



ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

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ANGUCHETTYPALAYAM, PANRUTI – 607 106.

DEPARTMENT OF MECHANICAL ENGINEERING

ME3791 Mechatronics and IOT

ME3791

MECHATRONICS AND IoT

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COURSE OBJECTIVES

- 1 To make students get acquainted with the sensors and the actuators, which are commonly used in mechatronics systems.
- 2 To provide insight into the signal conditioning circuits, and also to develop competency in PLC programming and control
- 3 To make students familiarize with the fundamentals of IoT and Embedded systems.
- 4 To impart knowledge about the Arduino and the Raspberry Pi.
- 5 To inculcate skills in the design and development of mechatronics and IoT based systems.

UNIT – I

SENSORS AND ACTUATORS

9

Introduction to Mechatronics - Modular Approach, Sensors and Transducers: Static and Dynamic Characteristics, Transducers - Resistive, Capacitive, Inductive and Resonant, Optical Sensors – Photodetectors - Vision Systems – Laser - Fibre optic - Non-fibre Optic, Solid State Sensors, Piezoelectric and Ultrasonic Sensors. Actuators – Brushless Permanent Magnet DC Motor – PM, VR and Hybrid Stepper motors – DC and AC Servo Motors

UNIT – II SIGNAL CONDITIONING CIRCUITS AND PLC

9

Operational Amplifiers – Inverting and Non-Inverting Amplifier – Wheatstone bridge Amplifier – Instrumentation Amplifier – PID Controller, Protection Circuits, Filtering Circuits, Multiplexer, Data Logger and Data Acquisition System –, Switching Loads by Power Semiconductor Devices Circuits – Thyristors – TRIAC – Darlington Pair – MOSFET and Relays. PLC – Architecture – Input / Output Processing – Logic Ladder Programming – Functional Block Programming using Timers and Counters – Applications.

UNIT – III FUNDAMENTALS OF IoT AND EMBEDDED SYSTEMS

9

The Internet of Things (IoT) - Introduction to the IoT Framework – IoT Enabling Technologies- The Effective Implementation of IoT: The Detailed Procedure. Embedded Systems: An Introduction - Single-Chip Microcontroller Systems - Single-Board Microcontroller Systems - Single-Board Computer Systems - Embedded Systems: Peripherals - Software Considerations

UNIT – IV

CONTROLLERS

9

Foundation topics: Programming Languages: C++ and Python - The Linux Operating System. Arduino: The Arduino Boards - Arduino Peripherals- Arduino IDE – ESP8266 Wi-Fi module. Raspberry Pi: The Raspberry Pi Boards - The Raspberry Pi Peripherals - The Raspberry Pi Operating System. (typical peripherals) Interfacing and Controlling I/O devices by Arduino and Raspberry Pi: LEDs - Push buttons - Light intensity sensor - Ultrasonic distance sensor – Temperature sensor- Humidity sensor - Sensor and Actuator interactions

UNIT – V

MECHATRONICS AND IoT CASE STUDIES

9

Mechatronics systems: Drone actuation and Control -Autonomous Robot with Vision System, Automotive Mechatronics: Electronic Ignition System - ABS - EBD - Adaptive Cruise Control. IoT case studies: Remote Monitoring Systems- Remotely Operated Autonomous Systems - Centralized Water Management System - IoT Enabled Robotic Camera Dolly - Portable, Wireless, Interactive IoT Sensors for Agriculture - IoT Vehicle Management System with Network Selection.

Total Hours: 45



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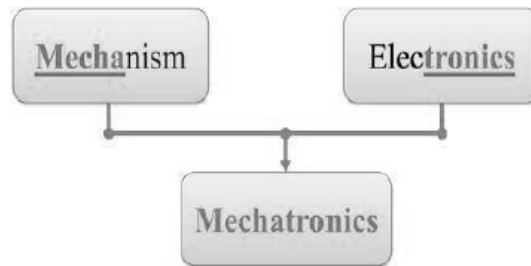
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UNIT – I

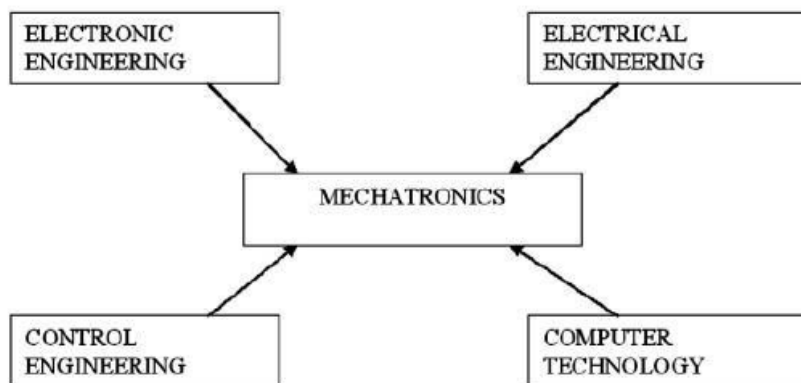
SENSORS AND ACTUATORS

MECHATRONICS

Mechatronics is a concept of *Japanese* origin and can be defined as the application of electronics and computer technology to control the motions of mechanical systems.



It is a multidisciplinary approach to product and manufacturing system design. It involves application of electrical, mechanical, control and computer engineering to develop products, processes and systems with greater flexibility, ease in redesign and ability of reprogramming. It concurrently includes all these disciplines.



SYSTEM:

A system may be defined as a black box which has an input and an output. System concerned only with the relationship between the input and output and not on the process going inside the box.

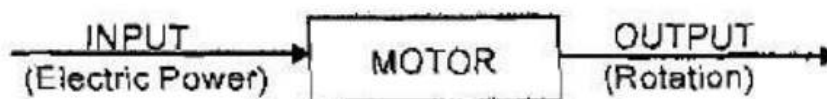


Fig 3: A system example



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MECHATRONIC SYSTEM

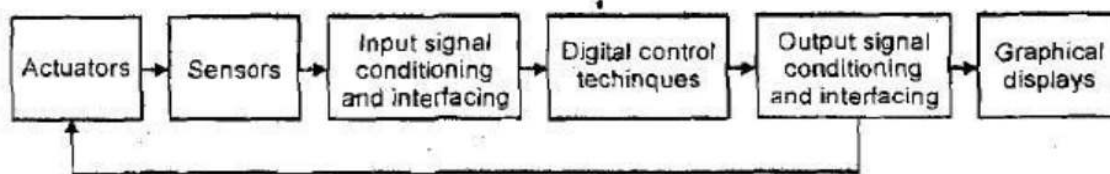


Fig 4: Elements of mechatronics

- ❖ **Actuators:** Solenoids, voice coils, D.C. motors, Stepper motors, Servomotor, hydraulics, pneumatics.
- ❖ **Sensors:** Switches, Potentiometer, Photo - electrics, Digital encoder, Strain gauge, Thermocouple, accelerometer etc.
- ❖ **Input signal conditioning and interfacing:** Discrete circuits, Amplifiers, Filters, A/D, D/D.
- ❖ **Digital control architecture:** Logic circuits, Microcontroller, SBC, PLC, Sequencing and timing, Logic and arithmetic, Control algorithm, Communication.
- ❖ **Output signal conditioning and interfacing:** D/A D/D, Amplifiers, PWM, Power transistor, Power Op -amps.
- ❖ **Graphical displays:** LEDs, Digital displays, LCD, CRT.

SENSORS AND TRANSDUCERS

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processors for controlling the whole system. Measurement system comprises of sensors, transducers and signal processing devices. Sensors in manufacturing are basically employed to automatically carry out the production operations as well as process monitoring activities. Sensor technology has the following important advantages in transforming a conventional manufacturing unit into a modern one.

1. Sensors alarm the system operators about the failure of any of the sub units of manufacturing system. It helps operators to reduce the downtime of complete manufacturing system by carrying out the preventative measures.
2. Reduces requirement of skilled and experienced labours.
3. Ultra-precision in product quality can be achieved.

Sensor It is defined as an element which produces signal relating to the quantity being measured. According to the Instrument Society of America, sensor can be defined as “*A device which provides a usable output in response to a specified measurand.*” Here, the output is usually an „electrical quantity” and measurand is a „physical quantity, property or condition which is to be measured”. Thus, in the case of, say, a variable inductance displacement element, the quantity being measured is displacement and the sensor transforms an input of displacement into a change in inductance.

Transducer It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measured into a usable output by using a transduction principle. It can also be defined as a device that converts a signal from one form of energy to another form. A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus, we can say that “sensors are transducers”.



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Static and dynamic characteristics:

Accuracy

- Accuracy is defined as the degree of closeness at which the instrument reading approaches the true value of the quantity to be measured.
- Due to the effects of temperature, humidity the measured quantity varies from the true value
- Accuracy is expressed in the “Percentage of Full-Scale Reading”, for instruments having a uniform scale.
- Specifying accuracy in terms of the percentage is better for the quantity being measured.

Sensitivity

- In steady-state conditions, Sensitivity is defined as the ratio of a change in output to a change in input.
- For a given instrument, sensitivity can be derived as the smallest change in the measured variable
- Sensitivity describes the maximum change in an input signal that will not initiate on the output.
- Note: The sensitivity of the instrument should be high.

Reproducibility

Under variable operating conditions, if the successive measurements produce agreed results for the same variables is called Reproducibility.

Precision

- Precision is the degree of exactness of the designed instrument.
- Precision is composed of two characteristics such as conformity and significant figures.
- With more significant figures, estimated precision is more.
- For example, consider two resistors of 1792 ohms and 1710 ohms, the continuous repeated measurement indicates 1.7 K ohms so an operator is unable to notify the true value from the scale.

Precision Error

- The precision error generated by the limitation of a measuring instrument.
- Since an operator evaluates a consistent reading of 1.5 K ohms, which is close to the true scale though there is no deviation from the observed value.
- The above example indicates that conformity is required because of the lack of significant figures obtained.



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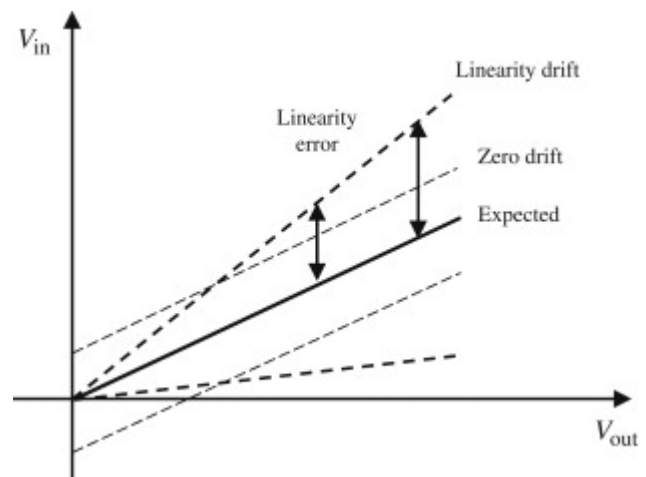
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Drift

- Drift is defined as an unexpected change in the output of a measured variable over some time unrelated to a change in output operating conditions.
- Drift is caused by environmental factors such as mechanical vibrations, temperature variation, stray electric fields, stray magnetic fields, and thermal EMFs.
- A drift in instrument calibration occurs due to the aging of parts.
- Drift in flow measurement occurs due to wear and tear of primary sensing elements such as orifice plates.
- Adrift in temperature measurement occurs due to scale formation on the thermowell.
- Drift in Thermocouples or RTD occurs due to the change of metallic properties of elements.
- For a measuring device, drift can be systematic or random, or sometimes both.
- Flow drift occurs systematic way because of wear and tear in the edge of an orifice plate

Drift is further classified as:

1. **Zero Drift:** Zero drift is defined as the deviation in the measured variable starting right from zero in the output with time.
2. **Span Drift:** The Span Drift is defined as a proportionate change in indication along the upward scale, this span drift or also known as sensitivity drift.
3. **Zonal Drift:** Zonal drift is defined as the drift that occurs at a certain portion of the span of an instrument.



Static Error

- Static Error is the variation between the true values of a measurable quantity to the values indicated by the measuring instrument which are not affected by operating conditions.
- Static error = True value of a measured quantity – Indicated Value.
- If the Static error is +ve, it means the instrument reads a high value.
- If the Static error is -ve, it means the instrument reads a low value.

Dead Zone

- For the largest range of values of a measured variable, to which the instrument does not respond.
- The dead zone occurs in indicating an instrument due to static friction.



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- Due to this static friction a control valve doesn't open for large signals from the controller.

Hysteresis

- Hysteresis is a phenomenon that defines various effects of output during loading and unloading.
- Generally, an instrument may indicate one set of output values for increasing input values of an instrument,
- It may indicate a different set of output values for the decreasing input values of an instrument.
- The maximum variation is observed at 50% of the full scale for increasing and decreasing inputs.

Resolution

- Resolution is the smallest quantity that can be detected with certainty by an instrument being measured.
- If a non-zero input quantity is raised slowly, the output will not rise until some minimum changes in the input are done. This minimum change causes the change in output to be termed resolution.

Dynamic Characteristics

The set of criteria defined for the instruments, which are changes rapidly with time, is called 'dynamic characteristics'.

The various static characteristics are:

i) Speed of response ii) Measuring lag iii) Fidelity iv) Dynamic error

Dynamic Error

Dynamic Error is the variation between the true values of a measurable quantity to the values indicated by the measuring instrument which are affected by operating conditions.

Response Speed

- Response Speed is defined as the rapidity of the instrument to responds to the changes in the measuring variable.
- It indicates how active and fast the system is.

Fidelity

Fidelity is defined as the degree to which a measuring instrument reproduces change in input faithfully without any dynamic error



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Lag

- The lag time is taken by the system to respond, since every instrument takes at least some time to respond, whatever time it may be to the changes in the measured variable.
- For Example Lag occurs in temperature measurement by temperature sensors such as Thermocouples or RTD or dial thermometers due to scale formation on the thermowell due to the process fluid.

Retardation Lag

The response of the measurement begins immediately after the change in measured quantity has occurred.

Time Delay Lag

In this case, after the application of input, the response of the measurement system begins with some dead times.

TRANSDUCER

A transducer is a device that converts energy from one form into another. Most commonly, it changes a physical quantity (like pressure, light, or temperature) into an electrical signal, or vice versa

Active Transducers: Self-generating devices that create an electrical output directly from physical input without needing an external power source (e.g., thermocouples, piezoelectric crystals).

Passive Transducers: Require an external power supply or auxiliary source to function, changing parameters like resistance or capacitance. Examples include strain gauges and thermistors.

Resistive transducer

The resistive transducer can be defined as; the resistance of a transducer can be changed due to the effects of the environment. Here, the resistance change can be calculated with the help of measuring devices like AC or DC. The main purpose of this transducer is to measure physical quantities such as vibration, displacement, temperature, etc. The major types of resistive transducer include potentiometers, resistive position transducers, resistive pressure transducers, thermistors, strain gauges, and LDR.

Working of Resistive Transducer



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This is the most frequently used transducer to calculate pressure, temperature, force, displacement, vibrations, etc. To understand the working of a resistive transducer, the conductor rod is considered as an example of this transducer.

These transducers work on the principle of the length of a conductor which is directly proportional to the conductor's resistance & it is inversely proportional to the conductor's area. So, the denominated length of the conductor is 'L', the area is 'A' and resistance is 'R' and the resistivity is 'ρ'. It is stable for every material which is used in conductor construction.

$$R = \rho L/A$$

From the above equation,

'R' is the resistance of the conductor.

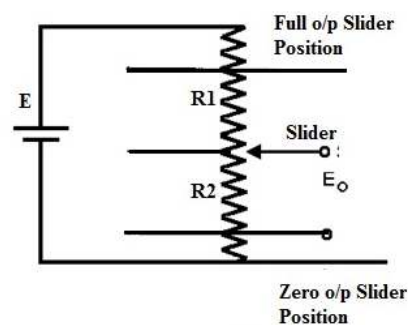
'A' is the side view part of the conductor.

'L' is the conductor's length.

'ρ' – the resistivity of the conductor.

The transducer's resistance can be changed because of the exterior environmental factors as well as the conductor's physical properties. The change in resistance can be measured using AC devices or DC devices. This transducer acts like a primary as well as the secondary transducer. A primary transducer is used to change the physical quantity to the mechanical signal whereas a secondary transducer is used to convert a mechanical signal to an electrical signal.

The best example of this circuit is the sliding contact device. The circuit diagram of this is shown below. The sliding contact of this transducer mainly includes a long conductor whose length can be changed. One side of the conductor is connected whereas another side of the conductor can be connected to a brush/slider which moves through the conductor's full-length



The displacement of the object can be calculated by connecting it to the slider.

Whenever energy is given to the object for moving them from its first position, then the slider moves with the conductor's length. So the length of the conductor will change to reflect on



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modify within the resistance of the conductor. A transducer like a potentiometer works on the sliding contact type principle which is used to calculate linear & angular displacement.

POTENTIOMETER

Linear potentiometer

This is a device, which converts mechanical displacement (to be measured) into an electrical output. Linear potentiometer can measure displacements in the range of 2.5 mm to 500 mm.

Principle of Working of Linear Potentiometer

“Change in the position of slider leads to change in resistance of potentiometer wire and corresponding change in output voltage generated is a measure of displacement of slider to be measured”.

