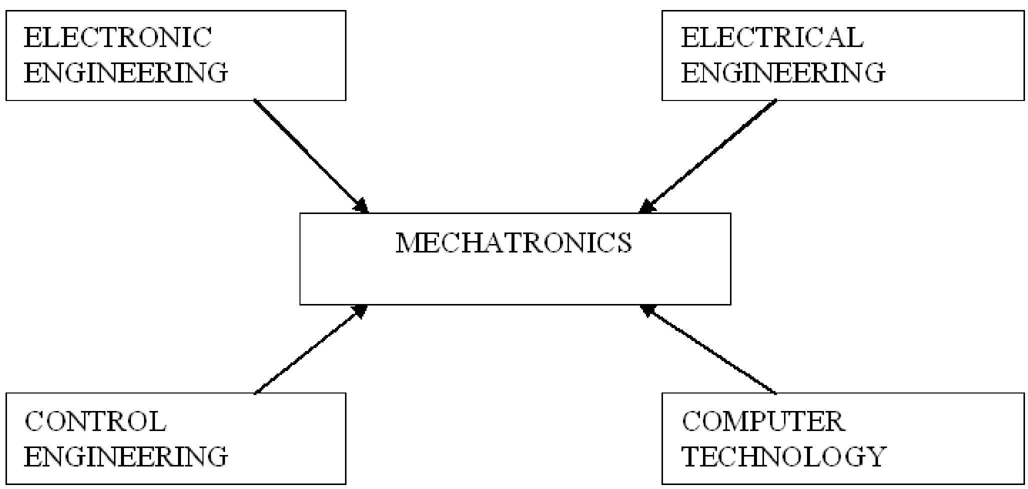
UNIT –I

MECHATRONICS

It field of study that implies the synergistic integration of electronic engineering, electrical engineering, control engineering and computer technology maintenance of a wide range of engineering products and Processes".with mechanical engineering for the design, manufacture, analyses and processes.

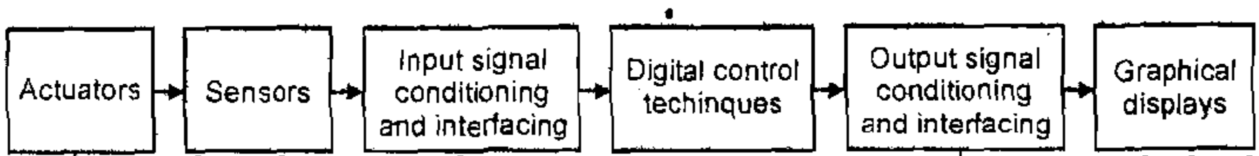


SYSTEM:

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

Here, the input is the electric power and the output after processed by the system is rotation. The system is motor.

MECHATRONICSYSTEM:



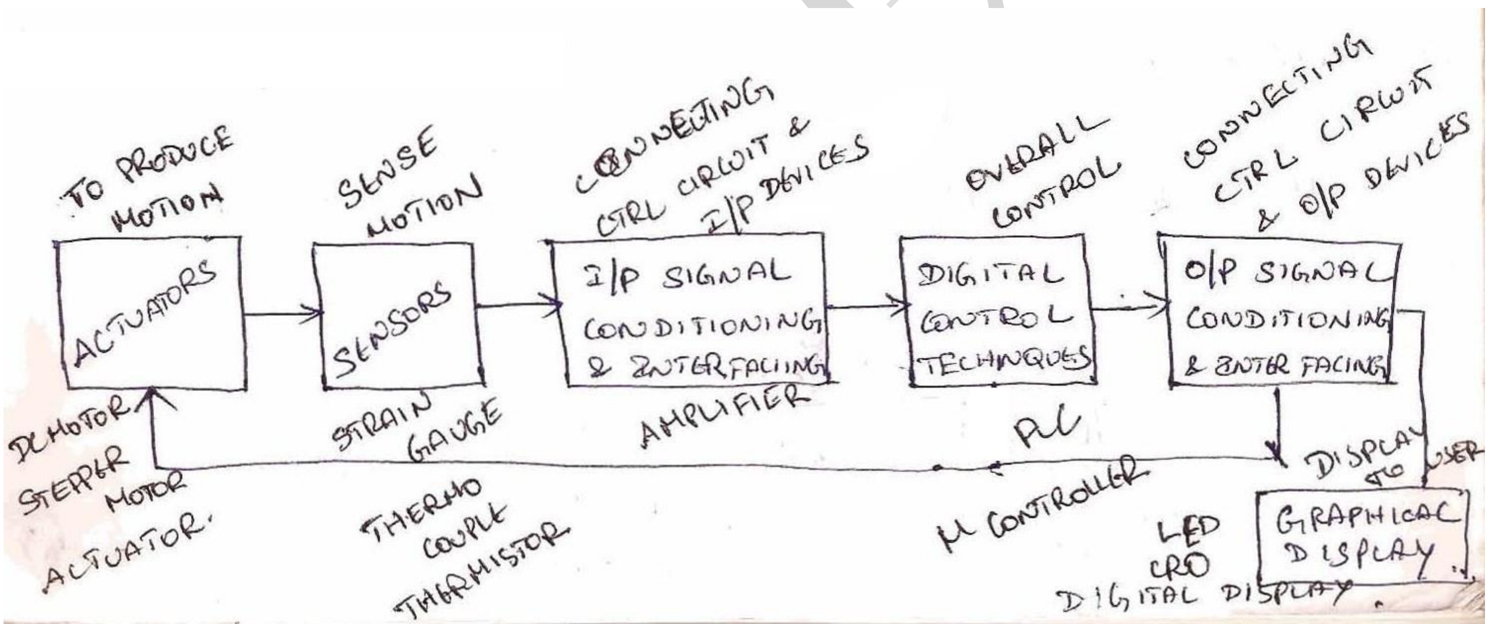
Actuators: Solenoids, voice coils, D.C. motors, Stepper motors, Servomotor, hydraulics, pneumatics.

Sensors: Switches, Potentiometer, Photoelectric, 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.

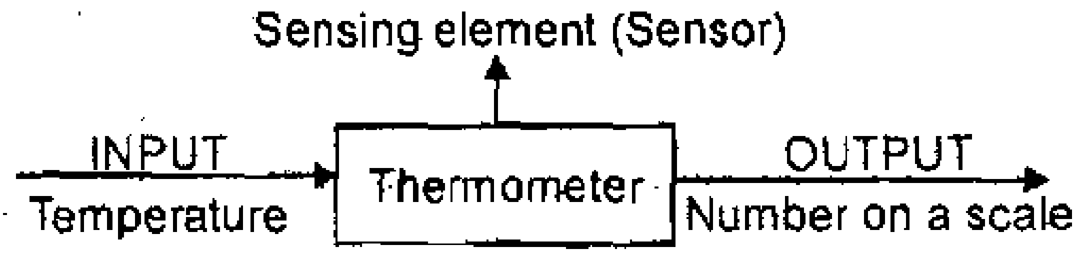
Output signal conditioning and interfacing: D/A D/D, Amplifiers, PWM, Power transistor, Power Op- amps.



Graphical displays: LEDs, Digital displays

MEASUREMENTSYSTEM:

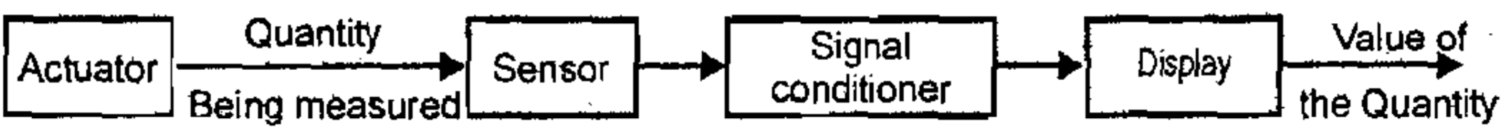
A measurement system can be defined as a black box which is used for making measurements. It has the input as the quantity being measured and the output as a measured value of that quantity.

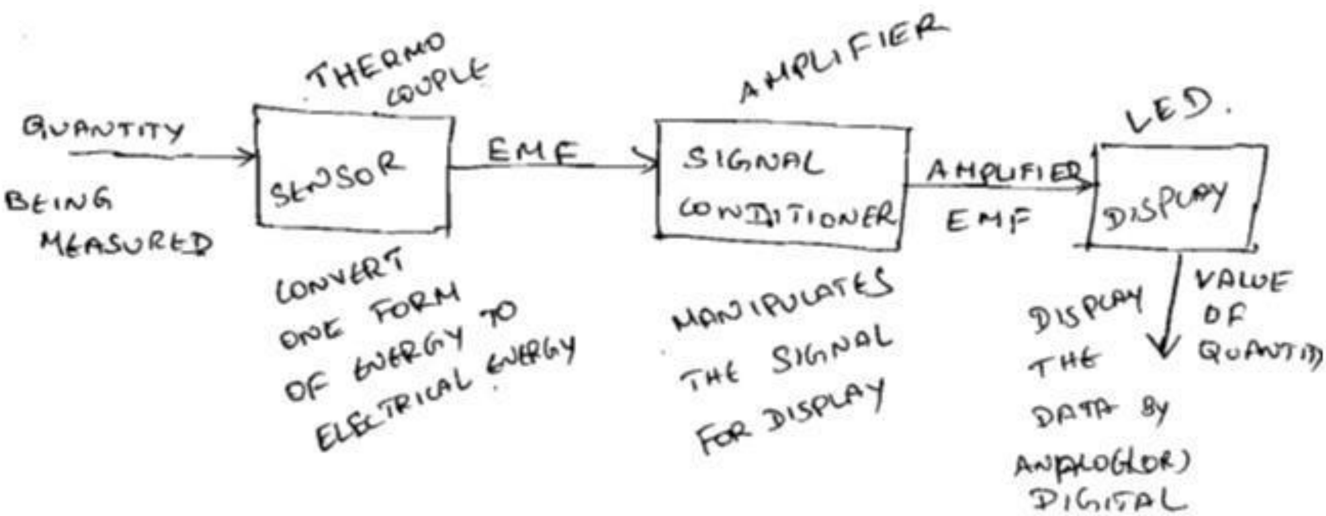


ELEMENTS OF MEASUREMENT SYSTEMS:

Measurement system consists of the following three elements.

a) Sensor b) Signalconditioner c) DisplaySystem





Sensor:

A sensor consists of transducer whose function is to convert the one form of energy into electrical form of energy. A sensor is a sensing element of measurement system that converts the input quantity being measured into an output signal which is related to the quantity.

Example:

Temperature Sensor –Thermocouple

Input –Temperature

Output –E.M.F (ElectricalParameter).

Signal Conditioner:

A signal conditioner receives signal from the sensor and manipulates it into a suitable condition for display. The signal conditioner performs filtering, amplification or other signal conditioning on the sensor output.

Example:

Temperature measurement –Single Conditioner function

(Amplifier) Input –Small E.M.F value (From sensor)

Output –Big E.M.F Value (Amplified).

DisplaySystem:

A display system displays the data (output) from the signal conditioner by an analog or digital. A digital system is a temporary store such as recorder.

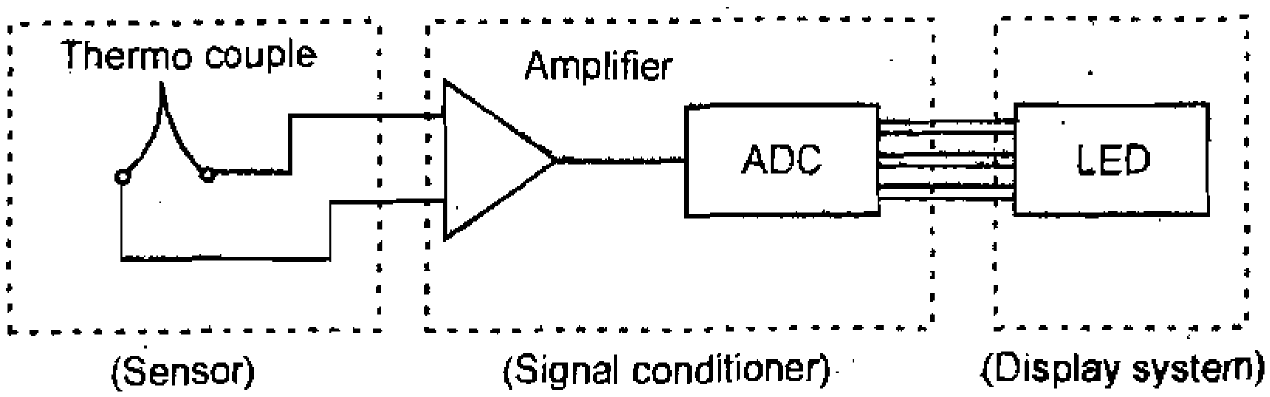
Example:

Display – L.E.D (or) Number on scale by pointer movement

Input –Conditioned Signal (from signal conditioner)

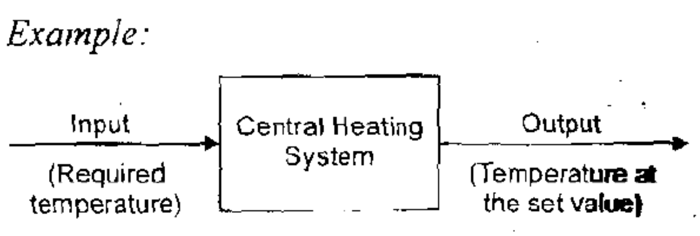
Output –Value of the quantity (Temperature)

TEMPERATURE MEASUREMENT SYSTEM:



SYSTEM CONTROL:

A black which is used to control its output in a pre-set value box



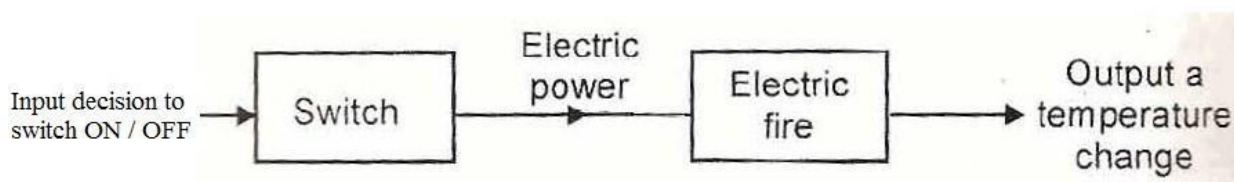
Control system - Air conditioning Unit

Input - Surrounding temperature

Output - Preset value (Temperature maintained in a house)

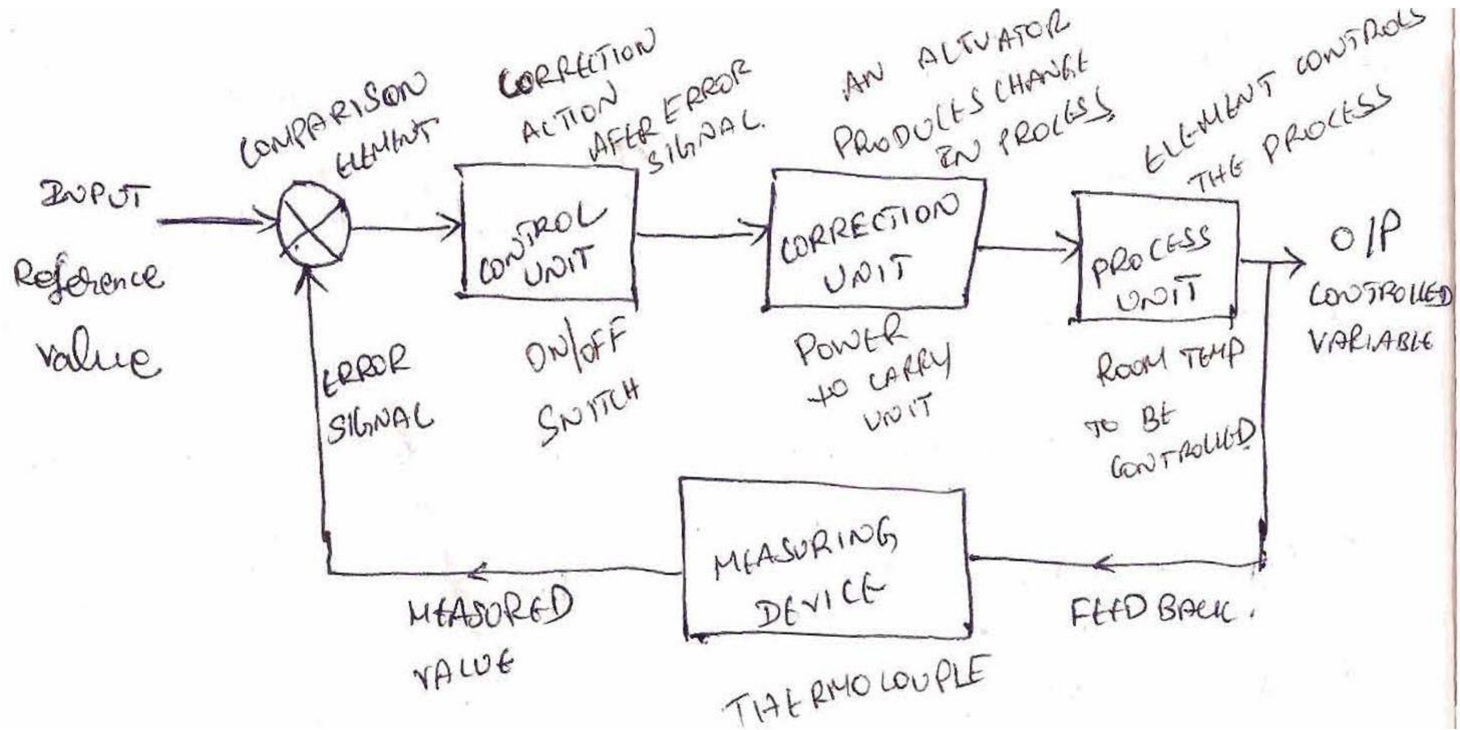
OPEN LOOP CONTROL SYSTEM:

- If there is no feedback device to compare the actual value with desired one.
- No control over its input



CLOSED LOOP CONTROL SYSTEM:

If there is feedback device to compare the actual value with desired one.



Elements of Closed Loop System:

The elements of closed loop control system are

- Comparison Unit
- Control Unit
- Correction Unit
- Process Unit
- Measurement Device

1. Comparison Element

This element compares the required or reference value of the variable **condition** being controlled with the measured value and produces an error signal.

Error Signal = Reference value – measured value

2. Control Element

This element decides the corrective action to be taken when an error signal is received by it.

