of the materials employed in the construction of magnetic circuits.

Flux density

The flux density depends on the material properties. The relationship between the magnetic field intensity and flux density is given as

$$B = \mu_0 \mu_r H \quad \frac{Wb}{m^2} \text{ or Tesla} \qquad \ldots (4.5)$$

The parameter μ is a scalar constant for a particular physical medium and is called the permeability of the medium. The permeability of a material is the product of the permeability of free space μ0 and the relative permeability μ_r. The permeability of free space = $4\pi \times 10^{-7}$. The relative permeability depends on the medium and its magnitude represents the measure of the magnetic properties of the material. The larger the value of permeability, the smaller the current required to produce a large flux density in an electromagnetic structure. The unit of permeability is given as:

Magnetic Circuits

$$\frac{Wb}{A\text{-}m}$$

Fig. 4.8 shows the permeability of different types of magnetic materials. The subscript shows whether the material is ferromagnetic, paramagnetic, free space or diamagnetic.

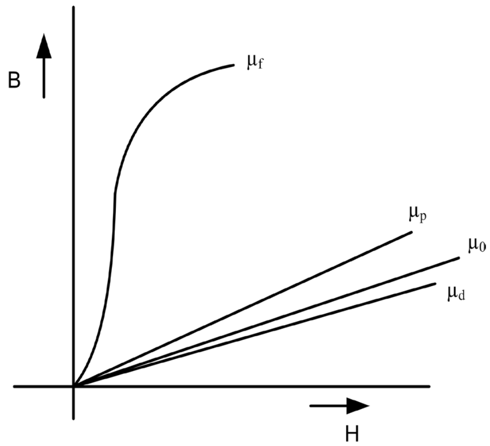


Fig. 4.8: B-H curve of different types of magnetic material

Magnetomotive Force

The magnetic field generated by a single conducting wire is not very strong. The field intensity can be increased by giving shape to a conductor as a tightly wound coil having N turns. The arrangement effectively increases the current linked by the flux lines N fold. The product N.I is called the magneto motive force F and its unit is ampereturns (AT). Fig. 4.8 shows a ferromagnetic material having circular cross section is excited by a coil having N turns and carrying a current I. The flux established in the magnetic core is circular in shape with major portion of the flux lines passing through the core due to its high permeability. The small portion of the flux line that passes through air is known as leakage flux.

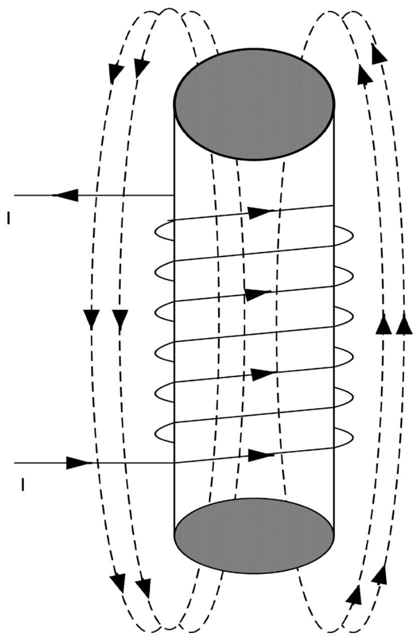


Fig.4.9: Flux

4.2.2 Magnetic Circuits

An electromagnetic core structure with circular cross section area as shown in Fig. 4.10 can be analysed by means of an equivalent magnetic circuit. The flux density for this circuit is given by equation

$$B = \frac{\mu NI}{l} \qquad \text{… (4.6)}$$

where l is the length of the flux mean path. Similarly, the flux density can also be represented as

$$B = \frac{\varnothing}{A} \qquad \text{… (4.7)}$$

where A is the cross sectional area of the electromagnetic structure and is perpendicular to the direction of flux lines. Equating the flux density equations, (4.6) and (4.7)

$$NI = \varnothing \frac{l}{\mu A} \qquad \text{… (4.8)}$$

The term $\frac{l}{\mu A}$ is known as the reluctance of the magnetic circuit and is designated the symbol R.

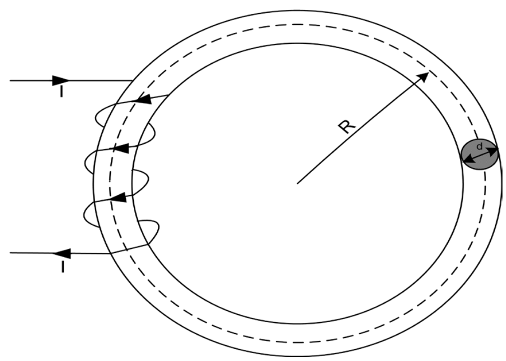


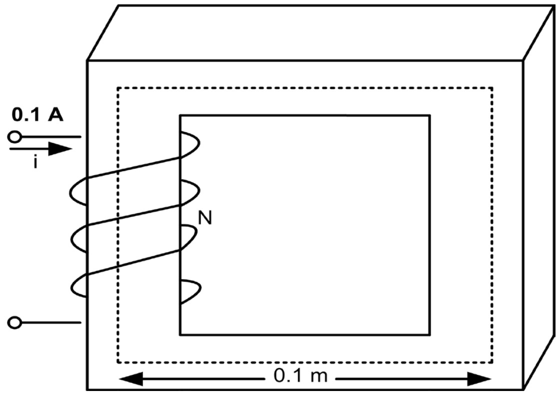
Fig.4.10: Ring of ferromagnetic material with exciting coil

Activity

Prepare a multi turn coil using a single strand bare copper conductor. Mark the two ends of coil as terminal 1 and 2. Connect a 9 V cell with the positive polarity connected to terminal 1 through a slider switch in series and terminal 2 to the negative polarity of the cell. Bring a magnetic compass near to the coil and switch on the slider switch Observe the position of the compass N-S pole needle. Now reverse the polarity of the terminals and observe the position of the N-S pole compass needle. Comment on the observations made.

Solved Problems

Example 4.2.1: Calculate the flux, flux density for the magnetic structure shown, given cross section area A = 0.0001 m^2, N = 500 turns, μ_r = 1000.



Solution: The magneto motive force F = mmf = Ni = 500× 0.1 = 50 AT
The mean length lc of the magnetic core is given as 4 × 0.1 = 0.4 m

The reluctance R = $\dfrac{lc}{\mu o \mu r A} = \dfrac{0.4}{1000\times 0.0001\times 4\pi\times 10^{-7}}$ = 2.865× 106 AT/Wb

The flux $\varphi = \dfrac{F}{R} = \dfrac{50}{2.865\times 10^{6}}$ = 1.75× 10^{-5} Wb

The flux density B = $\dfrac{\varphi}{A}$ = 0.175 Wb/m^2

4.3 ELECTROMAGNETIC INDUCTION

4.3.1 Faraday's law

When the magnetic flux φ passing through a surface changes in magnitude an electric field is induced along the outline of the surface. Faraday law states that a time varying flux causes an induced electromotive force or emf, and is given by

$$e = -\frac{d\varphi}{dt} \quad \text{... (4.9)}$$

words if a thin N turn coil is placed along the contour of the surface an emf is induced in it, which is given by

$$e = -\mathrm{N}\frac{d\varphi}{dt} = -\frac{d\lambda}{dt} \quad \text{... (4.10)}$$

where $\lambda = N\varphi$ = flux linkage of the coil.

The negative sign means that the induced emf would tend to cause a current to flow in the coil which would oppose the change in flux. This law is known as Lenz's law. The polarity of the induced emf can be determined from physical consideration and therefore the negative sign is omitted from the induced emf equation.

The change in flux linkage of a coil can occur in a variety of ways

Case-I: The flux is constant in value and the coil move relative to it.

Case-II: The coil remains stationary and the flux through it vary in magnitude (flux pulsations)

Case-III: The changes in flux and coil occur together i.e. the coil moving through a varying flux.

In Case-I, the flux cutting rule can be applied, where in the emf induced in a single conductor of length l moving with a velocity v and cutting a stationary magnetic field with flux density B is given by

$$e = Blv\ volts \quad \text{... (4.11)}$$

where l is in metre, v in metre per sec and B equals weber per square metre. The emf induced is known as dynamically induced emf or motional emf. The motional emf is always associated with electromechanical energy conversion.
The direction of the emf is given by Fleming's right hand rule.

In Case-II, the emf induced in a stationary coil is due to the time varying magnetic field. No motion is involved and there is no energy conversion. The emf so induced is known as statically induced emf or transformer emf and is same as equation 4.9.

In Case-III, both the emf's i.e. the motional emf and transformer emf are induced in the coil.

Mutual induction & inductance

4.3.2 SELF AND MUTUAL INDUCTANCE

Self-inductance

Self-inductance measures the voltage induced in a coil by the magnetic field created by a current flowing in the same coil. Consider a coil having N turns and carrying a current i as shown in Fig. 4.11.

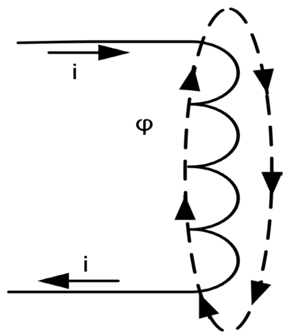


Fig. 4.11: Self Inductance

The coil creates a flux φ linking the turns of the coil. Then the emf induced in the coil as per Faradays law is given by

$$e = N\frac{d\varphi}{dt} \text{ volts}$$

$$= N\frac{d\varphi}{di}\frac{di}{dt}$$

$$= L\frac{di}{dt} \quad \text{... (4.12)}$$

$$\text{where } L = N\frac{d\varphi}{di}$$

is called the self-inductance of the coil and its unit is H(henrys). For a ferromagnetic material with B-H curve as shown in Fig. 4.8, the curve being nonlinear, the self-inductance corresponds to an incremental value corresponding to incremental change around an operating point on the curve.
Magnetic materials having linear B-H curve, the self-inductance can be expressed as

$$L = \frac{N\varphi}{i} = \frac{\lambda}{i} \text{ H}$$

Assuming no flux leakage, the above equation can be rewritten by multiplying numerator and denominator by N, as

$$L = \frac{N^2\varphi}{Ni}$$

Substituting the value of flux φ from equation, the above equation can be rewritten as

$$L = N^2 \mu \frac{A}{l}$$

$$= \frac{N^2}{R} \quad \text{... (4.13)}$$

The unit of self-inductance is Henry and the self-inductance of a coil depends only on the geometry, permeability of the magnetic material and the number of turns of the coil.

Mutual Inductance

When two coils are wound on a common core or are placed close to each other, a part of the flux produced by one coil also links the other coil as shown in Fig. 4.12. There is a magnetic coupling between the two neighbouring coils and this leads to the concept of mutual inductance.

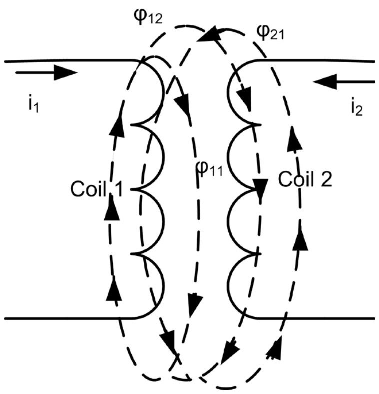


Fig. 4.12: Mutual inductance

Inductance, Self and Mutual inductance

Consider the current flowing through coil 1and 2 having the same number of turns N is i_1 and i_2 respectively. The total flux generated by current i_1 in coil 1 is φ_1 . A part of the flux φ_1 linking coil 2 is φ_{12} and similarly a part of the total flux φ_2 generated in coil 2 due to current i_2 linking coil 1 is φ_{21}. Then the mutual inductances of the coils are given as

$$M_{12} = N\frac{d\varphi_{12}}{dt} = \frac{\lambda_{12}}{i_1} \text{ H} \quad \text{...(4.14)}$$

$$M_{21} = N\frac{d\varphi_{21}}{dt} = \frac{\lambda_{21}}{i_2} \text{ H} \quad \text{...(4.15)}$$

For a tightly coupled coil there is no flux leakage and hence $M_{12} = M_{21} = M$. The unit of mutual inductance is also henry.

Activity

An air cored coil having N turns is made is made from a bare solid conductor of given length and diameter. Measure the self-inductance using LCR meter. Increase the number of turns to 2N, again measure the selfinductance. Compare the measured inductance value and draw the conclusion.

Solved Problems

Example 4.3.1: The total flux at the end of a long bar magnet is 500×10^{-6} Wb. The end of the bar magnet is withdrawn through a 1000 urn coil 1/10 sec. Find the emf generated across the terminals of the coil

Solution: From Faradays law the emf equation $e = N\frac{d\varphi}{dt}$

Given N =1 000 and $\frac{d\varphi}{dt} = \frac{500\times10^{-6}}{\frac{1}{10}} = 5000\times 10^{-6}$

$e = 1000 \times 5000 \times 10^{-6} = 5$ V

Example 4.3.2: Find the inductance of a long solenoid of length 1000mm wound uniformly with 3000 turns on a cylindrical iron tube of 60 mm diameter.
Solution: Given N = 3000, l = 1000mm = 1mtr,

Cross sectional area = $\pi \frac{0.060^2}{4} = 2.83\times 10^{-3}m^2$

The self-inductance $L = N^2\mu \frac{A}{l}$, the relative permeability of paper is 1.

Substituting the value of self-inductance

$$L = 3000 \times 3000 \times 4\pi \times 10^{-7} \times 1 \times \frac{2.83\times10^{-3}}{1} = 32mH.$$

4.4 ANALOGY BETWEEN ELECTRICAL AND MAGNETIC CIRCUITS

The analysis of a magnetic circuit is analogous to that of a resistive electric circuit. The analogous quantities are listed in Table 4.1.

Table 4.1: Analogy between electrical and magnetic circuits

Electrical quantity	Magnetic quantity
Electrical field intensity E, V/m	Magnetic field intensity H, A-turns/m
Voltage V, Volts	Magneto motive force F, A-turns
Current i, Amp	Magnetic flu x ϕ, Wb
Current density J, A/m^2	Magnetic flux density Wb/m^2
Resistance R,	Reluctance R, A-turns/Wb

The Kirchoff's law for electrical circuits is equally applicable for magnetic circuits. The KVL is interpreted as the magneto-motive force(mmf) of a mesh is equal to the mmf's expended in various parts of the mesh. Similarly, the KCL law is interpreted as the incoming and outgoing fluxes are equal at the junction of magnetic elements. A magnetic circuit as shown in figure can be analysed as a series magnetic circuit with the approximation that the flux density is same in the magnetic core and in air gap. The electrical analogy of the magnetic circuit is shown in Fig. 4.13 consisting of two magnetic elements connected in series having reluctance R_C and R_{ag}. The length of each element corresponds to its mean length.

Magnetic and electric circuit

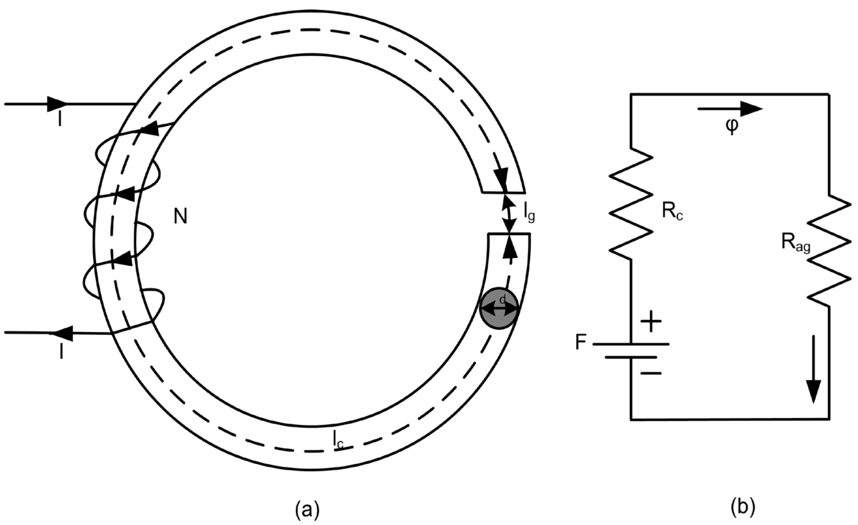


Fig. 4.13: (a) Magnetic core with air gap (b) Electric circuit analogy of the magnetic circuit

The reluctance of the magnetic core with a mean length of R_C where

$$R_C = \frac{l_C}{\mu o \mu r A}$$

Magnetic Circuits

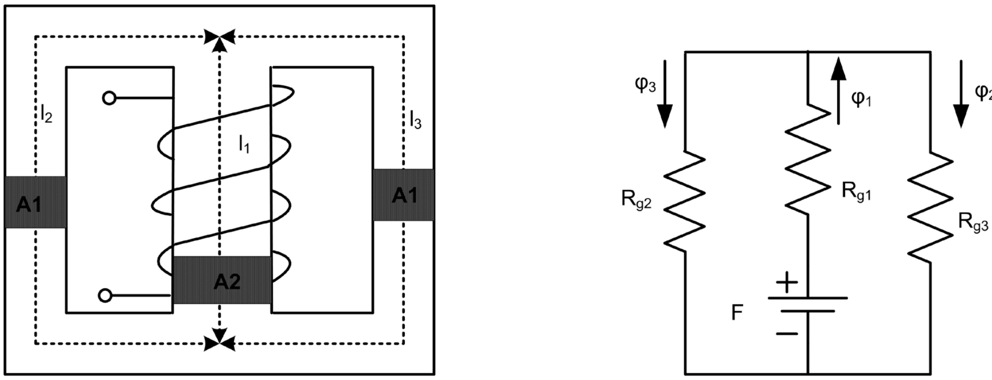
and the reluctance of the air gap is given by

$$R_{ag} = \frac{l_{ag}}{\mu o \mu r A}$$

Neglect fringing in the air gap the total reluctance $R = R_C + R_{ag}$
The flux in the circuit is given as

$$\varphi = \frac{F}{R}\text{, where } F = Ni$$

A parallel magnetic circuit and its electrical analogy is given in Fig.4.14 (a) and (b) respectively



(a) (b)

Fig. 4.14: (a) Magnetic structure with three limbs (b) Electrical analogy of the magnetic circuit

Activities

Make an electromagnet by wrapping a coil with fixed number of turns on a given iron nail.
Case-I. Connect two 1.5Volt cell in series and connect it across the terminals of the coil through a slider switch. Place some all pins near the coil. Switch ON the slider switch.
Case-II. Repeat the same procedures by replacing the 3 V cell by a 9 V battery. Observe the effect of the electromagnetic force on the all pins for Case-I and II and make necessary conclusions.

Solved Problems

Example 4.3.1: An iron ring with mean circumference of 140 cm and cross sectional area 12 cm^2 is wound with 500 turns of wire. When the exciting current is 2 A, the flux is found to be 1.2 milliweber. Determine relative permeability of iron.

Solution: Given $\varphi = \frac{F}{R}$, F = NI = 500× 2 =1000 and flux $\varphi = 1.2 \times 10^{-3}$ Wb.

The reluctance $R = \frac{1000}{1.2\times10^{-3}} = 833.33 \times 10^3$.

$R = \frac{1}{\mu o \mu l r A}$, The mean length l = 1.4 mtr and $A = 12 \times 10^{-4}\, m^2$.

Substituting the above value, we get. $833.33 \times 10^3 = \frac{1.4}{12\times10^{-4}\times\mu r \times 4\pi\times10^{-7}}$

$\mu r = 1114.69$

- The fundamental electrical quantity is called charge
- The flow of a very large number of the charged particle results in electric current.
- The work done in moving a unit charge from one point to another point is called voltage or potential difference.
- The power is defined as the work done per unit time.
- The interconnection of passive and active circuit elements is known as electric circuit.
- The most common circuit terminologies for analysis of an electric circuit are branch, node mesh and loop.
- The two fundamental laws for circuit analysis are the Kirchhoff's current and voltage law.
- A current carrying conductor creates a magnetic field surrounding the conductor.
- The flux density depends on the relative permeability of a material and the magnetic field intensity.
- The relative permeability represents the measure of the magnetic properties of a material and are categorized as ferromagnetic, diamagnetic and paramagnetic material.
- The time varying flux induces an emf in a conductor or coil and its magnitude depend on the rate of change of flux and the number of conductor turns.
- Self-inductance measures the voltage induced in a coil by the magnetic field created by a current flowing in the same coil.
- The mutual flux depends on the magnetic coupling between the two neighboring coils and accordingly are categorized as tightly coupled or loosely coupled coils.
- The unit of self and mutual inductance is henry
- The analysis of a magnetic circuit is same as that of a resistive circuit and the Kirchhoff's law are equally applicable for magnetic circuits.
- The reluctance of a magnetic core is directly proportional to the mean core length and inversely proportion al to the cross sectional area of the core.

EXERCISES

A. Objective Questions

Instruction: Please select the most appropriate answer.

