RQFLEVEL 3

GENEF302

NETWORKING AND INTERNET TECHNOLOGIES

Electronics Fundamentals

TRAINEE'S MANUAL

October, 2024

ELECTRONICS FUNDAMENTALS

2024

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TABLE OF CONTENT

ACRONYMS

µF: micro-farad

Ω: Ohm

AC: Alternative Current

ADC: Analog-to-digital converter

ANSI: American National Standards Institute

ATM: Automated Teller Machine

C: Capacitance

DAC: Digital-to-Analog converter

DC: Direct Current

DMM: Digital Multimeter

DVD: Digital Versatile Disc

ECU: Electronic Control Unit

ESD: Electrostatic discharge

F: Farad

FPGA: Field-programmable gate array

I: Current

IC: Integrated Circuits

IEC: International Electrotechnical Commission

IEEE: Institute of Electrical and Electronics Engineers

JIC: Joint Industry Council

KΩ: Kilo-Ohm

LANs: Local Area Networks

LCR: Inductance-Capacitance-Resistance

LDRs: Light Dependent Resistors

LED: Light Emitting Diode

MLCC: Multi-layer chip capacitor

MOV: Metal Oxide Varistor

nF: nano-Farad

NIT: Networking and Internet technologies

NTC: Negative Temperature Coefficient

OL: Open Line

PCB: Printed Circuit Board

PDA: Personal Digital Assistant

POS: Point of Sale

PPE: Personal Protective Equipment

PTC: Positive Temperature Coefficient

Q: Charge

R: Resistance

RQF: Rwanda Qualification Framework

RTB: Rwanda TVET Board

SPICE: Simulation Program with Integrates Circuit Emphasis

TQUM Project: TVET Quality Management Project

TV: Television

V: Voltage

VCRs: Video Cassette Recorder

VDR: Voltage dependent resistor

INTRODUCTION

This trainee's manual includes all the knowledge and skills required in Networking and Internet Technologies specifically for the module of **"Electronics Fundamentals".** Trainees enrolled in this module will engage in practical activities designed to develop and enhance their competencies. The development of this training manual followed the Competency-Based Training and Assessment (CBT/A) approach, offering ample practical opportunities that mirror real-life situations.

The trainee's manual is organized into Learning Outcomes, which is broken down into indicative content that includes both theoretical and practical activities. It provides detailed information on the key competencies required for each learning outcome, along with the objectives to be achieved.

As a trainee, you will start by addressing questions related to the activities, which are designed to foster critical thinking and guide you towards practical applications in the labor market. The manual also provides essential information, including learning hours, required materials, and key tasks to complete throughout the learning process.

All activities included in this training manual are designed to facilitate both individual and group work. After completing the activities, you will conduct a formative assessment, referred to as the end learning outcome assessment. Ensure that you thoroughly review the key readings and the 'Points to Remember' section.

MODULE CODE AND TITLE: GENEF302ELECTRONICS FUNDAMENTALS

Learning Outcome 1: Apply passive components
Learning Outcome 2: Apply Active components
Learning Outcome 3: Use electronic lab/workshop equipment
Learning Outcome 4: Use electronic circuit simulation software
Learning Outcome 5: Apply numbering system


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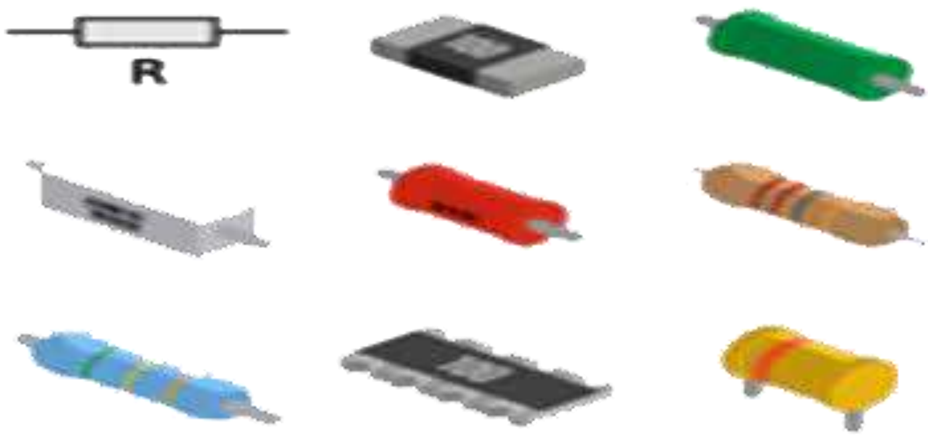
C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Indicative contents
1.1 Introduction to electronics components **1.2 Description of resistors** **1.3 Description of capacitors** **1.4 Description of inductors**

Key Competencies for Learning Outcome 1: Apply passive components

Knowledge	Skills	Attitudes
• Description of electronics component • Description of passive components • Description of electronic circuits design process	• Applying measurement of passive components • Connecting electronic passive components • Calculating passive components values	• Having Creative mindset • Being a Critical thinker • Being a team player

Duration: 20 hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Define clearly the term "electronics" as used in electronic field,
2. Describe correctly the passive component in accordance with their types and features,
3. Apply correctly the measurements of passive components respecting measuring techniques,
4. Implement properly passive components circuits according to their types and applications

Resources

Equipment	Tools	Materials
• Multimeter, • PPE, • Calculator	• Breadboard, • PCB, • Soldering iron,	• Resistors, • Capacitors, • Inductors, • Wires, • Soldering tin

Indicative content 1.1: Introduction to Electronics Components

Duration: 2 hrs

Theoretical Activity 1.1.1: Introduction to electronics

Tasks:

1. In small group formed, discuss and answer the following questions:
   i. What do you understand by the following:
      a) Electronics
      b) Electronic components
      c) Electronic circuit
   ii. Identify the types of electronic components.
2. Discuss and write the findings related to the given tasks on provided place
3. Present your findings to the whole class or your colleagues.
4. Follow the trainer when providing expert view
5. Ask questions for more clarification
6. Read the **Key readings 1.1.1** in their manuals to get more clarification.

Key readings 1.1.1.: Introduction to electronics

- **Definition of Electronics**

  Electronics is the branch of science and technology that deals with the study, design, and application of devices and systems that use the flow of electrons and other charged particles in various media, including semiconductors, conductors, and insulators.

  Electronics is a scientific and engineering discipline that studies and applies the principles of physics to design, create, and operate devices that manipulate electrons and other electrically charged particles.

- **Definition of Electronic component**

  An electronic component is any basic discrete device in an electronic system used to affect electrons or their associated fields. They are the elements of circuit which helps in its functioning. Electronic components have a number of electrical terminals. These terminals connect to other electrical components to create an electronic circuit.

- **Definition of Electronic Circuit**

  An electronic circuit can be defined as a complete path through which electricity flows. It contains various components like a power source, conductors (material that allows electricity to pass through them), resistors (these are opposite of conductors), wires, and junctions.

- **Definition of Electronic Device**

  The device which controls the flow of electrons is called electronic device. These devices are the main building blocks of electronic circuits.

- **Types of Electronic Components**

  There are two types of electronic components namely 1) **Passive components** and 2) **Active components.**

  Passive component consumes energy in the form of voltage from the source but does not produce or supply energy.

  Examples: Passive components include two-terminal components such as resistors, capacitors, inductors, and transformers.

  Active components are devices that can amplify an electric signal and produce power. An active component functions as an alternating current circuit in devices. This helps the device to augment power and voltage. This component can execute its operations because it is powered by a source of electricity. All active components necessitate some source of energy which commonly is extracted from a DC circuit.

  Examples: Transistors, Thyristors, Diodes, etc

- **Applications of Electronic Components**

  An electronic circuit is a structure that directs and controls electric current to perform various functions including signal amplification, computation, and data transfer.

- **Consumer Electronics:** Office Gadgets such as calculators, Personal computers, Scanners and Printers, FAX machine, Front Projector etc.

- **Industrial Electronics:** Electronic components are used for Industrial automation and motion control, Machine learning, motor drive control and robotics,
- **Smart grid systems:** It is an application of intelligence, computing, and networked electricity systems.
- **Medical applications:** Electronic components are being used in some of the medical devices and equipment is: Respiration Monitors for knowing the patient condition due to change in body temperature, pulse, respiration and blood flow.
- **Defense and Aerospace:** Defense and Aeronautical applications include: Missile Launching systems, Rocket Launchers for space, Aircraft systems, Cockpit controllers, Military Radars, Boom barrier for military applications
- **Automotive:** Anti-collision unit, Infotainment console, Anti-lock braking system, Cruise control, Traction control, Window regulators, Electronic Control Unit (ECU) and Airbag control.

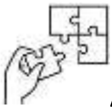
Some applications of electronic in real life are:

- ✓ Computers,
- ✓ Scanners,
- ✓ FAX machines,
- ✓ washing machines,
- ✓ refrigerators,
- ✓ TVs,
- ✓ Radios (Transmitters and Receivers),
- ✓ Loudspeakers

Points to Remember

- "Electronics" is the branch of science and technology that deals with the study, design, and application of devices and systems that use the flow of electrons and other charged particles in various media, including semiconductors, conductors, and insulators.
- Electronic components are any basic discrete device in an electronic system used to affect electrons or their associated fields.

- An electronic circuit is a complete path through which electricity flows. It contains various components like a power source, conductors, wires, and junctions.
- There are two types of electronic components namely 1) **Passive components** and 2) **Active components.**
- **Passive component** consumes energy in the form of voltage from the source but does not produce or supply energy.
- **Active components** are devices that can amplify an electric signal and produce power.



Application of learning 1.1.

A group of electronic operators are learning about basic electronic components. The supervisor plans a hands-on activity where participants will reinforce their understanding of the electronic components.
As one of the groups, you are tasked to go in an electronic operation room and pick devices and equipment made by electronic components among others.

Indicative content 1.2: Description of resistor

Duration: 6 hrs

Theoretical Activity 1.2.1: Introduction to Resistor

Tasks:

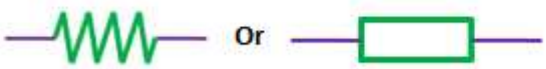
1. In small groups, you are requested to answer the following questions related to the description of Resistor
   i. Distinguish a resistor from resistance,
   ii. Identify the types of resistors.
   iii. What are the three ways resistors can be connected together?
   iv. Discuss on the ways of knowing the resistance of a resistor.
2. Provide the answer for the asked questions and write them on papers.
3. Discuss to the provided answers to choose the correct.
4. Follow your trainer while providing expert view,
5. In addition, ask questions where necessary for clarifications.
6. For more clarification, read the key readings 1.2.1.

Key readings 1.2.1.:

- **Definition of resistor**

The term "resistor" refers to a two-terminal passive electronic component that is used to limit or regulate the flow of electric current in electrical circuits.

Resistor is represented by the following schematic symbol:



- **Definition of resistance**

Resistance is the restriction of the flow of electrons. Resistance is the opposite of current. If the resistance in a circuit increases, the current will decrease.

Resistance is designated with **R** and its unit is the **ohm (Ω)**.

The resistance can be calculated with Ohm's law, when the voltage drop across the resistor and the current through the resistor are known:

R=V/I

The resistance property of a material is called resistivity. The electrical resistance of a resistor is proportional to the resistivity of the material. For a rectangular cross-section resistor, the resistance R is given by:

$$R = \frac{\rho \cdot l}{A}$$

Where:

ρ is the resistivity of the resistor material (Ωm),

l is the length of the resistor along direction of current flow (m), and

A is the cross-sectional area perpendicular to current flow (m^2).

- **Types of resistors**

There are two basics types of resistors as follows:

- ✓ Linear resistor
- ✓ Non-linear resistor

- **Linear resistors**

The resistors whose values change with change in applied temperature and voltage are known as linear resistors.

There are two types of linear resistors:

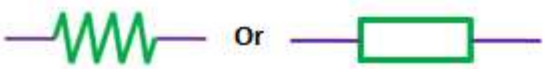
✓ **Fixed resistors**

Fixed resistors are the resistors whose resistance does not change with the change in voltage or temperature. Fixed resistors are available in various shapes and sizes.

A fixed resistor consists of two terminals. These two terminals are used to connect with the other components in the electronic circuit.

Symbol of fixed resistor is shown below:

The IEC (International Electro-technical Commission) standard and American standard fixed resistor symbol is shown in the below figure.



✓ **Types of fixed resistors**

The different types of fixed resistors include:

- **Carbon composition resistors**

The carbon composition resistor is a type of passive component, which restricts the flow of electric current to certain level.

- **Wire wound resistors**

A wire wound resistor is an electrical passive component that limits current. The resistive element is an insulated metallic wire that is wound around a core of non-conductive material.

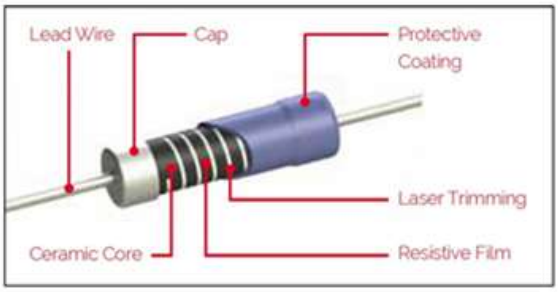
Applications of wire wound resistors

The **applications of the wire-wound** resistors include the following.

- Transducer devices
- Medical devices
- Audio devices
- Video devices
- Balancing of voltage & current

- **Thin film resistors**

A thin-film resistor is a resistor that employs a thin resistive layer. A ceramic base is positioned underneath this layer. This resistor has an extremely small thickness of only 0.1 microns compared to thick film resistors.



a) Construction of thin film resistor

b) Image of thin film resistor

Thick film resistors

Thick film resistors are produced by applying a resistive film or paste, a mixture of glass and conductive materials, to a substrate. Thick film technology allows high resistance values to be printed on a cylindrical or flat substrate either covered entirely or in various patterns.

- **Variable resistors:**

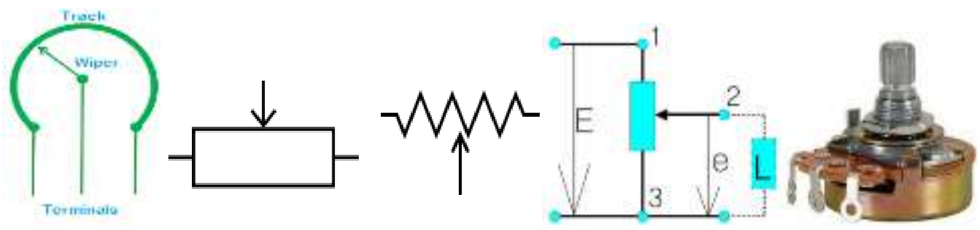
As the name implies, the resistance of the variable resistor is changeable. It is easy to vary or change the resistance of a variable resistor to a desired value.

- **Types of variable resistors**

Following are the different types of variable resistors: Potentiometers, Rheostats and Trimmers

✓ **Potentiometer**

The potentiometer consists of three terminals among which two are fixed and one is changeable. The slider or wiper moving along the resistive track changes the resistance of the potentiometer. The resistance of the potentiometer is changed when the wiper is moved over the resistive path.



(a) (b) (c) (d)

Figure (a): Construction of Potentiometer

(b) Symbol of Potentiometer

(c) Connection of Potentiometer

(d) Overview of Potentiometer

Applications of Potentiometer

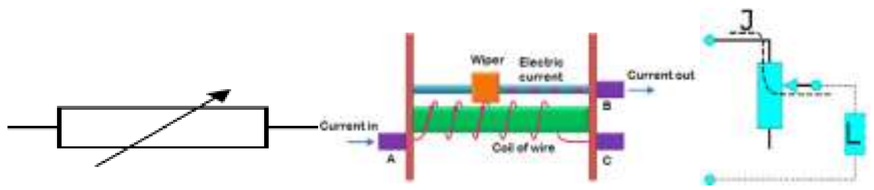
Potentiometers have a wide range of uses and can generally be applied to any application that requires control of a small amount of power or signal. Common applications include:

- Audio control (volume, tone, and EQ)
- Television parameter controls (obsolete)
- Motion control
- Displacement transducers
- Analog computing (function generation, etc.)

✓ **Rheostat**

The word rheostat is derived from the Greek word “rheos” and “-statis” which means a current controlling device or a stream controlling device.

The construction of rheostat is almost similar to the potentiometer. Like the potentiometer, the rheostat also consists of three terminals. However, in rheostat we use only two terminals for performing the operation.



(a) (b) (c)

Figure (a): Symbol of Rheostat

(b) Overview of Rheostat

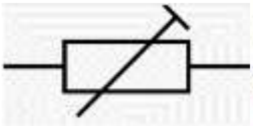
(c) Connection of Rheostat

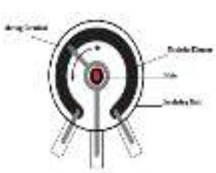
In the similar way, the maximum resistance is achieved when we move the wiper close to terminal C, because the length of the resistive path increases. As a result, a large amount of electric current is blocked and only a small amount of electric current is allowed.

- ✓ **Trimmers**

Trimmer resistors are also called trim pots or variable resistors that allow you to manually fine-tune the resistance in a circuit. A trimmer resistor is a resistor that can be adjusted or "trimmed" to an exact resistance by turning a screw.

The Trimmer resistor symbol, construction and overview are shown below:





(a)

(b) (c)

Figure (a): Symbol of Trimmer

(b) Overview of Trimmer

(c) Construction of Trimmer

- **Non-linear resistors**

The resistor values change according to the temperature and voltage applied and is not dependent on Ohm's law.

Types of non-linear resistors

Following are the different types of non-linear resistors: Thermistors, Varisters and Photo resistors

- ✓ **Thermistors**

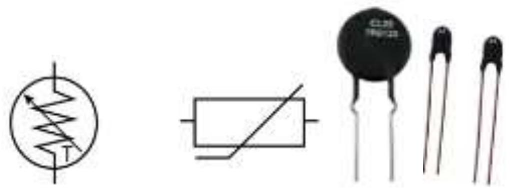
A thermistor is a resistance thermometer, or a resistor whose resistance is dependent on temperature. The term is a combination of "thermal" and "resistor".

There are two types of thermistors: Negative Temperature Coefficient (NTC) and Positive

Temperature Coefficient (PTC). With an NTC thermistor, when the temperature increases, resistance decreases. Conversely, when temperature decreases, resistance increases. This type of thermistor is used the most.

A PTC thermistor works a little differently. When temperature increases, the resistance increases, and when temperature decreases, resistance decreases.

The thermistor symbols are:



(a) (b)

Figure (a): Symbol of Thermistor

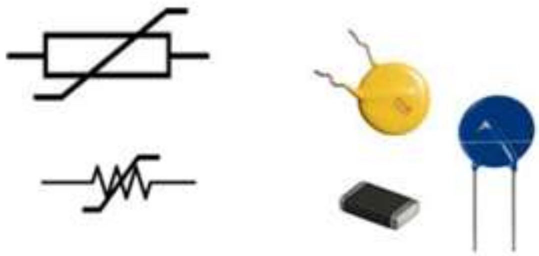
(b) Overview of Thermistor

Some of the most common uses of thermistors are in digital thermometers, in cars to measure oil and coolant temperatures, and in household appliances such as ovens and refrigerators, but they are also found in almost any application that requires heating or cooling protection circuits for safe operation.

- ✓ **Varistors**

A varistor is a voltage dependent resistor (VDR). The resistance of a varistor is variable and depends on the voltage applied.

Their resistance decreases when the voltage increases. In case of excessive voltage increases, their resistance drops dramatically. Varistors are nonlinear two-element semiconductors that drop in resistance as voltage increases. Voltage dependent resistors



Are often used as surge suppressors for sensitive circuits.

(a) (b)

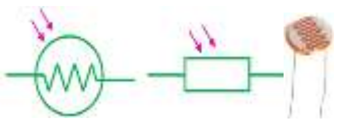
Figure (a): Symbol of Varistor

(b) Overview of Varistor

✓ **Photo resistors**

Photoresistors, also known as light dependent resistors (LDR), are light sensitive devices most often used to indicate the presence or absence of light, or to measure the light intensity. In the dark, their resistance is very high, sometimes up to 1 MΩ, but when the LDR sensor is exposed to light, the resistance drops dramatically, even down to a few ohms, depending on the light intensity.

Photoresistors are light sensitive resistors whose resistance decreases as the intensity of light they are exposed to increases.



(a) (b)

(a): Symbol of Varistor(b) Overview of Varistor

Applications of photo-resistors

- Photo-resistors are used in streetlights to control when the light should turn on and when the light should turn off.
- They are also used in various devices such as alarm devices, solar street lamps, night-lights, and clock radios.

- **Special resistors**

✓ **Surface mount resistor**

Surface mount resistors (SMRs) are a type of resistor designed for use on printed circuit boards (PCBs) using surface mount technology (SMT). Unlike traditional through-hole resistors, which have leads that pass through holes in the PCB, SMRs are soldered directly onto the surface of the PCB.

✓ **Resistance of SMD resistors**

SMD resistors are tidy and are commonly marked with three- or four-digit codes called SMD Resistor Codes that indicate their resistance values.

Here are more examples for SMD Resistor Codes.

✓ **Reading 3-Digit SMD Resistor Codes**

- The first two (2) digits or numbers will indicate the significant digits or numbers.
- The third one will be multiplier (in Power of Ten i.e. 10^ something) and then will indicate that how many Zeros should be added to the first Two (2) significant digits or number.
- The letter "R" is used for Decimal Point "." i.e. 1.1 Ω = 1R1 Ω
- Resistances below 10 ohms (Ω) do not have a multiplier.

Examples of 3-Digit SMD Resistor Codes

- 250 = 25 x 10^0 = 25 x 1 = 25 Ω (This is only and only 25Ω not 250 Ω)
- 4R7 = 4.7Ω
- R12 = 0.12 Ω

✓ **Reading 4-Digit SMD Resistor Codes**

- The first three (3) digits or numbers will indicate the significant digits or numbers.
- The fourth one will be multiplier (in Power of Ten i.e. 10^ something) and then

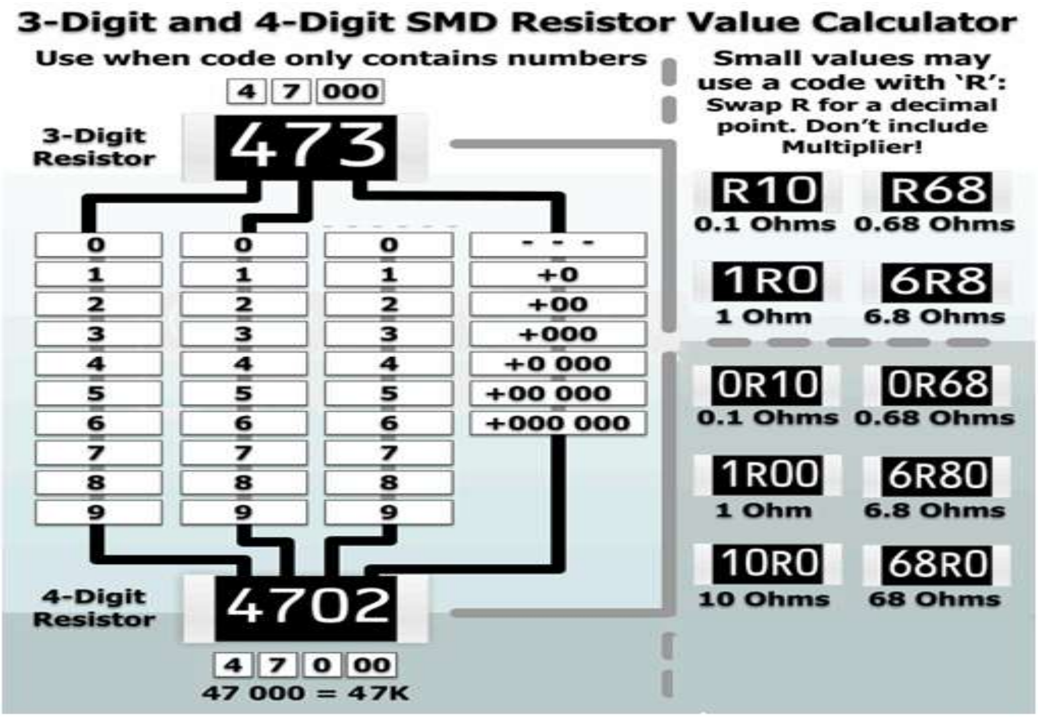
indicate that how many Zeros should be add to the first Two (2) significant digits or number.

- The letter "R" is used for Decimal Point "." i.e. 11.5 Ω = 11R5 Ω (4-digit SMD resistors (E96 series).
- Resistances below 10 ohms (Ω) do not have a multiplier.

Examples of 4-Digit SMD Resistor Codes

- 2500 = 250 x 10^0 = 250 x 1 = 250 Ω (This is only and only 250Ω not 2500 Ω)
- R102 = 0.102 Ω (4-digit SMD resistors (E96 series)
- 0R10 = 0.1 x 10^0 = 0.1 x 1 = 0.1 Ω (4-digit SMD resistors (E24 series)

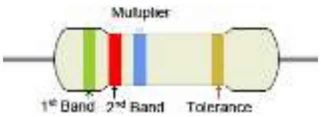
3 and 4 digit SMD resistor codes calculation table



- **Resistor color coding**

An electronic color code is a code that is used to specify the ratings of certain electrical components, such as the resistance in Ohms of a resistor.

Resistor values are often indicated with color codes. The coding is defined in the international standard IEC 60062. This standard describes the marking codes for resistors and capacitors. In addition to defining the color bands, the standard also includes numerical codes, as often used for surface mount SMD resistors.

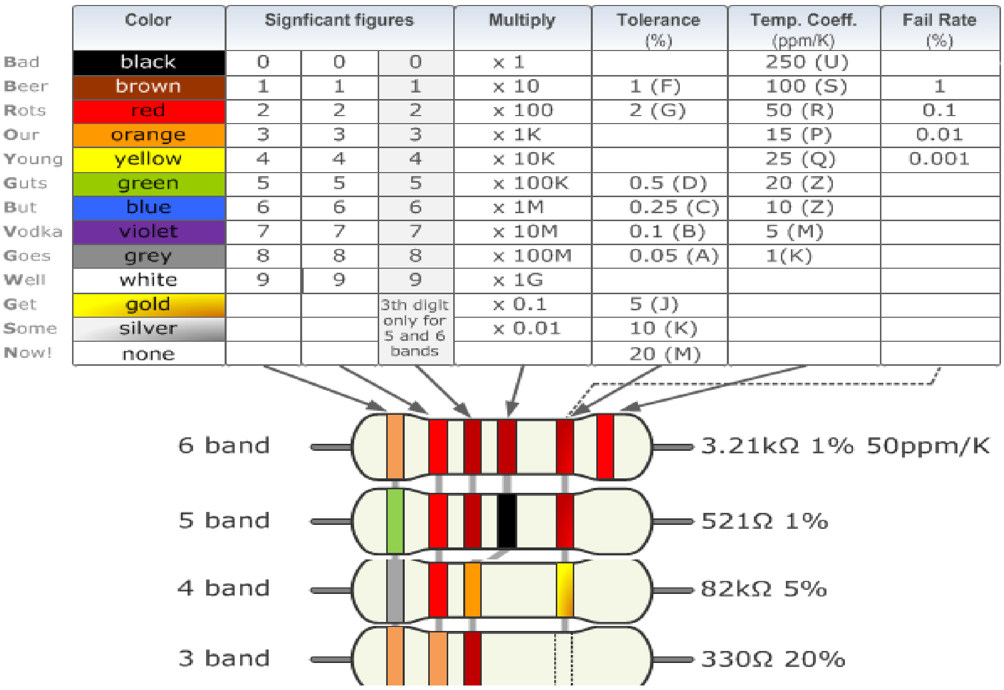


- ✓ **Reading Resistor colour bands**

The reading direction of colour bands might not always be clear.

Sometimes the increased space between bands 3 and 4 provides an indication of the reading direction. Also, the first band is usually the closest to a lead. A gold or silver band (the tolerance) is always the last band.

- ✓ **Resistor colour coding table**



	Color	Signficant figures			Multiply	Tolerance (%)	Temp. Coeff. (ppm/K)	Fail Rate (%)
Bad	black	0	0	0	x 1		250 (U)	
Beer	brown	1	1	1	x 10	1 (F)	100 (S)	1
Rots	red	2	2	2	x 100	2 (G)	50 (R)	0.1
Our	orange	3	3	3	x 1K		15 (P)	0.01
Young	yellow	4	4	4	x 10K		25 (Q)	0.001
Guts	green	5	5	5	x 100K	0.5 (D)	20 (Z)	
But	blue	6	6	6	x 1M	0.25 (C)	10 (Z)	
Vodka	violet	7	7	7	x 10M	0.1 (B)	5 (M)	
Goes	grey	8	8	8	x 100M	0.05 (A)	1(K)	
Well	white	9	9	9	x 1G			
Get	gold			3th digit only for 5 and 6 bands	x 0.1	5 (J)		
Some	silver				x 0.01	10 (K)		
Now!	none					20 (M)		

Then we can summarize the different weighted positions of each coloured band which makes up the resistors colour code above in the following table:

Number of Coloured Bands	**3 Coloured Bands (E6 Series)**	**4 Coloured Bands (E12 Series)**	**5 Coloured Bands (E48 Series)**	**6 Coloured Bands (E96 Series)**
1st Band	1st Digit	1st Digit	1st Digit	1st Digit
2nd Band	2nd Digit	2nd Digit	2nd Digit	2nd Digit
3rd Band	Multiplier	Multiplier	3rd Digit	3rd Digit
4th Band	–	Tolerance	Multiplier	Multiplier
5th Band	–	–	Tolerance	Tolerance

6th Band	–	–	–	Temperature Coefficient

- **Arranging resistors**

Resistors are circuit elements that impart electrical resistance. While circuits can be highly complicated, and there are many different ways in which resistors can be arranged in a circuit, resistors in complex circuits can typically be broken down and classified as being connected in series, in parallel and in mixed.

✓ **Resistors in series**

Resistors are said to be in series whenever the current flows through the resistors sequentially. Consider Figure below, which shows three resistors in series with an applied voltage equal to Vab. Since there is only one path for the charges to flow through, the current is the same through each resistor.

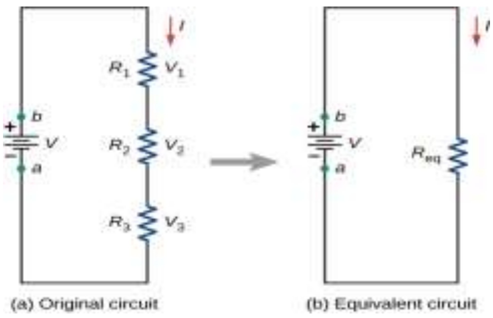


Figure (a) Three resistors connected in series to a Voltage source.

(b) The original circuit is reduced to an equivalent resistance and a voltage source.

In Figure shown above, the current coming from the voltage source flows through each resistor, so the current through each resistor is the same.

For Figure above, the sum of the potential drop of each resistor and the voltage supplied by the voltage source should equal zero:

$$V - V_1 - V_2 - V_3 = 0,$$
$$V = V_1 + V_2 + V_3,$$
$$= IR_1 + IR_2 + IR_3,$$

Solving for I

Since the current through each component is the same, the equality can be simplified to an equivalent resistance (RS), which is just the sum of the resistances of the individual resistors.

$$I = \frac{V}{R_1 + R_2 + R_3} = \frac{V}{R_S}.$$

Equivalent Resistance in Series Circuits: Any number of resistors can be connected in series. If N resistors are connected in series, the equivalent resistance is:

$$R_P = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_{N-1}} + \frac{1}{R_N}\right)^{-1} = \left(\sum_{i=1}^{N} \frac{1}{R_i}\right)^{-1}.$$

The equivalent resistance of a set of resistors in a series connection is equal to the algebraic sum of the individual resistances.

- ✓ **Resistors in Parallel**

Resistors are in parallel when one end of all the resistors are connected by a continuous wire of negligible resistance and the other end of all the resistors are also connected to one another through a continuous wire of negligible resistance.

The potential drop across each resistor is the same. Current through each resistor can be found using Ohm’s law I=V/R, where the voltage is constant across each resistor.

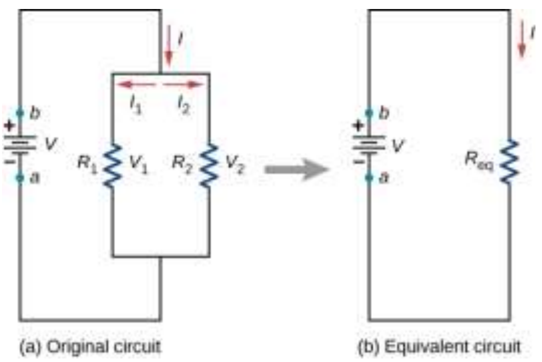


Figure (a) Two resistors connected in parallel to a voltage source.

(b) The original circuit is reduced to an equivalent resistance and a voltage source.

The current flowing from the voltage source in Figure depends on the voltage supplied by the voltage source and the equivalent resistance of the circuit. In this case, the current flows from the voltage source and enter a junction, or node, where the circuit splits flowing through resistors R1 and R2. As the charges flow from the battery, some go through resistor R1 and some flow through resistor R2. The sum of the currents flowing into a junction must be equal to the sum of the currents flowing out of the junction:

$$\sum I_{in} = \sum I_{out}.$$

In Figure above, the junction rule gives I=I1+I2. There are two loops in this circuit, which leads to the equations V=I1R1and I1R1=I2R2. Note the voltage across the resistors in parallel are the same (V=V1=V2) and the current is additive:

$$\begin{aligned} I &= I_1 + I_2 \\ &= \frac{V_1}{R_1} + \frac{V_2}{R_2} \\ &= \frac{V}{R_1} + \frac{V}{R_2} \\ &= V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V}{R_P} \end{aligned}$$

Solving for the RP

$$R_P = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}.$$

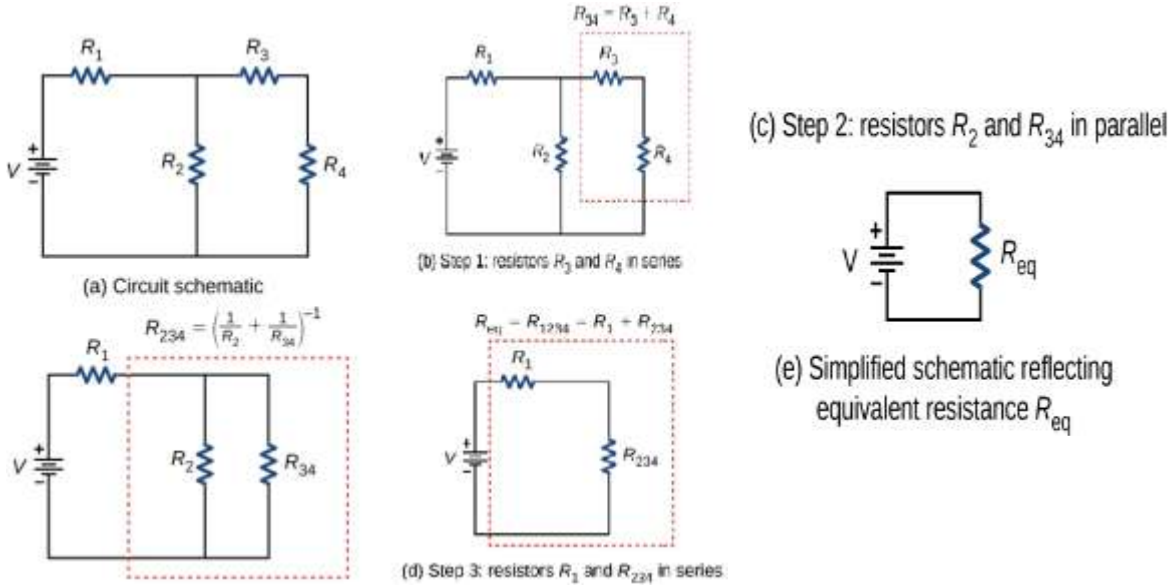
Equivalent Resistance in Parallel Circuits: Generalizing to any number of N resistors, the equivalent resistance RP of a parallel connection is related to the individual resistances by:

$$R_P = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_{N-1}} + \frac{1}{R_N}\right)^{-1} = \left(\sum_{i=1}^{N} \frac{1}{R_i}\right)^{-1}.$$

- ✓ **Combinations of Series and Parallel**

Complex connections of resistors are often just combinations of series and parallel connections. Such combinations are common, especially when wire resistance is considered. In that case, wire resistance is in series with other resistances that are in parallel.

Combinations of series and parallel can be reduced to a single equivalent resistance using the technique illustrated in Figure below. Various parts can be identified as either series or parallel connections, reduced to their equivalent resistances, and then further reduced until a single equivalent resistance is left. The process is more time consuming than difficult. Here, we note the equivalent resistance as Req.



- **Applications of resistors**

Resistors are fundamental components in electrical and electronic circuits, serving various essential functions.

Below are the primary applications of resistors:

1. Current Limiting: Resistors are often used to limit the amount of current flowing through a circuit. This is particularly important in protecting sensitive components like LEDs, which can be damaged by excessive current. A current limiting resistor is placed in series with the LED to ensure that only the appropriate amount of current flows through it.

2. Voltage Division: Resistors can be configured in series to create a voltage divider, which allows for the distribution of a higher input voltage into smaller output voltages suitable for different components within a circuit. This is useful when certain components require lower operating voltages than what is supplied.

3. Signal Conditioning: In electronic circuits, resistors help regulate signal levels and improve signal integrity by filtering out noise and stabilizing voltage levels. They play a crucial role in analog circuits where precise control over signal amplitude is necessary.

4. Biasing Active Components: Transistors and other active devices often require specific biasing conditions to operate correctly. Resistors are used to set these bias points, ensuring that transistors function within their optimal ranges.

5. Heating Applications: Due to their inherent resistance, resistors generate heat when current passes through them. This property is utilized in heating elements found in appliances such as toasters, electric stoves, and heaters.

6. Timing Circuits: Resistors are integral in timing applications where they work alongside capacitors to create time delays or oscillations in circuits (e.g., light flashers or sirens). The resistor value influences how quickly or slowly the capacitor charges and discharges.

7. Pull-up and Pull-down Resistors: In digital logic circuits, pull-up resistors ensure that inputs are at a defined high state when switches are open, while pull-down resistors ensure inputs are at a defined low state under similar conditions. This prevents floating states that could lead to unpredictable behavior.

8. Filtering Applications: Resistors are used in conjunction with capacitors and inductors to form filters that allow certain frequencies to pass while attenuating others, which is essential in audio processing and communication systems.

9. Load Resistor: In some applications, resistors serve as load devices that provide necessary resistance for testing purposes or simulate loads for power supplies without drawing excessive current.

These applications highlight the versatility of resistors across various fields including electronics, telecommunications, automotive systems, and consumer appliances.

Practical Activity 1.2.2: Apply the measurement of resistance

Task:

1. Referring to previous theoretical activity (1.2.1) you are requested to perform the given task below. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and measure the resistance of resistors using both colour coding and multi-meter then compare the results, Calculate the equivalent resistance of three resistors with 1kΩ for each, connected in series, parallel and combined connections.

2. Present out the procedures and formulas to measure and calculate resistance.
3. Referring to procedures provided on task 2, measure and calculate resistance.
4. Present your work to the trainer and whole class
5. Read key reading 1.2.1 and ask clarification where necessary
6. Perform the task provided in application of learning 1.2

Key readings 1.2.2

- **Resistance measurement**

Resistance of a resistor can be known or measured by using both ohmmeter (multimeter) and colour coding mounted on its surface.

✓ **Resistance measurement using Multimeter**

Steps to Measuring Resistance of Resistors Using a Multimeter

Step 1. Before starting any measurement, ensure that the power to the circuit is turned off.

Step 2. Turn the dial on your multimeter to the resistance measurement setting, usually indicated by the symbol Ω.

Step 3. Insert the black test lead into the COM jack (common) and the red test lead into the VΩ jack (voltage/ohms).

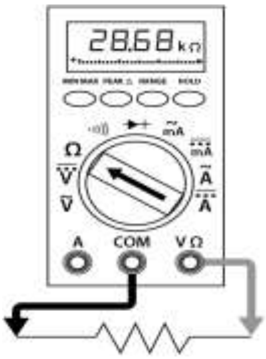
Step 4. Touch the tips of the test leads together. The display should show 0 Ω or a very small value, indicating that the leads are functioning properly. If it shows OL (over limit), check connections or replace batteries if necessary.

Step 5. Place the probes across the resistor you wish to measure.

Step 6. Observe and note down the resistance value displayed on your multimeter, this could be in ohms (Ω), kilohms (kΩ), or megaohms (MΩ).

Step 7. If you see an OL reading, switch to a higher range setting on your multimeter and repeat step 5 until you get a readable value.

Step 8. Once you have completed your measurements, turn off your multimeter to conserve battery life.



- ✓ **Resistance measurement using Color coding**

Steps of Resistance Measurement Using Color Coding:

Step1: Understand the Color Code Chart: The color code chart assigns values to each color

Step2: Identify the Resistor Orientation: Hold the resistor so that the tolerance band (usually gold or silver) is on your right side.

Step3: Note the Color Bands: Starting from the left, observe and write down the colors of all the bands in sequence.

Step4: Refer to the Color Code Chart: Use a resistor color code chart to determine what each color represents in terms of digits and multipliers.

Step5: Determine Tolerance: The last band indicates tolerance.

Step6: Final Result: Present your final result including both resistance value and tolerance range.

Example 1: 4-Band Resistor

Let's say you have a resistor with the following color bands:

- ✧ **Brown, Black, Red, Gold.**

First band (Brown): The first significant digit is 1.

Second band (Black): The second significant digit is 0.

Third band (Red): The multiplier is 10^2 = 100.

Fourth band (Gold): The tolerance is ± 5%.

Resistance Calculation:

- The significant digits are 10.
- Multiply by the multiplier 10^2: 10×100=1000 Ω
- With ± 5% tolerance, the resistance is 1000 Ω ± 5% (i.e., 950 Ω to 1050 Ω)

Example 2: 5-Band Resistor

Now, let's say you have a 5-band resistor with these color bands:

- **Yellow, Violet, Red, Orange, Brown.**

First band (Yellow): The first significant digit is 4.

Second band (Violet): The second significant digit is 7.

Third band (Red): The third significant digit is 2.

Fourth band (Orange): The multiplier is 10^3 = 1000.

Fifth band (Brown): The tolerance is ± 1%.

Resistance Calculation:

- The significant digits are 472.
- Multiply by the multiplier 10^3: 472×1000=472,000 Ωor 472 kΩ.
- With ± 1% tolerance, the resistance is 472 kΩ ± 1% (i.e., 467.28 kΩ to 476.72 kΩ).

- **Calculating the resistance of arranged resistors**
  - ✓ **Resistance of Resistors Connected in Series**

To calculate the total resistance of resistors connected in series, follow these steps:

Step1: Begin by determining the resistance values of each resistor in the series circuit.

Step2: Use the Series Resistance Formula: The total resistance (Rtotal) for resistors connected in series is calculated by simply adding the resistance values together.

Step3: Substitute the identified resistor values into the formula and perform the addition.

Step4: Clearly state your final result for total resistance.

Example1: Suppose the voltage output of the battery in Figure 2 is 12.0 V, and the resistances are $R_1 = 1.00\ \Omega$, $R_2 = 6.00\ \Omega$, and $R_3 = 13.0\ \Omega$. What is the total resistance?

Solution:

The total resistance is simply the sum of the individual resistances, as given by this equation:

Rs=R1+R2+R3

Rs=1.00 Ω+6.00 Ω+13.0 Ω=20.0 Ω

Example2: A battery with a terminal voltage of 9 V is connected to a circuit consisting of four 20Ω and one 10Ω resistors all in series.

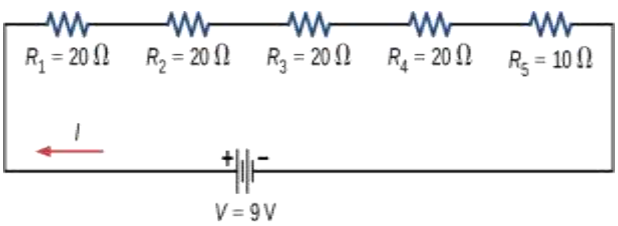
a) Draw the circuit of the scenario

b) Calculate the equivalent resistance of the circuit.

c) Calculate the current through each resistor.

Solution.

a) The circuit is drawn as below:



b) The equivalent resistance is the algebraic sum of the resistances:

RS=R1+R2+R3+R4+R5=20Ω+20Ω+20Ω+20Ω+10Ω=90Ω.

c) The current through the circuit is the same for each resistor in a series circuit and is equal to the applied voltage divided by the equivalent resistance:

$\boldsymbol{I = \frac{V}{Rs}}$=$\frac{9V}{90\Omega}$=**0.1A**

- ✓ **Resistance of Resistors Connected in Parallel**

To calculate the total resistance of resistors connected in parallel, follow these steps:

Step1: Determine the resistance values of each resistor that is connected in parallel.

Step2: Use the Parallel Resistance Formula.

Step3: Compute the reciprocal of each resistor's resistance.

Step4: Add all the calculated reciprocals together.

Step5: Finally, take the reciprocal of this sum to find the total parallel resistance.

Example: Three resistors R1=1.00Ω, R2=2.00Ω, and R3=2.00Ω, are connected in parallel. The parallel connection is attached to a V=3.00Vvoltage source.

a) What is the equivalent resistance?

b) Find the current supplied by the source to the parallel circuit.

Solution

a) The total resistance for a parallel combination of resistors is found. Entering known values gives

$\frac{1}{Rp}$=$\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}=\frac{1}{1\Omega}+\frac{1}{2\Omega}+\frac{1}{2\Omega}$ =**0.50Ω.**

The total resistance with the correct number of significant digits is Req=0.50Ω.

As predicted, RP is less than the smallest individual resistance

b) The total current can be found from Ohm's law, substituting RP for the total resistance.

This gives **I=**$\frac{V}{Req}$=$\frac{3V}{0.5\Omega}$**=6.00A.**

Current I for each device is much larger than for the same devices connected in series (see the previous example). A circuit with parallel connections has a smaller total resistance than the resistors connected in series.

The individual currents are easily calculated from Ohm's law, since each resistor gets the full voltage. Thus,

$\mathbf{I1=\frac{V}{R1}=\frac{3V}{1\Omega}=3.00A}$

Similarly,

$\mathbf{I2=\frac{V}{R2}=\frac{3V}{2\Omega}=1.50A}$

and

$\mathbf{I3=\frac{V}{R3}=\frac{3V}{2\Omega}=1.50A.}$

The total current is the sum of the individual currents:I1+I2+I3=6.00A

- ✓ **Resistance of Resistors Connected in Mixture**

When calculating the total resistance of a circuit that contains a mixture of resistors connected in series and parallel, follow these steps:

Step1: Examine the circuit diagram to determine which resistors are in series and which are in parallel.

Step2: Calculate the Resistances for resistors in series,

Step3: Calculate the Resistances for resistors in parallel,

Step4: Final Calculation by combining Series and Parallel Results,

Step5: Check your calculations by ensuring that units are consistent (ohms) and that your final result makes sense based on whether you expect it to be higher (for series) or lower (for parallel) than any individual resistor's value.

Example: Two resistors connected in series (R1, R2) are connected to two resistors that are connected in parallel (R3, R4). The series-parallel combination is connected to a battery. Each resistor has a resistance of 10.00 Ohms. The wires connecting the resistors and battery have negligible resistance. A current of 2.00 Amps runs through resistor R1.

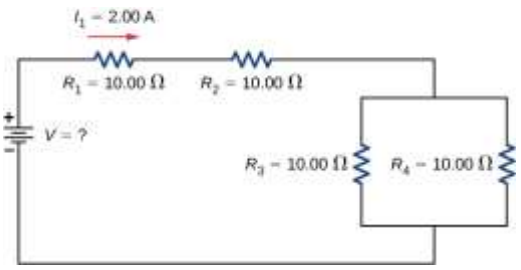
a) Draw the circuit in the scenario

b) Calculate the total resistance

c) Calculate the supply voltage of the circuit

Solution

a) The circuit in the scenario is drawn below:



b) To reduce the circuit, first consider the two resistors in parallel.

The equivalent resistance is $\frac{1}{R34}=\frac{1}{R3}+\frac{1}{R4}$

$\frac{1}{R34}=\frac{1}{10\Omega}+\frac{1}{10\Omega}$=5.00Ω.

This parallel combination is in series with the other two resistors, so the equivalent resistance of the circuit is

Req=R1+R2+R34= (5.00Ω+10.00Ω+10.00Ω=25.00Ω.

c) The voltage supplied by the battery is therefore **V=IReq=2.00A(25.00Ω)=50.00V**

Points to Remember

- "Resistor" refers to a two-terminal passive electronic component that is used to limit or regulate the flow of electric current in electrical circuits whereas Resistance is the restriction of the flow of electrons.
- There are two basics types of resistors as follows: Linear resistor and Non-linear resistor.
- Linear resistors are the resistors whose values change with change in applied temperature and voltage and are dependent on Ohm's law whereas n**on-linear resistors are t**he resistors whose values change according to the temperature and voltage applied and is not dependent on Ohm's law.