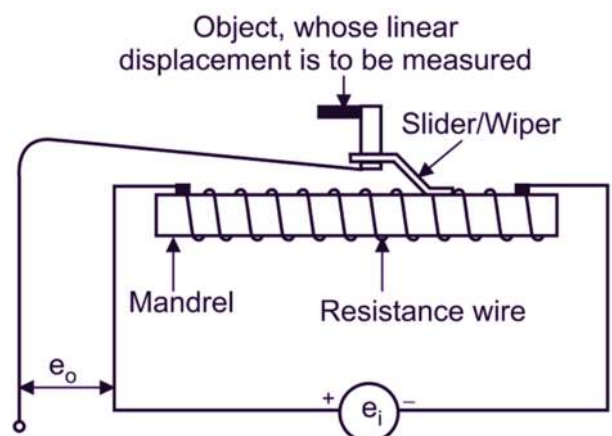
Construction of Linear Potentiometer

Linear potentiometer consists of a stretched resistance wire and a sliding or movable contact (wiper). The resistance element or resistance wire is made up of metal alloy. This resistance wire is wound on a former in such a way that, the slider or Wiper may be moved along the various turns axial y (i.e. translational or rectilinear movement). Former is a cylindrical piece made up of an insulating material, such as, ceramic or plastic. Former is also known as mandrel. The slider or wiper always maintains an electrical contact with the resistance wire and moves over it. The component, whose displacement is to be measured, is attached to slider or wiper. Linear potentiometer is also called as ‘Linear POT

Working of Linear Potentiometer

Linear potentiometer is a passive transducer because it requires external power source for its operation (Fig. 1). Therefore, the resistance wire is excited with either AC or DC voltage. It is represented as input voltage (e_i). When the slider moves or slides axially along the various turns of resistance wire, the effective resistance existing between one end of wire and slider also changes. Due to this, an output voltage (e_o) is generated, which can be measured.

Alternatively, this output voltage generated can be directly calibrated to give displacement. The output voltage generated is a linear function of the displacement to be measured.



Linear displacement of slider and hence, the component is calculated by using the following mathematical relation,

$$x_i = x_t \times (e_o / e_i)$$

e_i = Input voltage



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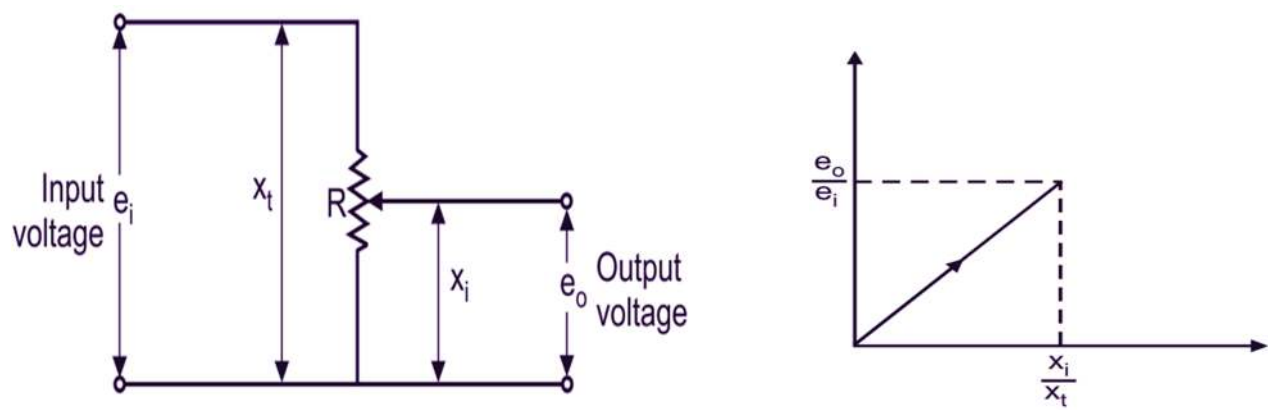
e_o = Output voltage

x_t = Total length of linear pot (i.e. translational potentiometer)

x_i = Displacement of slider from its zero position

R = Total resistance of potentiometer in Ω (ohms)

Above mathematical relation of x_i can be derived in the following manner. If the variation of resistance with respect to displacement is linear, then resistance per unit length is given by (R/x_t) .



The output voltage under idea condition is given by,

$e_o = (\text{Resistance of output terminals} / \text{Resistance of input terminals}) \times \text{Input voltage}$

$$= (R/x_t) R \times e_i$$

$$e_o = x_i x_t \times e_i$$

$$e_o e_i = x_i x_t$$

$$x_i = (e_o e_i) \times x_t$$

Advantages of Linear Potentiometer

1. Low cost.
2. Simple to operate.
3. Useful for measurement of large amplitudes of displacement.
4. Rugged construction.
5. Low maintenance.



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ROTATORY POTENTIOMETER

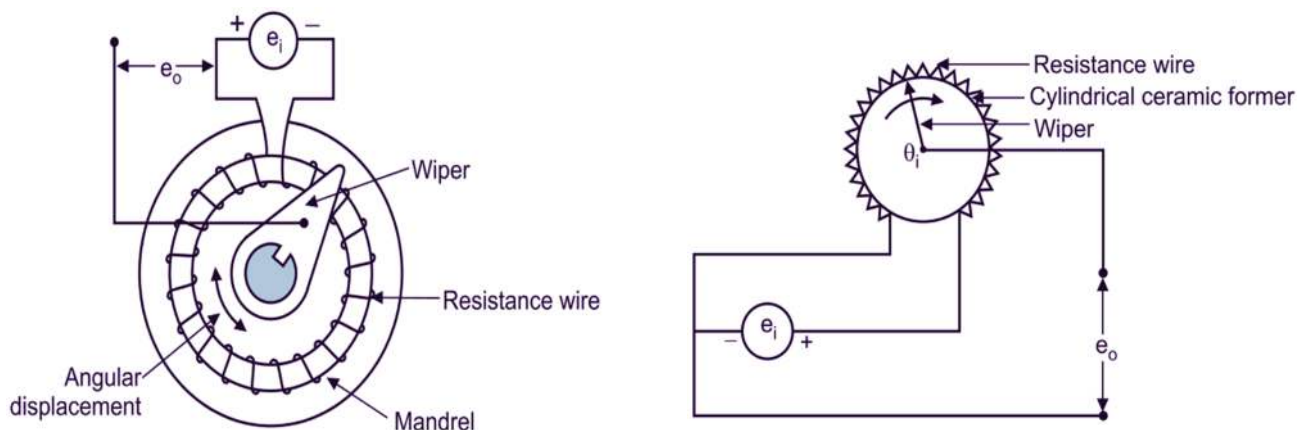
Rotary Potentiometer is used for measurement of angular displacement.

Construction of Rotary Potentiometer

Resistive elements are circular in shape in case of rotational type potentiometer. The resistive elements of potentiometer are metal alloys wound on a cylindrical ceramic former. Wiper (slider) is made up of phosphor bronze and it's gold plated for good

Working of Rotary Potentiometer

The resistance wire is wrapped around a circular former, so that, wiper may be rotated along with the various turns along an arc (angular movement). The circular former is also called a mandrel (Figure 1). The wiper always maintains an electrical contact with the resistance wire wound on a circular former made up of plastic or ceramic (i.e. any insulating material) and rotates over it. The resistance element is excited with either AC or DC voltage. The output voltage generated is a linear function of angular displacement (θ_i) to be measured



It is commonly used material for resistance wire is alloy metal.

- However, depending upon the specific requirements and applications, it is also made up of platinum, chromium, nickel, copper etc.
- Resistance wire has to carry large current at high temperature. Therefore, temperature coefficient of resistance wire material should be small.

Strain Gauge

A strain gauge is one of the imperative devices used in the field of geotechnical engineering to measure strain on diverse structures. By applying an external force, there would be a change in resistance of a strain gauge.



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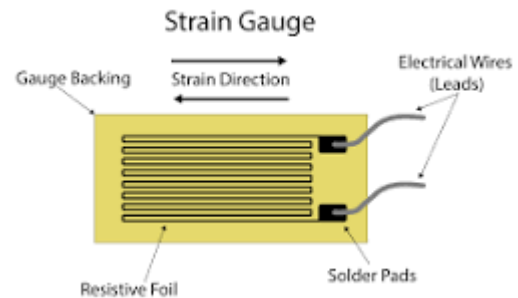
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The basic construction of a gauge has an insulating flexible backing to support a metallic foil structure. This metallic coil is glued to a thin backing called a carrier, and the entire setup is fixed to an object using a suitable adhesive. As the object is deformed due to force, pressure, weight, tension, etc., the electrical resistance of foil changes. A Wheatstone bridge measures the change in resistivity, which is related to strain through a quantity known as Gauge Factor. The small changes in resistance of a gauge are measured using the concept of Wheatstone bridge.



Strain Gauge Working Principle

As we know that the resistance is directly dependent on the length and cross-sectional area of a conductor, which is given by $R = L/A$

Where,

'R' = Resistance

'L' = Length

'A' = cross-sectional area

Clearly, the length of a conductor is altered with the change in size and shape of a conductor, eventually, altering the cross-sectional area and resistance.

Any normal gauge has a conductive strip that is long and thin, placed in a zig-zag fashion of parallel lines. The purpose of this zig-zag alignment is to elaborate on the small amount of stress that occurs between the parallel lines with much accuracy. Stress is **defined as the resisting force of an object**

Resistance temperature detector RTD:

The resistance of a conductor changes when its temperature is changed. This property is utilized for the measurement of temperature. The Resistance Thermometer working principle is an instrument used to measure electrical resistance in terms of temperature, i.e. it uses the change in the electrical resistance of the conductor to determine the temperature.

The main part of a resistance thermometer working principle is its sensing element. The characteristics of the sensing element determines the sensitivity and operating temperature range of the instrument.

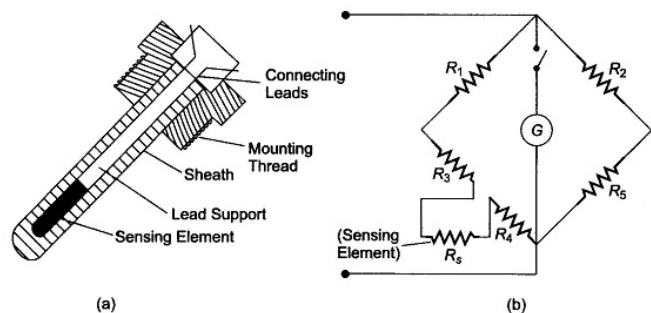


Fig. 13.11 (a) Industrial Platinum Resistance Thermometer (b) Bridge Circuit



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The changes in resistance caused by changes in temperature are detected by a Wheatstone bridge, as shown in Fig. 13.11(b). Hence, the temperature sensing element, which may be nickel, copper or platinum contained in a bulb or well, along with the balancing bridge, form the essential components of a temperature measuring system based upon this principle. The sensing element R_s is made of a material having a high temperature coefficient, and R_1 , R_2 , and R_5 are made of resistances that are practically constant under normal temperature changes. When no current flows through the galvanometer, the normal principle of Wheatstone's bridge states the ratio of resistance is

$$\frac{R_1}{R_2} = \frac{R_s}{R_5}$$

In normal practice, the sensing element is away from the indicator, and its leads have a resistance, say R_3 , R_4 . Therefore,

$$\frac{R_1}{R_2} = \frac{R_3 + R_s + R_4}{R_5}$$

Now if resistance R_s changes, balance cannot be maintained and the galvanometer shows a deflection, which can be calibrated to give a suitable temperature scale.

Advantages of Resistance Thermometer:

The measurement is very accurate.

- It has a lot of flexibility with regard to choice of measuring equipment.
- Indicators, recorders or controllers can also be operated.
- More than one resistance element can be clubbed to the same indicating/ recording instrument.
- The temperature sensitive resistance element can be easily installed and replaced.

Thermistor

The thermistor is a kind of resistor whose resistivity depends on surrounding temperature. It is a temperature sensitive device. The word thermistor is derived from the word, thermally sensitive resistor. The thermistor is made of the semiconductor material that means their resistance lies between the conductor and the insulator.

The variation in the thermistor resistance shows that either conduction or power dissipation occurs in the thermistor. The circuit diagram of thermistor uses the rectangular block which has a diagonal line on it.

Types of Thermistor

The thermistor is classified into types. They are the negative temperature coefficient and the positive temperature coefficient thermistor.



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1. **Negative Temperature Coefficient Thermistor** – In this type of thermistor the temperature increases with the decrease of the resistance. The resistance of the negative temperature coefficient thermistor is very large due to which it detects the small variation in temperature.
2. **Positive Temperature Coefficient Thermistor** – The resistance of the thermistor increases with the increases in temperature.

Construction of Thermistor

The thermistor is made with the sintered mixture of metallic oxides like manganese, cobalt, nickel, cobalt, copper, iron, uranium, etc. It is available in the form of the bead, rod and disc. The different types of the thermistor are shown in the figure below.

The relation between the absolute temperature and the resistance of the thermistor is mathematically expressed by the equation shown below.

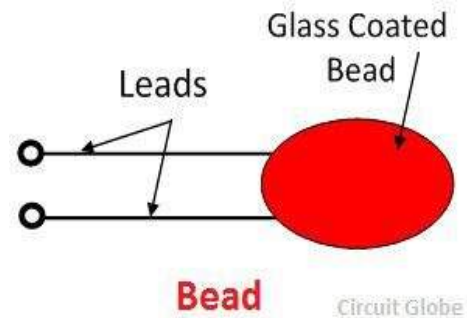
$$R_{T_1} = R_{T_2} \exp \left[\beta \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right]$$

Where R_{T_1} – Resistance of the thermistor at absolute temperature T_1 in Kelvin.
 R_{T_2} – Resistance of the thermistor at absolute temperature T_2 in Kelvin.
 β – a temperature depending on the material of thermistor.

The resistance temperature coefficient of the thermistor is shown in the figure below. The graph below shows that the thermistor has a negative temperature coefficient, i.e., the temperature is inversely proportional to the resistance. The resistance of the thermistor changes from 10^5 to 10^{-2} at the temperature between -100°C to 400°C .

INDUCTIVE TRANSDUCER

Inductive Transducer is the self-generating type otherwise the passive type transducer. The first type like self-generating uses the principle of fundamental electrical generator. The electric generator principle is when a motion among a conductor as well as magnetic field induces a voltage within the conductor. The motion among the conductor and the field can be supplied by transforms in the measured. An inductive transducer (electromechanical) is an electrical device used to convert physical motion into modifying within inductance. This article discusses what an Inductive Transducer, types of transducer, working principle, and its applications





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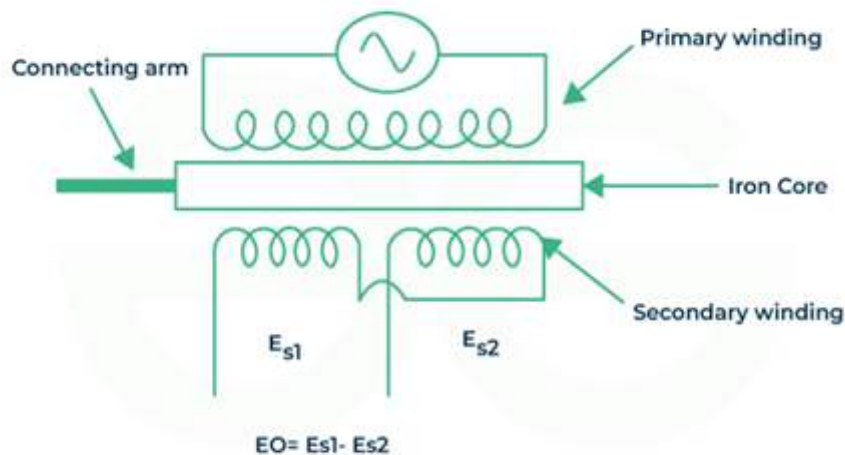
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Linear Variable Differential Transformer (LVDT)

LVDT stands for Linear variable differential transformer. It is one of the major types of Inductive transducers. LVDTs are considered the most accurate inductive sensors that measure displacement according to the polarity and magnitude of the net induced electromotive force (EMF) and are therefore also known as linear variable displacement sensors.

Construction of LVDT

The transformer and LVDT share a similar construction. It consists of one primary winding (P) and two secondary windings (S1 & S2). The primary and secondary windings are bounded by a hollow cylinder, known as the former. The primary winding is at the center and the secondary windings are present on both sides of the primary winding at an equal distance from the center. Both the secondary windings have an equal no. of turns and they are linked with each other in series opposition, i.e. they are wound in opposite directions, but are connected in series with each other. The entire coil assembly remains stationary during distance measurement. The moving part of the LVDT is an arm made of magnetic material.



Working Principle of LVDT

The working of LVDT is based on Faraday's law of electromagnetic induction, which states that "the electrical power in the network induction circuit is proportional to the rate of change of magnetic flux in the circuit."

As the primary winding of LVDT is connected to the AC power supply, The alternating magnetic field is produced in the primary winding, which results in the induced EMF of secondary windings. Let's assume that the induced voltages in the secondary windings S1 & S2 are E_1 & E_2 respectively. Now according to using the rate of change of magnetic flux i.e. $d\Phi/dt$



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is directly proportional to the magnitude of induced EMF i.e E_1 and E_2 . The total output voltage E_o in the circuit is given by $E_o = E_1 - E_2$. Depending on the position of the core some cases arise:

Case 1: When The Core is Moving Towards S1

When the core of LVDT moves towards the second winding S1 then the flux linkage S will be more as compared to S2. The EMF induced in S1 will be more than the EMF of S2. Hence E_1 is greater than E & net differential voltage $E_o(E_1 - E_2)$ will be +ve. The means output voltage V_o will be in phase with input AC voltage.

