Mechatronics

UNIT -I

Introduction to Sensors & Actuators

Basic Principle of Sensor

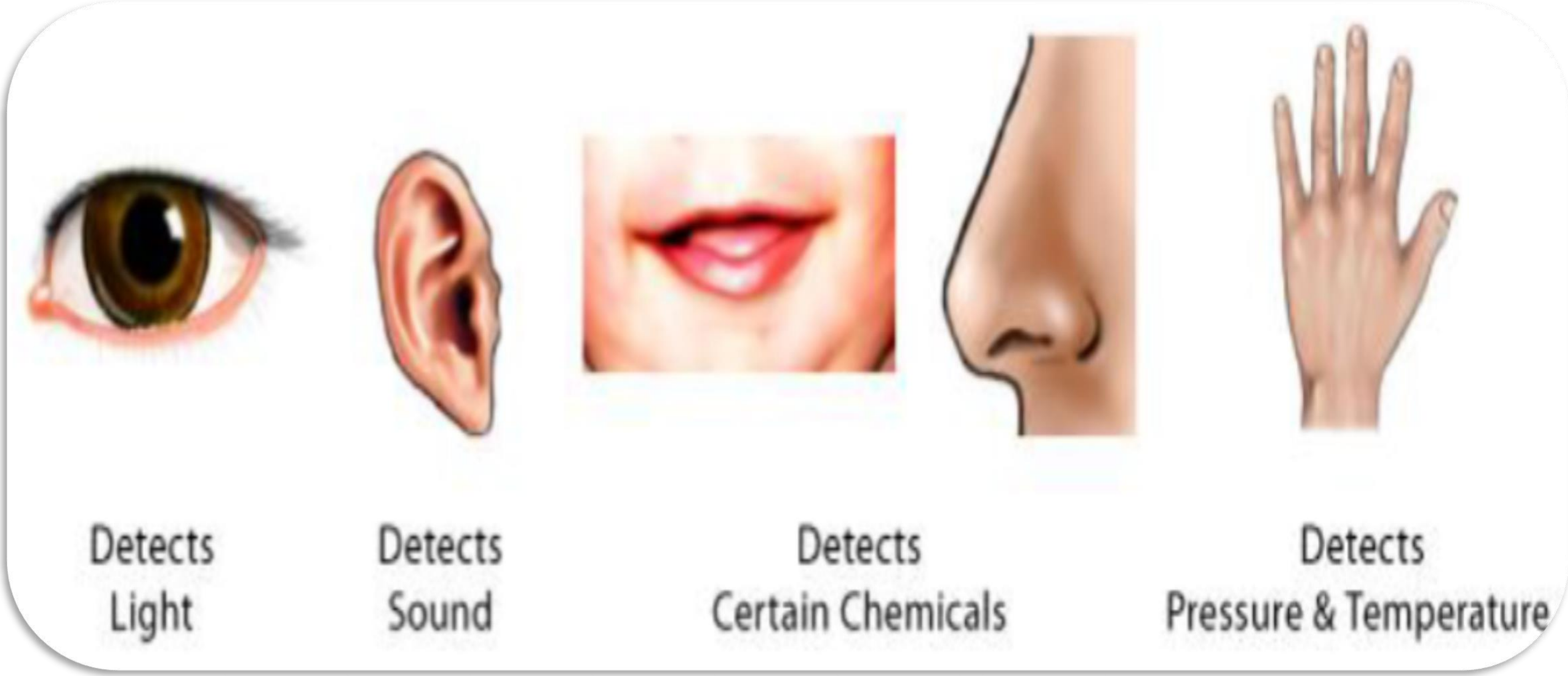
Measuring Parameter → **Conversion Device** → **Useful Signal**

Displacement, Temperature, Pressure etc....

