Sensors Technology-BECE409E

Module:1 Sensing Mechanism - 4 hours

Principles of Sensing: Resistive, Capacitive, Magnetic, Inductive, Piezoelectric, Piezo-resistance, Pyro-electric, Hall Effect, RF sensing. Sensor materials and material properties. Sensor Technologies: Micro Technology, Micro-Electro-Mechanical Systems Technology, Nanotechnology. Example of Smart Sensors in Nature (Vision, Hearing, Touch, and Smell).

Module:2 RLC and Self Generating Sensors - 4 hours

Resistive Sensors – Strain Gauges, Resistance Temperature Detectors, Thermistors, Light dependent resistors, Self and Mutual Inductive Transducers, LVDT, Capacitive Transducers, Variable Distance, Variable Area, Variable Dielectric Type Capacitive Sensors. Self-Generating Sensors – Thermoelectric Sensors, Piezoelectric Sensors, Pyroelectric sensors, Photovoltaic sensors, Electrochemical Sensors

Module:3 Sensor Signal Conditioning - 4 hours

DC Bridges for Resistance Measurements-Wheatstone Bridge, Kelvin Bridge. AC Bridges for Capacitance and Inductance Measurements-AC Bridge, Schering Bridge. Sensor Compensation Circuits-Temperature, Non-linearity and Offset Compensation.

Module:4 Sensor Fabrication - 4 hours

Thick and Thin Film Sensor Fabrication – Screen Printing Technology, PVD, CVD, Fabrication of MEMS and NEMS Sensors – Lithography, Micromachining Techniques

Module:5 Advanced Sensors - 4 hours

Position Encoders, Resonant Sensors, Sensors Based on Semiconductor Junctions, Fiber-Optic Sensors, Ultrasonic-Based Sensors, Biosensors, Superconducting Quantum Interference Devices (SQUIDs).

Module:6 Smart Sensors - 4 hours

Smart Transducers: Smart Sensors, Components of Smart Sensors, General Architecture of Smart Sensors, Evolution of Smart Sensors, Advantages, Application area of Smart Sensors.

Module:7 Sensors for IoT - 4 hours

Sensor-Cloud; Fog Computing, Smart Cities and Smart Homes, Connected Vehicles, Smart Grid, Industrial IoT, Case Study: Agriculture, Healthcare, Activity Monitoring

Module:8 Contemporary Issues - 2 hours

Module:1 Sensing Mechanism - 4 hours

What is sensor?:

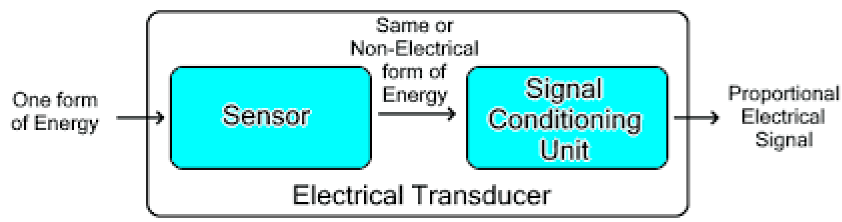
A sensor is a device that detects and responds to some type of input from the physical environment and converts it into data that can be interpreted by either a human or a machine. The input can be light, heat, motion, moisture, pressure or any number of other environmental phenomena. Sensor always directly connect to the measurand variables (the variable which is to be measured)

What is transducer?

A transducer is a device that transforms a signal from one energy form to another energy form. Usually it converts non-electrical to electrical signal. This is known as transduction phenomena.

One example is a speaker, which converts an amplifier's electrical energy into sound waves or mechanical energy.

