A Beginners Guide on Electronics

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Theories on Basics of Electricity

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1. *Introduction to Electronics*

- **What is Electronics?**
  Electronics is the branch of science and engineering dealing with the study and application of the flow of electrons in circuits to perform various tasks.

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2. *Materials in Electronics*

- **Conductors:** Materials that allow the free flow of electrons (e.g., copper, aluminum).
- **Insulators:** Materials that restrict the flow of electrons (e.g., rubber, plastic).
- **Semiconductors:** Materials that have properties between conductors and insulators (e.g., silicon, germanium).
  - **P-type Semiconductor:** Contains "holes" (positive charge carriers).
  - **N-type Semiconductor:** Contains free electrons (negative charge carriers).

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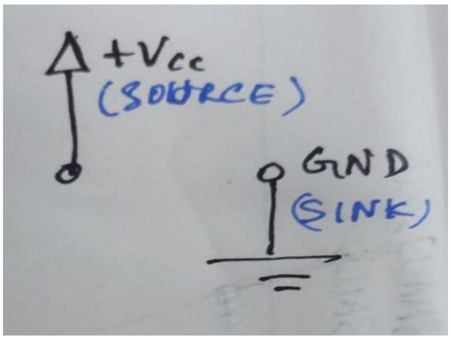
3. *Charges and Voltage*

- **Charge (Q):** Fundamental property of matter, measured in coulombs (C).
- **Voltage (V):** The potential difference that drives current, measured in volts (V).
  - **Source (+Vcc):** Positive terminal providing energy.
  - **Sink (GND):** Ground or reference point where current returns.



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4. ***Electromotive Force (EMF) and Current***

- **EMF:** Energy provided by a power source per unit charge, measured in volts (V).
- **Current (I):** Flow of electric charge, measured in amperes (A).

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5. ***Electric Circuit***

- **Open Circuit:** An incomplete path where current cannot flow.
- **Closed Circuit:** A complete path allowing current flow.

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6. ***Power and Energy***

- **Power (P):** Rate of energy consumption or generation, measured in watts (W).
- **Energy (E):** Total power consumed over time, measured in joules (J).

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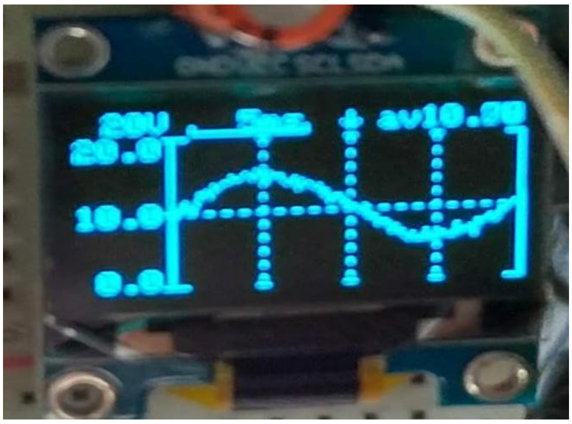
7. ***Signals in Electronics***

Electrical Signal:

- An **electrical signal** is a variation of electric current, voltage, or electromagnetic fields that conveys information.
- It can be used to represent data, transmit energy, or control electronic devices.
- **Types of Electrical Signals:**
    1. **Voltage Signals** (V): Measured as the difference in potential between two points.
    2. **Current Signals** (I): Represent the flow of charge in a circuit.

Analog Signal:

- **Definition:** An **analog signal** is a continuous signal that represents information with infinite possible values within a range.



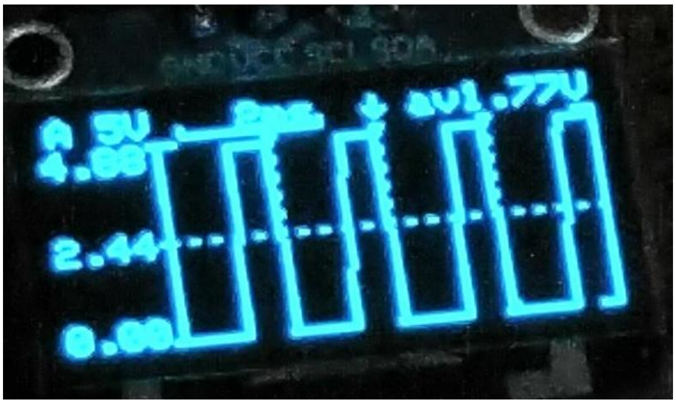
- **Characteristics:**
  - Changes smoothly over time.
  - Can take any value within a range.
  - Examples: Sound waves, light intensity, temperature.
- **Waveform:** Typically sinusoidal, triangular, or arbitrary shapes.

Example:

A microphone converting sound waves into an electrical signal.

Digital Signal:

- **Definition:** A **digital signal** represents information in discrete levels, typically as binary (0s and 1s).



- **Characteristics:**
  - Non-continuous; only specific values (usually high/low or on/off).
  - Resistant to noise compared to analog signals.
  - Examples: Computer data, digital audio.

Example:

A digital clock displaying time in discrete steps.

Analog vs. Digital Signals

Feature	Analog Signal	Digital Signal
Nature	Continuous	Discrete
Representation	Infinite possible values	Limited to predefined levels
Noise Sensitivity	High	Low
Example	Sound waves	Binary data in computers

What is ADC (Analog-to-Digital Converter)?

- **Definition:** An ADC converts continuous analog signals into discrete digital signals.
- **Working Mechanism:**
    1. **Sampling:** Measures the signal at regular intervals.
    2. **Quantization:** Converts sampled values into finite levels.
    3. **Encoding:** Outputs the data in binary form.
- **Key Parameters:**
    - **Resolution:** Number of bits used to represent the signal (e.g., 8-bit, 10-bit).
    - **Sampling Rate:** How often the signal is sampled (measured in Hz).
- **Applications:**
    - Microcontrollers (e.g., Arduino), digital audio processing, sensors.

What is DAC (Digital-to-Analog Converter)?

- **Definition:** A DAC converts discrete digital signals into continuous analog signals.
- **Working Mechanism:** Takes binary data and generates an equivalent analog voltage or current.
- **Key Parameters:**
    - **Resolution:** Determines the smoothness of the output signal.
    - **Sampling Rate:** Determines how fast the DAC can output signals.
- **Applications:**
    - Audio systems, motor control, video playback.

What is PWM (Pulse Width Modulation)?

- **Definition:** PWM is a technique to control the average power delivered to a load by varying the duty cycle of a digital signal.
- **Key Characteristics:**
  - The signal alternates between ON (high) and OFF (low).
  - **Duty Cycle:** The percentage of time the signal stays high during one cycle: $D\% = \frac{T_{ON}}{T_{ON} + T_{OFF}} \times 100$

T_{ON} is the time during the signal stays ON

T_{OFF} is the time during the signal stays OFF, both measured in Seconds.



D=100%, 5Vdc D=50%, 2.5Vdc D=0%, 0Vdc

- **Applications:**
  - Motor speed control, LED brightness, audio signal modulation.
- **Advantages:**
  - High efficiency.
  - Precise control.

Relationship Between These Concepts

Concept	Purpose
Analog Signal	Represents continuous information (e.g., audio signals).
Digital Signal	Represents discrete information (e.g., binary data).
ADC	Converts analog signals to digital for processing in microcontrollers or computers.
DAC	Converts digital signals to analog for outputs like sound or video.
PWM	Uses digital signals to approximate analog power levels.

8. Basic Properties of Conductors

- **Resistance (R):** Opposition to current, measured in ohms (Ω).

- **Inductance (L):** Ability to store energy in a magnetic field, measured in henries (H).This property tries to resist the flow of AC current, but allows DC current to flow freely.

- **Capacitance (C):** Ability to store energy in an electric field, measured in farads (F).This property tries to block the flow of DC but allows AC current to go through.

- **Impedance (Z):** Combined effect of resistance, inductance, and capacitance measured in ohms (Ω).

