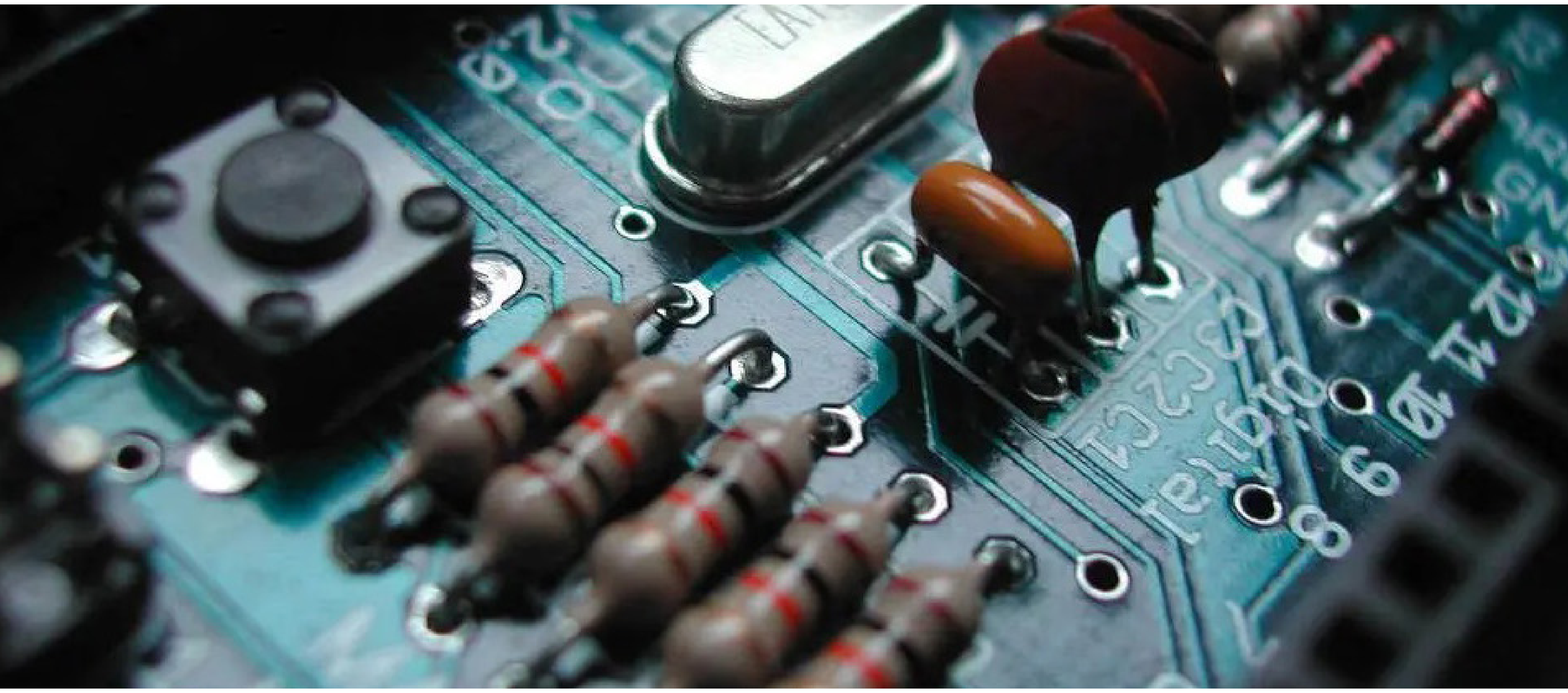
MINISTRY OF EDUCATION
TECHNICAL TEACHERS
ASSOCIATION OF GHANA

Electricals and Electronics Technology

(Applied Technology)

for Senior High Schools

Year 2



Gilbert Second Odjamgba
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FOREWORD

Ghana's new Senior High School Curriculum aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, knowledge, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, progress to further studies and enter the world of work. This is the first time that Ghana has developed a Senior High School Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

The Ministry of Education is proud to have overseen the production of these Learner Materials which can be used in class and for self-study and revision. These materials have been developed through a partnership between the Ghana Education Service, teacher unions (Ghana National Association of Teachers-GNAT, National Association of Graduate Teacher -NAGRAT and the Coalition of Concerned Teachers- CCT) and National Subject Associations. These materials are informative and of high quality because they have been written by teachers for teachers with the expert backing of each subject association.

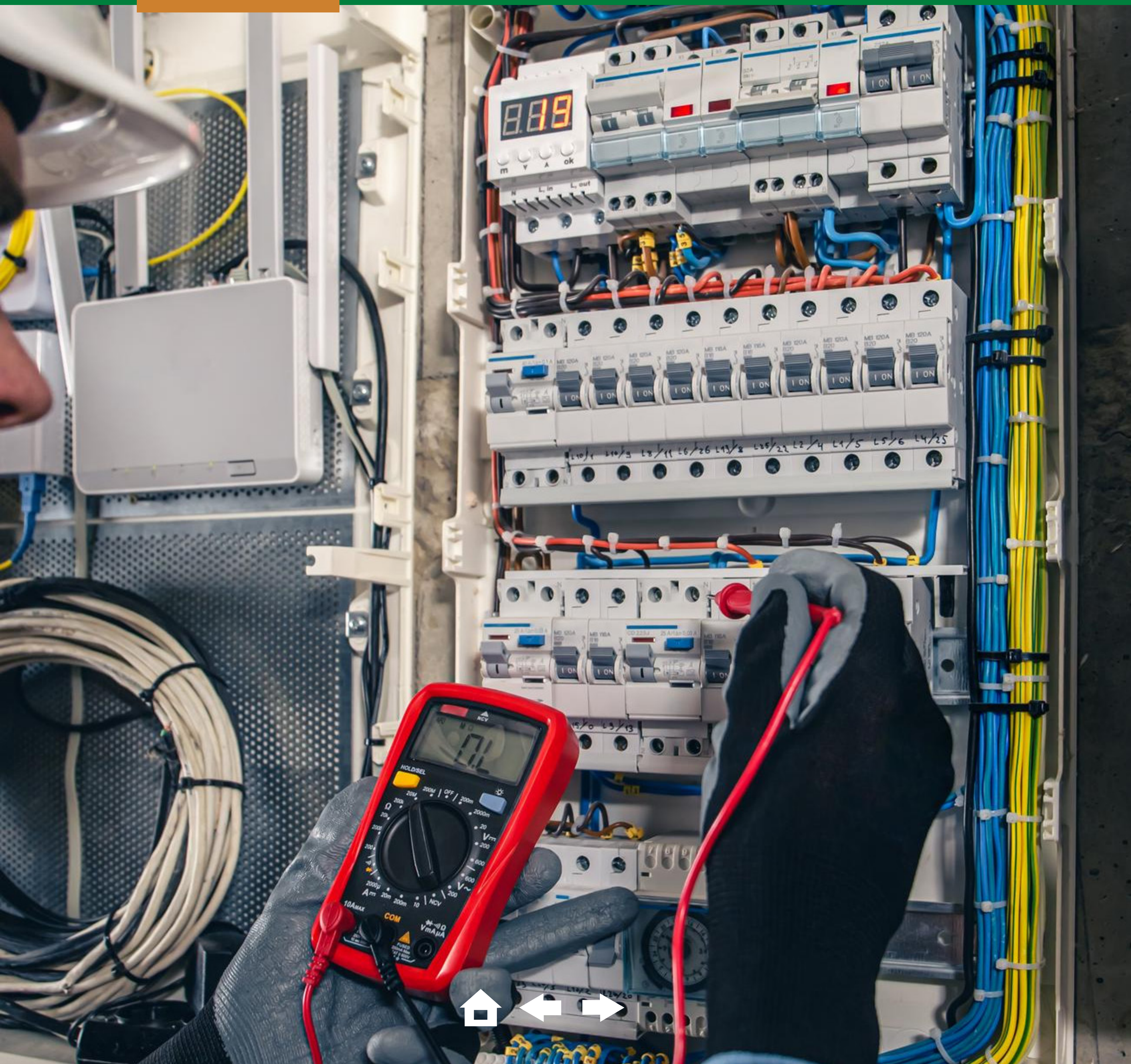
I believe that, if used appropriately, these materials will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

Haruna Iddrisu MP
Minister for Education

SECTION

1

DOMESTIC INSTALLATION



UNIT 1

ELECTRICAL TECHNOLOGY

Electrical System Design

HOUSE WIRING AND THE PROCESSES INVOLVED

Introduction

This section covers key aspects of Electrical and Electronics Technology through four units focused on house wiring. Unit 1 emphasises electrical systems design and the processes involved, enabling you to apply your knowledge practically. Unit 2 classifies tools and equipment essential for electricians, including hand tools, power tools, and safety gear. Unit 3 identifies materials and accessories needed for house wiring, discussing components like conductors and insulators, as well as the current-carrying capacity of various cable sizes. Finally, Unit 4 addresses supply-control equipment on a consumer's premises, exploring protective devices such as cutout fuses, meters, and distribution boards, highlighting their roles in safely managing electrical supply. Let us get started!

This unit covers the processes involved in house wiring and classification of tools and equipment used in wiring and their functions, as well as the sequence of supply-control equipment on a consumer's premises. Wiring a new home is a complex and multifaceted procedure that requires careful planning, precise execution, and thorough testing. From the initial layout planning to the final inspections, each step plays a vital role in creating a safe, reliable electrical system.

KEY IDEAS

- Understanding the planning process for house wiring is essential for ensuring a safe and effective electrical installation.
- A detailed wiring layout must be executed accurately to align with specified requirements and codes.
- Key testing procedures are crucial to verify the safety, compliance, and efficiency of the electrical installation.
- Familiarity with different categories of tools, such as hand tools, power tools, special tools, testing equipment and safety gear, is vital for successful wiring.
- Proper maintenance and care of tools and materials used in electrical installations significantly enhance their longevity and performance.

HOUSE WIRING

House wiring is the arrangement of electrical circuits and accessories such as distribution boards or circuit breaker panels, switches, lamp holders, socket outlets, light fittings, and cables that distribute electricity from the main supply and connect to equipment and appliances in different parts of a house.

Reasons for Good Wiring

Here are some of the key reasons why correct house wiring is fundamental:

1. **Safety**

   Correct installation of electrical wiring is imperative due to safety implications. Correct wiring is essential to ensure the protection of individuals and property from the risk of sparks, fires, electrocution/electric shock and damage to electrical appliances.

   Ensuring safety includes

   a. Using the right cable sizes for the current they have to carry, and the corresponding current capacity of protective devices such as fuses and circuit breakers.

   b. Providing good grounding or earthing systems.

   c. Correctly securing or terminating wires to prevent any damage or hazards.

2. **Compliance**

   It is important to comply with the Energy Commission code, Wire Coding (live wire-red or brown, neutral wire –black or blue, earth wire–yellow/green) and the relevant I.E.E regulations to ensure that all wiring is done correctly and up to standard to make sure there is a reliable electrical system that operates effectively.

3. **Functionality**

   Wiring that is **not** done correctly can lead to appliances **not** working or operating inefficiently, causing inconvenience and potential damage. Each electrical device, from light fixtures to appliances, requires a sufficient amount of power to operate correctly. Correctly wired circuits will provide the necessary voltage and current needed for all connected devices to function properly.

4. **Efficiency**

   Well-designed and properly installed wiring systems minimise energy losses and reduce electricity costs. By using appropriately sized wires or cables and routing or course-plotting them efficiently, voltage drops and energy waste can be minimised.

Planning for a Good Electrical Wiring Layout in a House

This phase requires precise measurements, accurate estimation, and the selection of suitable materials, as well as careful wiring placement to prevent future complications. It is important to:

1. Use the electrical graphic symbols to identify requirements for electrical points in each room, from the building working plan.
2. Build a sub-circuit materials schedule as shown in **Table 1.1.1** to estimate the accessories or fixtures required.

Table 1.1.1: Sub-Circuit material schedule

Location	Lamp	One-way switch	2-way switch	13 A socket	Cooker Unit	Ceiling fan	Consumer unit	Inter-mediate switch
Bedroom 1	1	0	2	2	0	1	0	0
Bedroom 2	1	0	2	2	0	1	0	0
Lobby 1	1	0	2	0	0	0	0	0
Lobby 2	1	0	2	0	0	0	0	0
Living room	4	0	2	6	0	2	0	1
Toilet &Bath	1	1	0	0	0	0	0	0
Dining	2	1	0	4	0	2	0	0
Security lamps	7	1	0	0	0	0	0	0
Kitchen lamp	1	1	0	0	1	1	0	0
Total	19	4	10	14	1	7	1	1

3. Decide the rated capacity for each point in a room (all capacities in watts (w). See **Table 1.1.2** for an example.

Table 1.1.2: Example rated capacity rooms in a house

Room	Requirement	Capacity
Bedroom 1	One lamp	11w
Living room	Four lamps	20w × 4
Kitchen	One lamp	25w
Security	Seven lamps	100w/50w × 7

4. Calculate the electrical load for each room.
   a. Start by adding the wattage of all lighting branch circuits. **For example:**

- Bedrooms 1 and 2 have 2 lamps of 11 W each, making $11 \times 2 = 22W$
- The living room has 4 lamps of 20 W each, making $20 \times 4 = 80$ W
- The kitchen has one 25W lamp, etc.

b. Check the wattage ratings of all plug-in outlets, such as blender - 50 W, TV-100 W, fridge -250 W, washing machine - 300 W, air-conditioner – 350 W, etc.

c. Add the wattage of all permanent appliances, such as water heaters, central air-conditioners.

d. Finally, add the wattages of all the appliances **(a + b + c)** to determine the **total** load.

If we used the items listed in the example above, this would be:

127w + 1050w + 4125 = 5302w (or 5 kilowatts)

5. Divide the total load in Watts by the supply voltage (230 V) to obtain the total current demand for the facility/home in amps.

Again, using the example above, this would **be 5302/230 = 23 amps (23A).**

So, the example house above would need at least 23A for the given electrical equipment.

6. Decide the rated capacity of the electrical cables (selection of cables): For safety purposes, the Institution of Electrical Engineers (I.E.E) regulations stipulate that:

a. cables must be sufficient in size for the current they have to carry,

b. their current rating must be higher than that of the protective fuse,

c. the potential (voltage) drop down the cable must be less than 2.5% of the supply voltage. The current-carrying capacity of cables, type of wiring, and the size of cable that would complement are tabulated in **Table 1.1.3** below from Appendix 4 of the I.E.E regulations.

Table 1.1.3: Current-carrying capacity of cables

Size of cable (mm^2)	Surface (Amp)	Conduit (Amp)
1.5	16	13
2.5	23	18
4.0	30	24
6.0	38	31
10.0	51	42
16.0	68	56

7. Decide the size of the main electrical control panel.

8. The total obtained in **Table 1.1.1**, referred to as *Bill of Quantities,* is transferred to the appropriate columns in the estimates form in **Table 1.1.4**.

Table 1.1.4: Estimates from the first row completed as an example.

S/N	Description of material	Quantity required	Unit price	Total price	Labour cost/unit	Labour hour	Total labour cost
1	1.5 mm^2 (lighting)	4 reels	GH¢ 940	GH¢ 3760	4 units	GH¢ 13.75	GH¢ 55
2	2.5mm^2 (Sockets)	5 reels					
3	10mm^2 (supply)	1 reel					
4	Lamps	19					
5	On-way switches	4					
6	Two-way switches	10					
7	13 A sockets	14					
8	Ceiling fan	7					
9	Intermediate switch	1					

Compile the overall cost as follows:

- **a.** Material cost
- **b.** Labour cost
- **c.** Total cost (material cost + labour cost)
- **d.** Add 10% for contingency allowance to the total cost.

In the above table, row one has been completed so the cost for that works out at:

GH¢ 3760 + GH¢ 55 = GH¢ 3815 + 10% = GH¢ 4196.50

In order to be accurate with the estimates, you must provide an accurate costing for the time required to complete the work, as this has a direct bearing on labour costs.

Processes Involved in the Layout of House Wiring

A well-designed and expertly installed electrical system is fundamental to any new home's comfort, functionality, and value.

The Process of New Home Wiring

1. **Planning the Electrical Layout**

   Before any physical work begins;

a. A detailed plan for the home's electrical layout is essential.

b. This plan involves creating blueprints /working drawings that outline the electrical outlets, switches, lighting fixtures, and major appliance locations.

c. Divide the entire electric load into several circuits, such as lighting circuits, power circuits, cooker circuits, air conditioner circuits, etc.

2. **Rough-In Wiring Phase**

The rough-in wiring phase begins after the home's framing is completed but before the walls and ceilings are finished. The locations of the electrical switch boards, switches, sockets and conduits for each room are marked, cut out or chiselled. Electrical boxes for outlets, switches, and fixtures are installed during this stage. Cables are run from the main electrical panel to each box, following the layout defined in the planning phase.

3. **Installing the Main Electrical Panel**

a. **Main Breaker:** It must be positioned in an accessible location where it is easy for the homeowners to cut off power to the entire house.

Connect the grounding wire from the main breaker to the home grounding system to ensure safety. Install the main panel, often referred to as the breaker box to which the service entrance cables from the utility company (ECG) are connected. The panel is then populated with circuit breakers designed to distribute and control the flow of electricity to different parts of the house.

Professional electricians will ensure the panel is properly grounded and all connections are secure and compliant with safety standards.

b. **Meter Installation:** Identify a location that is easily accessible for meter reading and maintenance, outside the home. Secure the meter base (the box that houses the meter) to the exterior wall, ensuring it is level and at the correct height.

The utility company will typically install the actual meter once everything is set up.

c. **Service Entry:** Identify the best location for the electrical service to enter the home. Work with the utility company. Set up a conduit from the entry point to the main panel, ensuring it meets local code requirements for depth and protection. Run the main service wires (one hot / live wire and one neutral) through the conduit into the main pane.

d. **Main Panel Connection:** The next step is to connect the main panel. This phase ensures that the home electrical system is safely connected to the grid, ready to distribute power throughout the residence.

4. **Testing and Inspection**

   After the installation, the entire electrical system undergoes rigorous testing to confirm its functionality and safety. Electricians check for continuity, measure voltage levels, and test each circuit to ensure it operates correctly under load.

5. **Residential electrical installation**

   Testing & verification phase: Each of the steps of the Testing & Verification Phase helps to ensure that the electrical installation is safe, efficient, and ready for use. These tests are designed to detect and correct any flawed issues before the system is energised, reducing the risk of electrical fires, shocks, or equipment damage.

   a. **Continuity Check:** Use a continuity tester or multimeter to ensure that electrical current can flow through each wire and circuit without interruption. If a break is detected in continuity, the location of the break is located and corrected as needed.

   b. **Polarity check:** Polarity tester is used to ensure that all outlets and connections are wired correctly, with hot/live and neutral wires in their proper places. If an incorrect polarity is detected, it is rewired to ensure proper orientation.

   c. **Voltage test:** Use a multimeter we measure the voltage at various points in the system, to ensure it falls within the expected range. If voltage levels are found to be outside the acceptable range, adjustments may need to be made at the main panel or at individual circuit breakers.

   d. **Grounding test:** Ensure all components are securely connected and free of corrosion. If the grounding system is inadequate, install additional grounding rods or clean and tighten existing connections.

   The final steps of the electrical installation ensure it is not only complete and functional, but also documented and understood by the homeowner, using correct documentation, accompanied by a successful final safety inspection.

Activity 1.1.1 Understanding house wiring

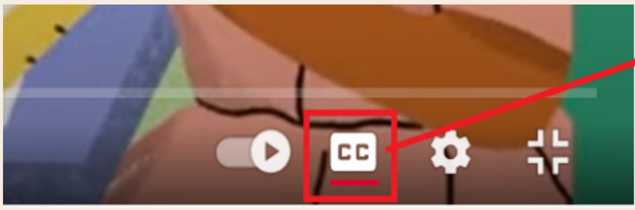
Scenario

As part of a community development project, your technical institute has been asked to support local households by improving their electrical installations. Your team will research, explain, and demonstrate what house wiring means and describe the processes involved in wiring a house. The aim is to ensure safety, efficiency, and affordability for rural homes in Ghana.

Video Guide

Watch the video on ***the basic steps of house wiring***

Link: https://youtu.be/xp8WPqrdGG8?si=RZDRVjx9rwR200XQ



Tap on the (CC) icon to enable transcript or subtitles, if you find it difficult to hear the audio clearly

While watching, answer the following. Your responses will be helpful in the tasks below, so do well to keep them.

1. What is meant by the term *house wiring*?
2. What materials and tools are shown?
3. What are the main processes followed in wiring a house?
4. Why is safety important at each step?

After watching the video and still focused on the scenario given above, do the following tasks.

Tasks

1. In your own words, explain what house wiring means. What are some of the reasons why proper wiring is important in homes?
2. Pair up with a friend and explore the meaning of house wiring. Share your ideas in class discussion.
3. Write your final definition in your notebook, worksheet or tablet.

Activity 1.1.2 Stages of wiring a house

1. Still in your pair, describe the stages followed when wiring a house (planning, installation of conduits, pulling of wires, fixing accessories, testing) with your partner.
2. Discuss why each stage is important. The steps below should guide you through this task.
   a. Watch the video again and list at least two processes of wiring.
   b. Summarise your findings in a table. *See the table below as an example.*
   c. Compare with other groups' processes and add missing points.

Process	Description	Importance	Safety Measures
Planning & Design			
Conduit Installation			
Wire Pulling			
Fixing Accessories			
Testing & Inspection			

Activity 1.1.3 Poster presentations

1. From ***Activity 1.1.2***, use posters or diagrams to show wiring processes.
2. Include sketches of wiring layouts.
3. Present your group's findings clearly.

Activity 1.1.4 Processes in house wiring

This activity can be done individually or with a group of friends.

1. Research using internet resources, notes or other resources available to you to find;
   a. at least three safety tips.
   b. Present them as a safety checklist. ***See example below***.
   c. Identify possible hazards during wiring and suggest safety measures to be followed to avoid these hazards.

	Safety Checklist: Identify the correct and wrong ones, use these conventions ☑ as correct and ✗ as wrong
☐	Always switch off the power supply before working on any electrical circuit or appliance.
☐	Wear protective equipment such as insulated gloves and safety boots to avoid electric shocks.
☐	Work on live wires to save time, as long as you are careful.
☐	Use the correct tools and materials for electrical work e.g. insulated screwdrivers, proper wire sizes.
☐	Stand on a wet floor while handling electrical wires, it makes no difference.
☐	Do not overload sockets or extension boards, as this may cause overheating and fire.
☐	Check wires and cables for damage before use, and replace faulty ones immediately.
☐	Touch electrical appliances with wet hands, especially when in a hurry.

Activity 1.1.5 Case Study Challenge

A rural family wants to wire a two-bedroom house. They have a limited budget but need safe and reliable wiring.

1. Suggest the processes they should follow.

2. Identify at least three mistakes to avoid during wiring.
3. Justify why safety testing is important before the house is occupied.

Questions to think about

a. Why is planning and design the first step in house wiring?

b. In what situation would you recommend surface wiring instead of concealed wiring in your community?

Reflect on the following after completing the activities above.

In your notebook, worksheet or tablet, reflect on the following.

1. What I learned about house wiring.
2. One process I found difficult to understand, and how I clarified it.
3. How can I use this knowledge to help my family or community?
4. What safety mistake do people in my community make most often, and how can I help correct it?

EXTENDED READING

- How to Read Electrical Diagrams
  https://www.tnr.co.uk/how-to-read-electrical-diagrams/#:~:text=Straight%20lines%20represent%20wires%2C%20the,A%20zigzag%20diagram%20represents%20resistors
- YouTube Video on Electrical Basics
  https://www.youtube.com/watch?v=fOvXVs6dYHA
- How to Tell if Electrical Wiring in Your House is Not Up to the Mark
  https://caslec.com.au/news/tell-electrical-wiring-house-not-mark/
- Electrical Installation Notes
  https://webpages.uidaho.edu/dev/Teaching/PDF/BE462_Labs_2018.pdf

Review Questions

1. Define house wiring.
2. Describe the processes involved in house wiring.
3. Describe two benefits of safely wiring a house.
4. Write out the steps involved in house wiring.

UNIT 2

TOOLS AND EQUIPMENT FOR HOUSE WIRING

Introduction

Tools are indispensable for various tasks, from construction, installation, to repair. They can either be manually operated or powered by electricity to augment or replace human effort for the completion of physical jobs. Each tool serves a specific purpose, making work more efficient, precise and safe. They range from simple hand tools to complex power tools. In this unit, electrical tools and equipment are classified according to their uses.

KEY IDEAS

- Tools and equipment are essential for construction, installation, testing, and repairs, with each tool designed to perform specific tasks efficiently, safely, and accurately.
- Electrical tools are grouped into categories such as hand tools, power tools, testing and measuring equipment, safety equipment, and special tools, each serving distinct functions in electrical work.
- Testing and measuring instruments like multimeters, insulation testers, and continuity testers are crucial for checking the accuracy, safety, and functionality of electrical systems.
- Proper care and maintenance of tools—including cleaning, rust protection, correct storage, and regular inspection—are necessary to extend their lifespan and ensure reliable performance.
- Using personal protective equipment (PPE) such as gloves, safety glasses, and hard hats is vital when handling tools to prevent accidents and promote a safe working environment.

BASIC HAND TOOLS

Hand tools do not require electric power to function; they are manually operated tools and used for a variety of tasks. They are essentially kept in a toolbox. The following are some examples.

A set of screwdrivers

Pliers: Various types

Side-cutting pliers *Wire strippers* *Cable cutters*

Utility knives *Measuring tape* *Voltage tester*

Spirit Level *Hammer* *Fish tape*

Figure 1.2.1: Various Hand Tools

Power/ Machine tools

Power tools are powered by electricity to perform various tasks more efficiently and accurately with less human effort. Examples include the images below.

Impact driver *Wall chaser machine* *Power chisel*

Power drill *Rotary hammer* *Jigsaw* *Angle grinder*

Figure 1.2.2: Power or Machine Tools

Testing and Measuring Equipment

Testing and measuring tools are essential for diagnostic (investigative) checking and verifying the quality, quantity, accuracy and functionality of various components and systems. The following are some examples.

Insulation resistance tester

Clamp meter

Multimeter

Electric circuit tester

Non-contact voltage detector

Continuity tester

Figure 1.2.3: *Testing and Measurement Equipment*

Safety Equipment

Tool and equipment safety encompasses a set of practices and guidelines designed to ensure the safe use, maintenance, and storage of tools and equipment in various settings. These safety measures are aimed at preventing accidents, injuries, and damage to the operator, equipment and property. The following are examples of safety equipment.

Fire extinguisher

Face shield

Electrician's suit

Gloves

Safety glasses

Hard hat

Ear protection devices

Safety boot for females

Male electrician's boot

Ear protection attached to hard hat

Figure 1.2.4: Safety Equipment

Special tools

Special tools are uniquely designed for specific purposes or tasks. These tools often possess features or functions that standard tools do not have, allowing them to perform specialised functions or tackle uncommon challenges. Some examples are seen below.

Conduit bender

Cable stripper

Crimping tool

Figure 1.2.5: Special Tools

Table 1.2.1: Account of functions of tools and equipment

Tool /Equipment	Function
Screw drivers	It is a fundamental hand tool used for driving screws into or removing them from different materials.
Pliers	Pliers are hand tools used to hold objects firmly. They are also useful for bending https://en.wikipedia.org/wiki/Bending and physically compressing a wide range of materials.
Side-cutting pliers	These are pliers that have sharp edges on the jaws to cut objects such as electrical wires and small cables.

Wire stripper	A wire stripper is a small hand-held tool that is used to remove the insulation from electric wires.
Cable cutters	They are designed for cutting through thick cables and wires in electrical installations and telecommunications.
Utility knife	A utility knife is any type of knife used for general manual work purposes. This small knife feature light-duty blades best suited for cutting thin, lightweight materials.
Tape measure	A tape measure or measuring tape is a flexible ruler used to measure length or distance. Its design allows for a measure of great length and to be easily carried in pocket or toolkit.
Spirit level	A spirit level, bubble level, or simply a level, is an instrument designed to indicate whether a surface is horizontal (level) or vertical (plumb).
Hammer	A hammer is a tool, most often a hand tool consisting of a weighted "head" fixed to a long handle that is swung to deliver an impact to a small area of an object.
Fish Tape	Guide wires and cables through tight spaces such as pulling electrical wire through conduits, holes in studs vertically from floor to floor.
Voltage tester	A testing instrument used for electrical power testing purposes. It works by measuring the amount of voltage between two points.
Impact driver	A tool designed to deliver high torque and quick bursts of power for driving screws and bolts.
Wall chaser machine	Is a powerful tool used to create narrow grooves or channels in walls, floors, or other surfaces.
Power chisel	The power chisel is like a superhero of chisels. It is an electrically-powered tool that adds to the precision and speed work in cutting.
Power drill/driver	A portable and convenient tool for drilling and driving screws.
Rotary hammer	A rotary hammer is a powerful tool designed for heavy-duty tasks like drilling and chiselling hard materials such as concrete.
Jigsaw	Is a versatile tool that is a go-to for making curved cuts, intricate shapes, and straight lines in wood and other materials. It uses a reciprocating blade that moves up and down at high speeds
Angle grinder	It is a handheld power tool used for grinding (abrasive cutting) and polishing of materials.
Multimeter	It is a handy tool for measuring properties such as voltage, current resistance and performs other diagnostic capabilities
Clamp meter	A clamp meter is an electrical testing tool that integrates a basic digital multimeter with a current sensor. Clamps measure current.
Insulation resistance tester	An electrical testing instrument used to measure the electrical resistance of insulating materials. It evaluates the integrity and quality of insulation in electrical systems, cables, wires, windings, and other components.

Circuit tester	It is a device used to verify the presence or absence of voltage in an electrical accessory by plugging into it and checking the light to indicate the state of the voltage.
Continuity tester	It checks if an electrical circuit is complete and uninterrupted.
Non-contact voltage detector	It is a convenient tool used to check the presence of a.c. voltage without direct contact with the wires. When the detector is near a live wire. It lights up or beeps to indicate the presence of voltage.
Ear protection	It is a personal protective equipment designed to safeguard hearing from loud noises often encountered on job sites by electricians.
Fire extinguisher	It is a crucial safety tool used to out small fires or control them until emergency services arrive.
Face shield	A face shield is a type of personal protective equipment (PPE) designed to protect the wearer from specific hazards that may affect the face.
Gloves	They are essential safety gear made from non-conductive materials intended to protect electricians from electric shocks and burns.
Safety glasses	They are designed to protect the eyes from potential hazards such as flying debris, chemical splashes, and intense light.
Hard hat	It is a safety head shield designed to protect it from impacts, falling debris, and other hazards commonly encountered in construction sites, industrial settings, and other potentially dangerous environments.
Crimping tool	A tool used to join or essentially press connectors onto cables to create a secure and reliable electrical connection to avoid potential disruptions.
Cable stapler	A tool used to secure cables and wires neatly to surfaces like walls or floors. It helps to keep the cables well organised to prevent tripping hazards and protects the cables from damage.
Conduit bender	A tool used to bend electrical conduit neatly and efficiently to fit around obstacles or run along a specific path to conform to the layout of a structure.
Cable Puller	It is used to draw electrical wires or cables through conduits, walls or tight spaces. It ensures the cables are installed efficiently and without damage.
Punch down	A tool used to insert and secure wires into insulation-displacement connectors, primarily in telecommunications.
Respirator	A respirator is a device designed to cover the nose and mouth and protect the individual from inhaling harmful fumes, vapours, gases and particulate matter such as dust and airborne pathogens (Viruses).

Care and Maintenance of Tools

Maintaining hand tools is crucial for their longevity and productivity. Preventive maintenance is cost-effective as compared to corrective maintenance. Adhering to the manufacturer's maintenance plans, implementing a robust maintenance routine, and investing in genuine parts can protect your equipment investment and ensure its reliable performance.

To maintain hand tools for longevity and performance, follow these essential practices.

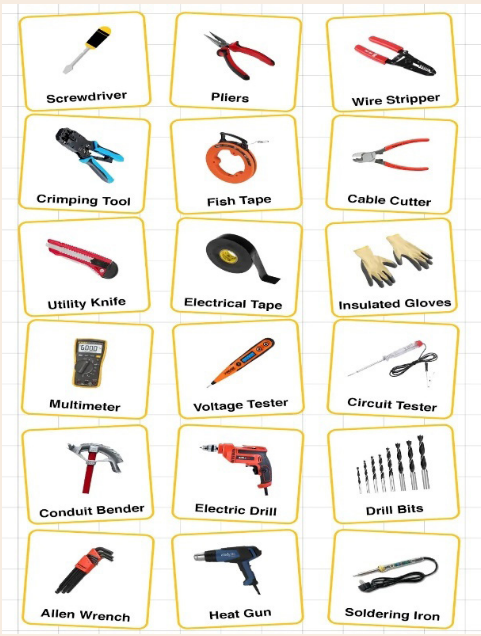
1. **Clean tools after use:** Thoroughly clean tools after use to remove dirt and debris.
2. **Rust Protection:** Apply a thin layer of machine oil or a rust inhibitor on metal surfaces after cleaning to protect the tools against moisture and rust.
3. **Correct Storage**
   a. Store tools in an ideal environment, such as a dry, cool place away from moisture and extreme temperature fluctuations.
   b. Keep tools off the floor and in a well-organised system such as toolboxes or racks to help prevent damage and make them easier to find.
4. **Regular Maintenance**
   a. Regularly lubricate moving parts with appropriate oils or greases to reduce friction and wear.
   b. Wipe off any excess lubricant to prevent dirt accumulation.
   c. Frequently inspect tools for signs of damage to insulation of power cords, loose wires at terminals, and wear, or malfunction.
   d. Address issues like loose screws or worn-out blades promptly to avoid further damage.
5. Use the right tool for the right job to ensure optimal performance.
6. **Handle tools with care:** Avoid dropping or mishandling tools to prevent damage. Use a tool belt or a tool bag to keep them secure.
7. **Correct Posture:** Maintain proper body posture while using hand tools to prevent injuries. Use a workbench or a table to keep tools at a comfortable height.

Safety Precautions

Use tools with the appropriate personal protective equipment (PPE) to ensure safety. Wear gloves, safety glasses, and other protective gear as needed.

Activity 1.2.1 Tools and equipment in electrical Operations

1. Watch a short video or pictures provided below or examine real tools brought to class: **Link:** https://youtu.be/OIO3hKyN7ko?si=Sn8MfWVT-p3jO5DU



2. While watching, pay close attention and answer the following questions.
   a. What tools and equipment are shown?
   b. How are tools different from materials?
   c. What functions does each tool perform?
   d. What must be done to keep the tools safe and effective for future use?

Activity 1.2.2 Tools and Equipment in Electrical Operations

1. In your own words, list the tools and equipment commonly used in electrical work.
2. Identify which ones you have seen in your school workshop or community.
3. Individually or with a group of friends, note down as many electrical tools as you can.

4. Share your answers in class discussion.
5. Write your final list in your notebook or worksheet or tablet.

Activity 1.2.3 Tools vs Materials

Aim: Differentiate between **tools** and **materials** in electrical work.

Steps

1. With your partner, discuss the following.
   a. What is a tool?
   b. What is a material?
2. Use at least two examples to explain the difference.
3. Write your definitions in your notebook.

Activity 1.2.4 Groups of tools and their functions

1. In a small group with your classmates;
   a. List at least ***three*** groups of electrical tools, e.g. cutting, measuring, and fastening.
   b. Write four examples under each group.
2. Still in your group, consider that electrical tools can be grouped into categories.
   a. Identify any 3 groups and provide at least 4 tools under each.
   b. Explain the functions of any 5 electrical tools you have studied.
3. Select five tools from your group chart and explain what each one is used for to the entire class.
4. Summarise your findings on a flipchart for presentation. See the table and outline below to guide you on how to present your findings.

Group Presentations

a. Each group presents their poster or chart.
b. Presentation must cover:
   i. List of tools and equipment.
   ii. Difference between tools and materials.
   iii. Groups of tools.
   iv. Functions and maintenance.
c. Other groups should ask at least one follow-up question.

Tool/Equipment	Group	Function
Screwdriver		
Pliers		
Measuring Tape		
Hacksaw		
Insulation Tester		

Case Study Challenge

A local electrician is asked to wire a rural health centre. He has the following items: screwdriver, hammer, pliers, nails, wires, insulation tape, hacksaw, and measuring tape.

- Which of these are tools and which are materials?
- Which three tools will be most useful for him in starting the work? Why?
- What mistakes should he avoid to keep the tools in good condition?

EXTENDED READING

- Electrical Tools and Equipment
  https://www.scribd.com/document/434766007/Electrical-Tools-and-Equipments
- 6 Must-Have Tools for Working with Electrical Wiring
  https://www.sepco-solarlighting.com/blog/6-must-have-tools-for-working-with-electrical-wiring

Review Questions

1.
   - **a.** Identify any four groups of electrical tools and equipment employed in house wiring.
   - **b.** List five hand tools and five power tools used in house wiring.

2.
   - **a.** What is the difference between electrical tools and electrical materials?
   - **b.** Explain the functions of any three measuring tools.
   - **c.** Describe the appropriate process of cleaning electrical tools.

3.
   - **a.** Why do you think measuring tools are indispensable to the electrician?
   - **b.** Compare and contrast hand tools and power tools in terms of performance?
   - **c.** The electrician can carry out their work without safety equipment; therefore, that equipment is not necessary. Explain why this is incorrect.
   - **d.** How do you identify defects in the power cord of a power tool?

UNIT 3

ELECTRICAL MATERIALS AND ACCESSORIES

Introduction

Electrical materials are the essential components used to create and complete electrical circuits. They include various components and supplies needed for electrical installations, such as electrical wires and cables, conduit and tubing, connectors and terminals, electrical boxes, insulation materials, cable trays and raceways that are crucial for ensuring a safe and functional electrical system. Wiring accessories are essential components used to connect appliances to electric circuits. They are used for convenience, safety, effectiveness and attractiveness to complete the wiring installation.

KEY IDEAS

- Electrical materials such as cables, conduits, junction boxes, and circuit breakers are essential for building safe, organised, and functional electrical circuits.
- Wiring accessories like switches, plug types, lamp holders, and ceiling roses enhance convenience, safety, and appearance in electrical installations.
- Each electrical component serves a specific purpose, for example, circuit breakers protect against overloads, while junction boxes provide a safe enclosure for wire connections.
- Conductors such as copper and aluminium carry electric current efficiently, while insulators like PVC and ceramic prevent electrical leakage and protect users.
- Grounding components, including copper earth rods and clamps, are critical for safely dissipating fault currents and protecting people and equipment from electric shocks.

MATERIALS

Examples of electrical wiring materials are as follows.

Electric Cables

Types of electrical conduit

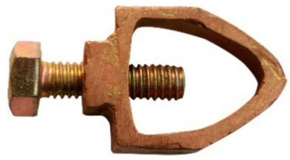
Circuit Breaker

Clips

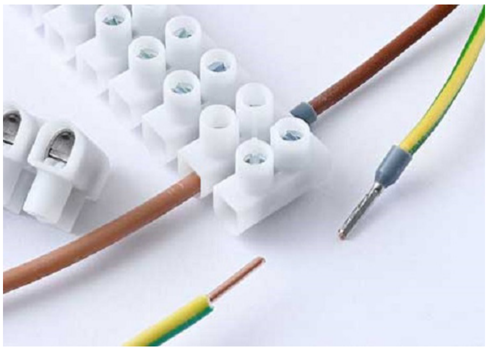
Staples

Junction Box

Copper Earth rod



Earth rod clamp



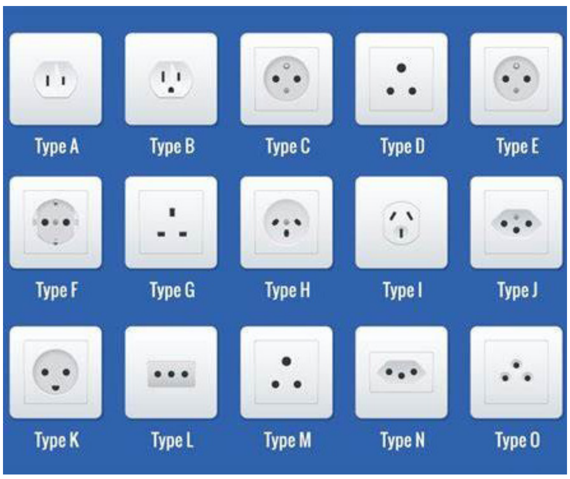
Wire Connectors

Electrical tape

Figure 1.3.1: Electrical wiring materials

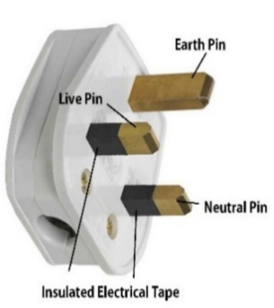
Accessories

Examples of electrical wiring accessories are shown in ***Figure 1.3.2***.



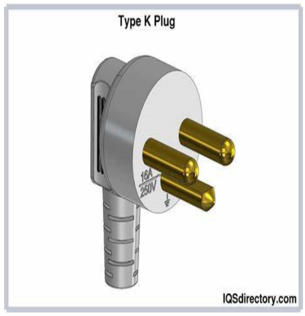
Socket outlets

A set of various lamp holders



Plug type G

Plug type B



Plug Type K

Ceiling rose with plug-in connection

Ceiling rose

Plaster modern ceiling rose

Picture of a switch

Piano modern switch

Modern switch

Figure 1.3.2: Electrical wiring accessories

The following are descriptions of various materials and accessories used in house wiring.

Table 1.3.1: Materials and accessories used in house wiring

Materials/ Accessories	Purpose
Cables	An electric cable is an assembly of one or more wires running side by side, or a bundle of wires wrapped together, designed to carry electricity from one place to another. They come in various types, each suited for different electrical tasks from powering small appliances to distributing electricity across neighbourhoods.

Conduit	It is a tube used to protect and route electrical wiring in a building or structure. It shields wires from damage and helps keep them organised, ensuring both safety and neatness in electrical installations. Conduits can be made of various materials, like metal or plastic.
Junction Box	It is a housing for electrical connections, intended to conceal them and prevent tampering. It provides a safe space where wires can be joined and distributed, ensuring they are protected and organised.
Circuit Breaker	It is a safety device designed to protect electrical circuit from damage caused by overloads or short circuit faults. It automatically interrupts the flow of electricity when it detects a fault and prevents potential fires and equipment damage.
Clips	They are used to secure and organise cables, preventing them from tangling or getting damaged. The clips can be attached to surfaces like walls, desks, or other structures, keeping the cables neat and tidy.
Staple	They are designed to hold cables firmly in place often in both residential and commercial wiring installations to ensure a tidy and safe environment. Staples are used to secure cables to surfaces like walls or floors keeping them neat and protected from damage or tangling.
Copper Earth Rod	The Earth rod is a long, conductive rod made of copper that is driven into the ground to provide a path for currents to safely dissipate into the earth. It helps protect electrical systems and people from electrical faults and lightning strikes
Copper earth rod clamp	The clamp is used to securely connect an earth rod to the earthing lead cable. It ensures a strong low resistance connection essential for grounding and lighting protection system.
Switches	Switches control the flow of electricity within a circuit, by allowing or stopping current from flowing through it. From the simple lighting switches to the more complex circuit breakers, they are essential for managing power safely and efficiently.
Outlets	Electrical outlets, or sockets, are the points where electrical devices connect to the power supply. They enable one to plug in and power up gadgets and appliances
Electrical Tape	It is a type of pressure-sensitive tape used to insulate electrical wires and other materials that conduct electricity to provide flexibility and long-lasting insulation
Plugs	Plugs connect electrical devices to a power source through outlets. They are designed to ensure a secure connection and prevent accidental disconnection while providing safe and reliable power transmission.
Lamp holders	Lamp holders, also referred to as light bulb holders or socket, are devices that support or securely hold light bulbs in place and connect to electrical circuits.
Ceiling Rose	A ceiling rose is a decorative element fastened to the ceiling from which a chandelier or light fittings are often suspended. They can also function as junction boxes to conceal electrical connections while adding a touch of elegance to the room

Conductors	Electrical devices often use copper conductors because of their properties, including their high conductivity, tensile strength, ductility, creep resistance, corrosion resistance, thermal conductivity, solderability, compatibility with electrical insulators and ease of installation. Copper is used in many types of electrical wiring. Aluminium wire has greater resistivity and requires larger conductors than copper.
Insulators	Electrical insulators are materials that resist the flow of electric current and prevent the conduction of electricity. They are used to protect and isolate electrical conductors and ensure safety and efficiency. Some examples are glass, polyvinyl chloride (PVC) and ceramic.

Activity 1.3.1 Materials and accessories used in house wiring

Your class has been tasked to help provide safe and affordable wiring solutions for homes in a rural community; to prepare for this assignment;

1. You need to research and discuss the different materials and accessories required in house wiring.
2. Explain the importance of each and identify the correct cable sizes suitable for lighting and sockets.

Activity 1.3.2 Exploring materials and accessories used in house wiring

Watch a short video or pictures provided below or examine real samples of materials and accessories used in house wiring: https://youtu.be/v_LSIzs5S2k?si=RyxHSpfwxoDdWjpI

While watching, answer the following questions. Use the template below to fill out your answers.

1. What materials and accessories are shown?
2. What is the purpose of each item?
3. Why is it important to use the correct cable gauge?
4. What problems can occur if the wrong accessories or materials are used?

Material/Accessory	Description	Importance	Correct Use
PVC Cables			
Switch			
Socket Outlet			
Lamp Holder			
Conduit Pipe			
Junction Box			

Activity 1.3.3 Correct Gauges of Cables

Pair up with a friend and do the following activities.

1. Research on the current-carrying capacity of different cable gauges.
2. Decide which gauge is suitable for lighting and which is suitable for socket outlets.
3. Share your results with the class.

Case Study Challenge

A family is building a two-bedroom house and wants to install lighting and socket outlets. They bought 1.0 mm^2 cable for the entire house.

Questions

1. Is this suitable for both lighting and sockets? Why or why not?
2. What cable size should they have used for the sockets?
3. What dangers could result from using the wrong cable gauge?

EXTENDED READING

- Wiring Material and Accessories
  https://www.scribd.com/document/528561707/Wiring-Material-and-Accessory
- Electrical Materials and Accessories Presentation
  https://www.slideshare.net/slideshow/electrical-materialsand-accessories-ch2pptx

Review Questions

1. List six materials and accessories used in house wiring.
2. Describe the importance of materials and accessories used in house wiring.
3. Discuss the correct gauges of cables used in lighting and socket outlet wiring.

UNIT 4

ELECTRICITY SUPPLY-CONTROL EQUIPMENT

Introduction

The electricity supply to a domestic installation begins at the meter cabinet, which houses the service fuse, meter and an isolator. This is referred to as the main supply point, and the supply cable is known as the service cable. The service fuse and meter are sealed to prevent any interference with this part of the installation. The control and distribution of the electricity supply to the installation is contained within one enclosure referred to as a distribution board. This unit has its own main switch fuse, or a separate main switch**,** main fuse, or miniature circuit breaker **(**MCB) and followed by individual circuit fuses or miniature **c**ircuit breakers to protect and isolate each circuit.

KEY IDEAS

- The importance of house wiring, tools and equipment used in house wiring, materials and accessories.
- The various methods used in house wiring, and the sequence of supply control equipment.
- Locating and placing the main supply point and distribution board.
- Excess current protection, wiring of final circuits, and earthing of an installation work in accordance with IEE regulations.
- Conducting a relevant test on an installation.

SUPPLY CONTROL EQUIPMENT ON A CUSTOMER'S PREMISES

The Supply Cut-out Fuse

In electrical power distribution in a consumer's premises, a fuse cut-out or cut-out fuse (often referred to as a cut-out) is a combination of a fuse and a switch**,** used in primary overhead feeder lines. When activated, it melts to protect distribution transformers from current surges and overloads or an overcurrent caused by a fault in the transformer. A cut-out and fuse assembly consist of three major components:

1. The cut-out body is an open frame that supports the fuse holder. It electrically isolates the conductive portions of the assembly from the support to which the insulator is fastened.

2. The fuse holder, or ***"fuse tube"*** or ***"door"***, is an insulating tube which contains the fuse element.
3. The fuse element, or "fuse link", is the portion of the assembly that melts and breaks the circuit when the electric current through it exceeds its rated current value.

(a) ***(b)***

Figure 1.4.1: Picture of (a) an opened Cut-out fuse and (b) a closed Cut-out fuse

The Meter

The electricity meter registers the energy consumed by a residence/premises for billing and monitoring purposes. It is typically calibrated in kilowatt hours (kWh).

Location

The location of an electricity meter varies with each installation. The possible locations include:

1. on a utility pole serving the property,
2. in a street-side cabinet (meter box) or
3. inside the premises adjacent to the consumer unit /distribution board.

It must be noted, however, that even though the meter is installed on the customer's premises, it belongs to the supply authorities and must never be tampered with by the customer. Any such actions warrant prosecution.

Figure 1.4.1*: Pictures of types of electric energy meters*

Wiring of an electric energy meter

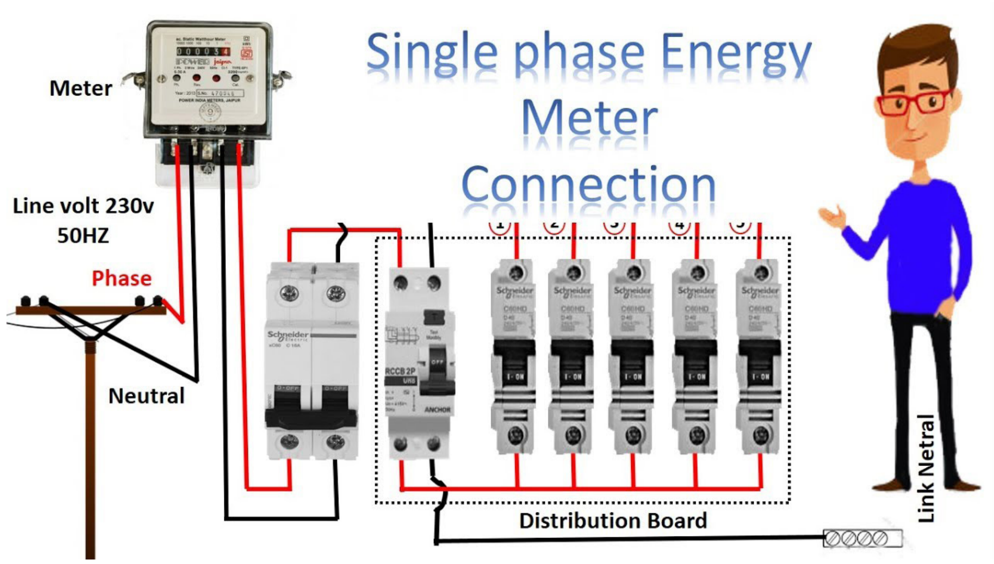


Figure 1.4.2: Picture showing a single-phase, post-paid electric energy meter

Wiring of the Meter

Even though the meter does not belong to the customer, the installation technician must make provision for its installation by ensuring proper sequencing of the supply cables. The following are critical steps to install the meter.

1. Disconnect the power supply by removing the cutout fuse.
2. Position the meter vertically on its centreline and securely tighten the bolts and nuts.
3. Connect the incoming live wire (L) to the 1st slot on the meter.
4. Connect the incoming Neutral (N) wire to the 2nd slot on the meter.
5. Connect the outgoing Neutral (leading to the isolator) to the 3rd slot.
6. Finally, connect the outgoing live wire (leading to the isolator) to the 4th slot

Caution

Please note that there may be some variations in meter connections depending on meter designs, supply systems and specific countries. Therefore, you should obtain information on every meter before commencing its connection.

The General Requirement for installing a 230V, single-phase meter into a consumer's premises is as follows:

a. Inform the electricity providers before any kind of service installation/ modification or wiring of a meter.

b. Use single-core PVC, double-insulated for all cables.

c. Use a minimum of 4mm2 (stranded copper wire) between the consumer unit and the electric meter.

d. The meter tails (cables used to connect the meter to the cutout or main breaker) should be double insulated and properly terminated into the meter slots.

e. The meter tails should be as short as possible.

f. The meter box must be installed on the external side of the wall which can be easily accessible.

g. Contact a licensed electrician to connect wires from the distribution board to the electric meter. The electricity will be provided later by power service providers, by showing them the BS7671 certificate signed by the electrician.

Pre-payment Meter

This type of meter requires the customer to make an advance payment before electricity can be used. If the available credit is exhausted, then the supply of electricity is cut off by a relay.

Prepaid meters are recharged by entering a unique, encoded twenty-digit number using a keypad. The tokens are electronically delivered or printed on a slip of paper at the point of purchase.

***Figure 1.4.3**: Picture of a keypad prepaid meter*

Isolator (Switch Gear)

An isolator switch is designed to interrupt or disconnect the flow of electric current to electric circuits from the power source and provides a physical barrier to prevent accidental contact with live electrical parts.

It provides a means of detaching circuits, equipment or a consumer's premise for

1. maintenance,
2. repair,
3. safety purposes.
4. emergency response,
5. energy management,
6. fault identification,
7. compliance

It is commonly used in industrial, commercial, and residential settings to ensure the safety of operating personnel.

***Figure 1.4.4**: Picture of an Isolator switch*

Distribution Board

A distribution board is an important part of an electricity supply system. It splits an incoming power main into multiple sub-circuits or secondary subsidiary circuits.

All fuses, circuit breakers and other circuit protection devices for the sub-circuits are held within this single enclosure. Distribution boards are also referred to as panel boards or breaker panels. Distribution boards come in various forms:

1. **Main switch consumer units**. They are considered among the safest and most robust protective devices for incoming mains power. All circuits are fully separated, and each is independently protected from earth leakage via residual current breaker (RCBOs) with overcurrent protection.
2. **Dual residual current device (RCD) consumer units** consist of two circuit banks, each protected by a pair of RCD breakers. They offer robust protection against overheating and electrical fires, and electric shock.

A single distribution board may be either 4-way, 8-way or 12-way and is often suitable for many domestic uses.

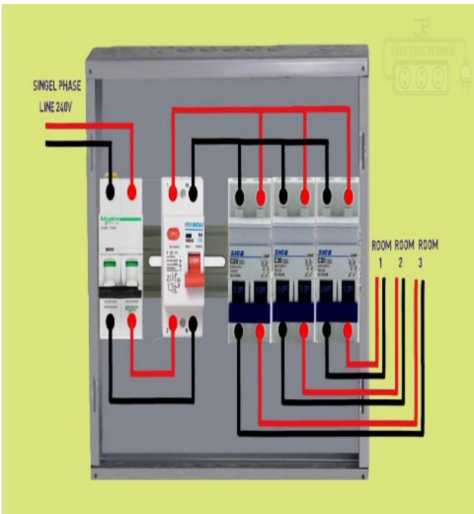


***Figure 1.4.5**: Picture showing the input and output connections to a distribution board.*

(a) *(b)*

Figure 1.4.6: (a) distribution board with circuit breakers and (b) a surface mount distribution board

Main Switch

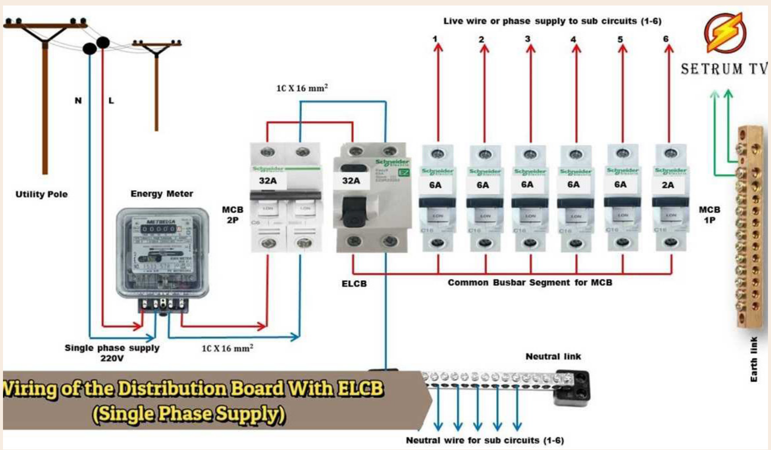
A main switch is a large and high-current electrical switch that controls the main power supply to a building. It is the main connection between the external supply and household wiring. Main switches play an important and fundamental role in the home's electrical system by safeguarding and creating a compliant electrical setup in the power supply system. In the event of an unexpected electrical surge or fault, the main switch provides a convenient means to cut off the electricity supply to the property, to ensure that no electricity enters the circuits, offers an emergency shutdown, and gives a quick and efficient way to reduce electric fires, shocks or other risks and damages.

Location

The main switch is usually located in the main electrical panel/distribution board, and this central location provides quick access in the event of an electrical emergency, allowing users to quickly and easily shut off the power to the entire building.

Activity 1.4.1 Supply-control equipment in electrical installations

Watch a short video or examine diagrams as shown in the figure below. You can also examine real-life examples of supply-control equipment, such as service cable, meter, main switch, distribution board, fuses, and circuit breakers. **Suggested link:** https://youtu.be/3qbDxpP0x4o?si=_A6_Gl1mwrbIcVPf



Pair up with a friend and discuss the following questions.

1. What supply-control equipment is shown?
2. In what order are they connected?
3. What function does each device perform?
4. What safety measures are necessary when wiring a meter?

Activity 1.4.2 Understanding the sequence of supply-control equipment

1. With a few of your classmates,
   a. discuss what is meant by "*sequence of supply-control equipment*."
   b. identify examples of such equipment from your class notes or observation.
2. Individually or with your classmates,
   a. draw the order in which supply-control equipment is connected (from service cable to final circuits).
   b. Label each stage clearly.
   c. Share your group diagram with the class for comparison.

Activity 1.4.3 Functions of supply-control equipment

1. Select at least five supply-control devices, e.g. service cable, meter, main switch, fuses, circuit breaker.
2. Explain the role of each one.
3. Share your answers with your sitting partner.

Activity 1.4.4 Demonstration - Wiring a meter

1. Observe a live or simulated demonstration by your teacher or the picture provided in class.
2. With a partner, practise wiring a meter on a trainer board.
3. Note down each step of the process in your notebook.

Activity 1.4.5 Safety Caution in wiring a meter

1. Brainstorm possible dangers of wiring a meter.
2. List safety precautions, e.g. ensuring supply is off, correct polarity, proper tightening of terminals, etc.