Difference between sensor and transducer



- ✓ All sensors are transducer but all the transducers are not sensor

Basis For Comparison	Sensor	Transducer
Definition	Senses the physical changes occurs in the surrounding and converting it into a readable quantity.	The transducer is a device which, when actuates transforms the energy from one form to another.
Components	Sensor itself	Sensor and signal conditioning
Function	Detects the changes and induces the corresponding electrical signals.	Conversion of one form of energy into another.
Examples	Proximity sensor, Magnetic sensor, Accelerometer sensor, Light sensor, Barometer, Gyroscope etc.	Thermistor, Potentiometer, Thermocouple, etc.

Characteristics of Transducers

The performance characteristics of a Transducer are key in selecting the best suitable transducer for a particular design. So, it is very important to know the characteristics of transducers for proper selection. Performance characteristics of transducers can be further classified into two types: Static Characteristics and Dynamic Characteristics.

Static Characteristics: The static characteristics of a transducer is a set of performance criteria that are established through static calibration i.e. description of the quality of measurement by essentially maintaining the measured quantities as constant values of varying very slowly.

Following is a list of some of the important static characteristics of transducers.

Range: The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25- 225 °C.

Span: The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

Error: Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2mm.

Accuracy: Accuracy measures how close results are to the true or known value

Precision: Precision on the other hand, measures how close results are to one another.

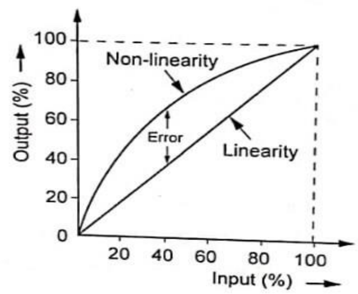
Accuracy	Precision
Accuracy is closeness with the true value of the quantity being measured.	Precision is a measure of the reproducibility of the measurement.
Measurement can be accurate but not necessarily precise.	Measurement can be precise but not necessarily accurate.
It can be determined with a single measurement.	It needs serveral measurements to be determined.
Accuracy may be affected with systematic error.	Precision may be affected with random error.
Accurate values have to be precise in most cases.	Precise values may or may not be accurate.
Degree of conformity.	Degree of reproducibility.

Sensitivity: Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change.

$$\text{Sensitivity} = \frac{\text{change in output}}{\text{change in input}}$$

$$\text{Sensitivity} = \frac{\Delta q_o}{\Delta q_i}$$

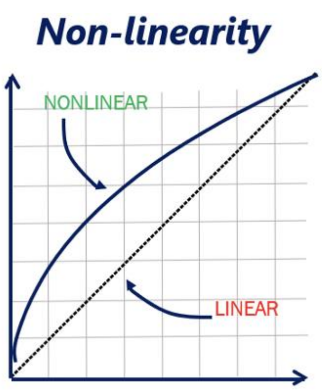
Linearity: Linearity is the best characteristics of an instrument or measurement system. Linearity of the instrument refers to the output is linearly or directly proportional to input over the entire range of instrument. So the degree of linear (straight line) relationship between the output to input is called as linearity of an instrument.



Nonlinearity: The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Figure shows a somewhat exaggerated relationship between the ideal, or least squares fit, line and the actual measured or calibration line. Linearity is often specified in terms of percentage of nonlinearity, which is defined as:

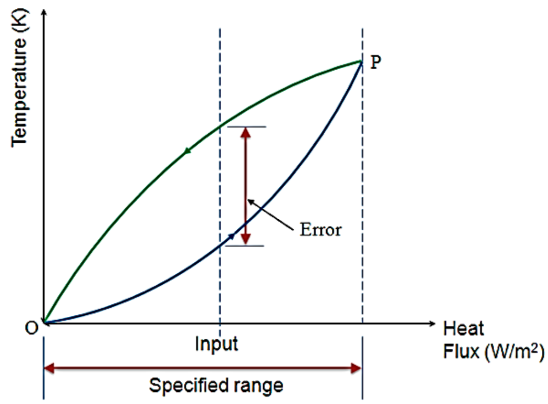
Nonlinearity (%) = (Maximum deviation in input ⁄ Maximum full scale input) × 100

The static nonlinearity defined by Equation is dependent upon environmental factors, including temperature, vibration, acoustic noise level, and humidity. Therefore it is important to know under what conditions the specification is valid.

