SENSOR AND TRANSDUCERS

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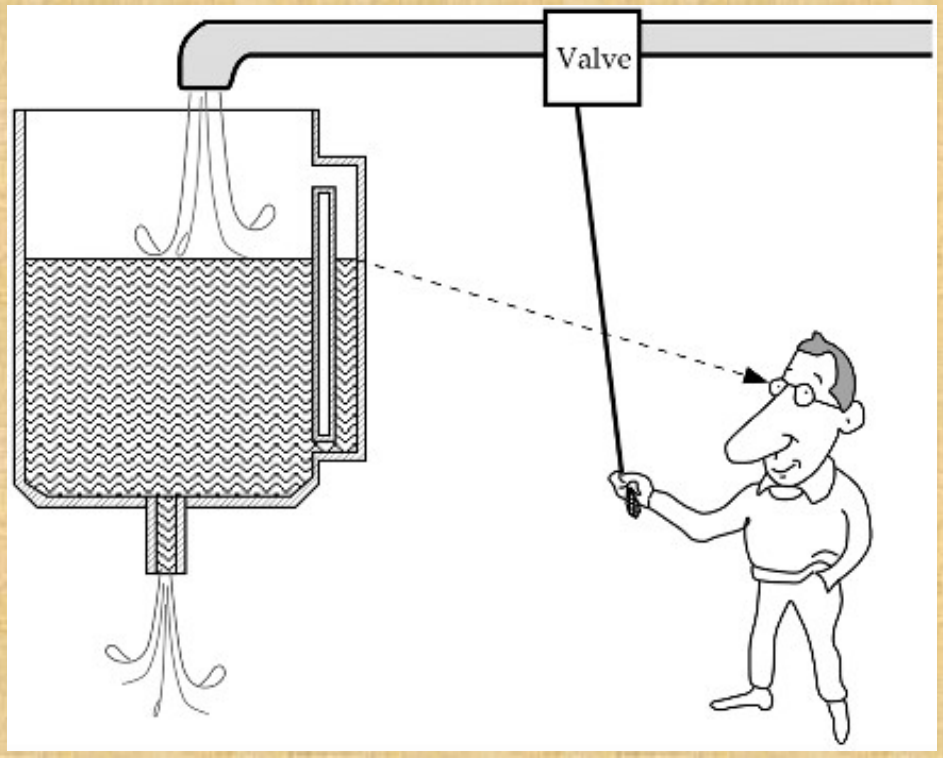
Sensor

A Device that receives and respond to a signal .

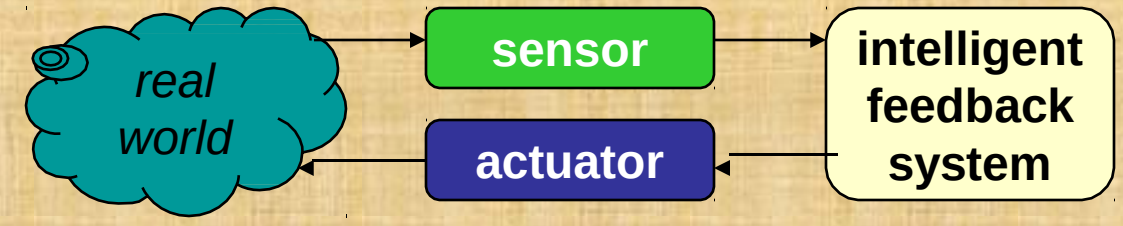


INTRODUCTION

- Transducer
  - a device that converts a primary form of energy into a corresponding signal with a different energy form
    - Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.
  - take form of a **sensor** or an **actuator**
- Sensor (e.g., thermometer)
  - a device that detects/measures a signal

–acquires information from the “real world”

- Actuator (e.g., heater)
  - a device that generates a signal

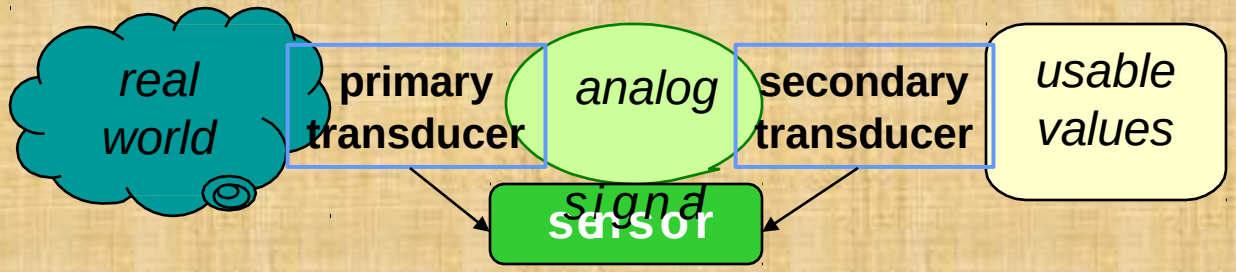


Sensor Systems

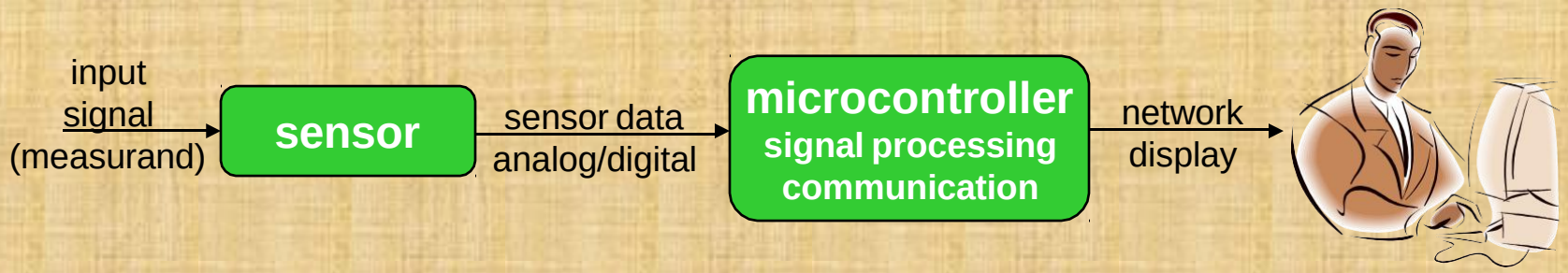
*Typically interested in **electronic sensor***

- convert desired parameter into electrically measurable signal

- General Electronic Sensor
  - primary transducer: changes “real world” parameter into electrical signal
  - secondary transducer: converts electrical signal into analog or digital values



- Typical Electronic Sensor System



Sensor Classification

- **Passive**
  - Doesn’t need any additional energy source
  - Directly generate an electric signal in response to an external stimuli
  - E.g. Thermocouple, photodiode, Piezoelectric sensor
- **Active**
  - Require external power called excitation signal
  - Sensor modify excitation signal to provide output
  - E.g. thermistor, resistive strain gauge

Sensor characteristics

- Span or Full scale input
  - represents the highest possible input value that can be applied to the sensor without causing an unacceptably large inaccuracy
  - g for accelerometer
- Full scale output
  - algebraic difference between the electrical output signals measured with maximum input stimulus and the lowest input stimulus applied
  - E.g. LM35

Sensor characteristics

- Accuracy
  - Accuracy is measured as a highest deviation of a value represented by the sensor from the ideal or true value at its input
  - accuracy limits generally are used in the worst-case analysis to determine the worst possible performance of the system
  - The inaccuracy rating may be represented in a number of forms:
    - Directly in terms of measured value *()*
    - In percent of input span (full scale)
    - In terms of output signal

Sensor characteristics

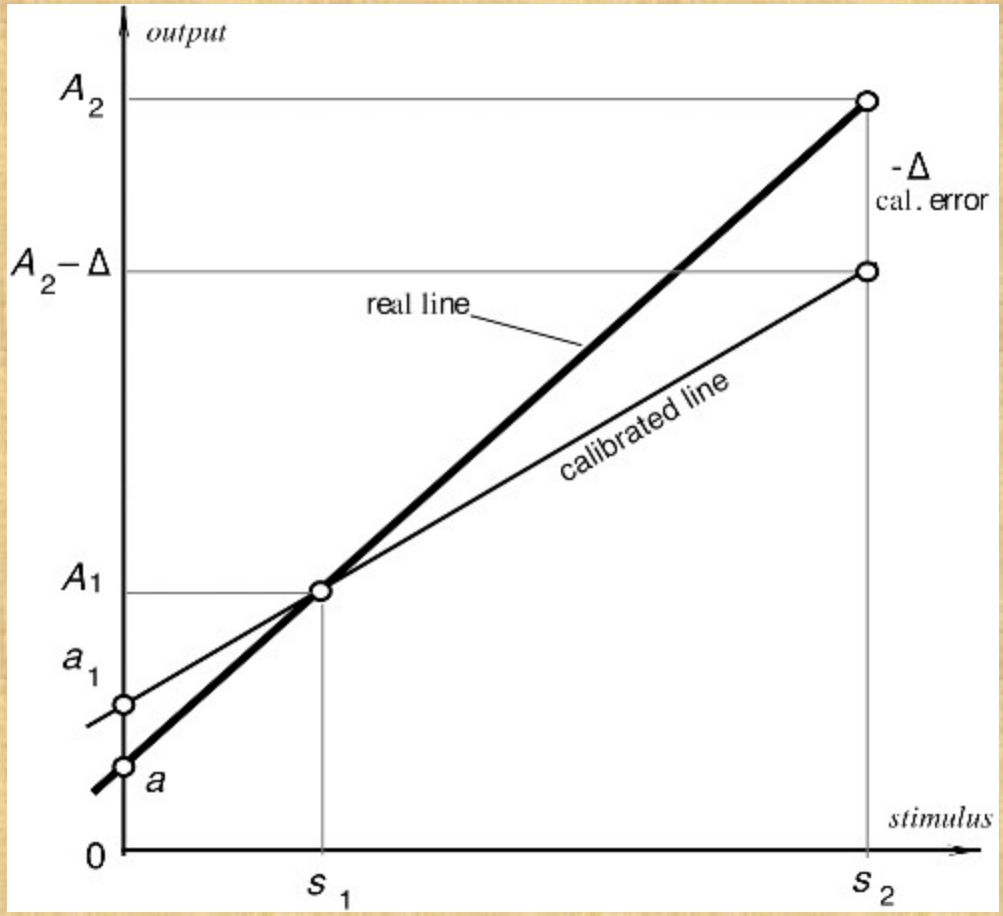
- Calibration
  - determination of specific variables that describe the overall transfer function
    - Overall means of the entire circuit, including the sensor, the interface circuit, and the A/D converter
  - E.g. use of forward biased diode for temperature measurement
    - Transfer function v=a+bt
    - Take measurement at two T's and solve and determine a and b
      - V1=a+bt1 and V2=a+bt2
  - For Non-linear function more than one point can be required depending on the transfer function
  - Another way is to use a piecewise approximation

Sensor characteristics

- Calibration error
  - inaccuracy

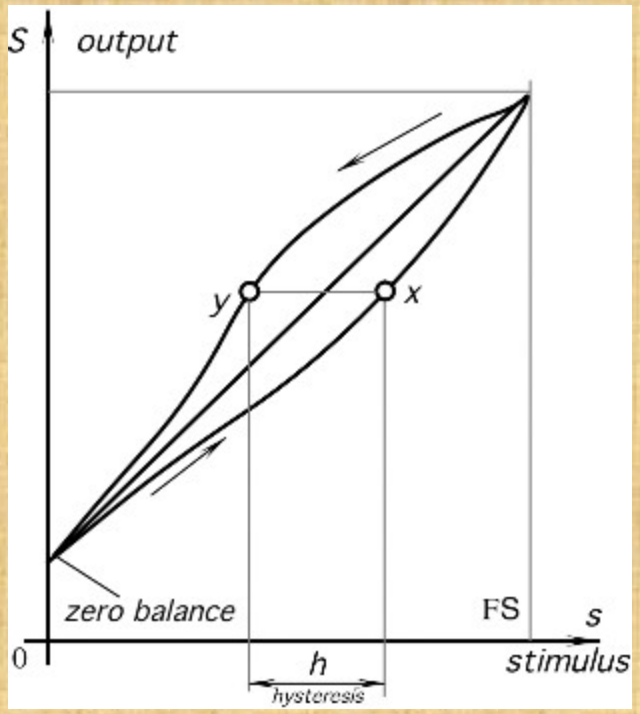
    permitted by a manufacturer when a sensor is calibrated in the factory

    Error is systematic in nature



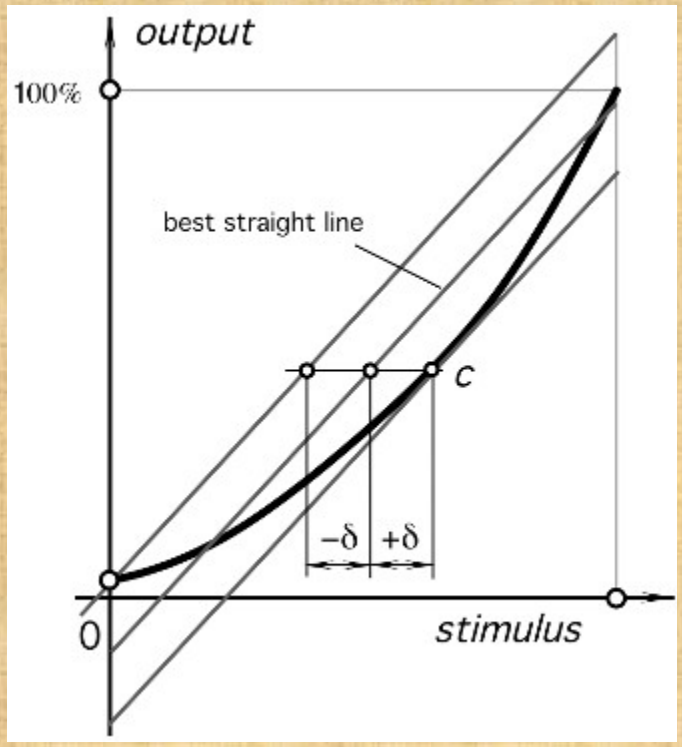
Sensor characteristics

- Hysteresis
  - deviation of the sensor's output at a specified point of the input signal when it is approached from the opposite directions



Sensor characteristics

- Non-linearity error
  - specified for sensors whose transfer function may be approximated by a straight line



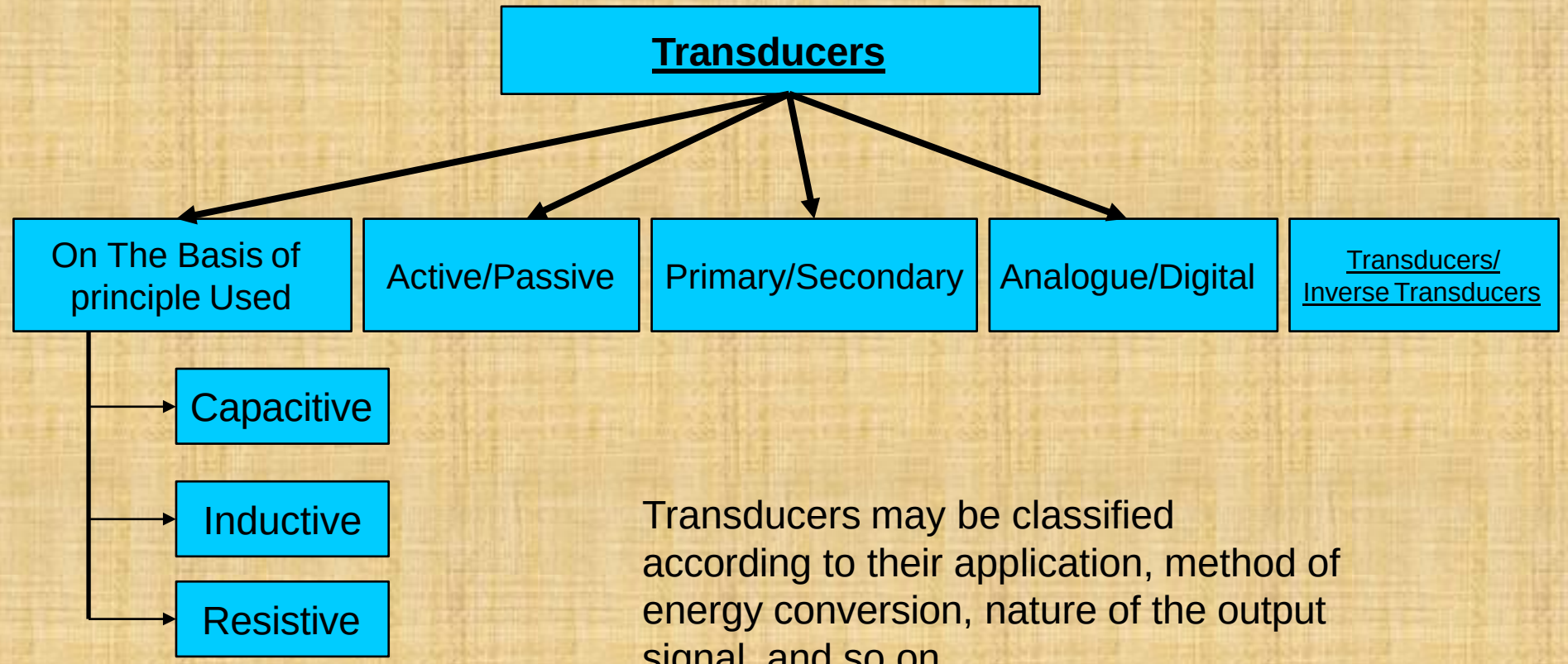
Sensor characteristics

- Repeatability
  - caused by the inability of a sensor to represent the same value under identical conditions
  - It is expressed as the maximum difference between output readings as determined by two calibrating cycles
  - It is usually represented as % of FS

Sensor characteristics

- Resolution
  - the smallest increments of stimulus which can be sensed
- Output impedance
  - The *output impedance Z_{out} is important to know to better interface a sensor with* the electronic circuit
  - For a current generating sensor should have an output impedance as high as possible and the circuit's input impedance should be low
  - For the voltage connection, a sensor is preferable with lower *Z_{out} and the circuit should have Z_{in} as high as practical*

Classification of Transducers



Transducers may be classified according to their application, method of energy conversion, nature of the output signal, and so on.