Example: A signal to operate switch ON/OFF or valve open / close.

3. Correction Element

Correction element is an actuator that produces a change in a process to correct or change the controller condition. It also provides the power to carry out the control action, hence it is known as actuator.

4. Process Element

An element that controls the process is known as process element.

Example: Room temperature of a house is being controlled.

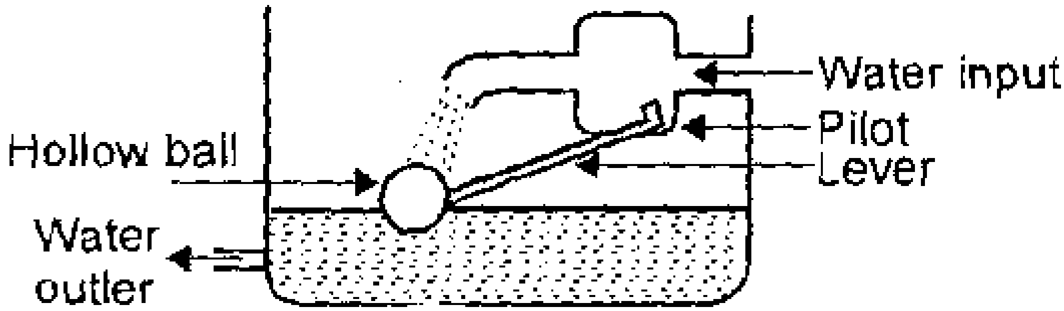
5. Measurement Element

The measurement element produces a signal related to the variable condition of the process that is being controlled.

Example: Thermocouple gives EMF related to temperature.

System of Controlling Water Level

Controlled variable	: Water level in the tank
Reference variable	: Initial setting of the float and lever position
Comparison Element	: The lever
Error signal	: Difference between the actual & initial setting of the lever



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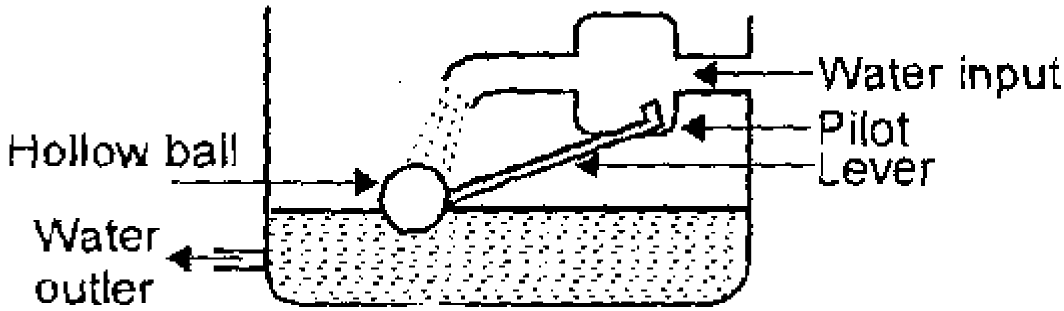
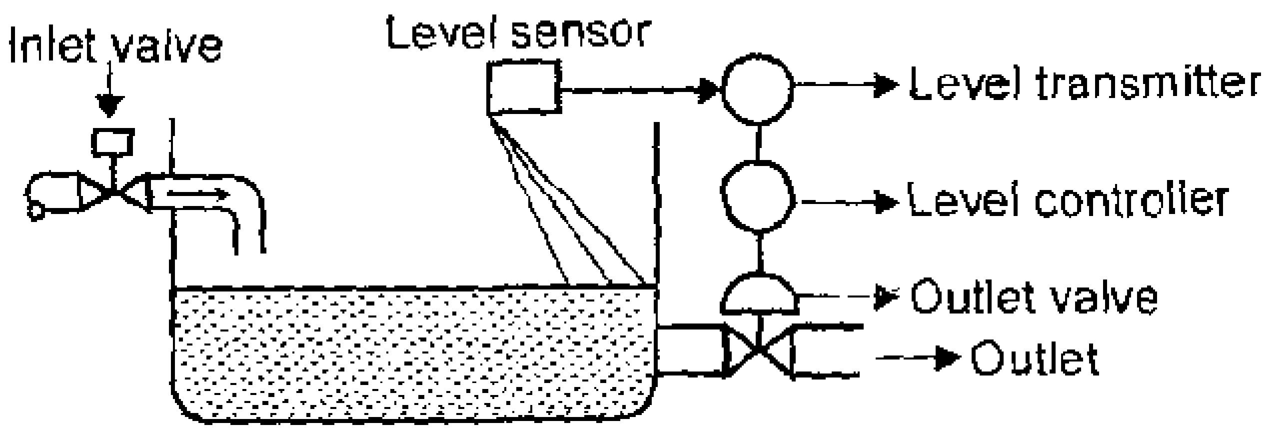


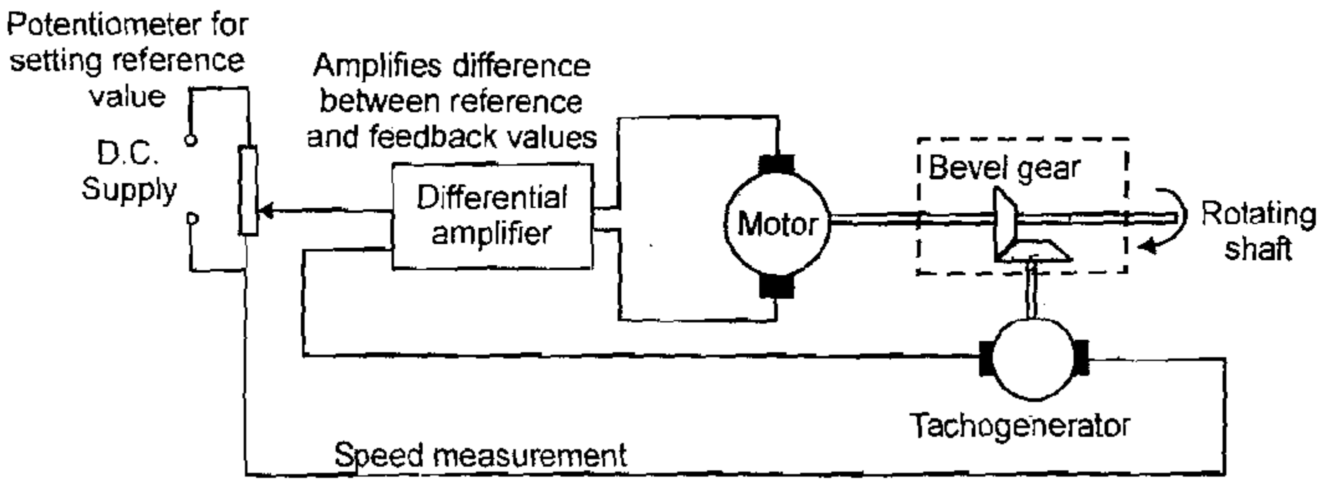


Automatic Speed Control of Rotating Shaft

Potentiometer - To set the reference value (Voltage to be supplied to differential amplifier)

Differential amplifier - To compare amplify the difference between the reference and feedback value

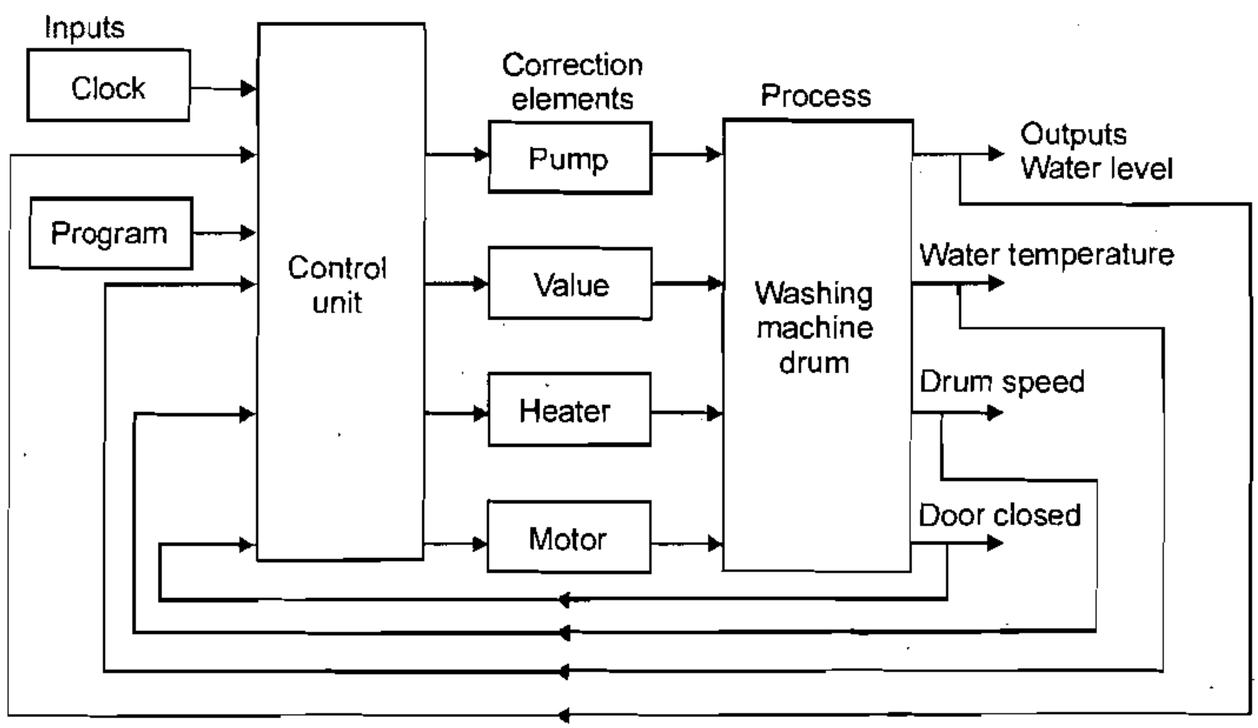
Tachogenerator - To measure the speed of the rotating shaft and is connected to the rotating shaft by means of a pair of level gears.



SEQUENTIAL CONTROLLERS:

It is used to control the process that are strictly ordered in a time or sequence

DOMESTIC WASHING MACHINE:



PRE WASHCYCLE:

- Pre-wash cycle may involve the following sequence of operations.
- Opening of valve to fill the drum when a current is supplied
- Microprocessor is used to operate the switch for opening closing the valve.
- Closing the valve after receiving the signal from a sensor when the required level of water is filled in the washing drum.
- Stopping the flow of water after the current is switched off by the microprocessor.
- Switch on the motor to rotate for stipulated time.
- Initiates the operation of pump to empty the water from the drum.
- Pre-wash cycle involve swashing the clothes in the drum by cold water.

Main wash cycle involves washing the clothes in the drum by hot water and the sequence of operations in main wash is as follows:

- Cold water is supplied after the Pre-wash cycle is completed.
- Current is supplied in large amount to switch on the heater for heating the coldwater.
- Temperature sensor switches off the current after the water is heated to required temperature.
- Microprocessor or cam switch ON the motor to rotate the drum
- Microprocessor or cam switches on the current to a discharge pump to empty the drum.

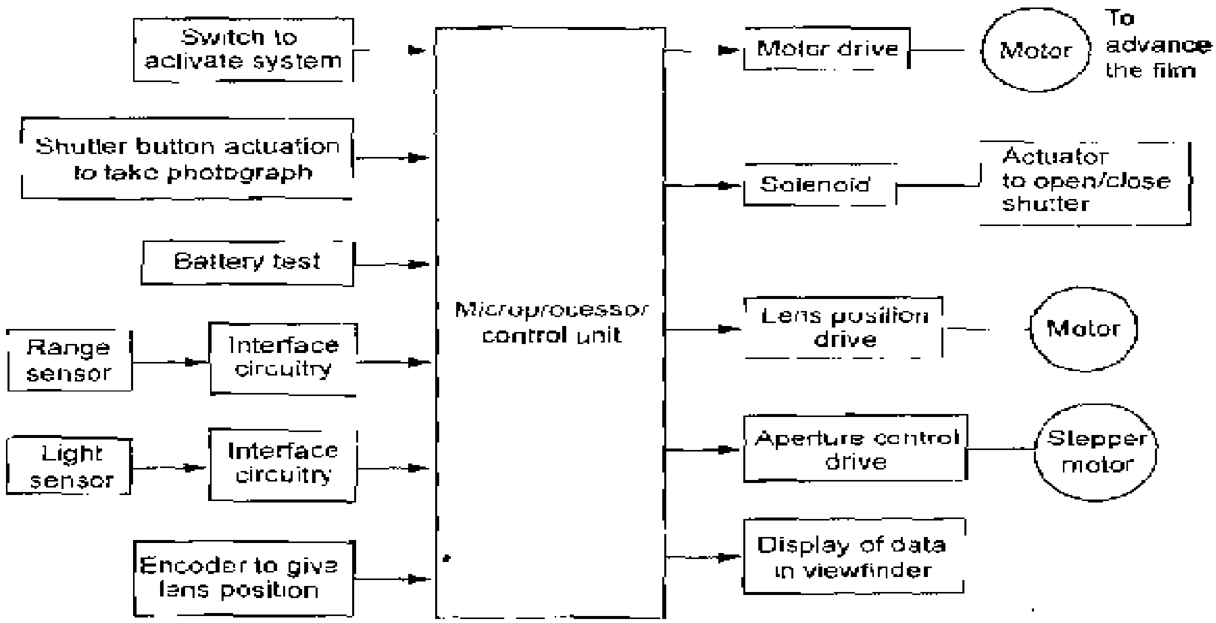
RINSE CYCLE:

- Rinse cycle involveswashingoutthe clotheswithcoldwater a number oftimesandthe sequenceofoperationsina Rinse cycle are as follows:
- Openingof valve toallowcoldwaterintothe drumwhenthe microprocessor aregiven signalstosupplycurrentafter the mainwashcycle iscompleted.
- Switchesoffthe supplycurrentbythesignalsfrommicroprocessor
- Operation of motor to rotate the drum
- Operation of pump to empty the drum and respect this sequence a number of times.

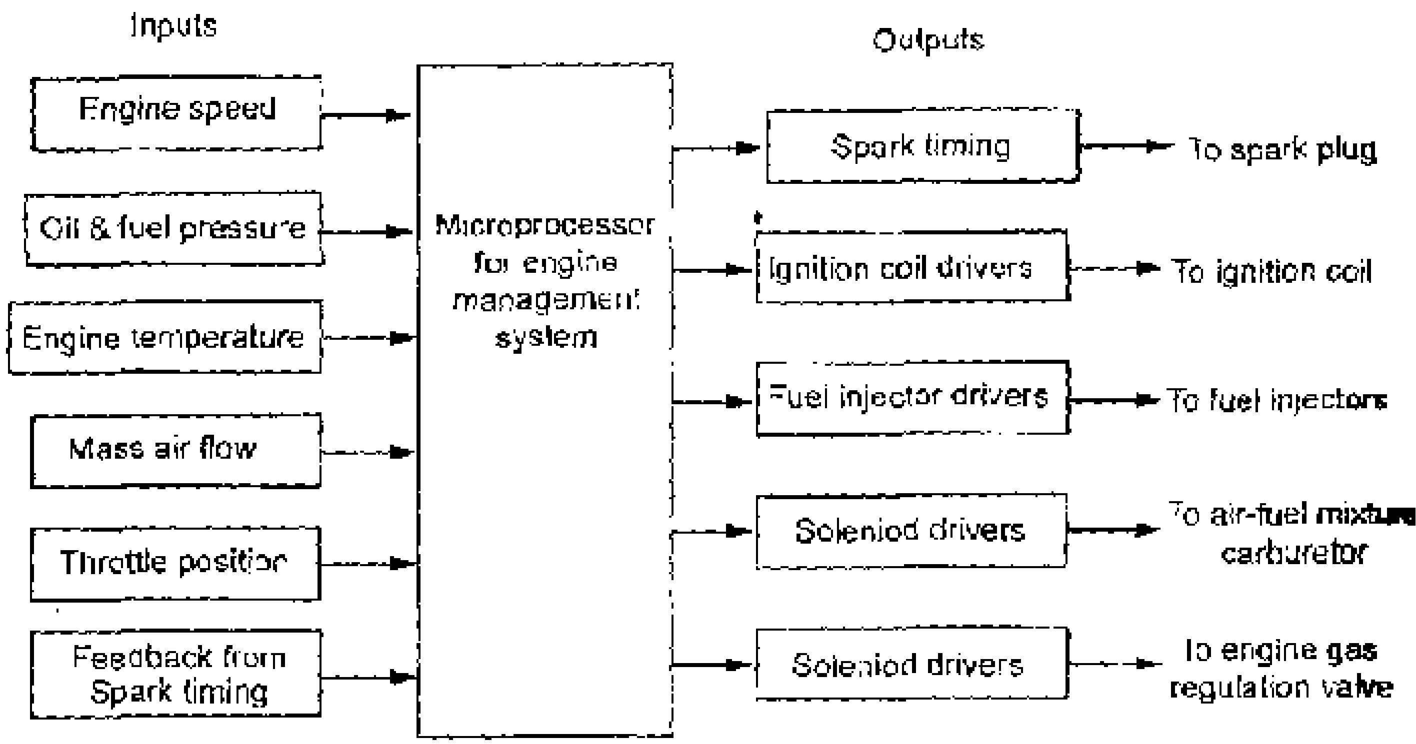
SPINNING CYCLE:

- Spinning cycle involves removing of water from the clothes and the sequence of operations Is carried out.
- Switching on the drum motor to rotate it at a higher speed than a rinsing cycle.

AUTOMATIC CAMERA:



ENGINE MANAGEMENT SYSTEM:



SENSORS

TRANSDUCERS:

It is an element which is subjected to physical change experience a related change.

Example: Tactile Sensors.

SENSORS:

It is an element which is not subjected to physical change experience a related change.

Example: LVDT

PERFORMANCE TERMINOLOGY:

STATIC CHARACTERISTICS:

Range and Span:

❖ The range of a transducer defines the limits between which the input can vary.

❖ The difference between the limits (maximum value - minimum value)is known as span.

❖ For example a load cell is used to measure force. An input force can vary from 20 to 100 N. Then the range of load cell is 20 to 100 N. And the span of load cell is 80 N (i.e., 10020)

Error:

❖ The algebraic difference between the indicated value and the true value of the measured parameter is termed as the error of the device.

❖ Error = Indicated value —true value

❖ For example, if the transducer gives a temperature reading of 30°C when the actual temperature is 29° C, then the error is + 1°C. If the actual temperature is 3 1° C, then the error is —1°C.