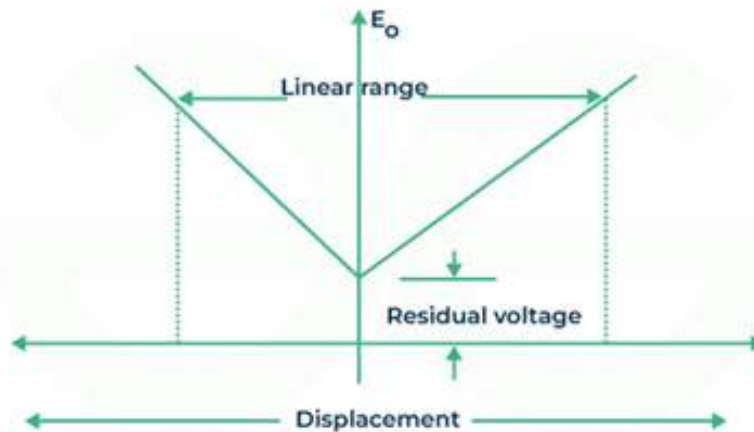
Case 2 : When the core is positioned at its null position

When the core is at a null position then the flux generated in both the secondary windings will be the same. The induced EMF E_1 & E_2 , and both the windings will be the same. Hence the net differential output voltage E_o will be 0. It shows 0 displacement of the core.

Case 3 : When The Core Moving Towards S2

When the core of LVDT moves towards secondary winding S2 then the flux linkage with S2 will be more than S1. It means the EMF induced in S2 will be more than the induced EMF of S1

Characteristics of LVDT



Capacitive Transducer

The capacitive transducer is used for measuring the displacement, pressure and other physical quantities. It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances. The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.



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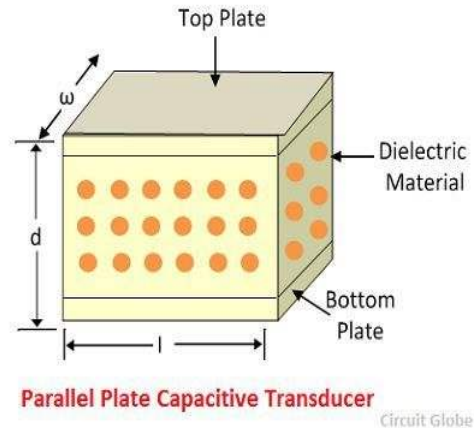
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Principle of Operation

The equations below express the capacitance between the plates of a capacitor

$$C = \epsilon A/d$$

$$C = \epsilon_r \epsilon_0 A/d$$



Where A – overlapping area of plates in m²

d – the distance between two plates in meter

ϵ – permittivity of the medium in F/m

ϵ_r – relative permittivity

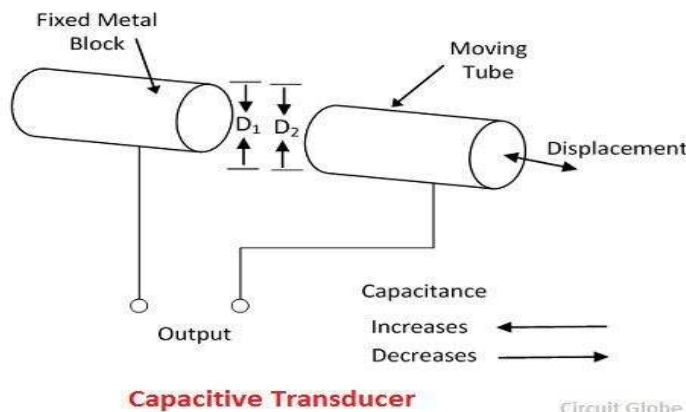
ϵ_0 – the permittivity of free space

The capacitive transducer is mainly used for measurement of linear displacement. The capacitive transducer uses the following three effects.

1. Variation in capacitance of transducer is because of the overlapping of capacitor plates.
2. The change in capacitance is because of the change in distances between the plates.
3. The capacitance changes because of dielectric constant.

The following methods are used for the measuring displacement.

1. **A transducer using the change in the Area of Plates** – The equation below shows that the capacitance is directly proportional to the area of the plates. The capacitance changes correspondingly with the change in the position of the plates.





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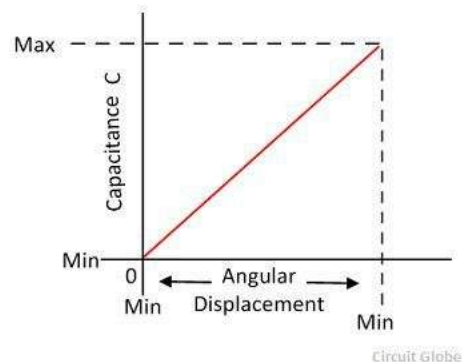
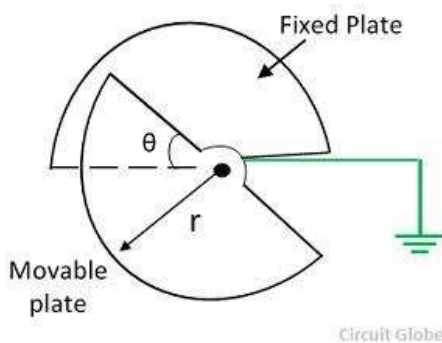
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The capacitive transducers are used for measuring the large displacement approximately from 1mm to several cms. The area of the capacitive transducer changes linearly with the capacitance and the displacement. Initially, the nonlinearity occurs in the system because of the edges. Otherwise, it gives the linear response

2.capacitance for angular displacement (Rotational)

The capacitive transducer is used for measuring the angular displacement. It is measured by the movable plates shown below. One of the plates of the transducer is fixed, and the other is movable. The angular movement changes the capacitance of the transducers. The capacitance between them is maximum when these plates overlap each other. The maximum value of capacitance is expressed as

$$C_{max} = \frac{\epsilon A}{d} = \frac{\pi \epsilon r^2}{2d}$$



Advantage of Capacitive Transducer

1. It requires an external force for operation and hence very useful for small systems.
2. The capacitive transducer is very sensitive.
3. It gives good frequency response because of which it is used for the dynamic study.
4. The transducer has high input impedance hence they have a small loading effect.
5. It requires small output power for operation.

Disadvantages of capacitive Transducer

1. The metallic parts of the transducers require insulation.
2. The frame of the capacitor requires earthing for reducing the effect of the stray magnetic field.
3. Sometimes the transducer shows the nonlinear behaviours because of the edge effect which is controlled by using the guard ring.
4. The cable connecting across the transducer causes an error.



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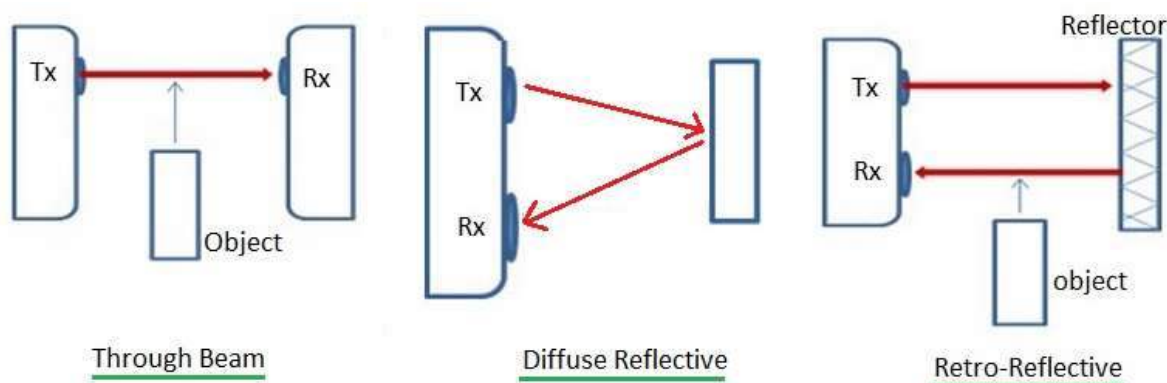
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Optical Sensor

An optical sensor definition is; a sensor that is used to convert the light rays into electronic signals. These sensors help in measuring the incident light's intensity & changing it into a readable form through an incorporated measuring device based on the type of sensor. Generally, this sensor is an essential part of a larger system which includes a light source, sensor, and measuring device itself.

Optical Sensor Working Principle



Through Beam Optical Sensors

Through-beam optical sensor includes both transmitter & receiver which are arranged by pointing to each other so that they can create a directly light ray path. Once any object approaches in the middle of this path then the light intensity will be changed & thus object is detected.

Diffuse Reflective Sensor

This diffuse reflective sensor has both transmitter & receiver which are arranged parallel to each other. Once the transmitter generates a light signal then it is reflected through the object. This light reflection can be simply measured through the receiver.

Retro-reflective Sensor

This kind of optical sensor has both transmitter & receiver which are arranged within one housing. The transmitter generates a light ray which is reflected through the reflector & obtained by the receiver. If any object approaches in the middle of this light ray path, then it breaks. So the object at the receiver is detected based on the variation between the intensity of the light beam & other parameters.

Phot Detectors

Photo means light. A detector is a device that detects something. So, a photodetector can be defined as a device that is used to detect light radiations by absorption. It converts light pulses(or radiations) energy into electrical signals in the form of current & voltage. Sometimes, it is also called photosensors. As the name implies, it detects incident photons or radiations by absorbing the incident lights. The principle behind this process is known as photodetections.



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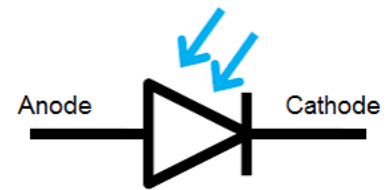
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Photodetector Types

Photodiodes

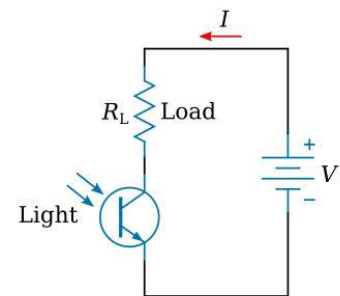
These are semiconductor devices with a PIN or PN junction structure where light is absorbed within a depletion region & produces a photocurrent. These devices are fast, highly linear, very compact and generate a high quantum efficiency which means it generates almost one electron for each incident photon & a high dynamic range. Please refer to this [link](#) to know more about Photodiodes.



Photodiode symbol

Phototransistor

The phototransistor is one type of photodiode which uses internal amplification of the photocurrent. But these are not frequently used as compared to photodiodes. These are mainly used for detecting light signals & change them into digital electrical signals. These components are simply operated through light rather than electric current. Phototransistors are low-cost and provide a large amount of gain, so they are used in various applications. Please refer to this [link](#) to know more about phototransistors.



Properties

Spectral Response – It is the photodetector's response as a photon frequency function.

Quantum Efficiency – The number of charge carriers generated for each photon

Responsivity – It is the output current separated by the total power of light dropping on the detector.

Noise-equivalent Power – It is the required amount of light power to generate a signal that is equivalent in size to the noise of the device.

Detectivity – The square root of the area of the detector separated by the noise equivalent power.

Gain – It is the photo detector's output current which is divided by the directly produced current by the incident photons on the detectors.

Dark Current- The flow of current throughout a detector even in the deficiency of light.

Response Time – It is the required time for a detector to go from 10 – 90% of the final output.

Noise Spectrum – The intrinsic noise current or voltage is a function of frequency that can be signified in a noise spectral density form.

Nonlinearity – The photo detector's nonlinearity limits the RF output.



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Vision System

A vision system acts as a complex optical transducer. It converts light energy (photons) from a visual scene into an electrical signal, then processes those signals into actionable data or digital images for industrial automation, inspection, and robot guidance.

Core Components

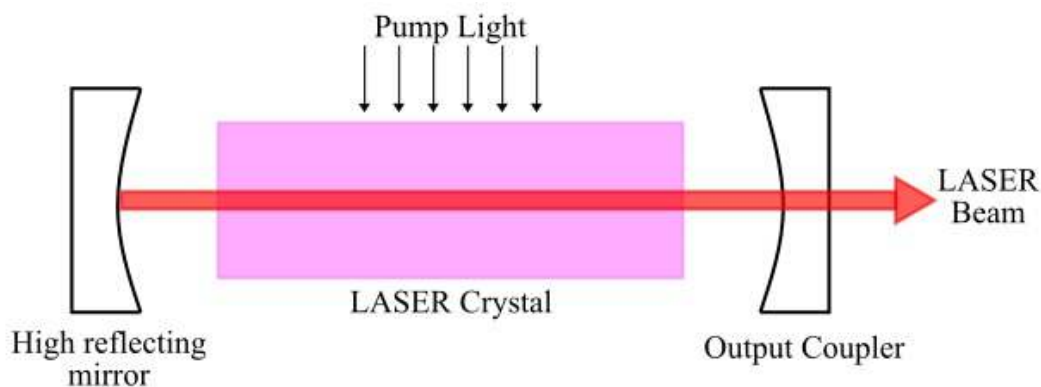
- **Lighting:** Shines light on the target so key features stand out clearly for the camera.
- **Lens (Optics):** Focuses incoming light waves onto the physical image sensor chip.
- **Image Sensor (Transducer):** Uses CMOS or CCD semiconductor technology to convert optical light energy into raw electronic pixel charges.
- **Processor / Controller:** Runs embedded software or algorithms to analyze the digital image and make pass/fail or coordinate judgments.
- **Communication Interface:** Sends discrete I/O signals or Ethernet data to a PLC, computer, or robotic arm

LASER

LASER stands for Light Amplification by Stimulated Emission of Radiation. A LASER is a source of light which produces a very narrow beam of light that is useful in many technologies and instruments.

Construction and Working of LASER

The construction of a typical red LASER is shown in the figure.



It contains a long crystal of made ruby with a flash tube (which is not shown for simplicity, instead directly pump light is shown) wrapped around it.

Here, a high voltage electric power supply makes the tube flash on and off. When the tube flashes, it pumps energy into the ruby crystal. The flashes it makes inject energy into the crystal in the form of photons. The atoms of the ruby crystal absorb this energy and thus the electrons of the atoms jump to a higher energy level.



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Now, after few milliseconds, the electrons return to their ground level by giving off a photon of light, this is known as **spontaneous emission**. The photons that atoms give off zoom up and down inside the ruby crystal and travelling at a speed of light. One of these photons stimulate an already existing atom. When this happens, the excited atom gives off a photon and we get the original photon as well. This is known as **stimulated emission**.

Now, one photon of light has produced two photons so the light has been amplified. The escaping photons from the crystal form a very concentrated beam of powerful LASER light

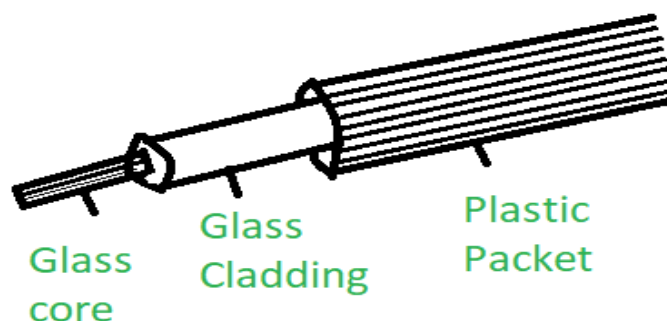
Fiber optic sensors

Fiber Optics or Optical Fiber is a technology that transmits data as a light pulse along a glass or plastic fiber. An Optical Fiber is a cylindrical fiber of glass that is hair-thin in size or any transparent dielectric medium. The fiber which is used for optical communication is waveguides made of transparent dielectrics.

Fiber optics refers to the technology and method of **transmitting data** as light pulses along a glass or plastic strand or fiber. **Fiber optic cables** are used for long-distance and high-performance **data networking**. They are capable of transmitting data over longer distances and at higher bandwidths (data rates) than electrical cables, making them a critical component in **modern telecommunications**, internet, and computer networking.

Main Elements of Fiber Optics

- **Core:** It is the central tube of very thin size made of optically transparent dielectric medium and carries the light transmitter to receiver and the core diameter may vary from about 5um to 100 um.
- **Cladding:** It is an outer optical material surrounding the core having a reflecting index lower than the core and cladding helps to keep the light within the core throughout the phenomena of total internal reflection.
- **Buffer Coating:** It is a plastic coating that protects the fiber made of silicon rubber. The typical diameter of the fiber after the coating is 250-300 um.





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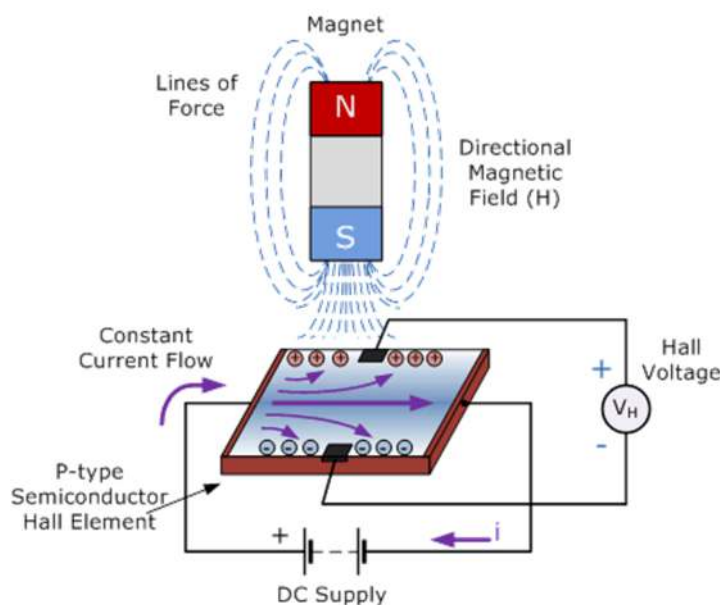
Solid State Sensors

Hall effect sensors

Hall Effect Sensors are devices which are activated by an external magnetic field. We know that a magnetic field has two important characteristics flux density, (B) and polarity (North and South Poles).