Selecting a Transducer

- What is the physical quantity to be measured?
- Which transducer principle can best be used to measure this quantity?
- What accuracy is required for this measurement?
  - Fundamental transducer parameters
  - Physical conditions
  - Environmental conditions
  - Compatibility of the associated equipment
- Reducing the total measurement error :
  - Using in-place system calibration with corrections performed in the data reduction
  - Artificially controlling the environment to minimize possible errors

Transducer, Sensor, and Actuator

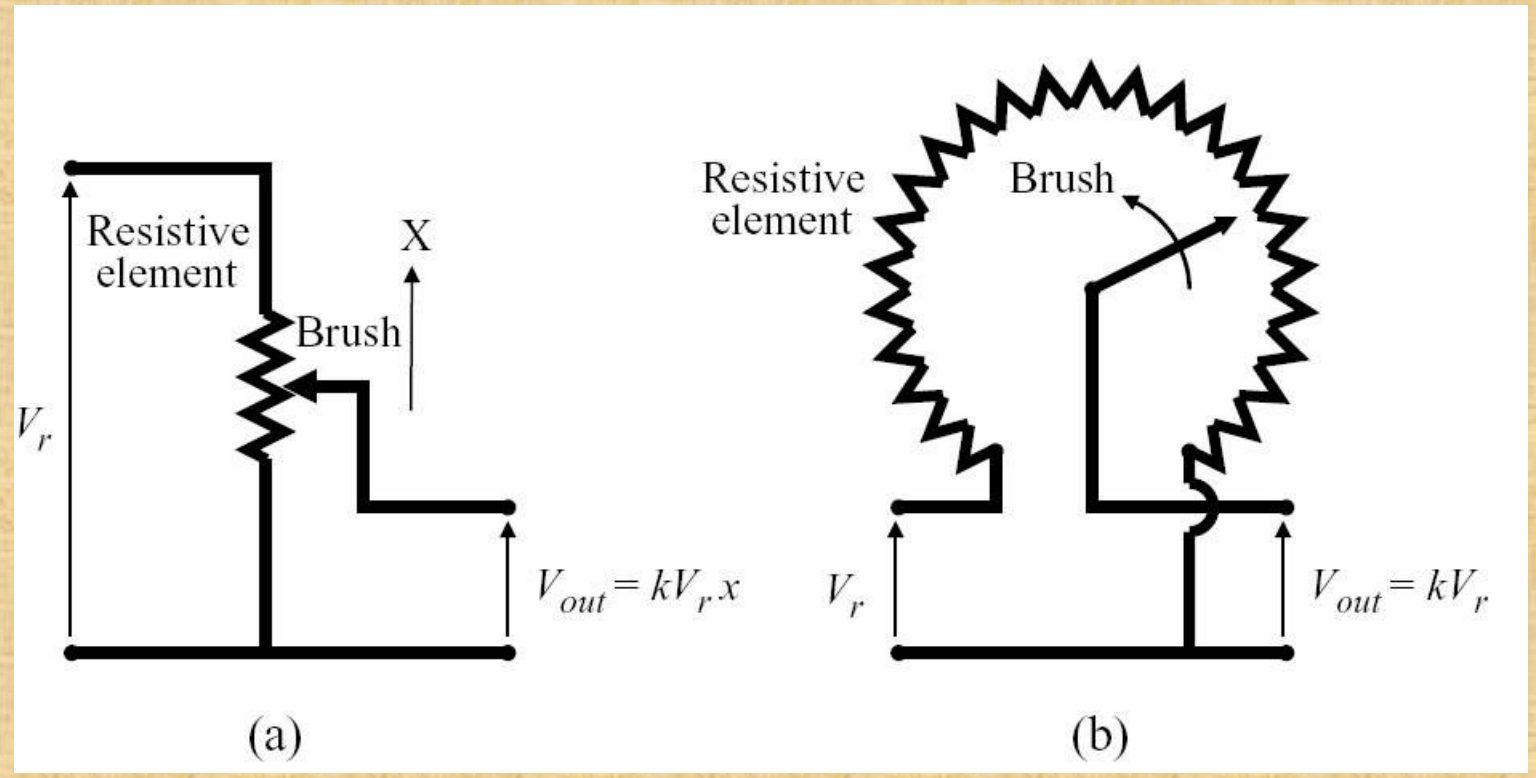
- Transducer:
  - a device that converts energy from one form to another
- Sensor:
  - converts a physical parameter to an electrical output (a type of transducer, e.g. a microphone)
- Actuator:
- converts an electrical signal to a physical output (opposite of a sensor, e.g. a speaker)

1.DISPLACEMENT,POSITION & PROXIMITY

- Displacement sensors are concerned with the measurement of the amount by which some object has been moved.
- Position sensors are concerned with the determination of the position of some object in relation to some reference point.
- Proximity sensors are a form of position sensor and are used to determine when an object has moved to within some particular critical distance of the sensor. They are essentially devices which give on/off outputs.

1.1 Potentiometer Sensor

- **Potentiometer** is one of the common sensors for position measurements.
- It relates the change in position (linear or rotary) into the change in resistance, as shown in Figure a and b



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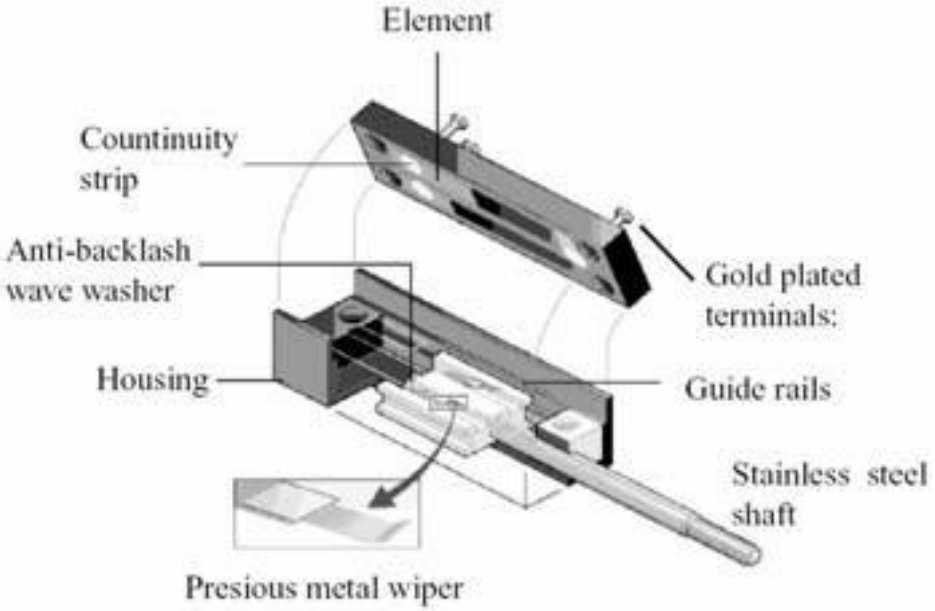
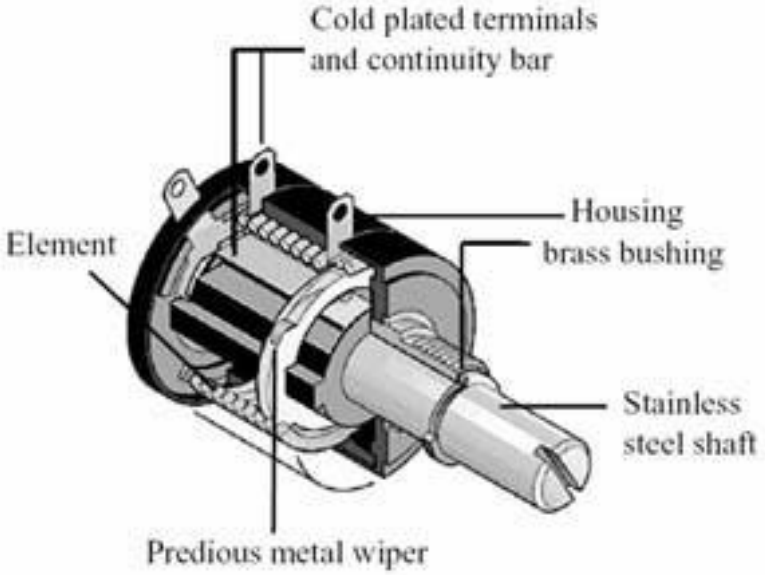
- The resistance change is then converted to a proportional voltage change in the electrical circuit of the sensor.
- Hence, the relationship between the measured physical variable, translational displacement *x* or rotary displacement θ, and the output voltage for a ideal potentiometer is

$$V_{out} = (k \cdot V_r) \cdot x \qquad \text{or} \qquad V_{out} = (k \cdot V_r) \cdot \theta$$

where the sensitivity, ($k * V_r$) , of the potentiometer is a function of the winding resistance and physical shape of the winding.

Potentiometer Picture

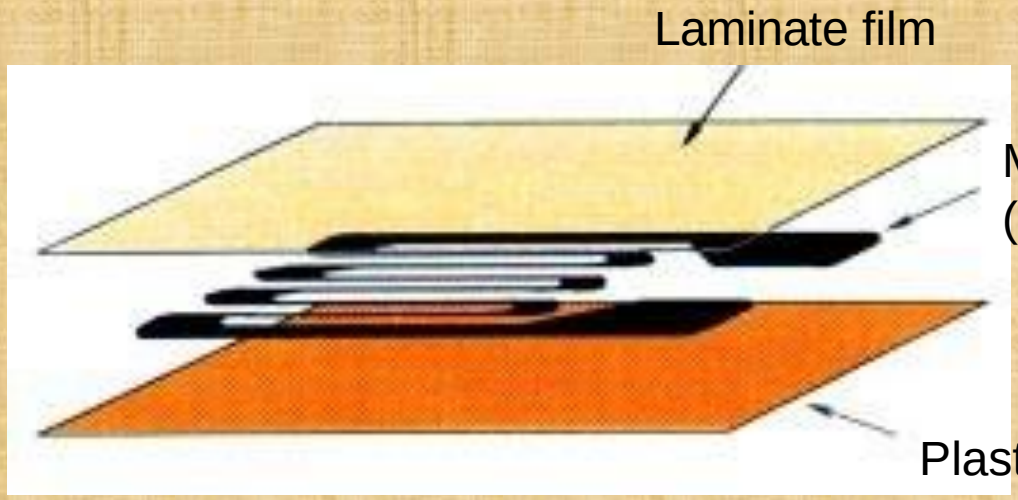




1.2 Strain Gauge

- Strain gauge: it is an electrical conductor whose resistance changes as it is strained.
- Structure of Strain Gauges

There are many types of strain gauges. Among them, a universal strain gage has a structure such that a grid-shaped sensing element of thin metallic resistive foil (3 to 6μm thick) is put on a base of thin plastic film (15 to 16μm thick) and is laminated with a thin film.



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- Principle of Strain Gages
- The strain gage is tightly bonded to a measuring object so that the sensing element (metallic resistive foil) may elongate or contract according to the strain borne by the measuring object.
- When bearing mechanical elongation or contraction, most metals undergo a change in electric resistance.
- The strain gage applies this principle to strain measurement through the resistance change. Generally, the sensing element of the strain gage is made of a copper-nickel alloy foil.
- The alloy foil has a rate of resist-ance change proportional to strain with a certain constant.

Let's express the principle as follows:

$$\frac{\Delta R}{R} = K.\varepsilon$$

where, R: Original resistance of strain gage, Ω (ohm)

ΔR: Elongation- or contraction-initiated resistance change, Ω (ohm)

K: Proportional constant (called gage factor)

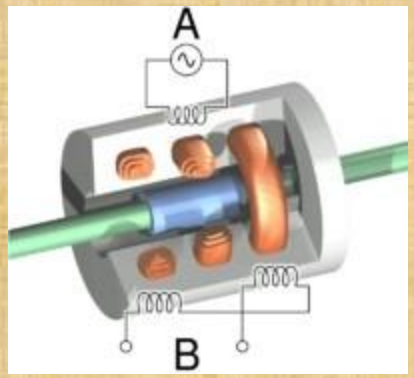
ε: Strain

1.3Linear Variable Differential Transformer (LVDT)

Principle of LVDT:

LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.

And the way how the energy is getting converted is described in working of LVDT in a detailed manner.



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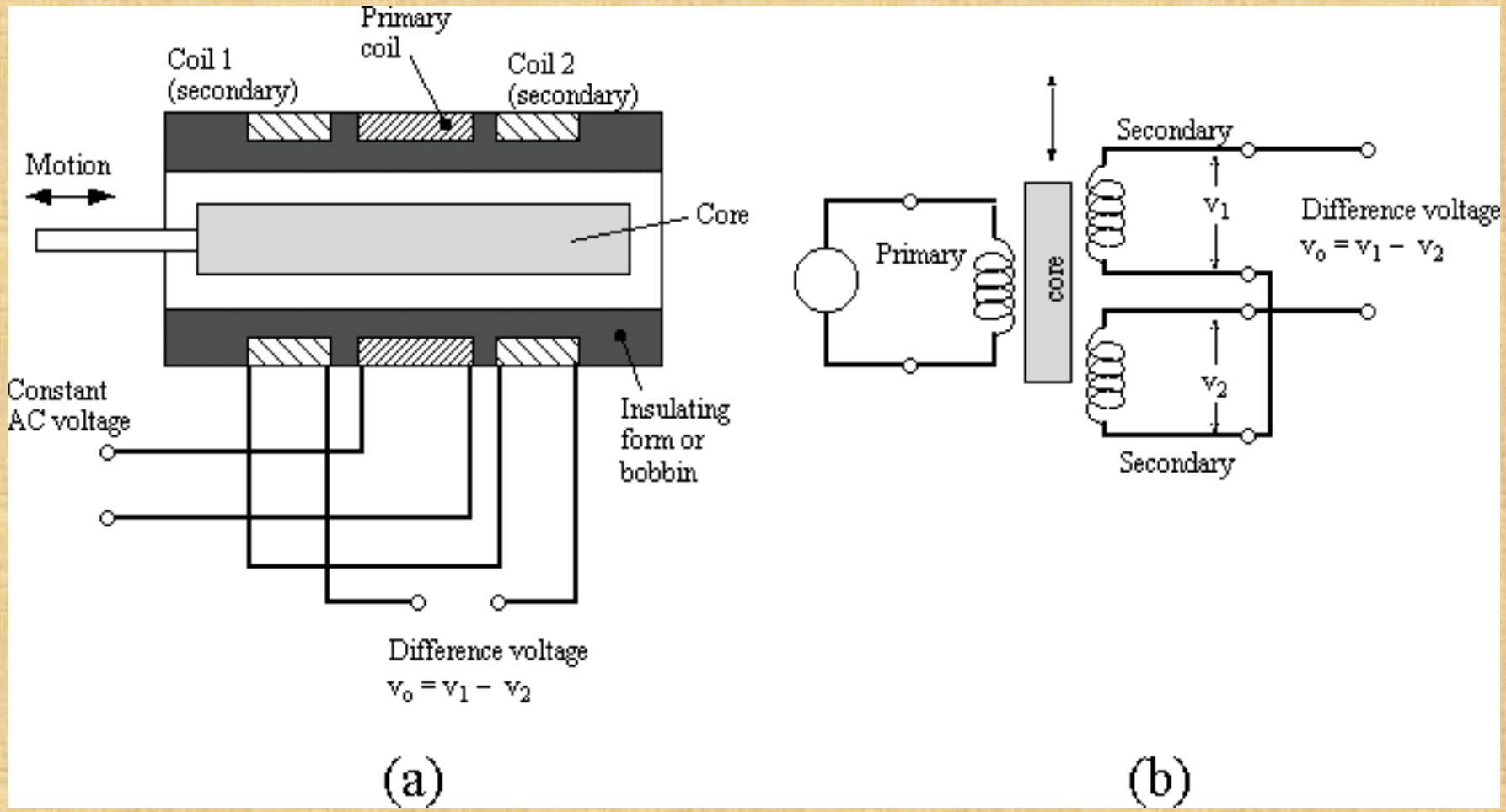
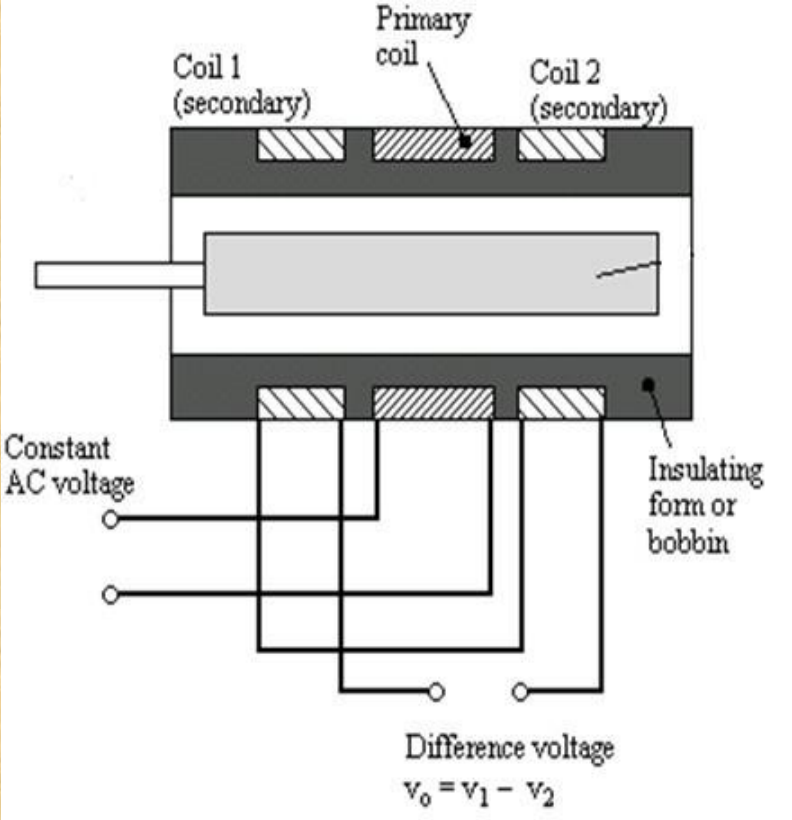
- **Construction of LVDT:**





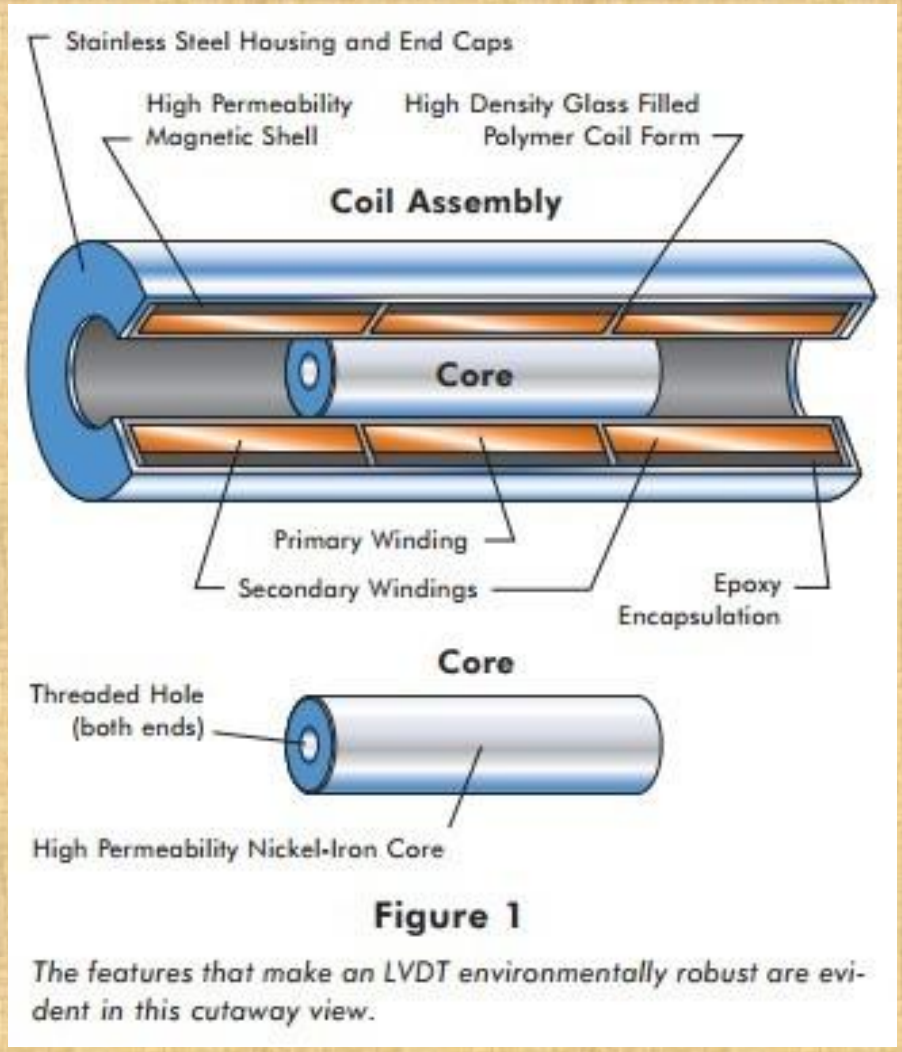


Figure 1

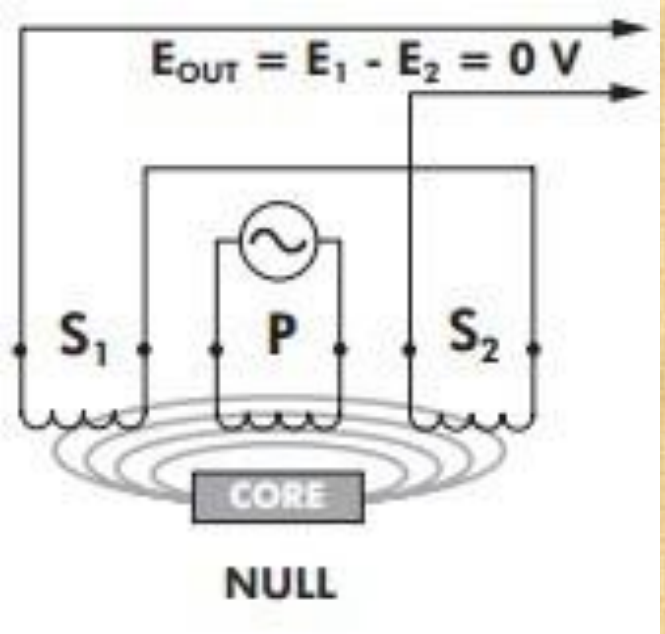
The features that make an LVDT environmentally robust are evident in this cutaway view.