Accuracy:

❖ Accuracy is defined as the ability of the instrument to respond to the true value of the measure variable under the reference conditions.

❖ For example, a thermocouple has an accuracy of ± 1° C. This means that reading given by the thermocouple can be expected to lie within + 1°C (or)— 1°C of the true value.

❖ Accuracy is also expressed as a percentage of the full range output (or) full scale deflection.

For example, a thermocouple can be specified as having an accuracy of ±4 % of full range output. Hence if the range of the thermocouple is 0 to 200°C, then the reading given can be expected to be within + 8°C (or)—8°C of the true reading.

Sensitivity:

❖ The sensitivity is the relationship showing how much output we can get per unit input.

❖ sensitivity = Output / Input

Precision:

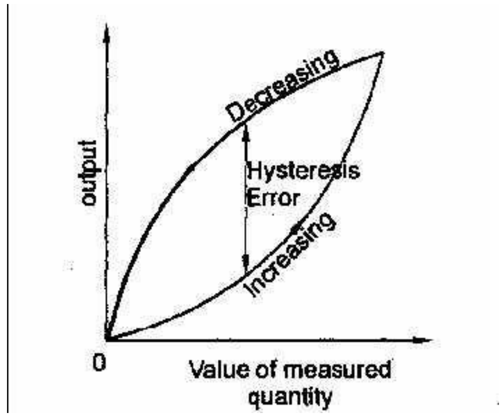
❖ It is defined as the degree of exactness for which the instrument is intended to perform.

Hysteresis error:

❖ When a device is used to measure any parameter plot the graph of output Vs value of measured quantity.

❖ First for increasing values of the measured quantity and then for decreasing values of the measured quantity.

❖ The two output readings obtained usually differ from each other.



Repeatability:

❖ The repeatability and reproducibility of a transducer are its ability to give the same output for repeated applications of the same input value.

Reliability:

❖ The reliability of a system is defined as the possibility that it will perform its assigned functions for a specific period of time under given conditions.

Stability:

❖ The stability of a transducer is its ability to give the same output when used to measure a constant input over a period of time.

Drift:

❖ The term drift is the change in output that occurs over time.

Dead band:

❖ There will be no output for certain range of input values. This is known as dead band.
There will be no output until the input has reached a particular value.

Dead time:

❖ It is the time required by a transducer to begin to respond to a change in input value.

Resolution:

❖ Resolution is defined as the smallest increment in the measured value that can be detected.

❖ The resolution is the smallest change in the input value which will produce an observable change in the input.

Backlash:

❖ Backlash is defined as the maximum distance (or) angle through which any part of a mechanical system can be moved in one direction without causing any motion of the attached part.

❖ Backlash is an undesirable phenomenon and is important in the precision design of gear trains.

SELECTION OF DISPLACEMENT, POSITION & PROXIMITY SENSOR:

❖ Size of the displacement (mm)
❖ Displacement type (Linear or angular)
❖ Resolution required
❖ Accuracy required
❖ Material of the object
❖ Cost

DISPLACEMENT SENSORS

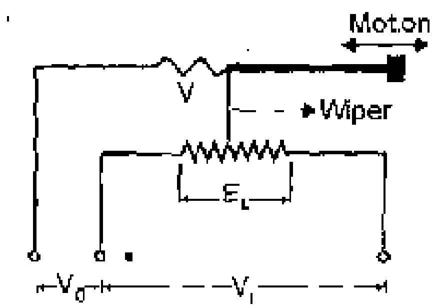
Types of Displacement sensors:

- Potentiometer
- Strain gauge
- Capacitive sensors
- Linear variable differential transformer

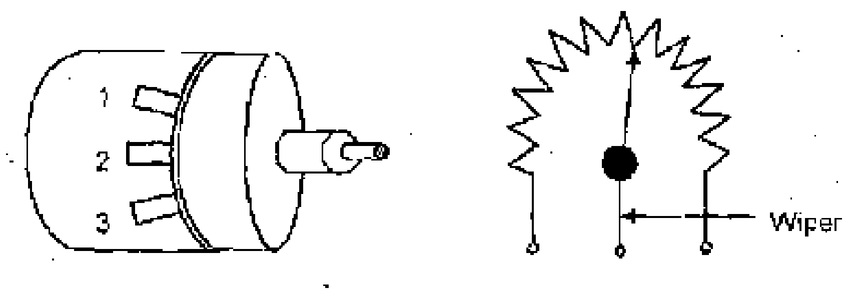
POTENTIOMETER

PRINCIPLE:

- It works on variable resistance transduction principle
- Linear or Rotary potentiometer is a variable resistance displacement transducer which uses the variable resistance transduction principle in which the displacement or rotation is converted into a potential difference due to the movement of sliding contact over a resistive element



Linear Potentiometer



Rotary Potentiometer

CONSTRUCTION & WORKING:

- A resistor with three terminals.
- Two end terminal & one middle terminal (wiper).
- Two end terminal are connected to external input voltage.
- One middle and one end terminal as output voltage.
- The slider determines the magnitude of the potential difference developed.

CHARACTERISTICS:

Resistance element = Precision Drawn wire with a diameter of about 25 to 50 microns, and wad over a cylindrical or a flat mandrel of ceramic, glass or Anodized.

Aluminium. 2mm to 500 mm in case of linear pot.

= For high resolution, wire is made by using ceramic (cermets)or conductive plastic film due to low noise levels.

Wipers (Sliders) = Tempered phosphor bronze, beryllium copper or other precious alloys.

Wire Material = Strong, ductile and protected from surface corrosion by enamelling or oxidation. Materials &e alloys of copper nickel, Nickel chromium, and silver palladium.

= Resistivity of wire ranges from 0.4 μΩm to 13 μΩm

Resistance range= 20Ω to 200KΩ and for plastic 500Ω to 80KΩ

Accuracy = Higher temperature coefficient of resistance than the wire and so temperature changes have a greater effect Accuracy.

STRAIN GAUGE:

Strain gauges are passive type resistance sensor whose electrical resistance change when it is stretched or compressed (mechanically strained)under the application of force. The electrical resistance is changed due to the change in length (increases) and cross sectional area (decreases) of the strain gauge.

This change in resistance is then usually converted into voltage by connecting one, two or four similar gauges as an arm of a Wheatstone bridge (known as Strain Gauge Bridge) and applying excitation to the bridge. The bridge output voltage is then a measure of strain, sensed by each strain gauge.

UNBONDED TYPE STRAIN GAUGES:

- In unbonded type, fine wire filaments (resistance wires) are stretched around rigid and electrically insulated pins on two frames.
- One frame is fixed and the other is movable.
- The frames are held close with a spring loaded mechanism.
- Due to the relative motion between two frames, the resistance wires are strained.
- This strain is then can be detected through measurement of the change in electrical resistance since they are not cemented with the surfaces, they can be detached and reused.

BONDED TYPE STRAIN GAUGES:

- Bonded type strain gauges consists of resistance elements arranged in the form of a grid of fine wire, which is cemented to a thin paper sheet or very thin Bakelite sheet, and covered with a protective sheet of paper or thin Bakelite.

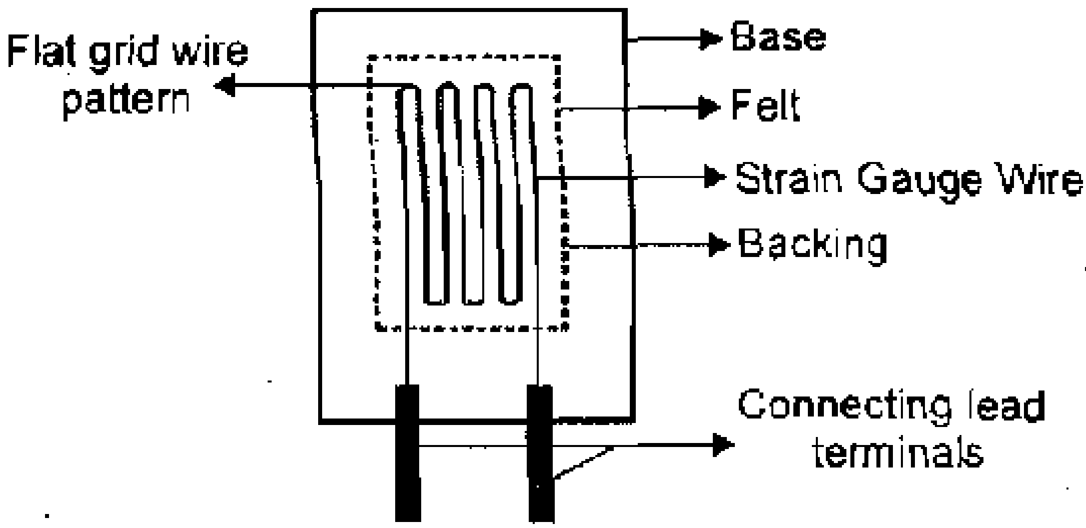
❖ The paper sheet is then bonded to the surface to be strained. The gauges have a bonding material which acts an adhesive material during bonding process of a surface with the gauge element.

Classification of Bonded Type Strain Gauges:

❖ Fine wire gauges
❖ Metal foil gauges
❖ Semiconductor filament type

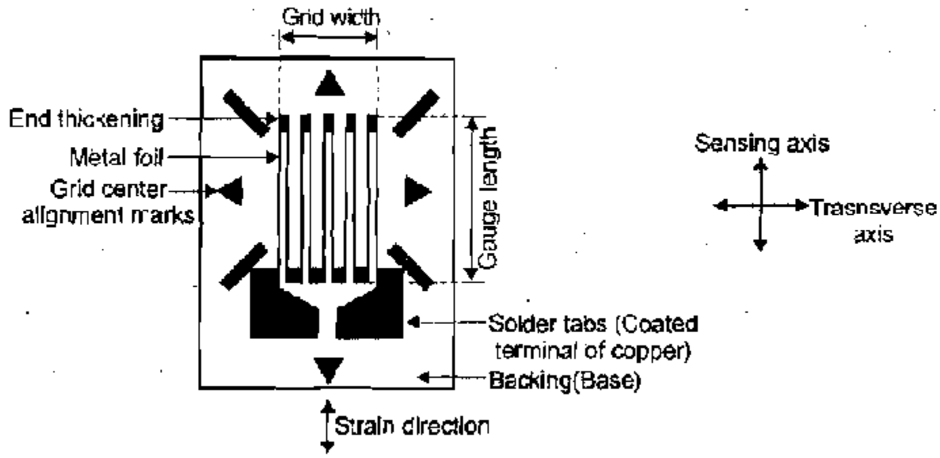
FINE WIRE GAUGES:

❖ Wire of 3 to 25 microns diameter is arranged in the form of grid consisting of parallel loops.



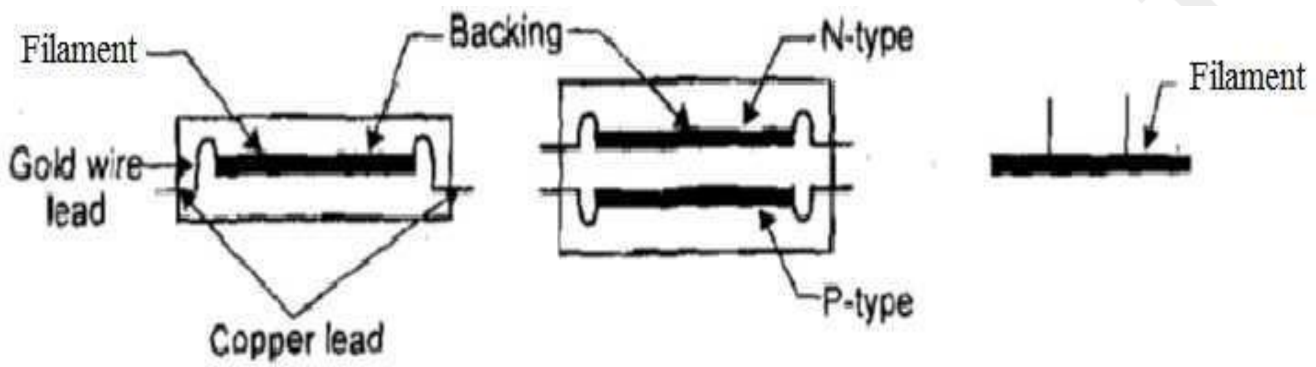
METAL FOIL GAUGES:

❖ A thin foil of metal, deposited as a grid pattern onto a plastic backing material using polyimide.
❖ Foil pattern is terminated at both ends with large metallic pads.
❖ Entire gauge size 5- 15mm.
❖ Adhesive directly bonded to the gauge usually epoxy.



SEMICONDUCTOR FILAMENT TYPE:

- The gauges are produced in wafers from silicon or germanium crystals.
- Special impurities such as boron is added.
- It is mounted on an epoxy resin backing with copper on nickel leads.
- Filament about 0.05mm thick 0.25mm wide and 1.25 to 12mm length.



CAPACITIVE SENSORS:

- It is used for measuring, displacement, velocity, force etc..

PRINCIPLE:

It is passive type sensors in which equal and opposite charges are generated on the plates due to voltage applied across the plate which is separated by dielectric material.

FORMULA:

The capacitance 'C' of a parallel plate capacitor is given by

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

where ε_r = Permittivity of the dielectric between the plates [= 1 for air]

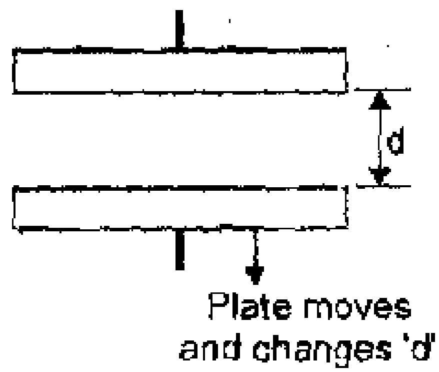
ε_0 = Permittivity of free space [= 8.854×10^{-12} F/m for air]

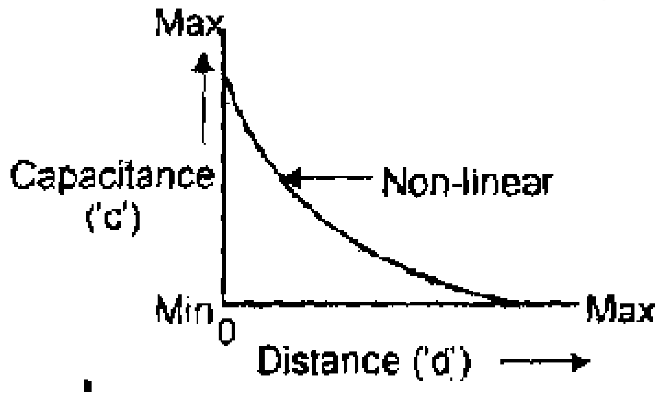
A = Area of overlap between two plates in m^2

d = Distance between two plates in m.

By Changing the Distance between Two Plates:

❖ The displacement is measured due to the change in capacitance

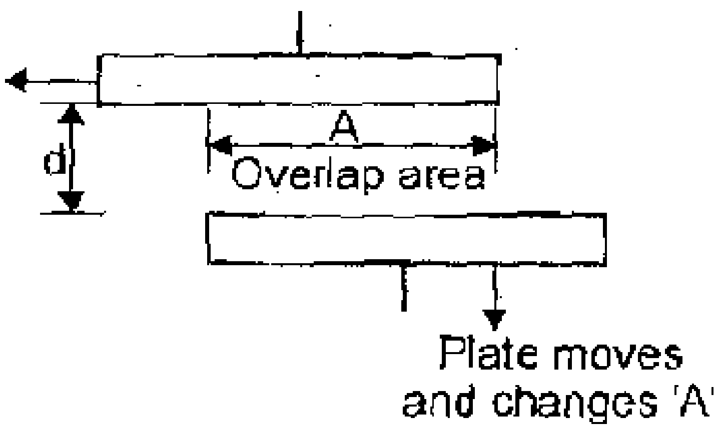


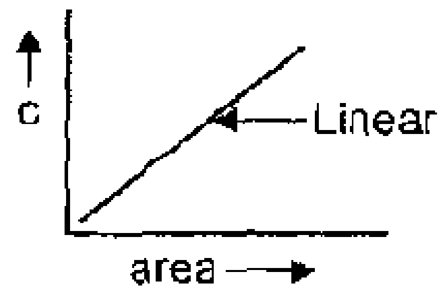


By Varying the Area of Overlap:

❖ The displacement causes the area of overlap to vary

❖ The capacitance is directly proportional to the area of the plates and varies linearly with changes in the displacement between the plates

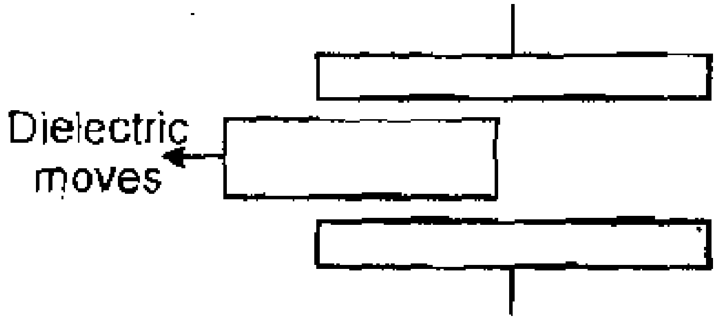




By Varying the Dielectric Constant:

❖ The change in capacitance can be measured due to change in dielectric constant as a result of displacement.

❖ When the dielectric material is moved due to the displacement, the material causes the dielectric constant to vary in the region where the two electrodes are separated that results in a charge in capacitance.

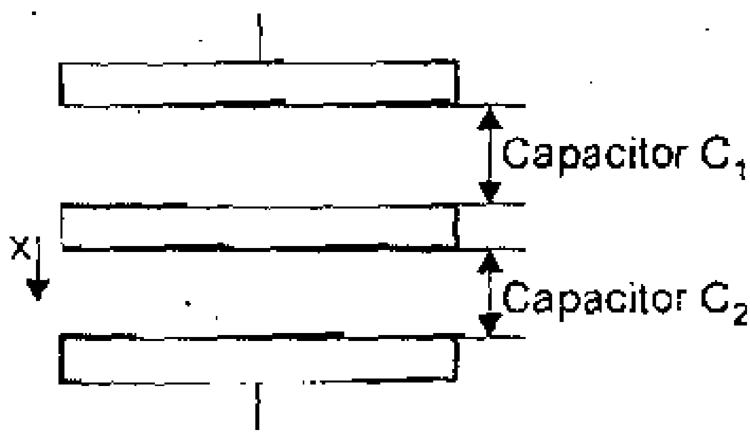


PUSH PULL SENSOR:

- Push pull displacement sensor is used to overcome the non-linearity error.
- The sensor consists of three plates with the upper pair forming one capacitor and the lower pair forming another capacitor.
- The displacement moves central plate between the two other plates.
- If the central plate moves downwards.
- The plate separation of the upper capacitor increases and the separation of the lower one decreases.