- The resistance of a resistor can be known by both measurements, color coding and digital codes.
- The Resistors in the circuit can be arranged in series, parallel and mixed connection and their resistance are calculated based the arrangement formula

Application of learning 1.2.

You're working on an electronics project, building a simple circuit that includes two resistors with 2k2 and 4k7 respectively to limit the current.

Your task is to measure the resistance of those resistors to ensure their resistances and also you'll need to calculate the correct resistance value of those resistors if arranged in parallel.

Indicative content 1.3: Description of capacitors

Duration: 6 hrs

Theoretical Activity 1.3.1: Introduction to capacitors

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of capacitors.

i. Differentiate a capacitor from capacitance
ii. Identify the types of capacitors.
iii. What are the ways capacitors can be connected together?
iv. Discuss the ways of knowing the capacitance of a capaciotor.

2: Provide the answer for the asked questions and write them on papers.

3: Discuss to the provided answers and choose the correct answers

4: Follow the trainer while providing expert view.

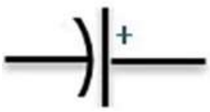
5: In addition, ask questions where's necessary.

6: For more clarification, read the key reading 1.3.1 in your manual.

Key readings 1.3.1.:

- **Definition of capacitor**

The capacitor is a passive component and it stores the electrical energy into an electrical field. It is made up of two close conductors and separated by the dielectric material. If the plates are connected to the power, then the plates accumulate the electric charge. One plate accumulates the positive charge and another plate accumulates the negative charge. The electric symbol of the capacitor is shown below.



A capacitor is a little like a battery but works completely differently. A battery is an electronic device that converts chemical energy into electrical energy, whereas a capacitor is an electronic component that stores electrostatic energy in an electric field.

- **Capacitance of capacitor**

Capacitance is the capability of a material object or device to store electric charge.

Every capacitor has a capacitance, which is its capacity to store electrical charge. The symbol for capacitance is C, which is measured in Farads. Farads are the number of coulombs that can be stored per volt:

$$1F=\frac{1C}{1V}$$

The standard unit of capacitance is the farad, abbreviated. This is a large unit; more common units are the microfarad, abbreviated as µF (1 µF $=10^{-6}$ F) and the picofarad, abbreviated as pF (1 pF = 10^{-12} F).

Capacitance can, therefore, be used to calculate the charge in coulombs:

Q=CxV

- *Q* = electric charge.
- *C* = capacitance.
- *V* = voltage.

✓ **The capacitance formula**

The capacitance is directly proportional to the surface areas of the plates, and is inversely proportional to the separation between the plates. Capacitance also depends on the dielectric constant of the substance separating the plates.

The capacitance can be calculated using the following equation:

$$C=K\frac{\varepsilon o A}{d}$$

- **C** = capacitance measured in coulombs per volt (F).
- **K** = relative dielectric constant, i.e., the dielectric constant of a material relative to the dielectric constant of free space. This is expressed as εr/ε0, where εr is the dielectric constant of the material. The relative dielectric constant is usually provided. For example, the air has a dielectric constant of 1.
- εo = epsilon nought, the dielectric constant of free space, which has a constant value of $8.85 \cdot 10^{-12}$ F/m.
- **A** = area of the plates measured in meters squared, which is directly

proportional to the plates.

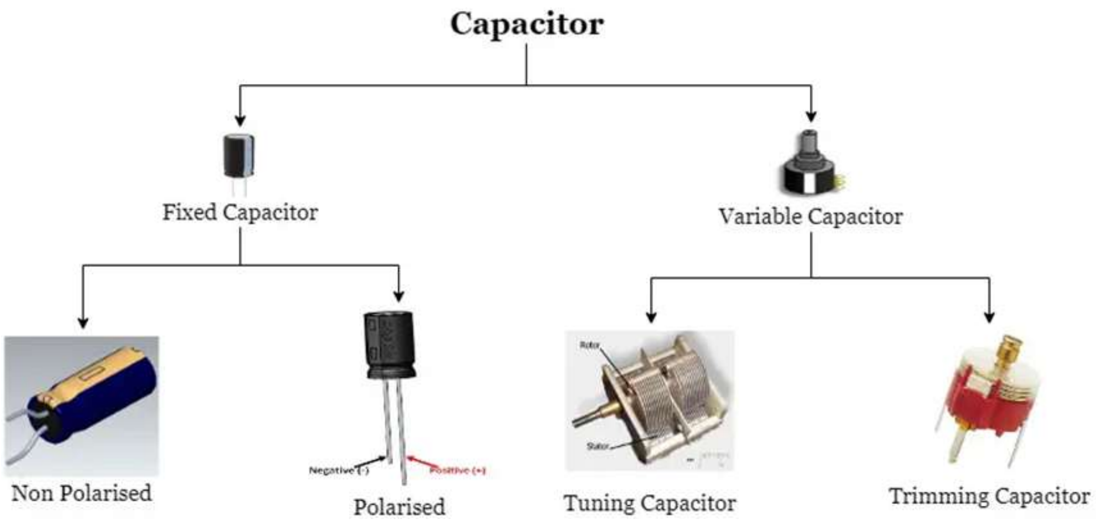
- **d** = distance between the plates measured in meters, which is inversely proportional to the capacitance.

- **Types of capacitors**

Now we will learn different types of capacitors and how they are classified. Also in this section, you can find out how these capacitors got their name we call them now.

Generally, capacitors are divided into two common groups:

- ✓ Fixed Capacitors
- ✓ Variable Capacitors



Many capacitors got their names from the dielectric used in them. But this is not true for all capacitors because some old electrolytic capacitors are named by its cathode construction.

- ✓ **Fixed Capacitors**

Fixed Capacitors are those capacitors with fixed capacitance values.

The important types of fixed capacitors are:

- **Ceramic capacitors: ceramic capacitor** is a fixed-value capacitor where the ceramic material acts as the dielectric
- **Film capacitors:** are electrical capacitors with an insulating plastic film as the dielectric, sometimes combined with paper as carrier of the electrodes.
- **Paper capacitors:** A paper capacitor stores electric charge by using paper as the dielectric.
- Aluminum, tantalum, and niobium electrolytic capacitors

- Polymer capacitors
- Super-capacitor
- Silver mica, glass, silicon, air-gap, and vacuum capacitors

Fixed capacitors include **polarized** and **non-polarized.**

Ceramic and Film capacitors are examples of **non-polarized capacitors**.

Electrolytic and Super Capacitors are included in the group of **polarized capacitors**.

✓ **Variable Capacitors**

Variable Capacitors have the variable (trimmer) or adjustable (tunable) capacitance values.

Variable capacitors include **Tuning capacitors** and **Trimming capacitors.**

- **Capacitance coding reading**

✓ **How to Read Capacitor Values?**

To use a capacitor in your electronic projects, understanding **capacitor color code** is required. For identifying the capacitor values and tolerances international color coding scheme (**electronic color coding**) was introduced. Every capacitor has colors or alphanumeric characters on the body which indicates the nominal capacitance value of the capacitor. The capacitance can range from 1pico farad to 1 farad.

- **Capacitor Color Code Table**

Here are the different colors used on the capacitor, each colour has its digit, multiplier tolerance and temperature co-efficient. The colour code chart is given below:

Color	Digit A	Digit B	Multiplier D	Tolerance T > 10pF	Tolerance T	Temperature co-efficient
Black	0	0	×1	±20%	±2.0pF	
Brown	1	1	×10	±1%	±0.1pF	-33×10-6
Red	2	2	×100	±2%	±0.25pF	-75×10-6
Orange	3	3	×1000	±3%		-150×10-6
Yellow	4	4	×10000	±4%		-220×10-6
Green	5	5	×100000	±5%	±0.5pF	-330×10-6
Blue	6	6	×1000000			-470×10-6
Violet	7	7				-750×10-6

Grey	8	8	×0.01	±80%, -20%		
White	9	9	×0.1	±10%	±1.0pF	
Gold			×0.1	±5%		
Silver			×0.01	±10%		

The following table shows the working voltage depends upon the capacitor:

Color	**Voltage Rating**				
	Type J	Type K	Type L	Type M	Type N
Black	4	100		10	10
Brown	6	200	100	1.6	
Red	10	300	250	4	35
Orange	15	400		40	
Yellow	20	500	400	6.3	6
Green	25	600		16	15
Blue	35	700	630		20
Violet	50	800			
Grey		900		25	25
White	3	1000		2.5	3
Gold		2000			
Silver					

Here:

Type J – Dipped Tantalum Capacitors,

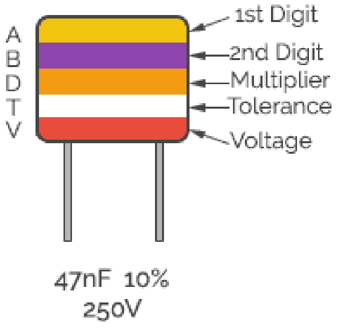
Type K – Mica Capacitors,

Type L – Polyester/Polystyrene Capacitors,

Type M – Electrolytic 4 Band Capacitors,

Type N – Electrolytic 3 Band Capacitors

Example:



In the code above A and B indicates 1st and 2nd digits and D is multiplier and T is tolerance. The last colour indicates the voltage rating.

This five-band polyester capacitor can be read as 47nF from the above colour code with 10% of tolerance and 250V working voltage.

- ✓ **Capacitor digital and Colour Code**
  - **Ceramic Disc Capacitor**

This capacitor uses ceramic as dielectric material (insulator). They are also known as multi-layer chip capacitor (MLCC) or disc capacitor. The values for ceramic disc capacitors vary from 1 nano farad to 1000 micro farad. They are mostly used in electronic circuits due to their low capacitance and resistance and better frequency response.

Its capacitance is written on its body in pF followed by handled voltage and sometimes it coded by three digits where the first and the second are digits whereas the third is the multiplier rated in PicoFarad, pF.

In **disc capacitor** or **ceramic capacitor** is shown below, there is a three-digit number written on it.

In this a 3-digit code 103 written on it. 3rd digit is a multiplier. So, we should take 1st and 2nd digit and multiply with a 3rd digit which gives the capacitance value of the particular capacitor. Here is the example, 103k= 10 x10^3 which is 10000pF or 10nF or 0.01µF.

Let's see one more example,

This capacitor has 224 written on it which gives the capacitance value of 22 x 10^4 = 220000pF or 220nF.

- **Aluminium Electrolytic Capacitor**

This type of electrolytic capacitor is made of aluminum used for power supply and switching DC circuits. The color code for this capacitor is written on the body as capacitance value and the voltage. These capacitors have low ESR values when compared with other group of capacitors.

- **Surface Mount Ceramic Capacitor**

This type of capacitor is suitable cost saving and space saving purpose. These are available from pico farads to micro farad range. The dielectric is varied for different ceramics and hence the temperature and voltage rating are also different.

Its capacitance is coded in three digits where the first and the second are the digits while the third is the multiplier rated in pF.

- **Arranging capacitors**

The variety of ways that combinations of capacitors can be made is divided into two methods. They are:

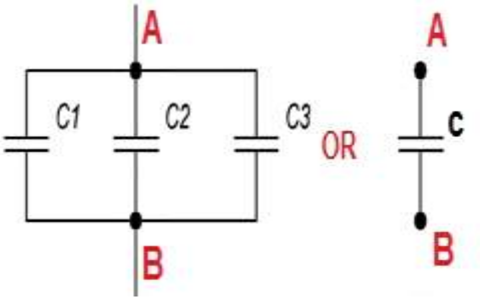
- ✓ Parallel Combination
- ✓ Series Combination
- ✓ Parallel and Series (mixed) Combination

These methods have different equivalent capacitance and we will be looking at them in detail.

✓ **Parallel Combination of Capacitors**

When the two terminals of one capacitor are connected to each terminal of another capacitor, the capacitors are said to be in a parallel combination. The voltage is the same across all the capacitors that are linked in parallel. This is the key to finding out the effective capacitance of the combination. Consider the case of three capacitors connected in a parallel combination. If each capacitor has a capacitance of C1, C2, and C3, the parallel equivalent capacitance is CP.

Figure (a) shows a parallel configuration of three capacitors, with one plate of each capacitor connected to one side of the circuit and the other plates to the other side of the circuit.



Since they are connected in parallel, they have the same voltage across their plates. But each capacitor can store different charges between their plates depending on their capacity. To find the equivalent capacitance of the combination, we first define the total charge Q stored by the combination. This is given as,

Q=Q1+Q2+Q3

Now, since we know that the voltage across all of them is the same, using the formula for capacitance, Q=CV we can write the formula for the charge of each capacitor as,

Q1=C1V,   Q2=C2V,   Q3=C3V

The total charge can be written as,

CPV=C1V+C2V+C3V

Simplifying this gives,

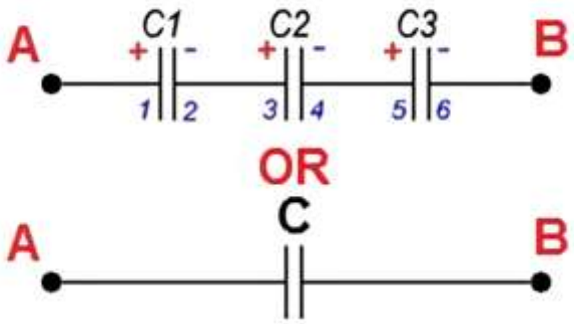
CP=C1+C2+C3

This equation can be generalized for n capacitors. The equivalent capacitance will be,

CP=C1+C2+C3+…+Cn

- ✓ **Series Combination of Capacitors**

The series combination of capacitors occurs when one terminal of a capacitor is connected to the terminal of another capacitor end to end (much like railway coaches connected one after the other). Each capacitor in a series receives the same charge. As seen in Figure (a) below, there are three capacitors in a series. Assume that each capacitance is C1, C2, and C3, respectively and that their equivalent capacitance is CS, as illustrated in Figure (b). The charge across each capacitor is the same Q because these capacitors are connected in series. The battery's potential difference V is divided into three parts: V1, V2, and V3.



The total voltage can be written as the sum of the individual voltages.

V=V1+V2+V3

We also have,

C=Q/V

We can write,

V=Q/C

Using this equation, we can write the total voltage as,

Q/CS=Q/C1+Q/C2+Q/C3

So the equivalent capacitance using the above equation can be written as,

1/CS=1/C1+1/C2+1/C3

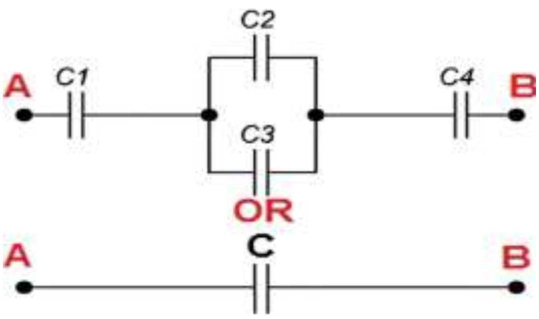
This formula can be generalized for n capacitors in a series connection. The formula will be,

1/CS=1/C1+1/C2+1/C3+…+1/Cn

✓ **Series-parallel (mixed) connection of capacitors**

A series-parallel connection of capacitors is a circuit that has sections of capacitors both in parallel and in series.

The illustration below shows an example of a mixed-capacitor circuit.



When calculating the total capacity of such a circuit section with a series-parallel connection of capacitors, this section is divided into the simplest sections consisting only of groups with series or parallel connections of capacitors. Further, the calculation algorithm is as follows:

- Determine the equivalent capacitance of the sections with a series connection of capacitors.
- If these sections contain capacitors connected in series, first calculate their capacitance.
- After calculating the equivalent capacitances of the capacitors, redraw the circuit. Usually, a circuit of equivalent capacitors connected in series is obtained.
- Calculate the capacitance of the resulting circuit.

- **Application of Capacitors**

Capacitors are essential components in various electronic and electrical systems, serving multiple purposes across different applications. Below are some of the key applications of capacitors:

- **Energy Storage in Electronic Devices:** Capacitors temporarily store electric energy, allowing electronic devices to function smoothly even during power fluctuations.
- **Power Supply in Electrical Systems:** In electrical grids, capacitors stabilize voltage and power flow.
- **Signal Processing in Communication Systems:** Capacitors play a vital role in filtering and processing electrical signals.
- **Touchscreen Technology:** Capacitors are integral to touchscreen technology

found in smartphones and tablets.

- **Motor Start and Run Capacitors:** Capacitors assist electric motors in appliances like air conditioners and refrigerators by providing a consistent voltage supply for efficient operation.
- **Pulsed Power Applications:** Large capacitor banks are utilized for pulsed power applications such as electromagnetic forming, pulsed lasers, particle accelerators, and detonators in specialty weapons.
- **Decoupling Circuits:** Decoupling capacitors protect sensitive components from noise generated by other circuit elements.

Practical Activity 1.3.2: Apply the measurement of capacitance.

Task:

1: Referring to previous theoretical activity (1.3.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and measure the capacitance of capacitors using both multi-meter, digital-coding and color-coding methods, then after calculate the equivalent capacitance of three capacitors of 1µF for each when connected in series, parallel and mixture.

2: Follow the trainer while explaining the task and providing the work instructions

3: Follow the trainer when demonstrating how to measure and calculate the capacitance of a capacitor.

4: Referring to procedures provided by the trainer in task 3, perform the given activity.

5: Present your work to the trainer and whole class

6: Read key reading 1.3.2 and ask clarification where’s necessary

Key readings 1.3.2

- **Capacitance measurement**
    - ✓ **Capacitance measurement using multi-meter**

Steps to Measuring Capacitance of Capacitors Using a Multimeter

Step1. Ensure that all power to the circuit is turned off. This is crucial for safety and to avoid damaging the multimeter or the capacitor.

Step2. Safely discharge the capacitor by connecting a resistor (preferably 20,000 Ω, 5-watt) across its terminals for about five seconds. This step is essential as capacitors can hold a charge even after power is removed.

Step3. Detach the capacitor from the circuit to ensure accurate measurements and prevent interference from other components.

Step4. Turn your digital multimeter (DMM) to the capacitance measurement mode, which is typically indicated by a symbol resembling –|(–. If your multimeter has multiple settings, select an appropriate range based on your expected capacitor value.

Step5. Attach the multimeter's test leads to the capacitor terminals.

Step6. If measuring low capacitance values, press the REL button on your multimeter while leads are open to zero out any residual capacitance from test leads.

Step7. Wait for a few seconds for the multimeter to stabilize and display a reading of capacitance in microfarads (µF). If it reads "OL" or overload, this may indicate that either the capacitor is faulty or its capacitance exceeds measurement range.

Note: Be sure that your hands do not touch the capacitor terminals. This can interfere with the measurement.

- **Reading capacitance of a capacitor using digital and color coding**
  - ✓ **Reading Small Capacitors Using Digital Codes**

When it comes to reading small capacitors, especially those that are physically compact and may not have their values printed directly on them, understanding the digital code used is essential.

Here's a step-by-step guide to help you decode the values of small capacitors.

Step 1: Identify the Code Format Small capacitors often use a three-digit code or a combination of letters and numbers to represent their capacitance value.

Step 2: Decoding Three-Digit Codes

Step 3: Understanding Letter Codes Sometimes capacitors will have letters in addition to numbers. Replace these letters with a decimal point.

Step 4: Tolerance Values Capacitors may also include tolerance codes represented by letters following the capacitance value.

Step 5: Voltage Ratings In addition to capacitance and tolerance codes, small capacitors may also have voltage ratings indicated by either numbers followed by 'V' or specific letter codes that correspond to standard voltage levels.

Example 1: Calculate the capacitance of a capacitor coded by 104

Code: 104

The first two digits are 10.

The third digit is 4, so the multiplier is 10^4 = 10,000.

Multiply the significant digits by the multiplier: 10×10,000=100,000pF

Conversion:

- 100,000 pF is equivalent to 100nF.

So, a capacitor marked "104" has a capacitance of 100,000 pF **(or 100 nF, or 0.1 µF).**

Example 2: Calculate the capacitance of a capacitor coded by 472

Code: 472

The first two digits are 47.

The third digit is 2, so the multiplier is $10^2=100$.

Multiply the significant digits by the multiplier: $47 \times 100=4700$ pF

Conversion:

- 4700 pF is equivalent to 4.7nF

So, a capacitor marked "472" has a capacitance of 4700 pF **(or 4.7 nF).**

Example 3: Calculate the capacitance of a capacitor coded by 223

Code: 223

The first two digits are 22.

The third digit is 3, so the multiplier is $10^3 = 1000$.

Multiply the significant digits by the multiplier: $22 \times 1000=22{,}000$pF

Conversion:

- 22,000 pF is equivalent to 22nF.

So, a capacitor marked "223" has a capacitance of 22,000 pF **(or 22 nF).**

✓ **Reading Small Capacitors Using Colour Codes**

When it comes to reading small capacitors, particularly ceramic or disc capacitors, understanding color codes is essential. These codes are used because the physical size of these capacitors often does not allow for extensive labeling. Here's a step-by-step guide on how to interpret these color codes effectively.

Step 1: Identify the Color Bands: Small capacitors typically have either colored bands or dots printed on their surface.

Step 2: Understand the Color Code Chart

Step 3: Determine Tolerance and Temperature Coefficient: After identifying the capacitance value from the first three bands, check for an additional band that indicates tolerance.

Example 1:

Calculate the capacitance of the capacitor having the following color bands: **Yellow, Violet, and Orange.**

First band (Yellow): The first digit is 4.

Second band (Violet): The second digit is 7.

Third band (Orange): The multiplier is 10^3 (or 1000).

Capacitance Calculation:

- Combine the significant digits: 47.
- Multiply by the multiplier: 47×10^3 = 47,000pF or 47 nF.

Thus, the capacitance is **47,000 pF** or **47 nF**.

Example 2: Calculate the capacitance of the capacitor having the following color bands: **Red, Black, Brown and Gold.**

First band (Red): The first digit is 2.

Second band (Black): The second digit is 0.

Third band (Brown): The multiplier is 10^1 (or 10).

Fourth band (Gold): Tolerance is ± 5%.

Capacitance Calculation:

- Combine the significant digits: 20.
- Multiply by the multiplier: 20×10^1=200pF.

The capacitance is **200 pF** with a tolerance of ± 5%.

- **Calculating the capacitance of arranged capacitors**
  - ✓ **Capacitance of Capacitors Connected in Series**

Steps to Calculate Capacitance of Capacitors Connected in Series

Step1: Determine the capacitance values of each capacitor connected in series.

Step2: Use the Series Capacitance Formula,

Step3: Calculate the reciprocal of each individual capacitance then dad these reciprocals together.

Step4: Finally, take the reciprocal of this sum to find CS.

Conclusion: The total capacitance for capacitors connected in series will always be less than any individual capacitor's value within that series connection.

- ✓ **Capacitance of Capacitors Connected in Parallel**

Steps to Calculate Capacitance of Capacitors Connected in Parallel

Step1: Determine the individual capacitances of all capacitors connected in parallel.

Step2: Use the Formula for Total Capacitance,

Step3: Substitute the values of each capacitor into the formula and perform the addition.

Units Check: Ensure that all capacitances are expressed in the same unit (e.g., Farads) before performing calculations to avoid discrepancies.

- ✓ **Capacitance of Capacitors Connected in Mixture**

Steps to Calculate Capacitance of Capacitors Connected in Mixture

Step1: Determine which capacitors are connected in series and which are connected in parallel. This may involve visualizing or drawing the circuit to clarify the connections.

Step2: Calculate the Capacitance for capacitors that are in series,

Step3: Calculate the Capacitance for capacitors that are in parallel,

Step4: Combine Results by adding the equivalent capacitance for a group of capacitors in series to that group is in parallel with another capacitor or group of capacitors.

Step5: If there are more groups of capacitors mixed together, repeat steps 2 through 4 until all combinations have been simplified down to a single equivalent capacitance.

Step6: Once all groups have been simplified into their respective equivalent capacitances, sum them up according to their configuration (series or parallel) to find the overall total capacitance for the entire network.

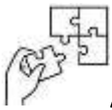
Points to Remember

- The capacitor is a passive component and it stores the electrical energy into an electrical field whereas a capacitance is the capability of a material object or device to store electric charge.
- Generally, capacitors are divided into two common groups:

  Fixed Capacitors are those capacitors with fixed capacitance values. Fixed capacitors include **polarized** and **non-polarized.**

  Variable Capacitors have the variable (trimmer) or adjustable (tunable) capacitance values. Variable capacitors include **Tuning capacitors** and **Trimming capacitors.**

- The capacitance of a capacitor is written on its body followed by handled voltage and sometimes it is coded by three digits where the first and the second are digits whereas the third is the multiplier rated in PicoFarad, pF.
- The variety of ways that combinations of capacitors can be made is divided into two methods. They are:
  - ✓ Parallel Combination When the two terminals of one capacitor are connected to each terminal of another capacitor, the capacitors are said to be in a parallel combination.
  - ✓ Series Combination when one terminal of a capacitor is connected to the terminal of another capacitor end to end
  - ✓ Parallel and Series (mixed) Combination a circuit that has sections of capacitors both in parallel and in series.



Application of learning 1.3.

You are an apprentice electronics technician working in a repair shop. Your supervisor has tasked you to apply your knowledge and skills for reading capacitor values and measuring capacitance using a multi-meter to know which one may replace others located in the computer power supply unit (PSU).

Indicative content 1.4: Description of inductors

Duration: 6 hrs

Theoretical Activity 1.4.1: Introduction to inductors

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of inductors.

i. Distinguish an inductor from inductance,

ii. Identify the types of inductors.

iii. What are the three ways inductors can be connected in a circuit?

iv. Discuss the ways of reading inductance of inductors.

2: Group representative; write them on reserved place/flip chart

3: Discuss the provided answers and choose the correct ones.

4: Follow the trainer while providing the expert view to clarify the findings.

5: In addition, ask questions where necessary.

6: For more clarification, read the key **readings 1.4.1.**

Key readings 1.4.1.:

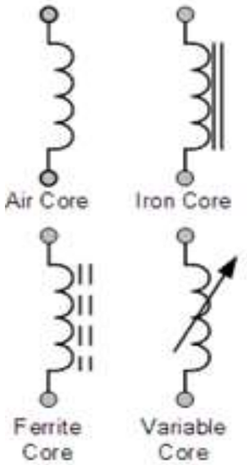
- **Description of Inductor**
  - ✓ **Definition of inductor**

An Inductor, also called a choke, is another passive type electrical component consisting of a coil of wire designed to take advantage of this relationship by inducing a magnetic field in itself or within its core as a result of the current flowing through the wire coil. Forming a wire coil into an inductor result in a much stronger magnetic field than one that would be produced by a simple coil of wire.

An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it.

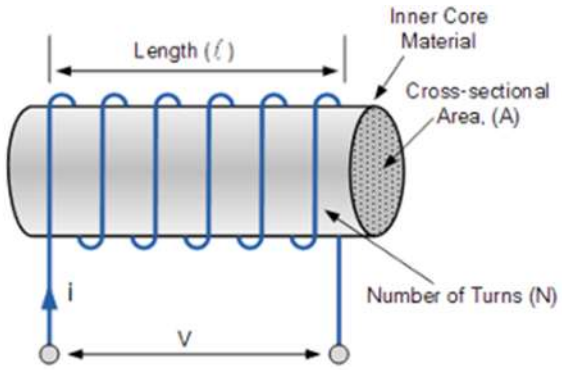
The schematic symbol for an inductor is that of a coil of wire so therefore, a coil of wire can also be called an Inductor.

Inductors usually are categorized according to the type of inner core they are wound around, for example, hollow core (free air), solid iron core or soft ferrite core with the different core types being distinguished by adding continuous or dotted parallel lines next to the wire coil as shown below:



- **Construction of an Inductor**

Inductors are formed with wire tightly wrapped around a solid central core which can be either a straight cylindrical rod or a continuous loop or ring to concentrate their magnetic flux.



- **Inductance of inductor**

Inductance is a property of an electrical conductor that causes it to resist changes in the electric current passing through it. The flow of electric current generates a magnetic field around a conductor. The field strength is proportional to the current magnitude and is unaffected by current fluctuations. According to Faraday's law of induction, any change in the magnetic field via a circuit generates an electromotive force (EMF) (voltage) in the conductors, a process is known as electromagnetic induction.

Inductance can be found in many electrical and electronic systems, as well as circuits. The gears are available in a range of shapes and sizes, as well as a variety of names. Examples include coils, chokes, transformers, inductors, and other parts. The SI unit of inductance is the Henry (H), which can be represented in the current and voltage rate of change.

- **Formula for Inductance**

Following is the inductance formula,

$$L = \mu N^2 A / l$$

Where,

L = Inductance (H),

μ = Permeability (H/m or N/(Amp^2)),

N = The coil's number of turns,

A = The coil's cross sectional area,

l = Length of coil (m).

With an inductance of L, the voltage induced in a coil (V) is equal to,

$$V = L \times (di/dt)$$

Where,

V = Voltage (volts),

L = Value of Inductance (H),

i = Current (A),

t = Time taken (s).

The inductance reactance is calculated as follows,

$$X = 2\pi f L$$

Where:

X = Reactance (ohm),

f = frequency (Hz),

L = Inductance (H).

- **Factors Affecting Inductance of inductor**

- **Length of the coil:** It is inversely proportional to the length of the coil. If the length of the coil is increased, the inductance is reduced, and vice versa.
- **Cross-sectional area of the coil:** It is directly proportional to the cross-sectional area of the coil. The higher the area of the coil, the higher the inductance.
- **Number of turns:** It is directly proportional to the number of turns square. Hence, the higher the number of turns, the higher the inductance.
- **Permeability of the core:** The permeability of the core material allows the magnetic field to form inside the core. The inductance is directly proportional to the permeability. The higher the permeability, the higher will be the inductance**.**

- **Types Of Inductors**

✓ **Air Core Inductor**

The commonly seen inductor, with a simple winding, is this Air-Core Inductor. This has nothing but air as the core material.

Uses: Air Core Inductors are used for constructing RF tuning coils. They are also used in filter circuits, snubber circuits, and high-frequency applications including TV and radio receivers.

✓ **Iron Core Inductor**

These Inductors have Ferromagnetic materials, such as ferrite or iron, as the core material. The usage of such core materials helps in the increase of inductance, due to their high magnetic permeability. These inductors have high power value but are limited in high-frequency capacity.

Uses: These Inductors are also used in the manufacture of a few types of transformers. Iron core inductors are applicable in audio equipment. When compared with other core indicators these have very limited applications.

- ✓ **Ferrite Core Inductor**

These types of inductors use ferrite cores. The ferrite core has very low electrical conductivity which reduces the eddy current in the core, resulting in very low eddy current loss at high frequency. Hence they can be used in high-frequency applications. They also offer advantages of decreased cost.

- ✓ **Iron Powder Core Inductor**

These are formed from very fine particles with insulated particles of highly pure iron powder. This type of inductor contains nearly 100% iron only. It gives us a solid-looking core when this iron power is compressed under very high pressure and mixed with a binder such as epoxy or phenolic. By this action iron powder forms like a magnetic solid structure which consists of a distributed air gap.

Due to this air gap, it is capable of storing high magnetic flux when compared with the ferrite core. This characteristic allows a higher DC level to flow through the inductor before the inductor saturates. This leads to the reduced permeability of the core.

- ✓ **Toroidal Core Inductor**

The construction of an aToroidal core inductor includes a wire wrapped around the core which has a ring or donut-shaped surface. These are generally made up of different materials like ferrite, powdered iron and tape wound, etc. This inductor has high coupling results between winding and early saturation.

Uses: These inductors are mainly used in medical devices, switching regulators, air conditioners, refrigerators, telecommunications, and musical instruments, etc.

- ✓ **Bobbin Core Inductor**

The bobbin core inductor is made of a bobbin-shaped core. It is a cylinder with two flat discs at each end. It is also known as the drum core inductor.

The coil is wrapped around the cylinder. The bobbin core does not provide a closed magnetic path; instead, the flux goes through the disc into the air gap and then enters the core through the second disc at the other end. It provides a large air gap for its magnetic field to store more energy, which increases the inductor's saturation current.

- ✓ **Multi-Layer Inductor**

As the name suggests, these inductors have multiple layers of wire wound on top of each other. Such inductors have large inductance due to an increase in the number of turns of the winding.

Uses: These types are applied at high frequencies to suppress noise, in signal processing modules like wireless LANs, Bluetooth, etc. They are also used in mobile communication systems.

- ✓ **Coupled Inductor**

Couple inductors are made of two windings around a common core. The changing magnetic flux due to the first winding induces EMF in the second winding; this phenomenon is known as mutual inductance. These both winding are electrically isolated. Thus a coupled inductor provides electrical isolation between two circuits. A Transformer is a coupled inductor.

Uses: They have multiple applications depending on their winding. 1:1 winding ratio inductors are mostly used for electrical isolation or increasing the series inductance. The winding ratio of 1: N coupled inductors (which can step up or step down voltages) are used in other energy conversion circuits such as fly back, SEPIC, ZETA, etc.

- ✓ **Variable Inductor**

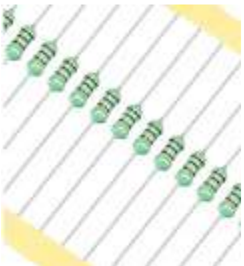
As the name suggests, these inductors are designed to have variable inductance. This variable inductor is designed in more than one possible way.

The most common design of variable inductors is having a movable ferrite core. Moving the core along the winding will increase or decrease the permeability which affects the inductance. The core can be designed to slide or screw in or out of the coil.

Uses: Variable inductors are used in radio and high-frequency applications where tuning is required. These inductors are typically ranged from 10 µH to 100 µH and in present days these are ranged from 10nH to 100 mH.

- ✓ **Colour ring inductor**

To make this type of inductor a very thin copper wire is wrapped around a dumbbell-shaped ferrite core, and two lids are connected at the top and the bottom of the dumbbell core. After that it goes through a molding process where the values are printed as colored bands, therefore, we can determine the value of the inductor just by reading the color bands and comparing them with the color code chart just like a resistor.



Uses: These types of inductors are used in the line filter, filter design, and boost converter.

- ✓ **Shielded Surface Mount Inductor**

It is built by winding a length of wire in a cylindrical bobbin and securing it in a specially made ferrite housing forms, shielded surface mount inductor.

Uses: These inductors are specially designed for PCB mounted applications and the shielding is there to reduce EMI and noise from the inductor and also to be able to use in a high-density design.

- **Inductor colour coding**

An inductor establishes a magnetic field when current passes through it. Most of the inductors are in the range of milli Henry (mH) or micro-Henry (µH).

Inductor values can be determined mainly by two ways, namely text coding and color-coding methods. Some inductors are larger in size, thus often their values are printed on their body (name plate details).

- **Inductor Value Identification using Text Marking**

In this, the value of the inductor is printed on inductor body which consists of numerical digits and alphabets. For this marking, micro-Henry is the fundamental unit of measurement (even if no units are given). The following are the steps of identifying the value of inductor by using text marking method.

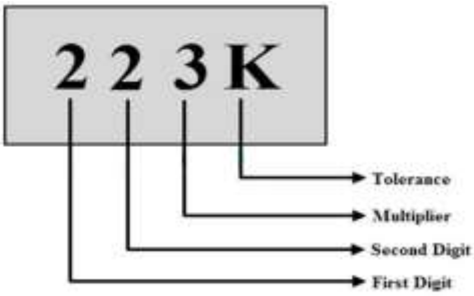
- It consists of three or four letters (including alphabets and numerical digits).
- First two digits indicate the value.
- Third digit is the power to be applied for the first two, this means it is the multiplier

and power of 10. For example, 101 is expressed as 10*101 micro-Henry (µH).

- Suffix or fourth letter or alphabet represents the tolerance value of the inductor. Suppose if this letter is K, then tolerance value is ± 10%, for J it is ± 5%, for M it is ± 20% and so on. Follow the tolerance value table given below to know each letter value.

Symbol	Tolerance
B	±0.15nH
C	±0.2nH
S	±0.3nH
D	±0.5nH
F	±1%
G	±2%
H	±3%
J	±5%
K	±10%
L	±15%
M	±20%
V	±25%
N	±30%

Example for Text Marking Method



Suppose if an inductor is labeled as 223K, find the exact value of inductor.

First two digits, i.e., 2 and 2 represent the first two digits of the inductor value. Third digit, 3 is the multiplier and hence it is 10^3 = 1000. Now, multiplying with first two digits we get 22000.

Now, it is to be noted that no units are given; hence this value is in micro-Henry (µH). Thus, the value becomes 22000 µH or 22mH.

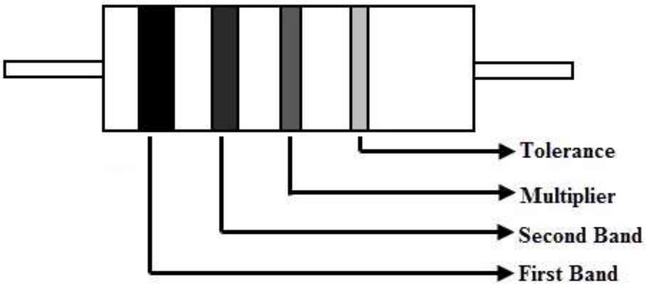
Last letter K represents the tolerance and is equal to ± 10%.

Therefore, this is a 22000 µH or 22mH inductor with ± 10% tolerance.

- ✓ **Inductor Value Identification using Colour Coding**

The color-coding system for inductors is very similar to that of resistors, especially in case of molded inductors. This color coding is in accordance with the color code table. Starting from the band closest to the one end, this color code sequence is identified. 4-band and 5-band color coding methods are described below with examples.

4-Band Inductor Color Code



The above figure shows the 4-band inductor consisting four different color bands. Similar to the number coding, first and second color bands represents the first and second digits of the value, third color band is the multiplier and fourth band is the tolerance.

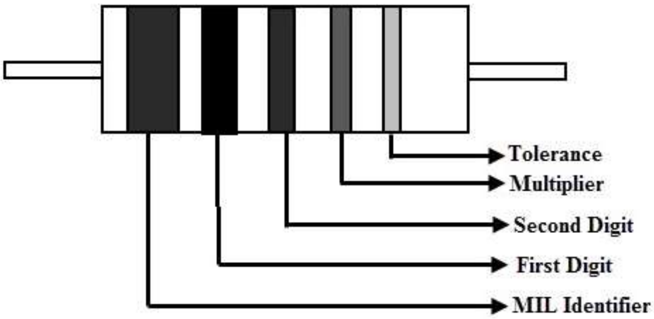
Therefore, the value of inductor can be determined by reading the colors of inductor body and comparing them with color code chart. It is to be noted that the result of this color-coded value is in the unit of micro-Henry (μH).

The table below shown gives the color corresponding to the numerical values for a four-band inductor.

Band	1	2	3	4
Meaning	1st Digit	2nd Digit	Multiplier(No of Zero)	Tolerence(%)
Gold			0.1(divide by 10)	±5%
Silver			0.01(divide by 100)	±10%
Black	0	0	×1(No of Zeros)	±20%
Brown	1	1	×10(0)	
Red	2	2	×100(00)	
Orange	3	3	×1000(000)	
Yellow	4	4	×10000(0,000)	
Green	5	5		
Blue	6	6		
Violet	7	7		
Grey	8	8		
White	9	9		

5-Band Inductor Color Code (Military Standard Inductor Color Code)

Usually, cylindrical molded inductors are marked with 5 coloured bands. In this, one end of the coil consists of a wide silver band which identifies the military radio-frequency inductors. The next three bands indicate the value of inductance in micro-Henries while 4th band indicates the tolerance.



The table below shown gives the color corresponding to the numerical values for a five-band inductor.

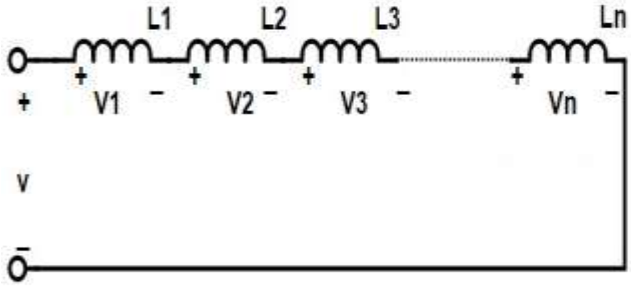
Band	1	2	3	4	5
Meaning	mil.spec	Digit or Dec point	Digit or Dec point	Multiplier(No of Zero)	Tolerence(%)
Gold		Decimal Point	Decimal point		±5%
Silver	Always silver double				±10%
Black		0	0	0 (or × 1)	±20%
Brown		1	1	(or × 10)	±1%
Red		2	2	2 (or × 100)	±2%
Orange		3	3	3 (or × 1000)	±3%
Yellow		4	4	4 (or × 10000)	±4%
Green		5	5	5	
Blue		6	6	6	
Violet		7	7	7	
Grey		8	8	8	
White		9	9	9	

These inductors consist of tolerance values from 1% to 20%. For inductance values less than 10, the second or third band is gold which represents the decimal point. Then remaining bands indicates the two significant bits, and tolerance.

For inductance values equal or more than 10, first two bands represent the significant bits, third one is multiplier and fourth one is tolerance while considering MIL band.

- **Calculation of inductance in series, parallel and mixed connection**
    - **Inductors Connected in Series**

The end-to-end connection of two or more inductors is called "series connection of inductors". In this connection the inductors are connected in series so the effective turns of the inductor increase. The series connection of the inductors is shown in below diagram:



The inductance of series connected inductors is calculated as the sum of the individual inductances of each coil since the current change through each coil is same.

This series connection is similar to that of the resistors connected in series, except the resistors are replaced by inductors. If the current I is flowing in the series connection and the coils are L1, L2, and so on, the common current in the series inductors is given by: $I_{Total} = I_{L1} = I_{L2} = I_{L3} . . . = I_n$

If the individual voltage drops across each coil in this series connection are VL1, VL2, V¬L3, and so on, the total voltage drop between the two terminals VT is given by: $V_{Total} = V_{L1} + V_{L2} + V_{L3} .... + V_n$

As we know that the voltage drop can be represented in terms of self inductance L, this implies: V = L di/ dt.

This can also be written as: LT di/dt = L1 di/dt + L2 di/dt + L3 di/dt + . . . + Ln di/dt

Therefore, the total inductance is: $L_{Total} = L_1 + L_2 + L_3 + ... + L_n$

This means the total inductance of the series connection is the sum of individual inductances of all inductors. The above equation is true when there is no mutual inductance affect between the coils in this series configuration.

The mutual inductance of the inductors will make a change in value of the total inductance in the series combination of inductors.

Assume that there are two inductors connected in series with the alternating voltage source which can generate a varying current in the circuit as shown in the above figure.

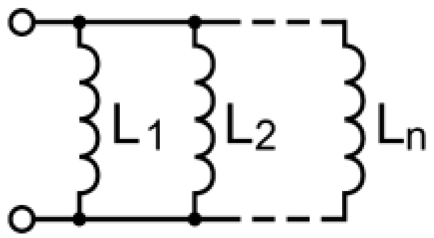
If there is no mutual inductance in the circuit, then the total inductance is given as**:**

$L_T = L_1 + L_2$

It is important to remember that the total inductance is always greater than the largest inductor in the series arrangement of inductors.

- **Inductors connected in parallel**

Inductors are said to be connected in parallel when two terminals of an inductor respectively connected to each terminal of other inductors or inductor.



We know that, in a parallel network the voltage remains constant and the current divides at each parallel inductor. If I_{L1}, I_{L2}, I_{L3} and so on I_{Ln} are the individual currents flowing in the parallel connected inductors L_1, L_2 and so on L_n, respectively, then the total current in the parallel inductors is given by

$I_{Total} = I_{L1} + I_{L2} + I_{L3} \ldots + I_n$

If the individual voltage drops in the parallel connection are V_{L1}, V_{L2}, V_{L3} and so on V_{Ln}, then the total voltage drop between the two terminals V_T is:

$V_{Total} = V_{L1} = V_{L2} = V_{L3} \ldots = V_n$

The voltage drop in terms of self inductance can be expressed as V = L di/ dt. This implies total voltage drop,

$V_T = L_T\, di/dt$

$\Rightarrow L_T\, di/dt\ (I_{L1} + I_{L2} + I_{L3} \ldots + In)$

$\Rightarrow L_T\ ((di1)/dt + (d_{i2})/dt + (di3)/dt \ldots)$

Substituting V / L in place of di/dt, the above equation becomes

$V_T = L_T\ (V/L_1 + V/L_2 + V/L3 \ldots)$

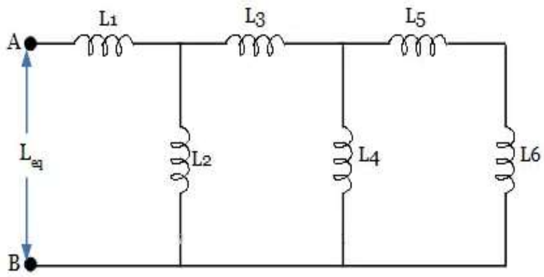
As the voltage drop is constant across the circuit, then v = V_T. So, we can write: $1/L_T = 1/L_1 + 1/L_2 + 1/L_3 \ldots$

This means that the reciprocal of total inductance of the parallel connection is the sum of reciprocals of individual inductances of all inductors. The above equation is true when there is no mutual inductance is affected between the parallel connected coils.

For avoiding complexity in dealing with fractions, we can use product over sum method to calculate the total inductance. If two inductors are connected in parallel, and if there is no mutual inductance between them, then the total inductance is given as: **$L_T = (L_1 \times L_2)/ (L_1 + L_2)$**

- **Inductors connected in mixed**

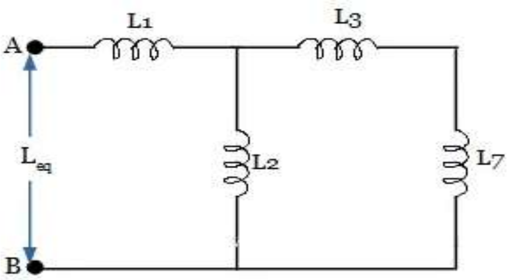
Let us solve a problem to calculate equivalent inductance of the given circuit.



In the above example, inductor L4 is in parallel with a series combination of L5 and L6. The equivalent inductance value of these three inductors L4, L5 and L6 are

L_7 $=\frac{L4*(L5+L6)}{L4+(L5+L6)}$

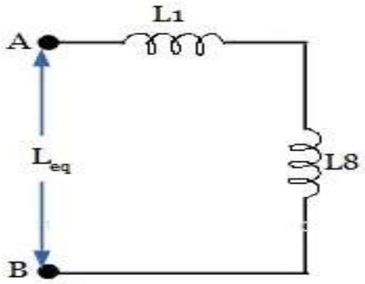
Now, the circuit get reduced as below,



If you look at the circuit, inductor L2 is in parallel with the series combination of inductors L3 and L7. The corresponding equivalent inductance value is

L_8 $=\frac{L2*(L3+L7)}{L2+(L3+L7)}$

Again the circuit is reduced as below,



In the reduced circuit, the inductors L1 and L8 are in series.

Thus, the equivalent inductance is given by,

$$Leq = L1 + L8$$

- **Uses and Applications**
  - ✓ To slow down current surges by temporarily storing electrical energy in an electromagnetic field and releasing it into the circuit
  - ✓ To choke or block high-frequency noise in an electric circuit
  - ✓ For storing and transferring energy in power converters, like dc-to-dc or ac-to-dc
  - ✓ For selecting the desired frequency in a tuned circuit like an LC circuit
  - ✓ To match the impedance of a power source to the impedance of an electrical load, known as impedance matching
  - ✓ To amplify the current in a proximity sense

Practical Activity 1.4.2: Apply the measurement and calculation of inductance

Task:

1: Referring to previous activity (1.4.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and measure the inductance of inductors using both LCR and color-coding, then after calculate the inductance four inductors marked with 2mH each when connected in series, parallel and mixed.

2: Follow the trainer while explaining the activity and providing related instructions.

3: Follow the trainer when demonstrating how to measure and calculate the inductance of the inductor.

4: Measure and calculate the inductance of the given inductors.

5: Read key reading 1.4.2 and ask clarification where's necessary

6: Perform the task provided in application of learning 1.4.

Key readings 1.4.2

- **Inductance measurement**
- **Inductance measurement using an LCR**

Key Considerations: Multi-meters cannot be used to measure inductance. They don't have the ability, but fortunately, we can use a handheld LCR meters.

Steps to Measuring Inductance of Inductors Using an LCR Meter

Step1. Power the LCR Meter: Turn on the LCR meter and allow it to initialize.

Step2. Set the Meter to Measure Inductance: Adjust the settings on the LCR meter to select the inductance measurement mode, usually indicated by "L" on the display or dial.