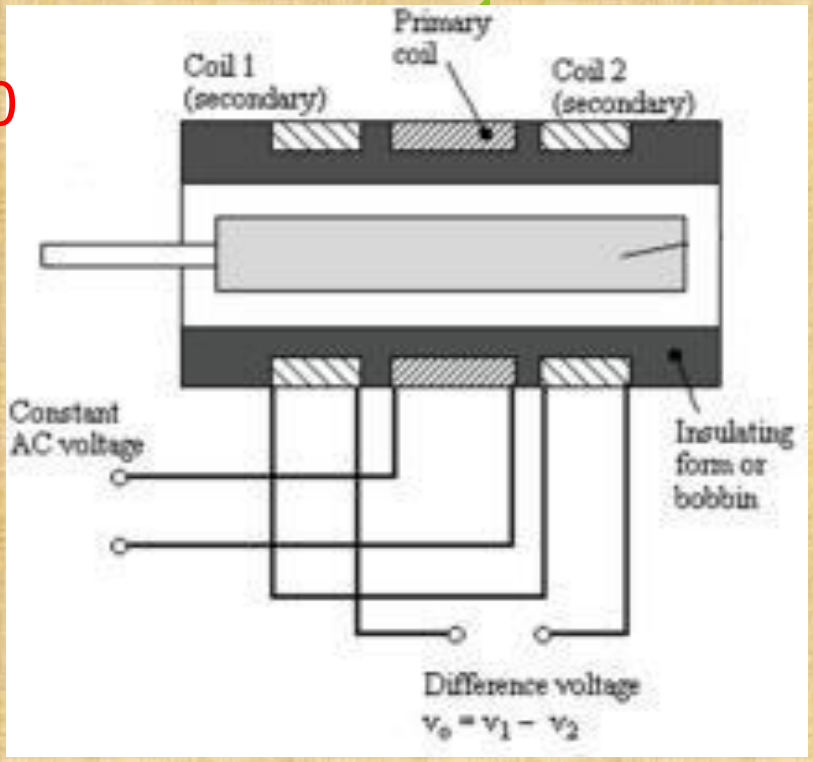
- LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides.

Working of LVDT:

On applying an external force which is the displacement, if the core reminds in the null position itself without providing any movement then the voltage induced in both the secondary windings are equal which results in net output is equal to zero

Esec1-Esec2=0

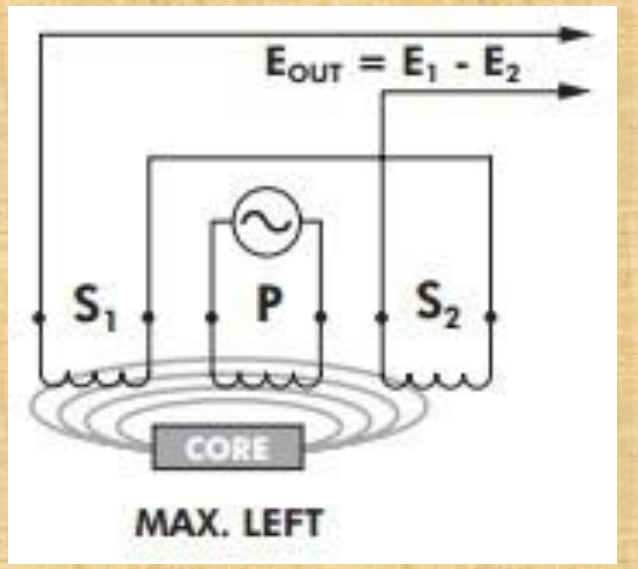


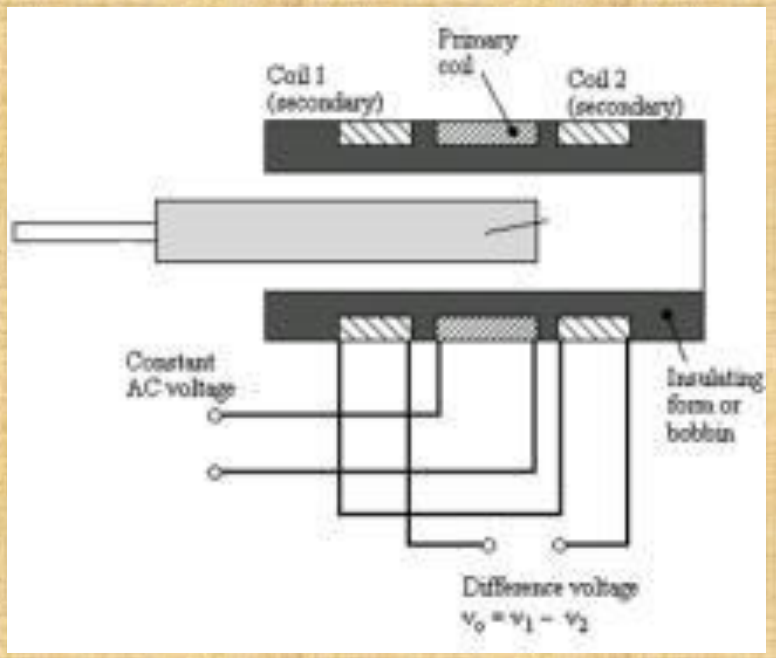


Working of LVDT:

When an external force is applied and if the steel iron core tends to move in the left hand side direction then the emf voltage induced in the secondary coil is greater when compared to the emf induced in the secondary coil 2.

Therefore the net output will be Esec1-Esec2

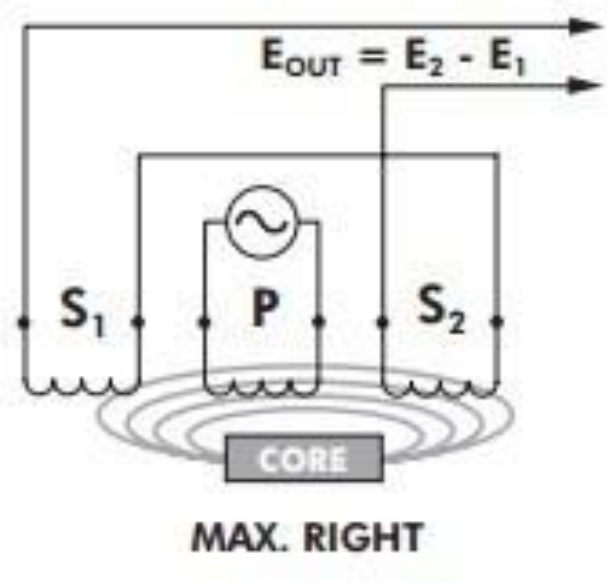


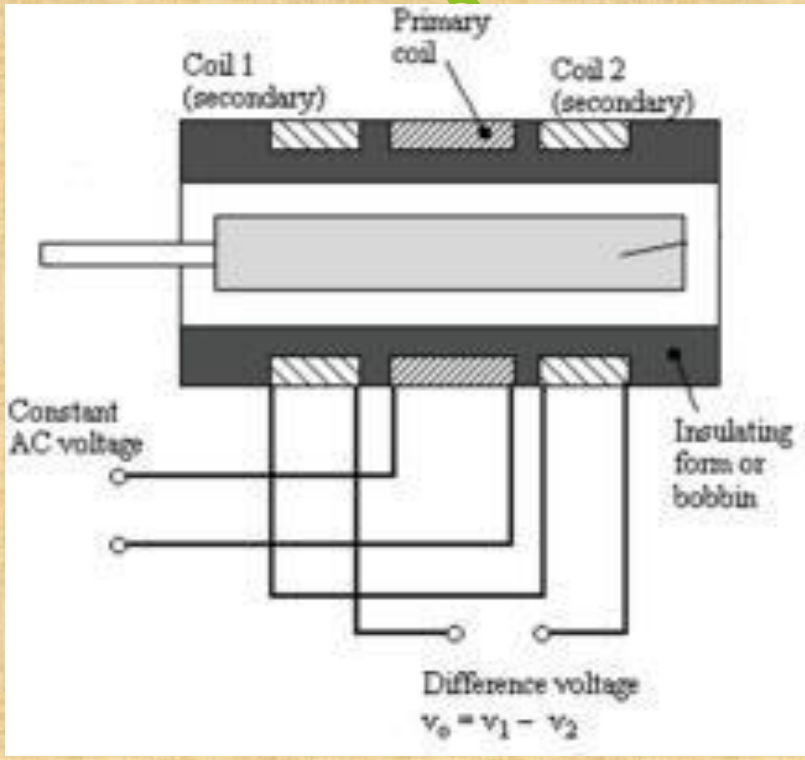


Working of LVDT:

When an external force is applied and if the steel iron core moves in the right hand side direction then the emf induced in the secondary coil 2 is greater when compared to the emf voltage induced in the secondary coil 1.

The net output voltage will be Esec2-Esec1





Advantages of LVDT:

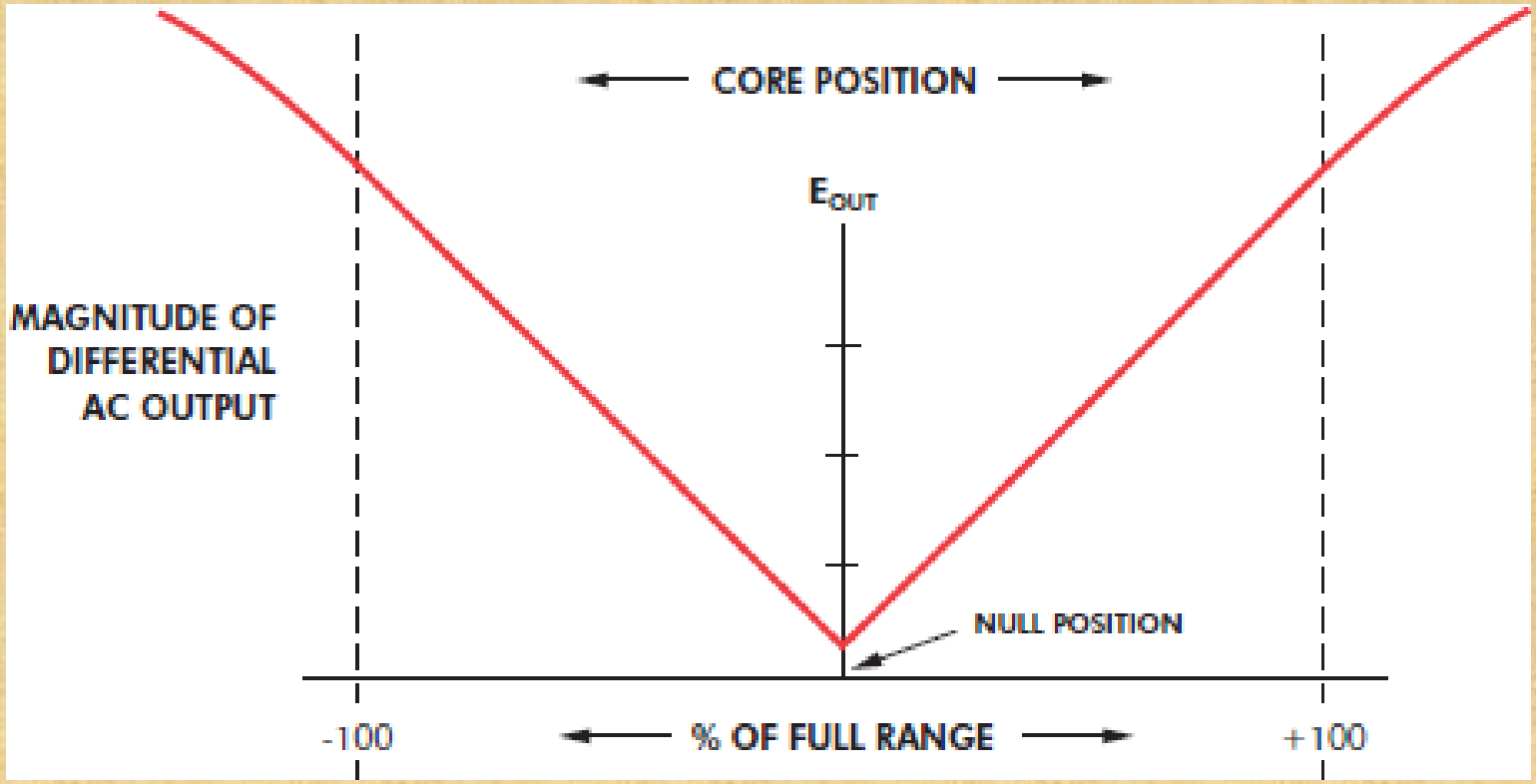
1) Infinite resolution is present in LVDT
2) High output
3) LVDT gives High sensitivity
4) Very good linearity
5) Ruggedness
6) LVDT Provides Less friction
7) Low hysteresis
8) LVDT gives Low power consumption.

Applications of LVDT:

1)LVDT is used to measure displacement ranging from fraction millimeter to centimeter.

2) Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc..

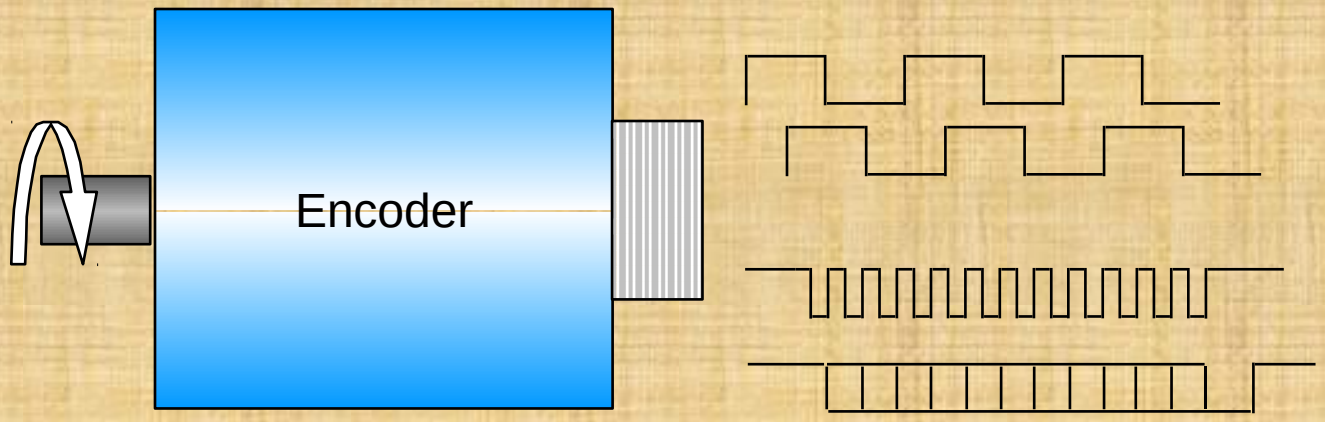
Characteristics of LVDT:



1.4 Optical Encoder

What is an encoder?

- An encoder is a device which converts a mechanical information of a shaft or position into an electrical signal.



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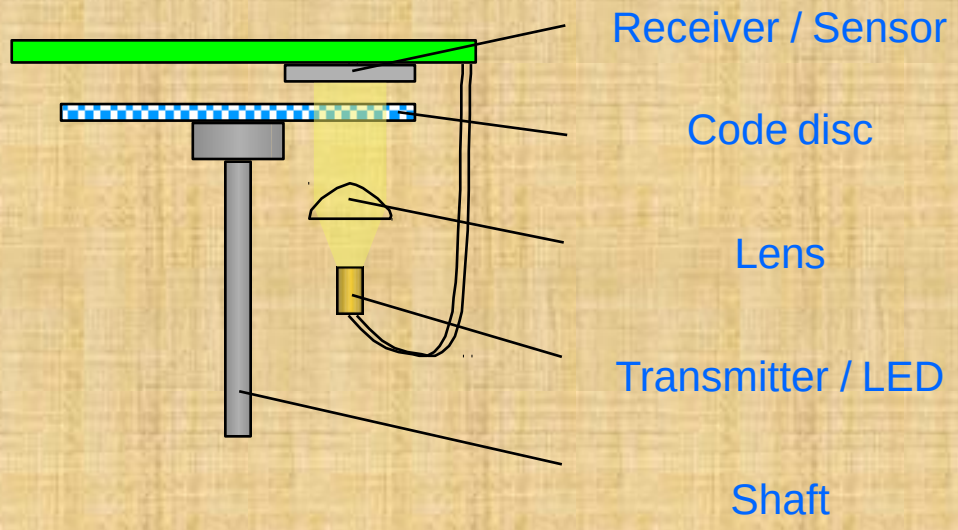
How is this accomplished?

As the code disc rotates, it shutters light from the LED and is received and transmitted as square\sine waveforms



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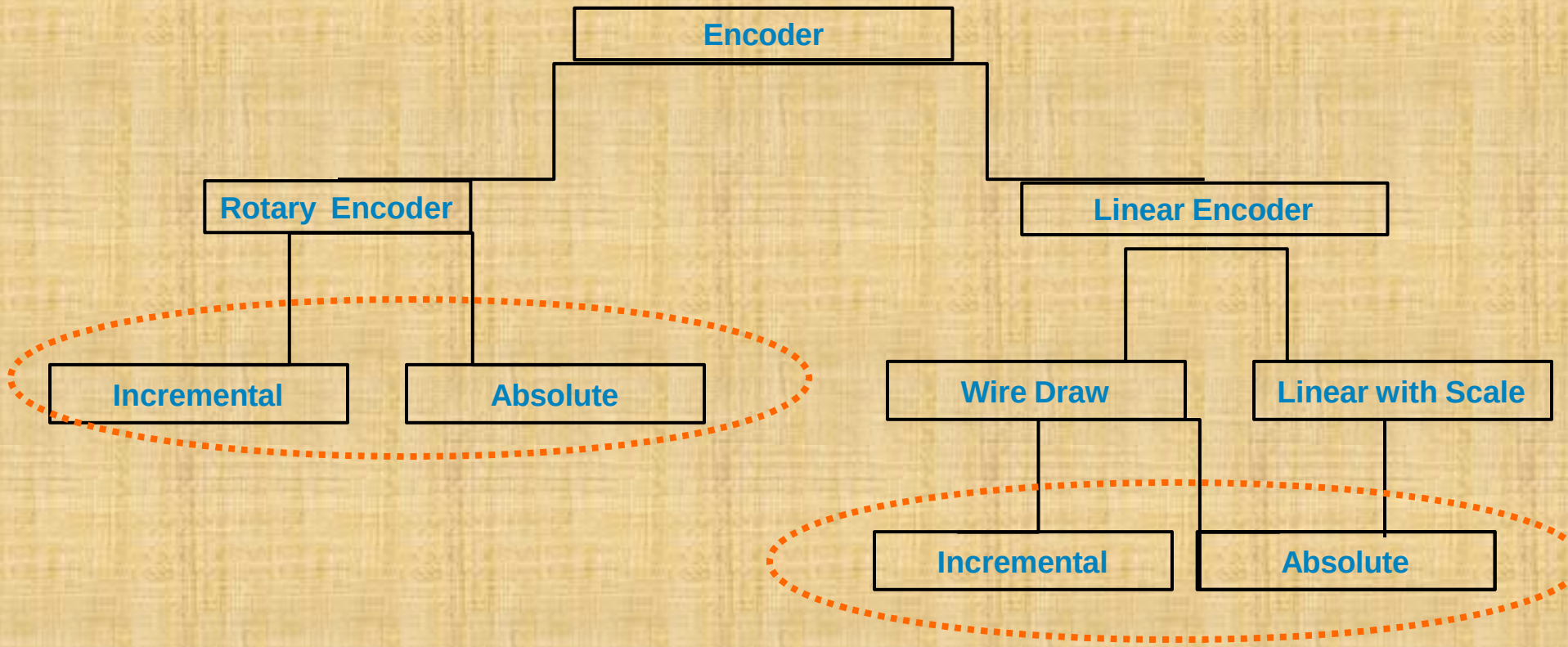
Types of Encoders