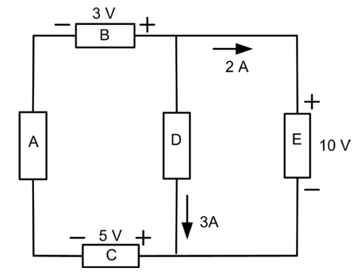
Sr. No.	MCQs	Sr. No.	MCQs
4.1	Which of the following are sources of steady magnetic field? 1. A permanent magnet 2. A charged disc rotating at uniform speed 3. An acceleration charge 4. An electric field which linearly changes with time a. 1, 3 and 4 only b. 3 and 4 only c. 1, 2, 3 and 4 d. 1, 2 and 4 only	4.4	According to Faradays law of electromagnetic induction an emf is induced in a conductor if a. Lies in a magnetic field b. Lies perpendicular to the magnetic field c. Cuts the magnetic flux d. Moves parallel to the direction of the magnetic field
4.2	The magnetic field developed by an infinite linear current carrying conductor in A/m is a. $H = \frac{\mu I}{2\pi R}$ b. $H = \frac{I}{2\pi R}$ c. $H = \frac{\mu I}{2r}$ d. $H = \frac{I}{r}$	4.5	Reluctance offered by a magnetic circuit depends on a. Nature of magnetic material b. Length of magnetic flux path c. Cross sectional area of the path d. All the above

4.3	The law of electromagnetic induction (Faraday and Lenz's law) are summarized in the following equation: a. $e = LR$ b. $e = L\frac{di}{dt}$ c. $e = -\frac{d\varphi}{dt}$ d. None of the above	4.6	A coil 250 turns is connected to a 50 V DC source. If the coil resistance is 10Ω, the magneto motive force developed is a. 500 b. 1250 c. 2500 d. 250

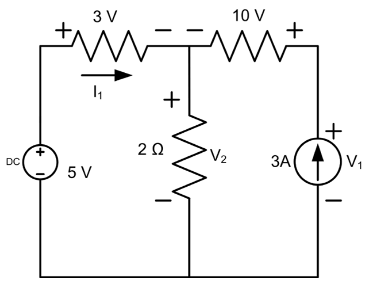
B. Subjective Questions

1. A magnetic circuit has 150 turns-coil, the cross sectional area and the length of the magnetic circuit is 5×10^{-4} m^2 and 25×10^{-2} m respectively. Find the value of magnetic field intensity and relative permeability when the current is 2 A and the total flux is 0.3×10^{-3} Wb.

2. For the circuit shown determine which components are absorbing power and which are delivering power.

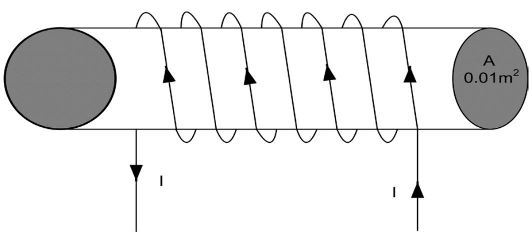


3. Apply KVL and KCL to find the voltage V_1 and V_2 and I_1 for the circuit shown.

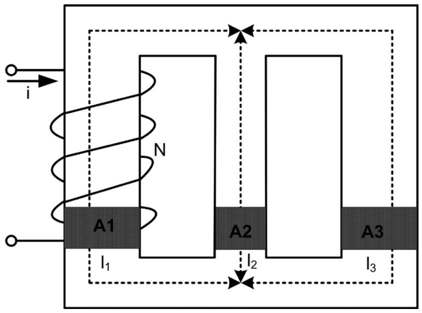


4. Consider a 230 V, 100 W incandescent lamp. Determine (i) the lamp resistance (ii) the lamp current (iii), the energy consumed by the lamp in 8 hrs.

5. For the electromagnetic circuit shown (i) Find the flux density in the core (ii) Sketch the magnetic flux lines and indicate their direction (iii) Indicate the north and south pole of the magnet. The cross sectional area is 0.01 m^2.



6. For the magnetic structure shown (i) draw the electric analogy of the magnetic circuit (ii) determine the total reluctance and (iii) the self-inductance of the coil. Given N=100 turns, $\mu_r = 3000\mu_0$. $A_1 = A_3 = 100$cm^2, $A_2 = 25$cm^2, $l_1 = l_3 = 30$ cm and $l_2 = 10$ cm



7. Explain with neat diagram statically induced and dynamically induced emf with one application each
8. Compare magnetic circuits and electric circuits
9. Derive an expression for self-inductance of the coil

PRACTICALS

I. P1- ES110: PERMEABILITY OF A MAGNETIC MATERIAL

P1.1 Practical Statement

Determine the permeability of magnetic material by plotting its B-H curve.

P1.2 Practical Significance

Magnetic Permeability is a value that expresses how a magnetic material responds to an applied magnetic field. If the dipoles of a magnetic material become easily oriented to an applied magnetic field, that magnetic material is regarded as having high-permeability. Based on the permeability, a magnetic material is classified as paramagnetic, diamagnetic or ferromagnetic material.

P1.3 Relevant Theory

For theory, refer topic 4.2 on 'parameters of a magnetic circuit' of this book.

P1.4 Practical Outcomes (PrO)

PrO1: Select the proper range of measuring instruments.

PrO2: Connect circuit and measuring instruments properly.

PrO3: Determine the permeability of a given magnetic material.

P1.5 Practical Setup (Circuit Diagram)

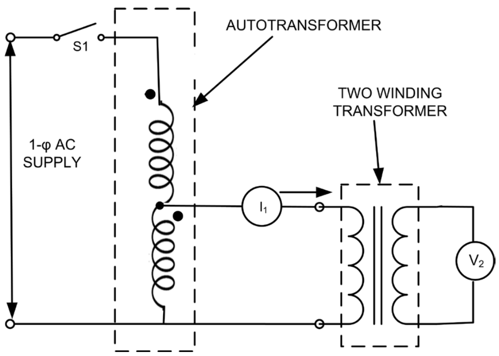


Fig. P1.1: Circuit diagram to determine the permeability of magnetic material

P1.6 Resources Required

Sr. No	Suggested Resources required Machines/Tools/ Instruments with vital specifications	Quantity	Actual Resources required Machines/Tools/ Instruments with broad specifications	Remarks (if any)
1.	Single phase AC source: 230V, 50Hz	1		
2.	Connecting wires: Multistrand Cu wire, 1.5 mm^2	L.S.		
3.	Single pole switch: 5A	2		
4.	1-phase Autotransformer: 2 KVA, 230V/270V	1		
5.	1-phase Transformer, 1 KVA, 230V/115V	1		
6.	Voltmeter: 0-300V AC	1		
7.	Ammeter: 0-1A, AC/Digital Ammeter	1		
8.	Connecting wires: Single strand Teflon coating (0.6mm diameter)	L.S.		

P1.7 Precautions

1. Select appropriate type and range of measuring instruments.
2. Connect ammeters and voltmeters as shown in the circuit diagram .
3. Check the circuit connections as per circuit diagram and ensure that the wire connections are tight, before switch S_1 is turned ON for power supply to the autotransformer.
4. Switch OFF the power supply after conduction of experiment.

P1.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P1.1.
2. Ensure proper connection of the auto transformer and the single phase transformer.
3. Keep the autotransformer rotary knob at zero voltage position.
4. Switch on the single pole switch S_1.
5. Increase the supply voltage to 1-phase transformer in steps of 10-15 volts up to the rated voltage by gradually turning the rotary knob of autotransformer.
6. Record the primary (V_1), current (I_1) and secondary voltage (V_2) of the two winding transformer in the observation table.
7. Plot the B-H curve and draw a tangent to the linear portion of the B-H curve as shown in Fig. P1.2.

P1.9 Observations and Calculations

Sr. No.	Primary current (I_1)	Secondary voltage(V_2)
1.		

Calculations:

1. Mark the current value on the x-axis of the graph paper and the voltage value on the y-axis of the graph paper.

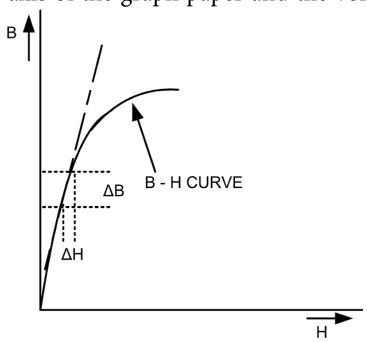


Fig. P1.2: B-H curve

P1.10 Results and Interpretation

The permeability μ of the magnetic material used for the given transformer is ………

P1.11 Conclusions and/or Validation

………

………

P1.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. State the differences between a soft and hard magnetic material.
2. List the need of a ferromagnetic material as core structure for a transformer.
3. Comment how the size of a transformer depends on supply frequency

P1.13 Suggested Learning Resources

B-H curve

KNOW MORE

Micro-Projects

Student shall undertake one or two micro project(s)/activit (ies) in a group of 5 - 6 students and under the guidance of faculty and present it as group with individual participation as well. A sample list is given below:

1. Develop a simple probe to detect the passing of current in a current carrying conductor
2. Develop a circuit to determine the parameters upon which the mutual inductance depends.

Video Resources

Electrical and magnetic circuits

Basic electric circuit

REFERENCES AND SUGGESTED READINGS

1. Seksena, S. B. Lal; Dasgupta, Kaustuv, *Fundamentals of Electrical Engineering*, Cambridge University Press, 2017.
2. Kothari, D P; Nagrath, I. J., *Basic Electrical Engineering*, New Delhi: Tata McGraw Hill Publishing Company Limited, 2002.
3. Wadhwa, C.L. , *Basic Electrical Engineering*, New-Age International Pvt Ltd Publishers, 2007.
4. Theraja, B. L., *Electrical Technology*, Vol. – I, New Delhi: S. Chand and Company, 2015.

5 AC Circuits

UNIT SPECIFICS

This unit discusses the following topics:

- Terms related with an alternating quantity like cycle, frequency, periodic time, amplitude, angular velocity, RMS value, average value, form factor peak factor, impedance, phase angle, and power factor
- Mathematical and phasor representation of alternating emf and current
- Voltage and current relationship in star and delta connections
- A.C in resistors, inductors and capacitors
- A.C in R-L series, R-C series, R-L-C series and parallel circuits
- Power in A. C. circuits and power triangle.

The practical applications of the topics are discussed for generating further curiosity as well as improving problem solving capacity. It is important to note that for getting more information on various topics of interest links in the form of QR codes of videos and websites have been provided. Multiple choice questions as well as subjective questions and number of numerical problems are provided for practice. Related practical's, followed up by a "Know More" section containing micro projects and activities as well as for supplementary information video resources along with ICT are given. A list of references and suggested readings are given in the unit so that one can go through them for further practice and enhancement of learning.

RATIONALE

Alternating Current (abbreviated as A.C./AC) plays a vital role in today's energy generation, distribution and consumption. Like DC circuits, AC circuits have a source of energy and load in which power conversion happens. The value of the magnitude and the direction of current and voltages is not constant in an AC circuit, it changes at a regular interval of time. AC is used for household and industrial applications such as television sets, computers, microwave ovens, fans, to the large motors used in the industry. In this unit the fundamentals and basic circuits of AC will be described.

PRE-REQUISITE

1. Applied Physics- 1: Work, Power and Energy (Semester I)
2. Mathematics-I: Trigonometry, Algebra (Semester I)

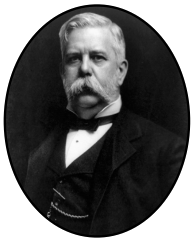
UNIT OUTCOMES

Upon completion of this chapter, the student will be able to:

U5-O1: Describe the various basic terms related to AC signals.
U5-O2: Represent the alternating e.m.f. and current in mathematical and phasor terms.
U5-O3: Analyse R-L series, R-C series, R-L-C series and parallel circuits when subjected to single phase AC.
U5-O4: Determine the voltage and current relationship in 3 phase AC system using Star/ Delta transformations.
U5-O5: Use the power triangle to determine AC circuit parameters.

Unit-5 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U5-O1	1	-	-	-	3	3
U5-O2	1	-	-	-	3	3
U5-O3	1	-	-	-	3	1
U5-O4	2	-	-	-	3	1
U5-O5	1	-	-	-	3	1

George Westinghouse (1846-1914)
was one of the most prolific inventors during the Industrial Revolution 2.0 and is best known for promoting alternating current technology, which revolutionized the world's illumination and power industries, and for inventing an air brake system that made railroads safe. After serving in the Union Army and Navy, he patented several devices, particularly for railroads. He would eventually start the Westinghouse Electric and Manufacturing Company to improve alternating current (AC) power generation.



5.1 ALTERNATING CURRENT FUNDAMENTALS

5.1.1 Introduction

Although alternating quantity has a much wider meaning, it is generally used to mean a sinusoidal quantity. Usually, alternating current (referred to as AC current) or alternating voltage (referred to as AC voltage) is a sinusoidal varying current or voltage. Almost all electrical power supply system's involve sinusoidal AC current, which is derived from sinusoidal AC voltage. A generator is used to produce AC voltage. The voltage generated by utility companies for our home, factories and offices is AC voltage.

5.1.2 Alternating Quantity

An alternating quantity changes continuously in magnitude and alternates in direction at regular intervals of time, as discussed in unit 1.3 of Unit 1. An alternating voltage or current may not always take the form of a smooth wave such as that shown in Fig. 5.1, yet sine wave is the ideal form and is the accepted standard. The waves deviating from the standard sine wave are termed as distorted waves. In general, however, an alternating current or voltage is one, the direction of which reverses at regularly recurring intervals.

Alternating Voltage and Current

When a coil is rotated in a magnetic field, an alternating electromotive force (e.m.f.) is induced in that coil. The value of e.m.f. induced depends on number of turns in the coil, strength of the magnetic field and the speed of which the coil is rotated in the magnetic field. Consider a conductor rotating in a uniform magnetic field with constant angular velocity of 'ω' radian per second as shown in Fig. 5.2. Its axis of revolution being perpendicular to the magnetic lines of force. As per the different position of conductor such as a, b, c and d, the corresponding value of electromotive force (emf) is shown in Fig. 5.2.

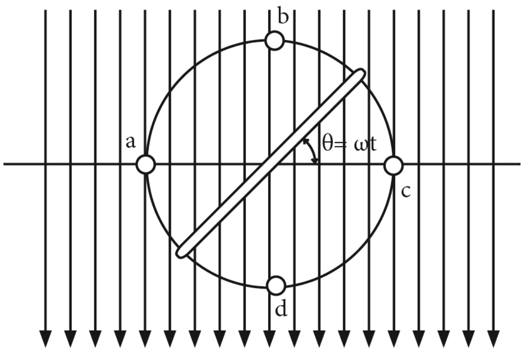


Fig. 5.1: EMF generated in a Coil rotating in a magnetic field

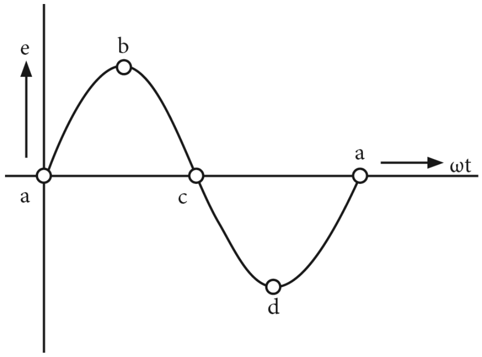


Fig. 5.2: Sinusoidal wave

At point a and point c, the conductor moves parallel to magnetic field. Hence, e.m.f. induced is zero. While at point b and d, the conductor moves in a direction perpendicular to the magnetic field. Hence, e.m.f. induced is maximum. In one complete revolution of a conductor, one complete cycle of e.m.f. is obtained. As the direction of e.m.f. is reversed at points a and c such e.m.f. is known as alternating e.m.f. or alternating voltage. When a coil with induced alternating e.m.f. is connected to external circuit, the alternating current starts flowing. The waveform of this alternating current is similar to waveform of an alternating voltage. Also, e.m.f. varies as sine function. The curve traced is sine curve and, hence, it is known as sinusoidal e.m.f.

5.1.3 Important terms related with an alternating quantity

Some of the important terms related with an alternating quantity, that should be understood are cycle, frequency, periodic time, amplitude, angular velocity, rms value, average value, form factor, peak factor, impedance, phase angle, and power factor; They are described in brief:

1. Cycle

One complete set of positive and negative values of alternating quantity is known as cycle. Hence, each diagram of Fig. 5.3 represents one complete cycle. A cycle may also be sometimes specified in terms of angular measure. In that case, one complete cycle is said to spread over 360° or 2π radians.

2. Frequency (f)

It is the number of cycles that occur in one second. The unit for frequency is Hz or cycles/sec. For example, 50 Hz is 50 cycles in one second.

3. Time Period or Periodic time (T)

It is the time taken in seconds to complete one cycle of an alternating quantity. It is denoted by T. The relationship between frequency and time period can be derived as follows:

Time taken to complete f cycles = 1 second

Time taken to complete 1 cycle = 1/f second

$$T = 1/f \qquad \ldots(5.1)$$

4. Amplitude

It is the maximum value, positive or negative, attained by an alternating quantity. It is also called as maximum or peak value.

5. Average Value

The arithmetic average of all the values of an alternating quantity over one cycle is called its average value. The average value of an alternating quantity over a cycle is zero. Therefore, it is defined over half a cycle. It is defined as that value of steady current which transfers the same electric charge as transferred by that alternating current.

Average value of a sinusoidal current, $i = I_m sin\ \omega t$ …(5.2)

$$I_{av} = \frac{1}{\pi}\int_0^{\pi} i\ d(\omega t)$$

$$I_{av} = \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t\ d\ (\omega t)$$

$$I_{av} = \frac{2I_m}{\pi} = 0.6371_m \qquad \text{…(5.3)}$$

∴ Sinusoidal alternating quantity, Average value = 0.637 x Maximum value.

6. R.M.S. Value

The R.M.S. (Root Mean Square) value of an alternating current is that value of steady current or direct current, which when flowing through a given circuit for a given time produces the same amount of heat as is produced by the alternating current flowing through the same circuit for the same time. It is also known as Effective Value. The value of an alternating current measured by ammeter is the R.M.S. value of the current. For sinusoidal alternating current;

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

$$I_{\text{rms}} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)}$$

$$I_{\text{rms}} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i^2{}_m sin^2 \omega t\ d(\omega t)}$$

$$I_{\text{rms}} = \frac{I_{\text{m}}}{\sqrt{2}} = 0.707 I_m \qquad \text{…(5.4)}$$

∴ R.M.S. value of a sinusoidal waveform = 0.707 × maximum value

7. Form Factor

The ratio of R.M.S. value of current to its average value is called form factor.

Form Factor = R. M.S. value/ Average value

= 0.707 I_m /0.637 I_m =1.11 …(5.5)

Thus, for sinusoidal waveform, the value of form factor is 1.11.

8. Peak Factor

The ratio of maximum value to R.M.S. value is called peak factor.

$$\text{Peak Factor} = \frac{Maximum\ value}{R.M.S.\ value} \qquad \text{…(5.6)}$$

For sinusoidal wave form, the value of peak factor is 1.414.

9. Angular Velocity

Angular frequency is defined as the number of radians covered in one second(i.e. the angle covered by the rotating coil). The unit of angular frequency is rad/sec.

$$\omega = \frac{2\ \pi}{T} = 2\pi f \qquad \text{…(5.7)}$$

10. Instantaneous Value

It is the value of the quantity at any instant.

Alternating Voltage and Current

$$v = V_m \sin\theta = V_m \sin\omega t = V_m \sin 2\pi ft = V_m \sin\frac{2\pi}{T}\ t \qquad \ldots(5.8)$$

where V_m = Maximum value of voltage,
f = Frequency in Hz, and t = Time in seconds

From the relationship expressed by equations 5.8,

i. the maximum value or peak value or amplitude of an alternating voltage is given by the coefficient of the sine of the time angle.
ii. the frequency f is given by the coefficient of time divided by 2π.

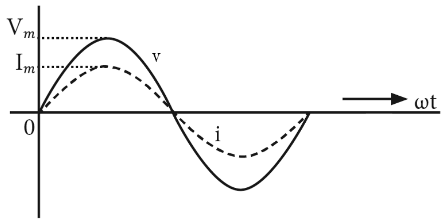


Fig. 5.3: Alternating Voltage and Current

For example, if the equation of an alternating voltage is given by v = 20 sin 31 then its maximum value is 20 V and its frequency is f = 314/2π = 50 Hz.
If the current is in phase with the above voltage and I_m is the maximum value of current then equation for instantaneous value of alternating current is

$$i = I_m \sin 2\pi ft = I_m \sin\omega\ t = I_m \sin\frac{2\pi}{T}\ t \qquad \ldots(5.9)$$

Comparison of AC system and DC system

A DC waveform is graphically shown in Fig 5.4. Some of the important advantages of AC system over DC system are as follows:

1. AC voltages can be efficiently stepped up/down using transformer.
2. As compared to DC motors, AC motors are cheaper and simpler in construction.
3. Switchgear for AC system is simpler than DC system.
4. Easy and cheaper generation and transmission, up to the break even distance.

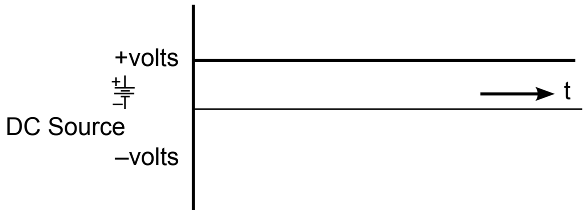


Fig. 5.4: DC Voltage

Single-phase and three-phase AC

AC can be single-phase or three-phase. Single-phase AC (Fig. 5.3) is used for small electrical demands such as in the home. Three-phase AC shown in Fig. 5.5 is used where heavy load i.e. large amount of power is required in commercial and industrial facilities. Three-phase is a continuous series of three overlapping AC cycles. Each wave represents a phase, and is offset by 120 degrees.