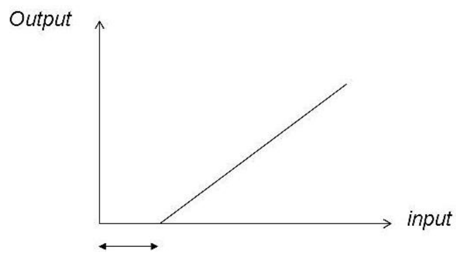


Resolution: Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full scale reading or in absolute terms. For example, if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2mm.

Hysteresis: The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.



Threshold: Threshold of a measuring instrument is the minimum value of input signal that is required to make a change or start from zero. This is the minimum value below which no output change can be detected when the input is gradually increased from zero. The minimum value of input for which the device just starts to respond.



Stability: Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time.

Drift: The term 'drift' is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output. Gradual shift in the measured value, over an extended period, when there is no change in input.

Repeatability: It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

Repeatability = (maximum – minimum values given) × 100 ⁄ full range

Reproducibility: Reproducibility is the degree of agreement between results of successive measurements of the same variable carried out under different measurement conditions (same operator but different transducers or same transducer but different operators).

Dead Zone: Dead zone or dead band is defined as the largest change of input quantity for which there is no output the instrument due the factors such as friction, backlash and hysteresis within the system. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

Response time: Response time indicates the time needed for the output to reach steady state for a step change in input. Typically the response time will be given as the time needed to reach 90% of steady state output upon exposure to a unit step change in input.

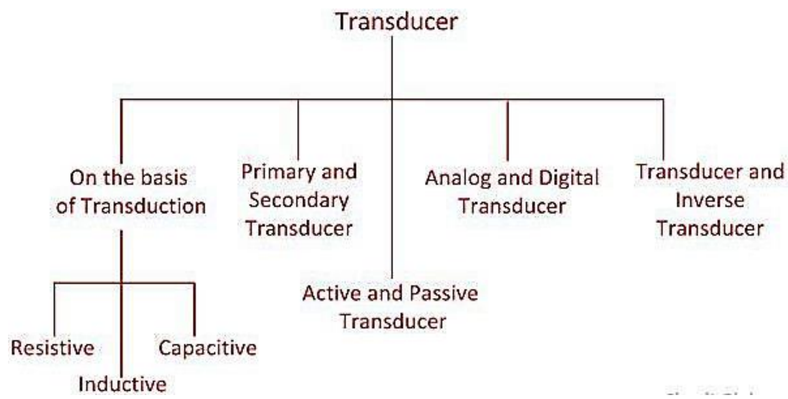
- Example: a sensors is designed for: –30 °C to +80 °C to output 2.5V to 1.2V
- Range: –30°C and +80 °C
- Span: 80– (–30)=110 °C
- Input full scale = 110 °C
- Output full scale = 2.5V-1.2V=1.3V
- Dynamic range=20log(140/30)=13.38db

Example: a digital voltmeter with resolution of 0.1V is used to measure the output of a sensor. The change in input (temperature, pressure, etc.) that will provide a change of 0.1V on the voltmeter is the resolution of the sensor/voltmeter system.

In digital systems generally, resolution may be specified as $1/2^N$ (N is the number of bit.)

Classification of Transducers

The transducers can be classified as:



1. Active and passive transducers.
2. Analog and digital transducers.
3. Primary and secondary transducer
4. Transducers and inverse transducers.
5. On the basis of transduction principle used

1. Active and passive transducers:

Active Transducer:

- ✓ These transducers do not need any external source of power for their operation. Therefore they are also called as self-generating type transducers.
- ✓ The transducers, which develop their output in form of electrical voltage or current without any auxiliary source are known as active transducers.
- ✓ They draw energy from the system under measurement.
- ✓ They give very small output and use of amplifier is essential.
- ✓ Examples: Tachogenerator, Thermocouple, Piezo-electric crystals, photovoltaic cell etc.