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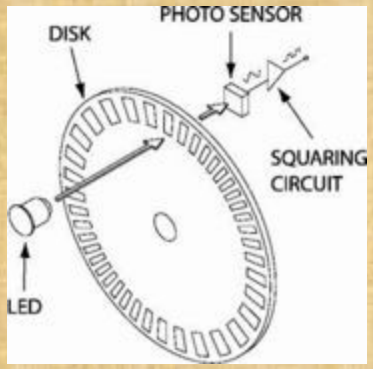
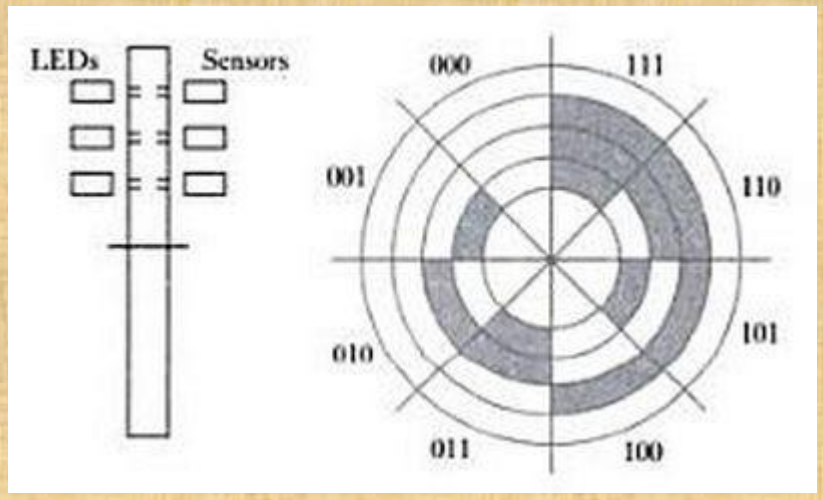
incremental encoders



Absolute encoders



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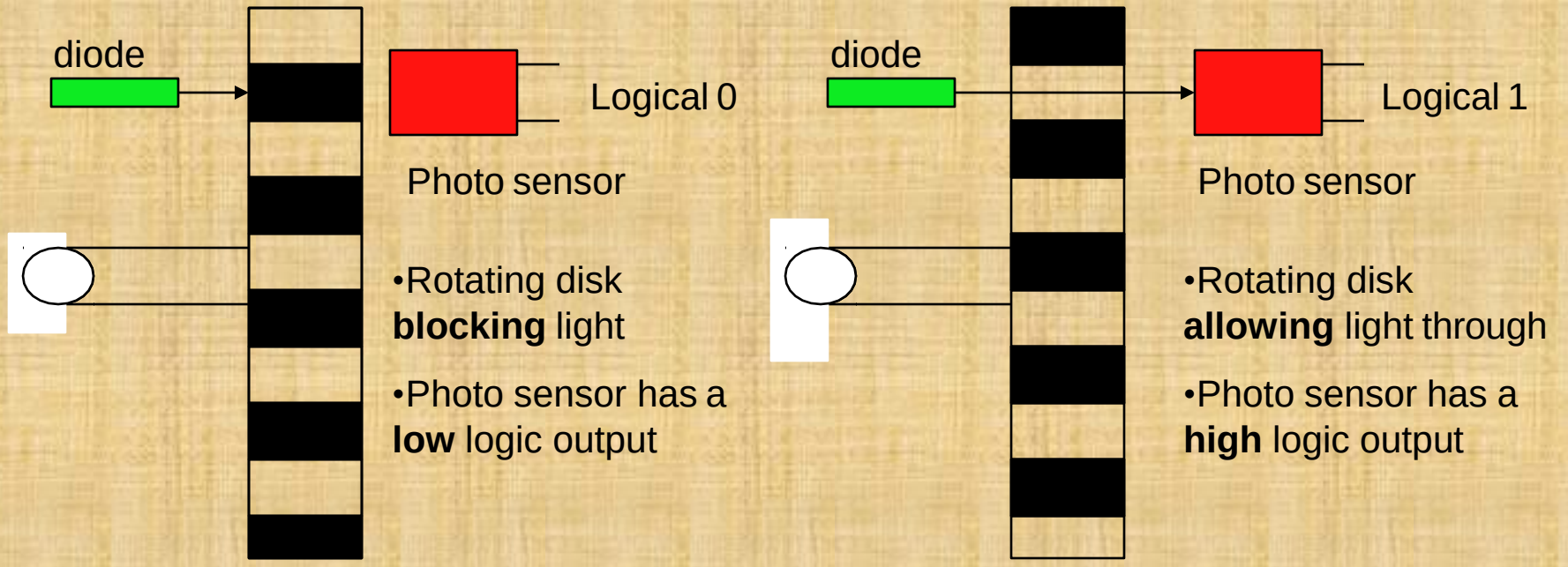
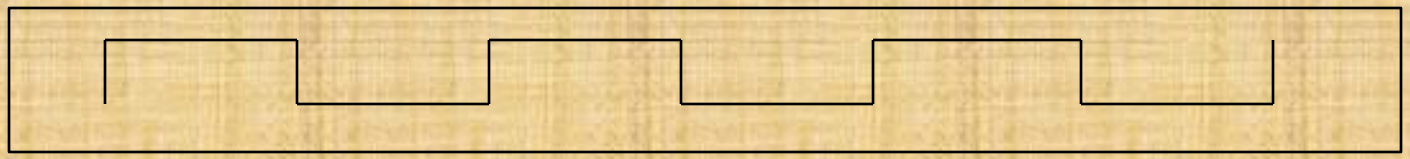
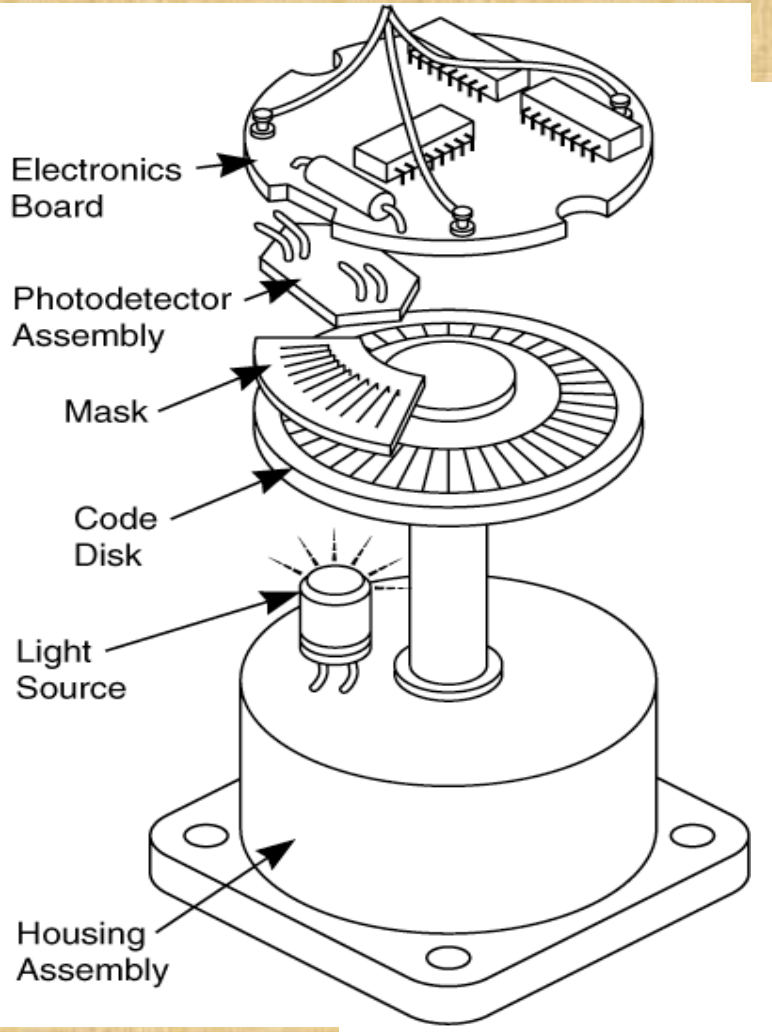




•Continuous train of pulses formed as the photo sensor traverses between logic high and logic low in response to the rotation of the disk

Absolute Optical Encoder



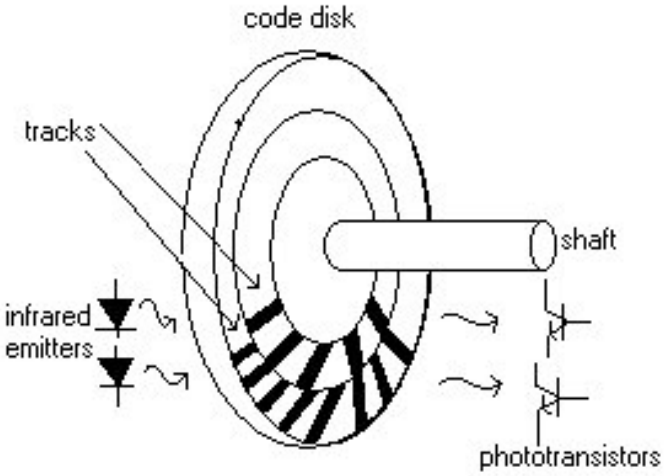
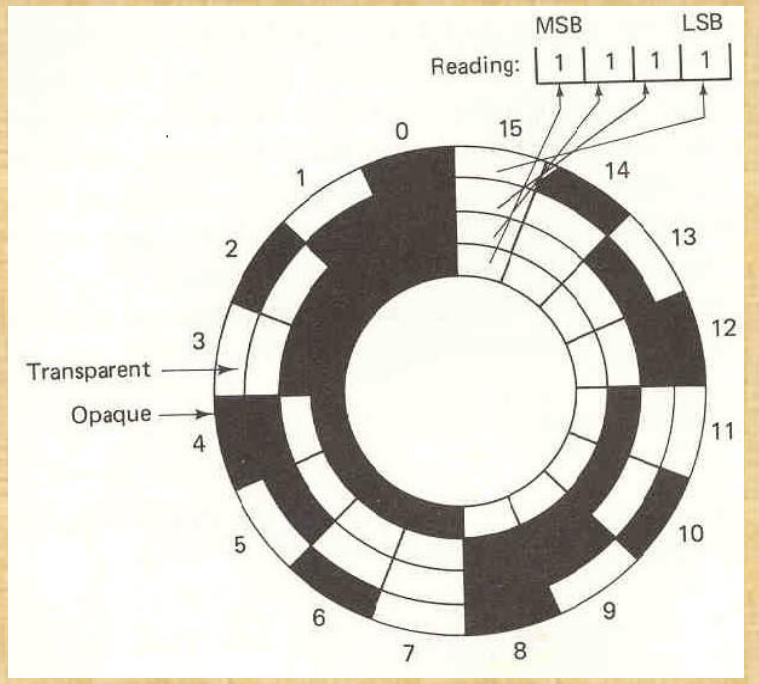
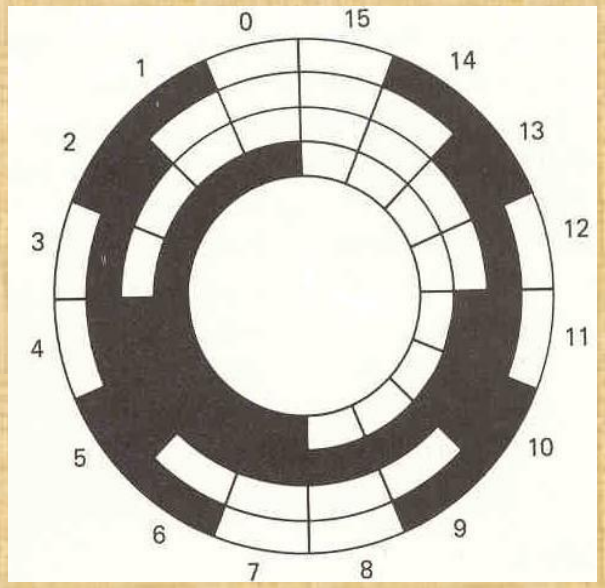


Fig 1. A rotary optical encoder

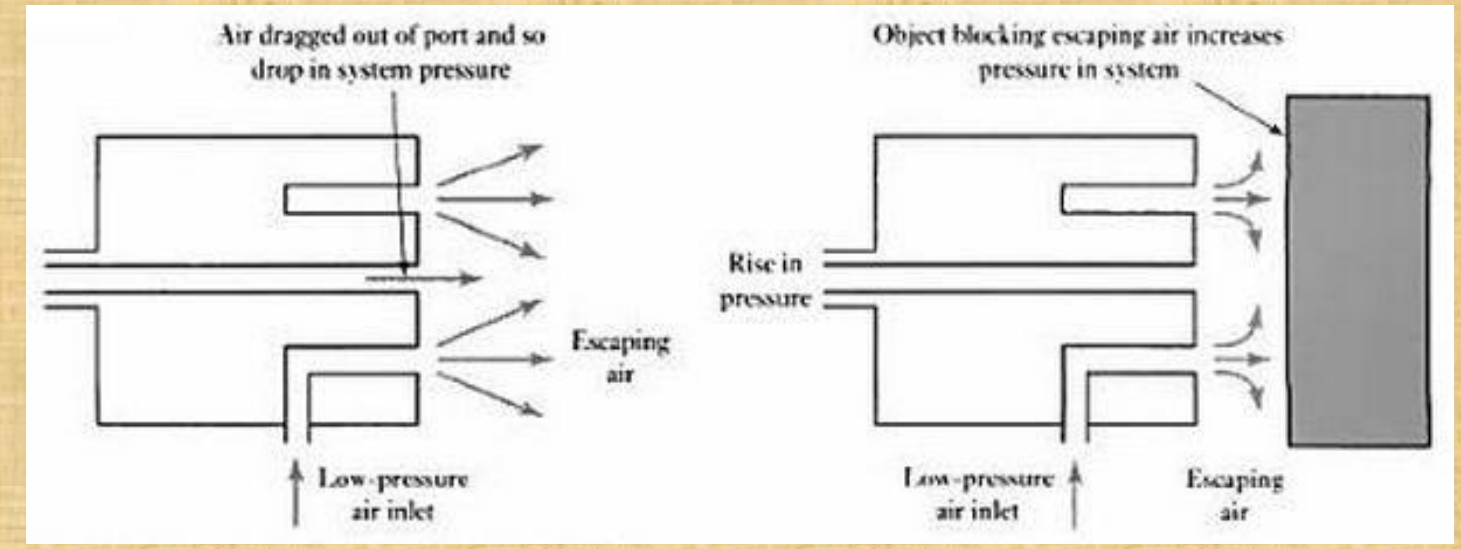
Absolute Optical Encoder





1.5 Pneumatic Sensor

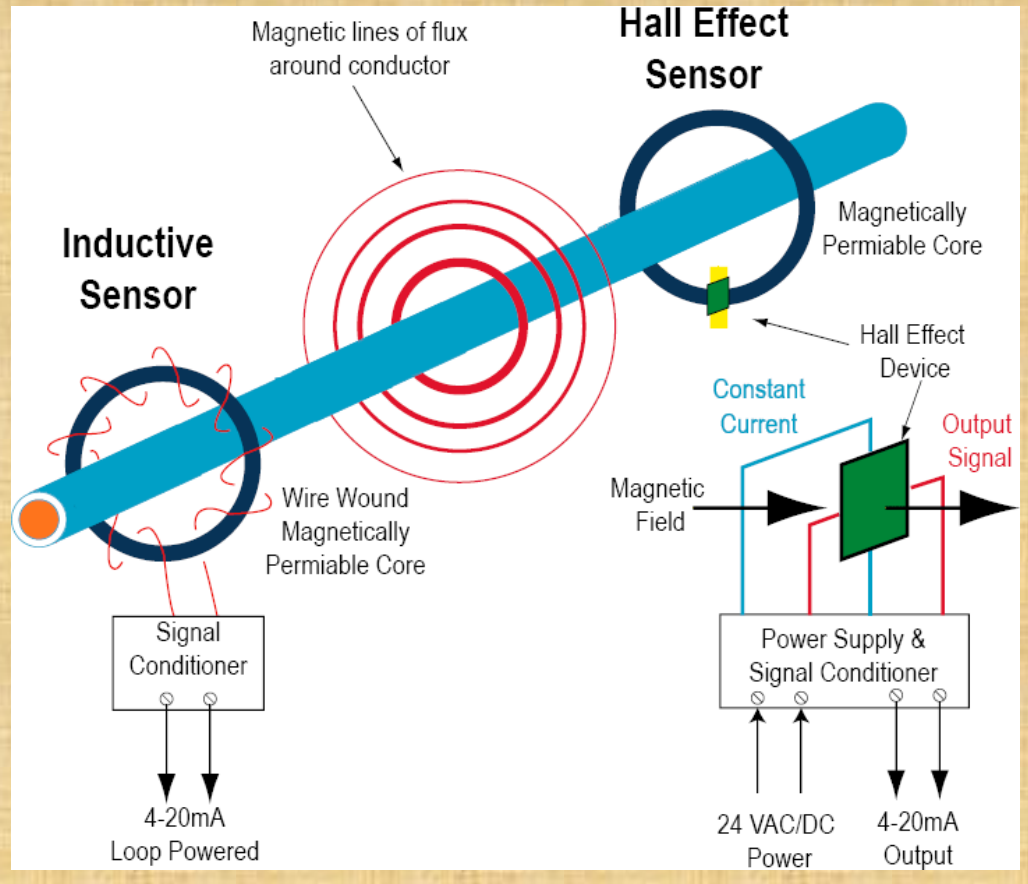
- **Pneumatic sensors are displacement sensors and use compressed air to measure the displacement of objects. Whenever the body whose displacement we want to measure changes its position will result in the change in air pressure.**
- **If we look at the working of pneumatic sensor, we have low pressure air escape from the port in front of sensor. If we don't have any object in front of sensor, this air will escape and reduce air pressure in the nearby output port. But if we have an object in the path of compressed air then air will escape and increase air pressure at sensor output port. The rise in output pressure depends upon the closeness of the**



These sensors are used to work for short range applications ranging from 3 mm to 12 mm.

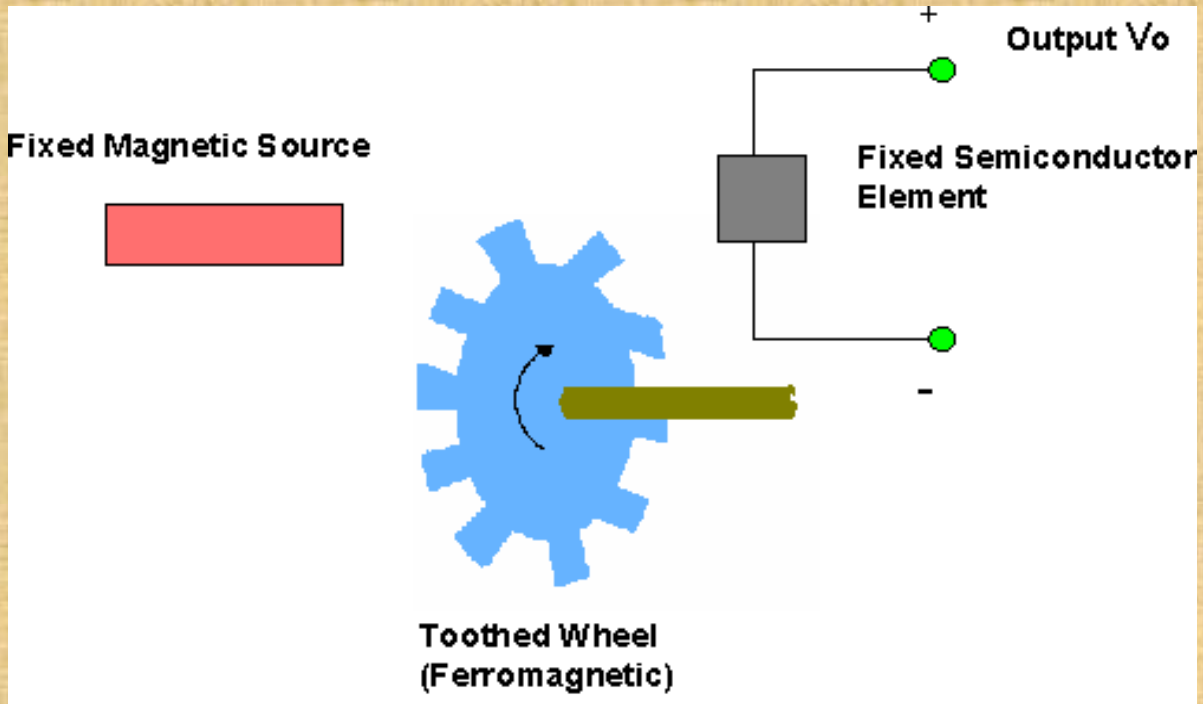
1.6Hall Effect Sensor

- **A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications.**



2Velocity sensors

2.1 Tachogenerator

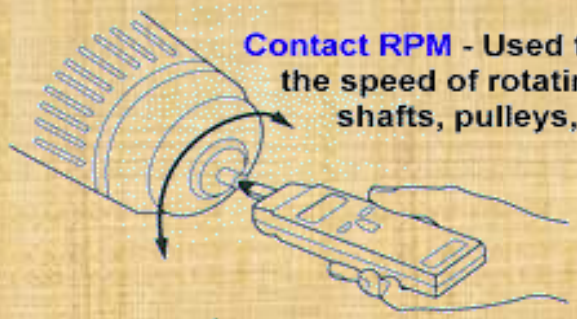


SCHEMATIC DIAGRAM OF A HALL EFFECT SHAFT ENCODER OR DIGITAL TACHOMETER

- The semiconductor element and the magnetic source are fixed relative to one another in a single package.
- By moving the ferromagnetic member into the air gap between the magnetic source and the semiconductor element, the flux linkage can be altered. This changes Vo.
- Suitable both as an analog proximity sensor and as a limit switch.
- The relationship between the output voltage Vo and the distance of a Hall effect sensor measured from the moving member is non linear. Linear Hall effect sensors use calibration to linearize their outputs.