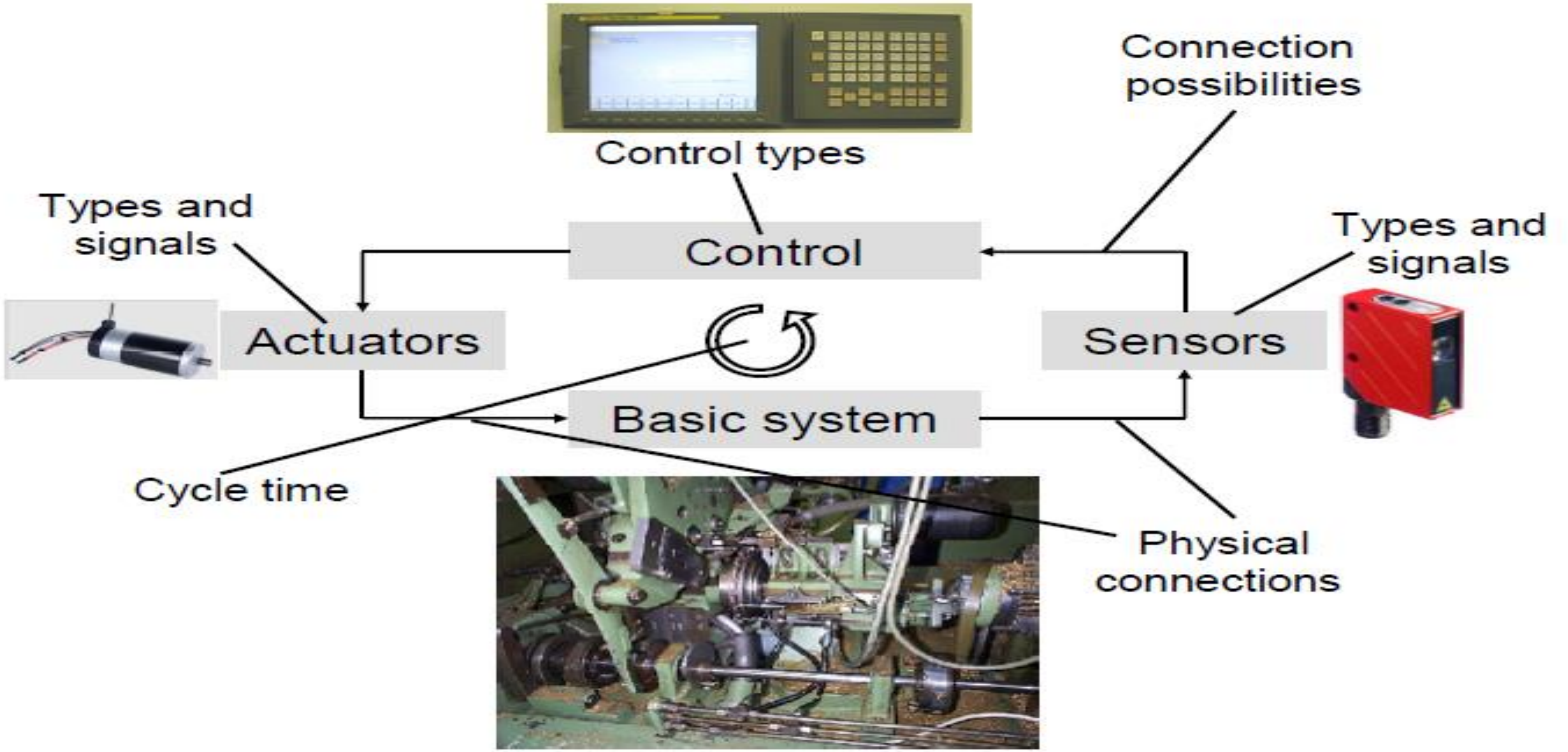
Voltage, current, capacitance

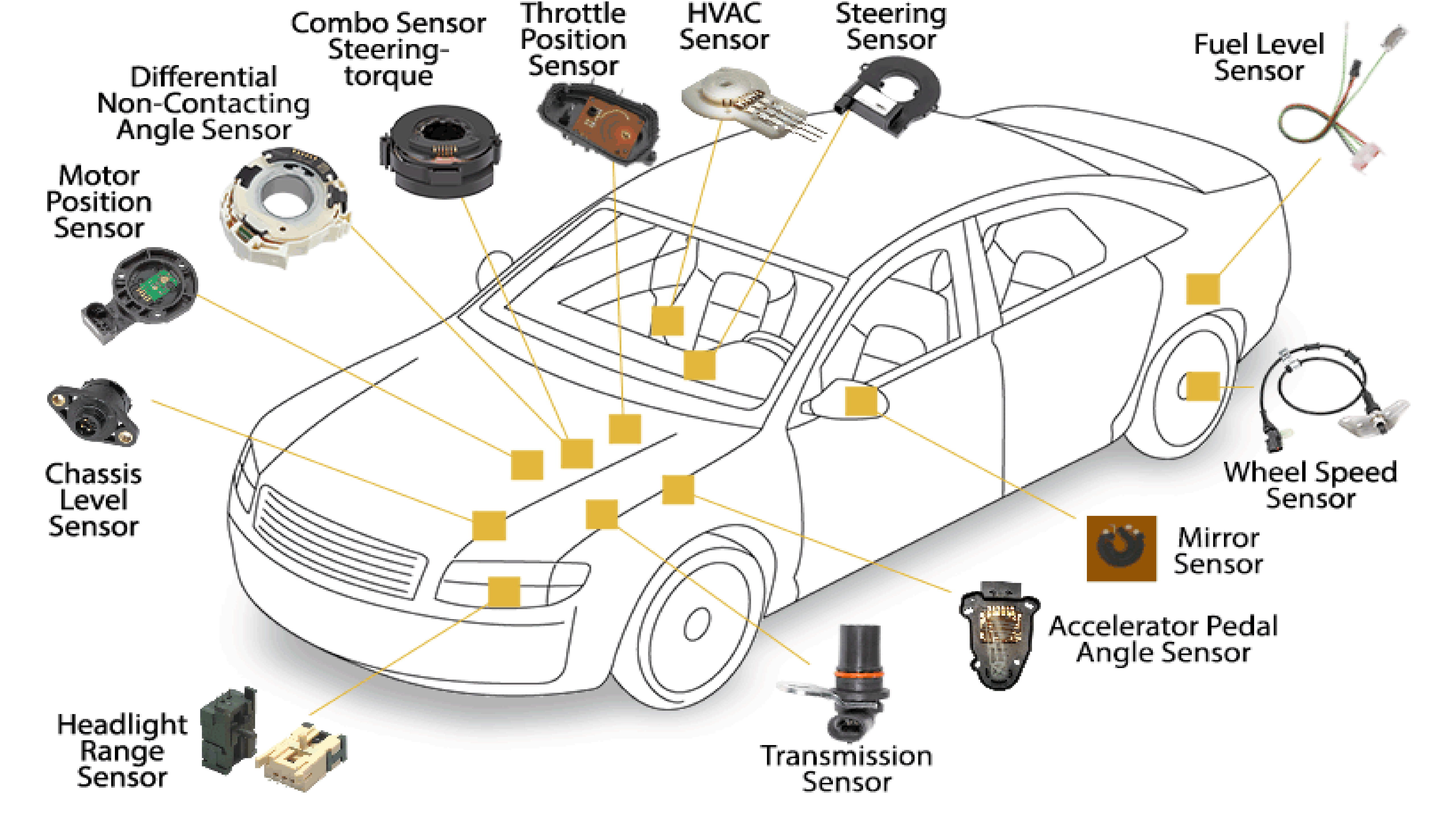
✓ **Sensor** is a device that ***when exposed to a physical phenomenon*** *(temperature, displacement, force, etc.)* ***produces a proportional output signal*** *(electrical, mechanical, magnetic, etc.).*

Human beings are equipped with 5 different types of sensors.



Mechatronic System Overview




Combo Sensor Steering-torque
Throttle Position Sensor
HVAC Sensor
Steering Sensor
Fuel Level Sensor
Differential Non-Contacting Angle Sensor
Motor Position Sensor
Chassis Level Sensor
Wheel Speed Sensor
Mirror Sensor
Accelerator Pedal Angle Sensor
Headlight Range Sensor
Transmission Sensor

Transducer

✓ *A device which converts one form of energy to another*

✓ ***When input is a physical quantity and output electrical → Sensor***

✓ ***When input is electrical and output a physical quantity → Actuator***

Sensors

Physical parameter

↓

Electrical Output

Actuators

Electrical Input

↓

Physical Output

e.g. Piezoelectric:

Force -> voltage

Voltage-> Force

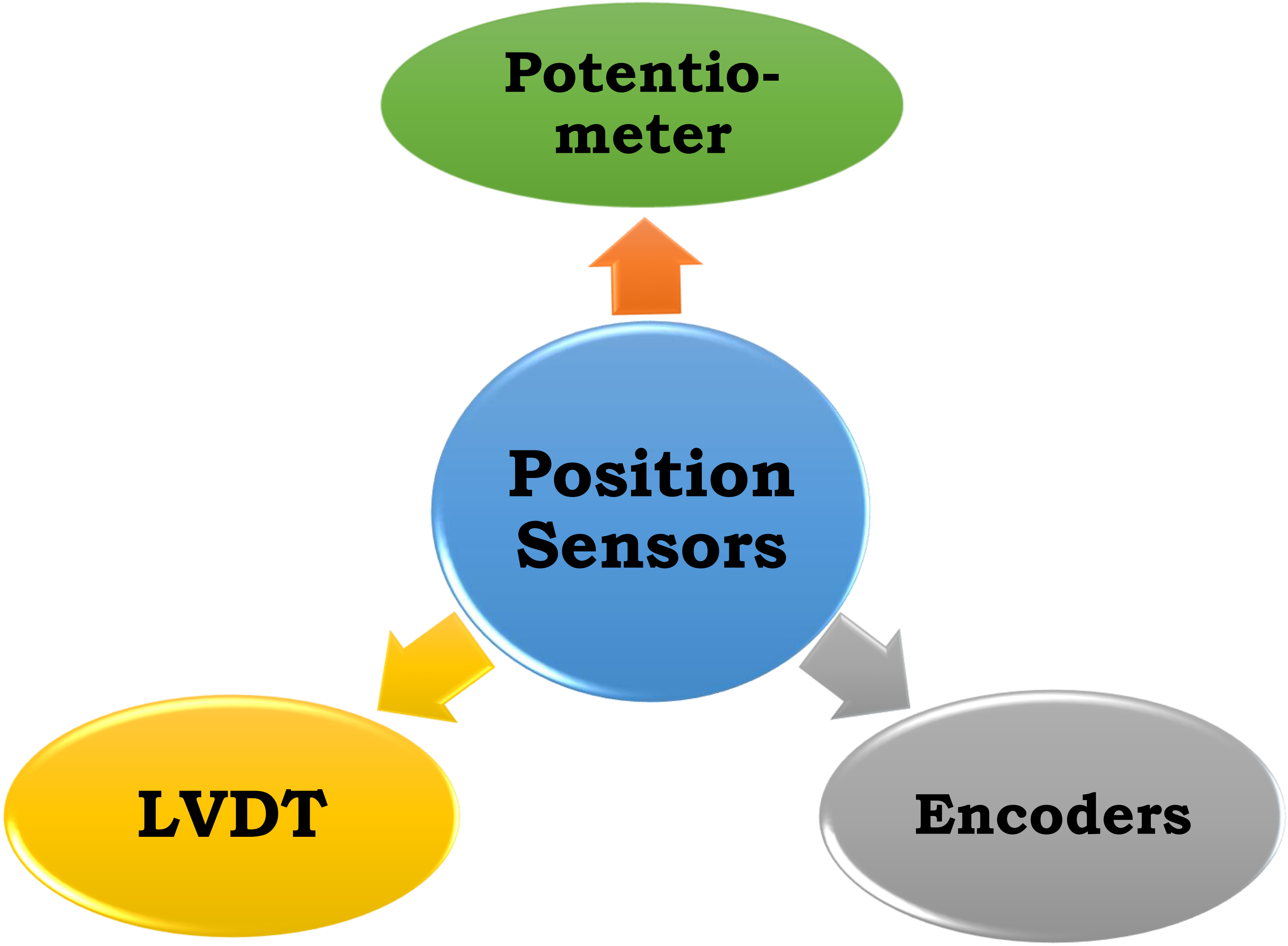
SENSOR , TRANSDUCER & ACTUATOR

- *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.Position Sensors



Potentiometer

- ✓A three-terminal resistor with a sliding contact that forms an adjustable voltage divider
- ✓Used to ***convert rotary or linear displacement to a voltage***
- ✓Resistance value can also be converted to a voltage
- ✓Used to detect angular position (i.e. of a robot arm, etc.)

Potentiometer

Rotary potentiometer | **Linear potentiometer**

- ✓A rotary and linear potentiometer is a variable resistance device that can be used to ***measure angular position and linear position***.
- ✓Through voltage division the change in resistance can be used to create an output voltage that is directly proportional to the input displacement.

