Benha University
Faculty of Engineering (Shoubra)
Electronics and Communications Engineering

ECE 211
Electrical and Electronic Measurements
(2020-2021)

Lecture 9: Sensors and Transducers
Part1: Displacement, Position and Proximity

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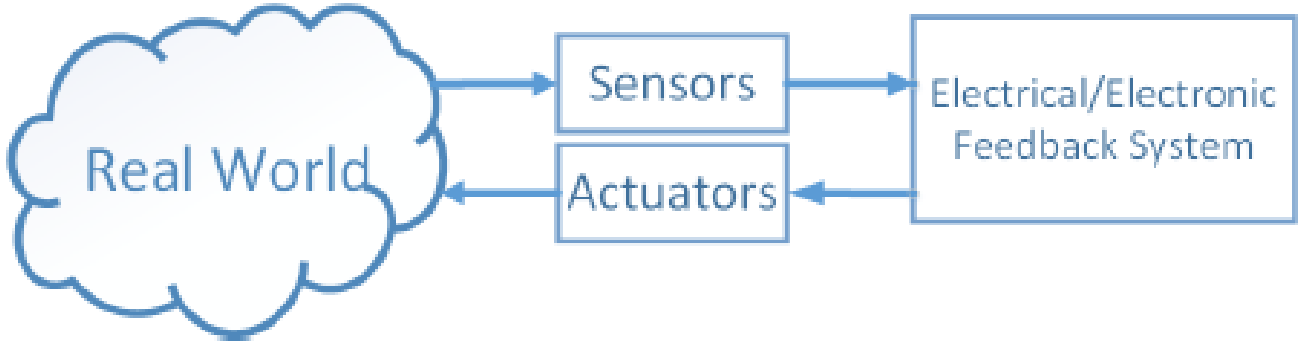
Lecture Outline:

1. Introduction to Sensors and Transducers.
2. Analog vs. Digital Sensors.
3. Signal Conditioning and Smart Sensors.
4. Displacement, Position and Proximity 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, or:
- 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.

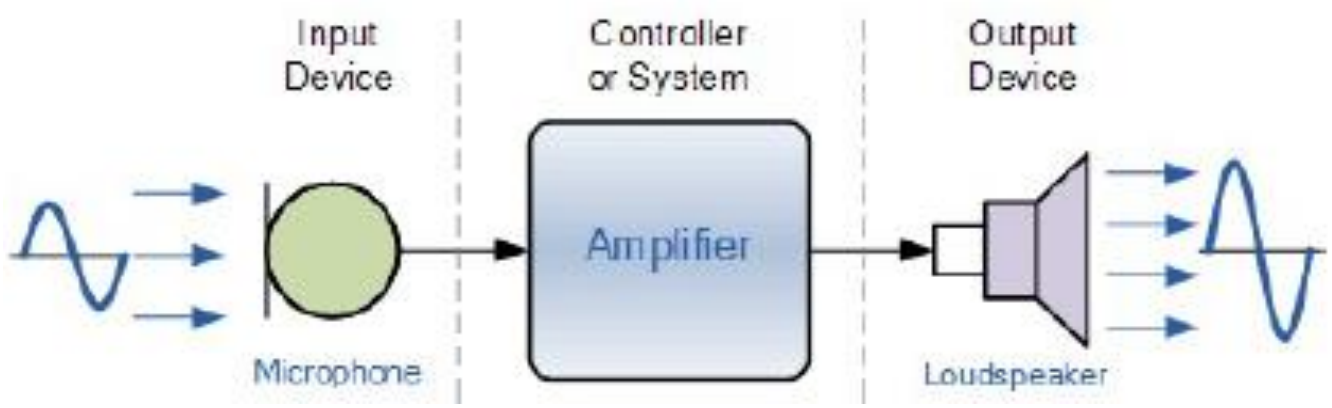
1. Introduction to Sensors and Transducers:

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:

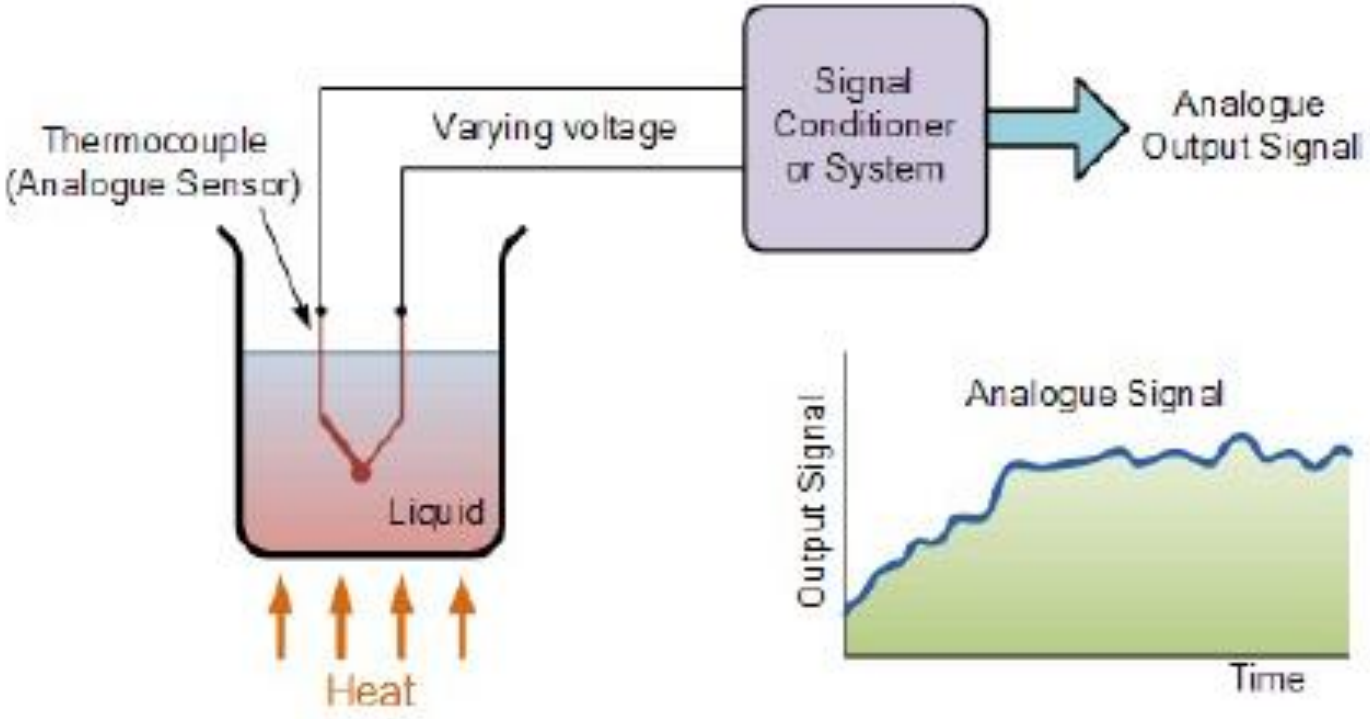
Types of Electrical Transducers:

- 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.
  - Load cells.
  - etc.
- Speed:
  - Tachogenerators.
  - Slotted optocoupler.
  - Doppler Effect Sensors.
  - etc
- Temperature:
  - Thermocouple.
  - Resistive Temperature Detector (RTD).
  - etc.
- etc.

2. Analog vs. Digital Sensors:
Analog Sensors:

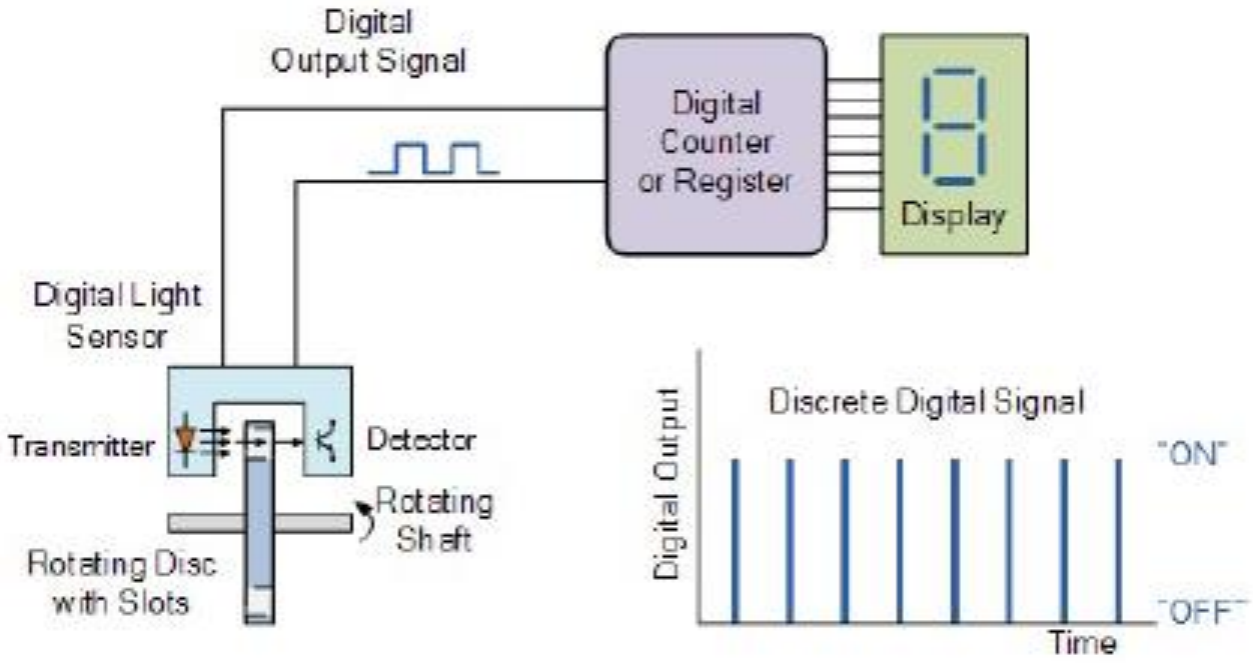
- Analog sensors produce a **continuous output signal** or voltage which is generally proportional to the **quantity being measured.**
- Physical quantities (such as Temperature, Speed, Pressure, Displacement, etc.) are all analog or continuous in nature.
- For example, the fluid temperature could be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



2. Analog vs. Digital Sensors:

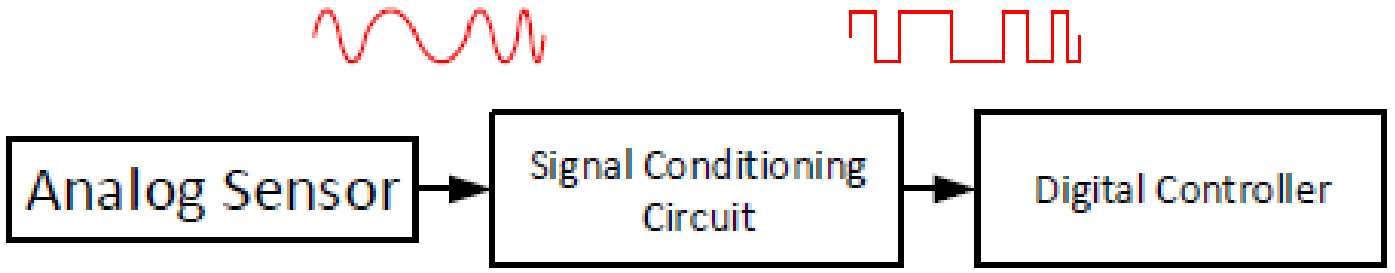
Digital Sensors:

- 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:

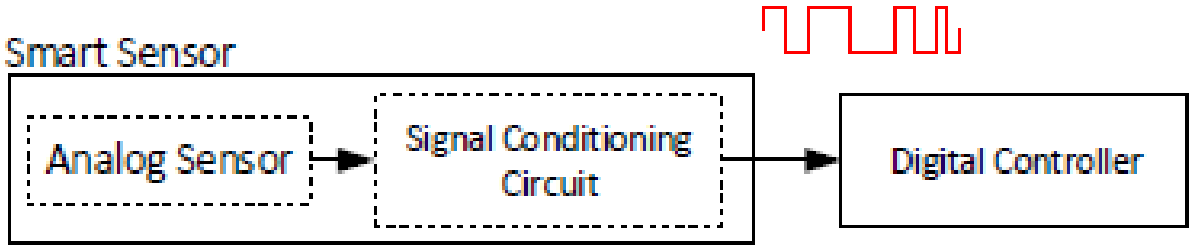
- Signal conditioning is defined as the operations done over an analog signal in such a way that it meets the requirements of the next stage for further processing.