The output signal from a Hall effect sensor is the function of magnetic field density around the device. When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the Hall Voltage, V_H . Consider the diagram below.

Hall Effect Sensor Principles



Hall Effect Sensors consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself.

When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.

As these electrons and holes move side wards a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers. Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shaped material.



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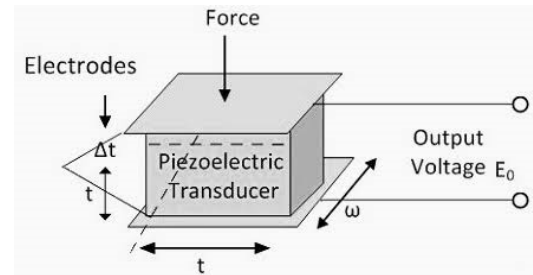
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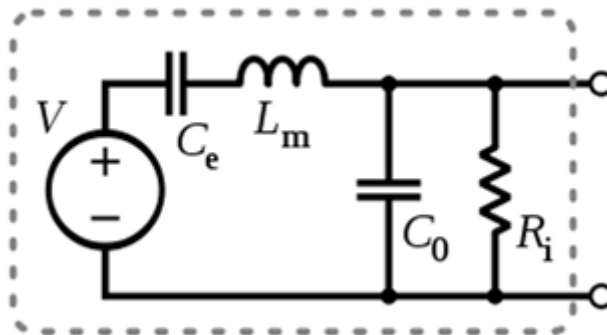
The output voltage, called the Hall voltage, (V_H) of the basic Hall Element is directly proportional to the strength of the magnetic field passing through the semiconductor material (output $\propto H$).

Piezo electric sensor

A sensor which works on the principle of piezoelectricity is known as a piezoelectric sensor. Where piezoelectricity is a phenomenon where electricity is generated if mechanical stress is applied to a material. Not all materials have piezoelectric characteristics.

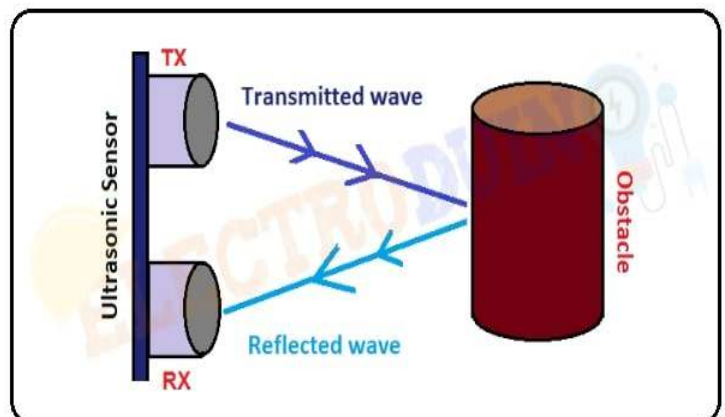


A piezoelectric sensor internal circuit is given above. The resistance R_i is the internal resistance or insulator resistance. The inductance is due to the inertia of the sensor. The capacitance C_e is inversely proportional to the elasticity of the sensor material. For the proper response of the sensor, the load and leakage resistance must be large enough so that low frequencies are preserved. A sensor can be called a pressure transducer in an electrical signal. Sensors are also known as primary transducers



Ultrasonic Sensor

Ultrasonic Sensor includes a transmitter & a receiver. This sensor is used to find out the distance from the objective. Here the amount of time taken to transmit and receive the waves will decide the distance between the sensor and an object. This sensor uses sound waves by using non-contact technology. By using this sensor, the distance which is required for the target can be measured without damage and provides accurate details.





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Working

When the power supply is given to this module, it generates the sound waves to travel throughout the air to hit the necessary object. These waves strike and come back from the object, then collect by the receiver module.

Here both the distance as well as time has taken is directly proportional because the time taken for more distance is high. If the trigger pin is kept high for 10 μ s, then the ultrasonic waves will be generated which will travel at the sound speed. So it creates eight cycles of sonic burst that will be gathered within the Echo pin. This ultrasonic sensor is interfaced with Arduino to gauge the necessary distance between sensor & object. The distance can be calculated using the following formula.

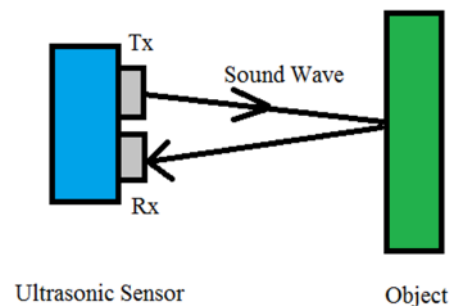
$$S = (V \times t)/2$$

Where the 'S' is the required distance

'V' is the sound's speed

't' is the time taken for sound waves to return back after striking the object.

The actual distance can be calculated by dividing its value with 2 as the time will be twice once the waves travel and get back from the sensor.



Actuators

An actuator is a mechanical or electromechanical device that takes an energy source and converts it into physical, controlled movement. It acts as the "muscle" of a system, turning a control signal into mechanical action like pushing, pulling, lifting, or turning.

Energy source: Energy sources provide actuators with the ability to do work. Actuators draw electrical or mechanical energy from external sources for carrying out their operation. The energy available to the actuator can be regulated or unregulated depending on the system that it is a part of.

Power converter: If the energy source attached to the actuators is unregulated, it requires some additional apparatus to regulate it and convert it into a form suitable for the actuation action. Hydraulic control valves or solid-state power electronic converters are examples of converters used in industrial actuators.



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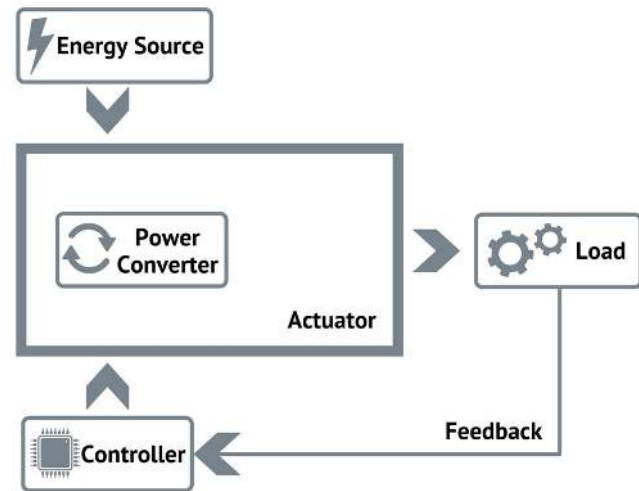
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Controller: In addition to enabling the operation of the power converter, a control unit is responsible for generating actuating electrical/control signals. In some systems, it provides the user with an interface to provide inputs or check the system's status.

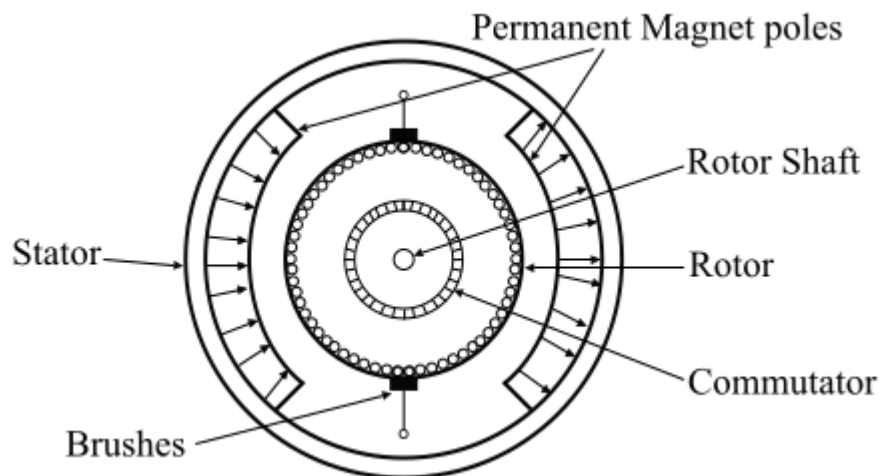
Load: The mechanical system attached to the actuator that uses the motion of the actuator is called the load.

Characteristics like Force/Torque and Speed are carefully tuned before interfacing an actuator with the load.



Permanent Magnet DC Motor (PMDC)

A permanent magnet DC (PMDC) motor is a type of DC motor whose field poles are made up of permanent magnets. The cross-sectional view of a 2-pole permanent magnet DC Motor



Construction

The PMDC motor's permanent magnets are maintained with a cylindrical-steel stator and these supplies like a return lane for the magnetic flux. The rotor supplies like an armature, and it includes commutator segments, winding slots, & brushes like in conventional dc machines. The permanent magnets used in this motor are classified into three namely Alnico magnets, Ceramic (ferrite) magnets, and Rare-earth magnets

Working

In this motor, a permanent magnetic field can be generated with the permanent magnets which communicate by the perpendicular field stimulated by the flow of currents within the rotor windings; therefore a mechanical torque can be created.



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When the rotor rotates in response to the created torque, then the position among the stator as well as rotor fields can be reduced, and the torque would be reversed in a 90-degree rotation. To maintain the torque performing on the rotor, PMDC motors include a commutator, set to the rotor shaft.

The commutator activates the current supply toward the stator thus as to continue a steady angle = 90, among two fields. As the flow of current is frequently activated among windings like the rotor twists, then the current within every stator winding is truly exchanging at a frequency comparative to the no.of motor magnetic poles as well as the speed.

Advantages and Disadvantages of the PMDC Motor

The advantages and disadvantages of the PMDC motor include the following.

- The size of these motors is smaller
- These motors are cheaper
- These motors do not need field windings, and they don't have the copper losses in the field circuit.
- The major drawback of this motor is, the generating capacity of working flux within the air gap is limited. But, due to the expansion of some latest magnetic material such as Samarium Cobalt & Neodymium Iron Boron, this trouble has been determined to some level.

Applications of the PMDC

- These are applicable in automobiles for operating windshield wipers as well as washers, to move up the lower windows, to drive blowers for air conditioners as well as heaters.
- These are used in computer drives, toy industries.
- These motors are applicable in food mixers, electric toothbrushes, and moveable vacuum cleaners,.
- These are used in a handy electric tool like hedge trimmers, drilling machines, etc.

Stepper Motor

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how may steps have been performed, with no need for a sensor.



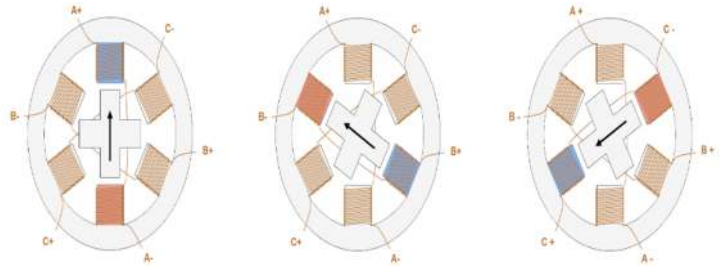
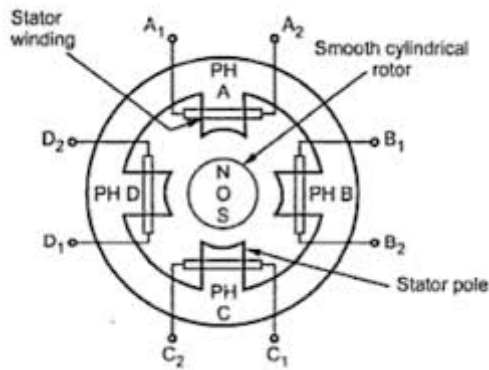
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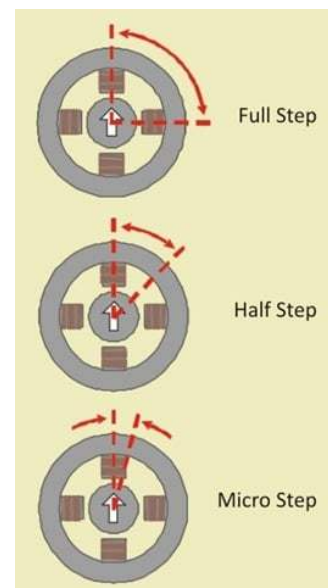
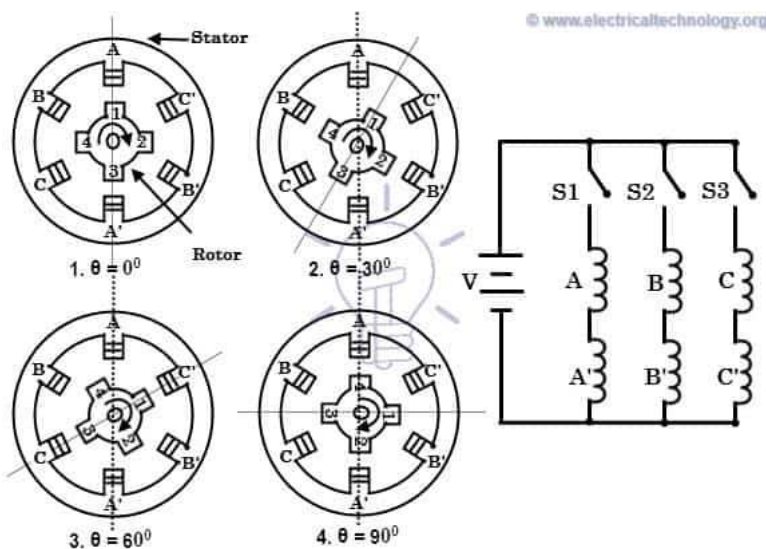
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Single Excitation Mode

The basic method of driving a stepper motor is a single excitation mode. It is an old method and not used much at present but one has to know about this technique. In this technique every phase otherwise stator next to each other will be triggered one by one alternatively with a special circuit. This will magnetize & demagnetize the stator to move the rotor forward.



Full Step Drive

In this technique, two stators are activated at a time instead of one in a very less time period. This technique results in high torque & allows the motor to drive the high load.

Half Step Drive

This technique is fairly related to the Full step drive because the two stators will be arranged next to each other so that it will be activated first whereas the third one will be activated after that. This kind of cycle for switching two stators first & after that third stator will drive



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the motor. This technique will result in improved resolution of the stepper motor while decreasing the torque.

Micro Stepping

This technique is most frequently used due to its accuracy. The variable step current will supply by the stepper motor driver circuit toward stator coils within the form of a sinusoidal waveform. The accuracy of every step can be enhanced by this small step current. This technique is extensively used because it provides high accuracy as well as decreases operating noise to a large extent.

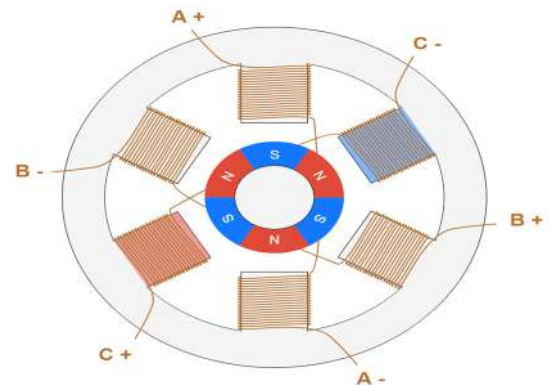
Types of Stepper Motor

- Permanent magnet stepper
- Hybrid synchronous stepper
- Variable reluctance stepper

Permanent Magnet Stepper Motor

Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets.

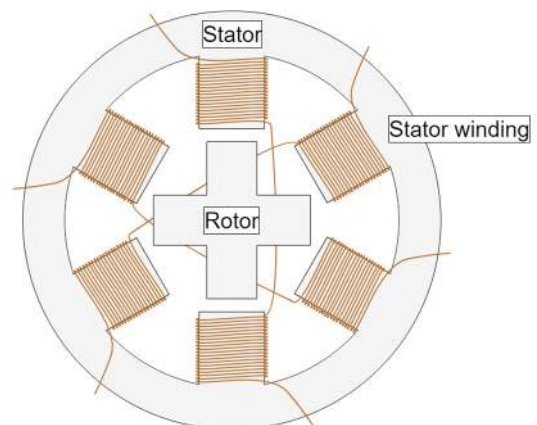
This is the most common type of stepper motor as compared with different types of stepper motors available in the market. This motor includes permanent magnets in the construction of the motor. This kind of motor is also known as tin-can/can-stack motor. The main benefit of this stepper motor is less manufacturing cost. For every revolution, it has 48-24 steps.



Variable Reluctance Stepper Motor

Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

The stepper motor like variable reluctance is the basic type of motor and it is used for the past many years. As the name suggests, the rotor's angular position mainly depends on the magnetic circuit's reluctance that can be formed among the teeth of the stator as well as a rotor.