3. Complete the checklist below and exchange your checklist with a friend for peer review.

Meter wiring safety checklist worksheet

No.	Action	Safe (✓)	Unsafe (X)	Why? (Explain)
1	Ensure the main supply is completely switched OFF before wiring.	☐	☐	
2	Use properly insulated tools when wiring.	☐	☐	
3	Work on the meter while the supply is still ON.	☐	☐	
4	Confirm correct polarity of live, neutral, and earth connections.	☐	☐	
5	Reversing polarity e.g. connecting neutral to live.	☐	☐	
6	Tighten all terminals firmly to avoid loose connections.	☐	☐	
7	Leave terminals loose or connections exposed.	☐	☐	
8	Use cables of the correct size and rating for the meter.	☐	☐	
9	Use undersized or oversized cables.	☐	☐	
10	Wear PPE such as gloves and safety boots.	☐	☐	
11	Work barefoot or without PPE.	☐	☐	
12	Follow the wiring diagram or manufacturer's instructions.	☐	☐	
13	Ignore the manufacturer's wiring instructions.	☐	☐	
14	Double-check connections before restoring supply.	☐	☐	
15	Restore supply without double-checking connections.	☐	☐	
16	Keep the working area dry and free from flammable materials.	☐	☐	
17	Wiring in wet or damp conditions without safety measures.	☐	☐	
18	Test the installation after wiring to ensure safety and accuracy.	☐	☐	
19	Fail to test the meter after installation.	☐	☐	

EXTENDED READING

- Electric Meter Overview
  https://energyeducation.ca/encyclopedia/Electric_meter
- Types of Fuse Cut-outs
  https://peakdemand.com/archived-knowledge-center/types-of-fuse-cutouts/
- Distribution Boards Guide
  https://uk.rs-online.com/web/content/discovery/ideas-and-advice/distribution-boards-guide?srsltid=AfmBOopz7FoBMOG8DmHK2QLn44yJxtGigh7wPMqgiAEjYvAyxBccR4J

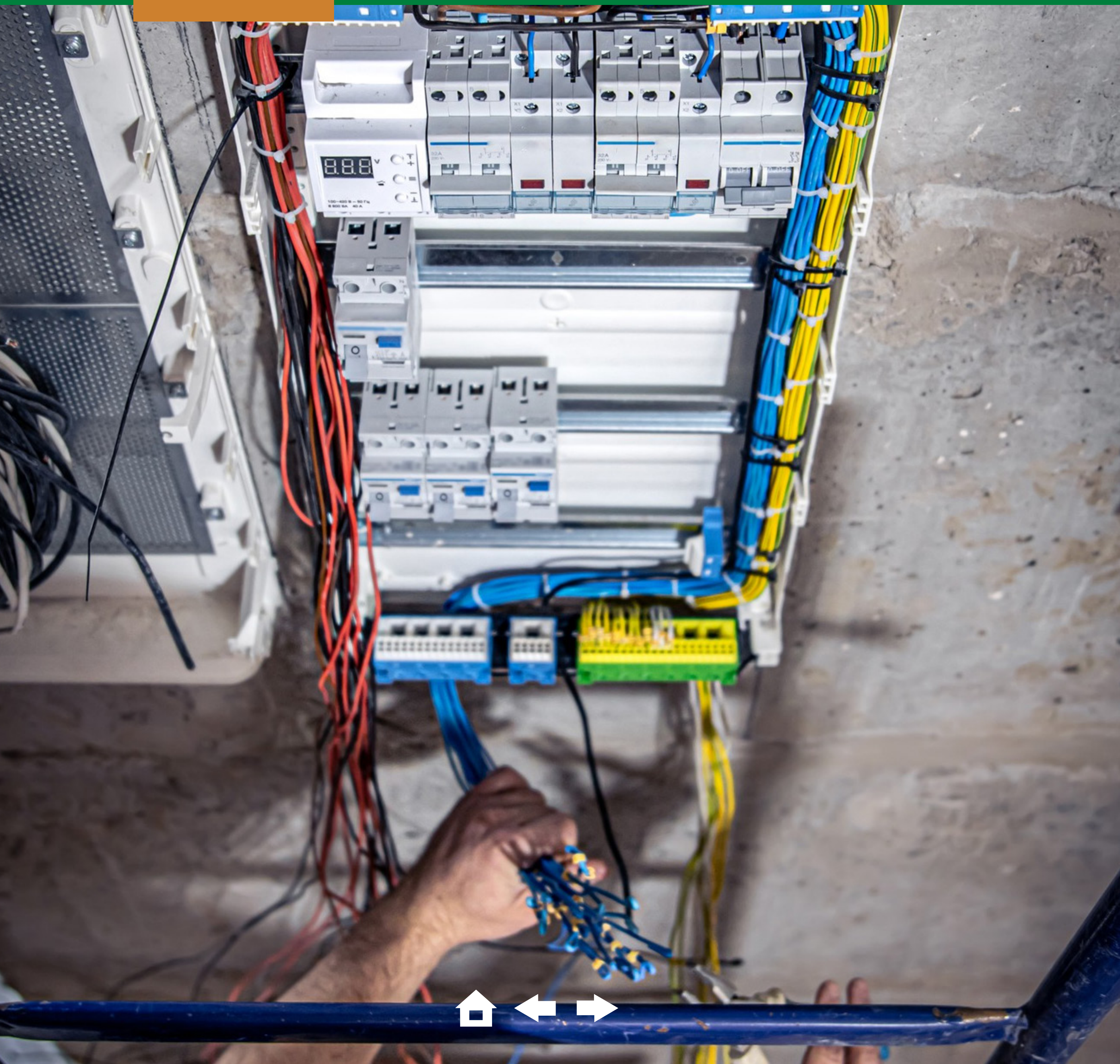
Review Questions

1. List 4 pieces of equipment installed on a consumer's premises for the control of the electrical power supply.
2. What do you understand by the term "sequence of supply-control equipment"?
3. Explain the function of each of the items of supply-control equipment on a consumer's premises.
4. Explain the correct order for connecting the electrical equipment that provides the electricity supply to the premises.

SECTION

2

DOMESTIC INSTALLATION



UNIT 5

ELECTRICAL AND ELECTRONICS TECHNOLOGY

Electrical Systems Design

EXCESS CURRENT PROTECTION

Introduction

This section spans Units 5 to 8, where we delve into the critical aspects of excess current protection and wiring methods in domestic installations! Imagine being the guardian of your home's electrical system—ensuring safety, efficiency, and reliability. Here, you will not only learn about the importance of excess current protection but also discover the various tools and techniques used in house wiring.

As we journey through Units 5 to 8, we will cover essential areas, including:

- understanding the concept and significance of excess current.
- identifying and using various excess current protection devices, like circuit breakers and fuses.
- exploring the diverse methods employed in house wiring and their implications for safety and functionality.
- learning about the regulations that govern electrical installations and how to wire circuits effectively.

Get ready to engage in discussions and hands-on activities! By the end, you will be equipped with the knowledge and skills necessary to ensure your electrical installations are safe and compliant. Let us get started and power up your learning experience!

KEY IDEAS

- Circuit breakers are resettable devices that interrupt current flow to prevent overheating and fires.
- Types of circuit breakers include Miniature Circuit Breakers (MCBs), Residual Current Circuit Breakers (RCCBs), and Thermal and Magnetic Circuit Breakers.
- Circuit breakers provide safety features, reset capabilities, and adaptability for modern installations.

- Fuses melt when excess current flows, disconnecting power and preventing damage.
- The fusing factor is the ratio of minimum fusing current to the fuse's current rating, indicating its safe operating limit.

In this unit on domestic installation, an essential area of electrical services. In this course, you will gain the knowledge, understanding, skills, and techniques necessary for effective domestic installation. You will explore the definition and importance of house wiring and the tools and equipment used in house wiring.

EXCESS CURRENT

Excess current is the amount of electric current that is more than necessary, permitted, or desirable in a circuit.

Excess Current Protection Devices

The following are excess current protection devices.

1. **Circuit breakers**

   A circuit breaker is essentially a resettable or an automatically operated electrical switch designed to interrupt current flow whenever the current rises above a safe level. They are used to avoid overheating, melting, and potential fires.

Types of Circuit Breakers

a. **Miniature circuit breakers**

A miniature circuit breaker, MCB, is defined as an automatically operated switch that protects low-voltage electrical circuits from excess current due to overload or short circuit. They use thermal and electromagnetic effects to detect and interrupt overcurrent, ensuring circuit protection. **They** are generally suitable for domestic applications and light commercial applications.

***Figure 2.5.1**: Pictures of miniature circuit breakers (MCB)*

b. **A residual current circuit breaker (RCCB)**

Residual Current Circuit Breaker or RCCB is basically a gadget that senses current and disengages any low voltage circuit whenever a fault occurs.

The working of RCCB is based on the principle that the incoming and the outgoing current in the circuit should be equal.

The main purpose of installing a Residual Current Circuit Breaker fundamentally is to protect people from electric shocks or death caused by earth faults or faulty wiring or chances of occurrence of an earth fault and a person can be electrocuted.

c. **Electronic Circuit Breaker (ECB)**

This device is typically used in domestic settings and is designed to handle a specific range of current and voltage. The maximum values it can safely handle are known as the device's rating. These ratings, provided by the manufacturer, indicate the range within which the device will function properly.

If problems occur due to fluctuations in the voltage which may arise from the power grid and if the device rating is exceeded, it trips cutting off the power supply. It offers remote control and monitoring, and a high switch-on capacity for different applications.

d. **Thermal circuit breakers (TCB)**

A thermal circuit breaker is a circuit protection device that contains an alloy reed, two precious metal contacts and interconnecting terminals. When an over current occurs, heat is generated as the current flows through the reed causing the reed to deflect and snap open.

This separates the contacts and safely interrupts the current flow. The relative speed at which the contacts separate is a measure of the cycle life under electrical loading demands.

e. **Magnetic circuit breakers (MCB)**

A magnetic circuit breaker is a type of switchgear device that protects an electric power distribution system by monitoring the electric current flowing through the wire. When the ampere level exceeds a circuit breaker's tripping threshold, it indicates an overcurrent electrical fault, or a short circuit, and the breaker's mechanism is activated. They are known for their precision-engineered control mechanisms and rapid response capabilities, and offer unparalleled levels of safety and reliability in electrical protection.

Advantages of Circuit Breakers

Circuit breakers are common in modern residential installations due to their ease of use, safety features, and compliance with contemporary electrical standards, their resettable nature and adaptability to different electrical loads and conditions. Circuit breakers offer several advantages that make them suitable for a wide range of applications including:

a. **Enhanced safety features**

i. **Trip indicators:** Many circuit breakers come equipped with trip indicators that provide immediate visual feedback on which breaker has tripped, greatly aiding in troubleshooting and restoration.

ii. Integrating test functions: Some circuit breakers include test buttons that allow for routine safety to ensure the mechanism is functioning correctly, which is critical for maintaining safety standards.

b. User Convenience and cost-effectiveness

i. Reset capability: Circuit breakers do not require replacement after an event. The reset capability not only reduces the cost associated with replacements but also minimises downtime.

ii. Adjustable settings: Advanced circuit breakers offer adjustable trip settings, allowing them to be customised to specific requirements, which enhances protection and flexibility in usage.

c. Enhanced safety mechanisms

i. Circuit breakers provide advanced safety features like ground fault protection, arc fault protection, and overload protection. These features do not only protect the wiring and prevent fire hazards but also safeguard against electrical shocks.

ii. Circuit breakers offer more sophisticated safety features, which can be crucial in environments where electrical hazards are a significant concern

Disadvantages of Circuit Breakers

a. Installation complexity

i. Installation of circuit breakers is generally more complex and might require professional installation to ensure safety and functionality

ii. Installation of circuit breakers is generally more costly

b. Maintenance Requirement: Circuit Breakers require regular testing to ensure their mechanical components function correctly. This might involve scheduled downtime and potentially hiring a technician, which could increase operational costs.

2. FUSES

A Fuse is an electrical or electronic device that protects the circuit from different electrical faults, such as overcurrent or overload. The principle of a fuse is based on the heating effect of the electric current. A simple fuse consists of a small conductive material/ fuse wire with low resistance, and it is placed in series with the circuit. The cross-sectional area of the fuse wire is designed such that it allows a certain amount of current that is permitted to flow in the circuit.

When the current in the circuit exceeds this permitted value due to overload, short circuit or load mismatch, the excessive current melts the fuse wire and opens the circuit. This disconnects the power supply, and the rest of the circuit is protected from being damaged. Fuses may still be found in older homes, but are generally being phased out in favour of the more versatile and safer circuit breakers.

Types of Fuses

a. Rewireable Fuse

A rewireable fuse consists of two main parts:

i. A fuse base that contains the in and out terminals and

ii. a fuse carrier, which holds the fuse element.

The fuse base is generally made up of porcelain, and the fuse element is made up of tinned copper, aluminium, lead, etc. The fuse carrier is easily plugged in or removed from the fuse base without the risk of any electric shock.

When the fuse is blown due to overcurrent, the fuse carrier is removed and the fuse wire replaced. They are mostly used in house wiring, small industries and other small current applications.

***Figure 2.5.2**: Picture of a rewirable fuse*

Advantages of Rewirable Fuse

i. Cheaper

ii. After blowing off, the fuse element and the bridge can be pulled out and again re-wired with a new fuse wire.

Disadvantages of Rewirable Fuse

i. Cannot be used for higher values of fault current.

ii. Protection is not reliable due to inaccurate characteristics.

iii. Slow speed, so current interruption is not quick.

iv. Risk of fire hazards due to external flash on blowing.

v. The wire is exposed to the air and subject to deterioration due to oxidation caused by heating.

b. Cartridge fuse

The Cartridge fuse is enclosed; the fuse link is enclosed in the container. This type of design and construction helps in keeping the resulting arc in the container in the event of a blown fuse.

Cartridge Type Fuses are a very important category of fuses that are used in almost all types of applications, like Low Voltage (LV), High Voltage (HV) and miniature fuses.

c. D – Type Cartridge Fuse

This type of fuse consists of a cartridge, fuse base, cap and adapter ring. The cartridge with the fuse element is fitted with the fuse cap and is inserted into the fuse base through the adapter ring. The connection is complete only when the tip of the cartridge touches the conductor. This type of fuse is used for low-voltage installations.

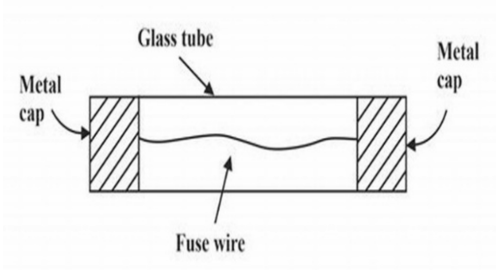
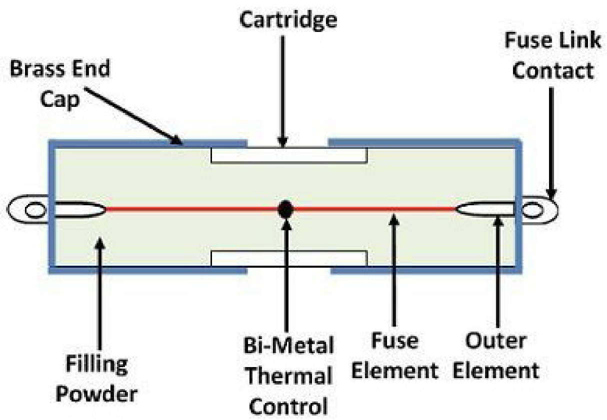


***Figure 2.5.3**: Pictures showing the structure of a cartridge fuse*

d. High Rupturing Capacity (HRC) Fuse

The HRC Fuse is a type of cartridge fuse in which the current flows through the fuse element under normal conditions. In case of a fault, the high current will be allowed to flow through the fuse for a short but known period.

If the fault is cleared in this time, the fuse element will not blow /melt. If the fault continues for a longer duration than allowed, the fuse blows by melting the fuse element. HRC Fuses are designed for high current rupturing in high voltage installations. Usually, the body of the fuse is made up of porcelain or ceramic, and the fuse element chamber is filled with silica sand.



(a) *(b)*

Figure 2.5.4: *Pictures showing (a) the structure of the HRC fuse and (b) the HRC fuse*

Advantages of a Cartridge Fuse

a. High breaking capacity
b. No risk of reclosing after tripping
c. Good selectivity values

d. High let-through energy performance
e. simple construction and compact size

Disadvantages of Cartridge Fuse

a. Risk of a one-phase trip on 3-phase lines.
b. Slow recovery time on the trip
c. Lack of accessories
d. Capable of performing only once, needs time to be changed after tripping

General Advantages of Fuses

They offer a straightforward, reliable solution for overcurrent protection, especially in stable, high-current environments where the higher interruption capacity of fuses is beneficial. Their lower upfront costs can make them attractive for smaller or more cost-sensitive projects. Despite being considered somewhat outdated, fuses have distinct advantages that may make them the better choice in certain scenarios, such as the following mentioned below.

Simplicity and high fault current rating

a. **No mechanical parts:** The absence of mechanical components in fuses reduces the likelihood of failure, providing a more reliable performance in critical applications.
b. **High interruption capacity:** Fuses can interrupt thousands of amperes of current, which is particularly useful in high-current industrial applications where safety and reliability are paramount.

Cost and installation

a. **Lower initial cost:** The simplicity of fuses makes them less expensive to purchase and install and can be beneficial for budget-conscious installations.
b. **Easy to replace:** Although they need to be replaced after blowing, fuses are typically simple and inexpensive to replace, making them cost-effective for systems with infrequent faults.
c. **Installation complexity:** Fuses are typically simpler to install because they do not involve complex wiring or configuration. However, the accuracy in selecting the correct type and rating of fuse is critical to prevent under-protection or frequent blowing.
d. **Maintenance Requirements:** The maintenance of fuses mainly involves replacing blown fuses. This could be seen as an advantage in critical systems where each blow provides a clear indication of circuit issues that need investigation. Maintenance of fuses is simpler.
e. **Safety features:** Fuses provide reliable and fail-safe operation, essential in applications where equipment protection and safety are critical.

Disadvantages of fuses

a. The cost and frequency of replacing fuses can accumulate, especially in systems with frequent problems.

b. Require replacement after every operation

c. Discrimination between fuses in series is difficult unless there is a considerable difference in their sizes.

d. Limited breaking capacity.

e. Slow speed of operation.

f. Not suitable for handling overload.

Fusing Factor

Fusing factor is defined as the ratio of the minimum fusing current to the current rating of the fuse element. *Fusing factor = Fusing current /Current rating*

Fusing Current is the minimum current causing the fuse to blow/melt.

Current rating is the maximum current that a fuse can sustain without blowing/melting. For example, if a 5 A fuse will blow only when a current of 9 A flows through it, then it has a fusing factor of Fusing current / Current rating =9 / 5 =1.8

This implies that the fuse is designed to melt at 1.8 times its current rating

Organise yourselves into groups of no more than 5 and complete the following activities. Discuss and record your answers.

Activity 2.5.1 Excess current and protection in house wiring

Scenario

During your safety training at the technical institute, you are learning how to prevent electrical risks in the community. A key danger is excess current, which can damage equipment, cause fires, and harm people; to stay safe, you must understand what excess current means, its main causes, and how protection devices prevent accidents.

Activity 2.5.1 Understanding the concept of excess current, its relevance and causes

Aim*: This task will help you understand why we need special devices to protect us from too much electricity, or what we call excess current.*

Why We Need Protection

1. Work with your classmates in a group to discuss why fuses, miniature circuit breakers (MCBs), and residual current devices (RCDs) are put in place in electrical systems.

   Your discussion should be based on these points

   a. What happens when an electrical appliance draws too much power?

   b. What could happen to the wires?

   c. Why is it a bad idea to plug too many things into one socket?

   d. How are these safety devices like a bodyguard for your home's electrical system?

2. Working with your group, name at least three dangerous things that can be avoided by having these protective devices.
3. Create a poster that clearly explains how these protection devices save both people's lives and their homes. Use clear drawings and simple language.

What Causes Excess Current?

4. Work with a partner from your group to brainstorm and list all the things that can cause an excess current. Think about situations like short circuits (when wires touch), overloading (when too many things are plugged in), and faulty appliances.
5. Share your list with the rest of the class. Compare your ideas and add anything you missed to your own list.
6. In your notebook, write down a summary of the three most important causes of excess current that you have discussed.

EXTENDED READING

- Describe how a circuit is protected against excess current-Fuses and circuit breakers. https://www.chintglobal.com/global/en/about-us/news-center/blog/differences-between-circuit-breaker-and-fuse.html#:~:text=What%20Are%20the%20Differences%20Between%20Circuit%20Breaker%20and%20Fuse

Review Questions

1. Define what is meant by excess current.
2. List the main thermal and electromagnetic methods of excess current protection.
3. State the type of protection preferred in modern-day domestic premises and why it is used?

UNIT 6

WIRING METHODS EMPLOYED IN HOUSE WIRING

Introduction

In electrical wiring, there are several different types of systems/methods that can be employed. The choice of any wiring system/ method and its accessories will depend on the environment in which it is to be installed. Once a wiring system has been chosen, decisions must be made as to how the system is to be installed.

KEY IDEAS

- **Conduits and trunking** are used to hide and protect cables inside walls or along surfaces. This makes the wiring neat and safe.
- **Earthing** is a vital safety measure that protects you from electric shock by providing a safe path for electricity to flow to the ground in case of a fault.
- **Final circuits** are the separate loops of wiring for the lights and sockets. Each circuit is protected by its own fuse or circuit breaker.
- The **main electrical components** are connected in a specific order: The electricity meter is followed by a main switch, then a fuse box or consumer unit, and finally, the switches for all the circuits in the house
- The **right tools and materials** must be used for each job, like screwdrivers, pliers, wire strippers, cables, and switches.
- There are different **methods of wiring a house**, such as cleat wiring, casing and capping, and conduit wiring. The method used depends on the building and what is needed.
- **Wiring must be done correctly in accordance with IEE regulations** to avoid fires and electric shocks. Conducting a relevant test on the installation work must be done.

TYPES OF WIRING

Under normal conditions, typical wiring systems include;

1. PVC or metal conduit
2. PVC or metal trunking.

Conduit Wiring System

A conduit is a tube or pipe in which conductors are run.

1. It replaces the PVC sheathing of a cable.
2. It provides mechanical protection for the insulated conductors.

A conduit wiring system involves running PVC-insulated electrical cables through a series of metal or plastic tubes called conduits. This method is commonly used in domestic, commercial and industrial buildings. Conduit wiring is a reliable and efficient method for organising and protecting electrical wires. It offers improved safety, easy maintenance, and adds to the visual appeal of a building. The conduits that are used in wiring may be metallic or non-metallic.

The metallic conduits are made of thin and thick layers of steel sheets. The thin-layered conduit is called a low-gauge conduit, and the thickly layered conduit is known as the high-gauge conduit. The non-metallic conduits are flexible and are of great use. They are mainly made up of solid PVC and other plastics. To install conduit wiring, the use of conduit boxes such as two-way through-boxes, hexagonal brass bush, tee boxes, angle boxes, multiple saddles, and cables is the basic requirement.

Conduit wiring, among other things, provides the following.

1. **Safety:** Conduit wiring provides a higher level of safety. The metal or plastic conduits shield the wires from moisture, mechanical damage, and exposure to external elements. This reduces the risk of electrical accidents, such as short circuits and fires.
2. **Ease of maintenance:** With conduit wiring, it is easier to identify and fix any issues with the electrical system. The conduits allow easy access to the wires, making it simpler to locate and repair faults or make modifications. This can save time and effort during routine maintenance or in case of any electrical faults.
3. **Aesthetic Appeal:** In addition to its functional benefits, conduit wiring can enhance the overall aesthetics of a building. The conduits can be neatly installed along walls or concealed within partitions, resulting in a clean and professional look. This makes it a popular choice for commercial spaces and modern residential buildings.

Types of Conduit Wiring

The types of conduit wiring depend on the methods of laying the conduits. The two types of conduit wiring are as follows:

1. Surface conduit wiring
2. Concealed conduit wiring

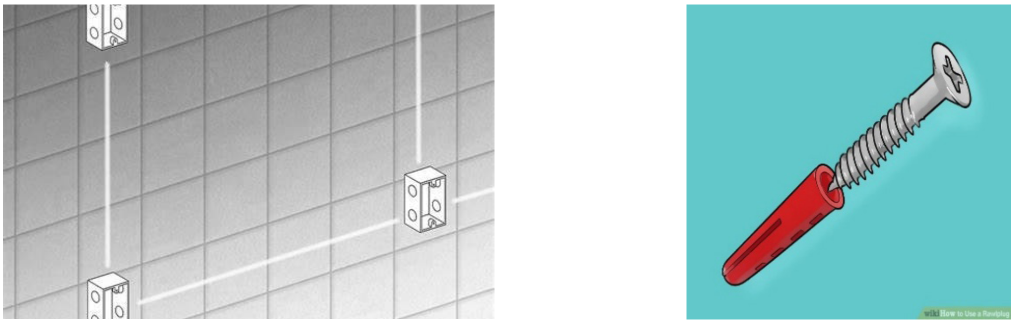
Surface conduit wiring

Surface conduit wiring is a popular method of electrical wiring where the conduits are mounted on the surface of walls or ceilings of the building. This type of wiring is often chosen for its flexibility, ease of installation, and the ability to modify or expand the electrical system without significant disruption.

The installation of surface conduit wiring is completed using Wall plugs commonly referred to as ***"Rawl plugs",*** which are small plastic fittings capable of gripping and holding screws when installed in hard walls. These plugs can be used in walls made of various materials, but work especially well in walls made from materials that do not expand, like plasterboard, brick, or cement. It is a type of anchor that allows screws to be fitted into masonry walls.

The installation process

1. ***Planning:*** Before installation,
    a. create a wiring plan to determine the placement of conduits, boxes, and other accessories.
    b. consider the electrical load, circuit requirements, and aesthetic preferences.
2. ***Marking and mounting:*** Mark the locations for conduits, boxes, and devices on the walls or ceilings. Secure the conduits using appropriate fasteners and mount the boxes at specified points.



(a) ***(b)***

Figure 2.6.1: Pictures of (a) locations marked boxes fitted and (b) Rawl plug matched to a screw(fastener).

3. ***Cutting and bending conduits:*** Cut conduits to the required lengths using a conduit cutter. If necessary, bend the conduits using a conduit bender to navigate corners or obstacles.
4. ***Connecting conduits and boxes:*** Use fittings to connect conduits and junction boxes. Ensure a secure fit and proper alignment for efficient wire routing.

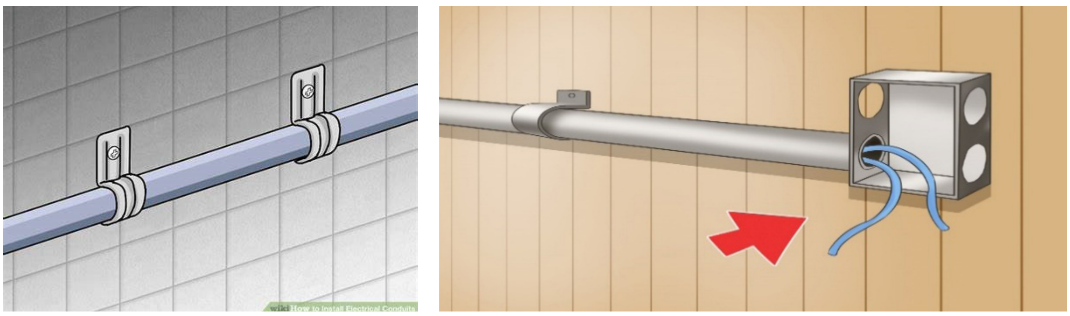


***Figure 2.6.2**: Fitting types used in conduits*

5. ***Installing wires:*** Thread the electrical wires through the conduits, ensuring proper insulation and colour coding. Connect wires to devices and secure them within the junction boxes.

6. *Testing:* Before closing the system, conduct thorough testing to ensure proper connections, polarity, and functionality. Use a voltage tester to check for live wires and ensure safety.

Advantages of Surface Conduit Wiring

1. **Flexibility:** Surface conduit wiring allows for easy modifications and additions to the electrical system without the need for major renovations.
2. **Accessibility:** Junction boxes provide easy access to wiring connections, making maintenance and troubleshooting simpler.
3. **Aesthetics:** Conduits can be chosen to complement the design of the space, and the visible wiring can be arranged neatly for a clean and industrial look.
4. **Cost-effective:** Surface conduit wiring is cost-effective due to reduced labour and material costs.

Safety Considerations

1. **Proper insulation:** Ensure that all wires are properly insulated to prevent electrical shocks and short circuits.
2. **Secure mounting:** Conduits and boxes must be securely fastened to the walls or ceilings. Using appropriate fasteners and mounting hardware helps to prevent sagging or displacement over time, especially in areas with vibration or movement.
3. **Compliance with codes:** Follow electrical codes and regulations applicable to the country. Compliance ensures that the installation meets safety standards and is less likely to pose hazards.
4. **Professional installation:** For complex installations or if unfamiliar with electrical work, it is advisable to hire a licensed electrician to ensure safety and code compliance.
5. **Avoid overloading:** Conduct a thorough analysis of the electrical load to avoid overloading circuits. Distribute the load evenly and use the correct wire sizes for the intended purpose.

Disadvantages of Surface Conduit Wiring

1. **Vulnerability:** Surface-mounted conduits are more susceptible to physical damage. They can be easily bumped, dented, or otherwise impacted, exposing the wiring within and potentially compromising safety.
2. **Limited concealment:** The wiring is visible, making it less suitable for locations where a seamless and hidden appearance is desired.
3. **Dust and dirt accumulation:** Over time, dust and dirt can accumulate on the surface of conduits and boxes, requiring regular cleaning to maintain a tidy appearance.

4. **Space limitations:** Surface conduit wiring may take up valuable wall or ceiling space, limiting design options and potentially conflicting with other installations or decorations.
5. **Temperature sensitivity:** In areas with extreme temperature variations, surface conduit wiring may be more prone to temperature-induced expansion and contraction, potentially affecting the integrity of the installation over time.
6. **Installation complexity:** While surface conduit wiring is generally simple to install, complex configurations or intricate designs may pose challenges and require careful planning.
7. **Not ideal for all environments:** Certain environments, such as high-humidity areas or locations with corrosive substances, may not be suitable for surface conduit wiring, as it may be more prone to environmental damage.

Precautions In Surface Conduit Wiring

1. Metal conduits must be terminated in a metal-clad board with a smooth-bore brass bush.
2. In steel conduits, the sharp edges of the conduit must be smooth, and curves or bends must be carefully made.
3. Select the correct size of conduit.
4. When using steel conduits, electrical continuity is essential for earthing.
5. Before drawing the cables/wires in a conduit, make sure that there is no moisture present in the interior.
6. Use the correct size of saddle according to the diameter of the conduit.
7. Always use a steel wire to draw the cables through steel or PVC conduits.
8. Always draw the exact number of cables into the conduit

Concealed Conduit Wiring

In this method, the conduits are rested in the walls or on the ceilings of the buildings. The conduits are hidden inside the walls, ceilings, and floors with the help of plaster and painting. It gives a beautiful look, and hence it has become the most popular wiring system. Concealed conduit wiring provides a stronger wiring network and a safer wiring system. The installation of conduit wiring involves properly threading and screwing the conduits and other accessories as prerequisites.

To install conduit wiring in the roof or ceiling of a building, it should be laid before pouring concrete into the shuttering of the ceiling. To securely fix the conduit buried in the walls, staples should be used at pre-defined intervals of distance. The conduits are terminated in switch boxes, and the switch boxes are flush with the plaster of the wall or ceiling.

Materials required for concealed conduit wiring

1. Box for junction
2. Box for the ceiling rose
3. Cable
4. Wall cutter
5. Conduit bender
6. Bushing

Installing concealed conduit wiring

Concealed conduit work is carried out after constructing masonry walls and before plastering.

1. The first step in conducting wall work is to mark the surface of the walls.
2. Cut the wall markings with wall cutter to avoid damaging the walls; the chasing depth must be 10mm deep.
3. Depending on the number of conduits, the width of chasings must be limited.
4. The chiselled surface should be filled with cement mortar and covered with chicken mesh after the conduits, boxes, and accessories have been installed.
5. The concealed box must be recessed 3 mm into the plastered surface.
6. If the direction of the pipe needs to be changed, use the pipe bender to bend the conduit.
7. Draw in the cables using a fish tape, terminate and fix the accessories.

Installing the switchback boxes and distribution boards

1. All concealed switchback boxes must be levelled correctly.
2. Distribution Boards should be concealed before plastering begins.
3. A distribution board box should be positioned in a properly aligned and levelled recess in the brickwork.
4. All conduit pipes must enter the distribution board only through the given entry holes.

The advantages of concealed conduit wiring

1. Provides excellent protection for the wiring.
2. Allows for easy modification and repair.
3. Suitable for both indoor and outdoor applications.
4. Can handle high voltage and current.
5. No damage to cable installations is possible.

6. Fire danger or mechanical deterioration is non-existent.
7. Cable insulation deterioration is not a concern.

Disadvantages of concealed conduit wiring

1. More expensive and time-consuming to install.
2. Requires skilled labour.
3. It can be more difficult to troubleshoot and diagnose faults.
4. The management of additional connections is complicated.

Precautions for concealed conduit wiring

1. Metal conduits must be terminated in a metal-clad board with a smooth-bore brass bush.
2. In steel conduits, the sharp edges of the conduit must be smooth, and curves or bends must be carefully made.
3. Ensure the correct size of conduit is chosen and used.
4. In the case of steel conduit, electrical continuity is essential for earthing.
5. Before drawing the cables/wires in a conduit, make sure that there is no moisture present in the interior of the conduit.
6. Use the correct size of saddle according to the diameter of the conduit.
7. Always use a steel wire to draw the cables through steel or PVC conduits.
8. Always draw the exact number of cables into the conduit.

Trunking System

Trunking refers to an enclosure that protects many small cables or multiple lengthy cables. It is normally square or rectangular in cross-section, has one removable side, and is made of steel sheets or plastic.

Housing the cables within the trunking prevents them from being exposed to potential hazards such as moisture, dust, or accidental contact, reducing the possibility of electrical shocks or fires caused by exposed wires. The protective casing also prevents cable wear and tear, extending its lifespan.

Trunking allows for easy labelling and segregation of different cables, improving troubleshooting and maintenance procedures. Additionally, it simplifies cable installations, ensuring that the right cables are routed to their designated locations.

Figure 2.6.3: Example of a trunking system for wiring

Cable Trunking

Cable trunking is a cable management method that conceals and protects electrical cables with a tray that is usually made of protective plastic or metal. The purpose of cable trunking is to bring order to the electrical landscape in buildings while protecting cables and providing space for other electrical equipment around them.

Cable trunking tends to be used in areas that have more complex installations and circuits. It allows users to create any shape of wiring pathway they need. Many workplaces and industrial settings use cable trunking to supply power to various machines and devices in different locations.

Figure 2.6.4: Example trunking showing sockets

Cable trunking, also known as cable management or wire duct, offers several benefits for organising and protecting cables in various settings.

Key Advantages of Cable Trunking

1. **Organisation:** Cable trunking helps to neatly bundle and route cables, reducing clutter and chaos. This makes it easier to identify, trace, and access specific cables when needed, simplifying maintenance and troubleshooting.
2. **Protection:** Trunking shields cables from physical damage, such as impact, crushing, or abrasion, which can lead to cable failure or safety hazards. It also protects against dust, dirt, and moisture, enhancing the lifespan and reliability of cables.

3. **Safety:** Proper cable management with trunking reduces the risk of tripping hazards caused by loose or tangled cables. This is especially important in high-traffic areas and workplaces, where safety is a primary concern.
4. **Fire Safety:** Some cable trunking materials are fire-resistant or low-smoke, low-toxicity (LSZH or LSF). This can help contain fires and reduce the release of toxic fumes, enhancing overall safety in buildings.
5. **Easy Maintenance:** Cable trunking makes it simpler to access and maintain cables. In the event of a cable fault or the need for expansion, repairs or additions can be done more efficiently and with minimal disruption.
6. **Aesthetics:** Cable trunking can be designed to blend with the decor of a room or building. This is particularly important in commercial and residential settings where aesthetics matter.
7. **Professional Appearance:** Properly installed cable trunking gives installations a polished and organised appearance, which can be important in professional and client-facing environments.
8. **Reduced Cable Stress:** Cable trunking prevents cables from being bent, twisted, or kinked, reducing the risk of signal degradation or electrical issues caused by cable stress.
9. **Long-Term Cost Savings:** While there is an initial investment in cable trunking, the long-term benefits, including reduced maintenance costs, fewer cable replacements, and improved system reliability, can lead to overall cost savings.

Busbar Trunking

A busbar trunking system (BTS) is a space-saving method of distributing electrical power using a set of copper or aluminium busbars enclosed in a protective casing. It is commonly used in data centres, factories, and office buildings. It ensures flexibility by providing tap-off units for the addition or removal of service easily.

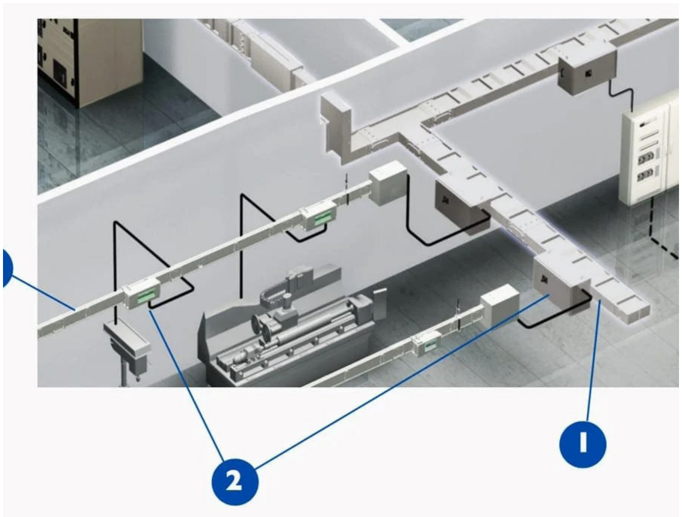


Figure 2.6.5: Picture of busbar trunking

Lighting Trunking

Lighting trunking is a flexible lighting system that combines power distribution, lighting fixtures, and data cabling into a single, integrated solution. It consists of a track that runs along the ceiling or wall, with various lighting modules and accessories that can be easily attached or detached and adjusted.

With lighting trunking, it is easy to modify and reconfigure the lighting setup to suit changing needs, without the bother of rewiring or hiring an electrician. The system is designed to be flexible, allowing for easy installation and maintenance.

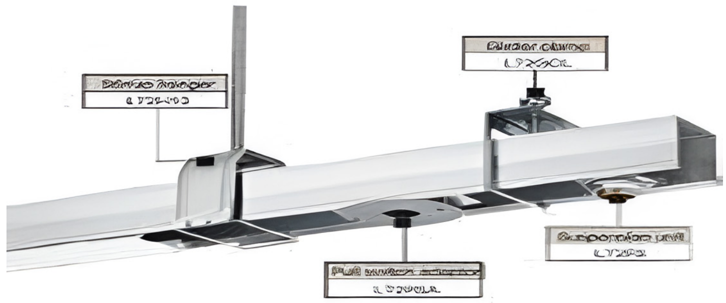


Figure 2.6.6: A picture of lighting trunking hangers, Multi-Compartment Trunking

The Multi-Compartment Trunking is the ideal solution to separate power, data and voice cables, specifically to ensure safety and convenience during installation. The larger compartment is capable of carrying numerous electrical power cables, while the smaller compartment is suited for Telephone and TV Cables.

A bridging retaining clip ensures quick and easy installation. These inserted clips into the pre-punched slots at the corner of the trunking base, together with the removable ‘snap-on’ cover lid, result in a very tidy and compact installation.

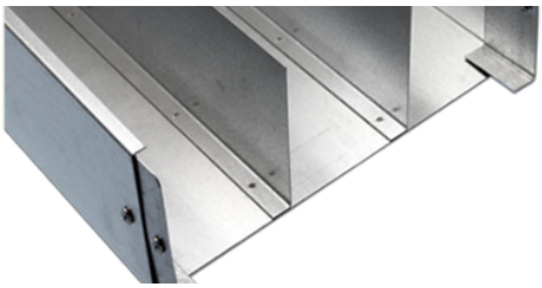


***Figure 2.6.7**: A picture of multi-compartment trunking*

Advantages of Trunking

1. Makes maintenance and alterations easier.
2. Has a longer life.
3. Keeps the wiring safe from dust, damage, and humidity.
4. Gives the wiring a clean and organised appearance.
5. Cable trunking allows for scalability and flexibility.

6. Improved cable organisation and management, cable clutter reduction. By grouping cables within trunking, the appearance of wires running haphazardly around a room is eliminated.
7. Enhanced accessibility for maintenance and upgrades.
8. Increased flexibility.
9. Aesthetic appeal.

Disadvantages of Trunking

1. Bulky and may require additional supports.
2. Limited capacity and difficult to modify or expand.
3. Requires frequent maintenance.
4. Can be complex to configure and manage.
5. Expensive to implement.

Activity 2.6.1 Systems of wiring

Read the scenario below and do the tasks that follow. You may use the internet and any available resources, such as books from the library, to support your work.

Scenario

As part of a community electrification initiative, your technical institute has been tasked to support the wiring of classrooms and small office spaces.

To complete the work successfully, you must do the following.

1. First, develop a clear understanding of the various systems of wiring, including their applications, benefits, and limitations.
2. In addition, you need to study the steps involved in surface conduit wiring and the essential precautions that ensure installations are safe, neat, and durable.
3. Present your final work in your notebook or on a chart paper or any other mode of presentation you are okay with and share with your class.

Activity 2.6.2 Exploring the different wiring systems

1. Watch the following videos or look at the picture below. Alternatively, you may examine real wiring setups in a workshop, your classroom or at home.

Links

a. https://share.google/B3LdffJWlQVpndfSd
b. https://share.google/jJwO0TJKE1GDGytma

While watching or observing, respond to the following and share your responses with a classmate.

1. The different systems of wiring that were noticed.
2. How surface wiring differs from concealed wiring.
   a. List ***three*** differences between them.
   b. Present your differences in a simple comparison table.
3. The difference between conduit wiring and trunking.
4. Steps followed in carrying out conduit wiring.
5. Precautions to ensure safety in wiring.

Activity 2.6.3 Understanding systems of wiring

1. Working with a partner, discuss what you think a **"system of wiring"** means. Consider how the wires are protected and organised to deliver power to all the lights and sockets.
2. Have a look around your classroom and other parts of the school. Can you see any of the wiring? Do you think it is a specific type of wiring system? Share what you've found with the rest of the class.
3. In a small group, look at some diagrams or real-life examples of **conduit wiring** and **trunking systems**. Discuss what the main differences are between them.

4. On your own, create a table that compares these two wiring methods. List at least two advantages and two disadvantages for each one. Consider factors such as *appearance*, *cost*, and *ease of adding* or *changing wires*.
5. Using your table, be prepared to share your findings in a class discussion. Explain which system you think is better for a school and why.

Activity 2.6.4 Safe and correct Surface Conduit Wiring

1. Working with your partner, talk about all the possible dangers and mistakes that could happen when installing conduit wiring. For example, what could happen if the conduit isn't bent properly, or if the fittings aren't secure?
2. Now, in your group, discuss the different safety precautions needed to prevent the dangers you identified. Think about things like;
   a. Making sure the conduit is aligned straight on the wall.
   b. Using secure fittings so the conduit doesn't move.
   c. How to bend the conduits correctly without kinking them.
3. Together, create a safety checklist for anyone doing a surface conduit wiring job. This checklist should have a clear list of things to do to stay safe and avoid mistakes.

Process of correct surface conduit wiring

1. Watch your teacher, a technician, or a video that shows how to install surface conduit wiring. Pay close attention to every step, from the very beginning of the job to the end.
2. As a group, list every step you saw in the demonstration. Start from the planning stage and go all the way to finishing the installation.
3. Write down these steps in your notebook. Get ready to either role-play or do a small demonstration for the class to show the correct process.

Note: *Refer to previous activities, Units 3,4, and 5, for an example of the checklist as a guide.*

EXTENDED READING

Describe the various methods of house wiring.

- https://goswitchgear.com/basic-electrical-wiring-guide/
- https://www.actelectricians.com/blog/understanding-the-process-of-new-home-wiring
- https://www.actelectricians.com/blog/understanding-the-process-of-new-home-wiring

Review Questions

1. Explain where surface wiring could be used to the best effect.
2. Explain where concealed wiring could be used to best effect.
3. State which method has more variants and list them.
4. Explain why the sharp edges of steel conduits must be rounded smooth or fitted with brass bush.
5. Identify some key characteristics between surface and concealed wiring

UNIT 7

WIRING OF FINAL CIRCUITS

Introduction

An electrical wiring system is a network of cables connecting various accessories for the distribution of electric energy from the supply meter and the distribution board to devices that dissipate energy. The Institution of Electrical Engineers (IEE) Regulations are the non-statutory standard essential for all those concerned with the design, installation, certification and maintenance of electrical installations in domestic, commercial and industrial settings. It provides an authoritative framework of information for anyone working in the electro-technical industry.

KEY IDEAS

- Wiring lighting points and controlling from various locations, and conforming to regulations
- Wiring ring and radial circuits for socket outlets under IEE regulations.

FINAL CIRCUIT

The final circuit means a circuit connected either directly to a device which utilises electricity directly, or indirectly to such a device by means of one or more socket outlets or other outlet points such as ceiling roses and lamp holders.

Regulations Governing Final Circuits

To avoid the risk of electric shock, fire or other possible danger from electrical wiring, the following rules should be observed:

1. Always use well-insulated tools; never attempt to remove cable insulation with the teeth.
2. Avoid working on live circuits. Always switch off the power before touching live parts of a circuit or equipment.
3. Joints in electrical conductors must be properly done to permit good electrical and mechanical continuity.
4. Use appropriate sizes and types of cables, fuses and accessories for wiring. The correct selection of conductor size and type is essential to ensure adequate current-carrying capacity and minimise voltage drop.
5. All single-pole devices, switches, thermostats, and fuses should be connected in the live conductors of the supply.

6. Sockets provide access to electrical power for devices and appliances. Switches control the flow of electricity to lighting fixtures and other loads. High-quality sockets and switches should be installed to withstand frequent use and prevent overheating. Switches, if not specially designed for bathroom wiring, should always be installed outside the bathroom; socket outlets should **not** be installed in bathrooms.
7. Ensure the continuity and durability of the earthing system, e.g. the earth electrode, earthing lead and earth continuity conductor used for the protection of circuits, equipment and consumers.

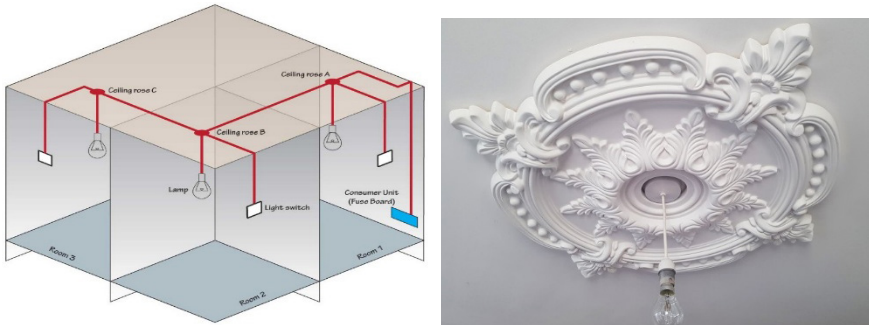


Figure 2.7.1: Wiring of compartment lighting points and Lamp holder connected to a ceiling rose.

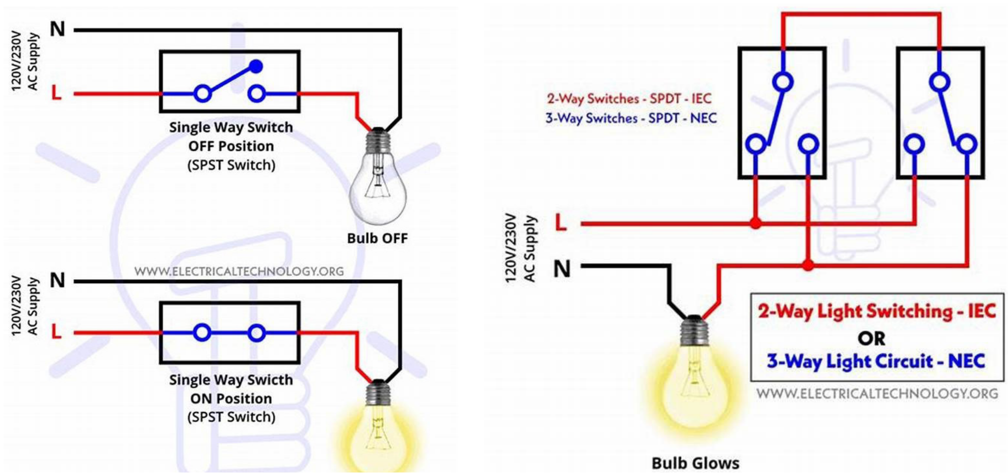
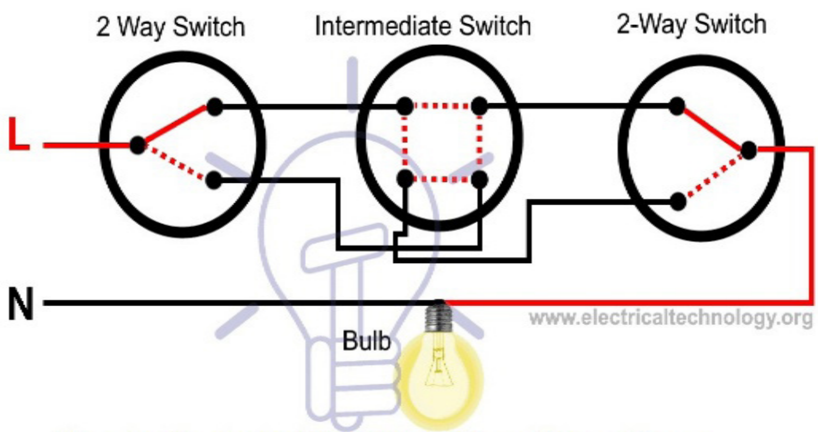


Figure 2.7.2: Picture of a lamp controlled from one location vs. picture of a lamp controlled from two locations.



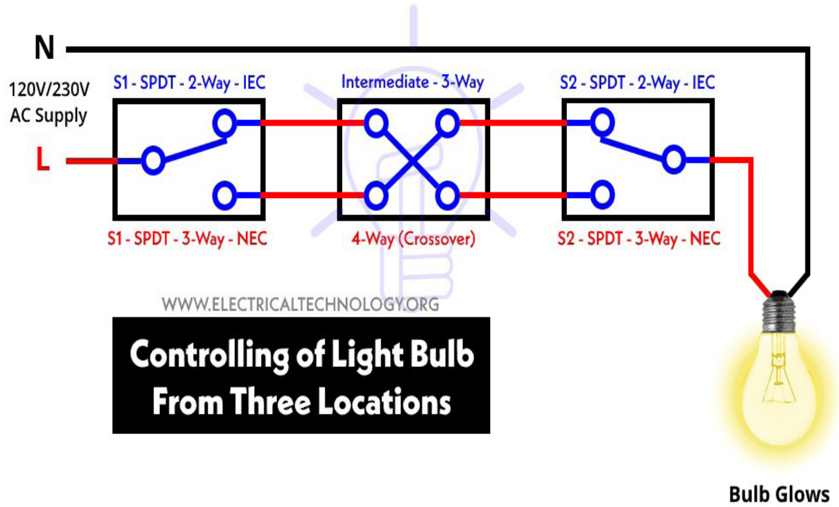


***Figure** 2.7.3: Picture of a lamp controlled from three locations*

Power Circuits

The Ring Circuit

This is a circuit which is wired from a single protective device, and runs via appropriate socket-outlets, connectors, and returns to the same protective device, forming an electrically continuous loop. A spur of a ring circuit is a branch cable having conductors of a cross-sectional area not smaller than that of the conductors forming the ring.

The main I.E.E Regulations relating to the wiring of ring circuits are as follows.

1. **Cable size:** minimum twin 2.5mm2 and earth p.v.c.
2. Maximum number of socket outlets allowed: unlimited number in floor area under 100m2, but spurs may not be more than half the socket outlets on the ring circuit, including stationary appliances.
3. Fused 13A plugs to be used at socket outlets supplying portable appliances.
4. Fixed appliances must be protected by a local fuse, i.e. a fused spur box.
5. A 30A fuse should be used to protect the ring circuit.
6. All socket outlets in any one room must be connected to the same phase.
7. Apparatus permanently connected to the ring circuit without a fused plug or socket outlet must be protected by a local fuse or circuit-breaker with a rating not exceeding 15A, and the apparatus must have an adjacent controlling switch.

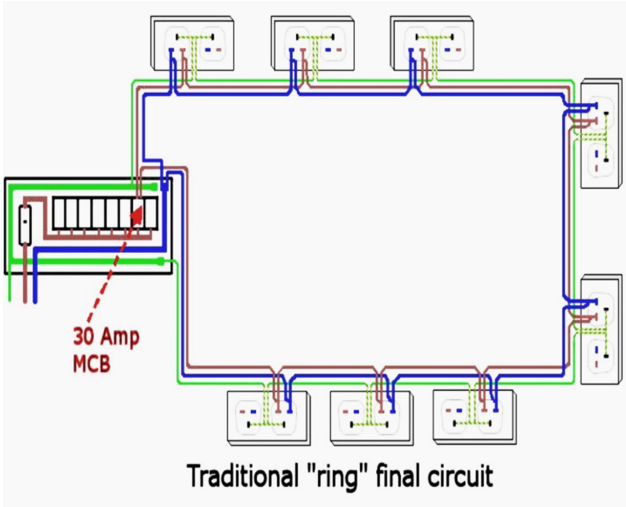


Figure 2.7.4: Picture of a ring circuit

Radial circuit

This is a circuit which is wired from a single protective device, and runs via appropriate socket-outlets, connectors, but does ***Not*** return to the same protective device, to form an electrically continuous loop.

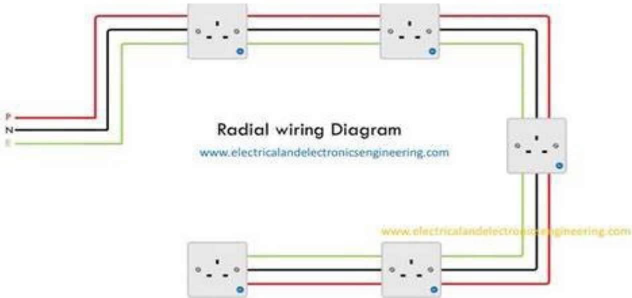


Figure 2.7.5: Picture of a radial circuit

Activity 2.7.1 Understanding Final Circuits

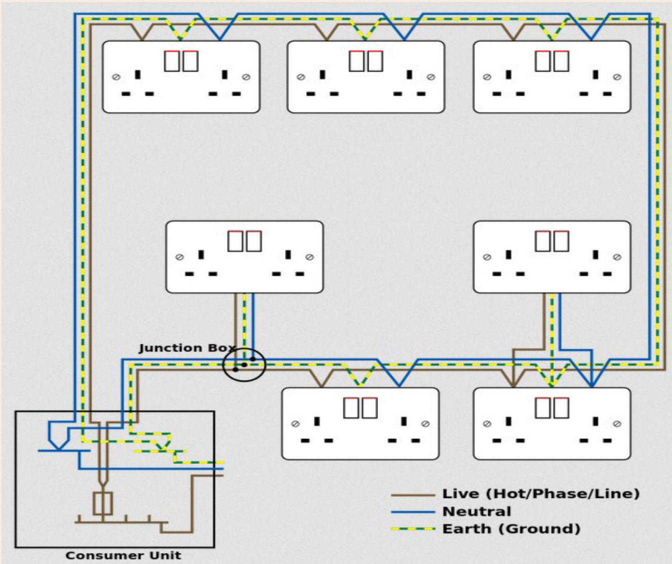
1. Pair up with a classmate and discuss what you think the term “final circuit” means in electrical installations.
   a. Share your ideas with the class and work together to come up with a single, clear definition.
   b. Make sure you write this in your notebook.
2. With your partner, list some examples of final circuits you would find in a home. Think about things like the wiring for the sockets or the lights.
3. Look at the diagrams of a **ring circuit** and a **radial circuit** provided below or by your teacher. Pay attention to how the wires are laid out for each one.
4. Watch the video by clicking the link below or one provided by your teacher. While you watch, note down;

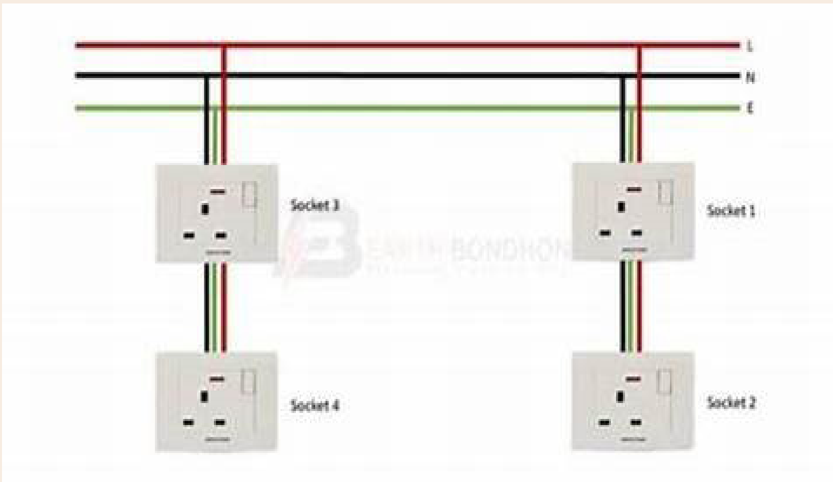
a. what the key differences are in the wiring layouts of ring and radial circuits.

b. How do these differences affect the way they work?

Video link: https://share.google/7F5JmAiLzuu5jCwFQ

5. In your notebook, summarise how ring and radial circuits differ and why specific wiring regulations are important for them.





Activity 2.7.2 Regulations Governing Final Circuits

1. Research from books in your school library on key regulations, e.g. maximum number of sockets, load limits, protection devices.
2. After, list the safety rules governing final circuits and explain why each is important.
3. Share your group's list as a "Final Circuit Safety Code" poster.

Activity 2.7.3 Ring and Radial Circuits

1. In your group, draw neat, clear diagrams of two different socket circuits:
   - A **ring circuit** for sockets.
   - A **radial circuit** for sockets.
2. Make sure you label all the key parts of your diagrams. You should show the **supply** from the consumer unit, the **protective device** (like a fuse or circuit breaker), and all the **connections** to the sockets.
3. Discuss the diagrams with your group. What are the main **advantages** and **disadvantages** of each system? Think about the amount of cable needed and how much current each can handle.
4. Prepare a short presentation for the class. Your group should be ready to present all the work you've done on final circuits. This includes:
   a. Explaining what a **final circuit** is.
   b. Showing your **safety code poster** that you created in the previous lesson.
   c. Showing your **diagrams** of the ring and radial circuits, with a short explanation of each.
5. After each presentation, other groups must ask at least **one follow-up question**. This will help everyone learn from each other.

Activity 2.7.4 Case Study Challenge

1. Read the Case Study below and discuss it in your group. Decide whether you would recommend a ring circuit or a radial circuit for the computer centre. Be ready to explain your choice and why it is the best option for the computers and their accessories.
2. After your decision, discuss which safety regulations you must follow to make sure the wiring is safe. Also, think about one common mistake you should definitely avoid when wiring the sockets.

Case Study: Computer Centre Wiring

A nearby computer training centre needs wiring for six socket outlets to power its computers and accessories.

- Should you recommend a ring circuit or a radial circuit? Why?
- What safety regulation(s) must you follow?
- What mistakes must you avoid?

Application Questions

a. Why do wiring regulations limit the number of sockets you can put on a single final circuit?

b. What would happen if a radial circuit were overloaded with too many devices plugged in at once?

c. How do ring circuits provide better current distribution than radial circuits?

EXTENDED READING

Indicator-Wire final circuits in accordance with IEE regulations.

- Requirement for electrical installations

  https://electrical.theiet.org/media/2422/bs-7671-2018_a1_2020-inc-corrigendum-may-2020_read-only.pdf

- Ghana electrical wiring regulations

  https://energycom.gov.gh/files/GHANA%20ELECTRICAL%20WIRING%20REGULATION%20GUIDL.pdf

  https://energycom.gov.gh/files/GHANA%20ELECTRICAL%20WIRING%20REGULATION%20GUIDL.pdf

Review Questions

1. Define what is meant by final circuit.
2. Outline the regulations governing final circuits to ensure safety in an electrical system.
3. Explain what the regulations recommend about the installation of switches in a bathroom.
4. Explain what the regulations endorse about the location of single-pole devices, switches, thermostats, and fuses in the supply system.

UNIT 8

WIRING OF FINAL CIRCUITS

Introduction

A distribution board unit is installed in buildings to receive the incoming single-phase electric supply (AC low voltage of 230 V) from the distribution company, the electric service provider's (ECG) outlet or the energy meter. The distribution board is a safe system designed to encompass protective devices, such as isolator switches, circuit breakers or fuses, to safely connect the live, neutral and earth cables to the sub circuits. The distribution board is also known as "Fuse Board", "Panel Board" or "Consumer Unit".

KEY IDEAS

- Identifying the key components of a distribution board.
- Understanding the wiring required for a single-phase distribution board.
- Follow the correct procedure for wiring an extension board.

WIRING ACCESSORIES FOR SINGLE-PHASE DISTRIBUTION BOARD

The main distribution board or fuse board (Consumer Unit) usually contains the following main units to control and distribute the electric supply to different appliances and devices connected through electrical wiring of cables.

1. Double Pole (DP) MCB (the main circuit breaker, main isolator or main switch).
2. Residual Current Devices RCD (Also DP) for safety.
3. Single Pole (SP) MCB (Circuit Breakers and Fuses).
4. Miniature Circuit Breaker and Circuit Breaker (MCB & CB).

Functions of the Consumer Unit Devices

1. ***Double Pole MCB (DP) (The Isolator or Main Switch):*** This is the main operating switch used to control the electric power supply in the residence. The main switch can be used to immediately turn ON or OFF the main electric supply to the connected appliances in case of emergencies like short-

circuits, electric shock, fire, or while working on the main board, sub-circuits to troubleshoot and for maintenance purposes.

2. ***The Residual-Current Circuit Breaker (RCD)*** is a safety electrical device or switch that disconnects or trips a circuit. Whenever it detects that the electric current is not balanced between the energised (live) conductor and the return neutral conductor (N), it instantly disconnects the electricity flow in the connected circuits by operating in safe mode automatically to avoid electric hazards.