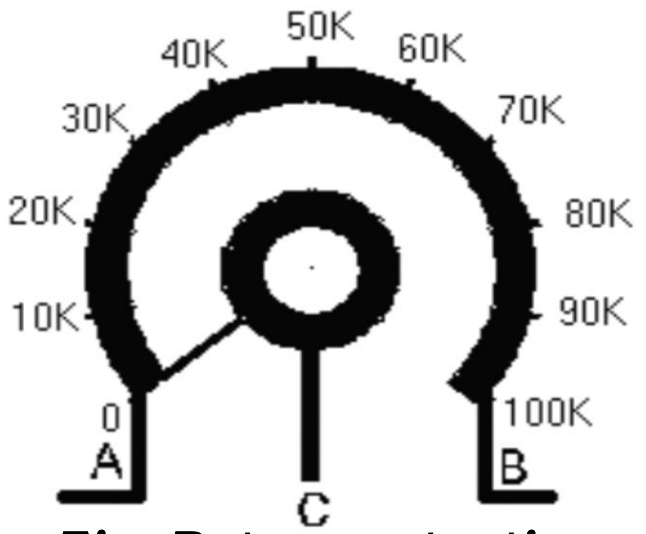


Fig. Rotary potentiometer

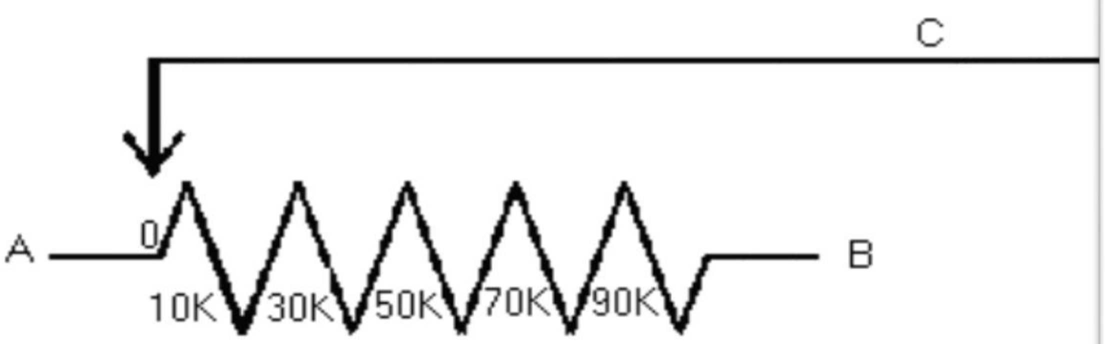
