BENHA UNIVERSITY
FACULTY OF ENGINEERING (SHOUBRA)
ELECTRONICS AND COMMUNICATIONS ENGINEERING

ECE 211

Measurements and Instrumentations

(2022 - 2023) term 231

Lecture 7: Sensors and Transducers.

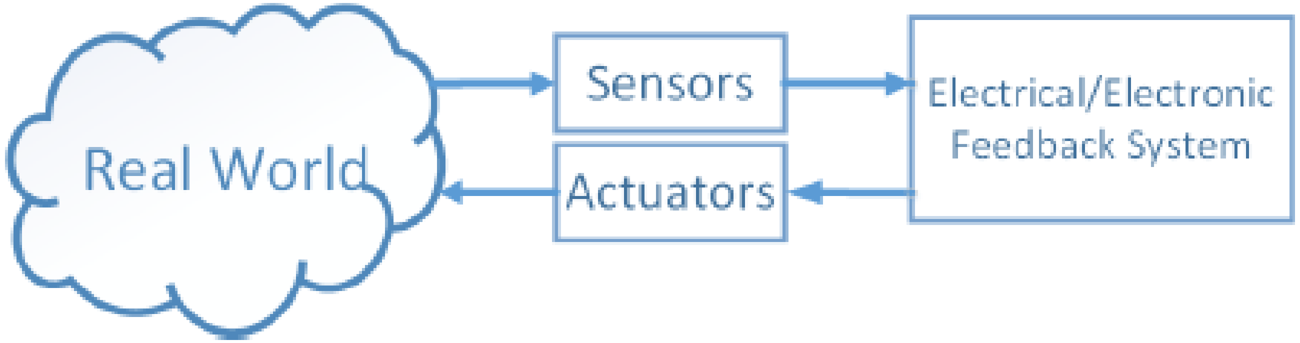
Dr. Ahmed Samir
https://bu.edu.eg/staff/ahmedsaied

Chapter Outline:

1) **Introduction to Sensors and Transducers.**
2) Analog vs. Digital Sensors.
3) Signal Conditioning and Smart Sensors.
4) Displacement, Position and Proximity Sensors.
5) Velocity Sensors.
6) Force Sensors.
7) Liquid Level Sensors.
8) Temperature Sensors.

1. Introduction to Sensors and Transducers:

- Electrical and Electronic systems need to **sense** and **react** with the **real world** either by:
  - Reading **(sensing)** an input quantity,
  - Activating **(actuating)** some form of output devices.



Sensor:
A sensor is a device that **measures/detects** a signal to acquire information from the real world.

Actuator:
An actuator is a device that **generates** a signal to affect the state of the real world.

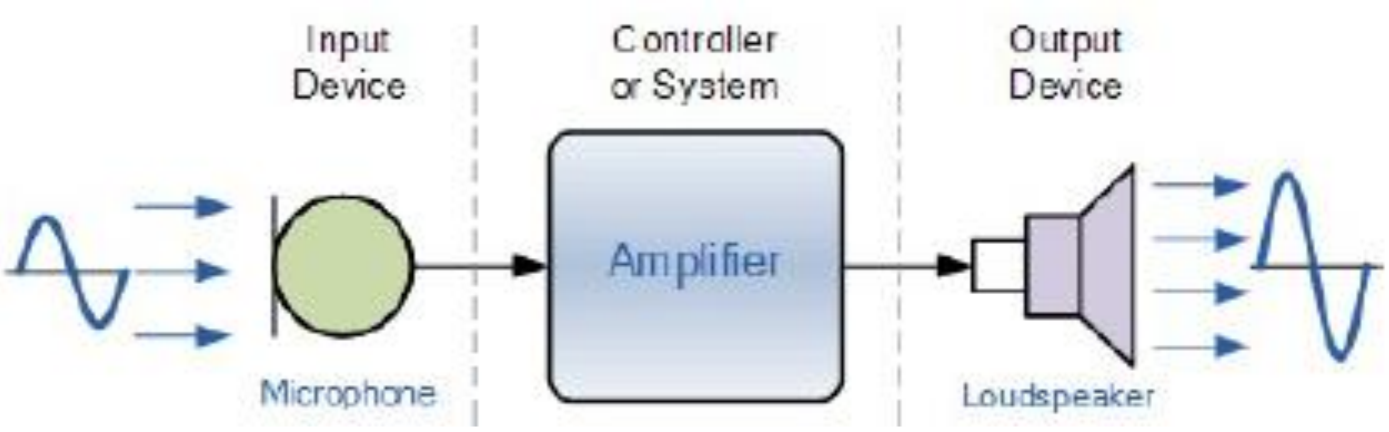
1. Introduction to Sensors and Transducers:

Transducer:

- It is a collective word used for both sensors and actuators.
- It is a device that converts a form of energy into a different form of energy.

Electrical Transducers:

Devices that are used to convert types of energy to/from electrical energy.



- ➢ A microphone (input device) converts **sound waves** into **electrical signals** for the amplifier.
- ➢ Also, a loudspeaker (output device) converts these **electrical signals** back into **sound waves**.

1. Introduction to Sensors and Transducers:

Types of Electrical Transducers:

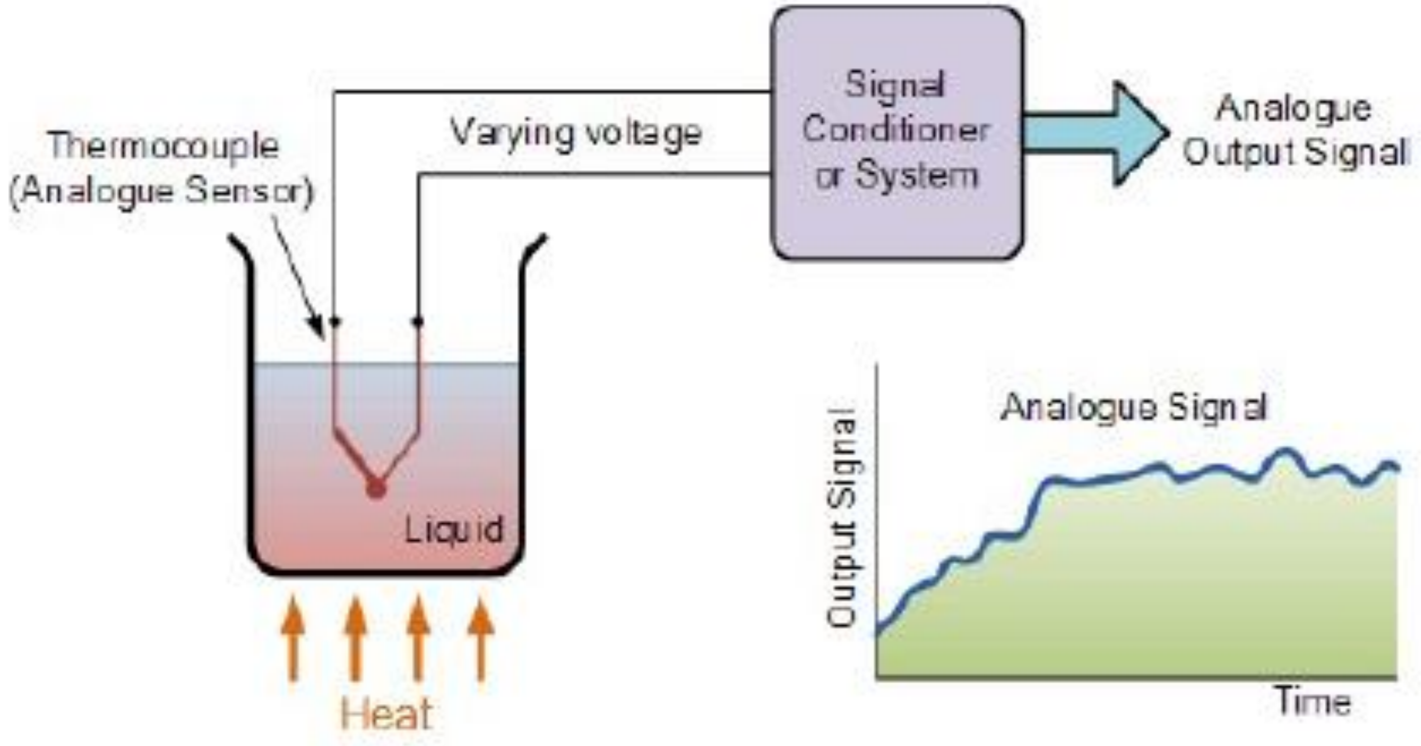
- In this part of the course, some types of **electrical sensors** will be discussed.
- There are many different types of sensors available in the marketplace.
- The choice of which sensor to use depends **upon the quantity to be measured.**

- Position and Displacement:
  - Potentiometers.
  - Encoders.
  - Linear Variable Differential Transformer (LVDT).
  - etc.
- Force:
  - Strain gauge.
  - etc.
- Speed:
  - Tacho generators.
  - Slotted optocoupler.
  - etc
- Temperature:
  - Thermocouple.
  - Resistive Temperature Detector (RTD).
  - etc.
- etc.