3. ***Single Pole Circuit Breaker SP (MCBs):*** These are automatic protection devices in the main switchboard or fuse-box that switch off a circuit if a fault is detected. Circuit Breakers may be single pole (SP), double pole (DP) and triple pole (TP). The illustration shown below is a single-phase home supply wiring diagram. It typifies the:

   a. main supply, the red-live and the black-neutral wires/cables coming from a 3-phase 4-wire system to the single-phase energy meter.

   b. live and neutral lines from energy meter connected to the double Pole MCB isolator switch.

   c. live Wire connected to the RCD and then to the common busbar segment of single-pole MCBs.

   d. outgoing lines from the MCBS (SP), connected to the final circuits and electrical devices like fans, lamps, switches, etc.

   e. neutral wire connected through the energy meter, MCB (DP), RCD and then to the neutral Link.

All of the sub circuits are connected to the Neutral Link. Care must be taken to make sure all electrical devices and appliances are connected to the earth.

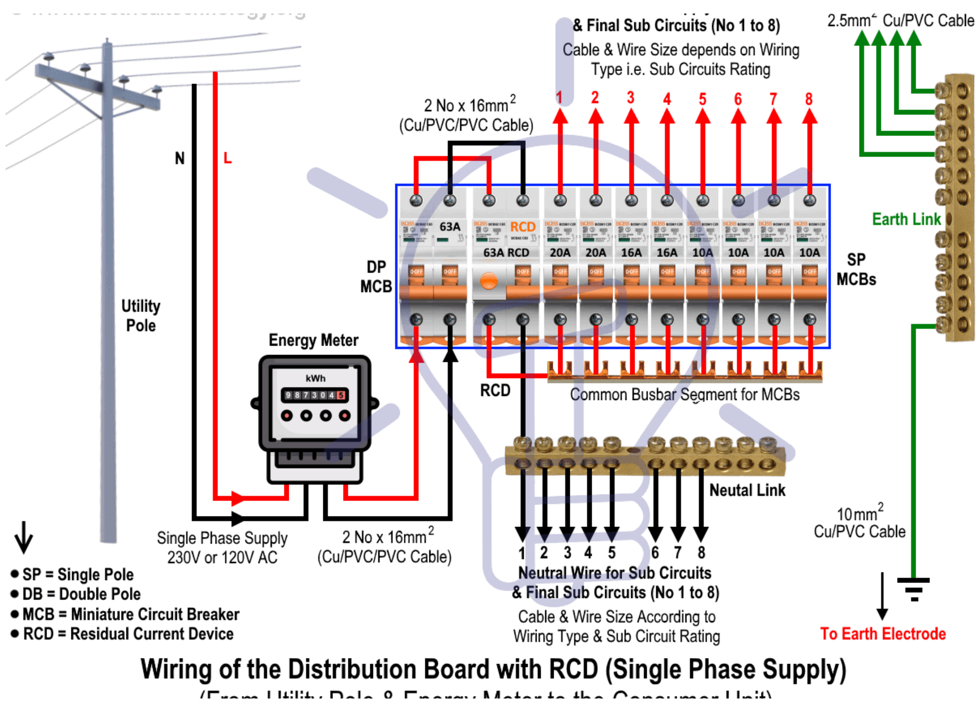


***Figure 2.8.1**: Single-phase home supply wiring*

Tests Carried out on Distribution Board or Consumer Unit

To test and commission an electrical distribution board, it is important to do the following.

1. Carry out a visual inspection to check for any damage or loose connections.
2. Test all of the electrical circuits for proper voltage, amperage, and continuity.
3. Verify nameplate details for rating in accordance with approved General Arrangement (GA) drawings.
4. Check for physical damage.
5. Check for electrical/functional checks.

Test Instruments

There are two main test instruments used.

1. Insulation resistance tester with variable voltage settings.
2. Multimeter.

Insulation Resistance Test Procedure

1. Open the power termination kit cover.
2. Check for the tightness of all conductors
3. Clean all the supporting insulators
4. Isolate (disconnect) the cables on the incoming side from out -going end.
5. Connect the black test lead to the grounding and the red test lead to the bus wires.
6. Apply a megger voltage of 1000 V DC with respect to the phase for one minute and record the value.
7. A passing test record should be at a minimum of 20 mega ohms (20 MΩ).

Electrical/functional test

1. Switch on the incoming control supply for the SMDB
2. Check the electrical operation of the switchgear
3. Check the operation of the indicating devices
4. Before energising, check the following:
   a. Busbar chamber, main and sub-main switch connectors, and bolts/nuts for tightness.
   b. Earth connection at compartments.

c. Clearance for live parts to prevent direct contact with tools or any likelihood of contact with stray conductors.

Wiring of an Extension Board

The Tools and materials required to construct the extension board shown in ***Figure 2.8.2*** can be found in the following table.

Table 2.8.1: Tools and materials required to construct an extension board

S/N	Item	Quantity
1	Wooden Board (90 x 90) cm	1
2	Double pole switch MCB	1
3	Twin socket	4
4	13 A plug	1
5	three 2.5mm^2 PVC insulated cables	4 yds each
6	2.5 mm^2 ,3-core flexible cable	5 yds
7	Portable drill	1
8	Screw drivers (flat and star)	1 each
9	Wire stripper	1
10	Plier	1
11	Side cutter	1
12	Multimeter	1
13	Tester	1

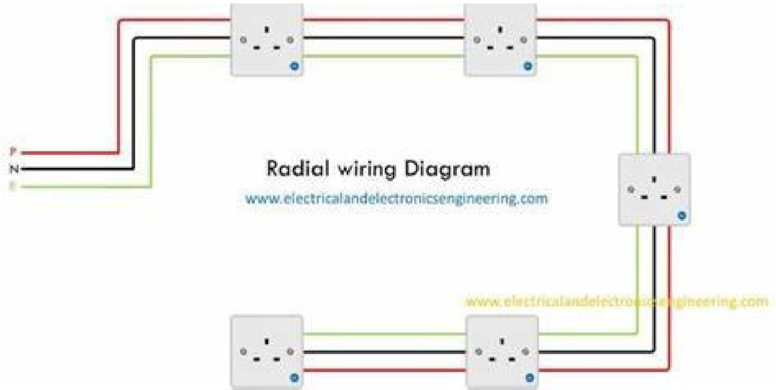


***Figure 2.8.2**: Wiring of socket outlets in radial circuit*

Procedure for Construction

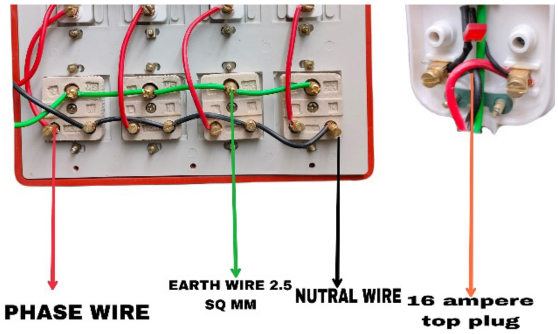
1. Plan out the positions of the socket outlets and the MCB on the wooden board.
2. Remove the covers of the socket outlets and MCB and place them in their various positions.

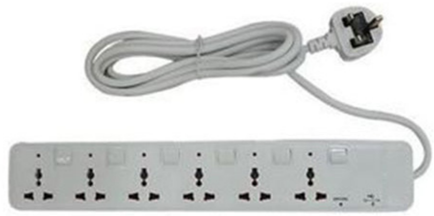
3. Mark positions of the socket and MCB screws and cable positions for both on the board.
4. Remove the socket outlets and the MCB and drill the holes for the various screws and cable positions on the board.
5. Run the cables through the drilled holes and terminate the input to the double pole of the MCB.
6. Use short pieces of wires to connect the output of the MCB to the first socket outlet, making sure to comply with the correct polarity of the terminals.
7. Connect the cables to each of the other socket outlets using the loop in system.
8. Position the MCB and the socket outlets and screw them tightly to the board.
9. Open the 13Amp plug and terminate the other end of the 3-core flexible cord into it, ensuring that the correct polarity is tracked.
10. Test for continuity, Polarity and short circuit.
11. Close plug.
12. Cover the base of the board with plywood and battens.
13. Plug the circuit into the power source and test the live terminal for power, and then with a gadget.

Activity 2.8.1 Wiring a circuit and building an extension board

For this activity, you need to get an extension board or observe one that your teacher may bring to the class. Alternatively, look at the pictures below and do this activity.

1. Observe the extension board and identify and list all the main parts. You should be able to find the **plug**, the **cable**, the **sockets**, and the **switches**.
2. Watch carefully as your teacher demonstrates how to wire the extension board. Pay attention to the order he or she does things, from preparing the cable to connecting the wires to the plug and the board itself. *Take notes on each step.*
3. Discuss with a partner the steps you observed. Try to list them in the correct order, from start to finish. For example, which wire goes to which terminal?
4. Work together to think of all the possible mistakes or dangers that could happen when wiring an extension board. Consider things like loose connections or using the wrong type of cable.
5. Make a list of the key mistakes that must be avoided to ensure the board is safe to use. You should have at least three points on your list.





Activity 2.8.2 Basic Requirements for Wiring a Circuit

1. With a partner, brainstorm what is needed before wiring a circuit. **Use the checklist as a guide.**

Tick (✔) the correct requirements and cross out (✕) the wrong ones.

☐	Use the correct size of cables for the intended load
☐	Use bare wires without insulation for easy connection
☐	Ensure a protective device such as a fuse or MCB, is provided
☐	Select the right tools for the job
☐	Allow wires to be loosely hanging for flexibility
☐	Confirm the power supply is switched off before starting work

2. List at least 5 safety precautions.
3. **Use the checklist to identify** the correct safety precautions. Tick (✔) the correct precaution, cross out (✕) the wrong ones.

☐	Test the circuit after wiring before switching on
☐	Work on live circuits to save time
☐	Ensure correct polarity when connecting
☐	Tighten all terminals properly
☐	Touch wires with bare hands to check if current flows
☐	Do not overload sockets with too many appliances

4. What dangers can occur if precautions are ignored?

Activity 2.8.3 Building an Extension Board

1. In a small group with three of your friends, outline the steps involved in building an extension board. Match the procedure to the appropriate step in the correct order.

STEP 1: Measure and cut the required length of cable

STEP 2: Fix sockets and switches firmly in place

STEP 3: Connect wires according to polarity (Live, Neutral, Earth)

STEP 4: Leave the earth wire disconnected since it is not important

STEP 5: Test the extension board with a multimeter before use

STEP 6: Allow exposed joints to save insulation tape

2. Draw a labelled diagram of a wired extension board in your notebook.
3. Present your step-by-step procedure to the class.

Case Study Challenge

A household needs a new extension board to power a television, a fan, and two phone chargers. Discuss these questions in your group from ***Activity 2.8.3***.

1. What **materials and tools** will you need to build this extension board? Think about the plug, the cable, the sockets, and the tools you'll use to cut and connect the wires.
2. What **size cable** is appropriate for this job? A television, a fan, and phone chargers don't require a huge amount of power, so consider a common household cable size.
3. What **mistakes should be avoided** when wiring this board? Think about things like loose connections, mixing up the wires (live, neutral, and earth), or not securing the cable properly in the plug.
4. How will you **test the board** to make sure it's safe to use before you give it to the household?

EXTENDED READING

- Apply knowledge of final circuits in a practical situation- wiring a single-phase distribution board.
  https://www.electrolesk.com/Work/Wiring%20of%20Single%20Phase%20Distribution%20Board.htm
- Wiring distribution board with RCD
  https://www.electricaltechnology.org/2013/05/wiring-of-distribution-board-with-rcd.html

Review Questions

1. What are the main requirements for wiring a Single-Phase Distribution board?
2. What tests must be carried out on a Distribution Board or Consumer Unit before it is made live?
3. What are the two main test instruments used when commissioning a Distribution Board or Consumer Unit to ensure it is safe to use?
4. What are each of the test instruments used for?

SECTION

3

INTRODUCTION - DOMESTIC INSTALLATION

UNIT 9

ELECTRICAL AND ELECTRONICS TECHNOLOGY

Electrical Systems Design

EARTHING AND INSTALLATION WORK

Introduction

Section 3 covers Units 9 to 12. As you continue your journey in domestic installation, this section will deepen your understanding of electrical and electronics technology, focusing on earthing and testing electrical circuits. Units 9 through 12 will guide you through the critical aspects of house wiring, providing you with the knowledge and skills necessary to ensure safety and compliance with regulations. You'll explore various wiring methods, the importance of proper earthing, and the procedures for conducting relevant tests on your installations. By actively engaging with the material and applying your skills in practical scenarios, you will enhance your ability to create safe and reliable electrical systems in residential settings.

KEY IDEAS

- Earthing ensures safety in electrical systems by providing a pathway for fault currents, reducing the risk of electric shock and fire.
- Key components of an earthing system include earth continuity conductors, earthing leads, and electrodes.
- Proper earthing practices protect both individuals and electrical equipment, enhancing overall system reliability.
- Various methods of earthing, such as plate, pipe, rod, and strip earthing, are employed for different applications.

This unit explores the essential concept of earthing in electrical systems, a critical practice for ensuring safety and reliability. By connecting electrical installations to the ground, earthing creates a safe pathway for fault currents, preventing hazards such as electrical shocks and fires. We will examine key components of an earthing system, including earth continuity conductors, earthing leads, and electrodes, along with various methods of earthing, such as plate, pipe, rod, and strip earthing, each having unique applications. The unit also emphasises the significance of proper earthing techniques in protecting individuals and electrical equipment.

EARTHING

Earthing is the process of connecting electrical systems and equipment to the ground (the Earth) to ensure safety and functionality. It involves creating a connection between the electrical system and the earth's conductive surface through grounding electrodes (such as ground rods or plates) and conductive wires. A metallic electrode or plate buried in the earth (underground) serves as the final component of the electrical earthing/grounding system.

A metallic plate, pipe, or solid copper rod is employed as an earth electrode, offering very low resistance and safely carrying fault current towards the ground (earth).

Reasons for earthing an electrical installation

Earthing is provided for the following reasons.

1. **To avoid electric shock:** This is a primary purpose of earthing. By connecting the electrical system to the ground, the risk of electric shock is significantly reduced.
2. **To avoid the risk of fire:** Earth leakage current, if not properly grounded, can follow unintended paths and lead to the risk of fire. Proper earthing helps direct such currents safely to the ground.
3. To ensure that no current-carrying conductor rises to a potential with respect to the general mass of earth beyond its designed insulation: Maintaining the designed insulation of conductors is critical. Earthing prevents conductors from reaching potentials that could compromise their insulation.

Parts of the Earthing System

1. ***Earth Continuity Conductor / Earth Wire***

   The part of the earthing system which interconnects all metallic components of an electrical installation, such as conduits, ducts, boxes, metallic shells of switches, distribution boards/main panels, fuses, regulating and controlling devices, and the metallic framework of electrical devices and components are installed is known as the earth wire or earth continuity conductor.

2. ***Earthing Lead***

   The conductor wire or conductive strip connected between the earth electrode and the electrical installation system and devices is called the Earthing lead or grounding conductor.

3. ***Earth Plate / Electrode***

The conductor (such as a copper earth rod or conductive earth plate) buried in the earth is known as the Earth Electrode. Earth electrodes come in different shapes, such as conductive plates, rods, metal water pipes, or any other conductor with low resistance.

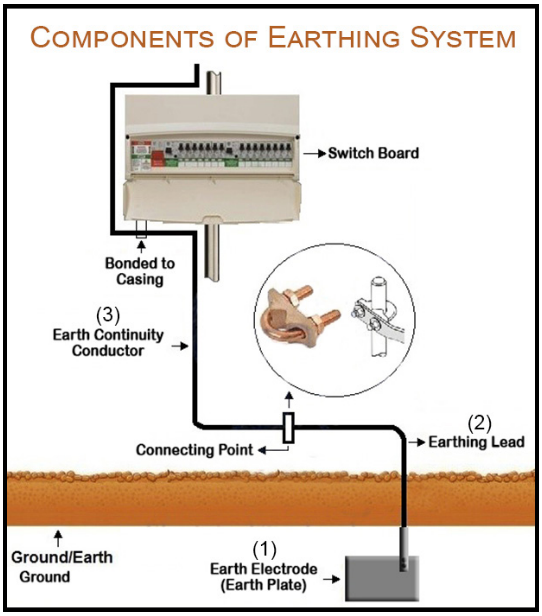


Figure 3.9.1*: A picture showing components of an earthing system*

Types of Electrical Earthing

Earthing can be achieved through various methods. The following approaches cover the various methods employed in earthing in-house wiring, factories and other connected electrical equipment and machines.

1. **Plate /Mesh Earthing**

In the plate earthing system, a plate made of copper is vertically buried in the earth (earth pit), and it should not be less than 3m from the ground level.

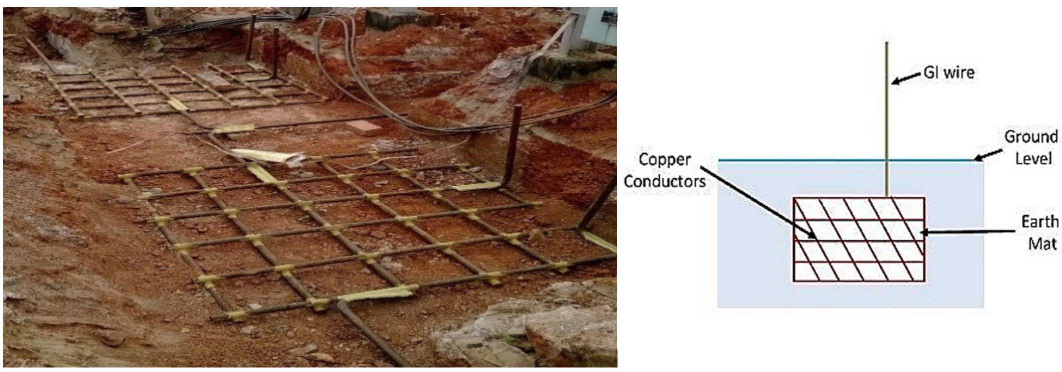


Figure 3.9.2*: Pictures of earthing method using wire mesh*

2. **Pipe Earthing**

In this type of earthing system, a galvanised steel and perforated pipes of approved length and diameter are placed vertically in wet soil. This is the most common earthing system. The size of the pipe used depends on the magnitude of the current and the type of soil.

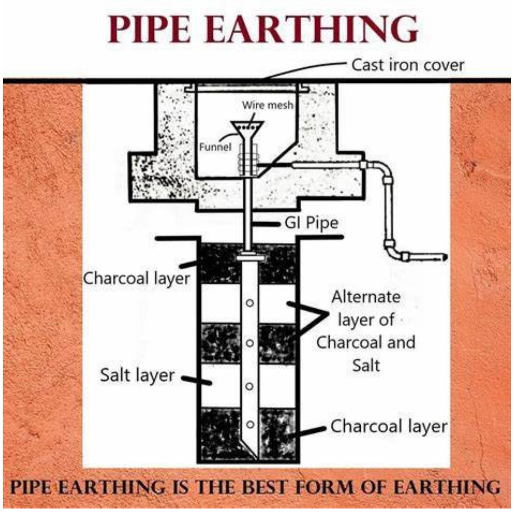


Figure 3.9.3: *A picture of the earthing method using a pipe*

3. Rod Earthing

Rod earthing is the same method as pipe earthing. A copper rod or a galvanised steel rod is buried upright in the earth either manually or with the help of a pneumatic hammer. The length of the embedded electrodes in the soil reduces earth resistance to a desired value.

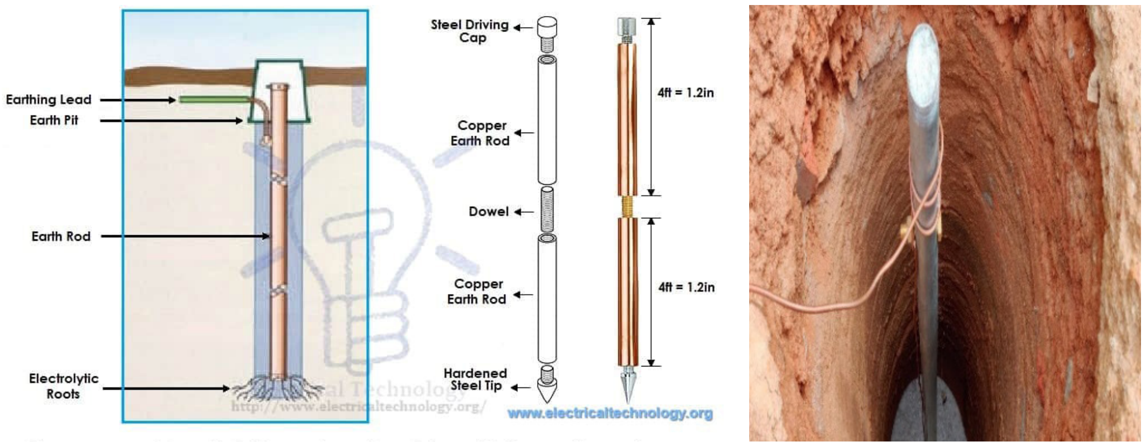


Figure 3.9.4: *Pictures of earthing methods using copper rod electrodes and a buried copper rod*

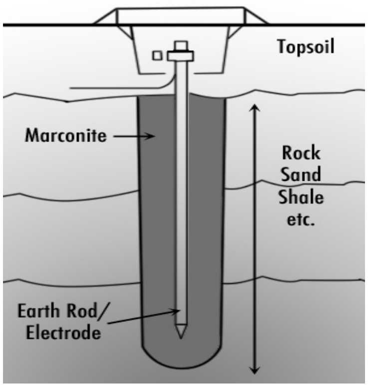


Figure 3.9.5: *Picture of copper rod surrounded by marconite*

4. **Strip or Wire Earthing**

   In this method of earthing, strip electrodes are buried in horizontal trenches with a minimum depth of 0.5m. The length of the conductor buried in the ground should provide sufficient earth resistance.

Figure 3.9.6: *A picture of the earthing method using copper strips*

General Method of Earthing an Installation

The standard step-by-step procedure for earthing electric equipment, devices, and appliances is as follows:

1. Begin by digging a pit, with a depth of (6-9 meters) into the ground. (Note that the depth and width depend on the nature and structure of the ground.)
2. Vertically bury an appropriate copper plate in the pit.
3. Attach earth leads (ground conductor) through nut bolts from two different places on the earth plate.
4. Use two earth leads for each earth plate (in case of two earth plates) and tighten them securely.
5. Apply grease around the joints to protect them from corrosion.
6. To maintain moisture conditions around the earth plate, surround it with a (30cm) layer of powdered charcoal (powdered wood coal) and lime mixture.
7. Ensure that the earth continuity conductor, connected to the body and metallic parts of all installations, is tightly connected to the earth lead.
8. Lastly, test the overall earthing system with an earth tester. If everything aligns with the plan, fill the pit with soil. The maximum allowable resistance for earthing is 1Ω. If it exceeds 1 ohm (1 Ω), increase the size (not length) of the earth lead and earth continuity conductors.
9. Keep the external ends of the pipes open and periodically add water to maintain the moisture condition around the earth electrode, crucial for a better earthing system.

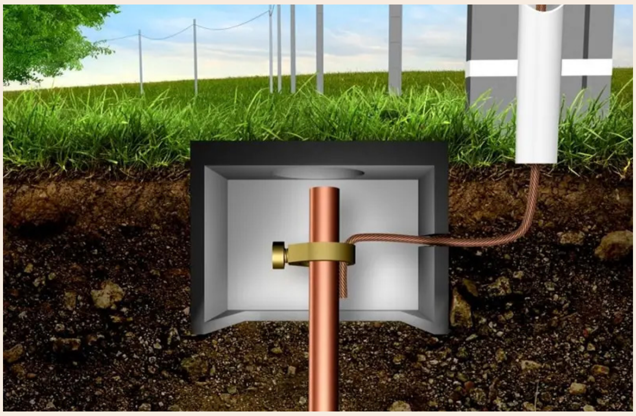
Activity 3.9.1 Understanding and Applying Earthing

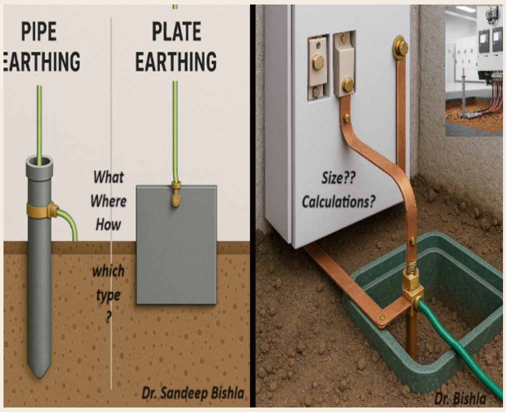
Aim: *This activity will help you understand the importance of earthing in electrical systems, particularly in sensitive environments such as a school science laboratory.*

1. Read the following scenario: A new school science lab is being built. It will have computers, microscopes, and other sensitive electrical equipment. Proper earthing is needed to protect both the students and the equipment from electric shocks and damage.
2. Watch the provided video (see link below) on earthing installation. Pay close attention to what earthing means, why it is important, and how it is carried out.

Video on earthing installation: https://youtu.be/1G6rOpTfY5M?si=rtEq6ni-02PrINoeE

3. In your group, examine the diagrams or pictures of different earthing systems, see the picture below (like plate or rod earthing) or one provided by your teacher. Think about how these systems work to protect people and equipment.
4. Based on the video and diagrams, discuss with your group the following questions:
    a. What is the main purpose of earthing in an electrical system?
    b. What are the most common materials used for earthing?
    c. What are the key steps involved in installing an earthing system?
5. As a group, come up with a clear definition of earthing and write it in your notebook.
6. Now, thinking back to the science lab scenario above, discuss why earthing is so important for the specific equipment mentioned (computers, microscopes, etc.).
7. As a class, share your answers and discuss any safety regulations (like those from the IEE code or British standards) that you think apply to this project.





Activity 3.9.2 Concept of Earthing

Aim: This activity will help you understand what **earthing** is, how it's done, and why it's so important for safety.

1. Working with a partner, talk about what you think "***earthing***" means in an electrical system. Think of it like a safety route for electricity.
2. Share some examples of places or situations where earthing is used to prevent dangers, such as in your home, a workshop, or a science lab.
3. Once you've discussed it, write your own definition of earthing in your notebook.

The Procedure for Earthing

4. In a group of four, research or recall the step-by-step process of installing an earthing system. Think about the actions needed, like digging a pit, preparing the electrode, and making the connections.
5. Create a short flowchart or a simple sketch to show the main steps of the procedure. Make sure it's easy to follow.
6. Once you're finished, place your group's flowchart on the classroom board so your classmates can look at it and give you feedback.

Materials Used in Earthing

7. Examine the earthing diagrams provided by your teacher. Identify and write down at least three materials used in earthing, such as a **copper rod** or a **galvanised iron plate**.
8. In your group, prepare a short **"Earthing Materials Fact Sheet."** For each material, write down its name, what it does (its function), and why it's important for creating a safe electrical path.

Activity 3.9.3 The Importance of Earthing

1. In your group, discuss the importance of earthing. Think about the key reasons why we need it, such as:
   a. **Protection from electric shocks:** How does earthing protect people from getting a shock if there's a fault?
   b. **Fire prevention:** How can earthing stop electrical fires from starting?
   c. **Stabilising voltage levels:** How does earthing help keep the electricity supply stable?
   d. **Equipment safety:** Why does it protect sensitive equipment like computers and projectors?
2. Create a poster or a presentation slide titled "Why Earthing Matters" that clearly explains at least four of the reasons you discussed. Use simple language and clear visuals.
3. Present your poster or slide to the class. The guide below should help you to put your presentation together.

Each group will now present all the work you've done on earthing. Your presentation should include:

- Your group's definition of earthing.
- The flowchart you created to show the earthing procedure.
- Your Earthing Materials Fact Sheet.
- Your ***"Why Earthing Matters"*** poster.

After each group presents, the other groups must be prepared to ask at least one follow-up question.

Case Study Challenge

An ICT lab at your community school needs proper earthing for 20 computers and projectors. Discuss these questions in your group.

1. Which type of earthing would you recommend for the lab—a rod, plate, or pipe?
2. Explain your choice and why it would be the most effective for this situation.
3. What materials would be required for this specific type of earthing installation?
4. What mistakes must be avoided during the installation process to ensure the system is safe and works correctly?

EXTENDED READING

- Earth is an installation work in accordance with the rules and regulations for earthing systems.
  https://uomustansiriyah.edu.iq/media/lectures/5/5_2020_10_10!10_46_33_AM.pdf
- Earthing. https://electrical.theiet.org/media/1549/earthing.pdfhttps://electrical.theiet.org/media/1549/earthing.pdf

Review Questions

1. Explain the concept of earthing.
2. State the reasons for carrying out earthing.

UNIT 10

RELEVANT TESTS ON AN ELECTRICAL CIRCUIT

Introduction

Testing typically involves conducting a series of assessments to ensure that the installation meets relevant safety standards and codes and that it is functioning properly.

KEY IDEA

- It is important to test new electrical installations for:
  - continuity of circuit
  - sufficiency of insulation resistance and
  - polarity to check all connections are aligned to the phase wire, ensuring the earth wire provides a low resistance path to earth in the event of overload.

TESTING

Testing of electrical installation is the process of evaluating the safety and performance of an electrical installation, such as the wiring and electrical systems in a building or facility. Electrical installation testing is one of the minimum technical requirements for most domestic and business premises. It is mandatory for the safety of every commercial or residential premise to be tested before connection to the supply to ensure that the installation is technically sound, free from any possible short circuits, and for the safety of the workers or tenants therein.

Types of Tests

The tests that should be conducted on a new electrical installation before it is commissioned are as follows.

1. Insulation resistance test between installation and earth.
2. Insulation resistance test between conductors.
3. Testing of polarity.
4. Testing of earth continuity paths.
5. Earth resistance test.

Insulation resistance test between installation and earth

This test is performed to know the standard of insulation of wires and cables used in the installation. It also ensures that the insulation is sufficient to avoid any possible leakage of current to earth.

Before performing an insulation resistance test between the installation and earth, the conditions are as follows: Put

1. main switch in OFF position,
2. fuses beyond the main switch should be in position.
3. all switches in ON position.
4. all lamps and other equipment should be in their position.

For testing the whole installation, the test is conducted on the main switch. A testing set known as megger is used for the test. It is a special form of the ohmmeter. To perform this test, the phase and the neutral are short-circuited temporarily at any suitable point as shown below.

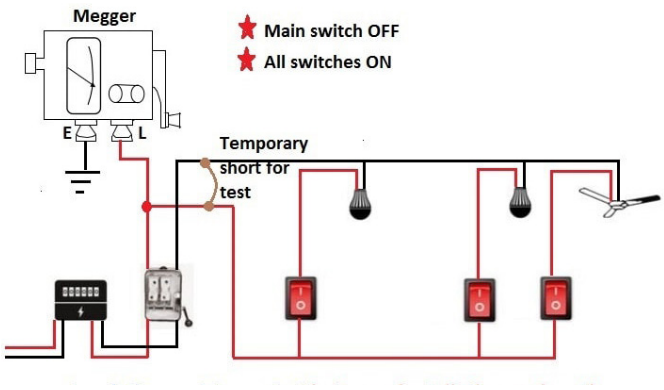


***Figure 3.7**: Installation resistance test between installation and earth*

The 'L' (line terminal) of the megger is connected to the short circuit point in the main switch and the earth terminal marked (E) is connected to earth continuity conductor or some good earth point near-by. The handle of the tester is turned at a high speed so that sufficient testing voltage is produced. The reading on the dial of the megger is noted. The insulation resistance thus measured should not be less than 0.5 MΩ on firm, sound and fixed wiring. If the insulation resistance is below this value, the wiring section giving that value should be rewired or checked thoroughly until the required value is obtained.

Insulation resistance test between wiring conductors

To ensure that the insulation of the cables or wires is not damaged and there is no leakage between them, this test is performed.

Before performing this test,

1. put all switches in the ON position,
2. disconnect all lamps and other appliances,
3. fuses beyond the main switch should be in ON position.

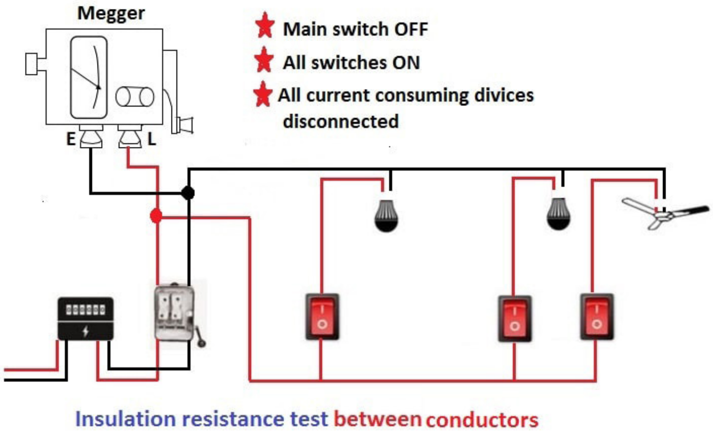


Figure 3.8: Installation resistance test between conductors

The line terminal of the megger is connected to the phase (live) terminal of the installation and the earth terminal of the megger is connected to neutral wire. The insulation resistance so measured should not be less than 0.5 MΩ and not more than 1 MΩ.

Polarity Test

In a low-voltage installation, this test is performed to verify that all single-pole switches have been connected to the phase wire throughout the installation. It is necessary to place all switches on the phase so that when a switch is made OFF, the connected appliance is dead. If the switch is connected to the neutral wire, then the connected appliance will get phase even if the switch is in the OFF position and remain alive. There is absolutely no difference in the functioning of the switch in either case, but from the safety point of view, to avoid shock, etc., the phase should always be given through the switch and neutral directly to the point.

The simple method of conducting the polarity test is by using a test lamp. Before performing this test,

1. put the main switch in the ON position,
2. put all switches in the OFF position,
3. disconnect all lamps and other appliances.

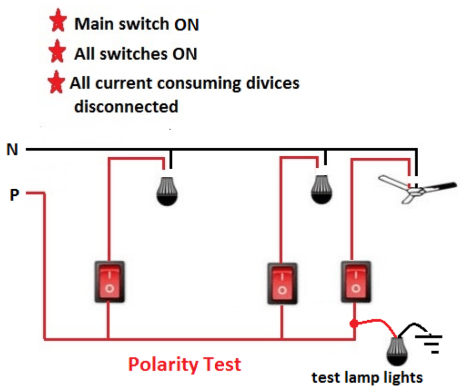


Figure 3.9: Polarity test

One end of the test lamp is connected to earth wire and the other end to the incoming terminal of the switch. If the lamp lights, it indicates that the switch is connected to phase wire, if not, then it is reversed (to neutral wire).

Earth continuity test

To perform this test with the help of megger, the main switch is opened, the main fuses are withdrawn, all the switches are made ON and all the lamps are put in position. The 'L' (line terminal) of the megger is connected to the phase conductor in the main switch and 'E' (earth terminal) of the megger is connected to an earth point.

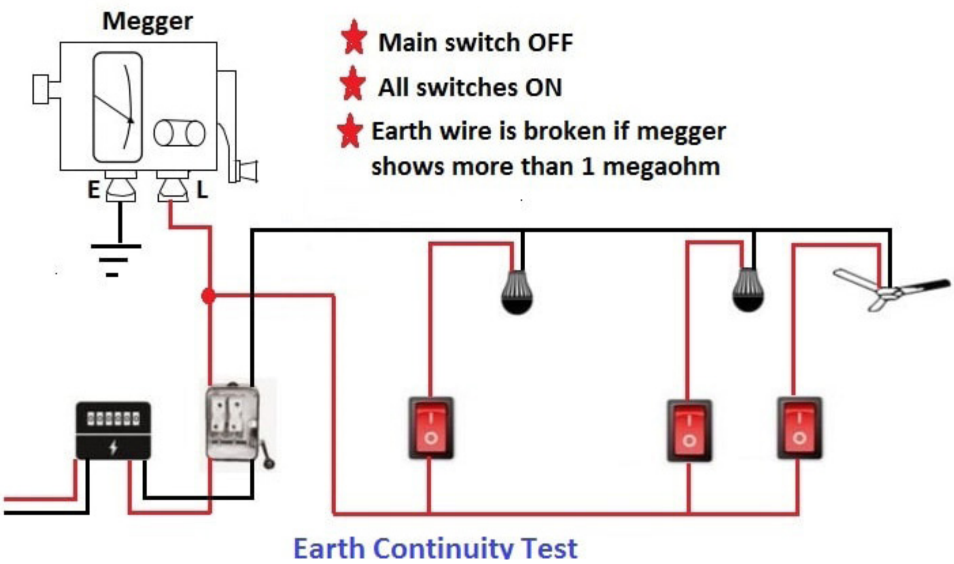


Figure 3.10: *Earth continuity test*

In this test, the megger should indicate a resistance value between 0.5 and 1 mega ohm. In this case, if the earthing of all the metallic parts and the earth wire is in good condition, enough current will flow through the test circuit, and the megger will show a reading up to 1 MΩ. However, if the megger shows a high reading (more than 1 MΩ), it means that the main switch or conduit is not properly earthed, or the earth wire is broken somewhere and requires correction.

Activity 3.10.1 Understanding electrical installation tests

The Concept of Electrical Tests

1. Working with a partner, discuss what you think each of the following tests means:
- Continuity test
- Polarity test
- Insulation resistance test

2. Talk about why these tests are so important for electrical wiring. What could happen if a new installation isn't tested properly?

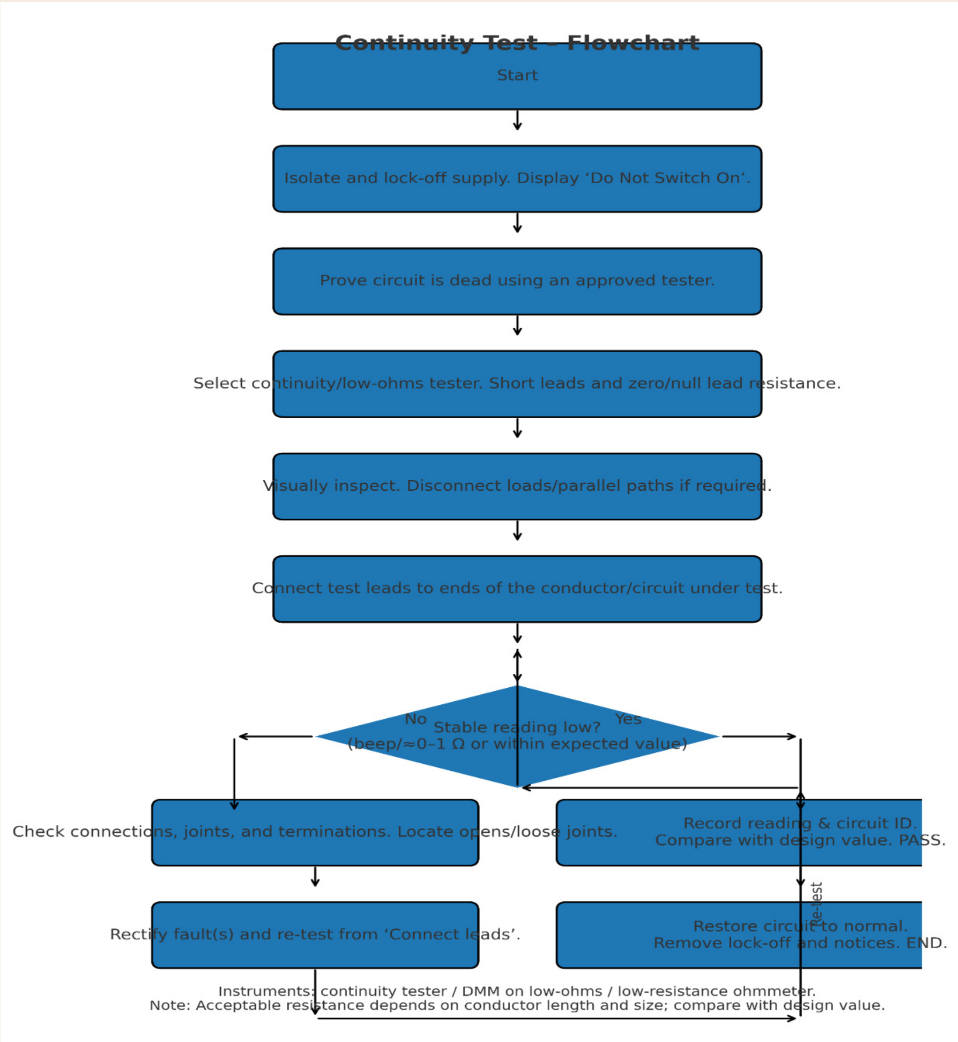
3. In your notebook, write a short, simple definition for each of the three tests.

The Purpose of Each Test

1. In a group with four of your classmates, research or discuss the specific purpose of each test. What exactly does each test check for?
2. Create a table that summarises your findings. It should have three rows, one for each test. The table should clearly state the name of the test and its purpose.
3. Share your group's table with the rest of the class.

The Procedure for Conducting Tests

1. Watch a demonstration video or study the diagrams provided by your teacher. Pay close attention to the tools used and the steps followed for each test.
2. In your groups, describe the step-by-step procedure for conducting a continuity test, a polarity test, and an insulation resistance test.
3. Create a simple flowchart for each procedure. For example, your flowchart for the continuity test might start with "Turn off the power" and end with "Check the reading on the multimeter." See example below.
4. Display your flowcharts on the classroom wall so you can compare them with other groups.



Practical Demonstration of Insulation Resistance Test

1. With guidance from your teacher, use an insulation resistance tester (megger) or picture and video provided to check the insulation of a sample circuit.
2. Record your observations, including the readings obtained.
3. Discuss what the readings mean, e.g. acceptable or faulty insulation

Case Study Challenge

A three-bedroom house has just been wired and must be tested before the supply is connected.

- Which test would you conduct first and why?
- How would you confirm that no wires are wrongly connected?
- What problems could arise if insulation resistance is low?

EXTENDED READING

- Guide on electrical inspection and testing
  https://mytrustedexpert.com/electricians/electrical-inspection-and-testing/
- Inspection and testing of electrical installations
  https://booksite.elsevier.com/samplechapters/9781856176071/9781856176071.pdf

Review Questions

1. What is the purpose of conducting a Polarity test, Continuity test and Insulation resistance test on a circuit?
2. Describe the procedure involved in carrying out each of the tests.

UNIT 11

FIELD TRIP EXPERIENCE

Introduction

The process of wiring involves planning the layout and routing of electrical conductors, selecting the appropriate wire size and the type of each application and properly connecting the conductors to the various electrical components.

KEY IDEA

- Observing the following processes of wiring an installation at a site on a field trip is important.
  - Concealed conduit.
  - Distribution Board.

FINAL CIRCUIT

Safety Precautions to Follow When Wiring A Circuit

The recommended guidelines to be observed when wiring a circuit are as follows:

1. Follow the National Electrical Code (NEC) for residential electrical wiring.
2. Properly connect wires: Black wires together, Red wires together, and earth wires together.
3. Route cables along safe pathways and avoid overcrowding electrical boxes to prevent overheating and fire hazards.
4. Use insulated hand tools.
5. Use the correct tools for the right job
6. Wear safety clothing.
7. Clean up spills or wet patches on the floor.

Observing Installation of Concealed Conduit Wiring at a Site

At the site, witness and take notes on the installation procedure and follow how the

1. The surface of the walls is marked.
2. Wall markings are cut with a wall cutter to avoid damaging the walls.

3. Conduit, boxes and accessories are installed.
4. Chiselled surface is filled with cement mortar and covered with thick mesh
5. Concealed boxes are recessed into the plastered surface.
6. A pipe bender is used to bend the conduit.
7. Accessories are fixed, and termination is done.
8. Concealed switchback boxes are levelled correctly.
9. The distribution board is concealed before plastering begins.
10. The distribution board box is positioned in a properly aligned and levelled recess in the block work.
11. Conduit pipes enter the distribution board only through the given entry holes.
12. Cables are drawn in using a fish tape.

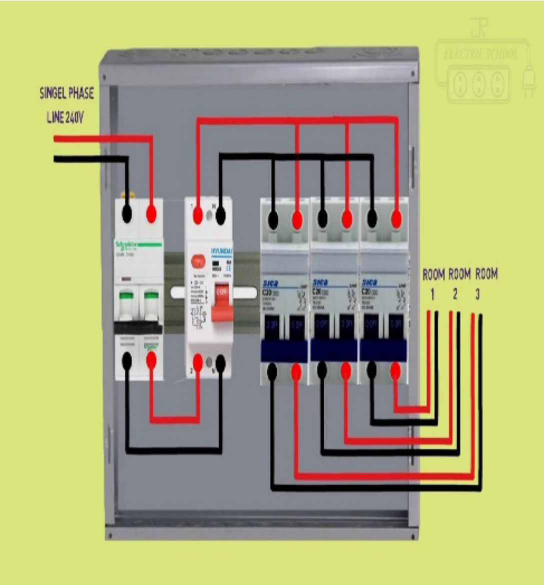


***Figure 3.11.1**: Picture of a consumer Unit with MCB (DP) RCCB and MCSs (SP)*

Wiring of Consumer Unit

The illustration in ***Figure 3.11.1*** is a single-phase home supply wiring diagram to a consumer unit. It typifies the:

The main supply, the live (Red) and the neutral (Black) wires/cables coming to the single-phase main consumer's unit.

Observe the following.

1. Live and neutral lines are connected to the double-pole MCB isolator switch.
2. Live and neutral wires are connected to the RCD and then to the common single-pole miniature circuit breakers (MCBs).
3. Outgoing lines from the MCBS (SP), connected to the final circuits, Room 1, etc

Wiring a Final Circuit

A final circuit is connected to any one-way of a distribution board, or a switch fuse feeding one or more outlets without the intervention of a further distribution board.

An outlet is the termination of fixed wiring feeding a luminaire, socket or any current-consuming appliance. A final circuit consists of a number of cables feeding a few lighting points or socket outlets from a circuit breaker or the main switchboard.

Regulation: Where an installation comprises more than one final circuit, each final circuit shall be connected to a separate way in the distribution board, and the wiring to each final circuit shall be electrically separate from that of every other final circuit

Observing the Procedure for Wiring a Final Circuit

Observe the following

1. Number of ways of the distribution board.
2. Live, neutral and the earth wires projected from the miniature circuit breaker (MCBS).
3. Different circuits, for example, cooker unit, immersion heater, lighting and sockets.
4. Tools used such as insulated screw drivers, wire strippers, pliers, cutters, etc.
5. Cables connected from the circuit breaker.
6. Cables run to other parts of the installation.
7. Type of accessories and how they are terminated.
8. Lighting circuits connected to one breaker or fuse.
9. Sockets connected to another breaker or fuse.
10. Cables drawn in accordance with the colour coding as per the phasing requirement.
11. Outlets equipped with a dedicated neutral and earth of similar size to the conductor.

Step-by-step procedure for wiring the circuit on a board

The wiring method to be implemented is trunking.

1. Mark out positions of the circuit breaker (MCB), the residual current circuit breaker (RCCB), the distribution board (DB) and accessories on the board provided.
2. Use a tape measure to measure the trunking to the appropriate lengths at all locations.
3. Cut the trunking to the measured length.
4. Position the trunking on the marked locations and secure them with raw plugs and screws.

5. Fix the boxes/fittings for switches and sockets at the marked locations.
6. Fix the consumer control unit at its location.
7. Run 1.5mm^2 cables to all lighting points.
8. Run 2.5mm^2 cables to the various socket final circuits.
9. Run the 6mm^2 wire for the cooker control unit.
10. Terminate all the accessories, correctly taking into account the colour code for the wires.
11. Screw all accessories in place.
12. Run the 16mm^2 cables to the consumer unit and terminate conforming to the given wiring diagram in ***Figure 3.11.1***.
13. Test for short-circuit by conducting an insulation resistance test.
14. The reading should read as infinity.
15. Conduct a continuity test and a polarity test
16. Fix all loads and connect the circuit to the power source satisfactorily.

Activity 3.11.1 Basic Requirements for Wiring a Circuit

Your class goes on a field trip to a nearby housing project where electricians are wiring circuits for lighting and socket outlets.

During the trip, you observe the tools, materials and procedures used. Back in class, you will work in groups to reflect on your observations and prepare a report. The report should cover the basic requirements for wiring a circuit, the precautions electricians followed, and the procedure of building the circuit (see guide notes on report writing below).

This activity will strengthen your practical knowledge and improve your report-writing skills.

1. Working with a partner, brainstorm and list all the essential **tools**, **materials**, and **safety regulations** you think are needed to wire an electrical circuit.
2. Compare the list you created with the observations you made during your field trip.
3. Did you remember all the items? Did you notice any tools or materials you didn't think of?
4. Record all of these requirements as the first part of your report.

Field Trip Guide Notes (to help with your report)

- **What tools and materials did you see?** Make a list of everything the electricians used, from wire strippers and screwdrivers to cables, switches, and consumer units.

- **What safety precautions did they follow?** Think about personal protective equipment (PPE) like gloves and safety goggles, and procedural precautions like locking off power.
- **How did they connect the circuits?** Describe the step-by-step process you saw, from running the cables to connecting them to the switches and socket outlets.
- **How was the consumer unit wired?** Note how the various circuits were connected to the circuit breakers and the main switch in the consumer unit.

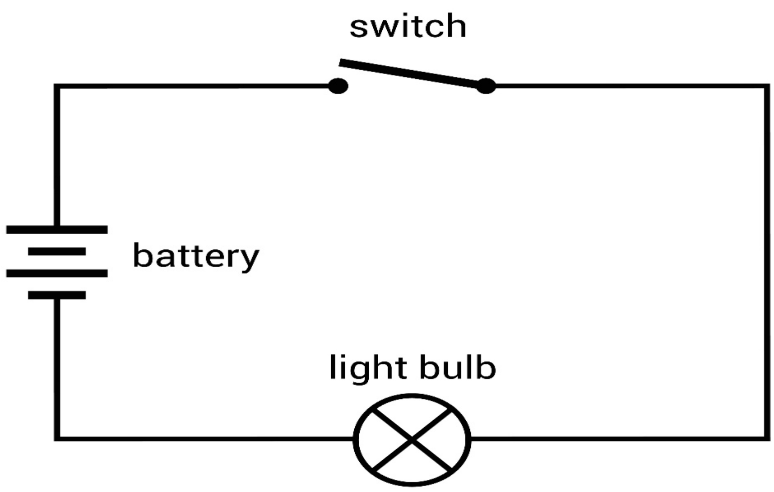
Report
Report Title: *Field trip report on wiring a circuit.* Your report should include the following.
• **Introduction**: Purpose of the field trip and what you set out to learn. • **Basic Requirements**: Tools, materials, and regulations required for wiring a circuit. • **Precautions**: Safety measures observed during the wiring. • **Procedure**: Step-by-step account of how the circuit was wired. • **Conclusion/Recommendations**: Lessons learned, challenges faced, and how this knowledge can be applied in your own practice.

Activity 3.11.2 Precautions When Wiring a Circuit

1. In a group with four of your classmates, recall all the safety measures you saw the electricians follow. Think about things like wearing protective gear and making sure the power supply is turned off before they start working.
2. Discuss with your group why each of these precautions is so important. What could happen if they didn't follow these safety rules?
3. Summarise your group's findings in your notebook. You'll need to include these safety precautions in your final report.

Activity 3.11.3 The Procedure for Building a Circuit

1. Using your observations from the field trip in **Activity 3.11.1**, draw the electrical circuit you saw being wired (*see diagram below as an example*). Make sure you include the consumer control unit, cables, switches, and sockets.



2. With your group, use your notes from the trip and your textbook to describe the step-by-step procedure for building the circuit. Start from the consumer control unit and go all the way to the final connection at the sockets or lights.
3. As a group, create a simple concept map of the procedure. Your map should show the main steps and how they link together. You can display this on the classroom wall for everyone to see.

EXTENDED READING

Indicator -Apply knowledge of house wiring in a practical situation

- Domestic wiring
  https://www.scribd.com/document/431809699/001-DOMESTIC-WIRING-pdf

  https://www.scribd.com/document/431809699/001-DOMESTIC-WIRING-pdf
- Wiring components and accessories
  https://ncert.nic.in/vocational/pdf/kvcj103.pdf

UNIT 12

WIRING OF A SINGLE-PHASE INSTALLATION AS A PROJECT WORK

Introduction

The planning and arrangement of final circuits, the control and distribution of supply to final circuits and equipment from the distribution board, the number of outlets per circuit, overload protection and the use of the correct size of cables will be covered in this chapter.

KEY IDEAS

- How to correctly and safely wire a consumer unit
- Drawing up an accurate material schedule for an installation
- Using the trunking system to wire an installation on a board

ESSENTIAL SAFETY PRECAUTIONS TO FOLLOW WHEN WIRING A CIRCUIT

1. Use the right tools for the right job.
2. Use tools with insulated handles.
3. Use a wire stripper to remove cable/wire insulation and not the teeth.
4. Wear protective clothing.
5. Avoid working in damp settings.
6. Keep the work environment tidy.
7. Do not scatter tools indiscriminately.
8. Do not work on live circuits, put the power off.

The Consumer's Unit

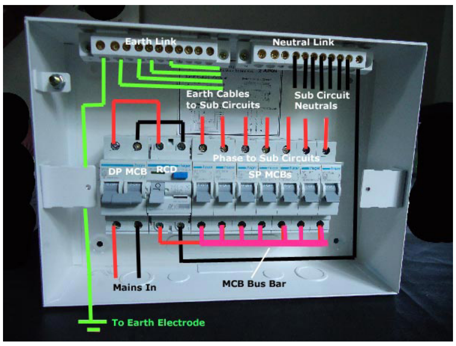


***Figure 3.12.1**: Picture of a consumer's unit*

The following items are essential for wiring a consumer unit to the mains power supply.

1. Consumer unit equipment
2. Double pole miniature circuit breaker DP MCB
3. Residual current device RCD
4. Single-pole miniature circuit breakers SP MCB
5. Earth link
6. Neutral link

Process for Wiring of the Consumer Unit

1. Connect the live (Red) wire from the mains to the DP MCB.
2. Connect from the DP MCB to the live terminal of the RCD.
3. Connect from the RCD to the Busbar in the SP MCBs.
4. Terminate wires firmly in the SP MCBs.
5. Connect the live (Red) wire from each SP MCB to a separate final circuit.
6. Track the neutral (black) wire from the mains through the DP MCB, the RCD to the neutral link and connect.
7. Connect the earthing lead to the earth link.
8. Connect from the neutral (Black) and earth links to the final circuits along the live red wire.

Final Circuit to be Wired

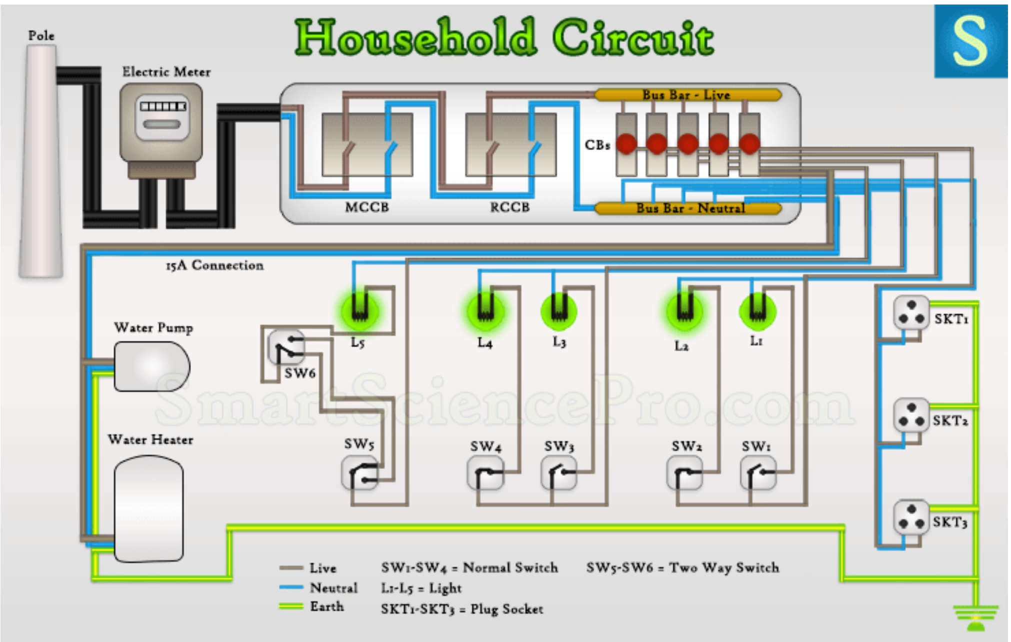


Figure 3.12.2*: Picture of wiring plan of an installation*

Table 3.12.1: Material schedule for wiring an installation

S/N	MATERIALS AND ACCESSORIES	QUANTITY
1	Plywood 120 x 240 cm^2	1
2	7-way distribution board	1
3	Double pole MCB	1
4	Single pole RCD	1
6	16mm x 25mm trunking	3
7	16x 16mm	3
8	Twin socket outlets	4
9	2-way switch	2
10	Single –pole switch	4
11	Batten lamp holder	5
12	Cooker control unit	1
13	1.5mm^2 cable (Red)	1 roll
14	1.5mm^2 cable (Blue)	1 roll
15	2.5mm^2 cable (Red)	1 roll
16	2.5mm^2 cable (Blue)	1 roll
17	2.5mm^2 cable Yellow/Green	1 roll
18	6mm^2 cable (Red)	5 yards
19	6mm^2 cable (Blue)	5 yards
20	6mm^2 cable (Yellow/Green)	5 yards
21	16mm^2 cable	12 yards
22	Pattress boxes	12
23	Water heater	1
24	Water pump	1
	TOOLS	
1	Portable hand drill	1
2	Screw driver	1 Set
3	Wire stripper	1
4	Plier	1
5	Side cutter	1
6	Hacksaw	1
7	Multimeter	1
8	Tape measure	1

Step-by-step procedure for wiring the circuit on a board

The wiring method to be implemented is trunking.

1. Mark out positions of the circuit breaker (MCB), the residual current circuit breaker (RCCB), the distribution board (DB) and accessories on the board provided.
2. Use a tape measure to measure the trunking to the appropriate lengths at all locations.
3. Cut the trunking to the measured length.
4. Position the trunking on the marked locations and secure them with Rawl plugs and screws.
5. Fix the boxes/fittings for switches and sockets at the marked locations.
6. Fix the consumer control unit at its location.
7. Run 1.5 mm2 cables to all lighting points.
8. Run 2.5 mm2 cables to the various socket final circuits.
9. Run the 6mm2 wire for the cooker control unit.
10. Terminate all the accessories, correctly taking into account the colour code for the wires.
11. Screw all accessories in place.
12. Run the 16 mm2 cables to the consumer unit and terminate conforming to the given wiring diagram in ***Figure 3.12.2***.
13. Test for short-circuit by conducting an insulation resistance test.
14. The reading should read as infinity.
15. Conduct a continuity test and a polarity test
16. Fix all loads and connect the circuit to the power source satisfactorily.

Activity 3.12.1 Wiring a residential circuit (Project-Based)

Scenario

Imagine you and your group have been hired to plan and demonstrate how to wire a circuit in a new house. Your task is to carry out research, design a wiring plan, with a group you form 4 of your classmates and show the correct procedure to the class.

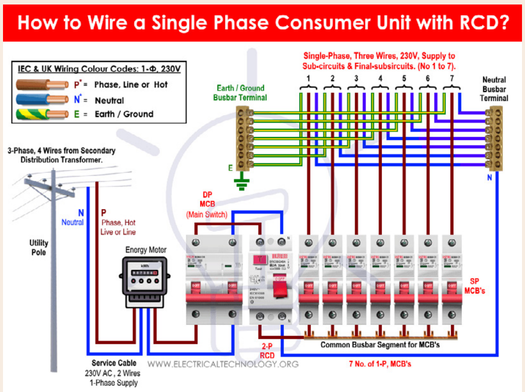
Your team must ensure that your plan covers the following.

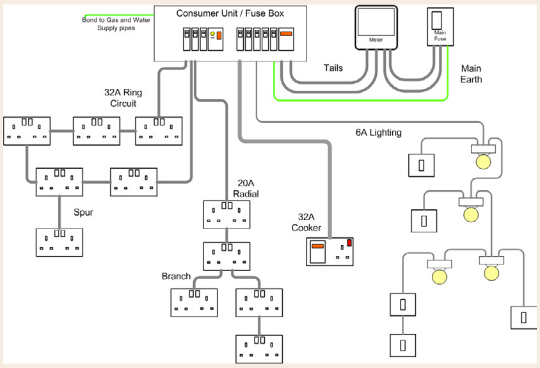
- All the necessary tools and materials.
- The safety precautions that must be followed.
- The correct procedure for building and connecting a circuit.