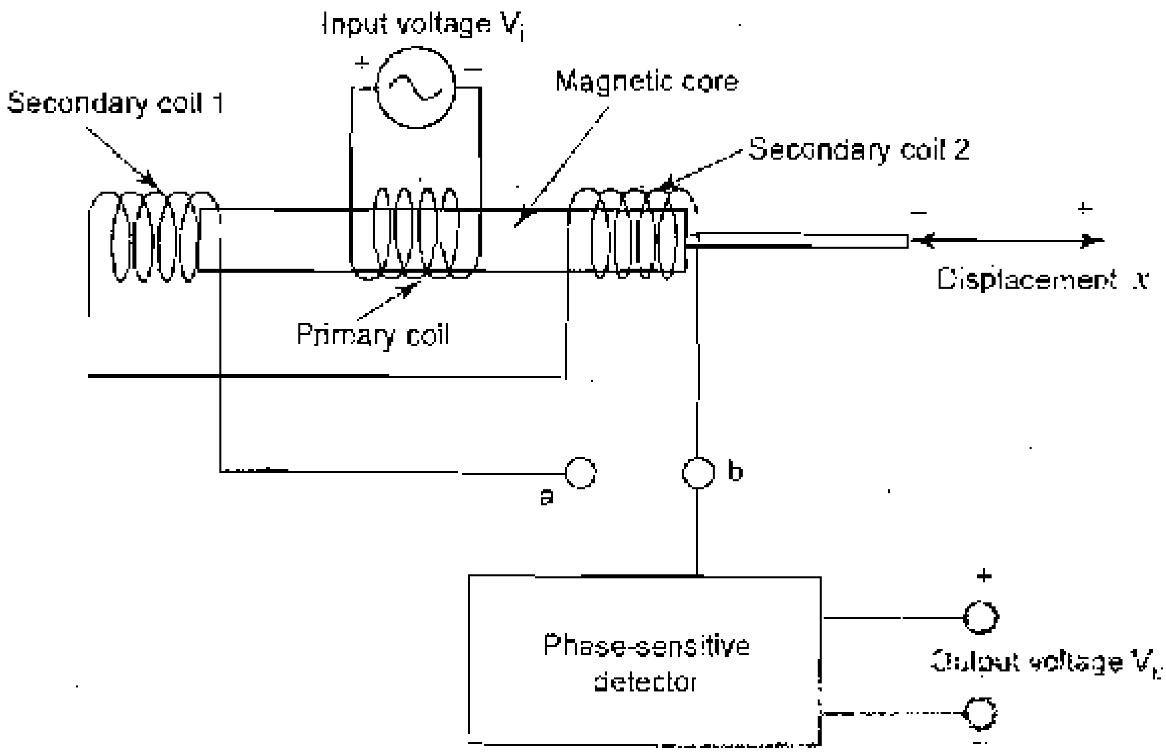
$$\therefore C_1 = \frac{\varepsilon_0 \varepsilon_r A}{d + x}$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d - x}$$



LINEAR VARIABLE DIFFERENTIAL TRANSFORMER:

- It consists of three symmetrically spaced coils.
- The centre coil is primary coil and other two are secondary coil
- Secondary coils are connected in series opposition and equally positioned with respect to primary coil
- The output voltage is proportional to the displacement of the core from null position



- Proximity sensors are non – contact type sensor.

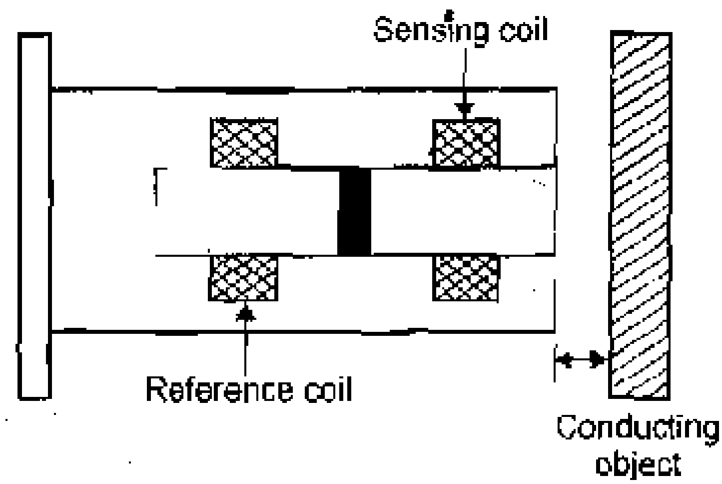
Types of Proximity Sensor:

- Eddy current proximity sensor
- Inductive proximity sensor
- Pneumatic proximity sensor
- Proximity switches

EDDY CURRENT PROXIMITY SENSOR:

PRINCIPLE:

When a coil is supplied with alternating current, an alternating magnetic field is produced which induces an EMF on it. If there is a metal near to this alternating magnetic field, on EMF is induced in it. The EMF cause current to flow. This current flow is eddy current.



CONSTRUCTION & WORKING:

❖ It has two identical coils.

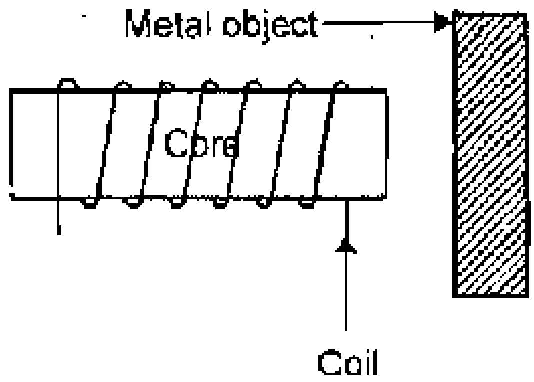
❖ One reference coil & another sensing coil which senses the magnetic current in the object.

❖ Eddy current start to flow due to AC (conducting object)close to sensor

❖ Eddy current produce a magnetic field to oppose the magnetic field generated by sensing coil.

❖ Due to this opposition reduction flux is created. To detect 0.001mm.

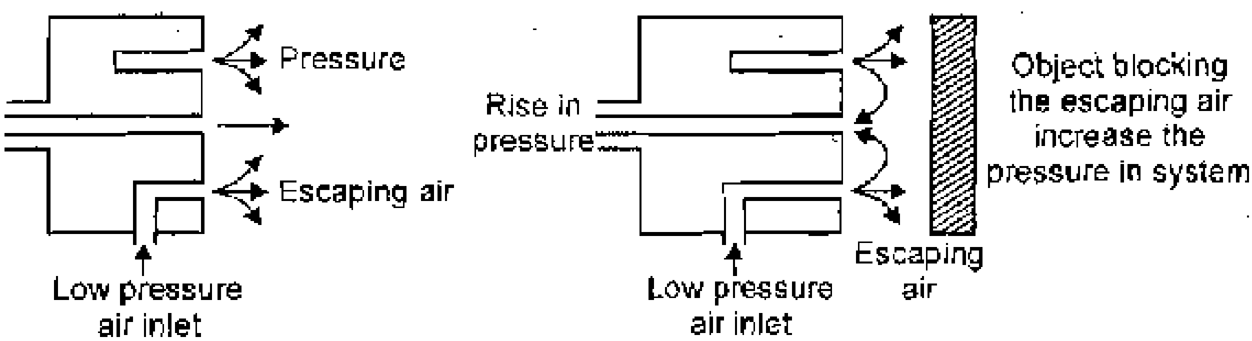
INDUCTIVE PROXIMITY SENSORS:



- ❖ It consists of coil wound round a core.
- ❖ Metal is close to coil Inductance changes occurs.
- ❖ It is suitable for ferrous metals

PNEUMATIC PROXIMITY SWITCHES:

- ❖ It is suitable for sensing non conducting materials
- ❖ Air is allowed to escape from the front side of the sensor.
- ❖ When there is no object air escapes freely.
- ❖ When there is an object, the escaping air is blocked and return backed to system.
- ❖ It is used to measure the range 3mm to 12mm.



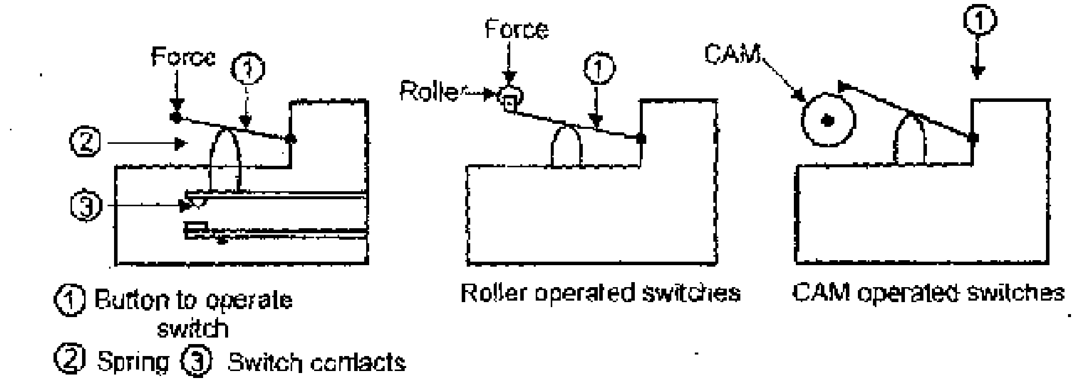
PROXIMITY SWITCHES:

❖ It is used in robotics for sensing elements

❖ It is also used in NC machines, material handling systems and assembly lines.

➢ Micro switch
➢ Reed switch
➢ Photo sensitive switch
➢ Mechanical switch

MICRO SWITCH:



❖ It is limit switch operated by levers, rollers & cams

❖ It is switch which requires physical contact and small force to close the contacts.

Example : a belt conveyor.

REED SWITCH:

❖ It is a non – contact proximity switch that consists of two magnetic switch contacts
enclosed in a glass tube fined with an inert gas.
❖ When magnet is closed switch is operated.
❖ Used for high speed applications.

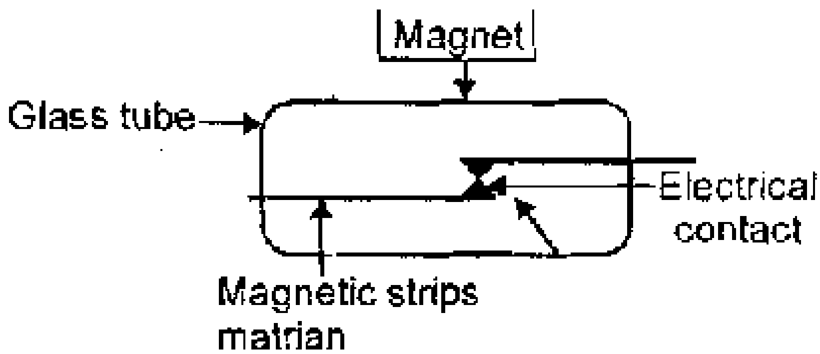
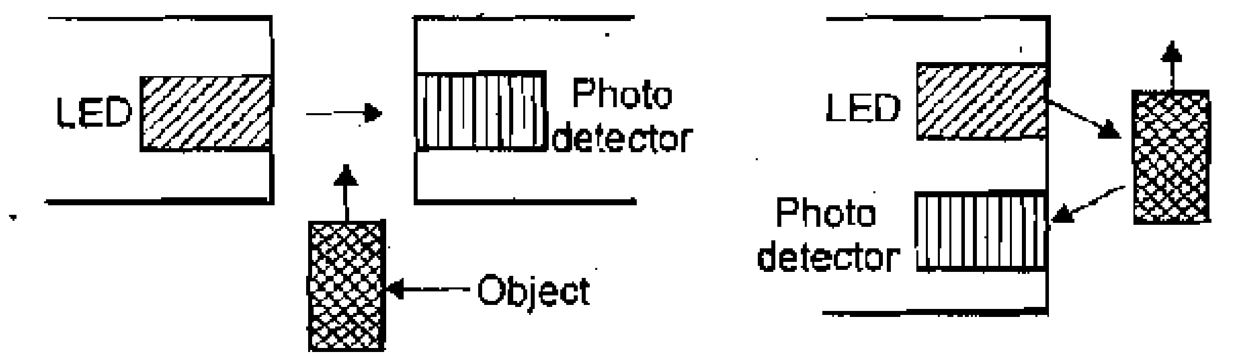


PHOTO SENSITIVE DEVICES:



(a) Object breaking the beam (b) Object reflecting the beam

❖ It is used to sense opaque object.
❖ Photo detector receives a beam of light produced by the LED.
❖ Object is passed the beam gets broken or reflected when is detected.

OPTICAL ENCODERS:

❖ It is used to measure position, velocity, acceleration and direction of movement of rotors.

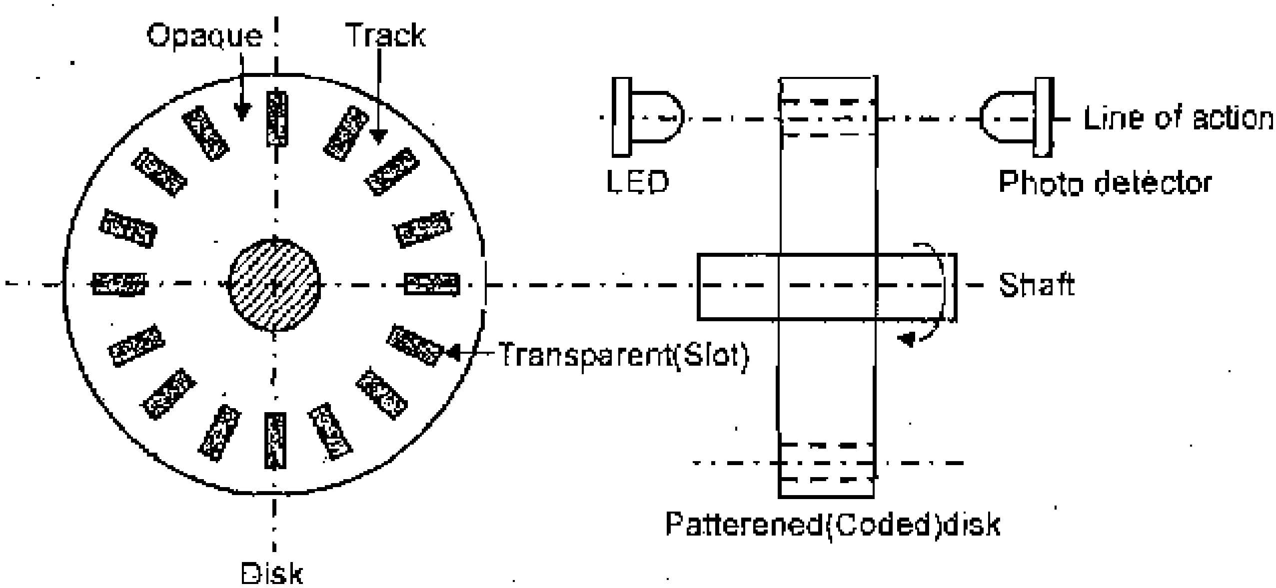
INCREMENTAL ENCODERS:

PRINCIPLE:

❖ When a beam of light passes through slots in a disc, it is sensed by the light sensor opposite to the light source.

❖ When the disk is rotated, a pulsed output is produced by sensor with number of pulses being proportional to the position of the disc and number of pulses per second determines the velocity of the disk.

CONSTRUCTION & WORKING:



❖ It consists three components light source, coded disk and photo detector

❖ The disk is made up of plastic or glass.

❖ The disk consists of opaque and transparent segment alternatively.

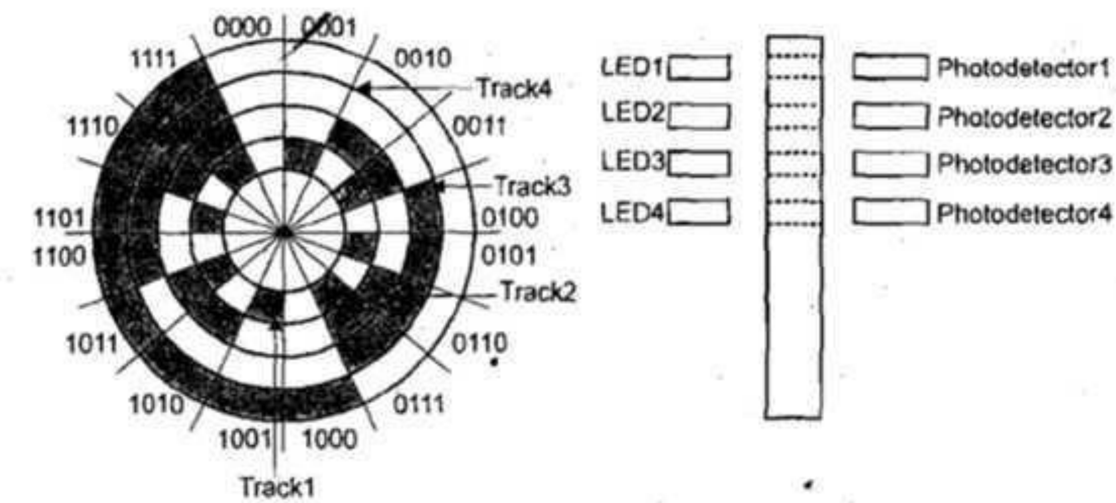
❖ The wheel is between light and photo detector.

❖ The photo detector receives the light signal alternatively which is converted into electrical signal.

ABSOLUTE ENCODERS

PRINCIPLE:

- The principle of operation is that they provide a unique output corresponds to each rotational position of the shaft.
- The output is in the form of binary numbers representing the angular position.



	Normal Binary	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

CONSTRUCTION & WORKING:

- The disc has four concentric slots and four photo detectors to detect the light pulse.
- The slots are arranged in such way that they give a binary number.
- It consist opaque and transparent segments. This pattern is called as track.
- The encoders have 8 to 14 slots.
- The number of the track determines the resolution of the encoder.
- The number of bits in binary number will be equal to the number of tracks.