2. Analog vs. Digital Sensors:

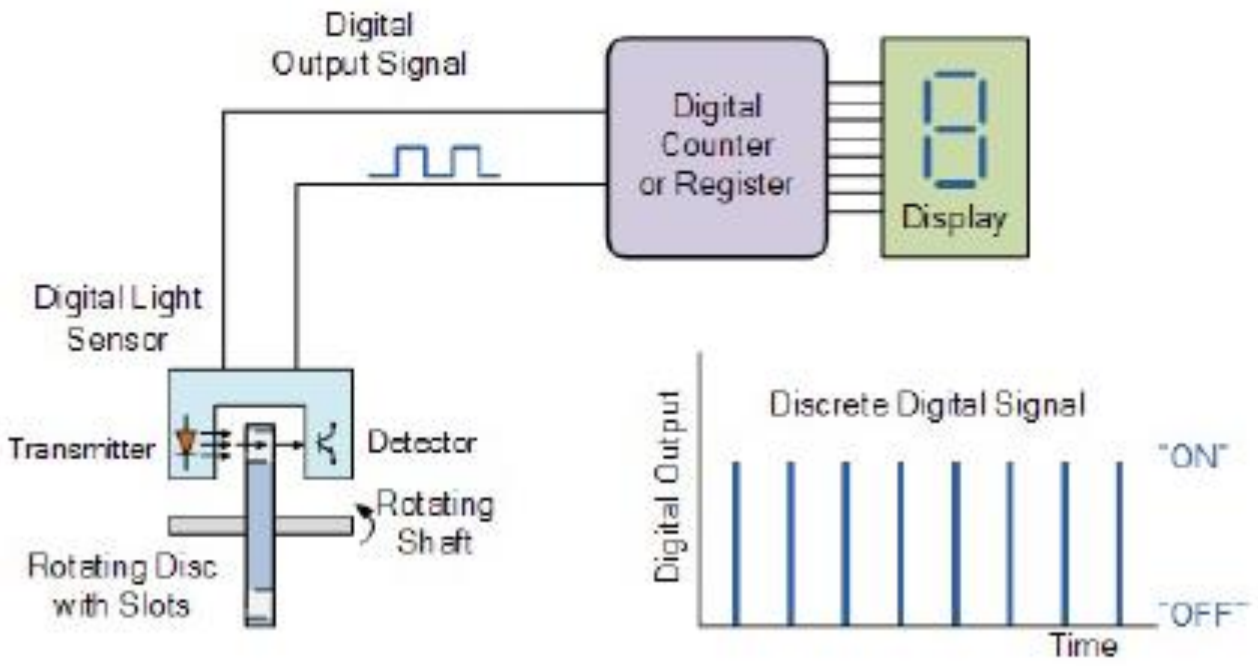
Analog Sensors:

- Analog sensors produce a **continuous output signal** or voltage which is generally proportional to the **quantity being measured.**
- Physical quantities (such as Temperature, Speed, Pressure, Displacement, etc.) are all analog or continuous in nature.
- For example, the fluid temperature could be measured by a thermometer which responds continuously to the temperature change.



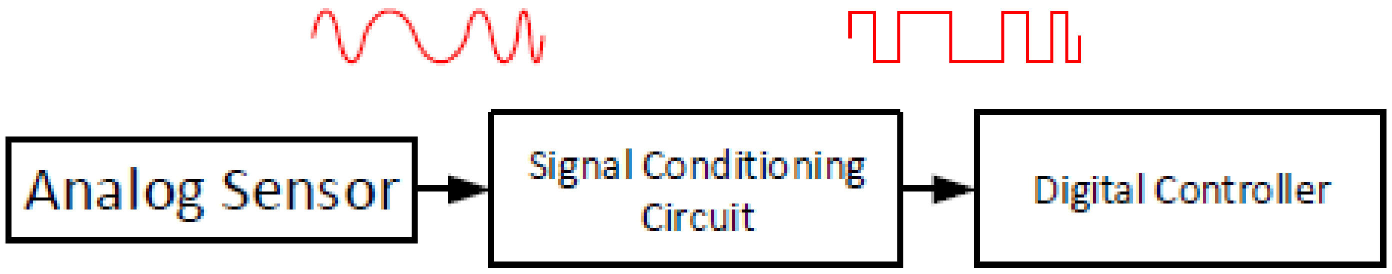
2. Analog vs. Digital Sensors:
Digital Sensors:

- Digital sensors produce **a discrete digital** output signal or voltage which is a digital representation of the quantity being measured.
- Digital sensors produces **Binary output** signal in the form of logic "High" or logic "Low".
- The digital representation of the measured quantity could be sent to the controlling device in **serial** (bit-by-bit) or in **parallel** (combination of bits) .
- For example, a shaft encoder is used to measure the speed of a shaft.



3. Signal Conditioning and Smart Sensors:

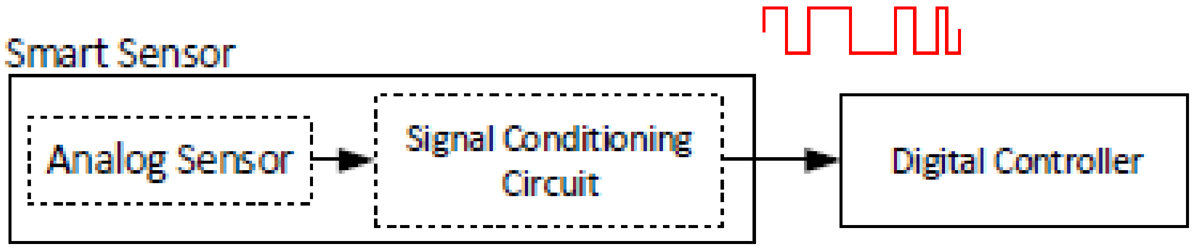
- Signal conditioning is defined as the operations done over an analog signal in such a way that it meets the requirements of the next stage for further processing.



- Signal conditioning includes: **amplification**, filtering, range changing and analog-to-digital conversion.

Smart Sensors:

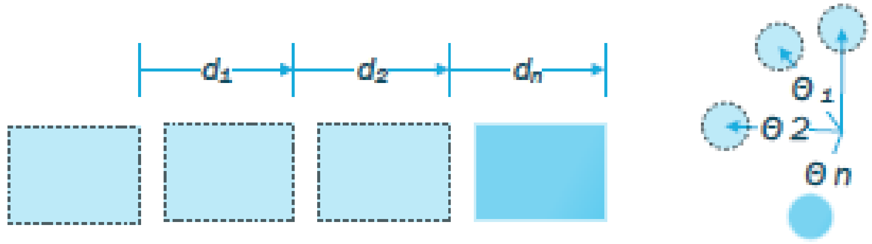
The sensors that come combined with their signal conditioning in the same package.



4. Displacement, Position and Proximity Sensors:

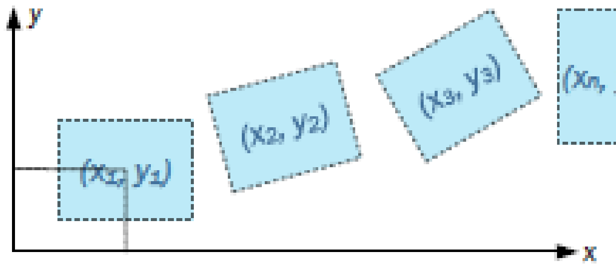
Displacement Sensors:

Sensors that are concerned with the measurement of the **amount by which some object has been moved.**



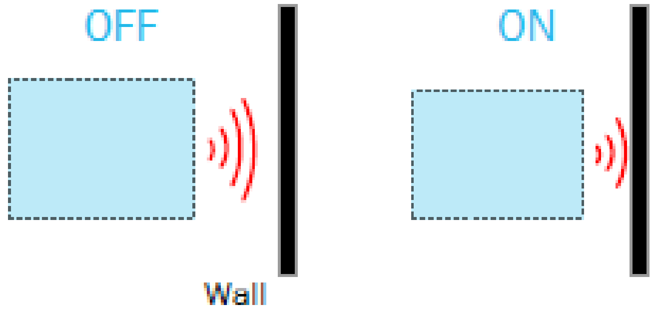
Position Sensors:

Sensors that are concerned with the determination of the **position of some object in relation to some reference** point.

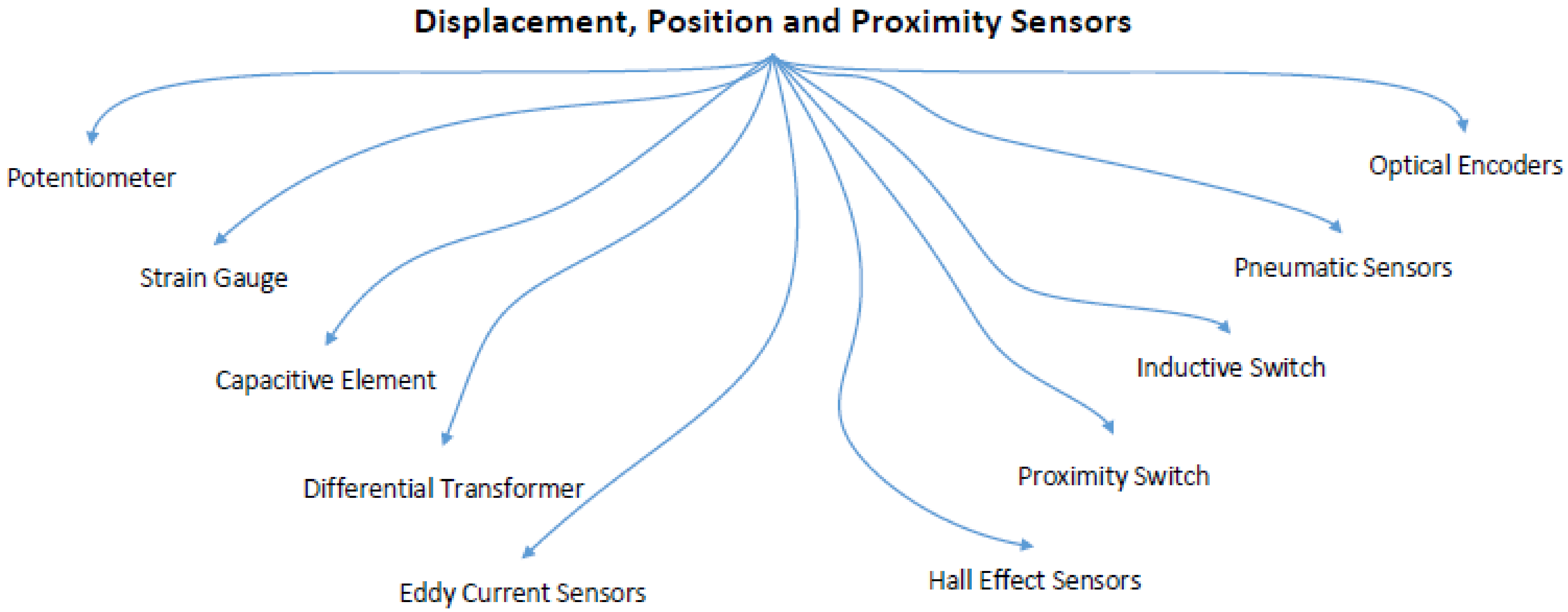


Proximity Sensors:

Sensors that are used to determine **if an object is within some particular critical distance** of the sensor. They give ON/OFF outputs.