Resource Guide

To help you with your project, examine the diagrams of consumer units and house wiring layouts provided by your teacher. You may also get to see some real objects. As you observe, take notes on these key points. (*Alternatively, you can observe the figure below*)

1. What are the basic requirements for wiring a circuit? Think about the essential tools, materials, and regulations needed.
2. What safety precautions must be followed when wiring? Look for things like personal protective equipment (PPE) and methods used to turn off the power.
3. What is the correct procedure for building a circuit, from the consumer unit all the way to the final connection? Note the step-by-step process.





Task 1: Project Planning & Safety

1. In your group, create a Project Plan Document that lists all the necessary tools, materials, and safety codes you'll need for wiring a circuit. Assign a role to each person in your group, such as planner or safety officer.
2. Have your group's safety officer lead the design of a "Safety Checklist Poster" for your project. This poster should list all the important safety precautions you'll follow, like wearing personal protective equipment (PPE) and making sure the power is off.
3. Display your Safety Checklist in the classroom and make sure you refer to it throughout the project.

Task 2: Project Execution

1. As a group, study the provided diagrams of consumer units and typical circuit layouts. Then, outline the step-by-step procedure for building your circuit, from fixing the consumer unit to running the cables and making all the connections.
2. Draw a clear wiring sketch that shows the complete circuit layout and how it will connect to the consumer unit.

3. Under the supervision of your teacher, use your project plan, safety checklist, and wiring sketch to practically wire a demonstration circuit.

Case Study Project Challenge

An ICT classroom requires wiring for 10 socket outlets and 4 lighting points. Your group has been hired to design the plan.

1. What are the basic requirements needed?
2. What safety precautions should be observed during installation?
3. How would you outline the procedure for wiring the circuit and connecting it to the consumer control unit?

Deliverable: Submit a mini "Project Report" outlining your answers. Use the project report format below:

Project Report Template: Wiring a residential circuit

Project Title: ____

Group Members: ____

Date: ______________________

1. **Introduction**
    - Briefly state the purpose of this project.
    - Mention the scenario (residential block under construction / ICT classroom wiring).
    - Explain why wiring must follow requirements, precautions, and proper procedures.
2. **Basic Requirements**

List all requirements for wiring a circuit, including

- **Tools,** e.g. pliers, screwdriver, tester, drilling machine.
- **Materials,** e.g. cables, sockets, lighting points, consumer control unit.
- **Safety Codes/Standards,** e.g. correct cable size, proper earthing, circuit breakers.

3. **Safety Precautions**

Present your group's Safety Checklist. Examples may include

- Use PPE (gloves, goggles, boots).
- Isolate the supply before working.
- Avoid overloading circuits.
- Keep wiring neat and organised.

4. **Procedure for Building the Circuit**

Step-by-step outline of your group's wiring procedure. See example below.

a. Fix the consumer control unit.
b. Measure and cut cables.
c. Run cables neatly through conduits.
d. Connect conductors to switches, sockets, and the control unit.
e. Check polarity and continuity.
f. Test insulation resistance.
g. Power up and test the circuit.

(Attach your sketch/diagram here)

5. **Observations and Results**
    - What did your group achieve in the practical wiring?
    - Did the circuit work as expected?
    - What challenges did you face and how did you solve them?
6. **Conclusion**
    - Summarise what your group learned about wiring requirements, precautions, and procedures.
    - State how this knowledge can be applied to real-life wiring in homes or community buildings.

EXTENDED READING

Apply knowledge of house wiring in a practical situation

- https://www.reddit.com/r/electrical/comments/1ghi5ww/full_electrical_wiring_diagram_house_wiring/?rdt=52691
- https://www.pennaelectric.com/6-types-of-electrical-wiring-for-your-house/#:~:text=The%20most%20common%20type%20of,is%20a%20flexible%20plastic%20jacket

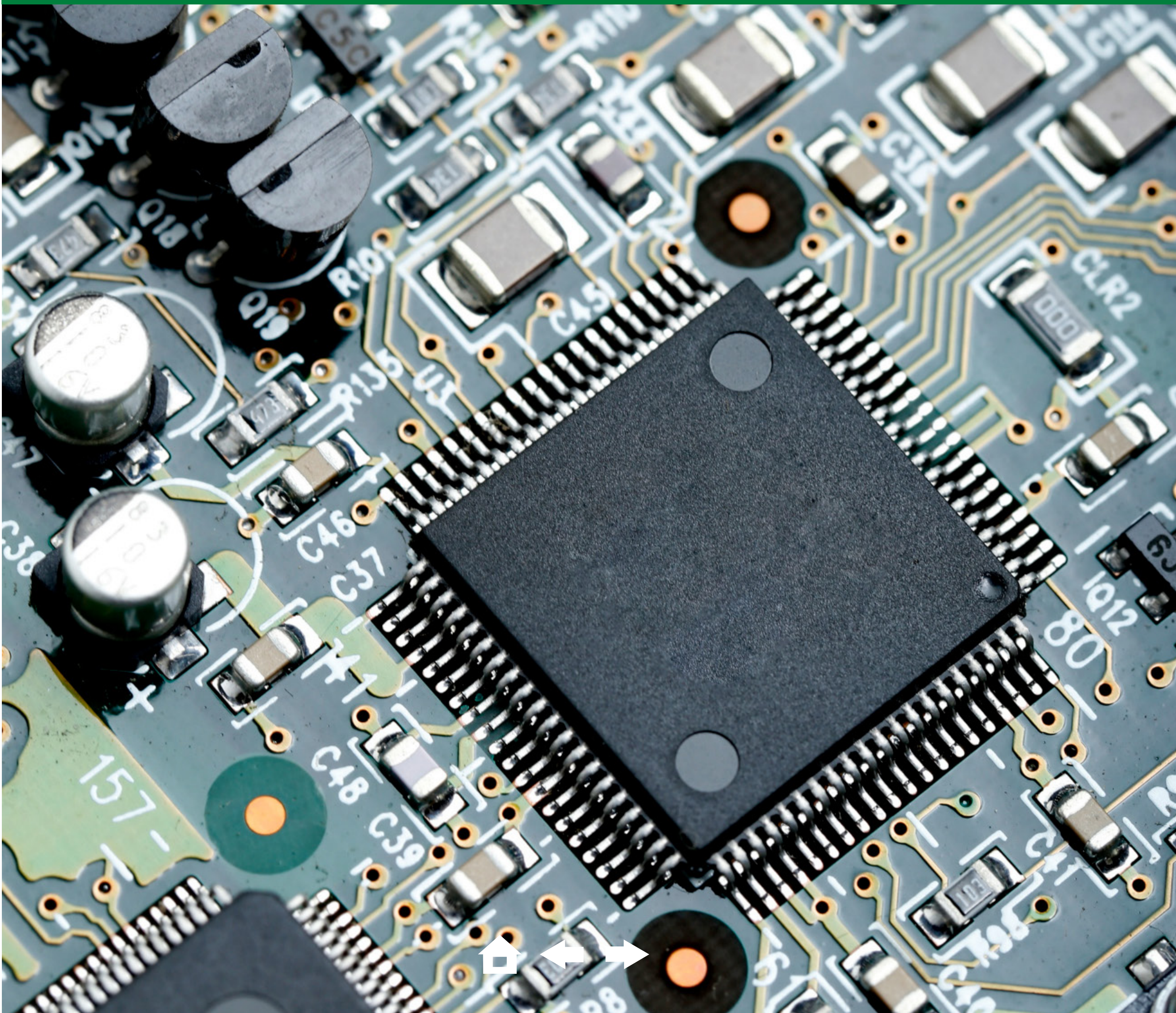
Review Questions

1. State the essential safety precautions to follow when wiring a circuit
2. What is meant by the term final circuit?

SECTION

4

PASSIVE ELECTRONIC COMPONENTS AND CELLS



UNIT 13

ELECTRICAL AND ELECTRONIC TECHNOLOGY

ELECTRONIC COMPONENTS AND CIRCUITS

Introduction

This section covers Units 13 to 16 and deals with passive electronic components, such as types of (resistors, capacitors, inductors), their configurations, applications and cells.

KEY IDEAS

- Resistors are passive electronic components that regulate the flow of electrons in a circuit.
- Different types of resistors serve essential functions in electrical circuits.

Resistors are specially made passive components that offer opposition to the flow of electric current. There are many types of resistors, and they vary in their construction, power dissipation capacities, tolerance and various other parameters.

PASSIVE COMPONENTS

Passive components are electronic devices that do not require an external power source to operate. They primarily resist, store, or control the flow of electric current or voltage in a circuit without actively amplifying or generating signals. These components include resistors.

Functions of a Resistor

Resistors can be used for the following functions

1. *Voltage divider:* Resistors can be used as a voltage divider to divide voltages into specific ratios in a circuit.
2. *Current limiting:* Resistors are used to control the flow of electrons in a circuit.
3. *Timing and Filtering:* Resistors are used together with capacitors and inductors for timing, filtering and frequency response shaping in electronic circuits.

4. *Load resistor:* Resistors can be used as load resistors to simulate the presence of a load in a circuit

Types of Resistors

Electricity and Electronics make regular use of resistors with definite resistance. Various types of resistors are made to fit the needs of low cost, small size, high power consumption, high accuracy, low temperature effects and so on.

The different types of resistors include those listed below.

1. **Fixed resistor**: The basic fixed resistor has a specific resistance value.
2. **Variable Resistor**: A resistor that allows its resistance value to be adjusted by a rotating shaft and a wiping or sliding contact. The most common one has a sliding contact moving over a circular segment of a carbon resistive film.

   It varies the current in the circuit as the sliding contact varies the length of the carbon track. It is used in volume control on radios, speed control on fans and control of spotlights in a theatre.

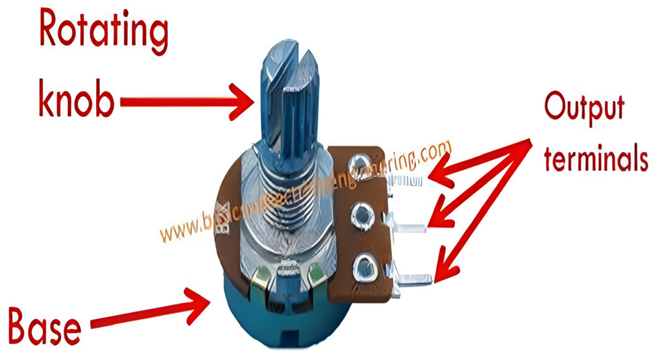


***Figure 4.13.1**: A Picture of a variable resistor with a carbon resistive film*

3. **Carbon resistor**

   The workhorse resistor of electronics is the carbon composition resistor with its hallmark colour coding. The structure is a small cylinder of carbon mixed with a non-conductor (clay). It has the following features.

   a. Connecting wire fixed into each end,

   b. Coat of paint to protect it from moisture,

   c. Colour code to indicate the value.

   d. Fairly small power rating capabilities as: 1/8, W ¼ W, ½ W, 1 W and 2 watts (W).

   The higher the rating, the larger the physical size. It is used where performance requirements are not demanding and low cost is the main requirement.

Figure 4.13.2: *Picture of a carbon resistor*

Carbon Resistor Colour Code

The colour bands indicate the nominal (stated) value of the resistance and the tolerance. A rhyme that can be used as a memory aid is as follows:

Bill Brown Realised Only Yesterday Good Boys Perform Good Work.

The first letter of each word represents the first letter of each colour in the correct order. The various colours and the associated codes are shown in ***Table 4.13.1***.

Table 4.13.1: Resistor colour code

COLOR	BAND 1	BAND 2	MULTIPLIER	TOLERANCE
BLACK	0	0	X1Ω	
BROWN	1	1	X10Ω	
RED	2	2	X100Ω	
ORANGE	3	3	X1KΩ	
YELLOW	4	4	X10KΩ	
GREEN	5	5	X100KΩ	
BLUE	6	6	X1MΩ	
PURPLE	7	7		
GREY	8	8		
WHITE	9	9		
GOLDEN			X0.1Ω	±5%
SILVER			X0.01Ω	

A colour-coded carbon resistor

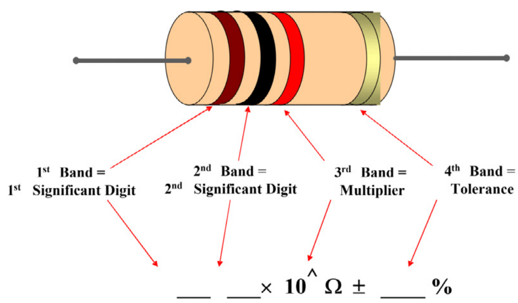


Figure 4.13.3: *Picture of a colour-coded carbon resistor*

Tolerance

Tolerance is a percentage mark of the noticeable (nominal) value of the **carbon** resistor. The percentages are as follows: Silver + 10%, Gold + 5%, No colour + 20%. For the resistor shown in ***Figure 4.13.3***, the colour band and code are as follows

1st Colour band, Brown; first significant digit of Brown from ***Table 4.13.1*** = 1
2nd Colour band, Black; second significant digit of Black = 0

3rd Colour band, Red; third significant digit Red from Table 1 = 2 (two zeros). The third significant digit is a multiplier, the number of zeros to be added to the first two digits.

4th Colour band, Gold, is the tolerance, + 5%. This defines the upper and lower limits of its resistance.

The Resistor Colour Code system is all well and good, but we need to understand how to apply it to get the correct value of the resistor. The "left-hand" or the most significant coloured band is the band which is nearest to a connecting lead, with the colour-coded bands being read from left to right as follows.

Digit, Digit, Multiplier = Colour, Colour × 10 colour in Ohm's (Ω)

Example 1

Determining the resistance value of the resistor in ***Figure 4.13.3*** using ***Table 4.13.1***

The value of the resistance is 1000 Ω + 5% or 1.0×103 Ω + 5%.

The maximum resistance is 1000 + 50 = 1050 Ω (Upper limit)

The minimum resistance is 1000 – 50 = 950 Ω (Lower limit)

The resistance lies between 1050 Ω and 950 Ω.

4. **Wire Wound Resistor**: This resistor has a ceramic body with a resistance wire wound on it. The wire is coated with Bakelite enamel, a heat-resistant insulating material, to repel the effect of ambient temperature variation on the resistance. High resistance values use wire of low conductivity with many turns of fine gauge wire.

   Different sizes and ratings of wire-wound resistors are easily obtained by using different lengths and diameters of the wire. The higher the rating, the smaller the physical size of the wire. Precision wire-wound resistors are used in measuring equipment such as resistance boxes and shunts of measuring instruments. They are not suitable for limited space and radio frequency applications, but are used for high-power applications.

Figure 4.13.4: *Resistors – wire wound, fixed wire wound and variable wire wound*

5. **Thermistor**: The thermistor is a thermally sensitive resistor, or a temperature sensor. Its resistance changes inversely with temperature. It is made of a semiconducting material. It makes use of the fact that increasing the temperature rapidly decreases the sensitivity of semiconductors. Increasing temperature generates more carriers by thermally shaking electrons loose from host atoms and consequently decreases the resistivity of the material. Its relatively large resistance change per degree change in temperature (called sensitivity) makes it an obvious choice as a temperature **transducer.**

Figure 4.13.5: *Pictures of a thermistor*

Applications

1. Temperature sensing circuits.
2. Liquid Level detectors.
3. Time delay circuits
4. Surge suppression circuits.
6. **Light Dependent Resistor (LDR)**: It is a resistor made of a semiconducting material that changes its resistance in response to the intensity of light falling on it. The LDR offers low resistance when light falls on it and high resistance in the dark.

Figure 4.13.6: *A picture of Light light-dependent resistor*

7. **Non-Linear Resistor or Varistor**: A varistor is a voltage-variable resistor or a voltage–dependent resistor. When the voltage across a varistor exceeds a given value, there is a sharp decrease in resistance. Varistors are used to:
   a. Protect power supplies and power switching circuits.
   b. Protect telephone and data communication lines.

   It is popular for having a non-linear (non-uniform) voltage-current (V-I) characteristics.

***Figure 4.13.7**: Picture of a Varistor*

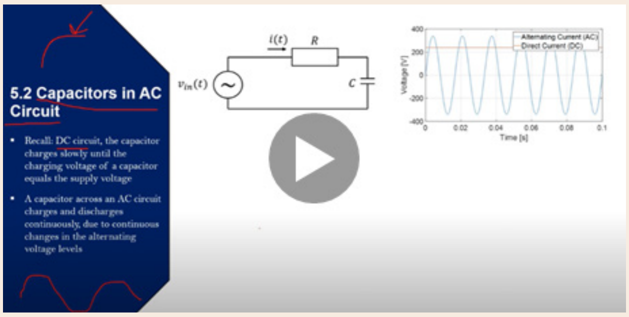
Activity 4.13.1 Understanding the concept of passive electronic components (resistors)

Aim: This activity will help you understand the purpose of **resistors** in electronic circuits and how to read their values using the **colour code** system.

Task 1: The Basics of Resistors

Watch the provided video on resistor types and colour codes. Alternatively, refer to the picture below if you are unable to access the video link and answer the questions in Task 2.

Link: https://youtu.be/c_wzzB61nAg?si=i4O5pQHgF9NYAgnG



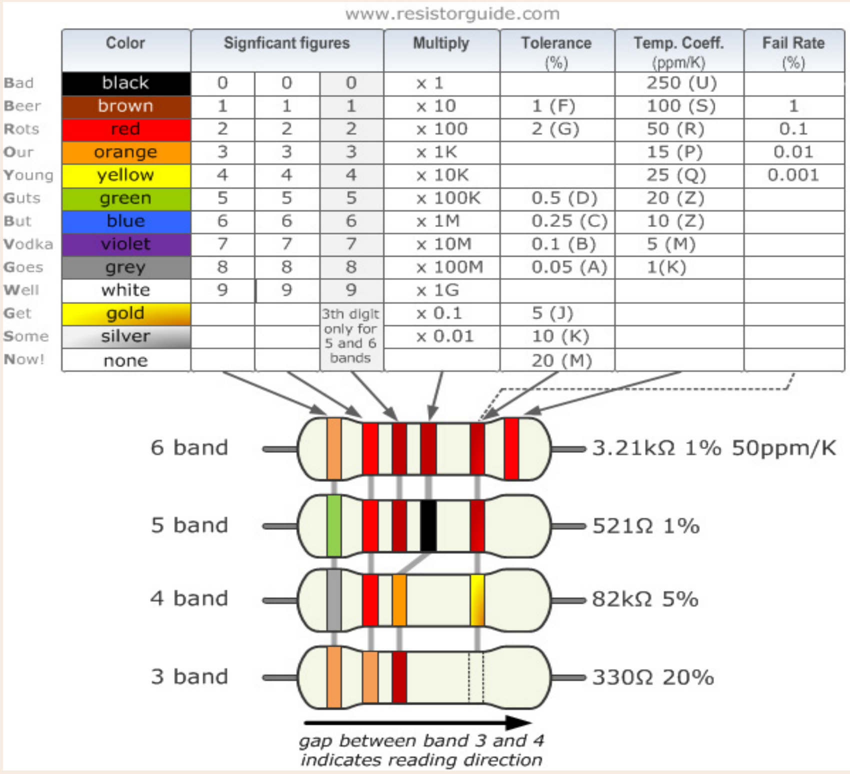
1. While watching, pay close attention to the terms and definitions used.
2. In your notebook, write down a clear definition for the following terms:
   a. **Passive Electronic Components**
   b. **Resistor**

Task 2: Resistor Types and Values

1. In the video or from the image below, identify the main types of resistors that are shown.
2. Make a list of the main resistor types and briefly describe their differences.
3. Using the colour code chart from the video or image, explain how to calculate the value of a resistor based on its coloured bands.

Task 3: Practical Application

1. Your teacher will provide you with a few different resistors.
2. Partner with a friend and use the colour code system to determine the value and tolerance of each resistor.
3. Write down your findings and share them with another pair to check if your calculations are correct.



www.resistorguide.com

	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)		

Task 4: Functions of Resistors

1. With 2 of your classmates, make a list of resistor functions.
2. Summarise your findings on a flipchart or poster. *Use the summary table below as a template.*
3. Compare with other groups' lists and add missing points.

Types of resistors

Type of Resistor	Description	Application Example	Advantage
Carbon Resistor			
Wire Wound Resistor			
Metal Oxide Resistor			
Variable Resistor			

Activity 4.13.2 Case Study Challenge

A technician wants to build a power supply circuit. He has carbon resistors available in different values, but needs a **4.7 kΩ** resistor.

1. Suggest how he can identify the correct resistor using colour codes.
2. List two possible mistakes he should avoid when selecting resistors.
3. Justify why using the correct resistor value is important.

EXTENDED READING

- D.C. Kulshreshtha (2008), Electronic Devices and Circuits, New Age International (P) Ltd, Publishers. New Delhi-110002
- E.C. Sraha (2016); Applied Electricity and Electronics for SHTS. Books Galore Ventures, Koforidua.
- Resistor: Functions, Types, Uses, and How to Choose the Right One | Cytech Systems

Review Questions

1. Identify the following resistor types

a. 
b. 
c. 

2. What is meant by the tolerance of a resistor?
3. What are the colour bands in sequence according to this rhyme:
4. Bill Brown Realised Only Yesterday Good Boys Perform Good Work
5. What are the resistance values of the following resistors?
   a. Brown – Black – Black
   b. Red – Violet – Black
   c. Brown – Black – Red

CAPACITORS AND CELLS

Introduction

Capacitors, as essential components in electronics, are designed to store and manage electrical energy. As passive components, capacitors do not require an external power source to operate, but store energy in the form of an electric field, and allow for rapid energy transfer over short durations. Their versatility makes them invaluable in tasks like energy storage, signal filtering, and frequency tuning in electronic circuits and are a cornerstone of both analogue and digital technologies with a wide range of practical functionalities.

KEY IDEAS

- Capacitors are essential as passive components in a circuit
- Different types of capacitors perform specific functions in electrical circuits.
- Capacitors are designed with specific constructions that enable them to perform their intended functions effectively.
- The arrangement of capacitors is crucial for effectively storing and managing electrical energy.

CONSTRUCTION OF CAPACITORS

Structurally, a capacitor consists of two conductive plates separated by an insulating material called a dielectric. The dielectric prevents direct contact between the plates and enhances the capacitor's ability to store charge. The conducting plates may be made in the form of either circular, rectangular or cylindrical shape. Capacitors are classified according to their dielectric, such as paper, mica, ceramic, electrolyte, etc.

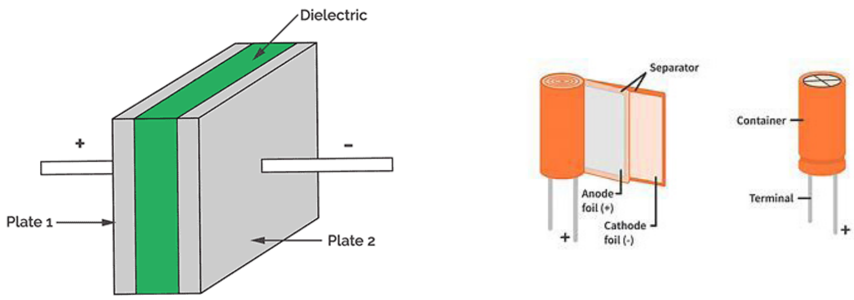


***Figure 4.14.1**: Pictures showing the structure of a capacitor*

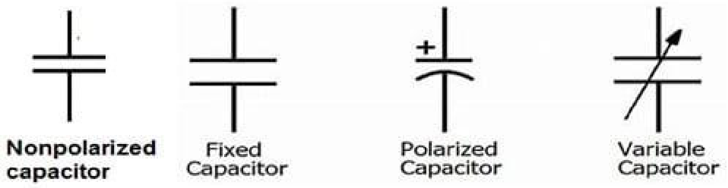


Figure 4.14.2*: Various capacitor symbols*

Principle of a Capacitor

When voltage is applied across the plates of a capacitor, an electric charge accumulates and creates an electric field between the plates. The primary characteristic of a capacitor is its capacitance, the property by which a capacitor accumulates (holds) charges when a potential difference is applied to it. Capacitance is expressed in Farads (**F**), the charge is denoted by **Q**, and is measured in coulombs, **C**. A conductor charges when a voltage source **V**, is connected to it. This charge, **Q**, is proportional to the applied voltage.

That is: $Q \propto V$

Therefore, $Q = kV$.

Where the constant k, is the capacitance C, of the conductor.

Therefore, $Q = CV$ and

$C = Q/V$.

From the relation above, the capacitance of a capacitor is;

- Directly proportional to the permittivity of the dielectric, $\mathcal{E}$
- Directly proportional to the area of the plate, **A**
- Inversely proportional to the distance between the plates, **d**.

This means;

- The larger the area of the plates, the more charge they can store.
- If the distance **d** increases, capacitance reduces, and if **d** decreases, capacitance increases.
- The capacitance will increase depending on the type of dielectric material used.

Specifications of Capacitors

All capacitors also have a maximum working voltage rating. Capacitors may be specified in terms of the following

1. ***Capacitance Value:*** The amount of charge the capacitor can store.
2. ***Voltage Rating:*** This is the maximum voltage the capacitor can handle without breaking. If the voltage rating is exceeded, it can break down.

3. ***Dielectric Strength:*** The maximum potential difference that a unit thickness of the medium can withstand without breaking down. Its value depends on factors such as the thickness, temperature, moisture and shape of the insulating medium.
4. ***Dielectric Constant:*** The permittivity, $\mathcal{E}$, of the insulating material, a characteristic of an insulator that allows electric flux to pass through it.
5. ***Temperature Coefficient:*** The **Temperature Coefficient** of a capacitor is the maximum change in its capacitance over a specified temperature range.
6. ***Frequency Range:*** The frequency range is the maximum frequency up to which the capacitor can work safely.
7. ***Power Factor:*** Power factor indicates the minimum loss in the capacitor. It states the fraction of input power dissipated as heat loss in the capacitor. Therefore, the quality of the capacitor depends on how low the power factor is. This is because the reciprocal of the power factor is the quality factor (**Q**) of the capacitor.

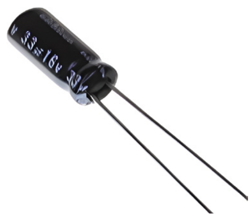
   For instance, if the power factor is 0.0001,

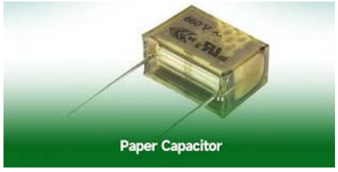
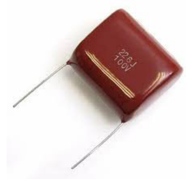
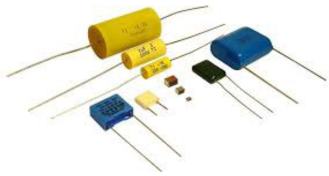
   then the quality factor (**Q**) is the reciprocal of 0.0001.

   So, Q = 1/0.0001 90 = 10000.

   Thus, the lower the power factor, the higher the quality factor, hence, the better the quality of the capacitor.

Types of Capacitors

Name of capacitor	Image(s)
1. Fixed Capacitor	
2. Mica Capacitor	
3. Ceramic Capacitor	

4. Paper Capacitor	
5. Plastic Capacitor	
6. Electrolytic Capacitors	
7. Film capacitors	
8. Adjustable Capacitors or Variable Capacitors	

Classification of Capacitors

Capacitors are classified according to structure or polarisation.

1. **Structure**
   a. **Fixed Capacitors:** These have a set capacitance value that does not change.
   b. **Variable Capacitors:** A capacitor in which the value is mechanically adjusted.
   c. **Trimmer Capacitors:** A small-value variable capacitor used for fine adjustment of a circuit. It is used in tracking the frequency of an oscillator.
2. **Polarisation**
   a. **Polarised Capacitors:** In these capacitors, the positive terminal is connected to the positive side of the battery; otherwise, the layer of

the insulator will be removed and the capacitor will cease to function. They are also called electrolytic capacitors and are needed for large capacitance. Polarised capacitors are also used on non-reversing supplies and must always be correctly connected into the circuit.

b. **Non-polarised Capacitors:** These capacitors have reversible polarity; they do not have fixed positive or negative terminals.

Uses of Capacitors

Capacitors are used for the following.

1. **Storing energy:** Capacitors can store electrical energy for later use.
2. **Smoothing Voltage:** They help smooth out the voltage in D.C power supplies.
3. **Coupling circuits:** Capacitors can connect two circuits together.
4. **D.C blocking:** It blocks D.C signals and allows A.C. signals to flow.
5. **Voltage multiplying circuits:** Produces voltage much higher than the supply voltage in certain applications.
6. Short-circuiting signals at switch contacts to prevent arcing.
7. Discriminating between frequencies or filtering
8. Detonation of nuclear weapons.

Values of Capacitors Using Colour Codes

The value of a capacitor is usually printed on its frame in microfarads (**μF**), but for a colour-coded capacitor, the value is designated with colour bands on the frame. The colour code chart is shown in ***Table 4.2***.

Table 4.2: Capacitor colour code

Band Color	1st Digit	2nd Digit	Multiplier	Tolerance (%)		Temperature Coefficient
				Above 10pf	Below 10pf	
BLACK	0	0	1	± 20%	± 2.0pF	0
BROWN	1	1	10	± 1%	± 0.1pF	-30
RED	2	2	100	± 2%	± 0.25pF	-80
ORANGE	3	3	1,000	± 3%	–	-150
YELLOW	4	4	10,000	± 4%	–	-220
GREEN	5	5	100,000	± 5%	± 0.5pF	-330
BLUE	6	6	1,000,000	± 6%	–	-470
VIOLET	7	7	–	± 7%	–	-750
GREY	8	8	0.01	+80%,-20%	± 0.25pF	+30
WHITE	9	9	0.1	± 10%	± 1.0pF	+120-750
GOLD	–	–	0.1	± 5%	–	–
SILVER	–	–	0.01	± 10%	–	–

How to Read Capacitor Values

Read the values or letters

Every capacitor has a special marking printed on its body. The marking represents the value of the capacitor. There are different types of capacitors and each has its specified capacitance value, voltage rating, temperature range, tolerance and life time. However, most of the capacitors have their value and their voltage printed on their body.

Look for Voltage Rating

The D.C voltage rating of a capacitor plays a major role in determining how strong the capacitor's insulation is. The voltage rating of a capacitor tells the ability of the capacitor to withstand high or low voltages when applied across its terminals. This feature may help you not to burn up your circuit.

Look for Tolerance Values

Tolerance of a capacitor shows the how much percentage the capacitance varies with respect to temperature. The tolerance value of the capacitor ranges from ±0.1 pF to 10%. The best tolerance is the lowest percentage one. As the tolerance value increases, the precision or rate of change of capacitance increases.

Look for (+), (-) signs

The sign or marking (+ or -) tells the polarity of the capacitor is positive or negative. Most of the time, leaded capacitors have + or -, while chip or ceramic capacitors have no marking. The colour coding on a capacitor indicates its value, voltage, and tolerance.

How to read it is as follows;

- **a.** First band is the first digit on the colour chart
- **b.** The second band is the second digit
- **c.** The third band is the multiplier
- **d.** The fourth band is the tolerance of the capacitor.
- **e.** The fifth band is the working voltage of the capacitor.

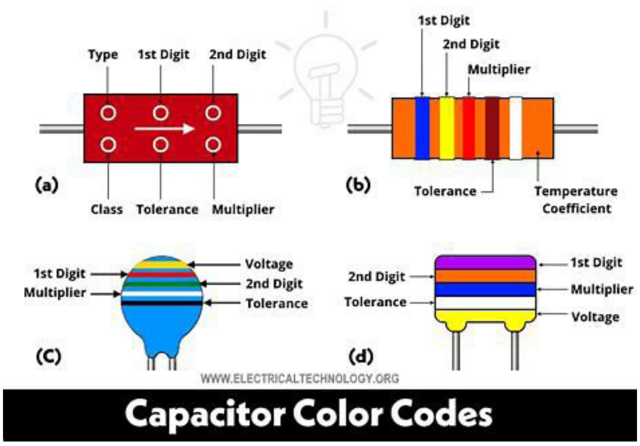


***Figure 4.14.3**: Capacitors colour codes*

Capacitors in Series

Capacitors in series are indeed connected one after the other, but it is not necessarily in a "loop." They are connected end-to-end.

Total Capacitance (**CT**) for capacitors in series is given by the formula:

This means that the total capacitance is less than the smallest individual capacitance in the circuit, which is correct.

Where **C1**, **C2** and **C3**are the individual capacitances of the capacitors.

Capacitors in Parallel

When capacitors are connected in parallel, the same potential difference (voltage) develops across all the capacitors. Total capacitance is equal to the sum of all individual capacitances and is expressed as: **CT = C1 + C2 + C3**

Where **C1**, **C2** and **C3** are the individual capacitances of the capacitors.

The Advantages and Disadvantages of Capacitors

Capacitors are electrical components used in a variety of electrical and electronic circuits, systems, and pieces of machinery for several different purposes. Like any electrical component, capacitors come with their own benefits and drawbacks.

Advantages of Capacitors

Capacitors are used in most systems and electrical circuits, and they have many benefits and useful features. The advantages of capacitors are discussed below.

1. **They can store energy fast**

   When a voltage is applied to a capacitor, it starts storing the charge instantly. This is useful in applications where speed is key. The amount of time it takes to fully charge the capacitor depends on its type and how much voltage it can store.

2. **Stored energy is released quickly**

   When a capacitor is fully charged, it holds energy, which we call stored energy. The stored energy in the capacitor can be delivered quickly to the component or point in the circuit where it is needed. As soon as the power source drops off, the capacitor will deliver voltage from itself.

3. **Losses are low**

   Capacitors have relatively low losses and are generally electrically efficient components when used in the correct applications under the correct conditions.

4. **No maintenance required**

   Capacitors require no maintenance when they are functioning in an electrical circuit. Only a visual inspection may be done every now and then to check the condition of the capacitor and its surroundings.

5. **Long service life**

   Capacitors have long service lives when they are used in the correct applications and in the correct environment. Environmental factors such as water, oil, and dust should be kept away from capacitors, as exposure can greatly reduce their service lives.

6. **Method of operation**

   Capacitors have a simple way of working as they store electrical energy between two plates. When the energy reaches a certain level, we consider the capacitor fully charged and ready to supply voltage.

7. **Work with A.C. and D.C**

   Capacitors can operate in both A.C. and D.C electrical circuits. They should not be interchanged, and you should always check the specifications of a capacitor before fitting it into an electrical circuit.

9. **Relatively cheap components**

   Capacitors are relatively low-cost and cheap components. Unless they are specialised and designed for a specific electrical circuit or system, they are low-cost and cheap to replace.

10. **Can be used for a wide range of applications**

    Capacitors come in a variety of different types, sizes, and operating voltage ranges. This means they are used in a wide variety of applications that include supplying power and assisting electrical motors when starting.

Disadvantages of Capacitors

The disadvantages of using capacitors are as follows:

1. **Less Capacity When Compared to Batteries:** Capacitors have a much lower energy capacity when compared to batteries. This is why batteries are used in applications that will need to supply energy for a longer period. Capacitors are generally used in applications where they will supply energy for a few seconds or less.
2. **Limited Energy Storage:** Capacitors only have a limited amount of storage. When a capacitor is fully charged, it cannot take any more energy, and the excess voltage is wasted.
3. **Stored Energy Eventually Depletes:** Capacitors cannot store charges for long periods of time. Once a capacitor holds energy for long periods of time, the level of voltage will start to drop. This is due to the characteristics of the capacitor and the materials that are used in its construction.
4. **Stored Voltage Level Can Vary:** The level of stored voltage in a capacitor can vary. What we mean by this is that the amount of energy in a capacitor is not fixed. If voltage is applied to a capacitor for a period of time, it may not be enough to charge it to its full level of charge. The voltage then that

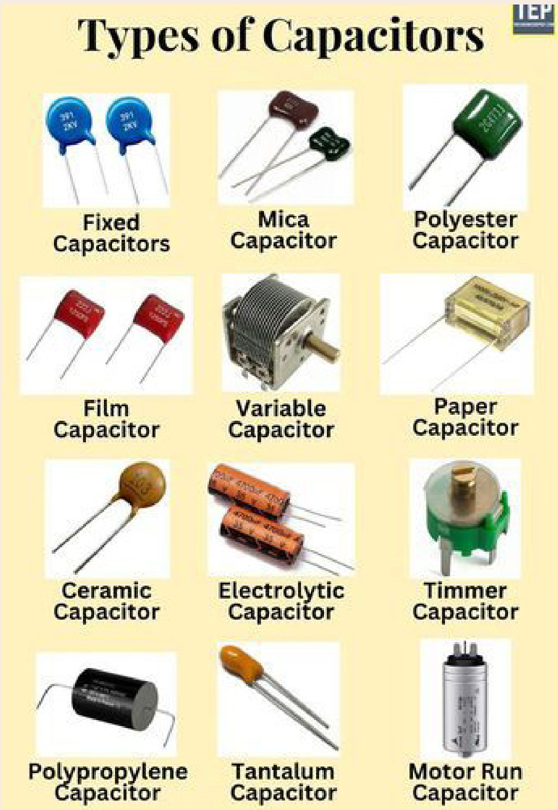
is supplied by the capacitor is then lower than its maximum and intended voltage. This is why we do not use low-cost capacitors in applications that require high levels of accuracy. Specialised capacitors are used in circuits that require high accuracy as they are charged faster and supply accurate levels of voltage.

Activity 4.14.1 Understanding Capacitors – The basics and beyond

This project-based activity will turn your classroom into an electronics repair shop. You'll work in teams to become experts on capacitors—how they work, their different types, and their role in common electronic devices.

Task 1: Understanding Capacitors

1. Examine the capacitors provided by your teacher or look at the image below.
2. Discuss with your team what you notice about their physical appearance, like their shape, size, and markings.
3. Based on your observations and what you already know, discuss and write down what you think a capacitor is and what its basic function is in a circuit.



Task 2: Types and Applications

1. Research the main types of capacitors, such as electrolytic, ceramic, and film capacitors. For each type, make note of its key characteristics and a real-world application (e.g., in a radio or phone charger).

2. Your team should create a small presentation or a poster that explains the different types of capacitors you researched and where they are used.

Task 3: *Capacitors in a Circuit*

1. Study the provided circuit diagrams and research how capacitors are represented. Draw a simple circuit that includes a capacitor and explain its role in that circuit.
2. Practice calculating the total capacitance of capacitors connected in both **series** and **parallel** circuits to build your practical problem-solving skills.

Task 4: *Safety in Handling Capacitors*

1. Still in your teams, discuss the potential hazards of working with capacitors, especially those that may hold a charge even after the power is turned off.
2. Based on your research, create a safety checklist (*see checklist below*) that outlines the key precautions you must take when handling and discharging capacitors in a workshop setting.

Safety in Handling Capacitors: Identify correct and incorrect safety practices. Use ☑ for correct and ✕ for wrong.
☐ Always discharge capacitors before handling.
☐ Touch capacitor leads immediately after removing from a live circuit; they are always safe.
☐ Use insulated tools when testing capacitors.
☐ Replace faulty capacitors with the correct specifications.
☐ It is fine to use a capacitor with a lower voltage rating if it fits.
☐ Store capacitors in a dry place away from heat.

Activity 4.14.2 Case Study Challenge

A solar technician wants to repair an inverter but must replace a **1000 μF, 25 V electrolytic capacitor**. The shop only has **1000 μF, 16 V** and **470 μF, 25 V** capacitors.

1. Which option(s) are wrong and why?
2. Suggest the correct action the technician should take.
3. Explain why using the wrong capacitor can damage the circuit.

Reflection

Use the questions below to reflect on what you've learned about capacitors. Write your answers in your notebook or on a worksheet.

a. **What I learned:** Write down the most important things you learned about capacitors and their functions in electronics.

b. **Circuit Diagrams:** Which circuit diagram did you find the most difficult to understand? Describe how you were able to clarify it.

c. **Community Impact:** How can you use your new knowledge about capacitors to help repair or build electronic devices in your community?

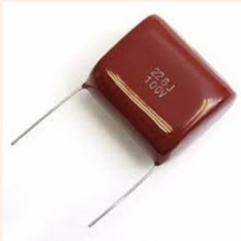
EXTENDED READING

- E.C Sraha (2016).Applied Electricity and Electronics for SHTS. Books Galore Ventures, Koforidua.
- Edward Hughes. Electrical Technology, London: Oxford Publishers Ltd.
- https://www.youtube.com/watch?v=ucEiEic-kZ4
- https://en.wikipedia.org/wiki/File:Capacitors_(7189597135).jpg
- Capacitor: Construction, Working Principle, Circuit & Its Applications (watelectrical.com)

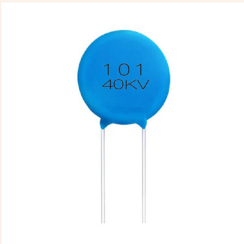
Review Questions

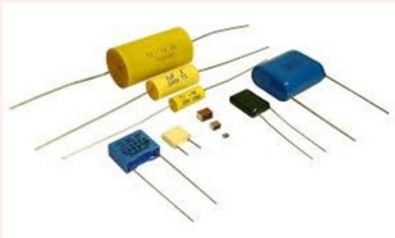
1. Determine the values of a capacitor with the following colour bands: Orange, orange, red, Gold, red.
2. Identify the following capacitors

a. 

b. 

c. 

d. 

e. 

UNIT 15

PASSIVE ELECTRONIC COMPONENTS (INDUCTORS)

Introduction

An inductor is a passive electronic component, or a coil of wire, that does not require an external power source to operate but stores electrical energy in its magnetic field. An inductor not only stores energy in its magnetic field when electric current flows through, but also controls current flow in a circuit. The cell is a chemically powered generator. Greater energy is obtained when two or more cells are joined in series, that is, the positive terminal of one cell connected to the negative terminal of the next cell to form a battery.

KEY IDEAS

- Inductors are passive electronic components that store energy in a magnetic field when an electric current flows through them.
- Inductors play many significant roles in an electronic circuit
- A cell is a device that converts chemical energy into electrical energy

INDUCTORS

An inductor is a coil of insulated wire with a core of air or a magnetic material that stores energy in a magnetic field when an electric current flows through it. An inductor has a property that opposes changing current.

Types of Inductors

The following are various types of inductors that are usually used in electrical and electronics circuits

1. **Iron-Core Inductors**

   Iron-core inductor (coil) has the central part made of ferromagnetic material such as iron or steel. In a current-carrying coil (inductor) with an iron core, the iron becomes magnetised, and the strength of the magnetic field is several times greater than the magnetic field due to the coil alone. It is suitable for low-frequency applications such as fluorescent lamps and smoothing chokes to control alternating current (a.c).

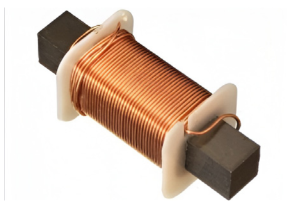


***Figure 4.15.1**: Iron-core inductor*

2. **Air-Core Inductors**

The air-core inductor (coil) has the central part freely filled with air. The opposition offered (reactance) is large to high frequencies but small to low frequencies. This property enables them to separate high-frequency signals from low-frequency signals.

***Figure 4.15.2**: Air-core Inductor*

3. **Choke Inductors**

Choke inductors are specially designed to block or "choke" high-frequency signals while allowing low-frequency signals to pass through. They are commonly used in power supply circuits and filtering applications to subdue noise and prevent high-frequency interference in electronic devices.

***Figure 4.15.3**: choke inductor*

4. **Toroidal Inductor**

A toroidal inductor is a coil wound around a ring-shaped ferromagnetic core. A toroidal inductor is used in circuits requiring high inductance and efficiency.

***Figure 4.15.4**: Toroidal Inductor*

Functions of Inductor

Inductors play a significant role in an electronic circuit, such as:

1. Developing an electromotive force in the direction that reduces instability when an unstable current flows.
2. Storing electric energy as magnetic energy.

3. Allowing direct current to flow easily while presenting high resistance against the flow of high-frequency currents.
4. Controlling signals.
5. Matching impedance in a high-frequency circuit
6. Stabilising voltage in a power circuit (smoothing)

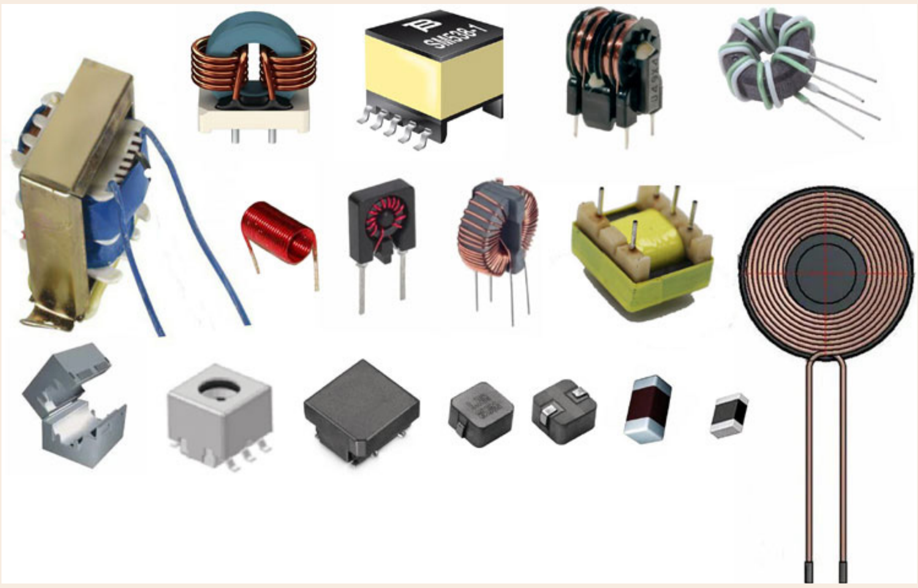
Activity 4.15.1 Understanding Inductors

Read the scenario, examine the pictures below (pay attention to their shape, size, and materials used)and answer the questions that follow either individually or with a partner.

Scenario

An electronics repair shop in your community is busy fixing common household devices, including radios, power supplies, and filters. The technicians have noticed that a lot of the problems they're seeing are due to faulty **inductors**.

As a team of future electrical technicians, your job is to figure out why these components are so important. You need to identify what inductors are, their different types, and how they function in a circuit. This practical knowledge will help you diagnose and fix common problems, preparing you for a career in electronics.



1. Based on the scenario and your observations, discuss and write down a definition for the following:
   a. What is an inductor?
   b. What are the common types of inductors?
   c. How do inductors function in circuits?

Activity 4.15.2 Types of Inductors

1. Work in a small group with two classmates to study pictures of inductors. If possible, get inductors from different devices around you or in the school electrical lab, if there is any.
2. Discuss their construction: air core, iron core, toroidal, variable.
3. Create a table in your notebook showing type, description, and use. Sample shown below.

Type of Inductor	Description	Common Use
Air Core Inductor		
Iron Core Inductor		
Toroidal Inductor		
Variable Inductor		

4. Still in your group, each member should examine pictures of circuits containing inductors, filters, transformers, tuning circuits, and energy storage.
5. Discuss the role of inductors in each case.
6. Record and share your answers with another group or with the entire class.

CELLS AND BATTERIES

Construction of a Cell

A cell is a device that changes chemical energy into electrical energy. The cell consists of the following.

1. **Electrolyte:** A compound which, when fused or dissolved in water, conducts an electric current and is decomposed in the process.
2. **Electrodes:** Metal or carbon rods by which the current enters or leaves the electrolyte.
3. Anode(+) is the electrode from which the electrons leave the electrolyte.
4. The cathode(-)is the electrode at which the electrons enter the electrolyte.

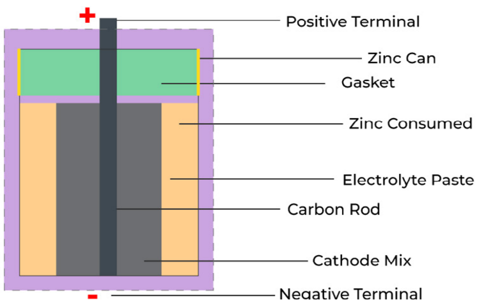


Figure 4.15.5: The makeup of a cell

Production of electricity in a cell

Chemical reaction causes e.m.f to appear between the electrodes, and when connected to an appliance by a conductor, current flows.

Difference between a cell and a battery

A cell is a single device that converts chemical energy into electrical energy, while a battery is a collection of cells that provides a steady source of electrical energy. A battery provides a higher voltage and more energy than a single cell

Types of Cells

The two types of cells are ***primary cells*** (non-chargeable cells) and ***secondary cells*** (rechargeable)

Primary Cell

1. Primary Cell is a type of electrochemical cell that is designed to be used once and disposed of or discarded after its useful life.
2. It lacks fluid inside and is hence referred to as a Dry cell.
3. It has a mechanism of an irreversible chemical reaction, and due to their high charge density, they discharge slowly.
4. A primary cell is not rechargeable and cannot be restored to its original charge once it has been depleted.
5. Primary cells are used in a wide range of applications, including portable electronic devices, flashlights, and other devices that require a portable power source.
6. Some examples of primary cells include alkaline cells, zinc-carbon cells, and lithium primary cells.

Some examples of primary cells

1. Alkaline Cells
2. Carbon-Zinc Cells
3. Lithium Cells
4. Zinc-Carbon Cells

Secondary Cell

1. Secondary Cell, also known as a rechargeable cell, is a type of electrical cell that can be recharged and used multiple times.
2. Secondary Cells consist of wet molten ions, and they undergo reversible chemical reaction mechanisms.

3. A secondary cell can be recharged by running an electric current through it in the opposite direction of the current that is used to discharge it.
4. Common examples of secondary cells include lead-acid batteries, nickel-cadmium batteries, and lithium-ion batteries.
5. These types of cells are used in a wide range of applications, including powering portable electronic devices, vehicles, and backup power systems.

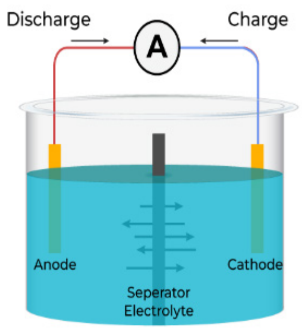


Figure 4.15.6*: A secondary or rechargeable cell*

Some examples of secondary cells

1. Lead-Acid Batteries (e.g. car batteries)
2. Nickel-Cadmium (NiCd) Batteries
3. Nickel-Metal Hydride (NiMH) Batteries
4. Lithium-Ion (Li-ion) Batteries

Difference between a Primary Cell and a Secondary Cell

Both types of cells are used extensively in various appliances, and these cells differ in size and the material used in them. A detailed difference between them is tabulated below:

Primary Cell	Secondary Cell
Primary cells are not rechargeable	Secondary cells can be recharged and used multiple times
Primary cells are typically made of non-rechargeable materials, such as zinc or carbon	Secondary cells are made of rechargeable materials like lead-acid or lithium-ion
Primary cells generally have a lower capacity than secondary cells	Secondary cells have a higher capacity than
Primary cells generally have a lower capacity than secondary cells	Secondary cells have a higher capacity than primary cells

Primary cells tend to have a lower voltage than secondary cells	Secondary cells tend to have a higher voltage than primary cells
Primary cells are designed to be used once and disposed of	Secondary cells can be recycled
Primary cells are typically smaller in size than secondary cells	Secondary cells are typically larger in size than primary cells
The cost of primary cells is lower than that of secondary cells.	Secondary cells are high expensive than primary cells
Primary cells are commonly used in portable electronic devices	Secondary cells are used in applications that require a long-lasting power source, such as electric vehicles

Advantages of Primary Cell and Secondary Cell

There are several advantages of Primary Cells.

1. They are convenient to use because they do not require any special charging equipment.
2. They are reliable because they are designed to be used only once, so there is less chance of failure due to wear and tear.
3. They are widely available and can be purchased at most stores that sell batteries.

There are also several advantages of Secondary Cells.

1. They are environmentally friendly because they can be recharged and used multiple times, reducing the need for disposable batteries.
2. They are cost-effective because they can be recharged and used multiple times, reducing the need to purchase new batteries.
3. They can be recharged quickly, making them convenient for use in devices that require a lot of power.

Disadvantages of Primary Cell and Secondary Cell

There are several disadvantages of Primary Cells

1. They are disposable, which can be wasteful and harmful to the environment.
2. They can be expensive in the long run because they need to be replaced frequently.
3. They may not provide as much power as secondary cells, especially for high-drain devices.

There are also several disadvantages to Secondary Cells

1. They require a charger, which can be inconvenient if you are on the go.

2. They can develop a "memory effect," which means that if they are not fully discharged before being recharged, their capacity can be reduced over time.
3. They may not last as long as primary cells, especially if they are not properly maintained.
4. They can be expensive to purchase initially, although they tend to be more cost-effective in the long run because they can be recharged and used

Battery

A battery is formed when a group of cells are connected to provide either a higher voltage or a higher current than that of a single cell. The total voltage in series is equal to the voltage of one cell multiplied by the number of cells.

The voltage $= 1.5 \times 6$

$= 9V$

The current, $I = 20mA$

Advantages and Disadvantages of Batteries

The main benefits and some disadvantages of batteries are mentioned below.

Advantages of batteries

1. They increase convenience for users since they enable the portability of devices.
2. Batteries can be used in places with no electrical supply, such as remote rural areas.
3. Batteries are easy to replace once they go beyond their useful lifespan.

Some disadvantages of batteries

1. They can only be used for a limited time.
2. Even rechargeable batteries eventually die.
3. Some batteries require maintenance and need to be checked periodically
4. Certain batteries are highly dangerous as they can explode, cause fire and lead to chemical pollution.
5. Rechargeable batteries take time to recharge, and this can be a big hindrance in case of an emergency.
6. In the case of larger equipment, batteries can increase their weight, and this is a disadvantage when there is a need to transport the equipment.

Factors affecting cell voltage

The voltage a cell produces depends on the types of electrodes and electrolyte present.

1. If the difference in reactivity between the electrodes is large, then the voltage of the cell will be high.
2. The type of electrolyte equally affects cell voltage. This is because different ions react differently with the metal electrodes.

Cells in Series and in Parallel

The value of the voltage produced by cells depends on the number of cells, the voltage of each cell and the way they are connected, whether in series or parallel. If cells are connected in series, the total supply voltage will be the sum of the voltages of all the cells connected in the circuit. However, the total current will be the current of one cell. On the other hand, if cells are connected in parallel, the supply voltage will be the voltage of one cell but the total current will be the sum of the currents of all the cells connected in the circuit.

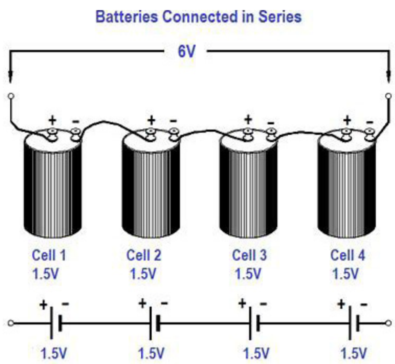


Figure 4.15.7: *Picture of cells connected in series*

Parallel connection of cells allows higher currents to be delivered. By connecting in parallel, the run time of the electrical device is increased.

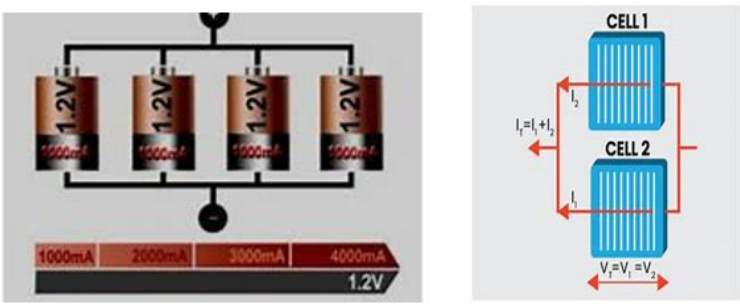


Figure 4.15.8: *Pictures of cells connected in parallel*

Example

A cell is rated 1.5V, 20mA. What will be the supply voltage and the total current if six of such cells are:

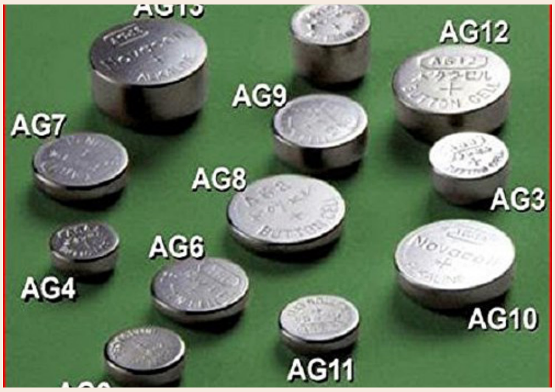
1. connected in series
2. connected in parallel

Solution

1. In series, the voltage = $1.5 \times 6 = 9V$ the current, I, = 20mA
2. In parallel, the voltage = 1.5V the current = $20mA \times 6 = 120mA$

Activity 4.15.2 Exploring Cells and Batteries

1. Observe the different types of batteries and cells shown in the images below. As you examine them, consider the following questions:
   a. What defines a cell, and how does it differ from a battery?
   b. How is a cell constructed?
   c. What process allows a cell to produce an electric current?
   d. What distinguishes primary cells from secondary cells?



Discussion

2. In pairs, discuss your understanding of the term “cell.”
3. Share and compare your ideas with another pair.
4. Summarise your group’s explanation in your notebook.

Activity 4.15.3 How a Cell Produces Current

1. Draw a labelled diagram of a simple cell, clearly indicating the electrolyte, positive electrode, and negative electrode.
2. Exchange your diagram with a classmate for review and corrections.

Activity 4.15.4 Constructing a Simple Cell

1. Using everyday materials such as a lemon, a copper coin, and a zinc nail, build a simple cell.
2. If available, measure the voltage of your cell using a multimeter.

3. Watch a demonstration—through video or your teacher—and follow the instructions carefully.
4. Work in small groups to construct your own simple cell.
5. Record your observations, including what worked well and the challenges you encountered.

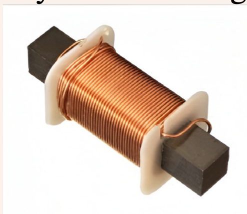
EXTENDED READING

- https://www.geeksforgeeks.org/difference-between-primary-cell-and-secondary-cell/#:~:text=Notes%20Class%2012-,Difference%20Between%20Primary%20Cell%20and%20Secondary%20Cell,but%20Secondary%20Cells%20are%20the%20ones%20that%20are%20rechargeable.%20Before%20learning,-about%20the%20detailed
- Click the links below to read more on cells and batteries

  https://unacademy.com/content/neet-ug/study-material/chemistry/cell-and-battery/

  https://byjus.com/jee/inductor/

REVIEW QUESTIONS

1. Identify the following types of inductors
   a. 
   b. 
   c. 
2. What is meant by the following terms?
   a. Impedance matching
   b. Oscillation
3. What is a cell in electrical and electronic system?
4. What is the difference between cells connected in series and cells connected in parallel
5. What is energy density, and why is it important in batteries?
6. Name four common applications of batteries.

UNIT 16

BIPOLAR JUNCTION TRANSISTOR

Introduction

The bipolar junction transistor is a three-layer, two-junction semiconductor device capable of controlling current. The concept of passing input current from a region of low resistance to a region of high resistance is referred to as a Transfer–Resistor (transistor).

KEY IDEAS

- Explaining what is meant by a bipolar junction transistor
- Understanding the formation of a Bipolar Junction Transistor (BJT)
- Identifying the main types of transistors found in electrical systems
- Explaining what is meant by biasing a bipolar Junction Transistor
- Outlining the advantages and disadvantages of a bipolar junction Transistor

THE CONSTRUCTION OF THE TRANSISTOR (BJT)

Formation of Bipolar Junction Transistor

1. The simplest and most common type of transistor is the bipolar junction transistor.
2. It is a semiconductor (solid state) component which has two PN junctions connected back-to-back and packaged in a single piece of semiconductor crystal.
3. In the BJT, conduction is due to electrons and holes, hence the name bi-polar.
4. The two junctions give rise to three regions with three leads called Emitter, Base and Collector.
5. The emitter is more heavily doped and supplies the majority charge carriers to the base.
6. The base forms the middle section; it is very thin and is the input control element.

7. The collector receives the majority charge carriers coming from the emitter and passing through the base.
8. The collector region is made physically larger than the emitter region because it must dissipate greater power. This difference makes it impossible to invert the transistor.

Types of Bipolar Junction Transistor

There are two types of transistors, namely NPN and PNP. The name is just a description of the type and arrangement of the semiconductor sections in the device.

NPN Transistor

In the NPN transistor, a very thin slice of P-type semiconductor is sandwiched between two thicker slabs of N-type semiconductor. There is an N-type section, a P-type section and then another N-type section.