Passive Transducer:

- ✓ These transducers need external source of power for their operation. So they are not self generating type transducers.
- ✓ The transducers in which, the electrical parameters i.e. resistance, inductance and capacitance changes with change in input signal.
- ✓ They require external power source for energy conversion.

- In this, electrical parameters causes a change in voltage, current or frequency of the
- external power source.
- They may draw some energy from the system under measurement.
- Examples: Resistive, Inductive and Capacitive transducers

2. Analog and digital transducers.

Analog transducer: These transducers convert the input quantity into an analog output which is a continuous function of time. Examples: Thermistor, Strain gauge, LVDT, Thermocouple.

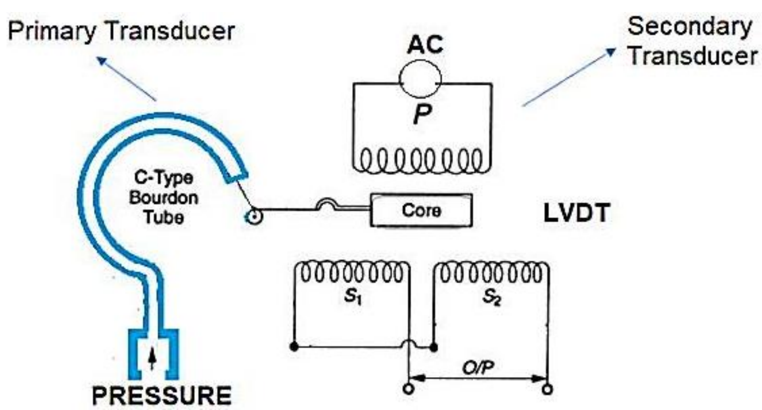
Digital Transducer:

- Digital transducer converts input signal into output signal of the form of pulses e.g. it gives discrete output.
- These transducers are becoming more popular.
- Sometimes, analog transducer combined with ADC (Analog-to-Digital Converter) is called digital transducer.
- Examples: Encoders, Hall effect sensors

3. Primary and secondary transducer

Primary Transducer: When input signal is directly sensed by transducer and physical phenomenon is converted into electrical form directly then such transducer called primary transducer. Examples: Thermistor

Secondary Transducer: When input signal is directly sensed first by some sensor and then its output being of some form other than input signal I given as input to a transducer for conversion into electrical form, then it's called secondary transducer. Examples: LVDT for used pressure measurement by using bourdon tube.



4. Transducers and inverse transducers

Transducers: It is a device that converts a non-electrical quantity into an electrical quantity. Examples: Thermocouple, Pressure gauge, Strain gauge, Photovoltaic cell

Inverse Transducer:

- It is a device that converts an electrical quantity into non-electrical quantity.
- It is a precision actuator having an electrical input and low-power non-electrical output.
- A most useful application of inverse transducer is in feedback measurement systems.
- Examples: Piezo-electric crystal

Principles of Sensing:

I. Resistive: Resistive sensors are those sensors in which the resistance changes due to the change in some physical phenomenon. It works on the principle that, the conductor length is directly proportional to resistance of the conductor and it is inversely related with area of the conductor. The resistance of a metal conductor is expressed by a simple equation.

$$R = \rho L/A$$

Where R = resistance of conductor in Ω

L = length of conductor in m

A = cross sectional area of conductor in m^2

ρ = resistivity of conductor material in Ω-m.