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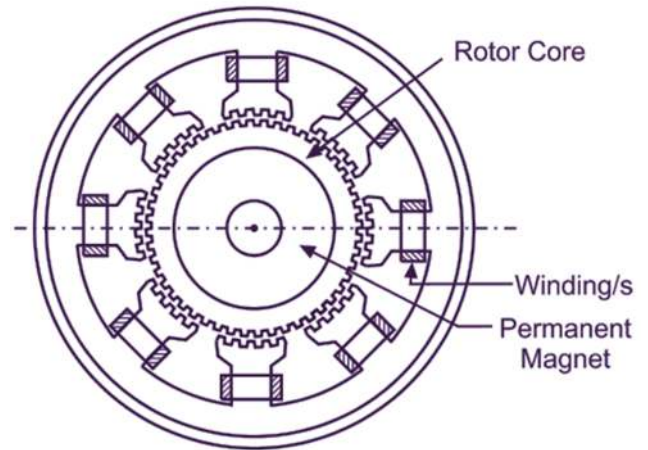
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Hybrid Synchronous Stepper Motor

Hybrid stepper motors are named because they use a combination of permanent magnet (PM) and variable reluctance (VR) techniques to achieve maximum power in small package sizes.

The most popular type of motor is the hybrid stepper motor because it gives a good performance as compared with a permanent magnet rotor in terms of speed, step resolution, and holding torque. But, this type of stepper motor is expensive as compared with permanent magnet stepper motors.

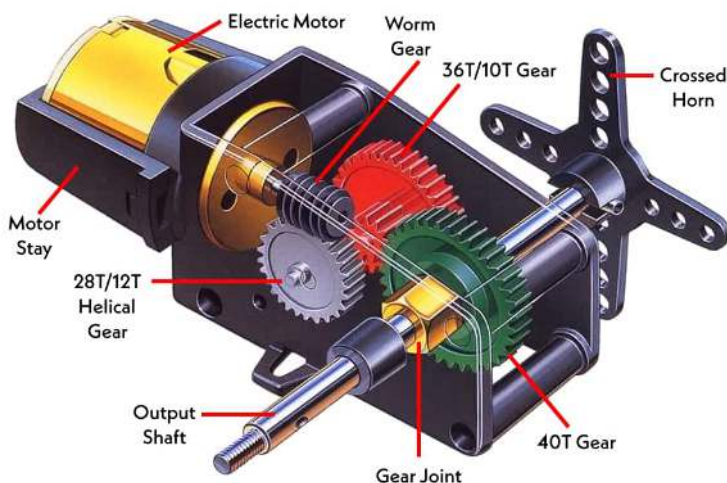
This motor combines the features of both the permanent magnet and variable reluctance stepper motors. These motors are used where less stepping angle is required like 1.5, 1.8 & 2.5 degrees.



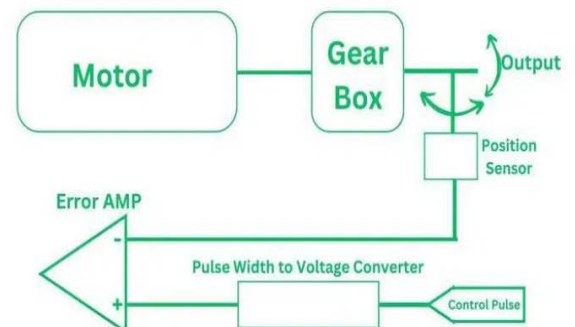
SERVO MOTOR

A **servo motor** is a precision motor that uses a servo motor working principle based on closed-loop feedback control, which can rotate to specific angles with exceptional accuracy. If you want to rotate an object to specific angles or distances, servo motors are the ideal choice due to their **servo mechanism** with built-in position feedback.

Construction of a Servo Motor



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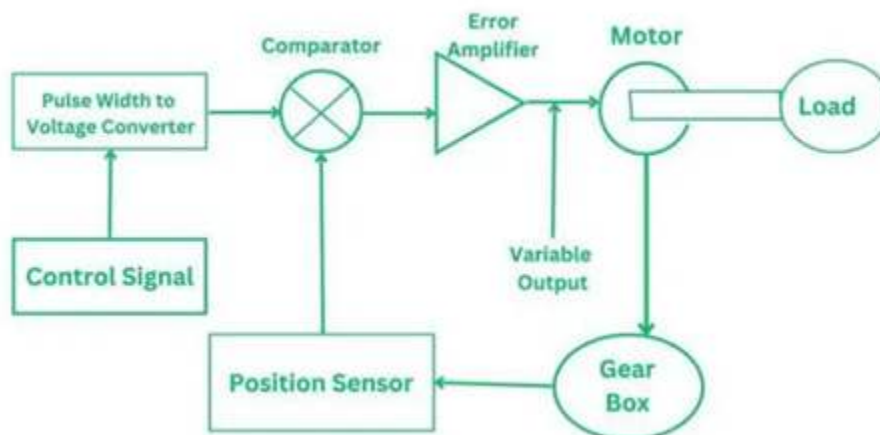
DC Servo Motor Construction and Working

Construction

- **DC Motor:** The core motor is a direct current motor that uses a field winding that is separately excited. According to the excitation mode, DC servo motors can be in two types, namely, the armature-controlled motor and the field-controlled motor.
- **Load:** The load could be as simple as a fan or an industrial load coupled to the mechanical shaft of the motor.
- **Gearbox:** Serves as a mechanical transducer to modify the motor's output signal — acceleration, position, or velocity— to fit the task at hand.
- **Position Sensor:** In general, it is a potentiometer that gives back information by generating a voltage corresponding to the angle of the motor shaft through a system of gears.
- **Comparator:** Compares a reference signal from the signal obtained from the position sensor to generate an error signal that is given to an amplifier.
- **Amplifier:** Increases the error signal coming out of the comparator section and gives it to the motor.
- **Pulse Width Modulator (PWM):** Compensates the feedback signal given to the motor to fine-tune the input towards it.

Working

When there is an input signal, the shaft of the DC motor and gears turn. This change is captured by the position sensor, where the rotation of the gear causes it to change its resistance in order to generate a voltage change. This voltage, being its error signal, is supplied to the controller, which produces a PWM signal to control the motor's input.





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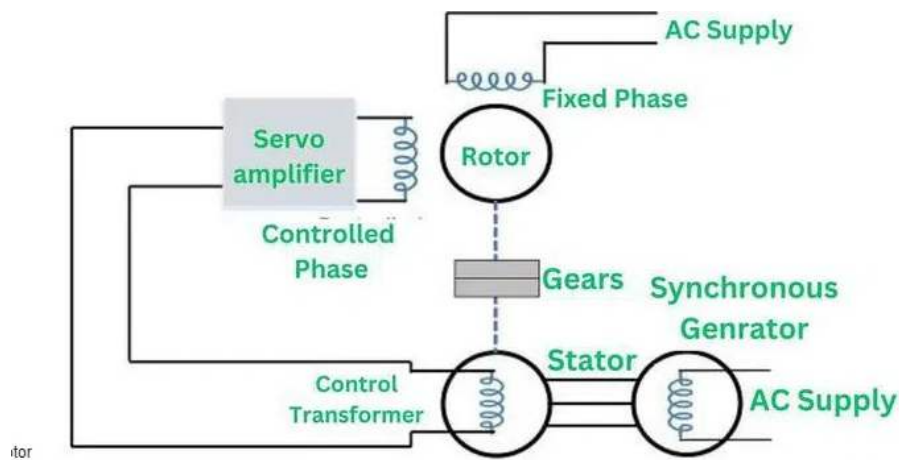
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AC Servo Motor

AC servo motors are a specific type of servomotor that converts AC electricity into precise mechanical movements, focusing on accurate angular velocity. Essentially, these motors are two-phase induction motors, featuring specific design distinctions. They produce mechanical power ranging from a few watts to several hundred watts, operating within a frequency range of 50 to 400 Hz. What sets them apart is their utilization of a closed-loop control system, employing encoders to monitor speed and position. This feature makes these motors exceptionally adept at precision and control, distinguishing them from others lacking such an advanced feedback system.





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UNIT II

SIGNAL CONDITIONING CIRCUITS AND PLC

OPERATIONAL AMPLIFIER

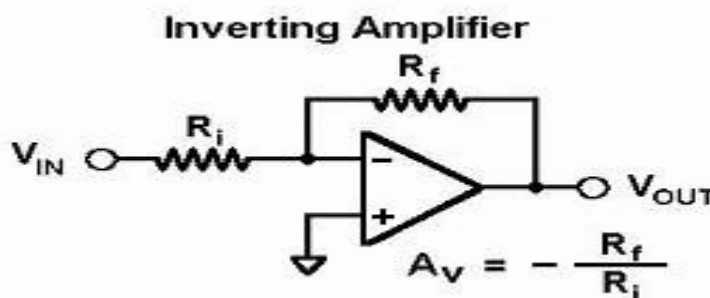
An operational amplifier (op-amp) is an integrated circuit that amplifies the voltage difference between its two inputs. It can be Voltage amplifiers, whose input is some voltage and output is also a voltage but amplified. Current amplifier, whose input is some current and output is also a current but amplified.

TYPES OF OP AMP

1. Inverting amplifier
2. Non Inverting Amplifier

Inverting amplifier

An Inverting operational Amplifier is a device used in electronics engineering for amplifying the output and generating an output voltage that has a phase opposite to the input waveform.



- The inverting terminal of inverting operational amplifier is fed with the input signal whereas the non-inverting terminal is usually connected to ground or some reference voltage.
- Next a feedback circuit is applied. In this a feedback resistor is connected between the output of op-amp and inverting input terminal. This resistor primarily controls the gain.
- Now an ideal op-amp amplifies the input voltage applied. The negative feedback from the output to the inverting input creates a stable condition. This helps us to control the output generated. The whole time op-amp works to ensure that the voltage at the inverting input is equal to the voltage at the non-inverting input.



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- Due to the inverting nature, the input signal is inverted. This means if input signal increases then output will decrease and vice-versa. The gain in final output is calculated using the formula $\text{gain} = R_f/R_{in}$.
- After the amplification and inversion of input signal along with phase inversion, the output wave is generated at the junction. The output voltage is denoted by V_{out}

By KCL ,

Input voltage = output voltage

$$\frac{V_{in} - V_2}{R_{in}} = \frac{V_2 - V_{out}}{R_f}$$

At $V_1 = V_2 = 0$

$$\frac{V_{in} - 0}{R_{in}} = \frac{0 - V_{out}}{R_f}$$

Finally

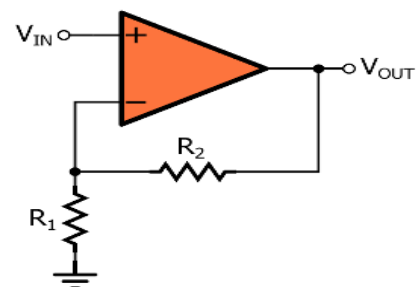
$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

voltage gain of the Inverting amplifier ;

$$\text{Gain (A}_v\text{)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

NON INVERTING AMPLIFIER

Non-inverting operational amplifier configuration, the input voltage signal, (V_{IN}) is applied directly to the non-inverting (+) input terminal. This results in the op-amps output signal being “in-phase” with its input signal. Thus the output voltage gain of the amplifier becomes “Positive” in value and the opposite to the previous inverting amplifier configuration.



Feedback control of the non-inverting operational amplifier is achieved by applying a small part of the output voltage signal back to the inverting (–) input terminal via a $R_f - R_2$ voltage divider network, again producing negative feedback.

This closed-loop configuration produces a non-inverting amplifier circuit with very good stability, a very high input impedance, R_{in} approaching infinity, as no current flows into the positive input terminal, (ideal conditions) and a low output impedance, R_{out}



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$$V_1 = \frac{R_2}{R_2 + R_F} \times V_{OUT}$$

Ideal Summing Point: $V_1 = V_{IN}$

Voltage Gain, $A_{(V)}$ is equal to: $\frac{V_{OUT}}{V_{IN}}$

$$\text{Then, } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = \frac{R_2 + R_F}{R_2}$$

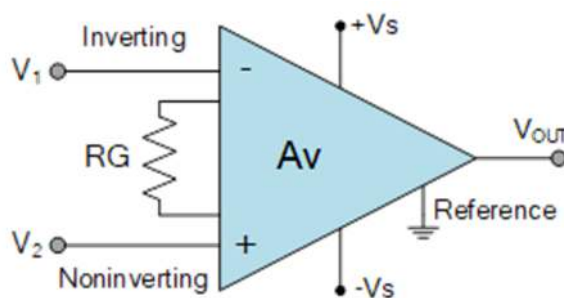
$$\text{Transpose to give: } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_2}$$

Non-inverting Amplifier Gain Formula

$$A_{(V)} = 1 + \frac{R_F}{R_2}$$

Instrumentational amplifier

The instrumentation amplifier circuit uses a differential amplifier and cross-coupled input buffer stages to improve its dc performance, making it ideal for accurate measurement and sensor applications.





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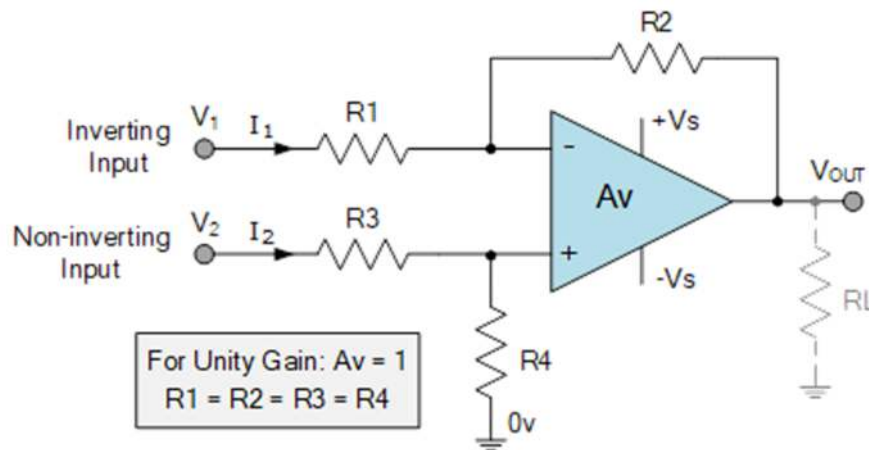
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The **Instrumentation Amplifier**, (INA) is another type of operational amplifier circuit consisting of two or more op-amps connected together to provide a very high impedance at both of its two input terminals.

Electrical output signals from sensors, transducers and resistive bridge networks are usually very small, a few millivolts or less. So some form of voltage amplification is required in order for them to be processed or measured.

Sensors are commonly connected to the input terminals of an amplifier, either in the form of a single-ended input transistor amplifier where the output voltage is a gain constant, “A” times the input voltage.

Or to an operational amplifier with an inverting and noninverting differential input and whose output is the differential gain times the difference between its two input voltages.



$$V_{OUT1} = V_1 \left(-\frac{R_2}{R_1} \right) \quad \text{and} \quad V_{OUT2} = V_2 \left(1 + \frac{R_2}{R_1} \right) \left(\frac{R_4}{R_3 + R_4} \right)$$

$$V_{OUT} = V_{OUT1} + V_{OUT2} = V_1 \left(-\frac{R_2}{R_1} \right) + V_2 \left(1 + \frac{R_2}{R_1} \right) \left(\frac{R_4}{R_3 + R_4} \right)$$

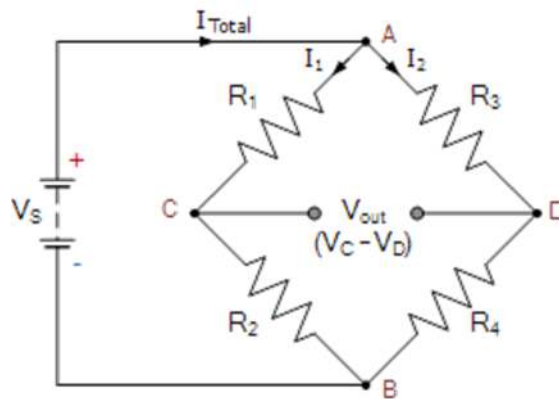
$$\text{For: } R_1 = R_3 \quad \text{and} \quad R_2 = R_4, \quad \text{that is the ratio: } \frac{R_3}{R_4} = \frac{R_1}{R_2}$$

$$\text{This reduces down too: } V_{OUT} = \frac{R_2}{R_1} (V_2 - V_1)$$



Wheatstone bridge amplifier

A Wheatstone bridge circuit has two input terminals and two output terminals consisting of four resistors configured in a familiar diamond-like arrangement as shown



When balanced, the Wheatstone bridge can be analysed simply as two series strings in parallel. In our tutorial about **Resistors in Series**, we saw that each resistor within the series chain produces an **IR** voltage drop across itself as a consequence of the current flowing through it as defined by Ohms Law.