4. Displacement, Position and Proximity Sensors:

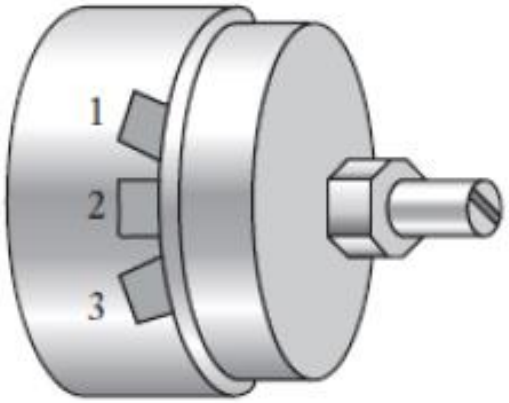


4. Displacement, Position and Proximity Sensors:

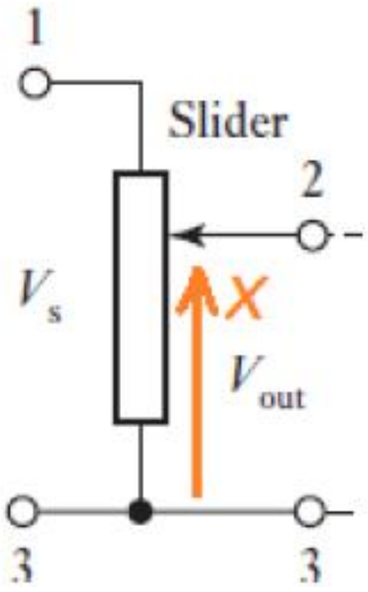
[1] Potentiometer Sensors:

- A potentiometer consists of a resistance element with a sliding contact that can move over the length of the resistance element.
- Such elements can be used for **linear** or **rotary** displacements.
- The moving object could be connected to the sliding contact to indicate the object **displacement as a change in resistance** then change in the **voltage**.

A linear potentiometer



A rotary potentiometer



4. Displacement, Position and Proximity Sensors:

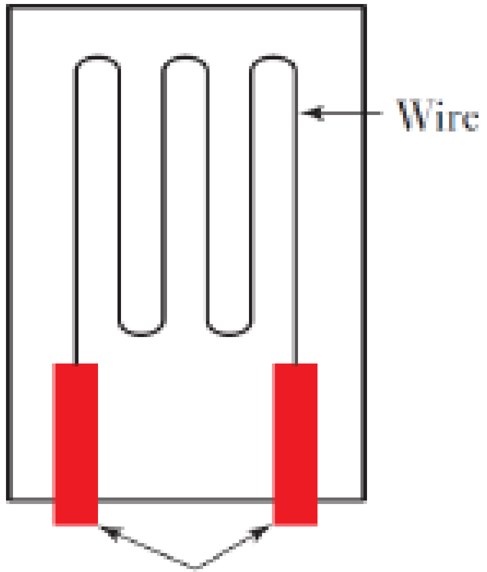
[2] Strain-Gauged Element:

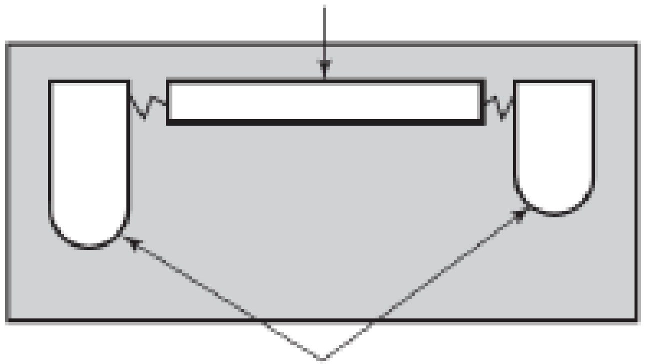
- **Strain** is defined as the ratio of the change in length to the original length of an elastic material (change in length/original length).
- **Strain gauge** is a metal wire or a strip of semiconductor that when subject to strain or elongation, its resistance R changes.
- The change in strain-gauge resistance, **ΔR/R**, is proportional to the applied strain, ε.

$$\frac{\Delta R}{R} = G\varepsilon$$

where G is the gauge factor constant.

- A problem with all strain gauges is that their **resistance changes with temperature**.

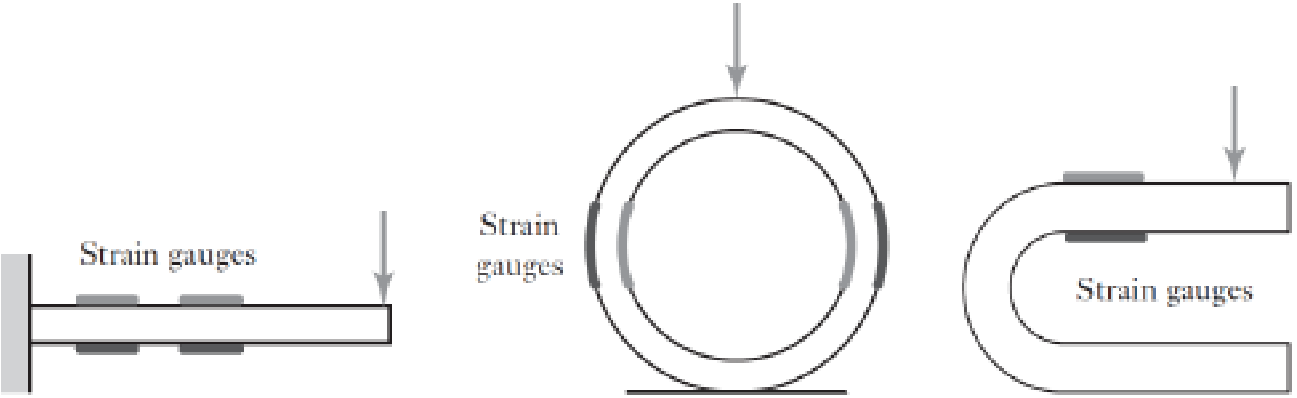


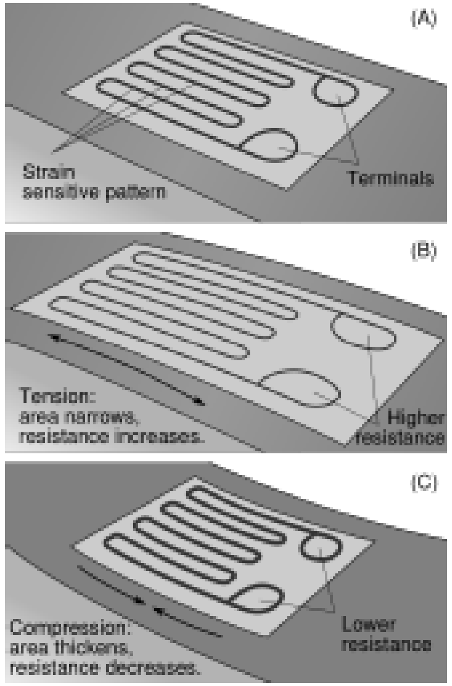


4. Displacement, Position and Proximity Sensors:

[2] Strain-Gauged Element:

- To monitor a displacement by a strain gauge, the moving object is attached a flexible to form either a **cantilevers, rings** or **U-shape**.
- When the flexible element is deformed as a result of moving object, the resistance of the strain gauges will change. The change in resistance is thus a measure of the **displacement** or deformation of the flexible element.