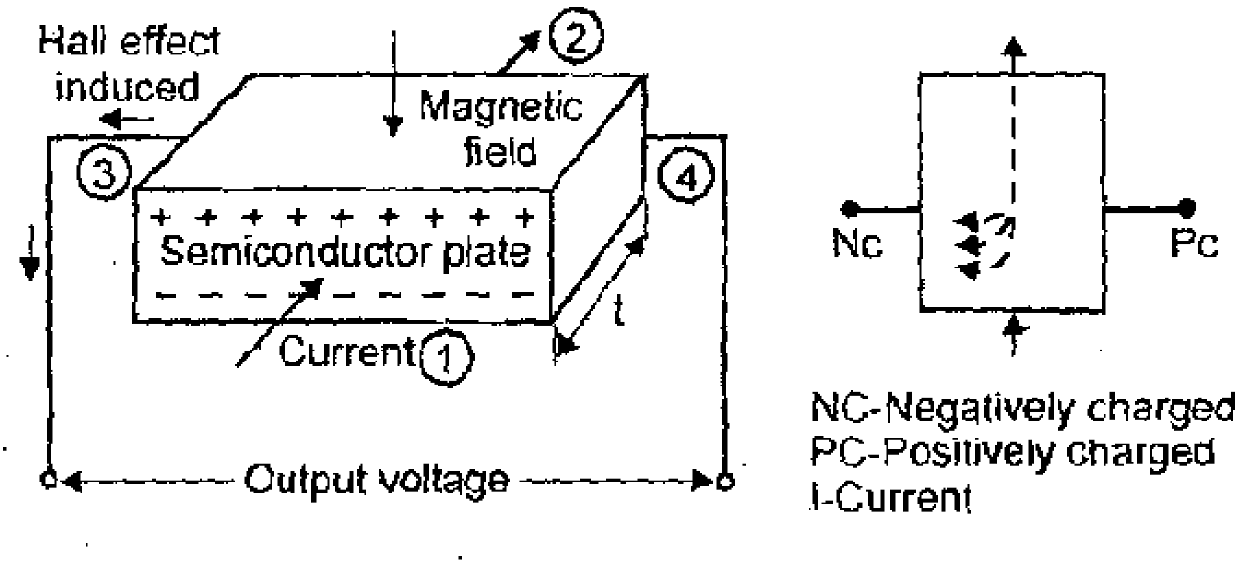
HALL EFFECT SENSORS:

PRINCIPLE:

❖ When a current carrying semiconductor plate is placed in a transverse magnetic field, it experiences a force (Lorentz force). Due to this action a beam of charged particles are forced to get displaced from its straight path. This is known as Hall Effect.

❖ A current flowing in a semiconductor plate is like a beam of moving charged particles and thus can be deflected by a magnetic field. The side towards which the moving electron deflected becomes negatively charged and the other side of the plate becomes positively charged or the electrons moving away from it.

❖ This charge separation produces an electrical voltage which continues until the Lorentz force on the charged particles from the electric field balances the forces produced by the magnetic field. The result is a traverse potential difference known as Hall voltage.



CONSTRUCTION & WORKING:

❖ Current is passed through leads 1 and 2 of the semiconductor plate and the output leads are connected to the element faces 3 and 4.

❖ These output faces are at same potential when there is no transverse magnetic field passing through the element and voltage known as Hall voltage appears when a transverse magnetic field is passing through the element.

❖ This voltage is proportional to the current and the magnetic field.

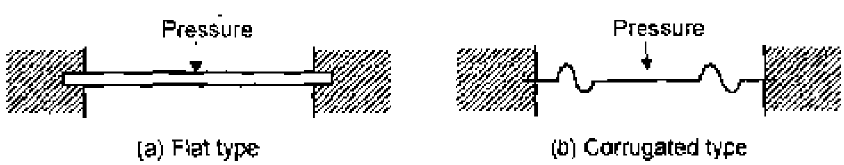
❖ The direction of deflection depends on the direction of applied current and the direction of magnetic field.

FLUID SENSORS

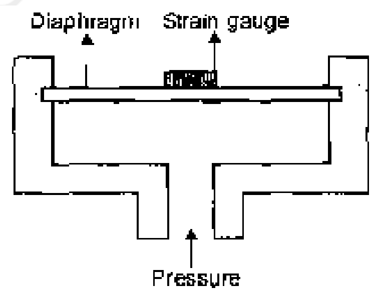
FLUID PRESSURE SENSORS:

DIAPHRAGM TYPE:

- ❖ In the diaphragm type sensor, when there is a difference in pressure between the two sides then the centre of the diaphragm becomes displaced.
- ❖ Corrugations in the diaphragm result in a greater sensitivity.
- ❖ This movement can be monitored by some form of displacement sensor, e.g: a strain gauge.
- ❖ A specially designed strain gauge is often used, consisting of four strain gauges with two measuring the strain in a circumferential direction while two measure strains in a radial direction
- ❖ The four *strain* gauges are then connected to form the arm of a Wheatstone bridge.
- ❖ While strain gauges can be stuck on a diaphragm, an alternative is to create a silicon diaphragm with the strain gauges as specially doped areas of the diaphragm.



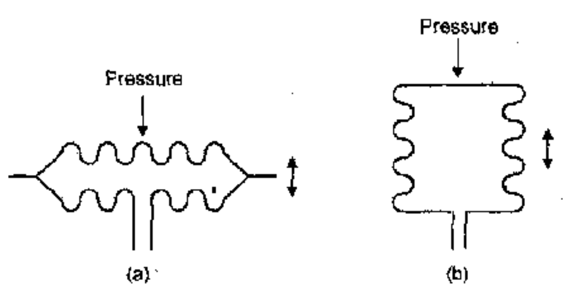
Diaphragm types



Diaphragm pressure gauge

CAPSULE AND BELLOW TYPES:

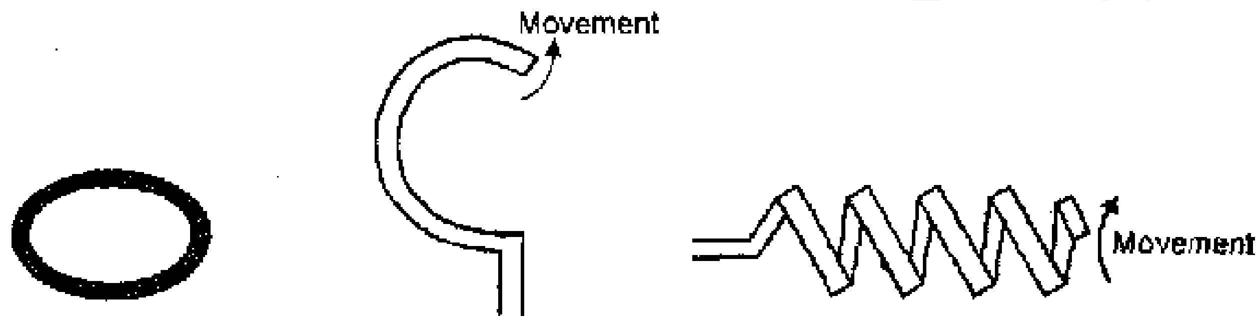
- ❖ Capsules are two corrugated diaphragms combined to give greater accuracy
- ❖ Capsules and bellows are made up of stainless steel, phosphor bronze, and nickel with rubber and nylon.
- ❖ Pressure range 10^3 to 10^8 Pa.



(a) Capsule, (b) bellows

TUBE PRESSURE SENSOR:

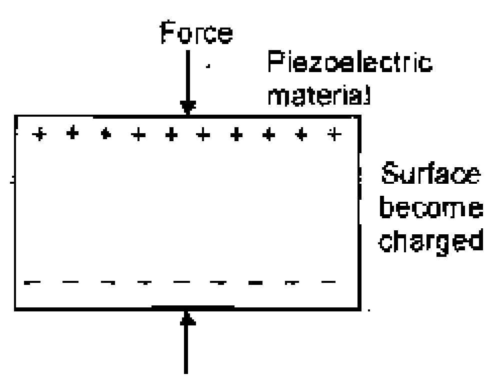
- A different form of deformation is obtained using a tube with an elliptical cross section
- Increase in pressure in tube causes it tend to circular cross – section
- C – Shaped tube is generally known as a Bourdon tube.
- C opens when pressure in the tube increases
- A helical form gives more sensitivity
- Tubes are made up of stainless steel, phosphor bronze, and nickel with rubber and nylon
- Pressure range 10^3 to 10^8 Pa.



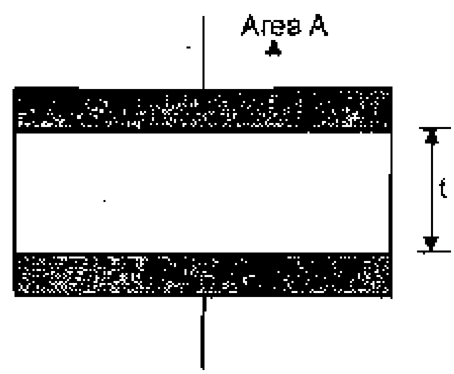
(a) Tube cross-section (b) C-shaped tube (c) Helical C/S tube

PIEZOELECTRIC SENSORS:

- Piezoelectric materials when stretched or compressed generate electric charges with one face of the managerial becoming positively charged and the opposite face negatively charged.
- As a result a voltage is produced. The net charge q on a surface is proportional to the amount x by which the charges have been displaced, and since the displacement is proportional to the applied force F.
- $q = kx = SF$
- Where k is a constant and S a constant termed the charge sensitivity.



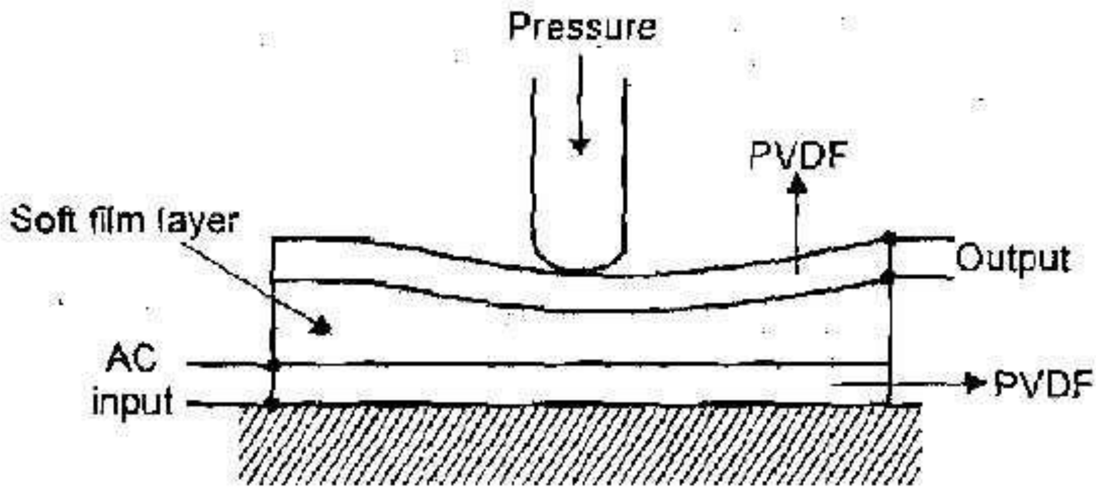
Piezoelectricity



Piezoelectric capacitor

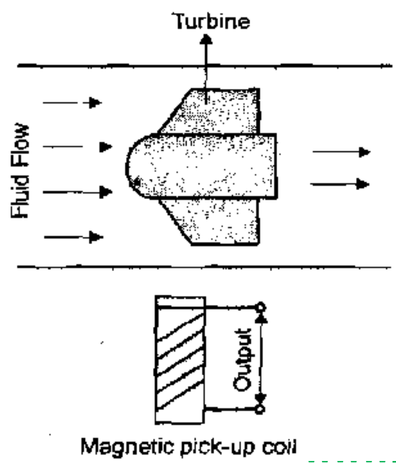
TACTILE SENSOR:

- It is used on fingertips of robot hands and for touch display screen
- It uses piezoelectric poly vinylidene fluoride (PVDF) film
- Two layers are separated by soft film.
- The lower PVDF film has an alternating voltage applied to it results in mechanical oscillations.
- Intermediate film transmits the vibration to upper film.



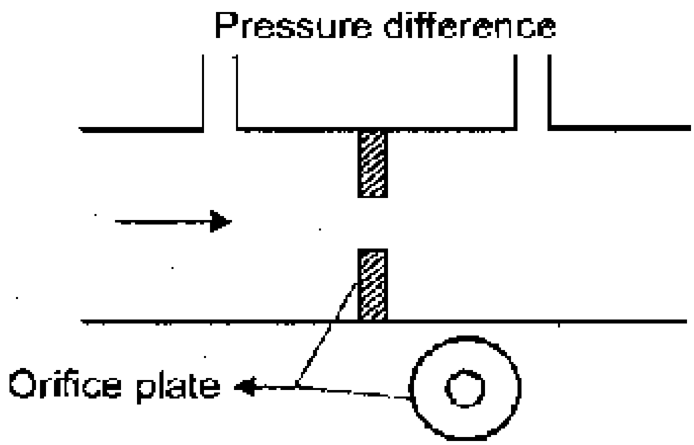
LIQUID FLOW SENSORS:
TURBINE FLOW METER:

- The turbine flow meter and it consists of a multi-bladed rotor which is supported in the pipe along with the flow occurs.
- The rotor rotation depends upon the fluid flow and the angular velocity is proportional to the flow rate.
- The rotor rotation is determines the magnetic pick-up, which is connected to the coil.
- The revolution of the rotor is determined by counting the number of pulses produced in the magnetic pick up. The accuracy of this instrument is ± 3%.



ORIFICE PLATE:

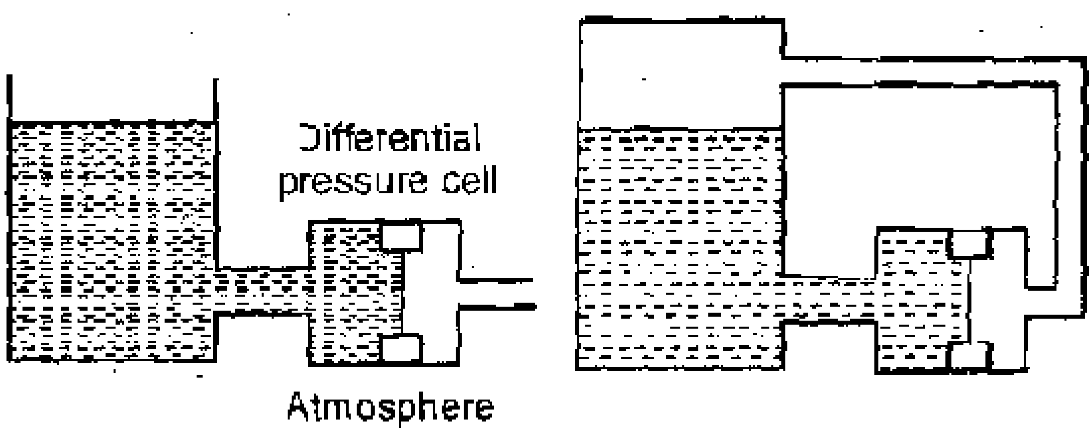
- It is a simple disc with a central hole and it is placed in the tube through which the fluid flows.
- The pressure difference measured between a point equal to the diameter of the tube upstream and half the diameter of downstream.
- The accuracy of this instrument is ±1.5%.



LIQUID LEVEL MEASUREMENT:

DIFFERENTIAL PRESSURE SENSOR:

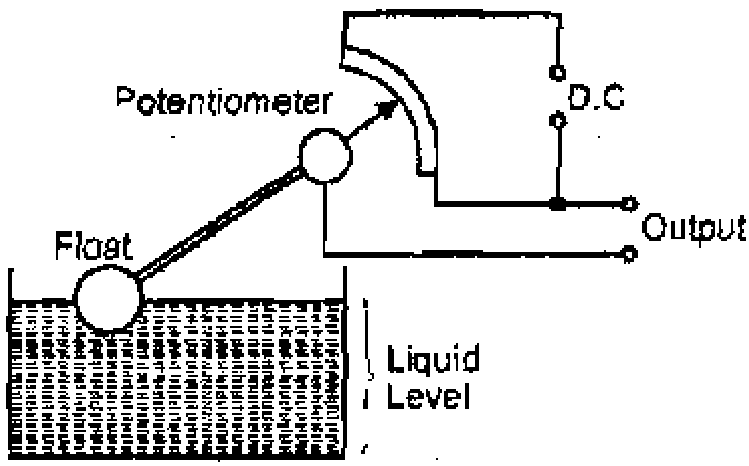
- In this the differential pressure cell determines the pressure difference between base of the liquid and atmospheric pressure.
- The differential pressure sensor can be used in either form of open or closed vessel system.



(a) Open Vessel type (b) Closed Vessel type

FLOAT SYSTEM:

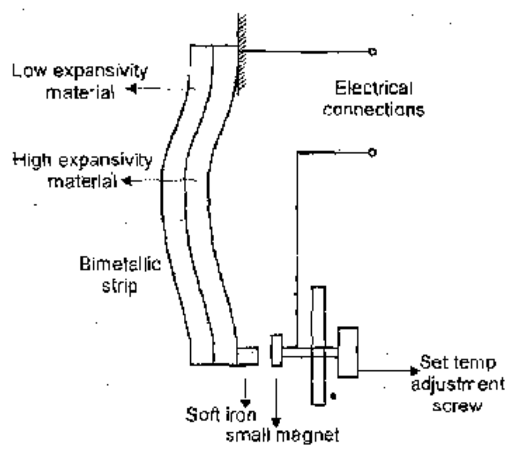
- In this method the level of liquid is measured by movement of a float.
- The movement of float rotates the arm and slider will move across a potentiometer.
- The output result is related to the height of the liquid.



TEMPERATURE SENSORS:

BIMETALLIC STRIPS:

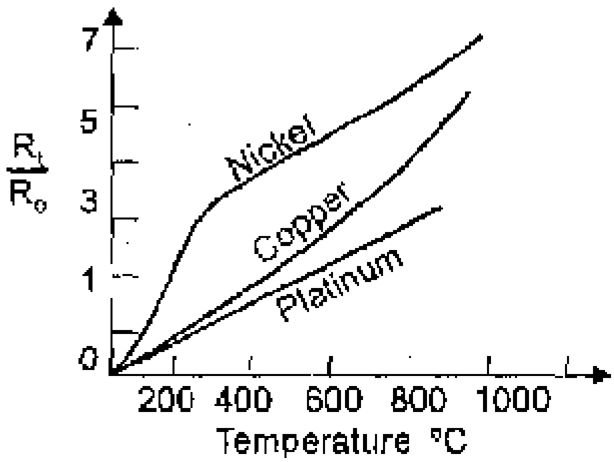
- A Bimetallic thermostat consists of two different metal strips bounded together and they cannot move relative to each other.
- These metals have different coefficients of expansion and when the temperature changes the composite strips bends into a curved strip, with the higher coefficient metal on the outside of the curve.
- The basic principle in this is all metals try to change their physical dimensions at different rates when subjected to same change in temperature.
- This deformation may be used as a temperature- controlled switch, as in the simple thermostat.