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

Smart Sensors:

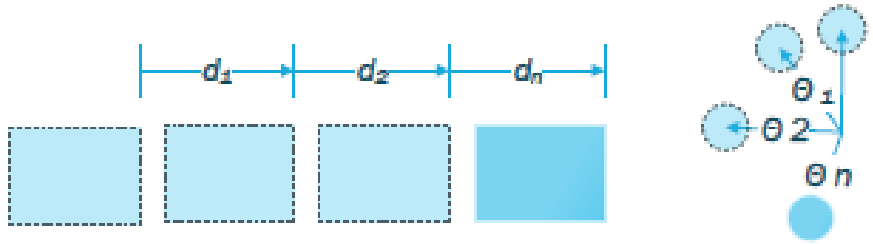
The sensors that come combined with their signal conditioning in the same package.



4. Displacement, Position and Proximity Sensors:

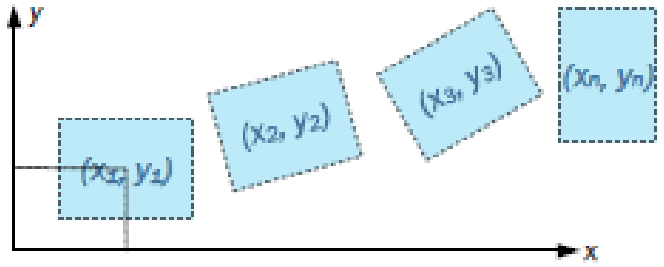
Displacement Sensors:

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



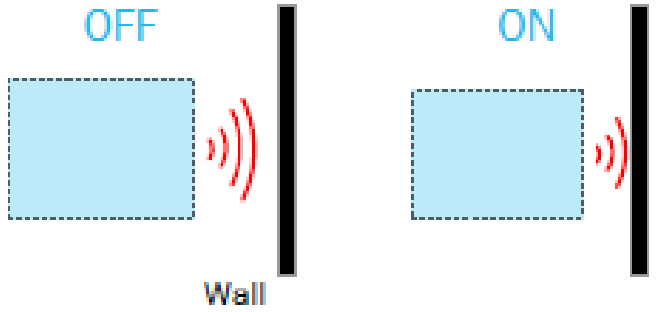
Position Sensors:

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

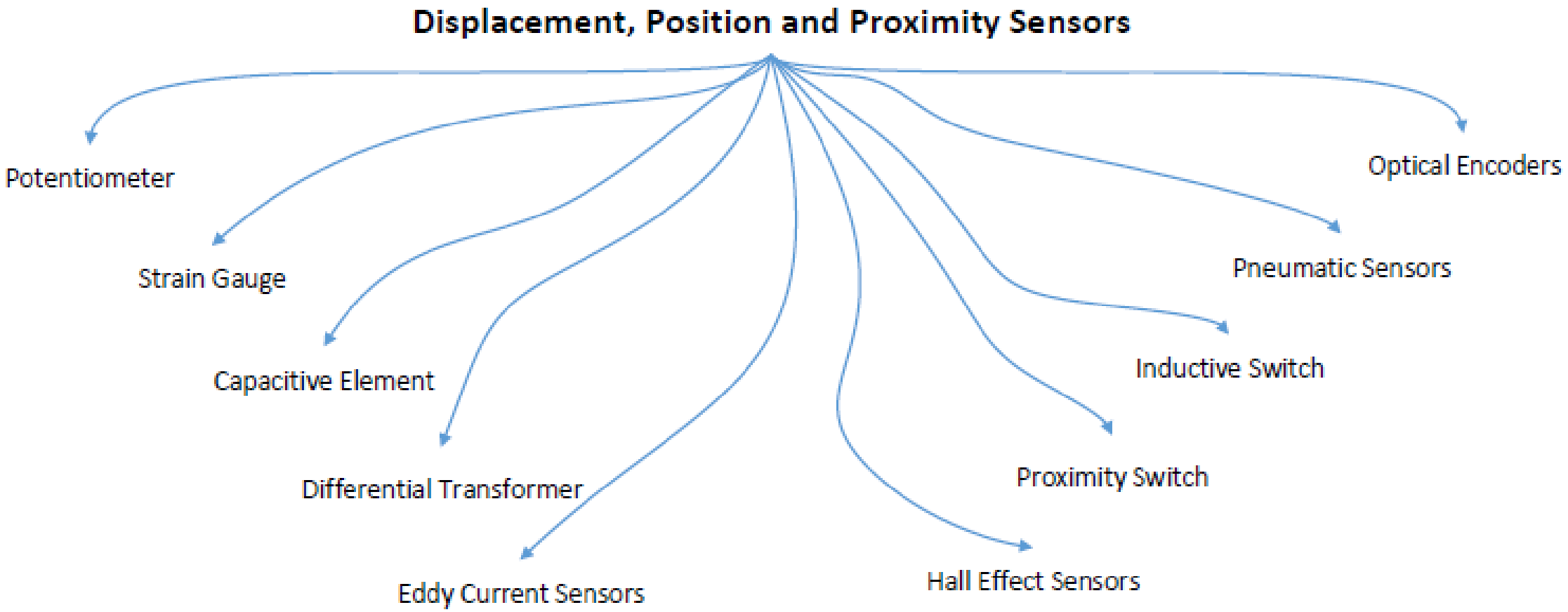


Proximity Sensors:

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:

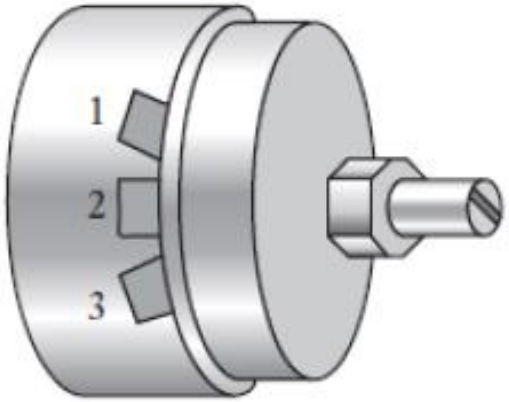


4. Displacement, Position and Proximity Sensors:

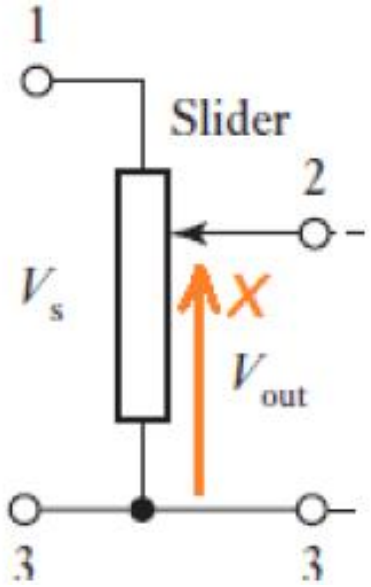
[1] Potentiometer Sensors:

- 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



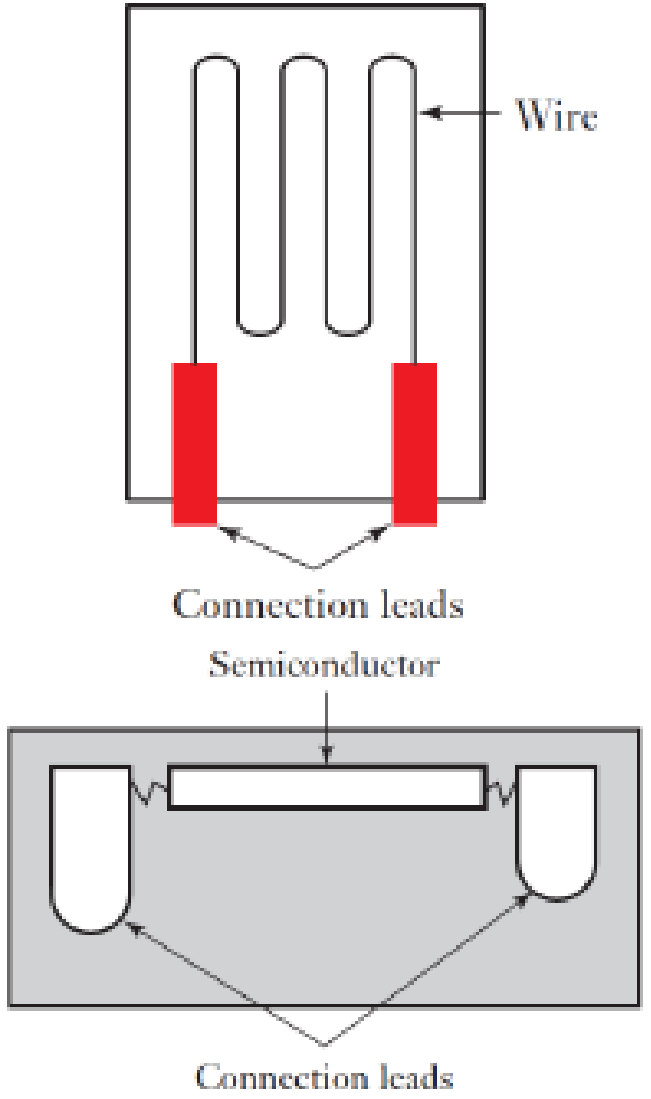
4. Displacement, Position and Proximity Sensors:

[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.

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

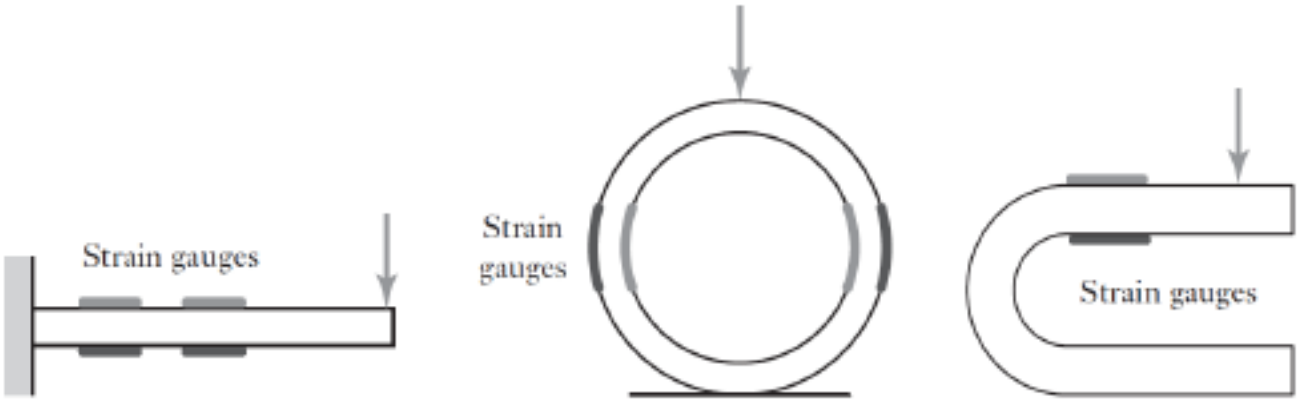
- where G is the gauge factor constant.
- A problem with all strain gauges is that their resistance changes with temperature.