Step3. Choose the Appropriate Test Frequency: Set the test frequency on the LCR meter, typically around 100 kHz at 1 volt for most inductors.

Step4. Connect the Leads to the Inductor: Attach the red lead of the LCR meter to one terminal of the inductor and the black lead to the other terminal.

Step5. Read and Record the Measurement: Observe and record the inductance value displayed on the screen of the LCR meter, which will be shown in microhenries (uH) or millihenries (mH).

Step6. Disconnect and Power Off: After taking your measurement, disconnect the leads from the inductor and turn off the LCR meter if you are finished using it.

- **Calculating the inductance of connected inductors**
  - ✓ **Inductance of Inductors Connected in Series**

Steps to Calculate Inductance of Inductors Connected in Series

Calculating the total inductance of inductors connected in series involves a straightforward process. Here are the detailed steps:

Step1: Identify the Inductors: Determine the individual inductances of all inductors that are connected in series.

Step2: Write Down the Formula: The formula for calculating the total inductance Ltotal when inductors are connected in series is: Ltotal=L1+L2+L3+…+Ln

Step3: Perform the Calculation: Substitute the values of each individual inductor into the formula and perform the addition.

- ✓ **Inductance of Inductors Connected in Parallel**

Steps to Calculate Inductance of Inductors Connected in Parallel

Calculating the total inductance of inductors connected in parallel involves a systematic approach. Here are the steps to follow:

Step 1: Understand the Configuration: Recognize that inductors are in parallel when both terminals of each inductor are connected to the same two points, allowing them to share the same voltage.

Step 2: Identify Individual Inductance Values: Note down the inductance values of each individual inductor.

Step 3: Use the Formula for Parallel Inductors: Apply the formula for calculating total inductance (LTotal) when inductors are connected in parallel: 1/LTotal=1/L1+1/L2+1/L3+⋯

Step 4: Calculate the Reciprocals: For each individual inductor, calculate the reciprocal of its inductance value.

Step 5: Sum the Reciprocals: Add all these reciprocal values together: S=1/L1+1/L2+1/L3

Step 6: Take the Reciprocal of the Sum: Finally, take the reciprocal of this sum to find the total inductance: LTotal=1/S

- ✓ **Inductance of Inductors Connected in Mixture**

Steps to Calculate Inductance of Inductors Connected in Mixture

When inductors are connected in a mixture of series and parallel configurations, calculating the total inductance requires a systematic approach. Here are the steps to follow:

Step1. Identify the Configuration: First, determine how the inductors are connected. Some may be in series while others are in parallel.

Step2. Calculate Series Inductance: For inductors that are connected in series, the total inductance Leq is simply the sum of all individual inductances: Leq(series)=L1+L2+L3+...+Ln

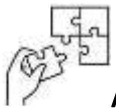
Step3. Calculate Parallel Inductance: For inductors that are connected in parallel, the total or equivalent inductance Leq can be calculated using the reciprocal formula:1/Leq(parallel)=1/L1+1/L2+1/L3+...+1/Ln

Step5. Combine Results: Once you have calculated both series and parallel combinations separately, combine these results based on their configuration within the overall circuit. If some groups are in series and others in parallel, treat them accordingly using steps 2 and 3.

Step6. Final Calculation: After determining all necessary equivalent values from both configurations, finalize your calculations by combining them into a single total equivalent inductance for the entire circuit.

Points to Remember

- An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it whereas Inductance is a property of an electrical conductor that causes it to resist changes in the electric current passing through it.
- Inductors are available with air, ferrite and iron cores.
- The end-to-end connection of two or more inductors is called “series connection of inductors”.
- Inductors are said to be connected in parallel when two terminals of an inductor respectively connected to each terminal of other inductors or inductor.
- Inductor values can be determined mainly by two ways, namely text coding and color-coding methods.



Application of learning 1.4.

You are working as an electronics technician in a company that manufactures power supplies. Your supervisor has asked you to measure the inductance values of several inductors used in a new power supply design.

Demonstrate your ability to read inductance values from inductor markings and measure inductance using a multimeter.

Learning outcome 1 end assessment

Theoretical assessment

Instructions: Attempt all provided questions below:

Q1. Capacitors are ________________ devices.

a) Polarity Devices b) Non-Polarity c)both a and b

Q2. Resistor is an _________________ component or device.

a) Active b) Passive

Q3. The two main characteristics of a resistor are _______________.

a) Resistance and Power b) Current and Power

c) Current and Voltage d) Resistance and Current

Q4. What is the maximum resistance which can be made using five resistors each of $1/5\Omega$ when connected in series?

a) $1/5\Omega$ b) 10Ω c) 5Ω d) 1Ω

Q5. A 100KΩ ± 10% resistor will have the color code:

(a) black, brown, yellow, silver (b) brown, green, black, gold

(c) brown, black, yellow, gold (d) brown, black, yellow, silver

Q6. A resistor's first three color bands are brown, black, and red. What is its value?

a) 10 ohms b) 10K ohms c) 200 ohms d) 1000 ohms

Q7. An electrical component that we use in electronics circuits to limit current though an active component or to reduce voltage in the circuit.

a) Capacitor b) Current c) Resistor d) Ancestor

Q8. What is the value of the capacitor if n27 is written on it?

a) 0.27 nF b) 0.27 pF c) 27 nF d) 27 pF

Q9. Capacitor is a device used to__________

a) store electrical energy b) vary the resistance

c) store magnetic energy d) dissipate energy

Q10. Paper capacitor is a type of _________

a) Fixed capacitor d) Neither fixed nor variable

b) Variable capacitor c) Either fixed or variable depending on its usage

Q11. A capacitor using chemical reactions to store charge is _______

a) Paper capacitor b) Ceramic capacitor

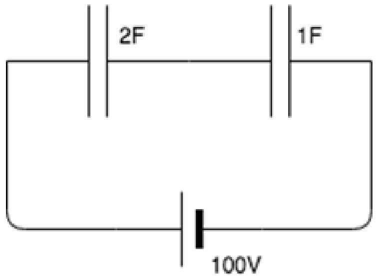
c) Polyester capacitor d) Electrolyte capacitor

Q12. When capacitors are connected in series ___________ remains the same.

a) Voltage across each capacitor b) Charge

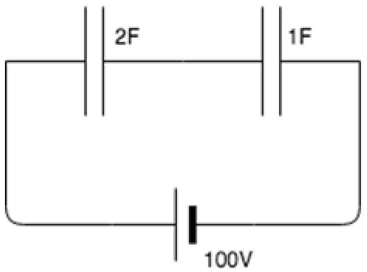
c) Capacitance d) Resistance

Q13. Calculate the charge in the circuit.



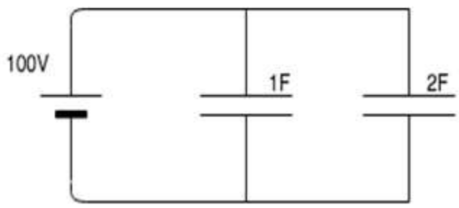
a) 66.67C b) 20.34C c) 25.45C d) 30.45C

Q14. Calculate the voltage across the 1F capacitor.



a) 33.33V b) 66.67V c) 56.56V d) 23.43V

Q15. Calculate the charge in the 1F capacitor.



a) 200C b) 100C c) 300C d) 400C

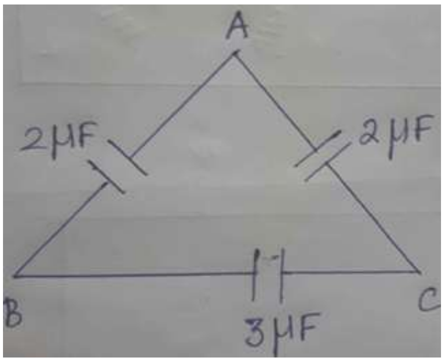
Q16. When capacitors are connected in parallel, the total capacitance is always __________ the individual capacitance values.

a) Greater than b) Less than c) Equal to d) Cannot be determined

Q17. Two capacitors having capacitance value 4F, three capacitors having capacitance value 2F and 5 capacitors having capacitance value 1F are connected in parallel, calculate the equivalent capacitance.

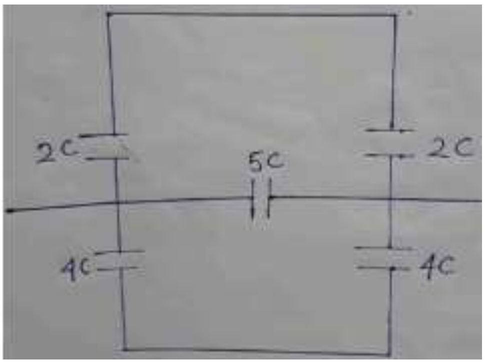
a) 20F b) 19F c) 18F d) 17F

Q18. Three capacitors are connected in the shape of a triangle ABC as shown below. A voltage of 4V is applied between B and C. Calculate the voltage between A and C.



a) 2V b) 3V c) 4V d) 5V

Q19. Find the equivalent capacitance of the combination shown below.



a) 7F b) 5F c) 6F d) 8F

Q20. Two inductors, each of 6.8 mH, are connected in parallel. The inductance of the combination will be:

(a) 3.4 mH (b) 6.8 mH (c) 13.6 mH

Q21. A 100 nF capacitor has a tolerance of ±5%. The maximum possible value for this component will be:

(a) 95 nF (b) 105 nF (c) 110 nF

Q22. An inductor of 100 mH has a tolerance of ±20%. The maximum possible value for this component will be:

(a) 80 mH (b) 110 mH (c) 120 mH

Q23. The resistance of a light dependent resistor:

(a) Falls with increasing light level (b) increases with increasing light level

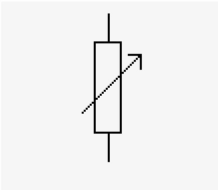
(C) remains constant irrespective of light level

Q24. If the resistance of a material falls with increasing temperature it is said to have:

(a) Negative temperature coefficient (b) positive temperature coefficient

(c) Zero temperature coefficients

Q25. The circuit symbol shown is a:



(a) Fixed resistor (b) preset resistor (c) variable resistor

Q26. LDR stands for ____?

a) Light Dependent Resistor b) Light Divide Resistor

c) Light Dive Resistor d) Both a and b

Practical assessment

You are hired by HAKATON Electronics Company that manufactures computer power supply Units.

Your supervisor has asked you to measure the resistance, capacitance and inductance values of several resistors, capacitors and inductors used in a new power supply design to ensure their rating specifications before use. Demonstrate your ability to read and measure inductance these quantities.

END

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For more information, search on the following sites:

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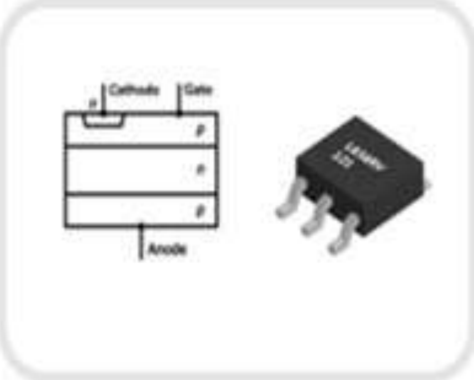
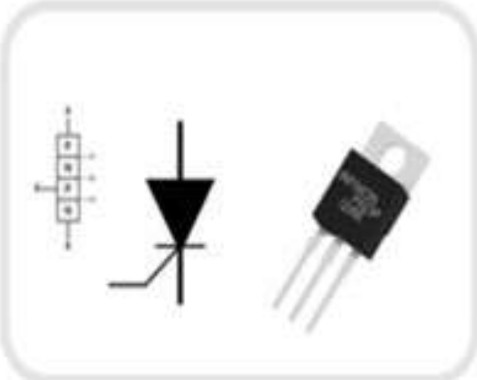
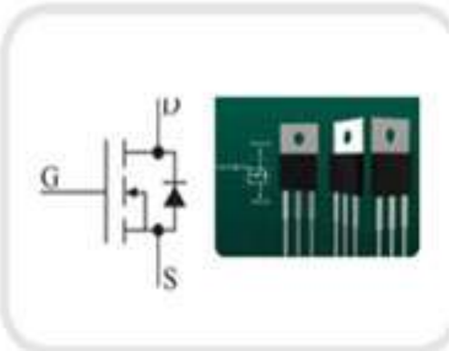

Cathode
Gate
Anode

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Indicative contents
2.1 Introduction to semiconductor devices **2.2 Description of diodes** **2.3 Description of transistors** **2.4 Description of thyristors** **2.5 Description of optoelectronic components** **2.6 Description of integrated circuits (IC)**

Key Competencies for Learning Outcome 2: Description of Active components

Knowledge	Skills	Attitudes
• Description of semiconductor Devices • Description of types of active components • Description of ICs • Description of Optoelectronic Components	• Testing active components • Applying the use of active components	• Having innovative mindset • Being a Critical thinker • Being a team player

Duration: 25 hrs

Learning outcome 2 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe clearly semiconductor devices in accordance with their types
2. Describe clearly active components in accordance with their types and features, and working principle
3. Describe properly analog Integrated Circuits according to their types and applications

4. Test properly active components based on their testing techniques

5. Implement properly active components circuits according to their application.

Resources

Equipment	**Tools**	**Materials**
• Multimeter, • Computer, • projector	• Breadboard or PCB, • Soldering iron, • Desoldering pump, • Toolbox set	• Diodes, • transistors, • thyristors, • optoelectronic components, • integrated circuits

Indicative content 2.1: Introduction to semi-conducteur devises

Duration: 2 hrs

Theoretical Activity 2.1.1: Description of semi-conductor devices

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of semiconductor devices.

i. What is semiconductor?

ii. Identify the types of semiconductor.

iii. What are the applications of semiconductor?

2: Provide the answer for the asked questions and write them on papers.

3: Discuss the findings/answers and choose the correct answers

4: Follow the trainer when providing expert view.

5: In addition, ask questions where necessary

6: For more clarification, read the key readings 2.1.1.

Key readings 2.1.1.:

- **Introduction to Semiconductor**

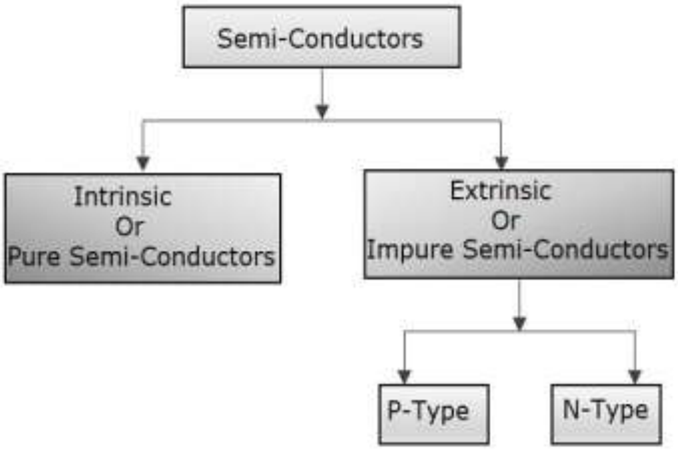
A **semiconductor** is a substance whose resistivity lies between the conductors and insulators. The property of resistivity is not the only one that decides a material as a semiconductor, but it has few properties as follows.

- ✓ Semiconductors have the resistivity which is less than insulators and more than conductors.
- ✓ Semiconductors have negative temperature co-efficient. The resistance in semiconductors increases with the decrease in temperature and vice versa.
- ✓ The Conducting properties of a Semiconductor change, when a suitable metallic impurity is added to it, which is a very important property.

- ✓ Semiconductor devices are extensively used in the field of electronics.

- **Types of Semiconductor**

The following illustration shows the classification of semiconductors.



✓ **Intrinsic Semiconductors**

A Semiconductor in its extremely pure form is said to be an **intrinsic semiconductor**. The properties of this pure semiconductor are as follows −

- The electrons and holes are solely created by thermal excitation.
- The number of free electrons is equal to the number of holes.
- The conduction capability is small at room temperature.

In order to increase the conduction capability of intrinsic semiconductor, it is better to add some impurities. This process of adding impurities is called as **Doping**. Now, this doped intrinsic semiconductor is called as an Extrinsic Semiconductor.

✓ **Doping**

The process of adding impurities to the semiconductor materials is termed as doping. The impurities added, are generally pentavalent and trivalent impurities.

Pentavalent Impurities

- The **pentavalent** impurities are the ones which has five valence electrons in the outer most orbits. Example: Bismuth, Antimony, Arsenic, Phosphorus
- The pentavalent atom is called as a **donor atom** because it donates one electron to the conduction band of pure semiconductor atom.

Trivalent Impurities

- The **trivalent** impurities are the ones which has three valence electrons in the outer most orbits. Example: Gallium, Indium, Aluminum, Boron
- The trivalent atom is called as an **acceptor atom** because it accepts one electron from the semiconductor atom.

✓ **Extrinsic Semiconductor**

An impure semiconductor, which is formed by doping a pure semiconductor, is called as an **extrinsic semiconductor**. There are two types of extrinsic semiconductors depending upon the type of impurity added. They are N-type extrinsic semiconductor and P-Type extrinsic semiconductor.

✓ **N-Type Extrinsic Semiconductor**

A small amount of pentavalent impurity is added to a pure semiconductor to result in N-type extrinsic semiconductor. The added impurity has 5 valence electrons.

For example, if Arsenic atom is added to the germanium atom, four of the valence electrons get attached with the Ge atoms while one electron remains as a free electron.

All of these free electrons constitute electron current. Hence, the impurity when added to pure semiconductor provides electrons for conduction.

- In N-type extrinsic semiconductor, as the conduction takes place through electrons, the electrons are majority carriers and the holes are minority carriers.
- As there is no addition of positive or negative charges, the electrons are electrically neutral.
- When an electric field is applied to an N-type semiconductor, to which a pentavalent impurity is added, the free electrons travel towards positive electrode. This is called as negative or N-type conductivity.

✓ **P-Type Extrinsic Semiconductor**

A small amount of trivalent impurity is added to a pure semiconductor to result in P-type extrinsic semiconductor. The added impurity has 3 valence electrons. For example, if Boron atom is added to the germanium atom, three of the valence electrons get attached with the Ge atoms, to form three covalent bonds. But, one more electron in germanium remains without forming any bond. As there is no electron in boron remaining to form a covalent bond, the space is treated as a hole.

The boron impurity when added in a small amount provides a number of holes which helps in the conduction. All of these holes constitute hole current.

- In P-type extrinsic semiconductor, as the conduction takes place through holes, the holes are majority carriers while the electrons are minority carriers.
- The impurity added here provides holes which are called as **acceptors**, because they accept electrons from the germanium atoms.
- As the number of mobile holes remains equal to the number of acceptors, the P-type semiconductor remains electrically neutral.
- When an electric field is applied to a P-type semiconductor, to which a trivalent impurity is added, the holes travel towards negative electrode, but with a slow pace than electrons. This is called as P-type conductivity.
- In this P-type conductivity, the valence electrons move from one covalent bond to another, unlike N-type.

- **Why Silicon is Preferred in Semiconductors?**

Among the semiconductor materials like germanium and silicon, the extensively used material for manufacturing various electronic components is **Silicon**. Silicon is preferred over germanium for many reasons such as −

- The energy band gap is 0.7ev, whereas it is 0.2ev for germanium.
- The thermal pair generation is smaller.
- The formation of SiO2 layer is easy for silicon, which helps in the manufacture of many components along with integration technology.
- Si is easily found in nature than Ge.
- Noise is less in components made up of Si than in Ge.

- **Semiconductor applications in Everyday Life**

Semiconductors are used in almost every sector of electronics.

- ✓ Temperature sensors are made with semiconductor devices.

- ✓ They are used in 3D printing machines
- ✓ Used in microchips and self-driving cars
- ✓ Used in calculators, solar plates, computers and other electronic devices.
- ✓ Transistors and MOSFET used as a switch in electrical circuits are manufactured using semiconductors.
- ✓ **Consumer electronics:** Mobile phones, laptops, games consoles, microwaves and refrigerators all operate with the use of semiconductor components such as integrated chips, diodes and transistors.
- ✓ **Embedded systems:** Embedded systems are small computers that form part of a larger machine.
- ✓ **Thermal conductivity:** Some semiconductors have high thermal conductivity, so can be used as a cooling agent in certain thermoelectric applications.
- ✓ **Lighting and LED displays:** Some semiconductors, usually those available in liquid or amorphous form as a thin-coated film, can produce light and are used in LEDs and OLEDs.
- ✓ **Solar cells:** Silicon is also the most commonly used semiconductor in the production of solar panel cells.

Points to Remember

- A **semiconductor** is a substance whose resistivity lies between the conductors and insulators.
- A Semiconductor in its extremely pure form is said to be an **intrinsic semiconductor**.
- An impure semiconductor, which is formed by doping a pure semiconductor, is called as an **extrinsic semiconductor**. There are two types of extrinsic semiconductors depending upon the type of impurity added. They are N-type extrinsic semiconductor and P-Type extrinsic semiconductor.
- Semiconductors are used in almost every sector of electronics.

- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.

Application of learning 2.1.

As a hobbyist electronician, visit the electronic repairer centre to ask about the active electronic components construction for understand the basic principles and functions of various semiconductor components, through hands-on activities.

Indicative content 2.2: Description of diodes

Duration: 5 hrs

Theoretical Activity 2.2.1: Introduction to diodes

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of a diode.

i. What is a diode?

ii. Identify the types of diode.

iii. What are the applications of diode?

2: Provide the answer for the asked questions and write them on papers.

3: Discuss the findings/answers and choose the correct answers

4: Follow the trainer when providing expert view.

5: For more clarification, read the key readings 2.2.1 and ask questions where necessary

Key readings 2.2.1.:

- **Definition of a diode**

A **diode** is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.

A diode is an electronic device having a two-terminal unidirectional power supply i.e it has two terminals and allows the current to flow only in one direction.

Diodes have polarity, determined by an **anode** (positive lead) and **cathode** (negative lead). Most diodes allow current to flow only when positive voltage is applied to the anode.

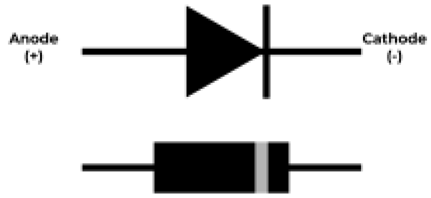


Figure: Symbol and overview of the Diode

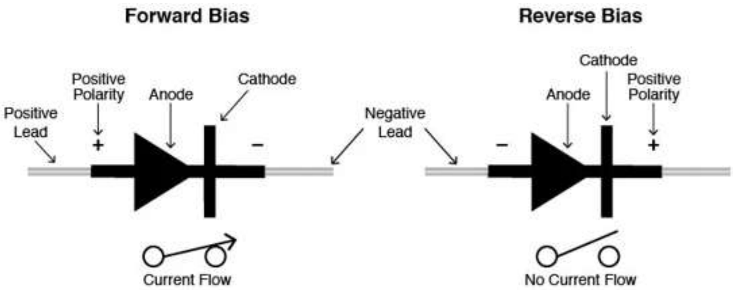
A variety of diode configurations are displayed in this graphic:

Figure: Diodes are available in various configurations. From left: metal case, stud mount, plastic case with band, plastic case with chamfer, glass case.

- **Working principle of diodes**

In the N-type region, the majority of charge carriers are electrons and the minorities of charge carriers are holes. Whereas, In the P-type region, the majority of charge carriers are holes and the minority of charge carriers are electrons.

- ✓ When the anode or p-type terminal of the diode is connected with a negative terminal and the n-type or cathode is connected with the positive terminal of a battery, this type of connection is called a **Reverse Bias condition.**
- ✓ When the anode or p-type terminal of the diode is connected with a positive terminal and the n-type or cathode is connected with the negative terminal of the battery, this type of connection is called a **Forward Bias condition.**



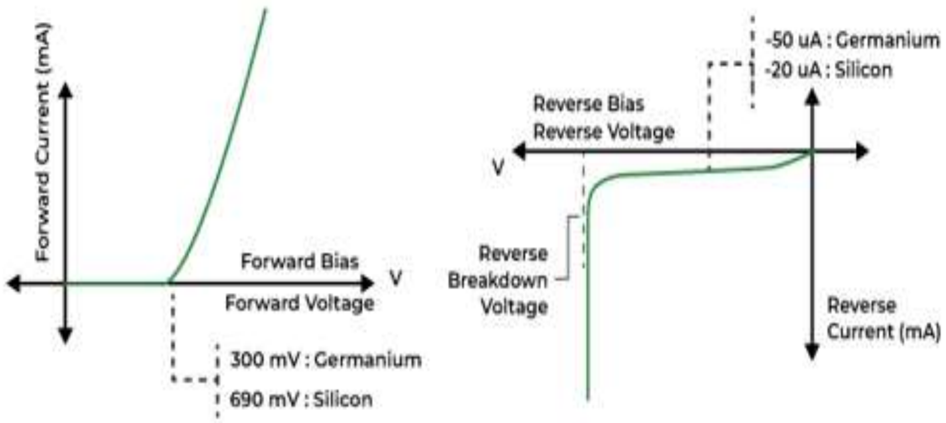
In the above diagram, we can see that there are two terminals that are known as anode and cathode. The arrowhead is the anode that represents the direction of the conventional current flow in the forward biased condition. The other end is the cathode.

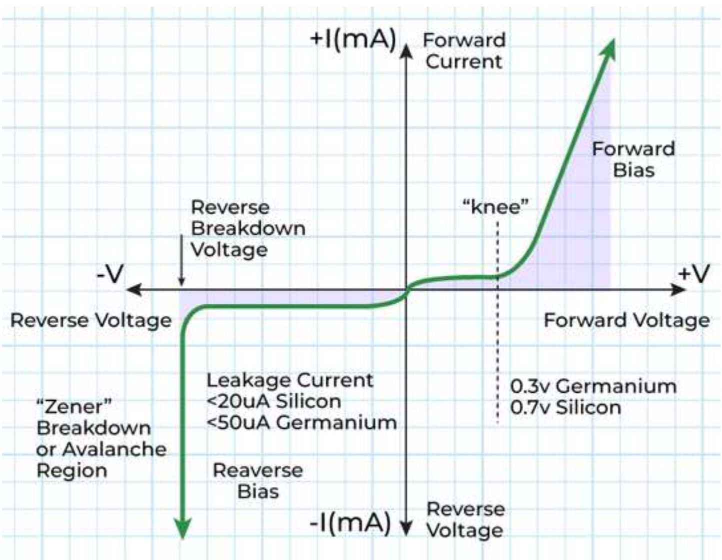
- **Characteristics of Diode**

The characteristics of the diode can easily be understood under the following three headings and they are discussed earlier.

- ✓ Forward-Biased Diode
- ✓ Reverse-Biased Diode
- ✓ Zero Biased Diode or Unbiased Diode

The V-I characteristic of a diode in forward and reverse-biased conditions are,





- **The types of diodes**
  - ✓ **Types of Diodes are named below:**

- Light Emitting Diode
- Laser diode
- Avalanche diode
- Zener diode
- Photodiode
- PN junction diode

- **Light Emitting Diode (LED)**

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current flows through it. When current passes through an LED, the electrons recombine with holes emitting light in the process. LEDs allow the current to flow in the forward direction and block the current in the reverse direction.

LED Symbol

The LED symbol is the standard symbol for a diode, with the addition of two small arrows denoting the emission of light.

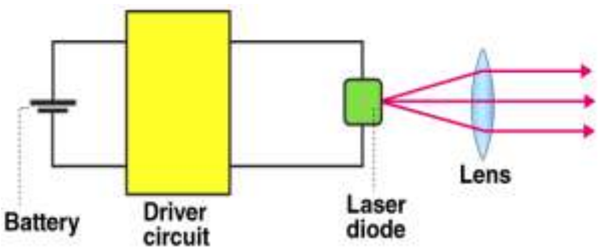
✓ **Uses of LED**

LEDs find applications in various fields, including optical communication, alarm and security systems, remote-controlled operations, robotics, etc. It finds usage in many areas because of its long-lasting capability, low power requirements, swift response time, and fast switching capabilities.

- **Laser Diode**

A laser diode is a semiconductor that uses a p-n junction for producing coherent radiation with the same frequency and phase which is either in the visible or infrared spectrum. It is also called an injection laser diode and the technology is similar to that found in LEDs.

It is a different type of diode as it produces coherent light. It is highly used in CD drives, DVDs and laser devices. These are costly when compared to LEDs and are cheaper when compared to other laser generators. Limited life is the only drawback of these diodes.



✓ **Applications of Laser Diode**

The following are the applications of laser diodes:

- **Consumer electronics:** This includes laser printers, CDs and DVD players, and fiber optic communication.
- **Industrial applications:** When it comes to industrial applications, laser diode is preferred as it is a source of a high-intensity laser beam and used for cutting, drilling, welding, etc.
- **Medical applications:** Laser diodes are used for the elimination of unwanted tissues and tumours and also in dental medication.

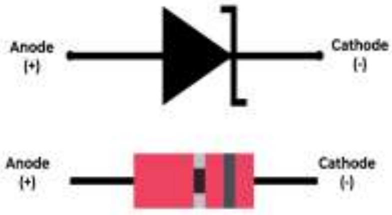
- **Zener Diode**

Zener diode that is also known as a breakdown diode is a heavily doped semiconductor device that has been specially designed to operate in the reverse direction. When the potential reaches the Zener voltage which is also known as Knee voltage and the voltage across the terminal of the Zener diode is reversed, at that point time, the junction breaks down and the current starts flowing in the reverse direction.

This effect is known as the **Zener effect**.

✓ **Zener Diode Circuit Diagram**

The figure given below is the circuit diagram of the Zener diode. The Zener diode has applications in various electronic devices and it works in reverse biasing conditions.



Zener diode can provide a stable reference voltage. These diodes can be operated in reverse biased and break down at a certain voltage. These diodes are mostly used in power supplies to provide a reference voltage.

In the forward biased condition, it allows current and in the reverse bias, it blocks the current. After this voltage has suppresses the breakdown point (in reverse bias), the diode falls in the Zener region, where it conducts without getting damaged. Current in this region is called avalanche current.

It is the most useful type of diode as it can provide a stable reference voltage. These are operated in reverse bias and break down on the arrival of a certain voltage. If current passing through the resistor is limited, a stable voltage is generated. Zener diodes are widely used in power supplies to provide a reference voltage.

- ✓ **Zener Diode Working**

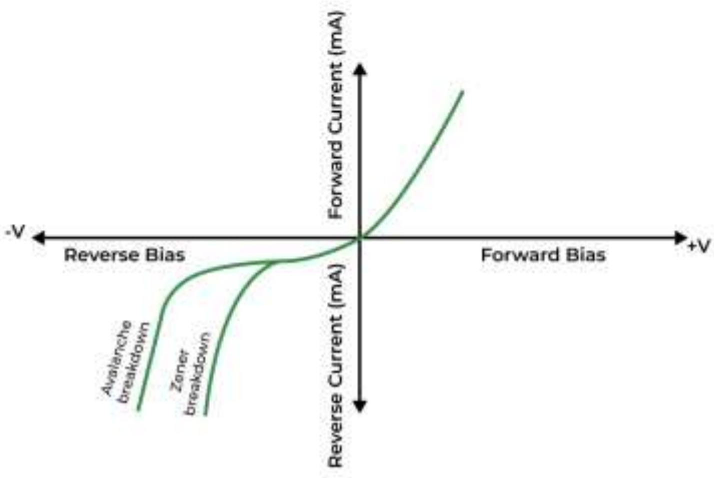
High-level impurities are added to a Zener diode to make it more conductive and thus the Zener diodes can easily conduct electricity compared to other p-n junction diodes. These impurities reduce the depletion layer of the Zener diode and make it very thin. Thus, this diode also works even if the voltage applied is very small.

In no biasing condition of the Zener diode, all the electrons accumulate in the valence band of the p-type semiconductor material and thus no current flow occurs through the diode.

In reverse bias conditions, if the Zener voltage is equal to the supplied voltage, the diode conducts electricity in the direction of reverse bias. When the Zener voltage equals the supplied voltage the depletion layer vanishes completely.

✓ **VI Characteristics of Zener Diode**

The graph given underneath shows the V-I characteristics of the Zener diode.



-I characteristics of a Zener Diode can be studied under the following two headings,

Forward Characteristics of Zener Diode

Forward characteristics of the Zener Diode are similar to the forward characteristics of any normal diode. It is clearly evident from the above diagram in the first quadrant that the VI forward characteristics are similar to other P-N junction diodes.

Reverse Characteristics of Zener Diode

In reverse voltage conditions a small amount of current flows through the Zener diode. This current is because of the electrons which are thermally generated in the Zener diode. As we keep increasing the reverse voltage at any particular value of reverse voltage the reverse current increases suddenly at the breakdown point this voltage is called Zener Voltage and is represented as V_z.

- **Applications of Zener Diode**

Zener diode is a very useful diode. Due to its ability to allow current to flow in reverse bias conditions, it is used widely for various purposes. Some of the common uses of Zener Diode are discussed below:

✓ Zener diode as Voltage Regulator

✓ Zener Diode in Over-Voltage Protection

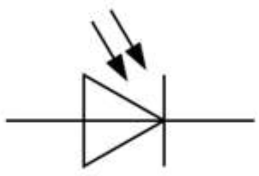
✓ Zener Diode in Clipping Circuits

- **Photodiode**

A photodiode is a PN-junction diode that consumes light energy to produce an electric current. They are also called a photo-detector, a light detector, and a photo-sensor. Photodiodes are designed to work in reverse bias condition. Typical photodiode materials are Silicon, Germanium and Indium gallium arsenide.

✓ **Symbol of Photodiode**

The following image shows the symbol of the photodiode:



The symbol of the photodiode is similar to that of an LED, but here the arrow points inwards.

✓ **Applications of Photodiode**

- Photodiodes with the help of optocouplers provide electric isolation.
- Photodiodes are used in safety electronics such as fire and smoke detectors.
- Photodiodes are used in solar cell panels.
- Photodiodes are used in logic circuits.
- Photodiodes are used in the detection circuits.

- **P-N Junction Diode**

✓ **Definition**

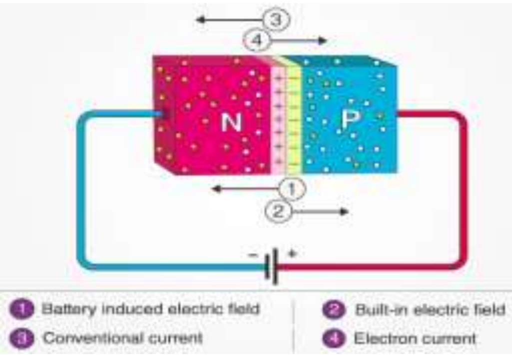
A P-N junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.

✓ **Biasing Conditions for the P-N Junction Diode**

There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:

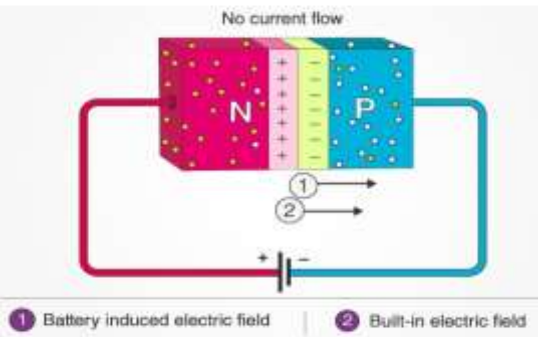
- **Zero bias:** No external voltage is applied to the P-N junction diode.
- **Forward bias:** The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.
- **Reverse bias:** The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

✓ **Forward Bias**



When the p-type is connected to the battery's positive terminal and the n-type to the negative terminal, then the P-N junction is said to be forward-biased. When the P-N junction is forward biased, the built-in electric field at the P-N junction and the applied electric field are in opposite directions. When both the electric fields add up, the resultant electric field has a magnitude lesser than the built-in electric field. This results in a less resistive and thinner depletion region. The depletion region's resistance becomes negligible when the applied voltage is large. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible, and the current flows across it unimpeded.

✓ **Reverse Bias**

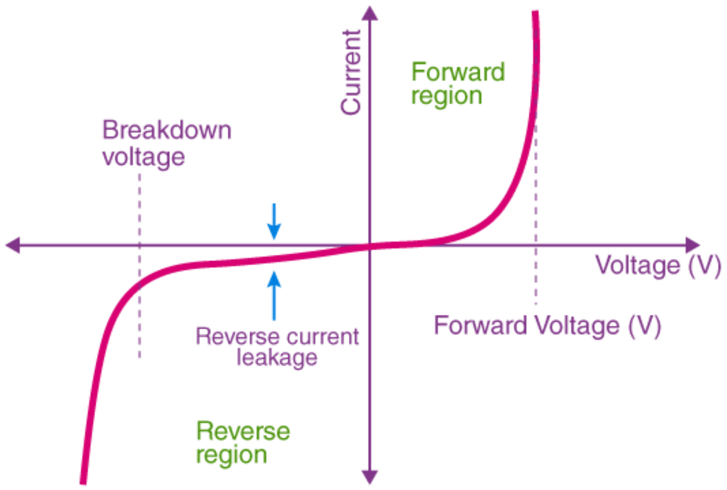


When the p-type is connected to the battery's negative terminal and the n-type is connected to the positive side, the P-N junction is reversing biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field, creating a more resistive, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.

✓ **How does current flow in the PN junction diode?**

The flow of electrons from the n-side towards the p-side of the junction takes place when there is an increase in the voltage. Similarly, the flow of holes from the p-side towards the n-side of the junction takes place along with the increase in the voltage. This results in the concentration gradient between both sides of the terminals. Due to the concentration gradient formation, charge carriers will flow from higher-concentration regions to lower-concentration regions. The movement of charge carriers inside the P-N junction is the reason behind the current flow in the circuit.

✓ **V-I Characteristics of P-N Junction Diode**



VI characteristics of P-N junction diodes are a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis.

- **Applications of diodes: rectification, Lighting, photo detection, voltage multiplier**
  - ✓ **Rectification**

The main application of p-n junction diode is in rectification circuits. These circuits are used to describe the conversion of A.C signals to D.C in power supplies. Diode rectifier gives an alternating voltage which pulsates in accordance with time.

- ✓ **Types of rectifier**

There are two primary methods of diode rectification:

- Half Wave Rectifier
- Full Wave Rectifier

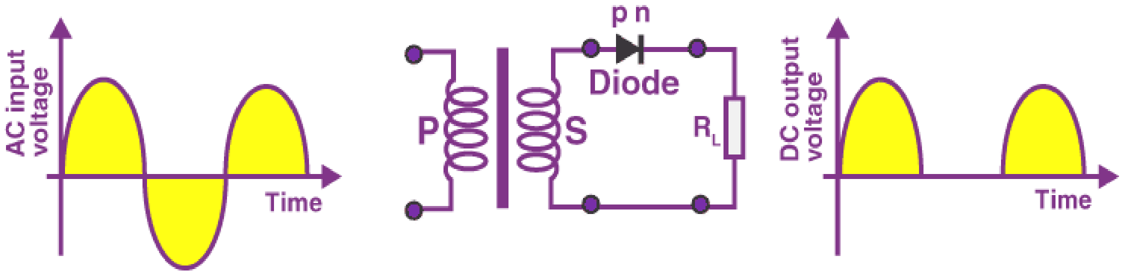
- ✓ **Half Wave Rectifier**

a) What Is Half Wave Rectifier?

In a half-wave rectifier, one half of each A.C input cycle is rectified. When the p-n junction diode is forward biased, it gives little resistance and when it is reversed biased it provides high resistance. During one-half cycles, the diode is forward biased when the input voltage is applied and in the opposite half cycle, it is reverse biased. During alternate half-cycles, the optimum result can be obtained.

b) Working of Half Wave Rectifier

The half-wave rectifier has both positive and negative cycles. During the positive half of the input, the current will flow from positive to negative which will generate only a positive half cycle of the A.C supply. When A.C supply is applied to the transformer, the voltage will be decreasing at the secondary winding of the diode. All the variations in the A.C supply will reduce, and we will get the pulsating D.C voltage to the load resistor.



In the second half cycle, the current will flow from negative to positive and the diode will be reverse biased. Thus, at the output side, there will be no current generated, and we cannot get power at the load resistance. A small amount of reverse current will flow during reverse bias due to minority carriers.

c) Applications of Half Wave Rectifier

Following are the uses of half-wave rectification:

- **Power rectification:** Half wave rectifier is used along with a transformer for power rectification as powering equipment.
- **Signal demodulation:** Half wave rectifiers are used for demodulating the AM signals.
- **Signal peak detector:** Half wave rectifier is used for detecting the peak of the incoming waveform.

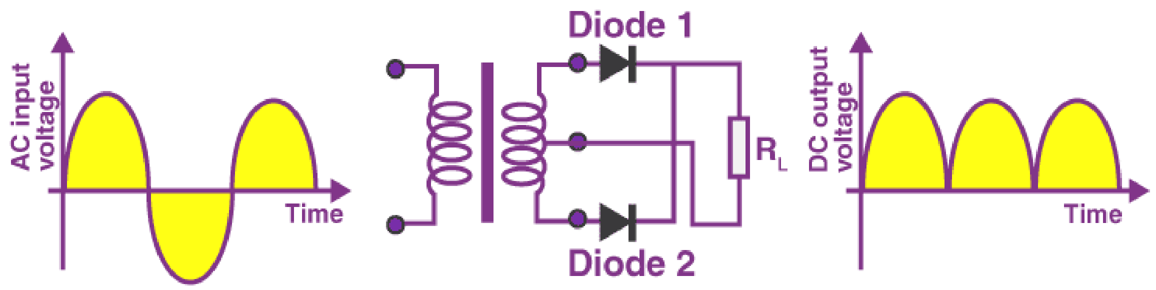
✓ **Full Wave Rectifier**

a) What Is Full Wave Rectifier?

Full-wave rectifier circuits are used for producing an output voltage or output current which is purely DC. The main advantage of a full-wave rectifier over half-wave rectifier is that such as the average output voltage is higher in full-wave rectifier, there is less ripple produced in full-wave rectifier when compared to the half-wave rectifier.

b) Working of Full Wave Rectifier

The full-wave rectifier utilizes both halves of each A.C input. When the p-n junction is forward biased, the diode offers low resistance and when it is reversing biased it gives high resistance. The circuit is designed in such a manner that in the first half cycle if the diode is forward biased then in the second half cycle it is reverse biased and so on.



c) Types of Full Wave Rectifier

There are two main types of full-wave rectifiers, and they are:

- **Two diodes full-wave rectifier circuit** (requires a center-tapped transformer and is used in vacuum tubes)
- **Bridge rectifier circuit** (doesn't require a centre-tapped transformer and is used along with transformers for efficient usage)

✓ **Applications of Full Wave Rectifier**

Following are the uses of full-wave rectifier:

- Full-wave rectifiers are used for supplying polarized voltage in welding and for this bridge rectifiers are used.
- Full-wave rectifiers are used for detecting the amplitude of modulated radio signals.

✓ **Diode used in Lighting**

LEDs are incorporated into bulbs and fixtures for general lighting applications. Small in size, LEDs provide unique design opportunities. Some LED bulb solutions may physically resemble familiar light bulbs and better match the appearance of traditional light bulbs. Some LED light fixtures may have LEDs built in as a permanent light source. There are also hybrid approaches where a non-traditional "bulb" or replaceable light source format is used and specially designed for a unique fixture. LEDs offer a tremendous opportunity for innovation in lighting form factors and fit a wider breadth of applications than traditional lighting technologies.

A voltage multiplier

✓ **Diode used in Voltage Multiplier**

A **voltage multiplier** is an electronic circuit consisting of capacitors and diodes and is used to multiply or rise the voltage level of an AC signal. The voltage multiplier receives an AC voltage of lower value, converts it into a DC voltage and increases its voltage level. Therefore, a voltage multiplier circuit performs both rectification and multiplication of voltage. Here, the rectification operation is performed by diodes and the increase in voltage is achieved by the capacitors.

A voltage multiplier is a specialized rectifier circuit producing an output that is theoretically an integer time the AC peak input, for example, 2, 3, or 4 times the AC peak input. Thus, it is possible to get 200 VDC from a 100 Vpeak AC source using a double, and 400 VDC from a quadrupler. Any load in a practical circuit will lower these voltages.

- ✓ **Types of Voltage Multipliers**

Based on the ratio of the input voltage to the output voltage, the voltage multipliers are classified into the following three types −

- Voltage Double
- Voltage Tripler
- Voltage Quadruple

- ✓ **Applications of Voltage Multipliers**

The voltage multipliers are used to produce a DC voltage of few volts for electronic circuits to millions of volts for applications like high energy physics experiments. Some common applications of voltage multipliers are as follows −

- Cathode ray tubes used in TV receivers, computer monitors, oscilloscopes, etc.
- Laser printers and photo copier machines
- X-ray machines
- Photo multiplier tubes
- Travelling wave tubes
- Ion pumps
- Bug zappers
- Voltage multiplier is also used in Cockcroft-Walton Generator, etc.
- In automobile manufacturing industries, the high voltage multipliers are used in spray painting machine

- ✓ **Photo detection using photo diodes:**

Photodiodes are used in safety electronics such as fire and smoke detectors. Photodiodes are used in numerous medical applications. They are used in instruments that analyze samples, detectors for computed tomography and also used in blood gas monitors.

Photodiodes are used in solar cell panels.

Practical Activity 2.2.1: Testing a diode

Task:

1: Referring to previous theoretical activity (2.2.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and test the ordinary diode using multimeter.

2: Follow the trainer while explaining the task and providing the work instructions

3: Follow the trainer when demonstrating how to test the ordinary diode

4: Referring to procedures provided on task 3, perform the given activity.

5: Read key reading 2.2.2 and ask clarification where's necessary

6: Perform the task provided in application of learning 2.2.

Key readings 2.2.2.:

- **Testing a Diode using a Digital Multimeter.**

Steps to Test a Diode Using a Multimeter

Step1. Gather Materials: You will need a digital multimeter (DMM) or an analog multimeter.

Step2. Identify the Anode and Cathode: Determine which lead of the diode is the anode (positive) and which is the cathode (negative). The cathode is usually marked with a band or a different colour.

Step3. Set the Multimeter to Diode Test Mode: Turn on your multimeter and set it to the diode test mode, often indicated by a diode symbol on the dial.

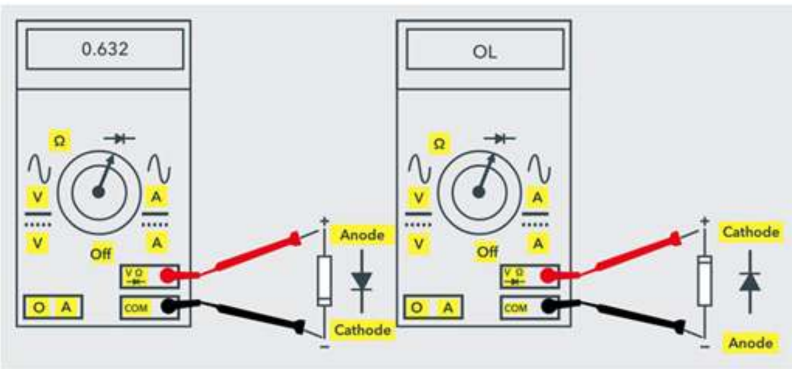
Step4. Test Forward Bias: Connect the red probe (positive) of the multimeter to the anode of the diode and the black probe (negative) to the cathode.

Observe and record the reading displayed on the multimeter. A healthy silicon diode should show a voltage drop between 0.5 to 0.8 volts, while germanium diodes typically show between 0.2 to 0.3 volts.

Step5. Test Reverse Bias: Reverse the probes by connecting the red probe to the cathode and the black probe to the anode.

In this configuration, a good diode should display "OL" (overload), indicating that it is not conducting in reverse bias.

Step6. Interpret Results: If you see a voltage drop in both forward and reverse bias, then the diode is likely faulty. If you see OL in reverse bias and a proper voltage drop in forward bias, then your diode is functioning correctly.



- **Testing LED (Light Emitting Diode)**

Steps to Test a LED Using a Multimeter

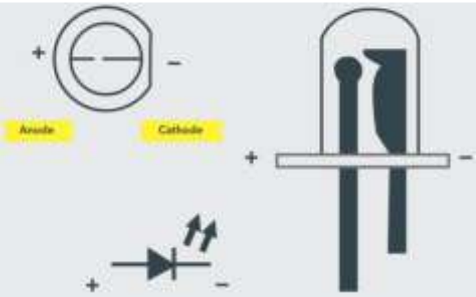
Step1: Identify the anode and cathode terminals of the LED.

Step2: Place the multimeter selector / knob in diode mode.

Step3: Connect the probes of the meter to LED such that it is forward-biased.

Step4: If the LED is working properly, then it glows otherwise the LED is defective.

Step5: Reverse-biased testing cannot be possible with LED since it doesn't work in reverse-biased condition.