DIGITAL TACHOMETER

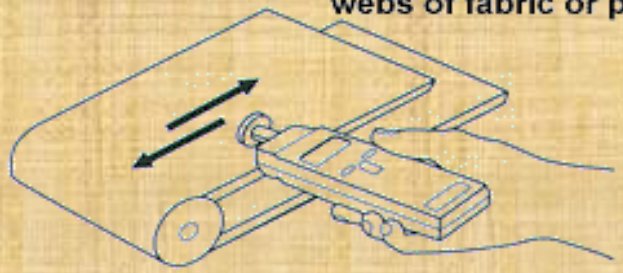
WHERE USED:

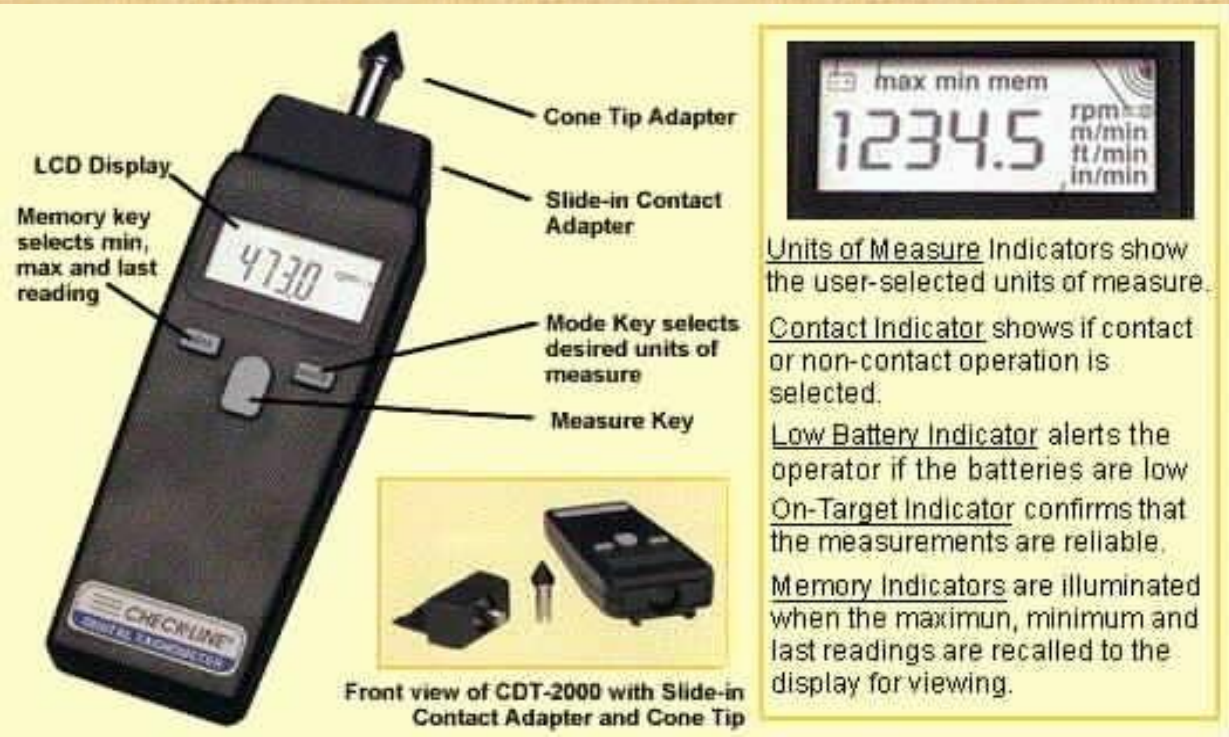


Contact RPM - Used to measure the speed of rotating motors, shafts, pulleys, gears, etc.

Non-Contact RPM - Used when contact measurement is not possible due to acess space restrictions, safety concerns etc,.

Linear Speed and Length - Used to measure the linear speed or length of moving surfaces, such as conveyor belts, printed materials, webs of fabric or paper, etc.

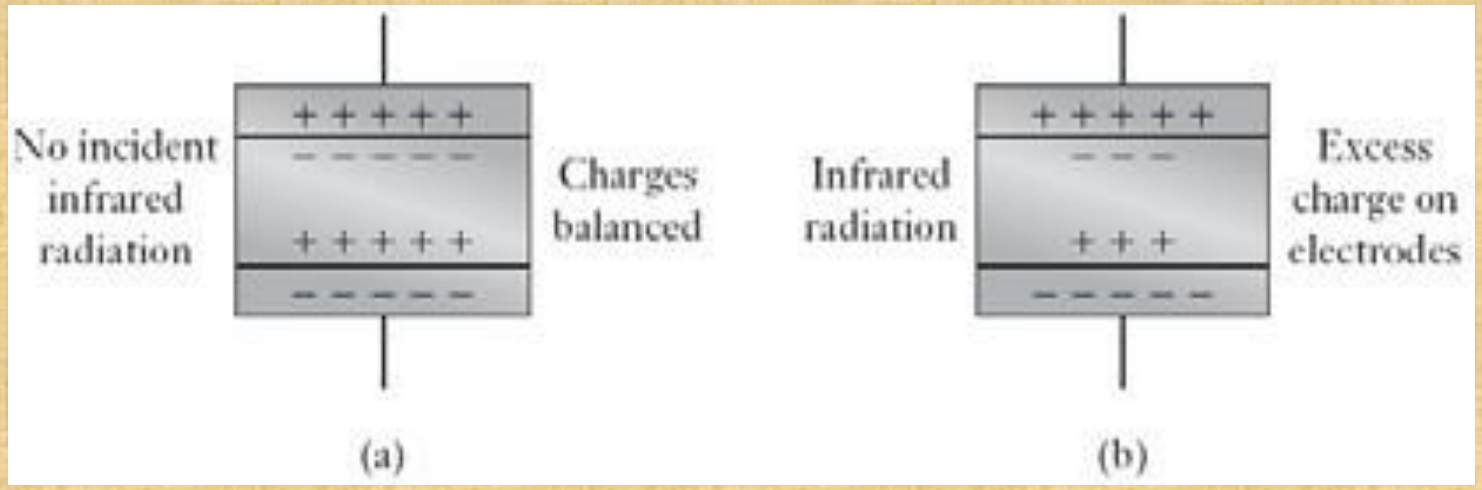




DIGITAL TACHOMETER AS A MEASUREMENT DEVICE

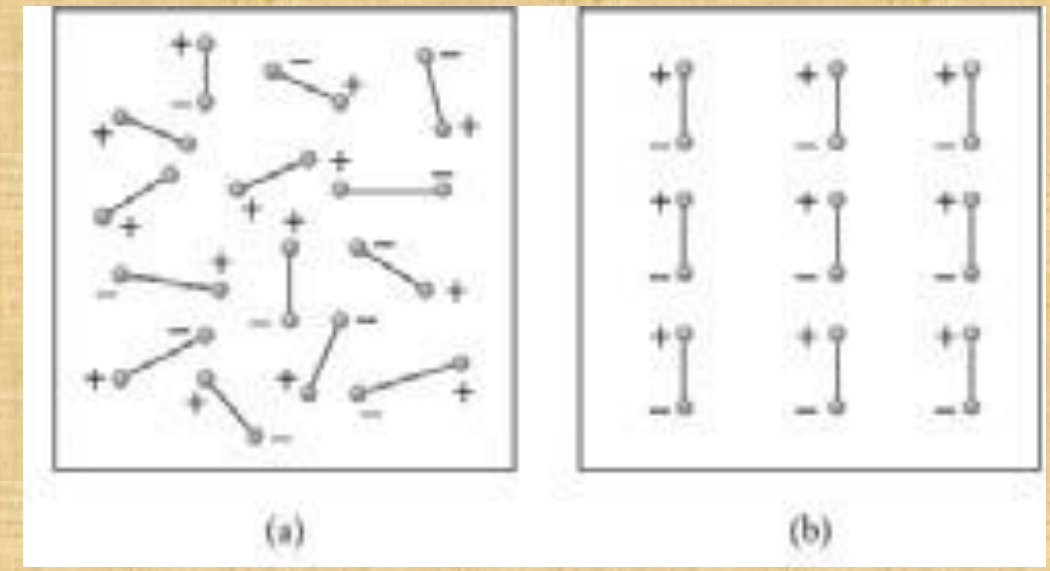
2.2Pyroelectric Sensor

This charge leaks away through the measurement circuit until the charge on the crystal once again is balanced by the charge on the electrodes.

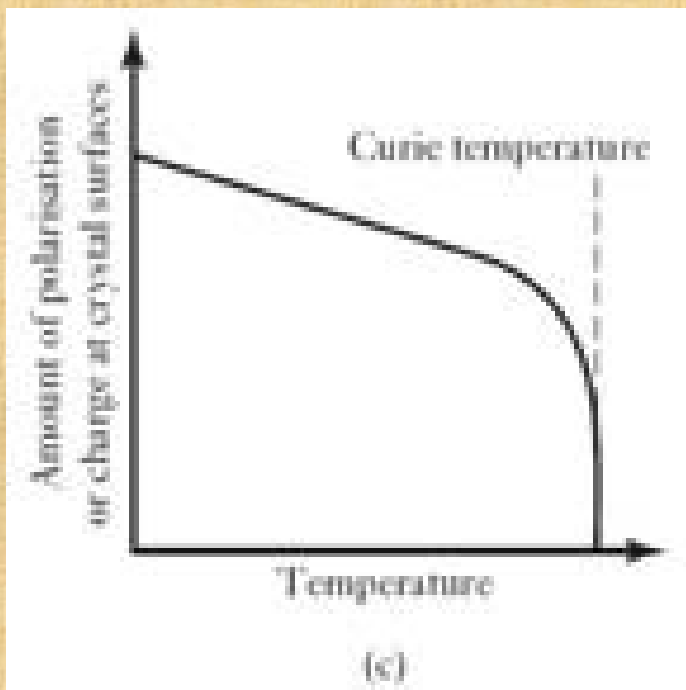


Cont.…

Pyroelectric (from the Greek pyr, fire, and electricity) materials, e.g. lithium tantalate, are crystalline materials which generate charge in response to heat flow.



Polarising a pyroelectric material

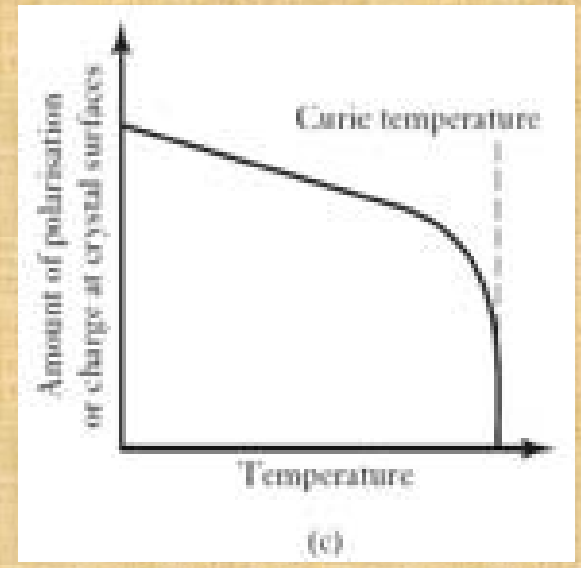


The effect of temperature on the amount of polarisation.

Cont.…

The pyroelectric sensor thus behaves as a charge generator which generates charge when there is a change in its temperature as a result of the incidence of infrared radiation.

For the linear part of the graph shown below , when there is a temperature change the change in charge is proportional to the change in temperature.



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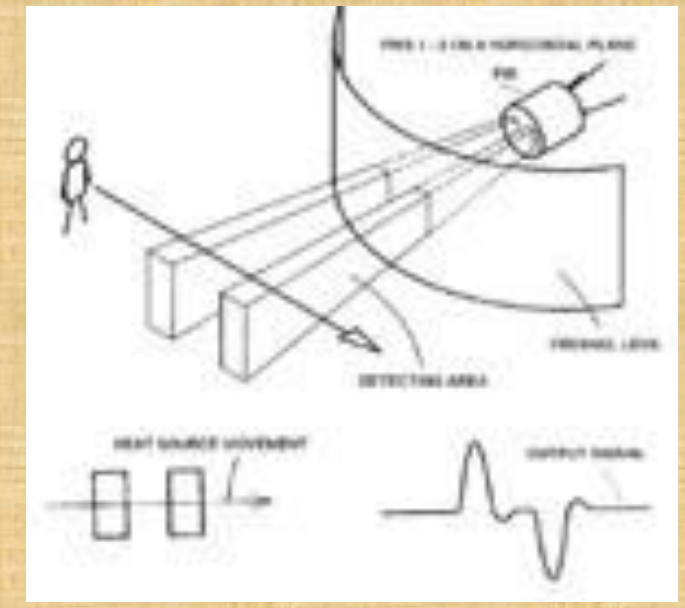
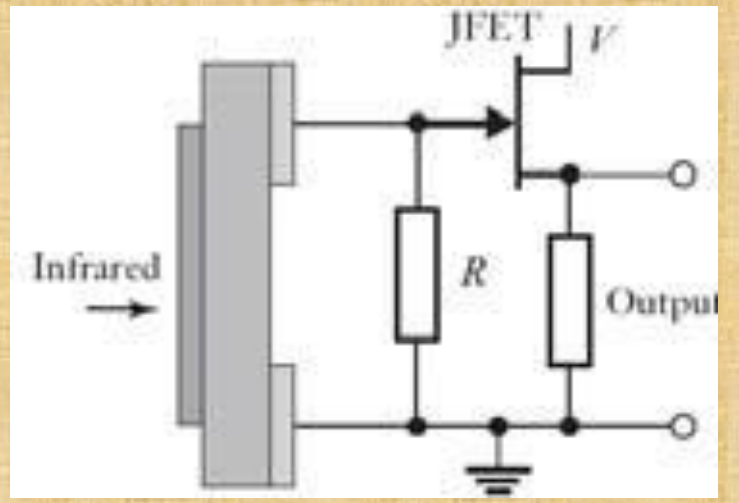
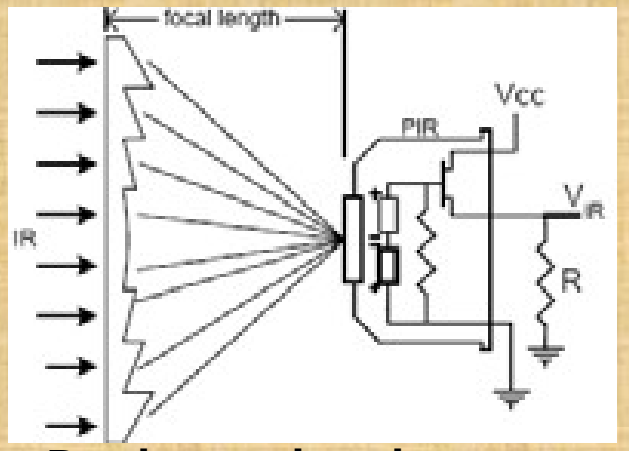




When the sensor is idle, both slots detect the same amount of IR, the ambient amount radiant from the room or walls or outdoors. When a warm body like a human or animal pass by, it first intercepts one half of the sensor, which causes a *positive differential* change between t two halves. When the warm body leaves the sensing area, reverse happens, whereby the sensor generate negative differential change.

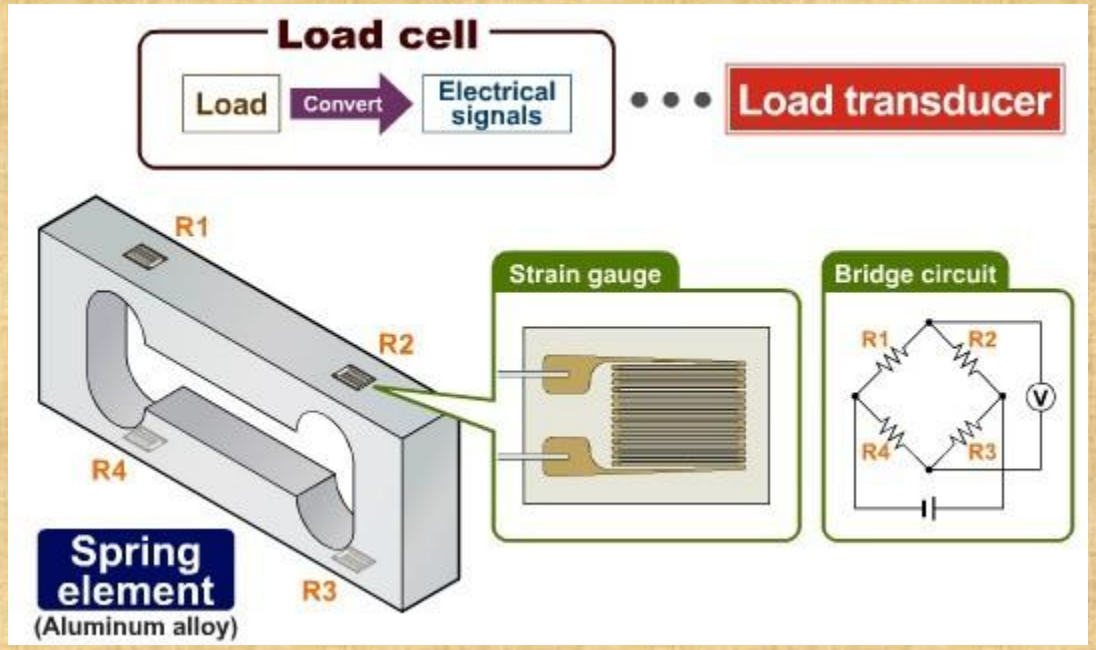


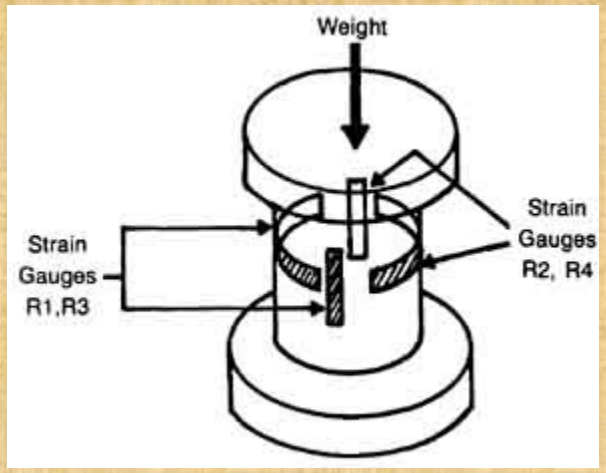
Dual pyroelectric sensor

3.FORCE SENSOR

3.1 Strain Gauge Load Cell

- A load cell is a “load transducer” which converts the weight or load acting on it into electrical signals.
- A load cell is composed of an aluminum alloy spring element, strain gauges (serving as sensors) and a bridge circuit.
- The strain gauges themselves are bonded onto four areas which become considerably distorted in the spring element. The load cell detects the force of the distortion as voltage change.