Resistance Temperature Detectors (RTDs):

❖ The materials used for RTDs are Nickel, Iron, Platinum, Copper, Lead, Tungsten, Mercury, Silver, etc.

❖ The resistance of most metals increases over a limited temperature range and the relationship between Resistance and Temperature is shown below.



❖ The Resistance temperature detectors are simple and resistive elements in the form of coils of wire

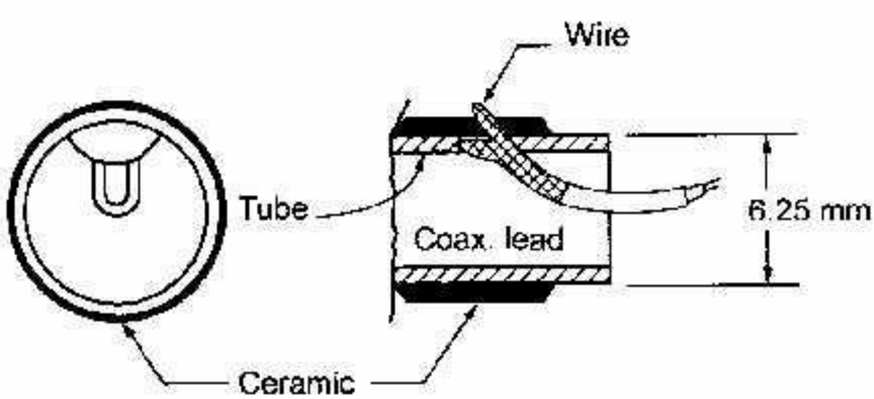
❖ The equation which is used to find the linear relationship in RTD is

$$R_1 = R_0 (1 + \alpha t)$$

CONSTRUCTIONAL DETAILS OF RTDS:

❖ The platinum, nickel and copper in the form wire are the most commonly used materials in the RTDs.

❖ Thin film platinum elements are often made by depositing the metal on a suitable substrate wire- wound elements involving a platinum wire held by a high temperature glass adhesive inside a ceramic tube.



THERMISTORS:

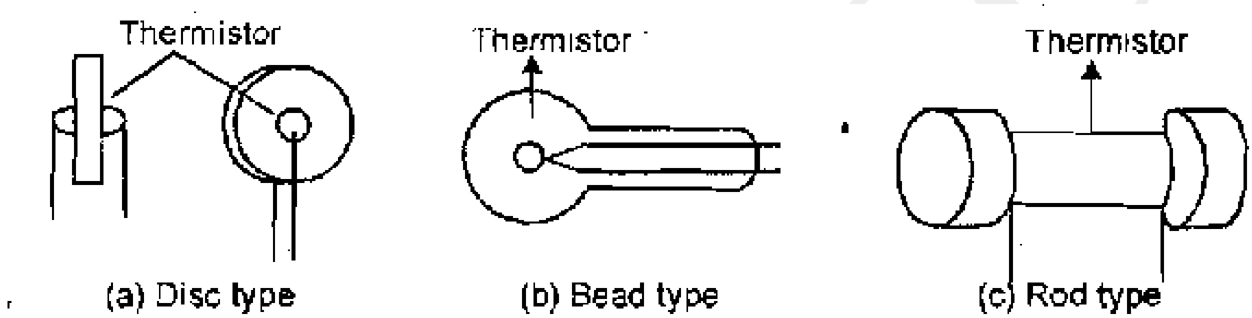
❖ Thermistor is a semiconductor device that has a negative temperature coefficient of resistance in contrast to positive coefficient displayed by most metals.

❖ Thermistors are small pieces of material made from mixtures of metal oxides, such as Iron, cobalt, chromium, Nickel, and Manganese.

❖ The shape of the materials is in terms of discs, beads and rods.

❖ The thermistor is an extremely sensitive device because its resistance changes rapidly with temperature.

❖ The resistance of conventional metal-oxide thermistors decreases in a very non-linear manner with an increase in temperature.

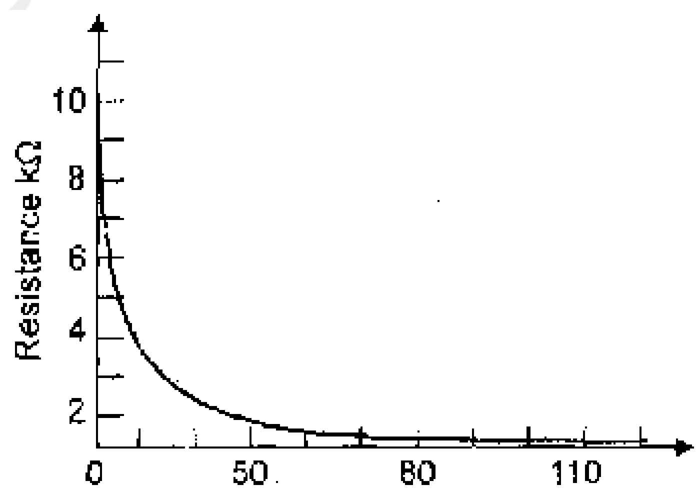


❖ The change in resistance per degree change in temperature is considerably larger than that which occurs with metals.

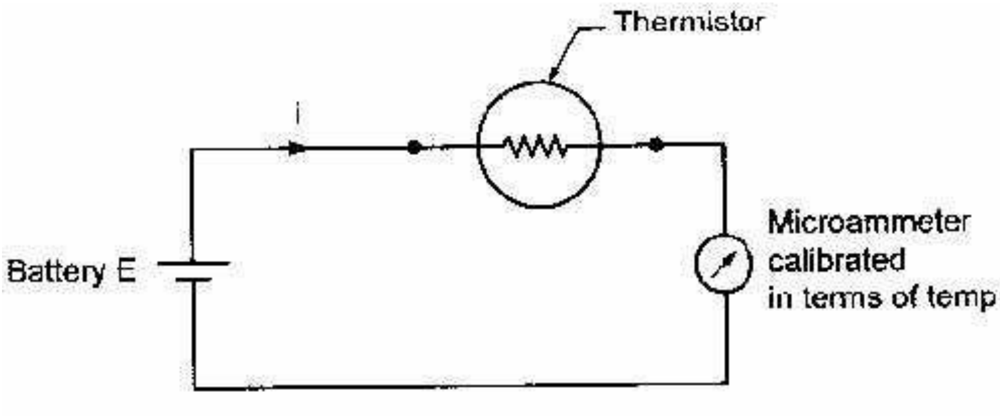
❖ The resistance-temperature relationship for a thermistor can be described by an equation of the form.

$$R_t = Ke^{\beta/t}$$

❖ Where R_t, is the resistance at temperature t, with K and ß being constant. Thermistors have many advantages when compared with other temperature sensors.



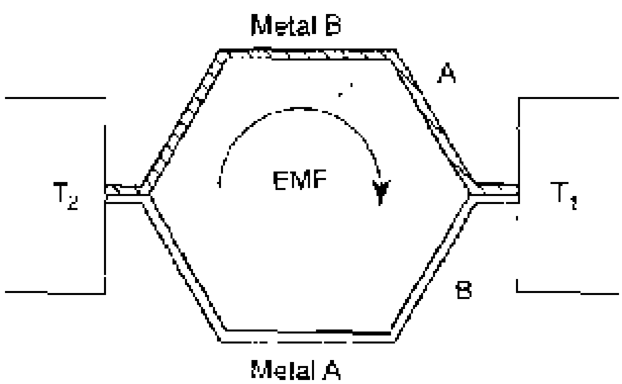
❖ The simple series circuit for measurement of temperature using a thermistor and thevariation of resistance with temperature for a typical thermistor.



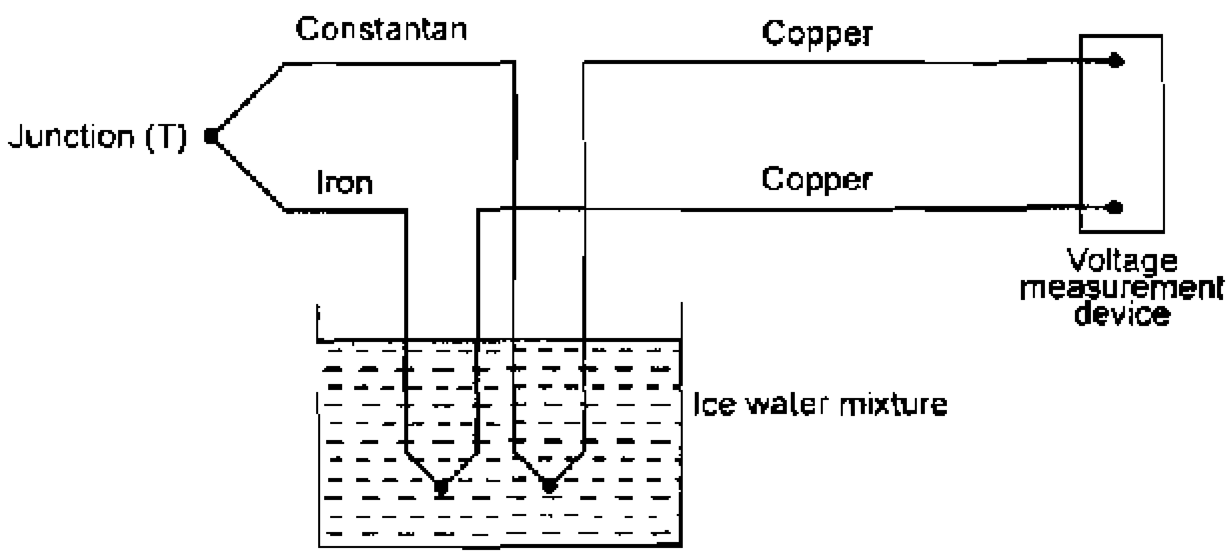
❖ The thermistor is an extremely sensitive device because its resistance changes rapidly with temperature.

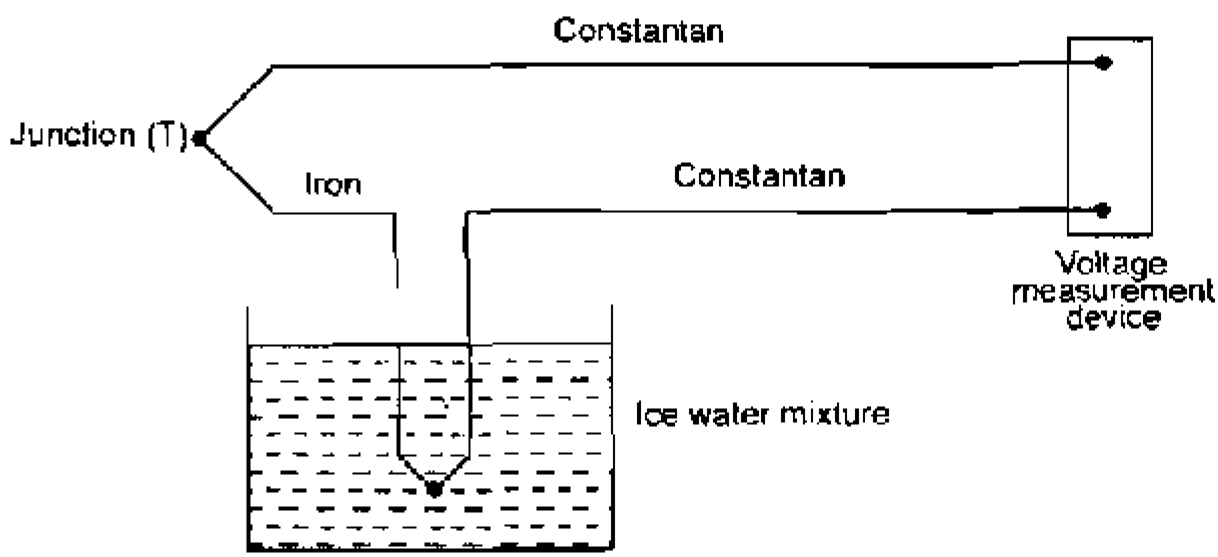
Thermocouples:

❖ Thermocouples are based on the See back Effect.
❖ The thermocouple temperature measurement is based on a creation of an electromotive force (emf).



❖ "When two dissimilar metals are joined together an e.m.f will exist between the two points A and B, which is primarily a function of the junction temperature. The above said to be principle is See back effect..
❖ The thermocouple consist of one hot junction and one cold junction
❖ Hot junction is inserted where temperature is measured
❖ Cold junction is maintained at a constant reference temperature.


Constantan
Copper
Junction (T)
Iron
Copper
Voltage measurement device
Ice water mixture


Constantan
Junction (T)
Iron
Constantan
Voltage measurement device
Ice water mixture

An Overview of Microprocessor

The first question comes in a mind "What is a microprocessor?”. Let us start with a more familiar term computer. A digital computer is an electronic machine capable of quickly performing a wide variety of tasks. They can be used to compile, correlate, sort, merge and store data as well as perform calculations.

A digital computer is different from a general purpose calculator in that it is capable of operating according to the instructions that are stored within the computer whereas a calculator must be given instructions on a step by step basis. By the definition a programmable calculator is a computer.

Historically, digital computers have been categorized according to the size using the words large, medium, minicomputer and microcomputer. In the early years of development, the emphasis was on large and more powerful computers. Large and medium sized computers were designed to store complex scientific and engineering problems. These computers were accessible and affordable only to large corporations, big universities and government agencies. In the 1960s’ computers were accessible & affordable only to large corporations, big universities & government agencies, In late 1960s, minicomputers were available for use in a office, small collage, medium size business organization, small factory etc. As the technology has advanced from SSI to VLSI & SLSI (very large scale integration & super large scale integration) the face of the computer has changed. It has now become possible to build the control processing unit (CPU) with its related timing functions on a single chip known as microprocessor. A microprocessor combined with memory and input/output devices forms a microcomputer. As for as the computing power is concerned the 32- bit microcomputers are as powerful as traditional mainframe computers.

The microcomputer is making an impact on every activity of mankind. It is being used in almost all control applications. For example analytical and scientific instruments, data communication, character recognition, musical instruments, household items, defence equipments, medical equipments etc.

Computers communicate and operate in binary numbers 0 and 1 also known as bits. It is the abbreviation for the term binary digit. The bit size of a microprocessor refers to the number of bit which can be processed simultaneously by the arithmetic circuit of the microprocessor. A number of bits taken as a group are this manner is called word. For example, the first commercial microprocessor the Intel 4004 which was introduced in 1971 is a 4-bit machine and is said to process a 4-bit word. A 4-bit word is commonly known as nibble and an 8-bit word is commonly known as byte. Intel 8085 is an 8-bit microprocessor. It should be noted that a processor can perform calculations involving more than its bit size but takes more time to complete the operation. The short word length requires few circuitry and interconnection in the CPU.

Microcontrollers

A µP does not have enough memory for program and data storage, neither does it has any input and output devices. Thus when a µP is used to design a system, several other chips are also used to make up a complete system. For many applications, these extra chips imply additional cost and increased size of the product. For example, when used inside a toy, a designer would like to minimize the size and cost of the electronic equipment inside the toy. Therefore, in such applications a microcontroller is used more often than a microprocessor.

A microcontroller is a chip consisting of a microprocessor, memory and an input/output device. There are 4 bit as well as 32 bit microcontrollers.

Evolution of the Microprocessors

The history of the µP development is very interesting. The first µP was introduced in 1971 by Intel Corporation. This was the Intel 4004, a processor on a single chip. It had the capability of performing simple arithmetic and logical operations. E.g. Addition, subtraction, comparison, logical AND and OR. It also had a control unit which could perform various control functions like fetching an instruction from the memory, decoding it and generating control pulses to execute it. It was a 4 bit µP operating on 4 bits of data at a time. The processor was the central component in the chip set, which was called the MCS-4. The other components in the set were a 4001

ROM, 4002 ROM and a 4003 shift register.

Shortly after the 4004 appeared in the commercial market place, there is other general purpose µP were introduced. These devices were the Rockwell International 4 bit PPS-4, the Intel 8 bit 8008 and the National Semiconductor 16 bit IMP-16. Other companies had also contributed in the development of µP.

The first 8 bit µP, which would perform arithmetic and logic operations on 8 bit words, was introduced in 1973, by Intel. This was 8008 that was followed by an improved version- the 8080 from the same company. The µPs introduced between 1971and 1972 were the first generator systems. They were designed using the PMOS technology. This technology provided low cost, slow speed and low output currents and was compatible with TTL.

After 1973, the second generation µPs such as Motorola 6800 and 6809, Intel 8085 and Zilog Z80 evolved. These µPs were fabricated using NMOS technology. The NMOS process offered faster speed and higher density than PMOS and was TTL compatible. The distinction between the 1st & 2nd generation devices was primarily the use of new a semiconductor technology to fabricate the chips. This new technology resulted in a significant increase in instruction execution speed & higher chip densities.

After 1978, the 3rd generation microprocessors were introduced. Typical µPs are Intel 8086/80186/80286 and Motorola 68000/68010. These µPs were designed using HMOS technology.

HMOS provides the following advantages over NMOS.

1) Speed power produced (SSP) of HMOS is 4 times better than that of NMOS. That is for NMOS, SSP is 4 picojoules (PJ) and for HMOS, SSP is 1 picojoules (PJ).

   Speed power product = speed * power

   = nanoseconds * mill watt

   = picojoules

2) Circuit densities provided by HMOS are approximately twice those of NMOS. That is for NMOS. It is 4128 μm^2/gate and for HMOS it is 1052.5 μm^2/gate, where 1 $\mu m = 10^{-6}$ meter.

Later, Intel initialized the HMOS technology to fabricate the 8085A. Thus, Intel offers a high speed version of the 8085A called 8085AH.

