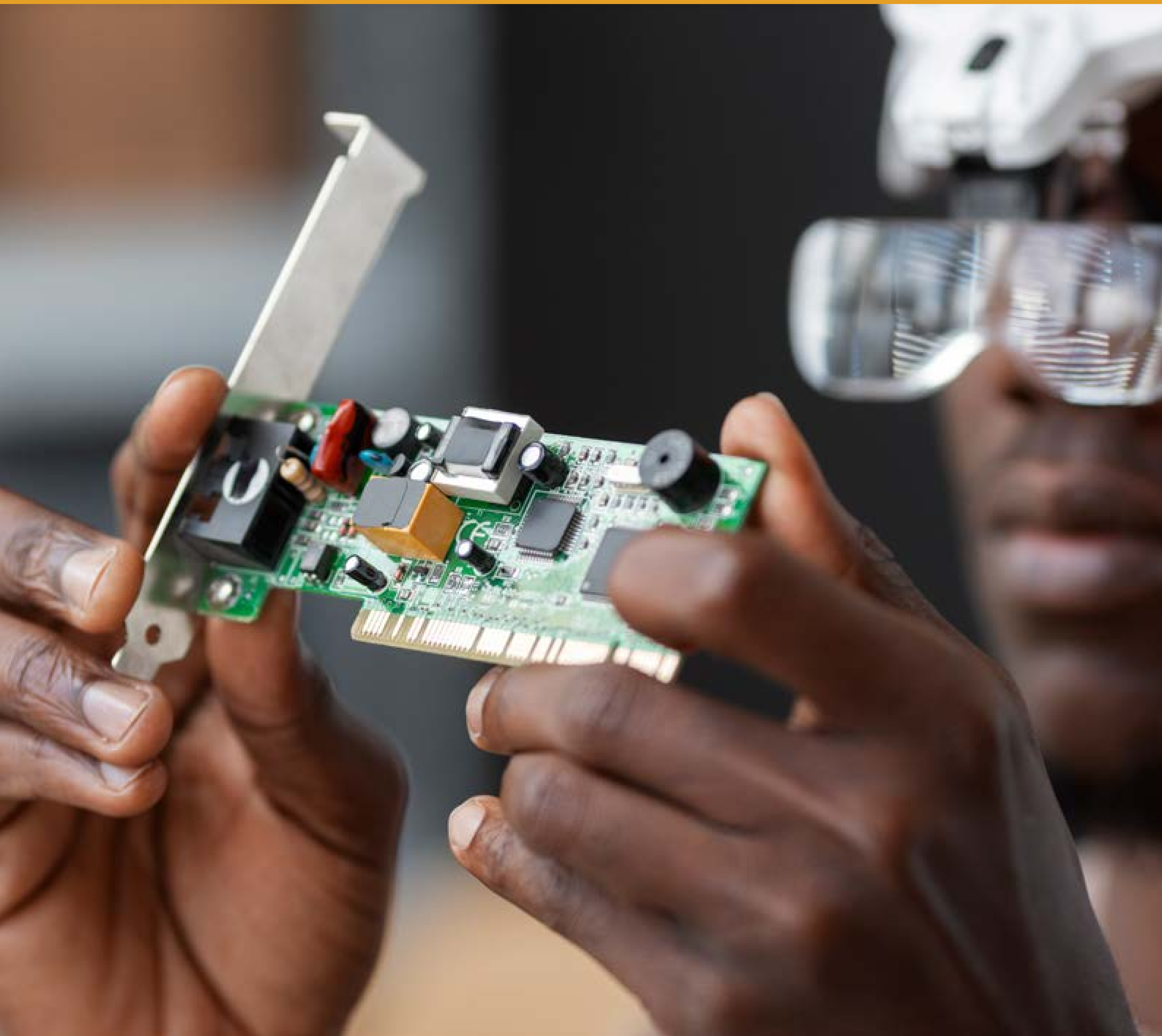
Engineering Year 1

SECTION 4

ELECTRICAL AND ELECTRONIC CIRCUIT



ENERGY SYSTEMS

Circuits And Machines

Introduction

Welcome to the section on circuits and machines. In this section, you will be introduced to the fundamentals of Direct Current (DC) electrical and electronic circuits. An electrical circuit is an interconnection of electrical elements in which current can flow. These circuit elements form the building blocks of electrical and electronic systems and devices that power our everyday lives and hence it is important to know them and understand their functions. The electrical circuit components can be classified as passive and active components. These passive and active components are fundamental components that play essential roles in controlling and regulating the flow of electric current. Electrical and electronic circuits are represented graphically using circuit diagrams. The circuit diagrams are used to convey information about the interconnections and functionality of various components within a circuit. Circuit diagrams use electrical symbols to represent the various electrical and electronic components. These symbols are standardised and universally recognised, making it easier for engineers, technicians, and electricians to communicate and understand complex circuit designs. Electrical circuit analysis involves the use of physical laws and mathematical equations to determine the relationship between electrical components in a circuit, the current flow through them and the voltages across them. Kirchhoff's laws are commonly used for analysing circuits so your understanding of Kirchhoff's Laws and their applications is an essential skill for studying electrical engineering or related fields. In the field of electronics, circuit simulation software enables the understanding, designing, and testing of electrical circuits without the need for physical components. These tools allow users to create and simulate circuits virtually, making them essential learning aids. Three common user-friendly circuit simulation software tools are Proteus, LTspice, and CircuitLab. The electrical and electronic circuits can also be built and instruments such as voltmeter, ammeter, and power meter can be used to measure the circuit terminal quantities.

At the end of this section, you will be able to:

- Identify the basic elements of DC electric and electronic circuits and sketch their circuit symbols.
- Classify circuit elements into passive and active elements.
- Explain Kirchhoff's laws.
- Use Kirchhoff's laws to find currents and voltages in DC circuits.
- Compute power in DC and single-phase AC circuits.
- Use a software tool to simulate simple circuits to derive current, voltage and power in DC circuits.

Key Ideas

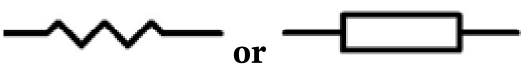
- When a conductor is used to connect electrical components such as resistors to an electrical power source, an electric circuit is formed. DC (Direct Current) circuits are electrical circuits where current flows in one direction.
- Basic elements of DC circuits are the voltage source, a resistor, a switch, and a conductor.
- Power in DC circuits is a fundamental concept used to determine the rate at which electrical energy is consumed or converted into other forms of energy.

BASIC ELEMENTS OF DC ELECTRIC AND ELECTRONIC CIRCUITS AND SKETCH THEIR CIRCUIT SYMBOLS

Let us begin by first introducing you to the various electrical and electronic components, their standard symbols, and their functions/applications. The components covered include resistors, capacitors, inductors, diodes, transistors, transformers, and integrated circuits.

1. Resistors

A resistor is an electronic component designed to impede or restrict the flow of electrical current in a circuit. Its primary function is to create a specific amount of resistance to control the flow of electrons. Resistors are commonly used to limit current, divide voltage, and protect sensitive components from excessive current flow. The resistance of a resistor is measured in ohms (Ω).



The Symbols of a Resistor

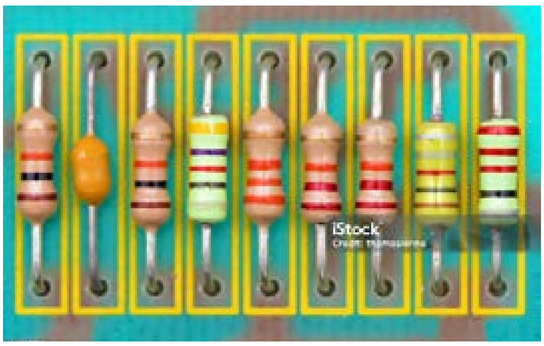


Figure 4.1: A picture of resistors mounted on a circuit board

Types of Resistors

a. **Fixed Resistors:** Fixed resistors have resistance values that cannot be changed by the user.

   i. **Carbon Composition Resistors:** They are made from a mixture of carbon dust and a binding material.

   ii. **Film Resistors:** They include carbon film, metal film, and metal oxide film resistors, which have a thin film of conductive material.

   iii. **Wire wound Resistors:** They are made by winding a wire (usually nichrome) around an insulating core.

b. **Variable Resistors (Potentiometers and Rheostats):** These allow the resistance value to be adjusted.

c. **Special Resistors:**

   i. **Thermistors:** Their resistance value changes with a change in temperature. Negative Temperature Coefficient (NTC) thermistors decrease resistance with increasing temperature, while Positive Temperature Coefficient (PTC) thermistors increase resistance with increasing temperature.

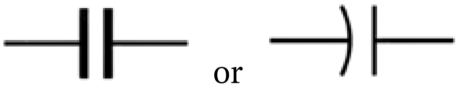
   ii. **Light-Dependent Resistors (LDRs):** Their resistance values change with a change in light intensity. They are commonly used to automatically switch on and off outdoor lights.

Applications of Resistors

- **Current Limiting:** It protects components by limiting the amount of current.
- **Voltage Division:** It creates specific voltage drops within a circuit.
- **Biasing Active Devices:** It sets the operating point for transistors and other active components.
- **Signal Attenuation:** It reduces signal strength in audio, radio, and other applications.
- **Pull-up and Pull-down:** It ensures that inputs to logic circuits settle at expected logic levels.

2. Capacitors

Capacitors are passive components used to store and release electrical energy in the form of an electric field. They consist of two conductive plates separated by an insulating material (dielectric). When a voltage is applied across the plates, electrons accumulate on one plate, creating a negative charge, while an equal number of electrons leave the other plate, creating a positive charge. Capacitors are used for filtering, energy storage, coupling, and timing applications in electronic circuits. The capacitance of a capacitor is measured in Farad (F).



The Symbols of a Capacitor

Figure 4.2: A picture of Capacitors

Types of Capacitors

a. **Fixed Capacitors:**

  i. Ceramic Capacitors: Made of ceramic materials, offering small size and high stability. Commonly used for high-frequency applications.

  ii. Electrolytic Capacitors: Have a larger capacitance-to-volume ratio, typically used for low-frequency applications. They are polarised, meaning they have a positive and a negative lead.

  iii. Tantalum Capacitors: Known for their stability and reliability, also polarised.

  iv. Film Capacitors: Made from plastic films, offering high precision and stability.

b. **Variable Capacitors:**

  i. **Trimmer Capacitors:** Adjustable capacitors used for fine-tuning circuits.

  ii. **Variable Air Capacitors:** Often used in radio tuning circuits.