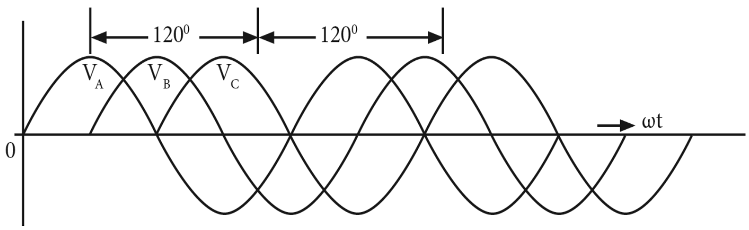


Fig. 5.5: Three-Phase Sine Wave

5.1.4 Phase, Phase Difference and Power Factor

During a cycle, the alternating current or voltage passes through various values. Starting from zero, it rises to a maximum and, then gradually reduces to zero. Then rises in the reverse direction, becomes maximum and finally, comes back to zero again. All alternating quantities go through these various stages. These various stages are termed as various phases in electrical engineering. By phase of an alternating quantity is meant the fraction of the time period of that alternating quantity, which has elapsed since the quantity last passed through the zero position of reference. Two alternating waves will be said to be in phase when they reach their maximum and zero values at the same time. Their maximum values may be different in magnitude. The actual phase at any particular instance of time is not that significant. However, the angle or time difference is important. The different quantities may be two different voltages or two different currents or a voltage and a current. The relative difference between two alternating quantiles is called 'phase difference' and, is expressed in terms of 'phase angle'.

Phase of I_m is $\pi/2$ rad or T/4 sec
Phase of $-I_m$ is $3\pi/2$ rad or 3T/4 sec

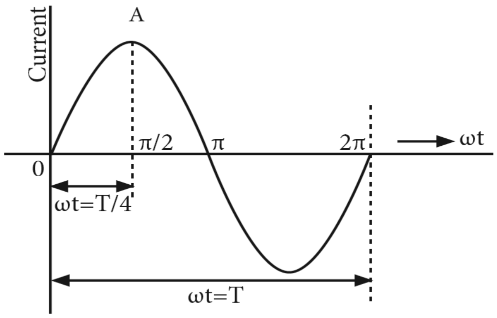


Fig. 5.6: Sine Wave with phase angle

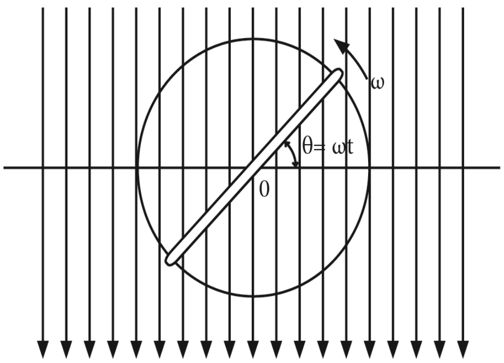


Fig. 5.7: Phase of rotating coil

For example, the phase of current at point A is T/4 second, where T is time period or expressed in terms of angle, it is $\pi/2$ radians (Fig. 5.6). Similarly, the phase of the rotating coil at the instant shown in Fig. 5.7 is θ that is equal to ωt which is therefore, called its phase angle.

Phase Difference

Consider three similar single-turn coils displaced from each other by angles and rotating in a uniform magnetic field having the same angular velocity as shown in Fig. 5.8 (a).

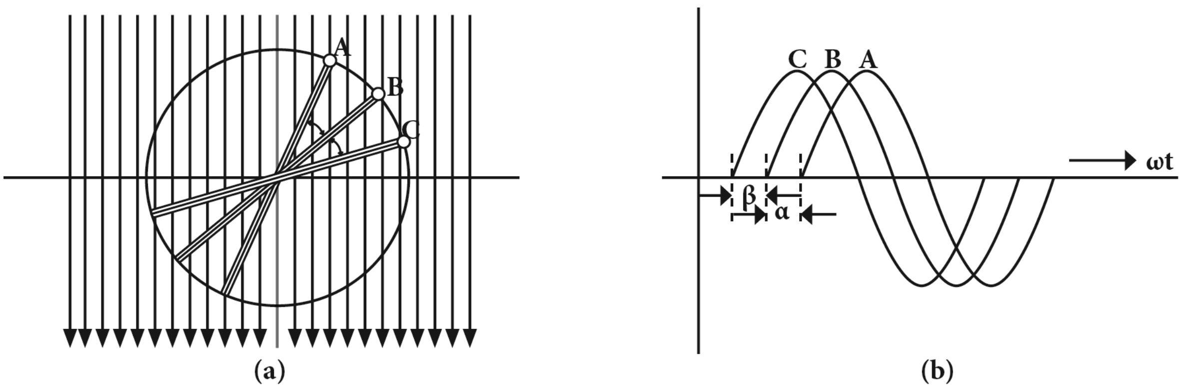


Fig. 5.8: Phase Difference

In this case, the value of induced e.m.fs. in the three coils are the same, but there is one important difference. The e.m.fs. in these coils do not reach their maximum or zero values simultaneously but one after another. The three sinusoidal waves are shown in Fig. 5.8 (b). It is seen that curves B and C are displaced from curve A at angles β and (α+ β) respectively. Hence, it means that phase difference between A and B is β and between B and C is α, but between A and C is (α+ β). The statement, however, does not give indication as to which e.m.f. reaches its maximum value first. This deficiency is supplied by using the terms 'lag' or 'lead'. A plus (+) sign when used in connection with phase difference denotes 'lead' whereas a minus (–) sign denotes 'lag'.

AC Circuits

A leading alternating quantity is one which reaches its maximum (or zero) value earlier as compared to the other quantity. Similarly, a lagging alternating quantity is one which reaches its maximum or zero value later than the other quantity. For example, in Fig. 5.8 (b), B lags behind A by angle β and C lags behind A by (α+ β) because they reach their maximum values later.

The three equations for the instantaneous induced e.m.fs are (Eq. 5.10 a, b and c)

$e_A = E_m \sin \omega t$ ...reference quantity (Eq. 5.10b)

$e_B = E_m \sin (\omega t - \beta)$ ...(Eq. 5.10a)

$e_C = E_m \sin [\omega t - (\alpha + \beta)]$ ...(Eq. 5.10c)

5.1.5 Phasor

A phasor is a vector that is used to represent a sinusoidal function. It rotates about the origin with an angular speed ω in anti-clock wise direction. Electrical quantities like current and voltage are represented by means of phasor with the length representing the magnitude and the arrow representing the direction. The vertical component of phasors represents the quantities that are sinusoidal varying for a given equation. Here, the magnitude of the phasors represents the peak or maximum value of the current (I_m) and voltage (V_m). From Fig. 5.6 and Fig. 5.7, the relation between a phasor and the sinusoidal representation of the function with respect to time can be observed. The projection of the phasor on the vertical axis represents the value of the quantity. For example, in the case of a current or a voltage phasor, the projection of the phasor on the vertical axis, given by $I_m \sin \omega t$ and $V_m \sin \omega t$ respectively, gives the value of the current or the voltage at that instant.

5.1.6 A.C in Pure Resistors, Inductors and Capacitors

5.1.6.1 Pure Resistive Circuit

From Ohm's law, $I = V/R$ or $V = IR$

When an alternating voltage V is applied across a pure resistance R as shown in Fig. 5.9, the instantaneous value of current flowing through the resistance in given by $i = I_m \sin 2\pi f t$.

Putting the value of V in terms of maximum voltage and $I_m = V_m/R$,

$$v = V_m \sin 2\pi f t.$$

From the expressions of v and i, we see that the quantities can be represented as shown in Fig. 5.10. From the phasor diagram of a pure resistive circuit as shown in Fig. 5.11, the phasors for the voltage and the current are in the same direction for all instances, the phase angle between the voltage and the current is zero, that is the phase difference is zero. Hence, the value of power factor or cos ø is unity, i.e. one.

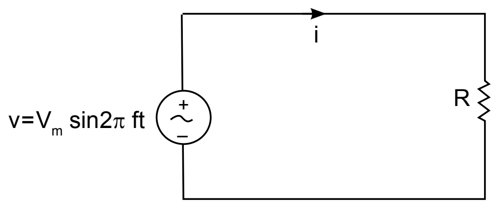


Fig. 5.9: Pure Resistive Circuit with AC Source

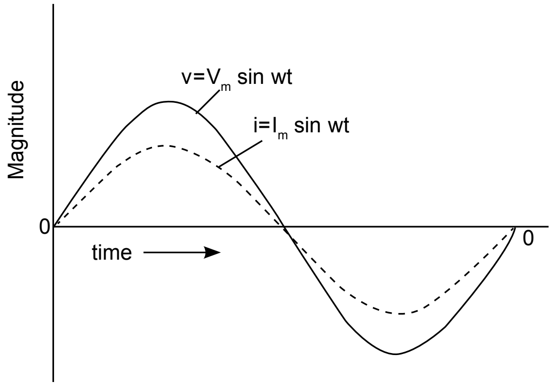


Fig. 5.10: Response of a pure resistive circuit to AC voltage input

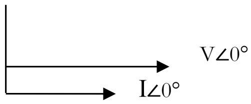


Fig. 5.11: Phasor diagram

5.1.6.2 Pure Inductive Circuit

An AC voltage is connected to a pure inductive coil as shown in Fig. 5.12. It results in e.m.f. getting induced in the coil due to self-inductance. This e.m.f. is dependent on the rate of change of current which flows through the coil. Due to this opposition, the current lags behind the applied voltage by an angle of π /2 or 90°.

Let $v = V_m \sin 2\pi f t$

∴ the value of current $i = I_m \sin (2\pi f t - \pi/2)$

$= - I_m \cos 2\pi ft$

This is shown in Fig. 5.13.

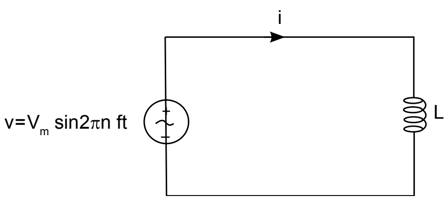


Fig. 5.12: Response of a to a ac voltage input

Also, the value of current $I_m = V_m/\omega L$

where "ωL" is known as "Inductive Reactance" and is denoted by X_L,

L is the value of inductance in Henry and ω = 2πfL.

X_L is measured in ohms.

In this circuit, the phase difference between voltage and current is 90° as shown in Fig. 5.14. Hence, the value of power factor or cos ø is zero.

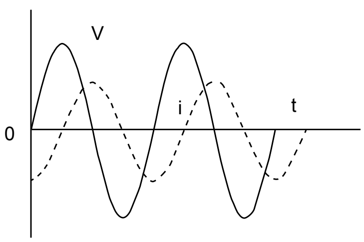


Fig. 5.13: Pure inductive circuit to AC

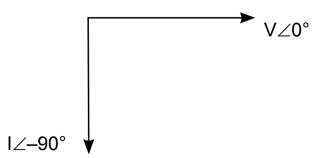


Fig. 5.14: Phasor Diagram

5.1.6.3 Pure Capacitive Circuit

When an alternating voltage is applied to a pure capacitance as in Fig. 5.15, the process of charging and discharging begins. It is charged in one direction and, then in the opposite direction. This results in flow of current. Due to charging and discharging process, the current leads the applied voltage by an angle π /2 as shown in Fig. 5.16.

Let $v = V_m \sin 2\pi ft$
then the value of current $i = I_m \sin(2\pi ft + \pi/2)$

Also, the value of current $I_m = V_m/(1/\omega C)$
where $1/\omega C$ plays the role of resistance and is known as
"Capacitive Reactance". It is denoted by X_C and is measured in Ohms.
C is the value of capacitance in Farads and $\omega = 2\pi ft$. X_C is measured in ohms.

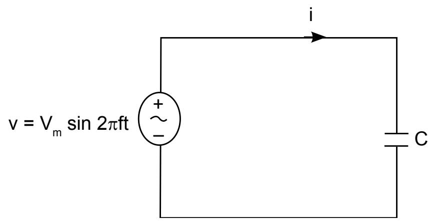


Fig. 5.15: Pure Capacitive Circui with AC

In this circuit, the phase difference between voltage and current is 90° as shown in Fig. 5.17. Hence, the value of power factor or cos ø is zero.

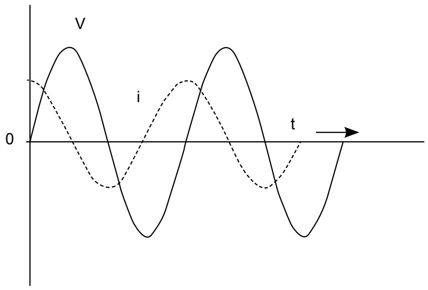


Fig. 5.16: Response of a pure capacitive circuit to AC voltage input

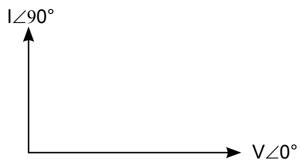


Fig. 5.17: Phasor Diagram a pure capacitive circuit

Applications

- Almost every home in the world is powered by AC. DC is generally not used for these purposes due to more power lost to heat compared to AC, higher risks of producing a fire, higher costs, and issues with converting high voltage to low voltage using transformers.
- With AC, it is also feasible to build electric generators, and power distribution systems that are far more efficient than DC, and so it is seen that AC is mainly used across the world in high power applications.
- AC is also more popular when it comes to powering electric motors, a device that converts electric energy into mechanical energy.
- Most of the household appliances that are used rely on AC like refrigerators, fans, air-conditioners, ovens, toasters, etc.
- The three basic linear passive components: the resistor (R), the capacitor (C), and the inductor (L) are used in number of AC applications on its own and may be combined as RC circuit, the RL circuit, the LC circuit, and the RLC circuit, with the acronyms indicating which components are used. These circuits, among them, depicts a large number of important types of behaviour that are fundamental to many electrical and analog electronic applications.

Alternating Current

Solved Problem

Example 5.1.1: An alternating current i is given by i = 141.4 sin 314t
Find i) The maximum value ii) Frequency iii) Time Period iv) The instantaneous value when t =5 ms .
Solution:
Given, i = 141.4 sin 314t

$i = I_m \sin \omega t$

i. Maximum value $I_m = 141.4$ A

ii. $\omega = 314$ rad/sec

$f = \omega/2\pi = 50$ Hz

iii. $T = 1/f = 0.02$ sec

iv. $I = 141.4 \sin(314 \times 0.005) = 3.87$ A

5.2 AC SERIES AND PARALLEL CIRCUITS

5.2.1 Introduction

In electrical engineering, when practical circuits are analysed, they normally consist of two or more of the elements of resistance, inductance and capacitance. Hence there are a number of situations in which calculation of different components related to AC series circuit is required. For studying the performance of AC machines, the knowledge of AC series circuit is quite essential. In this section, AC series circuits consisting the combinations of resistance, inductance and capacitance are described.

5.2.2 Resistance - Inductance (R-L) circuit

In the previous section, AC voltage applied across circuits consisting of pure resistance, inductance and capacitance in turn was explained. However, in a series circuit when AC voltage is applied across the combination of the two i.e. a circuit consisting of pure resistance R and pure inductance 'L' in series as shown in Fig.5.18, the current flowing in R and L will be same and therefore, will have same instantaneous value as also the R.M.S. and maximum value. 'i' is taken as reference, for the solution of the series circuit.

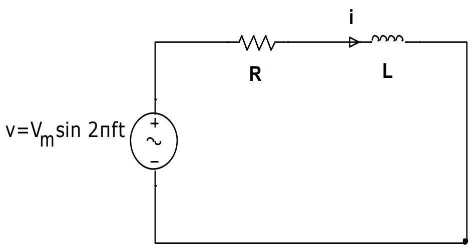


Fig. 5.18: R.L. Series circuit

Let $i = I_m \sin \omega t$ be the expression for current flowing. This will cause voltage drops across R and L.
The instantaneous voltage drop across 'R' is

$$V_R = i\,R = I_m \sin \omega t\, R \qquad \text{…(5.11)}$$

and, the instantaneous voltage drop across 'L' is

$$V_L = L\,\frac{di}{dt} = L\,\frac{d}{dt}\,(I_m \sin \omega t)dt$$

$$= (I_m \cos \omega t)\,\omega L \qquad \text{...(5.12)}$$

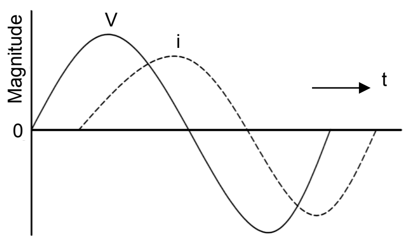


Fig. 5.19: Response of a R-L series circuit to AC input

Then, the total instantaneous value of the supply voltage is

$$v = V_R + V_L$$
$$= I_m R \sin \omega t + I_m \omega L \cos \omega t$$
$$= I_m (R \sin \omega t + \omega L \cos \omega t]$$

Substituting

R = $Z \cos \theta$ and $\omega L = X_L = Z \sin \theta$; …(5.13)

where Z is called impedance of the circuit.

$$V = I_m [Z \cos \theta \sin \omega t + Z \sin \theta \cos \omega t]$$
$$= I_m Z [\cos \theta \sin \omega t + \sin \theta \cos \omega t]$$
$$= I_m Z[\sin (\omega t + \theta)]$$
$$= V_m \sin (\omega t + \theta) \quad \text{…(5.14)}$$

Thus, the voltage leads over the current by an angle θ, this also means that, the current in an inductive circuit lag over the voltage by an angle θ.

The value of θ in terms of known parameters be found out by taking ratio of

$$Z \sin \theta / Z \cos \theta = \tan \theta$$
$$\text{or } \theta = \tan^{-1} \omega L / R \quad \text{…(5.15)}$$

It is a function of ' ω ' the frequency. The value of Z in terms of given parameters is

$$R = Z \cos \theta \,;\, \omega L = Z \sin \theta.$$

Squaring and adding it,

$$R^2 + \omega^2 L^2 = Z^2 (\cos^2 \theta + \sin^2 \theta) = Z^2$$

$$Z = \sqrt{R^2 + \omega^2 L^2} \quad \text{…(5.16)}$$

Fig. 5.19 shows variation of voltages and current across an R-L circuit.
Total power of the circuit, $P = VI \cos \theta$
where V and I are the r.m.s. values of voltage and current.

5.2.3 Resistance - Capacitance (R-C) circuit

On comparing RC circuit as shown in circuit Fig. 5.20 with R-L circuit, it is seen

$$\text{Impedance } Z = \sqrt{R^2 + (1/ \omega^2 C^2)} \quad \text{…(5.17)}$$
$$I_m = V_m / Z;\ \tan \theta = X_C / R. \text{ or } \theta = \tan^{-1} 1/ (\omega CR) \quad \text{…(5.18)}$$
$$\cos \theta = R/Z$$
$$i = I_m \sin (2\pi f t + ø) \quad \text{…(5.19)}$$

because current leads the voltage by an angle ø.
Total power of the circuit, $P = VI \cos ø$

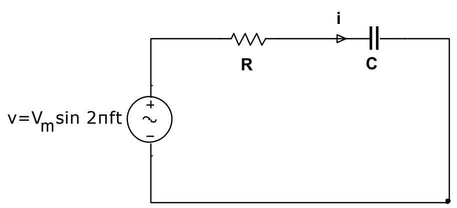


Fig. 5.20: R-C series circuit

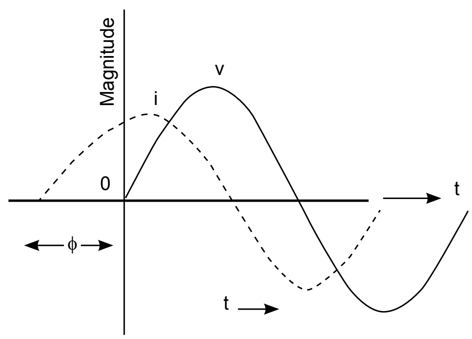


Fig. 5.21: Response of a R-C series circuit to AC voltage input

5.2.4 Resistance, Inductance and Capacitance Circuit (R.L.C. Circuit)

A pure resistance of R ohms ,pure inductive reactance of X_L ohm and pure capacitive reactance of X_C ohms are connected in series across AC voltage, $v = V_m \sin 2\pi ft$ as shown in Fig. 5.22.
In this case, the current is opposed by total combined resistance which is known as impedance. The impedance consists of resistance R and net reactance X.

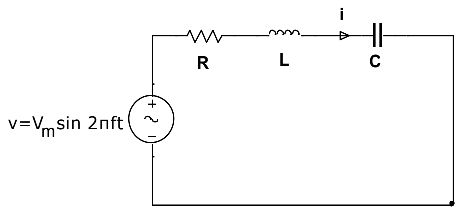


Fig. 5.22: R-L-C series circuit

The net reactance is given by $X = X_L - X_C$, when $X_L > X_C$
or $X = X_C - X_L$,, when $X_C > X_L$

Thus, the impedance $Z = \sqrt{(R^2 + X^2)}$ or $Z = R^2 + (X_L - X_C)^2$ or $Z = \sqrt{R^2 + (X_C - X_L)^2}$ . . . .(5.20)

The value of current $I_m = \frac{V_m}{Z}$; value of power factor $\cos ø = \frac{R}{Z}$; and phase angle $ø = \cos^{-1} \frac{R}{Z}$.

Impedance Triangle

Impedance Triangle is a right angled triangle whose base, perpendicular and hypotenuse represents Resistance 'R', Reactance 'X' and Impedance 'Z' respectively as shown in Fig. 5.23. It is basically a geometrical representation of circuit impedance.