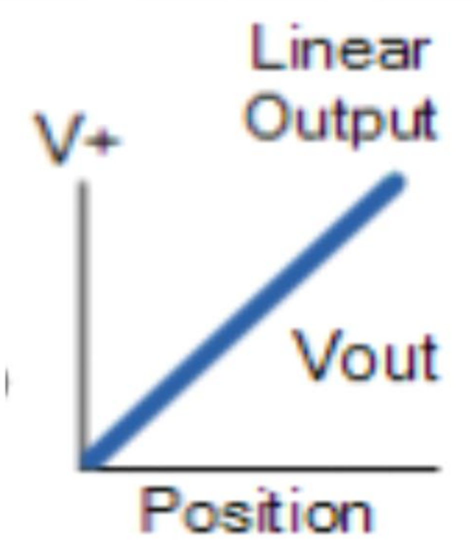
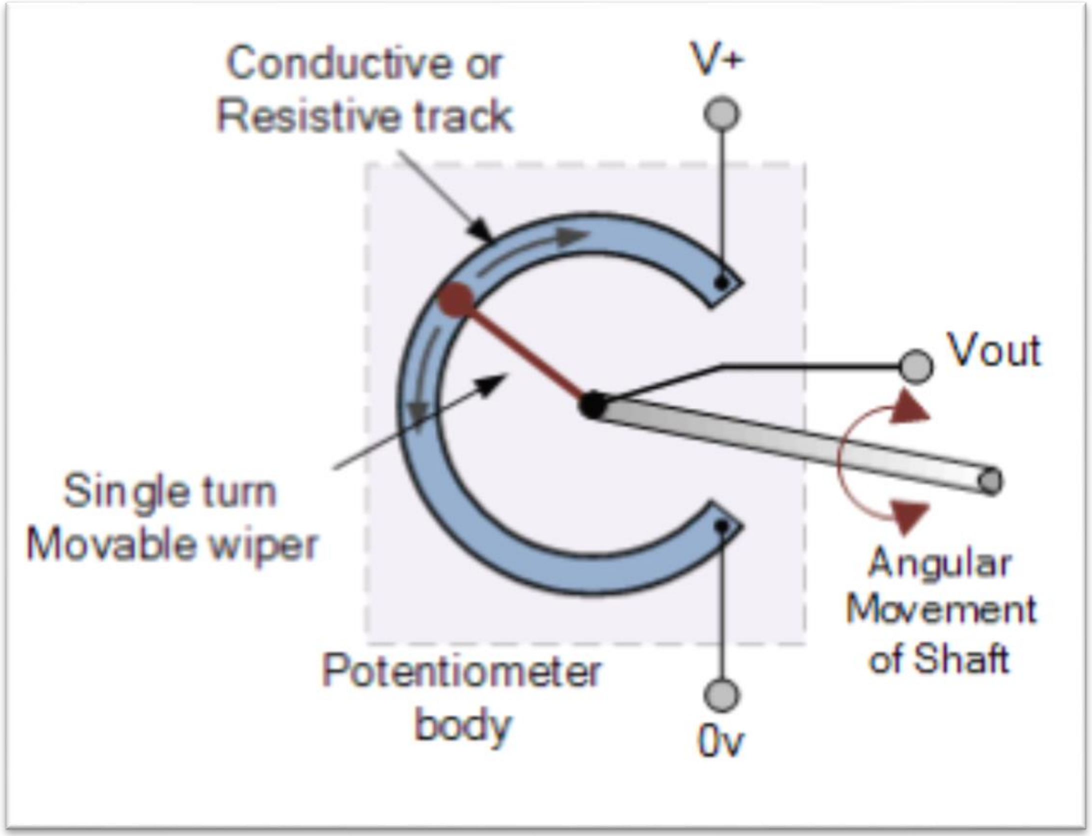
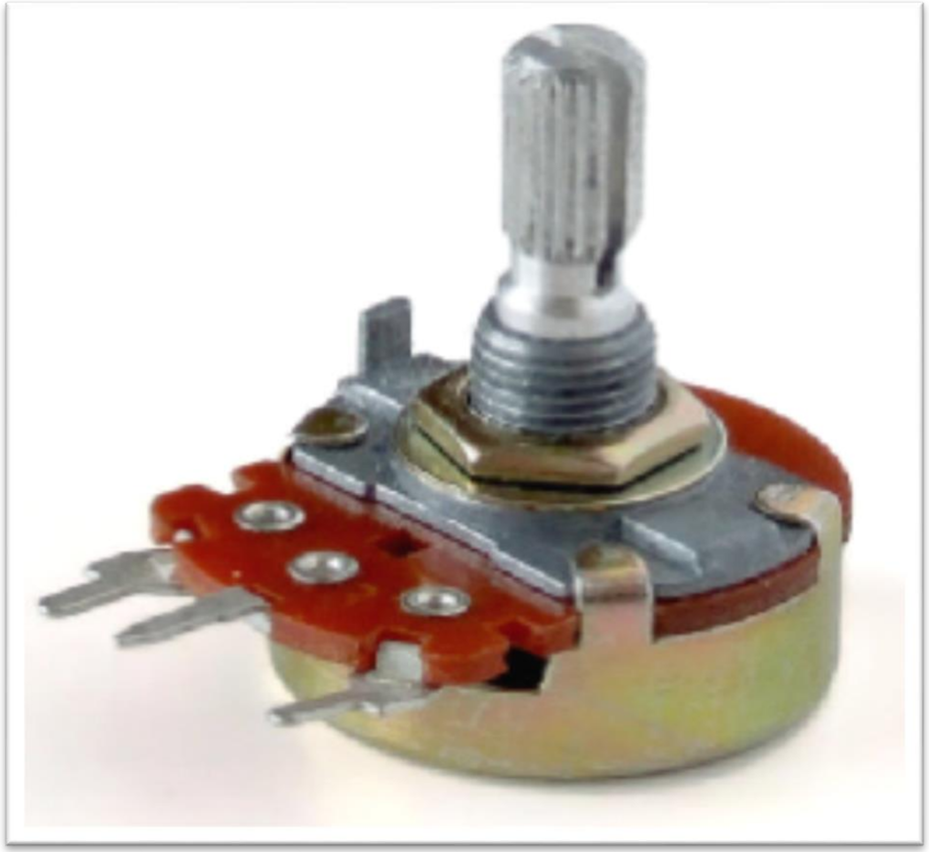