Applications of Capacitors

- **Energy Storage:** Stores energy for use in applications such as power supplies and camera flashes.
- **Filtering:** Removes unwanted frequencies from signals, such as in power supply smoothing and audio crossover networks.
- **Coupling and Decoupling:** Blocks DC components while allowing AC signals to pass, used in signal processing.
- **Timing Circuits:** Used in conjunction with resistors to create time delays in circuits.
- **Tuning Circuits:** Adjusts the frequency response of radio and TV receivers.

3. Inductors

Inductors are also passive components and are designed to store energy in the form of a magnetic field when an electric current flows through them. They consist of a coil of wire wound around a core material. When the current changes, the magnetic field induces a voltage across the inductor, resisting changes in current. Inductors are commonly used in filters, transformers, and various energy storage applications. The inductance of an inductor is measured in Henry, (H).

The Symbol of an Inductor

Figure 4.3: A picture of Inductors

Types of Inductors

a. **Air Core Inductors:** These have no magnetic core, only air inside the coil. They are used for high-frequency applications due to their low losses.

b. **Iron Core Inductors:** Use an iron core to increase inductance, suitable for low-frequency applications.

c. **Ferrite Core Inductors:** Use ferrite material as the core, providing higher inductance and used in applications like transformers and noise filters.

d. **Toroidal Inductors:** The wire is wound on a toroidal (doughnut-shaped) core, offering high inductance and low electromagnetic interference (EMI).

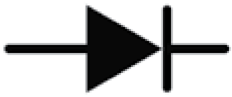
Applications of Inductors

- **Filtering:** Used in power supplies and audio circuits to filter out unwanted frequencies.
- **Energy Storage:** Store energy in switching power supplies and DC-DC converters.

- **Transformers:** Inductors with multiple windings that transfer energy between circuits through electromagnetic induction.
- **Tuning Circuits:** Adjust the frequency response in radio receivers and transmitters.
- **Chokes:** Block high-frequency AC signals while allowing DC or low-frequency signals to pass.

4. Diode

Diodes allow current to flow in one direction only and block it in the opposite direction. They are used for rectification, signal demodulation, and voltage regulation in both DC circuits. It has two terminals: the anode and the cathode. When a positive voltage is applied to the anode relative to the cathode, the diode becomes forward-biased and allows current to pass through. When a negative voltage is applied, the diode becomes reverse-biased and blocks current.



The Symbol of a Diode

Figure 4.4: A picture of Diodes

Types of Diodes

a. **Standard (Silicon) Diodes:** General-purpose diodes used for rectification and other applications.

b. **Zener Diodes:** Designed to conduct in the reverse direction when a specific breakdown voltage is reached, used for voltage regulation.

c. **Schottky Diodes:** Have a lower forward voltage drop and faster switching speed, used in high-frequency applications.

d. **Light Emitting Diodes (LEDs):** Emit light when forward biased, used for indicators and displays.

e. **Photodiodes:** Generate current when exposed to light, used in sensors and photovoltaic cells.

f. **Avalanche Diodes:** Operate in reverse breakdown with controlled breakdown characteristics, used in high-voltage applications.

g. **Varactor Diodes:** Variable capacitance diodes used in tuning circuits.

Applications of Diodes

- **Rectification:** Converting AC to DC in power supplies using diodes in rectifier circuits (half-wave, full-wave, and bridge rectifiers).
- **Voltage Regulation:** Zener diodes maintain a constant voltage across loads.
- **Signal Demodulation:** Extracting audio or data from modulated carrier waves in radios and communication devices.
- **Protection:** Clamping diodes protect circuits from voltage spikes and transients.
- **Switching:** Diodes in switching applications like logic gates and relay drivers.
- **Light Emission:** LEDs provide visual indicators and lighting.

Example Circuits

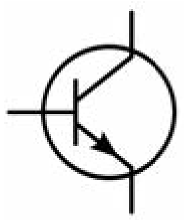
- **Half-Wave Rectifier:** Uses a single diode to rectify an AC signal, allowing only one half-cycle (positive or negative) of the AC voltage to pass through, resulting in pulsating DC.
- **Full-Wave Rectifier:** Uses multiple diodes (typically four in a bridge configuration) to rectify both halves of the AC signal, producing a smoother DC output.

Diode Characteristics

- **Forward Bias:** When the anode is more positive than the cathode, the diode conducts. The current-voltage relationship is exponential for small voltages and linear at higher currents.
- **Reverse Bias:** When the cathode is more positive than the anode, the diode blocks current, except for a small leakage current. Beyond the breakdown voltage, the diode conducts in reverse.

5. Transistor

Transistors are semiconductor devices that can amplify or switch electrical signals. They are fundamental components in electronic devices like computers, amplifiers, and other electronic circuits. Transistors come in two main types: bipolar junction transistors (BJTs) and field-effect transistors (FETs).



The Symbol of a Transistor

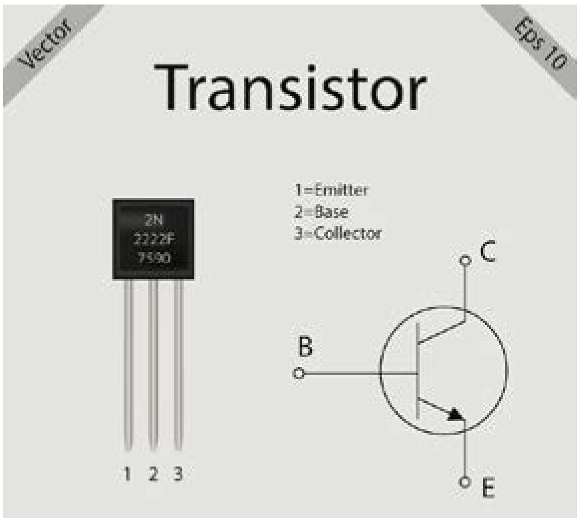


Figure 4.5: A picture of a transistor

Types of Transistors

Bipolar Junction Transistors (BJTs)

- **NPN Transistors:** Consist of two N-type semiconductor materials separated by a thin layer of P-type material.
- **PNP Transistors:** Consist of two P-type semiconductor materials separated by a thin layer of N-type material.

Operation:

- **Active Mode:** For NPN, the base-emitter junction is forward-biased, and the base-collector junction is reverse-biased. For PNP, the polarities are reversed.
- **Saturation Mode:** Both junctions are forward-biased.
- **Cutoff Mode:** Both junctions are reverse-biased.

Key Parameters:

- **Current Gain (β or h_{FE}):** The ratio of collector current (I_C) to base current (I_B).
- **Collector-Emitter Voltage (V_{CE}):** The voltage difference between the collector and emitter.
- **Field-Effect Transistors (FETs)**
- **Junction FETs (JFETs):** Use a voltage applied to the gate terminal to control current through the channel between the source and drain.
- **Metal-Oxide-Semiconductor FETs (MOSFETs):** Have an insulated gate that can control the conductivity of a channel.

Operation:

- **Depletion Mode:** Current flows without gate voltage; applying a voltage depletes the channel.
- **Enhancement Mode:** No current flows without gate voltage; applying a voltage enhances the channel.

Key Parameters:

- **Transconductance (g*m*):** The rate of change of the drain current with respect to the gate-source voltage.
- **Drain-Source Voltage (V_{DS}):** The voltage difference between the drain and source.

Applications of Transistors

- **Amplification:** Used in amplifiers to increase the power, voltage, or current of a signal.
- **Switching:** Used in digital circuits, power supplies, and motor controllers to turn current on and off.
- **Oscillators:** Generate oscillating signals in radios, clocks, and signal generators.
- **Regulation:** Stabilise voltage and current in power supply circuits.

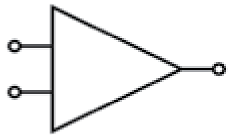
Example Circuits

Common Emitter Amplifier (using NPN BJT)

- **Configuration:** The emitter is common to both input and output circuits.
- **Operation:** Input signal at the base, amplified output is taken from the collector.
- **Biasing:** Requires proper biasing to set the transistor in active mode.

6. Integrated circuits (IC)

An integrated circuit (IC), also known as a microchip or chip, is a compact arrangement of electronic components such as transistors, capacitors, resistors, and diodes, fabricated on a single piece of semiconductor material, typically silicon. The components are interconnected in a way that allows them to perform specific functions, such as amplification, signal processing, logic operations, or memory storage. Integrated circuits are fundamental to modern electronics and are used in all electronic equipment.



The Symbol of an Integrated Circuit

Figure 4.6: A picture of an Integrated circuit (IC)

Types of Integrated Circuits

a. **Microprocessors:** The brain of computers and many other devices, executing a sequence of stored instructions.

b. **Microcontrollers:** Contain a microprocessor along with memory and input/output peripherals on a single chip.

c. **Memory ICs:** Include RAM (Random Access Memory) and ROM (Read-Only Memory).

d. **Digital Signal Processors (DSPs):** Specialised in processing digital signals in real-time.

e. **Application-Specific Integrated Circuits (ASICs):** Custom-designed for a specific application.

f. **Power Management ICs:** Manage power requirements of the host system.

g. **Sensors and Actuators ICs:** Integrate sensory functions and can directly interact with physical devices.

Applications of Integrated Circuits

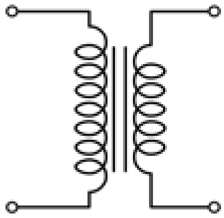
- **Computing:** Microprocessors, memory, and GPUs in computers, tablets, and smartphones.
- **Communication:** Signal processing in phones, radios, and networking equipment.
- **Consumer Electronics:** Embedded systems in TVs, cameras, and home appliances.
- **Automotive:** Engine control units, safety systems, and infotainment.
- **Industrial:** Automation, robotics, and process control.
- **Medical Devices:** Imaging systems, portable diagnostics, and patient monitoring.

Advantages of Integrated Circuits

- **Size and Weight:** Significantly smaller and lighter than discrete component circuits.
- **Cost:** Lower production costs due to mass manufacturing.
- **Performance:** Higher speed and efficiency due to reduced parasitic elements.
- **Reliability:** Enhanced reliability with fewer interconnections and solder joints.
- **Power Consumption:** Lower power consumption compared with equivalent discrete circuits.