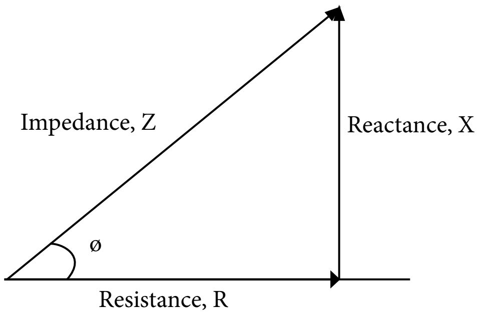


Fig. 5.23: Impedance Triangle

Parallel RLC Circuit

Consider a RLC circuit in which resistor, inductor and capacitor are connected in parallel to each other. This parallel combination is supplied by voltage supply, V as shown in Fig 5.24. In series RLC circuit, the current flowing through all the three components i.e the resistor, inductor and capacitor remains the same, but in parallel circuit, the voltage across each element remains the same and the current gets divided in each component depending upon the impedance of each component. That is why parallel RLC circuit is said to have dual relationship with series RLC circuit.
The total current is drawn from the supply is equal to the vector sum of the resistive, inductive and capacitive current, not the mathematical sum of the three individual branch currents, as the current flowing in resistor, inductor and capacitor are not in same phase with each other; so they cannot be added arithmetically.

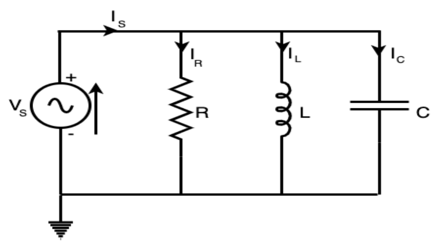


Fig. 5.24: R-L-C parallel circuit

Apply Kirchhoff's current law, which states that the sum of currents entering a junction or node, is equal to the sum of current leaving that node,

$$I_S^2 = I_R^2 + (I_L - I_C)^2$$

Phasor Diagram of Parallel RLC Circuit

Let V be the supply voltage;
I_S, the total source current;
I_R, the current flowing through the resistor;
I_C, the current flowing through the capacitor;
I_L, the current flowing through the inductor; and
θ, the phase angle difference between supply voltage and current.

For drawing the phasor diagram of parallel RLC circuit, voltage is taken as reference since voltage across each element remains the same and all the other currents i.e. I_R, I_C, I_L are drawn relative to the voltage vector. In case of resistor, voltage and current are in same phase; current vector I_R is drawn in same phase and direction to voltage. In case of capacitor, current leads the voltage by 90^0, so drawing I_C vector leading voltage vector, V by 90^0. For inductor, current vector I_L lags voltage by 90^0 so drawing I_L lagging voltage vector, V by 90^0. The resultant of I_R, I_C and I_L i.e. current I_S at a phase angle difference of θ with respect to voltage vector, V as shown in Fig. 5.25(a).

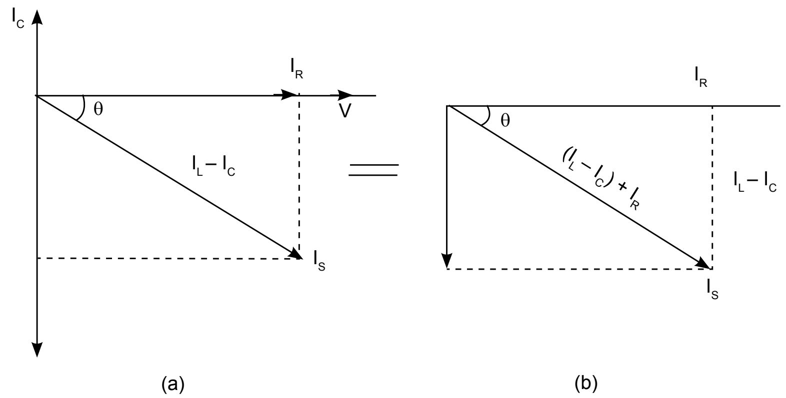


Fig. 5.25: Phasor Diagram of Parallel RLC Circuit

Simplifying the phasor diagram, simplified phasor diagram is obtained as shown in right hand side in Fig 5.25(b). On the phasor diagram of parallel RLC circuit, applying Pythagoras theorem,

$$I^2_S = I^2_R + (I_L - I_C)^2$$

Since $I_R = V/R$, $I_C = V/X_C$, and $I_L = V/X_L$, substituting the value of I_R, I_C, I_L in above equation,

$$I_S = \left(\frac{V}{R}\right)^2 + \left(\frac{V}{X_L} - \frac{V}{X_C}\right)^2$$

On simplifying, Admittance, $Y = \frac{1}{z} = \frac{I_S}{V} \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}$ …(5.21)

As shown above in the equation of impedance, Z of a parallel RLC circuit each element has reciprocal of impedance (1/Z) i.e. admittance, Y. For solving parallel RLC circuit, it is convenient if admittance of each branch is found and the total admittance of the circuit can be found by simply adding each branch's admittance.

Resonance in Series RLC Circuit

Resonance in AC circuit implies a special frequency determined by the values of resistance, inductance and capacitance. Inductive reactance $X_L = \omega L$ or $X_L = 2\pi f L$

and capacitive reactance $X_C = \frac{1}{\omega C}$ or $X_C = \frac{1}{2\pi f C}$;
where f is the frequency, L is inductance in Henry and C is the capacitance in Farad.

At certain value of frequency, it may happen that, the value of $X_L = X_C$. At this stage, net reactance will be zero. The series circuit in which, net reactance becomes zero; is said to be in "Electrical resonance." The frequency at which this happens is known as "resonant frequency" and can be derived using equation $X_L = X_C$.

Its value is given by $f_r = \dfrac{1}{2\pi\sqrt{LC}}$ …(5.22)

At resonant frequency, it is seen that, the value of Z = R ohm and current is opposed by resistance only and, hence, it is characterized by minimum impedance, maximum current and zero phase.

Resonance in Parallel RLC Circuit

Like series RLC circuit, parallel RLC circuit also resonates at particular frequency called resonance frequency i.e. there occurs a frequency at which inductive reactance becomes equal to capacitive reactance but unlike series RLC circuit, in parallel RLC circuit the impedance becomes maximum and the circuit behaves like purely resistive circuit leading to unity electrical power factor of the circuit.

Solved Problems

Example 5.2.1: A series circuit consists of a resistance of 6Ω and an inductive reactance of 8Ω. A potential difference of 141.4 V (r.m.s.) is applied to it. At a certain instant, the applied voltage is + 100 V, and is increasing. Calculate at this instant, (i) the current (ii) the voltage drop across the resistance and (iii) voltage drop across inductive reactance.

Solution: $Z = R + jX = 6 + j8 = 10 \angle 53.1°$

It shows that current lags behind the applied voltage by 53.1°. Let V be taken as the reference quantity.

Then $v = (141.4 \times 2) \sin t = 200 \sin t$; $i = (V_m/Z \sin t) -30° = 20 \sin (t -53.1°)$.

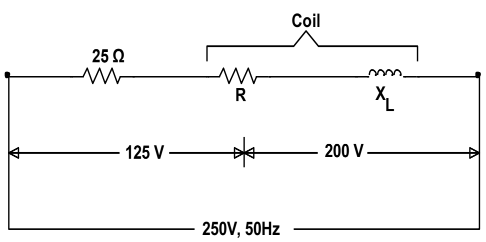
i. When the voltage is + 100 V and increasing; 100 = 200 sin t; sin t = 0.5; ωt = 30°. At this instant, the current is given by i = 20 sin (30° −53.1°) = −20 sin 23.1° = −7.847 A.

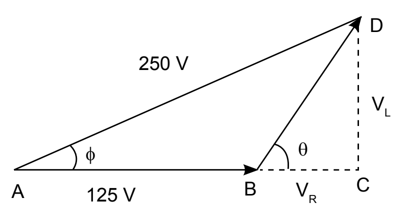
ii. Voltage drop across resistor = iR = −7.847 × 6 = −47 V.

iii. Let us first find the equation of the voltage drop V_L across the inductive reactance. Maximum value of the voltage drop = $I_m X_L = 20 \times 8 = 160$ V. It leads the current by 90°. Since current itself lags the applied voltage by 53.1°, the reactive voltage drop across the applied voltage by (90° − 53.1°) = 36.9°. Hence, the equation of this voltage drop at the instant when ωt = 30° is

$$V_L = 160 \sin (30° + 36.9°) = 160 \sin 66.9° = 147.2 \text{ V}.$$

Example 5.2.2: A current of 5 A flows through a non-inductive resistance in series with a choking coil, when supplied at 250-V, 50-Hz. If the voltage across the resistance is 125 V and across the coil 200 V, calculate (a) impedance, reactance and resistance of the coil (b) the power absorbed by the coil and (c) the total power.





Solution:

$I = 5$ A

As seen from the vector diagram drawn,

$BC^2 + CD^2 = 200^2$ ...(i)

$(125 + BC)^2 + CD^2 = 250^2$ ...(ii)

Subtracting Eq. (i) from (ii), we get, $(125 + BC)^2 - BC^2 = 250^2 - 200^2$

$\therefore$ BC = 27.5 V; CD = 200 − 27.5 = 198.1 V

a. Coil impedance = 200/5 = 40 Ω

$V_R = IR = BC$ or

5R = 27.5

$\therefore R = 27.5/5 = 5.5\Omega$

Also $V_L = I \cdot X_L = CD = 198.1$

$\therefore X_L = 198.1/5 = 39.62\ \Omega$

or $X_L = 40 - 5.5 = 39.62\ \Omega$

b. Power absorbed by the coil = Voltage across coil × current × cos θ

= 200 × 5 × 27.5/200 =137.5W

Also $P = I^2 R = 5^2 \times 5.5 = 137.5$W

c. Total power = VI cos φ = 250 × 5 × AC/AD = 250 × 5 × 152.5/250 = 762.5 W

The power may also be calculated by using I^2R formula.

Series resistance = 125/5 = 25 Ω

Total circuit resistance = 25 + 5.5 = 30.5 Ω

$\therefore$ Total power = $5^2 \times 30.5 = 762.5$ W

Applications

The applications of RC & RLC circuits include the following:

- RF Amplifiers
- Filtering Circuits
- Oscillator Circuits
- Processing of Signal
- Magnification of Current or Voltage
- Frequency, Amplitude Modulation Circuit
- Radio Wave Transmitters

RL combination is comparatively expensive , hence it is found in very less appliances e.g. choke of tube light, power supplies, etc. LC circuits and RLC Circuitbehave as electronic resonators, which are a key component in many applications like Oscillators, Filters, Tuners, Mixers, Contactless cards, Graphics tablets, electronic article surveillance (security tags), etc.

5.3 AC POWER AND THREE PHASE CIRCUIT

5.3.1 Introduction

In the earlier units, single phase circuit was discussed. Now a days, three phase systems are the most commonly used systems. Most of the electrical machines are operating on three-phase system. Not only that, the complete generation, transmission distribution as well as utilization of electrical energy is based on three phase system. Three phase motors are used in a floor mill and in most of the industries. The switches used normally in the house are double pole type while, the switches used in industries are of 'triple pole' type because three phase supply is commonly used in industries. Hence it is necessary to learn about basics of three-phase system.

5.3.2 Advantages of Three Phase System

Compared to single phase system, there are certain advantages in case of three phase system which are as follow:

i. The power in three phase system is about three times than that of single phase system.
ii. Compared to only one voltage available in single-phase system, the values of voltages in three-phase system are two phase and line voltages in case of star connection.
iii. Large amount of power can be transmitted in three-phase system compared to power transmitted in single phase system.
iv. Power factor of motors operated on three-phase system is higher, than the p.f. of single phase motors for same output and speed.
v. Three phase currents can produce rotating magnetic field (which is required for operation of AC motors) while single phase supply can produce only pulsating field.

5.3.3 Star and Delta Connection

The three phase circuits can be connected in two ways.

i. Star connection

In star connection as shown in Fig. 5.26, three ends of a coil or resistance are shorted together to make point N. This junction acts as a neutral point. Remaining three ends named as R, Y and B are the supply terminals.

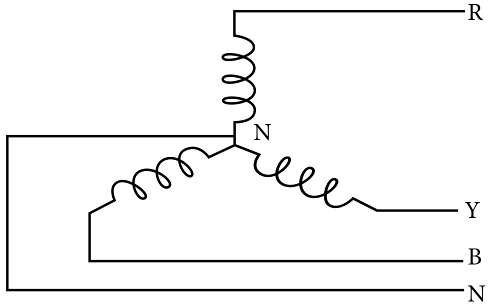


Fig. 5.26: Star Connection

ii. Delta connection

In delta connection two ends, one from one coil or resistance and, other from other coil or resistance are joined together. Thus, it forms three junctions as shown in Fig. 5.27. Three junctions named as R, Y and B are the supply terminals.

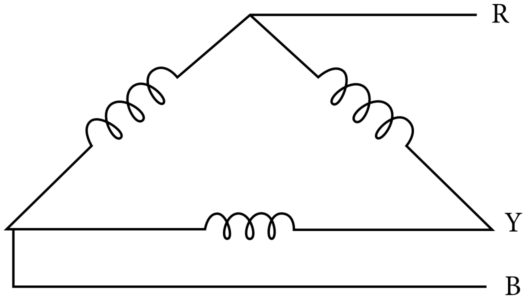


Fig. 5.27: Delta Connection

5.3.4 Relationship between Line and Phase Values of Voltages and Currents

In case of three phase connection, the voltage between two outer conductors or lines is called 'Line voltage'. It is denoted by V_L. The voltage across each coil or phase is called 'phase voltage'. It is denoted by V_p. Similarly, the current flowing in outer conductor or line is called 'Line current'. It is denoted by IL. The current flowing in a coil or phase is called 'phase current'. It is denoted by I_p. All these are shown in Fig. 5.28 and Fig 5.29 , and it will help in finding the relation between V_L and V_p, I_L and I_p in case of star and delta connections.

5.3.4.1 Star connection

In star connection as shown in Fig. 5.28, it is seen that line current is equal to phase current

i.e. $I_L = I_p$. …(5.23)

Regarding voltage, Line voltage is equal to $\sqrt{3}$ times the phase voltage

i.e. $V_L = \sqrt{3}\ V_p\ or\ V_p = V_L/\sqrt{3}$ …(5.24)

Also, phase current $I_p = \dfrac{\text{Phase voltage } (V_p)}{\text{Impedance per phase } (Z)}$ …(5.25)

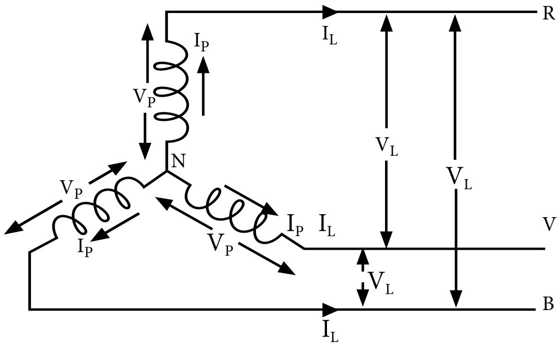


Fig.5.28: Star connection with Voltage and Current

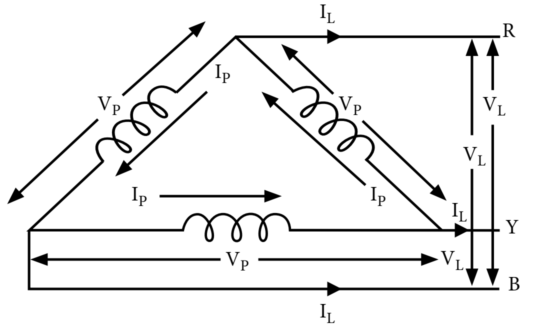


Fig.5.29: Delta connection with Voltage and Current

5.3.4.2 Delta connection

For delta connection as shown in Fig. 5.29, it is seen that line voltage equal to phase voltage
i.e. $V_L = V_p$. …(5.26)
Line current is equal to $\sqrt{3}$ times the phase current
i.e. $I_L = \sqrt{3}\, I_p$ or $I_p = I_L/\sqrt{3}$. …(5.27)

Also, phase current $I_p = \frac{Phase\ voltage\ (V_p)}{Impedance\ per\ phase\ (Z)}$ …(5.28)

5.3.5 Electric Power

Power is the rate at which work is performed, or the rate at which energy is expended. Work is often expressed in joules. In electrical terms, one joule of work is accomplished when a voltage of one volt causes one coulomb of electrons to pass through a circuit. When this amount of work is accomplished in one second, it is equal to one watt. Most of the times, electrical equipment are rated in watts. A watt is the basic unit of power. One watt is also defined as the amount of work that is accomplished when a voltage of one volt causes one ampere of current to pass through a circuit. This relationship between power, voltage, and current is expressed by the following formula:

Power = Volts × Amperes
or
P = V × I
In terms of other Ohm's Law components, the formula for power can be represented in two other ways as follows:
$P = I^2 R$ or $P = V^2/R$ …(5.29)
where P is power in watts or volt-amperes (VA), V is voltage in volts, I is current in amperes, R is resistance in ohms.

5.3.6 Power Triangle

Power Triangle is the representation of a right angled triangle whose sides represent the active, reactive and apparent power. Base, perpendicular and hypotenuse of this right angled triangle denotes the active, reactive and apparent power respectively. When each component of the current that is the active component (I cos ϕ) or the reactive component (I sin ϕ) is multiplied by the voltage V, a power triangle is obtained shown in the Fig 5.30.

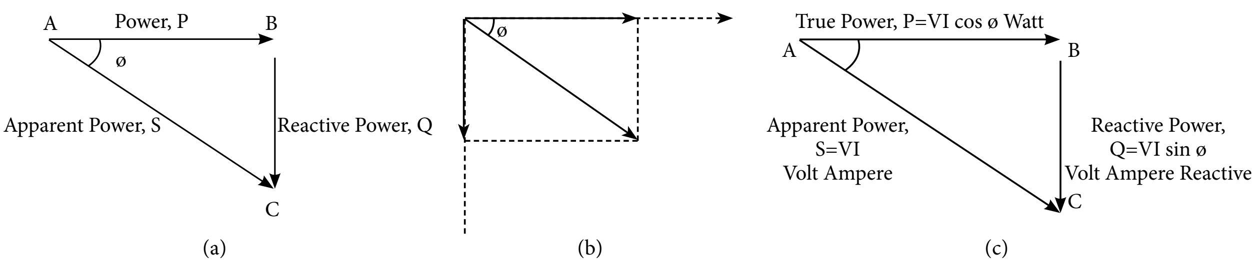


Fig. 5.30: Power Triangle

Fig 5.30 (a) shows a power triangle. Side AB, BC and AC represents P, Q and S respectively. The power triangle is obtained from the phasor diagram shown at Fig 5.30 (b). The power which is actually consumed or utilized in an AC Circuit is called true power or active power or real power. The unit is MW. The power which flows back and forth means it moves in both the direction in the circuit or can be reacted upon it is called Reactive Power. The reactive power is measured in kilovolt-ampere reactive (KVAR) or MVAR. The product of root mean square (RMS) value of voltage and current is known as apparent power. This power is measured in KVA or MVA.

Alternating Current (Ep 4)

The relationship between these quantities is explained by graphical representation called Power Triangle shown in Fig 5.30(c).

Delta-Y (Pi-T) Conversions

- When an active component of current is multiplied by the circuit voltage V, it results in active power. It is this power which produces torque in the motor, heat in the heater, etc. This power is measured by the wattmeter.
- When the reactive component of the current is multiplied by the circuit voltage, it gives reactive power. This power determines the power factor, and it flows back and forth in the circuit.
- When the circuit current is multiplied by the circuit voltage, it results in apparent power.
- From the power triangle shown above the power, the factor may be determined by taking the ratio of true power to the apparent power.

$$\text{power factor} = \frac{Active\ Power}{Apparent\ power} = \frac{KW}{KVA} \quad \ldots(5.30)$$

Basically, power means the product of voltage and current, but in AC circuit except for pure resistive circuit there is usually a phase difference between voltage and current and thus VI does not give real or true power in the circuit.

∴ True power, $P = VI \cos ø$. …(5.31)

For a pure inductance or a pure capacitance, the power consumed in the circuit is zero, as phase angle is 900. However, in the case of pure resistive circuit the power consumed which is given by P = VI watts where V and I are the r.m.s. values of voltage and current.

5.3.7 Power in Three Phase Connection

The power consumed in each phase for star and delta connections is $V_p I_p \cos \Phi$. The total power in the circuit is the sum of the three phase powers.

∴ Total power consumed is given by $W = 3V_p I_p \cos ø$ …(5.32)

Now $I_p = I_L$; $V_p = V_L/\sqrt{3}$ for star connection and $V_p = V_L$; $I_p = I_L/\sqrt{3}$ for delta connection

Converting these phase values of V_p and I_p into line values i.e. V_L and I_L, the above expression for total power in both star as well as delta connection becomes

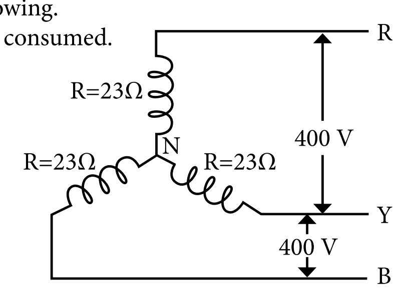
$W = \sqrt{3}\ V_L I_L \cos ø$. …(5.33)

Activity

Each batch will visit a nearby sub-station or industry and observe the arrangements for the 3- phase power supply and the power factor improvement. Each batch will prepare a brief report based on their observation.

Solved Problems

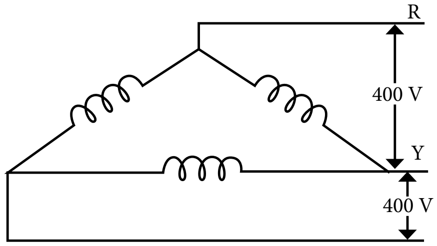
Example 5.3.1: Observe the circuit shown with the given data and determine the following.
(a) Phase current, (b) line current (c) power factor of each phase, and (d) Total power consumed.