One N-type section of the NPN transistor is identified as the emitter, which emits electrons. The P-type section in the middle is called the base. The other N-type section is the collector, which collects electrons.

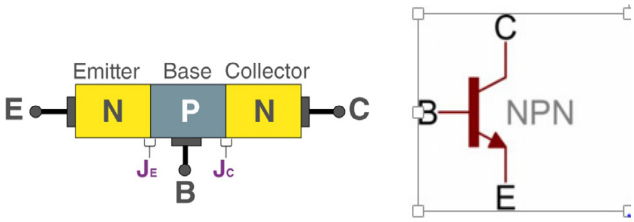


Figure 4.16.1: NPN transistor

PNP Transistor

In the PNP transistor, a thin slice of N-type semiconductor is sandwiched between two thicker slabs of P-type semiconductor.

One P-type section of the PNP transistor is also identified as the emitter, the middle N-type section is the base, and the other P-type section is known as the collector

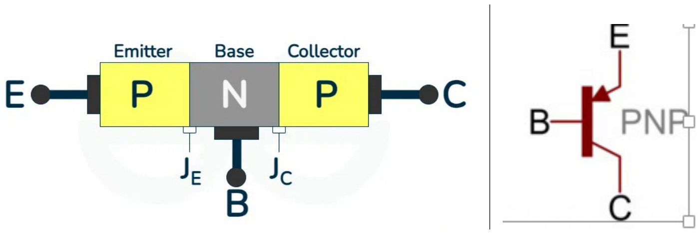


Figure 4.16.2: PNP transistor

The symbols of the NPN and PNP BJ transistors are shown below. Note that the arrow indicates the direction of current flow through the transistor and should be a guide when connecting the transistor in a circuit.

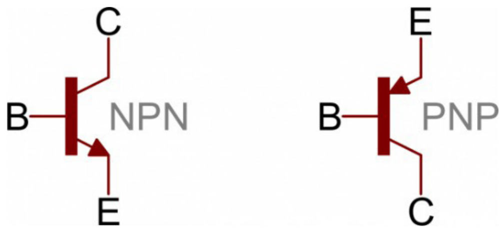


Figure 4.16.3: Direction of current flow

Transistor Biasing

To use the transistor for amplifying voltage or current or as control (ON or OFF) switching element, it is necessary to bias it. Transistor Biasing is setting the proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage (**VCE**) during the passage of a signal.

Direct current biasing deals with setting a fixed level of the currents **IB**, **Ic** and voltages **VBE** and **VCE**. The proper values of these currents and voltages allow a transistor to amplify weak signals faithfully.

1. **For normal operation of PNP transistor as an amplifier**

   a. The Emitter-Base junction is always forward biased; this means that a battery is connected to the transistor in such a way that the positive terminal of the battery is joined to the P-type Emitter for PNP and the negative terminal is connected to the N-type Base.

   b. The Collector–Base junction is always reversed; this implies that the positive terminal of the battery is joined to the N-type Base for PNP, and the negative terminal of the battery terminal is connected to the P-type Collector C

   c. Charges from the emitter cross the emitter-base junction into the base. Only small minority charges cross into the collector because it is reverse-biased.

   d. A large current flows through the emitter, but only a small current flows into the collector.

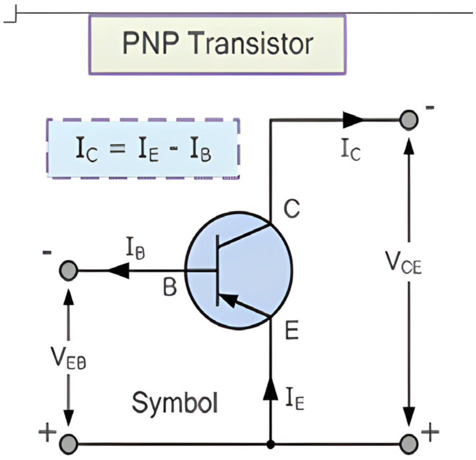


Figure 4.16.4: PNP Transistor

2. **For normal operation of NPN transistor as an amplifier**

   a. The Emitter-Base junction is always forward biased; this means that a battery is connected to the transistor in such a way that the negative terminal of the battery is joined to the N-type Emitter for NPN and the positive terminal is connected to the P-type Base.

   b. The Collector–Base junction is always reversed; this implies that the negative terminal of the battery is joined to the P-type Base for NPN and the positive terminal of the battery terminal is connected to the N-type Collector.

   c. Electrons defuse into the base from the emitter due to forward bias on the emitter-base junction.

   d. Under a strong attraction of the positive voltage on the collector, charges cross over to the collector-base junction and flow as current. A large current flows in the collector of the NPN transistor.

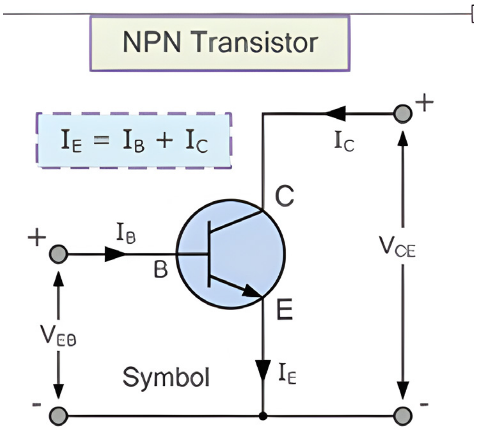


Figure 4.16.5: *NPN Transistor*

Single–Stage Common-Emitter Transistor Amplifier Circuit

It is an amplifier having one amplifying element connected in a common-emitter (CE) Configuration.

The resistors $\mathbf{R_1}$ and $\mathbf{R_2}$ provide the necessary bias $\mathbf{V_{BE}}$ for the base–emitter circuit. The Base-Emitter is then forward-biased, but the collector-base is reverse-biased.

The current $\mathbf{I_B}$ is regarded as the input current to the transistor, and $\mathbf{I_c}$ as the output current from it.

As a current amplifier, $\mathbf{I_c}$ is greater than I_B.

The current equation is $\mathbf{I_E = I_B + I_C}$

Where: $\mathbf{I_E}$ = emitter current

$\mathbf{I_B}$ = Base current

IC = Collector current

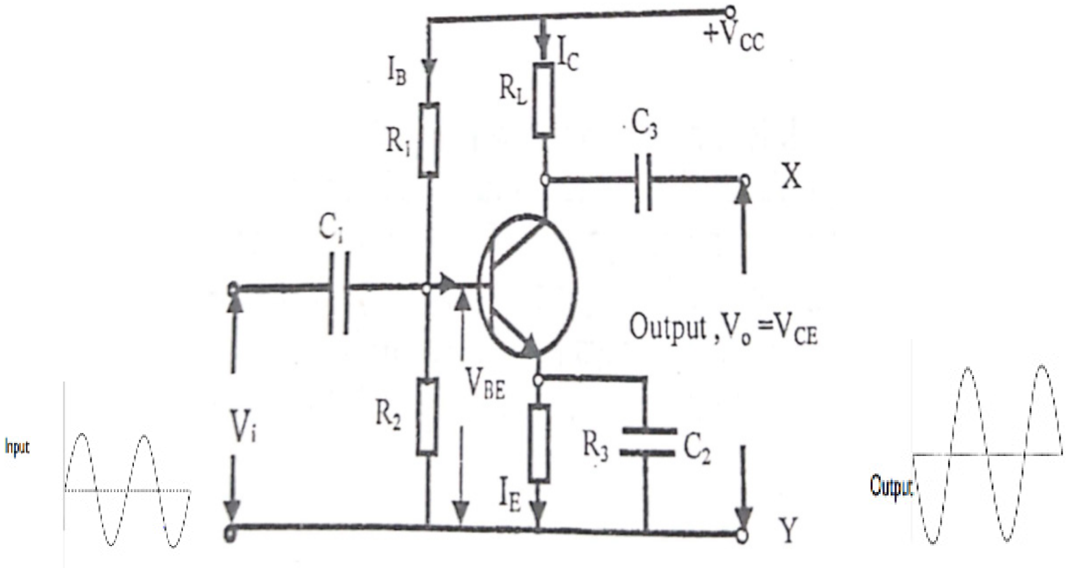


Figure 4.16.6: Single–stage common -emitter transistor amplifier with input and output waveforms

The Transistor as a switch

The transistor can be used as a solid-state switch. It has no moving parts or bouncing contacts; the average transistor can be switched at very fast rates of several MHz. To operate the transistor as a switch, it is either biased to be fully ON or OFF, ensuring that it is not biased anywhere in between these ON, OFF states.

The transistor acts as a switch when the base current IB turns on and controls the collector current, $\mathbf{I_C}$. If $\mathbf{I_B} = 0$, then $\mathbf{I_C} = 0$.

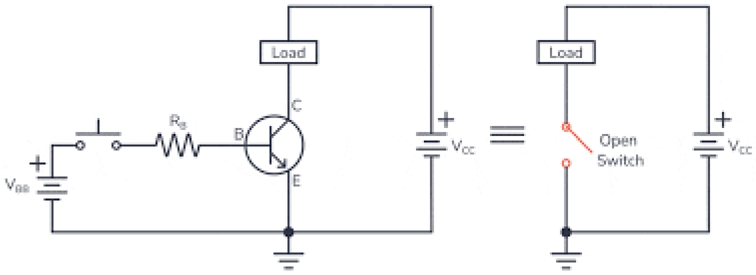


Figure 4.16.7: Transistor as a switch

Uses of the transistor

The transistor is used to/as

1. Boost or amplify electrical signals such as current or voltage.
2. Couple stages of an electronic circuit
3. A high-speed switch in electronic circuits
4. A current source (because it is a current device)
5. A linear circuit in radio, TV and communication circuits.

Advantages and Disadvantages of Bipolar Junction Transistor (BJT)

The advantages of the bipolar junction transistor (BJT)

1. The bipolar junction transistor (BJT) has a large gain bandwidth.
2. The BJT shows better performance at high frequency.
3. The BJT has a better voltage gain.
4. The BJT can be operated in low or high-power applications.
5. The BJT has high current density.
6. There is a low forward voltage drop.

The disadvantages of the bipolar junction transistor (BJT)

1. The bipolar junction transistor (BJT) produces more noise.
2. The BJTs are more affected by radiation.
3. BJT has a low thermal stability.
4. The switching frequency of the BJT is low.
5. It has a very complex base control. So, it may lead to confusion and requires skillful handling.

Activity 4.16.1 Understanding Bipolar Junction Transistors (BJTs)

Scenario

You are working on an electronics project in your school lab, where your class is asked to design simple amplifiers and switching circuits for a local radio repair shop. To complete this project, it's important to first understand what a transistor is, the construction details, the types of bipolar junction transistors (BJTs), and how they function in real-life circuits.

Questions

1. What is a transistor, and why is it important in electronic circuits?
2. How many main types of BJTs are there, and what distinguishes them?
3. Describe the construction of NPN and PNP transistors.
4. What are the main differences between the symbols for NPN and PNP transistors?
5. How do BJTs operate when used as switches and amplifiers?
6. What are some advantages and disadvantages of using BJTs?

Activity 4.16.2 Exploring Bipolar Junction Transistors (BJTs)

In a group with 4 of your classmates, do the following activities aimed at enabling you to understand BJTs and their everyday use.

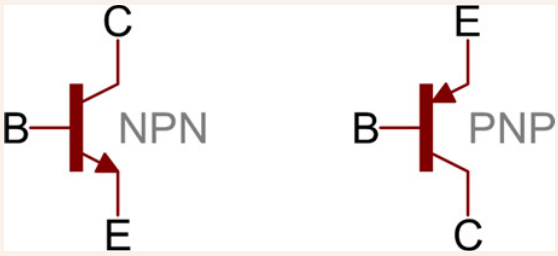
1. Discuss what a transistor is and list two functions it has in electronic circuits. During your discussion, consider the following points.
   - **a.** What materials are used to make a transistor (such as silicon or germanium).
   - **b.** The basic parts of a transistor: emitter, base, and collector.
   - **c.** How a transistor acts as an electronic switch and can also
   - **d.** Talk about how a transistor can be used to amplify signals.
   - **e.** Mention that transistors are very small and found in almost all electronic devices.
   - **f.** Think about why transistors are important in making circuits smaller and more reliable.
   - **g.** Share examples of where you might find transistors in real life (like computers, radios, or mobile phones).
2. Find out the various types of BJTs in everyday appliances and talk about how their layers and materials are arranged.
3. Draw diagrams showing how NPN and PNP transistors are built.
4. Look at the circuit symbols for NPN and PNP and make a simple chart to show the differences.
5. Draw a circuit with a BJT working as a switch, and another as an amplifier.
6. Share your findings and explanations with another group or the class.

EXTENDED READING

- John Watson (1989). Introductory Electricity and Electronics.
- E.C Sraha (2016).Applied Electricity and Electronics for SHTS. Books Galore Ventures Koforidua
- bipolar junction transistor bjt - Search
- https://byjus.com/jee/transistor/#:~:text=In%20simple%20words%2C%20we%20can%20say%20that%20a,of%20the%20electronic%20devices%20that%20are%20present%20today
- https://www.youtube.com/watch?v=J4oO7PT_nzQ

Review Questions

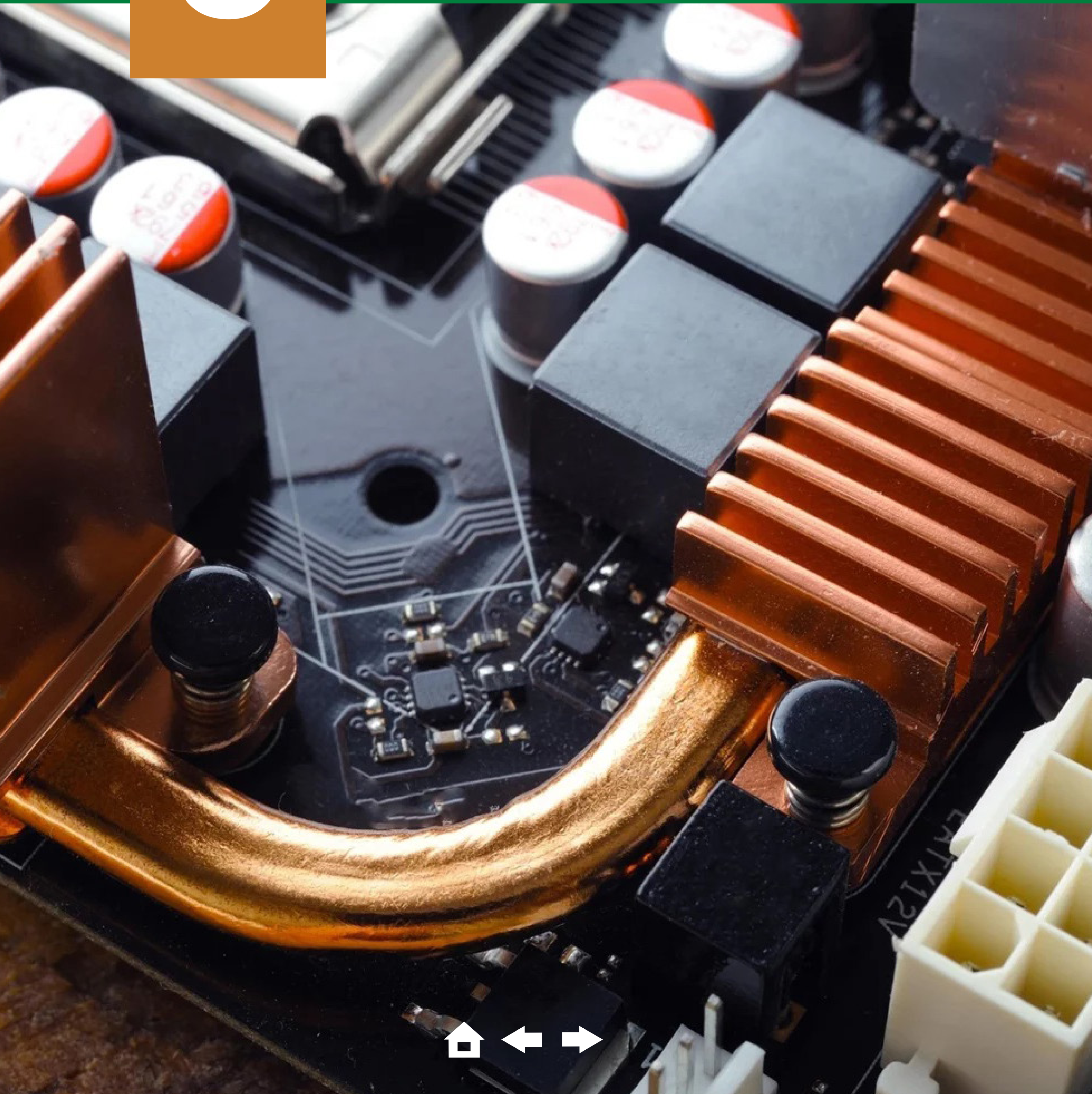
1. What do the letters E, C and B stand for in this diagram?



2. Give 4 applications of the BJ transistor.
3. Draw the diagram of the BJT as a switch and an amplifier, and explain how each works.

SECTION

5 TRANSISTORS



ELECTRICAL AND ELECTRONICS TECHNOLOGY

ELECTRONIC DEVICES AND CIRCUITS

THE PRINCIPLES OF OPERATION OF THE VARIOUS TRANSISTORS

Introduction

Section 5 covers Units 17 to 20. It includes the principles of operation of transistors, such as the bipolar junction transistor, the field-effect transistor and their applications. It also covers the effects of alternating current on resistors, inductors and capacitors in series a.c circuits. The control system unit, as part of electronic devices and circuits, is geared to exposure to the concept of control systems, types and the importance of applications of control systems in automation.

KEY IDEAS

- Understanding the principle of the Junction Field Effect Transistor
- Knowing the different types of the junction field effect transistor
- Understanding the Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
- Knowing the various applications of Field Effect Transistors

The junction field effect transistor is a transfer resistor in which current conduction is due to majority carriers only, either electrons or holes, **not** both. The junction field effect transistor is referred to as a **unipolar transistor** and a **voltage-controlled** device. The output current is controlled by an **electric field** created by the applied potential to the control terminal, hence the name “field effect transistor”.

FIELD EFFECT TRANSISTORS (FET)

The Field Effect Transistor (FET) is a three-terminal unipolar solid-state device. The current conduction is due to the majority carriers only, either electrons or holes, not both. The output current is controlled by an electric field created by the applied potential to the control terminal, hence the name “field effect transistor”. The conducting region is called the channel; either end of the conducting region is connected to the external potential through terminals called the ‘drain’ and the ‘source’.

The field effect transistor can be broadly divided into two main types.

1. Junction field effect transistor (JFET),
2. Metal oxide semiconductor field effect transistor (MOSFET).

Terminals of the Junction Field Effect Transistor

1. **Source:** It is a terminal through which majority carriers enter the bar.
2. **Drain:** It is the terminal through which majority charges leave the bar.
3. **Gate:** Is the terminal which controls the voltage
4. **Channel:** is the space between two gates through which majority carriers pass from source to drain when VDS is applied.

Operation

a. On the application of drain-source voltage (VDS) a drift of current along the channel called drain- current flows.

b. The channel conductivity is altered by varying the voltage at the control terminal called the “***gate***”.

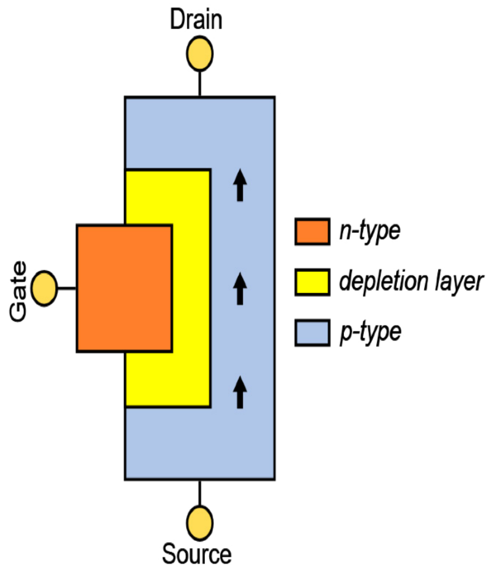


Figure 5.17.1*: Structure of the field effect transistor*

Types of the Junction Field Effect Transistor (JFET)

There are two types of Junction field effect transistor namely,

1. N- channel
2. P-channel

The N-channel has a bar of N-type silicon. In the N-channel of the JFET, the source terminal S is connected to the negative end of the drain voltage for supplying electrons. The terminals at the ends on the bar are called Drain (D) and source (S). Heavily doped P-regions are formed on the two sides, designated as P. The two P- regions are usually connected internally together to a common terminal called the gate (G). The region of N material between the two opposing P –regions is called the channel.

In the symbol of the N-channel JFET, the arrow on the gate is inward.

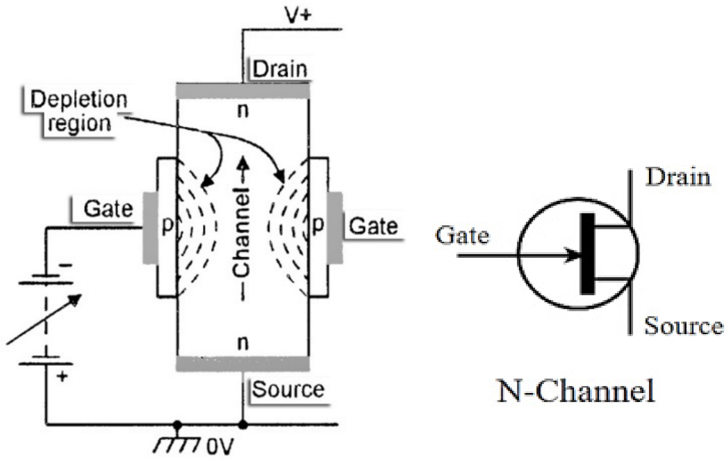


Figure 5.17.2*: N-channel JFET*

The P-type JFET

In the P-Channel, the source S, is connected to the positive end of the drain voltage supply for getting holes. In the p-channel, JFET, the bar is P-type, the gate is a heavily doped N-type

For the P-channel JFET symbol, the arrow on the gate is outward.

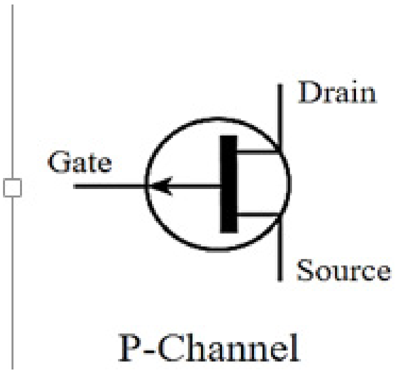


Figure 5.17.3*: P-channel JFET*

Metal- Oxide Semiconductor FETS (MOSFET)

1. The metal–oxide semiconductor Field Effect Transistor (MOSFET) is like the JFET.
2. The MOSFET has drain (D), source (S) and gate (G) terminals.

3. The channel conductivity of the MOSFET is controlled by gate-to-source voltage VGS.
4. The gate terminal of the MOSFET is electrically insulated from its channel, and this is why the gate current of MOSFET is extremely small.
5. The MOSFET is also either an N-channel or a P-channel type

Advantages of FETs

1. Small size
2. Long life
3. Low noise
4. High input impedance
5. High power gain
6. High frequency response
7. Better thermal stability.

Disadvantages of FETs

1. Small gain-bandwidth product
2. Greater susceptibility to damage in handling

Applications

The FET can be used in almost every application in which bipolar transistors are used. however, it has the following exclusive applications:

1. Input amplifiers in oscilloscopes, electronic voltmeters, etc.
2. Mixer operation of FM and TV receivers.
3. Voltage variable resistor in operational amplifiers and tone control.
4. Large-scale integration and computer memories.

Activity 5.17.1 Understanding Field Effect Transistors (FETs)

Read the scenario below and answer the questions that follow. Note down the responses and exchange your responses with a classmate for peer review.

Scenario

Your school electronics club has been invited to design a small radio receiver for the community information centre. To make the circuit efficient and reliable, you must understand the concept of Field Effect Transistors (FETs) as well as their practical applications in circuits.

Questions

1. Why is it important for the school electronics club to understand FETs before designing the radio receiver?
2. What are the two main types of FETs mentioned in the scenario?
3. How might the advantages and disadvantages of FETs influence the design of an efficient and reliable radio receiver?
4. In what ways can FETs be applied in electronic circuits, based on what is described in the scenario?
5. How do you think the knowledge of FET applications could benefit the community information centre?

Activity 5.17.2 Exploring Field-Effect Transistors Classroom and Community Applications

A local electronics repair shop set out to modernise its amplifier circuits by replacing ageing bipolar junction transistors (BJTs) with Field Effect Transistors (FETs). The technicians compared JFETs and MOSFETs, focusing on key requirements like low noise, high input impedance and energy efficiency. They discovered that FETs could boost amplifier performance with improved thermal stability and reduced power consumption—qualities highly valued in audio technology.

To choose the best option, the team built test circuits featuring both JFETs and MOSFETs and evaluated differences in sound clarity and ease of integration. The process also revealed practical challenges, including the need for careful handling of MOSFETs due to their sensitivity to static electricity and the importance of selecting the correct channel type (N-channel or P-channel) for proper circuit function.

Through these experiments, the shop realised that upgrading amplifiers with FETs would offer customers enhanced reliability and sound quality. This step forward not only improves their services but also strengthens their reputation as a leader in adopting modern solutions within the community.

1. What type of FET would you recommend (JFET or MOSFET) and why?
2. What advantages would the shop gain from using FETs?
3. What limitations might they face?

EXTENDED READING

- B.L Theraja, A.K Theraja (2002).Electrical Technology; Electrical Engineering Vol.1; New Delhi: S. Chand & company Ltd.
- D.C Kulshreshtha (2004). Electronic devices and circuits. New Age International(P) Limited Publishers. New Delhi
- Click the link to read more on JFET and MOSFET https://byjus.com/physics/fet-transistor/
- D.C Kulshreshtha (2004) Electronic devices and circuits. New Age International(P) Limited Publishers. New Delhi

Review Questions

1.
    a. Give ***three*** advantages and three disadvantages of Field Effect Transistors.
    b. State why thermal noise is low in FET
    c. State why thermal runaway does not exist in JFET.
2. What is the state of the gain-bandwidth product of the FET?
3. Give ***four*** applications of Field Effect Transistors

UNIT 18

DC CIRCUIT

Introduction

In direct Current (D.C.) circuits, current flows in one direction. Ohm's Law is used to determine current, voltage, and resistance in a circuit, and Kirchhoff's Laws are used to determine the magnitude and direction of current, potential difference and electromotive force (emf). Kirchhoff's laws are also used to determine the resistance of resistors connected as a load across the power sources. These laws analyse electrical circuits in detail, help solve problems and ensure circuits work efficiently.

KEY IDEAS

- Kirchhoff's Law is essential for analysing circuits with one or more emf sources.
- Ohm's Law can be used for both series and parallel circuits.
- The application of these laws helps determine current, voltage, and resistance, ensuring circuits function efficiently.

OHM'S LAW

Ohm's law defines the interlinking relationship between voltage (V), current (I) and resistance (R) at any point in any electrical circuit. This law states that, under constant physical conditions, the resistance V/I is a constant, independent of voltage (V) or current (I) and their directions.

Alternatively, Ohm's law states that the current flowing through a conductor is directly proportional to the potential difference between its ends provided the physical conditions do not alter.

Ohm's Law Relationship

By knowing any two values of the Voltage, Current or Resistance quantities, we can use Ohm's Law to find the third missing value.

a. To find the Voltage, (V) [$V = I \times R$] V (volts) = I (amps) × R (Ω)

b. To find the Current, (I) [$I = V \div R$] I (amps) = V (volts) ÷ R (Ω)

c. To find the Resistance, (R) [$R = V \div I$] R (Ω) = V (volts) ÷ I (amps)

Resistance

This refers to the property of any material which restricts or opposes the easy flow of current through it. The relation between the resistance (R) offered to a current (I) driven by a voltage (V) in a circuit is given by R = V/I

Voltage

Voltage is the difference in potential of one point with respect to another that pushes and pulls electrons through a conducting material. Voltage is defined as an electromotive force (emf). It is symbolised in formulas by the letter V.

Application of Ohm's Law

1. **Series Circuit**: Connecting resistors or light bulbs (loads) in series always reduces the brightness of the bulbs. If one bulb (load) is removed, it acts like a switch, and all light bulbs go out (off); each bulb or component affects the other.

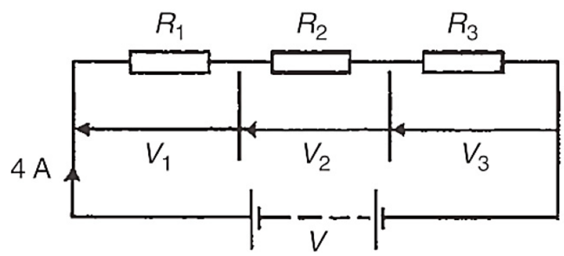


Figure 5.18.1: *Series circuit*

Characteristics of a Series circuit

a. The same current flows through all resistors or bulbs (load).

b. Total potential difference is equal to the sum of individual potential differences.

c. Individual p.d. is directly proportional to individual resistance.

d. Total resistance is equal to the sum of individual resistances.

e. Total power in a series circuit is equal to the sum of the individual values of power in the circuit.

Since the same current flows through each resistor, the supply voltage is equal to the sum of the potential difference across each resistor:

$V_S = V_1 + V_2 + V_3$ .... (i)

But,

V = IR

$V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$,

Substituting these into equation......(i)

$IR = IR_1 + IR_2 + IR_3$

$IR = I(R_1 + R_2 + R_3)$

Dividing through by I gives: $IR = R_1 + R_2 + R_3$

Total resistance, $R_T = R_1 + R_2 + R_3$

R_T is the total or equivalent resistance of the circuit.

1. **Parallel circuit**: A parallel circuit is a circuit in which the connection of the resistors is such that the same voltage appears across each resistor while the current is shared among them. The total resistance has a value less than the lowest resistor connected in the circuit.

Resistors connected in a Parallel circuit

When components or light bulbs are connected in parallel in the same circuit, they can work as if each bulb were connected in a separate circuit. If a bulb is added or taken away, the circuit works the same. If the source can supply enough electrical energy, a variety of other output devices can be used at the same time.

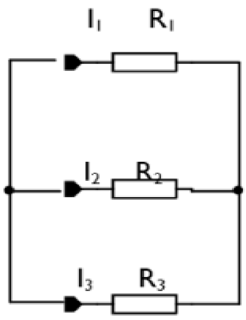


Figure 5.18.2: Parallel circuit

A parallel circuit is a circuit in which the connection of the resistors is such that the same voltage appears across each resistor while the current is shared among them. The total resistance has a value less than the lowest resistor connected in the circuit. A break in any branch does not affect the entire circuit. ***Figure 5.18.2*** shows a parallel circuit having three resistors R_1, R_2 and R_3. Because this is a parallel circuit, the current is shared among the various resistors (as stated earlier). The total current $I_T = I_1 + I_2 + I_3$. But according to Ohm's law, $I = V/R$. Therefore, multiplying through by I/V, we have

$$\frac{1}{Rtotal} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \text{ and so on}$$

Series - parallel circuit

A series-parallel circuit is one in which a parallel branch is connected in series with one, two or more other resistors, which are also connected in series, as shown in ***Figure 5.18.3*** or a parallel branch connected in series with another parallel branch, as shown in ***Figure 5.18.4***

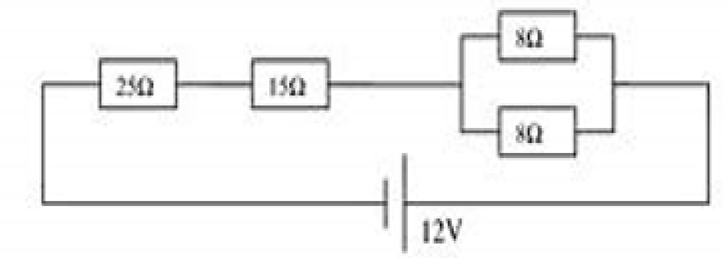


Figure 5.18.3: Series-parallel circuit

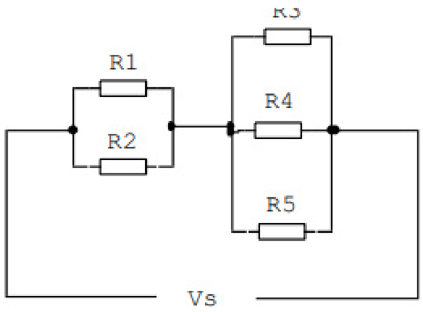


Figure 5.18.4: Series-parallel circuit with a branch

In ***Figure 5.18.4***, resistors R_1 and R_2 are connected in parallel, and R_3 and R_4 are also connected in series. The two arrangements are interconnected to form a compound arrangement and referred to as a series-parallel circuit.

To determine the overall resistance of this circuit;

1. Solve for the total resistance of the parallel circuit only.
2. Add the resistance obtained to the resistors in series.

   The overall resistance is given as

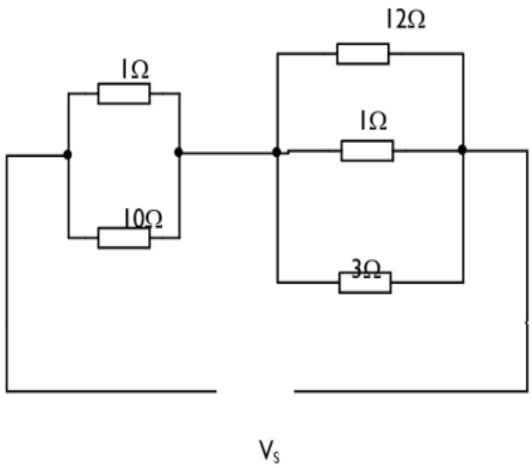


***Figure 5.18.5**: Series parallel circuit*

Solution for Figure 5.18.5

The total resistance for the first parallel branch would be;

$1\ 1 + 1\ 10 = 11\ 10 = 10\ 11 = 0.9\Omega$

For the RT of the second parallel branch $= 1\ 12 + 1\ 1 + 1\ 3 = 0.67\ 122$

The circuit is then redrawn as shown in ***Figure 5.18.6***

$RT = 0.91 + 0.67 = 1.58\ \Omega$.

Figure 5.18.6*: Re-drawn simplified solution for Figure 5.8*

Kirchhoff's Laws

Kirchhoff's current and voltage laws are useful in analysing circuits in detail.

Whilst Kirchhoff's current law applies only to junctions in a network,

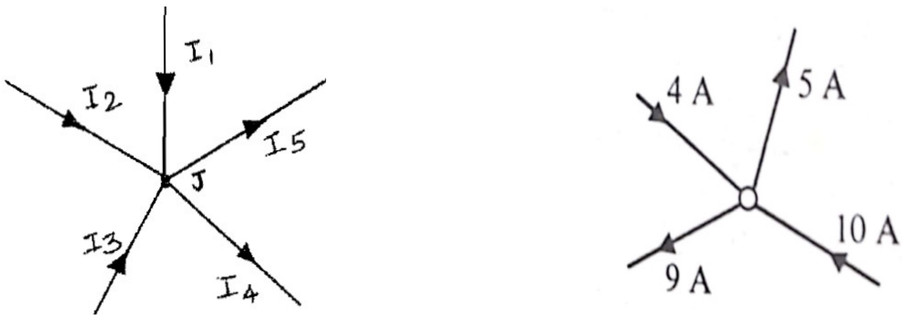
Kirchhoff's voltage law is concerned with (potential differences), IR drops and battery emfs.

1. The algebraic sign of an IR drop is primarily dependent upon the direction of current flow.
2. The emf is positive if and only if the loop is taken from the negative terminal to the positive terminal.

Kirchhoff's laws are applied by direct application to the network in conjunction with Ohm's law, resulting in a solution by simultaneous equations.

Kirchhoff's (First) Current Law (KCL)

1. It states that at any instant, the algebraic sum of the currents at a junction in a network is Zero.
2. Different signs are allocated to currents held to flow towards the junction and those away from it. This concept is more readily appreciated by the following examples in ***Figure 5.18.7*** (a) and (b)



(a) ***(b)***

Figure 5.18.7: Kirchhoff's (First) Current law

By the law,

$I_1 + I_3 + I_4 \quad = I_2 + I_5$

$\quad = I_1 + I_3 + I_4 - I_2 - I_5 = 0$

$= I_1 + I_3 + I_4 + (-I_2) + (-I_5) = 0$

In ***Figure 7.10*** suppose that $I_1 = 3A$, $I_2 = 4A$, $I_3 = 1A$, and $I_4 = 2A$. Then I_5 can be calculated as follows

$I_1 + I_3 + I_4 = I_2 + I_5$

$= I_1 + I_3 + I_4 - I_2 = I_5$

$= (3 + 1 + 2) - 4 = I_5$

$= 6 - 4 = I_5$

I_5 therefore $= 2A$

As a proof

$I_1 + I_3 + I_4 = I_2 + I_5$

$3 + 1 + 2 = 4 + 2$

$6 = 6$

Or

$I_1 + I_3 + I_4 - I_2 - I_5 = 0$

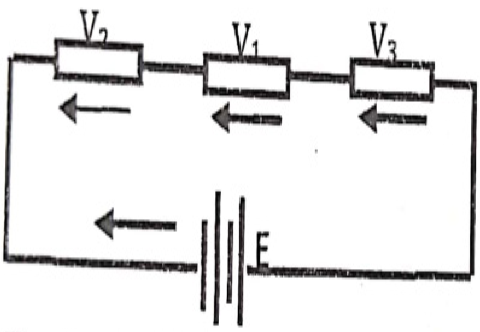
$3 + 1 + 2 - 4 - 2 = 0$

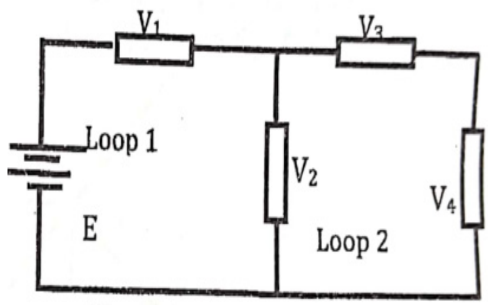
$6 - 6 = 0$

Kirchhoff's (Second) Voltage law (KVL)

It states that, at any instant in a loop, the algebraic sum of the emf's acting round the loop is equal to the algebraic sum of the potential differences round the loop.

This law is most readily exemplified by consideration of a simple series circuit shown in ***Figure 5.18.8***





(a) ***(b)***

Figure 5.18.8: *Kirchhoff's (Second) Voltage Law*

The voltage equation for ***Figure 5.11*(a)** is: E = V1 + V2 + V3 V1 + V2 + V3 + (- E) = 0

Kirchhoff's Laws and Network Solution

Kirchhoff's law may be applied to networks, resulting in a solution by simultaneous equations if two parallel emfs appear.

1. In ***Figure 5.18.9*** the current in resistor R is 2A. Use Kirchhoff's laws to calculate the values of R, I_1 and I_2

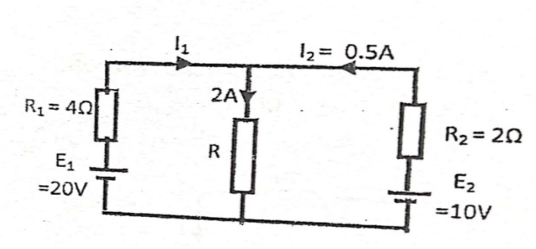
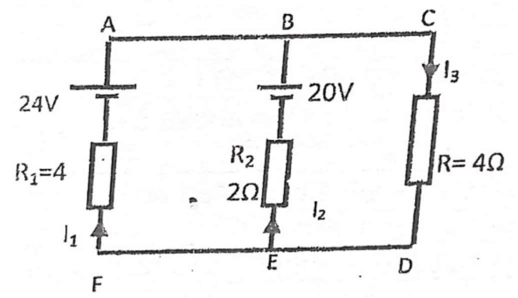


Figure 5.18.9*: Kirchhoff's Laws*

2. In the figure below, calculate the current, I_1 and I_2



Solution

Applying KCL at junction B, the current equation is

$I_1 + I_2 - I_3 = 0 \quad \Rightarrow I_3 = I_1 + I_2 \ldots\ldots (i)$

Applying KVL to loop AFEBE

$E_1 - I_1R_1 + I_2R_2 - E_2 = 0$
$E_1 - E_2 = I_1R_1 - I_2R_2$
$24 - 20 = 4I_1 - 2I_2$
$4 = 4I_1 - 2I_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$

Applying KVL to loop BEDCE

$E_2 = I_2R_2 + I_3R$
$E_2 = I_2R_2 + (I_1 + I_2)R$
$E_2 = I_2R_2 + I_1R + I_2R$
$20 = 2I_2 + 4I_2 + 4I_1R$
$20 = 4I_1 + 6I_2 \ldots\ldots\ldots\ldots\ldots (iii)$

Solving equations (ii) and (iii) simultaneously,

$20 = 4I_1 + 6I_2$
$-4 = 4I_1 - 2I_2$
$16 = 8I_2$
$\frac{16}{8} = I_2 = 2\ A$

Substituting I_2 into equation (ii)

$4 = 4I_1 - 2(2)$
$4 = 4I_1 - 4$
$4 + 4 = 4I_1$
$\frac{8}{4} = I_1 = 2A$

3. In ***Figure 5.13***, use Kirchhoff's laws to determine

a. Current I_1

b. Current I_2

c. Voltage drops across the 1_5 Ωresistor.

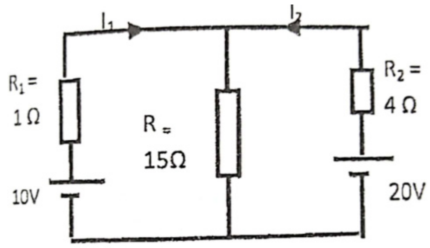


Figure 5.18.10

Solution

$KCL, I_1 - I + I_2 = 0$

$I_1 + I_2 = I$.......................(i)

$Applying\ kvl\ to\ loop\ 1$

$I_1R_1 + IR - E_1 = 0$

$1I_1 + 15(I_1 + I_2) = 10$

$1I_1 + 15I_1 + 15I_2 = 10$

$16I_1 + 15I_2 = 10$

$$I_1 = \frac{10 - 15I_2}{16}$$

$I_1 = 0.625 - 0.938I_2$....... (ii)

$Applying\ kvl\ to\ loop2$

$I_2R_2 + IR - E_2 = 0$

$2I_2 + 15(I_1 + I_2) = 20$

$2I_2 + 15I_1 + 15I_2 = 20$

$15I_1 + 17I_2 = 20$ ....(iii)

$Substituting\ equation\ (ii)\ into\ (iii)$

$15(0.625 - 0.938I_2) + 17I_2 = 20$

$9.38 - 14.07I_2 + 17I_2 = 20$

$-14.07\ I_2 + 17\ I_2 = 20 - 9.38$

$2.93\ I_2 = 10.62$

$$I_2 = \frac{10.62}{2.93} \quad = 3.6\ A$$

Substituting I_2 into equation (ii)

$16\ I_1 + 15(3.6) = 10$

$16\,I_1 + 54 = 10$

$I_1 = \dfrac{10 - 54}{16}$

$I_1 = \dfrac{-44}{16} = -\,2.75\ A$

$I = I_1 + I_2$

$\quad = -2.75\ + 3.6$

$I = 0.85\ A$

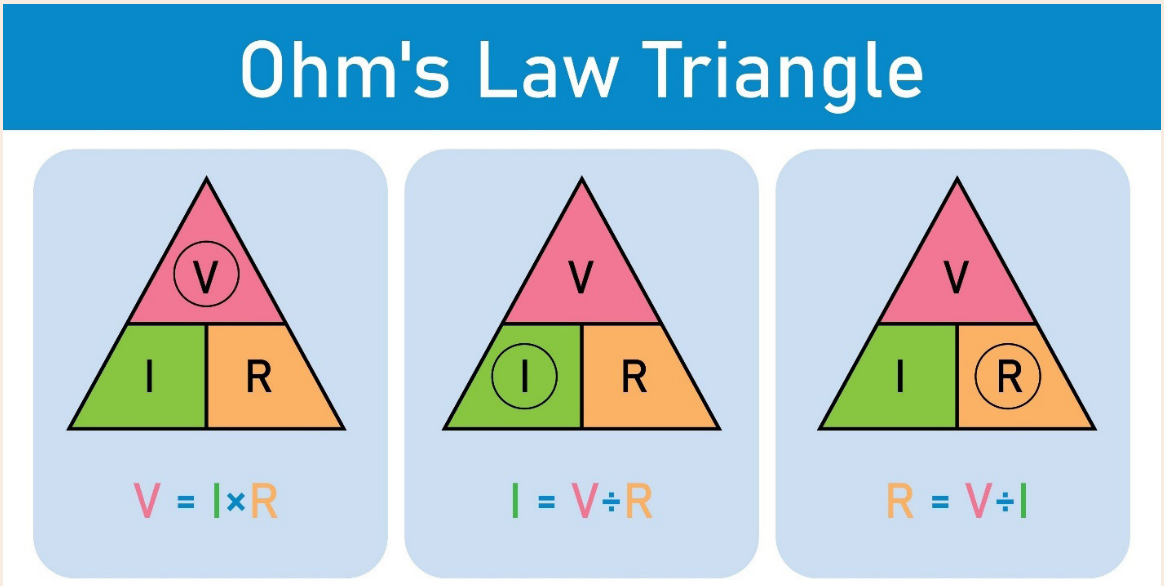
$V_R = IR\ = 0.85 \times 15\ = 12.75\ V$

Activity 5.18.1 Understanding Ohm's law and circuit analysis

This activity will help you understand the foundational principles of electrical circuits, including Ohm's Law and Kirchhoff's Laws. The various tasks may be done in groups with friends or in pair with a classmate.

Task 1: Ohm's Law

1. With your pair, discuss the relationship between voltage (**V**), current (**I**), and resistance (**R**).
2. Using the Ohm's law triangle diagram, identify the formula for calculating each of the three variables.



3. Share your explanations with the rest of the class.

Task 2: Series Circuits

1. Observe the provided diagram of a series circuit.

2. With your partner, identify three key features of a series circuit, such as how the current flows, how the voltage is distributed, and how resistance is calculated.
3. Record your findings in your notebook and be prepared to share them in class.

Task 3: Series-Parallel Circuits

1. In groups, study the diagram of a series-parallel circuit.
2. Brainstorm and list the steps required to calculate the total resistance of the circuit.
3. Apply your steps to solve a worked example provided by your teacher, and compare your answer with other groups.

Task 4: Kirchhoff's Current Law (KCL)

1. Observe a diagram that shows current flowing at a junction.
2. In your group, state Kirchhoff's Current Law in your own words.
3. Apply KCL to calculate the unknown current values in a simple junction circuit.
4. Present your group's explanation and calculation on the board for the class.

Activity 5.18.2 Exploring the Proof of Total Resistance in Series

1. In pairs, draw a simple series circuit with three resistors.
2. Write the formula for the voltage across each resistor.
3. Add the voltages to show the relationship with total resistance.
4. Derive the expression for total resistance.
5. Present your mathematical proof in class.

Activity 5.18.2 Case Study —Troubleshooting an ICT Centre

A new ICT centre in your community is experiencing frequent fuse blowouts. The electrician suspects the problem comes from a miscalculated total resistance in the circuits.

1. How would you apply **Ohm's law** and **KCL** to troubleshoot the problem?
2. What steps would you take to calculate the total resistance if the circuits are a mix of series and parallel?
3. How can proving RT = R1+R2+R3 help in such troubleshooting?

EXTENDED READING

- E.C Sraha (2016). Applied Electricity and Electronics for SHTS. Books Galore Ventures, Koforidua
- https://www.youtube.com/watch?v=HsLLq6Rm5tU&t=19s
- https://www.youtube.com/watch?v=VV6tZ3Aqfuc
- https://www.youtube.com/watch?v=fHAAHzpz5v4

Review Questions

1.

    a. Explain Ohm's law

    b. List the quantities ohm's is interlinking.

    c. State how Ohm's establishes the relation among the quantities.

    d. State one limit of Ohm's law.

2.

    a. Explain Kirchhoff's current law

    b. State a situation in which this law can be applied: State the direction assigned to currents in one direction. State the direction assigned to currents in the other route. State the amount of current that always remains at the joint.

3. ***Figure 1*** shows two cells with internal resistances of 2Ω and 1Ω respectively which are connected to a 20Ω resistor.

    a. What current will flow in each branch?

    b. Calculate the power that will be dissipated by the 20Ω resistor

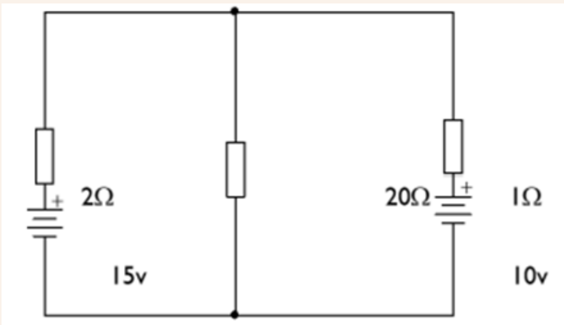


Figure 1

UNIT 19

ALTERNATING CURRENT AND TERMS ASSOCIATED WITH IT SINUSOIDAL WAVEFORMS

Introduction

Faraday discovered that any time there is a change in the magnetic flux through an area, an emf is produced. In a generator, either a magnetic field is moved across a coil, or the coil is moved across the magnetic field. As the coil assumes successive positions in the field, the flux linked with it changes, and an emf proportional to the rate of change of flux linkages is induced in it. As the coil completes one revolution, a sinusoidal voltage wave is produced. The frequency of the voltage wave is determined by the speed of revolution of the coil in cycles/sec.

KEY IDEAS

- **The Effects of Frequency on Capacitive Reactance**: The opposition of a capacitor to AC, called capacitive reactance, decreases as the frequency of the AC signal increases. This is why a capacitor acts like an open circuit for DC (zero frequency) but like a short circuit for very high frequencies.
- **The Various Arrangements of the Circuit Elements**: The three components (resistors, capacitors, and inductors) can be arranged in series or parallel circuits. The total opposition to current flow in these circuits is called impedance, which combines resistance and reactance.
- **Recognising Resonance in an AC Circuit**: Resonance occurs when the opposition from a capacitor and an inductor cancel each other out at a specific frequency. This leads to either the minimum impedance and maximum current in a series circuit or the maximum impedance and minimum current in a parallel circuit.
- **Understanding AC Circuit Elements**: In an AC circuit, the three main components are resistors, capacitors, and inductors. Resistors oppose current flow and have voltage and current in phase, while capacitors and inductors cause a phase shift between voltage and current.
- **Understanding AC Quantities**: AC voltage and current are measured by their effective value. The frequency of the AC signal is the number of cycles per second, measured in Hertz (Hz).

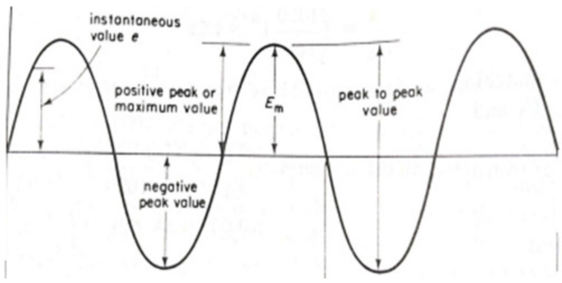


***Figure 5.19.1**: Picture of alternating current waveform*

A.C. QUANTITIES

Frequency

The rotational frequency is the number of rotations (cycles) of the phasor per second. It is measured in revs-1 or Hertz, Hz,

Period (Periodic Time)

It is the time taken to complete one revolution (cycle of oscillation). Its symbol is T and unit is second (s).

Angular Velocity

It is the rotational swiftness of the rotating vector (phasor). It is denoted by

Peak Value

The maximum value of a wave is measured from its zero value.

Instantaneous value

The instantaneous value is the magnitude of waveform at any instant in time or position of rotation. Instantaneous values are denoted by lower case, such as i, v, x, e.

The ***instantaneous value of current i*** at any angle is given by $i = Im\ sin$

$where\ Im$; the instantaneous value of current i at any angle is given by

$i = Im\ sin\ where\ Im\ is\ the\ maximum\ positive\ value$. And that of voltage, v, is given as

$v = Vmsin$

Angular frequency (ω)

A complete cycle of a waveform is equivalent to a rotation of 3600 or 2π radians of the generator.

Since ***f*** complete cycles occur in one second, the angular frequency, ω, is given by $\omega = 2\pi f\ rad/s$

The angle of rotation is the angular frequency x time

$that\ is\ q = \omega t = 2\pi ft$

OR

$i = Imsin\ \omega t$

$= Imsin\ 2\pi ft$

$v = Vmsin\ \omega t$

$= Vmsin\ 2\pi ft$

If θ is given in degrees, convert it to radians by using the expression

$\theta\ radians = \theta\ degrees \times 2\pi\ 360$

Cycle

This is one complete revolution of a waveform.

Average Value

It is the regular value of an a.c quantity taken over one half-cycle of the waveform.

The average value of a complete waveform is zero. The standard average value is 0.637

It is related to the maximum value by average voltage, **Vavg** = 0.637 Vm

Two points must be noted concerning this expression.

1. It only applies to sine waveforms
2. It is based on the average of a half cycle.

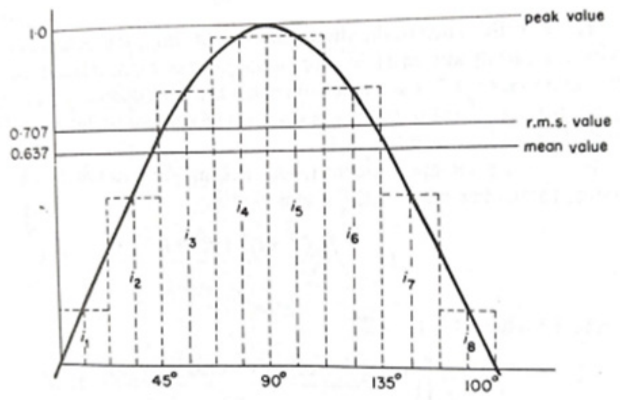


***Figure 5.19.2**: Sine waveforms*

The average value can be obtained from

Average value = $\dfrac{\text{sum of mid–ordinates}}{\text{Number of mid-ordinates over half a cycle.}}$

$$I_{av} = \frac{1}{n}[I_1 + I_2 + I_3 + I_4 \ldots I_n]$$

$$V_{av} = \frac{1}{n}[V_1 + V_2 + V_3 + V_4 \ldots V_n]$$

Where the ***V*** and ***I*** (terms) are instantaneous values of voltage and current, and ***n*** is the number of times ***V*** or ***I*** occurred.

Root mean square (r.m.s) value

It is the effective value of an a.c. which produces the same heating effect in a resistor as in a d.c. Alternatively, it is the $\frac{1}{\sqrt{2}}$ of the peak value of an a.c. It must be noted that alternating currents and potentials are stated in r.m.s. values.

The root mean square value can be obtained from:

$$V_{r.m.s} = \sqrt{\frac{1}{n}}[V_1^2 + V_2^2 + V_3^2 + V_4^2 + V_5^2 + \cdots . V_n^2]$$

Where (V) represents instantaneous values of voltage and ***n*** the number of times the voltage values occurred. The standard value of the root mean square value is 0.707.

$I_r ms = 0.707 I_m$ or $V = 0.707 V_{rms},$ also $V_r ms = \dfrac{V_m}{\sqrt{2}}$

I_m and V_m are the maximum values of current and voltage.

The form factor of a sinusoidal wave is given by $= \dfrac{r.m.s\ value}{average\ value} = \dfrac{0.707}{0.637} = 1.11$

Hence Root mean square (r.m.s) value = 1.11 × average value.

For any shape of waveform,

$$Peak\ or\ Crest\ Factor = \frac{Maximum\ value}{Root\ mean\ square}$$

$$1.414 = \frac{V_m}{r.m.s\ value}$$

Example 1

1. The following are values of an alternating current wave over a half-cycle. *I (A) 0, 0.023, 0.040, 0.050, 0.042, 0.033, 0.025, 0.016, 0*. Use the values to determine its
   - **a.** mean value
   - **b.** r.m.s value
   - **c.** form factor.

Solution

a. ***Average value of current***

$$I_{av} = \frac{1}{n}[I_1 + I_2 + I_3 + I_4 + I_5 + \cdots I_{n}]$$

$$I_{av} = \frac{[0.023 + 0.040 + 0.050 + 0.042 + 0.033 + 0.025 + 0.016 + 0]}{8}$$

$$I_{av} = \frac{0.229}{8} = 0.029\ A$$

b. ***Root mean square value***

$$I_{r.m.s} = \sqrt{\frac{1}{n}}[I_1^2 + I_2^2 + I_3^2 + I_4^2 + I_5^2 + I_n^2]$$

$$I_{r.m.s} = \sqrt{\frac{1}{8}}[0.023^2 + 0.040^2 + 0.050^2 + 0.042^2 + 0.033^2 + 0.025^2 + 0.016^2 + 0^2]$$

$$I_{r.m.s} = \sqrt{\frac{0.008363}{8}} = 0.001046\ A$$

c. ***Form factor***

$$\frac{r.m.s\ value}{average\ value} = \frac{0.001046}{0.029} = 0.0361$$

From Faraday's law, the instantaneous value of the induced emf,

Where Em is Amplitude, Peak or maximum value,

Example 2

2. An alternating current is given by

   Find the following
   - **a.** Amplitude
   - **b.** Frequency
   - **c.** Periodic time

d. Phase angle of oscillation

e. The value of the current when

i. t =0 sec.

ii. $t = 2 \times 10^{-3}$

Solution

Comparing $i = I_m sin(\omega t - \emptyset)\ A\ \ to\ \ i = 40\ sin(100\pi t - 0.32)\ A$

a. By inspection, amplitude = 40 A

b. Frequency is derived from the relation, $2\pi f t\ =\ \omega t$

$$2\pi f t = 100\pi t$$

$$\Rightarrow f = \frac{100\pi t}{2\pi t} = \frac{100}{2} = 50\ Hz$$

c. Periodic time, $T = \frac{1}{f} = \frac{1}{50} = 0.02\ sec.$

d. $Converting\ 0.32\ radians\ to\ degrees$

$$= 0.32\ rad \times \frac{180^0}{\pi} \Rightarrow 0.32\ rad \times \frac{180}{3.14\ rad} = 18.34^{\circ}$$

$$\Rightarrow \mathbf{0.32\ rad = 18.34^{\circ}}$$

e.

i. When t = 0. $= 40\ sin(0.32)\ \boldsymbol{rad}$.

Substituting $\emptyset\ = 18.34^{\circ}$ into the expression

$$i = 40\ sin(18.34^{\circ})$$

$$\Rightarrow i = 40 \times 0.3147 = 12.59\ \ A$$

ii. when $t\ = 2 \times 10^{-3}\ sec.$

$$i = 40\ sin(100 \times 3.14 \times 0.002 - 0.32)\ A$$

$$i = 40\ sin(0.628 - 0.32)\ A$$

$$i = 40\ sin(0.308)\ rad$$

$Converting\ (0.308\ )\ rad\ into\ degrees$

$$\Rightarrow 0.308\ rad \times \frac{180^{\circ}}{3.14\ rad} = 17.66^{\circ}$$

$$i = 40\ sin(17.66^{\circ})$$

$$= 40 \times 0.3034$$

$$i = 12.136\ A$$

Resistance, Inductance and Capacitance in A.C. Circuits

Impedance: This is the total opposition to current due to resistance and reactance. The symbol is Z. A circuit containing resistance and only one type of reactance will have the phase difference between current and voltage to be between 0 and 90o. If the circuit contains resistance and inductance, the current lags voltage and when it contains resistance and capacitance, the current leads voltage.

When it contains all three, the phase difference will depend on the relative values of the capacitance and inductance.

Phasors: A phasor is a line, the length of which represents the magnitude of an electrical quantity and the direction, the phase angle in electrical degrees. When handling questions involving phasors it is convenient to draw one phasor on the 0o line. This phasor thus becomes the reference to which the other phasors are related.

By convention, phasors are assumed to move in an anticlockwise or counterclockwise direction.

Resistance

Resistance is the property of a resistor to restrict the flow of alternating current. Resistance, R is a circuit constant, it is not affected by frequency. When a pure resistor is connected across a source of alternating potential, the current flowing on the spot is termed instantaneous current.

If the law of the potential difference across the resistor is $e = E_m \sin\omega t$...........*(i)*

the current will also obey the law, $e = I_m \sin\omega t$.....................................*(ii)*

Dividing eqn. (i) by (ii) gives $= \dfrac{E_m \sin \omega t}{I_m \sin \omega t}$

In a purely resistive circuit, voltage and current are in-phase.