4. Displacement, Position and Proximity Sensors:

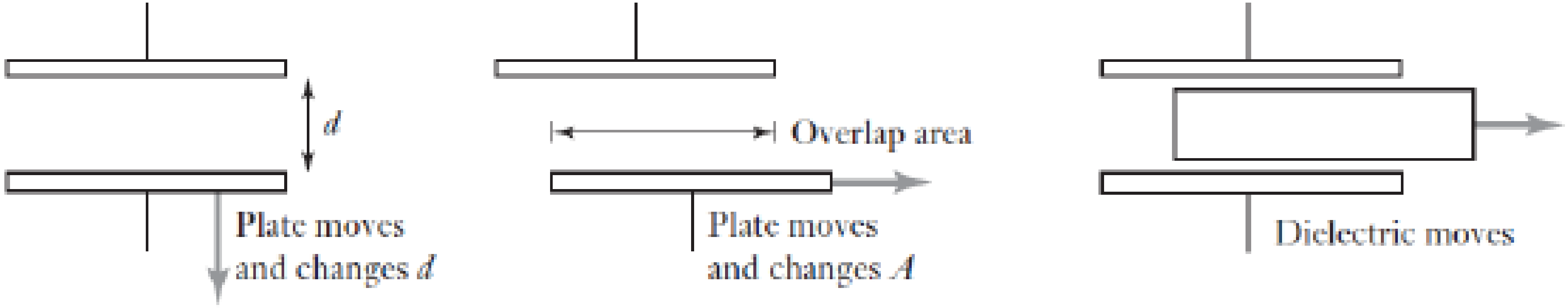
[3] Capacitive Elements:

- The capacitance C of a parallel plate capacitor is:

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

ε_r: Relative permittivity of the dielectric.
ε_o: Permittivity of free space.
A: Overlap area between the two plates.
d: Plates separation distance.

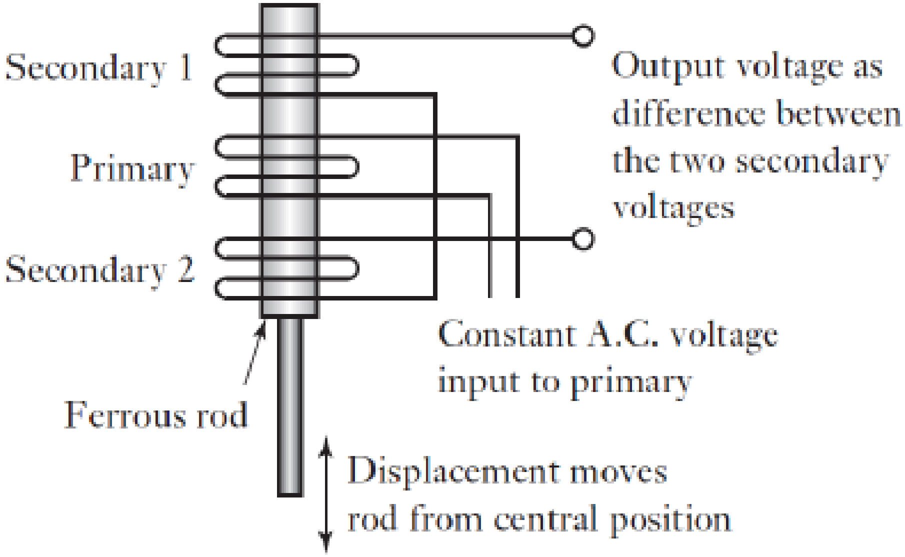
- To monitor a linear displacement, capacitive sensors is arranged in such a way that the displacement is either:
    1. Change of the plate separation distance.
    2. Change the plates overlap area.
    3. Change of the dielectric between plates.



4. Displacement, Position and Proximity Sensors:

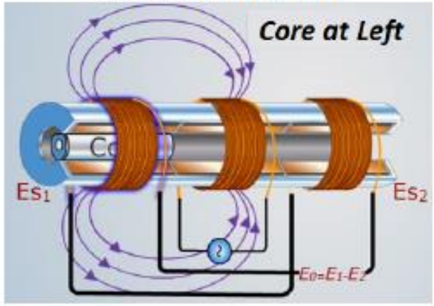
[4] Linear Variable Differential Transformer (LVDT):

- The LVDT consists of **three coils symmetrically** spaced along an insulated tube.
- **The central coil is the primary coil** which is connected to **an AC current source**.
- AC E.M.Fs, *Es1* and *Es2*, are generated in the two secondary coils. The two secondary coils are identical and are connected in series in such a way that their outputs oppose each other.
- A magnetic core is moved through the central tube which is connected to the displacement being monitored.
- The net E.M.F, *Eo is* depending on the position of the core inside the insulator.



$$E_o = E_{s1} - E_{s2}$$

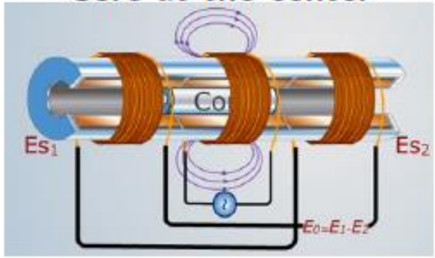
Core at the left



$$E_{s1} > E_{s2}$$

$$E_o = +ve$$

Core at the center

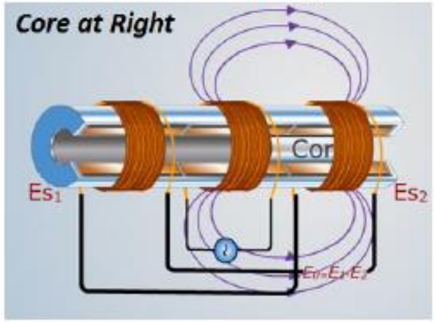


$$E_{s1} = E_{s2}$$

$$E_o = 0$$

Null Position

Core at the right



$$E_{s1} < E_{s2}$$

$$E_o = -ve$$

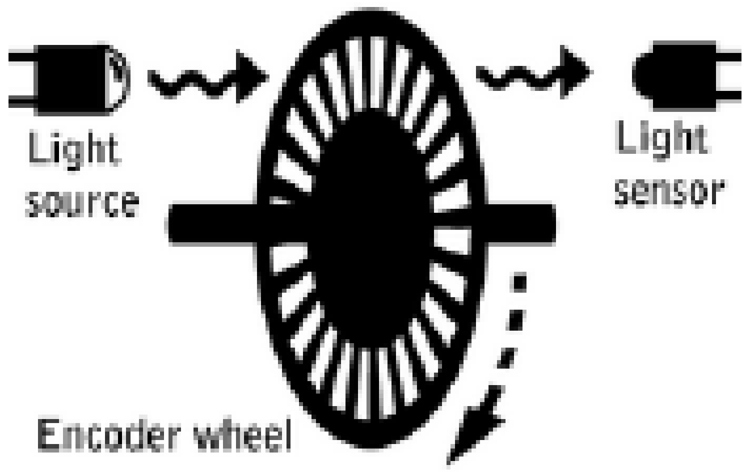
4. Displacement, Position and Proximity Sensors:

[4] Linear Variable Differential Transformer (LVDT):

4.Displacement, Position and Proximity Sensors:

[5] Optical Encoders:

- An optical encoder is a device that provides a digital output as a result of a linear or angular displacement.
- Position encoders can be grouped into two categories: **incremental encoders** and **absolute encoders**.
- **Incremental Encoder**: detects changes in rotation from some fixed starting position.
- **Absolute Encoder**: gives the actual angular position.(direction)
- A beam of light passes through slots in a disc and is detected by a suitable light sensor.
- When the disc is rotated, a pulsed output is produced by the sensor.
- The **number of pulses** is proportional to the **angle** being measured.



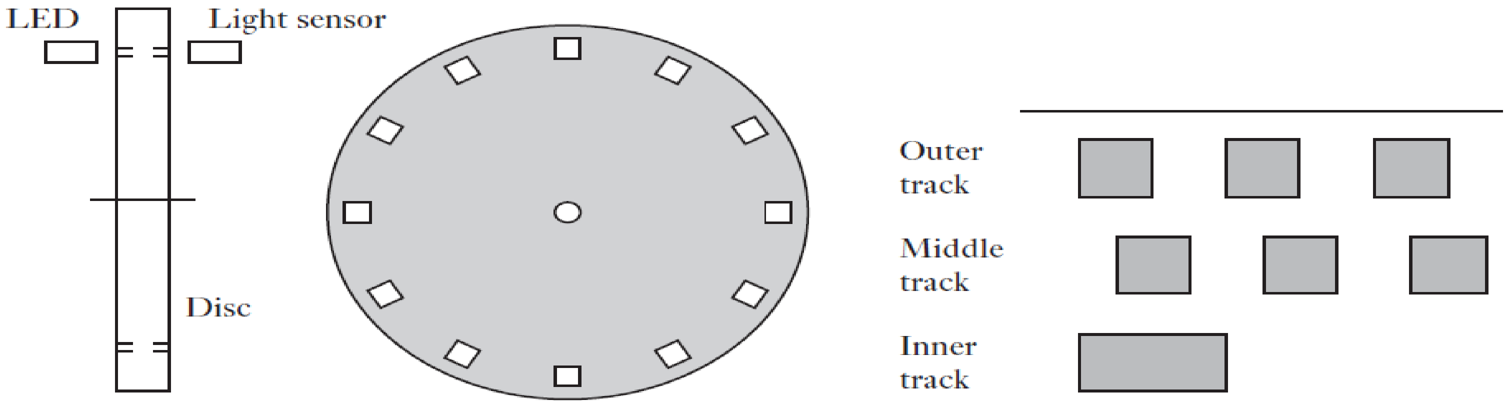
4. Displacement, Position and Proximity Sensors:

[5] Optical Encoders:

➢ Incremental Encoder:

- In practice three concentric tracks with three sensors are used.
- The inner track has just one hole as the home position.
- The other two tracks have a series of equally spaced holes with offset to enable the detection of direction of rotation.
- In a clockwise direction the pulses in the outer track lead those in the inner; in the anti-clockwise direction they lag.
- Resolution = 360 deg /No of slots.

EX: With 60 slots in 1 revolution then, since 1 revolution is a rotation of 360°, the resolution is 360/60 = 6°.