Solution : It is seen that line voltage V_L = 400 Volts
Resistance per phase R = 23 ohms
Now, phase voltage $V_p = 400/\sqrt{3} = 230$ volts
Current, $I_P = V_p/R = 230/23 = 10$ amps
Now, calculating line value of current from phase value
$I_L = \sqrt{3} \times I_P = 17.3$ amps.

Total power consumed $P = \sqrt{3}V_L I_L \cos\phi$
$= 3 \times 400 \times 17.3 \times 1$ ($\cos\phi = 1$ because of resistance circuit)
= 12000 watts
= 12 kW.

Example 5.3.2: Look at the circuit diagram. The impedance in each phase consists of 8 ohms resistance and 6 ohms inductive reactance. Calculate the following (i) Phase voltage, (ii) Phase current, (iii) Line current, (iv) Total power consumed.



Solution : As the circuit is delta connected,
The phase voltage (V_P) = 400 volts.

To find phase current, impedance is calculated for each phase i.e. z using the given values of R and X.

$z = 8 + j6 = \sqrt{8^2 + 6^2} = 10$ ohms.
The phase current $I_P = V_P/R = 400/10 = 40$ amps

From this line current $I_L = \sqrt{3} \times 40 = 69.2$ amps.
Power factor, $\cos ø = R/X = 6/8 = 0.8$
Now, total power consumed, $P = \sqrt{3}\, V_L I_L \cos ø = \sqrt{3} \times 400 \times 69.2 \times 0.8 = 38400$ watts = 38.4 KW

UNIT SUMMARY

- The r.m.s. value of an alternating current is given by that steady (DC) current which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current when flowing through the same circuit for the same time. It is also known as the effective value of the alternating current.
- Phase is a relative position of any electrical quantity with respect to a reference measured in term of time or angle.
- One complete set of positive and negative values of the alternating quantity is called cycle.
- Phase is defined as the fractional part of time period or cycle through which the quantity has advanced from the selected zero position of reference.
- There is a phase angle between the source voltage and the current in an AC circuit that can be found by dividing the resistance by the impedance.
- The power factor ranges from –1 to 1.
- A three-phase system possesses certain advantages over single-phase system.
  – Three-phase current supplied to a 3 phase winding produces a rotating magnetic field while single phase supply can produce only pulsating magnetic field.
  – In three-phase system less conducting material is required for transmitting same power as compared to single phase.
  – Power in three-phase system is about three times than that of single phase system.
  – Large amount of power can be transmitted in three-phase system compared to power transmitted in single-phase system.
- The three basic, linear passive components: the resistor (R), the capacitor (C), and the inductor (L) may be combined in the form of RC circuit, the RL circuit, the LC circuit, and the RLC circuit.
- In star connection, the line current is equal to phase current and Line voltage is equal to $\sqrt{3}$ times the phase voltage.
- For delta connection, the line voltage equal to phase voltage and line current is equal to $\sqrt{3}$ times the phase current.
- The power consumed in each phase for star and delta connections is $V_p I_p \cos\phi$. The total power in the circuit is the sum of the three phase powers.
- Power Triangle is the representation of a right angled triangle whose base denote the active or true power, Perpendicular denote the reactive power and Hypogenous denote the apparent power.

EXERCISES

A - Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
5.1	The peak value of a sine wave occurs a. Once each cycle at the positive maximum value. b. Once each cycle at the negative maximum value. c. Twice each cycle at the positive and negative maximum value. d. Twice each cycle at the positive maximum value.	5.4	An alternating current given by i(t) = 100 sin 314 t will achieve a value of 86.6 A after how may seconds after time instant the current value is zero a. $\frac{1}{300}$ sec b. $\frac{1}{600}$ sec c. $\frac{1}{1200}$ sec d. $\frac{1}{150}$ sec
5.2	The imaginary part of an impedance is called: a. Resistance b. Reactance c. Admittance d. Conductance	5.5	If v_1 = A sin ωt and v_2 = B sin (ωt−φ), then a. v_1 lags v_2 by φ b. v_2 lags v_1 by φ c. v_2 leads v_2 by φ d. v_1 is in phase with v_2
5.3	As sine wave has a frequency of 50 Hz. Its angular frequency in radian/second will be a. 50/π b. 50/2 π c. 50 π d. 100 π	5.6	For a star connection, the line current is 15 amps. The value of phase current will be a. 10 amps b. 12.5 amps c. 15 amps d. 17 amps

B - Subjective Questions

1. Define the term "Power factor". Determine the value of power factor in case of pure inductive circuit ?
2. If an alternating voltage 300 sin eft is applied across pure capacitance having reactance of 15 ohms. Determine the following:
   a. Expression of instantaneous value of current
   b. Power factor
   c. Phase angle difference between current and voltage, and Power consumed.
3. A circuit having a resistance of 12 Ω, an inductance of 0.15 H and a capacitance of 100 μf in series is connected across a 100V, 50Hz supply. Calculate the impedance, current, the phase difference between the current and supply voltage.
4. Two circuits with impedances of Z_1 = 10 + j15Ω and Z_2 = 6 – j8Ω are connected in parallel. If the supply current is 20A. Determine the power dissipated in each branch.
5. In a delta connected system, the values of phase voltage, phase current and power factor are 500 volts, 20 amps and 0.8 respectively. Calculate the total power consumed by the system.

PRACTICALS

I. P2- E110: MEASUREMENT OF CIRCUIT PARAMETERS FOR RESISTIVE LOADS

P2.1 Practical Statement

Measure voltage, current and power in 1-phase circuit with resistive load.

P2.2 Practical Significance

The measurement of parameters like voltage, current and power is significant to assess the performance of a given load as per the name plate specifications. For applications like heater loads the measurement will help to determine the sizing of the power supply cables and the ratings of the protective device like fuse, circuit breakers etc.

P2.3 Relevant Theory

For theory refer topic 5.1.3 (i) Pure Resistive Circuit. The power absorbed by a resistive load fed from a single phase AC supply is given as VIcosθ, where V and I are the voltage across and current through the load. For a resistive load the power factor cosθ is unity. Therefore, the power absorbed by the resistive load equals VI.

P2.4 Practical Outcomes (PrO)

PrO1: Select the proper range of measuring instruments.

PrO2: Connect circuit and measuring instruments properly.

PrO3: Measure voltage, current and power of the given resistive load.

P2.5 Practical Setup (Circuit Diagram)

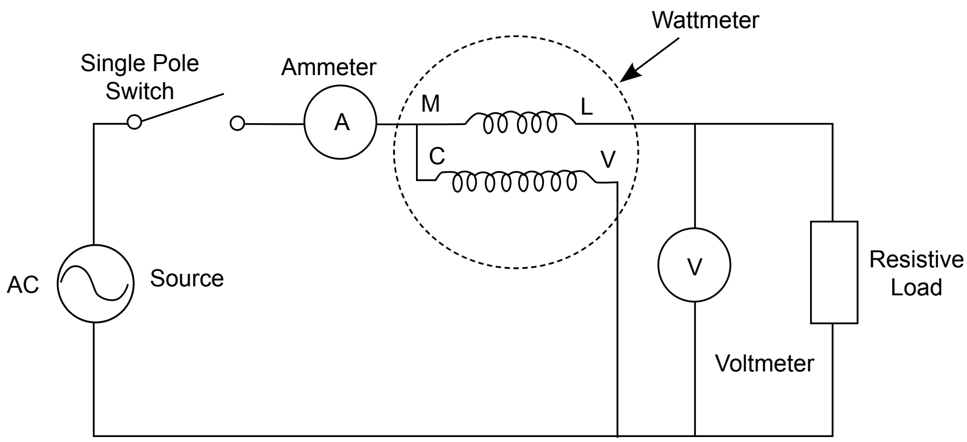


Fig. P2.1: Circuit diagram for measurement of voltage, current and power

P4.6 Resources Required

Sr. No	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specifications (to be filled by the student)	Remarks (if any)
1.	Single phase AC source: 230 V, 50 Hz	1		
2.	Connecting wires, Multistrand Cu wire, 1.5 sq.mm	L.S.		
3.	Single pole switch: 5 A	2		
4.	Resistive load: 1 kW	1		
5.	Voltmeter: 0-300 V AC	1		
6.	Ammeter: 0-5 A AC	1		
7.	Single phase wattmeter: Current coil0-5 A, Voltage coil 0-300 V	1		

P2.7 Precautions

1. Ensure proper selection of range of measuring instruments.
2. Connect voltmeter and ammeter as shown in the circuit diagram .
3. Check the circuit connections as per circuit diagram before switching ON the power supply.

P2.8 Suggested Procedure

1. Connect the circuit as shown in P2.1.
2. Ensure proper connection of ammeter, voltmeter and wattmeter.
3. Measure the resistance of the given resistive load.
4. Connect the single phase power supply.
5. Switch ON the single pole switch.
6. Record the multiplication factor of wattmeter according to the selected current and voltage coil rating.
7. Record the current, voltage and wattmeter reading in the observation table.

P2.9 Observations and Calculations

Sr. No.	Ammeter (A)	Voltmeter (V)	Wattmeter (W)
1.			

Calculations:

Calculate power of the given resistive load $P = V^2/R$ and current $I = V/R$

where V is the reading of the voltmeter and R is the resistance o f the given resistive load as measured in step 3 of the procedure.

P2.10 Results

Sr. No.	Parameter Observed	Measured Value	Calculated Value	Error
1.	Current			
2.	Wattmeter			

P2.11 Conclusions

....

....

P2.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. With the observed values determine the power factor of the given load.
2. State the reason for connecting ammeters in series and voltmeter in parallel to a load.

P2.13 Suggested Learning Resources

Types of Electrical load

II. P3- E110:MEASUREMENT OF CIRCUIT PARAMETERS FOR RL LOADS

P3.1 Practical Statement

Measure voltage, current and power in R-L series circuit.

P3.2 Practical Significance

The measurement of parameters like voltage, current and power is significant to assess the performance of a given load as per the name plate specifications. For domestic loads like fan, refrigerators, air conditioners etc. the measurement will help to determine the sizing of the power supply cables and the ratings of the protective device like fuse, circuit breakers etc.

P3.3 Relevant Theory

For theory, refer topic 5.2.2 of this unit. The power absorbed by a R-L load fed from a single phase AC supply is given as $VI\cos\theta$, where V and I are the voltage across and current through the load. For a R-L load the power factor $\cos\theta$ lies between zero and unity.

P3.4 Practical Outcomes (PrO)

PrO1: Select the proper range of measuring instruments.

PrO2: Connect circuit and measuring instruments properly.

PrO3: Measure voltage, current and power of the given resistive load.

P3.5 Practical Setup (Circuit Diagram)

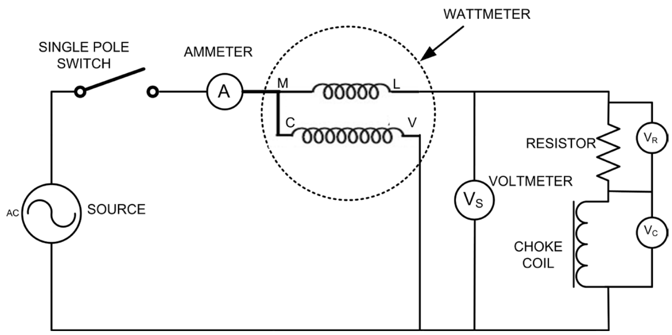


Fig. P3.1: Circuit diagram for measurement of voltage, current and power.

P3.6 Resources Required

Sr. No	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specifications (to be filled by the student)	Remarks (if any)
1.	Single phase AC source 230V, 50Hz	1		
2.	Connecting wires, Multistrand Cu wire, 1.5 sq.mm	L.S.		
3.	Single pole switch, 5A	1		
4.	Resistive load, 1 kW	1		
5.	Voltmeter, 0-300V AC	3		
6.	Ammeter, 0-5A AC	1		
7.	Single phase wattmeter, Current coil0-5A, Voltage coil 0-300V	1		
8.	Choke coil	1		

P3.7 Precautions

1. Select proper type and range of measuring instruments.
2. Connect voltmeters and ammeter as shown in the circuit diagram.
3. Check the circuit connections as per circuit diagram and the wire connections are tight before switching ON the power supply.
4. Switch OFF the power supply after conduction of experiment.

P3.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P3.1
2. Ensure proper connection of ammeter, voltmeters and wattmeter.
3. Measure the resistance of the given resistive load.
4. Connect the single phase power supply.
5. Switch on the single pole switch
6. Record the multiplication factor of wattmeter according to the selected current and voltage coil rating.
7. Record the current, voltages and wattmeter reading in the observation table no 3.1.

P3.9 Observations and Calculations

Sr. No.	Ammeter reading (A)	Voltmeter reading (V)			Wattmeter reading (W)
1.		V_S	V_R	V_L	

Calculations:

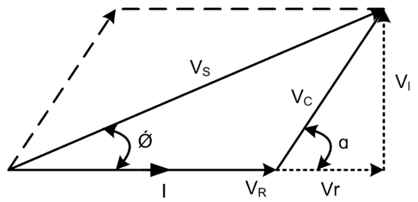


Fig. P3.2: Phasor diagram

1. The current flowing through the circuit is I, the voltage drop across resistive load is V_R, the voltage across choke coil is V_C, where $V_C = V_r + jV_L$, V_r, V_l the drop across resistance and inductance of choke coil.
2. Calculate the power factor of the given R-L load $\cos\emptyset = P/V_s I$ and load impedance $Z = V_s/I$
3. From the phasor diagram shown in Fig.3.2 $\cos\alpha = \dfrac{V_S^2 - V_R^2 - V_C^2}{2V_C V_R}$
4. Using sine law the power factor $\cos\emptyset = \cos(\sin^{-1}(V_C \sin\alpha / V_s)$
5. The input power = $V_s I \cos\emptyset$

P3.10 Results

Sr. No.	Parameter Observed	Measured Value	Calculated value	Error
1.	Power			
2.	p.f			

P3.11 Conclusions

....

....

P3.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. With the observed values determine the resistance of the choke coil.
2. State the difference between an ideal and practical inductor.
3. List the methods used to measure single phase power.
4. Infer the reasons for not connecting an ammeter across the circuit?

P3.1.3 Suggested Learning Resources

Inductors explained

KNOW MORE

Micro-Project

Group of 5 - 6 students should undertake one or two micro project(s) /activity(ies) under the guidance of faculty and present it as group with individual participation as well. A sample micro-project problem is given below:

Connect three chokes in series along with 40-watt lamp in series with a switch across a single phase AC supply. Analyze the effect of switching action and comment on variation of voltage and current with respect to time.

Activities

Collect the information regarding various types of resistors, inductors and capacitors used in different domestic appliances.

Each batch to observe the three phase power distribution panel in their own Institute/Commercial complex/mall etc. and prepare a report.

Use of ICT

Basic Electrical Technology

Fundamentals of Electrical Engineering

REFERENCES AND SUGGESTED READINGS

1. V.N. Mittle, and A. Mittal, *Basic Electrical Engineering*, McGraw Education, 2017.
2. M.S. Sukhija and T.K. Nagsarkar, *Basic Electrical and Electronics Engineering*, New Delhi: Oxford University Press, 2013.
3. B. L. Theraja, *Electrical Technology*, Vol. - I, New Delhi: S. Chand and Company, 2015.
4. S. K. Bhattacharya, *Basic Electrical Engineering*, Pearson Education, 2019
5. S. B. Lal Seksena and Kaustuv Dasgupta, *Fundamentals of Electrical Engineering*, Cambridge University Press, 2017.

6 Transformer and Machines

UNIT SPECIFICS

This unit discusses the following topics:

- Major parts of a transformer
- Working principle of a transformer
- Constructional features of a DC machine
- Types of DC motors and their characteristics
- Types of AC motors and their applications

The student self-learning activities at the end of each topic along with problem solving examples and ICT references are created for generating further curiosity and creativity as well as improving problem solving capacity.

A number of multiple choice questions as well as subjective questions following increased levels of Bloom's taxonomy, assignments through a number of problems provided in the books listed under references and suggested readings are given in the unit so that one can go through them for practice.

The related practical's are given followed by a "Know More" section so that the supplementary information provided becomes beneficial for the users of the book. In this section based on the unit content, "Micro Project" and "Activities" are given that have been judiciously designed to develop a day-to-day real life or/and industrial applications on variety of aspects. Additional video resources are provided to learn more about some of the sub-topics covered.

RATIONALE

Electrical power system of all sorts and at all levels are incomplete without the use of relevant transformer employed to change voltage or current levels according to applications. Electrical system application in industries and consumer use small and large electric motors. This chapter will make student familiar with the basic working and applications of a transformer. This chapter will also enable students with skills to select motors for specific application.

PRE-REQUISITE

1. Science: Electricity, Magnetic Effects of Electric Current (Class X)
2. Applied Physics-1: Work, Power and Energy (Semester I)
3. Mathematics-I: Trigonometry, Algebra (Semester I)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U6-O1: Describe the construction and classification of transformers.
U6-O2: Describe the principle of working of transformers.
U6-O3: Explain functioning of autotransformer.
U6-O4: Describe construction and working principle of motors.
U6-O5: Explain basic equations and characteristics of motors.
U6-O6: Suggest motors for specific applications.

Unit-6 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U6-O1	1	-	-	3	3	3
U6-O2	1	-	-	3	3	3
U6-O3	1	-	-	3	3	3
U6-O4	1	-	-	3	3	3
U6-O5	1	-	1	3	3	3
U6-O6	1	-	1	3	3	3

Nikola Tesla (1856-1943)
an Serbian-American engineer and physicist, while on a walk in 1882, came up with the idea for a brushless AC motor, making the first sketches of its rotating electromagnets in the sand of the path. Later that year he moved to Paris and got a job repairing direct current power plants with the Continental Edison Company. Two years later in 1884 he immigrated to the United States. He joined Westinghouse where he invented the first alternating current (AC) motor and developed AC generation and transmission technology. In the 1890s Tesla invented electric oscillators, meters, improved lights and the high-voltage transformer known as the Tesla coil. Together, Tesla and Westinghouse in partnership with General Electric installed AC generators at Niagara Falls, creating the first modern power station.

6.1 TRANSFORMER

6.1.1 Introduction

One of the most important advantages of an alternating current over direct current is the extreme ease with which the transformation from a low voltage to high voltage or vice versa can be accomplished with the help of transformers. The transformer is a static device (with no rotating parts) which transfers electrical energy from one alternating current circuit to another with the desired change in voltage or current level and without any change in frequency. The high-voltage long-distance transmission with the help of transformers has made possible the utilization of electrical energy generated in one geographical region to load centres located in other region.

The transformers are designed to operate either on single-phase or on three-phase supply and accordingly are known as single-phase or three-phase transformers. The discussion in this unit is confined to the single-phase transformers only. The three-phase transformers, however, work on similar principle as single-phase transformers.

6.1.2 Parts of a Transformer

A transformer mainly consists of the following parts: The first part consists of the limbs, yokes and clamping structure forming the magnetic circuit and the second part i.e. the electrical circuit consists of the primary winding, the secondary winding and insulation. With the increase in the size (capacity) and the operating voltage, there are several other parts such as tank body, bushings, conservator, breather, explosion vent, Buchholz relay, tapping switches etc. Fig. 6.1 shows the constructional details of transformer.

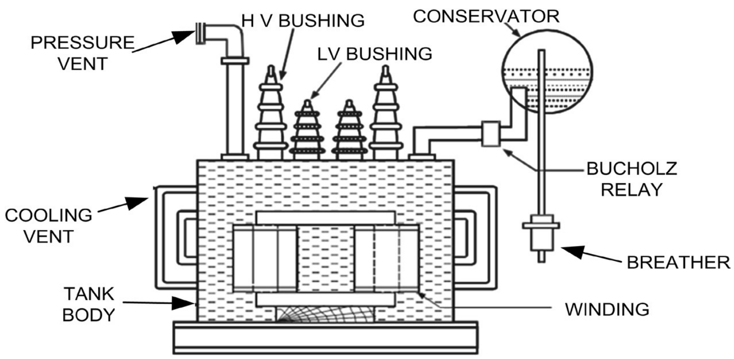


Fig. 6.1: Front view of a transformer

a. Core and Windings: The core of a transformer is made up of magnetic material and is used to provide the path of low reluctance for the flux. The lesser the reluctance of the magnetic circuit, the stronger is the field. The material actually used for the core is high grade silicon steel in the form of laminations about 0.35 to 0.5 mm thick. These laminations are varnished or coated with enamel to insulate them from each other.

The coils forming the primary and the secondary winding are former wound using well insulated copper conductor in the form of round wire or strip. These coils are then placed around the limbs of the core. These windings are insulated from each other and the core using cylinders of insulating material such as press board or Bakelite.

In the elementary transformer, the primary and secondary windings are shown on separate limbs of the core for simplicity. However, if such an arrangement is used in actual practice, all the flux produced by the primary winding will not link with the secondary winding as some of the flux will leak out through air. Such flux is known as leakage flux. More the value of the leakage flux, poorer is the performance of the transformer. Therefore, to reduce this leakage flux, the primary winding and the secondary winding are placed together on the same limb in actual transformer. These windings are either cylindrical in form or sandwich type as shown in Fig. 6.2.