- **Testing a Zener Diode**

Steps to Test a Zener Diode Using a Multimeter

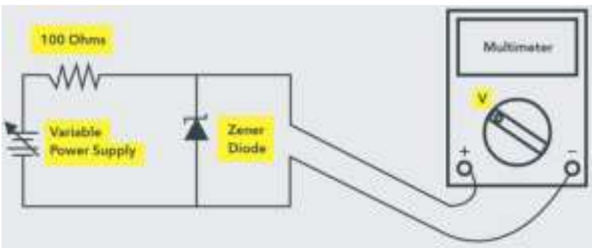
Step1: Identify the terminals anode and cathode of the Zener diode and its identification process is similar to the normal PN diode (using a mark).

Step2: Connect the test circuit as shown in the above figure.

Step3: Place the multimeter knob in voltage mode.

Step4: Connect the meter probes across the Zener diode as shown in figure.

Step5: Gradually increase the input supply to the diode, and observe the voltage on the meter display.



Points to Remember

- A **diode** is a semiconductor device that essentially acts as a one-way switch for current.
- **Types of Diodes are named below:**
  - ✧ Light Emitting Diode is a semiconductor device that emits light when an electric current flows through it.
  - ✧ Laser diode is a semiconductor that uses a p-n junction for producing coherent radiation with the same frequency and phase which is either in the visible or infrared spectrum.
  - ✧ Zener diode is a heavily doped semiconductor device that has been specially designed to operate in the reverse direction.
  - ✧ Photodiode a PN-junction diode that consumes light energy to produce an electric current.
  - ✧ PN junction diode is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor
- **Applications of diodes are described below:**
  - ✧ **Rectification: these circuits** are used to describe the process of converting theA .C signals to D.C in power supplies.
  - ✧ **Lighting: LEDs** are incorporated into bulbs and fixtures for general lighting application
  - ✧ **Photo detection:** Photodiodes are used in safety electronics such as fire and smoke detectors.
  - ✧ **Voltage multiplier:** a voltage multiplier circuit performs both rectification and multiplication of voltage.
- **Testing a Diode Using a Multimeter is summarized in the following steps:**
  - ✧ Identify the Anode and Cathode>>Set the Multimeter to Diode Test Mode>>Test Forward Bias>>Test Reverse Bias>>Interpret Results

Application of learning 2.2.

A hobbyist electronics team is working on repairing and upgrading an old analog radio that has started malfunctioning. The radio uses several diodes in its circuits for rectification and signal detection.

You as one of the team, use diode testing techniques to identify faulty diodes in the radio.

Indicative content 2.3: Description of Transistors

Duration: 5 hrs

Theoretical Activity 2.3.1: Introduction to Transistors

Tasks:

1: In small groups, you are requested to answer the following questions related to the description a Transistor

i. What is a transistor?

ii. Identify the types of transistor.

iii. What are the applications of transistor?

2: Provide the answer for the asked questions and write them on papers.

3: Discuss the provided findings and choose the correct answers

4: Follow the trainer when providing the expert view to clarify the given ideas.

5: In addition, ask questions where necessary.

6: For more clarification, read the key **readings 2.3.1.**

Key readings 2.3.1.:

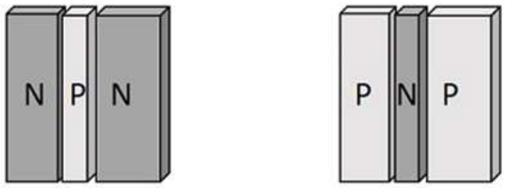
- **Definition of a transistor**

After having a good knowledge on the working of the diode, which is a single PN junction, let us try to connect two PN junctions which make a new component called Transistor. A Transistor is a three terminal semiconductor device that regulates current or voltage flow and acts as a switch or gate for signals.

- **Constructional Details of a Transistor**

The Transistor is a three terminal solid-state device which is formed by connecting two diodes back-to-back. Hence it has got two PN junctions. Three terminals are drawn out of the three semiconductor materials present in it. This type of connection offers two types of transistors. They are PNP and NPN which means an N-type material between two P-types and the other is a P-type material between two N-types respectively.

The construction of transistors is as shown in the following figure which explains the idea discussed above.



Construction of PNP & NPN Transistors

The three terminals drawn from the transistor indicate Emitter, Base and Collector terminals. They have their functionality as discussed below:

Emitter

- ✓ The left-hand side of the above shown structure can be understood as Emitter.
- ✓ This has a moderate size and is heavily doped as its main function is to supply a number of majority carriers, i.e. either electrons or holes.
- ✓ As this emits electrons, it is called as an Emitter.
- ✓ This is simply indicated with the letter E.

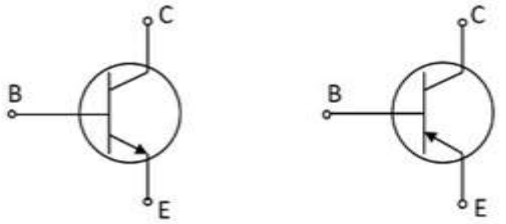
Base

- ✓ The middle material in the above figure is the Base.
- ✓ This is thin and lightly doped.
- ✓ Its main function is to pass the majority carriers from the emitter to the collector.
- ✓ This is indicated by the letter B.

Collector

- ✓ The right-side material in the above figure can be understood as a Collector.
- ✓ Its name implies its function of collecting the carriers.
- ✓ This is a bit larger in size than emitter and base. It is moderately doped.
- ✓ This is indicated by the letter C.

The symbols of PNP and NPN transistors are as shown below:



Symbol of NPN transistor

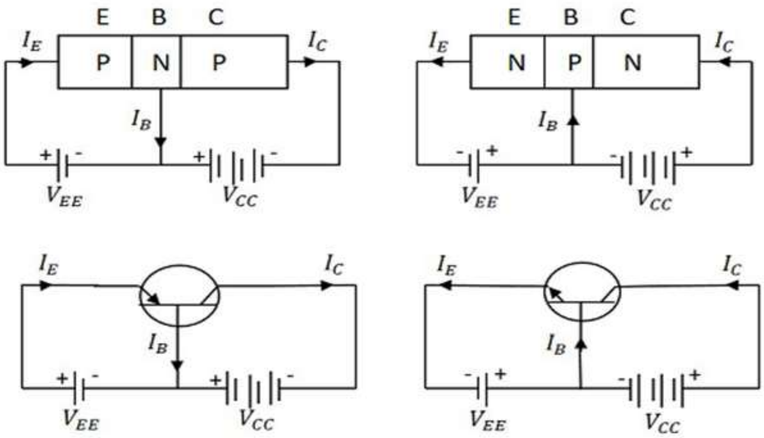
Symbol of PNP transistor

The arrow-head in the above figures indicated the emitter of a transistor. As the collector of a transistor has to dissipate much greater power, it is made large. Due to the specific functions of emitter and collector, they are not interchangeable. Hence the terminals are always to be kept in mind while using a transistor.

- **Transistor Biasing**

As we know that a transistor is a combination of two diodes, we have two junctions here. As one junction is between the emitter and base, that is called as Emitter-Base junction and likewise, the other is Collector-Base junction.

Biasing is controlling the operation of the circuit by providing power supply. The function of both the PN junctions is controlled by providing bias to the circuit through some dc supply. The figure below shows how a transistor is biased.



P-N-P Transistor biasing

N-P-N Transistor biasing

By having a look at the above figure, it is understood that

- ✓ The N-type material is provided negative supply and P-type material is given positive supply to make the circuit Forward bias.
- ✓ The N-type material is provided positive supply and P-type material is given

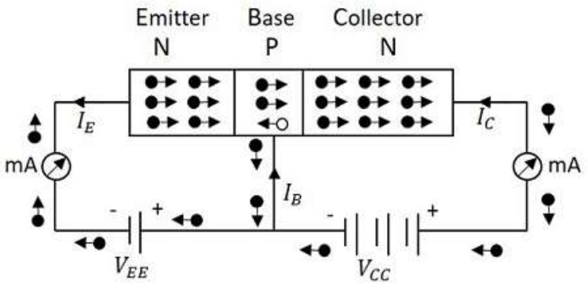
negative supply to make the circuit Reverse bias.

By applying the power, the emitter base junction is always forward biased as the emitter resistance is very small. The collector base junction is reverse biased and its resistance is a bit higher. A small forward bias is sufficient at the emitter junction whereas a high reverse bias has to be applied at the collector junction.

The direction of current indicated in the circuits above, also called as the Conventional Current, is the movement of hole current which is opposite to the electron current.

- **Operation NPN Transistor**

The operation of an NPN transistor can be explained by having a look at the following figure, in which emitter-base junction is forward biased and collector-base junction is reverse biased.



Operation of a NPN transistor

The voltage VEE provides a negative potential at the emitter which repels the electrons in the N-type material and these electrons cross the emitter-base junction, to reach the base region. There a very low percent of electrons recombines with free holes of P-region. This provides very low current which constitutes the base current IB. The remaining holes cross the collector-base junction, to constitute the collector current IC.

As an electron reaches out of the collector terminal, and enters the positive terminal of the battery, an electron from the negative terminal of the battery VEE enters the emitter region. This flow slowly increases and the electron current flows through the transistor.

Hence, we can understand that:

- ✓ The conduction in a NPN transistor takes place through electrons.
- ✓ The collector current is higher than the emitter current.
- ✓ The increase or decrease in the emitter current affects the collector current.

- **Advantages**

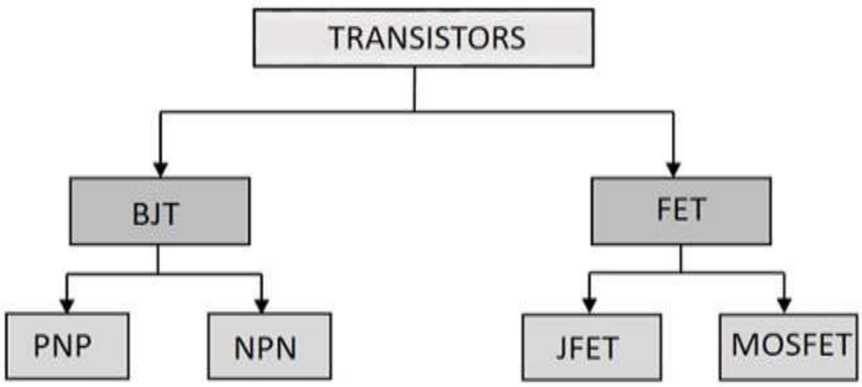
There are many advantages of a transistor such as:

- ✓ High voltage gain.
- ✓ Lower supply voltage is sufficient.
- ✓ Most suitable for low power applications.
- ✓ Smaller and lighter in weight.
- ✓ Mechanically stronger than vacuum tubes.
- ✓ No external heating required like vacuum tubes.
- ✓ Very suitable to integrate with resistors and diodes to produce ICs.

There are few disadvantages such as they cannot be used for high power applications due to lower power dissipation. They have lower input impedance and they are temperature dependent.

- **Types of transistors**

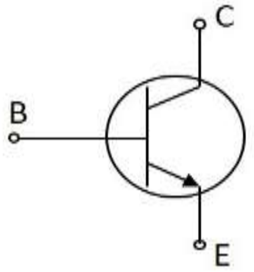
There are many types of transistors in use. Each transistor is specialized in its application. The main classification is as follows.



The primary transistor is the BJT and FET is the modern version of transistor. Let us have a look at the BJTs.

✓ **Bipolar Junction Transistor**

A Bipolar junction transistor, shortly termed as BJT is called so as it has two PN junctions for its function. This BJT is nothing but a normal transistor. It has got two types of configurations NPN and PNP. Usually, NPN transistor is preferred for the sake of convenience. The following image shows how a practical BJT looks like.



The types of BJT are NPN and PNP transistors. The NPN transistor is made by placing a p-type material between two n-type materials. The PNP transistor is made by placing an n-type material between two p-type materials.

BJT is a current controlled device. Normal transistors which we had discussed in the previous chapters come under this category. The functionality, configurations and applications are all the same.

✓ **Field Effect Transistor**

Definition

An FET is a three-terminal unipolar semiconductor device. It is a voltage-controlled device unlike a bipolar junction transistor. The main advantage of FET is that it has very high input impedance, which is in the order of Mega Ohms. It has many advantages like low power consumption, low heat dissipation and FETs are highly efficient devices. The following image shows how a practical FET looks like.

The FET is a unipolar device, which means that it is made using either p-type or n-type material as main substrate. Hence the current conduction of a FET is done by either electrons or holes.

Features of FET

The following are the varied features of a Field Effect Transistor.

- Unipolar − It is unipolar as either holes or electrons are responsible for conduction.
- High input impedance − the input current in a FET flows due to the reverse bias. Hence it has high input impedance.
- Voltage controlled device − as the output voltage of a FET is controlled by the gate input voltage, FET is called as the voltage-controlled device.
- Noise is low − There are no junctions present in the conduction path. Hence noise is lower than in BJTs.
- Gain is characterized as transconductance. Transconductance is the ratio of change in output current to the change in input voltage.
- The output impedance of a FET is low.

Advantages of FET over BJT

To prefer a FET over BJT, there should be few advantages of using FETs, rather than BJTs. Let us try to summarize the advantages of FET over BJT.

JFET	**BJT**
It is an unipolar device	It is a bipolar device
Voltage driven device	Current driven device
High input impedance	Low input impedance
Low noise level	High noise level
Better thermal stability	Less thermal stability
Gain is characterized by transconductance	Gain is characterized by voltage gain

Applications of FET

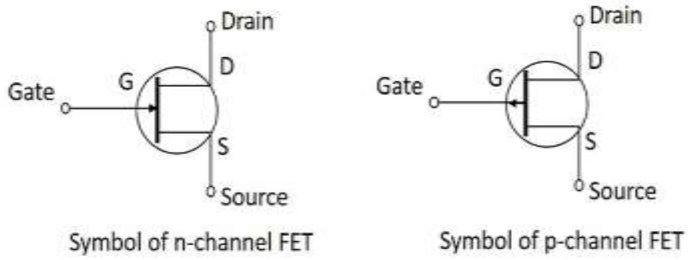
- FET is used in circuits to reduce the loading effect.

- FETs are used in many circuits such as Buffer Amplifier, Phase shift Oscillators and Voltmeters.

FET Terminals

Though FET is a three-terminal device, they are not the same as BJT terminals. The three terminals of FET are Gate, Source and Drain. The Source terminal in FET is analogous to the Emitter in BJT, while Gate is analogous to Base and Drain to Collector.

The symbols of a FET for both NPN and PNP types are as shown below



a) Source

- The Source terminal in a Field Effect Transistor is the one through which the carriers enter the channel.
- This is analogous to the emitter terminal in a Bipolar Junction Transistor.
- The Source terminal can be designated as S.
- The current entering the channel at Source terminal is indicated as IS.

b) Gate

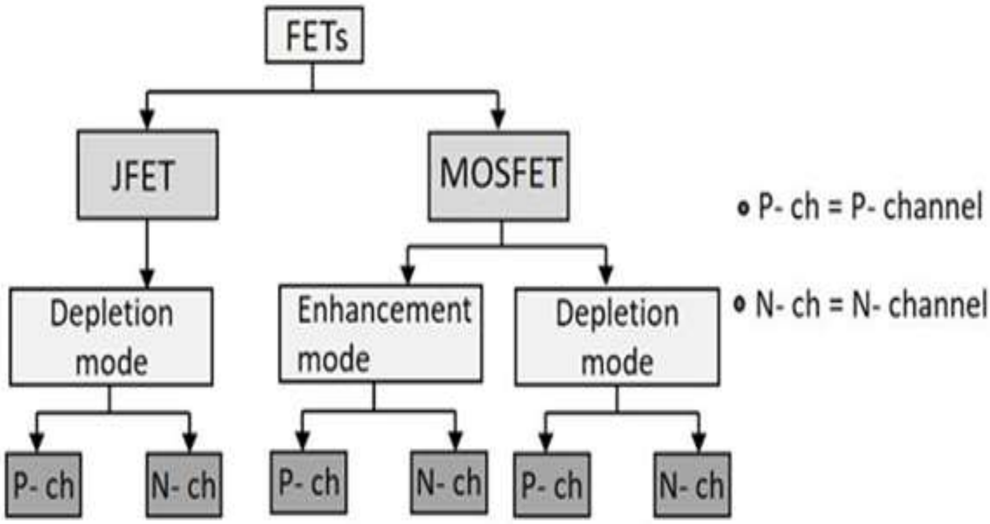
- The Gate terminal in a Field Effect Transistor plays a key role in the function of FET by controlling the current through the channel.
- By applying an external voltage at Gate terminal, the current through it can be controlled.
- Gate is a combination of two terminals connected internally that are heavily doped.
- The channel conductivity is said to be modulated by the Gate terminal.
- This is analogous to the base terminal in a Bipolar Junction Transistor.
- The Gate terminal can be designated as G.
- The current entering the channel at Gate terminal is indicated as IG.

c) Drain

- The Drain terminal in a Field Effect Transistor is the one through which the carriers leave the channel.
- This is analogous to the collector terminal in a Bipolar Junction Transistor.
- The Drain to Source voltage is designated as VDS.
- The Drain terminal can be designated as D.
- The current leaving the channel at Drain terminal is indicated as ID.

Types of FET

There are two main types of FETS. They are JFET and MOSFET. The following figure gives further classification of FETs.

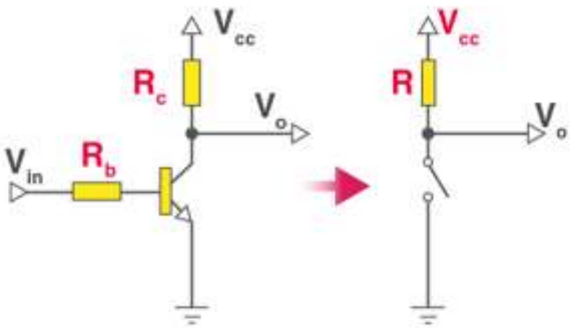


In the subsequent chapters, we will have a detailed discussion on JFET and MOSFET.

- **Applications of transistors: switching and amplification**
  - ✓ **Transistor as a switch**

Using a **transistor as a switch** is the simplest application of the device. A transistor can be extensively used for switching operations, either for opening or closing a circuit. On the other hand, the basic concept behind the operation of a transistor as a switch relies on its mode of operation. Generally, the low-voltage DC is turned on or off by transistors in this mode.

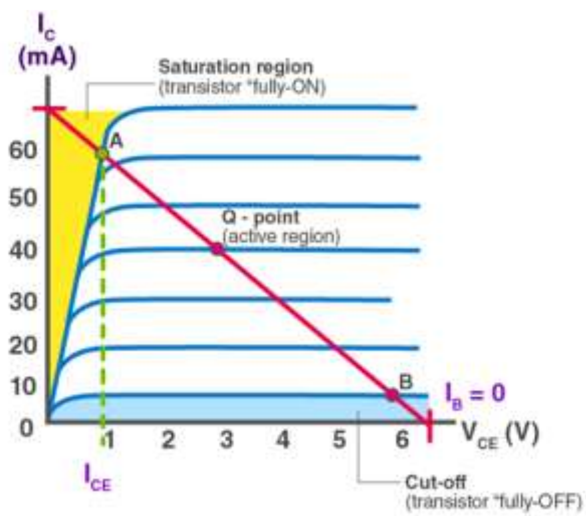
Both PNP and NPN transistors can be utilised as switches. A basic terminal transistor can be handled differently from a signal amplifier by biasing both NPN and PNP bipolar transistors with an “ON / OFF” static switch. One of the main uses of the transistor to transform a DC signal “ON” or “OFF” is solid-state switches.



Some devices, including LEDs, only require several milliamperes of DC voltages at the logical level and can be directly controlled via the logical gate output. High-power devices such as generators, solenoids or lamps usually need more power to use transistor switches than the usual logic gate.

Transistor Switch’s Working Regions or Operating Modes

The saturation zone and cut-off area are also known as the transistor switch’s working regions. This implies that, by switching between its “top-off” (saturation) and “absolute OFF,” the transistor is used as a switch to basically overwrite its Q-Point and the voltage divider circuit that is needed for amplification.



a) Cut-off Region

The “cut-off” area is at the bottom of the curves, the blue, shaded area and the yellow zone on the left is the transistor “saturation” region.

The transistor's operating specifications include the base current (IB), the collector current (IC) and the emitter-collector voltage (VCE).

✓ **Characteristics of Cut-off Region**

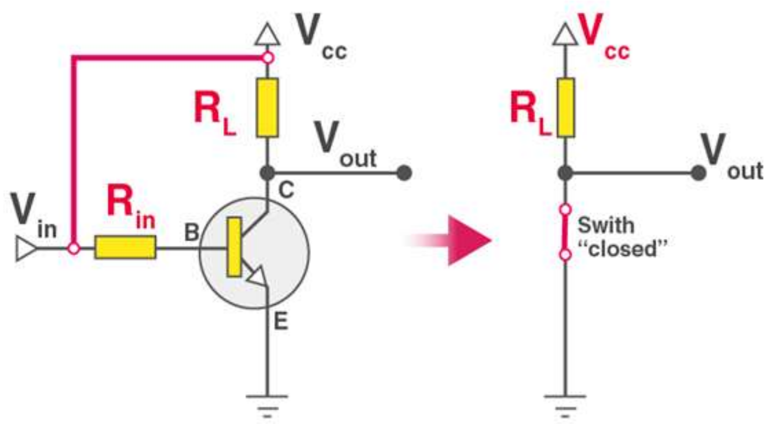
- The transistor is used as an "open switch"
- The bases and input are grounded (0v)
- The base emission voltage is VBE > 0.7 V
- The basic emitter is reversed
- The full-OFF (cut-off area) transistor ("Collector Flow = 0") • VOUT = VCC = "1''"
- No collector current flows (IC = 0)

Instead, we can describe the "cut-off region" or "OFF mode," both in reverse bias, with Vb < 0.7 V and IC = 0, when using a bipolar transistor as a switch.

b) Saturation Region

In this mode or region, the highest base current is applied, leading to the overall collector current, causing the average collector-emitter voltage to fall and the leakage surface as small as possible and the maximum current that flows across this transistor. That is why the "Fully ON" transistor is triggered.

Alternatively, we can define the "saturation field" or "ON step," all junctions forward, VW > 0.7 V and IK = complete when using a bipolar transistor as a switch.



Let us consider a base-biased transistor in a CE configuration. When we extend the voltage rule of Kirchhoff to the circuit's input and output side, we can write,

VBB = IBRB + VBE … (1)

VCE = VCC – ICRC … (2)

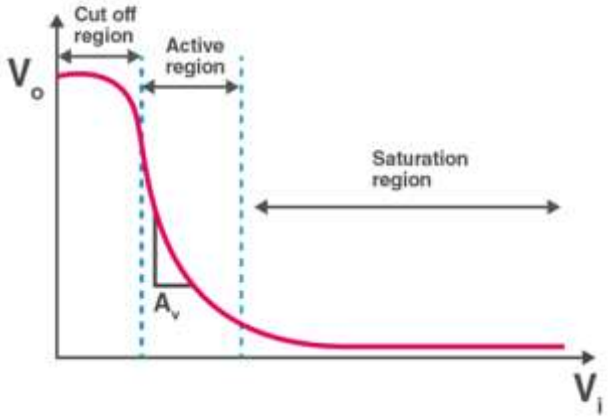
VBB is the input voltage (Vi), and VCE is the output voltage DC (Vo). That's why we get,

Vi = IBRB + VBE

Vo = VCC – ICRC

First, let's look at the shift in Vo as Vi rises from zero. A Silicon junction transistor remains in a cutoff state as long as Vi is less than 0.6 V. Also, IC= 0. Vo= VCC. Thus, the transistor switches into an active state when Vi goes past 0.6 V. IC >0, and Vo is also decreasing (because ICRC is increasing). Originally, with rising Vi, IC increases almost linearly.

Vo also decreases linearly until its value drops below 1 V. Post this, the change becomes non-linear, and the transistor moves into the state of saturation. Vo continues to decrease on increasing Vi but never becomes zero. Here's a Vo vs Vi plot (also referred to as the transition features of a reference transistor).



There are two things to remember here:

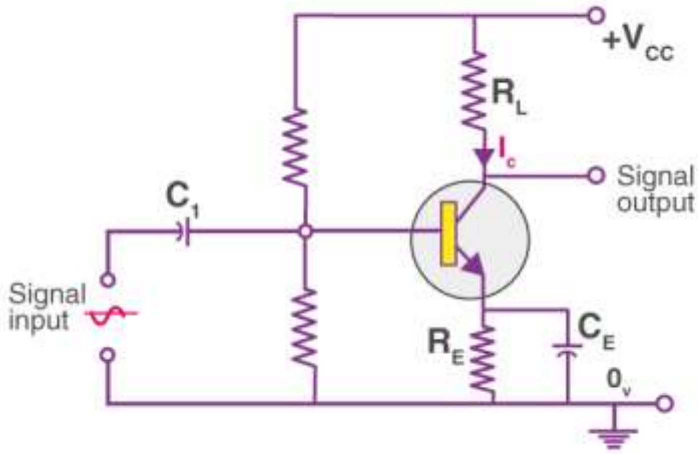
When Vi is low and the transistor is unable to forward bias, Vo is high (= VCC).

If Vi is sufficiently high to saturate the transistor, Vo is very low (~0).

It is also switched off when a transistor is not conducting. On the other side, it is turned on when it is in a state of depletion. Bringing these components together, imagine a resistor that determines the low and high values below and above those points of voltage.

Such levels suit the transistor's cutoff and saturation. We might say in such a situation that a small input turns off the transistor, and a high input switches on it. These circuits are designed to prevent the transistor from staying in an active state. This is how a transistor can act as a switch.

- ✓ **Transistor as an Amplifier**



As we saw earlier, a transistor in its active state acts as an amplifier, which lies in the active region of the curve between V0 and Vi. In this curve, the slope of the linear part represents the rate at which the signal output changes with respect to the signal input. We can say that the rate is negative as the output is not just ICRC but VCC – ICRC, which is why as we increase the input voltage of the CE amplifier, the output voltage decreases. Here, the output is out of phase with the input signal. Now, if we write the small changes in the output voltage and the input voltages as ΔVo and ΔVi correspondingly, then the ratio of the output signal to the input signal gives the gain in the signal. We can write,

V0 = VCC – ICRC

Therefore, we can write,

ΔV0 = 0 – RCΔIC

As we also have,

Vi = IBRB + VBE

Therefore, we can also write,

ΔVi = RBΔ IB + ΔVBE

But ΔVBE is negligibly small in comparison to ΔIBRB in this circuit. So, the voltage gain of this CE amplifier is given by

$$A_v = -\frac{R_C \Delta I_C}{R_B \Delta I_B} = -\beta_{ac}\frac{R_C}{R_B}$$

Here, βac is can be given as,

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

We can conclude that the linear portion of the active region of the above-mentioned curve can be used as an amplifier.

✓ **Performance of Amplifier**

We know that the most preferred mode of connection is the common emitter mode. When a transistor is used as an amplifier, the performance of the amplifier becomes important. Following are the terms that are used for describing the performance of the amplifier:

a. Input Resistance

The input resistance would be low since the input circuit is forward biased. This is the resistance offered by the emitter-base junction to the flow of the signal. Input resistance is defined as the ratio of small change in the emitter-base voltage to the change in the base current when the emitter-collector voltage is kept constant.

b. Output Resistance

The output resistance of the transistor as an amplifier would be very high. The output resistance is defined as the ratio of change in emitter-collector voltage to the change in the collector current when the base current is constant.

c. Current Gain

Current gain is defined as the ratio of change in the collector current to the change in the base current. The value of current gain may vary from 20 to 500.

d. Voltage Gain

Voltage gain is defined as the ratio of change in output voltage to the change in the input voltage.

e. Power Gain

The ratio of output signal power to the input signal power is known as power gain.

Practical Activity 2.3.2: Testing a Transistor

Task:

1: Referring to previous theoretical activity (2.3.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop totest the transistorusing multi-meter

2: Follow the trainer while explaining the task and providing the work instructions

3: Follow the trainer when demonstrating how to test the transistor and write down the procedures

4: Referring to procedures provided on task 3, perform the given activity.

5: Read key reading 2.3.2 and ask clarification where's necessary

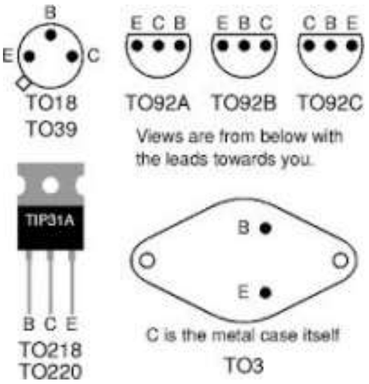
6: Perform the task provided in application of learning 2.3.

Key readings 2.3.2

- **Test a transistor with a multimeter.**

Steps to Test a Transistor Using a Multimeter

Step 1: Identify the Type of Transistor: Determine whether you are testing an NPN or PNP transistor. You need to know the type of transistor (NPN or PNP) and the pinout configuration. This information can be found in the transistor's datasheet.



Step 2: Set Up the Multimeter: Turn on your digital multimeter and set it to the "Diode" or "Continuity" mode. This setting allows you to measure voltage drops across the junctions of the transistor.

Step 3: Testing an NPN Transistor

a) **Base to Emitter:**

Connect the positive (red) probe of the multimeter to the base terminal (B) of the transistor.

Connect the negative (black) probe to the emitter terminal (E).

A good NPN transistor should show a voltage drop between 0.45V and 0.9V.

b) Base to Collector:

Keep the positive probe on the base and connect the negative probe to the collector terminal (C).

Again, a good NPN transistor should show a voltage drop between 0.45V and 0.9V.

c) Emitter to Base:

Switch probes; connect the positive lead to emitter (E) and negative lead to base (B).

The reading should show "OL" (Over Limit), indicating no conduction in reverse bias.

d) Collector to Base:

Connect positive lead to collector (C) and negative lead to base (B).

You should see "OL" again, confirming proper function.

e) Collector to Emitter:

Connect positive lead to collector (C) and negative lead to emitter (E).

A good transistor will read "OL". Reverse this connection; it should still read "OL".

Step 4: Testing a PNP Transistor

a) Base to Emitter:

Connect negative probe to base terminal (B) and positive probe to emitter terminal (E).

A good PNP transistor will show a voltage drop between 0.45V and 0.9V.

b) Base to Collector:

Keep negative on base and connect positive probe to collector terminal (C).

Expect a similar voltage drop as with NPN transistors.

c) Emitter to Base:

Switch probes; connect positive lead to emitter (E) and negative lead to base (B).

The reading should show "OL".

d) Collector to Base:

Connect positive lead from collector (C) and negative from base (B).

Expect "OL".

e) Collector to Emitter:

Positive on collector (C), negative on emitter (E); expect "OL". Reverse leads for confirmation.

Step 5: Interpret Results: If any of these tests do not yield expected results, such as showing continuity where there shouldn't be or failing any of these readings, then consider that the transistor may be faulty.

Points to Remember

- A Transistor is a three terminal semiconductor device that regulates current or voltage flow and acts as a switch or gate for signals.
- There are many types of transistors in use.
  - ✧ BJT is a current controlled device.
  - ✧ An FET is a three-terminal unipolar semiconductor device. It is a voltage-controlled device unlike a bipolar junction transistor.
- **Applications of transistors: switching and amplification**
  - ✧ A transistor can be extensively used for switching operations, either for opening or closing a circuit.

- ✧ A transistor acts as an amplifier in its active state

- Testing a Transistor Using a Multimeter involves the following steps:
  Identify the Type of Transistor>>Set Up the Multimeter>>Testing an NPN Transistor>>Testing a PNP Transistor>>Interpret Results.

Application of learning 2.3.

An electronics technician at a repair centre, you receive a client who bring a home stereo system that has stopped working. The supervisor confirms to repair the amplifier and need to test the transistors in the circuit.

You are one of the technician team and you are tasked to use a multimeter to test the transistors and determine if they need to be replaced.

Indicative content 2.4: Description of Thyristors

Duration: 3 hrs

Theoretical Activity 2.4.1: Describe of Thyristors

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of thyristors

i. What is a thyristor?

ii. Identify the types of thyristor.

iii. What are the applications of thyristor?

2. Discuss and write the findings related to the given tasks on provided place

3. Present your findings to the whole class or your colleagues.

4. Ask questions for more clarification

5. Read the **Key readings 2.4.1** in their manuals to get more clarification.

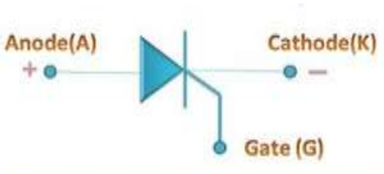
Key readings 2.4.1.:

- **Definition of Thyristors**

Thyristor is a **semiconductor device** which comprises of four layers made up of P-type and N-type material arranges in the alternate fashion. The word Thyristor is formed from two words **thyr**atron and trans**istor.** Besides, the characteristics possessed by a thyristor are the combination of the properties of thyratron and transistor.

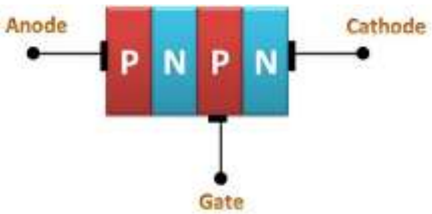
The thyratron has the property of **rectification** and the **transistor** has the property of **switching**. The thyristors are turned on using the control signal transferred by the transistor. Unlike the diodes, the thyristors have three terminals **Anode, Cathode** and **Gate terminal**.

The circuit symbol by which **thyristors** are identified in an electronic circuit is shown in the diagram below:



- **Construction of Thyristors**

Thyristors can be understood with the help of **two transistor** analogy. The collector of one transistor is connected to the base of the second transistor while the collector of the second transistor is connected to the base of the first transistor.



Thus, total four layers of semiconductor material are connected to each other and total three junctions are formed. In thyristors, there are three terminals that are anode, cathode and gate. Gate terminal provides the controlling voltage.

- **Working of Thyristor**

The collector current of one transistor acts as the base current of another transistor. Thus, the collector current of one transistor will trigger another one. Without the collector current in either of the transistor, the thyristor cannot be triggered.

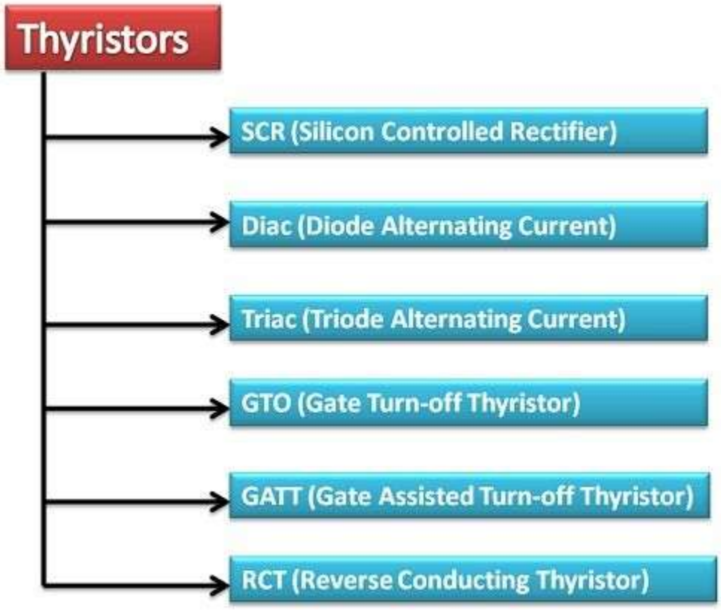
Now, suppose one **PNP transistor** is connected to the NPN transistor, then the P-terminal of the PNP transistor will be connected to one of the terminals of the battery. This will make the junction forward biased and current will start flowing in the transistor.

Due to this the collector current from PNP transistor will enter the base terminal of NPN transistor and thus the NPN transistor will also start conducting. In this way thyristor conducts.

The gate terminal when turned **ON** the thyristor performs rectification action but when it is turned **OFF** the rectification ceases. Thus, the thyristors can act as a rectifier and a switch but cannot act as an amplifier because it cannot amplify the signal.

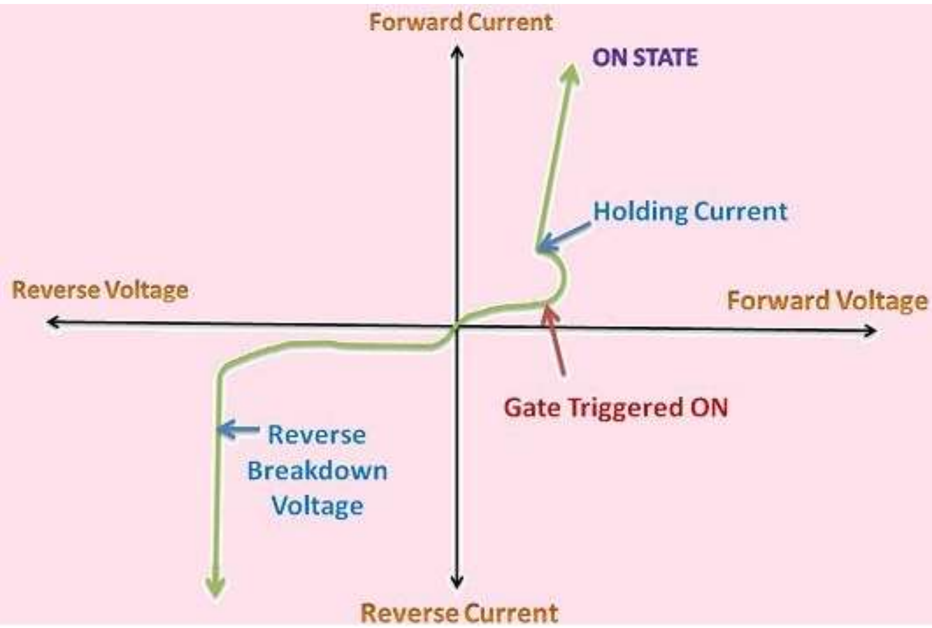
- **Types of Thyristors**

There are various semiconductor devices which can be classified under the thyristor family. Some of the most used devices are **SCR, DIAC, TRIAC, GATT** etc. We will discuss each of the devices in detail in our upcoming articles.



- **Characteristics of Thyristors**

The characteristics curve of Thyristors is shown in the diagram below. With the help of characteristics curve, we can understand its working in forward biased mode and reversed biased mode in a detailed manner.



- **Advantages of Thyristors**

  ✓ **Better Efficiency:** Thyristors possess better efficiency than transistors, thus it is used in various application of electronics.

- ✓ **Low cost of Fabrication:** The cost of fabrication of thyristors is low and thus it is economical to use in various electronics circuits for switching operation.
- ✓ **Ability to be controlled:** This is the robust characteristics of the thyristor as because of the gate terminal the thyristor can be controlled.
- ✓ **High Reliability:** The thyristor is the highly reliable device, and thus is used as a significant part in HVDC transmission.
- ✓ **High Voltage and Current Ratings:** The thyristor consists of four layers of semiconductor and thus the voltage and current ratings are higher in comparison to the transistor.
- ✓ **Large Power Handling Capacity:** The power handling capacity of the thyristor is much greater than the other semiconductor device.
- ✓ **Good Trigger Sensitivity:** The gate control terminal of thyristor provides the efficient controlling signal; thus, it possesses good trigger sensitivity.

- **Applications of Thyristors**

  - ✓ **Rectification Purpose:** The thyristors are used for rectification of AC signal. Thus, when the controlled signal is given to rectifier it converts AC into DC.
  - ✓ **Relay Control:** Thyristors are used in relay control.
  - ✓ **Phase Control:** The phase controller used thyristors for providing phase correction in the circuit.
  - ✓ **HVDC transmission:** They are also used in high voltage DC transmission.
  - ✓ **Control of temperature, level and Position:** Due to its robust controlling, it can be used for controlling the temperature, level, position and illumination.
  - ✓ **DC and AC Motors:** Thyristors are used in AC and DC motors as the speed controller.
  - ✓ **Transmission Lines:** To improve the power factor in transmission lines, thyristors can be used.
  - ✓ **Cycloconverter:** Thyristors play a crucial role in cycloconverters for converting AC of one frequency into AC of some other frequency.

Thyristors are the crucial power semiconductor devices. Due to its ability of rectification and switching it is used in various electronic circuits. Moreover, its four-layer architecture makes it more robust and efficient to use.

Practical Activity 2.4.1: Testing a thyristor

Task:

1: Referring to previous theoretical activity (2.4.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and test the thyristor using multimeter

2: Follow the trainer when demonstrating how to test the thyristor and write down the procedures.

3: Referring to procedures provided on task2, perform the given activity.

4: Read key reading 2.4.2 and ask clarification where's necessary

5: Perform the task provided in application of learning 2.4.

Key readings 2.4.2.:

- **Testing a thyristor using multimeter**

Testing a thyristor with a multimeter involves checking its basic functionality and ensuring it is not damaged.

Steps to Test a Thyristor Using a Multimeter are listed below:

Step1. Gather Required Tools: Ensure you have a high-quality digital multimeter with diode test mode, resistance measurement, and voltage measurement capabilities. Have safety equipment ready, such as safety glasses and insulated gloves.

Step2. Disconnect Power: Before testing, ensure that the electrical power to the circuit is completely disconnected to prevent electric shocks.

Step3. Identify Thyristor Terminals: Locate the three terminals of the thyristor: anode (A), cathode (K), and gate (G). The anode is usually marked with a "+" symbol, while the cathode may have a "-" symbol.

Step4. Testing Forward Voltage Drop: Set the multimeter to diode test mode.

- ✧ Connect the positive lead (red) of the multimeter to the anode and the negative lead (black) to the cathode.
- ✧ A healthy thyristor should show a forward voltage drop between 0.7 to 1.2 volts. If it shows significantly higher or lower readings, it may indicate a fault.

Step5. Testing Gate Triggering Functionality: Switch the multimeter to resistance measurement mode.

- ✧ Connect the positive lead to the gate terminal and the negative lead first to the anode and then to the cathode.
- ✧ In both cases, you should see high or infinite resistance readings if functioning correctly. A low resistance reading indicates a gate-cathode short.

Step6. Testing Reverse Blocking Capability: Again set your multimeter to diode test mode.

- ✧ Connect the positive lead to the cathode and negative lead to the anode.
- ✧ A healthy thyristor will display an open circuit reading, confirming it can block reverse current.

Step7. Interpreting Test Results: Analyze your readings:

- ✧ Forward voltage drop within range: Good condition.
- ✧ High or low resistance in gate triggering: Potential fault present.
- ✧ Open circuit in reverse blocking: Good condition.

Points to Remember

- **Thyristor** is a **semiconductor device** which comprises of four layers made up of P-type and N-type material arranges in the alternate fashion.
- There are various semiconductor devices which can be classified under the thyristor family. Some of the most used devices are **SCR, DIAC, TRIAC, GATT** etc
- **Applications of Thyristors includes the following:**

  ✓ Rectification Purpose

  ✓ Relay Control

  ✓ Phase Control

  ✓ HVDC transmission

- **Steps to Test a Thyristor Using a Multimeter are listed below:**

  Gather Required Tools>>Disconnect Power (Remove the thyristor from the circuit)>>Identify Thyristor Terminals>>Testing Forward Voltage Drop>>Testing Gate Triggering Functionality>>Testing Reverse Blocking Capability>>Interpreting Test Results.

Application of learning 2.4.

A group of technicians is faced with a malfunctioning power control system that uses thyristors to regulate power delivery to various components. The technicians need test the thyristors to determine if they are functioning correctly.

You are hired by the group to test the thyristors to identify any faulty components.

Indicative content 2.5: Description of optoelectronic components

Duration: 5 hrs

Theoretical Activity 2.5.1: Introduction to optoelectronic components

Tasks:

1: In small groups, you are requested to respond the following questions related to the description of an Optoelectronic component.

i. What is optoelectronic devices?

ii. Identify the types of optoelectronic devices.

iii. What are the applications of optoelectronic devices?

2: Provide the answer for the asked questions and write them on reserved place.

3: Discuss the provided answers and choose the correct answers

4: Follow the trainer while providing expert view.

5: Read the key reading 2.5.1 in your manual for more clarification and ask questions where necessary.

Key readings 2.5.1.:

- **Definition of Optoelectronics**

Optoelectronics is a branch of electronics that deals with converting electrical energy to light and converting light to electrical energy by way of materials called semiconductors. Optoelectronics is a field of technology that deals with the study and application of electronic devices that interact with light. This includes devices that emit, detect, or control light and often involves the use of semiconductors.

Optoelectronic devices are special types of semiconductor devices that are able to convert light energy to electrical energy or electrical energy to light energy. Solid crystalline minerals, which are heavier than insulators but lighter than metals, are used to make this device. An optoelectronic device is an electrical gadget that uses light. Numerous optoelectronics applications, including those in the military, telecommunications, automatic access control systems, and medical equipment, use this technology.

- **Properties of Optoelectronic Devices**
  - ✓ Such devices have a longer wavelength.
  - ✓ They can be easily fabricated.
  - ✓ They are cost-effective.
  - ✓ They have the size of a manometer.
  - ✓ Such devices use high-power light sources.
  - ✓ Optoelectronic junction devices are the p-n junction devices in which the carriers are generated by the photons.
- **Types Optoelectronics**

Optoelectronic devices can be categorized into two different types

- ✓ light detecting devices and
- ✓ Light generating devices.

Some examples of light-sensitive devices re photodiodes, phototransistors, and photo resistors.

Examples of light-generating devices include light emitting diodes (LED), cathode ray tubes (CRT), and laser diodes.

Some examples of optoelectronic devices are:

- ✓ Light-emitting diodes (LED),
- ✓ Solar cells, and
- ✓ Photodiodes.

Let us discuss these devices in detail.

- **Light Emitting Diode (LED)**
  - ✓ **Definition**

LED consists of a heavily doped p-n junction diode and is used in forward bias. As we know p side is rich in holes and the n side is rich in electrons. So when current is applied in forward bias, the electrons from the n side of the diode move towards the p side which has holes. The combination of 1 electron and 1 hole results in the release of a photon which is emitted in form of light that we see in LED.

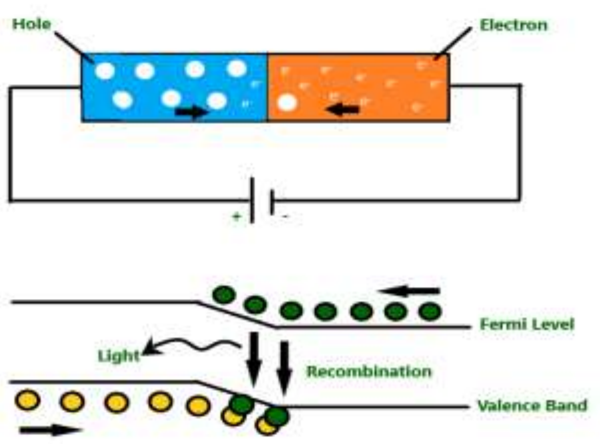


Figure: Working of a LED

- **Properties of LED**
  - The intensity of light emitted by an LED is directly proportional to the magnitude of the current because when more current is applied, more photons will be released and the intensity of light will be more.
  - The Colour of the emitted light depends upon the band gap (the gap between the conduction band and valence band) of the semiconductor.
  - The reverse breakdown voltage for an LED is low.
  - LED can be formed only using compound semiconductors like GaAs.
- **Symbol for LED**

In physics, LED can be represented using the following symbol:

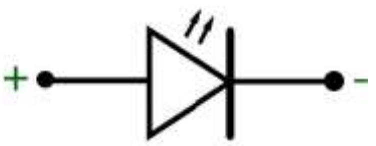


Figure: LED Symbol

- **Advantages of an LED**
  - They are rugged and don't require any maintenance.
  - They have a fast response time.
  - They emit monochromatic light.
  - They need low operational voltage and consume less power

- **Solar Cell**
  - ✓ **Definition**

A solar cell is an electrical device that converts light energy to electrical energy. It is a p-n junction semiconductor that generates electricity only when the energy of incident light is greater than its band gap.

  - ✓ **Working of Solar Cell**

The working of Solar Cells is explained in the article below.

- When the light (photons) of energy greater than the band gap of the semiconductor is thrown into the solar cell, the energy of the photons gets transferred to the cell.
- The energy of the photons is transferred to the electrons in the lower, p-type layer.
- Due to this energy, the electrons can jump to the upper layer i.e. n-type layer, and then move into the circuit through the metallic conducting strips.
- Due to the movement of the electrons, the current is produced in the circuit.

- **Photodiode**
  - ✓ **Definition**

It is a device that converts light energy into electric energy. It is used in reverse bias conditions and is generally made of materials such as Silicon, Germanium, and Indium gallium arsenide.

  - ✓ **Symbol of Photodiode**

In physics, a photodiode can be represented using the following symbol:

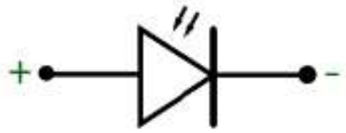


Figure: Photodiode symbol

The symbol for the photodiode is the same as LED except for the fact that the arrows point inwards which means the photodiode absorbs light energy whereas LED emits light energy.