By replacing R_4 above with a resistance of known or unknown value in the sensing arm of the Wheatstone bridge corresponding to R_X and adjusting the opposing resistor, R_3 to “balance” the bridge network, will result in a zero voltage output. Then we can see that balance occurs when:

$$\frac{R_1}{R_2} = \frac{R_3}{R_X} = 1 \text{ (Balanced)}$$

The Wheatstone Bridge equation required to give the value of the unknown resistance, R_X at balance is given as:

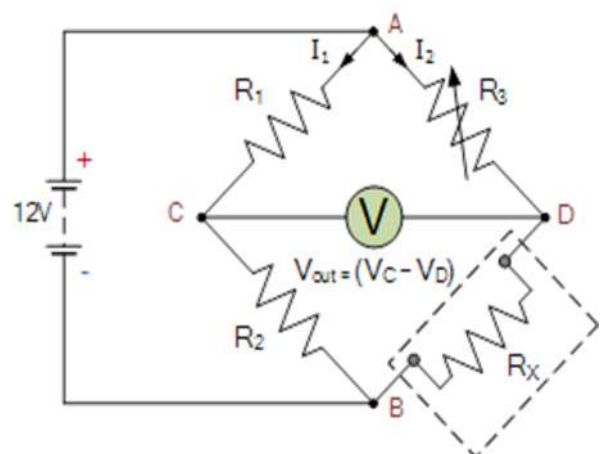
$$V_{OUT} = (V_C - V_D) = (V_{R2} - V_{R4}) = 0$$

$$R_C = \frac{R_2}{R_1 + R_2} \quad \text{and} \quad R_D = \frac{R_4}{R_3 + R_4}$$

$$\text{At Balance: } R_C = R_D \quad \text{So, } \frac{R_2}{R_1 + R_2} = \frac{R_4}{R_3 + R_4}$$

$$\begin{aligned} \therefore R_2(R_3 + R_4) &= R_4(R_1 + R_2) \\ R_2R_3 + \cancel{R_2R_4} &= R_1R_4 + \cancel{R_2R_4} \end{aligned}$$

$$\therefore R_4 = \frac{R_2R_3}{R_1} = R_X$$





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Data logger

A data logger is an electronic device that records measurements over time using a built-in sensor or external inputs. It consists of sensors, a microprocessor, a real-time clock, non-volatile memory, and a power source

Basic parts of a Data Logger Operation

1. Input scanner
2. Signal conditioner
3. A/D converter
4. Recording equipment
5. Programmer

The block diagram of a Data Logger Operation involving all these parts is shown

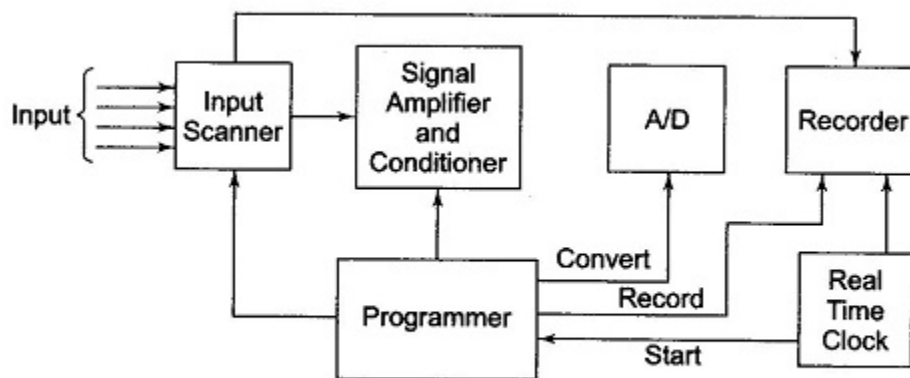


Fig. 17.24 Block Diagram of a Data Logger

The input scanner is an automatic sequence switch which selects each signal in turn. Low level signals, if any, are multiplied to bring them up to a level of 5 V. If the signals are not linearly proportional to the measured parameter, these signals are linearised by the signal conditioner.

The analog signals are then converted to digital signals suitable for driving the recording equipment (printer or punched paper tape).

The programmer (serialiser) is used to control the sequence operation of the various items of the logger. It tells the scanner when to step to a new channel, and receives information from the scanner, converter and recorder. The real time clock is incorporated to automatic the system. The clock commands the programmer to sequence one set of measurements at the intervals selected by the user

Applications of Data Loggers

- **Industrial Monitoring:** Manufacturers use data loggers to track machinery performance and prevent costly downtime.



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- **Environmental Studies:** Researchers deploy data loggers to monitor weather patterns, air quality, and water levels.
- **Transportation:** In the logistics industry, data loggers are used to maintain the quality of goods during transit, especially in cold chain management.
- **Healthcare:** Hospitals and labs rely on data loggers to monitor storage conditions for medicines and vaccines.

Data Acquisition system

A Data Acquisition System, often abbreviated as DAQ, consists of sensors, measuring instruments, and a computer. Its purpose is to gather and process essential data for understanding electrical or physical phenomena. This system plays a crucial role in tasks like monitoring heating coil temperature to evaluate efficiency in achieving desired levels. Data acquisition, also known as the process of collecting data, relies on specialized software that quickly captures, processes, and stores information.

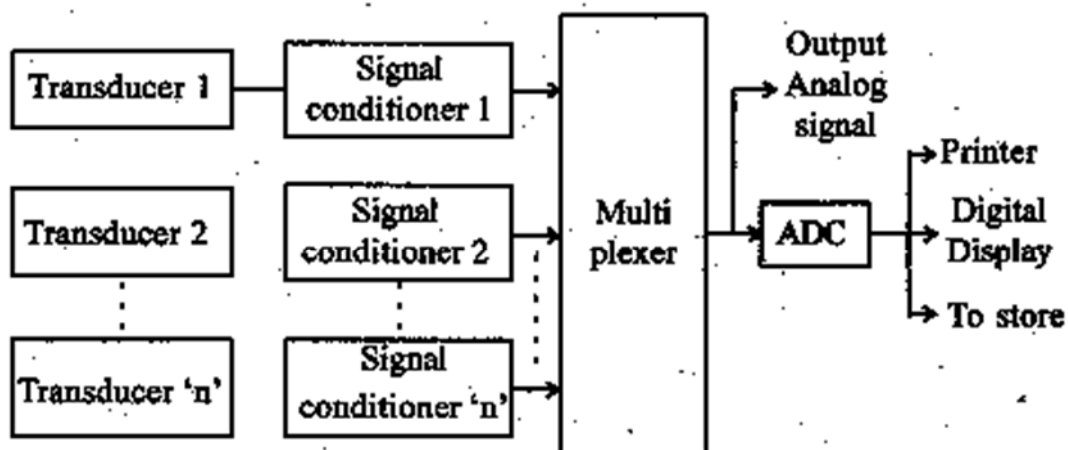


Figure 5.62 Generalized Data acquisition system

- **Sensors:** Devices that gather information about physical or environmental conditions, such as temperature, pressure, or light intensity.
- **Signal Conditioning:** To ensure accurate measurement, the raw sensor data undergoes preprocessing to filter out any noise and scale it appropriately.
- **Data Logger:** Hardware or software that records and stores the conditioned data over time.
- **Analog-to-Digital Converter (ADC):** Converts analog sensor signals into digital data that computers can process.
- **Interface:** Connects the data acquisition system to a computer or controller for data transfer and control.
- **Power Supply:** Provides the necessary electrical power to operate the system and sensors.



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- **Control Unit:** The management of the data acquisition system involves overseeing its overall operation, which includes tasks such as triggering, timing, and synchronization.
- **Software:** Allows users to configure, monitor, and analyze the data collected by the system.
- **Communication Protocols:** The transmission and reception of data between a system and external devices or networks is known as data communication.
- **Storage:** For storing recorded data, there are a range of options available, including memory cards, hard drives, or cloud storage. These provide both temporary and permanent storage solutions.
- **User Interface:** This system allows users to interact with and control the data acquisition system effectively.
- **Calibration and Calibration Standards:** To ensure accuracy the sensors and system are periodically calibrated against known standards.
- **Real-time Clock (RTC):** Accurate timing is maintained to ensure synchronized data acquisition and timestamping.
- **Triggering Mechanism:** Data capture is initiated based on predefined events or specific conditions.
- **Data Compression:** Efforts are made to reduce the size of collected data for storage and transmission in remote or resource limited applications.

Applications of Data Acquisition System

- Improving the efficiency and quality control of manufacturing processes by gathering real time data from sensors.
- Monitoring air quality and water pollution levels to safeguard health and comply with regulations.
- Collecting data from scientific fields to support analysis and hypothesis testing.
- In hospitals, it is crucial to constantly monitor the vital signs and patient data to ensure timely medical interventions.
- Assessing vehicle performance, safety, and emissions during research and development.
- During aircraft and spacecraft testing, the collection of data is crucial to ensure both safety and optimal performance.



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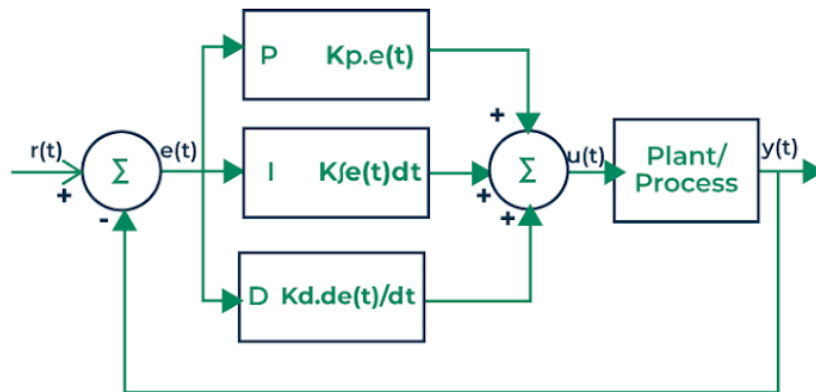
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PID controller

The term PID stands for proportional integral derivative and it is one kind of device used to control different process variables like pressure, flow, temperature, and speed in industrial applications. In this controller, a control loop feedback device is used to regulate all the process variables.



The PID controller serves the purpose of providing feedback to match a setpoint. For example, forcing a thermostat to turn on or off based on preset temperature. PID controllers are best used in systems which have relatively small mass and those that display quick reactions to changes in energy added in the process. It automatically compensates the amount of energy available or the mass to be controlled due to frequent changes in setpoint and is hence recommended in systems where the load changes often.

Working of PID controller

The output of a PID controller is equal to the control input to the plant. It is calculated from the feedback error. The following equation describes the calculation in the time domain:

$$u(t) = K_p * e(t) + K_i * e(t) * dt + K_d * de/dt$$

Here, $e(t)$ is the tracking error, i.e. the difference between the desired output (r) and the actual output (y). The actions taken by the PID controller broadly depend on this value. On receiving this value, the controller computes both the derivative and the integral of this error with respect to time. The control signal (u) is fed to the plant and the new output (y) is obtained. This new output (y) is then fed back and compared to the reference to find the new error signal (e).

The controller takes this new error signal and computes an updated control input. This procedure continues indefinitely. The transfer function of a PID controller is found by taking the Laplace transform:

$$K_p + K_i s + K_d s^2 = K_d s^2 + K_p s + K_i s.$$



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Filtering circuits:

1 Low-Pass 2. High-Pass and 3. Band-Pass

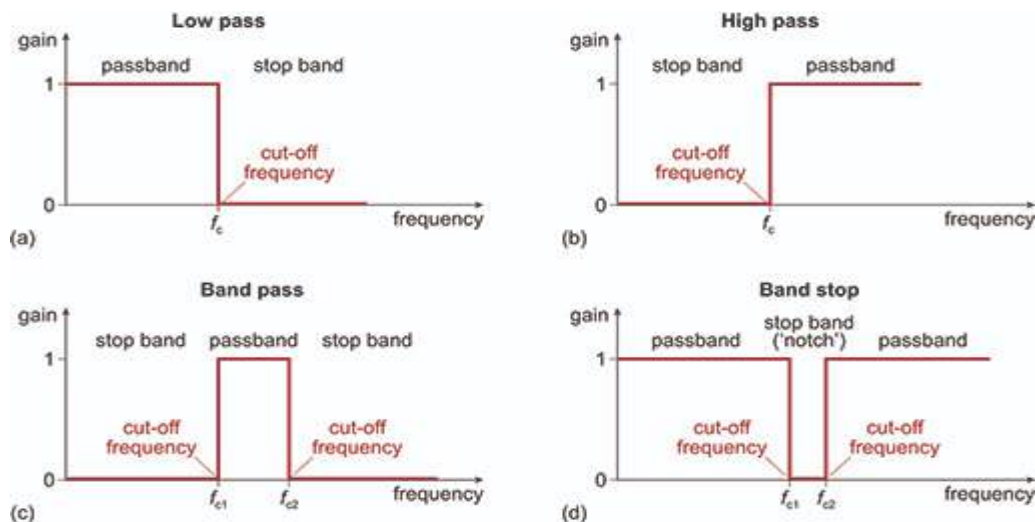
Filtering is one of the most vital signal conditioning techniques, used to remove unwanted noise and interference.

A **low-pass filter** allows signals below a certain frequency to pass while rejecting higher frequencies, commonly applied in temperature sensors or DC measurement circuits.

A **high-pass filter** removes DC components and allows rapid changes in signals, useful for vibration analysis or audio processing.

Band-pass filters combine both characteristics to isolate specific frequency ranges, such as the heartbeat frequency range in ECG systems. Filters can be designed using passive components (resistors, capacitors, inductors) or active circuits involving op-amps.

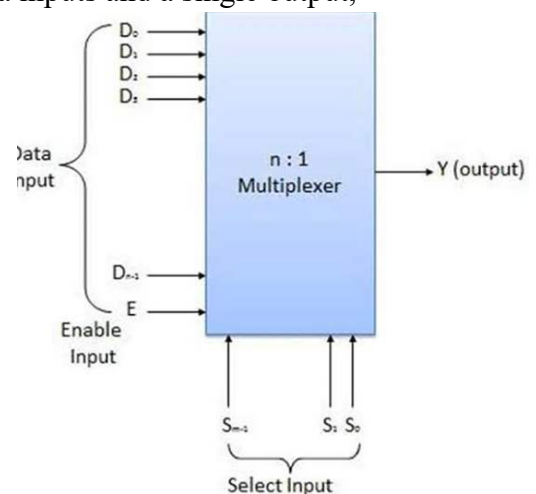
In digital systems, filters may also be implemented through software-based digital signal processing (DSP) algorithms. However, analog filtering before digitization is often preferred to prevent aliasing and maintain cleaner inputs to the ADC.



MULTIPLEXER

A multiplexer is a combinational circuit that has many data inputs and a single output, depending on control or select inputs. For N input lines, $\log_2(N)$ selection lines are required, or equivalently, for 2^n input lines, n selection lines are needed.

- Multiplexers are also known as "N-to-1 selectors," parallel-to-serial converters, many-to-one circuits, and universal logic circuits.
- They are mainly used to increase the amount of data that can be sent over a network within a certain amount of time and bandwidth.





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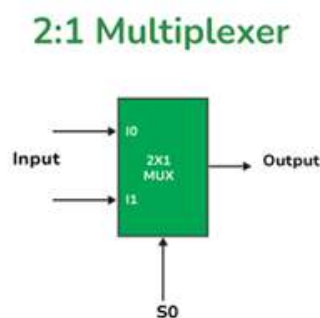
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Types of Mux

- 2x1 Mux
- 4x1 Mux

2x1 Multiplexer

The 2x1 is a fundamental circuit which is also known 2-to-1 multiplexer that are used to choose one signal from two inputs and transmits it to the output. The 2x1 mux has two input lines, one output line, and a single selection line. It has various applications in digital systems such as in microprocessor it is used to select between two different data sources or between two different instructions.



Truth Table

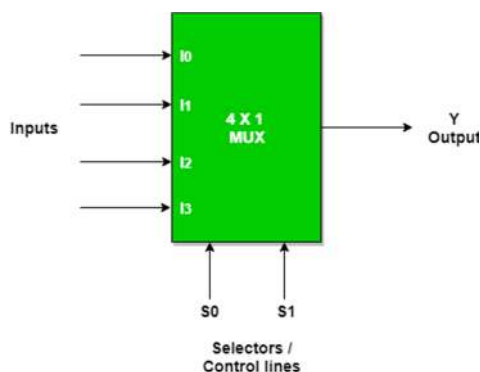
S_0	I_0	I_1	Y
0	0	X	0
0	1	X	1
1	X	0	0
1	X	1	1

4x1 Multiplexer

The 4x1 Multiplexer which is also known as the 4-to-1 multiplexer. It is a multiplexer that has 4 inputs and a single output. The Output is selected as one of the 4 inputs which is based on the selection inputs.

The output of the multiplexer is determined by the binary value of the selection lines

- When $S_1S_0=00$, the input I_0 is selected.
- When $S_1S_0=01$, the input I_1 is selected.
- When $S_1S_0=10$, the input I_2 is selected.
- When $S_1S_0=11$, the input I_3 is selected.