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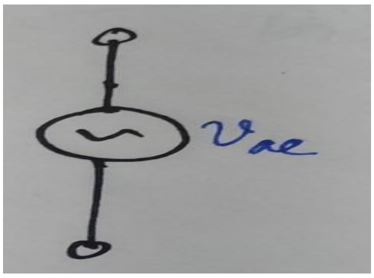
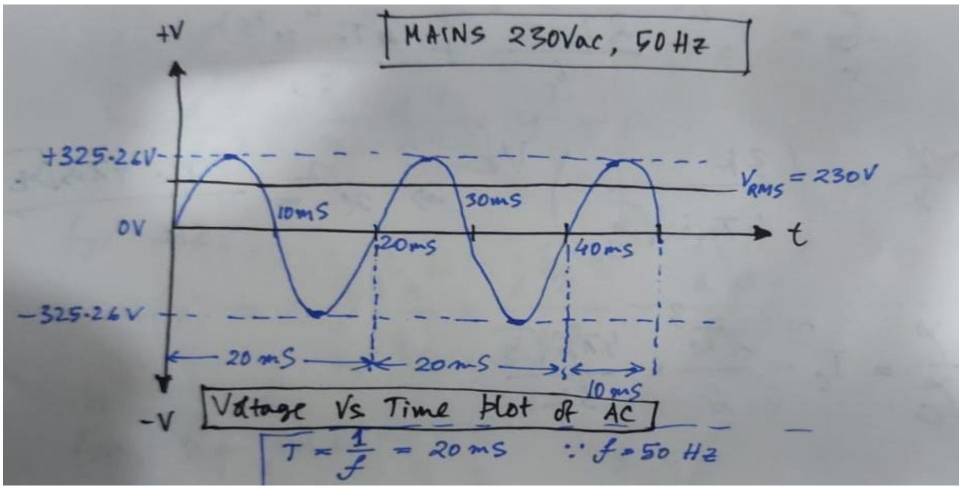
9. *Power Sources*

I. Alternating Current (AC)



Definition:

- AC is an electric current that periodically reverses its direction.
- The voltage also alternates between positive and negative, following a sinusoidal, square, or triangular
waveform.



Key Characteristics:

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1. Frequency (f)

- **Definition:** The number of cycles or oscillations of a wave that occur in one second.
- **Unit:** Hertz (Hz), where 1 Hz = 1 cycle/second.

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2. Wavelength (λ\\lambda**)**

- **Definition:** The distance between two successive points on a wave (e.g., crest to crest or trough to trough).
- **Unit:** Meters (m).

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3. Time Period (T**)**

- **Definition:** The time taken to complete one cycle of a wave.
- **Unit:** Seconds (s).

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4. Upper and Lower Half-Cycle

- **Definition:** Refers to the portions of a sinusoidal wave:
  - **Upper Half-Cycle:** The part of the waveform where the amplitude is positive (above the axis). The time taken to complete the upper half cycle is called on time period T_{upper}

  Lower Half-Cycle: The part of the waveform where the amplitude is negative (below the axis). The time taken to complete the upper half cycle is called on time period T_{lower}

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5. RMS Value (Root Mean Square Value)

- **Definition:** The **effective value** of an alternating current (AC) or voltage that delivers the same power as a corresponding DC value. For AC circuits, the **RMS (Root Mean Square)** value of voltage or current is used to calculate the **equivalent DC power** dissipation.
- **Applications:** Used to calculate the power in AC circuits.

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7. Amplitude

- **Definition:** The maximum displacement or height of the wave from its mean position.
- **Unit:** Depends on the wave type (e.g., volts for electrical signals, meters for mechanical waves).

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8. Intensity

- **Definition:** The power transmitted per unit area by a wave. It the square of the amplitude of the associated wave.

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9. Peak-to-Peak Amplitude

- **Definition:** The total vertical distance between the crest (maximum positive amplitude) and the trough (maximum negative amplitude) of a wave.

Applications:

  - Power transmission, household appliances, and industrial equipment.

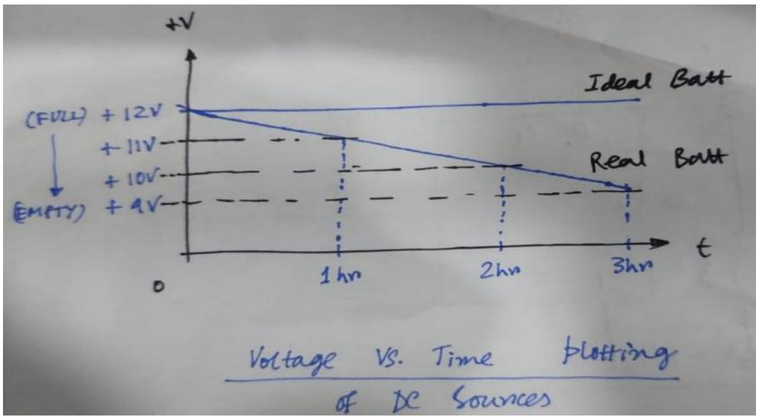
Advantages:

- Easily transformed to higher or lower voltages for efficient transmission over long distances.
- Less energy loss compared to DC.

I. Direct Current (DC)

Definition:

- DC is an electric current that flows in one direction only.
- The voltage remains constant (pure DC) or may vary but does not reverse polarity (unidirectional).



Key Characteristics:

1. **Waveform:** Straight line (pure DC) or may have ripples in case of rectified DC.
2. **Applications:**
    - Batteries, electronic devices, and low-voltage systems.
3. **Sources:**
    - Batteries, solar cells, and DC generators.

Advantages:

- Suitable for low-voltage, low-power applications.
- Easier to store (e.g., in batteries).

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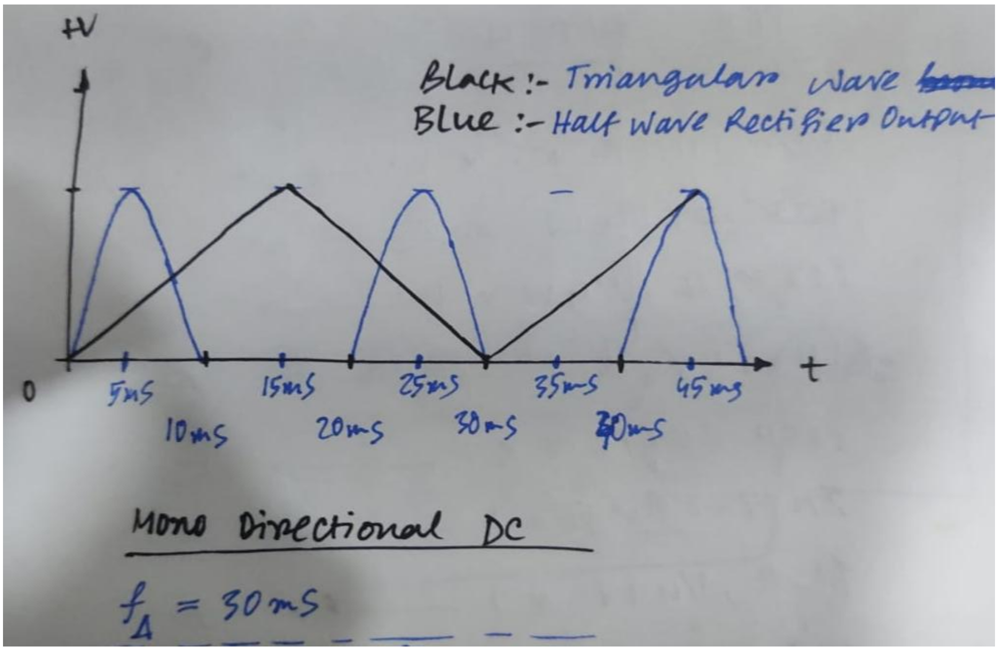
II. Mono-Directional DC

Definition:

- Mono-directional DC is a type of direct current that flows in one direction but is not constant. It varies in magnitude with time (e.g., pulsating DC).
- It is the result of rectifying an AC waveform (commonly produced by diodes).



Key Characteristics:

1. **Waveform:**

- Resembles a rectified sine wave or pulsating wave.

2. **Behavior:**
   - Current/voltage never goes negative (unlike AC) but is not constant like pure DC.

3. **Applications:**
   - Rectified power supplies, motor drives, and power conversion systems.

How It Differs from Pure DC:

- Pure DC has a constant value.
- Mono-directional DC varies in magnitude but remains unidirectional.

Comparison Table

Feature	AC (Alternating Current)	DC (Direct Current)	Mono-Directional DC
Direction	Changes periodically	Flows in one direction only	Flows in one direction only
Waveform	Sinusoidal, square, or triangular	Straight line	Pulsating or rectified sine wave
Frequency	Non-zero (e.g., 50 Hz, 60 Hz)	Zero	Zero
Voltage Polarity	Alternates between positive and negative	Constant	Always positive (unidirectional)
Sources	Generators, power plants	Batteries, solar cells	Rectified AC
Applications	Power grids, motors, transformers	Electronics, batteries	Power supplies, motor drives

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Key Example (Rectification of AC to DC):

1. **AC Input (50 Hz Sinusoidal):**
   - Alternates between positive and negative voltages.

2. **Half-Wave Rectification:**
   - Only positive cycles pass; the waveform becomes mono-directional DC.