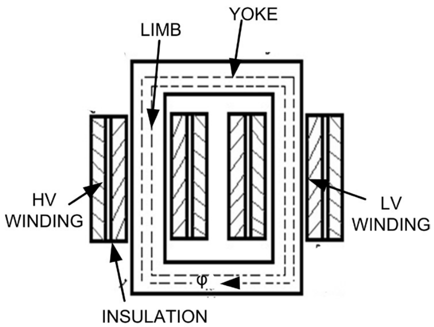


Fig. 6.2: Sectional view of a single phase core type transformer

b. Transformer Tank: In transformers with ratings more than 50 kVA, the whole transformer assembly i.e. the winding and core is placed in a fabricated sheet metal tank and immersed in the oil which serves both the purposes of providing insulation and cooling. The heat generated in the windings and the core is carried by the oil to the external surface of the tank. Cooling tubes are provided to increase the surface area of the tank for more effective cooling.

c. Terminal Bushings: The terminals of the primary and secondary windings of the transformer are brought out from the tank and are insulated from the tank body with the help of porcelain bushings. These bushings are fitted to the tank.

d. Conservator: In a transformer, provision of some space above the oil level is always essential to take up the expansion and contraction of the oil with changes of temperature in service. When the transformer becomes warm, the oil expands and the air at the top of the oil is expelled. When the transformer cools, oil contracts and outside air is drawn into the transformer. This process is known as breathing of the transformer. Unless proper precautions are taken, the outside air which enters the transformer during this process can have considerable moisture. When the oil in the transformer is exposed to such moist air, it readily absorbs the moisture from the air and looses its insulating value to some extent. This deterioration of oil can be prevented by using a conservator. The conservator is an airtight cylindrical metal drum supported on the transformer tank. This drum is connected by pipe to the transformer tank and is always partly filled with oil. The expansion and contraction of the oil in the main tank with the changes of temperature is now taken up by the conservator. With this arrangement, since the main tank remains always full with oil, the surface of the oil is not directly exposed to air.

e. Breather: The displacement of air above the oil level in the conservator during the breathing process of the transformer takes place through the apparatus known as a breather. It contains a drying agent, such as calcium chloride or silica gel, which extracts the moisture from the air. The breather also cleans the air by removing the dust particles present in it. Thus, only dry and clean air is allowed to come in contact with the oil in the transformer.

f. Buchholz Relay: It is a type of protective device mounted in the pipeline connecting the main tank to the conservator. During fault conditions excessive heat is developed due to losses in the winding, the oil in the tank in the vicinity of the winding gets decomposed and different types of the gases are liberated. These gases operate the Buchholz relay which in the initial condition gives alarm to the operator. If the fault developed is converted into a serious type of fault, then this relay trips off the main circuit breaker.

g. Explosion Vent: The bent up pipe fitted on the upper surface of the tank is known as explosion vent or relief valve. It is provided with a diaphragm made out of glass sheet or aluminium foil sheet. In the event of the fault condition, if excessive pressure is developed inside the tank due to vaporization of cooling oil, the diaphragm in the explosion vent bursts and releases the pressure, thus avoiding damage to the transformer.

6.1.3 Types of Transformers

Depending upon the arrangement of the core and the windings, there are two main types of the transformer: Core type and Shell type. Fig. 6.3 shows the two types of transformers.

a. Core Type Transformers: The distinguishing features of a core type transformer are as follows:

- The core type transformer is built of laminations to form a rectangular structure as shown in Fig. 6.3 (a) and provides a single magnetic circuit.
- The winding coils are normally cylindrical in form and concentric to reduce wastage, the low voltage winding being placed near the core. These windings surround considerable portion of the core
- The primary/ secondary or the low voltage/ high voltage windings are uniformly distributed over two limbs of the core.
- The windings being distributed on two limbs; the natural cooling becomes much more effective.
- The coils can be withdrawn for repair just by dismantling the top yoke.

b. Shell Type Transformers: The salient features of a shell type transformer are listed below:

- The core of this type of transformer provides double magnetic circuit.
- The windings are normally sandwich type, always placed on the central limb of the core.
- The H.V. and L.V. coils are wound in the form of pancakes and are interleaved. The top and bottom coils which are near the yoke of the core are of L.V. winding only.
- The core nearly surrounds the windings placed on the central limb of the core. The feature helps in providing mechan ical protection to the windings.
- The coils being placed on the central limb only and are surrounded by the outer core limbs, the natural cooling is therefore poor.
- The repair of coils is not as simple as it is for core type transformers.

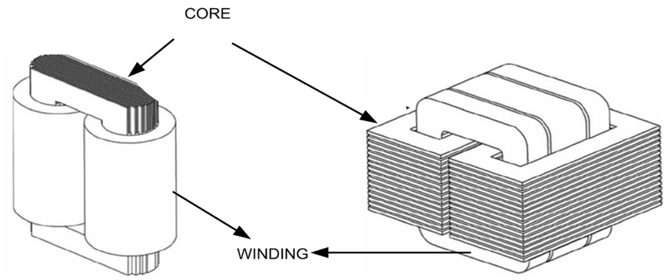


Fig. 6.3: (a) Core type transformer. (b) Shell type transformer

6.1.3.1 Principle of Working

The operation of the transformer is based on the principle of mutual induction between two circuits linked by a common magnetic field. Consider the transformer in its elementary form shown in Fig. 6.4.

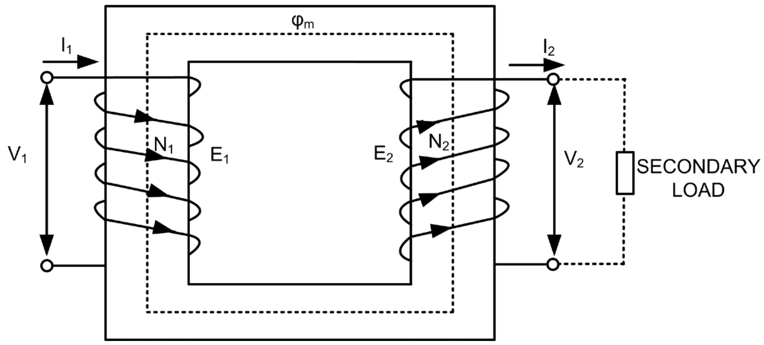


Fig. 6.4: Elementary Transformer

It essentially consists of two windings, primary and secondary winding, electrically separate but wound on a common laminated steel core. The vertical portions of the core on which these windings are placed are called as the limbs and the top and bottom portions are the yokes. The winding which is connected to the existing supply system and which receives energy from it is called as the primary winding. The other winding delivering energy to the load at the desired voltage is called the secondary winding.

When the primary winding is connected to an AC supply, an alternating current circulates through it. This current flowing through the primary winding produces an alternating flux. Most of this varying flux links with the secondary winding through the iron core and induces an emf in it in accordance with Faraday's law of electromagnetic induction. The phenomenon, due to which an alternating current in the primary winding produces an emf in the secondary winding, is known as mutual induction and the emf induced in the secondary winding is known as mutually induced emf. The frequency of this emf is the same as that of the supply voltage.

Transformer Basics

6.1.3.2 EMF Equation of Transformer

Suppose a transformer having N_1 and N_2 number of turns in the primary and secondary winding as shown in Fig. 6.4. When an AC voltage V_1 of frequency f is applied across the primary winding, a current I_m will flow through the primary winding and this will produce an alternating flux which complete its path through the core linking both the primary and secondary winding. The equation of the alternating flux is

$$\varphi = \varphi_m \cos\omega t \qquad \ldots(6.1)$$

As per Faraday law the induced emf equation in primary winding due to the alternating flux is given

$$e_1 = -N_1 \frac{d\varphi}{dt} \qquad \ldots(6.2)$$

Substituting the value of flux of equation 6.1.1 in 6.1.2 the equation becomes

$$e_1 = -N_1 \frac{d\varphi_m \cos\omega t}{dt}$$

$$e_1 = N_1 \omega \varphi_m \sin \omega t$$

$$e_1 = N_1 \omega \varphi_m \cos\left(\omega t - \frac{\pi}{2}\right)$$

$$\text{or } e_1 = E_m \cos\left(\omega t - \frac{\pi}{2}\right) \qquad \ldots(6.3)$$

where $E_m = 2\pi f N_1 \varphi_m$, the maximum value of the induced emf

The root mean square value of the induced emf in the primary winding is given by

$$E_1 = \frac{2\pi f N_1 \varphi_m}{\sqrt{2}} = 4.44 f N_1 \varphi_m \qquad \ldots(6.4)$$

Similarly, the emf in the secondary winding is given by

$$E_2 = 4.44 f N_2 \varphi_m \qquad \ldots(6.5)$$

6.1.3.3 Voltage Transformation ratio

Voltage Transformation ratio is defined as the ratio of the secondary voltage to the primary voltage. It is denoted by K. If $K < 1$, then the secondary voltage will be less than the primary voltage and the transformer will be called as step down transformer. If $K > 1$, then the transformer is a step up transformer.

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{K}$$

In an ideal transformer, the following assumptions are made:

- Winding resistance are negligible
- All the flux produced in confined to the core of the transformer and links fully both the windings.
- The permeability of the core is high so that the magnetizing current required to produce the flux and establish it in the core is negligible.
- Hysteresis and Eddy current losses are negligible.

With the above assumption, the input volt ampere and output volt ampere of a transformer can be approximated as equal i.e. $V_1 I_1 = V_2 I_2$. The above equation becomes

$$\frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = \frac{1}{K} \qquad \ldots(6.6)$$

6.1.3.4 Transformer Under No Load Condition

When a transformer is under no load condition, the current I_2 in the secondary winding as shown in Fig. 6.4 is zero while the primary winding carries a small current I_0 known as no load current . The current I_0 consists of following two components.

a. A reactive or magnetising component I_m and
b. An active or power component I_μ.

The magnetising component produce the magnetising flux, so it is in phase with the flux. The active component produces the power to supply the hysteresis and eddy current losses in the iron core, the active component is in phase with the applied voltage V_1. The induced emf E_1 in the primary winding lags the magnetizing flux by 90^° as shown in equation 6.1.3. Normally the active component is very small compared to the magnetising component of no load current. Fig. 6.5 shows the phasor diagram at no load condition of a transformer

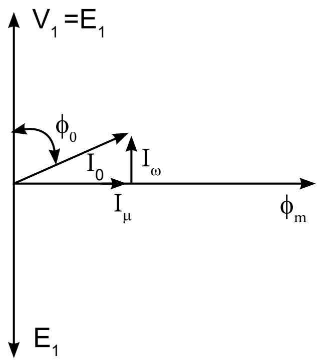


Fig. 6.5: Phasor diagram at No load

From the phasor diagram the magnetizing current $I_\mu = I_0 \sin Ø_0$ and the core loss component $I_\omega = I_0 \cos Ø_0$. The power input to the transformer at no load condition is given by

$$P_o = V_1 I_0 \cos Ø_0 \quad \ldots(6.7)$$

where $\cos Ø_o$ is the no load power factor and the no load current I_0 is given as

$$I_0 = \sqrt{I_\mu^2 + I_\omega^2} \quad \ldots(6.8)$$

6.1.4 Autotransformer

A transformer in which a part of the winding is common to both the primary and secondary circuit is known as an auto transformer. The primary is electrically connected to the secondary as well as magnetically coupled to it as shown in Fig. 6. 6. Unlike a two winding transformer, an autotransformer is not electrically isolated.

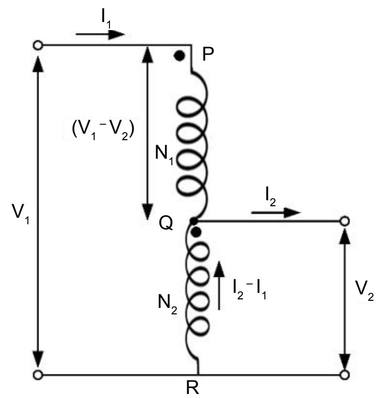


Fig. 6.6: Autotransformer

In Fig. 6.6, PR is the primary winding having N_1 turns and QR is the secondary winding having N_2 number of turns. The input voltage and current are V_1 and I_1 and the output voltage are V_2 and I_2 respectively. If the internal impedance drop &losses are neglected, then $V_1 I_1 = V_2 I_2$ or

$$\frac{V_1}{V_2} = \frac{I_1}{I_2} = \frac{N_1}{N_2} = \frac{1}{K} \quad ...(6.9)$$

The current in the section QR is $(I_2 - I_1)$ where $I_2 > I_1$

In an auto transformer only a part of the power input is transferred from the primary to the secondary side by transformer action. The remaining power is transferred directly from the primary to the secondary side. The relative amount of power inductively transferred and power conductively transferred depends upon the ratio of transformation.

Let the volt ampere power delivered to load by the auto transformer = $V_2 I_2$

The power transformed which is equal to the power in winding QR. The transformed power or the inductive power is given as

$$V_2(I_2 - I_1) = V_2 I_2\left(1 - \frac{I_1}{I_2}\right)$$

Substituting equation 6.9, the equation = $V_2 I_2(1 - K)$ …(6.10)

The power that is conducted directly equals the power delivered to load minus the power transformed and is equal to

$$V_2 I_2 - V_2 I_2(1 - K) = K V_2 I_2 \quad …(6.11)$$

Following are the advantages of an autotransformer when compared with a two winding transformer

- For the same capacity and voltage ratio the weight of copper required for an autotransformer is less.
- The size of an autotransformer is less for the same rating.

6.1.4.1 Applications of Autotransformer

1. To compensate for voltage drops on long feeder circuits.
2. To provide variable voltage control.
3. To adjust the transformer output voltage in order to keep the system voltage constant with varying load

Activities

1. Visit the college main power supply substation. Note down the name plate details of the distribution transformer installed. Prepare a report on the specification details given in the name plate.

2. Measure the primary and secondary winding resistance of a given 1-phase two winding transformer. Note down the resistance value and infer which winding is a HV winding.

Solved Problems

Example 6.1.1: A single phase transformer has 400 primary and 1000 secondary winding turns. The cross sectional area of the core is 60 cm^2. Determine the peak value of the flux density in the core if the primary supply voltage is 500V, with frequency = 50 Hz.

Solution: The rms value of the induced emf in the primary winding equals $E_1 = 4.44\, fN_1\, \varphi_m$.

Considering an ideal transformer $E_1 = V_1$,

Given, the primary supply voltage = 500 V.

Therefore, $500 = 4.44 \times 50 \times 400 \times B_m \times 60 \times 10^{(-4)}$, $B_m = 0.938$ Wb/m^2

Example 6.1.2: A 200/100 V, 50 Hz transformer to be excited at 40 Hz from the 100 V side. Find the voltage to be applied at the low voltage side if the exciting current to remain same.

Solution: Let the induced emf equation at 100 V side at 50 Hz equals $100 = 4.44 \times 50 \times \varphi_m \times N_2$. ...(1)

Given the exciting current I_μ has to remain same at 40 Hz also, i.e. φ_m to remain same.

The emf equation at 40 Hz = $E_2 = 4.44 \times 40 \times \varphi_m \times N_2$, ...(2)

Equating equation (1) and (2) E_2 = 80 Volts.

6.2 ELECTRIC MOTORS

6.2.1 Introduction

A rotating electrical machine consists mainly of two parts, the stator the stationary part and rotor, the rotating part. The stator is generally a cylindrical shaped magnetic core and the rotor again made of magnetic core rotates inside the stator. The stator and rotor core are separated by means of an air gap. The stator and rotor magnetic carries winding to establish a magnetic flux. The rotor is mounted on a bearing supported shaft and the shaft is connected to the mechanical loads by means of belt and pulley arrangement or through gear boxes.

6.2.2 DC Motor

An electric motor is a machine which coverts electrical energy into mechanical energy. If the electric energy is supplied in form of DC supply, the motor is called DC motor.

6.2.2.1 Construction of DC Motor

The field poles of a DC machine are located on the stator. The iron poles are projected inwards from the inside surface of the cylindrical shaped magnetic core called the stator yoke. The yoke serves as a return path for the magnetic flux. The iron pole consists of a narrow portion on which the field winding coils are placed. A pole shoe usually laminated distribute the pole flux over the rotor surface. The rotor or armature made of cylindrical silicon steel core consists of a stack of slotted laminations. The slots are cut on the surface of the laminated core along the axial length of the core, in which the coil sides of the armature winding are placed. The coils in the form of conductor wire or bars are made of copper or aluminium and the conductor size depends on the current and voltage requirement of the machine. The armature coils are held in place by wood wedges driven into the slot along the slot length. The coil terminal ends are connected to the commutator. The commutator consists of segments made of copper, the segments separated from each other by insulating material usually mica.

The current is conducted to the armature coils by carbon brushes. The brushes are held in brush holder and is fitted in such a way that they should slide freely over the commutator surface. To maintain proper contact between the brush contact and commutator, adjustable springs are placed in the brush holder assembly to ensure the contact force. The brushes must be inspected regularly and replaced if wear and tear of the brush occurs. Fig. 6.7 shows the sectional view of a DC machine.

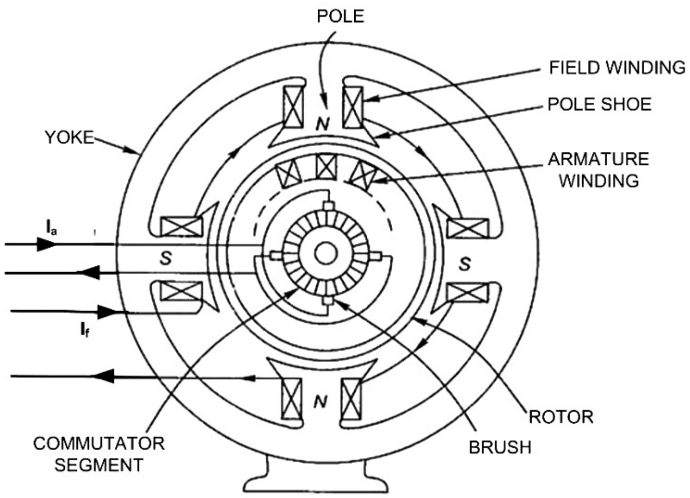


Fig. 6.7: Sectional view of a DC machine

6.2.2.2 Working Principle of DC Motor

The principle on which the DC motors work is based on Fleming's left hand rule. When a current carrying conductor is placed in a steady magnetic field, such that the conductor makes right angle with the field, it experiences a mechanical force, whose direction is given by the Flemings left hand rule. The movement of the conductor is in the direction of force. In short, when electric fields and magnetic fields interact, a mechanical force arises. The magnitude of the mechanical force in Newton experienced by the conductor is given by eq. 6.12.

$$F = BIL \qquad ...(6.12)$$

where, B is the field strength in $^{Wb}/_{m^2}$, I is the current flowing through the conductor in amperes and L is the length of conductor in metres.

6.2.2.3 Working of a DC Motor

When direct current is passed through armature and field-winding of a DC motor, magnetic flux is established by the field current (Ampere turns). Since the armature conductors are perpendicular to the magnetic field and they are carrying current, they experience mechanical force. The resultant of these forces is a torque. Under the influence of this torque rotor starts rotating. Any mechanical device(load) coupled to it does useful work. If the mechanical load is increased more torque will be produced by drawing more current from DC supply. Thus motor converts electrical energy into mechanical energy.

DC motor

Back EMF: When armature of a motor rotates, an emf is induced in the conductors as they cut the lines of magnetic force. The induced emf is in opposition to the applied voltage (V) and is called back or counter emf (E_b). Its magnitude is given by

$$E_b \propto \phi N \qquad \ldots(6.13)$$

where Ø is the field flux and N the armature speed.

6.2.2.4 Types of DC Motors

Depending on the nature of connection of armature winding and field windings, DC motors can be classified into two types:

i. DC series motor
ii. DC shunt motor

Another type of DC motor is the DC Compound motor, in which field winding is connected in series as well as in parallel that is not being discussed in this book.

i. **DC series motor:** A series motor is one in which field winding is connected in series with the armature as shown in Fig. 6.8 that the current drawn by the motor passes through the field winding as well as armature Field winding has a few turns of thick conductors. Magnetic flux varies with current till saturation.
ii. **DC shunt motor:** A shunt motor is one in which the field winding consisting of large number of turns of comparatively thin wire is connected in parallel with armature as shown in Fig. 6.9. In the case of shunt motor, the field current is costant because of the DC supply is constant. Therefore, flux remains practically constant.

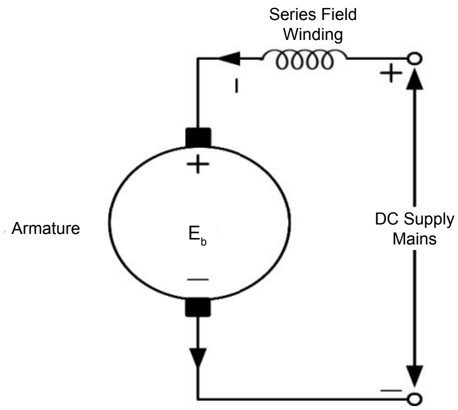


Fig. 6.8: DC series motor

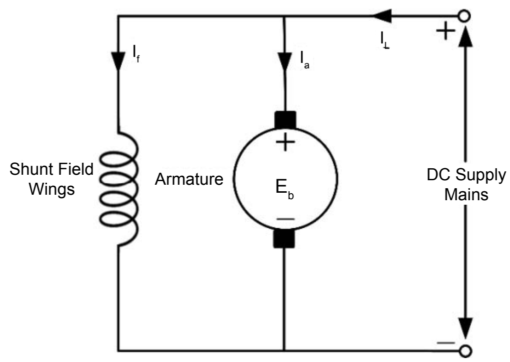


Fig. 6.9: DC shunt motor

6.2.2.5 Characteristics of DC Motors

The two most important characteristics of a DC motor are the torque characteristics and the speed characteristics.

a. Torque Characteristic (T vs. I_a): The torque characteristic represents the variation of torque with armature current. The torque developed in a motor is the result of the interaction between the magnetic flux produced by field current and the current flowing through armature conductor. If the magnetic flux increases due to increase in field current, torque produced for the same armature current will increase i.e. $T \propto Ø$ for I_a constant. Similarly, if the armature current increases because of increase in shaft load, then also torque will increase for the same value of magnetic flux i.e. $T \propto I_a$ for Ø constant. Now if both Ø and I_a are changing then in general, it can be written as

$$T \propto ØI_a \qquad \ldots(6.14)$$

i. DC series motor: The torque equation is given as $T \propto ØI_a$. For a series motor as shown in Fig. 6.8, the same current flows in the field winding as well as in the armature winding. So, up to magnetic saturation, the field flux $Ø \propto I_a$ and therefore the torque developed is

$$T \propto I_a^2 \qquad \ldots(6.15)$$

This means that the torque is proportional to square of the current up to magnetic situation.