II. Capacitive: In capacitive sensor the capacitance changes due to the change in some physical phenomenon. The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by

$$C = \varepsilon_0 \varepsilon_r A / d$$

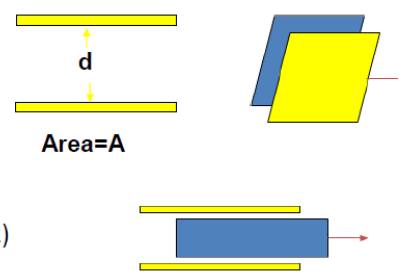
d is the separation distance of plates (m)

C is the capacitance (F, Farad)

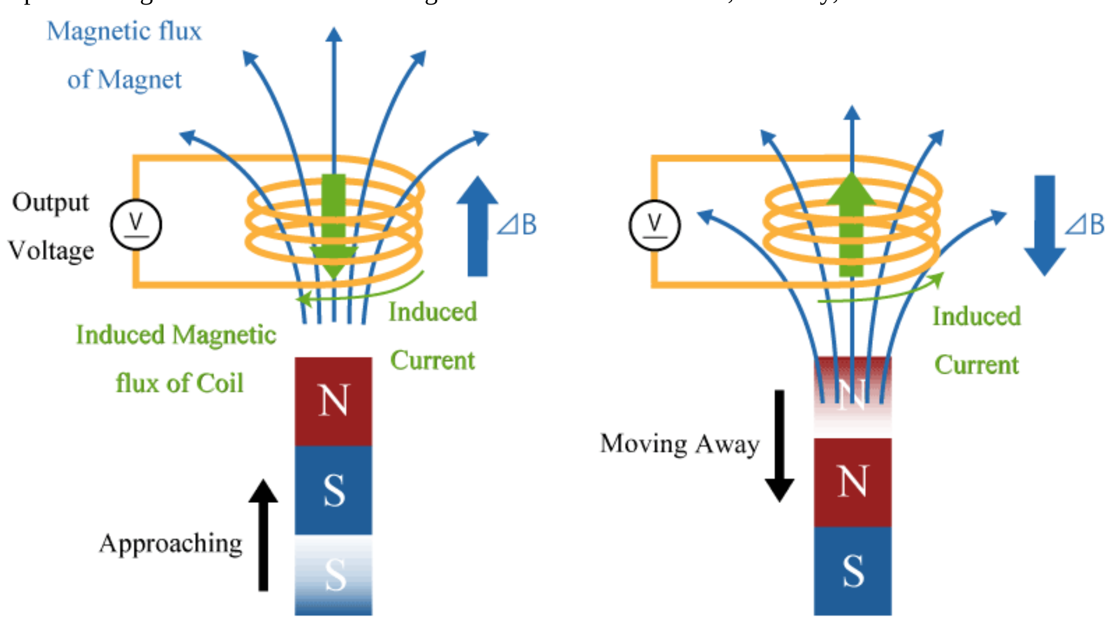
ε_0 : absolute permittivity of vacuum

ε_r : relative permittivity

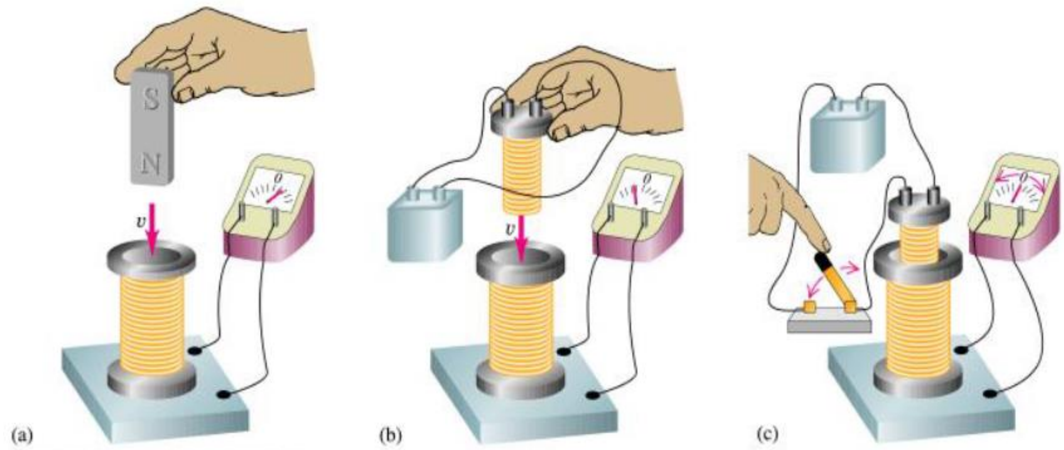
A is the effective (overlapping) area of capacitor plates (m2)