4.PRESSURE SENSOR

4.1 Diaphragm

LVDT WITH DIAPHRAGM

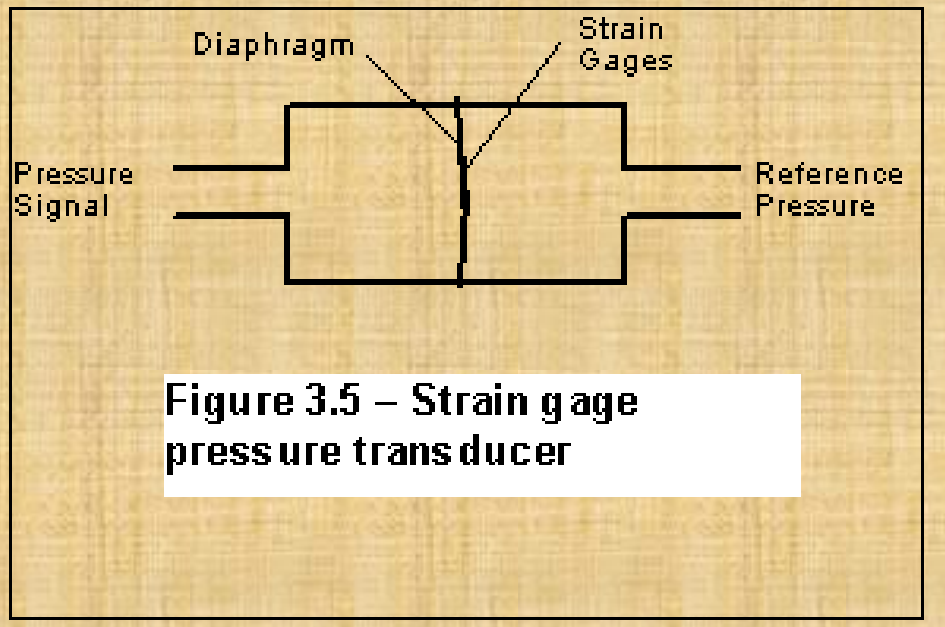
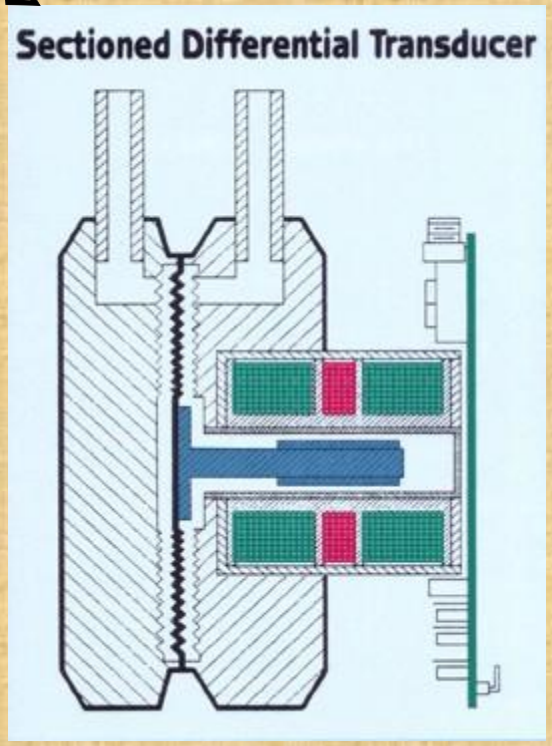


Figure 3.5 – Strain gage pressure transducer



4.2 BELLOWS

Fig. 2-11. Bellows sensor

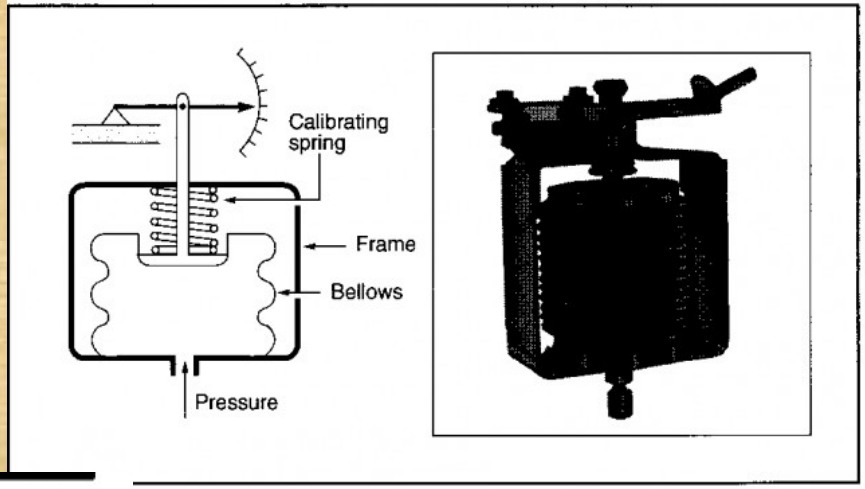
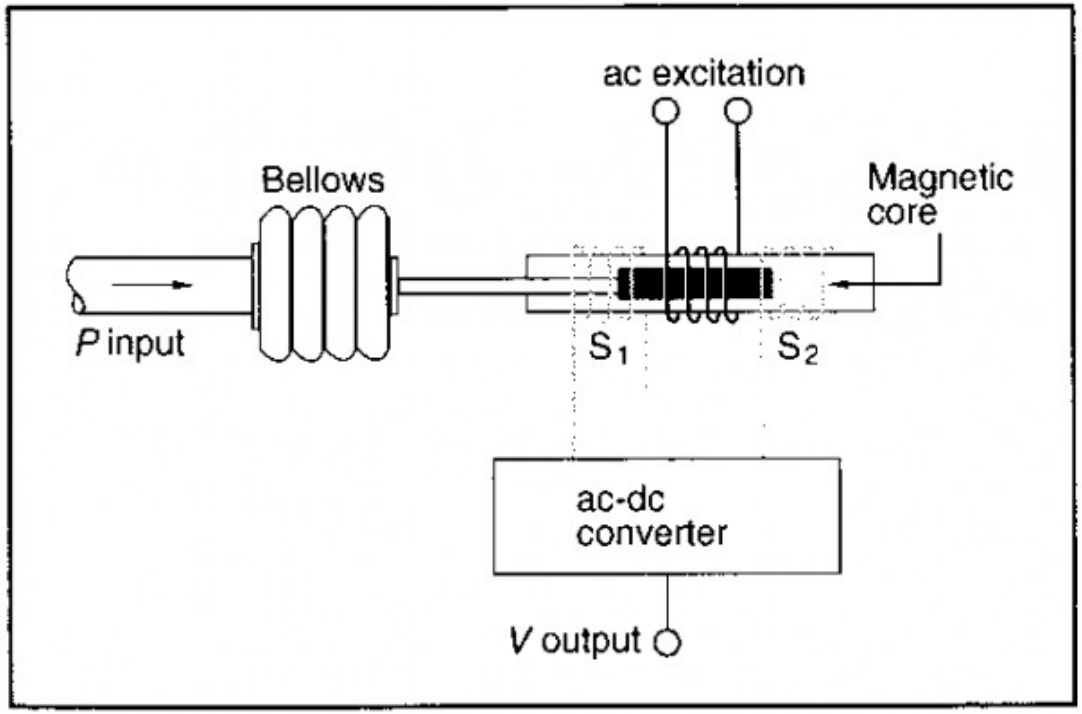
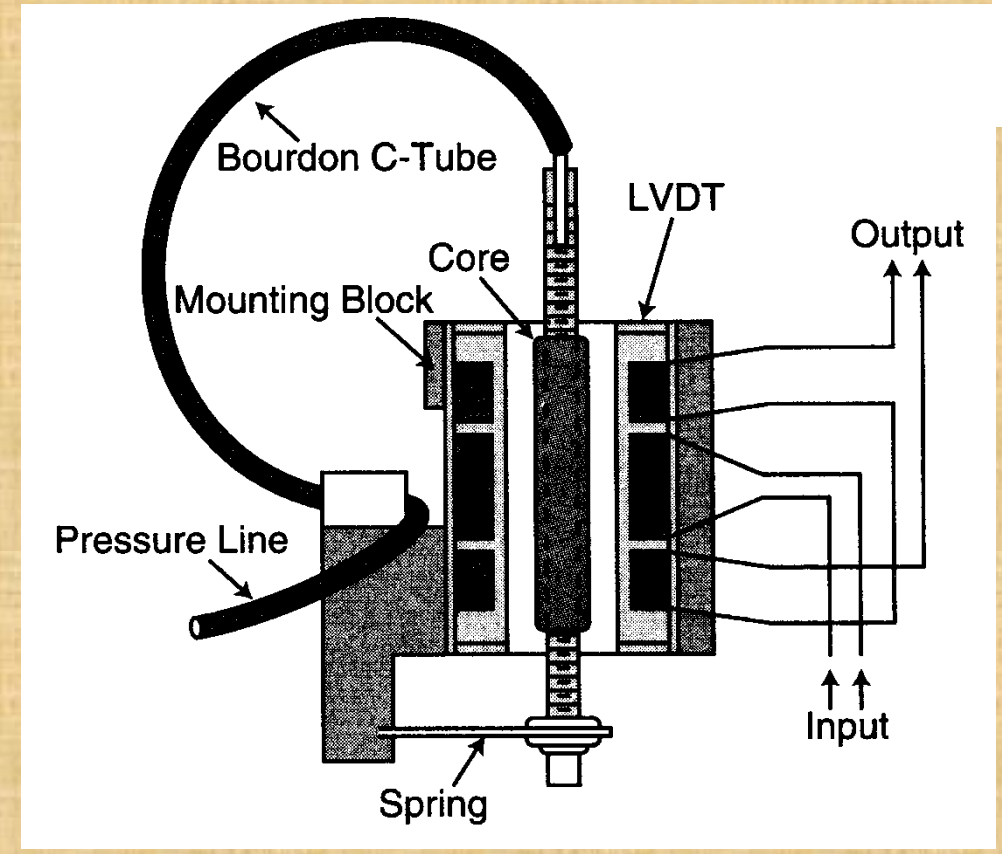
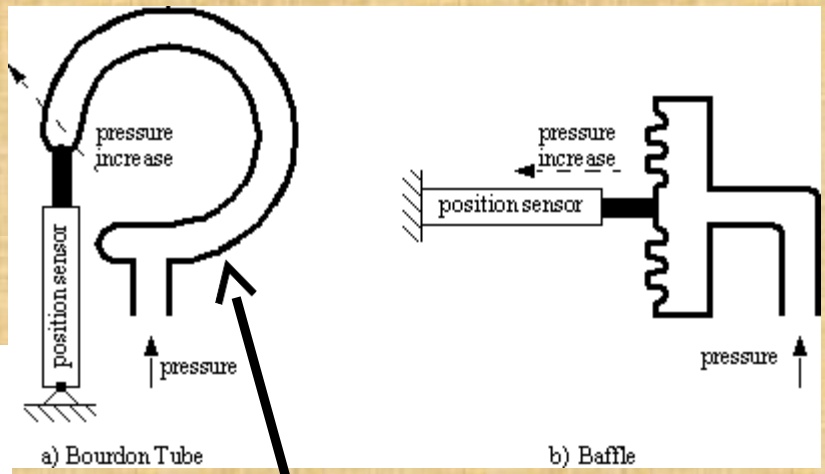


Fig. 3-8. LVDT pressure transducer



4.3TUBE PRESSURE SENSOR



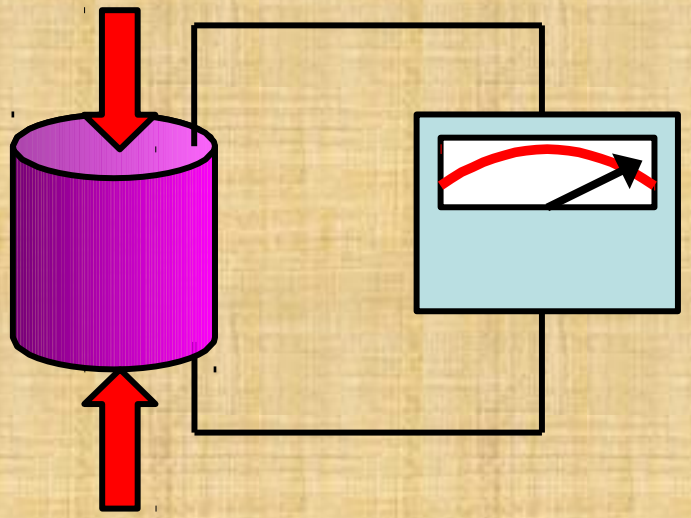


BOURDON TUBE

4.4Piezoelectric actuators and sensors

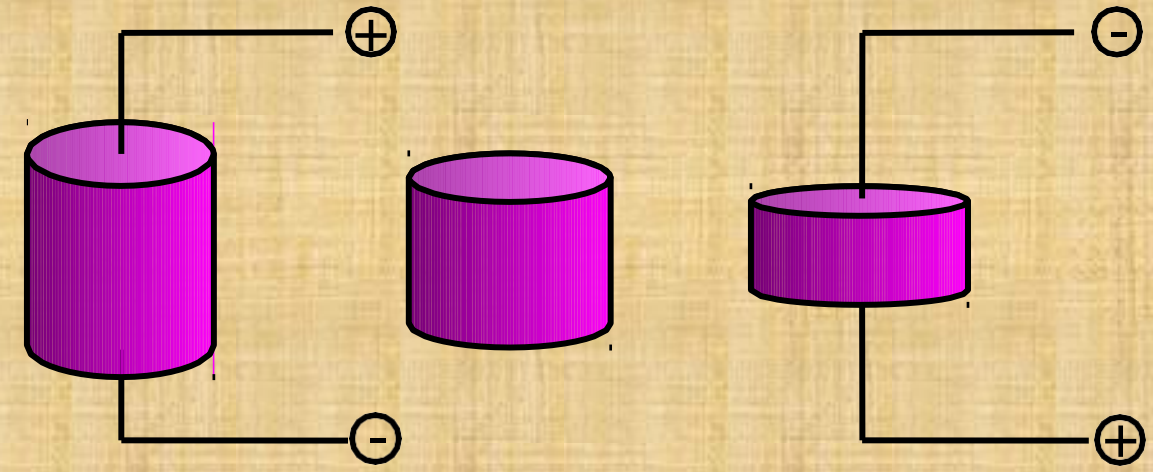
Piezoelectric effect
(sensor)

An electric field is generated due to a change in dimensions of a material
(Curie brothers 1880)



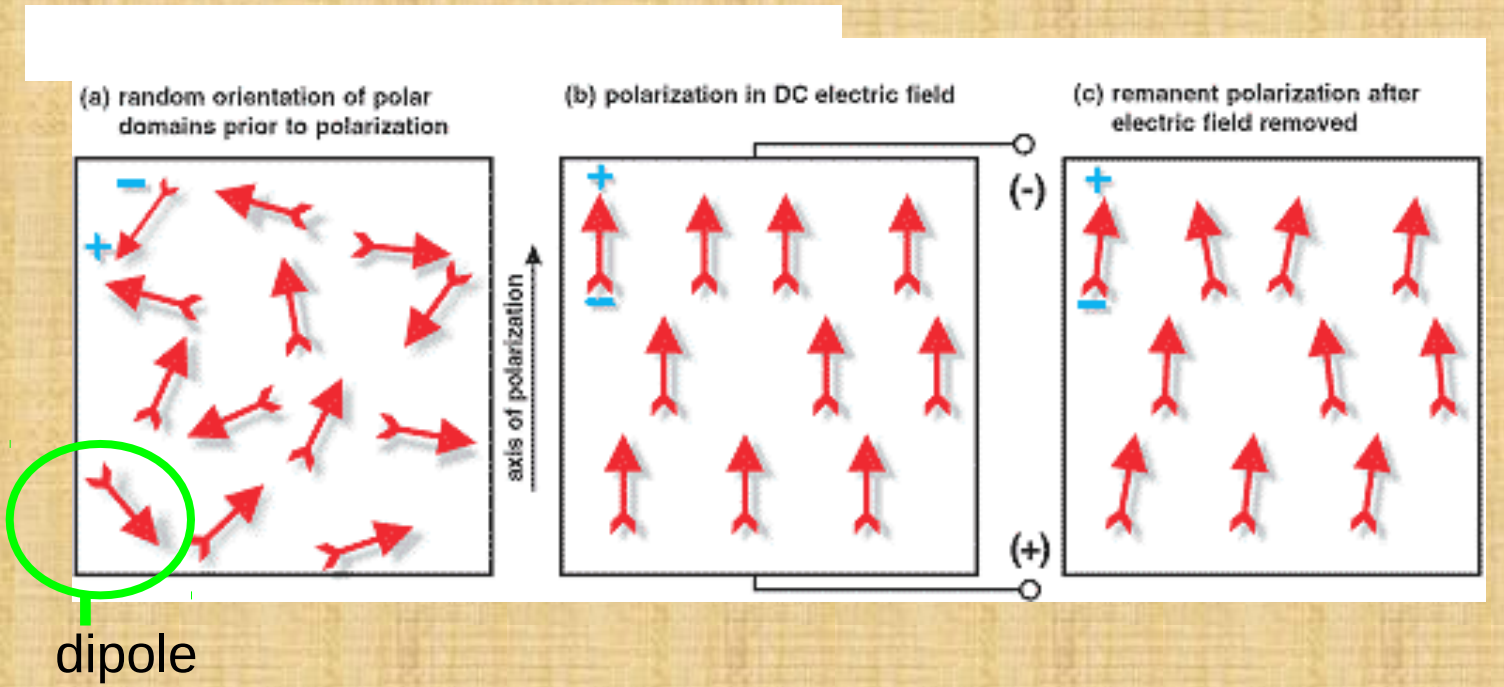
Converse Piezoelectric effect
(actuator)

A change in dimensions of a material due to the Application of an electric field



Polarisation of a piezoelectric material

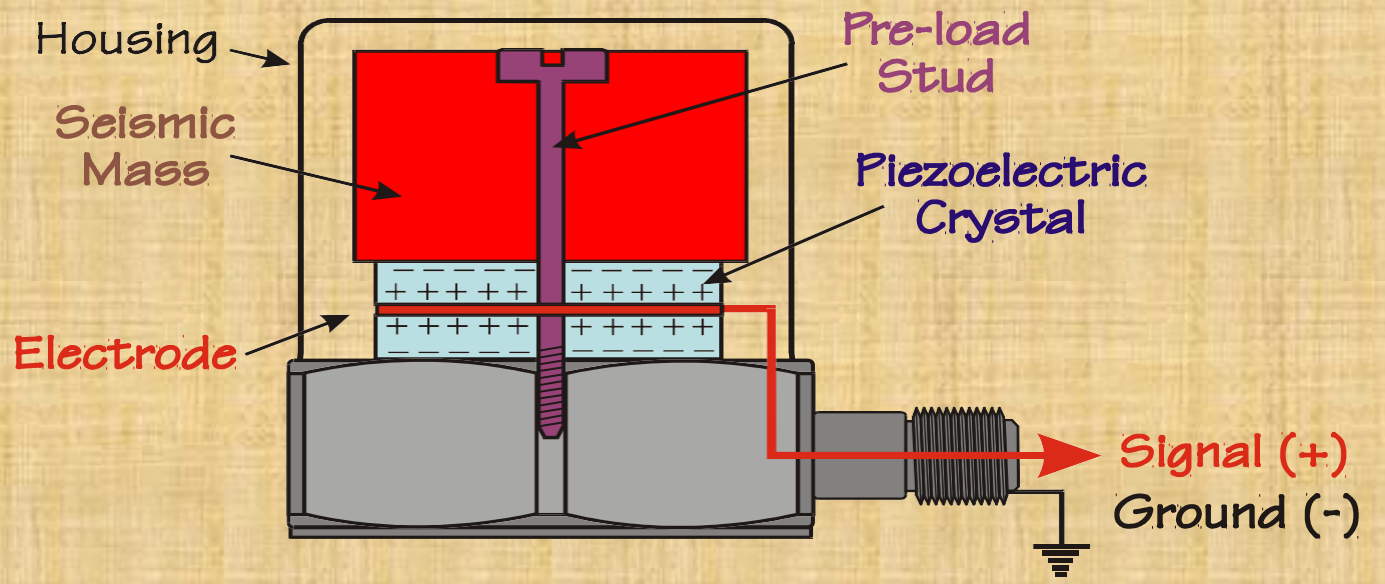
- Subject a piezoelectric material to a large voltage near the Curie temperature then the dipoles align



- Curie temperature is the temperature above which the material loses its piezoelectric property