The third generation introduced in 1978 is typically separated by the Intel 8086 iAPX 8086 iAPX 80186, iAPX 80286 Zilog 78000, and the Motorola 68000 which are 16- bit µPs with minicomputer like performances. One of the most popular 16 bit µP has been introduced by Intel, which is 8088. The 8088 has the same introduction set as the 8088. However, it has only an 8 bit data bus. The 8088 is the µP used in the IBM PC and its clones.A precursor to these microprocessors was the 16-bit Texas instruments 9900 microprocessor introduced in 1976. The latest microprocessor has the word length of 32-bit. Example of 32-bit microprocessors are Intel iAPX 80386, iAPX 432, Motorola MC68020, National semiconductor NS 32032. The characteristic for few microprocessors introduced by Intel are given in the Table. This shows that power of microprocessors has increased tremendously with advancement in integrated circuit technology & microprocessor systems architecture. Very large & cute integration, VLSI allow extremely complex system consisting of as many as a million of transistors on a single chip to be realized.

In 1980, the fourth generation µPs were evolved. Intel introduced the first commercial 32 bit microprocessor, Intel 432. This µP was discontinued by Intel due to some problem. Since 1985, more 32bit µPs have been introduced. These include the Motorola MC

68020/68030/68040 and Intel 80386/80486. These processors are fabricated using the low power version of HMOS technology called HCMOS, and they include an on-chip RAM called the cache memory to speed up program execution.

Table evaluation of major μp characteristics.

	4004	**8008**	**8085A**	**8086**	**80386**
Data	71	71	77	78	85
Lass	4-bit	8	8	16	32
Technology	PMOS	PMOS	NMOS	HMOS	CHMOS
Record size data/ must	4/8	8/8	8/8	16/16	32/32
Address capacity	4K	16K	64K	1M	4G
Clock kHz/phase	740/2	800/2	6250/2	8000/2	16000/2
Add time	10.8 s	20 s	1.3 s	0.375 s	0.125 s
Internal reg. al/gp	1/16	1/6	1/6	1/8	1/8
Tale size	3*12	7*14	RWM	RWM	RWM
Records/ bits	150-10,5*	-9.5v	+5V	+5V	+5V
Voltages	16pin	18pin	40pin	40pin	132pin
Package size introduction	45	48	74	133	135
Transition	2300	2000	6200	29000	275000
Chip size (mil)	117*159	125*170	164*222	225*230	390*390

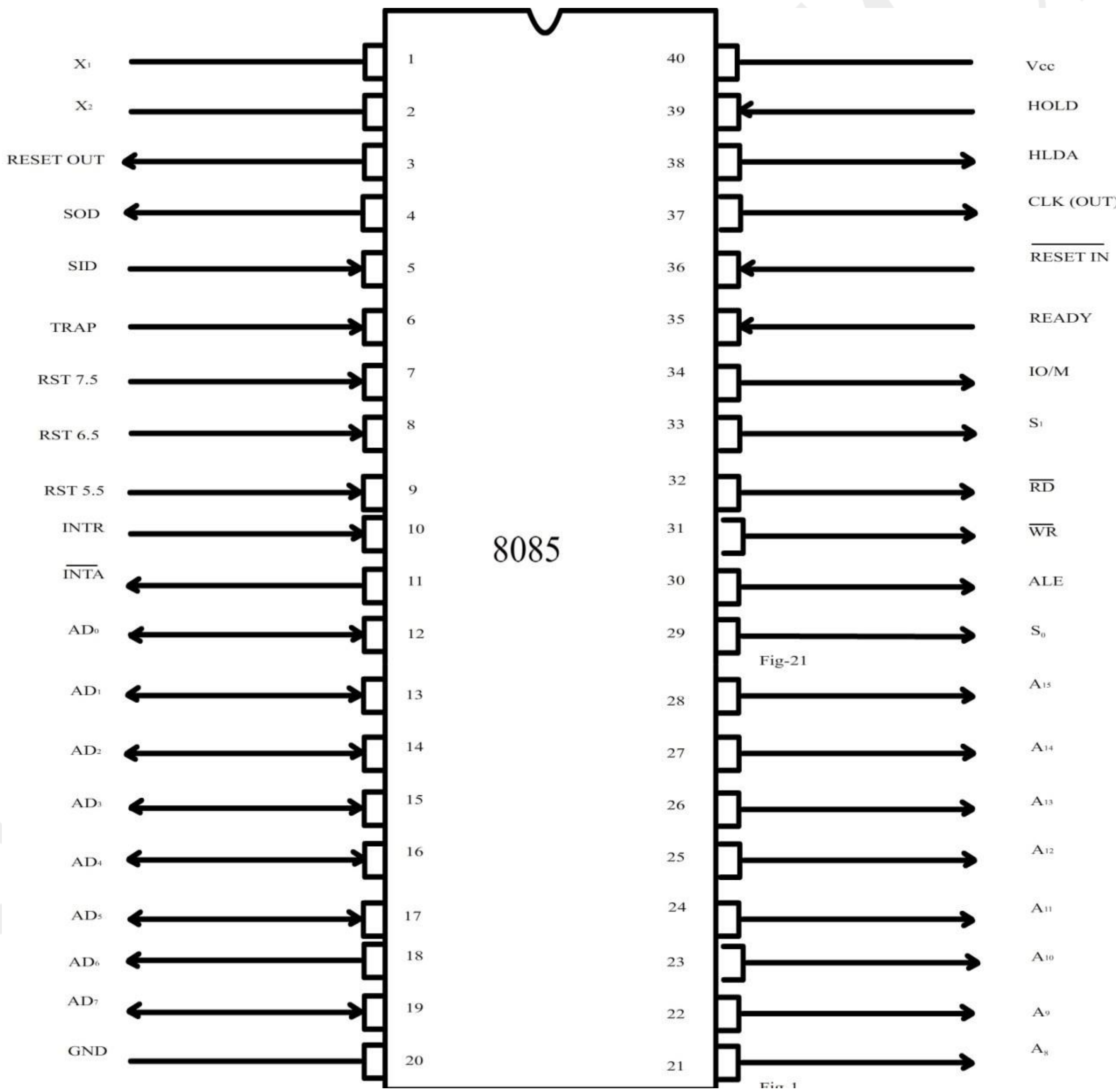
Manufactures	Intel	Intel	Intel	Intel	Intel

The performance offered by a32 bit µP is more comparable to that of super computers such as VAX 11. Recently, Intel and Motorola

introduced a 32 bit RISC (Reduced Instruction Set Computer) µP (Intel 80960 and Motorola 88100) with a simplified instruction set. The trend in µPs is not toward introduction of 64 bit µPs. Extensive research is being carried out for implementation of more on chip functions and for improvement of the speed of the memory and I/O devices; i.e. microcontrollers.

Intel 8085 Microprocessor

It is a 40-pin DIP(Dual in package) chip, base on NMOS technology, on a single chip of silicon. It requires a single +5v supply between Vcc at pin no 40 and GND at pin no 20. It can address directly 2^{16} memory locations or 6536 memory locations or 64k memory locations using 16 address line (A_{15}-A_0).



Pin no 28 to 21 gives as the higher order 8 bits of the address (A_{15}-A_8).these 8- address lines are uni-directional tri-state address lines these address lines becomes tri-state under three conditions namely.

(a)During DMA (direct memory access)operation

(b)When a HALT instruction is executed

(c)When μp is being RESET.

A_{15}-A_8 at pin no 19 to pin no 12 → pin no 19 to pin no 12, marked A_7-A_0 is used for dual purpose. The μp during it operation shall move from one state to the other. There are ten (10) different states for the μp namely.

(1)RESET STATE → (T_{RESET}) → μp can be in T_{RESET} state for an integral multiple clock cycle.

(2)WAIT STATE → (T_{WAIT}) → it can be in this state for an integral no of clock cycle. The duration being determined by an external control signal input marked READY.

(3)HOLD STATE → (T_{HOLD}) → H depends upon the external control signal input HOLD.

(4)HALT STATE → (T_{HALT}) → μp enter there state when an ILT instruction is executed by μp it remains in this state till such time when an external signal dictated by the use asked the μp to perform further duties.

(5)The other states, the μp can be IN are marked T_1,T_2,T_3,T_4,T_5 & T_6 states each of them states are of one clock period duration each of there states clearly identifies the predetermined timing slots T_1,T_2,T_3,T_4,T_5 & T_6 μp perform specific very well defined activities during these states.

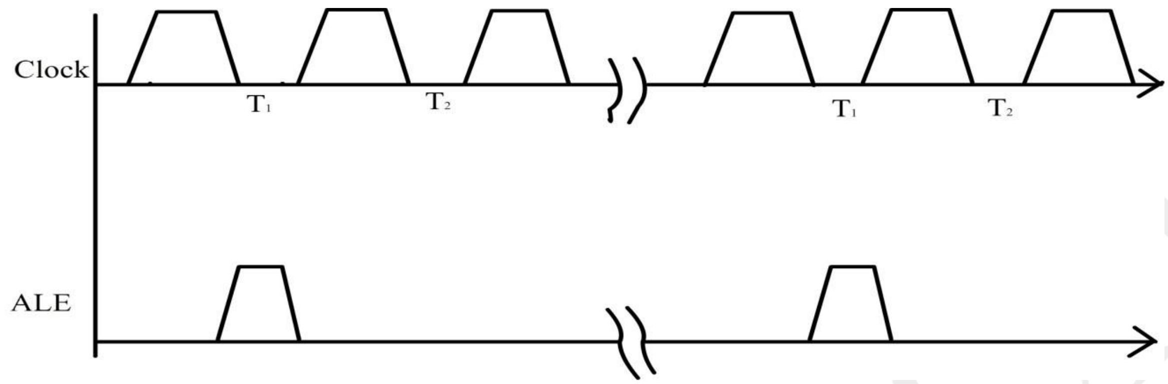
Pin Configuration of Intel 8085A Microprocessor:

Pin no 19 to pin no 12 shall be utilize by the μp to sent lower order bits of the 8^{16} –bit of information during T_1 timing slots and therefore, the same 8-points shall be utilized as bi-directional data bus (BDB) for data transfer operation in the subsequent timing slots T_2 & T_3 Hence these pins are designated AD_7 to AD_6

These 8- lines are also tri-state line they will be tri-stated during T_4, T5 & T_6 states. They will also be tri-stated during DMA operation and when a HALT instruction is executed. These lines will also be tri-stated for a very-short duration of time (few neon sec) between T_1 & T_2 states.

ADDRESS LATCH ENABLE (ALE) AT PIN NO 30

it is a single pulse issued every T_1 state of the μp as shown on fig-2.since the lower order 8-bits of the address information A_7 to A_0 is available at pin no 19 to 12, when ALE pulse exists at pin no 30. We can use these information to latch the lower order bits of the address externally using (say) an 8212 register latch once save on an external latch the lower order address A_7 to A_0 shall be available at the output of the register latch for the subsequent states T_2, T3, T4, T5 & T_6, while pin no 19 to 12 can then be utilized by the μp for bi-directional operation.

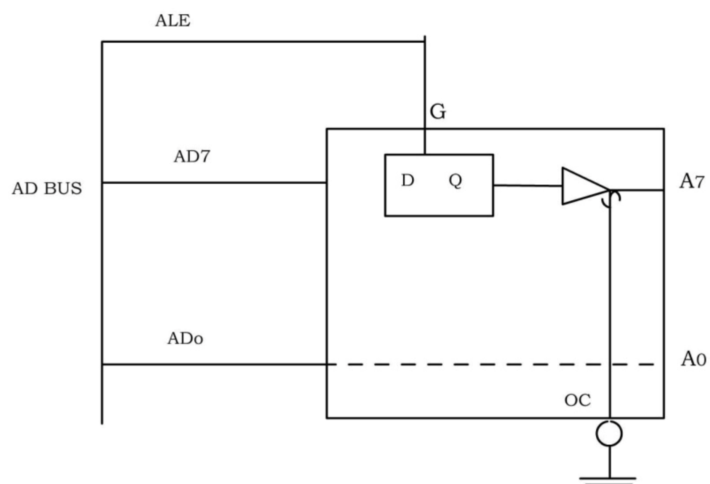


The manner of utilization of pins 19 to 12 is known as time multiplexed mode of operation.

De multiplexing the Address bus AD_1 –AD_0:

The 8085 A uses a multiplexed address-data bus. This is due to limited number of pins on the 8085A-IC. Low-order 8-bits of the memory address (or I/O address) appear on the AD bus during the first clock cycle. (T_1 state of an m/c cycle) It then becomes the data bus during the second and third clock cycles (T_2 and T_3 states). ALE, address latch enable signal occurring during the T_1 state of a m/c cycle is used to latch the address into the on-chip latch of certain peripherals such as 8155/8156/8355/8755A. These chips ALE input pin is connected to the ALE output pin of the 8085 A, thus allowing a direct interface with the 8085 A. Thus IC chips internally de multiplex the AD bus using the ALE signal. Since a majority of peripheral devices do not have the internal multiplexing facility, there is external hardware necessity for it.

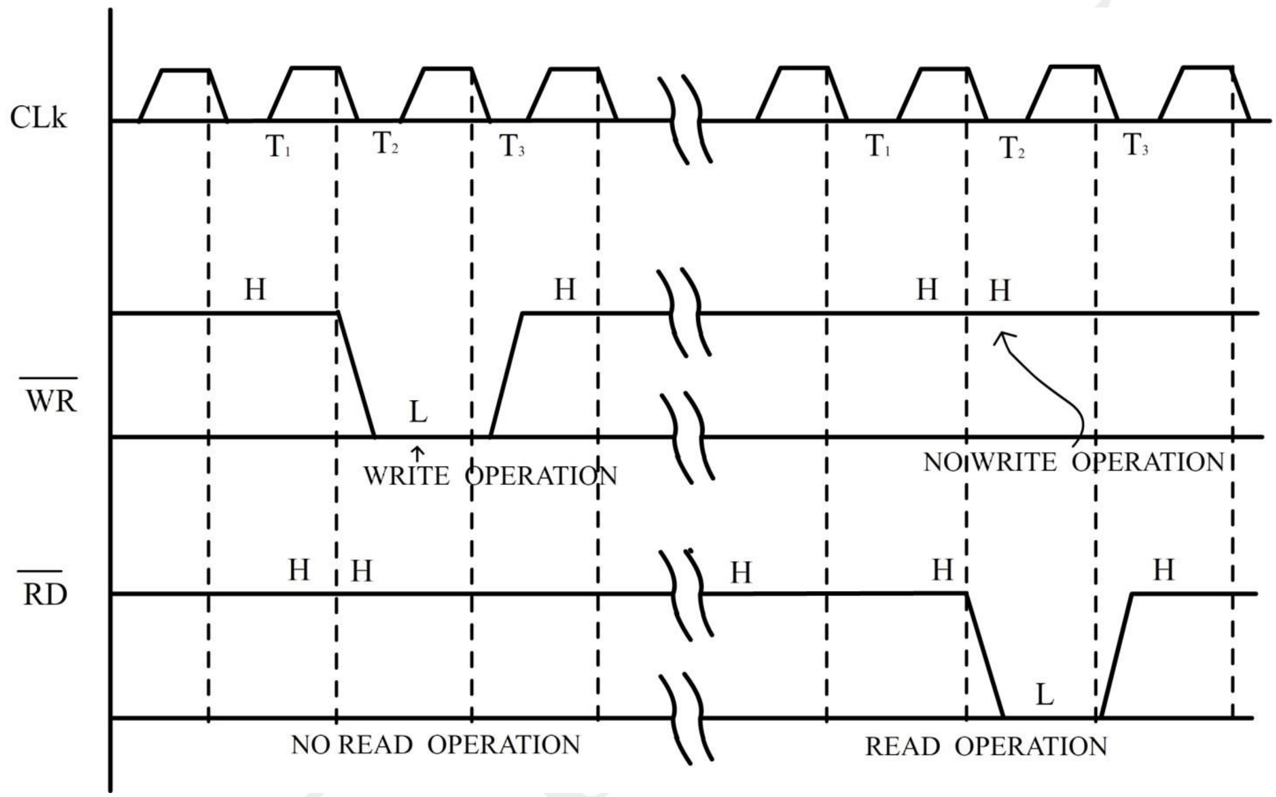
Fig. shows a schematic that uses a latch and the ALE signal to de multiplex the bus. The bus AD_1-AD_0 is connected as the input to the latch 74LS373. The ALE signal is connected to the enable (G) pin of the latch, and the output control (OC) signal of the latch is grounded. When ALE goes high during the T_1 state of a m/c cycle, the latch is transparent in the output of the latch changes according to the input. The CPU is putting lower-order bits of address during this time. When the ALE goes LOW, the address bits get latched on the output and remain so until the next ALE signal.



<u>Read & Write Control signals at pin no 32 & pin no 31 $\overline{RD}$ & $\overline{WR}$ →</u>

The BDB at pin no 19 to 12 are used for bi-directional data transfer operation T_2 & T_3 states when the BDB is inputting the information from the external world into the μp, we say that μp is in READ MODE and operation is READ operation. When the μp is outputting 8-bit of information to the external world through BDB we have a WRITE operation μp is in OUTPUT MODE or WRITE MODE. To tell the external world that μp is in WRITE MODE. μp Issues a control signal $\overline{WR}$ output at pin no 31 it is normally HIGH & becomes active & LOW.

It goes LOW during T_2 state and goes HIGH again during T_3 state of the. This is shown is fig.3



When the BDB is in the input mode for READ operation, RD the control signal. Output goes Low during T_2 state and goes HIGH during T_3 state. Note that the normal RD state of is HIGH. Also note that for obvious reasons RD & WR are not made active LOW simultaneously. Note further whenever, the BDB is made to be in the INPUT MODE by the μp, it issues the RD control signal output by making it active LOW as described and it is for the user to beep the appropriate 8-bit data either from the memory or from a peripheral device at this appropriate time similarly during a WRITE operation μp first send the desired address in the address lines during T_1 states. Thereafter, if places the desired 8-bit data on the BDB which is na in the output mode and then issues the $\overline{WR}$ control signal output as described. It is for the user to take appropriate action externally by it interfacing circuitry so that the data so placed goes to the appropriate device.

IO/ $\overline{M}$ at pin no 34 →

O/ $\overline{M}$ is an output tri-state control signal. It is active both way whenever the address issued by the μp on the address lines refers to the memory then the μp makes IO/ $\overline{M}$ LOW throughout T_1, T_2, T_3, T_4, T_5 & T_6 states to indicate the external world that the address so sent belongs to the memory and data on the BDB refers to the memory. Whenever the address in the address lines. Refers to an I/O device the μp makes IO/ $\overline{M}$ control signal output HIGH to tell the external world that the address in the address lines refer to I/O device and the data in the BDB refers to an I/O device.