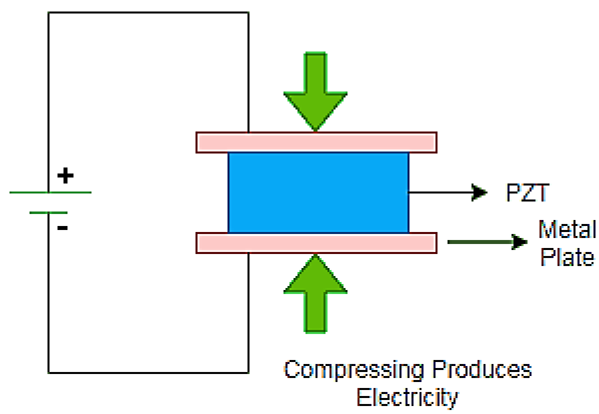
III. Magnetic: Magnetic sensor translates the magnitude and fluctuations of magnetic flux into electric impulses. Magnetic sensors measure magnetic fields in terms of flux, intensity, and direction.



IV. Inductive: Inductive sensor uses the principle of electromagnetic induction to detect or measure objects. In inductive transduction, the measured is converted into a change in the self-inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element When a force is applied to the ferromagnetic armature, the air gap changes, varying the reluctance of the magnetic circuit. Applied force is measure as change of inductance in the coil. It can measure both static and dynamic changes.

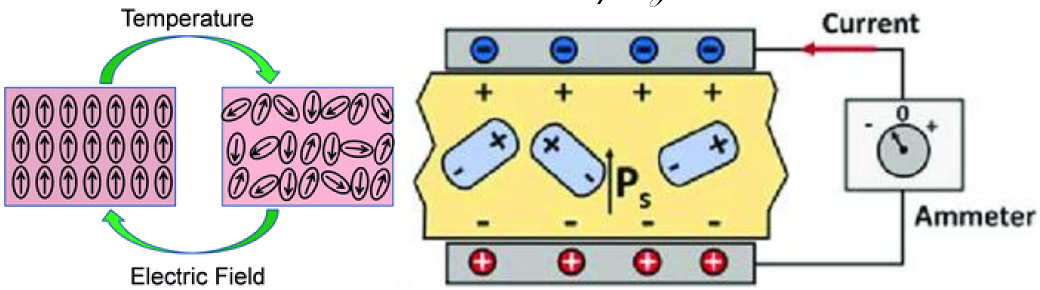


V. Piezoelectric: Piezo is a Greek term signifying "press" or "squeeze". Piezoelectricity (also called the piezoelectric effect) is the presence of an electrical potential across the sides of a crystal when mechanical stress is applied by squeezing it. In working system, the crystal acts like a tiny battery with a positive charge on one face and a negative charge on the opposite face. To make it as a complete circuit, two faces are connected together and current is passed through it. Piezoelectric sensor uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.