(a) (b)

Figure 5.19.3: *(a) Waveform diagram and (b) Phasor diagram*

The voltage and current equations are

- $v = V_m \sin\omega t$
- $i = I_m \sin\omega t$

where v and i are instantaneous values of voltage and current.

V_m and I_m are maximum values of voltage and current.

Reactance of an inductor or a capacitor in an A.C circuit

Reactance is the opposition offered by an inductor or capacitor to the flow of alternating current. The effect of the reactance is to replace resistance as a means of controlling current. Reactance is dependent upon the waveform frequency.

Inductive reactance

When the reactance is inductive (from an inductor/coil), it is called inductive reactance. At zero frequency, the reactance of the inductor is zero; its value increases in direct proportion to the supply frequency, therefore.

As inductive reactance increases, current diminishes in an inductor. Inductive reactance is the opposition offered by an inductor to the flow of alternating current in a circuit. The symbol of reactance is X, and inductive reactance is represented by X_L.

$X_L \Rightarrow \omega L = 2\pi fL$................(i)

In a purely inductive circuit, voltage leads current by 90° or $\frac{1}{2}\pi\ radians$. By purely inductive circuit/coil is meant a circuit/coil that has no ohmic resistance and no I^2R loss.

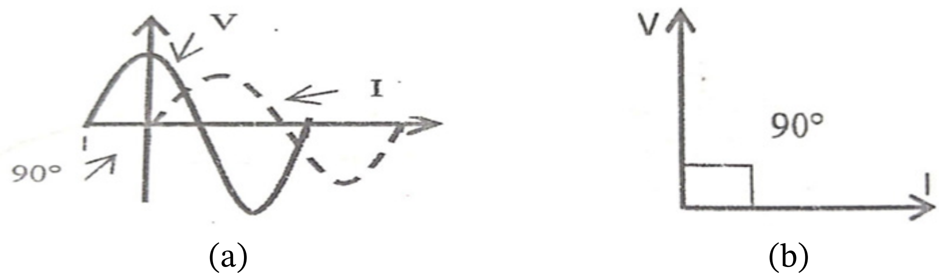


Figure 5.19.4: *(a) Waveform diagram and (b) Phasor diagram*

The voltage and current equations are

- $i = I_m sin\omega t$
- $v = V_m\ sin(\ \omega t + 1\ /2\ \pi\ rad)$

Capacitive Reactance

Capacitive reactance is the opposition offered by a capacitor to the flow of alternating current in the circuit. Capacitive reactance is inversely proportional to frequency,

$X_c \alpha \frac{1}{f}$, $Xc = \frac{1}{2\pi fc}\Omega$

As frequency **f**, increases, capacitive reactance **Xc**, decreases; if frequency **f,** decreases, capacitive reactance increases. In a purely capacitive circuit, voltage lags current by 90° or $\frac{1}{2}\pi radians$

A purely capacitive circuit is a circuit that has ***neither resistance nor dielectric loss***.

Figure 5.19.5: *(a) Waveform diagram and (b) Phasor diagram*

The voltage and current expressions are

- $i = I_m \sin \omega$t
- $v = V_m \sin\left(\omega t - \frac{1}{2}\pi rad\right)$

Frequency response of L - C series circuit X_L, I, and frequency, f

The equation $X_L= 2\pi f_L$ means that the reactance of a fixed inductance increases with frequency, XLα **f, so current through the inductor** does the following.

1. diminishes with ***increase*** in reactance
2. increases with ***decrease*** in reactance.

Figure 5.19.6: *(a) Inductive resistance graph and (b) Frequency graph*

Xc, I and frequency, f

For a fixed value of capacitance C, capacitive reactance, Xc decreases with an increase in frequency, $X_C \alpha \frac{1}{f}$. As capacitive reactance increases, current diminishes, and as capacitive reactance decreases, current increases.

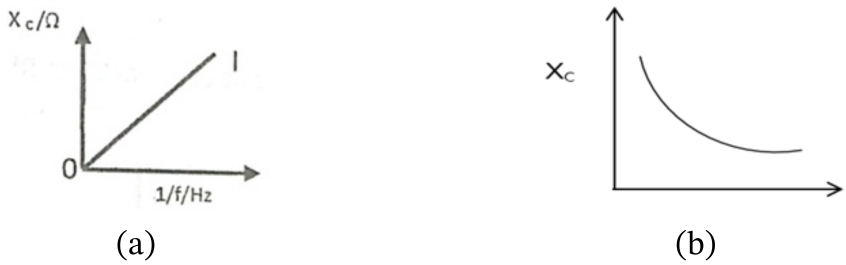


Figure 5.19.7: *(a) current or capacitive reactance and (b) frequency graph*

Impedance

Impedance is the overall opposition offered to the flow of alternating current by both the resistive and reactive circuit elements in a circuit. The symbol for impedance is Z.

R - L in Series

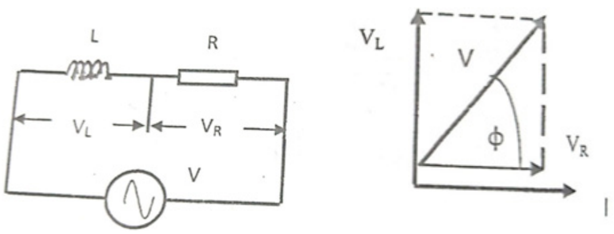


Figure 5.19.8: *(a) Circuit diagram and (b) Phasor diagram*

From the vector diagram in f ***Figure 5.19.8***(b) using Pythagorean Theorem,

$V = IZ, \quad V_R = IR\ , V_L = IX_L$

$V^2 = V_R^2 + V_L^2$

$(IZ)^2 = (IR)^2 + (IX_L)^2$

$I^2Z^2 = I^2R^2 + I^2X_L^2$

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

$Z^2 = R^2 + X_L^2$

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

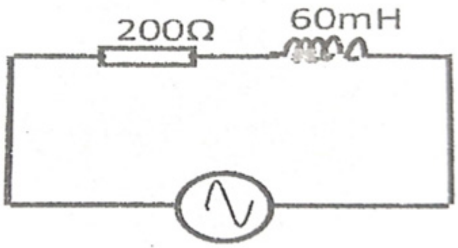


Figure 5.19.9: *Series RL circuit*

Calculate the following

a. inductive reactance

b. impedance

c. phase angle

Solution

a. Inductive reactance $X_L = 2\pi fL = 2 \times 3.14 \times 60 \times 60 \times 10^{-3} = 22.61\ \Omega$

b. Impedance, $Z = \sqrt{R^2 + X_L^2}$

$= \sqrt{200^2 + 22.61^2}$

$Z = \sqrt{40{,}000 + 511.21}$

$= \sqrt{40{,}511.21}$

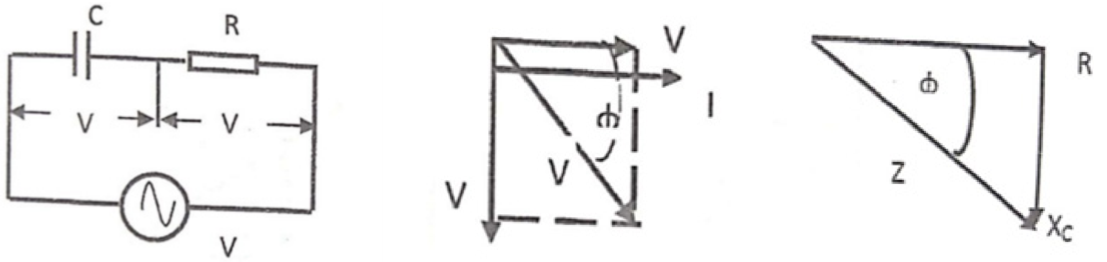
$= 201.27\ \Omega$

c. Phase angle, $\tan\varphi = \frac{X_L}{R}$

$= \frac{22.61}{200} = 0.11305$

$tan^{-1}\ 0.11305 = 6.45°$

R- C in Series



(a) ***(b)*** ***(c)***

Figure 5.19.10: *(a) Circuit diagram, (b) Phasor diagram and (c) Impedance triangle*

From the phasor diagram,

$$V = IZ, \quad V_R = IR\ , V_C = IX_C$$
$$V^2 = V_R^2 + V_C^2$$
$$(IZ)^2 = (IR)^2 + (IXc)^2$$
$$I^2Z^2 = I^2R^2 + I^2X_C^2$$
$$\frac{I^2Z^2}{I^2} = \frac{I^2}{I^2}(R^2 + X_C^2)$$
$$Z^2 = R^2 + X_C^2$$
$$Z = \sqrt{(R^2 + X_C^2)}$$

From the impedance triangle,

$$Cos\emptyset = \frac{R}{Z}, Tan\ \emptyset = \frac{X_C}{R}$$

Example

The following readings were obtained from a series circuit containing resistance and capacitance: *V=150V, I=2.5A, P=37.5W, f=60Hz.*

Calculate

- **a.** power factor
- **b.** effective resistance
- **c.** capacitive reactance
- **d.** capacitance of the capacitors

Solution

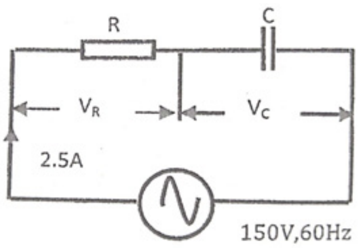


Figure 5.19.11: Solution

a. Power $P = IV\ Cos\theta$

$$\Rightarrow \text{Cos}\ \theta = \frac{P}{IV} = \frac{37.5}{2.5 \times 150} = \frac{37.5}{375} = 0.1$$

b. $P = I^2 R\ P = I^2 R \quad \Rightarrow R = \frac{P}{I^2} = \frac{37.5}{2.5^2} = 6\Omega$

Voltage across resistor, $V_R = IR = 2.5 \times 6 = 15\ V$

Supply voltage

$$V^2 = V_R^2 + V_C^2$$
$$V = \sqrt{[V_R^2 + V_C^2]}$$
$$V_C = \sqrt{[V^2 - V_R^2]}$$
$$= \sqrt{[150^2 - 15^2]}$$
$$= \sqrt{[22500 - 225]}$$
$$= \sqrt{22{,}275}$$
$$V_C = 149.25\ V$$

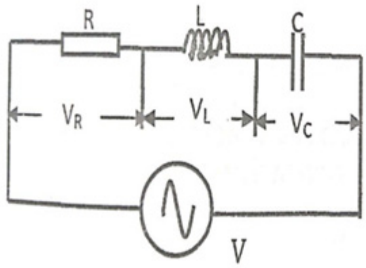
Voltage across the capacitor, $V_C = 149.25\ V$

c. Capacitive reactance, $X_C = \frac{V_C}{I} = \frac{149.25}{2.5} = 59.7\Omega$

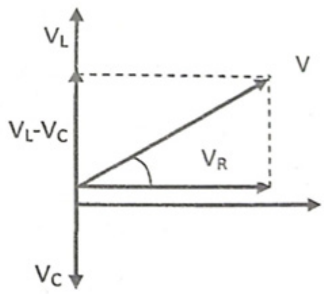
d. From $X_C = \frac{1}{2\pi f C}$,

$$\Rightarrow capacitance, C = \frac{1}{2\pi f X_C}$$
$$= \frac{1}{2 \times 3.14 \times 60 \times 59.7}$$
$$= \frac{1}{22494.96}$$
$$C = 44.45 \times 10^{-6} F$$

R-L-C in Series



(a)

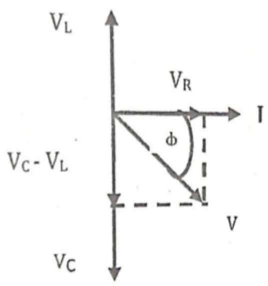


(b)

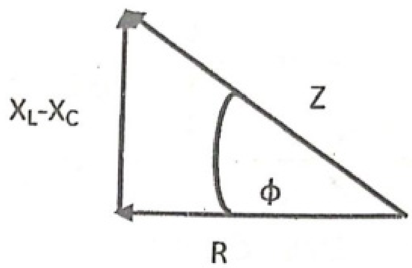
Figure 5.19.12: *(a) Circuit diagram and (b) Phasor diagram*

From the phasor diagram ***Figure 5.19.12 (b)***, $V^2 = V_R^2 + (V_L - V_C)^2$

$$(IZ)^2) = (IR)^2 + (IX_L - IXc)^2$$
$$I^2Z^2 = I^2R^2 + I^2(X_L - Xc)^2$$
$$\frac{I^2Z^2}{I^2} = \frac{I^2}{I^2}\{R^2 + \{X_L - Xc)^2\}$$
$$Z^2 = R^2 + (X_L - Xc)^2$$
$$Z = \sqrt{R^2 + (X_L - Xc)^2}$$
$$Current\,, I \; = \frac{V}{Z} \; = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$



(a)



(b)

Figure 5.19.13: *(a) Circuit diagram and (b) Impedance triangle*

$$Tan\emptyset = \frac{X_L - X_C}{R}, \qquad Cos\emptyset = \frac{R}{Z}$$

If inductive reactance is greater than capacitive reactance, tan ϕ is positive and the current lags behind the voltage. If X_L is less than Xc, tanϕ is negative and current leads the applied voltage.

Example

A series circuit consists of a 100Ω non-inductive resistor, a coil of 0.10 H inductance and negligible resistance, and a 20 × 10-6F capacitor is connected across a 100V, 60Hz power source. Find the

- **a.** current
- **b.** power loss
- **c.** phase angle between the current the source voltage.
- **d.** voltmeter reading across each element.

Solution

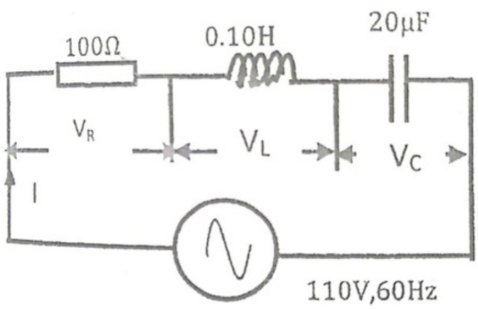


Figure 5.19.14: solution

a. Inductive reactance, $X_L = 2\pi f L = 2 \times 3.14 \times 60 \times 0.10 = 37.68\Omega$

Capacitive reactance, $X_C = \frac{10^6}{2\pi f C} = \frac{10^6}{2 \times 3.14 \times 60 \times 20} = \frac{10^6}{7536} = 132.7\ \Omega$

$$\begin{aligned}
\text{Impedance, } Z &= \sqrt{[R^2 + (X_C - X_L)^2]} \\
&= \sqrt{[100^2 + (132.7 - 37.68)^2]} \\
&= \sqrt{[100^2 + 95.02^2]} \\
&= \sqrt{[10000 + 9028.8]} \\
&= \sqrt{19028.8} \\
Z &= 138\ \Omega
\end{aligned}$$

Current, $I = \frac{V}{Z} = \frac{110}{138} = 0.797\ A$

b. Power loss, $P_L = I^2 R = (0.797)^2 \times 100 = 0.635 \times 100 = 63.5\ W$

c. $\tan\varphi = \frac{X_C - X_L}{R} = \frac{95.02}{100} = 0.9502$

$$tan^{-1}\ 0.9502 = 43.5°$$

d.

i. Voltmeter reading across R, $V_R = IR = 0.797 \times 100 = 79.7V$

ii. Voltmeter reading across L, $V_L = IX_L = 0.797 \times 37.68 = 30.03V$

iii. Voltmeter reading across C, $V_C = IX_C = 0.797 \times 132.6 = 105V$

Resonance in Series R– L– C Circuit

Resonance is a phenomenon of electrical circuits whereby at certain frequencies, large currents may be caused to flow in the circuit and large voltages may be developed across individual components such as an inductor, L, and capacitor, C.

Condition for resonance

The main condition for resonance to occur in an RLC circuit is Inductive reactance, X_L = Capacitive reactance, X_C. The following parities are derived from the main condition:

$$Since\ X_L = X_C$$

$$\Rightarrow\ X_L - X_C = 0.$$

$$\begin{aligned}
Z &= \sqrt{R^2 + (X_L - Xc)^2} \\
Z &= \sqrt{R^2 + 0} \\
Z^2 &= R^2, \Rightarrow\ Z = R
\end{aligned}$$

1. *The circuit impedance*, $Z = resistance, R$

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

$Since\ X_L = X_c$, and I is the $V_L = V_c\ and\ V_L - V_c = 0$

$$\begin{aligned}
\Rightarrow V &= \sqrt{V_R^2 + 0} \\
V^2 &= V_R^2 \\
V &= V_R
\end{aligned}$$

Supply voltage, V = Potential difference V_R, across the resistor.

2. $Circuit\ current\ , I = \frac{V_R}{R}$; $is\ maximum.$

The resonant frequency can be determined from,

$X_L = X_c$

$$It\ follows\ that, 2\pi f_o L = \frac{1}{2\pi f_0 C}$$

$$2\pi f_o L(2\pi f_o C) = 1$$

$$4^2\pi^2 f_o^2 LC = 1$$

$$f_o^2 = \frac{1}{4\pi^2 LC}$$

$$f_o = \sqrt{\frac{1}{4\pi LC}}$$

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

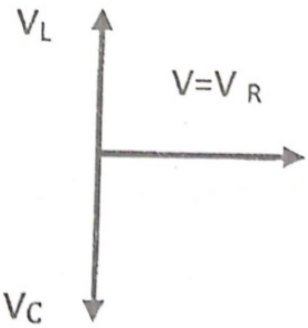


Figure 5.19.15: *Phasor diagram of voltages at resonance*

Example

The ***fig.*** shown is a series resonance circuit, calculate the

a. resonant frequency

b. inductive reactance

c. capacitive reactance,

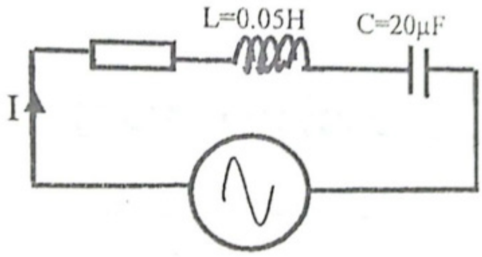


Figure 5.19.16: *series resonance circuit*

Solution

a. Resonant frequency, f_o

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2\times3.14\times\sqrt{[0.05\times20\times10^{-6}]}}$$

$$= \frac{1}{0.00628}$$

$$= 159.2\ Hz$$

b. Inductive reactance, $X_L = 2\pi f_L = 2 \times 3.14 \times 159.2 \times 0.05 = 50\Omega$

c. Capacitive reactance, $X_C = \frac{10^6}{2\pi f C} = \frac{10^6}{2 \times 3.14 \times 159.2 \times 20} = \frac{10^6}{19995.52} = 50\Omega$

Activity 5.19.1 AC Quantities Application

Read the scenario below and respond to the questions below with a partner.

Scenario

Your community is planning to set up a small radio broadcasting station and some simple AC-powered lighting. To make sure the new systems work correctly and are safe, the technicians need to understand and calculate key AC quantities.

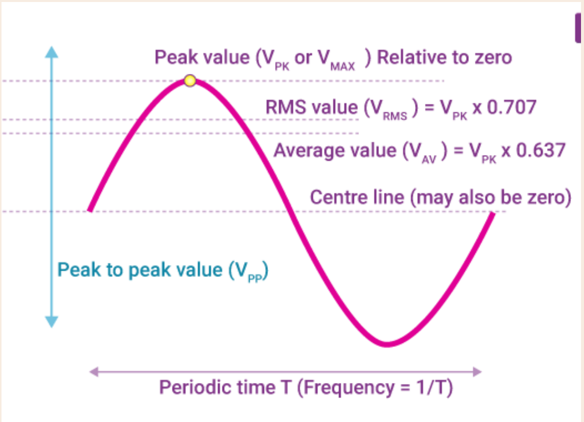
Questions

1. What is the **peak voltage (Vpeak)** of a sine wave that has an **RMS voltage (VRMS)** of 240V? What is the peak-to-peak voltage (Vp−p)?
2. A voltage waveform for the station's power supply is described by the equation: v(t)=340sin(314t).
   a. What is the **peak voltage (Vm)** of this supply?
   b. What is the **frequency (f)** of the supply in Hertz (Hz)?
3. Using the same voltage equation, calculate the **instantaneous voltage (v)** at a time of **0.005 seconds**.
4. Explain in your own words the difference between **peak voltage** and **RMS voltage**. Why is RMS voltage more commonly used to describe household electricity?

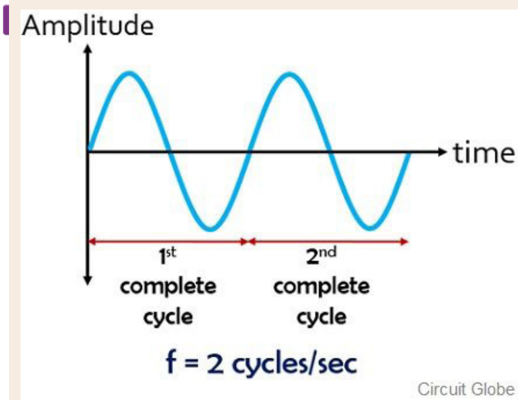
Activity 5.19.2 Investigating AC Circuits with Diagrams

Use diagrams, waveform pictures or simulations provided by your teacher for this activity.

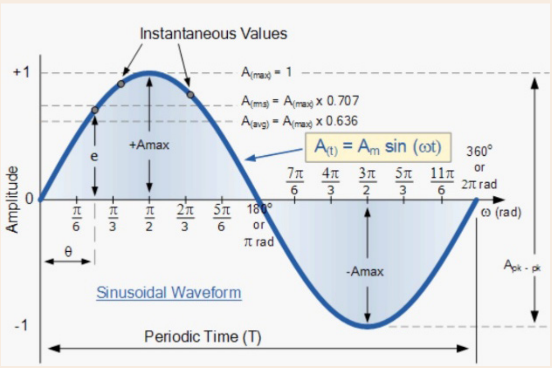
- **Figure A:** Sinusoidal AC waveform showing peak and rms values.
- **Figure B:** Graph showing one cycle, period (T), and frequency (f).
- **Figure C:** Example of instantaneous voltage from a sine wave.
- **Figure D:** Graphs of inductive reactance (XL) and capacitive reactance (XC) against frequency.



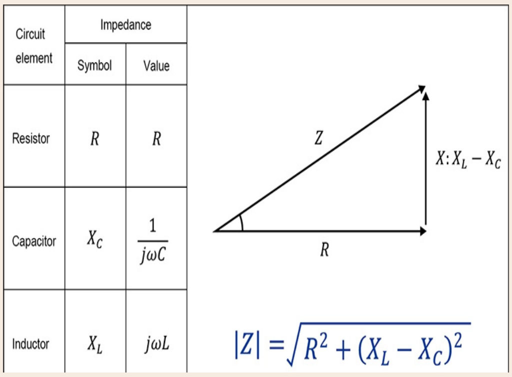
A



B



C



D

1. ***Observing Waveforms (Figure A and Figure B):*** Examine the sinusoidal AC waveforms provided. Note how the RMS value and the peak value are related. On a separate graph showing one full cycle, identify the period (T) and explain how it relates to the frequency (f).
2. ***Calculating RMS Voltage:*** Look at the example of instantaneous voltage from a sine wave (Figure C). From the equation provided, identify the steps you would take to calculate the RMS voltage.
3. ***Analysing Reactance and Frequency (Figure D):*** Study the graphs of inductive reactance (XL) and capacitive reactance (XC) against frequency. Note how they each change as the frequency increases.

4. ***Understanding Resonance:*** Using the graphs from Figure D, explain how resonance occurs in a series RLC circuit. What is the specific condition that must be met for this to happen?

Activity 5.19.3 Exploring the Reactance and Frequency Relationship

*This activity will help you apply the concepts of **reactance** and **resonance** to a real-world situation, using the example of a radio tuner.*

1. **With a partner**, research how a simple radio receiver circuit works. Pay special attention to the component that allows you to change the station.
2. **In your group**, identify the **variable capacitor** in the circuit diagram. Discuss how this component is different from a fixed capacitor.
3. **Using your research**, prepare a short presentation for the class. You must explain how the variable capacitor is used to change the circuit's **resonant frequency** to match the frequency of a desired radio station.
4. **Be prepared to answer questions** from your classmates about how your explanation applies to a real radio.

Case Study Challenge

A small workshop in your town is experiencing flickering lights whenever AC machines are operated. The electrician suspects the issue comes from the improper calculation of AC quantities.

1. How would you explain the role of rms value in ensuring proper voltage supply?
2. How would frequency changes affect the performance of inductive and capacitive circuits?
3. How could understanding resonance help prevent such issues in AC installations?

EXTENDED READING

Effects of alternating current on RLC circuits.

- E.C Sraha (2016). Applied Electrical and Electronics for SHTS. Books Galore Ventures, Koforidua.
- B.A Gregory (1981). An Introduction to Electrical Instrumentation And Measurement Systems, The Macmillan Press Ltd.
- T.A Lovelace (1970). Engineering Principles 2. Thomas Nelson and Sons Ltd. Great Britain.
- https://www.youtube.com/watch?v=YLGrugmDvc0
- https://brilliant.org/wiki/rlc-circuits-alternating-current/

Review Questions

1. Define the following terms
   a. Cycle
   b. Period
   c. Frequency
   d. Effective value
2.
   a. How do you add phasors that are displaced at 90o to each other?
   b. Explain the effect of frequency on inductive reactance.
3. A resistor of 10W, an inductor of 0.02H and a capacitor of 100 μF are connected in series to a 120V 50H3 supply.
   a. Calculate
      i. The impedance of the circuit
      ii. The circuit current
      iii. The pd across each component.
   b. At what frequency will the highest current flow in the circuit and what is the value of the current at that frequency?

UNIT 20

CONTROL SYSTEM

Introduction

When several elements or components are connected in a sequence to perform a specific function, the group thus formed is called a system. A control system is involved with the automatic control of modern manufacturing industrial processes. In a Control System, the output quantity is regulated by varying the input quantity. In this unit, the types of control systems and applications will be discussed.

KEY IDEAS

- The control system directs the behaviour of other units in the circuit.
- It is important to know the most common types and applications of control systems.

CONTROL SYSTEM

A control system is a set of coordinated devices that manage and direct the behaviour of other units to ensure that tasks are accomplished. This type of system is used in many areas in the electronic automation of manufacturing processes. Control systems have many parts, each with a specific function. The output is called the controlled variable or response, and the input is called the command signal or excitation.

Types of Control Systems

Open Loop Control System

In this system, the output quantity does not affect the input quantity. It is a physical system which does not automatically correct the variation in its output. In open loop system, the changes in output are corrected by changing the input manually.

Figure 5.20.1*: A block diagram of open control system*

***Figure 5.20.2**: Open loop - Irrigation sprinkler*

***Figure 5.20.3**: Open loop - Irrigation sprinkler*

Advantages of Open Loop Systems

1. simple and economical
2. easier to construct
3. Generally stable

Disadvantages of Open Loop Systems

1. The open loop systems are inaccurate and unreliable.
2. The changes in the output due to external disturbances are not corrected automatically.

Open Loop System Applications

1. Traffic control system: Traffic Control by means of traffic signals operated on a time basis constitutes an open loop control system. The sequence of control signals is based on the time slot given for each signal, based on a traffic study.
2. Washing machine: The length of wash time is completely dependent on the judgment and estimation of the human operator.
3. The irrigation sprinkler system is programmed to turn on at set times. It does not measure soil moisture as a form of feedback.
4. Circuit breaker: Having operated once, it has to be reset after tripping.
5. Toaster: It toasts bread for a fixed duration without sensing the colour or crispiness of the toast.

Closed Loop Control System

In the Closed Loop Control System, the output influences the input quantity to maintain the desired output value. The Closed Loop system is also called the Automatic Control System (ACS). It consists of an error detector, a controller, a plant (open loop system) and a feedback path element. Feedback is a control action in which the **output** is sampled and converted to a signal of the same type as that of the reference signal, and a proportional signal is given to input for automatic correction of any changes in the desired output.

The **error** signal generated by the error detector is the difference between the reference signal and the feedback signal. The provision of feedback automatically corrects the changes in output due to disturbances. The **Controller** modifies and amplifies the error signal to produce better control action. The modified error signal is then fed to the plant to correct its output. Controllers may be either electrical, electronic or hydraulic depending on the nature of the signal and the system.

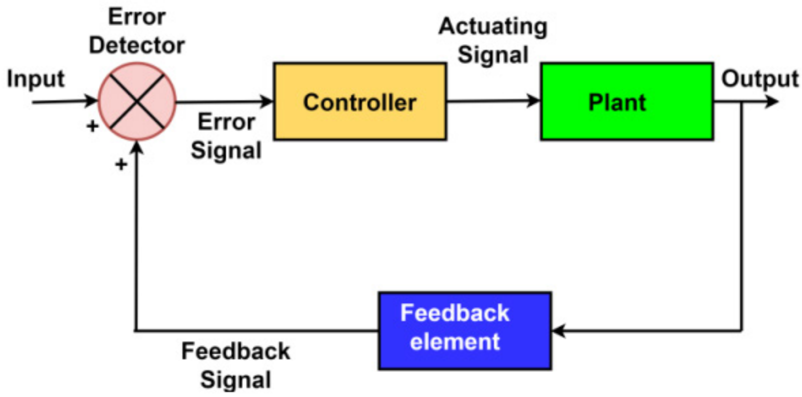


Figure 5.20.4: *A block diagram of closed loop system.*

Figure 5.20.5: *Closed loop – industrial refrigerator*

Figure 5.20.6: *Closed loop – electric iron*

Advantages of Closed Loop Systems

1. Accurate even in the presence of non-linearities
2. The sensitivity of the system, though small, makes the system more stable.
3. Less affected by noise.

Disadvantages of Closed Loop System

1. The closed loop systems are complex and costlier.
2. The feedback in closed loop systems may lead to an oscillatory response.
3. The feedback reduces the overall gain of the system.

4. Stability is a major problem in closed loop system and more care is needed to design a stable closed loop system.

Closed Loop System: additional applications

1. Refrigerator (industrial refrigerator)
2. Automatic Voltage Regulator (AVR): It measures the output voltage and adjusts the excitation to maintain a constant voltage.
3. Automatic devices that switch light at dusk
4. Electric iron
5. Smoke detection system

Table 5.20.1: Distinction between open loop and closed loop control systems

Open Loop System	Closed Loop system
Inaccurate and unreliable	Accurate and reliable
Simple and economical	Complex and costlier
They are generally stable	Great efforts are needed to design a stable system
The changes in output due to external disturbances are not corrected automatically.	The changes in output due to external disturbances are corrected automatically.

Applications of Control System

There are several applications of control systems including

1. Manufacturing and production processes
2. Transportation systems
3. Building and home automation.
4. Power generation, transmission and distribution.
5. Military and defence systems.
6. Medical equipment and operations.
7. Robotics.

Programmable Logic Controller (PLC)

A Programmable Logic Controller (PLC) is an industrial Computer in which control devices such as limit switches, push buttons, proximity or photoelectric sensors, float switches or pressure switches provide incoming control (input) signals.

The input signals interact with instructions specified in the user ladder programme. The ladder programme tells the PLC how to react to input signals. It also directs the

PLC on how to control field devices like motor starters, pilot lights, solenoids. The PLC is the tool that provides the control for an automated process.

Automation helps a manufacturing facility to, among other things to:

1. Increase productivity,
2. Lower the cost of quality, scrap and re-work,
3. Work in difficult or hazardous environments,
4. Improve quality and accuracy,
5. Achieve consistency in manufacturing.

Activity 5.20.1 Exploring control systems

1. Use diagrams, system flowcharts or simulations provided by your teacher. Alternatively, you may observe the images below.

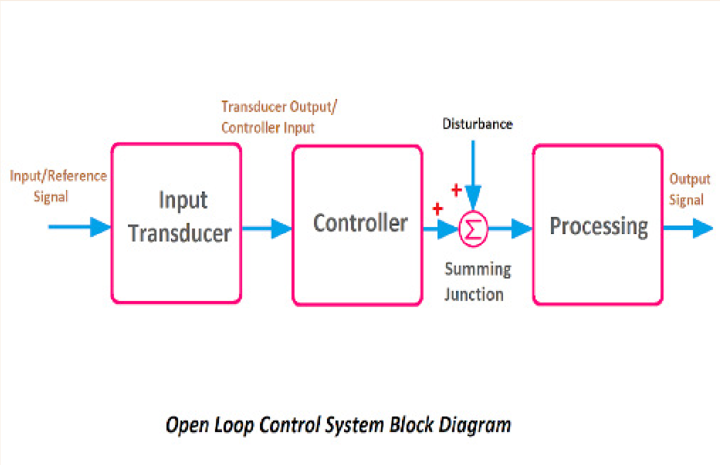


Figure A: *Block diagram of an open loop control system*

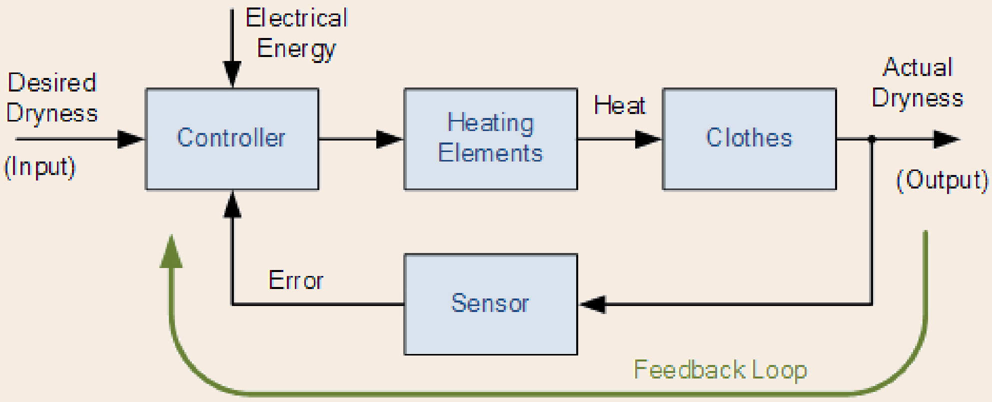


Figure B: *Block diagram of a closed loop control system with feedback.*

Figure C: *Examples of automated systems, e.g. traffic lights*

While observing, note down the following with a partner and share your responses with another pair.

2. The main components of a control system (input, controller, output, feedback).

3. The difference in signal flow between open loop and closed loop systems.

4. The benefits and limitations of each type.

5. Real-life applications of control systems in homes, industries, and communities.

Activity 5.20.2 Concept of Automation

This activity will help you understand ***automation*** *by having you apply it to a practical project.*

1. Work with a group of friends to discuss and brainstorm what automation means. Think about how a machine or system can perform a task without a person's constant help.

2. Come up with two examples of automation you see in your daily life (like a washing machine) and two examples you see in industry (like a factory assembly line). Discuss the benefits of each.

3. **Your Challenge:** As a group, your task is to design and build a simple automated system. You could build an automatic gate that opens when a car approaches, or a light that turns on when it gets dark.

  a. List the materials you will need (sensors, motors, batteries, etc.). Draw a simple circuit diagram of your automated system.

  b. Build and test your system. Follow your plan to construct the automated system. Make sure you test it to see if it works as intended.

  c. Present your project. Show your automated system to the class. Explain how it works and what real-world problem it solves.

If you cannot get basic materials for an automation project, you can improvise by using common household items and recycled waste.

Alternative Materials for an Automation Project

1. **For Sensors**
   - **a.** A simple switch can be made from two pieces of bent cardboard with aluminium foil on the inside. When they touch, they complete a circuit.
   - **b.** A light sensor can be improvised using a solar cell from a cheap calculator or a light-dependent resistor (LDR) from an old electronic toy.
2. **For Motors and Actuators**
   - **a.** Vibrating motors from old mobile phones or video game controllers can be used to create movement.
   - **b.** The motor from a broken toy car, a CD player, or a small fan can power a moving part.
3. **For Structural Components**
   - **a.** Cardboard, plastic bottles, or wooden stirrers can be used to build the frame or structure.
   - **b.** Rubber bands can act as belts to transfer motion, and paper clips can be bent into levers or connectors.
4. For Power Source
   - **a.** AA batteries or a 9V battery are often sufficient for small projects.
   - **b.** The power supply from an old phone charger can also be repurposed.

EXTENDED READING

- Click the link below to watch a video on the control system
  https://www.youtube.com/watch?v=DtV0ASunhqU
- Click the link below to read more on control systems
  https://www.electronicsforu.com/technology-trends/learn-electronics/control-system-definition-types-applications-and-faqs

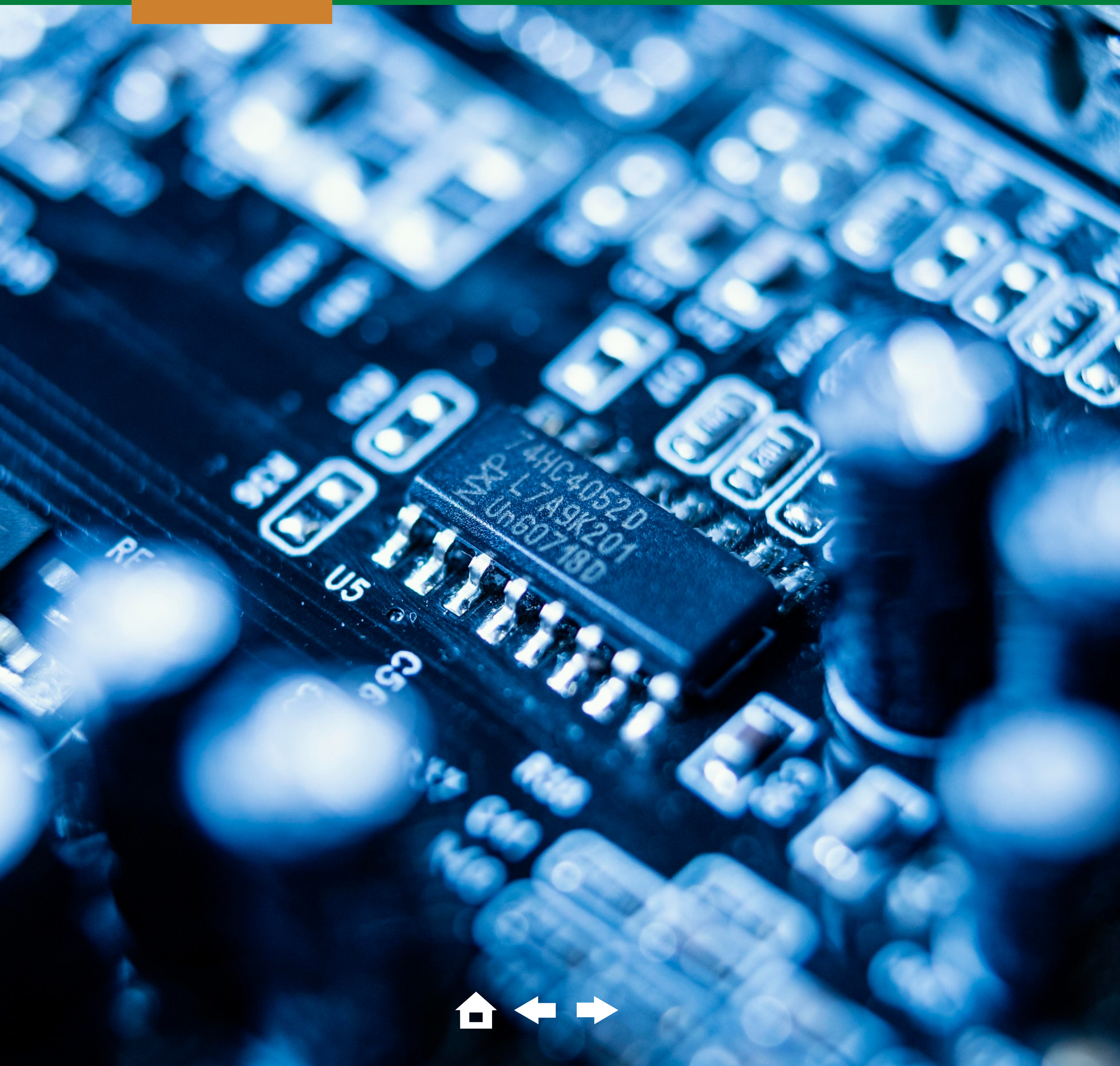
Review Questions

1. State at least four applications for control systems.
2. Explain why the circuit breaker is an open-loop control mechanism
3.
    a. What makes the traffic light system become a closed loop system
    b. Explain why the irrigation water sprinkler continues to sprinkle water even when rain is falling?
4. Explain what a Programmable Logic Controller (PLC) is used for.
5. Give 4 reasons why automation helps a manufacturing facility

SECTION

6

DIGITAL ELECTRONICS



UNIT 21

ELECTRICAL AND ELECTRONIC TECHNOLOGY

ELECTRONIC DEVICES AND CIRCUITS

Introduction

This final section covers Units 21 to 24, the conversion of binary numbers to decimal numbers and vice versa, converting the moving coil instrument into voltmeters and ammeters, and applying knowledge of electronic components in designing circuits such as a fire alarm and FM transmitter.

Before a computer can process data, the data has to be converted into a form acceptable to the computer. The decimal number system is used to input data into the computer. The base of the decimal number system is 10, and the units are,0,1,2,3,4,5,6,7,8, and 9. The computer works using the binary digit process. In this unit, the process of converting binary numbers into decimal and from decimal to binary equivalent will be explored.

KEY IDEAS

- What is meant by the binary number system
- What is meant by the decimal number system
- How to undertake binary to decimal conversion and decimal to binary conversion

BINARY NUMBER SYSTEM

The binary number system has only two digits, 0 and 1. The base of the binary number system is **2.** The abbreviation for a binary digit is "bit." The binary numbers 1100 and 101011 have 4 and 6 bits, respectively. The binary system is positionally weighted; by using the different digits in different positions, any number can be expressed.

Decimal Number System

The decimal number system is also known as the base 10 numeral system. It uses ten digits from 0 to 9. In the decimal number system, the positions continuous to the left of the decimal point represent units, tens, hundreds, thousands and so on. Thus, the base of the decimal number system is 10.

Binary to Decimal Conversion Steps

1. First, write the given binary number and count the powers of 2 from right to left (powers starting from 0).
2. Now, write each binary digit (right to left) with the corresponding powers of 2 from (right to left), such that the first binary digit (MSB) will be multiplied by the greatest power of 2.
3. Add all the products in the above step.
4. The final answer will be the required decimal number.

Example1

Convert $1\,1\,0\,1_2$ into its decimal equivalent.

Solution

1	1	0	1	→ **Binary number**
2^3	2^2	2^1	2^0	→ **Positional weights**
8	4	2	1	→ **Weights**
8	4	2	1	→ **Crossing out weights under zero**
8 +	4 +	0 +	1	→ **Adding weights**

Therefore, $1\,1\,0\,1_2 = 13_{10}$ → **Decimal equivalent of binary number**

Decimal to binary conversion

The systematic method to convert decimal number into its binary equivalent involves successive division by 2 and recording the remainder. The division is stopped when a quotient of **0** with a remainder of **1** is obtained. The remainder when read upwards gives the equivalent binary number.

Example 2

1. Convert the decimal number 10 into its equivalent binary number.

Solution

2	10	**Remainder**
2	5	0 (LSB)
2	2	1
2	1	0
	0	1(MSB)

The binary number is $\mathbf{1010_2}$

2. Convert the decimal number 25 into its binary equivalent.

Solution

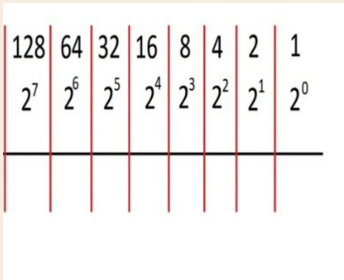
2	25	**Remainder**
2	12	1 (***Least significant bit LSB***)
2	6	0
2	3	0
2	1	1
	0	1 (***Most significant bit MSB***)

The binary equivalent of 2510 = $\mathbf{11001_2}$

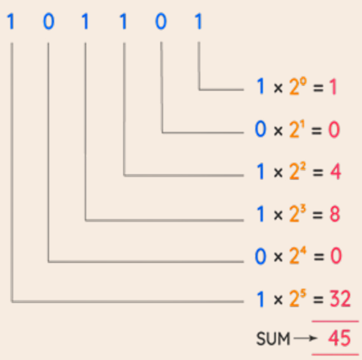
Activity 6.21.1 Understanding binary numerals

Use diagrams below, or place value charts or simulations provided by your teacher.

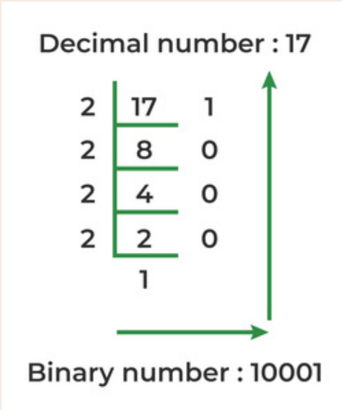
- **Figure A:** Binary place value chart (powers of 2).
- **Figure B:** Example of binary-to-decimal conversion.
- **Figure C:** Example of decimal-to-binary conversion (division by 2 method).



A



B



C

1. Look at the images of binary numbers and place values provided by your teacher. With your group, discuss why binary only uses 0s and 1s. Think of these as on and off switches. How do you think a device knows the difference?
2. Each binary digit has a special power! Study the place value chart and work together to figure out the powers of two. For example, the number 8 in binary isn't just an 8; it's a power of 2. Can you show how a binary number gets its value from these powers?

The Conversion Challenge.

1. Pick a binary number and, as a group, map out the steps to convert it into a decimal number.

2. Now, try the reverse! Pick a decimal number and, as a team, work through the steps to convert it into its binary form.
3. Present your findings to the class. Show them how you cracked the code and converted a number both ways.

Activity 6.21.2 Exploring Binary and Digital Electronics

Understanding Binary Numerals

1. In a pair with a classmate, discuss why digital devices like computers and phones use only two numbers, 0s and 1s. What makes this system so useful for machines?

   During your discussions, you should consider these points:

   a. **Simplicity**: Binary is the simplest number system, with only two states: on and off. This makes it easy for electronic circuits, which are essentially just switches, to represent and process information.

   b. **Reliability**: Using just two states makes the system very reliable and less prone to errors. A switch is either clearly on or off, with no in-between state to cause confusion.
2. Observe the provided binary place value chart (Figure A). Discuss how the value of a binary digit changes based on its position.
3. Share your ideas with the class.

Converting Between Binary and Decimal

1. In your group, practice converting a binary numeral to a decimal number. Use the place value method by writing down the binary digits and multiplying each by its place value (e.g., 16, 8, 4, 2, 1). Add the results together to get the final decimal number.
2. Now, try the reverse. With your group, use the division-by-2 method to convert a decimal number to a binary numeral. Make sure to record the remainders in reverse order.
3. Compare your group's answers with other groups.

The Concept of Digital Electronics

1. As a class, discuss how all digital devices, from your phone to a digital clock, use binary codes to process information.

   When discussing the concept of digital electronics, you should consider the following points.

   a. **Definition**: Digital electronics is the field of electronics that uses binary numbers to process, store, and transmit information. It deals with discrete signals, represented by 0s and 1s, rather than continuous signals.

b. **Application**: Think about how a digital clock, unlike an analogue one, shows a specific number (like 10:30) and then jumps to the next number (10:31). This is a great example of a digital signal.

c. **Comparison**: Compare digital electronics with analogue electronics. Analogue systems, like an old radio with a dial, use continuous signals that can have any value within a range. Digital systems only use specific, discrete values.

2. Take turns explaining in your own words the concept of digital electronics.
3. Write down the correct definition of both digital electronics and binary numerals in your notebook.

EXTENDED READING

E.C Sraha (2016). Applied Electricity and Electronics for SHTS Books Galore Ventures, Koforidua.

Review Questions

1. Explain the concept of Digital electronics
2. Identify 4 reasons why the binary numeral system is important.
3. Identify 4 reasons why the decimal numeral system is important

UNIT 22

MEASURING INSTRUMENTS AND CONTROL PRINCIPLE

Introduction

KEY IDEAS

- What is meant by electromagnetism and how it works
- What are Self –induction and Mutual induction
- The construction and operation of analogue moving-coil instrument
- Factors to consider when using a moving-coil instrument

ELECTROMAGNETISM

When a conductor carries an electric current, a magnetic field is produced around the whole length of the conductor. When the coil (conductor) is wound on a ferromagnetic material (iron core) it becomes a magnet when electric current flows through the coil wound around the iron core.

The iron core and the coil together are referred to as electromagnet and electromagnetism is the production of magnetic field by an electric current. A feature common to all magnets both permanent and electromagnets is the presence of two poles called north and south poles. Permanent Magnets are made from alloys such as Alnico, an alloy of aluminium, nickel iron, and cobalt. Electric currents produce magnetic fields as does permanent magnet.

Electromagnet and Permanent Magnet

An electromagnet is created by the current running through a coil of insulated wire that is wound around a piece of "soft" magnetic material. A permanent magnet is a hard ferromagnetic material that maintains its magnetism over long periods of time. An electromagnet needs electric current to generate magnetic fields. A permanent magnet does not need any external source; it creates its own magnetic field.

The major difference between an electromagnet and a permanent magnet is that the former can have a magnetic field when electric current flows through it and disappears when the flow of the current stops. On the other hand, permanent magnets are made up of magnetic material that is magnetised and has its own magnetic field. It will always display magnetic behaviour.

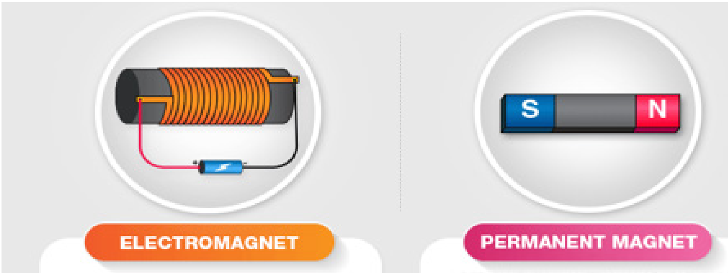


Figure 6.22.1: An electromagnet and permanent magnet

Table 6.1: Differences between electromagnets and permanent magnets

Electromagnet	Permanent magnet
The magnetic properties are revealed when current is passed through it	Magnetic properties exist when the material is magnetized
The strength is adjusted depending upon the amount of current flowing through it	The strength depends upon the nature of the used in its formation
Removal of magnetic properties is temporary	Once magnetic properties are lost, it becomes useless
It requires a continuous supply of electricity to maintain its magnetic field	It doesn't require a continuous supply of electricity to maintain its magnetic field
It is usually made of soft materials	It is usually made of hard materials
The poles of this kind of magnet can be altered with the flow of current	The poles of this kind of magnet cannot be changed

Effect of Passing A Current Through A Conductor

When a current is passed through a conductor, a magnetic flux is set up around the conductor, the direction of which can be detected using the corkscrew rule. Turning the screw clockwise will cause it (the screw) to move forward as indicated in figure below and that indicates the direction of current flow in to the conductor. The clockwise direction that the screw is being turned represents the direction in which the flux circulates around the conductor.

A magnetic Field around a current carrying conductor

1. A convenient way of remembering the direction of the field lines for a conductor is to consider a right-handed corkscrew being driven along the wire in the direction of the current. The corkscrew rotates in the direction of the magnetic field.

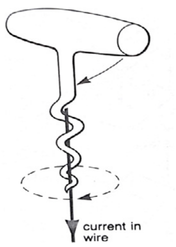
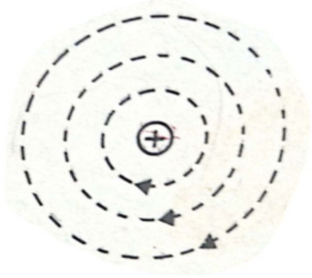
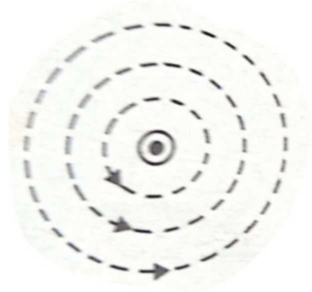


***Figure 6.22.2**: a corkscrew showing direction of current and magnetic field*

2. When a straight conductor carries current, a magnetic field is produced around that conductor. The field is in the form of concentric circles, along the whole length of the conductor as shown in the figures below.



(a)



(b)

Figures 6.22.3: *(a) Field of current flowing away from observer. (b) Field of current flowing towards observer.*

The direction of the field depends on the direction of the current. The clockwise direction is for current flowing away from the observer, and the anticlockwise direction is for current flowing towards the observer. These are also differentiated by the cross and the dot shown in the concentric circles.

Current carrying conductor placed in a magnetic field

When a straight conductor carries current, a magnetic field is produced around the conductor. The magnetic field can react with another magnetic field to produce a mechanical motion.

If a conductor is placed in the magnetic field existing between the poles of a magnet where the cross-section of the conductor appears as a circle and the magnetic field of the magnet is indicated by arrows going from the north pole to the south pole.

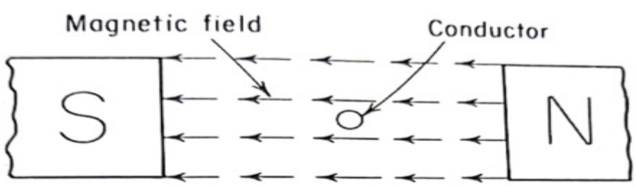


Figure 6.22.4: *A current-carrying conductor placed in an existing magnetic field*

If current is sent into the conductor in such a direction as indicated below (shown by the X appearing in the centre and represents the direction of current flow) the conductor is surrounded by a counter clockwise magnetic field, applying the left-hand rule.

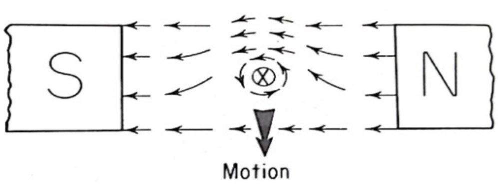


Figure 6.22.5: *Interaction between field of conductor carrying current and existing magnetic field*

Note that the magnetic field around the conductor aids the magnets above the conductor but opposes the field below. The effect is to distort the magnetic field. Since the magnet lines of force act as stretched rubber bands, the effect of the distorted field is to push the conductor downwards.

If the current flow in the conductor is reversed (indicated by the dot in the centre of the conductor) it represents the tip of an arrow showing the direction of current flow. The magnetic field around the conductor aids the magnet's field below the conductor but opposes the field above it.

The effect is to distort the magnet's field and the conductor is pushed upward.

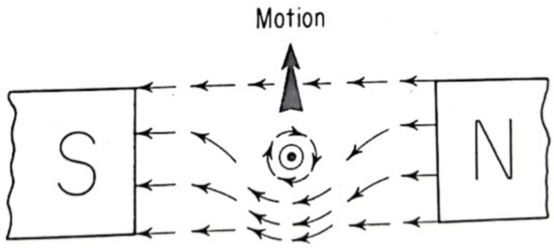


Figure 6.22.6: *Interaction between field of conductor carrying current and existing magnetic field*

A single loop of wire is mounted between two poles of a magnet so that it is free to rotate, on its axis. The two sides of the loop are seen in cross section and appears as two circles between the poles of magnet. The current flows in one direction in one side and the other direction in the other side.

As a result, the loop tends to rotate in a counterclockwise direction around its axis. The rotating effect produced by the reaction between the magnetic field of the magnet and the magnetic fields around the conductors of the loop is known as torque.

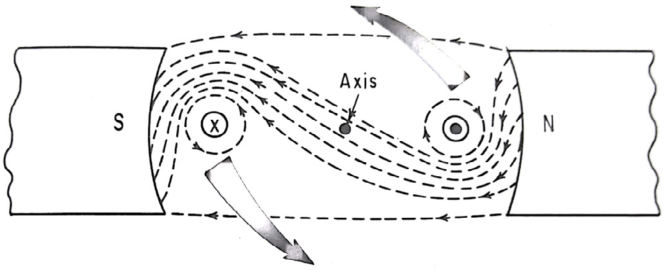


Figure 6.22.7: *Resultant interaction between field of conductor carrying current and existing magnetic field*

Fleming's Left-Hand Rule

If the thumb, first and second fingers of the left hand are placed at right angles to one another as depicted below the:

- First finger indicates the direction of Field,
- Second finger indicates the direction of Current,

Thumb points to direction of Motion of the force as shown in ***Figure 6.8***.

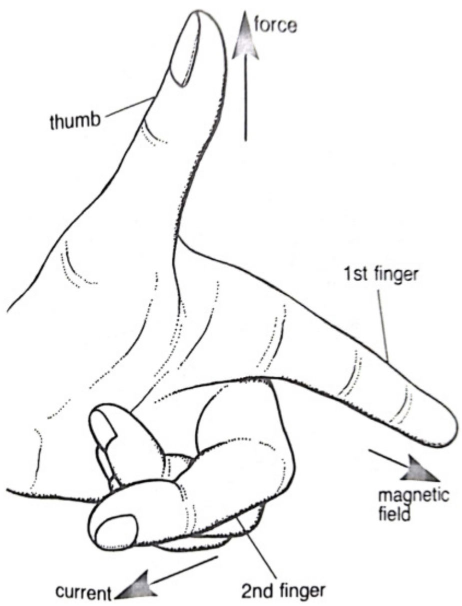


Figure 6.22.8: *Fleming's Left-Hand Rule*

When a current carrying conductor is placed at right angles to a magnetic field, it experiences a mechanical force. The force is proportional to the:

- Strength of the magnetic field, B,
- Magnitude of the current flowing through the conductor, I
- Active length of the conductor, ℓ
- Inclination, θ of the conductor to the magnetic field.

Mathematically, these factors are related to the mechanical force F, by F $\propto$ Bli

Introducing a constant of proportionality K,

$$F = kBli, \quad where\ k = 1$$

$$F\ is\ measured\ in\ newton, N, B\ in\ \frac{wb}{m^2}, l\ in\ metres\ (m), I\ in\ ampere\ (A)$$

If the conductor moves at an angle θ to the lines of flux, $F{=}Bli\ sin\theta$

Electromagnetic induction

Michael Faraday was an English physicist and chemist who contributed to the study of electromagnetism and electrochemistry. He found that if a wire is moved to cut across lines of force, then current is induced in the wire if there is a complete circuit. This is called electromagnetic induction.

A definite relationship between the direction of the induced current, flux and motion, of the conductor exists.

Magnitude of induced emf

The magnitude of the induced emf into a conductor moving through a magnetic field depends on the following factors:

1. The strength of the magnetic field, B
2. The active length of the conductor l
3. The velocity, v

If the conductor cuts the magnetic field at a very high velocity, then the induced emf will also be greater. Thus, the magnitude of an induced emf into a conductor cutting a magnetic field at a right angle is given by: 160 $emf = BLv$

If the conductor moves at an angle θ, the induced emf is given by $emf = BLv\ sin\ q$

The induced or generated emf can also be expressed as the rate of change of the magnetic flux. $ie\ emf = N\ d\Phi/d$t

Faraday's Law of electromagnetic induction states:

1. An induced emf is set up whenever the magnetic field linking that circuit changes.
2. The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit.'

Mathematically, it is given as $E \propto \frac{\delta \emptyset}{\delta t}$

$$\Longrightarrow E = -N\frac{\delta \emptyset}{\delta t}$$

Where E is the induced emf,

$\frac{\delta \emptyset}{\delta t}$ is the rate of change of flux linking the circuit and N is the number of turns of coil.

Faraday found out that the strength of the induced depends on the:

- speed of the movement
- strength of the magnet
- number of turns on the coil.

Types of Induction

According to Faraday's first law of electromagnetic induction, there are 2 main possible ways by which an emf can be induced in a circuit or conductor. These are self-induction and mutual induction.

Self-Induction

The current flowing through the conductor sets up a magnetic field through the conductor. If the current increases or decreases, the changing magnetic field gives rise to an induced emf. Self-induced emf is the emf developed in a coil due to the change of its own flux linked with it. Self-induction is the phenomenon or occurrence of emf in the same circuit in which the current is changing. The induced emf (e) is proportional to the rate of change of current and is expressed as;

$$e \propto \frac{\delta i}{\delta t} \Longrightarrow e = L\frac{\delta i}{\delta t}\,,$$
$$where\ L\ = inductance\ of\ the\ coil,$$

$$\frac{\delta i}{\delta t}\ = rate\ of\ change\ of\ current.$$

$$\Longrightarrow \frac{e}{\frac{\delta i}{\delta t}} = L$$

The property of a coil (self-induced emf) due to which it opposes any increase or decreases of current or flux through it is known as self-inductance.