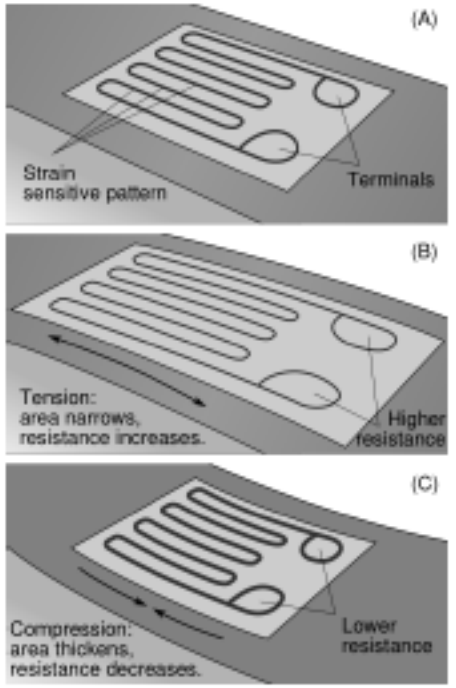


4. Displacement, Position and Proximity Sensors:

[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:

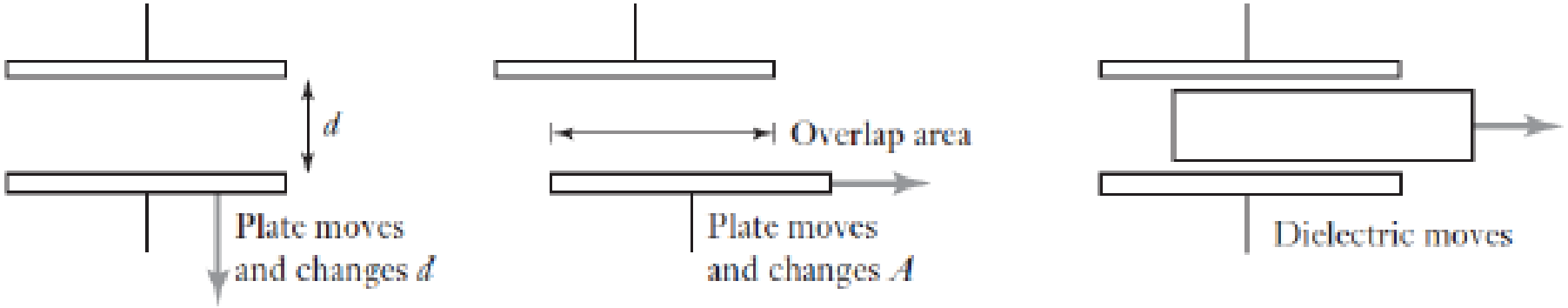
[3] Capacitive Elements:

- 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.

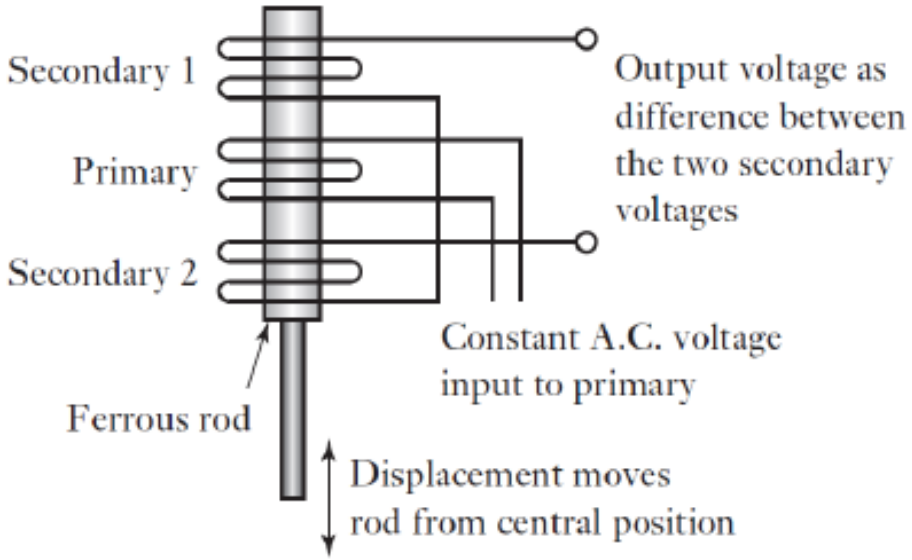
- To monitor a linear displacement, capacitive sensors is arranged in such a way that the displacement is either:
  1. Change of the plate separation distance.
  2. Change the plates overlap area.
  3. Change of the dielectric between plates.



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.



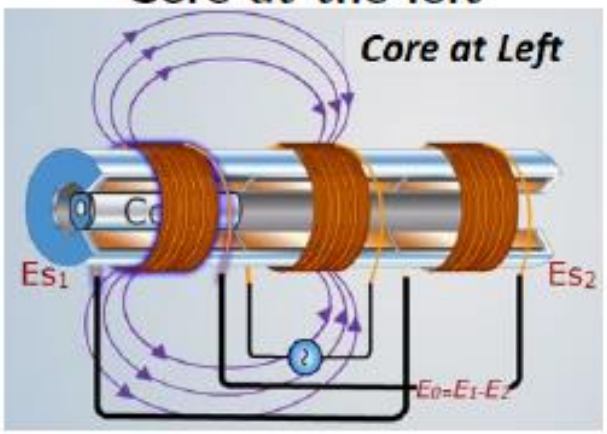
4. Displacement, Position and Proximity Sensors:

[4] Differential Transformers:

- The net E.M.F, E_o *is* depending on the position of the core inside the insulator:

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

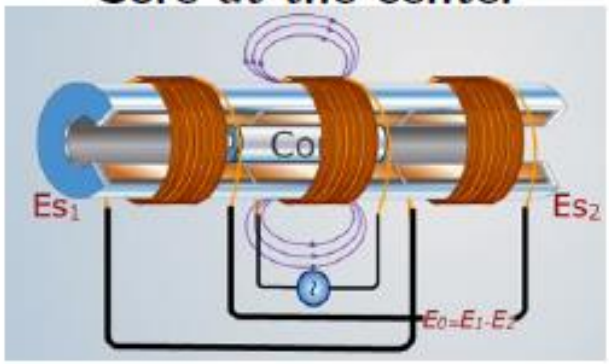
Core at the left



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

$$E_o = +ve$$

Core at the center

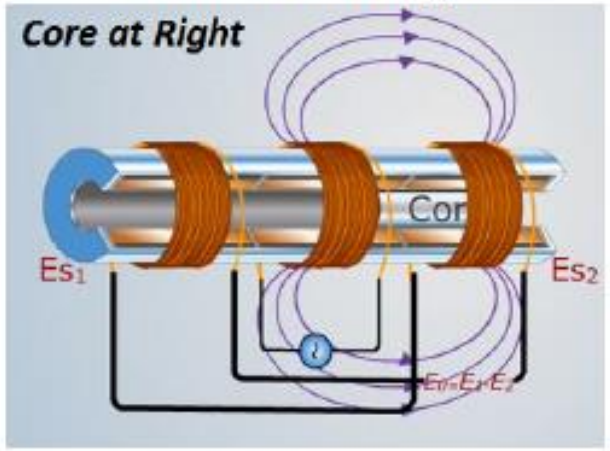


$$E_{s1} = E_{s2}$$

$$E_o = 0$$

Null Position

Core at the right



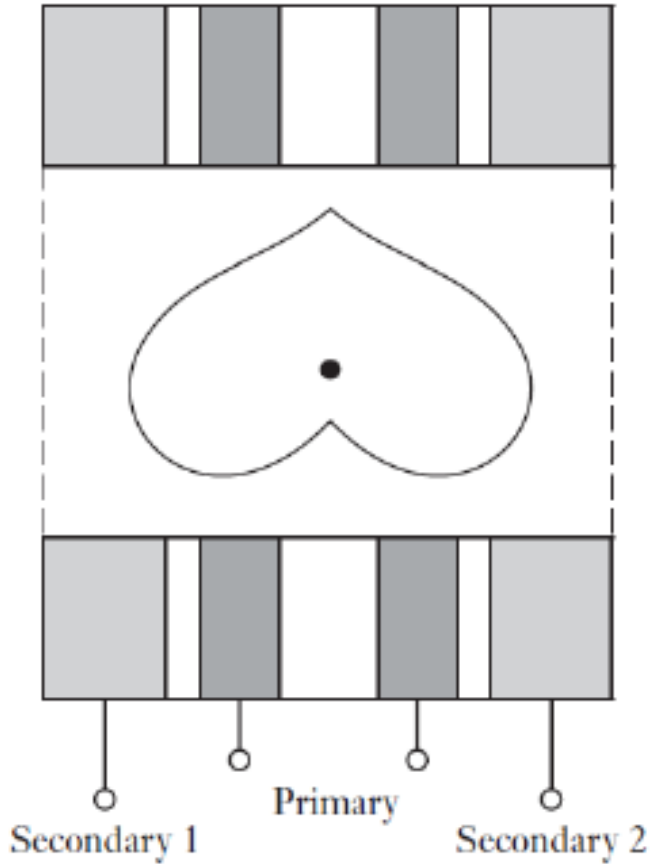
$$E_{s1} < E_{s2}$$

$$E_o = -ve$$

4. Displacement, Position and Proximity Sensors:

[4] Differential Transformers:

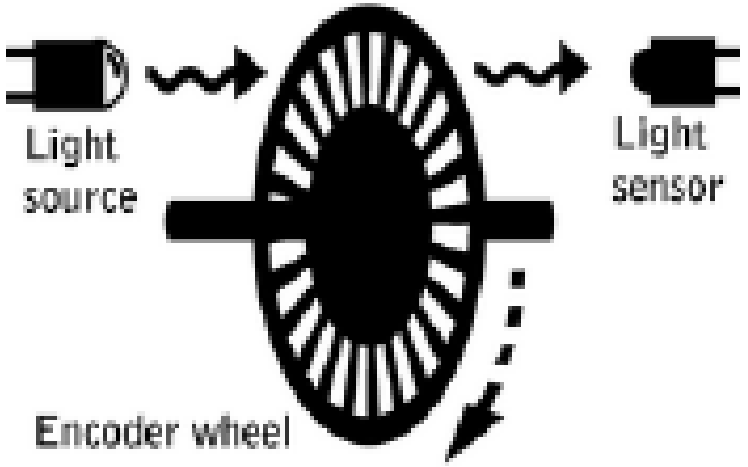
- A Rotary Variable Differential Transformer (RVDT) can be used for the measurement of rotation. It operates on the same principle as the LVDT.
- The core is a cardioid-shaped piece of magnetic material and rotation causes more of it to pass into one secondary coil than the other.



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 datum position.
- Absolute Encoder: gives the actual angular position.
- 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.

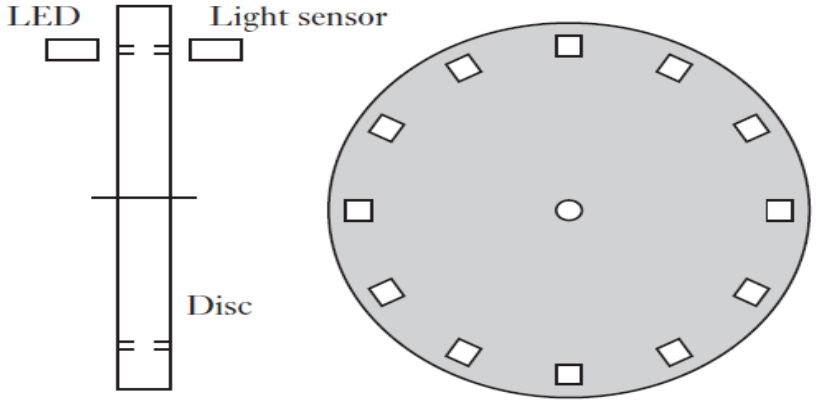


4. Displacement, Position and Proximity Sensors:

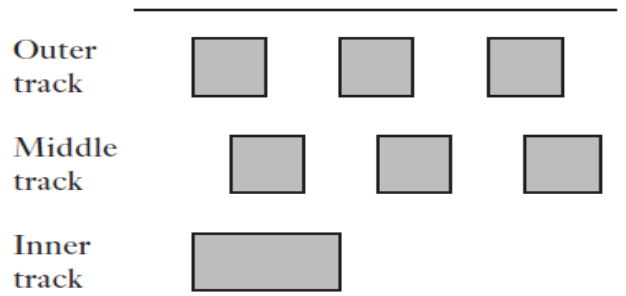
[5] Optical Encoders:

- **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°.