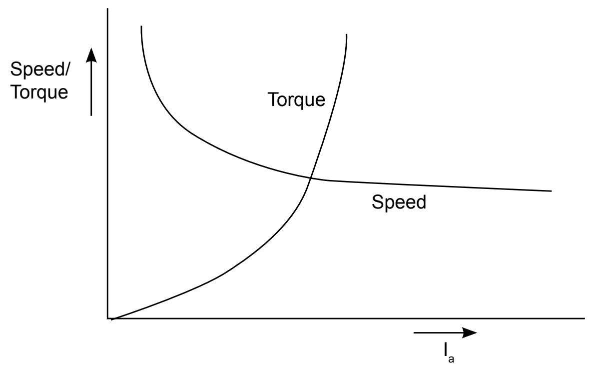


Fig. 6.10: Speed-Torque characteristics of a DC series motor

This part of the characteristic is a parabola. However, after magnetic saturation, T vs. I_a curve becomes straight line because flux Ø becomes independent of armature current and hence torque increases with armature current only. The characteristic curve is shown in Fig. 6.10. Since the torque is proportional to the square of current, the starting torque is extremely high. The high starting torque is advantageous for certain applications. Hence DC series motors are used where large starting torque is required.

ii. DC Shunt motor: In case of a DC shunt motor, the flux Ø is constant Hence the torque $T \propto ØI_a$ is directly proportional to the armature current, whatever the speed may be. As armature current (I_a) increases, torque (T) increases and vice-versa. Fig. 6.11 shows the torque characteristic of a DC shunt motor.

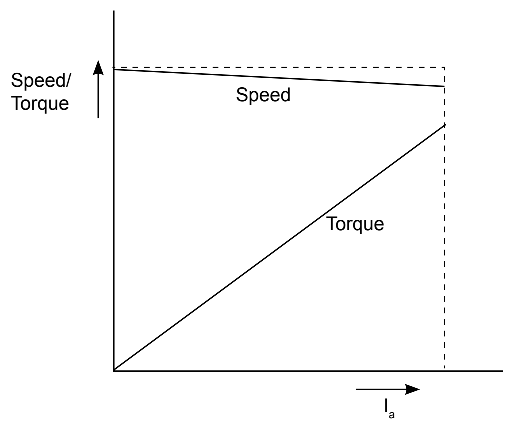


Fig. 6.11: Speed - Torque characteristics of a DC shunt motor

b. Speed characteristic (N vs. Ia):
The running or speed characteristic of a motor normally represents the variation of speed with input current.

i. DC Series motor: The speed equation of a DC motor is $N \propto \frac{E}{\emptyset}$

where, E_b is the back emf, Ø is the flux and N is the motor speed in rpm. For very low armature resistance the change in back emf, for different load currents is very small and so can be neglected.

Therefore, the rotor speed is inversely proportional to the field flux or $N \propto \frac{1}{\phi}$ …(6.16)

In a DC series motor, the flux (Ø) increases, with increase in armature current, that is, $\emptyset \alpha I_a$, the equation 6.16 modifies to

$$N \propto \frac{1}{I_a} \quad \text{...(6.17)}$$

This means that as load current i.e. the armature current (I_a) increases, the speed decreases and vice-versa. The characteristic is shown in Fig. 6.10. From the characteristic curve it is seen that, when load is large the speed is low. When the load is light, the speed is very high. Therefore, series motor should never be run without load otherwise it may get damaged due to very high centrifugal force.

ii. DC shunt motor: In DC shunt motor, the flux remains constant. As flux is constant, speed is also constant. Theoretically it is true but practically it is not possible. Actually, as the load is increased, the back emf (E_b) decreases and due to this fact, speed N = Eb/Ø decreases slightly. This decrease in speed is not significant and therefore DC shunt motor for all practical purposes is considered as a constant speed motor.

6.2.2.6 Applications of DC Motors

DC motors are used for many industrial applications, particularly those requiring constant torque across the motor's entire speed range. In portable applications using battery power, DC motors are a natural choice. The main applications of DC Series Motors and DC shunt motors are as follows:

i. DC series motors

The DC series motors are used where high starting torque is required, where constancy of speed is not required. and variations in speed are possible. Some of the applications of series motors are:

- Cranes
- Air compressor
- Lifts and Elevators
- Vacuum cleaner
- Electric traction
- Hair drier
- Sewing machine
- Power tools
- Electric footing, etc.

ii. DC shunt motors

The shunt motors are used where constant speed is required from no load to full load. and starting conditions are not severe. The various applications of DC shunt motor are :

- Lathe Machines
- Centrifugal pumps
- Conveyors
- Fans
- Boring machines
- Weighing machine
- Spinning machine
- Blowers
- Line shaft, etc.

6.2.3 AC Motors

6.2.3.1 Motor Construction

From the previous topic, the performance of a DC motor in terms of its characteristics and its applications has been studied. For operation of a DC motor, DC power supply is required. For this the AC supply is rectified to make it a DC supply by using semiconductor devices.

It would be more convenient if the single or three phase AC power supply can be used to directly drive a AC motor. Like a DC motor, the AC motor has also stator and rotor. A large number of identical slots are cut on the stator on which coil sides are placed. The coil ends are connected and the leads are brought out, depending on whether the type of AC supply is single phase or three phase. Accordingly, the motor is classified as 3-phase or 1-phase AC motor.

The rotor construction depends on the type of AC motor. Fig. 6.12 shows the rotor construction of a 3-phase induction motor.

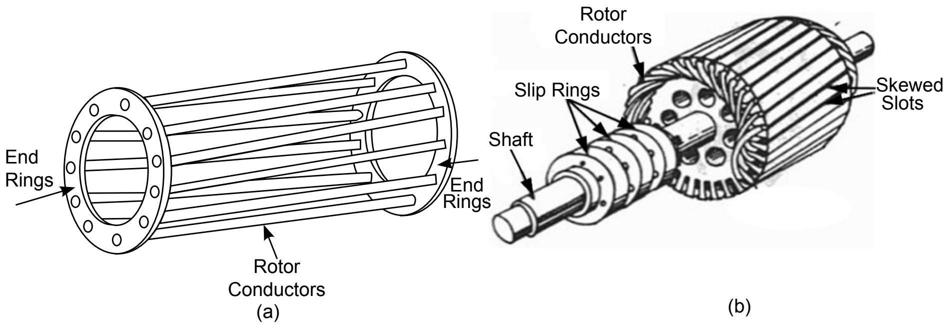


Fig.6.12: 3- Phase induction motor (a) Squirrel cage (b) Wound rotor

Table 6.1 shows the rotor construction details of two main types of 3 phase AC motors i.e. induction motor and synchronous motor. further, there are two types of 3 phase induction motor on the basis of construction : squirrel cage and wound rotor. similarly, synchronous motors are of two types on the basis of construction of rotors: salient pole rotors and non-salient pole rotors.

Table 6.1: Rotor construction details of 3-phase AC Motor

Sr. No.	Type of 3-phase AC motor	Type of rotor and their construction details	
1.	**Three phase Induction Motor**	**Squirrel Cage**	**Wound Rotor**
		i. Rotor core is cylindrical with slotted periphery. ii. The rotor conductor is made of uninsulated bars or rods made of copper or aluminum. iii. The bars are permanently shorted at each end with the help of conducting rings made of copper and are known as end rings.	i. Rotor core is cylindrical with slotted periphery. ii. The rotor winding is similar to the stator winding. iii. The three ends of the three phase rotor winding are permanently connected to the slip rings iv. The slip rings are mounted on the rotor shaft v. The rotor terminals are brought out for external connections through brushes mounted on brush holders placed on the slip rings

2.	Three phase Synchronous Motor	Salient pole rotors	Non salient pole rotors
		i. The term salient means projecting. A salient pole consists of poles that are projected out from the surface of rotor core. ii. Used for rotors with more than four poles. iii. The rotor winding coils known as field coils are placed on the pole body. iv. The two ends of the field windings are connected to the slip rings and connected externally to DC supply through brushes.	i. Non salient pole rotors are also known as cylindrical rotor. ii. The rotor is cylindrical in shape with no physical pole as in salient pole construction. iii. Slots are cut on the rotor periphery to place the rotor or field winding. iv. External connection of the field winding is same as that of salient pole rotor.

6.2.3.2 Three phase AC Motor

The fundamental principle of operation of AC machines is the generation of a rotating magnetic field. When a three phase balanced supply is given to the three phase coils placed on the stator slots which are space displaced by 120° a rotating magnetic field is created. The rotating magnetic field causes the rotor to turn at a speed that depends on the speed of the rotating magnetic field. The speed of the rotating magnetic field known as synchronous speed and is given as

$$N_s = \frac{120f}{P} \qquad \text{...(6.18)}$$

where f is the frequency of the AC supply and P the number of poles present in the stator. The electromagnetic torque developed in a motor is the interaction of the two magnetic fields in the air gap, F_s created by the stator currents and F_r created by the rotor currents. The torque equation is given by

$$T = F_s F_r \sin\lambda \qquad \text{...(6.19)}$$

For creation of a steady torque the following two conditions must be fulfilled i.e.

a. The two fields must be stationary with respect to each other and

b. The two fields must have the same number of poles.

Fig. 6.13 shows the torque interaction of an AC machine.

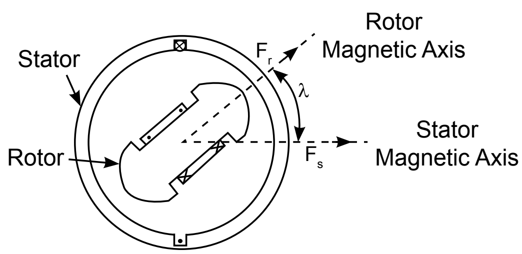


Fig. 6.13: Torque in round rotor machine

The three phase induction motor is a singly fed machine, the stator is excited from AC mains. The current flowing in the three phase stator winding give rise to a constant rotating magnetic field. As per Faraday's law the rotating magnetic field induces voltage in the stationary rotor conductors which is short circuited. The induced voltage circulates current in the rotor conductors which produce rotor magnetic field and the interaction of the rotor and stator magnetic field give rise to torque and the rotor starts rotating in the direction of magnetic field produced by stator winding according to Lenz's law. The rotor frequency automatically adjusts in accordance with the rotor speed, thus fulfilling the first condition required for a steady torque. In a synchronous machine, the stator carries the alternating current, while the rotor is DC excited. The two fields would be relatively stationary, causing torque production if and only if the rotor runs at synchronous speed i.e. the speed of the rotating magnetic field produced by stator. Fig. 6.14 shows the torque versus speed characteristics of a 3-phase induction motor and synchronous motor.

Induction Motors

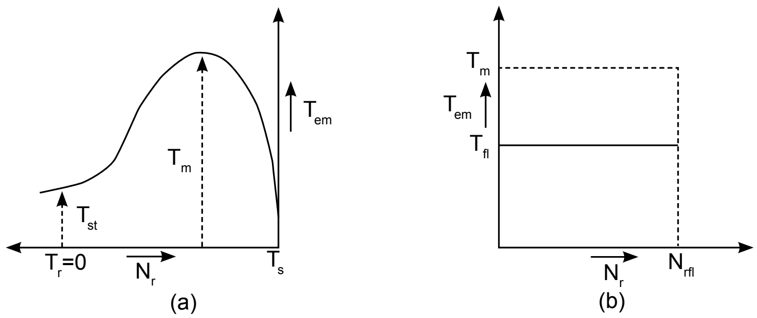


Fig. 6.14: Torque-Speed Characteristics of (a) 3-Phase Induction motor (b) 3-Phase Synchronous motor

6.2.3.3 Applications of 3-phase Motors

i. 3-phase Induction Motor

- Squirrel cage induction motor has not a very good conventional speed control method, so it used for constant speed applications.
- The three phase squirrel cage induction motor is used for centrifugal pump, milling machines, lathe machines, drilling machines, and large blowers and fans.
- The Slip ring induction motor has a high starting torque and good speed control method, so it can operate a high load with less speed.
- The slip ring motor is used for high load applications like elevators, cranes, hoists and equipment's of process industries.

ii. 3-phase Synchronous Motor

- Synchronous motor having no load connected to its shaft is used for power factor improvement. It is used in power system in situations where static capacitors are expensive.
- Synchronous motor finds application where operating speed is less than 500 rpm and high power ranging from 100 kW to 2500 KW is required. Ex- Reciprocating pump, compressor, crusher motors for rotary kiln of cement plants, motors in steel rolling mills etc.

6.2.4 Single phase AC Motors

The three phase AC motors are used for high power rating applications. Generally, the single phase AC supply is available to most homes and offices. This has led to the availability of a wide variety of small size motors or fractional horse power motors for domestic applications like fan, refrigerator, room air conditioners, kitchen and office equipment's etc. A single phase induction motor comprises a single phase winding on the stator and a squirrel cage rotor. Due to the pulsating magnetic field produced the single phase induction motors are not self-starting. To overcome this problem, 2-winding single phase motors are developed, in which the two windings, named as main and auxiliary winding are placed at 90° electrical in space, but are fed from single phase supply. The time difference in winding currents so as to develop a rotating magnetic field is obtained by placing suitable impedance in series with the auxiliary winding. Depending on the method of phase splitting the 2 –winding single phase motors are classified as Resistance split phase motor and Capacitor split phase motor.

6.2.4.1 Capacitor Split Phase AC Motors

The most widely used single phase AC motors for household applications. The capacitor split phase motors are classified as Capacitor start induction motor, Permanent split capacitor motor and capacitor start capacitor run motor. The connection diagram of a permanent split capacitor induction motor is shown in Fig. 6.15.

In order to make the single phase induction motor self-starting a capacitor is connected in series with the auxiliary winding. The auxiliary winding is generally made of thin copper wire as compared to the main winding which is made of thick copper wire. The two windings are connected across the single phase supply. The current I_a flowing through auxiliary winding leads the main winding current I_m due to the capacitor as shown in the phasor diagram. Thus the motor becomes a 2-phase motor with the main and auxiliary winding displaced electrically in space by 90° electrical. A starting torque is created and the rotor starts rotating. The typical rating of the capacitor is 40 - 100 μF.

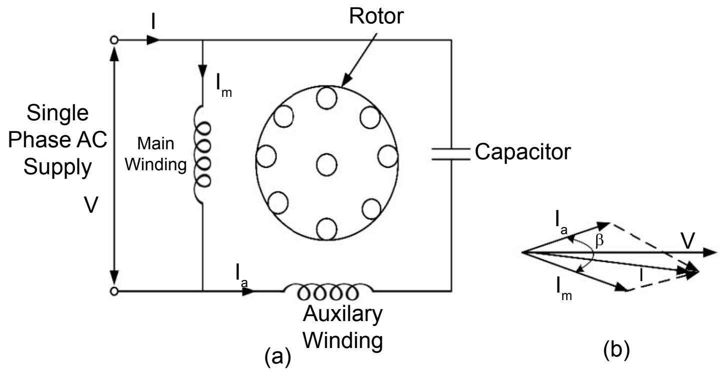


Fig. 6.15: 1-Phase capacitor split phase motor (a) Connection diagram (b) Phasor diagram

Activities

1. Prepare a power point presentation on 3- phase AC motor selection as per NEMA standards.
2. Prepare the circuit diagram and demonstrate how the direction of rotation of a given 1-phase induction motor can be changed.

Solved Problems

Example 6.2.1: A DC shunt motor having unsaturated magnetic field runs at 1000 rpm with rated voltage. If the applied voltage is half of the rated voltage. Find the motor speed.

Solution: Neglecting armature resistance, the back emf is assumed equal to the terminal DC voltage.

Given unsaturated magnetic field, implies Ø the field flux equals the field current.

With the given condition, the back emf $E_b = k \times I_f \times N$.

At rated terminal voltage V, the back emf equation can be written as $V = k \times I_f \times 1000$ ....(1)

With terminal voltage reduced to half of the rated voltage, the equation becomes

$V/2 = k \times I_f/2 \times N$ ....(2)

Equating (1) and (2) we get N = 1000 rpm.

Example 6.2.2: Define slip. A 3 –phase I. M. is wound for 4 poles and is supplied from 50 Hz system. Calculate: (1) Synchronous speed (2) Rotor speed, when slip is 4% (3) Rotor frequency.

Solution: The rotor never succeeds in catching up with the stator field because in doing so, there would be no relative speed, no emf, no rotor current and hence no torque. The rotor falls back behind the magnetic field by a certain speed which is necessary for the operation of an induction motor and the difference in speed depends upon the load on the motor. The difference between the synchronous speed N_s and the actual rotor speed N_r of the rotor is known as slip speed.

The slip $s = (N_s - N_r)/N_s$

Given P = 4, f = 50 Hz.

Therefore $N_s = 120f/P = (120 \times 50)/4 = 1500$ rpm.

From the above definition, the rotor speed $N_r = N_s(1 - s) = 1500(1 - 0.04) = 1500 \times 0.96 = 1440$ rpm

Rotor frequency $f_r = s \times f = 0.04 \times 50 = 2$ Hz.

UNIT SUMMARY

1. Transformers are basically of two types, the core type and shell type transformer.
2. A two winding transformer depending on the turns ratio can be designated as a step down or step up transformer.
3. The transformer is a static device which is used to change the voltage or current level, while frequency remaining same.
4. In autotransformer, the transfer of power takes place through conductive and inductive coupling.
5. In case of a DC series motor, the field winding consists of few turns of thick wire connected in series with the armature.
6. In case of a DC shunt motor, the field winding is made of many turns of thin wire and it is connected across the armature.
7. The starting torque of a DC series motor is higher as compared to other motor of same ratings.
8. A DC series motor is used for traction, cranes, hoists, etc.
9. Applications of DC shunt motor are lathe, centrifugal and reciprocating pumps, blowers, drilling machine etc.
10. The AC motors are labelled as 3-phase or 1- phase AC motors according to the supply given to stator windings.
11. The two main types of 3 phase AC motors are induction motor and synchronous motor.
12. The torque speed characteristics of a 3-phase induction motor is same as that of a DC shunt motor
13. For fractional horse power applications , single phase induction motors are used.
14. The most common applications of single phase induction motor are ceiling fans, compressor motor and household pumps etc.

EXERCISES

A. Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
6.1	The desirable properties of transformer core material are a. Low permeability and low hysteresis loss b. Low permeability and high hysteresis loss c. High permeability and high hysteresis loss d. High permeability and low hysteresis loss	6.4	High starting torque is required for which of the following applications? a. Air blower b. Weighing machine c. Locomotive d. Centrifugal pump

6.2	The size of a transformer core depends on a. Supply frequency b. Permissible flux density in the core c. Area of the core d. Both (a) and (b)	6.5	The most suitable 3-phase induction motor for high starting torque a. Squirrel cage b. Double cage c. Slip ring d. Deep bar squirrel cage
6.3	The direction of rotation of D.C motor is determined by which rule a. Coulomb's Law b. Lenz's Law c. Fleming's right hand rule d. Fleming's left hand rule	6.6	The capacitor in a capacitor start 1-phase induction motor is connected in series with a. Auxiliary winding b. Compensating winding c. Main winding d. Squirrel cage winding

B. Subjective Questions

1. Explain the working of a two winding transformer.
2. Describe the different components used in the construction of a Distribution transformer.
3. Explain the salient features of a Core type and shell type transformer.
4. A single phase 3000/220 Volt, 50 Hz core type transformer has cross section area 400 sq.cm. The flux density is 1 wb/m^2. Calculate the number of turns in primary and secondary winding of the transformer.
5. Draw and explain the phasor diagram of a transformer under no load condition.
6. Describe the working of an autotransformer? List the merits of an autotransformer over two winding transformer.
7. Explain what happens in case of DC series motor when load is removed.
8. Draw and explain the torque versus speed characteristics off a DC shunt motor.
9. Describe the construction of a 3-phase induction motor.
10. List the different types of single phase induction motor and state their applications.

PRACTICALS

I. P4- ES110: DETERMINE THE TURNS RATIO OF A TRANSFORMER

P4.1 Practical Statement

Determine the transformation ratio (K) of 1- phase transformer.

P4.2 Practical Significance

The turns ratio is an important parameter in transformer. The turns ratio determines which winding terminals will be the high voltage and which terminals will be the low voltage side. The turns ratio is very useful in determining the voltage regulation, efficiency of a transformer by referring the transformer parameters like winding resistance, leakage inductance, induced e.m.f, current and voltage either to the primary or secondary side of the equivalent circuit of a transformer.

P4.3 Relevant Theory

For theory refer sub topic 6.1.3.2 EMF equation of a transformer. The turns ratio of a transformer is given as $V^1/V^2 = N^1/N^2 = 1/K$.

P4.4 Practical Outcomes (PrO)

PrO1: Select the proper range of measuring instruments.

PrO2: Connect circuit and measuring instruments properly.

PrO3: Measure voltages for a given 1-phase two winding transformer:

PrO4: Determine the turns ratio of a transformer.