7. Transformer

A transformer is a device used to transfer electrical energy between two or more circuits through electromagnetic induction. It is commonly used to step up or step down voltage levels in power distribution systems. Transformers are crucial in power transmission and distribution systems, as well as in various electronic devices.



The Symbol of a Transformer

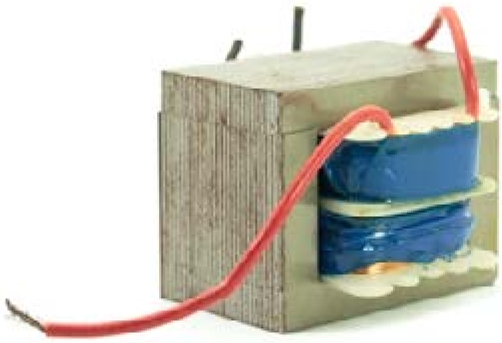


Figure 4.7: A picture of a Transformer

Types of Transformers

a. **Power Transformers:**

   i. **Step-Up Transformers:** Increase voltage for efficient long-distance power transmission.

   ii. **Step-Down Transformers:** Decrease voltage for safe distribution and usage in homes and businesses.

b. **Distribution Transformers:** Used in the distribution network to deliver electricity at usable voltage levels to end consumers.

c. **Isolation Transformers:** Provide electrical isolation between circuits without changing voltage levels significantly, enhancing safety.

d. **Autotransformers:** Have a single winding that acts as both primary and secondary winding, with a tap point. They are more efficient but lack isolation.

e. **Current Transformers (CTs):** Used to measure high currents by producing a lower, proportional current.

f. **Potential Transformers (PTs):** Used to measure high voltages by producing a lower, proportional voltage.

Applications of Transformers

- **Power Transmission and Distribution:** Stepping up and down voltages for efficient power transmission and safe distribution.
- **Electrical Isolation:** Isolating various parts of a circuit to prevent direct electrical connection and increase safety.
- **Voltage Regulation:** Maintaining constant voltage levels in power systems.
- **Signal Processing:** In audio equipment and telecommunications for impedance matching and signal coupling.
- **Measurement:** Using current and potential transformers in metering and protective relays.

8. Switches (S)

Switches are electrical components that can open or close a circuit, interrupting or allowing the flow of current. They can be either mechanical or electronic. When a switch is closed (turned ON), it allows current to flow through the circuit. When it is open (turned OFF), it interrupts the current path, preventing current flow. Switches play a crucial role in controlling the operation of electronic devices and systems. Switches are fundamental components in electronic and electrical systems, used to control devices, direct signals, and ensure safety.

A symbol of a Switch

Figure 4.8: A picture of some switches

Types of Switches

a. **Toggle Switches:** Operated by a lever, commonly used in household and industrial applications.

b. **Push Button Switches:** Operated by pressing a button, used in many control applications.

c. **Rotary Switches:** Operated by rotating a knob, used for selecting different circuit paths.

d. **Slide Switches:** Operated by sliding a button, used in small electronic devices.

e. **DIP Switches:** A set of small switches in a dual in-line package, used for configuration settings on circuit boards.

f. **Rocker Switches:** Operated by rocking a button back and forth, commonly used in power control.

g. **Limit Switches:** Automatically activated by the motion of a machine part, used for position sensing.

h. **Reed Switches:** Activated by a magnetic field, used in proximity sensing.

i. **Membrane Switches:** A thin, flexible switch used in keyboards and control panels.

j. **Proximity Switches:** Detect the presence of an object without physical contact.

Applications of Switches

- **Power Control:** Turning devices on and off in household appliances, industrial machinery, and consumer electronics.
- **Signal Control:** Directing signals in communication devices, computers, and audio equipment.
- **Safety:** Ensuring safe operation in electrical circuits by disconnecting power during faults.
- **User Interface:** Providing user input options in control panels, remote controls, and keyboards.
- **Automation:** Sensing and responding to conditions in automated systems and machinery.

CLASSIFICATION OF CIRCUIT COMPONENTS INTO PASSIVE AND ACTIVE COMPONENTS

Electrical and electronic components can be placed under two broad categories namely the passive and active components. Your understanding of the differences between these two types of components is crucial for designing and analysing electrical circuits.

Passive Components

These are components that do not introduce energy (on their own) into the circuit and cannot amplify signals. They can only receive, store, or dissipate energy. Examples of passive elements include:

1. **Resistor:** A resistor is a component that opposes the flow of current in an electrical circuit. It dissipates energy in the form of heat.
2. **Capacitor:** A capacitor is a component that stores electrical energy in an electric field between its plates. It can release stored energy over time.
3. **Inductor:** An inductor is a component that stores electrical energy in a magnetic field created by the current flowing through its coils. It can release stored energy over time.
4. **Transformer:** A transformer is a component that step-up or step-down voltage levels for efficient power transmission. It can release stored energy over time.

Active Elements

There are two categories of active elements namely (a) components that can introduce energy into the circuit and (b) components that can amplify or manipulate signals. In electrical circuits, active elements are the energy-producing elements (power source). However, in electronic circuits, active components are those that magnify or manipulate the characteristics of signals. They can amplify signals, produce energy, and perform complex functions that passive components cannot. They require an external power source to operate. Examples of active components in electrical circuits include:

1. **Batteries:** They convert chemical energy to electrical energy.
2. **Generators:** They convert thermal/mechanical energy to electrical energy.
3. **Solar Cells:** They convert solar energy (from the sun) to electrical energy.

Examples of active components in electronic circuit include

a. **Transistor:** A semiconductor device that can amplify and switch electronic signals and power. There are two main types: bipolar junction transistors (BJTs) and field-effect transistors (FETs).

b. **Diode:** A diode is a semiconductor device that allows current to flow in only one direction. It can be used for rectification (i.e. converting alternating current (A.C.) to a direct current (D.C.)) or signal conditioning.

Electronic circuits containing both passive and active elements are known as active circuits. Examples include:

a. **Operational Amplifier (Op-Amp):** An integrated circuit that amplifies the difference between two input voltages. It is often used for signal processing and amplification.
b. **Integrated Circuit (IC):** These are active components that contain a combination of transistors, resistors, capacitors, and other elements integrated onto a single chip. They can perform a wide range of functions, from simple amplification to complex digital signal processing.

Activity 4.1: Component Identification Scavenger Hunt

Objective: Learners will identify real-life examples of basic circuit elements in everyday objects.

Instructions:

a. Learners look out for spoilt electronic boards with a list of basic circuit elements (resistor, capacitor, inductor, diode, transistor).
b. Learners find examples of each component in electronic devices, or circuit boards.
c. Learners should make sketches of the components they find and label them with their names and symbols.
d. After collecting examples, learners should present their findings to their class Facilitator and explain the function of each component.

Activity 4.2: Circuit Symbol Matching Game

Objective: Learners will match circuit symbols with their corresponding components.

Instructions:

a. Use a set of cards previously prepared by the facilitator, each with a circuit symbol printed on one side and the name of the component on the other side.
b. Place the cards face down on a table.
c. Join a small group of your classmates (4 or 5).
d. Each group has a set of cards to use, and the group members take turns flipping over two cards at a time, trying to match the symbol with its component name.
e. If a match is made, you keep the pair of cards. If not, the cards are turned face down again, and the next learner takes a turn.
f. The game continues until all matches are made or a time limit is reached.
g. Review the matches as a class to ensure understanding.

Activity 4.3: Circuit Building Lab

Objective: Learners will build simple DC electric circuits using breadboards and electronic components.

Materials Needed:

- Breadboards
- Resistors
- Capacitors
- Inductors
- Diodes
- Transistors
- Jumper wires
- Power supply or batteries
- LED
- Switch
- Multimeter

Instructions:

a. The facilitator provides each group with a breadboard, a set of electronic components (resistors, LEDs, wires, batteries, switches), and a multimeter if available.

b. Demonstrate how to connect components on the breadboard and how to use jumper wires to create circuits.

c. Each person or group is assigned a specific circuit configuration to build, such as:

   - Series and parallel resistor circuits
   - RC time constant circuits
   - Diode rectifier circuits
   - Transistor amplifier circuits

d. You should sketch circuit diagrams before building them to visualise the connections.

e. After building the circuits, you should test their functionality and measure relevant parameters (e.g., voltage, current).

f. Then present your circuits to the class, explaining the purpose of each component and how they function together.

Steps to build LED circuit

a. Connect the positive (red) lead from the battery holder to the positive rail on the breadboard.

b. Connect the negative (black) lead from the battery holder to the negative rail on the breadboard.

c. Insert one leg of the resistor into a hole connected to the positive rail.
d. Insert the other leg of the resistor into a separate row on the terminal strip.
e. Identify the longer leg of the LED (anode) and insert it into the same row as the resistor.
f. Insert the shorter leg of the LED (cathode) into a new row.
g. Connect a jumper wire from the row with the LED's cathode to the negative rail on the breadboard.
h. Connect the battery to the battery holder.
i. Observe if the LED lights up, indicating the circuit is complete and functioning.
j. If the LED does not light up, troubleshoot by checking connections and component placement.

Activity 4.4: Circuit Symbol Sketching Challenge

Objective: You will practice sketching circuit symbols from memory.

Instructions:

a. Pick up a list of circuit elements and their corresponding symbols from your facilitator (e.g., resistor, capacitor, diode).
b. You will be given a set amount of time (e.g., 5 minutes) to sketch as many circuit symbols as you can from memory.
c. After the time is up, compare your sketches with the correct symbols and identify any discrepancies.
d. Discuss the correct symbols and their meanings as a class, emphasising any common mistakes or misconceptions.
e. Repeat the sketching challenge periodically to reinforce learning and improve accuracy over time.

Activity 4.5: Component Sorting Activity

Objective: You will sort a collection of circuit components into passive and active categories based on their characteristics.

Materials Needed:

- Assorted circuit components (resistors, capacitors, inductors, diodes, transistors)
- Sorting containers or labeled sections on a table

Instructions:

a. The facilitor will provide you with a collection of circuit components.
b. You will be instructed to examine each component and determine whether it is passive or active.

c. Then place each component into the appropriate sorting container or section labelled "Passive" or "Active."
d. Discuss your reasoning for classifying each component.
e. After sorting, review the classifications as a class, discussing the distinguishing characteristics of passive and active elements.

Activity 4.6: Component Identification Challenge

Objective: You will identify passive and active circuit elements in real-world circuits.