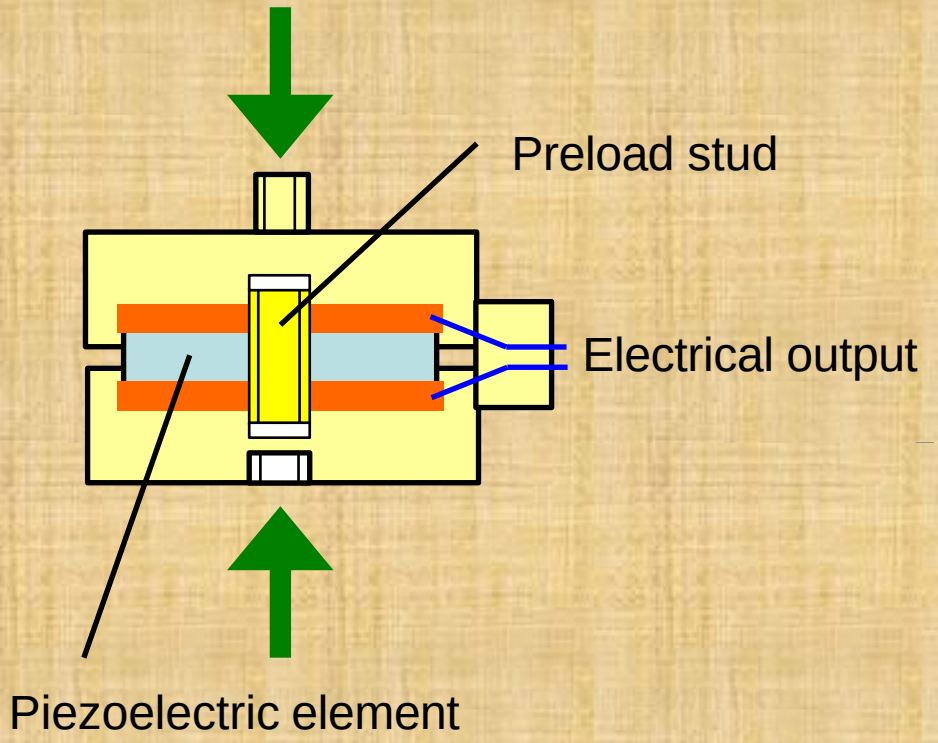
Practical Accelerometer Designs

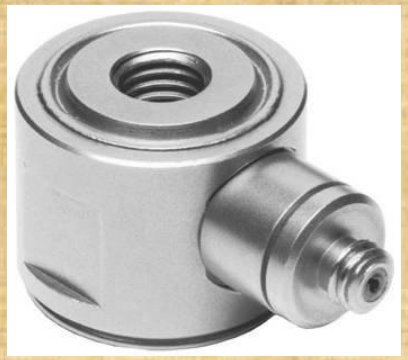
Compression Type



- **Advantages**
  - Few Parts / Easy to Fabricate
  - High Resonant Frequency
- **Disadvantages**
  - Very high thermal transient sensitivity
  - High base strain sensitivity

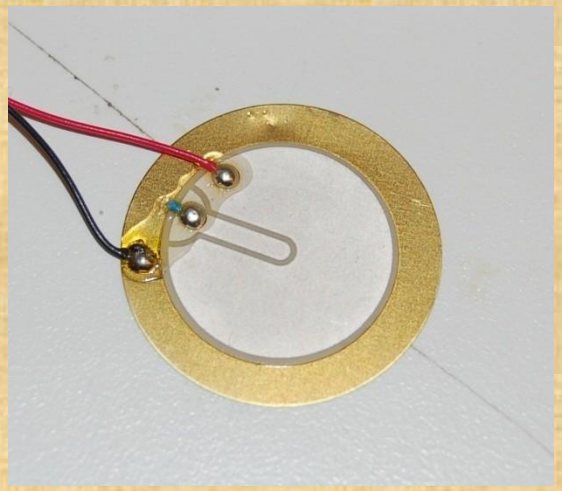
Piezoelectric Force Transducer





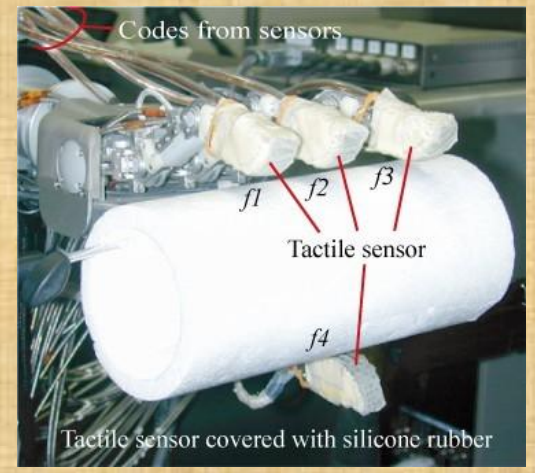
- Can be used in tension and compression
- Fragile to moments

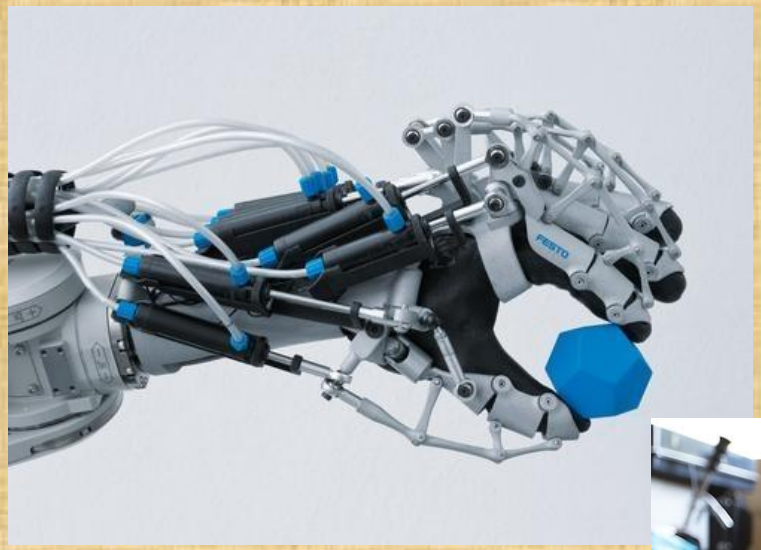
PIEZOELECTRIC SENSORS

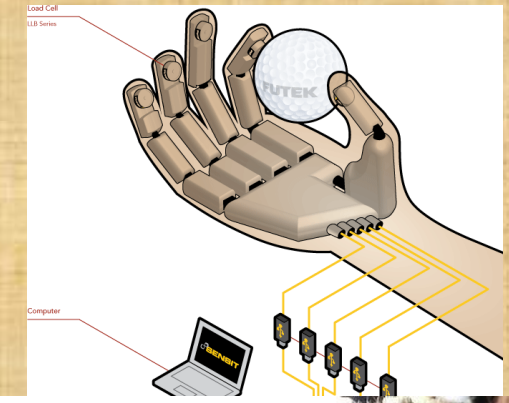


4.5 Tactile Sensor

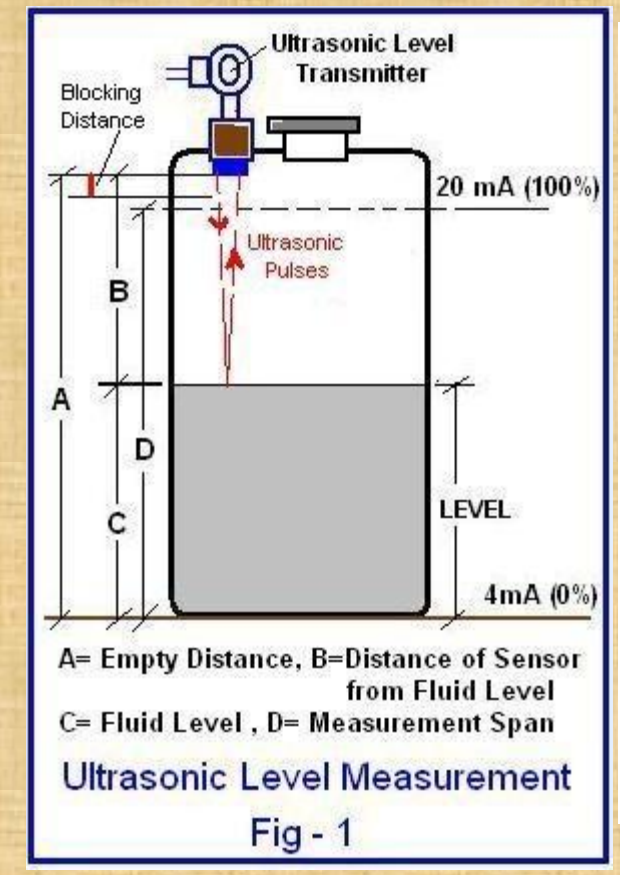
- The term **tactile sensor** usually refers to a transducer that is sensitive to touch, force, or pressure.
- The term **tactile sensor** usually refers to a transducer that is sensitive to touch, force, or pressure.
- Tactile sensors are useful in a wide variety of applications for robotics and computer hardware and even security systems.

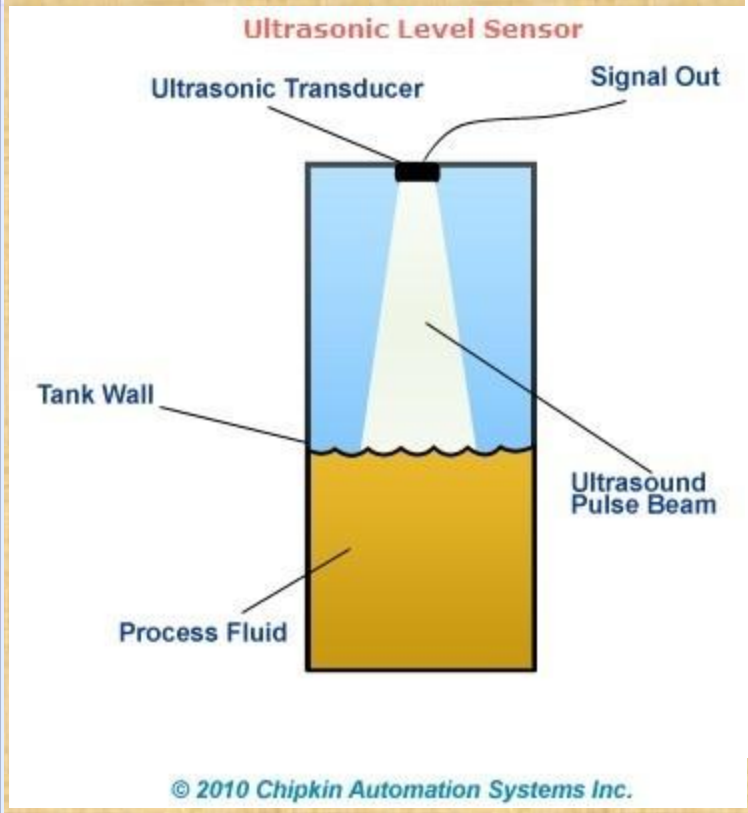






5. Level Sensor





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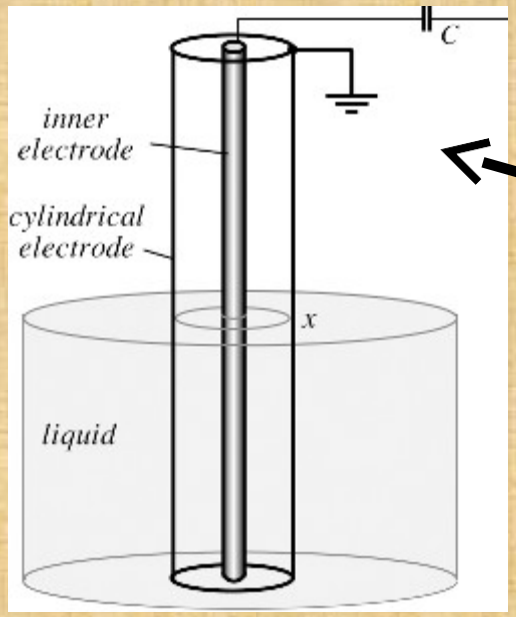
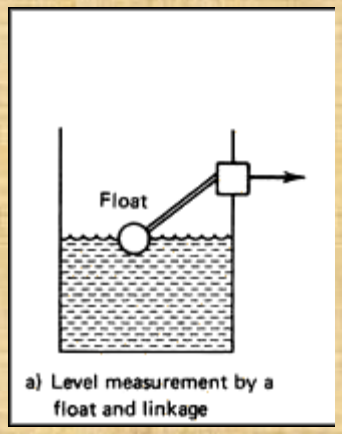


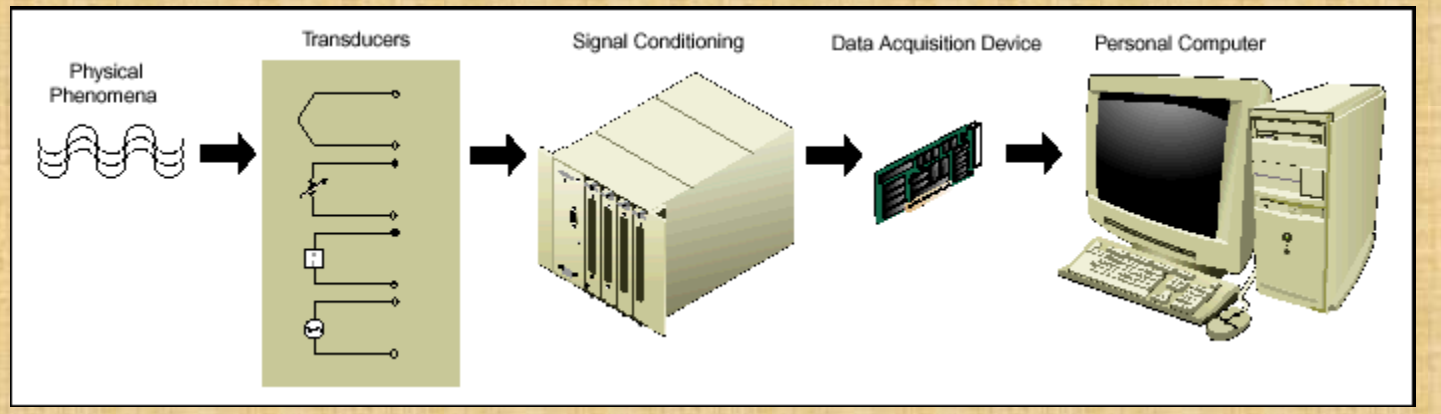
CAPACITIVE METHOD



BALL FLOAT

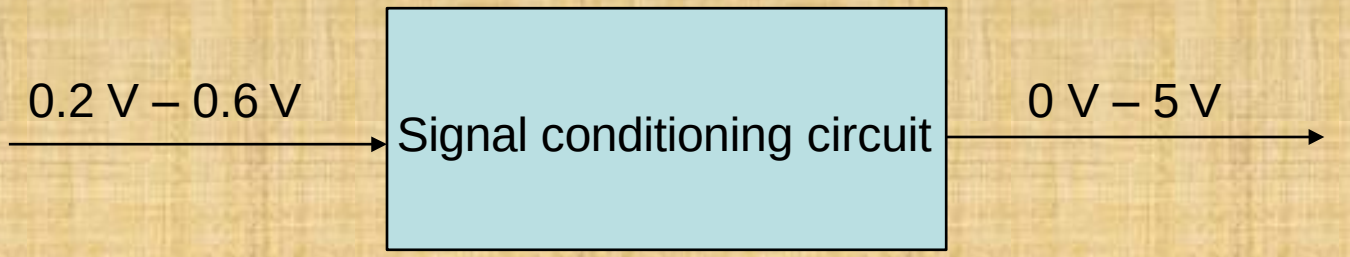
6.Signal Conditioning

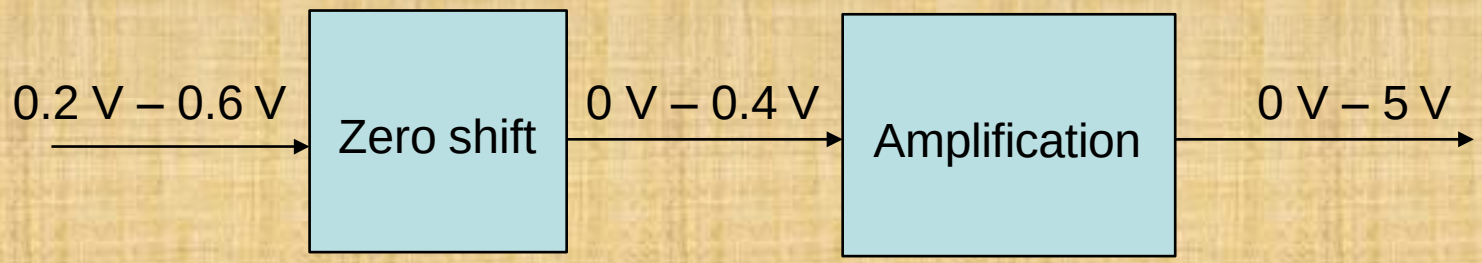
- Signal conditioning is the operation performed on the signal to convert them to a form suitable for interfacing with other elements in the process control



6.1 Signal-level and bias changes

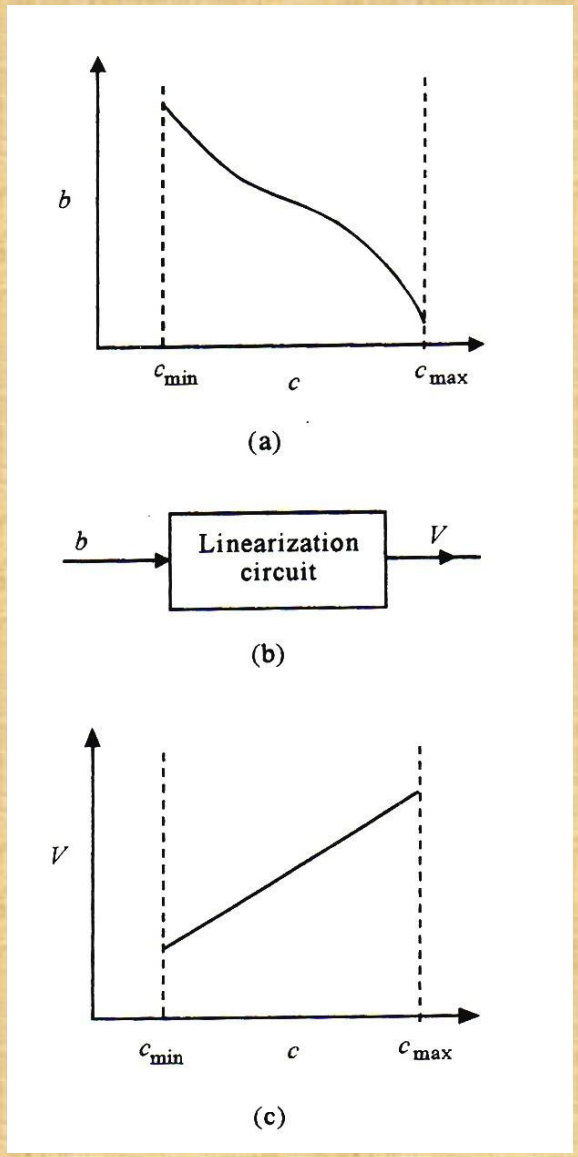
- The method to adjust the level (magnitude) and bias (zero value) of voltage signal
- For example




0.2 V – 0.6 V
Zero shift
0 V – 0.4 V
Amplification
0 V – 5 V

6.2Linearization

- Often, the characteristic of a sensor is nonlinear
- Special circuit were devised to linearize signals
- Modern approach is to use computer software to linearize



6.3Conversion

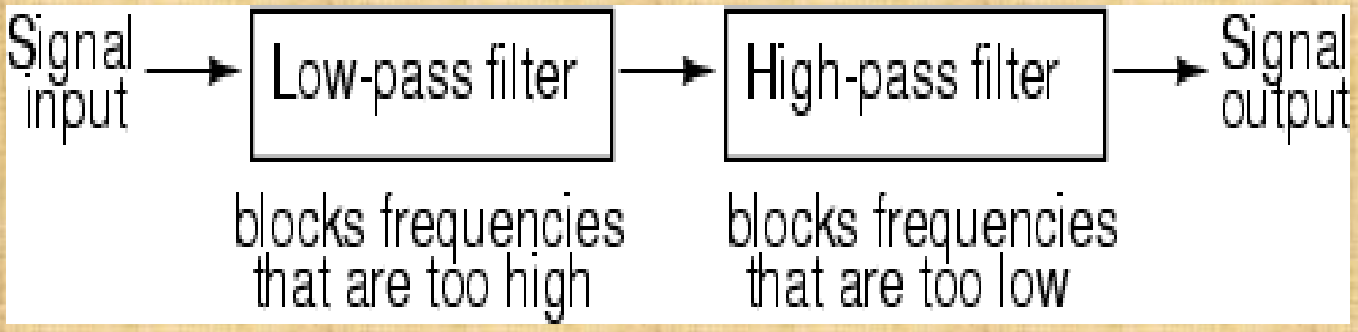
- The circuit to covert one form of signal or physical values into the other form
  - Resistance to voltage
- Typical conversion is to convert resistance or voltage to 4 to 20 mA and convert back to voltage at the receiving end
- Thus, voltage-to-current and current-to-voltage circuits are essential

6.4Digital Interface

- The use of computer is process control requires the conversion of analog to digital signal
  - ADC
  - DAC

6.5Filtering

- Some signals input are spurious (contain more than 1 frequency)
- It is necessary to filter the frequency matched with the devices
- Example
  - Highpass, lowpass, bandpass filter
  - **Band Pass Filters** passes signals within a certain "band" or "spread" of frequencies without distorting the input signal or introducing extra noise. This band of frequencies can be any width and is commonly known as the filters **Bandwidth**.