Fig. Linear potentiometer



Rotary Potentiometer



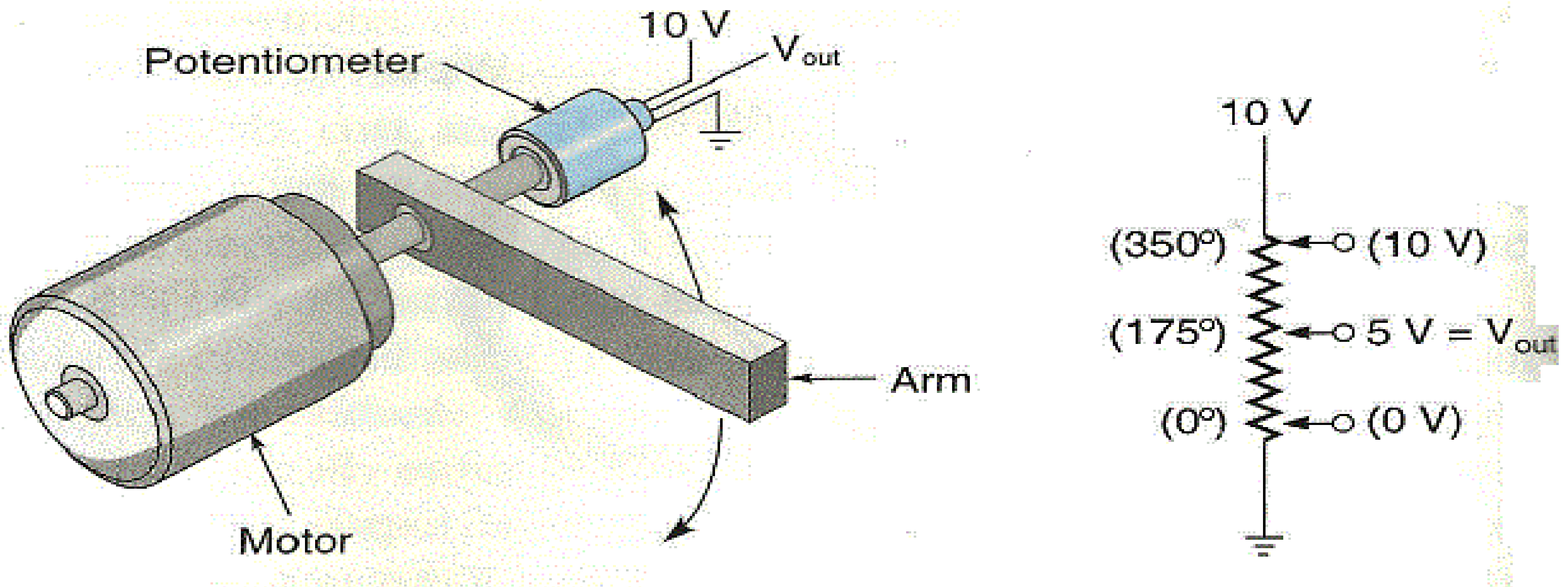


Resistive material has a uniform resistivity so that the ohms-per-inch value along its length is constant.

Eg-

✓The wiper can be used to control the voltage along an element.

✓The wiper taps off the voltage drop between its contact point and ground



(a) Motor driving robot arm; pot connected to a motor shaft

(b) Circuit

Advantages of the potentiometer are:

✓Easy to use

✓Low cost

✓High amplitude output

✓Easily available

✓Can be used for measuring even large displacements.

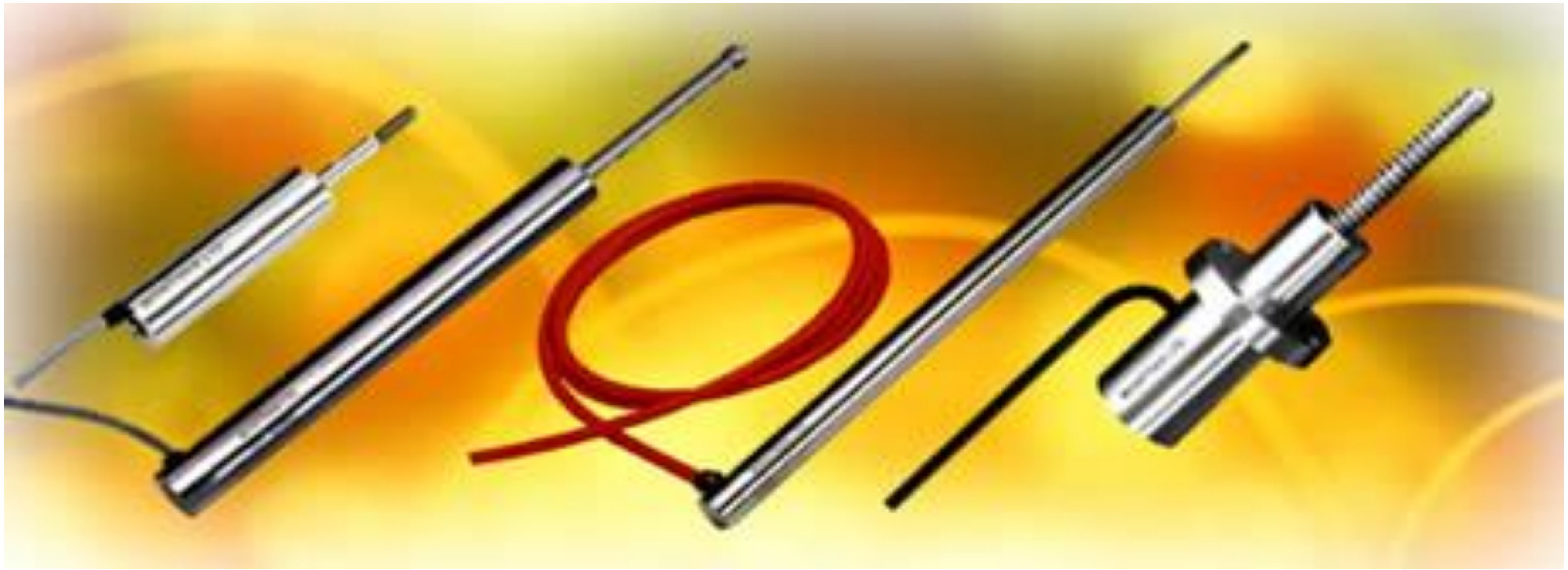
✓Can produce a high electrical efficiency