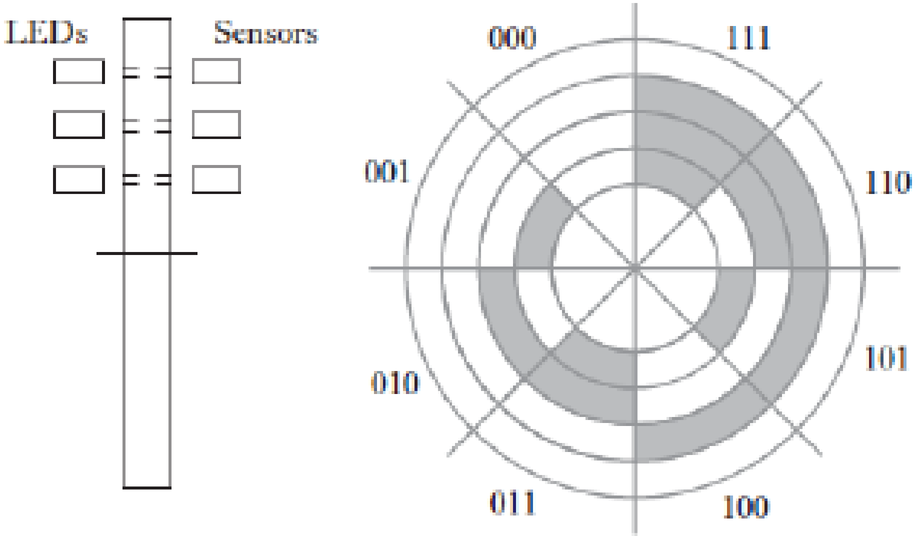


The disc with slots through which the light can pass

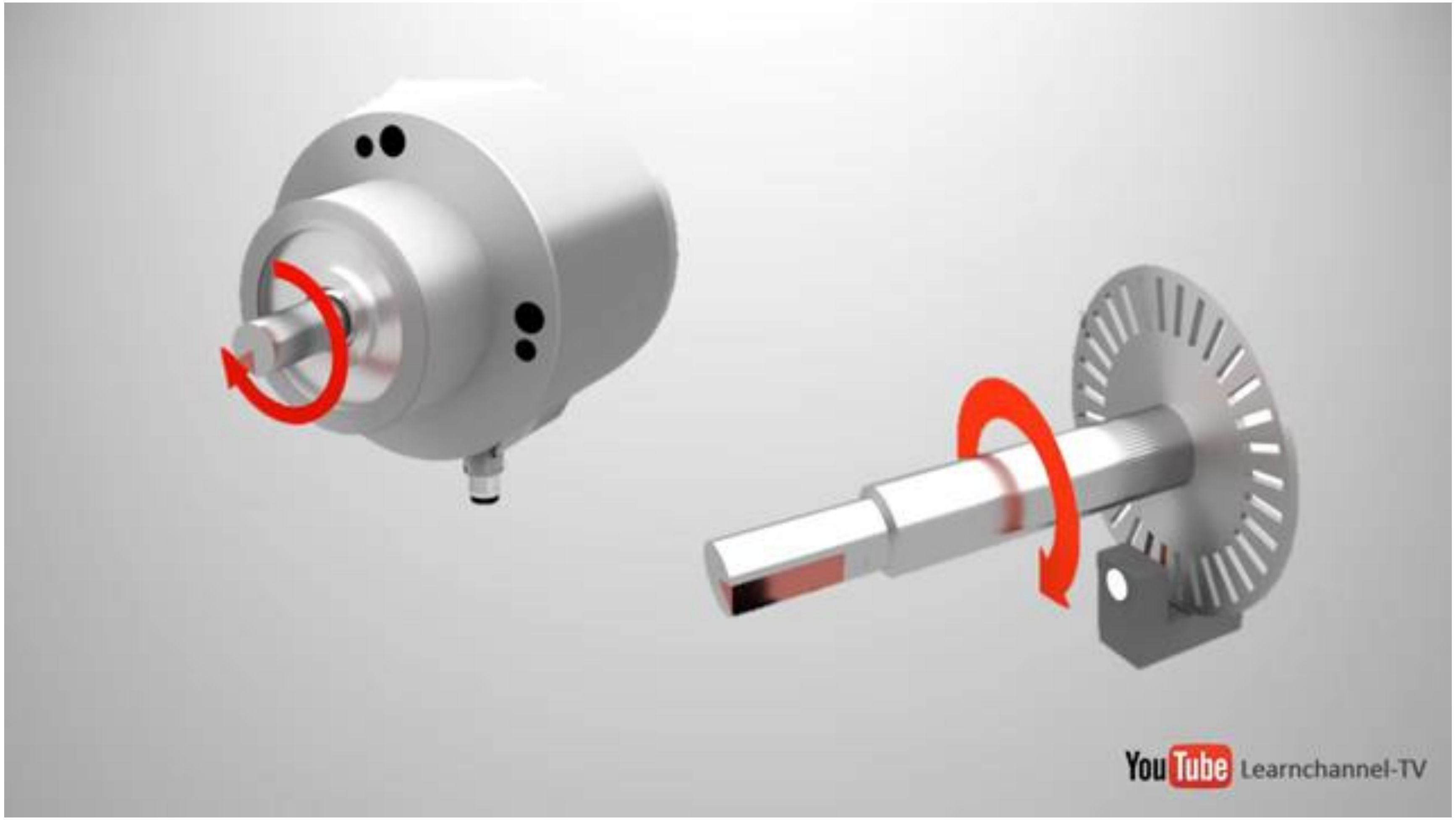
4. Displacement, Position and Proximity Sensors:

[5] Optical Encoders:

- **Absolute Encoder:**
  - The absolute encoder gives an output in the form of a binary number of several digits, each such number representing a particular angular position.
  - The rotating disc has three concentric circles of slots and three sensors to detect the light pulses. The slots are arranged in such a way that the sequential output from the sensors is a number in the binary code.
  - Resolution = $360/2^n$ (n is the number of bits = number of tracks)
  - Thus with 10 tracks there will be 10 bits and so the number of positions that can be detected is 2^{10}, i.e. 1024, a resolution of 360/1024 = 0.35°.



4. Displacement, Position and Proximity Sensors:
[5] Optical Encoders:



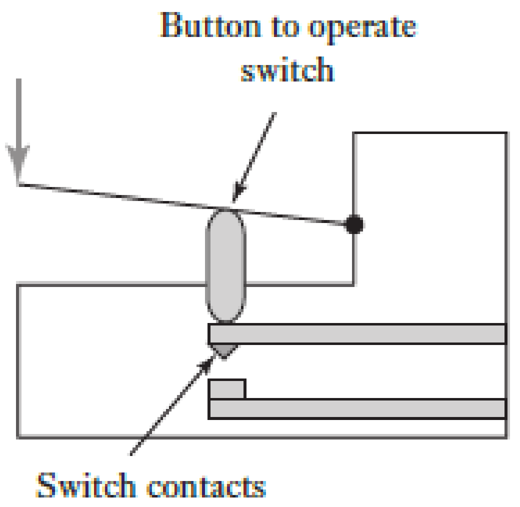
4. Displacement, Position and Proximity Sensors:

[5] Optical Encoders:

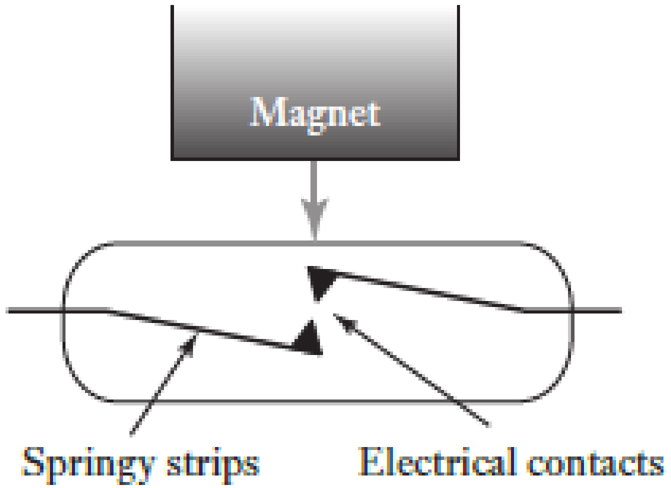
4. Displacement, Position and Proximity Sensors:

[6] Proximity switches:

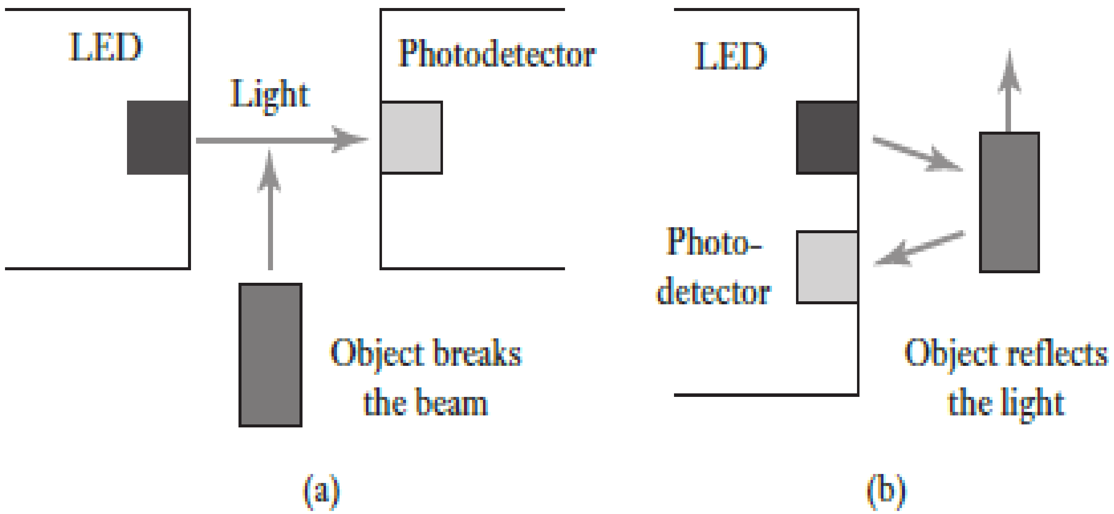
- There are many forms of proximity switch that can give either ON or OFF according to the presence of a certain object.