Materials Needed:

- Circuit diagrams or schematics
- Whiteboards or paper to write your answers on

Instructions:

a. You will be provided with circuit diagrams or schematics depicting various circuits.
b. Analyse each circuit and identify the passive and active elements present.
c. You should write down your answers on whiteboards or paper.
d. After you have completed the challenge, review the circuits as a class and discuss the correct classifications.
e. Address any misconceptions and provide explanations for why each component is classified as passive or active.

Activity 4.7: Hands-On Circuit Building

Objective: You will build circuits containing both passive and active elements to observe their behaviour.

Materials Needed:

- Breadboards
- Resistors, capacitors, inductors, diodes, transistors
- Jumper wires
- Power supply or batteries

Instructions:

a. The facilitator will provide you with breadboards and a variety of circuit components.
b. You will be assigned specific circuit configurations to build, incorporating both passive and active elements.
c. Sketch the circuit diagrams before building them to plan the connections.

d. Build and test your circuits, observing the behaviour of each component.
e. You should discuss your observations and compare the behaviour of passive and active elements in the circuits.
f. Join a class discussion to review the circuits and reinforce the classification of passive and active elements.

Activity 4.8: Discovering the Effects of Passive Components on Current Flow and Energy Dissipation

Objective: You will understand how passive components such as resistors and capacitors affect the flow of current in a circuit. You will also learn about energy dissipation in passive components such as resistors and capacitors and understand how this influences their classification and practical applications.

Materials Needed:

- Breadboards
- Resistors of various values
- Capacitors of various values
- Multimeters
- DC power supplies
- Connecting wires
- LED bulbs
- Worksheets for recording observations

Safety Notes:

- Always ensure the power supply is turned off while constructing circuits.
- Double-check connections before applying power to prevent short circuits.
- Handle resistors carefully during and after the experiment to avoid burns from heat dissipation.

Experiment A: Resistors in Series and Parallel:

a. **Step 1:** Connect resistors in series on the breadboard with an LED. Use the DC power supply to apply a constant voltage (e.g., 5V). Measure and record the current using the multimeter.
b. **Step 2:** Connect resistors in parallel on the breadboard. Apply the same voltage and measure the current.

Observation: Students should note how the total resistance changes in series and parallel configurations and how it affects the current.

c. **Step 3:** Measure and record the current using the multimeter. Calculate the power dissipation using the formula $P=I^2R$.
d. **Step 4:** Touch the resistor carefully to feel the heat generated.

Observation: Students should observe the LED lighting up and the resistor warming up due to energy dissipation as heat.

Worksheet Questions:

i. How does the current change when resistors are added in series versus parallel?
ii. What is the relationship between total resistance and current flow in each configuration?
iii. How does the resistor dissipate energy?
iv. Calculate the power dissipated by the resistor.
v. What practical implications does this energy dissipation have for circuit design?

Experiment B: Capacitors in DC Circuits and their Energy Behaviour:

a. **Step 1:** Connect a capacitor in series with a resistor and an LED. Apply a DC voltage and observe the LED.
b. **Step 2:** Measure the voltage across the capacitor and resistor over time as the capacitor charges and discharges.

   Observation: Learners should see that the LED gradually dims as the capacitor charges and the current decreases.
c. **Step 3**: Measure the voltage across the capacitor and resistor over time using a multimeter.

   Observation: You should see the LED gradually dimming as the capacitor charges and brightening as it discharges.

Worksheet Questions:

i. What happens to the current flow when the capacitor is fully charged?
ii. How does the capacitor affect the brightness of the LED over time?
iii. Does the capacitor dissipate energy as heat? Why or why not?
iv. Describe the energy storage and release process in the capacitor.
v. How does this behaviour classify the capacitor in terms of energy dissipation?

Conclusion and Discussion (10 minutes):

a. Discuss with the whole class the key points learned from the experiments.
b. Discuss real-world applications of resistors, capacitors, and inductors in electronic devices.
c. Discuss the classification of passive components based on their energy dissipation properties:
   i. Resistors as energy dissipating components.
   ii. Capacitors and inductors as energy-storing components.
d. You are encouraged to ask questions and share your observations.

Activity 4.9: Investigating the Role of Active Components in Signal Amplification and

Signal Processing

Objective: You will explore how active components such as transistors and operational amplifiers (op-amps) are used in signal amplification and signal processing within circuits.

Materials Needed:

- Breadboards
- NPN Transistors (e.g., 2N2222)
- Operational Amplifiers (e.g., LM741)
- Resistors (1kΩ, 10kΩ, 100kΩ)
- Capacitors (1μF, 10μF)
- DC power supplies (±15V and 5V)
- Signal generators
- Oscilloscopes
- Multimeters
- Connecting wires
- LEDs

Instructions:

Part 1: Understanding Transistors

Experiment 1: Transistor as a Switch

1. **Circuit Setup:** Connect the following components on a breadboard:
   a. Collector (C) of the NPN transistor to the positive terminal of the 5V power supply.
   b. Emitter (E) to ground.
   c. Base (B) through a 1kΩ resistor to the positive terminal of the power supply.
   d. LED in series with a 1kΩ resistor between the collector and ground.

2. **Procedure:**
   a. Measure the voltage across the LED when the base is connected to the power supply.
   b. Disconnect the base and measure the voltage across the LED again.

3. **Observations and Questions:**
   a. Record the voltage across the LED in both cases.
   b. What happens to the LED when the base is connected and disconnected?
   c. Explain the role of the transistor in this circuit.

KIRCHHOFF'S LAWS

Kirchhoff's Current Law (KCL) is one of the fundamental principles used in electrical circuit analysis. It is named after the German physicist Gustav Kirchhoff, who first formulated it in 1845. Gustav Robert Kirchhoff (1824-1887) was a renowned physicist and mathematician who made significant contributions to various fields of science. In electrical circuit theory, he is best known for formulating Kirchhoff's Laws, which he published in 1845 while he was a university student. To understand and apply the Kirchhoff's Laws, let us introduce briefly the Ohm's law.

Ohm's Law

Ohm's Law states that, the voltage drop (V) across a conductor or load is equivalent to the product of current (I) and resistance (R) of the conductor or load. This can be expressed mathematically as $V = I \times R$. This will be useful when applying the Kirchhoff's Laws below.

Kirchhoff's Current Law (KCL)

It states that at any instant, the algebraic sum of currents at any junction (or node) in a network is zero.

Or the law states:
"The total current entering a junction (or node) in an electrical circuit must equal the total current leaving the junction."

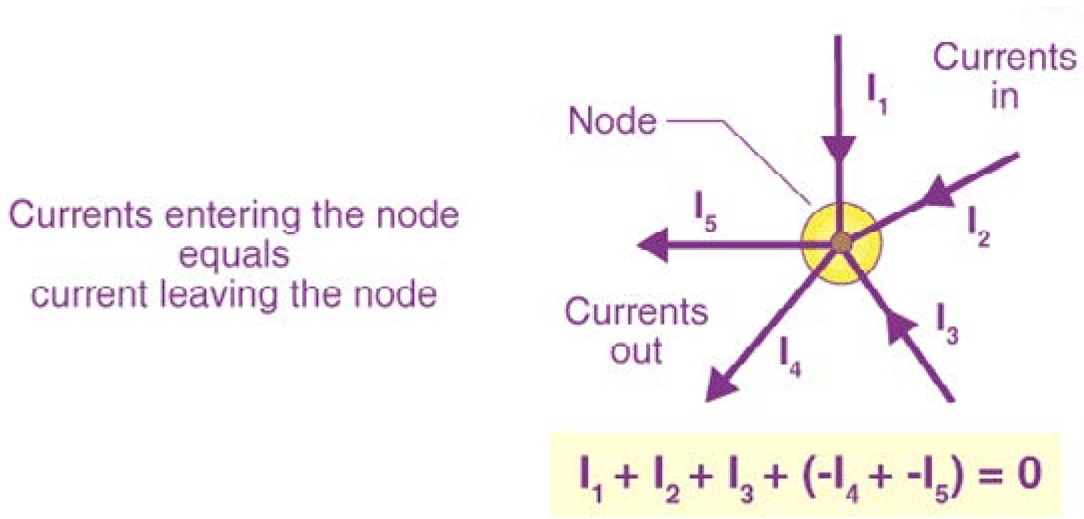


Figure 4.9: A picture illustrating KCL

In simple terms, this means that the total current flowing into a junction is equal to the total current flowing out of the junction. This is because the charge is neither created nor destroyed at a junction; it can only flow in or out.

In other words, the algebraic sum of currents at a node is zero. Mathematically, this can be expressed as:

$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

$$\mathrm{I_1 + I_2 + I_3 = I_4 + I_5}$$

The currents entering the node are considered positive, and the currents leaving the node are considered negative (or vice versa, if the sign convention is consistent).

Application of KCL

To apply Kirchhoff's Current Law in analysing a circuit:

a. **Identify Nodes:** Determine all the junctions (nodes) in the circuit where currents converge.
b. **Assign Currents:** Assign a direction to each current flowing into or out of the node. The actual direction does not matter initially; if the current is in the opposite direction, the result will be a negative value.
c. **Write Equations:** For each node, write an equation that represents the sum of currents entering and leaving the node.
d. **Solve the Equations:** Use the system of equations to solve for the unknown currents.

Example

Consider four gadgets in a house which are connected in parallel to a power source namely a refrigerator, television, computer, and lamp. Given that the refrigerator draws 5A, the television draws 3A, the computer draws 2A and the lamp draws 1A. Find the total current drawn by the three gadgets.

Solution

Using the Kirchhoff's Current Law

$$I_{total} = I_{refrigerator} + I_{television} + I_{computer} + I_{lamp}$$

$$I_{total} = 5A + 3A + 2A + 1A = 11A$$

Kirchhoff's Voltage Law (KVL)

It states that *at any instant in a loop, the algebraic sum of the EMFs acting around the loop is equal to the algebraic sum of the potential differences around the loop.* A loop is a path that starts and ends at the same node/junction, without passing through any electrical element more than once.

Application of KVL

a. **Identify the Loop**: Choose a closed loop within the circuit for analysis.
b. **Assign Voltage Polarities**: For resistors, assume a direction for the voltage drop (from positive to negative terminal). For voltage sources, mark their polarities according to their orientation within the loop.

c. **Write the Voltage Equation**: For each loop, write the Kirchhoff's voltage equations using KVL.
d. **Solve for Equations**: Use the systems of equations to solve for the unknowns.