P4.6 Resources Required

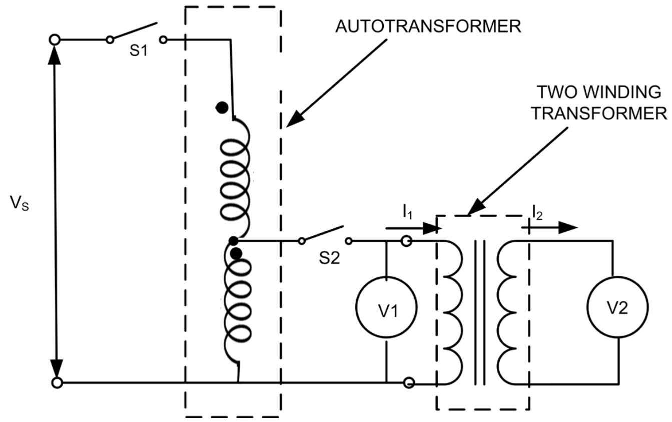


Fig. P4.1: Circuit diagram for determining turns ratio of transformer

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specifications (to be filled by the student)	Remarks (if any)
1.	Single phase AC source 230V, 50Hz	1		
2.	Connecting wires, Multistrand Cu wire, 1.5 sq.mm	L.S.		
3.	Single pole switch, 5A	1		
4.	1-phase Autotransformer, 2 KVA, 230V/270V	1		
5.	1-phase Transformer, 2KVA, 230V/115V	1		
6.	Voltmeter, 0-300V AC	2		

P4.7 Precautions

1. Select proper type and range of measuring instruments.
2. Connect voltmeters and ammeter as shown in the circuit diagram.
3. Check the circuit connections as per circuit diagram and the wire connections are tight before switching ON the power supply to the autotransformer.
4. Switch OFF the power supply after conduction of experiment.

P4.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P4.1.
2. Ensure proper connection of the auto transformer and the single phase transformer.
3. Keep the autotransformer rotary knob at zero voltage position.
4. Switch on the single pole switch S_1.
5. Switch on the single pole switch S_2.
6. Increase the supply voltage to 1-phase transformer in steps by gradually turning the rotary knob of autotransformer.
7. Record the primary (V_1) and secondary voltage (V_2) reading of the two winding transformer in the observation table.
8. Repeat step 6 in steps till the rated voltage of the primary of the 1-phase two winding transformer is reached.

P4.9 Observations and Calculation

Sr. No.	Primary voltage (V_1)	Secondary voltage (V_2)
1.		

Calculations:

1. Calculate the turns ratio as $N_1/N_2 = V_p/V_s$, where V_p and V_s are the rated primary and secondary voltage given in the name details of the 1- phase two winding transformer.
2. Calculate the turns ratio by calculating the ratio of V1 and V2 recorded in observation table.

P4.10 Results

Sr. No.	Parameter	Using measured Primary/Secondary voltage Value	Using rated Primary/Secondary voltage value	Error
1.	Turns ratio N_1/N_2			

P4.11 Conclusions

....

....

P4.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. State the difference between an autotransformer and a two winding transformer.
2. List the factors on which the induced e.m.f of a transformer depends.

II. P5- ES110: MEASURE THE ELECTRICAL QUANTITIES OF A TRANSFORMER

P5.1 Practical Statement

Connect single phase transformer and measure input and output quantities.

P5.2 Practical Significance

The observation of the input and output parameters mainly the voltage and current is important to assess the satisfactory working of a transformer. The performance test at no load will give an indication of the transformer core losses and the magnitude of no load current. The test at rated load will assess whether the voltage and current observed at the primary and the secondary side of the transformer are as per the transformer name plate rating details given.

P5.3 Relevant Theory

For theory refer sub topic 6.1.3.1 to 6.1.3.3 subtopics.

P5.4 Practical Outcomes (PrO)

PrO1: Connect circuit and measuring instruments choosing proper ranges.

PrO2: Determine the no load current and no load losses of a transformer.

PrO3: Determine the change in secondary voltage from no load to full load.

PrO4: Measure voltages for a given single phase two winding transformer.

P5.5 Practical Setup (Circuit Diagram)

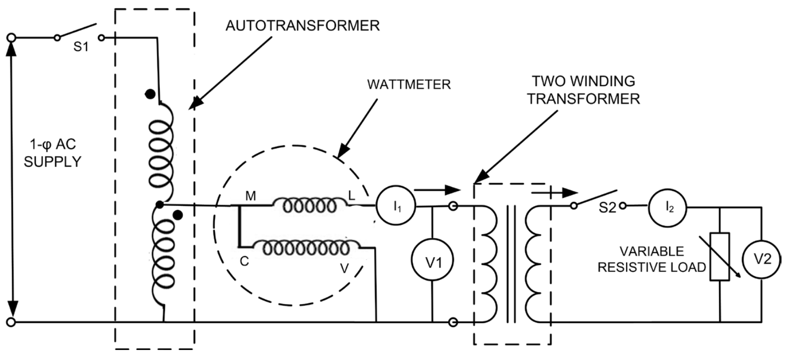


Fig. P5.1: Circuit diagram for determining transformer parameters

P5.6 Resources Required

Sr. No.	Suggested Resources required with vital specifications	Quantity	Actual Resources required with broad specifications (to be filled by the student)		Remarks (If any)
1.	Single phase AC source: 230V, 50Hz	1			
2.	Connecting wires: Multistrand Cu wire, 1.5 mm^2	L.S.			
3.	Single pole switch: 5A	2			
4.	1-phase Autotransformer: 2 KVA, 230 V/270 V	1			
5.	1-phase Transformer: 2 KVA, 230 V/115 V	1			
6.	Voltmeter: 0-300 V AC	2			
7.	Ammeter: 0-10 A, AC	2			
8.	LPF Wattmeter: 0-75-150-300 V, 0-2.5-5-10 A	1			
9.	UPF Wattmeter: 0-75-150-300 V, 0-2.5-5-10 A	1			

P5.7 Precautions

1. Select proper type and of range of measuring instruments.
2. Connect ammeters, voltmeters and wattmeter as shown in the circuit diagram.
3. Check the circuit connections as per circuit diagram and the wire connections are tight before switch S_1 is turned ON for power supply to the autotransformer.
4. Switch OFF the power supply after conduction of experiment.

P5.8 Suggested Procedure

1. **C**onnect the circuit as shown in Fig. P5.1.
2. Ensure proper connection of the auto transformer and the single phase transformer.
3. Keep the autotransformer rotary knob at zero voltage position.
4. Switch on the single pole switch S_1.
5. Increase the supply voltage to 1-phase transformer in steps up to the rated voltage by gradually turning the rotary knob of autotransformer.
6. Record the primary (V_1), current (I_1), secondary voltage (V_2), and LPF wattmeter reading of the two winding transformer in the observation table 1.
7 Bring the autotransformer rotary knob to zero position.
8. Switch on the single pole switch S_2.
9. Increase the supply voltage to 1-phase transformer in steps up to the rated voltage by gradually turning the rotary knob of autotransformer.
10. Record the secondary voltage V_2.
11. Record the primary voltage (V_1), primary current (I_1), secondary voltage (V_2), and UPF wattmeter reading of the two winding transformer in the observation table no 2 by varying the resistive load in steps.
12. Repeat step 10 in steps till the rated current on the secondary side of the 1-phase two winding transformer is reached.

P5.9 Observation and Calculation

Table 5.1

Sr. No.	Primary voltage (V_1)	Primary current (I_1)	Wattmeter reading
1.			

Table 5.2

Sr. No.	Primary Voltage (V_1)	Primary Current (I_1)	Secondary Voltage (V_2)	Secondary current (I_2)	Wattmeter reading
1.					
2.					

Calculations :

1. Using table. 1 calculate the no load power factor $\cos \emptyset_0 = \frac{P}{V_1 I_1}$. The magnetizing current $I_\mu = I_1 \cos\emptyset_0$ and the core loss current $I_c = I_2 \sin\emptyset_0$. The voltage V_1 is the rated primary voltage for the given transformer and I_1 is the primary current observed with no load connected to the secondary or low voltage side of the given transformer.
2. Observe and record the secondary voltage with the primary voltage at its rated value with switch S_2 in OFF position in table 2. Let this voltage be termed as V_{2nl}. Observe and record the secondary voltage with rated current flowing through secondary winding. Let this voltage be termed as V_{2fl}.
3. Calculate the percentage change in secondary voltage which equals to $\frac{V_{2nl} - V_{2fl}}{V_{2fl}} \times 100\%$.

P5.10 Result

Sr. No.	Parameters	Using measured Primary/ Secondary voltage Value	Using rated Primary/ Secondary voltage value	Error
1.	Turns ratio= $\frac{N_1}{N_2}$			

P5.11 Conclusions and/or Validation

……

……

P5.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes.

1. State the reason for low power factor of a transformer under no load condition.
2. State why the no load current of a transformer is only 2-5% of the rated current of a transformer.
3. List the factors on which the core loss of a transformer depends upon.

III. P6- ES110: MEASURE LINE AND PHASOR VALUES OF AN INDUCTION STARTER

P6.1 Practical Statement

Make Star and Delta connection in induction motor starters and measure the line and phase values.

P6.2 Practical Significance

When a three phase induction motor is started by directly switching on the power supply, it takes 5 to 7 times its rated current. The large starting current produces a large voltage drop in the supply lines, which may affect the operation of other equipment/devices connected to the same supply line. The Star/Delta three phase induction motor starter reduces the starting current taken by a three phase induction motor.

P6.3 Relevant Theory

There are different methods for starting a three phase induction motor. An induction motor is similar to a transformer with secondary shorted. The different starting methods of a three phase induction motor are (i) Direct Online (DOL) starting,(ii) Auto transformer starting and Star/Delta starting. In DOL starting, the rated voltage to the motor is applied by directly switching on the power supply. Small three phase induction motor less than 25 kW uses Direct online starting. Usually the stator winding of three phase motor using DOL starters are delta connected. In autotransformer starting, a reduced voltage is applied to the stator of the three phase induction motor at the time of starting. The reduced supply voltage to the motor reduces the line current at the time of starting. When the motor gathers appropriate speed the supply voltage is increased to the rated voltage of the motor. The Star/delta starter is used in three phase induction motors where the terminals of each phase of the motor are brought out. The starter employs a 2-way switch which connects the stator winding in star at the time of starting and in delta during normal running. The reduced voltage across the winding due to star connection at the time of starting reduces the line/supply current.

P6.4 Practical Outcomes (PrO)

PrO1: Select the proper type and range of measuring instruments.

PrO2: Prepare necessary circuit diagram and connect measuring instruments properly.

PrO3: Measure the line current and line voltage of a three phase induction motor

P6.5 Practical Setup (Circuit Diagram)

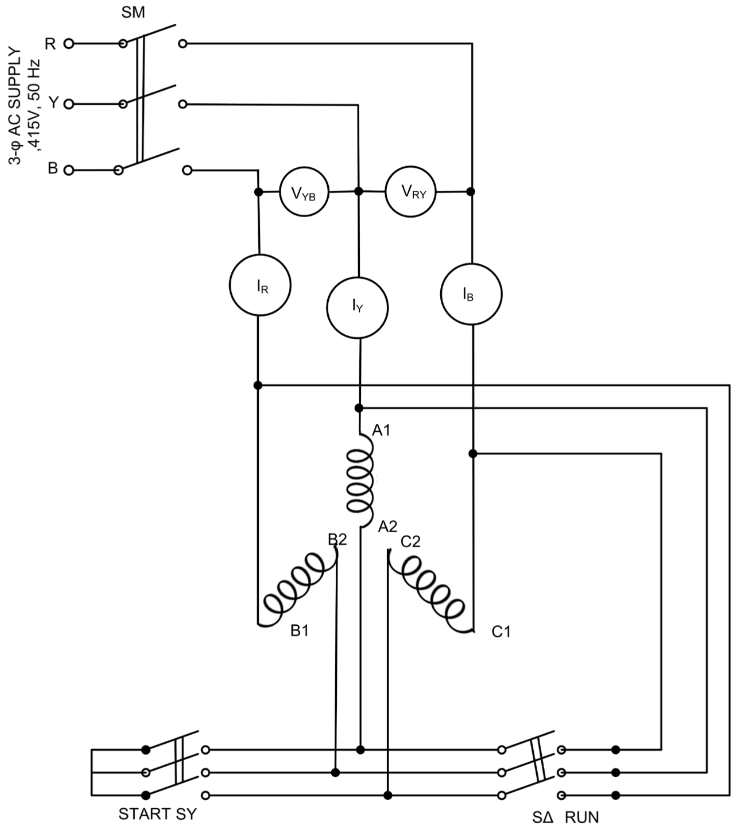


Fig. P6.1: Circuit diagram of Manual Star/Delta starter

P6.6 Resources Required

Sr. No.	Suggested Resources require with vital specifications	Quantity (No.)	Actual Resources required with broad specifications (to be filled by the student)		Remarks (If any)
1.	Three phase Induction motor, 5 HP, 415 V,Squirrel cage I M with six terminals brought out at the motor terminal block	1			
2.	Manual Star Delta starter	1			
3.	Connecting wires: Multistrand Cu wire, 2.5 mm^2	L.S.			
4.	Three phase MCB, 25 A	1			
5.	3-phase supply 415 V	1			
6.	Voltmeter: 0-500V AC	2			
7.	Ammeter: 0-10A, AC	3			

P6.7 Precautions

1. Select proper type and range of measuring instruments.
2. Connect ammeters and voltmetersas shown in the circuit diagram.
3. Check the circuit connections as per circuit diagram and the wire connections are tight before three pole MCB SM is turned ON for power supply to Manual Star/delta starter.
4. Switch OFF the three phase power supply after conduction of experiment.

P6.8 Suggested Procedure

1. Connect the circuit as shown in Fig. P6.1.
2. Ensure proper connection of the motor phase terminals A_1, A_2 of phase A winding, B_1, B_2 of phase B winding and C_1, C_2 of phase C winding with the three pole change over switch terminals of the manual star and delta starter.
3. The handle of the manual Star/Delta starter should be in "NORMAL" position.
4. Switch on the three pole MCB switch SM.
5. Turn the handle of the Star/Delta starter to the Star position i.e. the three pole switch SY "ON". The motor stator windings are now in star connection.
6. Record the line currents I_R, I_Y,I_B or the stator phase currents and the line voltage V_{RY} and V_{YB} in the observation table. The observed currents are the starting currents taken by the motor.
7. Turn the handle from the Star to the Delta position, i.e. the three pole switch SΔ will turn "ON" and the switch SY will turn "OFF". The motor stator winding is now delta connected.
8. Repeat Step No.6. The measured currents I_R, I_Y,I_B will be the stator line currents. The observed current in the three supply phases are the currents taken by the motor during normal running conditions.
9. Switch off the motor by turning "OFF" the three pole switch "SM".

P6.9 Observations and Calculations

Sr. No.	Manual Starter in Star position					Manual Starter in Delta position				
	Current			Voltage		Current			Voltage	
	I_R	I_Y	I_B	V_{RY}	V_{YB}	I_R	I_Y	I_B	V_{RY}	V_{YB}
1.										

P6.10 Results

Sr. No.	Motor starting Current	Motor running Current
1.		

P6.11 Conclusions

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....

P6.12 Practical related Questions

(Use separate sheet for answer)

Note: Below given are few sample questions for reference. Teachers must design more such questions in order to ensure the achievement of pre-defined course outcomes

1. State why the starting current of a three phase induction motor is high.
2. Collect information about the type of starters used in workshop for starting of three phase induction motors.
3. Record the starting current drawn with the stator winding of the 3-phase induction motor (i) Star connected (ii) Delta connected. Comment on the difference in starting current if observed any.

P6.13 Suggested Learning Resources

Three phase Induction motors

KNOW MORE

Micro-Project

Undertake one or two micro project(s) /activity(ies) in a group of 5 - 6 students under the guidance of faculty and present it as group with individual participation as well. A sample micro-project problem is given below:

1. Develop testing procedures and testing circuit for finding the fault of a given faulty ceiling fan.

Activities

1. Visit the college main power supply substation. Note down the name plate details of the distribution transformer installed. Prepare a report on the specification details given in the name plate.
2. Measure the primary and secondary winding resistance of a given 1-phase two winding transformer. Note down the resistance value and infer which winding is a HV winding.
3. Collect information such as specification details of various types of DC Motors from different manufactures and prepare a brief report based on information collected.
4. Develop a power point presentation and give seminar on DC motor and its applications.
5. Prepare a power point presentation on 3- phase AC motor selection as per NEMA standards and its applications.
6. Develop the circuit diagram and demonstrate how the direction of rotation of a given 1-phase induction motor can be changed.

Video Resources

DC Motors

Electrical Machines-I

REFERENCES AND SUGGESTED READINGS

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3. M.S. Sukhija and T.K. Nagsarkar, *Basic Electrical and Electronics Engineering*, New Delhi: Oxford University Press, 2013.
4. B. L. Theraja, *Electrical Technology*, Vol. - I, New Delhi: S. Chand and Company, 2015.
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Appendix – A

Lab Assessment Record

Sr. No.	Page No.	Name of Experiment	Date			Marks	Signature
			Actual	Repeat	Remark		
1.		Determine the permeability of magnetic material by plotting its B-H curve.					
2.		Measure voltage current and power in 1 phase circuit with resistive load.					
3.		Measure voltage current and power in R L series circuit.					
4.		Determine transformation ratio (K) of 1 phase transformer					
5.		Connect single phase transformer and measure input output quantities.					
6.		Make star and delta connection in induction motor starters and measure the line and phase values.					
7.		Identify various passive electronic components in the given circuit.					
8.		Connect resistor in series and parallel combination on bread board and measure its value using multimeter.					
9.		Connect capacitors in series and parallel combination on bread board and measure its value using multimeter.					
10.		Identify various active electronic component in the given circuit.					
11.		Use LCR meter to measure the value of inductance and resistance.					
12.		Use LCR-Q meter to measure the value of given capacitor.					
13.		Determine the value of given resistor using digital multimeter to confirm with colour code.					
14.		Test PN junction diode using digital multimeter.					
15.		Test the performance of PN junction diode.					
16.		Test the performance of Zener diode.					
17.		Test the performance of LED.					
18.		Identify three terminals of transistor using digital multimeter.					
19.		Test the performance of NPN transistor.					
20.		Determine current gain of CE configuration transistor.					
21.		Test the performance of transistor switch circuit.					
22.		Test the performance of transistor amplifier circuit.					
23.		Test Op Amp as amplifier and integrator.					

Appendix – B

Instructions when Working in the Laboratory

Brief Guidelines to Teachers

Teacher shoud provide the guideline with demonstration of practical to the students with all features.

1. Teacher shall explain prior concepts to the students before starting of each practical.
2. Involve students in performance of each practical.
3. Teacher should ensure that the respective skills and competencies are developed in the students after the completion of the practical exercise.
4. Teachers should give opportunity to students for hands on experience after the demonstration.
5. Teacher is expected to share the skills and competencies to be developed in the students.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected the students by the industry.
7. Finally give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions.
8. Teacher is expected to refer and motivate students to refer related data manual and standards.
9. Teacher is expected to refer complete curriculum document and follow guidelines for implementation.

Instructions for Students

1. Listen carefully the lecture given by teacher about course, curriculum, learning structure, skills to be developed.
2. Organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and gain confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. those included in scope of manual.
6. Student shall refer technical magazines, IS codes and data books.
7. Student should develop habit to submit the practical on date and time.
8. Student should well aware about safety practices and environmental issues, waste management relaled to practical.

Appendix – C

Indicative Evaluation Guidelines for Practicals/ Micro-Projects / Activities in Group

Process Related Skills

Criteria and Level	Developing	Competent	Proficient
Handling the Set-up			
Recording of Data			
Time management			
Team Work			
Individual Work			
Safety Precautions			

Product Related Skills

Criteria and Level	Developing	Competent	Proficient	Remarks (if any). If not applicable, Mention 'NA'
Content				
Research/Survey				
Use of latest Technology				
Stays on Topic				
Preparedness				
Confidence of Presentation				
ICT Usage including ppt Making Skill				
Time Management				
Group Efforts				
Individual Efforts				

Answers to Objective Questions

Unit-1: Overview of Electronic Components and Signals

Sr. No.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10
Ans.	a	d	b	d	c	b	d	b	a	c

Unit-2: Overview of Analog Circuits

Sr. No.	2.1	2.2	2.3	2.4	2.5	2.6
Ans.	b	c	b	b	d	d

Unit-3: Overview of Digital Electronics

Sr. No.	3.1	3.2	3.3	3.4	3.5	3.6
Ans.	c	b	a	c	d	d

Unit-4: Electric and Magnetic Circuits

Sr. No.	4.1	4.2	4.3	4.4	4.5	4.6
Ans.	d	b	d	c	d	b

Unit-5: AC Circuits

Sr. No.	5.1	5.2	5.3	5.4	5.5	5.6
Ans.	c	b	d	a	b	c

Unit-6: Transformer and Machines

Sr. No.	6.1	6.2	6.3	6.4	6.5	6.6
Ans.	d	d	d	c	c	a

References for Further Learning

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CO and PO Attainment Table

Course outcomes (COs) for this course can be mapped with the programme outcomes (POs) after the completion of the course and a correlation can be made for the attainment of POs to analyze the gap. After proper analysis of the gap in the attainment of POs, necessary measures can be taken to overcome the gaps.

Course Outcomes	**ATTAINMENT OF PROGRAMME OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)**						
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**	**CO-7**
U6-O1							
U6-O2							
U6-O3							
U6-O4							
U6-O5							
U6-O6							

The data filled in the above table can be used for gap analysis.

Index