3. **Full-Wave Rectification:**

- Both positive and negative cycles are converted to positive, resulting in pulsating DC.

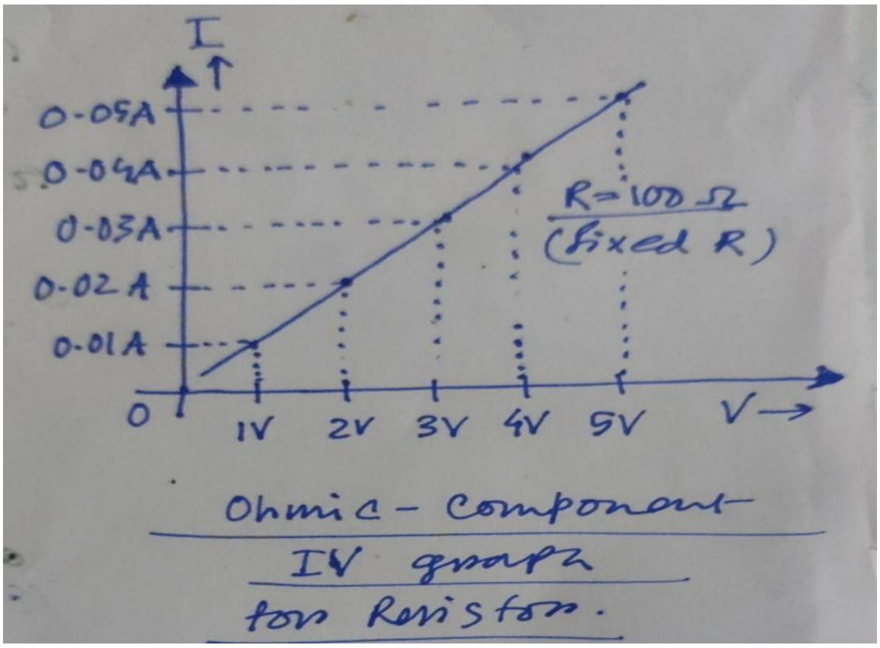
Ohmic and Non-Ohmic Electronic Components

The distinction between **ohmic** and **non-ohmic components** depends on whether their current (I) versus voltage (V) relationship follows **Ohm's Law** or not.

Ohmic Components

Definition:

- Ohmic components are those that obey **Ohm's Law**, meaning the current flowing through them is directly proportional to the applied voltage.
- Their resistance remains **constant** over a wide range of voltage and current.



Characteristics:

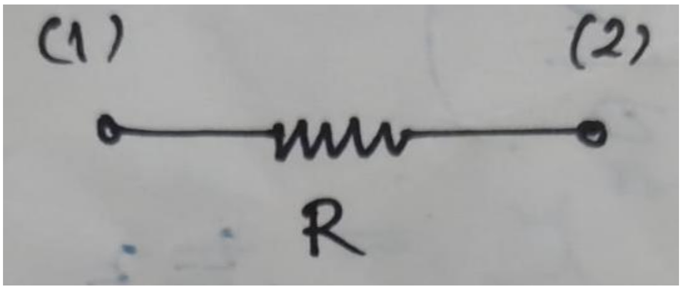
1. Linear I-V relationship (straight-line graph passing through the origin).
2. Resistance (R) is constant: V = IR
3. No significant temperature dependence (within normal operating conditions).

Examples of Ohmic Components:

A. Resistors

Function:

- Resistors oppose the flow of electric current in a circuit, reducing the voltage and controlling current.



Construction Mechanism:

- Typically made from carbon, metal oxide, or wire-wound materials. A resistive material is placed between two conducting terminals.

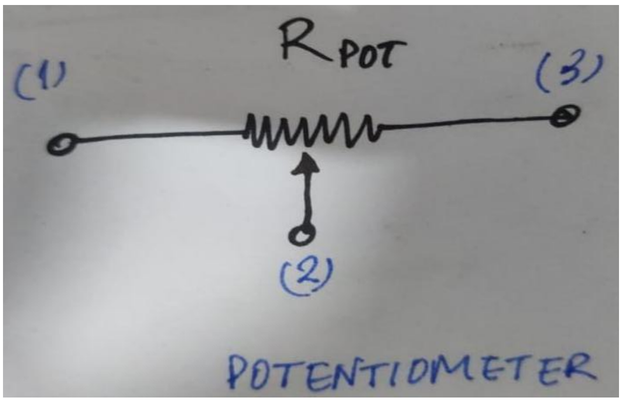
Key Parameters:

- **Resistance (**R**)**: Measured in ohms (Ω\OmegaΩ).
- **Power Rating**: Maximum power a resistor can dissipate without damage.

B. Potentiometer (Pot):

Definition:

A potentiometer is a three-terminal variable resistor used to adjust voltage, resistance, or control electrical devices such as volume controls. It consists of a resistive element with a movable wiper (slider or rotary knob) that changes the resistance when adjusted.



Construction:

1. **Resistive Track:**
    1. A fixed resistive element made from carbon, cermet, or wire wound.
2. **Wiper:**
    1. A movable contact that slides or rotates over the resistive track.
3. **Terminals:**
    1. **Two fixed terminals** connected to the ends of the resistive element.
    2. **One terminal** connected to the wiper.

Working Principle:

- When the wiper moves, it divides the resistive track into two parts:
    - One part between the wiper and one fixed terminal.
    - The other part between the wiper and the other fixed terminal.
- By varying the position of the wiper, the resistance changes, thus altering the output voltage.

Applications:

- Volume control in audio systems.
- Brightness control in lighting systems.
- Sensor calibration.
- Adjustable voltage dividers.

Linear Potentiometer

Definition:

A linear potentiometer produces a linear relationship between the wiper position and the resistance or output voltage.

Characteristics:

1. **Resistance vs. Wiper Position:**
    - Resistance changes **proportionally** with wiper movement.

- If the wiper moves halfway, the resistance is approximately half the total resistance.

2. **Use Case:**
   - Ideal for applications requiring predictable and proportional control, such as joysticks, sliders, or measuring displacement.

3. **Construction:**
   - Straight resistive track, typically used in slider pots.

Logarithmic Potentiometer (Log Pot)

Definition:

A logarithmic potentiometer produces a logarithmic (non-linear) relationship between the wiper position and resistance.

Characteristics:

1. **Resistance vs. Wiper Position:**
   - Resistance changes **exponentially** with wiper movement.
   - A small movement near one end of the track results in a small resistance change, while the same movement near the other end results in a much larger resistance change.

2. **Use Case:**
   - Common in audio applications to match the logarithmic nature of human hearing (e.g., volume controls).
   - Also used for tone controls or mixing desks.

3. **Construction:**
   - The resistive track is designed to have varying density, or different materials are used for the resistive layer.

Comparison Table:

Feature	Linear Potentiometer	Logarithmic Potentiometer
Resistance Behavior	Changes linearly with wiper movement	Changes logarithmically with wiper movement
Output Voltage Curve	Straight line	Exponential/logarithmic curve

Feature	Linear Potentiometer	Logarithmic Potentiometer
Applications	Joysticks, displacement measurement	Volume control, audio systems
Ease of Prediction	Highly predictable and proportional	Non-linear, designed for specific needs

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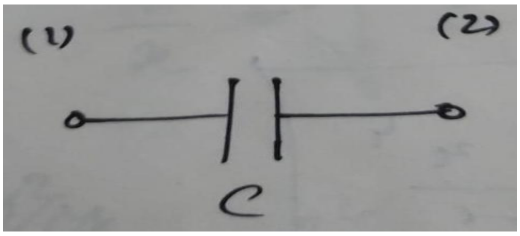
Specialized Types of Potentiometers:

1. **Rotary Potentiometers:**
    - Circular resistive tracks with a rotary wiper.
    - Common in knobs for audio systems.
2. **Slider Potentiometers:**
    - Straight resistive tracks with a sliding wiper.
    - Used in mixing desks or volume sliders.

C. <u>Capacitors</u>



Function:

- Capacitors store electrical energy in the form of an electric field and release it when needed.
- Allows AC but blocks DC.
- The higher the capacitance value the more lower AC frequencies are allowed. And the lower the capacitance value the more higher frequencies are allowed.

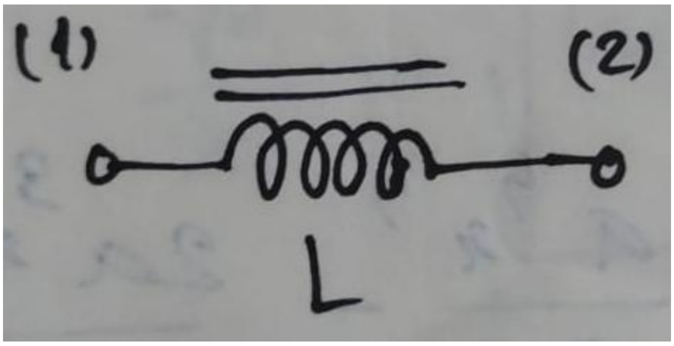
Construction Mechanism:

- A capacitor consists of two conductive plates separated by an insulating material called a dielectric (e.g., ceramic, plastic, mica).