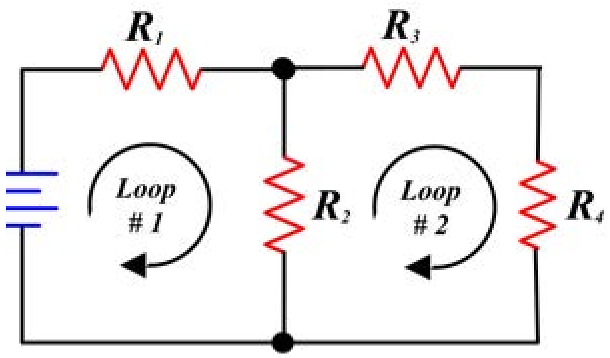


Figure 4.10: A picture illustrating KVL

$$I_1 = I_2 + I_3 \quad \text{..........................KCL equation 1}$$

$$V = I_1R_1 + I_2 R_2 \quad \text{..........................KVL equation 2}$$

$$V = I_1R_1 + I_3 (R_3 + R_4) \quad \text{................KVL equation 3}$$

Example
Consider four gadgets in a house connected in series across battery sources, namely a washing machine, lamp, fan, and radio. Given that the washing machine has a voltage drop of 6V, the lamp has a voltage drop of 3V, the fan has a voltage drop of 2V, and the radio has a voltage drop of 1V. Find the voltage of the battery source.

Solution
Using the KVL,

$$V_{total} = V_{washing\ machine} + V_{lamp} + V_{fan} + V_{radio}$$

$$V_{total} = 6A + 3A + 2A + 1A = 12A$$

Series and Parallel Circuits

In series circuits, resistors are connected one after another, creating a single path for current flow. The equivalent resistance (R_T) of series resistors is the sum of individual resistances.

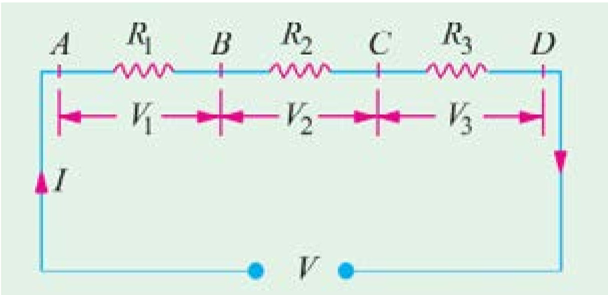


Figure 4.11: Three resistors in Series

Characteristics of a Series circuit

a. The same current flows through all resistors
b. Total potential difference is equal to the sum of individual potential differences
c. Individual potential difference 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 differences across each resistor:

$$V = V_1 + V_2 + V_3$$

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

$$IR_T = IR_1 + IR_2 + IR_3$$

Dividing through by I

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

Question:

You have a 12V battery and three resistors with values $R_1 = 2\,\Omega$, $R_2 = 3\,\Omega$, and $R_3 = 5\,\Omega$ connected in series.

a. Calculate the total resistance:

$R_{total} = 2 + 3 + 5 = 10\,\Omega$

b. Calculate the current

$I = V / R_{total} = 12\,V / 10\,\Omega = 1.2\,A$

c. Calculate the voltage drop across each resistor:

$V_1 = I \times R_1 = 1.2\,A \times 2\,\Omega = 2.4\,V$

$V_2 = I \times R_2 = 1.2\,A \times 3\,\Omega = 3.6\,V$

$V_3 = I \times R_3 = 1.2\,A \times 5\,\Omega = 6.0\,V$

d. Verify the total voltage:

$V = V_1 + V_2 + V_3 = 2.4 + 3.6 + 6.0 = 12\,V$

Resistors connected in parallel

When resistors are connected in parallel in the same circuit, they can work as if each resistor were connected in a separate circuit.

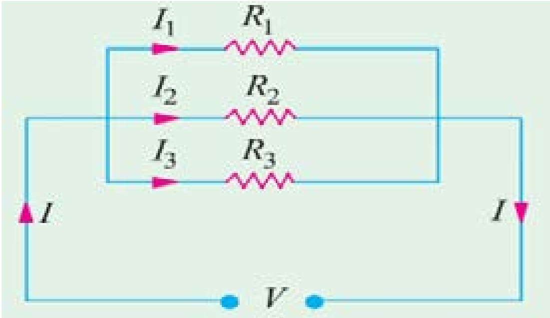


Figure 4.12: Three resistors in Parallel

Characteristics of a parallel circuit

a. The same potential difference is across each resistor.
b. Total current is equal to the sum of individual currents.
c. Individual currents are inversely proportional to the individual resistances.
d. Total power in a parallel circuit is equal to the sum of the individual values of power in each branch.

When two (2) Resistors are connected in parallel

$$\mathbf{I = I_1 + I_2}$$

$$I = \frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2}$$

Where V is the applied voltage

R_T is the total resistance of the parallel combination

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2}$$

Dividing through by **V**

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

Find the LCM

$$\frac{1}{R_T} = \frac{R_2 + R_1}{R_1 \times R_2}$$

Hence, total resistance for the parallel combination,

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

When three (3) Resistors are connected in parallel,

$\mathbf{I = I_1 + I_2 + I_3}$

$$I_T = \frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Where **V** is the applied voltage

$\mathbf{R_T}$ is the total resistance of the parallel combination

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Dividing through by **V**

$$I = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Find the LCM

$$\frac{1}{RT} = \frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1\,R_2\,R_3}$$

Hence, total resistance for the parallel combination, $\mathbf{R_T} = \dfrac{R_1.R_2.R_3}{R_2.R_3 + R_1.R_3 + R_1.R_2}$

Question:

Consider a parallel circuit with a 12 V battery and three resistors R_1 =2 Ω, R_2 =3 Ω, and R_3 = 6 Ω.

a. **Total Resistance**:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

$$= \frac{1+2+1}{6}$$

$$= \frac{6}{6}$$

$$= 1$$

$$\mathbf{R_T} = 1\,\Omega$$

b. **Current through each Resistor:**

$$I_1 = \frac{V}{R_1} = \frac{12}{2} = 6A$$

$$I_2 = \frac{V}{R_2} = \frac{12}{3} = 4A$$

$$I_2 = \frac{V}{R_2} = \frac{12}{6} = 2A$$

c. **Total Current:** Using KCL,

$$I_T = I_1 + I_2 + I_3$$

$$I_T = 6A + 4A + 2A$$

$$I_T = 12A$$

USING KIRCHHOFF'S LAWS TO FIND CURRENTS AND VOLTAGES IN DC CIRCUITS

Analysing DC circuits using Kirchhoff's laws is an essential skill for anyone studying electrical engineering or related fields. Kirchhoff's laws are two fundamental principles that govern the behaviour of electrical circuits. Sample problems solved using Kirchoff's Laws are presented below:

Question 1:

Using figure 4.13 below,

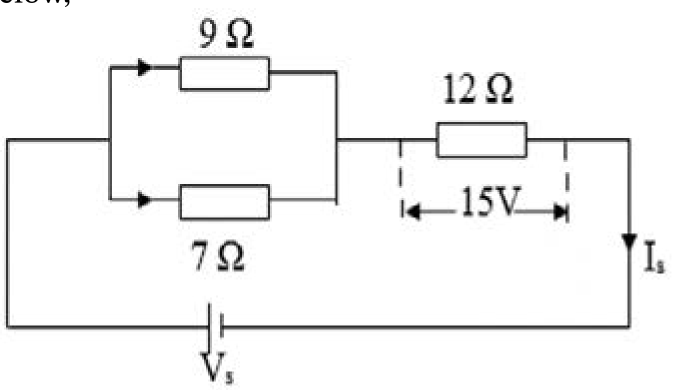


Figure 4.13

Calculate:

a. the total resistance R_T;
b. current, I_s;
c. voltage, V_s.
d. the voltage across the 9Ω resistor

Solution:

a. The 9Ω resistor is in parallel with the 7Ω resistor. Using the concept of series and parallel resistors above,

$$\frac{1}{RP} = \frac{1}{9} + \frac{1}{7}$$

$$\frac{1}{RP} = \frac{7+9}{7 \times 9}$$

$$RP = \frac{9 \times 7}{9 + 7}$$

$$= 3.9375\ \Omega$$

The combination of the 9Ω resistor and the 7Ω is in series with the 12Ω, therefore

$$R_T = R_p + 12$$

$$= 3.9375 + 12$$

$$= 15.9375\ \Omega$$

∴ The total resistance of the circuit, $R_T = 15.94\Omega$

b. Using the Ohms law, the voltage drop across the total resistance is (which is equal to the source voltage), $V_s = I_s R_T$,

$$\text{hence } I_s = \frac{V_S}{R_T}$$

The voltage drop across the 12Ω has been given as V = 15V, using ohms law,

$$I_s = \frac{15}{22}$$

$$= 1.25A$$

c. Applying the KVL to the loop that contains the 9Ω resistance, the 12Ω resistor and the source voltage,

$$V_s = V_p + 15V$$

$$V_p = I_s R_p$$

$$I_s = 1.25A \text{ and } R_p = 3.9375\Omega$$

$$V_p = 1.25 \times 3.9375$$

$$= 4.921875V$$

$$V_s = 4.921875 + 15$$

$$= 19.921875V$$

d. Voltage across 9Ω Resistor, $V_p = 4.9218V$

Question 2:

Using Kirchhoff's laws in figure 4.14,

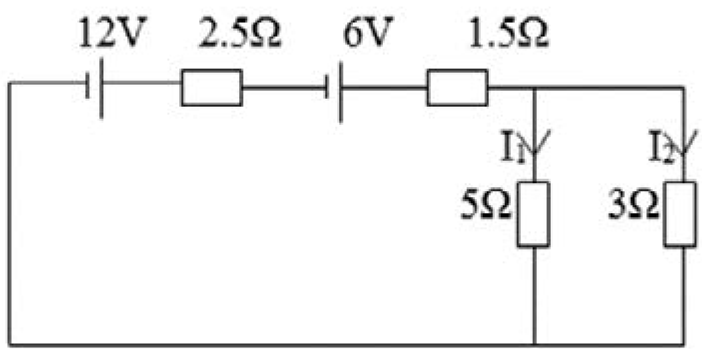


Figure 4.14

Calculate the

a. I_1
b. I_2
c. the voltage across the 3Ω resistor

Solution

The 2.5Ω and the 1.5Ω resistors are in series hence,

$R_s = 2.5\Omega + 1.5\Omega$
$= 4.0\Omega$

The Total Voltage, $Vs = 12V + 6V$
$= 18V$

From the circuit diagram

$I_2 = I - I_1$ --------- Equation 1
$18 = 4I + 5I_1$ -------- Equation 2
$18 = 4I + 3I_2$ ------- Equation 3