Note that IO/ $\overline{M}$ signal is LOW or HIGH as the case may be throughout six timing slots T_1, T_2, T_3, T_4, T_5 & T_6 states. It is for the user to make use of the facilities give to develop proper interfacing circuitry.

Microcontroller

Contents

•Introduction
•Inside 8051
•Instructions
•Interfacing

Introduction

- Definition of a Microcontroller
- Difference with a Microprocessor
- Microcontroller is used where ever

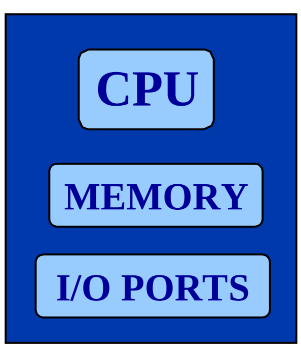
Definition

- It is a single chip
- Consists of Cpu, Memory
- I/O ports, timers and other peripherals

Difference

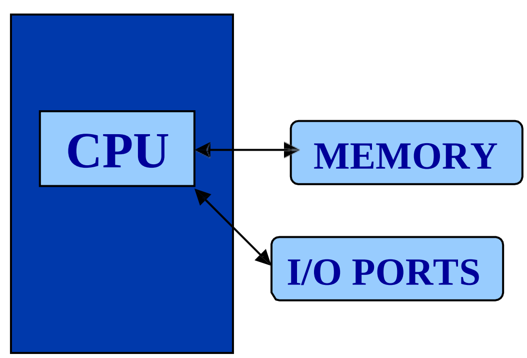
MICRO CONTROLLER

- It is a single chip
- Consists Memory,
- I/o ports



MICRO PROCESSER

- It is a cpu
- Memory, I/O Ports to be connected externally.



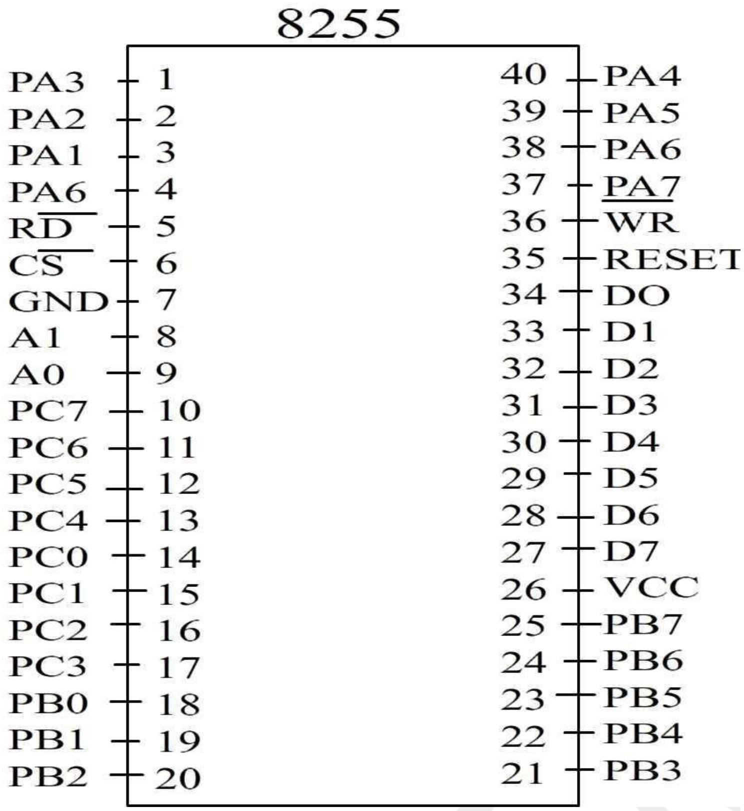
Where ever

- Small size
- Low cost
- Low power

Unit – 3 8255: (Programmable Peripheral Interface)

The 8255A is a general purpose programmable I/O device designed for use with Intel microprocessors. It consists of three 8-bit bidirectional I/O ports (24I/O lines) that can be configured to meet different system I/O needs. The three ports are PORT A, PORT B & PORT C. Port A contains one 8-bit output latch/buffer and one 8-bit input buffer. Port B is same as PORT A or PORT B. However, PORT C can be split into two parts PORT C lower (PC_0-PC_3) and PORT C upper (PC_7-PC_4) by the control word. The three ports are divided in two groups Group A (PORT A and upper PORT C) Group B (PORT B and lower PORT C). The two groups can be programmed in three different modes. In the first mode (mode 0), each group may be programmed in either input mode or output mode (PORT A, PORT B, PORT C lower, PORT C upper). In mode 1, the second's mode, each group may be programmed to have 8-lines of input or output (PORT A or PORT B) of the remaining 4-lines (PORT C lower or PORT C upper) 3-lines are used for hand shaking and interrupt control signals. The third mode of operation (mode 2) is a bidirectional bus mode which uses 8-line (PORT A only for a bidirectional bus and five lines (PORT C upper 4 lines and borrowing one from other group) for handshaking.

The 8255 is contained in a 40-pin package, whose pin out is shown below:



<u>PIN Names</u>

RESET – Reset input

$\overline{CS}$ - Chip selected

$\overline{RD}$ - Read input

$\overline{WR}$ - Write input

A_0 A_1 – Port Address

PA_7 – PA_0 – PORT A

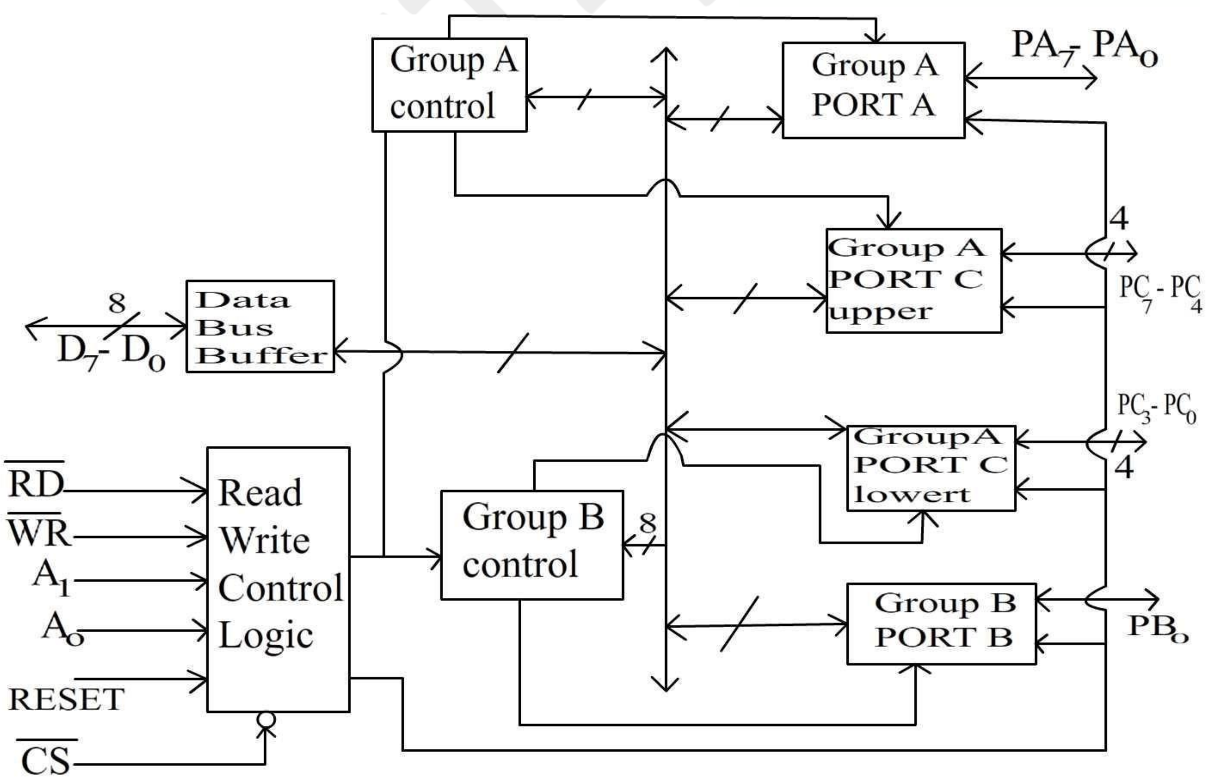
PB_7 – PB_0 – PORT B

PC_7 – PC_0 – PORT C

VCC - +5v

GND - Ground

The block diagram is shown below:



Functional Description:

This support chip is a general purpose I/O component to interface peripheral equipment to the microcomputer system bus. It is programmed by the system software so that normally no external logic is necessary to interface peripheral devices or structures.

Data Bus Buffer:

It is a tri-state 8-bit buffer used to interface the chip to the system data bus. Data is transmitted or received by the buffer upon execution of input or output instructions by the CPU. Control words and status information are also transferred through the data bus buffer. The data lines are connected to BDB of p.

Read/Write and logic control:

The function of this block is to control the internal operation of the device and to control the transfer of data and control or status words. It accepts inputs from the CPU address and control buses and in turn issues command to both the control groups.

$\overline{CS}$ Chip Select:

A low on this input selects the chip and enables the communication between the 8255 A & the CPU. It is connected to the output of address decode circuitry to select the device when it $\overline{RD}$ (Read). A low on this input enables the 8255 to send the data or status information to the CPU on the data bus.

$\overline{WR}$ (Write):

A low on this input pin enables the CPU to write data or control words into the 8255 A.

A_1, A_0 port select:

These input signals, in conjunction with the $\overline{RD}$ and $\overline{WR}$ inputs, control the selection of one of the three ports or the control word registers. They are normally connected to the least significant bits of the address bus (A_0 and A_1).

Following Table gives the basic operation,

A_1	A_0	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	Input operation
0	0	0	1	0	PORT A → Data bus
0	1	0	1	0	PORT B → Data bus
1	0	0	1	0	PORT C → Data bus
0	0	1	0	0	Output operation Data bus → PORT A
0	1	1	0	0	Data bus → PORT B
1	0	1	0	0	Data bus → PORT C
1	1	1	0	0	Data bus → control

All other states put data bus into tri-state/illegal condition.

RESET:

A high on this input pin clears the control register and all ports (A, B & C) are initialized to input mode. This is connected to RESET OUT of 8255. This is done to prevent destruction of circuitry connected to

Ppppppppppppppp

reset, the port might try to output into the output of a device connected to same inputs might destroy one or both of them.

PORTs A, B and C:

The 8255A contains three 8-bit ports (A, B and C). All can be configured in a variety of functional characteristic by the system software.

PORTA:

One 8-bit data output latch/buffer and one 8-bit data input latch.

PORT B:

One 8-bit data output latch/buffer and one 8-bit data input buffer.

PORT C:

One 8-bit data output latch/buffer and one 8-bit data input buffer (no latch for input). This port can be divided into two 4-bit ports under the mode control. Each 4-bit port contains a 4-bit latch and it can be used for the control signal outputs and status signals inputs in conjunction with ports A and B.

Group A & Group B control:

The functional configuration of each port is programmed by the system software. The control words outputted by the CPU configure the associated ports of the each of the two groups. Each control block accepts command from Read/Write content logic receives control words from the internal data bus and issues proper commands to its associated ports.

Control Group A – Port A & Port C upper

Control Group B – Port B & Port C lower

The control word register can only be written into No read operation if the control word register is allowed.

Operation Description:

Mode selection:

There are three basic modes of operation that can be selected by the system software.

Mode 0: Basic Input/output

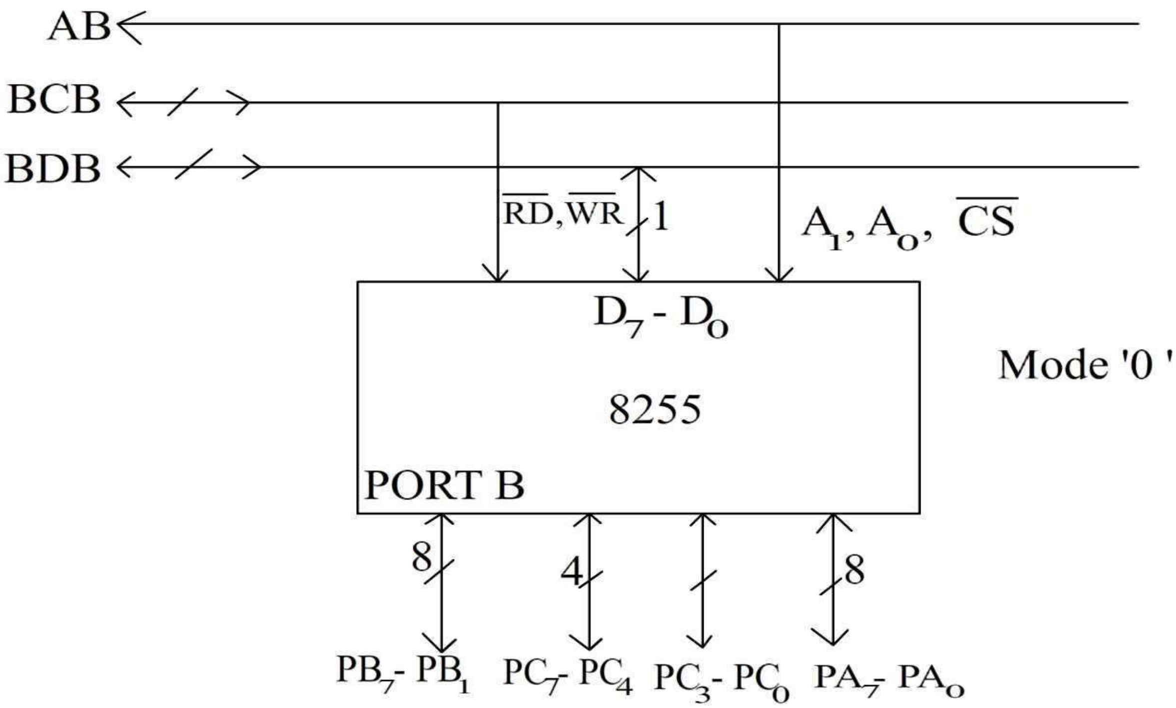
Mode 1: Strobes Input/output

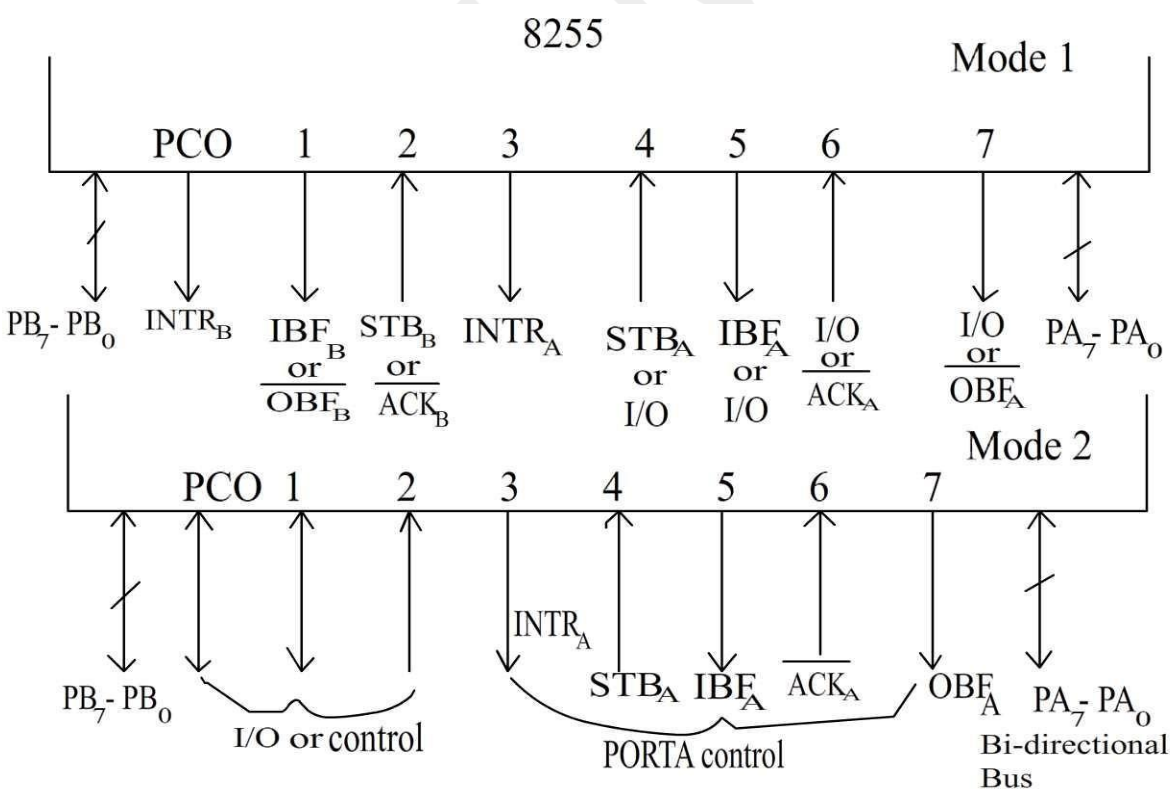
Mode 2: Bi-direction bus.

When the reset input goes HIGH all poets are set to mode'0' as input which means all 24 lines are in high impedance state and can be used as normal input. After the reset is removed the 8255A remains in the input mode with no additional initialization. During the execution of the program any of the other modes may be selected using a single output instruction.

The modes for PORT A & PORT B can be separately defined, while PORT C is divided into two portions as required by the PORT A and PORT B definitions. The ports are thus divided into two groups Group A & Group B. All the output register, including the status flip-flop will be reset whenever the mode is changed. Modes of the two group may be combined for any desired I/O operation e.g. Group A in mode '1' and group B in mode '0'.

The basic mode definitions with bus interface and the mode definition format are given in fig (a) & (b),


AB
BCB
BDB
RD, WR
1
A1, A0, CS
D7 - D0
8255
Mode '0 '
PORT B
8
4
8
PB7 - PB1
PC7 - PC4
PC3 - PC0
PA7 - PA0


8255
Mode 1
PCO
1
2
3
4
5
6
7
PB7 - PB0
INTRB
IBFB or OBFB
STBB or ACKB
INTRA
STBA or I/O
IBFA or I/O
I/O or ACKA
I/O or OBFA
PA7 - PA0
Mode 2
PCO
1
2
3
4
5
6
7
PB7 - PB0
I/O or control
INTRA
STBA
IBFA
ACKA
OBFA
PORTA control
PA7 - PA0
Bi-directional Bus