Key Parameters:

- **Capacitance (C)**: Ability to store charge, measured in farads (F).
- **Voltage Rating:** Maximum voltage it can handle without damage.

D. Inductors



Function:

- Inductors store energy in a magnetic field when current flows through them. They oppose changes in current.
- Allows DC but blocks AC.
- The higher the inductance value, the lower frequencies are allowed to pass through. And the lower the inductance value, the higher frequencies are allowed to pass through.

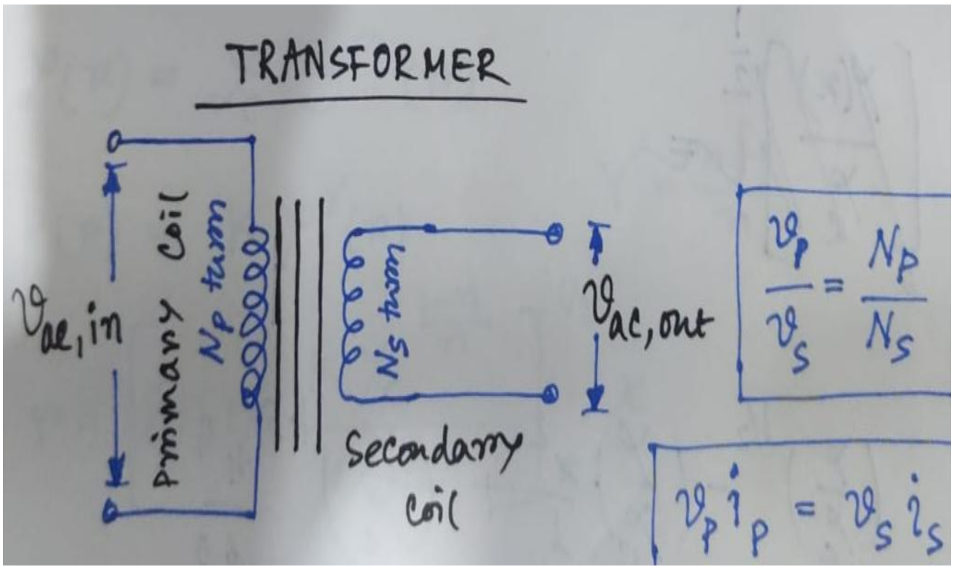
Construction Mechanism:

- Consists of a coil of wire wound around a magnetic or non-magnetic core.

Key Parameters:

- **Inductance** : Measured in henries (H).
- **Current Rating:** Maximum current it can carry without saturating the core.

Transformers



Function:

- Transformers transfer electrical energy between two circuits through electromagnetic induction, often changing voltage levels.

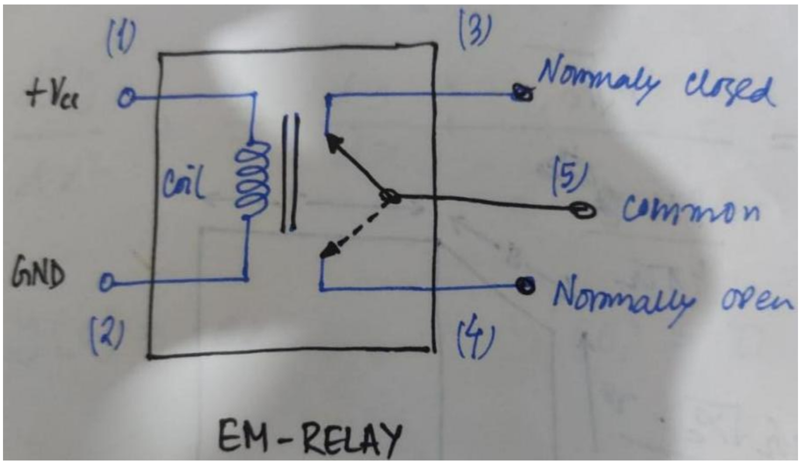
Construction Mechanism:

- A transformer consists of two coils (primary and secondary) wound on a shared magnetic core.

Key Parameters:

- **Turns Ratio :** Determines the voltage transformation.
- **Core Material:** Determines efficiency and magnetic properties.

Relays



Function:

- Relays are electrically operated switches used to control high-power devices with low-power control signals.

Construction Mechanism:

- A coil generates a magnetic field when energized, moving a mechanical armature to open or close contacts.

Key Parameters:

- **Coil Voltage:** Required to energize the relay.
- **Contact Ratings:** Maximum current/voltage the relay can handle.

Motors

a. ***BO (Battery-Operated) Motor***

- **Function:** Simple DC motors often used in robotics. They are cost-effective and easy to use.
- **Construction:** A rotor with a permanent magnet and commutator brushes for current switching.

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b. ***Servo Motor***

- **Function:** Provides precise angular control.
- **Construction:**
  - A small DC motor coupled with gears.
  - Controlled by a feedback system and PWM signals.

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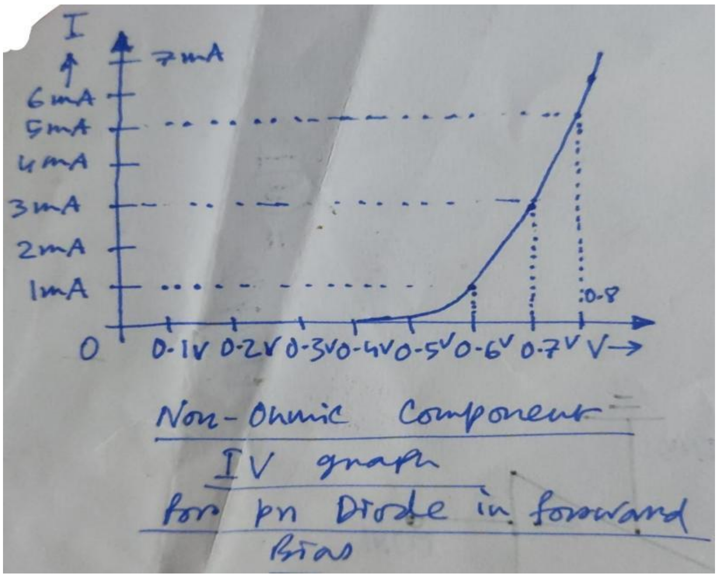
c. ***Stepper Motor***

- **Function:** Rotates in precise steps for accurate positioning.
- **Construction:** Multiple electromagnet windings create discrete steps.

Non-Ohmic Components

Definition:

- Non-ohmic components do **not obey Ohm's Law**, meaning their I-V relationship is non-linear.
- Their resistance varies depending on the applied voltage, current, or environmental conditions like temperature or light intensity.



Characteristics:

1. Non-linear I–V relationship (curved graph).
2. Resistance is not constant and may change with:
   - Applied voltage
   - Current
   - Temperature
   - Light or other external factors.

Examples of Non-Ohmic Components:

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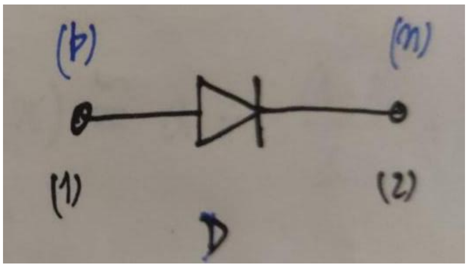
1. <u>Junction Diode</u>



Function:

- Allows current to flow in one direction (forward bias) and blocks it in the opposite direction (reverse bias).

Construction:

- Made by joining a p-type semiconductor (holes) with an n-type semiconductor (electrons) to form a PN junction.

Key Parameters:

- **Forward Voltage:** Typical values: ~0.7V for silicon, ~0.3V for germanium.
- **Reverse Breakdown Voltage:** Voltage at which reverse current increases sharply.

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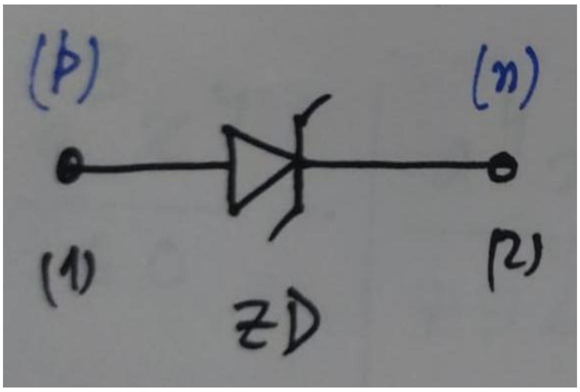
2. Zener Diode



Function:

- Operates in reverse bias and is designed to maintain a stable voltage (Zener voltage) by breaking down at a specific reverse voltage.