Self-inductance value of a coil

From the formulae $e = L\frac{\delta i}{\delta t}$ $and\ \ e\ = N\frac{\delta \emptyset}{\delta t}$

$$\Longrightarrow L\left(\frac{\delta i}{\delta t}\right) = N\left(\frac{\delta \emptyset}{\delta t}\right)$$

$$N\ \frac{\delta \emptyset}{\delta t} \div \frac{\delta i}{\delta t}$$

$$\Longrightarrow L = N\left(\frac{\delta \emptyset}{\delta t}\right)\left(\frac{\delta t}{\delta i}\right)$$

$$L = N\left(\frac{\partial \emptyset}{\partial i}\right)$$

$$B = \mu H\ \Longrightarrow \emptyset = \mu HA, from \ldots i$$

$$also\ H = \frac{NI}{L}$$

$$\Longrightarrow \emptyset = \frac{\mu NIA}{L} \ldots\ldots .ii$$

$$but\ S = \frac{L}{\mu A}\ , making\ L = S\mu A, and\ substituting\ L\,, into \ldots ii$$

$$\Longrightarrow \emptyset = \frac{\mu NIA}{S\mu A} = \frac{NI}{S}$$

$$\delta\emptyset = \frac{N\delta i}{S}\ \ ;\ \ \delta\emptyset(S) = N\delta i\ \ (cross\ multiplying)$$

$$\Longrightarrow \frac{\delta \emptyset}{\delta i}\ = \frac{N}{S}$$

$$Therefore, substituting\ \frac{\delta \emptyset}{\delta i} = \frac{N}{S}\ \ into\ L = N\left(\frac{\delta \emptyset}{\delta i}\right)$$

$$\Longrightarrow L = N\frac{N}{S} = \frac{N^2}{S}$$

$$where\ l, is\ in\ \ henrys\ (H), S\ is\ in\ \ ampere - turn\ per\ weber\left(\frac{At}{wb}\right)$$

$$and\ N\ is\ the\ number\ of\ turns\ of\ the\ coil.$$

Mutual Induction

If two coils A and B are placed adjacent to one another, part of the flux produced by coil A links with coil B. If the field of coil A is increased or decreased, there is a corresponding increase or decrease of the field in coil B, and this induces an emf in coil B. This emf is said to be induced by mutual induction.

Coil A, connected to the supply and produces the original flux is called the primary coil and coil B is called the secondary coil. The emf induced in one coil by the influence of the other coil is called mutually induced emf.

The property of the arrangement is termed the mutual inductance. Its symbol is (M) and unit is Henry (H). Mutual induction is the production of emf in one coil by the influence of another coil placed adjacent to each other.

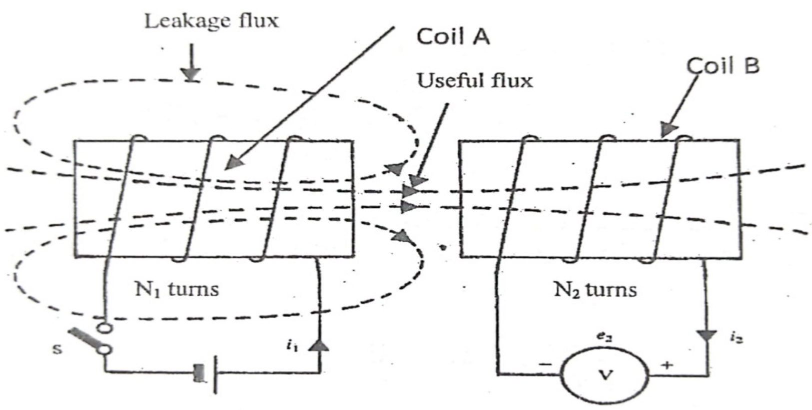


***Figure 6.22.9**: Mutual induction*

The induced emf is given by the following relation provided that the mutual inductance M, is a constant;

$$E_s \propto \frac{\delta i_p}{\delta t}$$

$$\Rightarrow E_s = M\frac{\delta i_p}{\delta t} \ldots\ldots i\ , \quad where\ M\ is\ the\ mutual\ inductance.$$

Making M the subject, $M = \frac{E_s}{\frac{\delta i_p}{\delta t}}$

The secondary induced emf will be high due to the large number of secondary turns and the rapid fall of primary current, *it follows that;* $E_S = -N_S(\frac{\delta\phi}{\delta i})$*...............(i)*

Equating (i) to (ii) and making M the subject,

$$E_s = M\left(\frac{\delta i_p}{\delta t}\right) = -N_s\left(\frac{\delta\emptyset}{\delta t}\right)$$

$$\therefore \quad M\left(\frac{\delta i_p}{\delta t}\right) = -N_s\left(\frac{\delta\emptyset}{\delta t}\right)$$

$$= -N_s \frac{\delta \emptyset}{\delta t} \div \frac{\delta i_p}{\delta t}$$

Making M the subject, $M = -N_s \frac{\delta \emptyset}{\delta t} \times \frac{\delta t}{\delta i_p}$

$$\Longrightarrow M = -N_s \left(\frac{\delta \emptyset}{\delta i_p}\right)$$

Examples

1. When the current in a certain coil is changing at a rate of 3 A/s, it is found that an emf of 7 mH is induced in a nearby coil. What is the mutual inductance of the combination?

Solution

$$E_s = M\left(\frac{\delta i_p}{\delta t}\right) \Longrightarrow M\delta i_p = E_s \delta t$$

$$\therefore M = E_s \frac{\delta t}{\delta i_p} = 7 \times 10^{-3}\left(\frac{1s}{3\ A}\right) = 2.33 \times 10^{-3}\ H$$

2. Two coils are wound around the same iron rod so that the flux generated by one pass through the other. The primary coil has N_p loops when a current of 2 A flows through it. The flux in it is 2.5×10-4 Wb. Determine the mutual inductance of the two coils if the secondary coil has NS loops.

Solution

$$M = N_s\left(\frac{\delta \emptyset_s}{\delta i_p}\right) \Longrightarrow N_s\left(\frac{2.5 \times 10^{-4} \ - \ 0 \quad Wb}{2 - 0\ A}\right) = (1.25 \times 10^{-4} N_s)\ \ H$$

3. The mutual inductance between the primary and secondary of a transformer is 0.3 H. Compute the induced emf in the secondary when the primary current changes at the rate of 4 A/s.

Solution

$$E_s = M\left(\frac{\delta i_p}{\delta t}\right) \quad \Longrightarrow e = 0.3(4) \ = 1.2\ V$$

Application of electromagnetism

1. Generator
2. Moving coil galvanometer
3. Electric bell
4. Lifting magnet
5. Transformer
6. Magnetic separators

Principle of the analogue measuring instrument

The principle used in the construction of analogue type of instrument is that, current passing through a conductor generates a magnetic field around the conductor and if this field is arranged to interact with that of a permanent magnetic field, a force acts on the current carrying conductor.

If the conductor (coil) is constrained to move in a rotary manner, an angular deflection or movement proportional to the current is obtained, resulting in an instrument that has a linear scale but which due to its inertia can only respond to ***steady state*** and slowly varying quantities.

Construction of The Moving-Coil Instrument

The general arrangement of the moving coil instrument is as shown below.

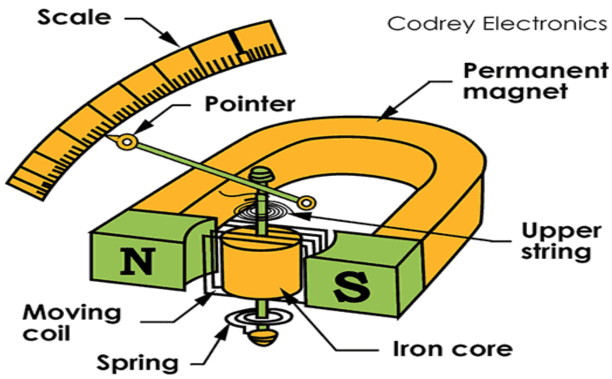


Figure 6.22.10*: Moving-coil instrument*

The arrangement consists basically of:

1. A rectangular coil of many turns wound on a former,
2. A powerful radial magnetic field between curved pole pieces,
3. A soft iron cylinder core. Its functions are to:
    a. intensify the magnetic field by reducing the length of the air gap.
    b. give a radial magnetic flux of uniform density thereby enabling the scale to be uniformly divided.
4. Springs to (i) control the rotation of the coil, (ii) lead current in and out of the coil.
5. A light pointer
6. A uniform scale

Damping is the system employed to reduce any tendency for the moving part including the pointer to oscillate. The method of damping in the moving coil instrument is by eddy current induced in the metal former.

The moving-coil instrument is unsuitable for use on alternating current because:

1. with very low frequency a.c, the pointer would oscillate with the frequency of the current.

2. at normal frequency, the inertia of the moving system is such that no movement at all takes place, the pointer remains at zero.

Range Extension

Most ammeter movements are such that a full-scale deflection is caused by current of the order of milliamperes.

Higher current can be measured by allowing some of the current to flow through a resistor of low resistance placed in parallel with the moving-coil instrument.

The parallel-connected resistor is called a **SHUNT** and shown below.

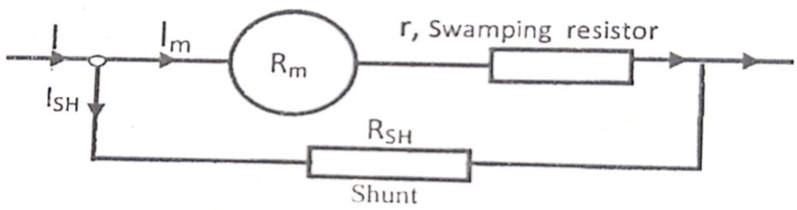


Figure 6.22.11: *A Shunt*

Key:

- R_m = resistance of the moving coil meter
- R_{sh} = resistance of the shunt resistor
- I_m = full-scale deflection current
- I_{sh} = current through the moving–coil shunt
- R = swamping resistor

The function of the swamping resistor is to reduce the error due to the variation of resistance. Materials such as Constantan also known as Eureka and manganin that have a negligible temperature coefficient of resistance are used for shunt.

From Kirchhoff's first law, $I = I_m - I_{SH} = 0 \Rightarrow I = I_m + {}_{ISH}$

The potential difference across Rm and Rsh is the same because they are connected in parallel where,

$$V = V_{sh} = V_m$$

$$\Longrightarrow I_{sh}R_{sh} = I_mR_m \ ,$$

$$R_{sh} = \frac{I_mR_m}{I_{sh}} \ or \ \frac{I_mR_m}{I - I_m}$$

Moving Coil Galvanometer to a Voltmeter

Higher potential differences can also be measured by allowing some of the p.d to fall across a resistor of high resistance placed in series with the meter. This resistor is called a *multiplier*. The p.d being measured is applied across the two resistors in series, Rm (resistance of the moving coil meter) and R (resistance of the multiplier) as shown below.

$$Hence\ V = I_m(R_m + R)$$
$$\frac{V}{I_m} = (R_m + R)$$
$$\Rightarrow \frac{V}{I_m} - R_m = R$$
$$where\ \frac{V_m}{I_m} = R_T$$
$$\therefore R = R_T - R_m$$

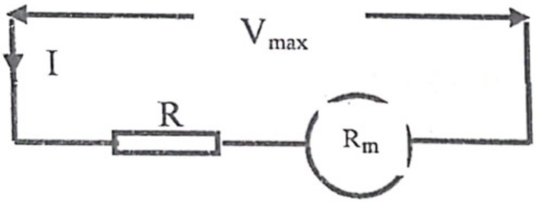


***Figure 6.22.12**: Moving Coil galvanometer to a Voltmeter*

Example

A coil of a moving–coil meter has a resistance of 5Ω and give full-scale deflection when a current of 15mA passes through it. What modification must be made to the instrument to convert it into:

a. an ammeter reading to 15A.

b. a voltmeter reading to 15V

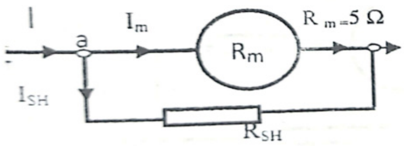


***Figure 6.22.13**: Example moving coil meter*

Solution

Applying Kirchhoff's first law at junction a,

a. $I - I_m - I_{sh} = 0$

$$I_{sh} = I - I_m$$
$$I_{sh} = 15 - 0.015 = 14.985A$$

Potential difference across moving coil, $V_m = I_m R_m$

Potential difference across shunt resistance, $V_{sh} = I_{sh} R_{sh}$

In a parallel circuit, $I_{sh} R_{sh} = I_m R_m$

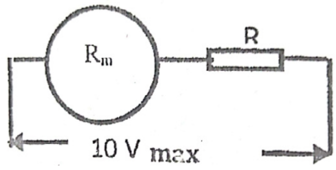
Shunt resistance required, $R_{sh} = \frac{I_m R_m}{I_{sh}}$

$$= \frac{0.015 \times 5}{14.985}$$

$$= \frac{0.075}{14.985}$$
$$= 5005 \times 10^{-6}$$

A resistance of $5005 \times 10^{-6}\ \Omega$ should be connected is parallel with the moving-coil to measure higher current.

b.



Voltage across the circuit, $V = I(R_m + R)$

Multiplier resistance, $R = \frac{V}{I} - R_m$

$$= \frac{15}{0.015} - 5$$
$$= 995\Omega$$

A resistance of 995 Ω should be connected is series with the moving-coil to measure higher voltage.

Factors considered when using measuring instruments

The performance of a measurement is defined by its **dynamics:**

- measurement range, response time,
- accuracy (repeatability, precision, and sensitivity),
- stability (tolerance for aging and harsh environments).

Safety

1. Make sure the test instrument is rated for the measurement environment.
2. Be familiar with and know how to use the equipment
3. Measure at the lowest energy point.
4. Keep the eyes on the area being probed.
5. Wear the appropriate personal protective equipment (PPE)
6. Do not work alone in hazardous areas.
7. Don't try to watch the meter while you make your measurement.
8. Always keep eyes first on the test probes.
9. Use test probes with a minimum amount of exposed metal such as metal tip probes.

Accuracy

1. Inherent accuracy of the instrument
2. Accuracy in the way measurements are taken
3. The degree of accuracy required for the task

Activity 6.22.1 Understanding magnets, electromagnetism and moving-coil instruments

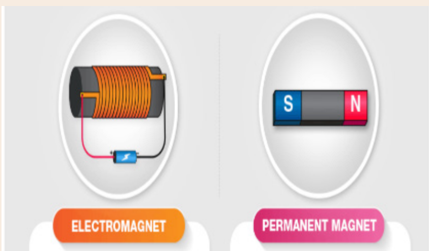
Scenario

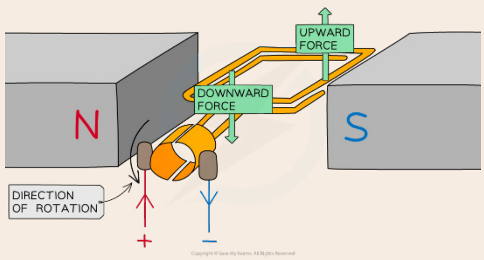
Your community is developing a small workshop to repair electric motors and measuring devices like ammeters and voltmeters; to successfully work with these machines and instruments, you must understand the differences between permanent magnets and electromagnets, the effect of placing a current-carrying conductor in a magnetic field and the factors affecting induced emf. You will also learn how a moving-coil instrument can be converted into an ammeter or a voltmeter, which is essential for electrical measurements.

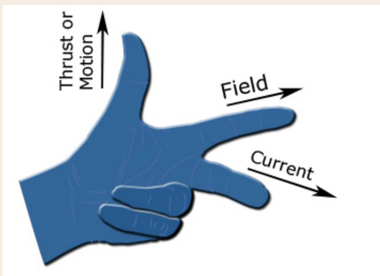
Resource Guide

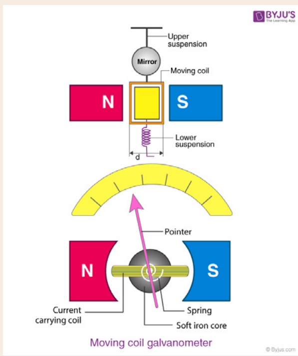
Use diagrams, pictures or demonstrations provided by your teacher.

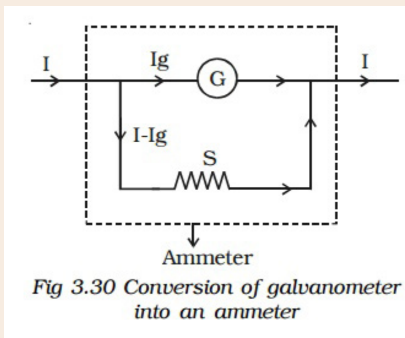
- **Fig. 1:** Permanent magnet vs electromagnet.
- **Fig. 2:** Conductor in a magnetic field (illustrating force).
- **Fig. 3:** Fleming's Left-Hand Rule diagram.
- **Fig. 4:** Moving-coil instrument (basic galvanometer).
- **Fig. 5:** Conversion of galvanometer into an ammeter and voltmeter.











While observing, note:

1. The difference between permanent magnets and electromagnets.
2. The force experienced by a current-carrying conductor in a magnetic field.
3. The factors that affect induced emf in a conductor.
4. How to modify a moving-coil instrument for different measurements.

Task 1: Permanent vs Electromagnets

Learning Task: Compare permanent magnets and electromagnets.

Activity Steps:

1. In pairs, list properties of permanent magnets and electromagnets.
2. Complete a comparison table (strength, control, applications, limitations).
3. Share your answers in a class discussion.

Task 2: Conductor in a Magnetic Field

Learning Task: What is the effect of placing a current-carrying conductor in a magnetic field?

Activity Steps:

1. Observe ***Fig. 2*** showing a conductor inside a magnetic field.
2. In groups, discuss what happens to the conductor and why.
3. Apply Fleming's Left-Hand Rule ***(Fig. 3)*** to show the direction of force.
4. Present your group's explanation to the class.

Task 3: Factors Affecting Induced emf

Learning Task: State and explain 3 factors that affect the emf induced into a conductor moving in a magnetic field.

Activity Steps:

1. Recall Faraday's law of electromagnetic induction.
2. In pairs, identify factors such as:
   - Strength of magnetic field
   - Speed of motion
   - Angle between conductor and magnetic field lines
3. Write short explanations for each factor.
4. Share your list with the class.

Task 4: Conversion of Moving-Coil Instruments

Learning Task: How can you convert a moving-coil instrument into:

a. An ammeter
b. A voltmeter

Activity Steps:

1. Study ***Fig. 4*** and ***Fig. 5*** of a moving-coil instrument.
2. In small groups, discuss how connecting a low resistance in parallel converts it to an ammeter.
3. Discuss how connecting a high resistance in series converts it to a voltmeter.
4. Present your findings with labelled diagrams.

Task 5: Group Work on Induction

Learning Task: Explain self-induction and mutual induction.

Activity Steps:

1. In small groups, brainstorm the concept of induction.
2. Record short definitions of self-induction and mutual induction.
3. Draw simple circuit symbols for current entering and leaving a conductor.
4. Present your group's findings.

Case Study Challenge

A technician is repairing an electric motor but notices that the motor fails to start. On inspection, he suspects the problem lies in the interaction between the conductor and the magnetic field.

- How can Fleming's left-hand rule help him troubleshoot the motor?
- What factors should he consider about the induced emf when the motor is rotating?
- How could knowledge of electromagnets vs permanent magnets guide the repair?

Application Questions

1. Why are electromagnets preferred over permanent magnets in electric motors?
2. How does Fleming's left-hand rule help determine the direction of force?
3. What would happen if a galvanometer were used directly to measure large currents?
4. Why is induced emf important in generators?

Reflection

In your notebook, worksheet or tablet, reflect and write:

1. One new thing I learned about electromagnets and induction.
2. The most interesting application of induced emf in real life.
3. AHow I can apply the principle of converting a galvanometer to an ammeter/voltmeter in practical work.

EXTENDED READING

John Watson (1989). Introductory Electricity and Electronics. Macmillan Publishers Ltd, London and Basingstoke.

Review Questions

1.
   a. Define electromagnetism
   b. List 3 application of electromagnetism
2.
   a. Explain Faraday's laws of electromagnetic induction
   b. Explain the following
      i. Self-induction.
      ii. Mutual induction
3. The active length of a conductor moving in a magnetic field of 0.05T is 0.4m. If the velocity at which the conductor moves through the magnetic field is 500m/s. calculate the average value of the induced emf if:
   a. The conductor moved at right angles to the field.
   b. The conductor moved at an angle of 30o to the field solution.

UNIT 23

MOVING-IRON INSTRUMENT

Introduction

Many analogue instruments make use of the fact that when an electric current flows along a conductor, the conductor becomes surrounded by a magnetic field. This property is used in electromechanical instruments to obtain deflection of a pointer between the ferromagnetic vanes in the coil's magnetic field.

KEY IDEAS

- What is a cathode-ray oscilloscope and how it works
- What is a digital multimeter and how it works
- How to go about measuring current in a circuit
- How to go about measuring voltage in a circuit
- What is an analogue Multimeter and how it works

Construction and Operation of Moving Iron Instrument

A moving-iron instrument is a device that measures voltage or current in an electrical circuit. It's an analogue instrument that uses a soft iron core and a magnetic field to measure the strength of an electric current.

There are two types of moving iron meters

i. The repulsion type

ii. The attraction type

Features of the repulsion type

- fixed iron;
- movable iron which carries a pointer that moves over a calibrated scale as shown below
- fixed coil

Operation

- The current to be measured, either a.c or d.c is passed through the fixed coil.

- The coil sets up its own magnetic field which magnetises the fixed iron and moving iron rods or sheets similarly.
- The design of the iron ensures that the repulsion is always in the same direction.
- The resulting repulsion deflects a pointer attached to the moving iron against the controlling torque of a spring.

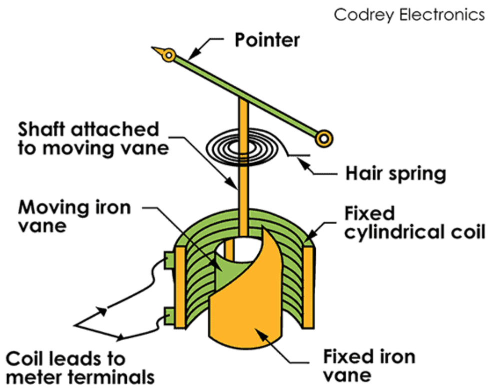


Figure 6.23.1: Moving iron instrument – repulsion type

The amount of movement depends on the square of the supply current. A small current produces a small movement and a large current produces a larger movement. Hence the scale tends to be cramped at lower values of the current.

Advantages of the repulsion type

1. **Accurate RMS measurement:** Due to the repulsion principle, it can accurately measure the root mean square (RMS) value of an AC signal, even if the waveform is non-sinusoidal.
2. **Wide frequency range:** It can operate over a wider frequency range compared to other types of instruments.
3. **Insensitivity to waveform distortion:** Less affected by waveform variations, making it suitable for measuring complex AC waveforms.

Disadvantages of the repulsion type

1. **Non-uniform scale:** The scale of a repulsion-type moving iron instrument is not evenly spaced, making accurate readings more difficult to interpret.
2. **High power consumption:** It can draw significant power due to the design, potentially affecting the circuit being measured.
3. **Stray field sensitivity:** Susceptible to errors caused by external magnetic fields, requiring proper shielding.
4. **Hysteresis error:** Although less pronounced than in attraction type MI instruments, hysteresis can still introduce errors.
5. **Temperature sensitivity:** May experience accuracy issues due to temperature fluctuations

The attraction type of moving iron instrument

An “attraction type moving iron instrument” is a type of electrical measuring device where a single piece of soft iron is attracted towards a coil carrying current, causing it to move and register a measurement on a scale; essentially, the moving iron is drawn into the stronger magnetic field produced by the coil when current flows through it, resulting in deflection on the meter.

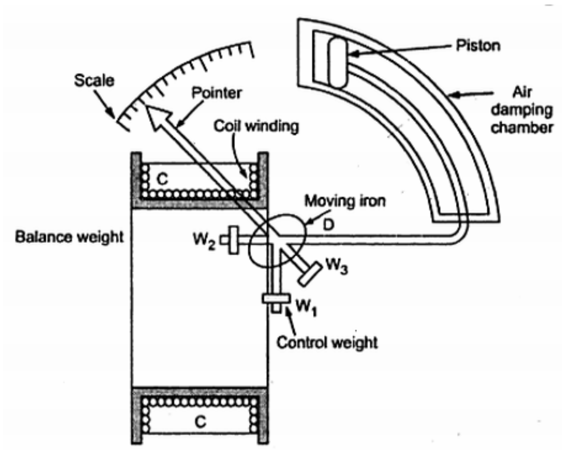


Figure 6.23.2: *moving iron instrument – attraction type*

Advantages of Attraction Type Moving Iron Instruments

- **Simple Construction:** Relatively straightforward and inexpensive to manufacture.
- **Robustness:** Durable and can withstand moderate overloads.
- **Versatility:** Can be used for both AC and DC measurements.
- **High Torque-to-Weight Ratio:** Provides good sensitivity and quick response.

Disadvantages of Attraction Type Moving Iron Instruments

- **Non-Linear Scale:** The scale is not uniform, making accurate readings more difficult.
- **Low Accuracy:** Compared to other types of instruments, they generally have lower accuracy.
- **Affected by Frequency:** The accuracy of AC measurements can be affected by changes in frequency.

Cathode Ray Oscilloscope

The cathode ray oscilloscope is a device that allows the amplitude of electrical signals, whether voltage, current or power etc. to be displayed primarily as a function of time on a screen.

This tool utilises a cathode ray tube (CRT) to visualise waveforms so, it is also known as ‘Cathode ray tube (CRT)’ oscilloscope.

The heart of the oscilloscope is the cathode ray tube.

In the cathode-ray tube, electrons are emitted by a heated cathode and pass through a hole in the grid.

A pair of anodes at successively higher potentials, accelerate and focus the electrons on to the screen.

The stream of electrons leaving the cathode and shooting across the vacuum are called cathode-rays.

The cathode ray tube has a phosphor screen where the electron beam eventually becomes visible after being deflected to form a luminous spot.

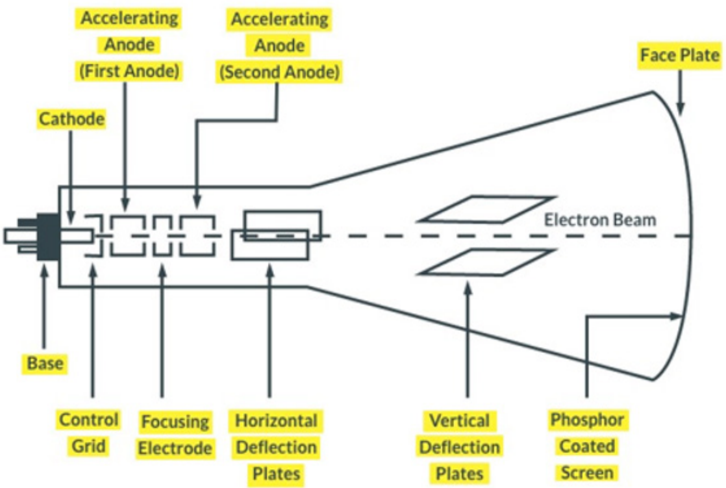


Figure 3: *Cathode Ray Oscilloscope*

Functions of the Parts

The electron gun assembly. The sole function of the electron gun assembly is to provide a focused beam of electrons which is accelerated towards the fluorescent screen. It consists of:

- An ***indirectly-heated cathode***: It produces or generates and (emits) the electron beam.
- A ***control grid*** in which the amount of current which governs the intensity of the spot is controlled. It is used for the correct brightness of the trace on the screen.
- ***Accelerating anodes*** for fast-tracking the beam of electrons.
- ***Focusing anodes***. The electron is focused with electrostatic lens for producing a narrow electron beam that converges on the phosphor screen.

The ***Deflecting plates, horizontal, X and vertical Y, plates*** are used for controlling the path of the electron beam. While the X plate deflects the beam horizontally, the Y plate deflects it vertically.

An evacuated glass envelope with a phosphorescent screen produces a bright spot when struck by a high velocity electron beam.

Application of the Cathode Ray tube

- CRT television
- Computer visual display,
- Cathode ray tube

Types of Oscilloscopes

Basically, Oscilloscopes are of two types.

- Analogue
- Digital

Analogue Oscilloscope

The analogue oscilloscope displays and measures the continuous and direct visualisation of waveforms. It uses the CRT (cathode ray tube) technology to observe the shape, amplitude, and frequency of signals in real-time.

They are very simple as there is no need for any sort of signal processing and the electrical signals are displayed as a waveform. The electron beam inside the CRT goes through deflected movements (sweeps) across the face of the tube (screen) in response to the input signals creating a visual trace on the screen representing the waveform. The disadvantage is that, it has less accuracy than the digital oscilloscope.

Digital Oscilloscope

The main feature of Digital Storage Oscilloscopes or DSOs, is that a portion of the trace is captured and can be analysed later.

A digital oscilloscope produces a trace by sampling the signal at set intervals. The digital oscilloscope has the best features to capture the momentary event and perform complex analysis in modern electronics.

The advantage of using Digital Oscilloscopes is that data can be easily stored the digital memory. Before the usage of LCD displays, digital oscilloscopes still used CRTs for displaying the signal. Such oscilloscopes require a digital to analogue converter to convert the digital signals back to analogue signals and display them on the CRT.

Difference between analogue and digital oscilloscope

The main difference between analogue and digital oscilloscopes is that in Digital Oscilloscopes, the analogue signal is captured and converted into a digital signal using an Analogue to Digital Converter.

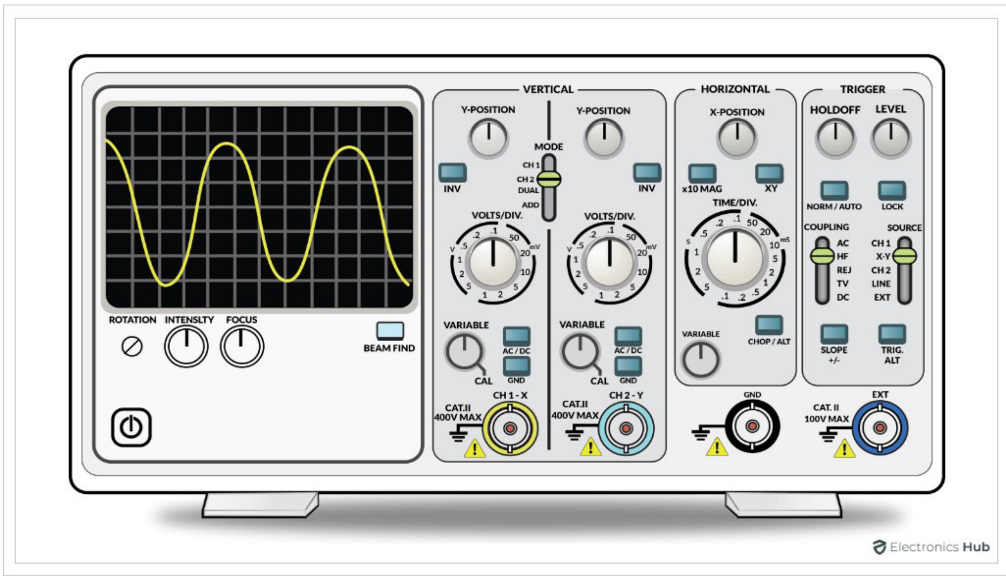


Figure 6.23.4: *Front face panel of oscilloscope*

How to use an oscilloscope

- Plug it in to a power source
- Turn it on by pressing the power push button.
- Connect the probe to the input channel of the oscilloscope.
- Connect the probe to the signal to be analysed.
- Adjust the vertical and horizontal scales to display the waveform correctly.
- Adjust the trigger settings to stabilise the waveform.

Applications of the CRO

- Visual display of wave shapes such as sine, square and many other combinations.
- Measurement of amplitude (voltage)
- Measurement of frequency.
- Time measurement Phase
- Phase-shift measurement

Measurement of Amplitude (Voltage)

The amplitude of the waveform is determined from the size of the vertical deflection on the screen. The graticule (square grid on the screen), often is 1cm square.

This grid is used to determine the height of the waveform.

A sine wave is displayed on the screen as shown below.

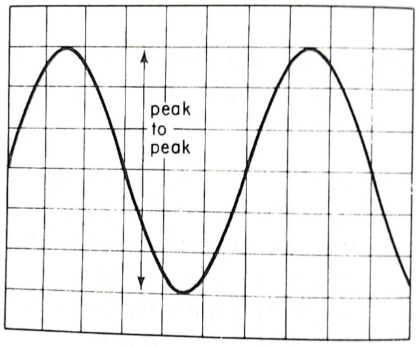


Figure 6.23.5: *Sine wave*

The parameter of voltage that is mostly determined using the oscilloscope is for a sinewave, peak-to-peak value. The magnitude is determined using the engravings on the graticule, in conjunction with the calibrated ranges of the input amplifier. Given that for the waveform in ***figure 6.23.5*** above:

- The peak-to-peak height is 6 divisions (the number of divisions or centimetres)
- The Y-gain setting is used to determine the number of volts/division.
- Given that the amplifier sensitivity is set to 20 mV/division, the peak –to-peak amplitude is $20 \times 6 = 120$ mV.

Multimeter

The multimeter is a general-purpose instrument (a device used to determine the present value of the quantity under measurement). It has the necessary circuitry and switching arrangement for measuring a.c / d.c voltage or current or resistance. It is reputed for its excellent reliability, and operational simplicity.

A digital instrument is a type of multimeter that displays its output in numerical reading form. It is simple, compact, and portable. The main drawback of the digital multimeter is the confusing display, where the measured value is not constant. This is known as the 'Fruit Machine Effect'. The digital meter samples the input conditions and if each update is different, readings are difficult to take.

Figure 6.23.6: *Digital multimeter*

Figure 6.23.7: *Analogue multimeter*

Common features of multimeter

A multimeter is a versatile and essential tool for working with electrical circuits. Each feature enhances the multimeter's utility and makes it a powerful tool for diagnostics and troubleshooting in electrical and electronic work. Some of its key operational features are as follows:

- **Voltage Measurement**: AC and DC voltage measurements.
- **Current Measurement**: AC and DC current measurements.
- **Resistance Measurement**: Measures the resistance in a circuit.
- **Continuity Test**: Checks if there is a continuous path between two points in a circuit, often with an audible beep for confirmation.
- **Diode Test**: Tests the forward voltage drop of a diode to check its condition.
- **Capacitance Measurement**: Measures the capacitance of capacitors
- **Frequency Measurement**: Measures the frequency of AC signals.
- **Temperature Measurement** (in some models): Measures temperature using a thermocouple probe.
- **Data Hold Function**: Holds the displayed measurement value for easy reading.
- **Auto-Ranging**: Automatically selects the appropriate measurement range for the parameter being measured.
- **Backlit Display**: Enhances readability in low-light conditions.
- **Safety Feature**: Overload protection to prevent damage to the meter.
- **Analog Bar Graph** (in some models): Provides a visual representation of the measured value.

Using the Multimeter

Ohm-meter (resistance measurement)

For measuring resistance, the ohm-meter leads are connected across the unknown resistance after switching off the power in the circuit under test. The meter terminals are never connected to an energised circuit when measuring resistance. Also ensure that there is no parallel branch connected across the component whose resistance is being measured.

The ohm-meter battery can provide current for the meter movement. When the leads are open, the meter current becomes zero. The resistance scale is non-linear due to the reciprocal function of $\boldsymbol{I = V/R}$.

The procedure to measuring resistance is as follows:

1. Insert the black lead jack of the meter into the port marked 'COM'

2. Insert the red lead jack into the port marked 'VΩ'.
3. Select the appropriate resistance range on the meter. The caution here to select a range that is higher than the estimated resistance of the circuit or component.
4. Switch off power to the circuit or in the case of electronic components, remove the component from the circuit.
5. Connect the probes of the meter to the two points of the circuit or the component whose resistance is to be measured.

Note that measuring resistance measurement is not polarised. Once the multimeter is connected, it will display the resistance value of the component. If the component is a resistor, the reading should be close to its nominal value as indicated on its body. If the component is a conductor, the reading should be very low, close to zero ohms.

- Ensure that the connections are secure (tight) to obtain accurate readings.
- A reading that deviates significantly from the expected value may indicate a **faulty component** or a problem in the circuit

Common Mistakes to Avoid

To ensure accurate resistance measurements, it is essential to avoid common mistakes.

These include:

1. Using the wrong multimeter range: Selecting an inappropriate range can result in inaccurate or even damaging readings.
2. Improper connections: Loose or incorrect connections can lead to unreliable measurements.
3. Measuring resistance while the component is powered: This can result in incorrect readings and potential damage to the multimeter.
4. Not considering the component's tolerance: Resistors have a specified tolerance, which indicates the deviation from their nominal value.

Current Measurement

The current meter must be connected in series with the circuit. The d.c meter must be connected with the correct polarity for the pointer to read up-scale to the right. Reversed polarity deflects the pointer down scale to the left, and sometimes bends the pointer. To measure current in a circuit, the following procedure must be followed:

1. Break the positive wire of the circuit and ensure that the conductors are exposed.
2. Insert the black lead jack of the meter into the port marked 'COM'
3. Insert the red lead jack into the port marked 'mAVΩ'. Note that if the current being measured is very high use the port marked '10A' Select the appropriate current range on the meter depending on whether it is ac (ACA) or dc (DCA)

4. Connect the red probe of the meter to the wire leading to the source of power supply.
5. Connect the black probe to the other wire leading to the circuit. Finally, connect the multimeter in series with the circuit and observe the current value displayed.
6. Take the reading on the meter. If the multimeter displays 'OL,' select the next range.

Voltage Measurement

The Voltmeter is connected in parallel with the load whose voltage is to be measured.

1. The procedure for measuring voltage is as follows:
2. Insert the black lead jack of the meter into the port marked 'COM'
3. Insert the red lead jack into the port marked 'mAVΩ'.
4. Select the appropriate voltage range on the meter depending on whether it is ac (ACV) or dc (DCV). If there is uncertainty about what voltage setting to use, start at the highest one and work the way back until an accurate result is obtained.
5. Connect the probes of the meter parallel to the circuit.

   Note that the polarity of the probes does not matter when measuring AC voltages. However, if it is DC, the **red** probe must be on the positive side of the power source and the **black** on the negative side.

   - Read the measurement on the meter, If the multimeter displays 'OL,' select the next range.

Operation of Analog Multimeter

The analog multimeter is very easy to use. With the knowledge of how to make voltage, current and resistance measurements, it is only necessary to know how to use the analogue multimeter.

For the measurement of current and voltage, there is no need for batteries in the analogue multimeter. But, if resistance is to be measured, batteries need to be installed in the multimeter.

Steps for the use of analogue multimeter

1. Insert the probes into the correct connections.
2. Set switch to the correct measurement types and range for the measurement to be made. While selecting the range, ensure that the maximum range is above than that is expected. The range of multimeter is then optimised for the best reading.

3. Once the measurement is completed, it is wise precaution to place the probes into the voltage measurement sockets and set the range to maximum voltage. In this way if the meter is accidently connected across a high voltage point, there is a little chance of damage to the multimeter.

Measuring hFE of a transistor: The hFE is the current gain of a transistor. It has no unit. To measure the hFE, first be sure of the type of transistor being tested, whether it is an NPN or PNP.

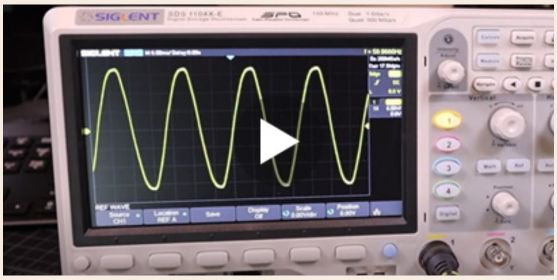
Activity 6.23.1 Understanding and using CRO versus LCD oscilloscopes

Scenario

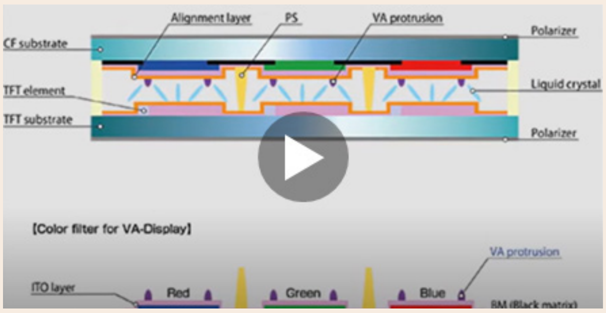
Your laboratory has recently received both a Cathode Ray Oscilloscope (CRO) and a modern Liquid Crystal Display (LCD) oscilloscope. As future electrical technicians, you need to understand how these devices work, how to differentiate them, and how to use them effectively in making measurements. You will also explore the advantages of using an LCD over a CRO.

Video Guides

- Link to oscilloscope video: https://youtu.be/lSHAE_Y6snc?si=RbkOkUids_Wevzpb



- Link to LCD video: https://youtu.be/RZacFDPW_34?si=GHJ-iKN_KiPOW06h



While observing, note:

1. The differences between CRO and LCD.
2. How the LCD produces a trace.
3. How the oscilloscope is used to take measurements.

Task 1: CRO vs LCD

Learning Task: Differentiate between the CRO and the LCD.

Activity Steps:

1. In pairs, list properties of CRO and LCD using internet, books or other resources available
2. Complete the comparison table below.
3. Share your answers in a class discussion.

Comparison Table: CRO vs LCD Oscilloscope

Feature	CRO (Cathode Ray Oscilloscope)	LCD (Liquid Crystal Display Oscilloscope)
Display type		
Power consumption		
Portability		
Clarity of display		
Applications		

Task 2: Trace Production in LCD

Learning Task: How does the LCD produce a trace?

Activity Steps

1. Observe a diagram or video showing CRO and LCD displays.
2. In groups, discuss how electrons form a trace on a CRO and how liquid crystals produce a trace in an LCD.
3. Define and explain the terms SWEEP and FLYBACK.
4. List three advantages of LCD over CRO.
5. Present your group's explanation to the class.

Task 3: Using the Oscilloscope for Measurements

Learning Task: Explain how the oscilloscope is used to take measurements.

Activity Steps

1. Study a demonstration of an oscilloscope connected to a test circuit.
2. In small groups, practise identifying how to measure voltage, time period, and frequency using the oscilloscope.
3. Draw labelled diagrams of typical oscilloscope screen readings.
4. Present your findings to the class.

Task 4: Experiential Measurement with Instruments

Learning Task: Practise measuring quantities using a multimeter and compare with oscilloscope readings.

Activity Steps

1. Measure voltage, current and resistance in a simple circuit using a digital multimeter.
2. Observe how the oscilloscope trace gives more information about the waveform than the multimeter.
3. Record your observations in a table (Instrument, Quantity Measured, Observation).
4. Share your findings with the class using the table below:

Observation table: Multimeter vs Oscilloscope

Instrument Used	Quantity Measured	Observation / Reading
Digital Multimeter	Voltage (V)	
Digital Multimeter	Current (A)	
Digital Multimeter	Resistance (Ω)	
Oscilloscope	Voltage (V) waveform	
Oscilloscope	Time period / Frequency	
Oscilloscope	Waveform shape	

Case Study Challenge

Your school has limited funds and is considering whether to continue using CROs or invest in LCD oscilloscopes. As a technician-in-training:

- What advantages would LCD oscilloscopes provide in terms of portability, clarity and power use?
- How would you explain the difference in trace production between CRO and LCD to first-year students?
- In what situations might the CRO still be the preferred instrument?

Application Questions

1. State three differences between CRO and LCD.
2. Explain the meaning of the terms SWEEP and FLYBACK.
3. How can you measure the frequency of a waveform using an oscilloscope?
4. Why is the oscilloscope more useful than a multimeter for analysing signals?

Reflection

In your tablet, notebook or worksheet, reflect and write:

1. One new thing I learned about CRO and LCD.
2. The most interesting measurement I can make with an oscilloscope.
3. How I can apply oscilloscope knowledge in real-life technical work.

EXTENDED READING

- E.C Sraha (2016).Applied Electricity and Electronics for SHTS Books Galore Ventures, Koforidua.
- Oscilloscope - Wikipedia
- https://www.watelectronics.com/multimeter/#google_vignette
- https://www.tek.com/-/media/sites/default/files/images/xyz-of-scope-image/tek-xyz-primer-c4-figure66-750x336.png?w=750
- https://www.infotransistor.com/defining-and-measuring-current-gain-hfe-in-transistors/#:~:text=Checking%20hFE%20with,at%20the%20number.
- https://www.ntchip.com/electronics-news/what-is-transistor

Review Questions

1. Define the following terms as they relate to measuring instruments
    a. Oscilloscope
    b. Multimeter
2.
    a. What are the functions of the following as they relate to multimeters
        i. OHM
        ii. DCA
        iii. ACA
        iv. DCV
        v. ACV
    b. Describe the procedure for measuring Resistance and hFE with a multimeter.
3. Input a signal with the following characteristics into an oscilloscope
    a. 1 volt (2v peak-to-peak) signal. In other words, it has a peak of 1 volt and a negative “peak” at -1 volt.
    b. A frequency of 1000 Hz (i.e. 1 KHz).

UNIT 24

DESIGNING ELECTRONIC CIRCUITS

Introduction

To understand the concepts in this unit, there is a requirement for you to make a simple fire detector alarm circuit using a BC547 transistor and an IR detector LED on a Breadboard. This circuit can easily detect any fire nearby and accordingly start the buzzer.

Transmitters are a necessary component of all electronic devices that communicate by radio, such as radio (audio) and television broadcasting stations, cell phones, walkie-talkies, wireless computer networks, Bluetooth devices, navigation beacons, etc.

An FM transmitter circuit is a high-frequency wireless device which is able to transmit voice signals into the atmosphere so that they can be received by a corresponding FM receiver circuit for reproducing the voice signals in a loudspeaker.

KEY IDEAS

Applying knowledge of electronic components to design and build a:

- Fire alarm circuit
- Frequency modulated (FM) transmitter circuit

This unit requires you to work individually at times to build functioning electronic circuits.

FIRE ALARM SYSTEM

The ways a fire alarm system works to protect property and its occupants from the dangers of fire are by:

1. Detecting fire, through smoke and heat.
2. Alerting occupants of a building using, loud, bright and intolerable audible and visible alarms.
3. Managing risk, by reacting to potential risks using control measures. When the alarm is activated, some systems perform a set of tasks that help prevent fire smoke from spreading.
4. Notifying the fire department, this ensures the fire department is en route as quickly as possible, so they can respond and extinguish the fire before it becomes an even bigger threat.

Project one: Building a Fire Alarm Circuit

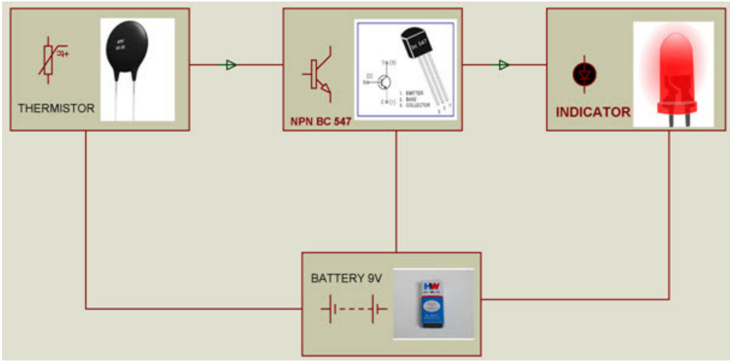


Figure 6.24.1: *A block diagram of a fire alarm circuit*

Working Principle of Fire Detector

In this fire alarm circuit, is an infrared detector LED. The infrared radiation emitted from the fire is detected by the infrared LED and voltage across the infrared led changed. The Anode of the infrared LED is connected with the base of the BC547 NPN transistor. Due to the positive pulse in the base, the transistor turns on and current can flow in through buzzer – Collector – Emitter.

If there is no fire then no positive pulse fed to the transistor base so the BC547 transistor remains in off mode. So that time current cannot flow through the buzzer. Buzzer is an audio signalling device that serves as an audible indicator. Its main function includes emitting sound when activated providing warnings as alarm devices.

Circuit Diagram of Fire Detector

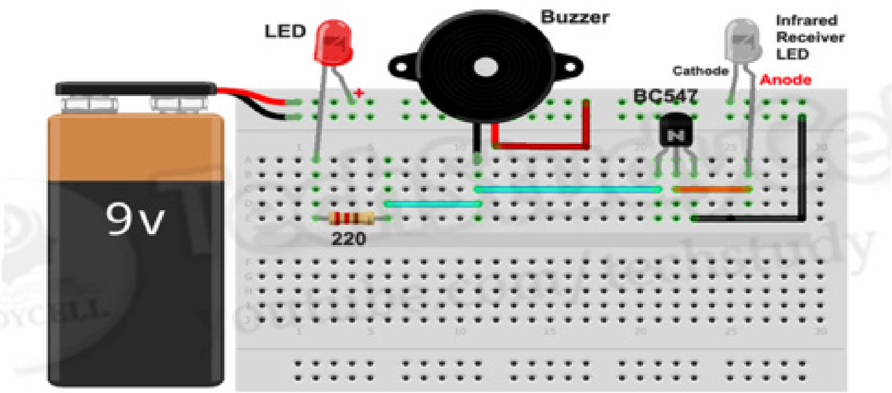


Figure 6.24.2: fire *detector circuit diagram*

Table 1: Components and materials for building a fire alarm circuit

Component/material	Quantity
Thermistor	1
Transistor (NPN BC547)	1
LED	1

9V Battery	1
Toggle switch	1
Resistor 220Ω, 1/2W	1
Bread board	1
Connecting wires	1
Matrix board	1
Soldering iron and solder	1
Solder sucker	1

Procedure for Connecting the Circuit

1. Place the breadboard on the table.
2. Observe the location of the circuit components on the breadboard. Take the short lead of the LED and place it in one hole in line with the red wire from the battery on the board.
3. Drop the other lead into another hole.
4. Plant the other components, the buzzer, transistor BC 547, resistor, infrared LED/ thermistor in their positions.
5. Cut the connecting wires into short pieces and peel both ends with a small cutter.
6. Use the connecting wires to link the terminals of the components as carefully observed on the board in fig.3
7. Use the multimeter to test the circuit for continuity.
8. Connect the battery to the circuit.
9. Bring a heat source close to the Infrared LED/thermistor and observe the behaviour of the buzzer.

FM TRANSMITTER

In electronics and telecommunications transmitter (TX) is an electronic device which produces radio waves with an antenna for the purpose of transmitting a signal up to a radio receiver.

The transmitter itself generates the radio frequency alternating current and applies it to the antenna. The antenna is excited by the alternating current and radiates radio waves.

The term transmitter is usually limited to equipment that generates radio waves for communication purposes, or radiolocation such as radars and navigational transmitters. The term is popularly used more specifically to refer to a broadcast transmitter, a transmitter used in broadcasting as in FM radio transmitter or television transmitter

Building an F.M Transmitter Circuit

Table 2: Components and materials for building an F.M. transmitter circuit

Component/material	Quantity
Resistor (R1) = 15KΩ	1
Resistor (R2) = 1KΩ	1
Capacitor (C1) = 0.001μF	1
Variable Capacitor (C2) = 10-40 PF	1
Capacitor (C3) = 4.7 PF	1
Inductor (L) = wire coil	1
Antenna = 15 inch	1
Audio jack pin/headphone jack pin.	1
Bread board	1
Connecting wires	1
Matrix board	1
Soldering iron and solder	1
Solder sucker	1

This project is aimed at making the simplest FM transmitter using one transistor. This project is being made with a smaller number of components to make it an easy and simple project for beginners. The schematic diagram displays the components required for making an FM transmitter. The transmission range of this transmitter circuit is approximately 10-20 meters.

The schematic of FM transmitter is given below:

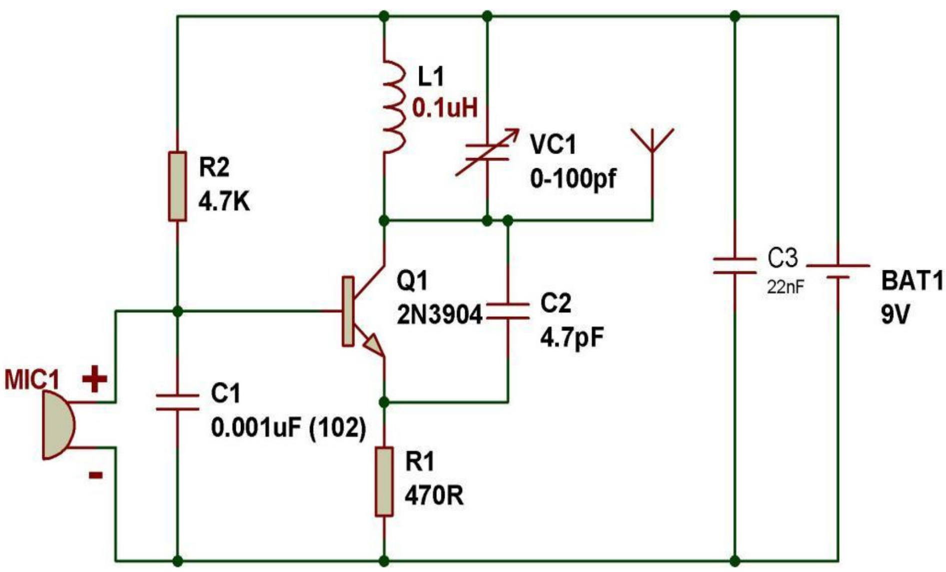


Fig. 6.24.3: *A schematic diagram of FM transmitter*

The components for this project are as follows:

1. Q1- Transistor - 2N3904

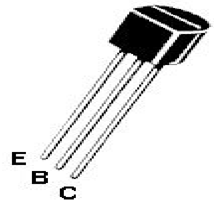


Fig. 6.24.4: *Picture of a transistor*

2. Capacitors - 4.7pF, 20pF, 0.001uF, 22nF
3. Variable capacitor *VC1). It is also called trimmer capacitor. The capacitance range should be 0-100pF or 10-100pF. A trimmer capacitor that has minimum capacitance of 20pF can also be used.

Fig. 6.24.5: *Picture of a variable capacitor.*

4. Resistors - 4.7 kΩ, 470 Ω

Fig.6.24.6: *Picture of resistor*

5. Condensor/ Electret microphone

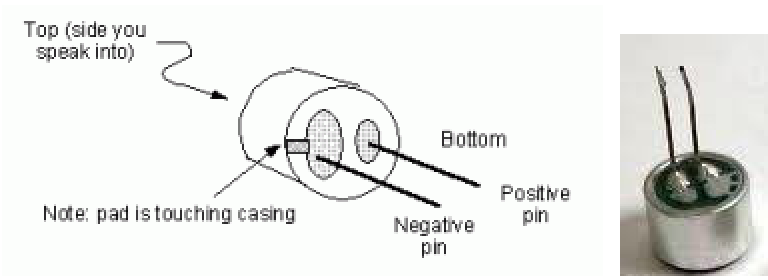


Fig. 6.24.7: *A picture of an Electret microphone*

On one of the pins of the electret microphone, there is solder pad connected to the case of microphone, it is always negative terminal.

6. Inductor- 0.1uF. 6-7 turns using 26 SWG wire. Scrap the ends of inductor, otherwise, the inductor won't work, or use another inductor of value 0.1 μH.

Fig. 6.24.8: *A picture of a coil*

7. **Antenna:** Use 15cm to 1-meter-long wire for the antenna. The longer the antenna, the signal transmission will be better.
8. A fixed 20 pF capacitor can be used in place of a trimmer/ variable capacitor.

Procedure for building FM Transmitter circuit

Follow the steps below to build the project. Insert the:

- Transistor
- Resistors
- Capacitors
- Electret microphone on the breadboard.
- Use pieces of wires to link the components on the board.
- Use 15cm long normal wire for the antenna.
- With a non-conductive tool, adjust the capacitor for the clearest reception, rotate it till the receiver receives a sound from the microphone of the transmitter.
- Set your FM receiver for a clear, blank station.

Tools:

- Wire cutters
- Pliers or wire strippers
- Multimeter (optional)

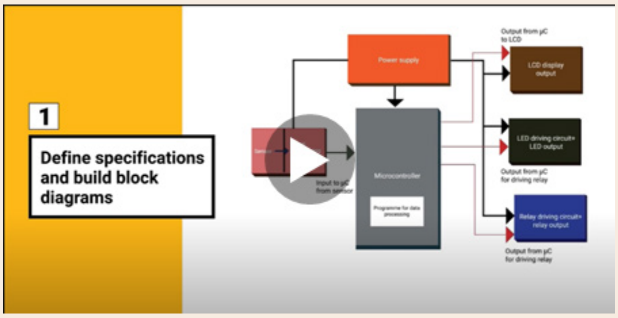
Activity 6.24.1 Designing and understanding fire alarm circuits

Scenario

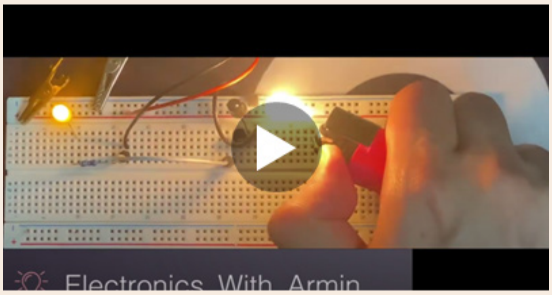
Your community recently experienced a fire outbreak in a student hostel; to prevent future disasters, you and your classmates have been tasked with designing a simple electronic fire alarm circuit that can detect smoke or heat and trigger an alarm. As upcoming electrical technicians, you must understand the concept of electronic circuit design, identify the necessary components and explain the importance of each component in building a reliable fire alarm system.

Video Guides

- Link to circuit design video: https://youtu.be/RzRCgOBgr18?si=hD-Mq3fjzIDUWQ5c4



- Link to fire alarm video: https://youtu.be/jc5K2RMGQY0?si=d-J5WQeK10JJOixUc



While observing, note:

1. The concept of electronic circuit design.
2. The components and materials needed to build a fire alarm circuit.
3. The importance of at least four electronic components used in the circuit.

Task 1: Concept of Electronic Circuit Design

Learning Task: Explain the concept of electronic circuit design.

Activity Steps:

1. In pairs, discuss what electronic circuit design means.
2. Share real-life examples of simple electronic circuits e.g. fire alarm, FM transmitter, light sensor.
3. Record a short definition of electronic circuit design in your notebook.
4. Present your definition to the class for comparison and refinement.

Task 2: Identifying Fire Alarm Circuit Components

Learning Task: Identify at least three components and materials needed to build a fire alarm circuit.

Activity Steps:

1. In small mixed-ability groups, brainstorm and list possible components e.g. resistors, thermistor, buzzer, power source, transistors, etc.
2. Use circuit diagrams or teacher-provided resources to confirm your choices.
3. Record your group's list in a table (Component, Symbol, Use).
4. Present your findings to the class the table format below:

Table: Fire Alarm Circuit Components

Component	Symbol	Use/Function

Task 3: Importance of fire alarm circuit components

Learning Task: Describe the importance of at least four electronic components used in building the fire alarm circuit.

Activity Steps

1. In your groups, select four components e.g. thermistor, transistor, buzzer, etc.
2. Write down the role of each component in the circuit.
3. Create a poster or chart showing these components and their functions.
4. Display your poster in class and explain it to your peers.

Task 4: Group Project – Fire Alarm Circuit

Learning Task: Collaboratively build or simulate a simple fire alarm circuit.

Activity Steps:

1. In groups, collect materials (breadboard, resistors, thermistor, transistors, buzzer, power supply).
2. Assemble the circuit step by step with guidance from your teacher or video guide.

3. Test the circuit by simulating heat/smoke to trigger the alarm.
4. Record observations and improvements needed.
5. Share your project results with the class

Case Study Challenge

A school dormitory wants to install fire alarm systems in each block. The administration must decide whether to use simple electronic fire alarm circuits or purchase expensive imported systems.

- How would you explain the benefits of designing a local fire alarm circuit?
- Which components are essential, and why?
- How could teamwork and knowledge of electronic circuit design help reduce costs and improve safety

Application Questions

1. What is meant by electronic circuit design?
2. List at least three components needed to build a fire alarm circuit.
3. Explain the function of:
   a. Thermistor
   b. Transistor
   c. Resistor
   d. Buzzer
4. Why is the fire alarm circuit important in schools and workplaces?

Reflection

In your tablet, notebook or worksheet, reflect and write:

1. One new thing I learned about electronic circuit design.
2. The most important component in a fire alarm circuit and why.
3. How I can apply knowledge of circuit design to solve safety challenges in my community.