- **Working of Photodiode**
  - ✓ When light having energy greater than the band gap of the semiconductor used in the photodiode is thrown on the photodiode, electron-hole pairs are generated near the depletion region of the p-n junction diode.
  - ✓ These electrons and holes are separated from each other due to the electric field of the depletion region and do not recombine.
  - ✓ Electrons move toward the n side and holes move toward the p side of the semiconductor.
  - ✓ Due to this movement, an emf is observed.
  - ✓ When an external load is connected to a photodiode, the flow of current can be observed in the load.
- **Applications of Optoelectronic devices**

Below mentioned are some of the applications of Optoelectronic devices:

- ✓ LED's have revolutionized lighting system and used in areas like computer components, watches, medical devices, fiber optic communication, switches, household appliances, consumer electronics and 7 segment displays
- ✓ Solar Cells are used in several solar energy based projects for measurement systems, auto irrigation system, solar power charge controller, Arduino based solar street lights, and sun tracking solar panels
- ✓ Optical Fibers are used in telecommunication, fiber lasers, sensors, bio-medicals and other industries
- ✓ Laser Diodes find their use in military applications, surgical procedures, optical

memories, CD players, local area networks and in electrical projects like RF controlled robotic vehicles

Optoelectronic semiconductor devices have a major impact on almost all areas of Information Technology. These devices can be classified based on their functional roles like output, input, processing, transmission, memory and others.

Many technologies and physical properties are exploited by applications using Optoelectronics. Several such applications have come to our understanding and control only during the previous decade.

Practical Activity 2.5.1: Testing optoelectronics components

Task:

1: Referring to previous theoretical activity (2.5.1) you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and test the optoelectronics components using multimeter

2: Follow the trainer when demonstrating how to optoelectronics components

3: Referring to procedures explained by the trainer, perform the given activity.

4: Present your work to the trainer and whole class

5: Read key reading 2.5.2 and ask clarification where's necessary

Key readings 2.5.1

- **Testing optoelectronics components using multimeter**

Testing optoelectronic components, such as LEDs, photodiodes, and optocouplers, using a multimeter involves checking their basic functionality and characteristics.

- **Safety and Precautions:**

- ✓ **Polarity:** Always observe correct polarity to prevent damage to components.
- ✓ **Low Voltage Testing:** Use only the necessary low voltages to avoid damaging sensitive components.
- ✓ **Component Ratings:** Ensure the testing does not exceed the component's voltage and current ratings.

Here's a step-by-step guide for testing some common optoelectronic components:

- **Testing LEDs (Light Emitting Diodes)**
  - ✓ **Objective:** Verify that the LED lights up and check its forward voltage drop.

Steps to follow while testing a LED:

Step1: **Set Multimeter to Diode Mode:** This mode typically has a diode symbol and may also show a forward voltage (V_f) value.

Step2: **Connect Multimeter Leads: Red Lead (Positive)** to the LED's anode (longer leg or marked with a +) and **Black Lead (Negative)** to the cathode (shorter leg or marked with a -).

Step3: **Observation:**

- **LED Lights Up:** If the LED lights up, it is functioning properly. The multimeter display will show the forward voltage drop.
- **No Light or High Voltage Reading:** If the LED does not light up or shows a high voltage reading, it may be faulty or connected in reverse.

- **Testing Photodiodes**
  - ✓ **Objective:** Check the photodiode's response to light.

Steps:

Step1: **Set Multimeter to Voltage Mode:** Set the multimeter to measure DC voltage.

Step2: **Connect Multimeter Leads: Red Lead (Positive)** to the anode and **Black Lead (Negative)** to the cathode.

Step3: **Expose Photodiode to Light:** Shine a light source on the photodiode and observe the voltage reading.

Step4: **Observation:**

- **Voltage Increase:** An increase in voltage indicates the photodiode is responsive to light.
- **No Voltage Change:** If there is no voltage change, the photodiode may be damaged.

- **Testing Optocouplers (Optoisolators)**
  - ✓ **Objective:** Verify the optocoupler's functionality by testing the LED and the phototransistor or photodiode inside.

Steps:

- ✓ **Testing the LED:**

Step1: Use the **diode mode** on the multimeter.

Step2: Connect the red lead to the anode and the black lead to the cathode of the LED side of the optocoupler.

Step3: The multimeter should show a voltage drop, indicating the LED is working.

- ✓ **Testing the Output Side (Phototransistor/Photodiode):**

Step4: **Set Multimeter to Resistance or Continuity Mode:** Connect the leads to the output side (collector and emitter for a phototransistor, or anode and cathode for a photodiode).

Step5: **Apply a Small Voltage (Optional):** You can apply a small voltage to the input side (LED) to activate the optocoupler.

Step6: **Observation: Change in Resistance or Continuity:** A change indicates the output component is responding to the LED's activation. No change may indicate a fault.

Using these methods, you can perform basic functionality tests on various optoelectronic components with a multimeter, verifying that they operate as expected in electronic circuits.

Points to Remember

- Optoelectronic devices are special types of semiconductor devices that are able to convert light energy to electrical energy or electrical energy to light energy.
- Optoelectronic devices can be categorized into two different types
  - ✓ light detecting devices and
  - ✓ Light generating devices.
- Below mentioned are some of the applications of Optoelectronic devices:
  - ✓ LED's are used in areas like computer components, watches, medical devices, fiber optic communication,
  - ✓ Solar Cells are used in auto irrigation system, solar power charge controller, Arduino based solar street lights, and sun tracking solar panels
  - ✓ Laser Diodes find their use in military applications, surgical procedures, optical memories, CD players, etc
- Testing optoelectronic components involves several steps and considerations to ensure accurate measurements.

Steps to follow while testing a LED:

Step1: Set Multimeter to Diode Mode

Step2: **Connect Red Lead** to the LED's anode and **Black Lead** to the cathode

Step3: If the LED lights up, it is functioning properly but if the LED does not light up it may be faulty or connected in reverse.

Steps to follow when Testing Photodiodes

Step1: Set the multimeter to measure DC voltage.

Step2: **Connect Red Lead** to the anode and **Black Lead** to the cathode.

Step3: Shine a light source on the photodiode and observe the voltage reading.

Step4: An increase in voltage indicates the photodiode is responsive to light and if there is no voltage change, the photodiode may be damaged.

Steps to follow when Testing Optocouplers

✓ **Testing the input side made by LED:**

Step1: Use the **diode mode** on the multimeter.

Step2: Connect the red lead to the anode and the black lead to the cathode of the LED side of the optocoupler.

Step3: The multimeter should show a voltage drop, indicating the LED is working.

✓ **Testing the Output Side (Phototransistor/Photodiode):**

Step4: Connect the leads to the output side (collector and emitter for a phototransistor, or anode and cathode for a photodiode).

Step5: You can apply a small voltage to the input side (LED) to activate the optocoupler.

Step6: A change indicates the output component is responding to the LED's activation. No change may indicate a fault.

Application of learning 2.5.

You are working as a technician in an electronics repair workshop and you receive a customer who brought a security system that uses an optoelectronic sensor (such as an infrared LED and photodiode pair) to detect motion. The system is no longer detecting motion.

Your task is to test the optoelectronic sensor and identify if it is faulty.

Indicative content 2.6: Description of integrated circuits (IC)

Duration: 5 hrs

Theoretical Activity 2.6.1: Description of integrated circuits (IC)

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of integrated circuits (IC).

i. What is Integrated Circuits?
ii. Identify the types of Integrated Circuits.
iii. Identify the packaging of Integrated circuits
iv. What are the applications of Integrated Circuits?

2. Discuss and write the findings related to the given tasks on provided place
3. Present your findings to the whole class or your colleagues.
4. Follow the trainer when providing expert view
5. Ask questions for more clarification, if any.
6. Read the **Key readings 2.6.1** in their manuals to get more clarification.

Key readings 2.6.1.:

- **Definition of Integrated Circuits (IC)**

Integrated circuit (IC), also called microcircuit, microchip and chip, is a miniaturized way of circuits (which mainly contains semiconductor devices) that can be machined on the surface of semiconductor wafers to produce various circuit element structures, in other words, it is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material. Therefore, it is also a general name for semiconductor component products, and it put into protective packages to allow easy handling and assembly onto printed circuit boards and to protect the devices from damage.

Thus, integrated circuits (ICs) are a keystone of modern electronics Integrated circuits, also called thin-film integrated circuits, which fabricated on the surface of a semiconductor chip, in addition, another thick-film hybrid integrated circuit is composed of independent semiconductor devices and passive components, which integrated into a substrate or circuit board to form a miniaturized circuit.

- **Types of ICs (Integrated Circuits)**

Integrated Circuits are classified into three types:

- ✓ Based on Mode of Operation
- ✓ Based on Fabrication
- ✓ Based on Complexity

✓ **Based on Mode of Operation**

IC's are classified into two types based on the Mode of Operation or the signal processed. They are:

- Digital IC or Non-Linear IC
- Analog IC or Linear IC

Digital IC or Non-Linear IC

Digital Integrated Circuits are the logical networks capable of performing mathematical calculations and are commercially available as Memory Chip, Microprocessor, Microcontroller, Counters, Logic gates, Registers etc. The input/ output value is either logical high/low (0 or 1).

Analog IC or Linear IC

Analog Integrated Circuits are the discrete networks, which processes the signals that are continuously variable like an audio signal. The values of voltage or current may vary continuously between minimum and maximum values. They are available commercially as Voltage comparators, regulators, op-amps etc.

✓ **Based on Fabrication**

IC's are classified into three types based on the fabrication. They are:

- Monolithic IC
- Thick-Thin Film IC
- Hybrid IC

Monolithic IC

In Monolithic type of Integrated Circuits, all the active and passive components are formed simultaneously by diffusion process on a single silicon chip. It is followed by metallization process to interconnect the components to obtain the required circuit. They are generally used in low power applications.

Thick-Thin Film IC

These are slightly larger than Monolithic IC's and passive components like resistors and capacitors are integrated whereas diodes and transistors are connected as discrete components to obtain the required circuit. Thus, Thick-Thin film IC's incorporating both integrated and discrete components.

Hybrid IC

Hybrid IC's are the combination of two or more monolithic IC's or it is produced using Monolithic IC and Thick-Thin film Integrated Circuit. These are used for high power applications.

✓ **Based on Complexity**

The circuit complexity can be determined by the number of active devices used. Hence Integrated Circuits can be classified in to six types based on the number of components used on a chip. They are:

- Small Scale Integration (SSI)
- Medium Scale Integration (MSI)
- Large Scale Integration (LSI)
- Very Large-Scale Integration (VLSI)
- Super Large-Scale Integration (SLSI)
- Ultra Large-Scale Integration (ULSI)

Small Scale Integration (SSI)

It consists of 10 Transistors or few Gates such as AND, OR, NOT within a single chip.

Medium Scale Integration (MSI)

Transistor count ranges between 10-100 or tens of Gates per chip and are able to perform digital operations like Adders, Decoders, Multiplexers etc.

Large Scale Integration (LSI)

The range is between 100-1,000 Transistors or hundreds of Gates that performs logical operations. LSI is implemented for memory units, ALU etc.

Very Large-Scale Integration (VLSI)

VLSI fabrication is used for Processors, Programmable Logic Devices where the Transistor count ranges between 1,000-10,000 or thousands of Gates.

Super Large-Scale Integration (SLSI)

SLSI is implemented for circuits which require 10,000-100,000 Transistors within a single package like Microprocessor chips, Microcontrollers etc.

Ultra Large-Scale Integration (ULSI)

In this type of fabrication more than 1 Million Transistors are integrated on a single chip. This technique is being used in CPU's, GPU's, FPGA's etc.

- **Packaging of integrated circuits**
  - ✓ **What is IC packaging?**

IC packaging refers to the material that contains a semiconductor device. The package is a case that surrounds the circuit material to protect it from corrosion or physical damage and allow mounting of the electrical contacts connecting it to the **printed circuit board (PCB)**. There are many different types of integrated circuits, and therefore there are different types of IC packaging systems designs to consider, as different types of circuit designs will have different needs when it comes to their outer shell.

  - ✓ **Types of IC Packages**

Many manufacturers are trying to move away from actual lead finish lead-frame IC packages, but they have been in such frequent use for so long that it is a difficult transition for some. The most **common packages** include the following:

- **Pin-grid array:** These are for socketing.
- **Lead-frame and dual-inline packages**: These packages are for assemblies in which pins go through holes.
- **Chip scale package:** A chip scale package is a single-die, direct surface mountable package, with an area that's smaller than 1.2 times the area of the die.
- **Quad flat pack:** A lead-frame package of the leadless variety.
- **Quad flat no-lead:** A tiny package, the size of a chip, used for surface

mounting.

- **Multichip package:** Multichip packages, or multichip modules, integrate multiple ICs, discrete components and semiconductor dies onto a substrate, making it so the multichip package resembles a larger IC.
- **Area array package:** These packages offer maximum performance while still conserving space by allowing any portion of the chip's surface area to be used for interconnection.
- **Small outline packages:** A thin small outline package (TSOP) is an IC component that consists of a rectangular shape with small pins along the horizontal edges. TSOPs are common on ICs that power RAM and flash memory.
- **Quad flat packages:** A quad flat package (QFP) is a flat, square IC component with leads along each of the four edges. QFPs cannot be through-hole mounted, and sockets are rarely available for packages of this type. QFPs can have as few as 32 pins or as many as 304 pins, depending on the pitch range. Variants of the QFP include low-profile and thin.
- **Ball grid arrays:** A BGA is a chip-carrying surface-mount package commonly seen in computer equipment. Unlike other IC packages, where only the perimeter can connect, the entire bottom surface can mount on a BGA. Due to the shorter ball connections, BGAs offer some of the highest speeds of all IC packages. BGAs are common on RAM sticks and USB cards, including RAM and speaker cards. The soldering process on a BGA necessitates precision.

- **Advantages of ICs**

ICs have advantages over those that are made by interconnecting discrete components some of which are:

- ✓ Its small size. It is a thousand times smaller than the discrete circuits. It is an all in one (components and the interconnections are on a single silicon chip).
- ✓ It has little weight.
- ✓ Its cost of production is also low.
- ✓ It is reliable because there are no soldered joints.

- ✓ ICs consume little energy and can easily be replaced when the need arises.
- ✓ It can be operated at a very high temperature.

- **Limitation for different types of ICs**

Despite the advantages that ICs provide us with, it has limitations some of which are:

- ✓ Limited power rating
- ✓ It operates at low voltage
- ✓ High grade of PNP is not possible
- ✓ It produces noise during operation
- ✓ Its components such as resistors and capacitors are voltage dependent
- ✓ It is delicate i.e it cannot withstand rough handling etc.

- **Applications of Integrated Circuit**

The applications of IC's include:

- ✓ **Consumer Electronics:** ICs are widely used in consumer electronics, such as smartphones, tablets, laptops, televisions, home appliances, calculators and digital watches.
- ✓ **Computing:** ICs are integral to computing devices such as desktops, laptops, and servers. In these devices, ICs perform functions such as processing data, storing information, and managing power.
- ✓ **Communications:** ICs are critical in communication systems, including wired and wireless networks, satellite systems, and cellular networks.
- ✓ They are used in **control systems.**
- ✓ **Automotive:** ICs are used extensively in the automotive industry to improve vehicle performance, safety, and convenience.
- ✓ **Healthcare:** ICs are used in medical devices such as pacemakers, ultrasound machines, and insulin pumps. ICs play a critical role in these devices by processing signals, monitoring vital signs, and controlling the delivery of drugs.

Practical Activity 2.6.1: Testing Integrated Circuits

Task:

1: Referring to instructions given the tour trainer, you are requested to perform the given task. The task should be done individually.

As electronician, you are asked to go in the electronic workshop and test the Integrated Circuits using multimeter

2: Follow the trainer while explaining the task and providing the work instructions

3: List out procedures to be used to perform the activity given in task1.

4: Follow the trainer when demonstrating how to test the Integrated Circuits

5: Receive the activity distributed and referring to procedures provided on task 3, perform the given activity.

6: Present your work to the trainer and whole class

7: Read key reading 2.6.2 and ask clarification where's necessary

8: Perform the task provided in application of learning 2.6.

Key readings 2.6.2.:

- **Testing integrated circuits**
  - ✓ **Introduction**

Testing integrated circuits (ICs) with a multimeter is a basic diagnostic procedure that can help determine if an IC is functioning correctly or if it is faulty. Although a multimeter has limitations in testing complex ICs comprehensively, it can still provide valuable information, especially for simple ICs or to check for basic issues like short circuits or incorrect connections.

Testing an Integrated Circuit (IC) under various conditions helps to verify its integrity and performance. Below are the detailed steps for testing an IC using **Shorting Condition**, **Leakage Condition**, **Heating Condition**, and **Input and Output Supply Condition** techniques.

a) Testing an IC Using Input and Output Supply Condition

Testing for short circuits ensures that no unintended connections exist between pins, which could cause malfunction or damage to the IC.

Steps Testing an IC Using Input and Output Supply Condition:

Step1: Power Off the Circuit: Ensure that the circuit containing the IC is powered off to avoid damaging the IC or test equipment.

Step2: Set Multimeter to Continuity/Resistance Mode: Use a multimeter set to continuity or low resistance mode to check for short circuits between pins.

Step3: Test Pins for Shorting: Place the multimeter probes on pairs of adjacent pins (or any pins where a short might occur).

For each pair, the multimeter should show either:

- ✧ **Low resistance (or a beep in continuity mode):** Indicates a short circuit, which should not happen unless the pins are designed to be connected internally.
- ✧ **High resistance/no beep:** Shows that no short exists.

Step4: Verify with the IC Datasheet: Use the IC's datasheet to verify which pins are supposed to be connected. Ensure there are no shorts between pins that should be isolated.

Step5: Repeat for All Pin Combinations: Continue testing all pin combinations until you have checked every possible pair for short circuits.

Step6: Power On and Observe Operation: After testing, power on the circuit and observe if the IC operates correctly without unexpected behavior.

b) Testing an IC Using Leakage Condition

Leakage testing helps identify unwanted small currents that may flow through the IC when it is supposed to be in a non-conductive state, which can cause malfunctions.

Steps Testing an IC Using Leakage Condition are:

Step1: Power Off and Disconnect the IC: Remove the IC from the circuit or ensure the power is off to prevent false readings.

Step2: Set the Multimeter to Current or Diode Mode: Use the multimeter to measure small leakage currents. Set the multimeter to a low current range (nano/microamperes) or diode check mode for specific components.

Step3: Check Diode Junctions (for digital ICs or diodes within the IC): Use the diode test mode to check for proper behavior of PN junctions between pins

Step4: Measure Leakage Current: If the IC is powered, measure the current at specific pins where leakage may occur (e.g., inputs or outputs when they are supposed to be off) and Compare the measured current with the expected leakage current in the datasheet (usually in the microampere or nanoampere range).

Step5: Analyze Results: If the leakage current is significantly higher than the datasheet specifies, the IC may be damaged or defective.

c) Testing an IC Using Heating Condition Techniques

Testing an IC under heating conditions ensures that it operates correctly within its thermal limits and doesn't overheat, which could cause failure.

Steps of Testing an IC Using Heating Condition are:

Step1: Power the Circuit: Power the IC as it would be in normal operation.

Step2: Use an Infrared Thermometer or Thermocouple: Use a non-contact infrared thermometer or attach a thermocouple to measure the IC's temperature.

Step3: Observe IC's Normal Operation Temperature: Monitor the IC's temperature as it operates under normal conditions. Most ICs operate between 25°C and 85°C depending on the type and application. Check the thermal limits in the IC's datasheet.

Step4: Increase Workload (if applicable): If the IC is part of a high-power circuit, increase the load or stress (such as increasing input/output signals) to see how the IC handles higher thermal conditions.

Step5: Check for Overheating Symptoms: Observe if the IC heats up excessively or beyond its specified operating range.

Signs of overheating include:

- Sudden circuit failure.
- Unstable performance.
- Temperature rising above the thermal limit in the datasheet.

Step6: Cool and Retry (if IC overheats): If the IC overheats, turn off the power, allow it to cool, and re-test after ensuring there is adequate cooling (e.g., heat sinks, fans).

Step7: Thermal Shutdown: Some ICs have built-in thermal shutdown protection. Check whether this protection activates under excessive heating, and ensure the IC recovers once it cools.

d) Testing an IC Using Input and Output Supply Condition

This test involves verifying that the IC receives the correct input and produces the expected output under operating conditions.

Steps of Testing an IC Using Input and Output Supply Condition are:

Step1: Connect the IC to the Circuit: Set up the IC in the test circuit, ensuring that all input/output pins are connected properly as per the circuit design and datasheet.

Step2: Set the Multimeter to Voltage/Current Mode:

- For voltage measurements, set the multimeter to the appropriate voltage range (AC or DC depending on the IC).
- For current measurements, set the multimeter to measure current (typically DC for digital ICs).

Step3: Measure Input Voltage: Identify the **Vcc** and **GND** pins from the IC's datasheet and place the multimeter probes on the **Vcc** and **GND** pins to measure the input voltage and ensure it matches the IC's required operating voltage.

Step4: Apply Input Signals: Provide input signals to the IC according to its expected operation (e.g., logic high/low for digital ICs, or analog signals for amplifiers).

Step5: Measure Output Voltage/Current: Identify the output pins from the datasheet then use the multimeter or oscilloscope to measure the output signal or voltage from the IC and after compare the output values with the expected results from the datasheet.

Step6: Test Under Different Loads: Apply different loads to the IC's output (if applicable) and verify that the IC maintains proper output levels across varying conditions.

Step7: Observe for Correct Functionality: Ensure the IC operates as expected under different input and output conditions.

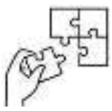
Points to Remember

- Integrated circuit (IC) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material.
- Integrated Circuits are classified into three types:
  - ✧ Based on Mode of Operation (Digital IC or Non-Linear IC and Analog IC or Linear IC)
  - ✧ Based on Fabrication (Monolithic IC, Thick-Thin Film IC and Hybrid IC),
  - ✧ Based on Complexity (Small Scale Integration (SSI), Medium Scale Integration (MSI), Large Scale Integration (LSI), Very Large-Scale Integration (VLSI), Super Large-Scale Integration (SLSI) and Ultra Large-Scale Integration (ULSI))
- The most **common packages** include the following:
  - ✧ Pin-grid array
  - ✧ Lead-frame and dual-inline packages
  - ✧ Chip scale package
  - ✧ Quad flat pack
  - ✧ Quad flat no-lead
  - ✧ Multichip package

- ✧ Area array package
- ✧ Small outline packages
- ✧ Quad flat packages
- ✧ Ball grid arrays

- **Applications of Integrated Circuit**
  - ✧ Consumer Electronics
  - ✧ Computing
  - ✧ Communications
  - ✧ They are used in control systems.
  - ✧ Automotive
  - ✧ Healthcare
- **Steps to Test an IC**

  Testing an Integrated Circuit (IC) under various conditions helps to verify its integrity and performance. Below are the detailed steps for testing an IC using **Shorting Condition**, **Leakage Condition**, **Heating Condition**, and **Input and Output Supply Condition** techniques.



Application of learning 2.6.

You’re working in a repair lab for electronic equipment. A customer has brought in a computer power supply unit (PSU) that’s not functioning correctly. The PSU contains integrated circuit (IC) on the circuit board.

Your task is to test the circuit IC to determine whether it needs to be repaired or replaced.

Learning outcome 2 end assessment

Theoretical assessment

Multiple choice questions:

Q1. A *pn* junction allows current flow when

a) the *p*-type material is more positive than the *n*-type material

b) the *n*-type material is more positive than the *p*-type material

c) both the *n*-type and *p*-type materials have the same potential

d) there is no potential on the *n*-type or *p*-type materials

Q2. When a diode is forward biased, the voltage across it

a) is directly proportional to the current

b) is inversely proportional to the current

c) is directly proportional to the source voltage

d) remains approximately the same

Q3.The diode schematic arrow points to the:

a) trivalent-doped material

b) positive axial lead

c) anode lead

d) cathode lead

Q4. ……………………… cannot be used to fabricate on an IC

a) Transistors

b) Diodes

c) Resistors

d) Large inductors and transformers

Q5. We use ………………..ICs in Computers

a) Digital

b) Linear

c) Both digital and linear

d) None of the above

Q6. **The element that has the biggest size in a transistor is ……………….**

a) collector
b) base
c) emitter
d) collector-base-junction

Q7. In a pnp transistor, the current carriers are …………

a) acceptor ions
b) donor ions
c) free electrons
d) holes

Q8. In a transistor ………………..

a) $I_C = I_E + I_B$
b) $I_B = I_C + I_E$
c) $I_E = I_C - I_B$
d) $I_E = I_C + I_B$

Short answer questions:

Q9. What is VLSI?

Q10. Why are ICs so cheap?

Q11. Why an inductor cannot be fabricated on IC?

Practical assessment

You are an electronics technician tasked with repairing a malfunctioning power supply unit (PSU) from an electronic device. The PSU uses diodes, transistors, and thyristors in its rectification and regulation circuits.

By applying testing techniques, identify the faulty diodes, transistors and thyristors that are shorted (zero resistance in both directions) or open (no conduction in either direction).

END

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Learning Outcome 3: Use electronic lab/ workshop equipment

Indicative contents
3.1 Introduction to electronic workshop **3.2 Description of different electronic lab/ workshop equipment** **3.3 Usage of different electronic lab/ workshop equipment**

Key Competencies for Learning Outcome 3: Usage of different electronic lab/ workshop equipment

Knowledge	Skills	Attitudes
• Description of electronic workshop • Description of electronic workshop equipment	• Applying the use of electronic workshop equipment	• Having innovative mindset • Being a Critical thinker • Being a team player

Duration: 10 hrs

Learning outcome 3 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe appropriately the term “electronic workshop” as used in electronics field.
1. Identify correctly electronic lab/workshop equipment according to their functions
2. Operate adequately electronic lab/workshop equipment according to the their functions
3. Test properly electronic lab/workshop equipment according to their features

Resources

Equipment	Tools	Materials
• Multimeter, oscilloscope, • power supply, • function generator, • Computer, • projector, • soldering station	• Soldering iron, • pliers, • screwdrivers, • breadboard,	• Electronic components, • soldering wire, • jumper wires, • probes,

Indicative content 3.1: Introduction to electronic workshop

Duration: 1 hr

Theoretical Activity 3.1.1: Description of Electronic workshop

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of Electronic workshop.

i. What is electronic workshop?

ii. Identify the conditions of a good workshop

iii. Identify the layout of a good workshop

2: In respective group, pick the question paper and answer for the asked questions

3: Present the findings/answers to the whole class

4: Follow the trainer while providing expert view to clarify your ideas

5: For more clarification, read the key **readings 3.1.1**and ask questions if any.

Key readings 3.1.1.:

Description of Electronic workshop

- **Definition of Electronic workshop**

An **electronic workshop** is a specialized workspace equipped for the design, assembly, testing, and repair of electronic circuits and devices. It typically contains a variety of tools, equipment, and materials needed to work with electronic components such as resistors, capacitors, transistors, integrated circuits, and more.

Basic Workshop is a place where students acquire knowledge on the operation of various processes involved in manufacturing and production. The Workshop Practice course makes students competent in handling practical work in engineering environment. Basic Workshop is also involved in different maintenance/repair works for the Institute or school.

Workshops are spaces designated for the production and repairing of manufactured goods to take place.

Workshops were the only places of production until the advent of industrialization and the development of larger factories. Engineering workshop is the laboratory which provides both the area and tools (or machinery) that may be required for the manufacture or repair of manufactured goods.

- **Purpose of Electronic workshop**

The purpose of the Electronics Workshop is the manufacture and assembly of the electronic equipment and systems necessary for the scientific projects. It also provides services to companies and other agencies by developing specific electronic equipment not commercially available.

For designing electronics components and boards, the workshop technicians have workstations with specific computer applications for the realization of electronic detailed diagrams, printed circuit board (PCB) design and technical documentation.

For the realization of assemblies there are four workstations fully equipped with welders, power supplies, multimeters, smoke filtration stations, as well as the necessary tools and instrumentation for the construction, assembly of components, wiring, and verification of electronic modules.

As an auxiliary infrastructure, there is a small machining workshop for drilling, cutting, sanding, etc. the modules and boxes housing the electronic components. Finally, the workshop is also used to work with microcontrollers, programming of automation, circuit inspecting, and assembly and repair surface mount technology (SMD) circuits.

- **What is a workshop layout?**

A workshop layout refers to the placement of storage, machines, and workbenches in a confined space relative to each other. A workshop layout requires excessive traveling and handling between areas or may have too much disruption or clutter.

- **How do you organize tools in a workshop?**

Firstly, tools should be categorized in a workshop and each tool can be organized further by having a designated and outlined location. Cabinets, chests, and lockers are means of providing storage for these grouped tools. If an open display and increased visibility is preferred, a pegboard or slat wall can be used to hang various kinds of tools either on hooks or in baskets.

- **Design considerations should be made when planning a workshop layout.**

When planning a workshop layout, the most important factor to consider is safety. Appropriate lighting, ventilation, and space work in combination to increase the safety of a workshop. Typical workshop equipment includes storage areas, a workbench, and stationary machines. It is important to note that tools themselves take up and require an amount of space, and this square footage increases when considering the operating space surrounding them.

Points to Remember

- **Definition of Electronic workshop:**
  An **electronic workshop** is a specialized workspace equipped for the design, assembly, testing, and repair of electronic circuits and devices.
- **Purpose of Electronic workshop**
  The purpose of the Electronics Workshop is the manufacture and assembly of the electronic equipment and systems necessary for the scientific projects.
- **Layout of a good workshop**
  A workshop layout requires excessive traveling and handling between areas or may have too much disruption or clutter.
- Tools, materials and equipment should be categorized in a workshop and each can be organized further by having a designated and outlined location.
- Appropriate lighting, ventilation, and space work in combination to increase the safety of a workshop.

Application of learning 3.1.

A local community center has the purpose of hosting a workshop to build simple electronic devices and provide practical skills to its members. They have various tools, materials and equipment that are not arranged.

In short term, you are hired by the company to setup the workshop environment so that they can apply the knowledge and skills to the hosted members effectively.

Indicative content 3.2: Description of different electronic lab/ workshop equipment

Duration: 3 hrs

Theoretical Activity 3.2.1: Description of electronic workshop equipment

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electronic workshop equipment.

i. What is an electronic workshop equipment?

ii. Describe the types of electronic workshop equipment.

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class.

4: Follow the trainer while providing the expert view.

5: For more clarification, read the key **readings3.2.1** and ask questions where necessary.

Key readings 3.2.1.:

- **Introduction**

An electronic workshop is equipped with various tools and equipment essential for designing, building, testing, and repairing electronic circuits and devices.

Electronic workshop equipment refers to the tools, instruments, and devices used in the design, assembly, testing, and repair of electronic circuits and devices. These workshops are essential for professionals and hobbyists working in electronics, enabling them to create and troubleshoot electronic systems.

When working with electronic circuits, you may need hand tools, measuring instruments, power supplies, and soldering stations to set up, test, or operate the actual circuit. It is important that your electronics lab design includes critical electronics equipment. Depending on the budget, you can add more items to your electronic laboratory equipment list, but there are a few standard items that are essential for any electronics lab.

- **Types of workshop equipment**
  - ✓ **Multimeter**

What is a multimeter?

Multimeter, also called a volt-ohmmeter (VOM), is an electronic instrument used to measure various electrical quantities in a circuit. It is a multifunctional tool that combines several measurement functions into one device. The most common measurements for multimeters include voltage, current and resistance.

- **Types of multimeters**

Multimeters are divided into two types depending on the way the indication is displayed: analog and digital.

- ✓ **Analog multimeters** are multifunction electrical measuring instruments with indication by means of an arrow (analog) scale.

Advantages of analog multimeters:

- Possibility to carry out measurements at low temperatures down to -30 ° C.
- Fast operation with a large amount of measurements, when high precision is not required.
- Do not require power consumption from the built-in power supply in the mode of voltage and current measurement.
- Instant display of the dynamics of the signal change.

Disadvantages and features:

- Non-linear scale and setting zero before starting measurements.
- Absence of automatic detection of voltage polarity.
- A small set of functions: most models can measure only DC and AC voltage,

DC current and resistance.

- Low input resistance and, consequently, a high error in low-voltage measurements.
- Sensitivity to mechanical damage, vibration.

✓ **Digital multimeters** are modern, reliable measuring devices characterized by high measurement accuracy and various functional capabilities. Digital devices have replaced analogue in connection with the possibility of wide application of semiconductor technologies. Today most of the produced multimeters are digital. Specialists working with electrical equipment, if necessary, can choose among the digital multimeters a model focused on a specific task.

Advantages of digital multimeters:

- Maximum possible measurement accuracy.
- Automatic polarity detection: If the probes are connected incorrectly, the correct values with a minus sign appear on the screen.
- Possibility of automatic and manual selection of measuring ranges.
- Multifunctionality.
- Does not require mandatory zero adjustment.
- The accuracy of the meter reading does not depend on the battery charge.
- Resistance to mechanical damage.
- The ability to record measurement results in memory and synchronize with a PC.

Digital multimeters can be classified by number of digits, accuracy class, size, protection class, and availability of additional functions or other parameters. For example, the line of multimeters ZEN, depending on the size and purpose of models is divided into 4 groups:

- **What are the functions of multimeter?**

A multimeter is an instrument with multiple functions. Common features include:

✓ **Voltage measurement:** It can measure direct current (DC) voltage and alternating current (AC) voltage. Enables the user to measure the voltage of the component, circuit or power supply.

✓ **Current measurement:** The multimeter can measure DC and AC current. Allows the user to measure the current flowing through a circuit or component.

- ✓ **Resistance measurement:** The multimeter can measure resistance. This feature is useful for testing resistors, checking continuity, and identifying opens or shorts.
- ✓ **Diode test:** usually has a diode test mode function, which allows users to test the forward and reverse bias characteristics of the diode. Helps identify faulty or damaged diodes.
- ✓ **Capacitance measurement:** Some multimeters have a flashlight measurement function, which can measure the capacitance of capacitors. Useful for testing and selecting capacitors in electronic circuits.
- ✓ **Temperature measurement:** Some multimeters also have the function of temperature measurement. Allows the user to measure temperature using a temperature probe or thermocouple. This feature is helpful in a variety of applications including HVAC systems and temperature-sensitive electronic components.
- ✓ **Frequency Test:** Advanced multimeters may have a frequency measurement mode that enables the user to measure the frequency of an AC signal. It is especially useful in electronic circuit analysis and troubleshooting.
- ✓ **Continuity Test:** The multimeter has a continuous mode, which can check whether there is a continuous electrical connection between two points, when there is continuity, it will beep or display a value close to zero ohms, indicating that the circuit or connection is complete.

Key Consideration: Different multimeters may have different additional and specialized functions. This depends on its design and intended application. Always consult the owner's manual or guide before use.

- **How does the multimeter work?**

The working principle of the multimeter is to use different measurement techniques to measure electricity.

While there are many types of multimeters, the common type is the digital multimeter (DMM), which uses analog-to-digital conversion to display measurements on a digital screen.

Here is an overview of how a multimeter generally works:

- ✓ **Voltage measurement:** When measuring voltage, connect the multimeter in parallel to the circuit or component under test. In this mode, the multimeter acts as a high-resistance voltmeter. It uses a voltage divider circuit and an analog-to-digital converter to measure the voltage and display it on the screen.
- ✓ **Current measurement:** Connect the multimeter in series to the circuit when measuring current. In this mode, the multimeter acts as a high-resistance voltmeter. It uses a voltage divider circuit and an analog-to-digital converter to measure the voltage and display it on the screen.
- ✓ **Resistance measurement:** When measuring resistance, the multimeter makes a known small current flow through the component, measures the voltage drop across it, and then uses Ohm's law to calculate the resistance.
- ✓ **Diode test:** When testing a diode, the multimeter applies a small forward bias voltage and measures the resulting current. It detects the direction of current flow and displays the forward voltage drop across the diode, indicating its functionality.
- ✓ **Other measurements:** Advanced multimeters can use other techniques to measure capacitance, frequency, temperature, and other quantities. These measurements involve different measurement circuits and sensors specific to the respective quantities.

Key considerations: Different multimeters have different accuracies, measurement ranges, and capabilities, so it is critical to refer to the manufacturer's instructions and specifications to ensure proper use and accurate measurements for your particular multimeter model.

- **Oscilloscope**
  - ✓ **Definition**

Oscilloscopes or scopes are an important tool in the armory of the electronics engineer or tester. An oscilloscope is an item of electronic test equipment that enables waveforms to be seen and in this way makes it very much easier to see any problems occurring in an electronics circuit.

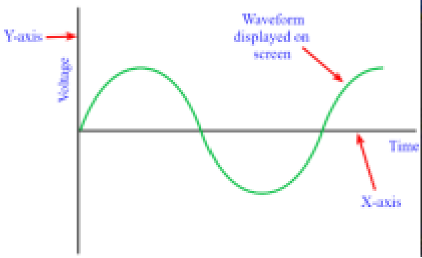
The name oscilloscope comes from the fact that it enables oscillations to be viewed. Sometimes the name cathode-ray oscilloscope, or CRO was used. The reason for this was that cathode ray tubes (CRT) were used to display the waveforms. Nowadays these test instruments just tend to be referred to as oscilloscopes, or just scopes.

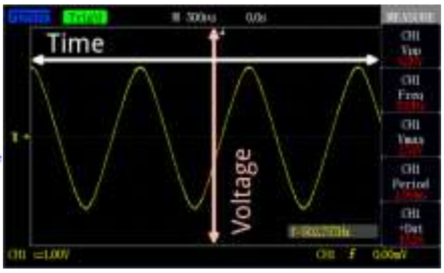
Today, LCDs, or plasma displays are used as they are smaller, and more convenient to use, especially as they do not require the very high voltages of the old CRTs.

- ✓ **Function of an oscilloscope**

The function of an oscilloscope is to be able to display waveforms on some form of display. In the normal mode of operation time is displayed along the X-axis (horizontal axis) and amplitude is displayed along the Y axis (vertical axis).

By seeing a waveform in this manner it is possible to see analyse the operation of the circuit and discover why any problems may exist.





The oscilloscope is one of the most important electronic instruments available for making circuit measurements. It displays a curve plot of time-varying voltage on the oscilloscope screen.

- ✓ **The controls on the oscilloscope are as follows:**
  - The **TIME BASE** control adjusts the time scale on the horizontal axis in time per division when Y/T is selected. When B/A is selected, the horizontal axis no longer represents time. The horizontal axis now represents the voltage on the channel A input and vertical axis represents the voltage on channel B input.

When A/B is selected, the horizontal axis represents the voltage on the channel B input and the vertical axis represents the voltage on the channel A input. The X_POS control determines the horizontal position where the curve plot begins.

- The **CHANNELA** control adjusts the volts per division on the vertical axis for the channel A curve plot. The Y-POS control determines the vertical position of the channel A curve plot relative to the horizontal axis. Selecting AC places a capacitance between the channels A vertical input and the circuit testing point. Selecting “0” connects channel A vertical input to ground.
- The **CHANNEL B** control adjusts the volts per division of the vertical axis for the channel B curve plot. The Y-POS determines the vertical position of the channel B curve plot relative to the horizontal axis. Selecting AC places, a capacitance between the channel B vertical input and the circuit test point. Selecting “0” connects the channel B vertical input to ground.
- The **trigger** settings control the conditions under which a curve plot is triggered (begins to display). Triggering can be internal (based on one of the input signals) or external (based on a signal applied to the oscilloscope external trigger input). With internal triggering AUTO, A, or B. If A is selected, the curve plot will be triggered by channel A input signal. If B is selected, the curve plot will be triggered by channel B input signal. If you expect a flat input wave shape or you want the curve plot displayed as soon as possible, select AUTO. The display can be set to start on positive or negative slope of the input by selecting the appropriate EDGE selection. The trigger LEVEL control determines the voltage level of the input signal waveform, in divisions on the vertical axis, before the waveform will begin to display.

✓ **Key oscilloscope topics**

When looking at oscilloscope there are several key topics and areas of interest:

- **Types of oscilloscope:** There are several different types of oscilloscope from analogue to digital and more. The first types of oscilloscope were analogue, but with the advances in digital technology, virtually all new test instruments these days are processor controlled and use digital signal processing to provide excellent displays of the waveforms.

Not only are there oscilloscopes contained in standard bench style boxes, but some scopes are designed to link to computers, using their display and processing to assist. Often they are USB oscilloscopes, connected via USB links but other types are also available linked via other bus systems or for use within rack systems like PXI and the older VXI systems.

- **Scope specifications:** The specifications for oscilloscopes can sometimes be confusing. A basic understanding of the terms and what they mean is very useful. Understanding the basic oscilloscope specifications can provide an understanding of the limitations of any given test instrument and also help in the selection when one needs to be hired, bought or even booked out of a common store.

The scope specifications are slightly different between the analogue and digital scopes. Although basic concepts like accuracy, time base range, upper frequencies and the like are essentially the same, digital scopes also have specifications to items like the number of DAC bits, memory depth and the like that are specific to digital oscilloscopes.

- **Oscilloscope triggering:** The trigger function is one of the most important functions on an oscilloscope. The scope trigger enables the timebase to "start" at the same point on each cycle of the waveform and this enables to be displayed so it appears still on the screen.

The oscilloscope trigger function has developed considerably since most scopes moved to use digital technology. The digital signal processing available enables the trigger to provide more flexibility and greater functionality so that signals can be investigated more closely to discover problems and issues.

- **Oscilloscope probes:** Any oscilloscope will need probes to attach to the unit under test. The performance and use of these scope probes enables the best to be made of the actual test instrument, so knowing which probes to select, how to set them up, and the limitations are essential for a true understanding of the measurements made.

- **Function/ Signal Generator**
  - ✓ **Definition**

Signal generators come in various forms able to produce a variety of waveforms for different test applications. Some of these test instruments address the RF testing arena, whilst others are used for audio testing, possibly as a sine wave generator, etc and others for providing pulses, possibly for exciting digital circuits. There are thousands of different applications for signal generators.

Signal generators have different types for different purposes and applications. It includes function generators, RF and microwave signal generators, pitch generators, arbitrary waveform generators, digital pattern generators, and frequency generators. Most of these are in electrical and electronics laboratories.

The function generator is a voltage source that supplies different time-varying voltage functions. The Multisim Electronics Workbench can supply sine wave, square wave, and triangular wave voltage functions. The wave shape, frequency, amplitude, duty cycle, and dc offset can be easily changed. It has three voltage output terminals. Connect the COM terminal to ground symbol. The +ve terminal provides output voltage that is positive with respect to the COM terminal and the –ve terminal proves an output voltage that is negative with respect to the COM terminal.

- ✓ **The controls on the function generator are as follows:**
  - You can select a **wave shape** by clicking the appropriate wave shape on the top of the function generator.
  - The **frequency** control allows you adjust the frequency of the output voltage up to 999 MHz. Click up or down arrow to adjust the frequency, or click the

frequency box and type the desired frequency.

- The **AMPLITUDE** control allows you to adjust the amplitude of the output voltage measured from the reference level (common) to peak level. The peak-to-peak value is twice the amplitude setting.
- The **OFFSET** control adjusts the dc level of the voltage curve generated by the function generator. An offset of 0 positions the curve plot along the x-axis with an equal positive and negative voltage setting. A positive offset raises the curve plot above the x-axis and a negative offset lowers the curve plot below the x-axis.

✓ **Types of function generator**

There are a number of ways of designing function generator circuits. However there are two main approaches that may be used:

- **Analogue function generator:** This type of function generator was the first type to be developed. First models appeared in the early 1950s when digital technology was not widely used.

Despite the fact that they use analogue technology, these analogue function generators offer a number of advantages:

- **Cost effective:** Analogue function generators are very cost effective, being at the lower end of the function generator price range.
- **Simple to use:** Analogue function generators provide an effective test instrument that is able to meet most user needs, while remaining simple and easy to use.
- **Maximum frequencies:** The analogue function generators do not have the high frequency limitations on non-sinusoidal waveforms such as triangles and ramps as do the digital functions generators.

- **Digital function generator:** As the name indicates, digital function generators utilise digital technology to generate the waveforms. There are a number of ways in which this can be done, but the most versatile and most widely used technique for digital function generators is to use direct digital synthesis, DDS.

✓ **Signal generator formats**

There are several forms that the function generator can take. With modern digital technology there are many formats for this type of test equipment.

The format for the function generator will depend on factors including the approach that will be adopted for testing, and the environment in which it will be used - rack testing, bench-top testing, or will an accompanying computer be available for control.

- **Soldering station**
  - ✓ **Definition**

A soldering station is an electrical device used for soldering tasks. It comprises soldering tools connected to the control unit, desoldering tools, soldering tip cleaners, holders, stands, and other accessories.

The control unit consists of temperature adjustment knobs, display areas, and an electrical transformer.

- ✓ **Types of Soldering Stations**

Soldering stations are either analog or digital, depending on their mode of operation.

- **An analog soldering station** has a heating element that heats the soldering iron tip to the recommended temperature and then goes off. With time, the iron cools off to a specific limit where the heating element is triggered to heat the iron tip again.
- **A digital soldering station** has a Proportional–Integral–Derivative (PID) controller within its microprocessor to regulate the temperatures. A digital soldering station is more precise and controls the temperature automatically, unlike the analog soldering station, where you must adjust the temperature using an adjustment

knob. A digital soldering station will be the best option if you work on a soldering project that requires high accuracy.

- ✓ **Applications of Soldering**

Soldering is mainly used in electrical engineering to join electrical components in electronics. Other soldering applications include:

Plumbing – to join pipes and fittings

Automobiles – to join radiator cores in automobiles

Electrical industries – to join cables and wires to lugs

Soldering stations are preferred for most soldering tasks because of the different tools that come with them and the flexibility in temperature regulation.

- ✓ **Selection Criteria for a Soldering Station**

The soldering station you use affects the overall outcome of the soldered pieces. You have to consider a few factors so that you can select a soldering station that works well to meet your soldering needs.

Here are some of the considerations to make:

Type of the soldering station – Choose whether to use the digital or analog soldering station keeping in mind their differences in temperature control and accuracy.

The power needed– The wattage for soldering stations ranges from 40-80 watts, and higher wattage allows you to work faster.

Heating element– You can choose whether to use ceramic or nichrome heating elements as they both behave differently when heating. For example, Nichrome is resistant to heat and may heat up slower than ceramic, which heats us fast.

Standards for lead-free soldering – Consider using lead-free components according to the standards for soldering materials.

Temperature adjustment range – It should be wide enough to allow you to solder on larger components that may require more heat.

- **AC/DC power supply**
  - ✓ **Definition**

Power supplies are designed to convert a power source into the type of electricity you need. Some of the most well-known devices convert from AC to DC power, but you also have the option of DC to DC power supplies.

Knowing the differences between AC vs. DC power supplies and when to use each will help you make an informed decision when you need to make a purchase.

- ✓ **What is AC power Supply?**

Alternating current (AC) power is the standard electricity format that comes out of outlets. The name comes from the waveform the current takes. To understand the composition of the AC wave, you need to understand that electrical currents come from a flow of electrons. As the electrons in an AC wave move, they can move in a positive direction, which corresponds to the upward part of the sinusoidal wave created by the current. When the electrons have a negative flow, the wave drops down.

These waves come from alternators at electrical power plants creating AC power. Inside an alternator, a wire loop spins inside a magnetic field. The spinning creates the waves of alternating current when the wire moves into areas of different magnetic polarity. For instance, the current changes direction when the wire spins from the north to the south pole areas of the magnetic field. The waves created in the alternator are significant for AC power's use.

The wave-like motion of AC power gives this electricity form an advantage over DC power. Because it moves in waves, this electricity format can travel farther than DC power. Most outlets in buildings provide AC power. While many electrical devices such as lamps and appliances use AC power, others require converting the electricity into DC format.

- ✓ **What is DC power supply?**

Direct current (DC) power uses electrons that move in a straight line. This linear movement, in contrast to AC's wave motion, gives this current its name. This form of current comes from batteries, solar cells, fuel cells, alternators equipped with commutators that create direct energy, and rectifiers that convert from AC to DC power.

Because DC power is so consistent in the voltage delivered, most electronics require this power type. That's why most electronics have DC power sources in the form of batteries or need to convert AC power from the outlets to DC power through a rectifier. Power supplies often have rectifiers built in along with transformers to raise or lower the voltage to the appropriate level.

Constant voltage for some devices is preferable, such as notebook computers. For such devices, you need an AC-DC power converter if you want to run these electronics from an outlet. The converter transforms the waveform into a steady, straight line. Direct current for electronics is preferable because the highs and lows of alternating current can damage the delicate components inside electronic devices.

- ✓ **AC vs. DC power supply – What's the difference?**

As noted, the main difference between AC and DC power is the direction the electrons flow. This distinction leads to all other differences between these types of electricity. The wave motion of AC power helps this power source travel farther very efficiently because power plants can easily generate large amounts of AC power and deliver it via power lines, which then feed to transformers to step down the voltage until it reaches homes and businesses. When changing the voltage, DC power does not increase or decrease as easily, and therefore cannot travel long distances efficiently.