Construction:

- Similar to a junction diode but heavily doped to control the breakdown voltage.

Applications:

- Voltage regulation, surge suppression.

Key Parameters:

- **Zener Voltage**: The fixed voltage it maintains.
- **Power rating:** The maximum power of the zener diode which it can safely handle without being destroyed.

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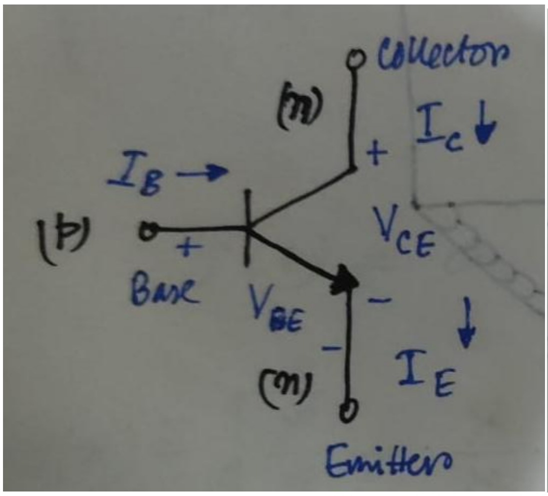
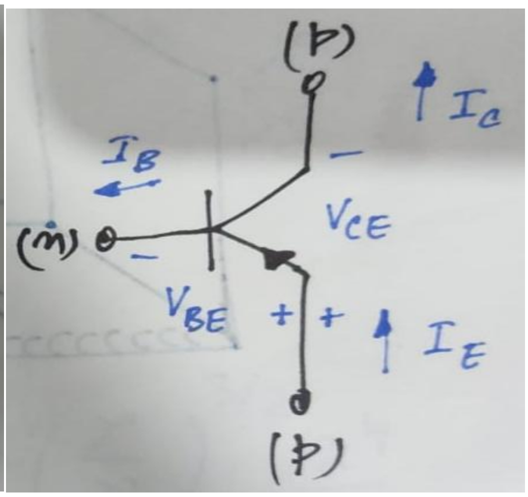
3. Bipolar Junction Transistor (BJT)





Function:

- Amplifies current and acts as a switch.

Construction:

- Made of three layers: NPN or PNP. Includes emitter, base, and collector.

Key Parameters:

- **Current Gain (β\beta):** Ratio of collector current I_C to base current I_B. So $\beta = \frac{I_C}{I_B}$
- And $I_E = I_C + I_B$, where I_E is the emitter current.

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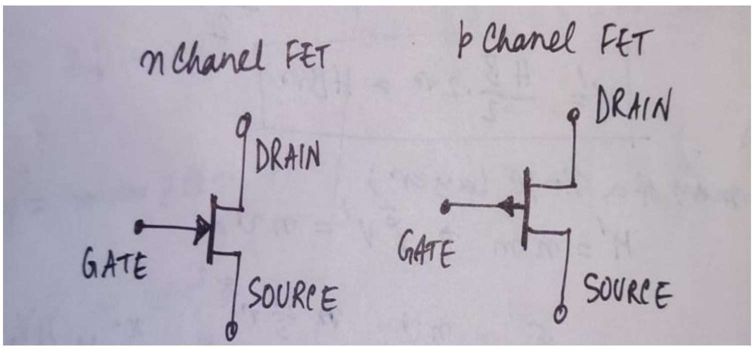
4. **Field Effect Transistor (FET)**



Function:

- Voltage-controlled device used for switching and amplification.

Construction:

- Consists of a gate, drain, and source. Common types: JFET and MOSFET.

Key Parameters:

- **Gate Threshold Voltage:** Minimum voltage to turn on the device.

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5. Integrated Circuit (IC)

Function:

- A miniaturized circuit consisting of transistors, resistors, capacitors, etc., integrated onto a semiconductor chip.

Applications:

- Widely used in digital, analog, and mixed-signal systems.

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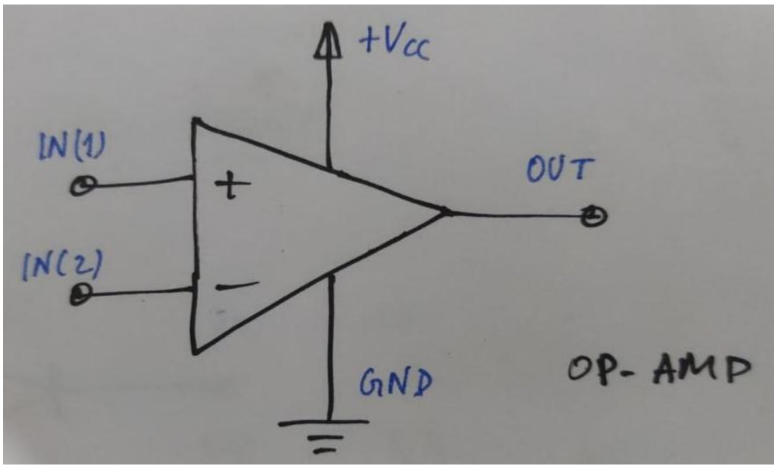
4. **Operational Amplifier (Op-Amp)**



Function:

- High-gain voltage amplifier used for signal amplification, filtering, and mathematical operations (e.g., addition, subtraction).

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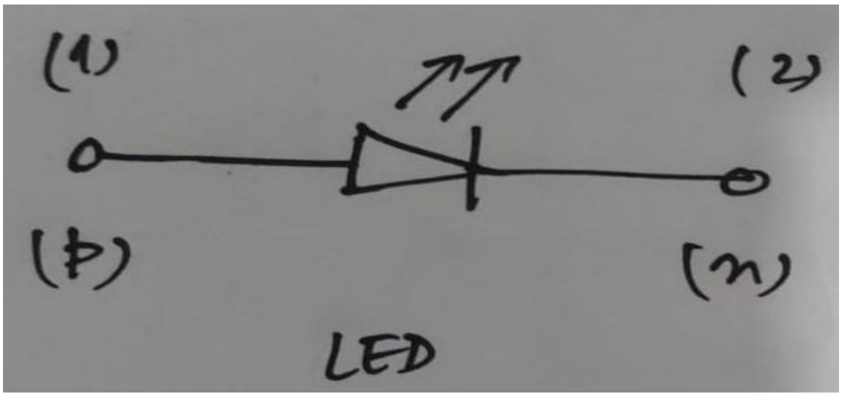
5. **Light Emitting Diode (LED)**



Function:

- Emits light when forward biased.

Construction:

- Made of semiconductors with energy band gaps corresponding to visible light.

Key Parameter:

- **Forward Voltage :** Typically 1.8–3.3V depending on the color.

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8. <u>Infrared LED (IR LED)</u>

Function:

- Emits infrared light used in remote controls, sensors, etc.

Applications:

- Proximity sensors, communication.

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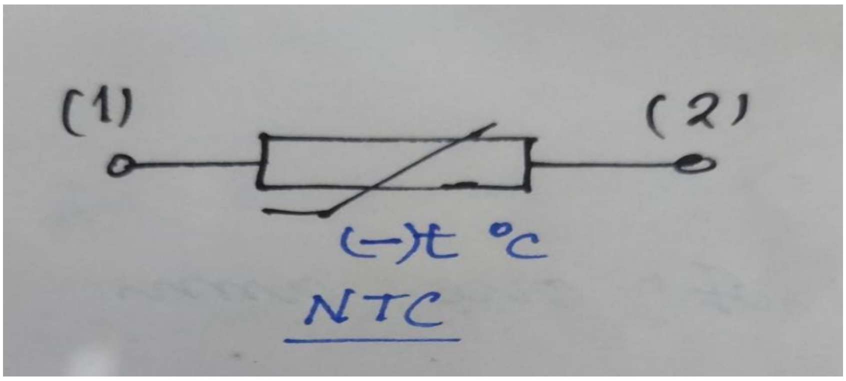
9. <u>Negative Temperature Coefficient (NTC) Thermistor</u>



Function:

- Resistance decreases as temperature increases.

Applications:

- Temperature sensing.