Truth Table

S_0	S_1	Y
0	0	I_0
0	1	I_1
1	0	I_2
1	1	I_3

So, final equation,

$$Y = S_0'.S_1'.I_0 + S_0'.S_1.I_1 + S_0.S_1'.I_2 + S_0.S_1.I_3$$



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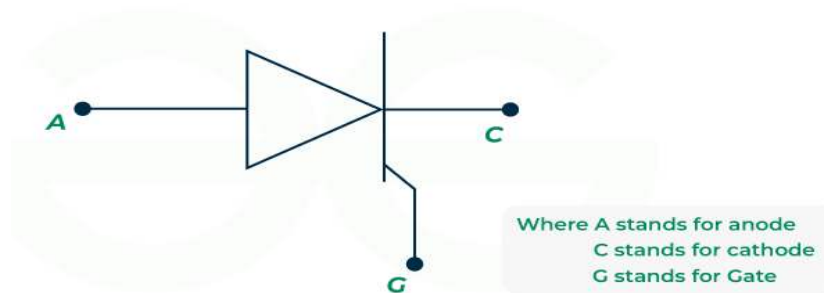
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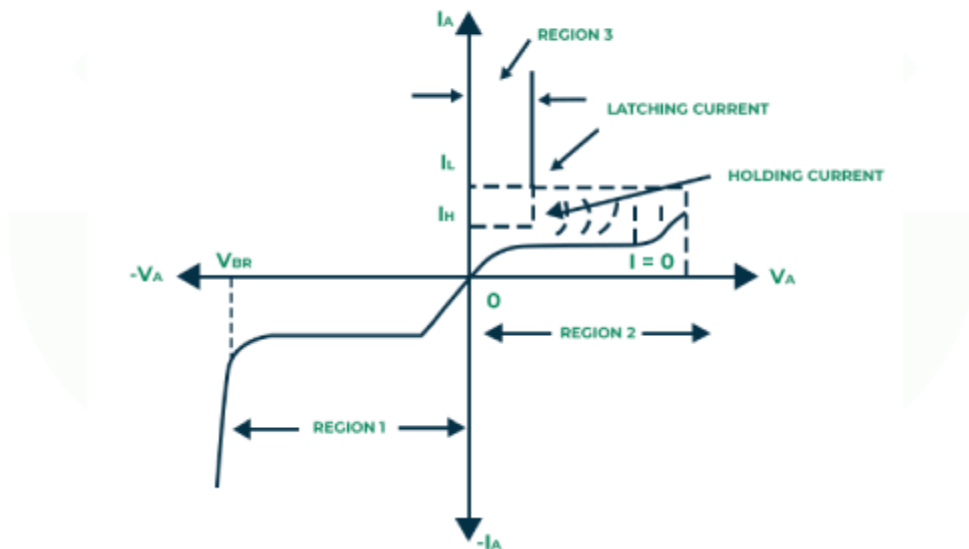
Switching loads of semiconductor devices

Power Semiconductor Devices are electronic devices that need an external power source to operate actively. Materials used to make semiconductor devices are neither excellent insulators nor conductors. They mainly manipulate, amplify, switch, or control the flow of electric current or voltage in a circuit. Power Semiconductor Devices, like diodes, transistors, thyristors, and sensors require power to do their job.



The V-I characteristics of thyristor is a graph between the anode current I_A and the anode-cathode voltage V_A for different values of gate current I_G . These characteristics can be drawn by considering the basic operation of the SCR. The below figure shows the V-I characteristics which is also called as static-cathode characteristics.

VI characteristics of Thyristor



Region 1

When the positive terminal of the supply is connected to cathode and the negative terminal is connected to anode with gate circuit open then thyristor operates in region 1. In this region junction J1 and J3 becomes reverse biased, whereas the junction J2 becomes forward



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biased. The reverse biased junctions (J1 and J3) acts as open circuit and the forward biased junction(J2) acts as a short circuit, as shown in figure.

Region 2

When the positive terminal of the supply is connected to anode and the negative terminal is connected to cathode with gate circuit open then thyristor operates in region 2. In this region junction J1 and J3 becomes forward biased, whereas the junction J2 gets reverse biased. The forward biased junctions (J1 and J3) acts as short circuit and the reverse biased junction(J2) acts as a open circuit, as shown in figure. Even in this region, the thyristor does not conduct any current expect a very small value of the leakage current. This mode of thyristor is called as forward blocking mode. Just as the region 1, i.e., reverse blocking mode, the thyristor can be made to conduct in the forward blocking mode by increasing the anode-cathode voltage to a value called as forward breakdown voltage (VBO). Even this method is not recommended as it may also damage the thyristor. Hence, the thyristor does not conduct even in this mode and is treated as open switch.

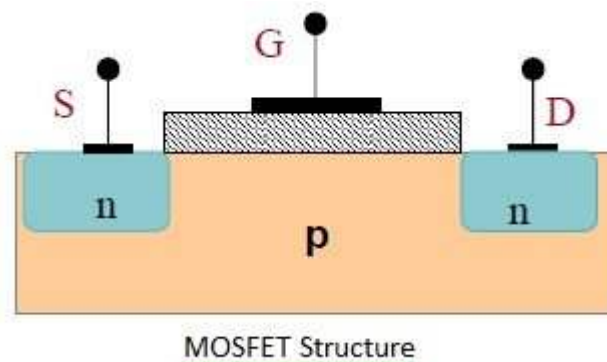
Region 3

When the positive terminal of the supply is connected to anode and the negative terminal to cathode with gate circuit closed the operates in region 3. In this region, all the three junctions (J1, J2 and J3) act as short circuit shown in figure and hence conducts current. In this region thyristor is said to be in a forward conduction mode and hence acts as a closed switch. This method of conducting the thyristor is the most efficient, as it requires a voltage which is very much less than VBO. The only extra thing we require is a gate signal for a small period of latching current. Once the anode current attains this value, the gate losses the control and hence can be removed. The removal of the gate signal will not have any effect on the thyristor conduction. However, if the anode current decreases to a value called ad holding current, the thyristor will once again go back to the forward blocking gate. Hence, care must be taken that, the anode current should not drop below the holding current after the gate signal is removed.

MOSFET

A **Metal Oxide Semiconductor Field-effect Transistor** is a field-effect transistor (FET with an insulated gate) where the voltage determines the conductivity of the device.

It is used for switching or amplifying signals. The ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals.





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It is a four-terminal device with **Source (S)**, **Drain (D)**, **Gate (G)**, and body (B) terminals. The body (B) is frequently connected to the source terminal, reducing the terminals to three. It works by varying the width of a channel along which charge carriers flow (electrons or holes).

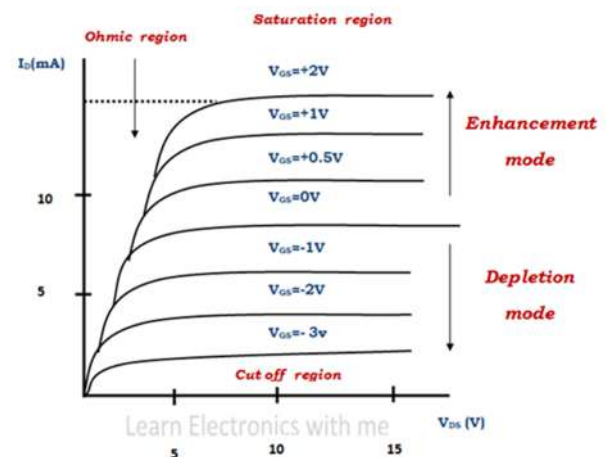
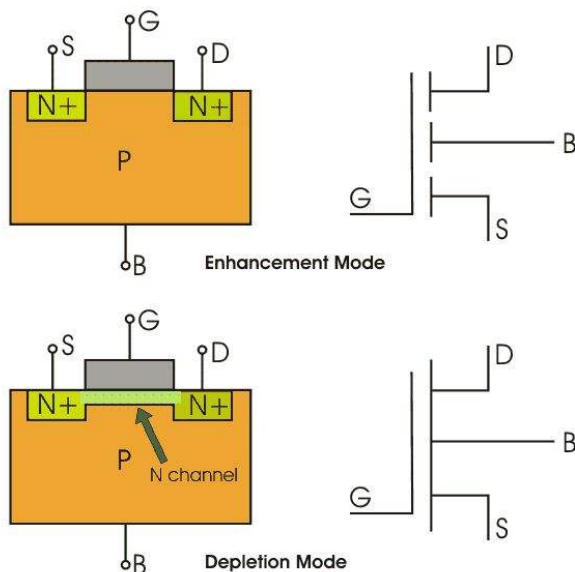
The charge carriers enter the channel at the source and exit via the drain. The width of the channel is controlled by the voltage on an electrode called Gate which is located between the source and the drain. It is insulated from the channel near an extremely thin layer of metal oxide.

Different Types of MOSFET

MOSFET works in two modes-

1. Depletion Mode: The transistor requires the Gate-Source voltage (V_{GS}) to switch the device “OFF”. The depletion-mode MOSFET is equivalent to a “Normally Closed” switch.

2. Enhancement Mode: The transistor requires a Gate-Source voltage (V_{GS}) to switch the device “ON”. The enhancement mode MOSFET is equivalent to a “Normally Open” switch.



Applications

- Amplifiers
- Regulation for DC Motors
- Constructions of Chopper Amplifiers
- Switching and Amplifying Signals



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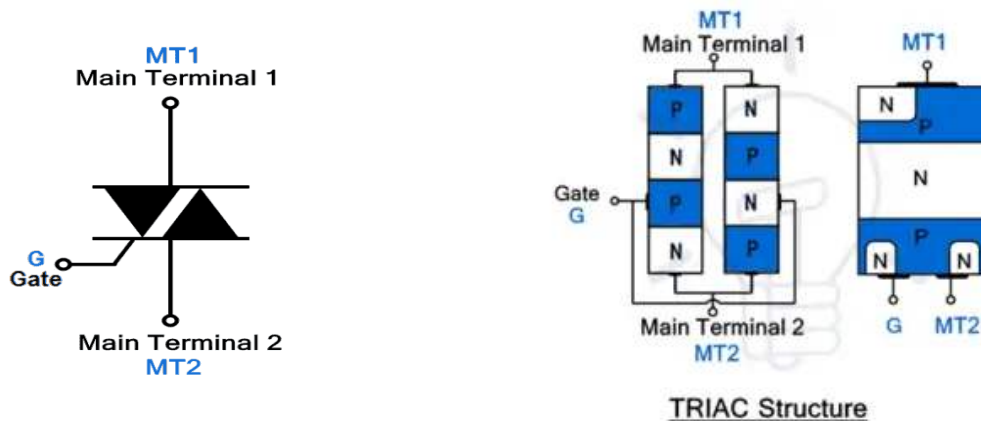
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TRIAC

TRIAC is an acronym that stands for “Triode for Alternating Current”. **Triode** means a **three-terminal device** while AC means that it is used for switching Alternating current. It is a three-terminal bi-directional [switch](#) that conducts in both directions. It is made from the combination of two [SCRs](#) in anti-parallel with their gates joined together.



Construction of TRIAC

TRIAC is a four-layer device that is made from a combination of two antiparallel SCRs having three terminals Gate, MT1 and MT2.

Both main terminals (MT1 and MT2) electrodes are connected with both P and N regions of both SCRs. So that it can conduct current in both directions. The gate metallic electrode is also connected with both P and N regions. It allows the TRIAC to be triggered by both positive as well as negative gate currents.

Operation of TRIAC

The operation of TRIAC resembles thyristor. When the voltage is applied, it will not conduct unless the voltage does not exceed the break over voltage V_{BO} or a gate pulse is applied.

As we know that TRIAC can conduct for both polarities of applied voltage and it can be triggered by both polarities of gate voltage for either direction. Therefore, the TRIAC can operate in 4 modes. The following voltages are taken with respect to the MT2 terminal such as MT1 voltage with respect to MT2 and Gate voltage with respect to MT2.

Mode 1 : MT1= +ve, Gate= +ve

In this mode, the applied voltage at MT1 is positive with respect to MT2. By applying a positive gate pulse, the TRIAC will trigger into **forward conduction** and the current will flow from MT1 to MT2.

Mode 2 : MT1= +ve, Gate= -ve



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In this mode, the applied voltage is the same i.e. MT1 is positive with respect to MT2. But the gate pulse is negative. Since the gate is connected with the N region of TRIAC, it will trigger it into **forward conduction** while the current direction will remain the same.

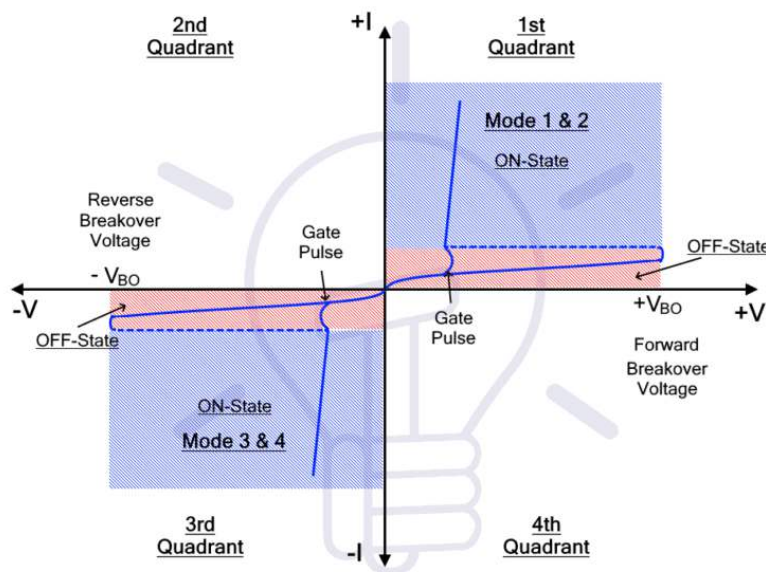
Mode 3 : MT1= -ve, Gate= +ve

In this mode, the applied voltage polarities are swapped i.e. MT1 is negative with respect to MT2. But the gate pulse is positive. The gate pulse will trigger TRIAC into **reverse conduction** from MT2 to MT1.

Mode 4 : MT1= -ve, Gate= -ve

In this mode, both the applied voltage and the gate voltage are negative. The negative gate pulse triggers the TRIAC into **reverse conduction**

Mode 1 and mode 2 represents an operation in the 1st quadrant where the current and voltage are positive while mode 3 and mode 4 represent operation in the 3rd quadrant where the voltage and current both are negative.



V-I Characteristics of TRIAC

Applications of TRIAC

They are used for controlling the speed of motors, fans and light dimmers as well as heat control applications.

Darlington pair:

The Darlington Transistor named after its inventor, Sidney Darlington is a special arrangement of two standard NPN or PNP bipolar junction transistors (BJT) connected together in such a way as to provide high gain and current amplification compared to just one single BJT.



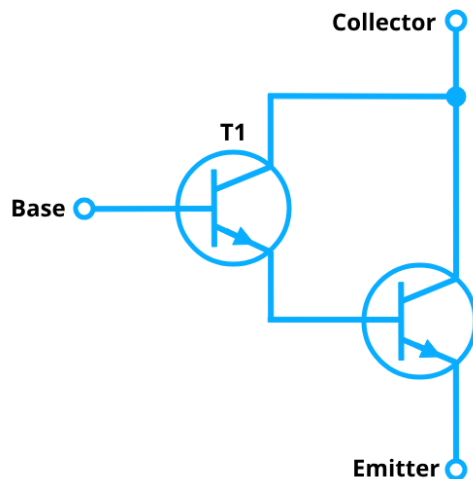
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A Darlington transistor pair comprises of a couple of bipolar transistors that are coupled in order to deliver a very high-current gain from a low-base current. In this transistor, the emitter of the input transistor is connected to the base terminal of the output transistor, base and collectors of these transistors are wired together. Therefore, the current that is amplified by the first transistor then by the second transistor.

Darlington Transistor Pair Applications

The applications of Darlington transistor pair involve where a high gain is required at a low frequency like Power regulators, Audio amplifier output stages, Display drivers, Motor controllers, Touch and [light sensors](#) and solenoid control.

RELAY CIRCUIT

A relay is an electrically operated switch that uses a small control signal from a low-power circuit to open or close a separate high-power circuit. It isolates input from output, allowing a safe, low-voltage trigger (like from a microcontroller or sensor) to manage heavy electrical loads.

Working Principle of Relay

It works on the principle of an electromagnetic attraction. When the circuit of the relay senses the fault current, it energises the electromagnetic field which produces the temporary magnetic field.

This magnetic field moves the relay armature for opening or closing the connections. The small power relay has only one contacts, and the high power relay has two contacts for opening the switch. Electrical Relays



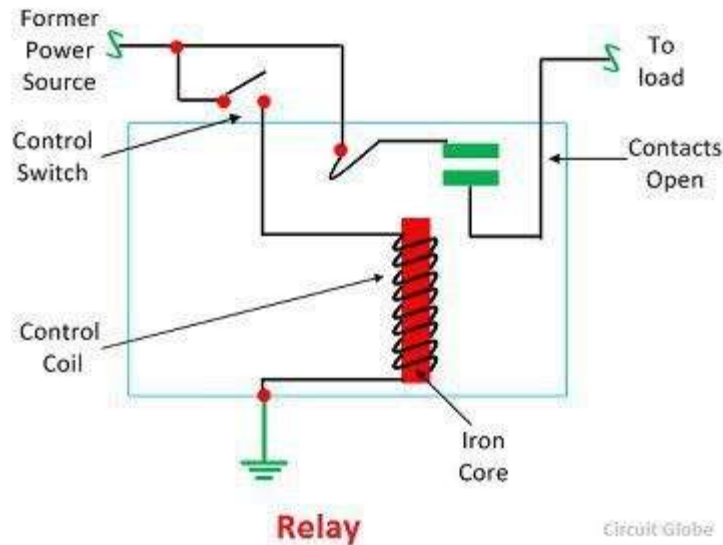
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The inner section of the relay is shown in the figure below. It has an iron core which is wound by a control coil. The power supply is given to the coil through the contacts of the load and the control switch. The current flows through the coil produces the magnetic field around it.

Due to this magnetic field, the upper arm of the magnet attracts the lower arm. Hence close the circuit, which makes the current flow through the load. If the contact is already closed, then it moves oppositely and hence open the contacts.

PLC

A programmable Logic Controller (PLC) is a specialized digital computer employed in industrial settings for automation and control

Architecture

PLCs play a pivotal role in industrial automation, efficiently managing machinery and processes. They receive data from sensors, execute programmed logic, and control actuators, enhancing precision and reducing manual interactions.