What is also important to note is the difference between AC and DC power transmission. The power source and its supply are different — the source comes from the transmission lines and feeds electricity directly into a device or through a power supply that converts the power into another form or voltage.

When comparing the difference between AC power and DC power sources, consider whether the electricity comes from a battery or an outlet. Most outlets supply AC power, whereas batteries are the most common source of DC power.

Points to Remember

- **Definition of electronic workshop equipment**

  Electronic workshop equipment refers to the tools, instruments, and devices used in the design, assembly, testing, and repair of electronic circuits and devices.

- **Types of workshop equipment are:**
  - **Multimeter,** also called a volt-ohmmeter (VOM), is an electronic instrument used to measure various electrical quantities in a circuit.
  - **Oscilloscopes** or scopes are an important tool in the armoury of the electronics engineer or tester.
  - **Signal generators** come in various forms able to produce a variety of waveforms for different test applications.
  - **A soldering station** is an electrical device used for soldering tasks.
  - **Power supplies** are designed to convert a power source into the type of electricity you need.

Application of learning 3.2.

You've just been hired as the head technician for a high school's newly established electronics lab. The school wants to ensure that students get hands-on experience with various electronic components and lab equipment. Your tasks involve setting up the lab, ensuring that all equipment is properly installed and calibrated, and preparing a guide for students on how to use the equipment safely and effectively.

Indicative content 3.3: Usage of different electronic lab/ workshop equipment

Duration: 6 hrs

Practical Activity 3.3.1: Apply the use of different electronic lab/ workshop equipment

Task:

1: Referring to the explanation given by your trainer, you are requested to perform the given task. The task should be done individually.

As a Technician, you are asked to go in the electronic workshop, solder two resistors of different resistances in parallel connected in series with one inductor and one capacitor to the Printed Circuit Board (PCB). After, apply the measurement of total resistance of these resistors, supply the circuit with 9Vdc and analyse the output waveform of the circuit.

2: Follow the trainer when demonstrating how to solder, supply and analyse the waveform of the circuit

3: referring to procedures written on task 2, perform the given activity.

4: Read key reading 3.3.2 and ask clarification where's necessary

5: Perform the task provided in application of learning 3.3.

Key readings 3.3.1

- **Use of Soldering Stations**
  - ✓ **How to Use Soldering Stations?**

Once you've got your soldering station set up in place, following these steps will make sure you're ready to solder safely and efficiently:

Step1: Start with safety: the first step should always be to prepare the space and put on appropriate personal protective equipment (PPE) such as gloves, glasses and long sleeves. Making sure all the tools you need, such as desoldering tools, support racks and a sponge, are close by and that anything flammable or potentially dangerous is removed from the workbench will enable you to work safely.

Step2: Power on the device: To start using the soldering station, you need to supply it and power it on.

Step3: Get a clean soldering tip: as well as choosing a soldering tip that's the right size and shape for your needs, making sure it's completely clean will stop any dangerous or damaging particulates from entering your electronic components.

Step4: Select a temperature: whether you're using a digital or analogue main control unit, you need to set the right temperature for your task. This is usually done by turning a dial or adjusting the controls on a digital display

Step5: Add soldering material: once the tip has reached the right temperature, add your soldering material of choice to it. Make sure you don't have too much excess, as this will cause problems when you start your detailed work

Step6: Begin the assembly or repair: using the pencil at an angle and maintaining the right amount of material on the tip will help you to achieve a good solder. The final product shouldn't have any gaps or cracks and leave a visible glossy line.

- **Use of Multi-meter**
  - ✓ **How to use a multimeter?**
- ✓ **General Steps for Using a Multimeter**
    - **Preparation:**
      - **Turn off Power:** For safety, turn off the power to the circuit you're testing, especially when measuring resistance or continuity.
      - **Select Measurement Mode:** Turn the multimeter dial to the desired measurement type (Voltage, Current, Resistance, etc.).
- **Voltage Measurement:**
  - ✓ **AC Voltage:**
    - Set the multimeter to the AC voltage mode (usually indicated by a "V~" symbol).
    - Connect the multimeter leads to the circuit or component where you want to measure voltage.

- Red lead to the point you want to measure voltage from.
- Black lead to the ground or reference point.

- Read the voltage value displayed on the multimeter.

- ✓ **DC Voltage:**
  - Set the multimeter to the DC voltage mode (indicated by a "V—" symbol).
  - Connect the leads similarly to measure DC voltage.
  - Read the voltage value displayed.

- **Current Measurement:**
  - ✓ **AC or DC Current:**
    - Turn off the power to the circuit and open the circuit where you want to measure current.
    - Set the multimeter to the appropriate current mode (AC or DC, indicated by "A~" for AC or "A—" for DC).
    - Connect the multimeter leads in series with the circuit:
      - Red lead to the positive side of the open circuit.
      - Black lead to the negative side.
    - Turn the power back on and read the current value on the multimeter.

Note: Use the correct current range setting on the multimeter to prevent damage. For high currents, use a dedicated high-current range or a clamp meter.

- **Resistance Measurement:**
  - ✓ **Resistors and Circuits:**
    - Set the multimeter to the resistance mode (indicated by the symbol "Ω").
    - Connect the multimeter leads across the resistor or circuit segment where you want to measure resistance.
      - Red lead to one end of the resistor.
      - Black lead to the other end.
    - Read the resistance value displayed. If the resistor is in-circuit, ensure there is no parallel path affecting the measurement.

- **Continuity Testing:**
  - ✓ **Checking Connections:**
    - Set the multimeter to continuity mode (often indicated by a symbol

resembling a sound wave or a diode symbol with a beep).

- Connect the leads across the points you want to test for continuity.
- If the circuit is continuous (low resistance), the multimeter will beep or show a low resistance value. No beep or infinite resistance indicates any continuity.

- **Diode Testing:**
  - ✓ **Testing Diodes:**
    - Set the multimeter to diode mode (usually indicated by a diode symbol).
    - Connect the leads to the diode terminals:
      - Red lead to the anode.
      - Black lead to the cathode.
    - The multimeter will display the forward voltage drop of the diode if it's functioning correctly. Reverse the leads, and the meter should show "OL" or high resistance, indicating the diode is blocking current.
- **Capacitance Measurement:**
  - ✓ **Measuring Capacitors (if supported):**
    - Set the multimeter to the capacitance mode (indicated by a symbol of a capacitor).
    - Connect the leads to the capacitor terminals.
    - Read the capacitance value displayed.
- **Inductance Measurement:**
  - ✓ **Measuring Inductors (if supported):**
    - Set the multimeter to the inductance mode (if available).
    - Connect the leads to the inductor terminals.
    - Read the inductance value displayed.
- **Safety Tips**

  - ✓ **Avoid Measuring High Voltages:** Be cautious when measuring high voltages or currents. Use appropriate multimeter settings and safety precautions.
  - ✓ **Check Multimeter Limits:** Ensure the multimeter's range and limits are suitable for the measurements you're performing to avoid damage.
  - ✓ **Inspect Leads and Probes:** Regularly check that leads and probes are in good

condition and properly connected.

Using a multimeter correctly helps in troubleshooting and ensuring the proper functioning of electrical and electronic circuits.

- **Use of Oscilloscope**
  - ✓ **Steps of using an oscilloscope**

Using an oscilloscope is quite easy once one has been used and it is possible to become familiar with the use of the controls:

- **Turn power on:** This may appear obvious but is the first step. Usually the switch will be labeled "Power" or "Line". Once the power is on, it is normal for a power indicator or line indicator light to come on. This shows that power has been applied.
- **Wait for oscilloscope display to appear:** Although many oscilloscopes these days have semiconductor-based displays, many of the older ones still use cathode ray tubes (CRTs), and these take a short while to warm up before the display appears. Even modern semiconductor ones often need time for their electronics to "boot-up". It is therefore often necessary to wait a minute or so before the oscilloscope can be used.
- **Find the trace:** Once the oscilloscope is ready it is necessary to find the trace. Often it will be visible, but before any other waveforms can be seen, this is the first stage. Typically, the trigger can be set to the centre and the hold-off turned fully counter-clockwise. Also set the horizontal and vertical position controls to the centre, if they are not already there. Usually, the trace will become visible. If not the "beam finder" button can be pressed and this will locate the trace.
- **Set the gain control:** The next stage is to set the horizontal gain control. This should be set so that the expected trace will nearly fill the vertical screen. If the waveform is expected to be 8 volts peak to peak, and the calibrated section of the screen is 10 centimeters high, then set the gain so that it is 1 volt / centimeter. This way the waveform will occupy 8 centimeters, almost filling the screen.

- **Set the time base speed:** It is also necessary to set the time base speed on the oscilloscope. The actual setting will depend on what needs to be seen. Typically, if a waveform has a period of 10 ms and the screen has a width of 12 centimeters, then a time base speed of 1 ms per centimeter or division would be chosen.
- **Apply the signal:** With the controls set approximately correctly the signal can be applied and an image should be seen.
- **Adjust the trigger:** At this stage it is necessary to adjust the trigger level and whether it triggers on the positive or negative going edge. The trigger level control will be able to control where on the waveform the time base is triggered and hence the trace starts on the waveform. The choice of whether it triggers on the positive or negative going edge may also be important. These should be adjusted to give the required image.
- **Adjust the controls for the best image:** With a stable waveform in place, the vertical gain and time base controls can be re-adjusted to give the required image.

- **Use of Function generator**
  - ✓ **How do you set up a function generator?**

The typical specifications for a general-purpose function generator are as follows:

- Produces pulse output, saw tooth, triangular, square, and sine.
- Output amplitude up to 10 V peak-to-peaks.
- Support for phase modulation, frequency modulation, or amplitude modulation.
- Some function generators are able to be phase-locked to an external signal source, which could be another function generator or a frequency reference.
- Frequency stability of 500 ppm for a digital generator or 0.1 per cent per hour for analogue generators.
- It can generate a broad range of frequencies.
- An output impedance of 50 Ω.
- Some function generators will supply a DC offset voltage.

- You can modify the amplitude, typically by a calibrated attenuator with continuous adjustment for every decade step.

Of course, there are differences with every function generator, but this should help you to get an understanding of what to expect.

- ✓ **Steps of using a function generator**

Let's take a look at them so you can get a better understanding:

- Power on the generator and choose the desired output signal, i.e. triangle wave, sine wave, and square wave.
- The output leads should now be connected to an oscilloscope so that the output signal is visualized.
- Use the frequency and amplitude controls to set the parameters.
- The function generator's output leads need to be attached to the input of the circuit you want to test.
- The output of your circuit needs to be attached to an oscilloscope or meter so that the resulting change in signal is visualized.

- **Use of power supply**

Here is a step-by-step guide on how to use a DC power supply:

- Choose the correct DC power supply for your needs. There are many different types and sizes of DC power supplies available on the market. Select one that will be able to provide the correct amount of power for your project.
- Connect the DC power supply to your device. Make sure that the polarity is correct before turning on the power supply. Incorrect polarity can damage your equipment.
- Turn on the DC power supply and slowly increase the voltage until you reach the desired level.
- Once you have reached the desired voltage, you can begin using your device.
- When you are finished, turn off the power supply and disconnect it from your device.

Follow these simple steps and you will be able to use a DC power supply properly. Remember to exercise caution when working with electricity and always consult a professional if you are unsure about something.

Points to Remember

Apply the use electronic workshop equipment including:

- **Procedures of using a Soldering Stations**

Step1: Prepare the space and put on appropriate personal protective equipment (PPE)

Step2: You need to supply the soldering station and power it on.

Step3: Choose a soldering tip that's the right size and shape for your needs,

Step4: You need to set the right temperature for your task.

Step5: Add your soldering material of choice to it.

- **Procedures of Using a Multimeter**

Step1: Preparing the Multimeter by checking the Probes: Before using the multimeter, ensu re that the probes are in good condition.

Step2: Select Measurement Type: Turn the selection knob to choose what you want to meas ure: AC voltage (V~), DC voltage (V–), resistance (Ω), or current (A).

- **Procedures of Using an Oscilloscope:**

Step1: Turn power on the oscilloscope by pressing the power button

Step2: Find the trace: Usually, the trace will become visible. If not the "beam finder" button can be pressed and this will locate the trace

Step3: Apply the signal: With the controls set approximately correctly the signal can be appl ied

- **Procedures of using the Function generator**

Step1: Power on the function generator.

Step2: Connect the output of the function generator to the oscilloscope and circuit under te st.

Step3: Select the type of waveform you want using the waveform selector.

Step4: Set the frequency and adjust the amplitude using the frequency control knob and the amplitude knob.

Step5: Enable the output to start generating the signal.

Step6: Verify the waveform on the oscilloscope to ensure everything is set correctly.

- **Step-by-step guide on how to use a DC power supply:**

Step1: Choose the correct DC power supply for your needs.

Step2: Connect the DC power supply to your device.

Step3: Turn on the DC power supply to start using your device.

Step4: When you are finished, turn off the power supply and disconnect it from your device.

Application of learning 3.3.2

A group of electronics students has completed a course on electronic components and lab equipment usage and engage in starting their own company. They decide to apply their knowledge by designing and building a power supply unit. Their goal is to create a non-regulated power supply with specific features, and they will use various electronic lab/workshop equipment for this project.

Learning outcome 3 end assessment

Theoretical assessment

1. Name the parts of the following equipment labeled from (1) to (4).

2. Match the items in column A to its corresponding function in columnB:

ColumnA: Items	ColumnB: Functions (Uses)
1. Function generator	a. It converts AC power from a standard outlet into a stable DC power source.
2. Multimeter	b. It tests and displays voltage signals as waveforms, visual representations of the variation of voltage over time.
3. DC power supply	c. It is a piece of electronic test instrument used to generate and deliver standard waveforms, typically sine and square waves, to a device under test.
	d. It is a test tool used to measure two or more electrical values. It is a standard diagnostic tool for technicians in the electrical/electronic industries.

Practical assessment

There is a company, which is hiring technicians, and you are one among them and after passing written exam, you are invited to pass practical exam where you have been asked to build up a simple charger comprising of a step down transformer with 9Vac, a full rectifier circuit and a smoothing capacitor of 2200μF and then analyse the output of each stage using an a multi-meter and oscilloscope.

END

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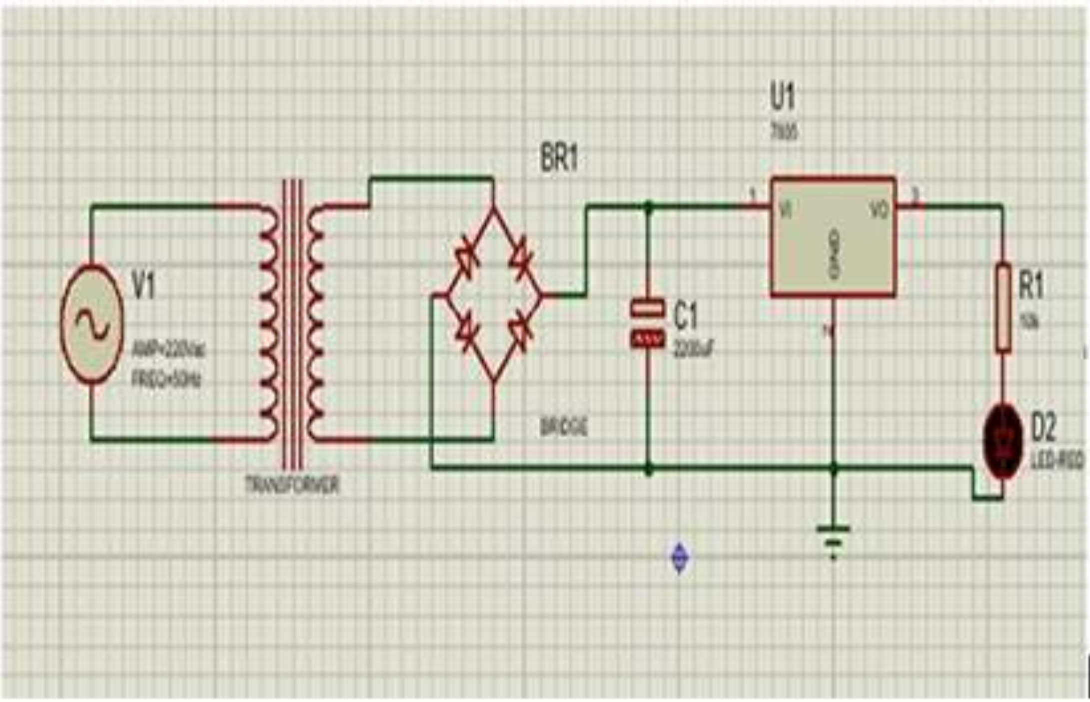

U1
BR1
V1
C1
R1
D2
BRIDGE
TRANSFORMER

Indicative contents

1.1 Introduction to electronic symbols

1.2 Identification of electronic symbols

1.3 Identification of electronic simulation software

1.4 Description of electronic simulation software environment

1.5 Designing circuits diagrams in electronic simulation software

Key Competencies for Learning Outcome 4: Use electronic circuit simulation software

Knowledge	Skills	Attitudes
• Description of electronic circuit simulation software, • Description of electronic circuits, • Description of electronic symbols	• Applying the use of simulation software • Designing electronic circuits, • Designing PCB layout	• Being a team player • Having innovative mindset • Being a Critical thinker

Duration: 10 hrs

Learning outcome 4 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify appropriately electronic symbols according to the standards
2. Identify properly electronic circuits simulation (ECS) software according to their types and uses
3. Describe correctly ECS software graphic interface according to its settings functions.
4. Design accurately circuits diagrams according to the given tasks
5. Simulate successfully Circuits diagrams according to the given tasks

6. Design appropriately the Printed Circuit Board according to the given tasks.

Resources

Equipment	**Tools**	**Materials**
• Computer, • Projector	• Simulation software	• Various cables, • Flash disk/memory card

Indicative content 4.1: Introduction to electronic symbols

Duration: 1 hr

Theoretical Activity 4.1.1: Description of electronic symbols

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electronic symbols

i. What is an electronic symbol?
ii. Identify the role of electronic symbol.

2. Discuss and write the findings related to the given tasks on provided place
3. Discuss on the provided findings and choose the correct answers
4. Follow the trainer when providing expert view
5. Ask questions for more clarification if any.
6. Read the **Key readings 4.1.1** in their manuals to get more clarification.

Key readings 4.1.1.:

- **Introduction of Electronic symbol**
  - ✓ **Definition of Electronic symbol**

Electrical symbols are a graphical representation of basic electrical and electronic devices or components. These Symbols are used in circuits and electrical diagrams to recognize a component. It is also called a schematic symbol. Each component has typical functionality according to its operational characteristics.

An electronic circuit or schematic drawing uses a wired path between electronic components to complete the circuit. These components are represented by respective symbols for it. Electrical and electronic symbols used in circuits are defined by various national and international standards. E.g. IEC standard, JIC standard, ANSI standard, IEEE standard, etc.

Though electrical symbols are standardized, they may vary from country to country, or engineering disciplines, based on traditional conventions.

This enables anyone to read electrical circuits or Electrical schematic diagrams and floor plans with ease and clarity.

- ✓ **Roles of the Symbols**

Electronic symbols primarily use for simplifying drafting and making circuit diagrams easier to understand. The whole industry uses the same symbols. A symbol's precise meaning is provided by the inclusion of a dot, line, letter, letter spacing, shading, and number. One has to be familiar with the basic structure of various symbols to comprehend circuits and their corresponding symbol meanings.

These symbols, which are represented by electronic drawings, are required for circuit design to communicate information about wiring, layouts, equipment locations, and its intricacies so that component arrangement may be done with ease.

- **Simple Accessibility** - A symbol undergoes production once, and, from that onward, it is accessible to anybody on the network.
- **Reduces confusion in production** - By using a defined set of electrical symbols, it is impossible to assign various symbols to similar components.
- **Lessens Rework** - By developing and using a single, standardized set of electrical symbols, unnecessary and redundant schematic rework is eliminated. You won't need to go back and use the proper symbol on the second or third review if you use the authorized one the first time.
- **Saves Time** - Standardized electrical symbols not only save time on rework and misunderstandings, but they also make it much simpler to find the right symbol in your company's shared symbol library. You may be sure you're taken to the right file by using the search's symbol name, type, or manufacturer filters. There's no need to look for or try to discern which symbol's incarnation to utilize.

Points to Remember

- **Definition of Electronic symbol**

  Electrical symbols are a graphical representation of basic electrical and electronic devices or components.

- **Roles of the electronic Symbols**

  Electronic symbols primarily use for simplifying drafting and making circuit diagrams easier to understand.

Application of learning 4.1.

A group of electronics students has completed a course on electronic components and lab equipment usage and engage in starting their own company. They need to create a schematic diagram using electronic symbols to clearly communicate their circuit design. The project involves building a basic flashing LED circuit to learn about electronic symbols and circuit design.

Using electronic symbols, create a clear and accurate schematic diagram for a basic flashing LED circuit (This comprises a battery, a switch, a resistor and a LED).

Indicative content 4.2: Identification of electronic symbols

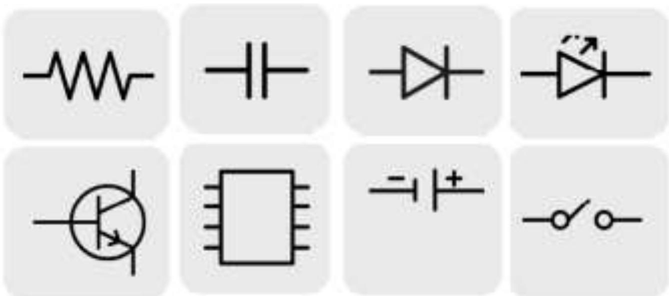
Duration: 2 hrs

Theoretical Activity 4.2.1: Identification of electronic symbols

Tasks:

1: In small groups, you are requested to answer the following questions related to the identification of electronic symbols.

a) Identify the electronic components of given symbols on the figure provided below:



2. Discuss and write the findings related to the given tasks on provided place
3. As group representative, present your findings to the whole class or your colleagues.
4. Ask questions for more clarifications, if any.
5. Read the **Key readings 4.2.1** in their manuals to get more clarification.

Key readings 4.2.1.:

- **Identify electronic symbols**
  - ✓ **Power sources symbols**

There are many different types of power sources, and here some of the most common types that are mainly used in electronics. These can be classified into two main types: AC and DC.

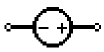
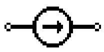
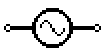
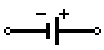
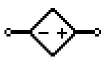
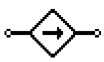
DC have its subtypes, DC voltage and DC current, same goes for AC.

DC voltage can be supplied by using a battery or by a power supply circuit; power supply circuit is also a variable type supply depending on its design construction.

AC on the other hand is be supplied by the "power sockets" that are readily available at homes, or a generator that generates power using fuel. There are also variable types of AC power but it still depends on its design construction.

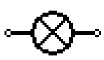
The following table lists some power sources used as electronics symbols:

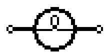
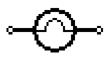
Symbols of power sources

Symbol	**Component name**	**Meaning**
	Voltage Source	Generates constant voltage
	Current Source	Generates constant current.
	AC Voltage Source	AC voltage source
	Generator	Electrical voltage is generated by mechanical rotation of the generator
	Battery Cell	Generates constant voltage
	Battery	Generates constant voltage
	Controlled Voltage Source	Generates voltage as a function of voltage or current of other circuit element.
	Controlled Current Source	Generates current as a function of voltage or current of other circuit element.

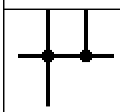
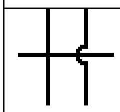
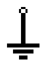
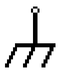
✓ **Inputs and loads symbols**

Electronic loads are load devices that can be set to the desired resistance value. Internally, they are made up of a combination of semiconductor elements. Since the repeated and rapid changing of loads is not possible by human hands, electronic loads is used to evaluate batteries and power supplies.

1. Lamp / Light Bulb Symbols		
	Lamp / light bulb	Generates light when current flows through

	Lamp / light bulb	
	Lamp / light bulb	

Symbols of wiring

Symbol	**Component name**	**Meaning**
	Electrical Wire	Conductor of electrical current
	Connected Wires	Connected crossing
	Not Connected Wires	Wires are not connected
Ground Symbols		
	Earth Ground	Used for zero potential reference and electrical shock protection.
	Chassis Ground	Connected to the chassis of the circuit
	Digital / Common Ground	

Points to Remember

- Identify symbols of basic electronic components such as:
  - ✓ **Power sources symbols**

There are many different types of power sources, and here some of the most common types that are mainly used in electronics. These can be classified into two main types: AC and DC.

DC have its subtypes, DC voltage and DC current, same goes for AC.

  - ✓ **Wiring symbols**

Electronic loads are load devices that can be set to the desired resistance value. Internally, they are made up of a combination of semiconductor elements. They include lamps or any other consumer.

Application of learning 4.2.

An Electrical Company is tasked with designing a new simple automatic LED lighting. Before designing, they need to create a schematic diagram for their design using electronic symbols to ensure proper component connections and functionality.

You are one of the team, draw a schematic diagram for a simple automatic LED lighting, ensuring all electronic components are correctly identified and connected using standard electronic symbols.

Indicative content 4.3: Identification of electronic simulation software

Duration: 1 hr

Theoretical Activity4.3.1: Describing the electronic simulation software

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electronic simulation software

i. What is electronic simulation software?

ii. Enumerate the types of electronic simulation software.

iii. Identify the most popular simulation software.

2: Provide the answer for the asked questions and write them on reserved place.

3: Discuss on the provided answers and choose the correct answers.

4: Follow the trainer when providing expert view.

5: In addition, ask questions where necessary.

6: For more clarification, read the key **readings 4.3.1.**

Key readings 4.3.1.:

- **Description of electronic simulation software**
  - ✓ **Definition of electronic simulation software**

Circuit Simulation and Designing is a process of simulating, analyzing, and creating electronic circuits. Using special simulation and design software, we can easily and efficiently analyze the overall circuit behavior, performance, and characteristics instead of doing it all manually.

A circuit simulator is a piece of software that emulates the behavior of a real hardware circuit before it is built. The circuit simulator can be used to verify that a hardware design is behaving correctly and producing the desired output signal for a specified set of inputs.

We can analyse complex circuits, and get to know how a circuit behaves for different conditions, current and voltage characteristics, component requirements, etc. According to that, we can optimize our circuit and overall device performance.

- ✓ **Need for Circuit Simulation**
  - It is clear that using circuit simulation, we can test the functionality of a circuit without actually building the circuit.
  - Circuit simulation is cost efficient, time saving and we can easily design complex circuits using the software. This saves design engineers and companies a lot of time and money.
  - Engineers can reduce the wastage of valuable hardware resources and proceed to build hardware only after they get satisfactory and accurate results from simulation.
  - We can easily re-design the circuit based on the simulation results. At each stage of design and simulation, engineers can verify the performance and compare it to the theoretical responses.
  - Circuit Simulation Software is the starting point of a new concept or idea. You could also modify existing projects without designing PCBs.
  - Just like physical probing and observing waveforms on an oscilloscope, we can do the same in circuit simulation. You can easily probe different points in a circuit and view the virtual waveforms.

- **Types of Circuit Simulation**

Let us now see different types of circuit simulations. We can categorize simulation into the following three way:

- ✓ Analog Circuit Simulation
- ✓ Digital Circuit Simulation
- ✓ Mixed-Mode Circuit Simulation

Analog

As the name suggests, in analog simulation, we usually work with analog components and signals. In this simulation, the mathematical models must be highly accurate to run frequency domain (AC), time domain (transient) and non-linear quiescent (DC) modes.

SPICE and Fast SPICE are two popular analog simulators that use very accurate linear and non-linear component models to analyze a circuit's behavior.

Digital

When we compare the complex mathematical models of analog simulators, digital simulators are relatively simple. HDL such as Verilog and VHDL are the backbone of digital simulation.

Unlike analog simulators, where we need continuously varying signals, in digital simulation, we actually work with two discrete voltage levels. In digital electronics, we call them as Logic 0 and Logic 1.

Mixed-Mode

It is a combination of both analog and digital simulations. This type of simulation is very useful in mixed circuit system design and analysis. With the mixed-mode simulation, the analog and digital parts are separate entities with respective tools and resources.

- **Popular Simulation Software**

There are several circuit simulator tools and software in the market. SPICE, which is short for Simulation Program with Integrates Circuit Emphasis, is an extremely popular circuit simulator. University of Berkeley's Electronics Research Laboratory developed this software, originally intended for U.S. Department of Defense.

Since it is open-source software, it became extremely popular choice for several other designers, who designed their own simulators using SPICE algorithms. One such tool is LTspice.

Another popular SPICE based circuit simulator is NI's Multisim. But unlike LTspice, it is paid software. Here is a list of some popular circuit simulator software.

- ✓ NI Multisim
- ✓ Autodesk Eagle
- ✓ LTspice
- ✓ PSIM
- ✓ EasyEDA
- ✓ KiCAD
- ✓ CEGAR Logic Simulator
- ✓ Tina TI
- ✓ idealCircuit
- ✓ Proteus

Points to Remember

- Definition of electronic simulation software
  A circuit simulator is a piece of software that emulates the behavior of a real hardware circuit before it is built.
- We can categorize simulation into the following three types:
  - Analog Circuit Simulation we usually work with analog components and signals.
  - Digital Circuit Simulation we actually work with two discrete voltage levels
  - Mixed-Mode Circuit Simulation It is a combination of both analog and digital simulations
- Here is a list of some popular circuit simulator software:
  - NI Multisim, Autodesk Eagle, LTspice, PSIM, EasyEDA, KiCAD, CEGAR Logic Simulator, Tina TI, idealCircuit, Proteus

Application of learning 4.3.

An Electrical Company is tasked with designing a new simple electronic gadget- an automatic LED lighting. They are now tasked with designing a prototype for automatic LED lighting. They decide to use electronic simulation software to design, test, and refine their system before building a physical prototype.

You as one of the team, develop a simulation model for a automatic LED lighting before physical implementation.

Indicative content 4.4: Description of electronic simulation software environment

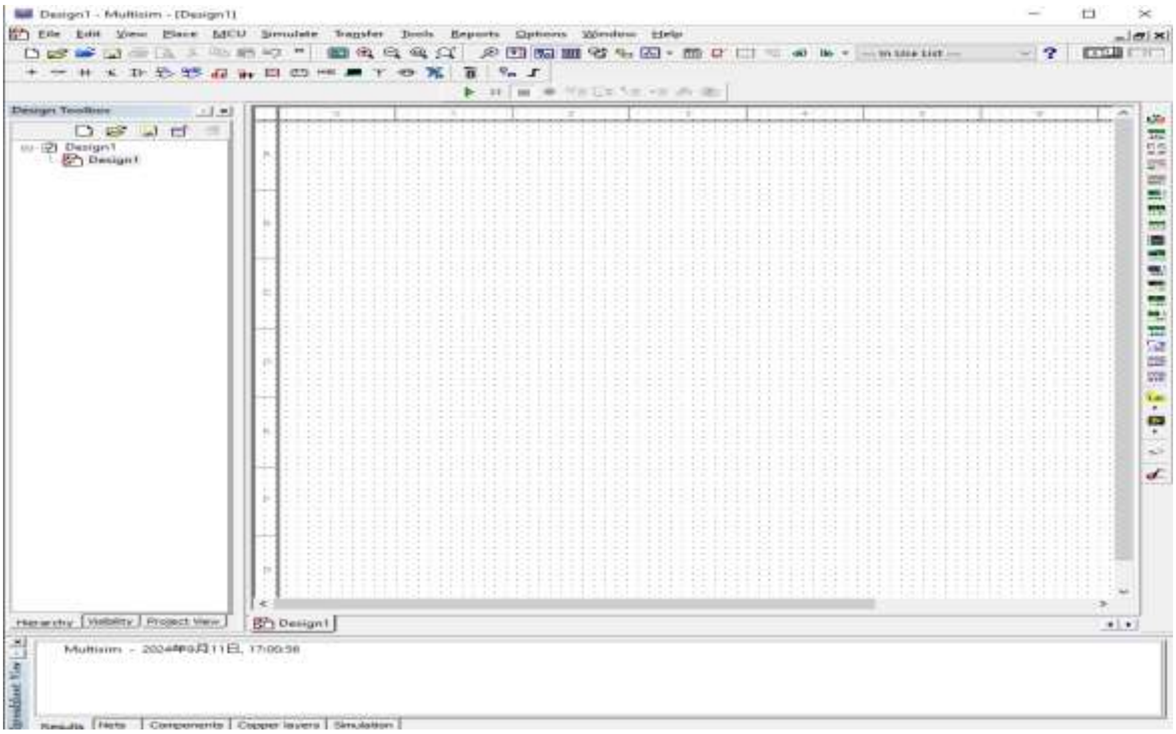
Duration: 2 hrs

Theoretical Activity 4.4.1: introduction to electronic simulation software environment

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electronic simulation software environment

a) Observe the image below and discuss the electronic simulation software environment:



b) What are the key features to consider when choosing the simulation software?

2: Answer for the asked questions and write them on reserved place.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 4.4.1**and ask questions where's necessary.

Key readings 4.4.1.:

- **Description of simulation software**
  - ✓ **Definition of Simulation software environment**

A software environment is a collection of programs, libraries, and utilities that allow users to perform specific tasks. Software environments are often used by programmers to develop applications or run existing ones. A software environment for a particular application could include the operating system, the database system, specific development tools, or compilers.

- ✓ **What are examples of software environments?**

The Java Development Kit (JDK) is one example of a software environment. The JDK contains tools for developing Java-based applications. The JDK also includes an integrated development environment (IDE), which allows developers to write code in one window while viewing output from another window. IDEs are designed with features such as syntax highlighting and auto-completion to make programming easier for developers.

Other examples of software environments include MATLAB and RStudio, both of which provide advanced statistical analysis capabilities; Python 3, which provides a high-level programming language; and Ubuntu Studio, which is based on Linux but has additional multimedia editing capabilities built-in.

- ✓ **Key Features to Look for in Circuit Simulation Software**

When choosing circuit simulation software, several key features are essential to consider:

- **User-Friendly Interfac**e: Intuitive and easy-to-use software allows users to quickly design and simulate circuits without a steep learning curve.
- **Wide Component Library**: A comprehensive component library with various electronic components, including resistors, capacitors, transistors, and integrated circuits, allows for versatile circuit design possibilities.
- **Simulation Accuracy**: Accurate simulation results are crucial for reliable circuit design. Look for software that uses advanced algorithms and models to provide accurate predictions of circuit behavior.
- **Real-Time Analysis**: Real-time analysis capabilities enable users to monitor circuit performance dynamically and make adjustments on the

fly.

- **Integration with Design Tools**: Integration with popular design tools, such as schematic capture and PCB layout software, streamlines the design process and facilitates seamless transfer of designs.
- **Accuracy and Speed:** Another crucial factor is how accurate and fast the software can simulate your hardware designs. You want software that can produce realistic and reliable results, without compromising on speed and efficiency. You want software that can handle complex and large-scale models, with multiple levels of abstraction and detail, and can simulate different scenarios and conditions, such as temperature, voltage, noise, or faults.
- **Collaboration and Communication:** You want software that can enable you to share and access your models and results online, with cloud-based or web-based features. You also want software that can allow you to communicate and interact with your collaborators, with chat, comment, or feedback functions, and can protect your data and privacy, with encryption, authentication, or backup features.

Points to Remember

- **Definition of simulation software environment**

  A software environment is a collection of programs, libraries, and utilities that allow users to perform specific tasks.
- When choosing circuit simulation software, consider the following **key features:**
  - User-Friendly Interface, Wide Component Library, Simulation Accuracy, Real-Time Analysis, Integration with Design Tools, Accuracy and Speed, Collaboration and Communication

Application of learning 4.4.

An Electrical Company is tasked with designing a new simple LED blinking circuit. The company’s goal is to understand how to use the software environment to design, simulate, and analyze the circuit before building it physically.

As one of the team, you are tasked by the supervisor to explore the environment of the simulation software and if it meet the requirement before use.

Indicative content 4.5: Design circuits diagrams in electronic simulation software

Duration: 4 hrs

Theoretical Activity 4.5.1: Description of Multisim and Proteus

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of Multisim and Proteus as electronic simulation software.

i. Explain Multisim and Proteus as electronic simulation software.

ii. State the advantages and disadvantages of Proteus and Multisim as electronic simulation software.

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class.

4: Follow the trainer when providing expert view.

5: Ask questions where necessary to get more clarifications.

6: For more clarification, read the key **readings 4.5.1.**

Key readings 4.5.1.:

- **Description of Multisim and Proteus**
  - ✓ **Multisim**

Definition of Multisim

NiMultisim or Multisim, developed by National Instruments, is a schematic capture and simulation program for analog, digital and mixed analog/digital circuits, it is popular electronic circuit simulation software widely used in educational institutions and industry. It offers a comprehensive set of simulation and analysis tools, making it suitable for both beginners and experienced engineers.

Multisim provides a vast component library and simulation models, enabling accurate representation of real-world circuits. Its intuitive graphical user interface and interactive simulations enhance the learning and design experience.

Features:

- Circuit simulation
- Waveform analysis
- Schematic capture
- Component library
- PCB design
- Virtual instruments
- Monte Carlo analysis
- Sensitivity analysis

Advantages:

- Intuitive user interface
- Vast component library
- Support for virtual instruments
- Integration with NI hardware

Disadvantages

- Relatively expensive circuit simulator
- Steeper learning curve for beginners
- Limited PCB design capabilities compared to specialized tools

Best Suitable for:

- Educational institutions
- Circuit design and analysis
- Virtual instrument simulation

✓ **Proteus**

Definition of Proteus

Proteus is comprehensive electronic circuit design and simulation software widely used in the industry. It offers a seamless design flow, combining schematic capture, PCB layout, and circuit simulation in a single integrated environment. Proteus provides a vast component library and advanced simulation models, allowing users to simulate and verify complex circuits accurately. Its interactive simulation capabilities enable real-time testing and debugging, enhancing the design iteration process. Proteus also offers advanced features like mixed-mode simulation, SPICE models, and microcontroller simulation, making it suitable for both analog and digital circuit designs.

Features:

- Circuit simulation
- PCB design
- Component library
- Microcontroller simulation
- Virtual instruments
- Circuit visualization

Advantages:

- Integrated PCB design
- Microcontroller simulation
- Real-time debugging
- Breadboard simulation
- Arduino compatibility

Disadvantages:

- Relatively expensive circuit simulator
- Steeper learning curve for beginners
- Limited component library compared to specialized tools

Best Suitable For:

- Professional PCB design
- Microcontroller-based projects
- Industrial automation

Practical Activity 4.5.2: Designing circuits diagrams in electronic simulation software

Task:

1: You are requested to perform the given task. The task should be done individually.

a) Go in the Computer Lab and using electronic simulation software, draw a simple electronic circuit that comprises the following components:

- A battery,
- a SPST switch,
- a LED and
- Resistor

These components should be connected in series to the source.

2: Follow the trainer when demonstrating how to design the circuit diagram using electronic simulation software.

3: Referring to the explanation given, perform the given activity.

4: Read key reading 4.5.2 and ask clarification where's necessary

5: Perform the task provided in application of learning 4.5.

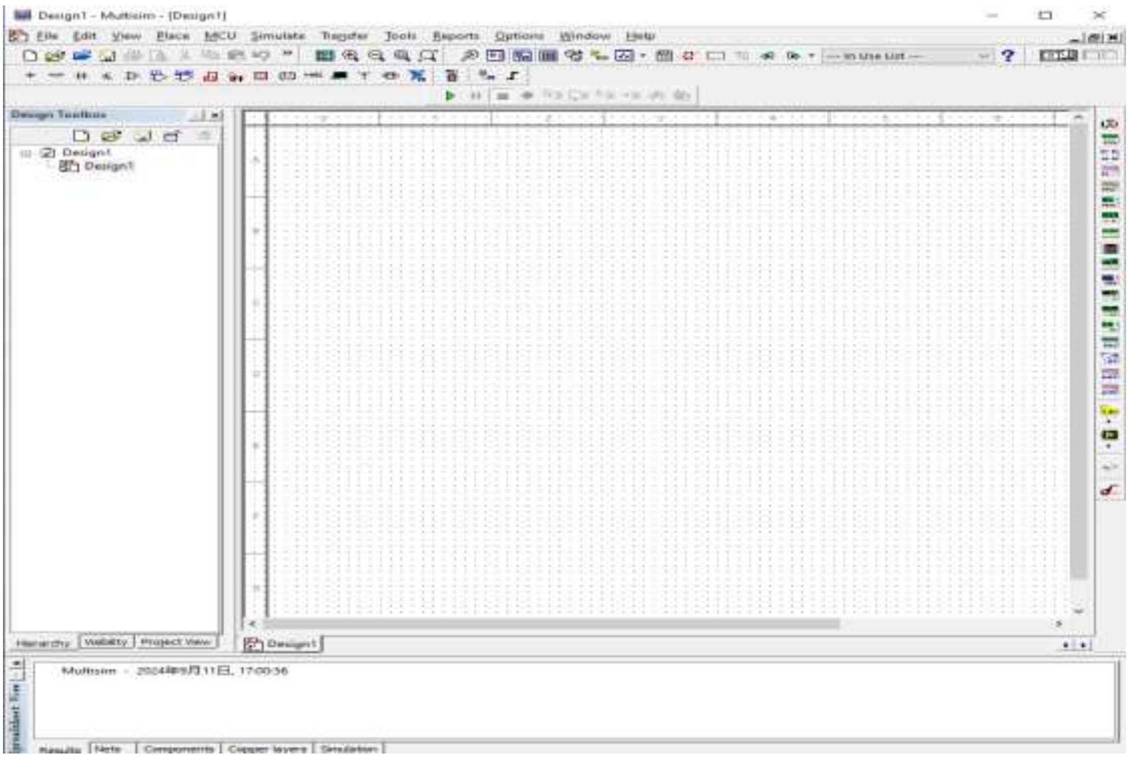
Key readings 4.5.2

- **Using NiMultisim to design an electronic circuit**
  - ✓ **Procedures of using NiMultisim to design an electronic circuit:**

Here's a step-by-step guide on how to use NI Multisim to design and simulate an electronic circuit:

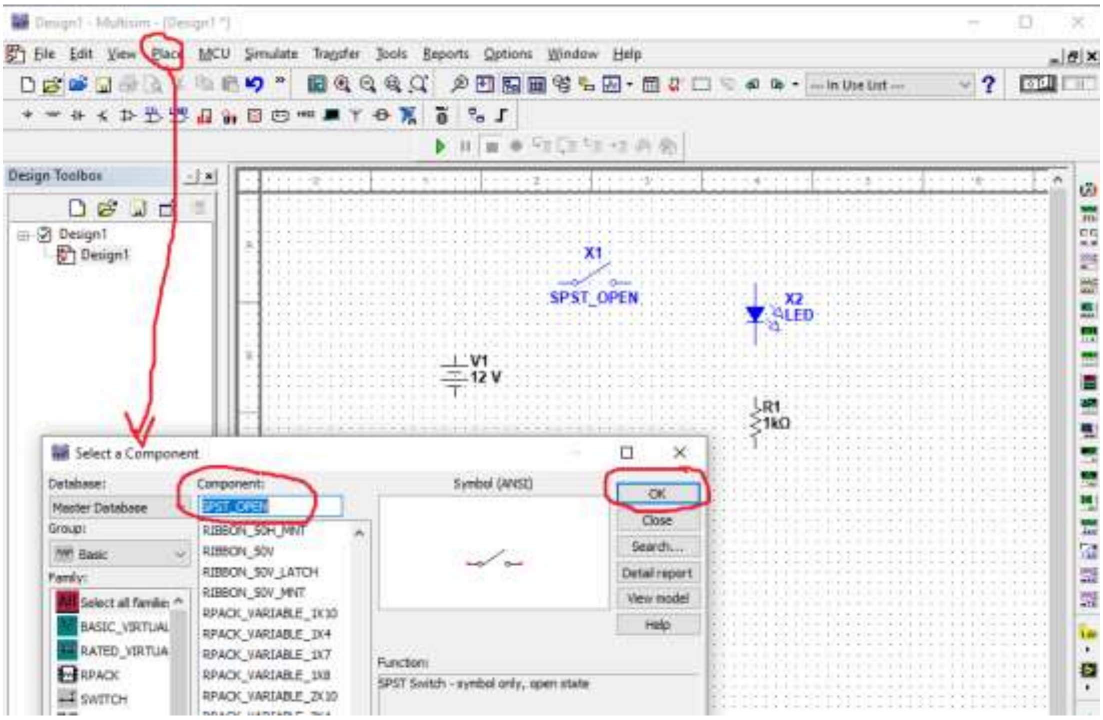
Step 1: Launch NI Multisim: Open **NI Multisim** on your computer the Create a new project by selecting **File > New > Design**.

Step 2: Set Up the Workspace: In the new project window, you will see a blank schematic workspace where you can build your circuit and familiarize yourself with the components toolbar, which contains various electronic components like resistors, capacitors, diodes, transistors, etc.



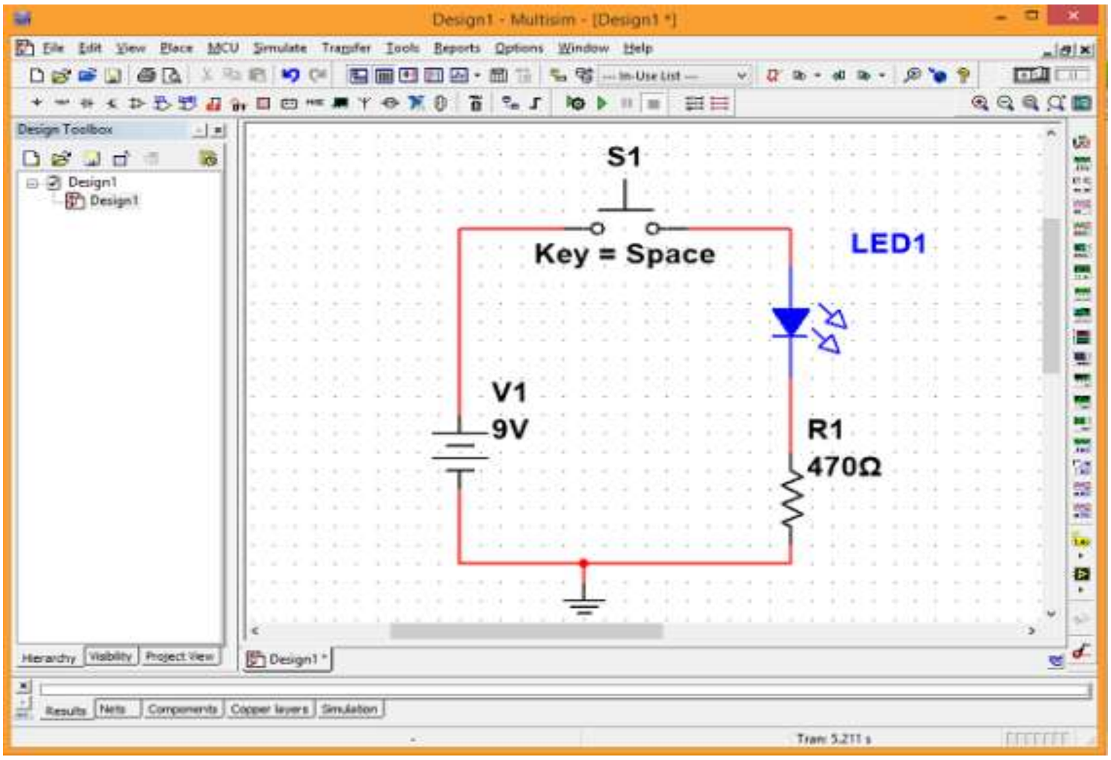
Step 3: Select and Place Components: To place a component, click on the **Place** menu and select **Component** (or press **Ctrl + W**) then **select a component** window will pop up. After selecting a component, move your mouse cursor to the schematic area.

- Repeat this process to place all necessary components for your circuit (e.g., power sources, resistors, transistors, etc.).



Step 4: Wiring the Circuit: Move the mouse pointer to a component's terminal (you'll see a crosshair), click and drag to another terminal to create a connection then after release the mouse button once the connection is established. Repeat for all connections.

- To cancel a wire during drawing, press the **Esc** key.



Step 5: Add Ground and Power Sources: Every circuit in Multisim needs a ground reference. Go to **Place > Component**, then search for "GROUND" under the **Sources** category and add a power source (e.g., DC voltage source) by selecting it from the **Sources > Power Sources** category.

Step 6: Configure Component Values: Double-click on any component to open its properties and modify values such as resistance for resistors, capacitance for capacitors, or input voltage for voltage sources.

Step 7: Set Simulation Type the after **Run the Simulation**: Go to the **Simulate** menu and select **Analyses and Simulation** by Clicking the green **Run** button (a play icon) at the top of the screen to start the simulation.