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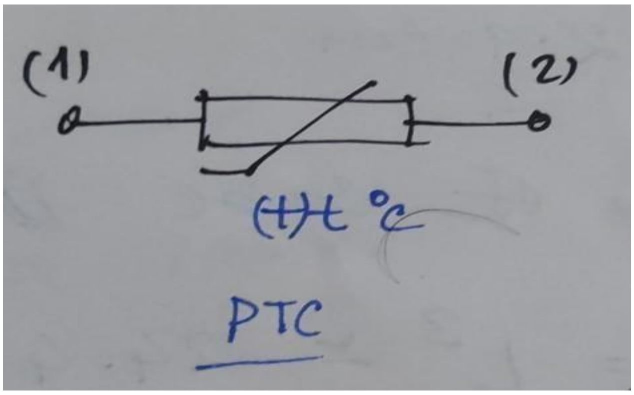
10. **Positive Temperature Coefficient (PTC) Thermistor**



Function:

- Resistance increases as temperature increases.

Applications:

- Overcurrent protection, heaters.

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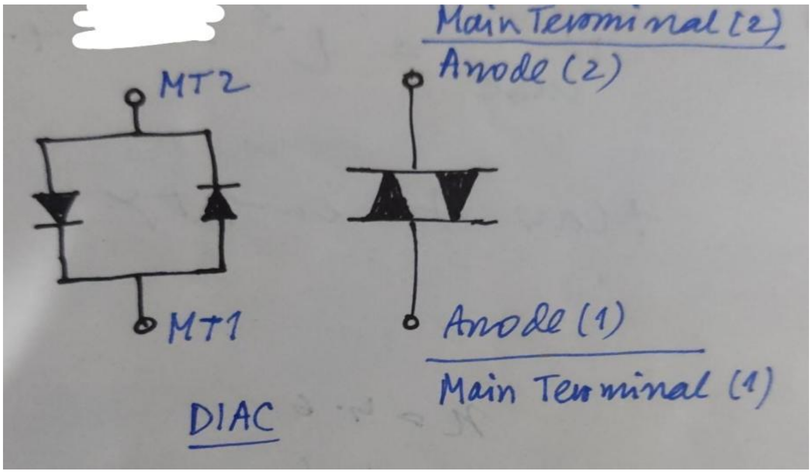
11. **DIAC**



Function:

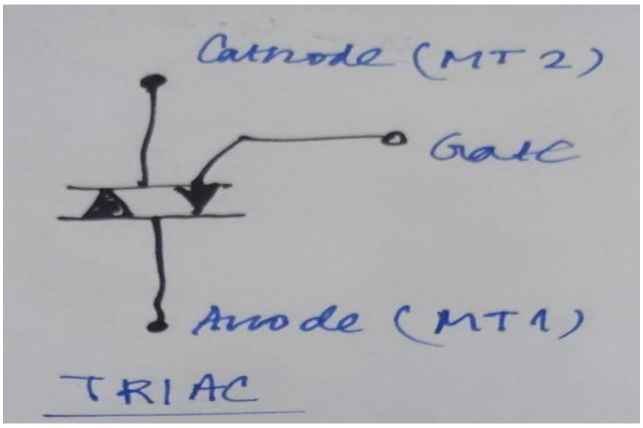
- Bidirectional switch used for triggering TRIACs.

Construction:

- Two-terminal device with symmetrical breakdown characteristics.

---

12. TRIAC



Function:

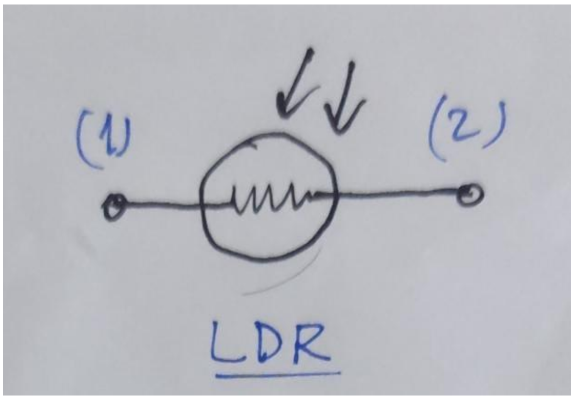
- Controls AC power by acting as a bidirectional switch.

Applications:

- Light dimmers, motor speed control.

---

13. Light Dependent Resistor (LDR)



Function:

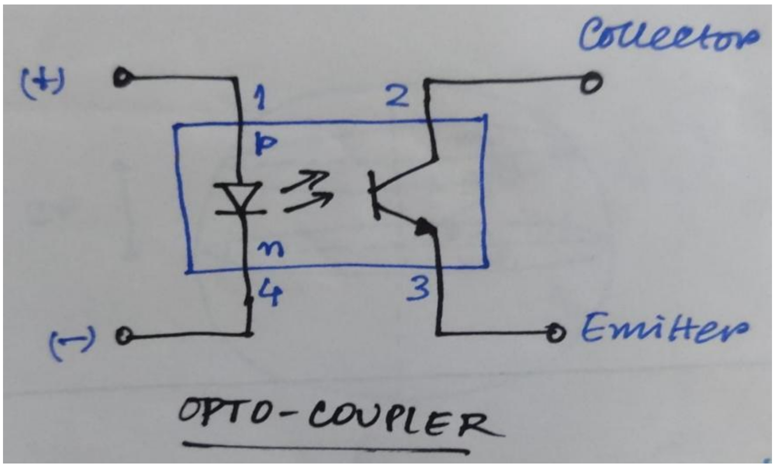
- Resistance decreases with increasing light intensity.

Applications:

- Automatic lighting, light sensors.

---

14. <u>Optocoupler</u>



Function:

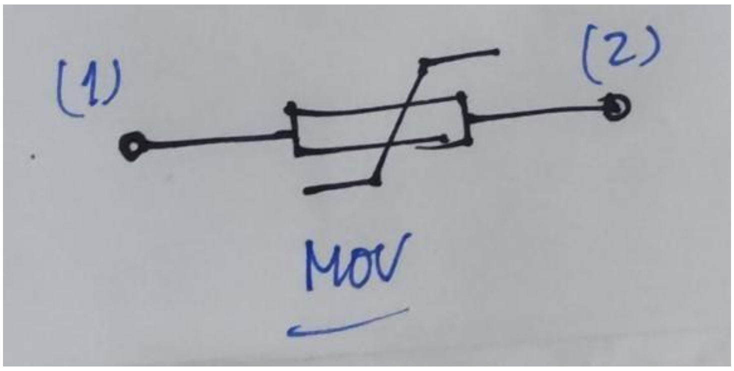
- Isolates two circuits using light. An LED and a phototransistor are housed together.

Applications:

Electrical isolation, signal transmission.

---

15. <u>Metal Oxide Varistor (MOV)</u>



Function:

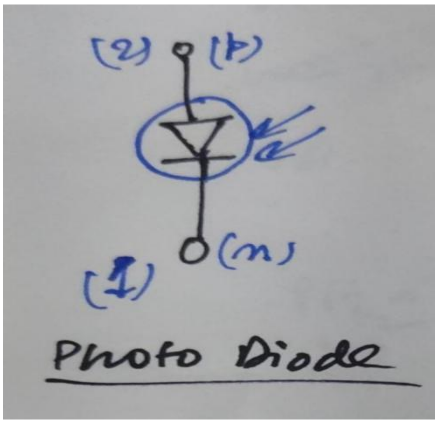
- Protects circuits from voltage surges by clamping excessive voltage.

Applications:

- Surge protectors.

---

16. Photodiode



Function:

- A photodiode is a semiconductor device that converts light into an electrical current. It operates in reverse bias and is highly sensitive to light.

Construction:

- Made of a PN-junction semiconductor with a transparent window or lens to allow light to strike the junction. Common materials include silicon or gallium arsenide.

Working Mechanism:

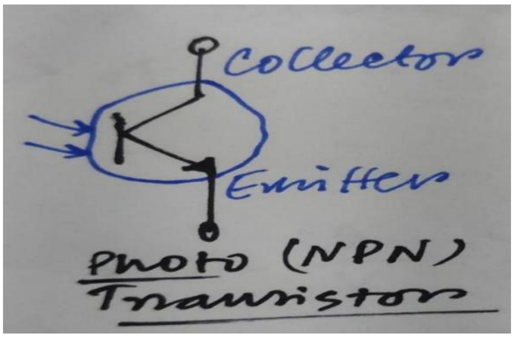
- When light photons strike the depletion region, electron-hole pairs are generated, resulting in a small current proportional to light intensity.

Applications:

Optical communication, light sensors, solar energy measurement, barcode scanners.

---

17. <u>Phototransistor</u>



Function:

- A phototransistor is a transistor that is controlled by light intensity rather than electrical current at its base. It acts as an amplifier for the light-induced current.