Main Components of a PLC

Their are mainly 6 major part of a PLC that are :

- Processor
- Memory(RAM/ ROM)
- Input device
- Output device
- Power supply
- Programming device



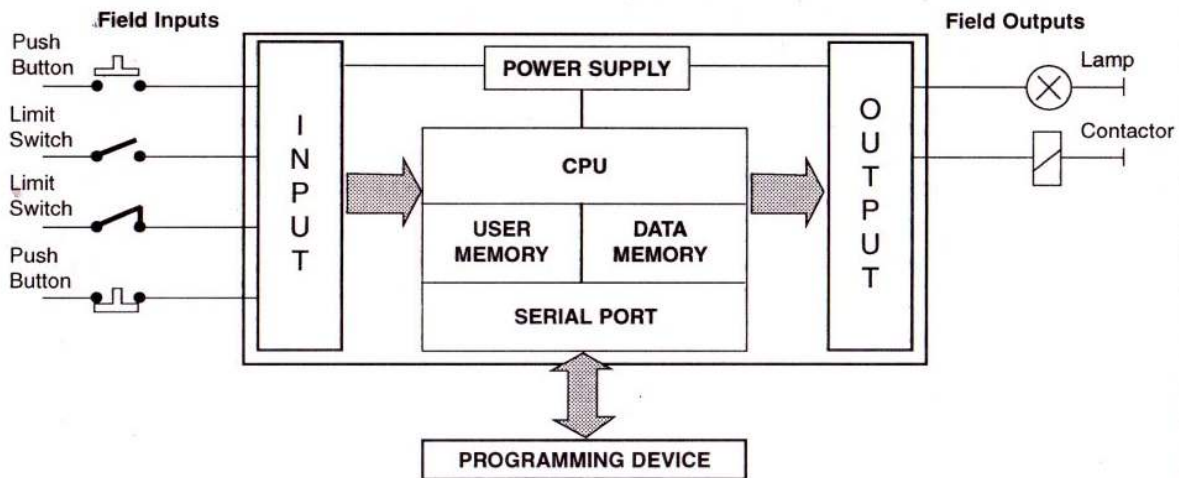
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- **CPU :** CPU is the brain of a PLC, responsible for executing the control program stored in memory. It performs tasks such as data processing, decision-making and communication with other devices.
- **Memory(RAM/ROM) :** PLCs have main type of memory one is ram and another is rom. RAM is used for storing data and variables temporarily during the execution of the program. ROM is used to store the operating system of a PLC and the user program. The program typically consists of two ladder logic, function block diagrams or other programming languages.
- **Input Device :** This is responsible for interacting with the machine and the instructor which can be external [sensors](#), switches etc. This part helps to take input and send to the CPU to response accordingly.
- **Output Device :** Output device is responsible for interacting with the end point external device like motor, valve or indicator. It converts control signal from the PLC that these devices can interpret.
- **Power Supply :** PLC requires a stable power supply to run its program and match the voltage levels that needed for a PLC components.
- **Programming Device :** As PLC is mainly a programmable device, so we need a device where we can write code and execute it, just like a monitor and keyboard.

Input /Output process of PLC

The Input-Output Processor (IOP) is just like a CPU that handles the details of I/O operations. It is more capable than typical DMA controller. The IOP can fetch and execute its own instructions that are specifically designed to characterize I/O transfers. In addition to the I/O tasks, it can also perform other processing tasks like arithmetic, logic, branching, and code translation. The main memory unit plays a pivotal role. It communicates with the processor via DMA.

Working of Input-Output Processor



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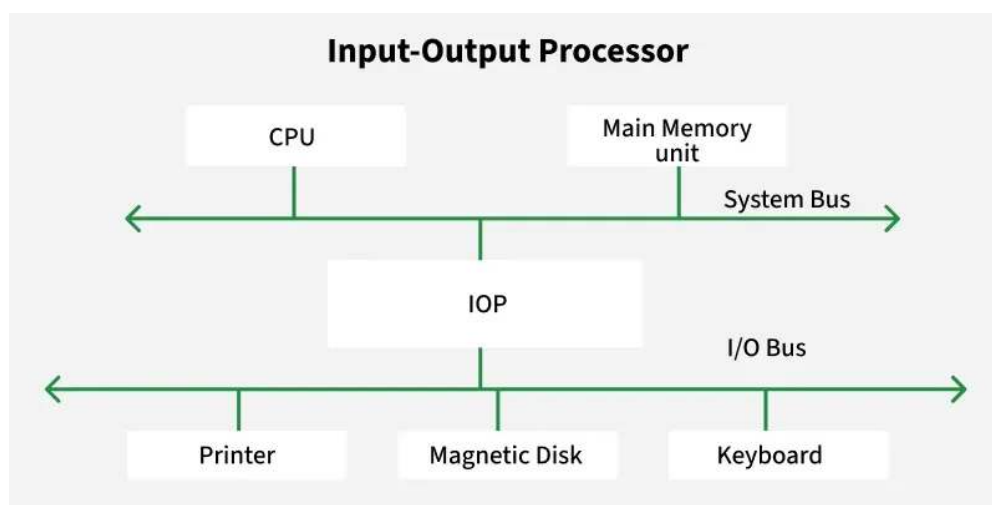
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The Input-Output Processor is a specialized processor which loads and stores data in memory along with the execution of I/O instructions. It serves as an interface between the system and devices. It follows the given below sequence of steps to perform I/O operations and then store the results in memory:

1. The I/O processor is triggered by a request from the system or peripheral device to initiate an I/O operation.
2. It fetches instructions specifically designed for I/O transfers from its own instruction set.
3. Memory space is allocated in the main memory to hold the data being transferred.
4. Direct Memory Access (DMA) is used to transfer data directly between the I/O device and memory bypassing the CPU.
5. Data is buffered temporarily between the I/O device and memory to ensure efficient processing.
6. I/O commands, such as read, write, or synchronize, are executed to control the data transfer process.
7. If errors occur, interrupts are handled and error corrections are managed independently.
8. Once the data transfer is complete, the results are stored in memory and the operation is marked as complete.
9. The system or peripheral device is informed that the I/O operation has been completed and the results are available.
10. After the I/O operation, control of the resources is released and the CPU resumes processing other tasks.





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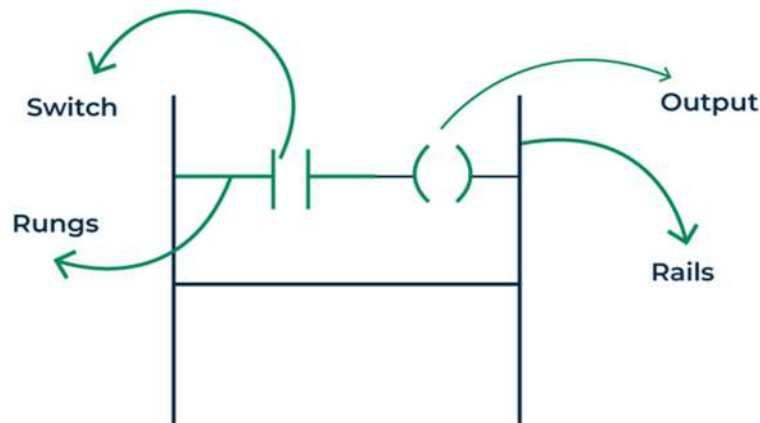
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Ladder logic programming

Ladder logic is basically a program that is represented by a graphical diagram, which is based on a circuit diagram of relay logic. This program contains two vertical lines called 'rails' and horizontal lines called 'rungs' which makes it look like a perfect ladder. The graphical representation of an ladder logic program is called as Ladder Logic diagram(LLD).



Ladder logic diagram are graphical programming language which executes through real time input. It has two vertical line, which is called as rails, the left rail supplies power to the circuit, then it passes through each rung. Each rung has switches and output coil. Switches can perform OR, AND and NOT operation, and through these basic logic operation we can make any programming logic in PLC. A ladder logic diagram executes from left to right and top to bottom. When all the condition of a rung met the connected output coil get energized. then it activate the real world system, such as turning on a motor or turning off a motor. This process is continuously scanned and repeated by the PLC and control system to ensure the automation of operating system.

Ladder Logic Components

There are some Ladder logic components given below :

Rail and Rung

Vertical lines are called rails and the horizontal lines are called rungs.

Concept of NO/NC switch

NO(Normally Open) and NC(Normally Closed) are used to represent the state of current flow or contact in electronics circuit, which is also used in PLC ladder logic programming. These terms define whether the switch is open or closed.

Normally Open

- A normally open switch or contact is open when not actuated.
- It closes the circuit when pressed or activated, allowing current flow.



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- In ladder logic diagrams, a normally open contact is shown as an open gap and becomes a solid line when activated.

Normally Closed

- Normally closed switch/contact is closed when not actuated.
- Activation of the switch opens the circuit, stopping current flow.
- In ladder logic diagrams, it's represented as a solid line, becoming an open gap when activated.

Normally-Open



Normally-Closed



Coil/Output



Output/Coil

Output devices are such as motor, valve, indicator, lights etc. but in LLD it is represented by vertical line with a label representing the output device.

Description and Working of Ladder Logic

- Firstly two rails are taken, and then a rungs. The rails will work here as a supply of source or current supply.
- The left rail is connected to the input switch and the right rail is connected to the output coil. and the switch and coils are connected through a wire.
- Then add input switch, it can be NO or NC depending on the logic to be created. Switches should be placed at the left side rail. The number of switch and placement of it can vary depending on the logic is creating.
- For creating this logic, we create truth table, and according to that, put the switch, if input is '0', generally NO switch is used, but NC switch can also be used, but in that case we have to make it opened, or false. For '1' input, NC switches are used, but same like previous NO switch can also be used.
- An output coil should be connected to the right side rails.

Advantages

- A graphical diagram of electrical relay diagram, which makes it easy to understand.
- The visual representation of rungs reduces maintenance.
- LLD allow real time monitoring of the system status, which makes it more reliable.



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- LLDs are modular and can be easily modified or expanded to accommodate changes in the control process.
- LLD is widely accepted as so many engineers and technicians are already familiar to this.

Disadvantages

- LLD can face problem in complex control system as the lack in sophistication of high level programming language.
- it is not suitable for time based operation or sequential problem.
- Proper documentation and version control can be challenging.
- It is not suitable for data processing task.

Applications of Ladder Logic

Ladder logic programming used in various industries such as

- LLDs are widely used in manufacturing control to control different machinery to sort item, quality control, packaging etc.
- LLD can control pressure, chemical balance in Water treatment.
- It controls HVAC (Heating, Ventilation, and Air Conditioning) in buildings to ensure temperature, ventilation and energy efficiency.
- LLDs often used in traffic control to maintain the time and sequence of traffic light.
- To control Elevator LLD can be used for floor selection, door opening and closing etc.
- Ladder logic is also used in food packaging and beverage processing.
- LLDs control various aspects of chemical manufacturing, including temperature, pressure, mixing, and safety systems
- LLD play some crucial role to store renewable energy in system.

TIMER

A timer in PLC is a internal software instruction that stimulates the physical timing relay. It measures the set duration of time to delay, extend or monitor actions in an automated industrial process without needing external wiring or moving parts.

Programmable Logic Controllers (PLCs) use three primary types of internal timers in ladder logic to control time-based events: **On-Delay Timer (TON)**, **Off-Delay Timer (TOF)**, and **Retentive On-Delay Timer (RTO)**



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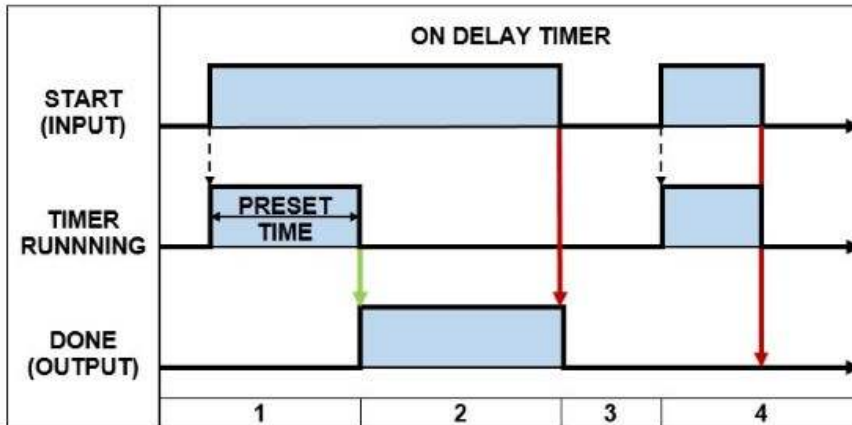
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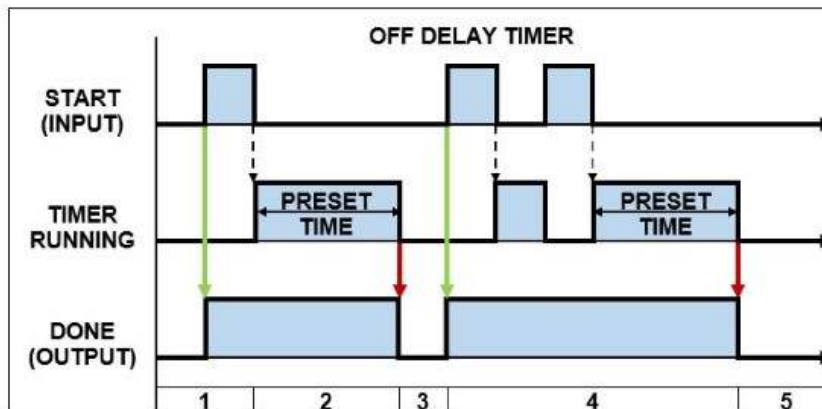
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On-Delay Timer (TON): Delays turning an output *on* after the input goes true. If the input turns false before time runs out, the accumulated time resets to zero.



Off-Delay Timer (TOF): Keeps an output *on* after the input goes false. It starts timing when the input drops and turns the output off once the preset time finishes.



Retentive On-Delay Timer (RTO): Counts time when the input is true. If the input turns false or power drops, it *saves* the accumulated time instead of resetting. It needs a separate reset instruction to clear.



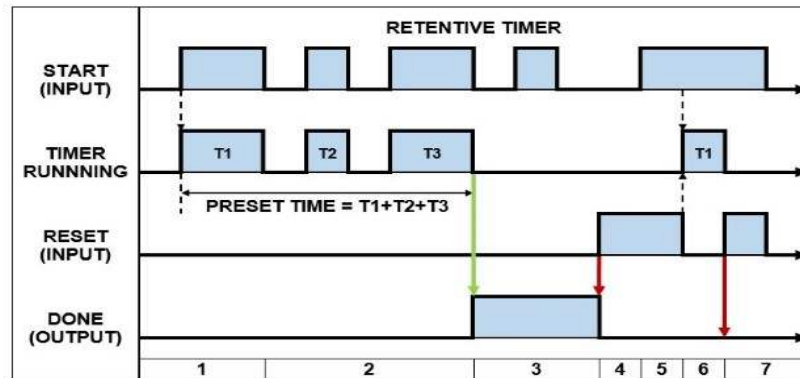
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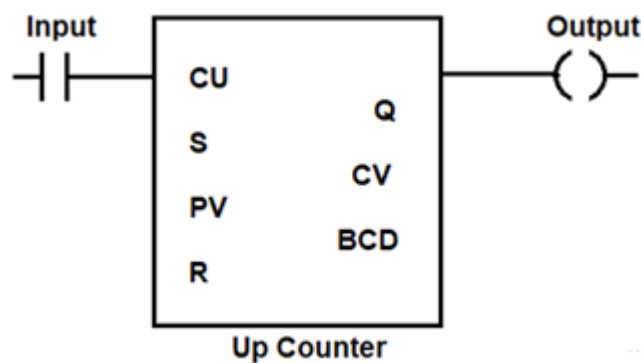
Counters

A counter in a Programmable Logic Controller (PLC) is an internal software instruction that tracks and counts a specific number of events, pulses, or operations, such as products passing a sensor or machine cycles

The main types of counters in a Programmable Logic Controller (PLC) are Up Counters (CTU), Down Counters (CTD), and Up/Down Counters (CTUD). These instructions track input pulses and manage internal values to control automated industrial processes.

Up Counter (CTU):

- Increases the accumulated value by 1 on each false-to-true transition of the count-up input.
- Triggers the output (Done bit) when the accumulated value reaches or exceeds the preset limit.



Down Counter (CTD):

- Decreases the accumulated value by 1 on each pulse from the count-down input.



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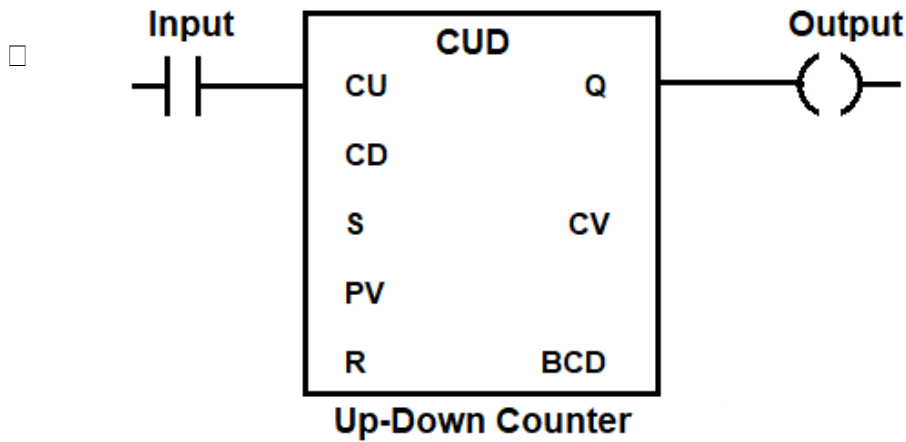
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- Activates the output when the count drops to zero or below.



Up/Down Counter (CTUD):

- Combines both functions using separate inputs to increment or decrement the same accumulator.
- Handles bidirectional tracking, such as monitoring parts moving in and out of a restricted area