Cont.…

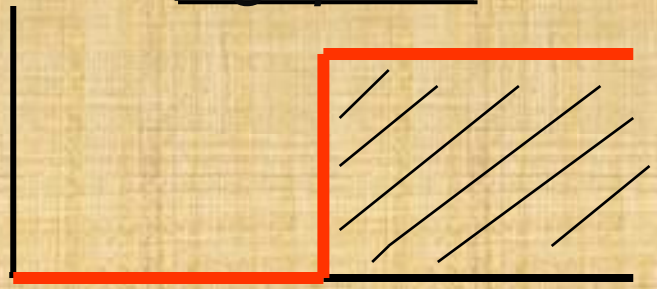
- The passive filter networks use only passive elements such as resistors, inductors and capacitors.
- The active filter circuits use the active elements such as op-amps, transistors along with the passive element.
- Modern active filters do not use inductors as they are bulky, heavy & non-linear.
- The inductors generate the stray magnetic fields. They dissipate considerable amount of power.

PASSIVE FILTERS

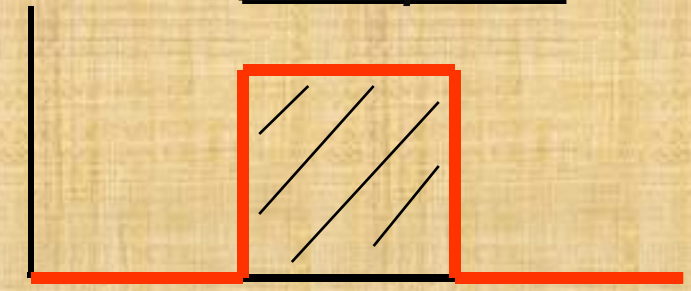
Four types of filters - "Ideal"

lowpass

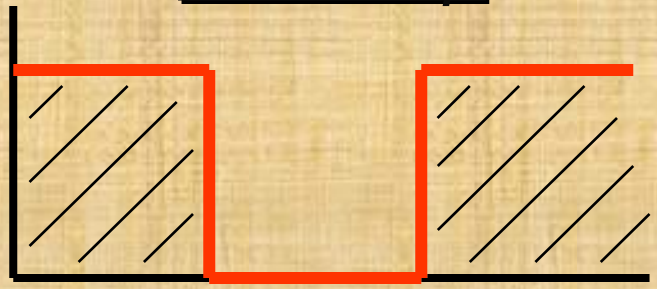
highpass



bandpass

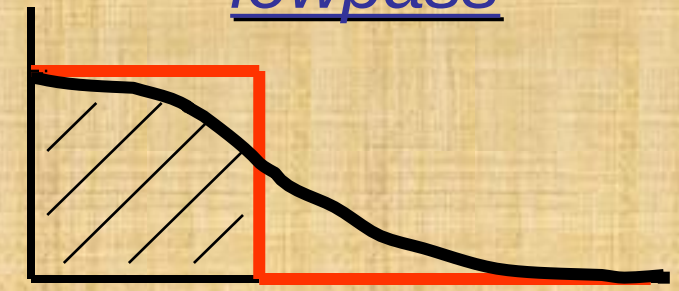


bandstop



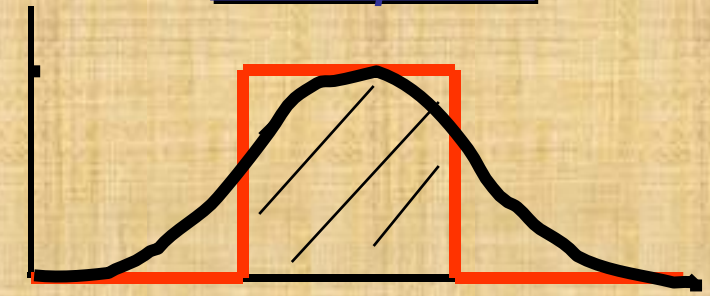
Realistic Filters:

lowpass

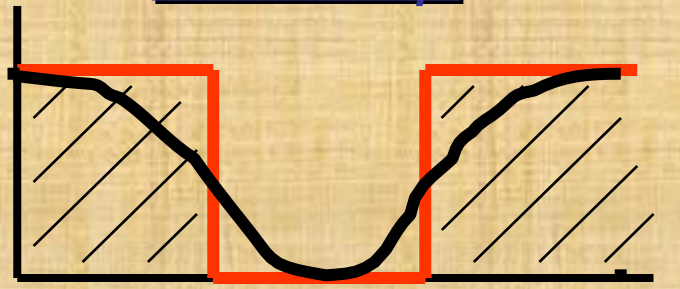


highpass

bandpass

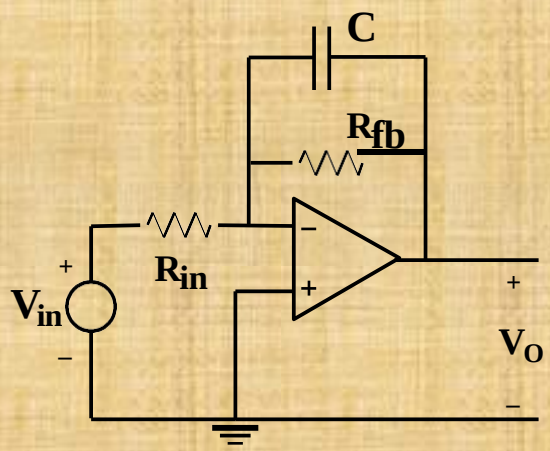


bandstop

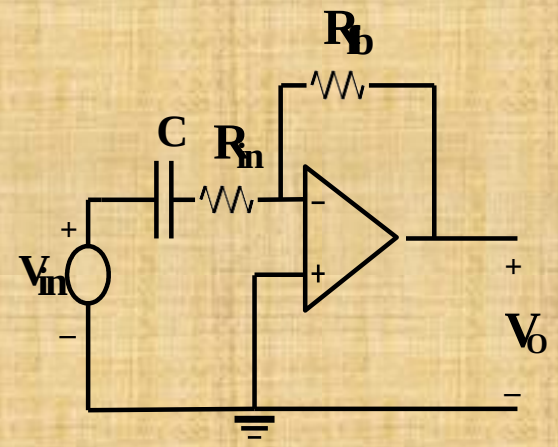


Basic Active Filters

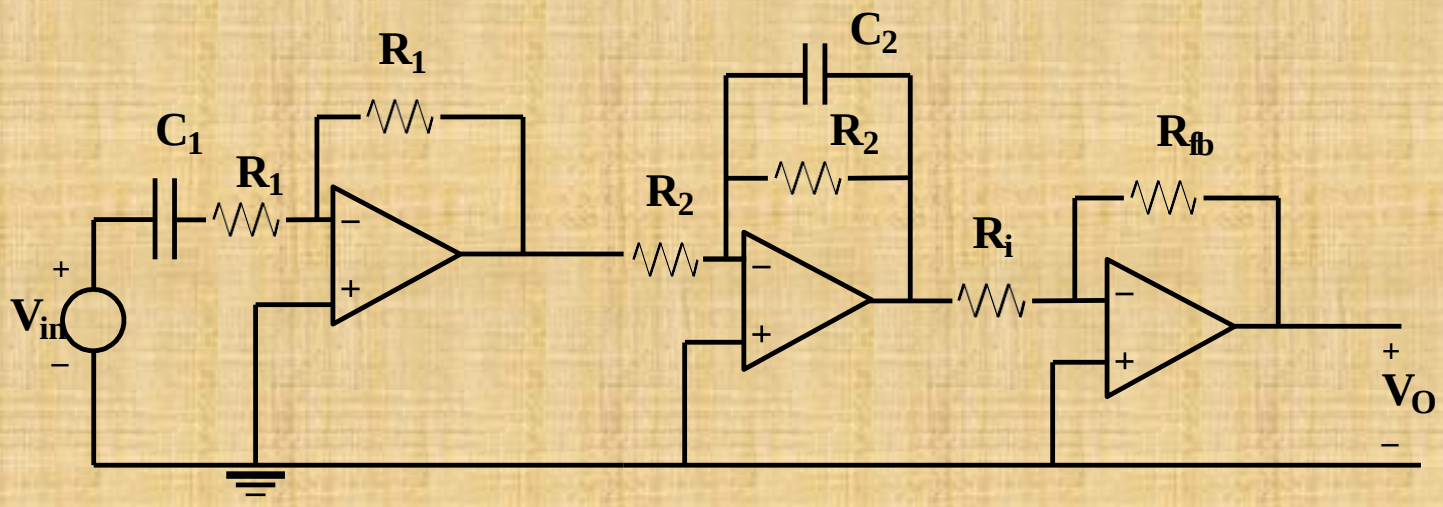
Low pass filter



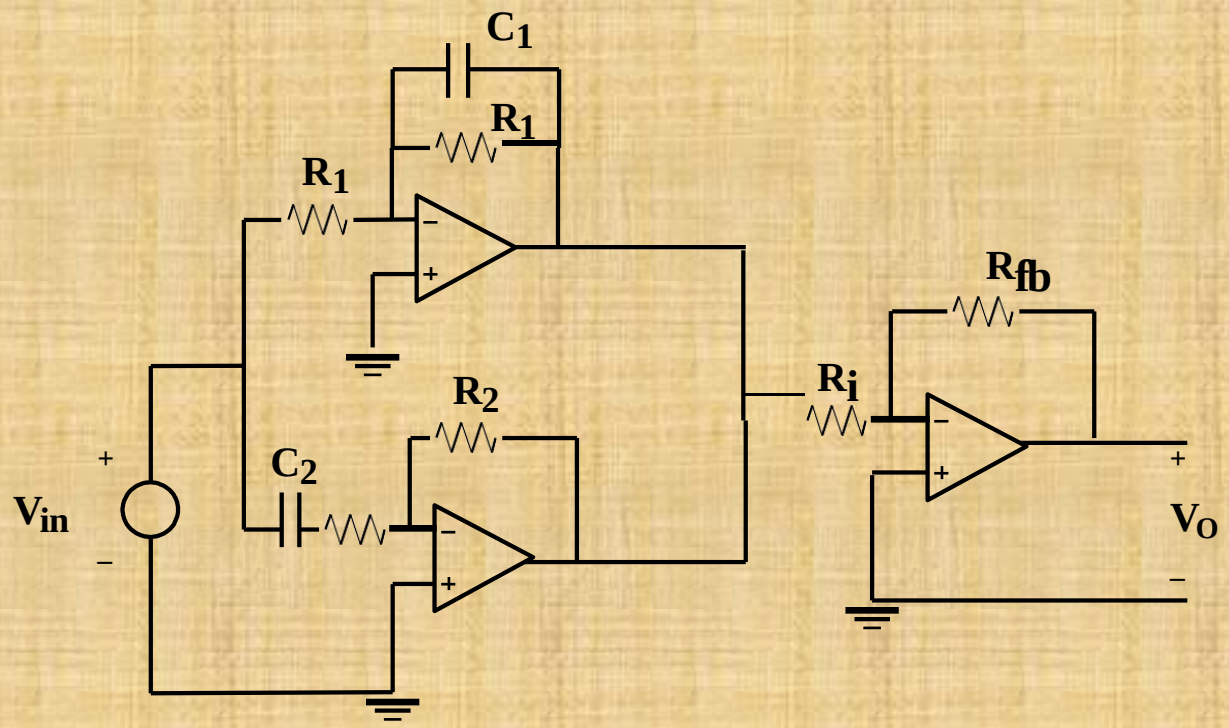
High pass



Band pass filter



BAND STOP FILTER



6.6Impedance Matching

- Connecting the sensors or process control element with different impedance causes signal reflection
- The network or circuit to match impedance thus to reduce signal reflection

6.7Concept of Loading

- When the sensor or circuit is connected to load, this will introduce the uncertainty in the measurement (amplitude of voltage)

- The output voltage is calculated using voltage division as

$$V_y = V_x \left(\frac{R_L}{R_L + R_x} \right)$$

$$= V_x \left(1 - \frac{R_x}{R_L + R_x} \right)$$

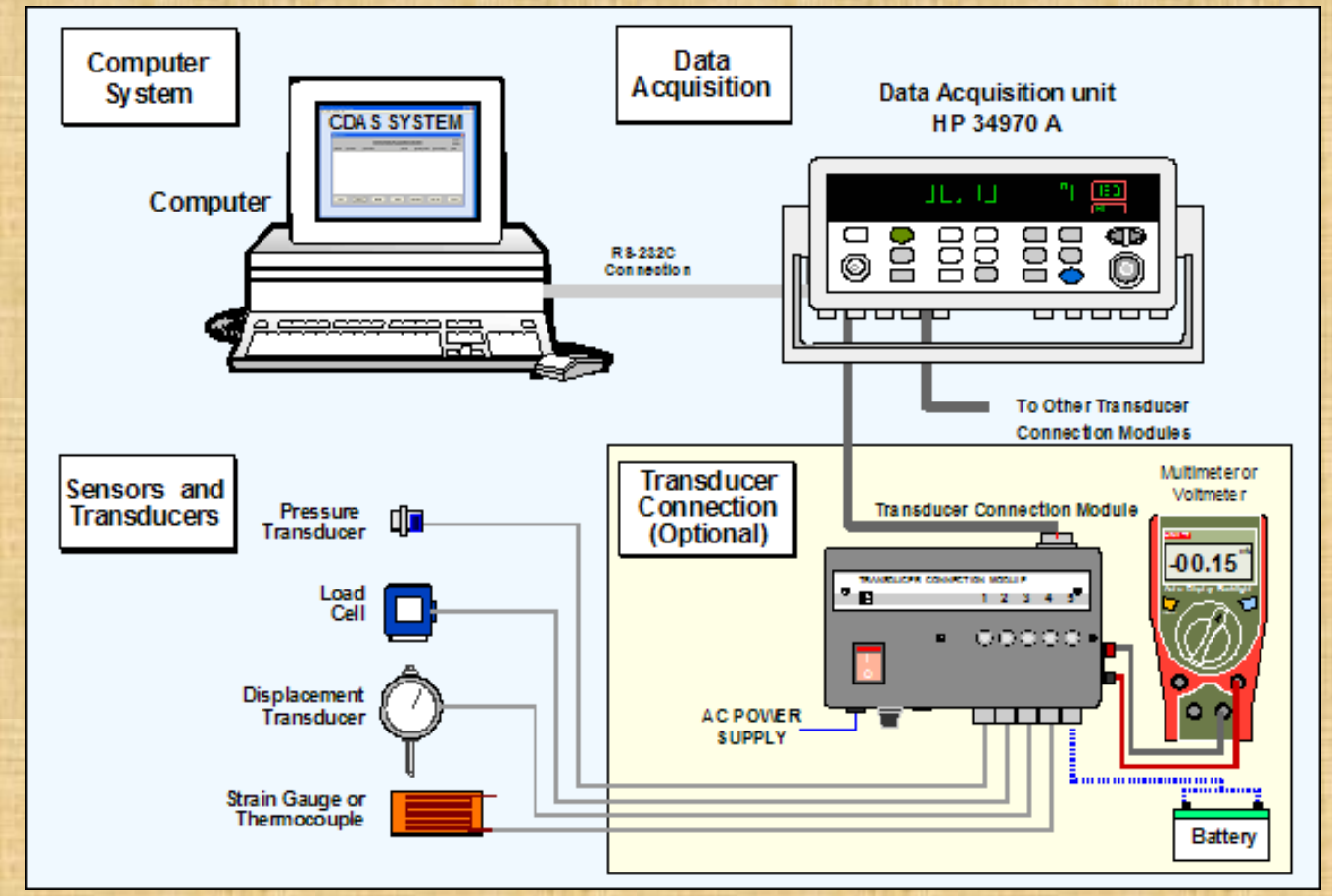
- Output voltage is reduced by the voltage drop
- To reduce the uncertainty, $R_L \geq R_x$

7.Data acquisition

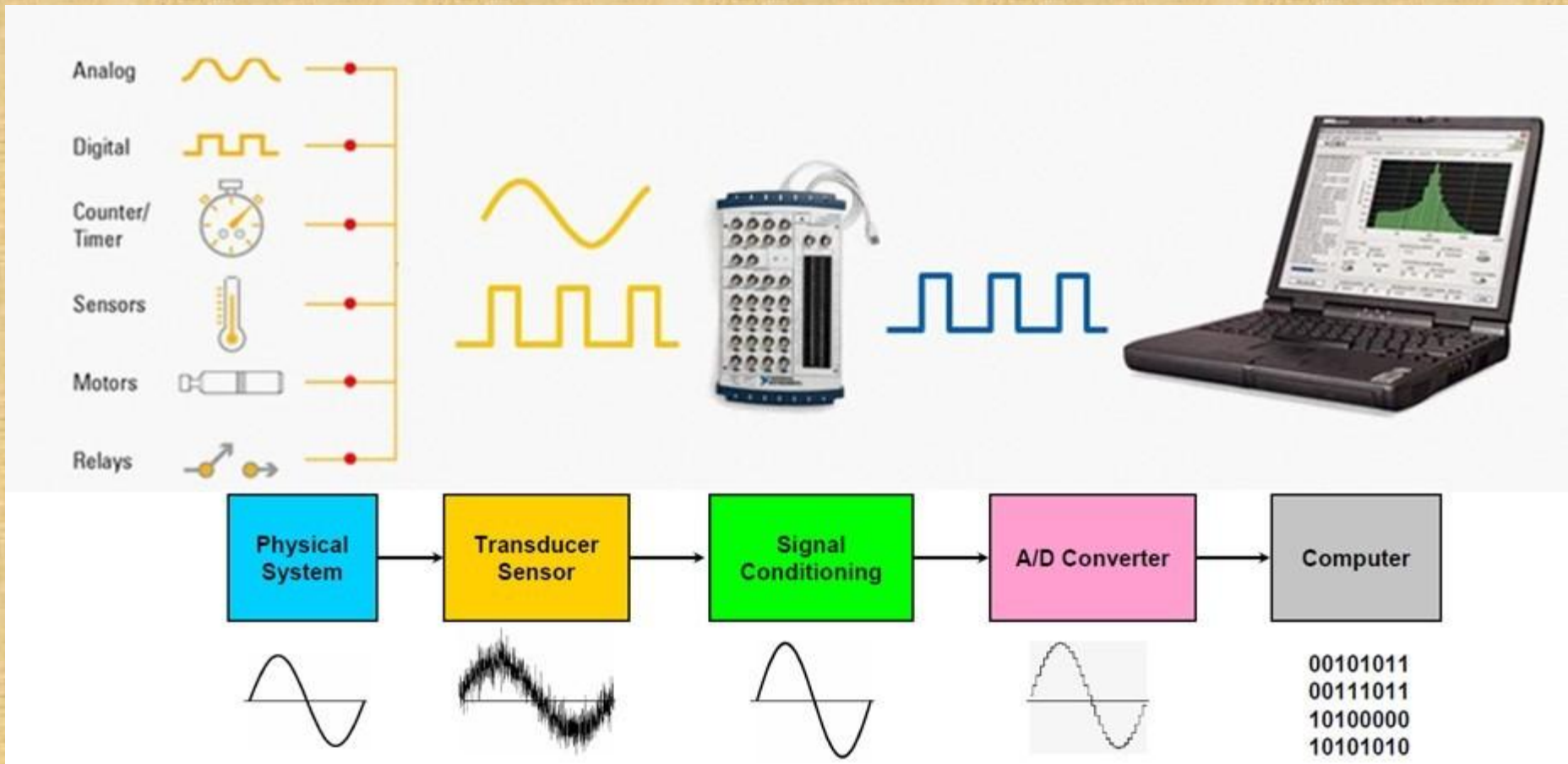
- Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer.

- **Data acquisition** is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer

Cont.…



A DAQ system **consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement**


Analog
Digital
Counter/
Timer
Sensors
Motors
Relays
Physical System
Transducer Sensor
Signal Conditioning
A/D Converter
Computer
00101011
00111011
10100000
10101010

Data acquisition system