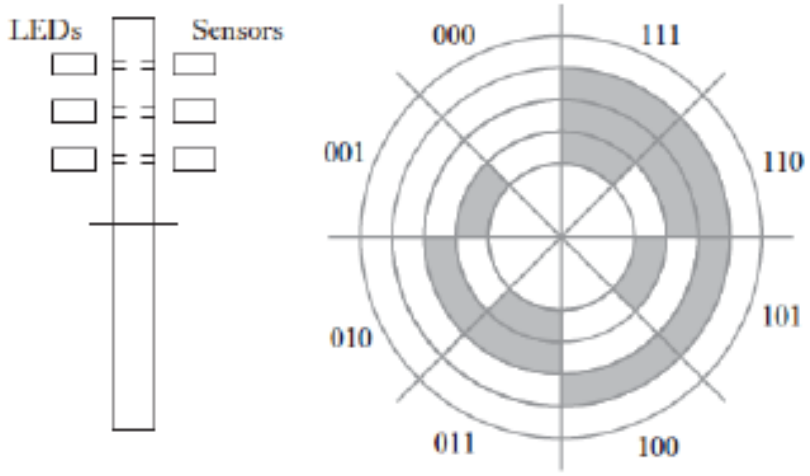
The disc with slots through which the light can pass

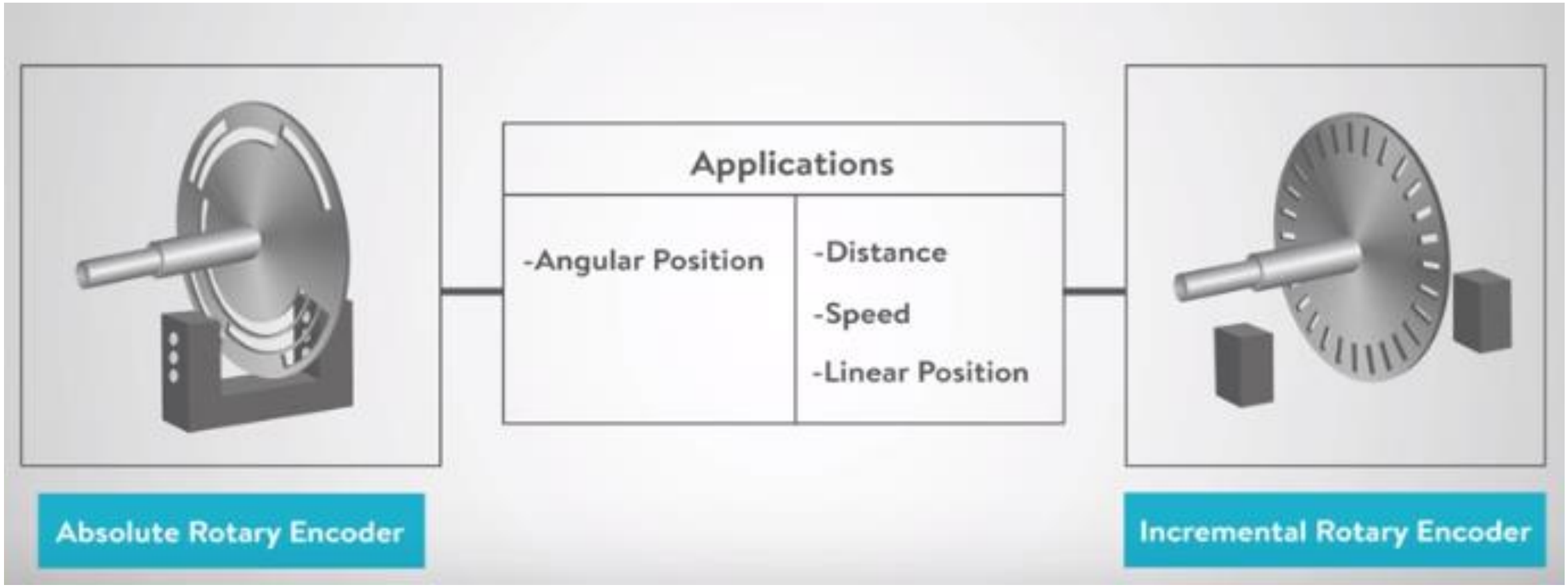


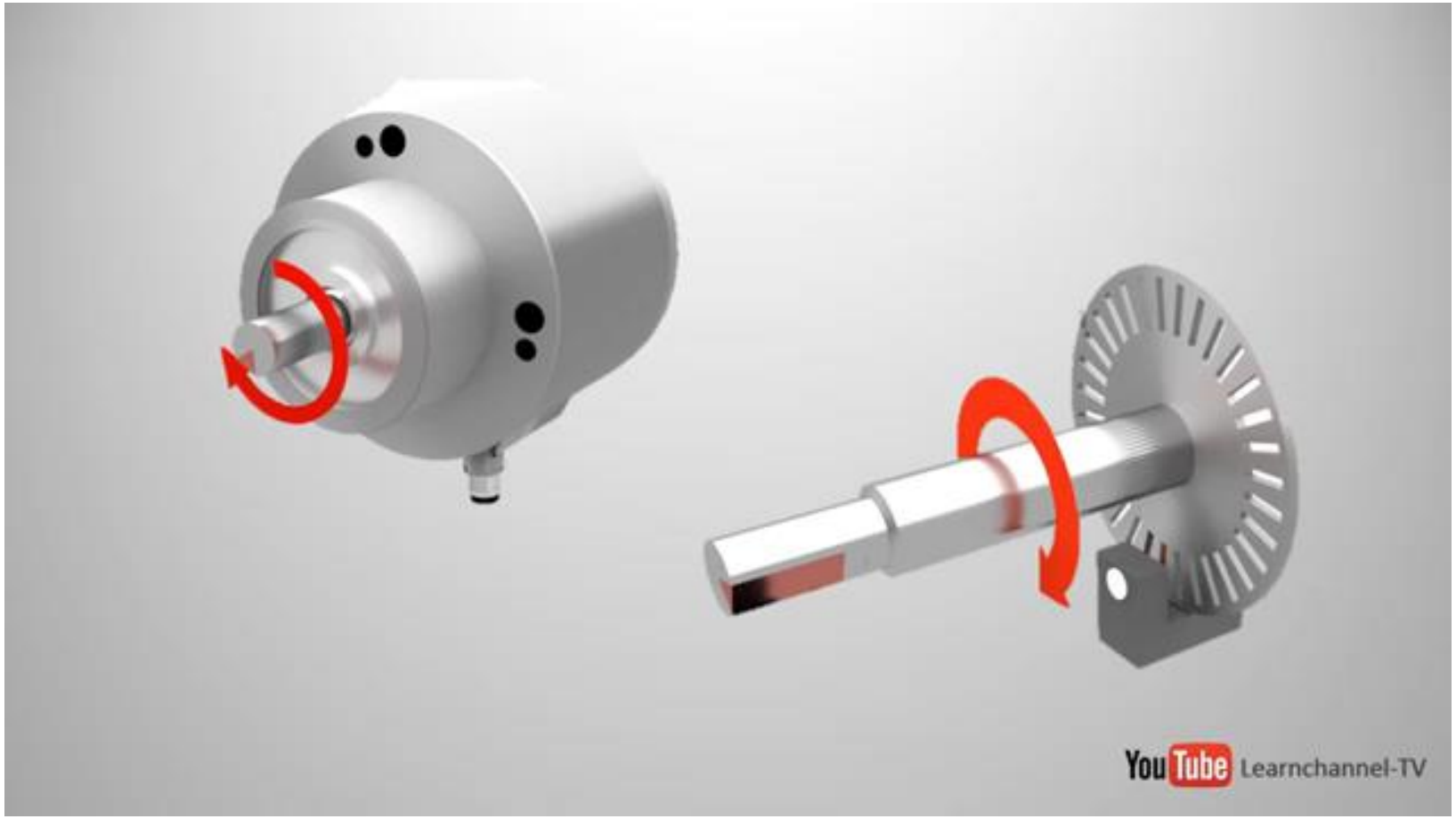
4. Displacement, Position and Proximity Sensors:
[5] Optical Encoders:

- **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°.



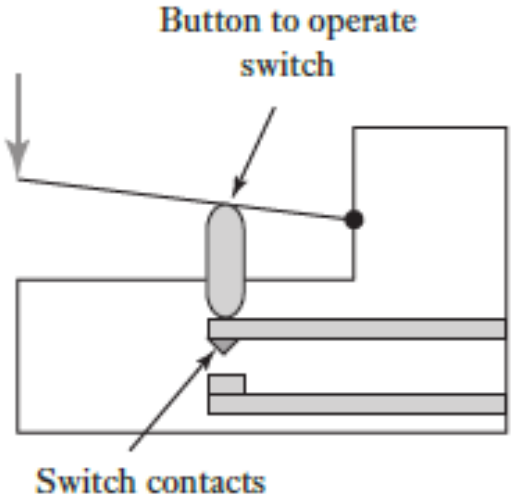

Applications
-Angular Position
-Distance
-Speed
-Linear Position
Absolute Rotary Encoder
Incremental Rotary Encoder


YouTube Learnchannel-TV

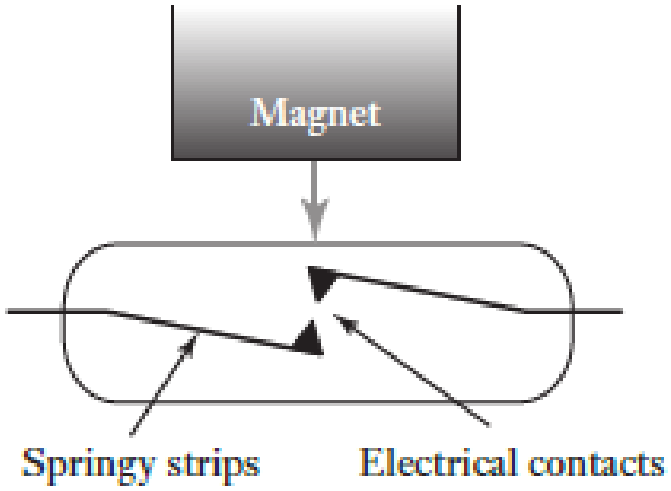
4. Displacement, Position and Proximity Sensors:

[6] Proximity switches:

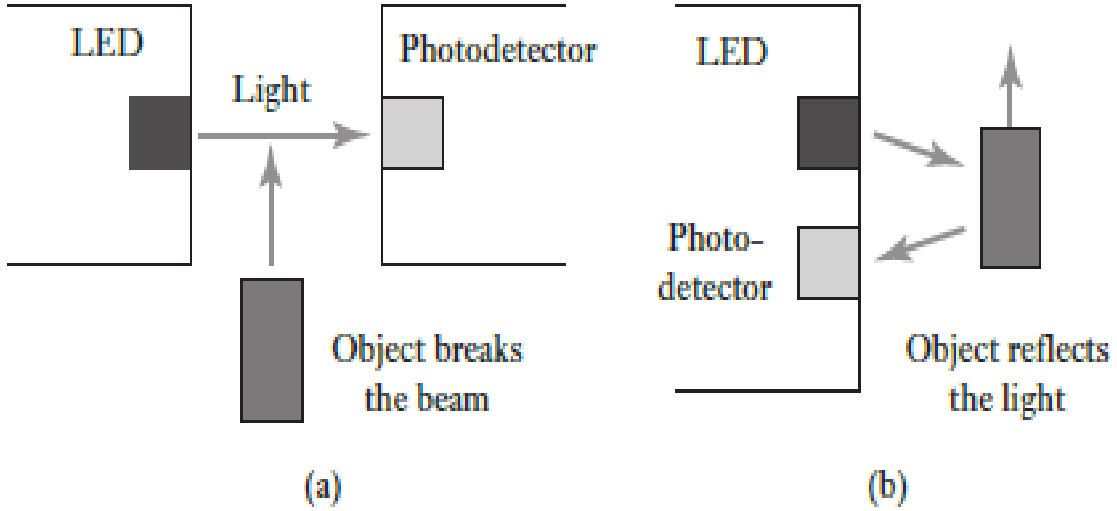
- There are many forms of proximity switch that can give either ON or OFF according to the presence of a certain object.



Micro Switch
Requires physical contact



Reed Switch (Magnet)
No physical contact



Photosensitive Switch
No physical contact

End of Lecture

Best Wishes