Construction:

- Similar to a regular transistor but with a transparent casing that allows light to hit the base region. It may be NPN or PNP in configuration.

Working Mechanism:

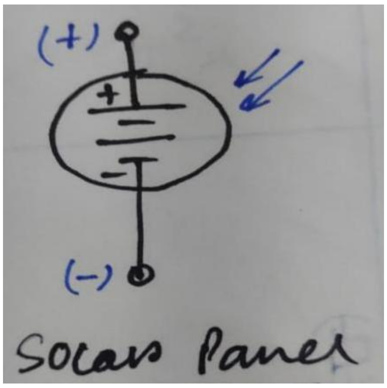
- Light striking the base region generates electron-hole pairs, leading to a base current that is amplified by the transistor's current gain.

Applications:

- IR receivers, object detection, light intensity measurement, optical communication.

---

18. <u>Solar Panels</u>



Function:

- Solar panels convert sunlight into electrical energy using the photovoltaic effect. They are used to generate renewable energy.

Construction:

- Composed of many **solar cells**, each made of semiconductor materials like silicon. A solar cell consists of a PN junction with a large surface area exposed to sunlight.

Working Mechanism:

1. Photons from sunlight strike the solar cell.
2. Energy from photons creates electron-hole pairs in the depletion region of the PN junction.
3. The electric field in the depletion region drives the electrons and holes towards opposite terminals, generating a current.

Applications:

- Residential and commercial power generation, solar-powered devices, satellites, and water heating systems.

Key Differences Between Ohmic and Non-Ohmic Components

Property	Ohmic Components	Non-Ohmic Components
Ohm's Law	Obey Ohm's Law (V=IR)	Do not obey Ohm's Law
I-V Relationship	Linear	Non-linear
Resistance	Constant	Varies with voltage, current, or external factors
Examples	Resistors, metallic conductors	Diodes, transistors, LEDs, thermistors, LDRs

---

1. Series and Parallel Combinations

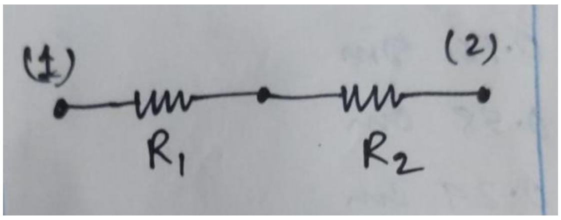
- **Series:** Components connected end-to-end; current is the same.
- **Parallel:** Components connected across the same nodes; voltage is the same.

Here are the formulas for **series and parallel combinations** of two resistors, capacitors, and inductors, along with specific cases like anti-series and anti-parallel for inductors.

---

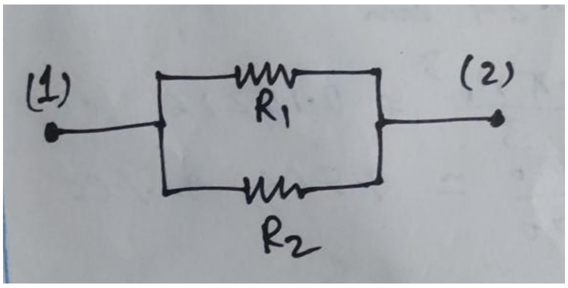
1. <u>Resistors</u>

a. Series Combination of Resistors



$$R_T = R_1 + R_2$$

b. Parallel Combination of Resistors

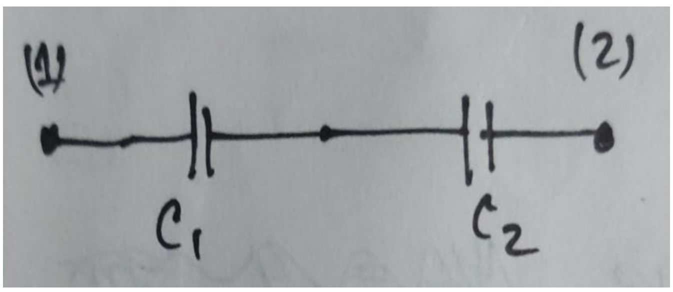


$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

---

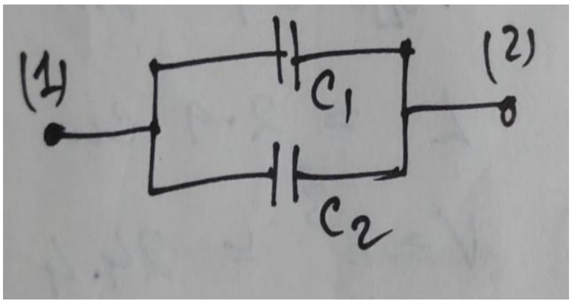
2. <u>Capacitors</u>

a. Series Combination of Capacitors



$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

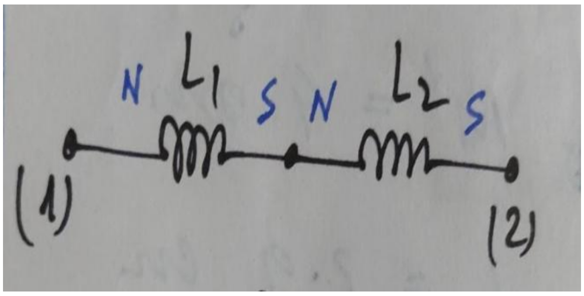
b. Parallel Combination of Capacitors



$$C_T = C_1 + C_2$$

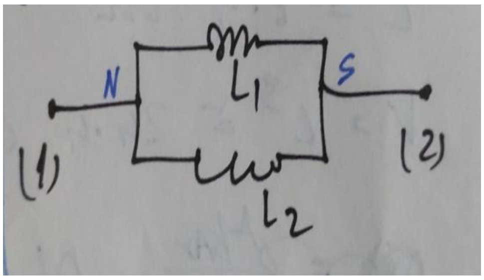
---

3. <u>Inductors</u>a. Series Combination of Inductors



$$L_T = L_1 + L_2$$

b. Parallel Combination of Inductors



$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

---

4. <u>Special Cases of Inductors</u>

a. Anti-Series of Inductors

When inductors are connected in series but with opposite polarities:

$$L_T = (L_1 \sim L_2) = |L_1 - L_2|$$

b. Anti-Parallel of Inductors

When inductors are connected in parallel but with opposite polarities:

$$L_T = \frac{|L_1 L_2|}{L_1 + L_2}$$

---

2. <u>Fundamental Physical Laws</u>

- **Ohm's Law:** $V = IR$, relation between R, V and I
- **Joule's Law:** $H = I^2R$ amount of heat generated
- **Coulomb's Law:** $F = k\frac{Q_1Q_2}{d^2}$

electrostaic force between two charges, k is called the dielectric constant of the medium.

- **Electrical Power:** $W = VI$, power consumed in a electrical component

- **Thevenin's Theorem:** Simplifies a network into a voltage source and resistance.
- **Norton's Theorem:** Simplifies a network into a current source and parallel resistance.
- **Maximum Power Transfer Theorem:** Maximum power is transferred when load resistance equals source resistance.
- **Superposition Principle:** In linear circuits, total response is the sum of individual responses.
- **Kirchhoff's Current Law (KCL):** $\sum I_{in} = \sum I_{out}$

- **Kirchhoff's Voltage Law (KVL):** $\sum V = 0$

---

12. *<u>SI Units</u>*

Quantity	SI Unit	Symbol
Charge	Coulomb	C
Voltage	Volt	V
Current	Ampere	A
Resistance	Ohm	Ω\Omega

Quantity	SI Unit	Symbol
Capacitance	Farad	F
Inductance	Henry	H
Power	Watt	W
Energy	Joule	J
Frequency	Hertz	Hz
Energy	Joule	J
Impedance	Ohm	Ω\Omega
Force	Newton	N
Speed		m/S
Distance	Meter	m
Time	Second	S
Angular speed		Rad/S
Angular Displacement	Radian	Rad
Temperature	Kelvin	K
Pressure	Pascal	Pa
Area	Square Meter	Sq.m
Mass	KiloGram	Kg
Luminosity	Lumen	Lu
AC Power	VoltAmp	VA

Basics of Practical Circuit Building
(Proto-Type)

1.Breadboard Basics

A breadboard is a reusable platform for prototyping circuits without soldering.

Breadboard Layout:

Power Rails:

1. Long horizontal rows along the top and bottom are typically reserved for power supply lines (+ and GND).
2. Ensure you know if your breadboard's power rails are split (may require a jumper to connect them).

Terminal Strips:

1. Vertical columns in the center of the breadboard are interconnected.
2. Each column is isolated from the others, making them ideal for component connections.