Micro Switch
Requires physical contact



Reed Switch (Magnet)
No physical contact

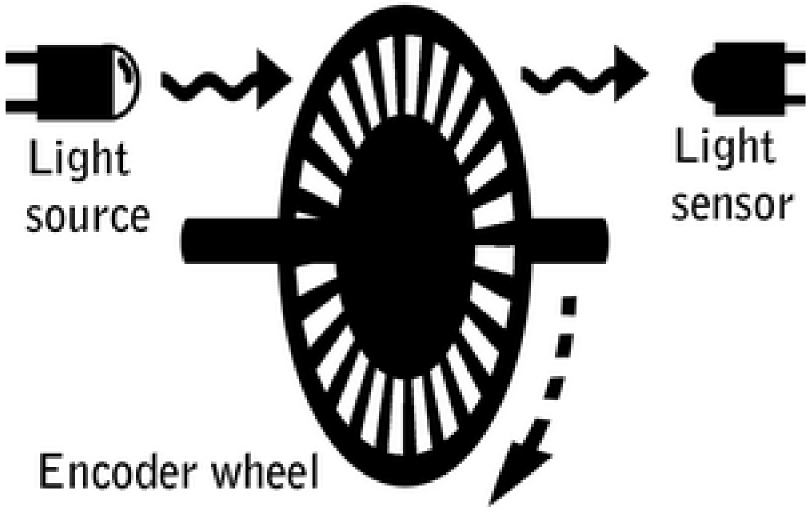


Photosensitive Switch
No physical contact

5. Velocity Sensors:

[1] Incremental Encoders:

- The incremental encoder used for displacement sensing can be used for the measurement of angular velocity.
- The velocity could be determined by counting the number of pulses produced per second.
- Two tracks of slots could be used to determine the direction of velocity (clockwise or counter clock wise).



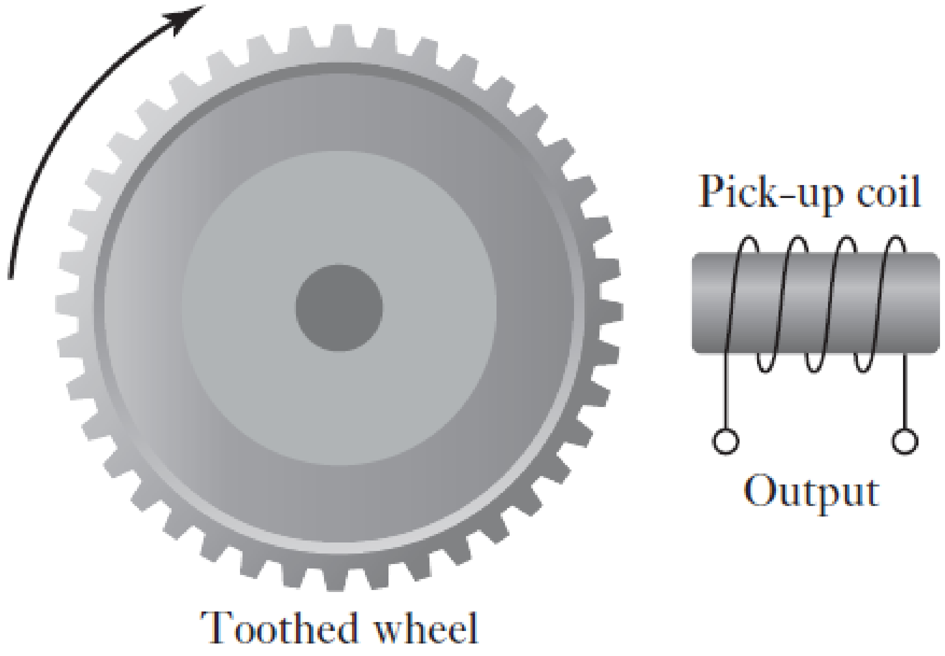
5. Velocity Sensors:

[2] Tachogenerators:

- The tachogenerator is used to measure angular velocity. It has two forms:

i. **Variable Reluctance Tachogenerator**:

- A toothed wheel of ferromagnetic material is attached to the rotating object.
- A pick-up coil is wound on a permanent magnet.
- As the wheel rotates, the air gap between the coil and the ferromagnetic material changes.
- The flux linked by a pick-up coil will be changed due to the change in the air gap. The resulting cyclic change in the flux produces an alternating e.m.f. in the pickup coil.



5. Velocity Sensors:

[2] Tachogenerators:

The flux ϕ changes with time as:

$$\phi = \phi_0 + \phi_a cos(n\omega t)$$

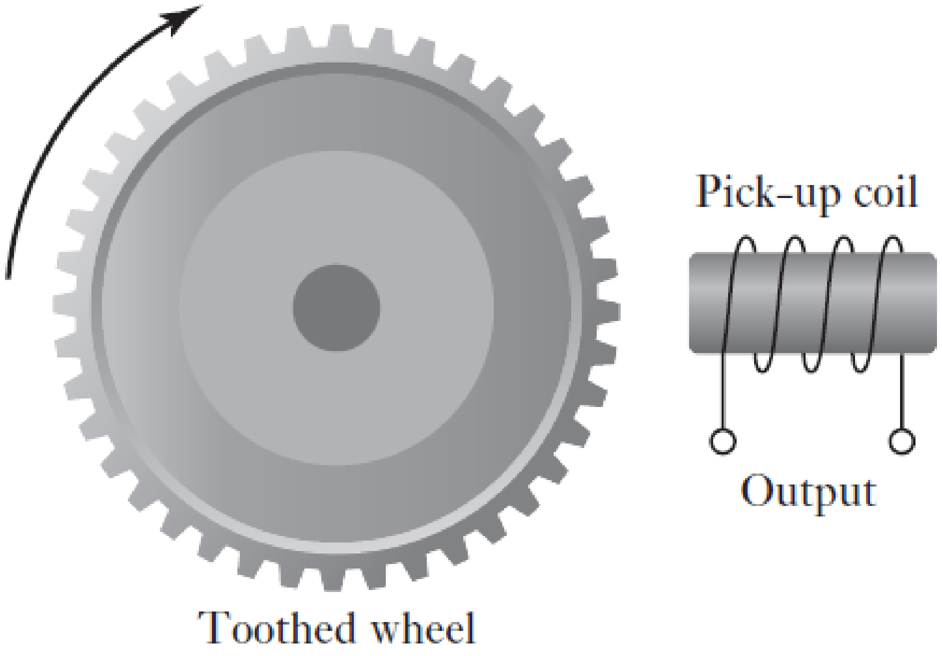
ϕ_0: The mean flux.
ϕ_a: Flux variation amplitude.
ω: Rotation speed
n: No. of teeth.

$$e.m.f = -N\frac{d\phi}{dt} = N\phi_a n\omega sin\omega t$$

N: No. of turns of pickup coil.

$$\boxed{e.m.f = E_{max} sin\omega t} \qquad E_{max} \propto \omega$$

The induced e.m.f. could be shaped to a series of pulses that could be counted as a measure of angular velocity.



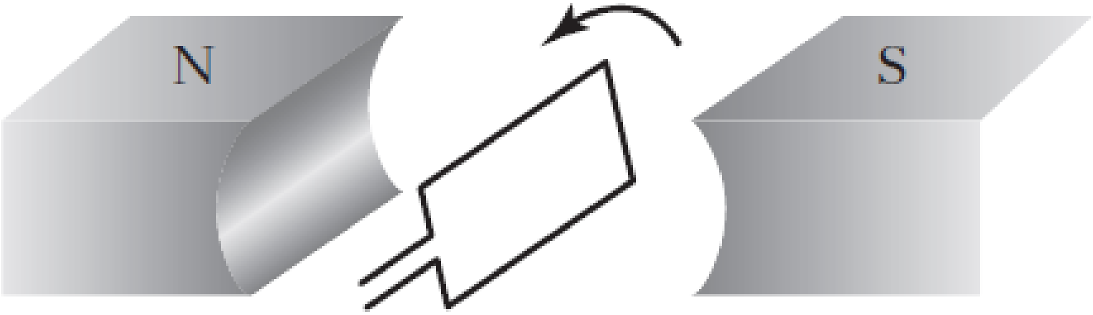
5. Velocity Sensors:

[2] Tachogenerators:

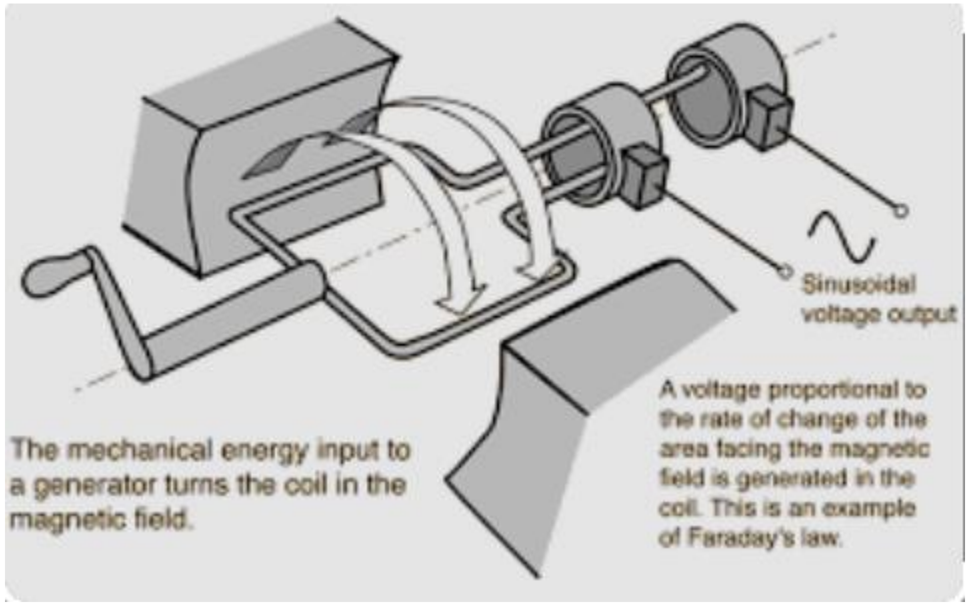
- The tachogenerator is used to measure angular velocity. It has two forms:

ii. **A.C. Generator:**

- It consists of a coil, termed the rotor, which rotates with the rotating shaft inside a magnetic field produced by a stationary permanent magnet.
- When the coil rotates, an alternating e.m.f. is induced in it.
- The amplitude or frequency of this alternating e.m.f. can be used as a measure of the angular velocity of the rotor.
- The output may be rectified to give a d.c. voltage with a size which is proportional to the angular velocity.



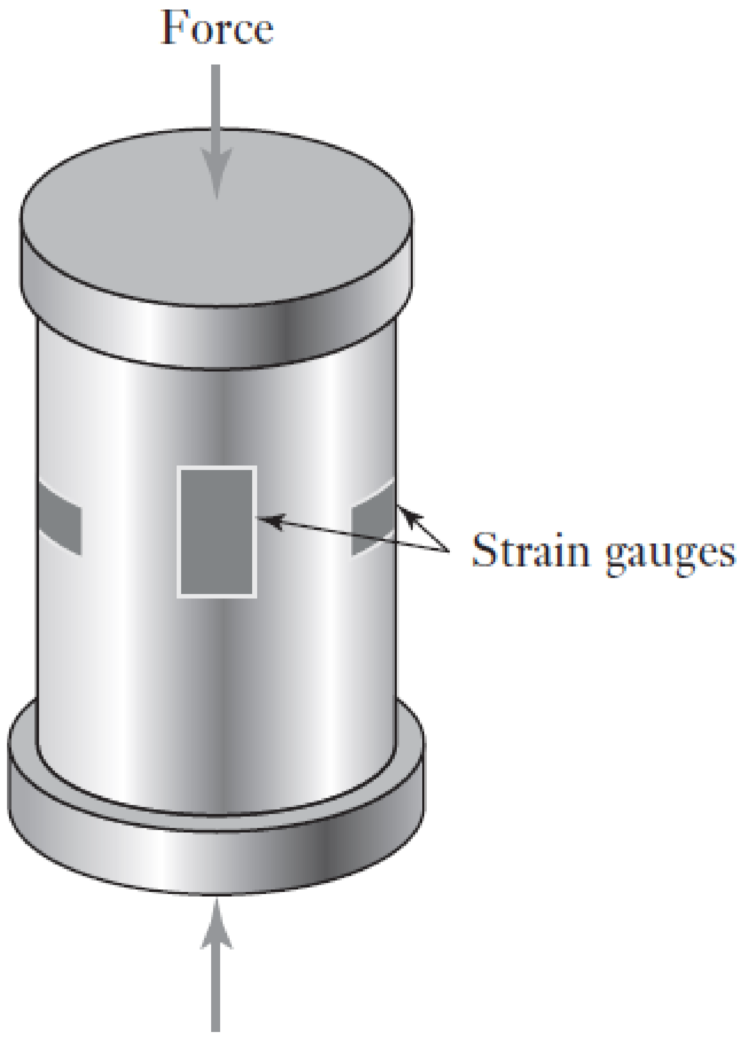
Rotating coil



6. Force Sensors:

[1] Strain Gauge Load Cell:

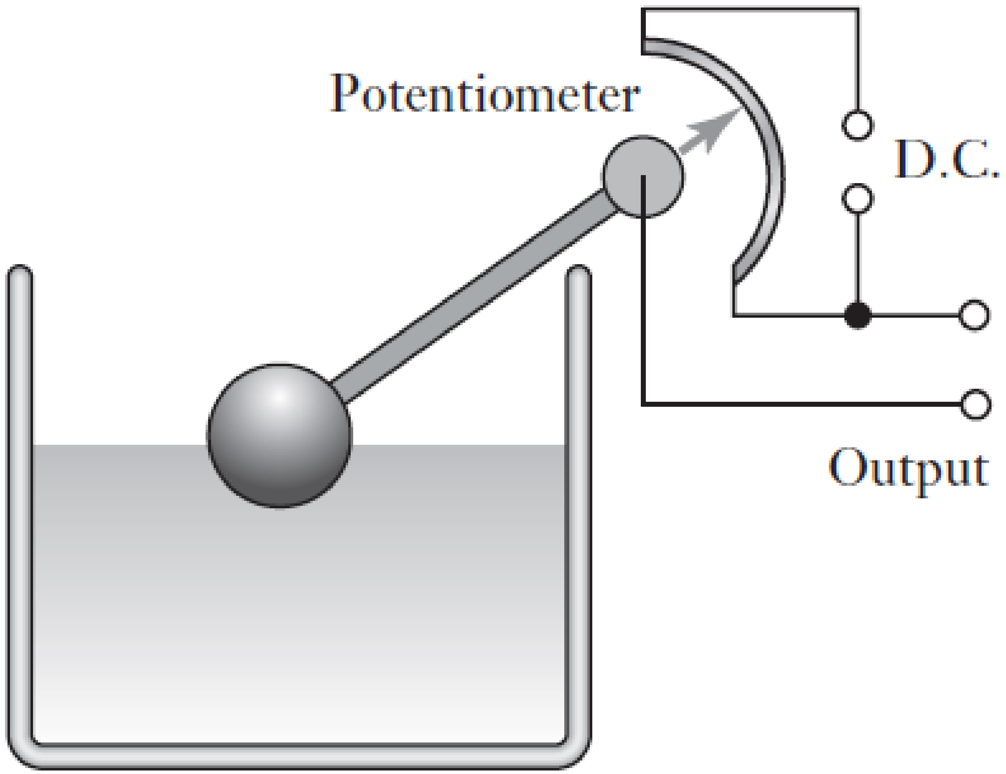
- Forces are commonly measured by the measurement of displacements.
- Strain gauges are used to monitor the strain produced in some member when stretched, compressed or bent by the application of the force.
- The arrangement for measuring the force is generally referred to as a load cell.
- Load cell is a cylindrical tube to which strain gauges have been attached. When forces are applied to the cylinder the resistance will change which is a measure of the applied force.
- A signal conditioning circuit is required to eliminate the effect of temperature change on the strain gauge.



7. Liquid Level Sensors:

[1] Floats:

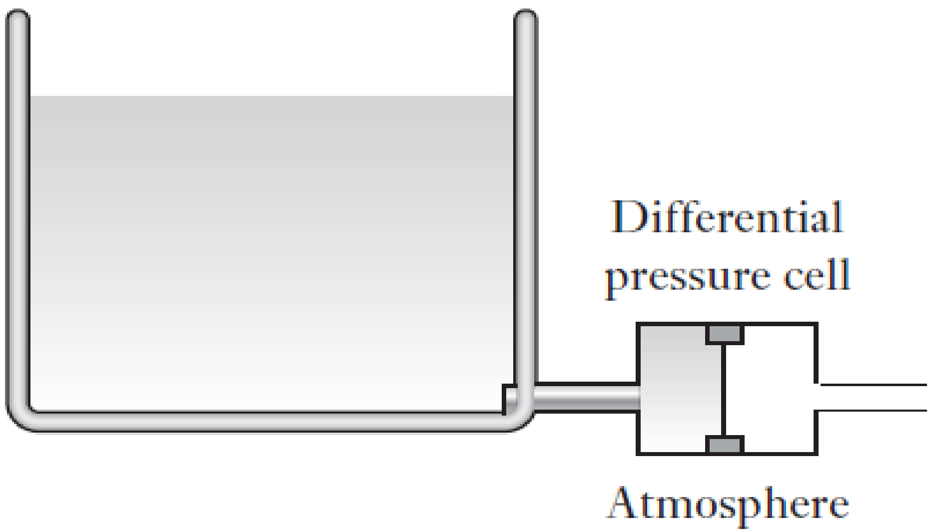
- A direct method of monitoring the level of liquid in a vessel is by monitoring the movement of a float inside that vessel.
- The displacement of the float causes a lever arm to rotate and so move a slider across a potentiometer.
- The result is an output of a voltage related to the height of liquid.