Observe the behavior of the circuit in real-time. You can use measurement tools such as voltmeters, ammeters, and oscilloscopes (available under **Instruments > Measurement Probes**).

Step 8: Analyzing Simulation Results: After running the simulation, you can visualize waveforms, voltages, currents, and other parameters.

Step 9: Making Adjustments: Based on the simulation results, you may need to tweak component values or modify the circuit design and after making changes, run the simulation again to observe the effects.

Step 10: Save and Document the Circuit: Once satisfied with your design, save the project by going to **File > Save As**.

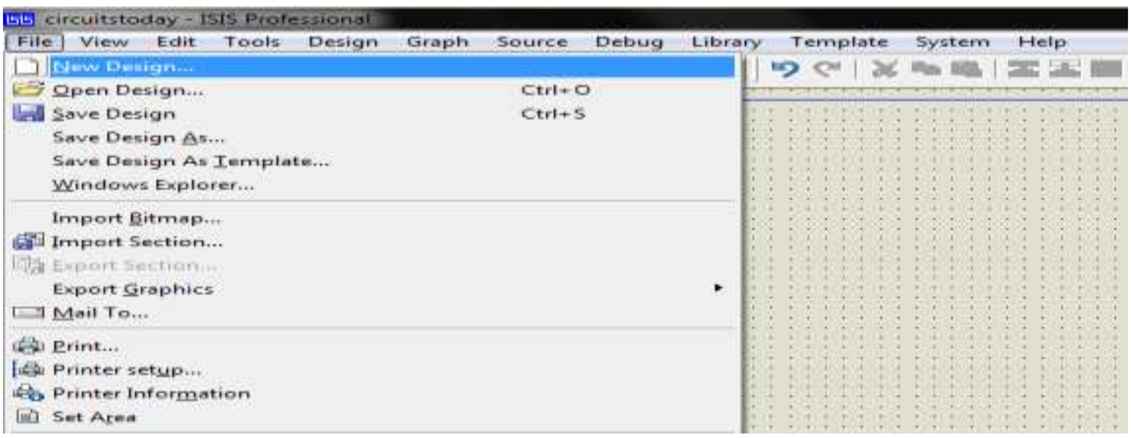
- If you are working on a more complex design, create a **Bill of Materials (BOM)** or print the schematic by going to **Reports > Bill of Materials**.

Step 11: Printing or Exporting the Design: To print or export your schematic for presentation or further analysis, go to **File > Print** or **File > Export > Export PDF** to save the design in a portable format.

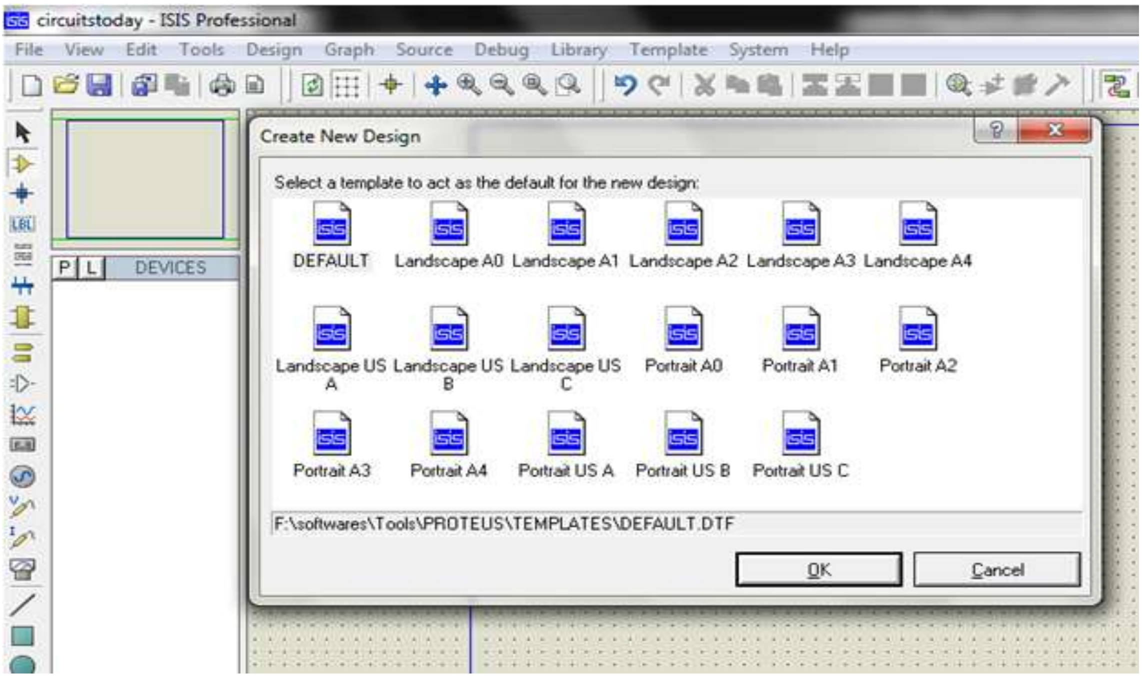
- **Using Proteus to design electronic circuit**
  - ✓ **Steps in modeling and analysis of a circuit**

Below are step-by-step procedures for designing a simple electronic circuit using Proteus:

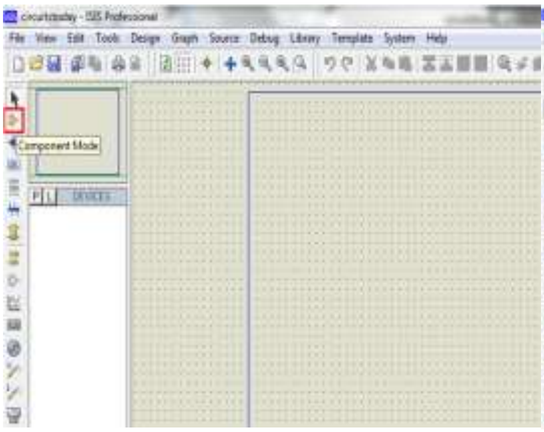
Step1. Install Proteus and Start a New Project: Launch the Proteus application then **Create New Project**: Go to **File > New Project**.

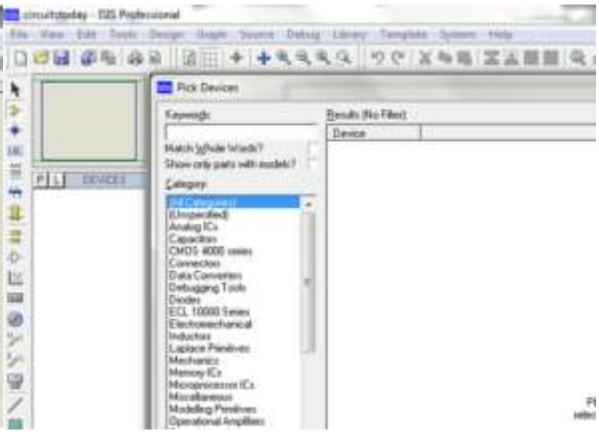


Step2. Add Components to the Schematic: In the left-hand toolbar, select **Schematic Capture** to open the design environment then Click on the **P** button (Pick Devices) on the left toolbar or select **Library > Pick Devices**.

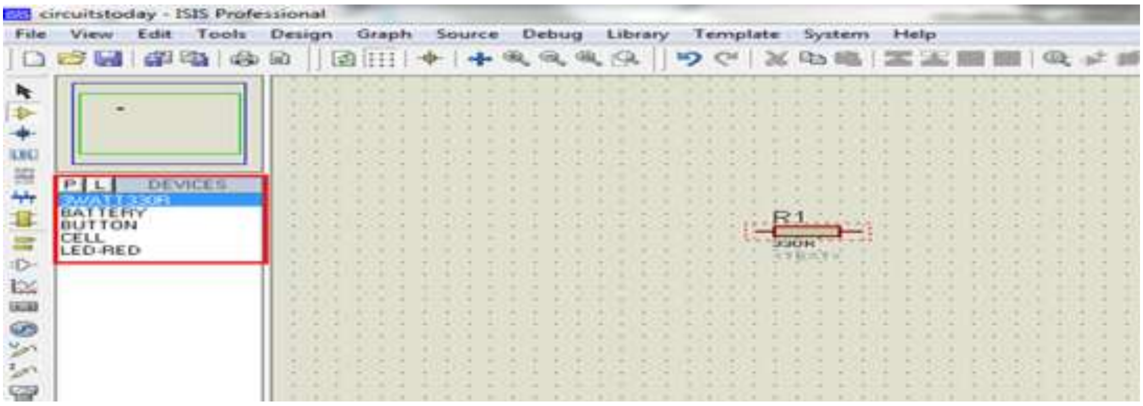


Step3. Place and Connect Components: Click on the workspace to place them then Click on the endpoint of a component (such as a pin) and drag to connect it to the next component.

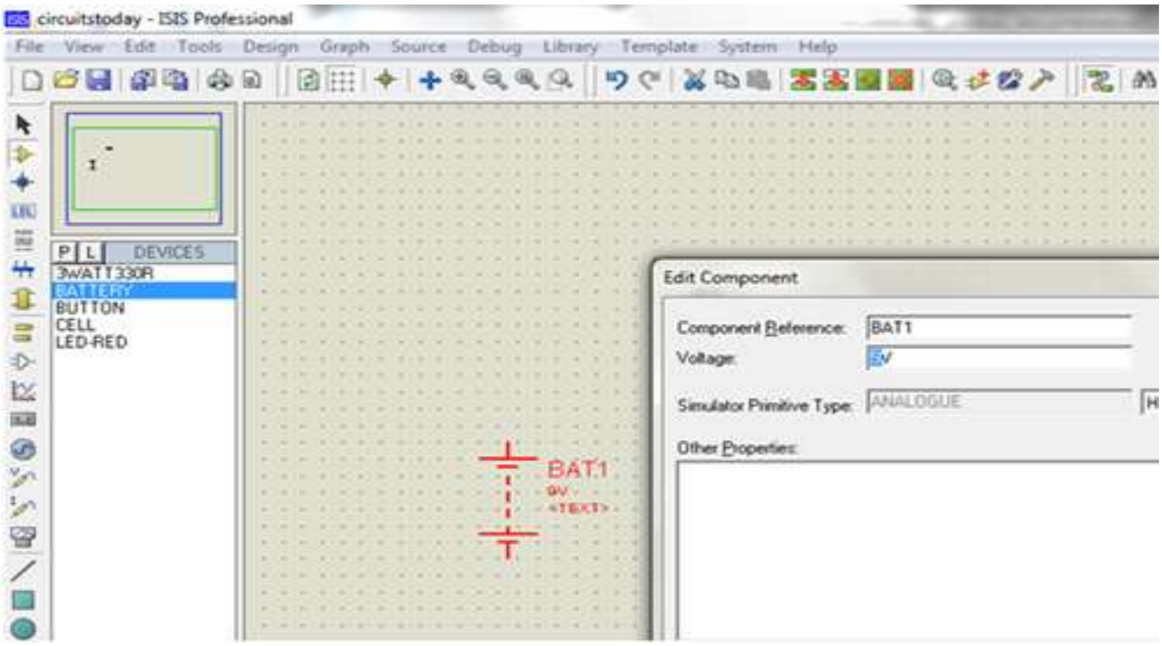




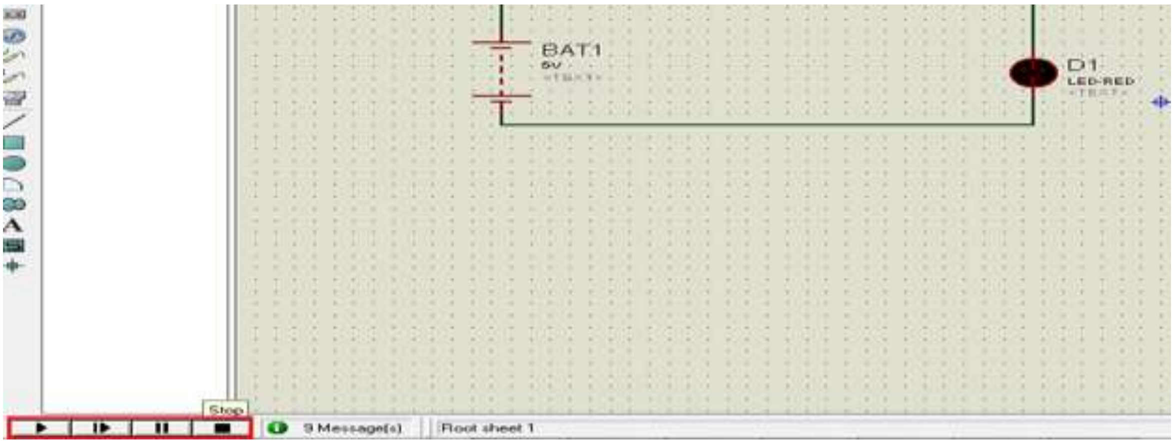
Step4. Assign Values to Components: Right-click on any component to edit its properties (e.g., resistance, capacitance, transistor gain, etc.) the assign appropriate values based on your circuit requirements. For example, for resistors, assign values in ohms (e.g., 1kΩ).



Step5. Add Power Sources and Ground: Go to the **Library** and search for **DC Voltage Source** or **Battery** and connect the ground to the relevant part of your circuit.



Step6. Simulate the Circuit: After completing the design, go to **Debug > Run Simulation** or click the play button in the toolbar.



Step8. Design PCB (Optional): You can switch to the **PCB Layout Mode** by clicking on the

PCB Layout button in the toolbar.

Step9. Save and Export the Project: Save your project regularly by clicking **File > Save** then after Go to **File > Export** to export in different formats.

Points to Remember

- **Definition of Multisim**

  NiMultisim or Multisim, developed by National Instruments, is a schematic capture and simulation program for analog, digital and mixed analog/digital circuits, it is popular electronic circuit simulation software widely used in educational institutions and industry.

- **Definition of Proteus**

  Proteus is comprehensive electronic circuit design and simulation software widely used in the industry.

- Advantages and disadvantages of Multisim and Proteus

Software	Advantages	Disadvantages
Multisim	Intuitive user interface, Vast component library, Support for virtual instruments, Integration with NI hardware,	Relatively expensive circuit simulator, Steeper learning curve for beginners, Limited PCB design capabilities
Proteus	Integrated PCB design Microcontroller simulation Real-time debugging Breadboard simulation Arduino compatibility	Relatively expensive, Steeper learning curve for beginners, Limited component library compared to specialized tool

- **Procedures of using NiMultisim to design an electronic circuit:**

Procedures of Using NI Multisim to Design an Electronic Circuit

Step 1: Open NI Multisim on your computer the Create a new project by selecting File > New > Design.

Step 2: Place a component by clicking on the Place menu and select Component (or press Ctrl + W) then select a component window will pop up. After selecting a component, move your mouse cursor to the schematic area.

Step3: Move the mouse pointer to a component's terminal, click and drag to another terminal to create a connection then after release the mouse button once the connection is established. Repeat for all connections.

Step4: Add a power source (e.g., DC voltage source) by selecting it from the Sources > Power Sources category.

Step5: Go to the Simulate menu and select Analyses and Simulation by Clicking the green Run button (a play icon) at the top of the screen to start the simulation.

Step6: After running the simulation, you can visualize waveforms, voltages, currents, and other parameters.

Step7: Save and Document the Circuit: Once satisfied with your design, save the project by going to File > Save As.

Step8: Go to File > Print or File > Export > Export PDF to save the design in a portable format.

- **Steps in Using Proteus to design electronic circuit are:**

Below are step-by-step procedures for designing a simple electronic circuit using Proteus:

Step1. Launch the Proteus application then Create New Project: Go to File > New Project.

Step2. In the left-hand toolbar, select Schematic Capture to open the design environment then Click on the P button (Pick Devices) on the left toolbar or select Library > Pick Devices.

Step3. Click on the workspace to place them then Click on the endpoint of a component (such as a pin) and drag to connect it to the next component.

Step4. Right-click on any component to edit its properties then assign appropriate values based on your circuit requirements.

Step5. Go to the Library and search for DC Voltage Source or Battery and connect the ground to the relevant part of your circuit.

Step6. After completing the design, go to Debug > Run Simulation or click the play button in the toolbar.

Step7. Save your project regularly by clicking File > Save then after Go to File > Export to export in different formats.

Application of learning 4.5.

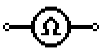
An electronically company is tasked with designing an audio amplifier power supply. They use Multisim and Proteus software to simulate and refine their designs before building physical prototypes.

As one of the member of the company, draw and simulate an audio amplifier power supply circuit diagram. The Unit comprises a step down transformer of 12Vac output, a rectifier IC, and a filtering capacitor of 2200microFarads.

Learning outcome 4 end assessment

Theoretical assessment

1. Refer to the schematic symbols; fill the gap in the following table:

Symbol	**Component name**	**Meaning**
	Connected Wires	
	Polarized Capacitor	
		Measures voltage. Has very high resistance. Connected in parallel.
		
	Potentiometer (IEEE)	

Practical assessment

You are a technician in an electronics lab, and you've been given a practical assessment to design and test a power supply circuit.

Using electronic simulation software, you are tasked with drawing and simulating a two outputs stable DC power supply that converts 230V AC mains voltage to a 12Vdcand 5Vd as outputs. The design must include components such as a transformer, rectifier, filter, and voltage regulators.

END

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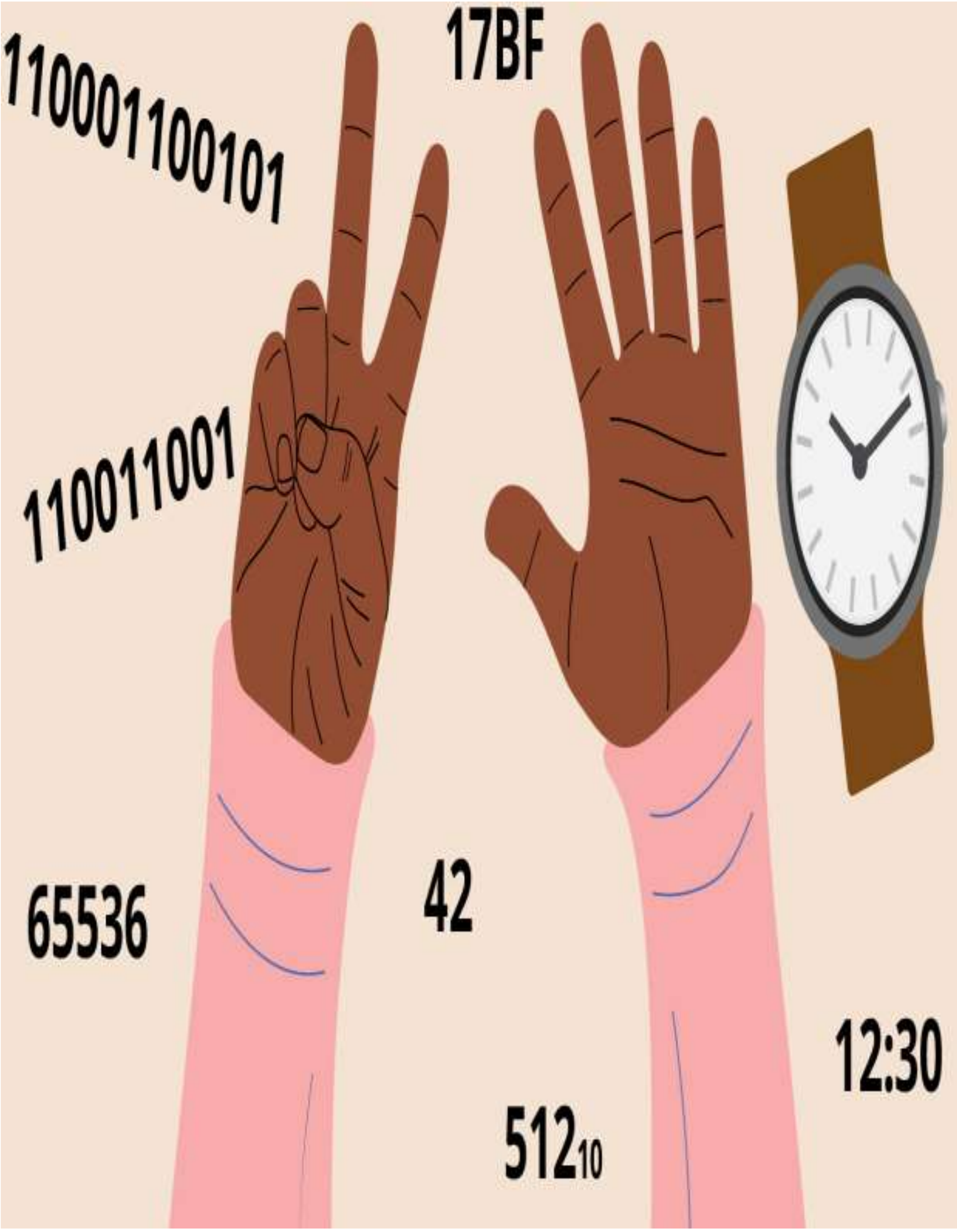
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Indicative contents

5.1 Description of number system

5.2 Number system base conversion

5.3 Application of Number system arithmetic

Key Competencies for Learning Outcome 5: Applying numbering system

Knowledge	Skills	Attitudes
• Description of number system	• Converting Number system base, • Applying Number system arithmetic	• Being a problem Solver, • Being a critical thinker, • Being a communicator, • Being a team player

Duration: 15 hrs

Learning outcome 5 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe properly numbering system according their types
2. Convert properly numbering system according to their types(base)
3. Apply appropriately arithmetic operations based on numbering system

Resources

Equipment	Tools	Materials
• Computer • Projector • Scientific calculator	• NA	• Internet

Indicative content 5.1: Description of number system

Duration: 3 hrs

Theoretical Activity 5.1.1: Introduction to number system

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of number system

i. What is a number system?

ii. Identify the type's number system.

iii. Enumerate the type's number system base.

2: Discuss and write the findings related to the given tasks on provided place

3: Present your findings to the whole class or your colleagues.

4: Ask questions for more clarification if any.

5: Read the **Key readings 5.1.1** in their manuals to get more clarification.

Key readings 5.1.1.:

- **Description of number system**

✓ **Definition of Number system**

A number system is a mathematical notation for representing numbers of a given set using a specific base or radix. It defines how numbers are expressed and the rules for arithmetic operations like addition, subtraction, multiplication, and division.

A number is a mathematical value used for counting or measuring or labeling objects. Numbers are used to performing arithmetic calculations. Examples of numbers are natural numbers, whole numbers, rational and irrational numbers, etc. 0 is also a number that represents a null value.

A number has many other variations such as even and odd numbers, prime and composite numbers. Even and odd terms are used when a number is divisible by 2 or not, whereas prime and composite differentiate between the numbers that have only two factors and more than two factors, respectively.

In a number system, these numbers are used as digits. 0 and 1 are the most common digits in the number system that are used to represent binary numbers. On the other hand, 0 to 9 digits are also used for other number systems. Let us learn here the types of number systems.

✓ **Types of Number Systems**

There are various types of number systems in mathematics. The four most common number system types are:

- Decimal number system,
- Binary number system,
- Octal number system,
- Hexadecimal number system.

- **Introduction to number system base**

✓ **Definition of number system base**

A number base is the number of digits or combination of digits that a system of counting uses to represent numbers. A base can be any whole number greater than 0. The most commonly used number system is the decimal system, commonly known as base 10. Its popularity as a system of counting is most likely due to the fact that we have 10 fingers.

Base, in math, is defined as the total count of digits used to express numbers in a number system. The base of a number system is also referred to as "radix." There are many number systems and each one of them has different bases.

Number System	**Base**
Binary	2
Ternary	3
Quaternary	4
Quinary	5
Senary	6
Septenary	7
Octal	8
Nonary	9

Decimal	10
Undecimal	11
Duodecimal	12
Hexadecimal	16
Vigesimal	20
Sexagesimal	60

✓ **Types of number system base**

The most commonly and widely used bases are binary number system (Base-2), octal number system (Base-8), decimal number system (Base-10), and hexadecimal number system (base-16).

Number System	**Base**
Binary	2
Octal	8
Decimal	10
Hexadecimal	16

✓ **Binary Number System**

Definition

The number system with base two is called as the binary number system. Only 0 & 1 are the symbols used in this system. 0 & 1are called as binary digits or bits. The left most bit is called the Most Significant Bit (MSB) The right most bit is called the least significant Bit (LSB). A group of character (either digits or letters) write one after another is called string. In binary number system, group of 4 bits called Nibble & a group of 8 bits is called a Byte.

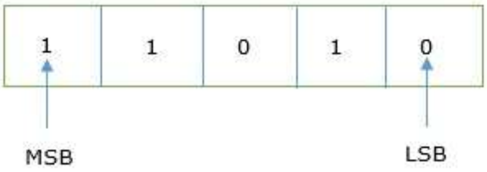
Subscript 2 is used to identify a base-2 number. Let's see how to convert 1012 to the decimal number system with the help of this example, 1012 = (1 × 20) + (0 × 21) + (1 × 22) = 5.

The easiest way to vary instructions through electric signals is two-state system – on and off. On is represented as 1 and off as 0, though 0 is not actually no signal but signal at a lower voltage. The number system having just these two digits – 0 and 1 – is called binary number system.

Each binary digit is also called a bit. Binary number system is also positional value system, where each digit has a value expressed in powers of 2, as displayed here.

2^5	2^4	2^3	2^2	2^1	2^0

In any binary number, the rightmost digit is called least significant bit (LSB) and leftmost digit is called most significant bit (MSB).



And decimal equivalent of this number is sum of product of each digit with its positional value.

110102 = 1×24 + 1×23 + 0×22 + 1×21 + 0×20

= 16 + 8 + 0 + 2 + 0

= 2610

Computer memory is measured in terms of how many bits it can store. Here is a chart for memory capacity conversion.

- 1 byte (B) = 8 bits
- 1 Kilobytes (KB) = 1024 bytes
- 1 Megabyte (MB) = 1024 KB
- 1 Gigabyte (GB) = 1024 MB
- 1 Terabyte (TB) = 1024 GB
- 1 Exabyte (EB) = 1024 PB
- 1 Zettabyte = 1024 EB
- 1 Yottabyte (YB) = 1024 ZB

Characteristics of the binary number

Characteristics of the binary number system are as follows:

- Uses two digits, 0 and 1
- Also called as base 2 number system
- Each position in a binary number represents a 0 power of the base (2). Example 20
- Last position in a binary number represents a x power of the base (2). Example 2x where x represents the last position - 1.

✓ Octal Number System

Definition

Octal number system (Base-8 number system) uses only 8 digits ranging from 0 to 7 (0, 1, 2, 3, 4, 5, 6 and 7). Since there are 8 distinct digits used to express a number, the base of this number system is 8. Octal numbers are represented using 3 digits (composed of 0s and 1s). The octal number system uses a lesser number of digits compared to many other number systems, so there are fewer computational errors. The subscript 8 is used to identify the base-8 number. An example of a number in octal number system is 4238 = (3 × 80) + (2 × 81) + (4 × 82).

Each digit is multiplied by the power of 8 based on its position (position starts from right to left) and the products are added.

Characteristics of the octal number

Characteristics of the octal number system are as follows –

- Uses eight digits, 0,1,2,3,4,5,6,7
- Also called as base 8 number system
- Each position in an octal number represents a 0 power of the base (8). Example 80
- Last position in an octal number represents a x power of the base (8). Example 8x where x represents the last position - 1

✓ Decimal Number System

Definition

Decimal Number System (Base-10 number system) uses only digits from 0 to 9. Since there are only ten digits involved in representing any number, it is called base-10 or the decimal number system. It is one of the most commonly used number systems around the world. (The number system that we use in our day-to-day life is the decimal number system.)

Let us see how we count in the base-10 number system. The subscript 10 is used to identify a base-10 number.

For example, 74310 = (3 × 100) + (4 × 101) + (7 × 102). Generally, we do not write 10 as the subscript to represent the decimal number system. So, if you see any number without any subscript written, it is a base-10 number.

Each position represents a specific power of the base (10).

For example, the decimal number 1234 consists of the digit 4 in the units position, 3 in the tens position, 2 in the hundreds position, and 1 in the thousands position. Its value can be written as

(1 x 1000) + (2 x 100) + (3 x 10) + (4 x l)

(1 x 103) + (2 x 102) + (3 x 101) + (4 x l00)

1000 + 200 + 30 + 4

1234

Let us take another example to understand this.

Say we have three numbers – 734, 971 and 207. The value of 7 in all three numbers is different−

- In 734, value of 7 is 7 hundreds or 700 or 7 × 100 or 7 × 102
- In 971, value of 7 is 7 tens or 70 or 7 × 10 or 7 × 101
- In 207, value 0f 7 is 7 units or 7 or 7 × 1 or 7 × 100

The weightage of each position can be represented as follows –

10^5	10^4	10^3	10^2	10^1	10^0

In digital systems, instructions are given through electric signals; variation is done by varying the voltage of the signal. Having 10 different voltages to implement decimal number system in digital equipment is difficult. So, many number systems that are easier to implement digitally have been developed.

✓ **Hexadecimal Number System**

Definition

Hexadecimal Number System (The base-16 number system) uses numbers and alphabets to represent numbers. Numbers from 0 to 9 and alphabets from A to F are used. It takes 4 bits (composed of 0s and 1s) to represent any digit. The base-16 system is used in computers and digital systems to store very large numbers. It is also used to represent colors in computers.

Let us look at the representation of hexadecimal digits. We start to count from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 1A, 1B, 1C, 1D, 1E, 1F, etc. Here, 10 does not refer to the number after 9 but it is 1-0, which means that there is 1 group of 16 numbers starting from 0 to 9 and A to F and there are no more leftover numbers. For example, 6AB16= (11 × 160) + (10 × 161) + (6 × 162)

Characteristics of hexadecimal number

Characteristics of hexadecimal number system are as follows:

- Uses 10 digits and 6 letters, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
- Letters represent the numbers starting from 10. A = 10. B = 11, C = 12, D = 13, E = 14, F = 15
- Also called as base 16 number system
- Each position in a hexadecimal number represents a 0 power of the base (16). Example, 160
- Last position in a hexadecimal number represents a x power of the base (16). Example 16x where x represents the last position - 1

- **Number System Relationship**

The following table depicts the relationship between decimal, binary, octal and hexadecimal number systems.

HEXADECIMAL	DECIMAL	OCTAL	BINARY
0	0	0	0000
1	1	1	0001
2	2	2	0010
3	3	3	0011
4	4	4	0100
5	5	5	0101
6	6	6	0110
7	7	7	0111
8	8	10	1000
9	9	11	1001
A	10	12	1010
B	11	13	1011
C	12	14	1100

D	13	15	1101
E	14	16	1110
F	15	17	1111

- **Practical Applications of number system**
  - ✓ **Computer Systems:** Binary and hexadecimal are used extensively in programming and digital systems, as they map directly onto binary hardware states.
  - ✓ **Network Addresses:** IP addresses and other network-related identifiers often use hexadecimal notation.
  - ✓ **Digital Displays:** Octal and hexadecimal systems are sometimes used in digital displays and instrumentation.

Understanding and performing base conversions is a fundamental skill in various technical fields, particularly in computer science and electrical engineering.

Points to Remember

- **Definition of Number system.**

A **number system** is a mathematical notation for representing numbers of a given set using a specific base or radix. It defines how numbers are expressed and the rules for arithmetic operations like addition, subtraction, multiplication, and division.

- ✧ Types There are various types of number systems in mathematics. The four most common number system types are:
- ✧ Decimal number system,
- ✧ Binary number system,
- ✧ Octal number system,
- ✧ Hexadecimal number system.

- A number base is the number of digits or combination of digits that a system of counting uses to represent numbers.
- The most commonly and widely used bases are:
  - ✧ Binary number system base (Base-2),
  - ✧ Octal number system base (Base-8),
  - ✧ Decimal number system base (Base-10), and

✧ Hexadecimal number system base (base-16).

Application of learning 5.1.

A group of electronic operators are learning about numbering system. The supervisor plans a hands-on activity where participants will reinforce their understanding.

As one of the team, you are tasked to go and visit automatic visitors counter located nearby Bank office to understand the different number systems used in computing.

Indicative content 5.2: Number system base conversion

Duration: 5 hrs

Theoretical Activity 5.2.1: Description of number system base conversion

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of number system base conversion.

i. What is number system base conversion?

ii. Identify the types of number system base conversion.

2: Provide the answer for the asked questions and write them on reserved place.

3: Present the findings/answers to the whole class.

4: Ask questions where necessary to get more clarifications.

5: For more clarification, read the key **readings 5.2.1.**

Key readings 5.2.1.:

- **Number system base conversion**

Number system base conversion is the process of changing a number from one base (or radix) to another. Number systems are mathematical representations used to express quantities, and the base of a number system indicates how many digits are available and the value each position represents.

- **Common Number Systems:**
  - ✓ **Binary (Base-2):** Uses two digits, 0 and 1. Each digit represents an increasing power of 2.
  - ✓ **Decimal (Base-10):** Uses ten digits, 0 through 9. It is the most commonly used system in everyday life and represents increasing powers of 10.
  - ✓ **Octal (Base-8):** Uses eight digits, 0 through 7. Each position represents an increasing power of 8.

- ✓ **Hexadecimal (Base-16):** Uses sixteen digits, 0 through 9 and A through F (where A=10, B=11, ..., F=15). Each position represents an increasing power of 16.

- **Types of number system base conversion.**

Number system base conversion refers to the process of converting numbers from one base (or radix) to another. Each number system is characterized by its base, which indicates the number of unique digits, including zero, used to represent numbers.

Here are the common types of number system base conversions:

- ✓ **Decimal to Binary Conversion (Base 10 to Base 2):**
  - **Decimal (Base 10):** Uses digits 0-9.
  - **Binary (Base 2):** Uses digits 0 and 1.
  - This conversion is often used in computing and digital electronics, where binary numbers represent data and instructions.
- ✓ **Binary to Decimal Conversion (Base 2 to Base 10):**
  - Converting a binary number into its equivalent decimal value.
- ✓ **Decimal to Octal Conversion (Base 10 to Base 8):**
  - **Octal (Base 8):** Uses digits 0-7.
  - This conversion is sometimes used in computing systems and in scenarios where grouping binary numbers into sets of three bits simplifies reading and interpreting data.
- ✓ **Octal to Decimal Conversion (Base 8 to Base 10):**
  - Converting an octal number into its equivalent decimal value.
- ✓ **Decimal to Hexadecimal Conversion (Base 10 to Base 16):**
  - **Hexadecimal (Base 16):** Uses digits 0-9 and letters A-F (or a-f), where A represents 10, B represents 11, and so on up to F, which represents 15.
  - Hexadecimal is widely used in computing and digital electronics because it provides a more compact representation of binary data, with each hex digit representing four binary bits.
- ✓ **Hexadecimal to Decimal Conversion (Base 16 to Base 10):**
  - Converting a hexadecimal number into its equivalent decimal value.
- ✓ **Binary to Octal Conversion (Base 2 to Base 8):**

- Converting binary numbers directly into octal by grouping binary digits in sets of three (starting from the right) and then replacing each group with its octal equivalent.

✓ **Octal to Binary Conversion (Base 8 to Base 2):**
  - Converting each octal digit to its three-digit binary equivalent.

✓ **Binary to Hexadecimal Conversion (Base 2 to Base 16):**
  - Grouping binary digits in sets of four (starting from the right) and converting each group to its hexadecimal equivalent.

✓ **Hexadecimal to Binary Conversion (Base 16 to Base 2):**
  - Converting each hexadecimal digit to its four-digit binary equivalent.

✓ **Octal to Hexadecimal Conversion (Base 8 to Base 16):**
  - Often involves an intermediate conversion to binary, then to hexadecimal.

✓ **Hexadecimal to Octal Conversion (Base 16 to Base 8):**
  - Typically involves converting the hexadecimal number to binary first, then from binary to octal.

Each of these conversions serves different purposes in various applications, such as computing, digital electronics, data representation, and communication.

Practical Activity 5.2.2: Converting Number System bases.

Task:

1: Referring to instructions from your trainer, you are requested to perform the given task. The task should be done individually.

As Network Technician, you are asked to follow the instructions from your trainer to perform the binary to decimal conversion and vice versa, binary to octal conversion and vice versa, binary to hexadecimal conversion and vice versa, decimal to octal conversion and vice versa, decimal to hexadecimal and vice versa, octal to hexadecimal and vice versa.

2: Follow the trainer when demonstrating how to convert Number System base. While demonstrating, explain the converting procedures.

3: Referring to procedures of converting, perform the distributed activity.

4: Read key reading 5.2.2 and ask clarification where's necessary

Key readings 5.2.2

- **Conversion from Binary Number System to Other Number Systems**

Following are the conversion of the Binary Number System to other Number Systems:

- **Binary to Decimal Conversion:**

Steps for Converting Binary to Decimal

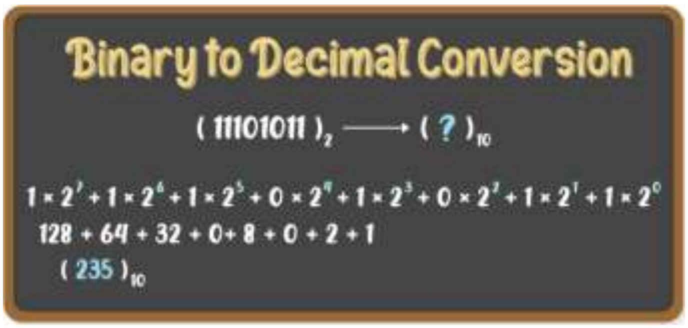
Step1: Write Down the Binary Number: Start with the binary number you wish to convert.

Step2: Assign Powers of 2: Assign powers of 2 to each digit in the binary number, starting from the rightmost digit (which is 2^0) and moving left.

Step3: Multiply Each Digit by Its Power of 2: Multiply each binary digit by its corresponding power of 2.

Step4: Sum All the Products to get the result: Add all the products obtained from step three.

Example1: To convert $(11101011)_2$ into a decimal number



Example 2: Convert the following binary number to its decimal equivalent: 0.011

Solution: (a) 0.011 = (0 × 2-1) + (1 × 2-2) + (1 × 2-3)

= 0 + 1/4 + 1/8 = 0.25 + 0.125 = 0.375

- **Binary to Octal Conversion:**

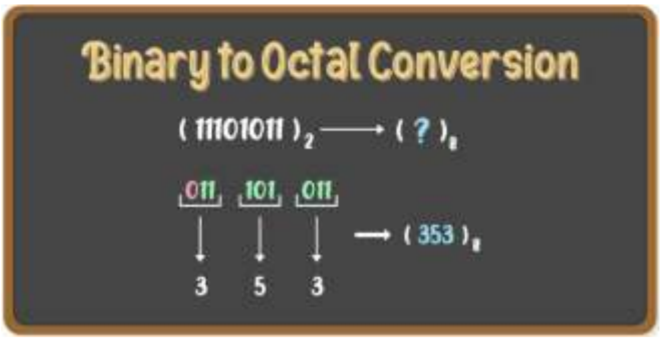
Follow the steps given below:

Step1: Divide the binary number into groups of three digits starting from right to left i.e.

from LSB to MSB.

Step 2: Convert these groups into equivalent octal digits.

Example1: To convert $(11101011)_2$ into an octal number



Example2: Convert 11010101.01101 to an octal-number.

Solution:

011	010	101	.	011	10
011	010	101		011	010
3	2	5		3	2

$11010101.0110_1 = 325.32_8$

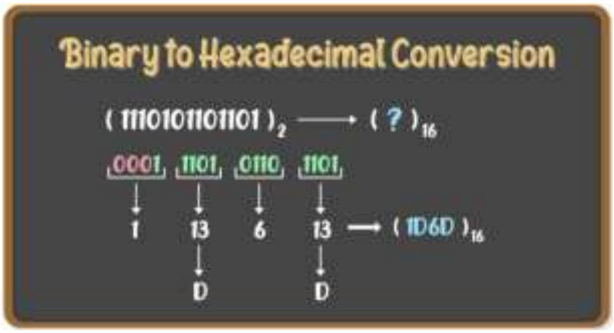
- **Binary to Hexadecimal Conversion:**

Follow the steps given below:

Step 1: Divide the binary number into groups of four digits starting from right to left i.e. from LSB to MSB.

Step 2: Convert these groups into equivalent hex digits.

Example: To convert $(1110101101101)_2$ into a hex number



✓ **Conversion from Decimal Number System to Other Number Systems**

Following are the conversion of the Decimal Number System to other Number Systems:

- **Decimal to Binary Conversion:**

Steps for Converting Decimal to Binary

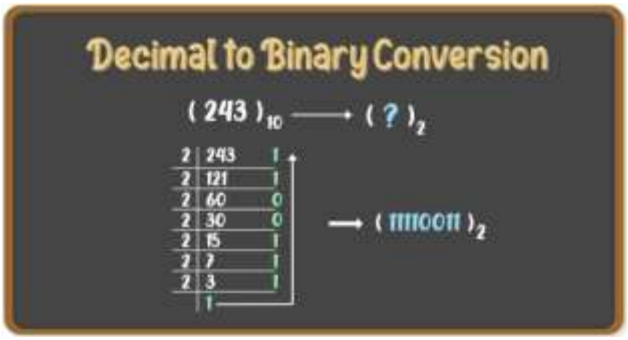
Step1: Write Down the Decimal Number: Start with the decimal number you wish to convert.

Step2: Divide by Two: Divide the decimal number by two and record the quotient and remainder.

Step3: Record Remainders: Keep dividing the quotient by two until it equals zero, recording each remainder along the way.

Step4: Reverse Remainders: Once you reach a quotient of zero, reverse the order of your recorded remainders; this will give you your binary representation.

Step5: Result: The sequence of remainders read from bottom to top represents your binary number.



When converting decimal fraction to binary, multiply repeatedly by 2 any fractional part. The equivalent binary number is formed from the 1 or 0 in the unit's position. The following examples illustrate the procedure.

Example: Convert the decimal number 0.625 to binary.

Solution:

$0.625 \times 2 = 1.250$	1 (M S B)
$0.250 \times 2 = 0.500$	0
$0.25 \times 2 = 1.00$	1 (L S B)
$0.625 = 0.101$	

- **Decimal to Octal Conversion:**

Follow the steps given below:

Step1: Write Down the octal Number: Start with the octal number you wish to convert.

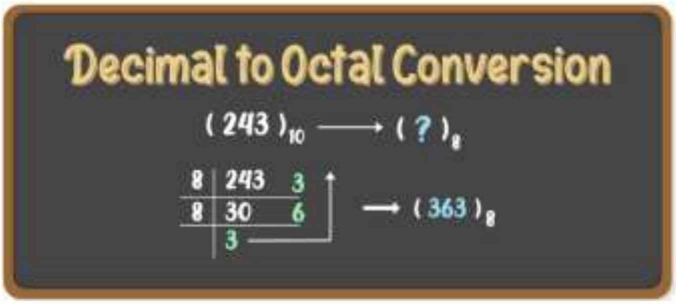
Step2: Divide the Decimal Number by 8: Take the decimal number you want to convert and divide it by 8. Keep track of the quotient and the remainder.

Step3: Record the Remainder: The remainder from this division will be one of the digits in your octal number.

Step4: Repeat with the Quotient: Take the quotient from your previous division and divide it by 8 again. Record the new remainder.

Step5: Continue Until Quotient is Zero: Repeat this process until your quotient becomes zero.

Step6: Read Remainders in Reverse Order: The octal number is formed by reading all the remainders in reverse order (from last to first).



Example: Convert decimal 65 to octal:

65 ÷ 8 = 8, remainder = 1

8 ÷ 8 = 1, remainder = 0

1 ÷ 8 = 0, remainder = 1

Reading remainders from bottom to top gives us octal 101.

- **Decimal to Hexadecimal Conversion:**

Follow the steps given below:

Step1: Divide the Decimal Number by 16: Take the decimal number you want to convert and divide it by 16. Record the integer quotient and the remainder.

Step2: Record the Remainder: The remainder will be a value between 0 and 15. If the remainder is between 10 and 15, replace it with its corresponding hexadecimal character

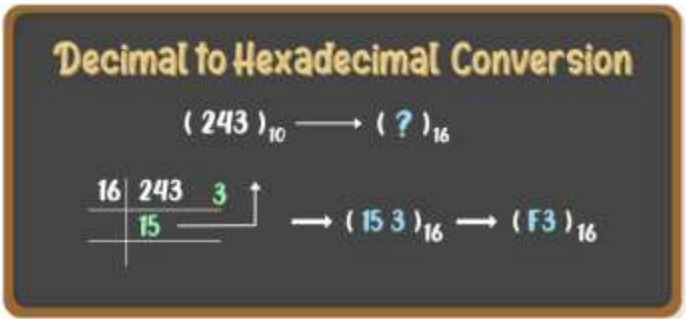
(A for 10, B for 11, C for 12, D for 13, E for 14, F for 15).

Step3: Repeat Division: Take the integer quotient from the previous division and divide it by 16 again. Record this new quotient and remainder.

Step4: Continue Until Quotient is Zero: Repeat step 3 until your quotient becomes zero.

Step5: Reverse the Remainders: Once you have all your remainders recorded, write them in reverse order to get the hexadecimal equivalent of your original decimal number.

Example:



✓ **Conversion from Octal Number System to Other Number Systems**

Octal Numbers are represented with digits 0-7 and with base 8. Conversion of a number system means conversion from one base to another. Following are the conversions of the Octal Number System to other Number Systems:

- **Octal to Decimal Conversion:**

Follow the steps given below:

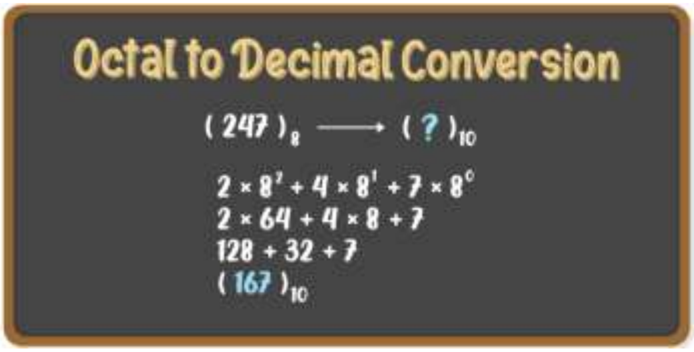
Step1: Understand Position Values: Each digit in an octal number represents a power of 8, starting from right to left (8^0, 8^1, 8^2, etc.).

Step2: Write Down the Octal Number: Start with your octal number and identify each digit's position.

Step3: Multiply Each Digit by its Power of Eight: For each digit in the octal number, multiply it by 8position, where position starts at zero on the right.

Step4: Sum All Products Together: Add all these products together to get your decimal equivalent.

Example1:



Example2: Convert octal 101 to decimal:

$1\times8^2=64$

$0\times8^1=0$

$1\times8^0=1$

Adding these gives us 64+0+1=65 in decimal.

Octal to Binary Conversion:

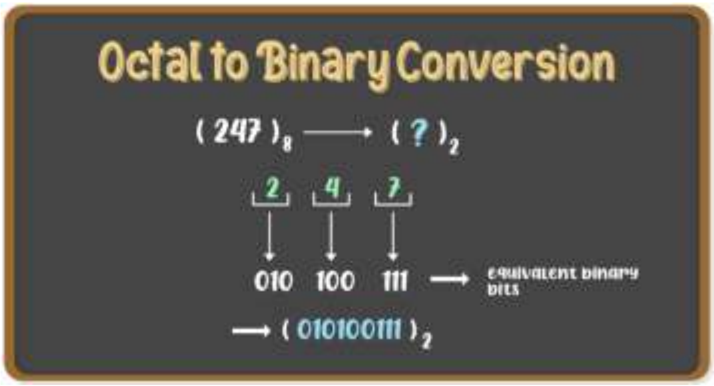
Octal numbers are represented in base 8, but the binary numbers are of base 2. Hence, to convert an octal number to a binary number, the base of that number is to be changed. Follow the steps given below:

Step 1: Write each digit of the octal number separately.

Step 2: Convert each digit into an equivalent group of three binary digits.

Step 3: Combine these groups to form the whole binary number.

Example: $(247)_8$ is to be converted to binary



Octal to Hexadecimal Conversion:

Octal numbers are represented in base 8, but the hexadecimal numbers are of base 16. Hence, to convert an octal number to a hex number, the base of that number is to be changed. Follow the steps given below:

Step 1: We need to convert the Octal number to Binary first. For that, follow the steps given in the above conversion.

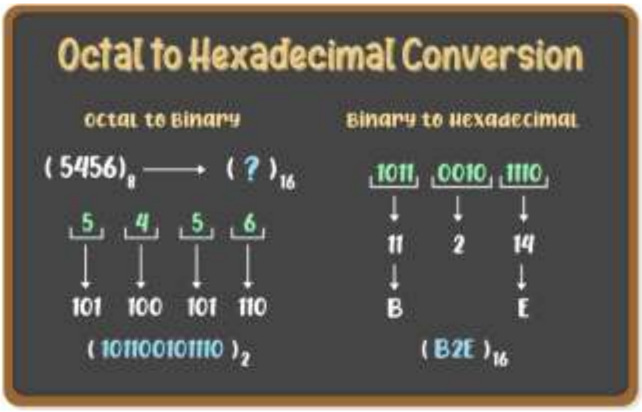
Step 2: Now to convert the binary number to Hex number, divide the binary digits into groups of four digits starting from right to left i.e. from LSB to MSB.