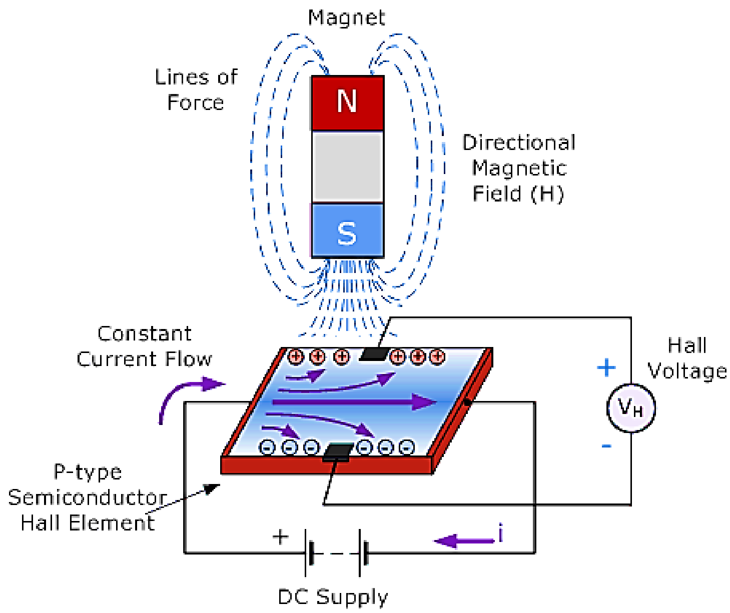


VI. Piezo-resistance: When an external force or strain is applied to a metal or semiconductor, its electrical resistance changes, the change in electrical resistance under mechanical strain is called the piezoresistive effect. The change in resistance due to external input is more dominant in semiconductors when compared to metals. The piezoresistive effect is different from the piezoelectric effect. Piezoelectric transducers use the piezoresistive effect to convert physical quantities to electrical quantities.

VII. Pyro-electric: Pyroelectricity is the property of a polar crystal to produce electrical energy when it is subjected to a change of thermal energy. Ferroelectric materials are expected to be strongly pyroelectric because ferroelectric materials have a large range of temperature-dependent spontaneous polarization.



VIII. **Hall Effect:** The principle of the Hall effect states that when a current-carrying conductor or a semiconductor is introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path.



IX. **RF sensing:**

Sensor materials and material properties

Sensor Technologies:

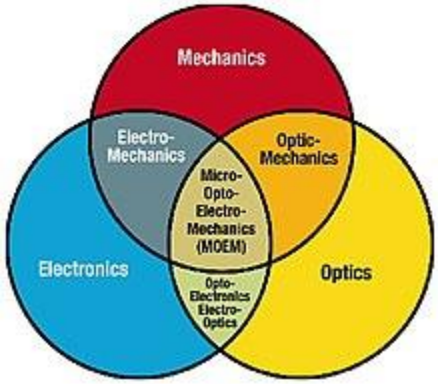
I. **Micro Technology:**

Microtechnologies are technologies that contribute to the design, creation, manufacture or use of components, systems or devices that are small in size and/or high precision. Microtechnology deals with technology whose features have dimensions of the order of one micrometre (one millionth of a metre, or 10^{-6} metre, or 1µm).

Microfabrication technologies originate from the microelectronics industry, and the devices are usually made on silicon wafers even though glass, plastics and many other substrate are in use. To fabricate a microdevice, many processes must be performed, one after the other, many times repeatedly. These processes typically include depositing a film, patterning the film with the desired micro features, and removing (or etching) portions of the film.

II. **Micro-Electro-Mechanical Systems Technology:**

Micro-electromechanical systems (MEMS) is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres.



III. **Nanotechnology:** Nanotechnology refers to the branch of science and engineering devoted to designing, producing, and using structures, devices, and systems by manipulating atoms and molecules at nanoscale, i.e. having one or more dimensions of the order of 100 nanometres (100 millionth of a millimetre) or less.

Example of Smart Sensors in Nature (Vision, Hearing, Touch, and Smell)

- **I. Vision sensor in Nature**
- **II. Hearing sensor in Nature**
- **III. Touch sensor in Nature**
- **IV. Smell sensor in Nature**

The five senses of the human body include vision, hearing, touch, taste and smell. The human body has specific sensory organs for each of these senses. The five basic sensory organs are the eyes, ears, skin, tongue and nose.