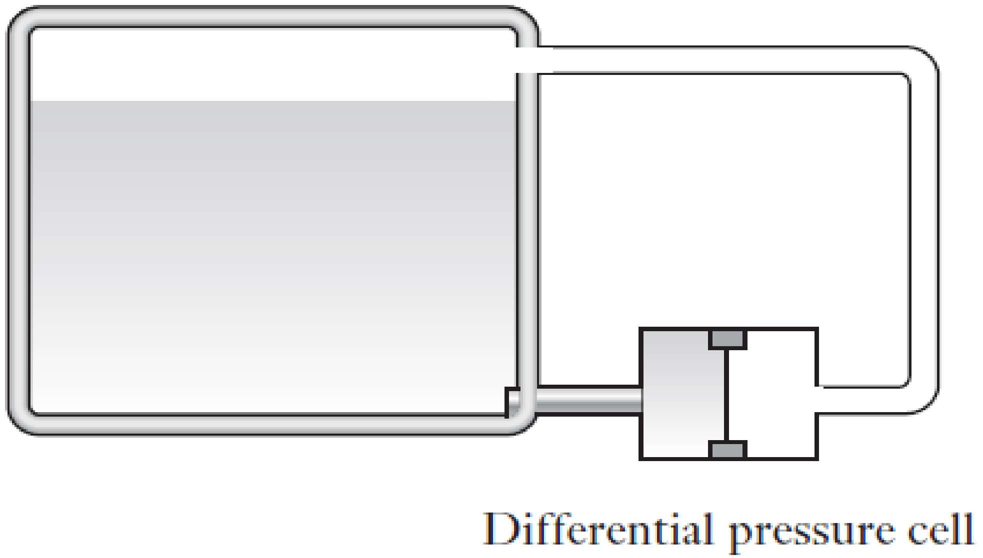


7. Liquid Level Sensors:

[2] Differential pressure:

- An indirect method for measuring the level of a liquid is measure the liquid which is changed according to the liquid level.
- The differential pressure cell can be used to monitor the difference in pressure between the base of the vessel and the atmospheric pressure.
- In case of closed vessel, the differential pressure cell monitors the difference in pressure between the base of the vessel and the air above the surface of the liquid.





8. Temperature sensors:

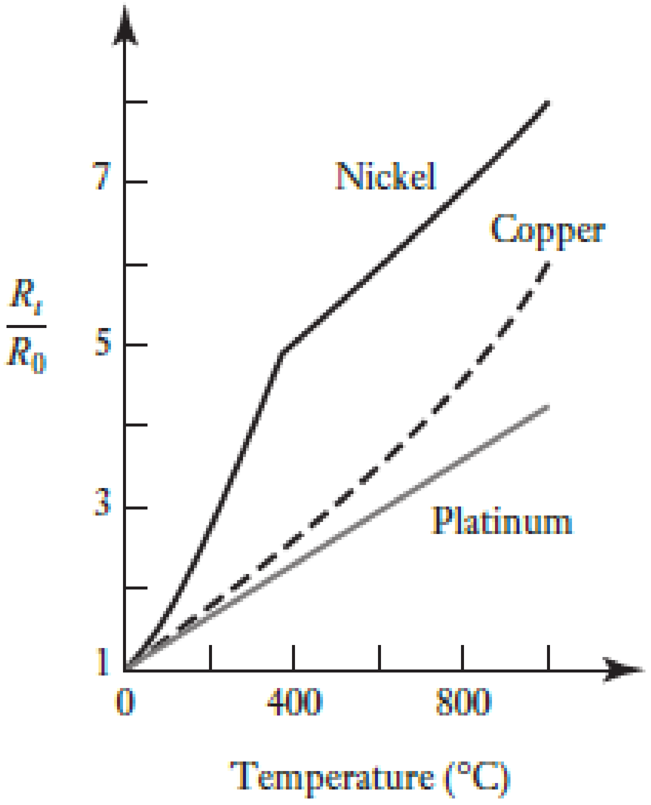
[1] Resistance temperature detectors (RTDs):

- The resistance of most metals increases, over a limited temperature range, in a reasonably linear way with temperature. For such a linear relationship:

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

where R_t is the resistance at a temperature t° C,
R_0 is the resistance at 0°C and
α is a constant for the metal termed the temperature coefficient of resistance.

- Resistance temperature detectors (RTDs) are simple resistive elements in the form of coils of wire of such metals as platinum, nickel, or copper alloys; platinum is the most widely used.



Variation of resistance with temperature for metals.

8. Temperature sensors (Cont.):

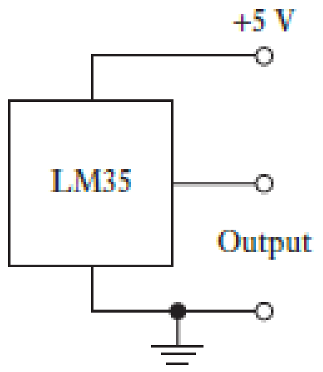
[2] Thermodiodes and transistors

- A junction semiconductor diode is widely used as a temperature sensor.
- When the temperature of doped semiconductors changes, the mobility of their charge carriers changes and this affects the rate at which electrons and holes can diffuse across a p–n junction. Thus when a p–n junction has a potential difference V across it, the current I through the junction is a function of the temperature, being given by

$$I = I_0\left(e^{eV/kT} - 1\right)$$

$$V = \left(\frac{kT}{e}\right)\ln\left(\frac{I}{I_0} + 1\right)$$

where T is the temperature on the Kelvin scale,
e the charge on an electron, and
k and I_0 are constants.

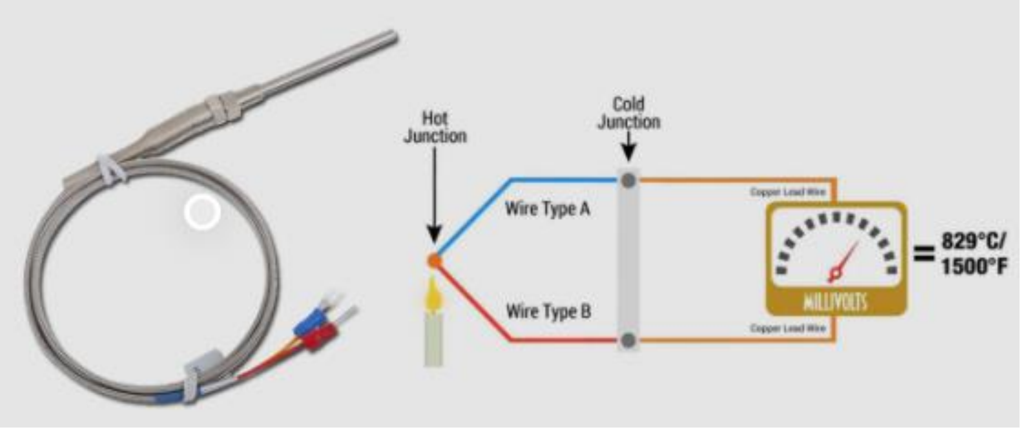


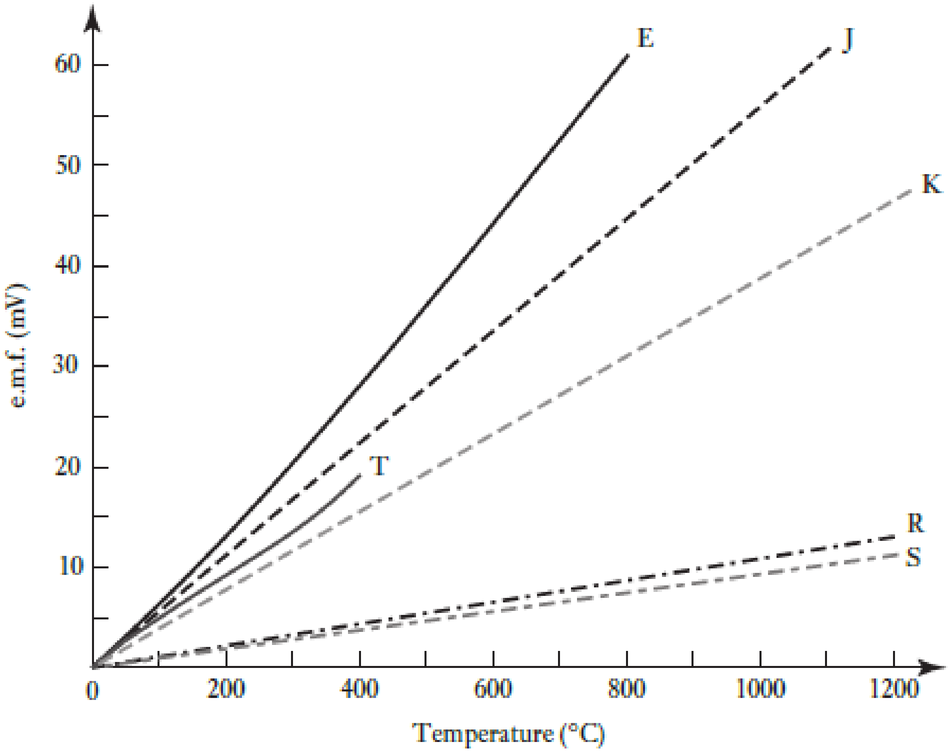
This sensor can be used in the range 240 to 110°C and gives an output of 10 mV/°C.

8. Temperature sensors (Cont.):

[3] Thermocouples:

- If two different metals are joined together, a potential difference occurs across the junction. The potential difference depends on the metals used and the temperature of the junction.





(b)

Ref.	Materials	Range (°C)	(μV/°C)
B	Platinum 30% rhodium/platinum 6% rhodium	0 to 1800	3
E	Chromel/constantan	−200 to 1000	63
J	Iron/constantan	−200 to 900	53
K	Chromel/alumel	−200 to 1300	41
N	Nirosil/nisil	−200 to 1300	28
R	Platinum/platinum 13% rhodium	0 to 1400	6
S	Platinum/platinum 10% rhodium	0 to 1400	6
T	Copper/constantan	−200 to 400	43

END OF LECTURE

BEST WISHES