Substituting equation 1 into equation 3

$18 = 4I + 3(I - I_1)$
$18 = 4I + 3I - 3I_1$

$18 = 7I - 3I_1$--------------- Equation 4

Equation 2 × 3

$54 = 12I + 15I_1$----------- Equation 5

Equation 4 × 5

$90 = 35I - 15I_1$----------- Equation 6

Equation 5 + Equation 6

$144 = 47I$

$I = \frac{144}{47}$

$= 3.0638A$

a. Substituting $I = 3.0638$ into equation 2

$18 = 4I + 5I_1$

$18 = 4(3.0638) + 5I_1$

$18 = 12.2552 + 5I_1$

$5I_1 = 18 - 12.2552$

$5I_1 = 5.7448$

$I_1 = \dfrac{5.7448}{5}$

$\therefore I_1 = 1.14896A$

b. Substituting $I = 3.0638$ into equation 3

$18 = 4I + 3I_2$

$18 = 4(3.0638) + 3I_2$

$18 = 12.2552 + 3I_2$

$3I_2 = 18 - 12.2552$

$3I_2 = 5.7448$

$I_2 = \dfrac{5.7448}{3}$

$I_2 = 1.9149A$

c. The voltage across the 3Ω resistor,

$V = 3I_2$

$= 3 \times 1.9149$

$= 5.7447V$

Question 3:

Figure 4.15 is a resistive network. If the power dissipated in the 12Ω resistor is 48W, calculate the:

a. current flowing in the 12Ω resistor
b. the total current (I) in the circuit
c. value of the resistor, **R**.

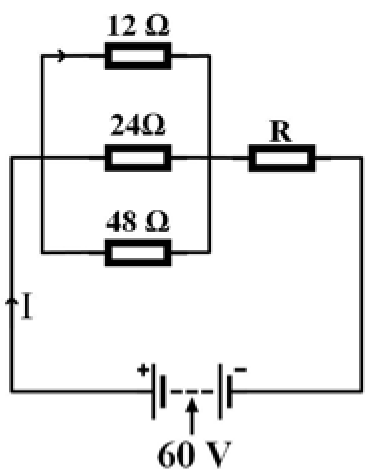


Figure 4.15

Answers

a. Current flowing in the 12Ω resistor, $I_1 = 2.0$A
b. The total current $I = 3.5$A
c. The value of Resistor R = 10.2Ω

Question 4:

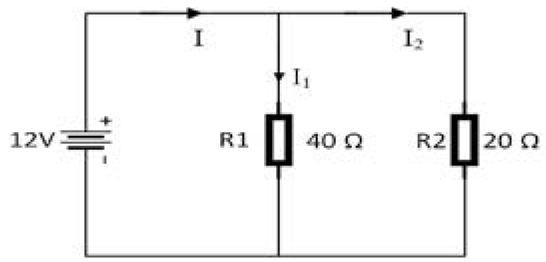


Figure 4.16

Figure 4.16 is a circuit diagram. Using the diagram, calculate the:

a. current (I_1) flowing through resistor R_1
b. current (I) flowing through the circuit
c. current (I_2) flowing through resistor R_2

Answers

a. The current, $I_1 = 0.3$A
b. The Total current, $I = 0.9$A
c. The current, $I_2 = 0.6$A

Question 5:

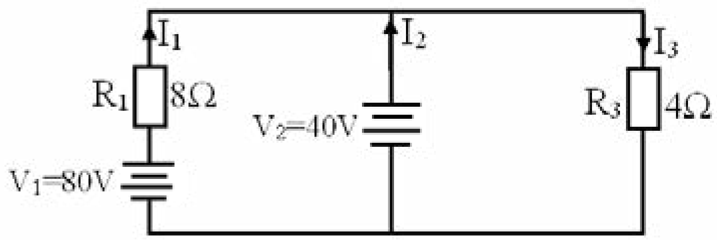


Figure 4.17

Using Kirchhoff's law in Figure 4.17, calculate

a. the value of current I_1
b. the value of current I_2

Answers

a. Current $I_1 = 5$A
b. Current $I_2 = 10$A

Activity 4.10

1. Using the circuit diagram in Figure 4.18 below, Calculate
   a. the total resistance in the circuit
   b. the currents I_1, I_2 and I_3 in the circuit
   c. the voltage drops across R_1

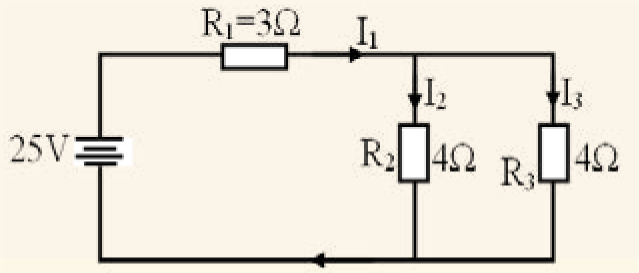


Figure 4.18

Answers:

a. $R_T = 5\Omega$
b. $I_1 = 5A$, $I_2 = 2.5A$ and $I_3 = 2.5A$
c. $V_{R1} = 15V$

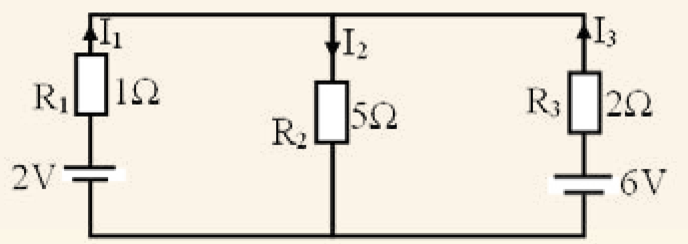


Figure 4.19

2. Using Kirchhoff's law in Figure 4.19, calculate
   a. the total resistance in the circuit
   b. the value of current I_1
   c. the value of current I_2
   d. the value of current I_3
   e. the voltage drops across R_2

Answers:

a. $R_T = 0.588\Omega$
b. $I_1 = 5.333A$
c. $I_2 = - 0.667A$
d. $I_3 = 4.667A$
e. $V_{R2} = 2.224V$

3.

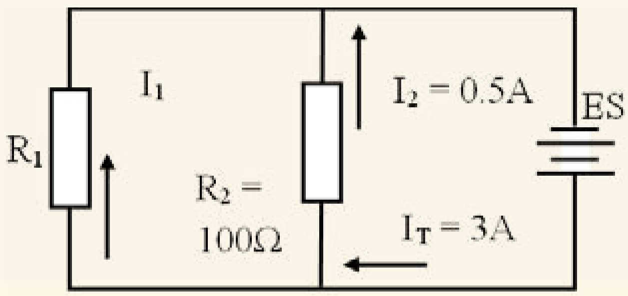


Figure 4.20

Using Figure 4.20, Calculate:

a. the current, I_1 through the resistor R_1
b. the total voltage across the circuit, E_S
c. the resistance of the resistor, R_1

Answers:

a. $I_1 = 2.5A$
b. $E_S = 50V$
c. $R_1 = 20\Omega$

COMPUTING POWER IN DC AND SINGLE-PHASE AC CIRCUITS

Power is the rate at which work is done or the rate of energy transfer. It measures how quickly energy is converted or used in a system. The SI unit of power is the watt, represented by the symbol "W."

$$\text{Power (P)} = \frac{\text{Energy (E)}}{\text{Time (t)}} \quad \text{or } P = \frac{E}{t}$$

Where: P = Power in watts (W)
E = Energy in joules (J)
t = Time in seconds (s)

Relationship between Power, Voltage, and Current:

P = VI for resistive circuits

Where: P = Power in watts (W),
V = Voltage in volts (V)
I = Current in amperes (A)

Power in DC Circuits

$$P = VI$$

$$P = I^2R$$

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

Question 1:

If a resistor connected to a 12V DC supply has current of 1.2A flowing through it, calculate the power dissipated by the resistor.

Solution:

$$P = IV$$
$$P = 1.2 \times 12$$
$$P = 14.4\text{ W}$$

Question 2:

An electrical circuit consists of a 24 V DC power source and a resistor of resistance 6Ω connected across it. Calculate the power dissipated.

Solution:

$$P = \frac{V^2}{R}$$
$$P = \frac{24^2}{6}$$
$$P = \frac{576}{6}$$
$$P = 96\text{ W}$$

Question 3:

Two resistors of resistances 4Ω and 8Ω are connected in series. If a current flowing through them is 1.67A, determine the total power dissipated in the circuit.

Solution:

Total Resistance, $R = 4 + 8$

$= 12\ \Omega$

Current, $I = 1.67\text{A}$

$$P = I^2R$$
$$P = 1.67^2 \times 12$$
$$P = 33.4668\text{ W}$$

Activity 4.11

1. In a DC circuit, a 12 V battery is connected to a resistor with a resistance of 8Ω. Calculate the power dissipated in the resistor. Also, explain how the power value changes if the resistance is doubled while keeping the voltage constant.
2. A DC motor consumes 10 A of current from a 24 V battery while operating. The motor has an output shaft power of 180W. Calculate the efficiency of the motor. If the efficiency is found to be low, suggest some possible ways to improve it.
3. Solve for terminal quantities such as voltage and current in the DC circuit and then compute the power.

SOFTWARE TOOL TO SIMULATE SIMPLE CIRCUITS TO DERIVE CURRENT, VOLTAGE, AND POWER IN DC CIRCUITS

Circuit Simulation Software

In the field of electronics, circuit simulation software plays a crucial role in understanding, designing, and testing electrical circuits without the need for physical components. These tools allow users to create and simulate circuits virtually, making them an essential learning aid in education. Three commonly used user-friendly circuit simulation software tools are **Proteus, LTspice** and **CircuitLab**.

Proteus

Proteus is a popular circuit simulation tool that is widely used in education and hobbyist projects. It offers a simple and intuitive interface that makes it suitable for beginners. Proteus circuit builder allows learners to drag and drop components onto the canvas, making it easy to assemble circuits.