Step 3: Add zeros prior to MSB to make it a proper group of four digits(if required)

Step 4: Now convert these groups into their relevant decimal values.

Step 5: For values from 10-15, convert it into Hex symbols i.e from A-F

Example: $(5456)_8$ is to be converted to hex



✓ **Conversion from Hexadecimal Number System to Other Number Systems**

Following are the conversions of the Hexadecimal Number System to other Number Systems:

Hexadecimal to Decimal Conversion:

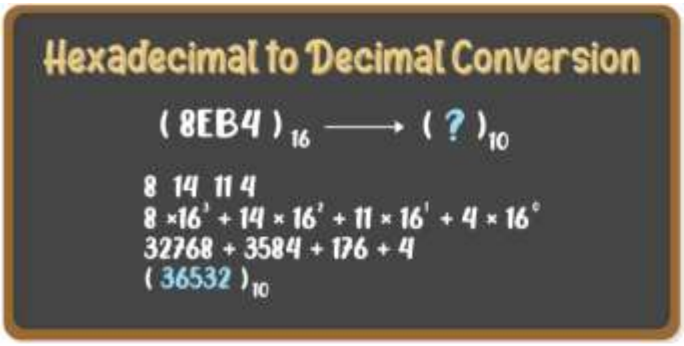
Steps for Converting Hexadecimal to Decimal:

Step1: Identify Each Digit's Value: Write down each digit of the hexadecimal number along with its positional value based on powers of 16 (starting from right to left).

Step2: Multiply Each Digit by its Positional Value: Multiply each digit by 16 raised to its position index (starting from 0).

Step3: Sum All Values Together: Add all these products together to get the decimal equivalent of the hexadecimal number.

Example: To convert $(8EB4)_{16}$ into a decimal value



- **Hexadecimal to Binary Conversion:**

Hex numbers are represented in base 16, but the binary numbers are of base 2. Hence, to convert a hexadecimal number to a binary number, the base of that number is to be changed. Follow the steps given below:

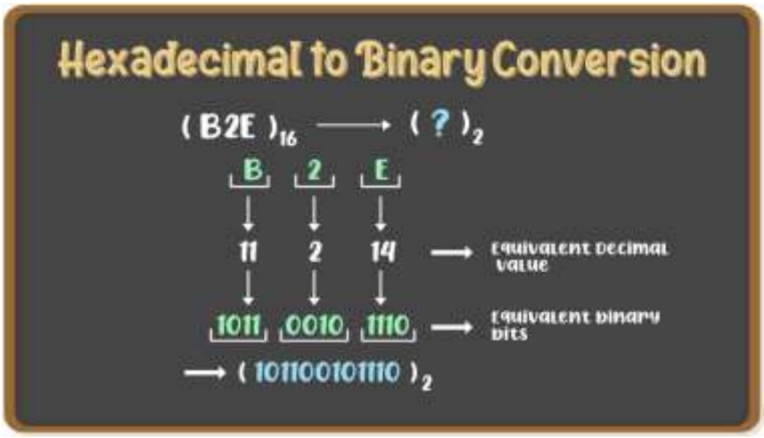
Step 1: Convert the Hex symbols into its equivalent decimal values.

Step 2: Write each digit of the Hexadecimal number separately.

Step 3: Convert each digit into an equivalent group of four binary digits.

Step 4: Combine these groups to form the whole binary number.

Example: $(B2E)_{16}$ is to be converted to binary



- **Hexadecimal to Octal Conversion:**

Hexadecimal numbers are represented in base 16, but the octal numbers are of base 8. Hence, to convert a hex number to an octal number, the base of that number is to be changed. Follow the steps given below:

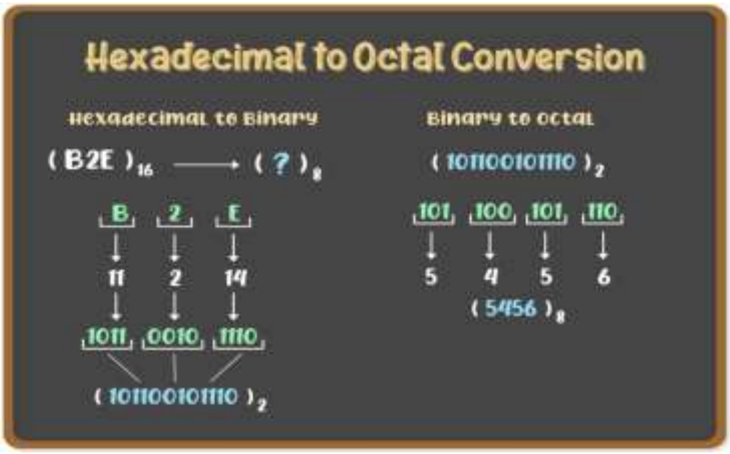
Step 1: We need to convert the Hexadecimal number to Binary first. For that, follow the steps given in the above conversion.

Step 2: Now to convert the binary number to Octal number, divide the binary digits into groups of three digits starting from right to left i.e. from LSB to MSB.

Step 3: Add zeros prior to MSB to make it a proper group of three digits(if required)

Step 4: Now convert these groups into their relevant decimal values.

Example: $(B2E)_{16}$ is to be converted to hex



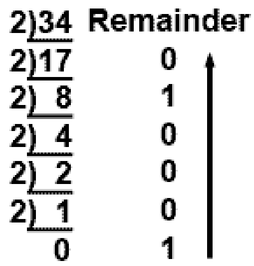
- **Numbers with Fractions**

It is very common in the decimal system to use fractions; that is any decimal number that contains a decimal point, but how can decimal numbers, such as 34.62510 be converted to binary fractions?

In electronics this is not normally done, as binary does not work well with fractions. However, as fractions do exist, there has to be a way for binary to deal with them. The method used is to get rid of the radix (decimal) point by NORMALISING the decimal fraction using FLOATING POINT arithmetic. As long as the binary system keeps track of the number of places the radix point was moved during the normalisation process, it can be restored to its correct position when the result of the binary calculation is converted back to decimal for display to the user.

However, for the sake of completeness, here is a method for converting decimal fractions to binary fractions. By carefully selecting the fraction to be converted, the system works, but with many numbers the conversion introduces inaccuracies; a good reason for not using binary fractions in electronic calculations.

✓ **Converting the Decimal Integer to Binary**



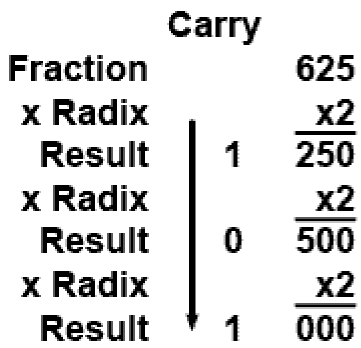
Example: Converting the Integer to Binary

The radix point splits the number into two parts; the part to the left of the radix point is called the INTEGER. The part to the right of the radix point is the FRACTION. A number such as 34.62510 is therefore split into 3410 (the integer), and .62510 (the fraction).

To convert such a fractional decimal number to any other radix, the method described above is used to convert the integer.

So 3410 = 100010_2

✓ **Converting the Decimal Fraction to Binary**



Example: Converting the Fraction to Binary

To convert the fraction, this must be MULTIPLIED by the radix (in this case 2 to convert to binary). Notice that with each multiplication a CARRY is generated from the third column. The Carry will be either 1 or 0 and these are written down at the left-hand side of the result. However, when each result is multiplied the carry is ignored (don't multiply the carry). Each result is multiplied in this way until the result (ignoring the carry) is 000. Conversion is now complete.

For the converted value just read the carry column from top to bottom.

So, 0.62510 = .1012

Therefore, the complete conversion shows that 34.62510 = 100010.1012

However, with binary, there is a problem in using this method, .625 converted easily but many fractions will not.

For example, if you try to convert .626 using this method you would find that the binary fraction produced goes on too many, many places without a result of exactly 000 being reached.

With some decimal fractions, using the above method will produce carries with a repeating pattern of ones and zeros, indicating that the binary fraction will carry on infinitely. Many decimal fractions can therefore only be converted to binary with limited accuracy. The number of places after the radix point must be limited, to produce as accurate an approximation as required.

- **Quick Conversions**

The most commonly encountered number systems are binary and hexadecimal, and a quick method for converting to decimal is to use a simple table showing the column weights, as shown in Tables 1.2.1a and 1.2.1b.

✓ **Converting Binary to Decimal**

To convert from binary to decimal, write down the binary number giving each bit its correct 'weighting' i.e. the value of the columns, starting with a value of one for the right hand (least significant) bit. Giving each bit twice the value of the previous bit as you move left.

Example:

To convert the binary number 010000112 to decimal. Write down the binary number and assign a 'weighting' to each bit as in Table below:

Table 1.2.1a								
Bit	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Value (weighting) of each bit	128	64	32	16	8	4	2	1
8 Bit Binary	0	1	0	0	0	0	1	1

Now simply add up the values of each column containing a 1 bit, ignoring any columns containing 0.

Applying the appropriate weighting to 01000011 gives 64 + 2 + 1 = 67

Therefore: 010000112 = 67_{10}

✓ **Converting Hexadecimal to Decimal**

A similar method can be used to quickly convert hexadecimal to decimal, using Table below:

Table 1.2.1b				
Column	16^3	16^2	16^1	16^0
Value (weighting) of each column	4096	256	16	1
Hex value	2	5	C	B

2 x 4096 = 8192
5 x 256 = 1280
C (12_{10}) x 16 = 192
B (11_{10}) x 1 = 11
9675

The hexadecimal digits are entered in the bottom row and then multiplied by the weighting value for that column.

Adding the values for each column gives the decimal value.

Therefore: 25CB16 = 9675_{10}

Points to Remember

- Number system base conversion is the process of changing a number from one base (or radix) to another.
- **Types of number system base conversion are:**
    - ✧ Decimal to Binary Conversion and vice versa
    - ✧ Decimal to Octal Conversion and vice versa
    - ✧ Decimal to Hexadecimal Conversion and vice versa
    - ✧ Binary to Octal Conversion and vice versa
    - ✧ Binary to Hexadecimal Conversion and vice versa
    - ✧ Octal to Hexadecimal Conversion and vice versa
- **Steps of number system base conversion:**

✧ **Steps for Converting Binary to Decimal**

Write down the Binary Number you wish to convert>> Assign powers of 2 to each digit in the binary number, starting from the rightmost digit (which is 2^0) and moving left>>multiply each binary digit by its corresponding power of 2>>Add all the products obtained from step three.

✧ **Steps for Converting Decimal to Binary**

Write down the Decimal Number>>Divide the decimal number by two and record the quotient and remainder>>Keep dividing the quotient by two until it equals zero, recording each remainder along the way**>>**Once you reach a quotient of zero, reverse the order of your recorded remainders; this will give you your binary representation.

✧ **Converting Decimal to Octal**

Write Down the octal Number>>Take the decimal number you want to convert and divide it by 8>>the remainder from this division will be one of the digits in your octal number**>>**Take the quotient from your previous division and divide it by 8 again.

Record the new remainder>>Repeat this process until your quotient becomes zero>>The octal number is formed by reading all the remainders in reverse order (from last to first).

✧ **Converting Octal to Decimal**

Understand Position Values>>Start with your octal number and identify each digit's position>>for each digit in the octal number, multiply it by 8position, where position starts at zero on the right>>Add all these products together to get your decimal equivalent.

✧ **Steps for Converting Decimal to Hexadecimal**

Take the decimal number you want to convert and divide it by 16>>Record the remainder that will be a value between 0 and 15. >> Take the integer quotient from the previous division and divide it by 16 again>>Continue until Quotient is Zero>> Once you have all your remainders recorded, write them in reverse order to get the hexadecimal equivalent of your original decimal number.

✧ **Steps for Converting Hexadecimal to Decimal**

Write down each digit of the hexadecimal number along with its positional value based on powers of 16 (starting from right to left)>>Multiply each digit by 16 raised to its position index (starting from 0)>>Add all these products together to get the decimal equivalent of the hexadecimal number.

Application of learning 5.2.

A group of students leaving high school commit to startup their own networking company. One day, they receive the clients who want to expand his/her network.

As one of the team, the supervisor gave you the worksheet with subnet problems involving conversions between binary, octal, decimal, and hexadecimal numbers

Indicative content 5.3: Application of Number system arithmetic

Duration: 7 hrs

Theoretical Activity 5.3.1: Description of number system arithmetic

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of number system arithmetic.

i. What is number system arithmetic?

ii. Identify the types of number system arithmetic.

2: Provide the answer for the asked questions and write them on reserved place.

3: Present the findings/answers to the whole class.

4: Follow the trainer when providing expert view.

5: For more clarification, read the key **readings 5.3.1.**

Key readings 5.3.1.:

- **Number system arithmetic**

Number system arithmetic is a fundamental aspect of mathematics and computing, involving operations on numbers in different number systems. A number system is a writing system for expressing numbers, using a consistent set of symbols and rules.

- **Types of Number System Arithmetic Operations**
  - ✓ **Addition:**
    - **Decimal:** Similar to regular addition; numbers are added digit by digit, carrying over as needed.
    - **Binary:** Follows similar rules, but carries over occur when the sum exceeds 1.
    - **Octal & Hexadecimal:** Similar principles apply, but carrying over happens according to the base.
  - ✓ **Subtraction:**

- **Decimal:** Subtracts numbers digit by digit, borrowing as needed.
- **Binary:** Uses borrowing similar to decimal, but in base 2.
- **Octal & Hexadecimal:** Subtracts using borrowing in base 8 and base 16, respectively.

✓ **Multiplication:**

- **Decimal:** Standard multiplication rules apply, using base 10.
- **Binary:** Uses base-2 multiplication rules, with shifts representing powers of 2.
- **Octal & Hexadecimal:** Similar to decimal but based on their respective bases.

✓ **Division:**

- **Decimal:** Divides numbers, following standard rules.
- **Binary:** Division operates similarly, but with binary representation.
- **Octal & Hexadecimal:** Similar to decimal but based on their respective bases.

Understanding these different systems and their arithmetic is crucial in fields like computer science, engineering, and digital electronics, where binary, octal, and hexadecimal systems are often used to simplify the representation and manipulation of data.

✓ **Complements of numbers**

Complements are used in the digital computers in order to simplify the subtraction operation and for the logical manipulations. For each radix-r system (radix r represents base of number system) there are two types of complements.

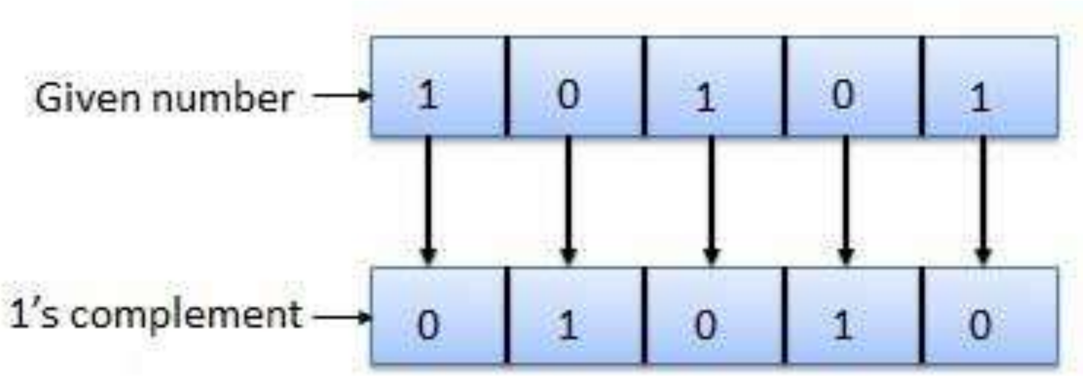
S.N.	Complement	Description
1	Radix Complement	The radix complement is referred to as the r's complement
2	Diminished Radix Complement	The diminished radix complement is referred to as the (r-1)'s complement

✓ **Binary system complements**

As the binary system has base r = 2. So, the two types of complements for the binary system are 2's complement and 1's complement.

- **1's complement**

The 1's complement of a number is found by changing all 1's to 0's and all 0's to 1's. This is called as taking complement or 1's complement. Example of 1's Complement is as follows.



- **Use of 1's complement**

1's complement plays an important role in representing the signed binary numbers. The main use of 1's complement is to represent a signed binary number. Apart from this, it is also used to perform various arithmetic operations such as addition and subtraction.

In signed binary number representation, we can represent both positive and negative numbers. For representing the positive numbers, there is nothing to do. But for representing negative numbers, we have to use 1's complement technique. For representing the negative number, we first have to represent it with a positive sign, and then we find the 1's complement of it.

Let's take an example of a positive and negative number and see how these numbers are represented.

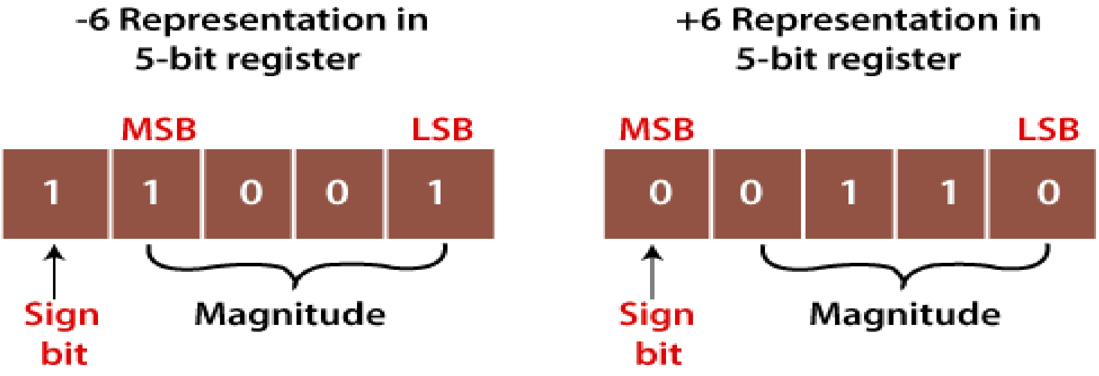
Example 1: +6 and -6

The number +6 is represented as same as the binary number. For representing both numbers, we will take the 5-bit register.

So the +6 is represented in the 5-bit register as 0 0110.

The -6 is represented in the 5-bit register in the following way:

- +6=0 0110
- Find the 1's complement of the number 0 0110, i.e., 1 1001. Here, MSB denotes that a number is a negative number.



Here, MSB refers to Most Significant Bit, and LSB denotes the Least Significant Bit.

Example 2: +120 and -120

The number +120 is represented as same as the binary number. For representing both numbers, take the 8-bit register.

So the +120 is represented in the 8-bit register as 0 1111000.

The -120 is represented in the 8-bit register in the following way:

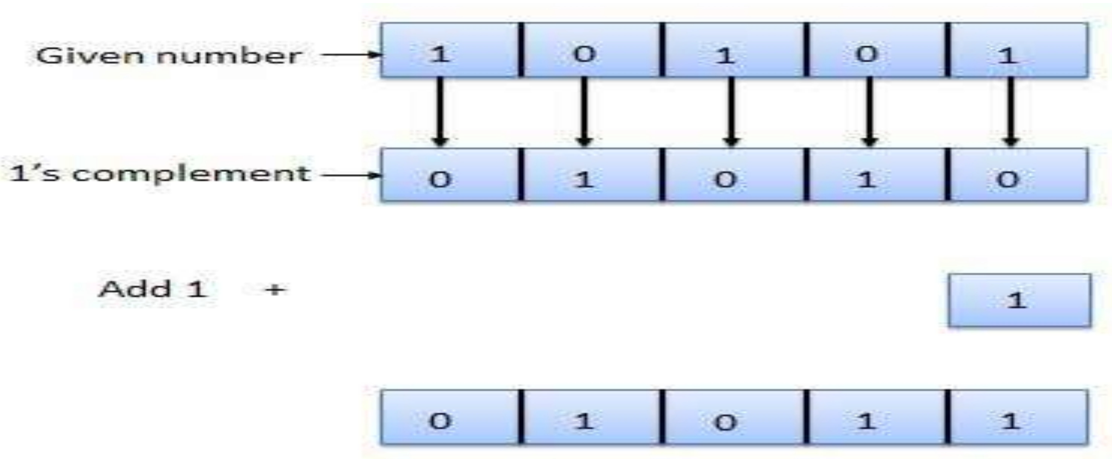
- +120=0 1111000
- Now, find the 1's complement of the number 0 1111000, i.e., 1 0000111. Here, the MSB denotes the number is the negative number.

2's complement

The 2's complement of binary number is obtained by adding 1 to the Least Significant Bit (LSB) of 1's complement of the number.

2's complement = 1's complement + 1

Example of 2's Complement is as follows.



- ✧ **Use of 2's complement**

2's complement is used for representing signed numbers and performing arithmetic operations such as subtraction, addition, etc. The positive number is simply represented as a magnitude form. So there is nothing to do for representing positive numbers. But if we represent the negative number, then we have to choose either 1's complement or 2's complement technique. The 1's complement is an ambiguous technique, and 2's complement is an unambiguous technique. Let's see an example to understand how we can calculate the 2's complement in signed binary number representation.

Example 1: +6 and -6

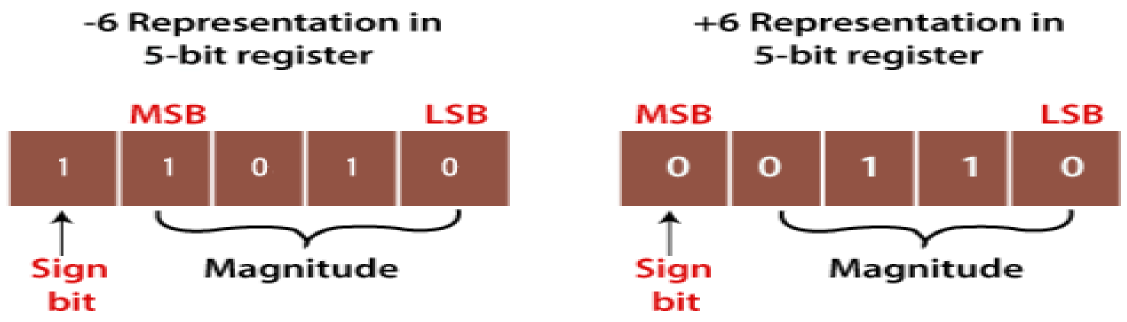
The number +6 is represented as same as the binary number. For representing both numbers, take the 5-bit register.

So the +6 is represented in the 5-bit register as 0 0110.

The -6 is represented in the 5-bit register in the following way:

- +6=0 0110
- Now, find the 1's complement of the number 0 0110, i.e. 1 1001.
- Now, add 1 to its LSB. When we add 1 to the LSB of 11001, the newly generated number comes out 11010. Here, the sign bit is one which means

the number is the negative number.



Example 2: +120 and -120

The number +120 is represented as same as the binary number. For representing both numbers, take the 8-bit register.

So the +120 is represented in the 8-bit register as 0 1111000.

The -120 is represented in the 8-bit register in the following way:

- +120=0 1111000
- Now, find the 1's complement of the number 0 1111000, i.e. 1 0000111. Here, the MSB denotes the number is the negative number.
- Now, add 1 to its LSB. When we add 1 to the LSB of 1 0000111, the newly generated number comes out 1 0001000. Here, the sign bit is one, which means the number is the negative number.

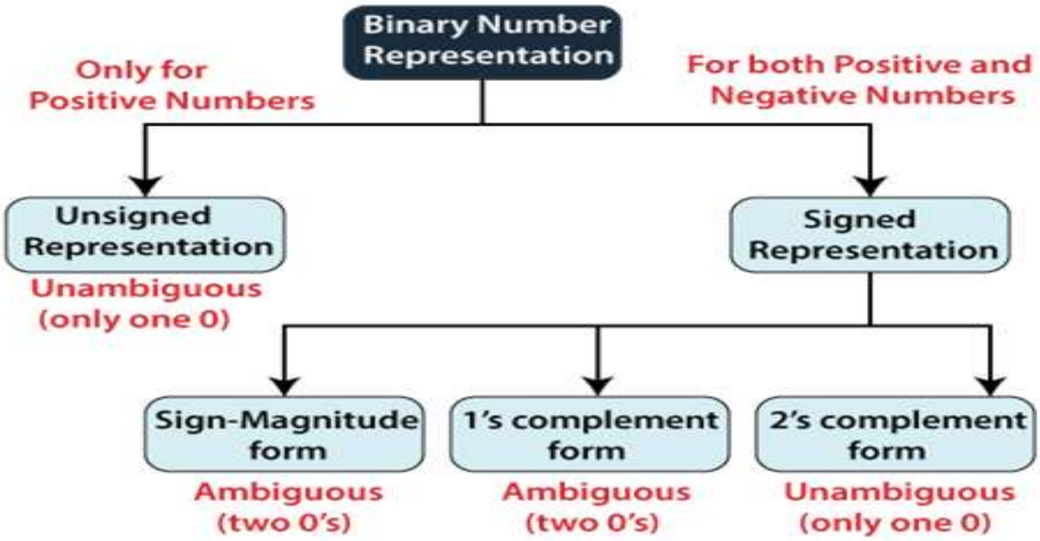
- **Signed and unsigned numbers**
  - ✓ **Signed Binary Numbers**

The integer variables are represented in a signed and unsigned manner. The positive and negative values are differentiated by using the sign flag in signed numbers. The unsigned numbers do not use any flag for the sign, i.e., only positive numbers can be stored by the unsigned numbers.

It is very easy to represent positive and negative numbers in our day-to-day life. We represent the positive numbers without adding any sign before them and the negative number with - (minus) sign before them. But in the digital system, it is not possible to use negative sign before them because the data is in binary form in digital computers. For representing the sign in binary numbers, we require a special notation.

- ✓ **Binary Numbers Representation**

Our computer can understand only (0, 1) language. The binary numbers are represented in both ways, i.e., signed and unsigned. The positive numbers are represented in both ways- signed and unsigned, but the negative numbers can only be described in a signed way. The difference between unsigned and signed numbers is that unsigned numbers do not use any sign bit for positive and negative numbers identification, but the signed number used.



- ✓ **Unsigned Numbers**

As we already know, the unsigned numbers don't have any sign for representing negative numbers. So the unsigned numbers are always positive. By default, the decimal number representation is positive. We always assume a positive sign in front of each decimal digit. There is no sign bit in unsigned binary numbers so it can only represent its magnitude. In zero and one, zero is an unsigned binary number. There is only one zero (0) in this representation, which is always positive. Because of one unique binary equivalent form of a number in unsigned number representation, it is known as unambiguous representation technique. The range of the unsigned binary numbers starts from 0 to (2^n-1).

Example: Represent the decimal number 102 in unsigned binary numbers.

We will change this decimal number into binary, which has the only magnitude of the given name.

Decimal	Operation	Result	Remainder
102	102/2	51	0
51	51/2	25	1
25	25/2	12	1
12	12/2	6	0
6	6/2	3	0
3	3/2	1	1
1	1/2	0	1

So, the binary number of $(102)_{10}$ is $(1100110)_2$, a 7-bit magnitude of the decimal number 102.

- ✓ **Signed Numbers**

The signed numbers have a sign bit so that it can differentiate positive and negative integer numbers. The signed binary number technique has both the sign bit and the magnitude of the number. For representing the negative decimal number, the corresponding symbol in front of the binary number will be added.

The signed numbers are represented in three ways. The signed bit makes two possible representations of zero (positive (0) and negative (1)), which is an ambiguous representation. The third representation is 2's complement representation in which no double representation of zero is possible, which makes it unambiguous representation. There are the following types of representation of signed binary numbers:

- **Sign-Magnitude form:**

In this form, a binary number has a bit for a sign symbol. If this bit is set to 1, the number will be negative else the number will be positive if it is set to 0. Apart from this sign-bit, the n-1 bits represent the magnitude of the number.

- **1's Complement:**

By inverting each bit of a number, we can obtain the 1's complement of a number. The negative numbers can be represented in the form of 1's complement. In this form, the binary number also has an extra bit for sign representation as a sign-magnitude form.

- **2's Complement:**

By inverting each bit of a number and adding plus 1 to its least significant bit, we can obtain the 2's complement of a number. The negative numbers can also be represented in the form of 2's complement. In this form, the binary number also has an extra bit for sign representation as a sign-magnitude form.

✓ **Basic law for arithmetic operations**

Just as we get a number when two numbers are either added or subtracted or multiplied or are divided. The binary operations associate any two elements of a set. The resultants of the two are in the same set. Binary operations on a set are calculations that combine two elements of the set (called operands) to produce another element of the same set.

Basic Laws for Various Arithmetic Operations:

These representation techniques hold basic laws for various arithmetic operations:

- **Associative law:** Addition and multiplication of binary numbers are associative.
- **Commutative law:** Addition and multiplication of binary numbers are commutative.
- **Distributive law:** Multiplication of binary numbers is distributive over two or more terms in addition.

✓ **Associative Property**

This law states that the operation can be performed in any order when the variables priority is same. As '*' and '/' have same priority. In the below diagram, the associative law is applied to the 2-input OR gate.

For three variables, the associative law of addition is written as:

A + (B + C) = (A + B) + C

For three variables, the associative law of multiplication is written as:

A(BC) = (AB)C

According to this law, no matter in what order the variables are grouped when ANDing more than two variables.

- ✓ **Commutative Property**

This law states that no matter in which order we use the variables. It means that the order of variables doesn't matter. In Boolean algebra, the OR and the addition operations are similar. In the below diagram, the OR gate display that the order of the input variables does not matter at all.

For two variables, the commutative law of addition is written as:

A+B = B+A

For two variables, the commutative law of multiplication is written as:

A.B = B.A

- ✓ **Distributive Property**

According to this law, if we perform the OR operation of two or more variables and then perform the AND operation of the result with a single variable, then the result will be similar to performing the AND operation of that single variable with each two or more variable and then perform the OR operation of that product. This law explains the process of factoring.

For three variables, the distributive law is written as:

A(B + C) = AB + AC

Binary operations subtraction and division are not distributive

- **Binary number system arithmetic**

In the binary number system, there are only two digits—0 and 1—and any number can be represented by these two digits. The **arithmetic of binary numbers** involves binary addition, binary subtraction, binary multiplication, or binary division.

Binary arithmetic operation starts from the least significant bit i.e. from the rightmost side. We will discuss the different operations one by one in the following article.

Binary arithmetic is essential part of all the digital computers and many other digital system.

Practical Activity 5.3.2: Applying of Number system arithmetic

Task:

1: Referring to the instructions provided by the trainer you are requested to perform the given task. The task should be done individually.

As Networking Technician, you are asked to follow the instructions from your trainer to perform the binary number complement, binary number system arithmetic, decimal number system arithmetic and octal number system arithmetic

2: Follow the trainer when demonstrating how to perform the arithmetic operations and write down the procedures used.

3: Referring to procedures provided on task 2, perform the given tasks

4: Read key reading 5.3.1 and ask clarification where necessary

5: Perform the task provided in application of learning 5.3.2

Key readings 5.3.2

- **Application of Number system arithmetic**
  - ✓ **Binary Addition**

Steps of adding Binary Numbers are:

Step1: Align the Numbers: Write the binary numbers one above the other, aligning them to the right.

Step2: Add from Right to Left: Start adding from the rightmost bit (least significant bit).

Step3: Carry Over if Necessary

- If the sum is 0, write down 0.
- If the sum is 1, write down 1.
- If the sum is 2 (10 in binary), write down 0 and carry over 1 to the next column.
- If the sum is 3 (11 in binary), write down 1 and carry over 1 to the next column.

There are four rules of binary addition.

Case	A	+	B	Sum	Carry
1	0	+	0	0	0
2	0	+	1	1	0
3	1	+	0	1	0
4	1	+	1	0	1

In fourth case, a binary addition is creating a sum of (1 + 1 = 10) i.e. 0 is written in the given column and a carry of 1 over to the next column.

Example – Addition

0011010 + 001100 = 00100110

```
   11       carry
  0011010  = 26₁₀
 +0001100  = 12₁₀
 --------
  0100110  = 38₁₀
```

Example:

111

1011

+ 1101

11000

✓ **Binary Subtraction**

Steps for Subtracting Binary Numbers are described below:

Step1： Align the Numbers: Write the larger number on top and smaller below it, aligned to the right.

Step2： Subtract from Right to Left.

Step3： If you can subtract without borrowing, do so normally.

Step4： If you need to borrow:

✧ Borrow from the next left bit that has a value of '1'.

✧ Change that ‘1’ to ‘0’, and add ‘2’ (or ‘10’ in binary) to your current position.

There are four rules of binary subtraction.

Case	A	-	B	Subtract	Borrow
1	0	-	0	0	0
2	1	-	0	1	0
3	1	-	1	0	0
4	0	-	1	0	1

Example:

0011010 - 001100 = 00001110

```
      1 1        borrow
  0 0 1 1 0 1 0  = 26₁₀
 -0 0 0 1 1 0 0  = 12₁₀
 ---------------
  0 0 0 1 1 1 0  = 14₁₀
```

✓ **Binary Multiplication**

Steps for Multiplying Binary Numbers are described below:

Step1: Write Down Both Numbers: Align them as you would for decimal multiplication.

Step2: Multiply Each Bit of the Bottom Number by Each Bit of the Top Number, shifting left for each new row:

Step3: Multiply by ‘0’: Result is all zeros for that row.

Step4: Multiply by ‘1’: Result is just a copy of the top number shifted appropriately.

Ste54: Add All Rows Together using binary addition rules.

There are four rules of binary multiplication.

Case	A	x	B	Multiplication
1	0	x	0	0
2	0	x	1	0
3	1	x	0	0
4	1	x	1	1

Example:

0011010 x 001100 = 100111000

```
      0011010   = 26₁₀
     x0001100   = 12₁₀
   -----------
      0000000
     0000000
    0011010
   0011010
   -----------
   0100111000   = 312₁₀
```

- ✓ **Binary Division**

Steps for dividing Binary Numbers are described below:

Step1: Set Up Division Like Decimal Division, with dividend inside and divisor outside.

Step2: Compare Bits Starting from Left: Bring down bits until you have enough to compare with divisor.

Step3: Subtract divisor from this portion if it's less than or equal; otherwise, bring down another bit.

Step4: Record Quotient and Remainder, repeating until all bits are processed.

Binary division is similar to decimal division. It is called as the long division procedure.

Example:

101010 / 000110 = 000111

```
              111      = 7₁₀
000110 ) 101010        = 42₁₀
         -110          = 6₁₀
         ----
          1001
          -110
          ----
            110
           -110
           ----
              0
```

- **Decimal number system arithmetic**
  - ✓ **Adding Decimals**

To add decimals numbers we follow those steps:

Step 1: Write numbers under each other and line up vertically the decimal points.

Step 2: Pad up zeros if the decimals are of different decimal places.

Step 3: Add the numbers as they are in column.

Step 4: Put up the decimal point on the sum.

Example:

a) 41.8 + 0.15 =

Line up the decimal points

```
   41.80 }  Pad with 0
+   0.15 }  and add
---------
   41.95
```

b) 0.166 + 2.2 =

Line up the decimal points

```
   0.116 }  Pad with 0
+  2.200 }  and add
---------
   2.316
```

c) 5 + 21.2 + 0.12

Line up the decimal points

```
    5.00 }  Change the whole number into decimal
   21.20 }
+   0.12 }  Pad with 0 and add
---------
   26.32
```

d) 0.1 + 0.92 + 0.08

Line up the decimal points

```
   1 1
   0.100 }
   0.920 }  Pad with 0 and add
+  0.080 }
---------
   1.100
```

✓ **Subtracting Decimals**

To subtract decimals is the same as adding them, so we follow the same steps:

Step 1: Write numbers under each other and line up vertically the decimal points.

Step 2: Pad up zeros if the decimals are of different decimal places.

Step 3: Subtract the numbers as they are in column.

Step 4: Put up the decimal point on the difference.

Example:.

a) 87.5 - 1.2 =

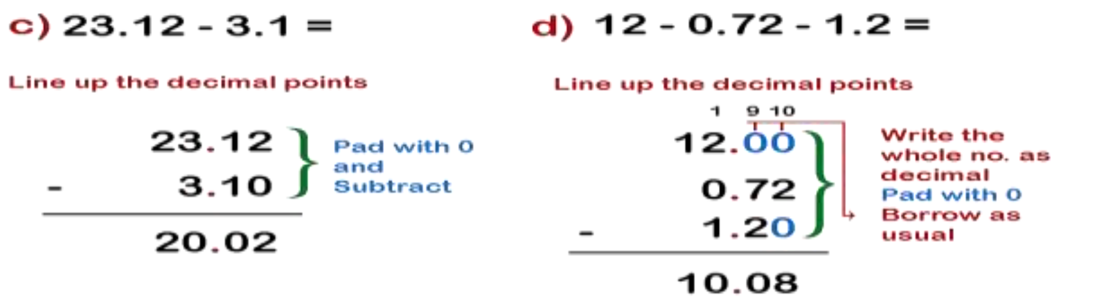
Line up the decimal points

```
   87.5 }
-   1.2 }  Subtract
--------
   86.3
```

b) 14.9 - 2.23 =

Line up the decimal points

```
      8 10
   14.90 }  Pad with 0
-   2.23 }  Borrow as usual and Substract
---------
   12.67
```



✓ Multiplying Decimals

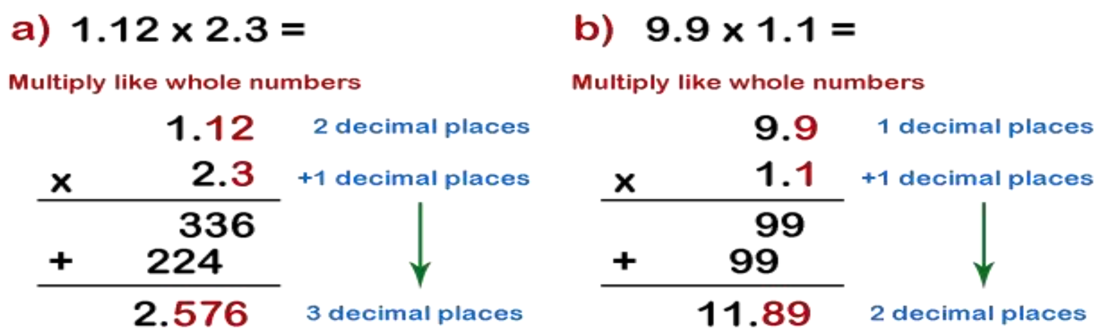
To multiply decimal numbers we follow the steps:

Step 1: Multiply the numbers as they were whole numbers.

Step 2: Determine how many decimal places have all the numbers that are being multiplied.

Step 3: Put the decimal point on the answer starting from the right and moving as many decimal places have all the numbers that are being multiplied.

Example:

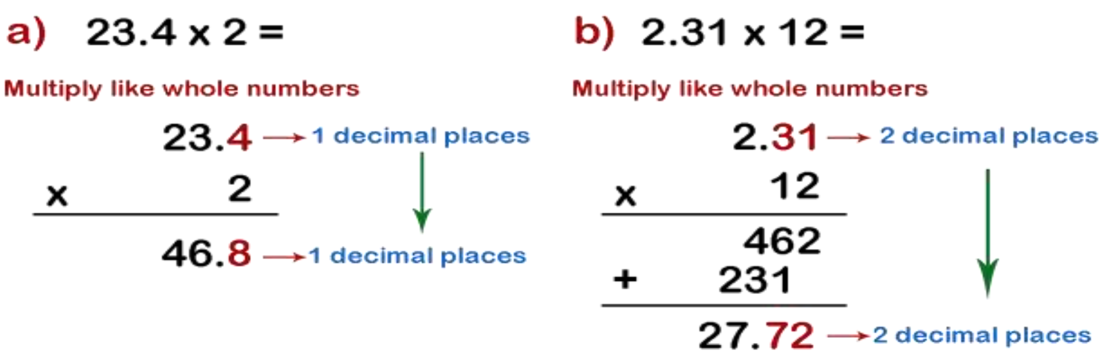


✓ Multiplying Decimals by Whole Numbers

Step 1: Assume that the decimal is a whole number and multiply them as whole numbers.

Step 2: Put in the product the same number of decimal points as there are in the decimal number.

Example:



- ✓ **Dividing Decimals**

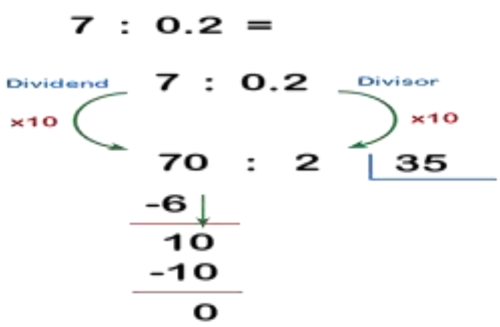
To divide decimal numbers, we follow the steps:

Step 1: Convert the divisor from a decimal number into a whole number by multiplying with 10 as many times as to turn into a whole number.

Step 2: Multiply the divided the same many of times you multiplied the divisor with 10.

Step 3: If the divided is still a decimal number we can ignore the point and do the normal division and put it back later at the quotient, or we can divide the numbers as whole numbers.

Example:



- ✓ **Dividing decimals with whole numbers**

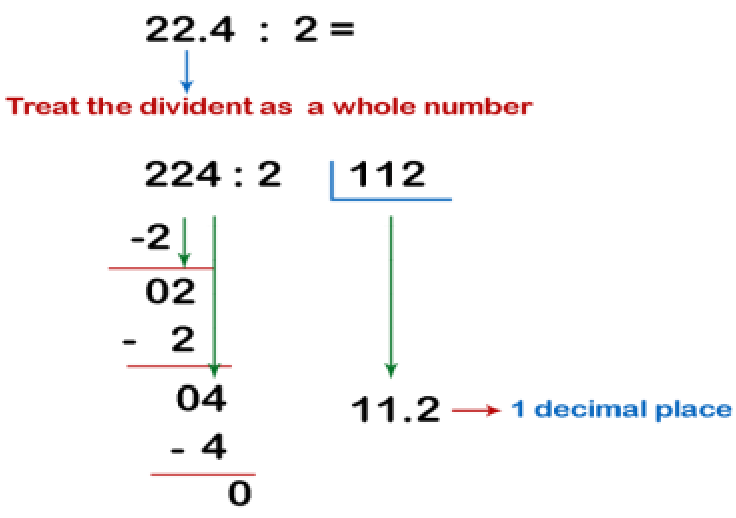
To divide decimal numbers with a whole number, we follow the steps:

Step 1: Treat the divided as a whole number by ignoring the point.

Step 2: Divide it by the divisor using the regular long division.

Step 3: Insert in the quotient the same number of decimal points as they are in the dividend.

Example 6: Divide



- **Octal number system arithmetic**
  - ✓ **Octal Addition**

Step-by-Step Guide to Octal Addition are as follow:

1. **Arrange the Numbers:** Write the octal numbers to be added, one below the other, aligning the digits based on their place values (just like in decimal addition).
2. **Add the Rightmost Digits:** Start adding the rightmost digits (least significant digits). If the sum is less than 8, write the result below. If the sum is 8 or more, write down the remainder after subtracting 8 (this is the equivalent of carrying over in base 10).
3. **Carry Over if Necessary:** If the sum of two digits is 8 or more, subtract 8 from the sum and carry over 1 to the next higher place value. Repeat this for each column of digits.
4. **Repeat for Remaining Digits:** Move to the next column (leftward) and repeat the process of adding, carrying over, and writing the result. Continue this until all digits have been added.
5. **Write the Final Result:** After completing all the columns, the result (including any final carry over) gives the sum in octal.

Example: Perform this $(162)_8+(531)_8$

```
 1 1    <---- carry
 1 6 2
 5 3 7
 -----
 7 2 1
```

✓ **Octal Subtraction**

Step 1: Write down the numbers: Align the two numbers just as you would in decimal subtraction.

Step 2: Subtract each column from right to left: Start subtracting the digits in each column, beginning from the rightmost digit.

Step 3: Borrow from the next column: When borrowing in octal, remember you're borrowing "1" from the next column, which represents 8 in base-8.

Step 4: Continue with the next column: Move to the next column (the second column from the right).

Step 5: Write the result: Now combine the digits and write the final result.

Example – Subtraction

$456_8 - 173_8 = 333_8$

```
   8        borrow
 ³4 5 6   = 302₁₀
 -1 7 3   = 123₁₀
 ------
  2 6 3   = 179₁₀
```

✓ **Multiplication of Octal Numbers**

Step 1: Write Down the Numbers: Write the two octal numbers you want to multiply. Remember, each digit in the number can range from 0 to 7.

Step 2: Multiply Each Digit: Multiply the digits as if you were performing decimal multiplication. However, when the product exceeds 7 (because the base is 8), you'll need to convert the result into octal.

Step 3: Shift and Multiply Remaining Digits: Just like in decimal multiplication, move one position to the left and multiply by the next digit, shifting the results appropriately to the left.

Step 4: Add the Partial Products: Add the results of the multiplication for each digit. The addition is done in octal as well, following octal rules: If a sum exceeds 7, convert it to octal by dividing by 8 (the quotient becomes the carry).

Step 5: Check for Carry: Make sure to account for any carry that was generated during the multiplication or addition steps.

Example: Evaluate:

(i) $6_8 \times 23_8$

Solution:

We have 6 × 3 = 18 in decimal, which when divided by 8 gives a remainder 2 and carry 2. Again 6 × 2 = 12 in decimal, and 12 + 2 = 14. This when divided by 8 gives a remainder 6 and a carry 1.

6 × 3 = 18

18/8 = 2 with remainder 2 → l,s,d,

6 × 2 = 12 + 2 (carry) = 14

14/8 = 1 with remainder 6.

Hence $6_8 \times 23_8 = 162_8$

Points to Remember

- Number system arithmetic is a fundamental aspect of mathematics and computing, involving operations on numbers in different number systems.
- Types of Number System Arithmetic Operations are: Addition, Subtraction, Multiplication and Division.
- A "complement number" refers to a method of representing negative numbers in binary or other number systems.
- The most commonly used is two's complement, but there's also one's complement.

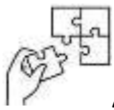
- 1's complement plays an important role in representing the signed binary numbers.
- 2's complement is used for representing signed numbers and performing arithmetic operations such as subtraction, addition, etc.
- Basic laws for various arithmetic operations:

Associative law: Addition and multiplication of binary numbers are associative.

Commutative law: Addition and multiplication of binary numbers are commutative.

Distributive law: Multiplication of binary numbers is distributive over two or more terms in addition.

- The **arithmetic of binary numbers** involves binary addition, binary subtraction, binary multiplication, or binary division
- Binary number system arithmetic involves binary addition, subtraction, multiplication and division operations.
- Decimal number system arithmetic involves binary addition, subtraction, multiplication and division operations.
- Octal number system arithmetic involves binary addition, subtraction, multiplication and division operations.



Application of learning 5.3.

A group of students leaving high school commit to startup their own networking company. To reinforce their understanding, the team supervisor designs a practical activity where students convert numbers between different systems and perform arithmetic operations.

As one of the team, you are tasked to converting numbers between different number systems and perform arithmetic operations accordingly.

Learning outcome 5 end assessment

Theoretical assessment

1. Convert the following binary numbers to decimal form:

(a) 1012 (b) 101012 (c) 11101012

2. Convert E716 into its decimal equivalent.

3. Convert 2F116 into its decimal equivalent.

4. Calculate the sum of the following binary expressions:

11102 + 11112

5. Convert (89)16 into a binary number.

6. Convert (100111)2 into the decimal system.

7. Convert (1010111100)2 to the equivalent decimal system.

8. Convert (300)10 into the binary system with base 2.

9. Convert 5BC16 into its equivalent decimal number system.

10. Convert (13056)8 to its equivalent decimal system.

11. Convert 1448 into the decimal system.

12. Convert each of the following octal numbers to binary, decimal, and hexadecimal formats.

$(7777)_8$

$(247)_8$

13. Convert each of the following hexadecimal numbers to binary, octal, and decimal formats.

$(4FB2)_{16}$

$(88BAE)_{16}$

14. 1's complement of 1011101 is ____________

a) 0101110

b) 1001101

c) 0100010

d) 1100101

15. 2's complement of 11001011 is ____________

a) 01010111

b) 11010100

c) 00110101

d) 11100010

Practical assessment

A group of students leaving high school commit to startup their own networking company. To reinforce their level of understanding about binary, decimal, octal, and hexadecimal systems, they want to recruit another expert in the field so that they can handle the issues related.

You as one recruited by the company, demonstrate your ability to convert numbers between different numbering systems, perform arithmetic operations, and understand their applications in digital circuits.

END

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