Separation by Gap:

1. The middle gap separates the two sides, commonly used for IC placement (pins on each side of the gap).

2.Basic Circuit Building Rules

Power and Ground:

1. Always connect the **GND** of all modules and the microcontroller together to ensure a common reference point.
2. Clearly identify **VCC** (positive supply) and **GND** connections to avoid reversing polarity.
3. Use different color wires for clarity:
    1. **Red** for VCC (positive power).
    2. **Black** or **blue** for GND (negative/ground).
    3. Other colors for signal wires.

Component Placement:

1. Place components as close as possible to where they are electrically connected to minimize signal loss and noise.
2. Insert ICs and DIP components across the central gap for easy access to all pins.

Wiring:

1. Use **short wires** where possible to avoid clutter and reduce resistance.
2. Avoid crisscrossing wires unnecessarily to keep the layout clean.
3. Route power and signal lines separately to reduce electrical noise.

Power Supply:

1. Use a regulated and sufficient power supply for the circuit.
2. Verify voltage and current requirements of components and ensure the power supply matches.
3. Use **decoupling capacitors** (e.g., 0.1 µF) close to IC power pins to stabilize the power supply and filter noise.

---

3. Connections Between Modules and MCUs

Jumper Wires:

1. Use **high-quality jumper wires** for reliable connections.
2. Ensure wires are not loose and firmly inserted into breadboard holes or MCU headers.
3. Avoid excessively long wires to reduce noise and voltage drops.

Signal Connections:

1. Double-check pin assignments in the module and MCU datasheets before making connections.
2. Pay attention to communication protocols (e.g., I2C, SPI, UART):
    1. Match **SCL/SDA** lines for I2C.
    2. Match **MOSI, MISO, SCK, and CS** lines for SPI.
    3. Match **TX/RX** for UART.

Voltage Levels:

1. Verify voltage compatibility between modules and the MCU:
    1. Some modules operate at 3.3V, while others use 5V.
    2. Use **logic level shifters** if the voltage levels differ.
2. Avoid exceeding the MCU's input voltage limits to prevent damage.

Powering Modules:

1. Ensure each module receives sufficient current from the power supply.
2. Use external power supplies for high-power modules like motors or LEDs, and connect the GND to the MCU GND.

---

4. Debugging Techniques

Check Connections:

1. Use a **multimeter** to verify continuity in your connections.
2. Confirm correct voltages at critical points (e.g., power supply rails).

Use LEDs for Debugging:

1. Use LEDs with current-limiting resistors to visualize power and signal activity.
2. Place an LED on the GND rail as a basic power indicator.

Test in Stages:

1. Test each module or circuit section individually before integrating it into the larger system.
2. For MCUs, upload and test simple test sketches for individual modules (e.g., blink an LED, read a sensor).

---

6. Safety Rules

1. **Double-Check Connections:**

- Cross-check wiring against circuit diagrams before powering up.

2. **Avoid Overloading:**
   - Ensure the total current draw does not exceed the power supply or MCU limits.

3. **Prevent Short Circuits:**
   - Inspect for loose or exposed wires that might cause a short.

4. **Work on Unpowered Circuits:**
   - Disconnect power when making or modifying connections.

Measurements of some Electrical Quantities

Multimeter: An Overview

What is a Multimeter?

A **multimeter** is a versatile electronic measuring tool used to measure basic electrical quantities such as **voltage**, **current**, and **resistance**. Modern multimeters can also test components like diodes, transistors, and continuity in circuits.

Types of Multimeters

1. **Analog Multimeter:**
   1. Uses a needle and scale for readings.
   2. Provides continuous and smooth readings but less precise compared to digital.
2. **Digital Multimeter (DMM):**
   1. Displays measurements on an LCD screen.
   2. Offers high accuracy, auto-ranging, and additional features like frequency and temperature measurements.

Basic Quantities Measured by a Multimeter

1.Voltage (DC/AC):

1. **Function:** Measures the potential difference between two points.
2. **Steps:**
   1. Set the multimeter to the appropriate voltage range (DCV 0.2Vdc-100Vdc for DC, ACV 200Vrms-750Vrms for AC).

2. Connect the probes: Red to the positive terminal and Black to the negative terminal.
3. Read the voltage directly on the display.
4. **Example Use:** Checking the voltage of a battery or a power supply.

2.Current (DC/AC):

1. **Function:** Measures the flow of current in a circuit.
2. **Steps:**
   1. Set the multimeter to the appropriate current range (DCA 0.2mA-10A for DC, ACA for AC).
   2. Connect the multimeter in series with the circuit.
   3. Read the current value on the display.
   4. **Example Use:** Measuring current drawn by a motor.

3.Resistance:

1. **Function:** Measures the opposition to current flow, called the magnitude of the resistance(200Ohm-2000KOhm).
2. **Steps:**
   1. Set the multimeter to the resistance (Ω\OmegaΩ) mode.
   2. Disconnect the power from the circuit.
   3. Place the probes across the component to measure resistance.
   4. **Example Use:** Checking the resistance of resistors or wires.

4.Continuity:

1. **Function:** Checks if a circuit is complete.
2. **Steps:**
   1. Set the multimeter to continuity mode (usually indicated by a soundwave or diode symbol).
   2. Place the probes on the two ends of the circuit.
   3. If the circuit is complete, the multimeter will beep.
   4. **Example Use:** Verifying connections in a PCB.

Testing Basic Components with a Multimeter

1. Testing Resistors

- **Standalone:**
  - Set the multimeter to resistance mode.
  - Place probes across the resistor.
  - Compare the measured resistance with the resistor's color code or specifications.

- **In-Circuit:**
    - Disconnect the circuit's power.
    - Measure resistance, but note that parallel components may affect readings.

2. Testing Capacitors

- **Standalone:**
    - Use a multimeter with capacitance mode.
    - Connect probes to the capacitor terminals (polarity matters for electrolytic capacitors).
    - Compare the measured value with the specified capacitance.
- **In-Circuit:**
    - Disconnect the power and discharge the capacitor before testing.
    - In-circuit readings may be affected by other components, so remove the capacitor for accurate results.

3. Testing Diodes

- **Standalone:**
    - Set the multimeter to diode test mode.
    - Connect the red probe to the anode (+) and the black probe to the cathode (-).
    - A forward voltage drop (0.6–0.7V for silicon diodes, 0.2-0.3V for germenium diodes) indicates a working diode.
    - Reverse the probes; a high resistance indicates proper blocking in reverse bias.
- **In-Circuit:**
    - Test similarly, but note that surrounding circuitry may affect results. Remove the diode for conclusive testing.

4. Testing Transistors (BJT)

- **Standalone:**
    - Use the diode mode to test junctions:
        - Base to emitter and base to collector should show forward voltage in one direction and high resistance in reverse.
        - Collector to emitter should show high resistance in both directions.
- **In-Circuit:**

- Testing can be inconclusive due to surrounding components. For accurate results, remove the transistor from the circuit.

5. Testing LEDs

- **Standalone:**
  - Use diode mode.
  - Place the red probe on the anode and the black probe on the cathode.
  - The LED will light dimly if functional, and the multimeter will display the forward voltage.
- **In-Circuit:**
  - Test similarly, but ensure the circuit power is off.

6. Testing Inductors

- **Standalone:**
  - Measure resistance using the multimeter in resistance mode.
  - A low resistance indicates the inductor is intact (no open winding).
- **In-Circuit:**
  - Similar to standalone testing, but surrounding circuitry can affect readings.

7. Testing Continuity in Wires

- Set the multimeter to continuity mode.
- Place probes at each end of the wire.
- A beep indicates the wire is continuous.

Techniques for Testing Components in Circuits

1. **Always Turn Off Power:**
   - Disconnect the circuit's power before testing to prevent damage to the multimeter and obtain accurate readings.
2. **Isolate Components When Needed:**
   - Lift one terminal of a component from the circuit if surrounding components affect readings.
3. **Use Proper Modes:**

- Select the correct measurement mode (e.g., resistance, diode, capacitance).

4. **Check for Visual Damage:**
    - Look for burns, cracks, or discoloration in components, which might indicate failure.

Advanced Features in Digital Multimeters

1. **Frequency Measurement:**
    - Measures signal frequency in Hz.
2. **Temperature:**
    - Some multimeters include a thermocouple for temperature measurement.
3. **Transistor Testing:**
    - Some multimeters have a dedicated transistor testing port (hFE mode).
4. **Auto-Ranging:**
    - Automatically selects the appropriate measurement range.

Safety Tips

1. Always start with the highest range to prevent overloading the multimeter.
2. Use insulated probes to avoid accidental short circuits.
3. Verify the multimeter's battery level; low batteries can affect accuracy.

END