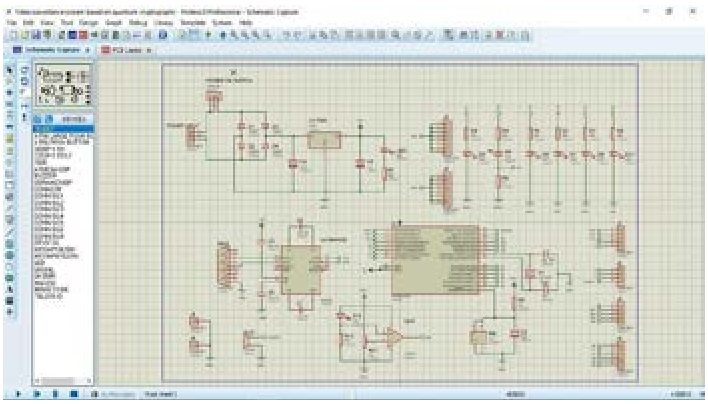


Figure 4.21: A picture of Proteus interface

Here are steps to simulate a simple circuit to derive current, voltage, and power in DC circuit using Proteus.

Step 1: Configure and Simulate the Circuit

a. *Set Component Values:*
   i. Draw the circuit diagram you want to simulate.
   ii. Open the proteus schematic editor window.
   iii. Select the components from the component list and place them on the simulation interface.
   iv. Perform all the necessary connections.
   v. Double-click on each component to set its properties, such as the resistance value for resistors or voltage for the DC source.

b. *Place Measurement Instruments:* Add virtual instruments like voltmeters and ammeters to measure voltage and current at various points in the circuit.

c. *Run the Simulation:*
   i. Click the “Play” button (triangle icon) to run the simulation.
   ii. Observe the behaviour of the circuit and the readings from the virtual instruments

Step 2: Measure and Record Values

a. *Measure Voltage:* Place a voltmeter across the components where you want to measure the voltage.

b. *Measure Current:* Place an ammeter in series with the components where you want to measure the current.

c. *Calculate Power:*
   i. Use the formula $P = V \times I$ to calculate power, where P is power, V is voltage, and I is current.
   ii. Alternatively, you can place a wattmeter to directly measure the power if available.

Example Circuit: Series and Parallel Resistor Network

Series Circuit:

- Place a DC voltage source.
- Connect two or more resistors in series with the voltage source.
- Place voltmeters across each resistor and an ammeter in series with the circuit to measure the total current.
- Run your simulation and record the values for the current and the voltages.

Parallel Circuit:

- Place a DC voltage source.
- Connect two or more resistors in parallel with the voltage source.

- Place voltmeters across each resistor and an ammeter in series with each branch to measure the individual currents.
- Run your simulation and record the values for the currents and the voltage.

Step 3: Analyse and Interpret Results

a. *Analyse Measurements:* Compare the measured values of voltage, current, and power with theoretical calculations using Ohm's Law, Kirchhoff's Current Law and Kirchhoff's Voltage Law.

b. *Interpret Results:* Discuss any discrepancies between the measured and theoretical values, considering possible sources of error or limitations of the simulation.

Step 4: Report Findings

a. *Document the Process:* Write a report detailing the circuit design, simulation setup, measurements taken, and the results obtained.

b. *Include Screenshots*: Take screenshots of your Proteus circuit design and measurement readings.

c. *Present Results:* Prepare a presentation or a report to share your findings with the class, explaining how Proteus helped in understanding the principles of DC circuits.

LTspice

LTspice is a powerful circuit simulation software widely used in engineering and educational settings. It offers more advanced features than Tinkercad but may have a steeper learning curve. It provides a **s**chematic editor where students can design circuits by placing components and connecting them with wires.

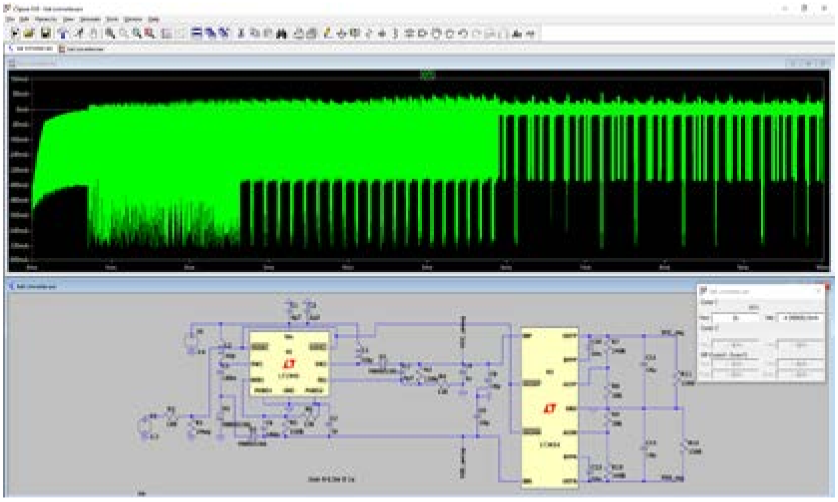


Figure 4.22: A picture of LTspice interface

Here are steps to simulate a simple circuit to derive current, voltage, and power in DC circuit using LTspice.

Step 1: Run the Simulation

a. **Set Up Simulation:**
   i. Click on the Simulate menu and select Edit Simulation Command.
   ii. In the simulation command window, choose the type of analysis you want to run (e.g., DC operating point, Transient, or AC Analysis). For DC circuits, choose DC operating point.
   iii. Click OK and place the simulation command on the schematic.

b. **Run the Simulation:** Click on the Run icon (a running man symbol) or press F9 to run the simulation.

Step 2: Measure and Record Values

a. **Measure Voltage:**
   i. Click on the Voltage probe (red probe icon) and then click on the node where you want to measure the voltage.
   ii. LTspice will display the voltage at that node.

b. **Measure Current:**
   i. Click on the Current probe (current meter icon) and then click on the component that you want to measure the current flowing through.
   ii. LTspice will display the current through that component.

c. *Calculate Power:*
   i. Use the formula $P = V \times I$ to calculate power, where P is power, V is voltage, and I is current.
   ii. Alternatively, you can right-click on a component and select Power to display the power directly.

Example Circuit: Series and Parallel Resistor Network

Series Circuit:

- Place a DC voltage source.
- Connect two or more resistors in series with the voltage source.
- Measure the voltage across each resistor and the total current in the circuit.

Parallel Circuit:

- Place a DC voltage source.
- Connect two or more resistors in parallel with the voltage source.
- Measure the voltage across each resistor and the current through each branch.

Step 3: Analyse and Interpret Results

a. *Analyse Measurements:* Compare the measured values of voltage, current, and power with theoretical calculated values.

b. *Interpret Results:* Discuss any discrepancies between the measured and theoretical values, considering possible sources of error or limitations of the simulation.

Step 4: Report Findings

a. *Document the Process:* Write a report detailing the circuit design, simulation setup, measurements taken, and the results obtained.

b. *Include Screenshots:* Take screenshots of your LTspice circuit design and measurement readings.

c. *Present Results*: Prepare a presentation or a report to share your findings with the class, explaining how LTspice helped in understanding the principles of DC circuits.

CircuitLab

CircuitLab is another user-friendly online circuit simulator with a focus on simplicity and ease of use. It features a schematic editor that enables learners to create circuits quickly and efficiently. It also includes a wide range of components and supports various simulation types.

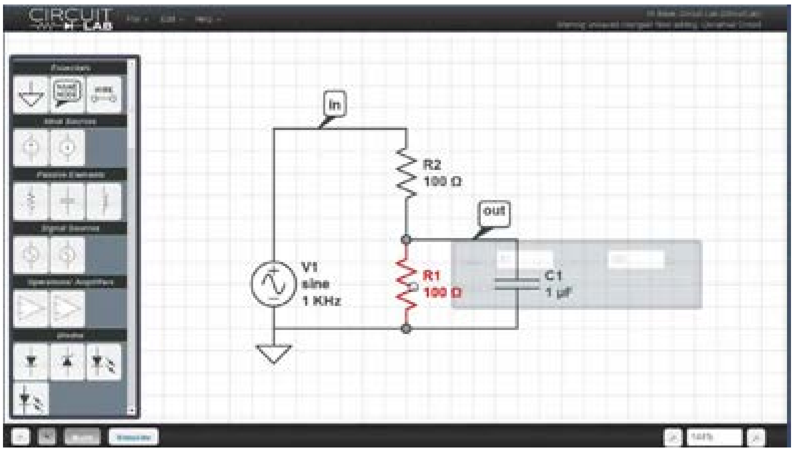


Figure 4.23: A picture of Circuitlab interface

Here are steps to simulate a simple circuit to derive current, voltage, and power in DC circuit using Circuitlab.

Step 1: Run the Simulation

a. **Set Up Simulation:**

   i. Click on the Simulate button in the top toolbar.

   ii. In the simulation settings window, choose the type of analysis you want to run (e.g., DC, Transient, or AC Analysis). For DC circuits, choose DC.

b. **Configure Analysis:**

   i. Set the parameters for the DC analysis, such as the range of values to be swept if needed.

   ii. Click Run DC Solver to start the simulation.

Step 2: Measure and Record Values

a. **Measure Voltage:**
   i. Click on the Voltage probe tool and then click on the node where you want to measure the voltage.
   ii. CircuitLab will display the voltage at that node.

b. **Measure Current:**
   i. Click on the Current probe tool and then click on the component through which you want to measure the current.
   ii. CircuitLab will display the current through that component.

c. **Calculate Power:**
   i. Use the formula $P = V \times I$ to calculate power, where P is power, V is voltage, and I is current.
   ii. Alternatively, you can use CircuitLab's built-in measurement tools to directly display power if available.

Example Circuit: Series and Parallel Resistor Network

Series Circuit:

- Place a DC voltage source.
- Connect two or more resistors in series with the voltage source.
- Measure the voltage across each resistor and the total current in the circuit.

Parallel Circuit:

- Place a DC voltage source.
- Connect two or more resistors in parallel with the voltage source.
- Measure the voltage across each resistor and the current through each branch.

Step 3: Analyse and Interpret Results

a. *Analyse Measurements:* Compare the measured values of voltage, current, and power with theoretical calculations.

b. *Interpret Results*: Discuss any discrepancies between the measured and theoretical values, considering possible sources of error or limitations of the simulation.