EXTENDED READING

- Fire Alarm System Basics: The 4 Purposes of Your System - Vanguard
- https://easyelectronicsproject.com/wp-content/uploads/2020/04/Fire_Alarm_BC547_2-1024x576.jpg

Review Questions

1. Explain the concept of electronic circuit design.
2. Identify at least three components and materials needed to build a fire alarm circuit.
3. Describe the importance of at least four electronic components used in building the fire alarm circuit.

ANSWERS TO REVIEW QUESTIONS

UNIT 1

1. House wiring is the arrangement of electrical circuits and accessories such as distribution boards or circuit breaker panels, switches, lamp holders, socket outlets, light fittings, and cables that distribute electricity from the main supply to equipment and appliances in different parts of a house.
2. Proper installation practices are crucial for the safety and functionality of house wiring systems. By following these important steps and techniques, homeowners can avoid electrical hazards and ensure the longevity of their electrical systems.
    - **Planning and design:** Before embarking on any house wiring installation, it is essential to have a well-thought-out plan and design. Consider factors such as the electrical load requirements, placement of outlets and switches, and the size and capacity of the electrical panel. Engaging a qualified electrician or professional electrical engineer can help ensure a comprehensive plan that adheres to safety standards.
    - **Gathering the right tools and materials:** Having the right tools and materials is crucial for a successful house wiring installation. Some essential tools include wire cutters, cable strippers, screwdrivers, electrical tape, and wire connectors. When it comes to materials, high-quality wires, cables, switches, and outlets from reputable brands are indispensable for a safe and reliable electrical system.
    - **Adhering to safety standards:** Safety should always be the top priority during the installation process. Use appropriate personal protective equipment, such as gloves and safety glasses. Adhere to all electrical and building codes and guidelines to prevent accidents and ensure compliance with legal requirements.
    - **Proper wire routing and placement:** Wires should be routed and placed carefully to minimise the risk of damage and ensure efficient power distribution. Keep wires away from heat sources, sharp edges, and areas prone to moisture. Properly secure the wires to prevent them from sagging or coming in contact with other objects or surfaces that may cause damage.
    - **Correct wire termination:** Proper wire termination is essential to maintain a secure electrical connection. Use appropriate wire connectors and terminals, ensuring that the right gauge and size are used for the specific wire type. Follow manufacturer guidelines for proper stripping, twisting, and connecting techniques to ensure a reliable connection.

- **Thorough testing and inspection:** After the installation is complete, thorough testing and inspection should be conducted to ensure the system's functionality and safety. Test each circuit, outlet, and switch to verify proper wiring, grounding, and connection. Consider engaging a qualified electrician for a comprehensive inspection to identify any potential issues or areas of improvement.

3. Two benefits of safely wiring a house

- **Safety:** Proper wiring is essential to ensure the protection of individuals and property from the risk of sparks, fires, electrocution, and electric shock and damage to electrical appliances.
- **Functionality:** Properly wired circuits provide the necessary voltage and current needed for all connected electrical devices to function properly.

4. Write out the steps involved in house wiring

- Obtain the electrical detailed/working building plan and identify the electrical symbols.
- Mark out the locations of the electrical switchboard/circuit breaker, switches, sockets and conduits for each room on the walls.
- Chisel the wall markings for the conduit and other electrical fixtures.
- Install the conduit and electrical boxes for outlets, switches, and fixtures at this stage and hold them in place with mortar.
- Run the cables from the main electrical panel to each box, following the layout defined in the planning phase for all sub-circuits.
- Conduct tests designed to detect and correct any flawed issues before the system is energised to reduce the risk of electrical fires, shocks, or equipment damage.
- Check for continuity, measure voltage levels, and test each circuit to confirm its functionality and safety.

UNIT 2

1.

a.

- Hand tools
- Power tools
- Testing and Measuring equipment
- Safety equipment
- Special tools

b. **Five Hand Tools:** Screw drivers, Wire strippers, Pliers, Utility knife, Side-cutting pliers.

Five Power tools: Impact driver, Wall chaser, Power drill, Rotary hammer, Power chisel

2.

a. **Tools** are gadgets used to manipulate materials to carry out specific tasks or operations in the electrical installation work. They are usually handheld and are manipulated by hand to perform various actions while **materials** refer to the components or elements used to create or undertake the electrical wiring task.

b.

- **Multimeter:** It is a versatile tool used to measure different electrical quantities such as voltage, current, and resistance. It is also used for detecting electrical problems to ensure that circuits function correctly.
- **Continuity tester:** It is used to check if an electrical circuit is complete or continuous and uninterrupted to ensure free flow of electricity.
- **Insulation resistance tester:** an electrical testing instrument used to measure the electrical insulation resistance of cables. It values the reliability and quality of insulation in electrical cables and wires.

c. Various methods are available for cleaning electrical equipment, with the most suitable choice depending on factors such as the type of apparatus and the operating environment. Regardless of the method chosen, it is crucial to follow manufacturer guidelines, industry standards, and safety protocols when cleaning electrical equipment

- **Rags and Brushes:** Wiping off dirt with a clean, dry, lint-free cloth or soft brush is usually satisfactory if the apparatus is small, the surfaces to be cleaned are accessible, and only dry dirt is to be removed. Use care to avoid damage to delicate parts. Rags can easily catch on edges and other sharp objects, which could damage small plastic or moving parts. Do not use waste rags when cleaning electrical equipment because lint /fur will adhere to the insulation, acting as a further dirt-collecting agent. Cloth rags should be clean and free of oil, grease, and metallic deposits.
- **Liquid Solvents and Water:** Accumulated dirt, oil, or grease might require a solvent to be removed. A rag barely moistened (not wet) with a non-flammable solvent can be used for wiping. Solvents used for cleaning electrical equipment should be selected carefully to ensure compatibility with the materials being cleaned. Do not use any liquid cleaners, including spray cleaners, unless specified by the equipment manufacturer, because of the risk of residues causing damage, interfering with electrical or mechanical functions, or compromising the integrity of insulation

surfaces. Allow sufficient time for drying after cleaning equipment with a liquid solvent or water! Wear the required personal protective equipment (PPE), such as goggles, gloves, aprons, and respirators, when working with potentially hazardous solvents.

- **Vacuum Cleaning:** Loose dust, dirt, and particles can be removed using a vacuum-type cleaner with non-metallic attachments and hoses. Blowing equipment out with compressed air is likely to spread contamination and damage insulation. Equipment enclosures and substation room filters should be cleaned at regular intervals and replaced if they are damaged or clogged.
- **Sweeping and Moping:** If sweeping a substation room is required, use a sweeping compound to limit the amount of dirt and dust becoming airborne. When mopping, keep the mop bucket as far as practical from the switchgear to prevent damage from spillage.
- **Compressed Air Methods for Cleaning Electrical Equipment:** Where dirt cannot be removed by wiping or vacuuming, compressed air blowing might be necessary.

3.

a. Measuring instruments ensure that:

- electrical circuits operate within precise specifications,
- there is no guess work,
- there are no errors, inefficiencies and potential safety hazards,
- the electrician's work cannot be done without measuring instruments.

Measuring tools make measurement better and safer, and enhance the quality and quantity processes. Their ability to measure physical properties accurately adds tremendous value to work schedules.

b. Evaluating Tool Performance: When choosing between hand tools and power tools, the primary considerations is often the performance of the tool. This includes:

- **Speed:** Power tools excel in speed as they can cut rapidly through materials, whereas doing the same with a hand tools would take a lot more time and effort.
- **Precision:** Power tools can achieve consistent and accurate results, especially in repeat tasks. Hand tools allow for intricate control but may require more skill to achieve similar levels of accuracy.

c. In today's technologically advanced world, electricity is a vital energy source that powers homes, offices, factories, and other industrial facilities. However, this resource can bring serious hazards from electrical fires and burns, electrical shocks and fatalities (electrocution) if safety requirements /standards are not complied with. These dangerous incidents, in turn, can make a huge dent on the individual's or company's finances. For this reason, basic electrical safety is of utmost importance in any workplace that utilises electricity as a fundamental part of its day-to-day operations.

d. Visually inspect cords for defects such as:

- cracking, fraying/ wearing and signs of faults in the outer jacket of the cord or the insulation (pinched or crushed),
- heat damage,
- placing cords under stress,
- correct mating of plugs to cords.

UNIT 3

1. Materials

- electrical wires and cables
- conduit and tubing
- connectors and terminals
- electrical junction boxes
- insulation materials
- Clips and staples

Accessories

- Ceiling rose
- Lamp holder
- Socket outlets
- Switches
- Plugs

2. Materials refer to the components or elements used to create or undertake the electrical wiring task to distribute electricity from the main supply to equipment and appliances in different parts of a house. Without materials, there will be no electricity in our homes. Wiring accessories are essential components used to connect, protect and manage electrical circuits. They are used for convenience, safety, effectiveness and attractiveness to protect and complete the wiring installation.

3.

- Wiring is subject to safety standards for design and installation.

- Allowable wire and cable types and sizes are specified according to the circuit operating voltage and electric current capability.
- International, National and local regulations
- Restrictions on the environmental conditions, such as ambient temperature range, moisture levels, and exposure to sunlight and chemicals.
- Type of occupancy and size of the building also play important parts in what gauges are used, as lighting types and socket numbers/types will differ widely between residential housing types.

UNIT 4

1. Electricity Meter, cutout fuse, Isolator, Distribution Board.
2. The order in which the electrical equipment is arranged regulates the flow of electricity supply to the consumer.
3.
    - **Energy Meter:** The electricity supply starts from the energy meter, which measures the amount of electricity consumed.
    - **Main Switch or Circuit Breaker (MCB):** The main switch or double-pole circuit breaker (DP MCB) acts as the primary control to cut off the power supply to the entire system.
    - **Residual Current Device (RCD):** The RCD detects any leakage current and disconnects the circuit to prevent electric shocks.
    - **Distribution Board:** The distribution board, also known as the consumer unit, houses the circuit breakers, fuses, and other protective devices.
    - **Circuit Breakers (MCBs):** Single-pole circuit breakers (SP MCBs) are connected to protect individual circuits.
4. The energy meter is connected to the main switch or circuit breaker; the main switch is connected to the Residual Current Device (RCD), and then to the distribution board and individual circuit breakers.

UNIT 5

1. Excess current, also known as overcurrent, occurs when the amount of electric current flowing through a conductor is higher than intended. This can lead to overheating, which can cause damage to equipment or even start a fire.
2. Thermal magnetic circuit breakers and thermal overload are the main methods of excess current protection.
3. The preferred type of protection in modern-day domestic premises is the Residual Current Device (RCD).

- **Fast Response:** RCDs are incredibly sensitive to small current imbalances (as little as 30mA) and react very quickly (within milliseconds) to trip and cut off the power supply. This rapid response significantly reduces the risk of electric shock
- **Enhanced Safety:** They provide protection against earth faults, which are dangerous electrical faults that can occur when live wires come into contact with the earth or a person.
- **Protection in Damp Conditions:** RCDs are particularly important in areas with higher moisture levels, such as bathrooms and kitchens, where the risk of electric shock is increased.

In essence, RCDs offer a crucial layer of safety by quickly interrupting the power supply in the event of a dangerous electrical fault, minimising the risk of injury or even death.

UNIT 6

1. Surface wiring can be used to the best effect in several situations such as Retrofitting Older Homes, Temporary Installations, Adding Circuits to Existing Rooms, Exposed Architectural Styles and Limited Access.
2. Concealed wiring is best used in situations where aesthetics and safety are paramount such as New Construction, Existing Homes with Renovations, High-Traffic Areas and Historic Buildings:
3. Surface wiring generally has more variations than concealed wiring.
   - Offers greater flexibility in terms of appearance and installation methods. Variations include:
   - Casing and Capping
   - Trunking
   - Conduit
   - Wiring
   - Batten Wiring
4. Sharp edges on steel conduits must be rounded, smoothed or fitted with brass bushes for several critical reasons:

Safety

a. **Injury Prevention:** Sharp edges pose a significant risk of cuts and abrasions to electricians during installation, maintenance, and repairs.

b. **Cable Damage:** Sharp edges can damage the insulation of electrical cables as they are pulled through the conduit, potentially leading to short circuits or electrical faults.

Ease of Installation

a. **Smooth Passage:** Rounded edges or brass bushes facilitate the smooth and easy pulling of cables through the conduit, reducing the risk of cable damage and installation time.

b. **Reduced Friction:** Smooth surfaces minimise friction, which can generate heat and potentially damage the insulation of cables.

Corrosion Resistance

a. **Brass Bushings:** Brass is more resistant to corrosion than steel, especially in damp environments. This helps to prevent the conduit from corroding and damaging the cables within.

Electrical Conductivity

Grounding: In some cases, steel conduits are used as part of the grounding system.

Rounded edges and smooth surfaces ensure good electrical contact and proper grounding

5. Characteristics can include

Characteristics	Surface conduit wiring	Concealed conduit wiring
Installation complexity	simple	complex
Aesthetic	Not Appealing	Appealing
Risk of damage	High	Does not exist
Risk of electric shock	High	None
Humidity and chemical effects	Unsafe	safe

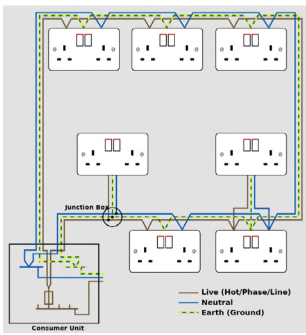
UNIT 7

1. A final circuit in an electrical system is the last part of the electrical distribution that directly supplies power to the end-use devices.

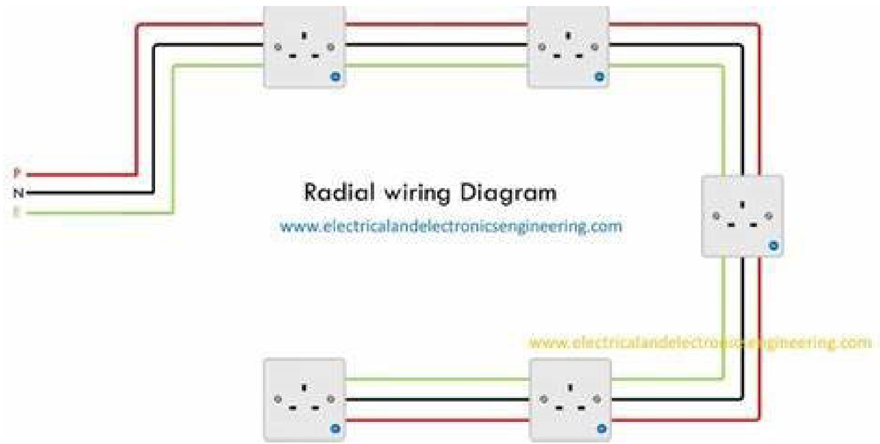
2. Write a short overview of the regulations

3. Find the appropriate answer within the IOEE regulations

4. Find the appropriate answer within the IOEE regulations



A wiring diagram of a ring circuit



A wiring diagram of a radial circuit

UNIT 8

1. Double Pole (DP) MCB (the main circuit breaker, main isolator or main switch).
   - Residual Current Devices RCD (Also DP) for safety.
   - Single Pole (SP)
   - MCB (Circuit Breakers and Fuses).
   - Miniature Circuit Breaker and Circuit Breaker (MCB & CB).
2. To test and commission an electrical distribution board, it is important to;
   - Carry out a visual inspection to check for any damage or loose connections.
   - Test all of the electrical circuits for proper voltage, amperage, and continuity.
   - Verify nameplate details for rating in accordance with approved General Arrangement (GA) drawings.
   - Check for physical damage.
   - Check for electrical/functional checks.
3. There are two main test instruments used, namely:
   - Insulation resistance tester with variable voltage settings.
   - Multimeter.
4. Uses of the main test instruments:
   - Insulation resistance tester with variable voltage settings is used to determine the insulation resistance of a cable, installation, motor, or appliance. The principle is to apply a known DC voltage and then measure the flowing current.
   - Multimeter is used to measure and display electrical properties like voltage, current, and resistance.

UNIT 9

1. Earthing, or grounding, is the process of connecting parts of electrical apparatus, such as metallic coverings and the earth terminals of socket cables, as well as stray wires that do not carry current, to the earth or ground.
2. Earthing is provided for the following reasons:
   - **To avoid electric shock:** This is a primary purpose of earthing. By connecting the electrical system to the ground, the risk of electric shock is significantly reduced.
   - **To avoid the risk of fire:** Earth leakage current, if not properly grounded, can follow unintended paths and lead to the risk of fire. Proper earthing helps direct such currents safely to the ground.
   - To ensure that no current-carrying conductor rises to a potential with respect to the general mass of earth beyond its designed insulation.
   - Maintaining the designed insulation of conductors is critical. Earthing prevents conductors from reaching potentials that could compromise their insulation.

UNIT 10

1. The purpose of the tests is as follows:
   - A polarity test ensures that electrical conductors are connected correctly to their terminals. This test is important for electrical safety because incorrect connections can lead to electrocution, fires, and damaged appliances
   - A continuity test is the checking of an electric circuit to see if current flows (that it is a complete circuit). A continuity test is performed by placing a small voltage (wired in series with an LED or noise-producing component such as a piezoelectric speaker) across the chosen path.
   - The purpose of an insulation resistance test is to assess the integrity of electrical insulation and identify potential problems. Insulation resistance tests can help prevent electrical shocks, short circuits, and other hazards.
2. Procedures for each test:
   - **Polarity test:** One end of the test lamp is connected to the earth wire and the other end to the incoming terminal of the switch. If the lamp lights, it indicates that the switch is connected to phase wire, if not, then it is reversed (to the neutral wire).
   - **Continuity test:** The ‘L’ (line terminal) of the megger is connected to the phase conductor in the main switch and ‘E’ (earth terminal) of the megger is connected to an earth point. The megger should indicate a resistance value between 0.5 and 1 mega ohm.

- The 'L' (line terminal) of the megger is connected to the short circuit point in the main switch, and the earth terminal marked (E) is connected to the earth continuity conductor or some good earth point nearby. The handle of the tester is turned at a high speed so that sufficient testing voltage is produced. The reading on the dial of the megger is noted. The insulation resistance thus measured should not be less than 0.5 MΩ on firm, sound and fixed wiring.

UNIT 11 & 12

1. Essential safety precautions
- Use the right tools for the right job.
- Use tools with insulated handles.
- Use a wire stripper to remove cable/wire insulation and not the teeth.
- Wear protective clothing.
- Avoid working in damp settings.
- Keep the work environment tidy.
- Do not scatter tools indiscriminately.
- Do not work on live circuits; put the power off.

2. A final circuit is one which is connected to any one way of a distribution board, or a switch fuse feeding one or more outlets without the intervention of a further distribution board.

UNIT 13

1. a. Fixed wire wound resistor

b. Light-dependent resistor

c. Thermistor

2. Tolerance is a percentage mark of the noticeable (nominal) value of the carbon resistor.

3. What are the colour bands in sequence according to this rhyme:
Black: Brown: Red: Orange: Yellow: Green: Blue: Purple: Grey: White

4. What are the values of the following resistors?

a. Brown – Black – Black
- **Brown:** 1st digit = 1
- **Black:** 2nd digit = 0
- **Black:** Multiplier = ×1
- **Resistance** = 10 × 1 = 10 ohms

b. Red – Violet – Black

- **Red:** 1st digit = 2
- **Violet:** 2nd digit = 7
- **Black:** Multiplier =× 1
- **Resistance** = 27 × 1 = 27 ohms

c. Brown-Black-Red

Brown: 1st digit = 1

Black: 2nd digit = 0

Red: Multiplier = ×100

Resistance = 10 × 100 = 1000 ohms (or 1 kΩ)

UNIT 14

1.

- Determine the first two significant digits
  - Orange = 3
  - Orange = 3
- Determine the multiplier: Red = × 100
- Calculate the capacitance: 33 x 100 = 3300 picofarads (pF)
- Determine the tolerance: Gold = ±5%
- Determine the voltage rating (from the red band): Red band for voltage rating indicates a voltage rating of 200 volts.

Therefore, the capacitor has the following values:

Capacitance: 3300 pF (3.3 nF)

Tolerance: ±5%

Voltage Rating: 200 volts

2. The capacitors

a. Fixed

b. Plastic

c. Electrolyte

d. Ceramic

e. Film

UNIT 15

1.

a. Iron core

b. Toroidal

c. Choke

2.

a. Impedance matching is the practice of designing or adjusting the input impedance or output impedance of an electrical device for a desired value.

b. **Oscillation:** Inductors can produce oscillations when combined with capacitors to form a resonant circuit.

3. A cell is a single electrochemical unit that converts chemical energy into electrical energy.

4. ***Cells in Series***

- **Voltage:** The total voltage is the sum of the individual cell voltages. Example: If you connect two 1.5V batteries in series, the total voltage is 3V.
- **Current:** The same current flows through each cell.
- **Application:** Used to increase the overall voltage of the system.

Cells in Parallel

- **Voltage:** The voltage remains the same as the voltage of a single cell.
- **Current:** The total current capacity increases. Example: If you connect two 1.5V batteries in parallel, the voltage remains 1.5V, but you can draw more current from the combination.
- **Application:** Used to increase the current capacity and provide longer operating time.

5. Energy density is the amount of energy stored in a battery relative to its weight or volume. It is important because it enables the battery to store more energy in a smaller or lighter package, which is essential for portable devices and electric vehicles.

6. Any four from

- Smartphones
- Laptops
- Tablets
- Cameras
- Portable music players

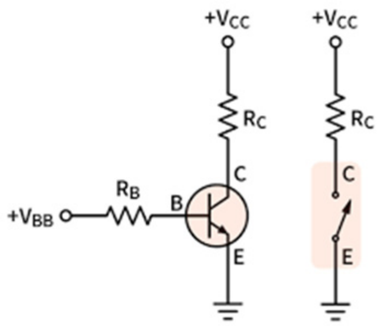
UNIT 16

1. E = Emitter; C = Collector; B = Base

2.

- It is used as a switch
- It is used as an amplifier
- It is used as an oscillator
- It is used as a demodulator

3. BJT as a switch

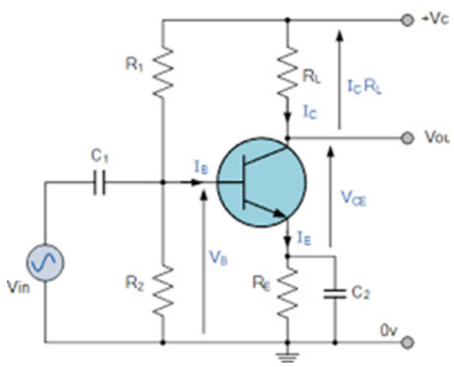


Switching Action

- **Off State:** When no or very little voltage is applied to the base, the transistor is in the "off" state. Very little current flows from the collector to the emitter. It acts like an open switch.
- **On State:** When a sufficient voltage is applied to the base, it allows a significant current to flow from the emitter to the collector.

  This current flow is amplified, and the transistor acts like a closed switch, allowing current to flow through the load connected to the collector.

  BJT as an amplifier



Operation

- **Biasing:** The voltage divider (R1 and R2) sets a DC voltage at the base of the transistor. This biases the transistor into the active region, allowing it to amplify small input signals.

- **Input Signal:** A small AC input signal is applied to the base of the transistor through the coupling capacitor C1.
- **Current Amplification:** The small input signal at the base causes a much larger change in the collector current. This current amplification is the primary function of the BJT.
- **Output Signal:** The change in collector current results in a corresponding change in voltage across the collector resistor (RC). This amplified voltage signal is the output of the amplifier.

UNIT 17

1.

a. ***Advantages of Field Effect Transistors (FET)***

- Low noise
- High switching speed
- Low voltage operation
- High current capacity
- Immunity to thermal runaway

Disadvantages of Field Effect Transistor (FET)

- Limited voltage range
- High output capacitance
- Temperature dependence
- Noise sensitivity
- Limited gain bandwidth product

b. The combination of high input impedance, gate isolation, and reliance on majority carriers contributes to the low thermal noise characteristics of FETs, making them highly desirable for low-noise applications like sensitive amplifiers and radio receivers.

c. FETs are inherently more resistant to thermal runaway due to their negative temperature coefficient. This is a significant advantage of FETs over BJTs, especially in high-power applications.

2. The gain-bandwidth product of FETs is generally high due to their high transconductance, smaller internal capacitances, and advancements in semiconductor technology.

3. **Any 4 from:** 1. Amplifier 2. Power supplies 3. Switching circuits 4. Medical equipment 5. Power management circuits

UNIT 18

1.

a. It states that the current flowing through a conductor is directly proportional to the voltage across the conductor, and inversely proportional to the resistance.

b. **Voltage (V):** This represents the electrical potential difference or "pressure" that drives the flow of electric current. It's measured in volts (V).

- **Current (I):** This is the flow of electric charge through a conductor. It's measured in amperes (A), often simply called "amps."
- **Resistance (R):** This is the opposition to the flow of electric current. It's measured in ohms (Ω).

c. Ohm's Law establishes a direct proportional relationship between voltage and current in a conductor, provided the temperature and other physical conditions remain constant.

d. **Temperature dependence:** Ohm's Law assumes constant temperature. In reality, the resistance of most materials changes with temperature. For example, the resistance of most metals increases with increasing temperature.

2.

a. At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node.

b. **Scenario:** Imagine a junction box in your home where the main electrical line splits into three branches: one leading to the living room lights, one to the kitchen outlets, and one to the bedroom outlets.

Application of KCL: The total current flowing into the junction box from the main line must be equal to the sum of the currents flowing out to each of the three branches. This ensures that no current is "lost" or "created" at the junction.

3.

a. We can use Ohm's Law to calculate the current in each branch:

- Branch 1 (with cell 1)
  - I1 = E1 / (r1 + R-external)
  - I1 = 4 V / (2 Ω + 20 Ω)
  - I1 = 4 V / 22 Ω
  - I1 ≈ 0.18 A

- Branch 2 (with cell 2)
  - I2 = E2 / (r2 + R-external)
  - I2 = 8 V / (1 Ω + 20 Ω)
  - I2 = 8 V / 21 Ω
  - I2 ≈ 0.38 A

b. Calculate Power Dissipated by the 20Ω Resistor

- Power (P) = I2 * R
- P = (0.32 A)2 * 20 Ω
- P ≈ 2.05 W

Therefore

- The current flowing in branch 1 (with cell 1) is approximately 0.18 A.
- The current flowing in branch 2 (with cell 2) is approximately 0.38 A.
- The power dissipated by the 20Ω resistor is approximately 2.05 Watts.

UNIT 19

1.

a. **Cycle:** A cycle in the context of alternating current (AC) refers to one complete set of variations in the direction of current or voltage.

b. **Period (T):** The period is the time taken for one complete cycle to occur. It's measured in seconds.

c. Frequency is the number of complete cycles that occur in one second. It is measured in Hertz (Hz), where 1 Hz is equal to one cycle per second.

d. **Effective Value (RMS):** The effective value of an AC waveform is the equivalent DC value that would produce the same heating effect in a resistor.

2.

a. **Graphical Method**

- Represent Phasors as Vectors
  - Draw one phasor (let's call it A) as an arrow on a graph.
  - Since the second phasor (let's call it B) is 90 degrees out of phase, draw it perpendicular to the first phasor.
- Tail-to-Head Addition
  - Place the tail of phasor B at the head of phasor A.

- The resultant phasor (R) is the vector that starts from the tail of phasor A and ends at the head of phasor B.

- **Determine Magnitude and Phase**
  - The magnitude of the resultant phasor can be found using the Pythagorean theorem:
    $|R| = \sqrt{(A^2 + B^2)}$
  - The phase angle of the resultant phasor can be found using trigonometry:
    $\theta = \arctan(B/A)$

b. Higher Frequency, Higher Reactance: As the frequency of the AC signal increases, the inductor's opposition to current flow also increases. This is because at higher frequencies, the rate of change of current is faster. Inductors resist changes in current flow due to the phenomenon of electromagnetic induction.

Lower Frequency, Lower Reactance: At lower frequencies, the rate of change of current is slower, and the inductor's opposition to current flow is reduced. In the limit of DC (frequency = 0 Hz), the inductive reactance becomes zero, and the inductor behaves like a short circuit.

3.

a. **Calculate Reactance**

Inductive Reactance (XL)

$XL = 2 * \pi * f * L$

$XL = 2 * \pi * 50\ Hz * 0.02\ H$

$XL = 6.28\ \Omega$

Capacitive Reactance (XC)

$XC = 1 / (2 * \pi * f * C)$

$XC = 1 / (2 * \pi * 50\ Hz * 100 * 10^{\wedge}\text{-}6\ F)$

$XC = 31.83\ \Omega$

i. Calculate Impedance (Z)

In a series RLC circuit:

$Z = \sqrt{(R^2 + (XL - XC)^2)}$

$Z = \sqrt{(10^2 + (6.28 - 31.83)^2)}$

$Z = \sqrt{(100 + 646.56)}$

$Z \approx 27.44\ \Omega$

ii. Calculate Circuit Current (I)

Using Ohm's Law:

$I = V / Z$

$I = 120\ V / 27.44\ \Omega$

$I \approx 4.37\ A$

iii. Calculate Voltage across each component

Voltage across Resistor (VR):

$VR = I * R$

$VR = 4.37\ A * 10\ \Omega$

$VR \approx 43.7\ V$

Voltage across Inductor (VL)

$VL = I * XL$

$VL = 4.37\ A * 6.28\ \Omega$

$VL \approx 27.48\ V$

Voltage across Capacitor (VC):

$VC = I * XC$

$VC = 4.37\ A * 31.83\ \Omega$

$VC \approx 139.23\ V$

Summary

- Impedance of the circuit: 27.44 Ω
- Circuit current: 4.37 A
- Voltage across Resistor: 43.7 V
- Voltage across Inductor: 27.48 V
- Voltage across Capacitor: 139.23 V

b.

- The highest current will flow in the circuit at its **resonant frequency**.
- In an RLC series circuit, resonance occurs when the inductive reactance (XL) equals the capacitive reactance (XC).

$XL = XC$

$2\pi fL = 1 / (2\pi fC)$

Solving for the resonant frequency (f):

$f = 1 / (2\pi\sqrt{(LC)})$

$f = 1 / (2\pi\sqrt{(0.02\ H * 100 \times 10^{-6}\ F)})$

$f \approx 112.54\ Hz$

Calculate the Current at Resonance

- At resonance, XL = XC, and the impedance of the circuit is purely resistive

  Z = R = 10 Ω

- Using Ohm's Law

  I = V / Z

  I = 120 V / 10 Ω

  I = 12 A

Therefore

- The highest current will flow in the circuit at a frequency of approximately **112.54 Hz.**
- The value of the current at resonance is **12 Amperes**.

UNIT 20

1. **Any 4 from:** 1. Manufacturing and production processes 2. Transportation systems 3. Building and home automation. 4. Power generation, transmission and distribution. 5. Military and defence systems. 6. Medical equipment and operations. 7. Robotics.
2. The circuit breaker operates independently of the consequences of its action (tripping). It doesn't "learn" or adjust its behaviour based on the outcome. This lack of feedback makes it an open-loop control system.
3.
   a. A traffic light system can become a closed-loop system when it incorporates feedback mechanisms that adjust the signal timing based on real-time traffic conditions.

   b. An irrigation water sprinkler system is programmed to turn on at set times. It does not measure soil moisture as a form of feedback.
4. The Programmable Logic Controller (PLC) is an industrial computer in which control devices such as limit switches, push buttons, proximity or photoelectric sensors etc. are used in controlling signals.
5. Any 4 from: 1. Increase productivity 2. Lower cost of quality, scrap and rework. 3. Work in difficult or hazardous times. 4. Improve quality and accuracy. 5. Achieve consistency in manufacturing.

UNIT 21

1. Digital electronics is the field of electronics that deals with the representation and manipulation of data in digital form. It uses devices such as transistors, diodes, and microcontrollers to process and transmit digital signals

2. Any 4 from the following.

Foundation of Digital Electronics

- Computers and most modern electronic devices operate on the principle of binary, using two states (on/off, 1/0) to represent information.
- This simplicity allows for easy implementation using electronic components like transistors.

Data Representation

- Binary code is used to represent all types of data within computers, including:
  - **Numbers:** Integers, floating-point numbers.
  - **Text:** Letters, symbols, and characters are represented using coding systems like ASCII and Unicode.
  - **Images:** Images are broken down into pixels, and each pixel's colour is represented by binary values.
  - **Audio and Video:** Sound and video signals are digitised and stored as sequences of binary data.

Computer Logic

- Binary logic gates (AND, OR, NOT) are the fundamental building blocks of computer circuits.
- These gates perform operations on binary inputs to produce binary outputs, enabling complex computations.

Data Storage

- All digital data, from computer files to the information stored in your phone, is ultimately represented and stored in binary format on storage devices like hard drives, SSDs, and memory chips.

Communication

- Binary is the foundation of digital communication, including the internet, mobile networks, and other forms of data transmission

3. **Foundation of Mathematics**

- It provides the basis for arithmetic operations (addition, subtraction, multiplication, division).
- It forms the foundation for more advanced mathematical concepts, such as algebra, calculus, and geometry.

Commerce and Finance

- The decimal system is essential for financial transactions, including counting money, calculating prices, and managing budgets.

- It's used in all aspects of finance, from personal finances to international trade and global markets.

Science and Measurement

- The metric system, the most widely used system of measurement, is based on the decimal system (e.g., meters, grams, litres).
- It simplifies scientific calculations and facilitates communication of measurements across different fields.

Everyday Life

- The decimal system is used constantly in daily life
  - Telling time (hours, minutes, seconds)
  - Measuring distances and weights
  - Using percentages and decimals in various contexts

UNIT 22

1.

a. Electromagnetism is the production of a magnetic field by an electric current. Essentially, it describes how electric currents and magnetic fields are interrelated and how they can produce each other.

b. Generator, Electric motor, lifting magnet.

2.

a. Faraday's Laws of Electromagnetic Induction consists of two laws. The first law describes the induction of emf in a conductor, and the second law quantifies the emf produced in the conductor.

b.

i. Self-induction is the phenomenon or occurrence of emf in the same circuit in which the current is changing

ii. Is the phenomenon in which the magnetic field produced in one coil tends to link with another coil placed adjacent to it, leading to the generation of emf in the other coil.

3.

a. Conductor Moving Perpendicular to the Field

Formula: The average induced EMF (electromotive force) in a conductor moving perpendicular to a magnetic field is given by:

EMF = B * L * v

where: B is the magnetic field strength (0.05 T)

L is the length of the conductor (0.4 m) v is the velocity of the conductor (500 m/s)

Calculation: EMF = 0.05 T * 0.4 m * 500 m/s = 10 Volts

b. Conductor Moving at an Angle of 30 Degrees to the Field

Formula: When the conductor moves at an angle (θ) to the magnetic field, the formula for induced EMF becomes:

EMF = B * L * v * sin(θ)

where:

θ is the angle between the velocity of the conductor and the magnetic field (30 degrees)

Calculation

EMF = 0.05 T * 0.4 m * 500 m/s * sin(30°)

EMF = 0.05 T * 0.4 m * 500 m/s * 0.5 EMF = 5 Volts

UNIT 23

1.

a. An **oscilloscope** (informally **scope** or **O-scope**) is a type of electronic test instrument that graphically displays varying voltages of one or more signals as a function of time.

b. A measuring instrument that is used to measure different electrical properties like resistance, voltage and current is known as a multimeter.

2.

a. **OHM**: Measures resistance.

DCA: Measures DC current, ranging from 200 μA to 2 A.

ACA: Measures AC current, ranging from 200 μA (microamperes) to 2 A (amperes).

DCV: Measures DC voltage, ranging from 200 mV (millivolts) to 1000 V (volts).

ACV: Measures AC voltage, ranging from 200 mV to 700 V.

b. The procedure for measuring resistance is as follows.

- Insert the black lead jack of the meter into the port marked 'COM'
- Insert the red lead jack into the port marked 'VΩ'.
- Select the appropriate resistance range on the meter. The caution here is to select a range that is higher than the estimated resistance of the circuit or component.
- Switch off power to the circuit or, in the case of electronic components, remove the component from the circuit.

- Connect the probes of the meter to the two points of the circuit or the component whose resistance is to be measured.
- Note that the polarity of the probes does not matter when measuring resistance.
- Once the multimeter is connected, it will display the resistance value of the component.

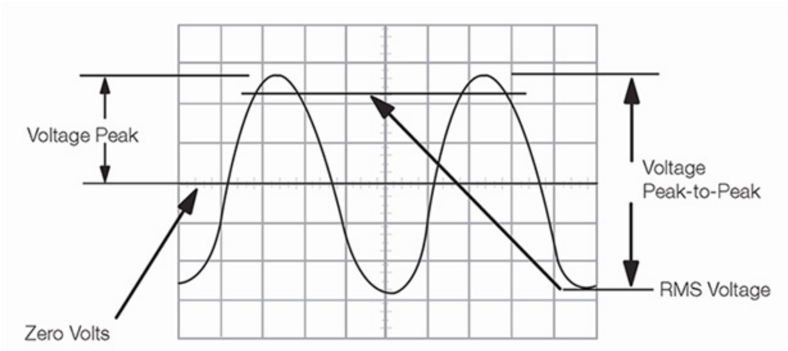
Checking hFE with a Multimeter

·Many digital multimeters can measure the **hFE** or current gain of a transistor.

·The first step is to identify the transistor's emitter, base, and collector.

·Set the multimeter to **hFE** mode. Then, connect the leads to the multimeter.

·This setup makes the multimeter display the **hFE** number



UNIT 24

1. Electronic circuit design is the process of conceiving, analysing, and synthesising electronic circuits. It involves:
   - **Defining the Circuit's Purpose**
     - Clearly understanding the desired function of the circuit.
     - Specifying the input and output signals, power requirements, operating conditions, and performance criteria (e.g., gain, bandwidth, noise level).
   - **Selecting Components:** Choosing the appropriate electronic components (resistors, capacitors, inductors, transistors, diodes, integrated circuits, etc.) based on their electrical characteristics and the circuit's requirements.
   - **Designing the Circuit Schematic**
     - Creating a diagram that shows the interconnection of the selected components.
     - This schematic serves as a blueprint for the physical circuit.
   - **Circuit Simulation and Analysis**

- Using computer-aided design (CAD) software to simulate the circuit's behaviour.
- Analysing the simulation results to identify potential problems, optimise performance, and refine the design.

- **PCB Layout Design**
  - Designing the physical layout of the circuit on a printed circuit board (PCB).
  - This involves placing components on the board, routing the connections between them, and ensuring proper signal integrity and grounding.
- **Prototyping and Testing**
  - Building a prototype of the circuit and testing its performance against the design specifications.
  - Identifying and correcting any issues that arise during testing.
- **Production and Refinement**
  - Once the prototype is successful, the circuit can be manufactured in larger quantities.
  - Continuous refinement and improvement of the design may be necessary based on testing and feedback.

2. Any 3 from the list will be a good response.

- Thermistor
- Transistor (NPN BC547)
- L.E.D 4. A 9V Battery
- Toggle switch

3.

Thermistor

- ***Importance:*** This is the heart of the system.
- ***Function:*** Thermistors are temperature-sensitive resistors. In a fire alarm, a thermistor is placed where it can detect a significant temperature rise.
- ***How it works:*** As the temperature increases, the resistance of the thermistor decreases. This change in resistance is crucial for triggering the alarm.

Transistor (NPN BC547)

- ***Importance:*** Acts as a switch or amplifier.
- ***Function:*** The thermistor's resistance change affects the current flowing through the transistor's base.

- When the temperature rises and the thermistor resistance drops, the transistor's base current increases.
- This amplifies the small signal from the thermistor, allowing it to trigger the alarm.

LED (Light Emitting Diode)

- ***Importance:*** Provides visual indication of the alarm state.
- ***Function***: When the circuit detects a fire condition (due to the thermistor's resistance change and the transistor's amplification), the LED lights up brightly.
- ***Purpose***: This visual cue serves as an immediate warning to people in the vicinity.

9V Battery

- ***Importance:*** Provides the power source for the entire circuit.
- ***Function:*** Supplies the necessary voltage to operate the thermistor, transistor, and LED.
- ***Considerations:*** The battery should be chosen for its appropriate voltage and capacity to ensure reliable operation of the alarm.

Toggle Switch

- ***Importance:*** Controls the on/off state of the fire alarm circuit.
- ***Function:*** Allows you to turn the alarm system on or off manually.
- ***Safety:*** Enables you to disable the alarm during maintenance or testing without affecting its functionality.

REFERENCES

- A.S Aduku (2018), Beginner's Handbook of Electrical Installation and Maintenance Work
- Heroes Printing Press, Lokoja, Kogi State.
- E.C. Sraha, (2016). Applied Electricity and Electronics for SHTS Books Galore Ventures, Koforidua.
- The Ultimate Guide to Electrical Wiring Installation: Step-by-Step Instructions for Beginners
- https://www.difference.wiki/images/tool-vs-equipment-41693.webp Electrical Safety: Importance & Safety Tips | SafetyCulture
- What Is the Difference Between Hand Tools and Power Tools: A Comprehensive Guide - EXTOL
- Microsoft Copilot: Your AI companion
- Insulation Resistance Test Methods, A Beginners Guide
- Cleaning Methods for Electrical Preventive Maintenance - Tech Library / Articles - TestGuy Electrical Testing Network
- https://www.bing.com/ck/a?!&&p=a29e6793fd8eff2aJmltdHM9MTczM-DE2MDAwMCZpZ3VpZD0wODFiODI3YS0zNTY0LTZjMmYtMzhkOC05N-jk4MzRjZTZkYzcmaW5zaWQ9NTEyNA&ptn=3&ver=2&hsh=3&fclid=-081b827a-3564-6c2f-38d8-969834ce6dc7&u=a1L2ltYWdlcy9zZWFyY2g_cT13YWxsK2NoYXNlcittYWNoaW5lJnFwdnQ9d2FsbCtjaGFzZXIrbWFjaG-luZSZGT1JNPUlHUkU&ntb=1
- Electrical Cord Visual Inspection and Use - Safesite Template Library of Inspections, Audits, Toolbox Talks, Checklists
- Inspect cords for defects: check the power cord for cracking, fraying, and other signs of wear or faults in the cord insulation. Check for damaged switches and ones with faulty trigger locks. Inspect the plug for cracks and for missing, loose or faulty prongs - Search
- All About Electrical Wiring Types, Sizes, Installation
- https://www.thespruce.com/thmb/I30iPpacuq2EFVetYxZrasEiK1A=/750x0/filters:no_upscale():max_bytes(150000):strip_icc():format(webp)/electrical-wiring-1152909_03_color_coding-49e8a933548d44c488495999ed836093.jpg
- Electrical wiring - Wikipedia
- https://www.bing.com/ck/a?!&&p=adb48d2128b2644cb5c94ae36502de-00ce7bb69a6b477c427109fb3000c3bea3JmltdHM9MTczMDI0NjQwMA&pt-n=3&ver=2&hsh=4&fclid=081b827a-3564-6c2f-38d8-969834ce6dc7&psq=elec-trical+insulator&u=a1aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa-2kvSW5zdWxhdG9yXyhlbGVjdHJpY2l0eSk&ntb=1

- https://th.bing.com/th/id/OIP.-mCy_xI-t0xNisdbMXAJUgHaHa?rs=1&pid=ImgDetMain
- Electricity meter - Wikipedia
- sequence of connection of electricity supply control equipment - Search
- What is a Main Switch and How Does It Work | Fantastic Electricians
- https://en.wikipedia.org/wiki/Fuse_cutout#:~:text=A%20cutout%20and,fuse%20elements%20for
- B.L Theraja, A.K Theraja (2002). Electrical Technology; Electrical Engineering Vol.1; New Delhi: S. Chand & company Ltd.
- **E**.C Sraha (2016). Applied Electricity and Electronics for SHTS. Books Galore Ventures, Koforidua.
- Junction field effect transistor pdf - Search
- **E**.C Sraha (2016). Applied Electricity and Electronics for SHTS Books Galore Ventures, Koforidua
- https://th.bing.com/th?id=OIF.qyAQVeST1Mg%2bDzDW9JSAS-w&w=121&h=157&c=7&r=0&o=5&dpr=6.3&pid=1.
- E.C Sraha (2016). Applied Electrical and Electronics for SHTS. Books Galore Ventures, Koforidua.
- B.A Gregory (1981). An Introduction to Electrical Instrumentation and Measurement Systems. The Macmillan Press Ltd.
- Electricity meter - Wikipedia
- https://media.rs-online.com/image/upload/w_620,h_413,c_crop,c_pad,b_white,f_auto,q_auto/dpr_auto/v1482288269/R8496406-03.jpg
- https://th.bing.com/th/id/OIP.-mCy_xI-t0xNisdbMXAJUgHaHa?rs=1&pid=ImgDetMain
- Electricity meter - Wikipedia
- https://www.electronicshub.org/
- A.S ADUKU (2018). Beginner's Handbook of Electrical Installation and Maintenance Work. Heroes Printing Press, Lokoja, Kogi State- Nigeria
- Atkinson, B., Lovegrove, R. & Gundry, G. (2013). *Electrical Installation Design. Fourth Edition*. New York: John Wiley & Sons Ltd.
- Darrell L. (2008). *Guide to the Wiring Regulations* (17th ed.). IEE Wiring Regulations (BS 7671: 2008)
- Thompson, F. G. (1992). *Electrical Installation and Workshop Technology. Fifth Edition*. Harlow: Longman Group Ltd.
- Trevor L. (2008). *Advanced Electrical Installation Work* (5thed.). Elsevier Ltd
- R.D. Puckering, S. Brough (1992) Electronics and Electrical Installation, Great Britain: Hartroll.

- Staircase Wiring Diagram - Controlling a Bulb from 2 Places
- https://www.electricaltechnology.org/2012/11/stair-case-wiring-circuit-diagram-or.html?nowprocket=1
- https://www.wiring-regulations.co.uk/wiring-regulations-history/
- Evans C. Sraha (2016) Applied Electricity and Electronics for SHTS
- What is a thermistor - Search Light Dependent Resistors (LDRs) | How it works, Application & Advantages
- What is a wire-wound resistor - Search
- What is a carbon resistor - Search
- Passive components - Search
- https://th.bing.com/th/id/OIF.DEHGSqygnUmx14hVdm6cyA?rs=1&pid=ImgDetMain
- https://th.bing.com/th/id/OIP.YggXVSab0-Aaq2fIceut6QHaC9?w=297&h=140&c=7&r=0&o=5&dpr=2.2&pid=1.7
- https://store.nerokas.co.ke/image/cache/catalog/Accesories/Varistor%2010D471K-500x500.jpg
- https://www.electrical4u.com/types-of-resistor/#:~:text=The%20Different%20Types%20of%20Electrical%20Resistors%20Explained%20(And%20How%20They%20Are%20Used)
- https://img.lazcdn.com/g/p/9a9c77ff90f36fbf4ce6c696add579d1.jpg_720x720q80.jpg
- https://www.bing.com/images/search?q=light-dependent+resistor+5+mm&qpvt=Light-Dependent+Resistor+5+mm&FORM=IGRE
- Capacitor Types - Symbols, Functions, Applications, Value, and FAQs (byjus.com) https://byjus.com/physics/capacitor-types/physics/capacitor-types/. Capacitor - Wikipedia
- https//en.wikipedia.org/wiki/capacitor Types of Capacitors: Working and Their Applications (elprocus.com)
- https//www.elprocus.com/capacitors-types-applications/
- What Are the Advantages and Disadvantages Of Capacitors? (engineerfix.com)
- https//engineerfix.com/electrical/capacitors/advantages-and disadvantages-of-capacitors/#google vignette
- Capacitor Characteristics and Capacitor Specifications
- What Are The Advantages and Disadvantages Of Capacitors?
- https://th.bing.com/th/id/OIP.x7p-m7qiScH8k5XvOkAA7wHaFF?w=154&h=106&c=7&r=0&o=5&dpr=5&pid=1.7
- Capacitor Colour Code Values with Examples - Codrey Electronics

- https://th.bing.com/th/id/OIP.G_9ypDOhsCwiKzX_sXARRwHaF3?w=121&h=96&c=7&r=0&o=5&dpr=6.3&pid=1.7
- What Are the Advantages and Disadvantages of Batteries?
- What Are the Advantages and Disadvantages of Batteries?
- images of cells connected in series and parallel - Search Images
- Tom Duncan(1991).Electronics for Today and Tomorrow John Murray (Publishers) Ltd
- https://www.bing.com/search?q=Inductors&cvid=ee2c92f95ff64adca029fd-8581f5bc8f&gs_lcrp=EgRlZGdlKgYIABBFGDkyBggAEEUYOdIBCTExNjI5a-jBqN6gCALACAA&FORM=ANNTA0&PC=U531#:~:text=Inductor,passive%20electrical%20component
- E.C Sraha (2016). Applied Electricity and Electronics for SHTS. Books Galore Ventures Koforidua
- • Advantages and disadvantages of bipolar junction transistor (BJT) - Polytechnic Hub
- E.C Sraha(2016).Applied Electricity and Electronics for SHTS Books Galore Ventures, Koforidua
- https://cdn1.byjus.com/wp-content/uploads/2018/11/physics/wp-content/uploads/2018/08/difference-between-electromagnet-and-permanent-magnet.png
- Safety Considerations for Live Measurements | Automation World
- how is the effect of temperature minimized in measuring instruments - Search
- E.C Sraha (2016).Applied Electricity and Electronics for SHTS. Books Galore Ventures, Koforidua.
- Dr. Helfrick and Dr. Cooper. Modern Electronics Instrumentation and Measurement Technics
- https://www.electronicshub.org/wp-content/smush-webp/2021/12/CRO-Trigger-System.png.webp
- https://www.electronicshub.org/wp-content/smush-webp/2021/12/Oscilloscope-Front-Panel.png.webp
- How to Use an Oscilloscope: Complete Setup Guide | Tektronix
- how to use an oscilloscope screen - Search
- Types of Oscilloscopes | Definition, Functions, Purposes & Uses
- https://courses.cs.washington.edu/courses/csep567/05au/tools/oscopefordummies/OscopeBasics.html
- https://www.electronicshub.org/what-is-an-oscilloscope/#:~:text=What%20is%20a,with%20some%20transformation).

- https://www.elprocus.com/wp-content/uploads/2016/01/Fire-Alarm-System-Block-Diagram-by-www.edgefxkits.com_.jpg
- Fire Detector Alarm with BC547 - Electronics Projects
- what is the function of a buzzer - Search
- what is the function of a buzzer - Search
- https://robodocbd.com/product/variable-capacitor-trimmer?srsltid=AfmBOoq61hsI2awI-4Jbb5yad9KIzyqOHNM-5zrV51wdF-05vcSYR5NN

GLOSSARY

2-way switch	A type of light switch that allows one to control a single light from two different locations. It is used on a staircase and, living rooms.
Accuracy	The degree to which a measurement conforms to the desired value.
Air Core Inductor	An inductor that uses air as its core material, typically used in high-frequency applications.
Amplifier	A device that increases the power of a signal, often used in audio and communication systems.
Amplitude	The maximum height of a wave at a given time.
An Intermediate switch	is a type of switch used when one needs to control a single light from multiple locations.
Analogue	A system in which changing values are represented by a continuously variable electrical signal.
Anode	The positive electrode in a battery.
Antenna	A transmitting or receiving device for radiated waves.
Audio	Relating to a system concerned with frequencies within the range of human hearing
Bandwidth	The range of frequencies to which a system will respond in the required manner.
Base	The input terminal of a bipolar transistor.
Base	The middle layer of a transistor that controls the flow of current between the emitter and collector.
Bill of quantities	A list of materials, labour, and components needed to build a structure.
Binary	A number system to the base 2 (0, 1).

Bipolar Junction Transistor (BJT)	A type of transistor that uses both electron and hole charge carriers in the conduction of electricity.
Breadboard	A temporary assembly, purpose-built plug-in board for testing purposes.
Buzzer	An Electronic device that makes a vibrant sound.
Cable Trunking	A protective routing and covering system for electrical cables and wires, which prevents accidental damage.
Calibration	The process of adjusting an instrument to ensure its accuracy.
Capacitance	The ability of a capacitor to store an electric charge.
Capacitor	An electronic component that stores electrical energy in an electric field.
Capacity	The amount of electric charge a battery can store.
Cathode	The negative electrode in a battery.
Cathode-rays	A stream of electrons leaving the cathode and shooting across the vacuum in a cathode ray tube.
Charge	The amount of electric energy stored in a capacitor.
Circuit breaker	An electrical safety device designed to protect an electrical circuit from damage caused by excess current.
Circuit	A path for electric current, consisting of a path through active and passive components; or a complete path through which electric current can flow. It typically includes a power source, conductors, and load.
Closed-loop	A control system that uses feedback to compare the output with the desired input and make adjustments to achieve the desired result.
Collector	The output terminal of a bipolar transistor

Collector	The part of a transistor that draws charge carriers from the base and allows current to flow through the device.
Concealed conduit	A system of electrical wiring where protective tubes for cables are hidden within walls ceilings or floors.
Condenser	A small electronic component that stores and discharges electricity.
Consumer unit	An apparatus in the electrical supply at the point it enters a domestic property, which contains a switch and circuit breakers.
Controller	A device that modifies and amplifies the error signal to produce better control action.
Conversion	The process of changing a number from one base to another.
Current Flow	The movement of electric charge through a conductor.
Current Gain	The ratio of the output current to the input current of an amplifying device.
Current	The flow of electric charge through a conductor.
Cutout fuse	An electrical device that combines a fuse and a switch typically used in overhead power lines to protect over current situations.
Damping	The reduction or prevention of the amplitude of oscillations in a circuit.
Deflection	The movement of a pointer or indicator in a measuring instrument, or the movement of an electron beam in a cathode ray tube.
Depletion layer	A region in a semiconductor around a junction in which there are no mobile charges.
Dielectric	An insulating material placed between the plates of a capacitor to increase its capacitance.
Digital	It relates to technology that uses discrete voltage levels (0,1) to represent information.

Distribution board	A vital part of an electrical system that distributes electricity to a building.
DP MCB	Double-pole miniature circuit breaker
Drain	The charge-collecting electrode of a field-effect transistor
Earth link	A piece of metal that acts as a terminal point specifically designed to connect and terminate earth wire.
Electrical Accessories	Connecting leads, switches, sockets, lamp holders etc.
Electrical Equipment	Any machine that uses electricity to operate.
Electrical materials	A wide range of products used to generate, distribute and use electricity.
Electrochemical Reaction	A chemical reaction that occurs in a battery, converting chemical energy into electrical energy.
Electrolyte	A chemical substance that allows the flow of electrical charge between the anode and cathode in a battery.
Emitter	The part of a transistor that releases charge carriers into the collector through the base region.
Energy Density	The amount of chemical energy stored in a battery relative to its weight or volume.
Farad	The unit of measurement for capacitance.
Feedback	The return signal as part of the of the input to an amplifier of a signal that is obtained from the output.
Ferrite	A finely divided ferrous dust, suspended in a plastic material and has useful magnetic properties.
Final circuit	A circuit connected directly to equipment using electricity.
Fire alarm	A unit which uses visual and audio signalling to warn people about a possible fire occurrence.

Fixed Capacitor	A capacitor with a set capacitance value that cannot be adjusted.
FM	Frequency modulation
Forward Bias	A bias in the direction that causes current to flow easily.
Frequency Response	Generally, is the range of frequencies that can be produced by an electronic system.
Fuse	A safety device designed to protect an electrical circuit by interrupting the current flow when excess current flows.
Gain	The ratio of signal output to signal input for an amplifier; or the factor by which the output of a system exceeds the input. It also refers to a measure of how much a control system amplifies or attenuates a signal. It determines the strength of the system's response to an input.
Gate	One terminal of a field-effect transistor (FET) or another semiconductor device.
House wiring	The electrical system that supplies power to a home's appliances and devices.
Impedance	The total opposition offered by a resistor, inductor and capacitor to the flow of current in an a.c circuit.
Inductance	The property of an inductor that opposes changes in current.
Inductor	A passive electronic component that stores energy in a magnetic field when electric current flows through it.
Instrument	A Device used to determine the present value of the quantity under measurement.
Iron Core Inductor	An inductor that uses iron as its core material, typically used in low-frequency applications.
Isolator	A switch that separates an electrical circuit from the power supply.

Junction	A point where wires are joined.it is also known as node
Ladder	A network that is made by connecting alternate sections of filters.
Loop	A closed path in a circuit in which current can flow continuously.
Magnetic Field	The area around a magnetic material or a moving electric charge within which the force of magnet has influence.
Marconite	A synthetic granular material used to improve electrical conductivity in concrete and earthing. It is used in place of traditional sand and aggregate.
Measurement	The process of comparing an unknown quantity with an accepted standard quantity.
Megger	A tool used to measure high electrical insulation resistance.
Multimeter	A handheld vital tool or instrument used to measure electrical properties like voltage, current and resistance.
Multimeters	Instruments that can measure multiple electrical quantities, such as voltage, current, and resistance.
Multiplier	A high resistance device used to extend the range of a voltmeter.
Natural Frequency	The frequency at which a system naturally oscillates when not subjected to external forces.
Neutral link	A small metal piece that acts as a terminal point specifically designed to connect and terminate neutral wires.
NPN Transistor	A type of bipolar junction transistor (BJT) in which a very thin slice of P-type semiconductor is sandwiched by two thicker slabs on N-type semiconductor.
Open-loop	A type of control system in which the output quantity has no effect upon the input quantity.

Oscilloscope	An instrument for displaying electrical signals on a cathode ray tube
Parallel	A circuit connected in a way that makes it possible to share current across a common potential difference.
Passive Component	An electronic component that does not require an external power source to operate.
Phase Shift	The difference in phase between the input and output signals in a circuit.
PNP Transistor	A type of bipolar junction transistor (BJT) in which a very thin slice of N-type semiconductor is sandwiched by two thicker slabs on P-type semiconductor.
Polarised Capacitor	A capacitor with a positive and a negative terminal that must be connected correctly in a circuit.
Precision	A measure of the consistency of measurement.
Primary Cell	A non-rechargeable cell/battery that is used and then discarded when it runs down, such as alkaline batteries.
Quality Factor (Q Factor)	The magnification factor of a resonant circuit used for describing the behaviour of a circuit near resonance.
Reactance	The opposition to the flow of current in an inductor or capacitor.
Rechargeable	A type of battery that can be recharged and used multiple times, such as lithium-ion batteries.
Resistance	The property of a material that resists the flow of electric current.
Resonance	A condition in an RLC circuit where the circuit naturally oscillates at a specific frequency, causing maximum energy transfer and amplitude; or the maintenance of oscillation with minimum driving signal.
Resonant Circuit	A circuit in which capacitors and inductors are used to select specific frequencies.

Reverse Bias	A bias in the direction that causes leakage current to flow.
Secondary Cell	A rechargeable battery that can be used multiple times, such as nickel-cadmium or lithium-ion batteries.
Sensor	A device that detects changes in physical conditions and sends information.
Series Connection	A way of connecting capacitors end-to-end to increase the total voltage rating.
Series	A type of circuit configuration in which the same current flows through each in turn.
Shunt	A low-resistance device used to extend the range of an ammeter.
Source	An emitter of charge carriers in a field-effect transistor or any device that produces signals.
SP MCB	Single-pole miniature circuit breaker.
Stability	The ability of a control system to maintain its performance after a disturbance
Surface conduit	A method of electrical wiring where the conduit pipes are installed directly on the surface of walls or ceilings
Switch fuse	It is essentially a combination of a switch and a fuse.
Switch	A device that makes or breaks electrical circuits.
Switchgear	A collection of devices that control and protect electrical circuits.
Tolerance	The accuracy of the capacitance value of a capacitor.
Tool	A device or implement especially used in the hand to carry out a particular function
Toroidal Inductor	An inductor with a circular-shaped core, providing high inductance with minimal electromagnetic interference.

Transducer	A device that converts one form of energy into another.
Transistors	Semiconductor devices used to amplify or switch electronic signals and electrical power.
Transmitter	A device that sends out a carrier signal at radio frequency.
Trimmer capacitor	A small-value preset capacitor for fine adjustment of a circuit.
Variable Capacitor	A capacitor of adjustable capacitance value.
Variable	A quantity that can change and is measured or controlled in a process.
Voltage	The electrical potential difference between the anode and cathode.
Voltage	The electrical potential difference between two points in a circuit.
Voltmeter	An instrument used for measuring electrical potential difference.
Zero Adjustment	The process of setting an instrument to read zero when the measured quantity is zero.

This book is intended to be used for the Year Two Electricals and Electronics Technology Senior High School (SHS) Curriculum. It contains information and activities to support teachers to deliver the curriculum in the classroom as well as additional exercises to support learners' self-study and revision. Learners can use the review questions to assess their understanding and explore concepts and additional content in their own time using the extended reading list provided.

All materials can be accessed electronically from the Ministry of Education's Curriculum Microsite.

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