Step 4: Report Findings

a. *Document the Process:* Write a report detailing the circuit design, simulation setup, measurements taken, and the results obtained.

b. *Include Screenshots:* Take screenshots of your CircuitLab circuit design and measurement readings.

c. *Present Results:* Prepare a presentation or a report to share your findings with the class, explaining how CircuitLab helped in understanding the principles of DC circuits.

Example of Detailed Steps for a Series Circuit:

a. **Start a New Schematic:** Click New Document.

b. **Add Components:**
   i. From the left toolbar, click DC Voltage Source and place it on the workspace.
   ii. Click Resistor and place two resistors in series with the voltage source.
   iii. Click Ground and place it at the bottom of the voltage source.

c. **Connect Components:**
   i. Use the Wire tool to connect the positive terminal of the voltage source to one end of the first resistor.
   ii. Connect the other end of the first resistor to one end of the second resistor.
   iii. Connect the other end of the second resistor to the ground.

d. **Set Values:**
   i. Double-click the voltage source and set its value (e.g., 10V).
   ii. Double-click each resistor and set their values (e.g., 1kΩ each).

e. **Run Simulation:**
   i. Click Simulate.
   ii. In the simulation settings, select DC.
   iii. Click Run DC Solver.

f. **Measure and Record:**
   i. Use the Voltage probe to measure the voltage across each resistor.
   ii. Use the Current probe to measure the current through the series circuit.

Running Simulations

After setting up the circuit parameters, it's time to run the simulation. Most software tools have a "simulate" or "run" button that initiates the analysis. The software will calculate the behaviour of the circuit based on the specified parameters and generate simulation results, such as voltage and current waveforms, which can be displayed on the screen.

Introduction to DC Circuits Simulation

1. Open the circuit simulation software (e.g., SPICE, LTspice, or any other tool you prefer) and create a new project.
2. Design your DC circuit on the simulation interface by placing components like resistors, capacitors, and voltage/current sources.
3. Once the circuit is ready, you can begin the simulation setup.

Setting Simulation Time and Analysing Transient or Steady-State Behaviour:

a. Before running the simulation, determine the time span you want to observe. For transient analysis, set the simulation time long enough to capture the behaviour of interest. For steady-state analysis, you can set a shorter simulation time.

b. Configure the simulation settings, selecting either transient or steady-state analysis.

c. Run the simulation and observe the behaviour of the circuit over time (transient analysis) or once it reaches a stable state (steady-state analysis).

Measuring Current, Voltage, and Power:

a. To measure current and voltage at specific locations in the circuit, place measurement probes accordingly. Probes are typically voltage probes (for voltage measurement) and current probes (for current measurement).

b. After running the simulation, examine the waveforms displayed on the oscilloscope or plotter. You can use the cursors or markers to measure specific values.

c. Analyse the measured values to understand how voltage and current change over time or at specific points in the circuit.

Analysing Power in DC Circuits:

a. To calculate power dissipation in resistive elements (e.g., resistors), use the formula: Power (P) = Voltage (V) × Current (I). This is valid for resistive elements in both DC circuits.

b. Sum up the power dissipated across all resistors in the circuit and verify power conservation, which states that the total power supplied by voltage sources must equal the total power consumed by resistive elements.

Activity 4.12

The teacher will draw and explain the power relations of Apparent Power, Real Power and Reactive Power, including power factor and provide all relevant equations.

Interactive Simulation

Objective: Use an online simulation tool to explore the behaviour of passive and active circuit elements.

Materials Needed:

- Computer or tablet with internet access
- Circuit simulation software (e.g., CircuitLab, Falstad Circuit Simulator)

Instructions:

a. The teacher will introduce you to the basics of circuit simulation software and how to use it.

b. You will be assigned specific circuits or circuit elements to simulate, including both passive and active components.

c. Observe and analyse the behaviour of each component as they vary circuit parameters (e.g., resistance, voltage, frequency).

d. You are encouraged to compare the behaviour of passive and active elements and identify any differences.

e. Join a discussion based on your observations, focusing on the roles and characteristics of passive and active components in circuits.

Activity 4.13: Simulating Simple DC Circuits Using Circuit Simulation Software

Objectives:

- Understand the basic principles of DC circuits.
- Learn how to use circuit simulation software.
- Derive current, voltage, and power in simple DC circuits.

Materials:

- Computer with internet access
- Circuit simulation software (e.g., Proteus, Circuit Lab, or LTspice)
- Worksheet for recording observations and calculations

Instructions:

Part 1: Introduction to Circuit Simulation Software

a. *Introduction to the Software:*

   i. The teacher will provide a brief tutorial on how to use the selected circuit simulation software.

   ii. The teacher will show you how to create a new circuit, add components (resistors, batteries, wires, etc.), and connect them.

b. *Exploration:* Explore the software and familiarise yourself with its interface and tools.

Part 2: Simulating a Simple Series Circuit

a. *Build a Series Circuit:*

   i. Build a simple series circuit with one battery (DC power source) and two resistors.

   ii. Example: Connect a 9V battery in series with a 10Ω resistor and a 20Ω resistor.

b. *Simulate and Observe:*
   i. Run the simulation and observe the current and voltage across each resistor.
   ii. Use the software's measurement tools to measure the current through the circuit and the voltage across each resistor.

c. *Record Observations:*
   i. Record the current and voltage values in a worksheet.
   ii. Calculate the total resistance, total current, and power dissipated in each resistor using Ohm's Law and the power formula.

d. *Analysis:*
   i. Compare the simulated results with theoretical calculations.
   ii. Discuss any discrepancies and possible reasons (e.g., measurement errors, ideal vs. real components).

Part 3: Simulating a Simple Parallel Circuit

a. *Build a Parallel Circuit:*
   i. Build a simple parallel circuit with one battery (DC power source) and two resistors.
   ii. Example: Connect a 9V battery in parallel with a 10Ω resistor and a 20Ω resistor.

b. *Simulate and Observe:*
   i. Run the simulation and observe the current and voltage across each resistor.
   ii. Use the software's measurement tools to measure the current through each branch of the circuit and the voltage across each resistor.

c. *Record Observations:*
   i. Record the current and voltage values in a worksheet.
   ii. Calculate the total resistance, total current, and power dissipated in each resistor using Ohm's Law and the power formula.

d. *Analysis:*
   i. Compare the simulated results with theoretical calculations.
   ii. Discuss any discrepancies and possible reasons.

Part 4: Reflection and Discussion

a. *Summary of Findings:*
   i. Summarise your findings from the series and parallel circuit simulations.
   ii. Discuss the differences between series and parallel circuits in terms of current, voltage, and power distribution.

b. *Applications:*
   i. Discuss real-world applications of series and parallel circuits.
   ii. Explore how understanding these circuits is important in designing electronic devices and electrical systems.

Activity 4.14

Build the same circuits (in series and in parallel) using components from the lab on a breadboard and measure the current, voltage and power using instruments like ammeter and voltmeter.

1. Assess the accuracy and limitations of the simulation software in replicating real-world circuit behaviour. Compare the software's predictions with actual measurements from a physical circuit and identify areas where the simulation may not accurately represent reality.
2. Critique the effectiveness of the software tool in helping you understand the fundamental concepts of current, voltage, and power in DC circuits. Identify any areas where the software may have helped or hindered.

Review Questions

1. How would you explain the function of a resistor in a DC circuit? Provide an example of where resistors are commonly used.
2. Describe the role of a capacitor in DC circuits. What are the different types of capacitors and where are they typically used?
3. Discuss the function of an inductor in DC circuits. Where are inductors commonly found in electronic devices?
4. Explain how a diode works in a DC circuit. What is the purpose of using diodes in electronic circuits?
5. Compare and contrast an LED with a regular diode. How does an LED emit light, and where are LEDs commonly used in modern electronics?
6. Discuss the importance of understanding circuit symbols in electronics. Why are standardised symbols used across electronic circuits?
7. Define passive and active elements in electrical circuits. Provide examples of each.
8. Classify the following circuit elements as passive or active:
   a. Resistor
   b. Capacitor
   c. Transistor
   d. Inductor
   e. Operational Amplifier (Op-amp)
9. Explain why resistors, capacitors, and inductors are classified as passive elements in electrical circuits.
10. Discuss the role of active elements such as transistors and op-amps in electronic circuits. Provide an example of where each is commonly used.
11. Describe a scenario where understanding the classification of circuit elements into passive and active is crucial in circuit design.
12. Compare the characteristics of passive and active elements in terms of energy consumption and signal handling capabilities.
13. Discuss the importance of identifying and correctly classifying circuit elements in troubleshooting and repairing electronic devices.
14. How do Kirchhoff's laws differ from Ohm's law? Explain with examples.
15. In a DC circuit with a voltage of 12V and a current of 2A, find the power consumed.

Extended Reading

1. Hiley, J., Brown, K. E., & Hughes, E. (2001). Hughes Electrical & Electronic Technology- either edition.

References

Name of Image	Reference (link)
A picture of resistors mounted on a circuit board	https://www.istockphoto.com/photo/colored-resistors-in-a-row-gm1026481050-275266904,
A picture of Capacitors	https://www.istockphoto.com/photo/capacitors-various-kinds-gm485813632-73621583?searchscope=image%2Cfilm
A picture of Inductors	https://stock.adobe.com/search?k=inductor&asset_id=144467511
A picture of Diodes	https://education.ni.com/teach/resources/926/diodes
A picture of a transistor	https://www.shutterstock.com/image-vector/transistor-electronic-component-symbol-diagram-vector-2169223279
A picture of an Integrated circuit (IC)	https://www.indiamart.com/proddetail/integrated-circuit-15619107491.html
A picture of a Transformer	https://www.shutterstock.com/image-photo/small-transformers-audio-573684904
A picture of some switches	https://www.alamy.com/stock-photo-various-electrical-switches-35091447.html?imageid=64F111E3-4E51-4B54-BC73-9461F2AC64A9&p=33979&pn=1&searchId=3e3f87cf7257ca5452f937978778f91b&searchtype=0
A picture illustrating KCL	https://www.shutterstock.com/image-vector/illustration-first-law-current-2297629107
A picture illustrating KVL	https://www.pinterest.com/pin/689473024184809854/
Circuit diagrams	No source
A picture of Proteus interphase	https://images.app.goo.gl/M24yajruTLYgJuvH7,
A picture of LTspice interphase	https://images.app.goo.gl/eodaM4uoggKNXcq26,
A picture of Circuitlab interphase	https://images.app.goo.gl/mmZ1YVEApAncuo9F9

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