Disadvantages

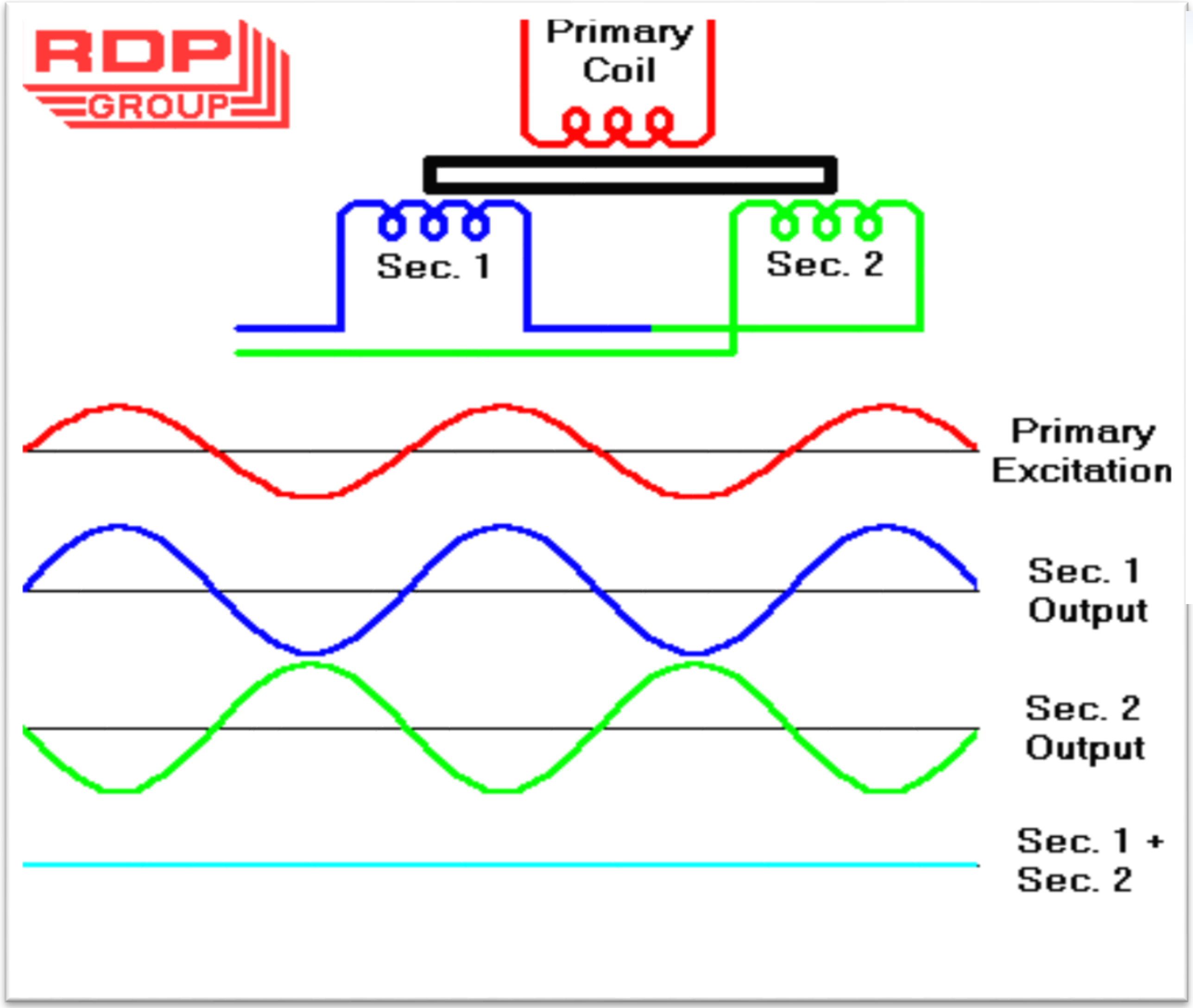
✓Since the wiper is sliding across the resistive element there is a possibility of friction and wear. Hence the number of operating cycles are limited.

Linear Variable Differential Transformer

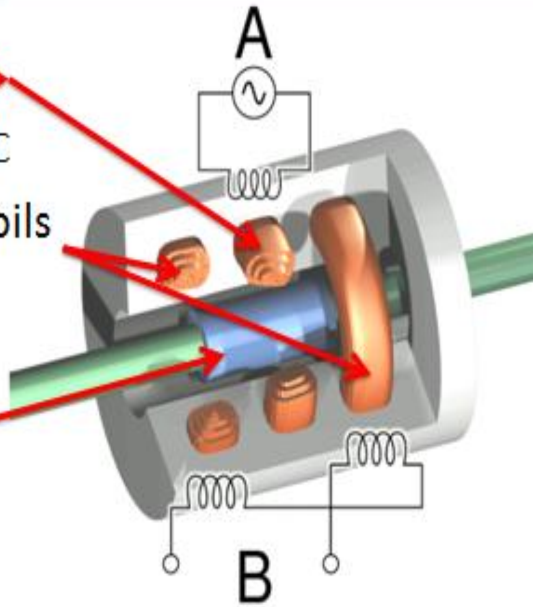
- ✓'LVDT' is a transducer for measuring linear displacement
- ✓It must be excited by an AC signal to induce AC response on secondary.
- ✓The core position can be determined by measuring secondary response.

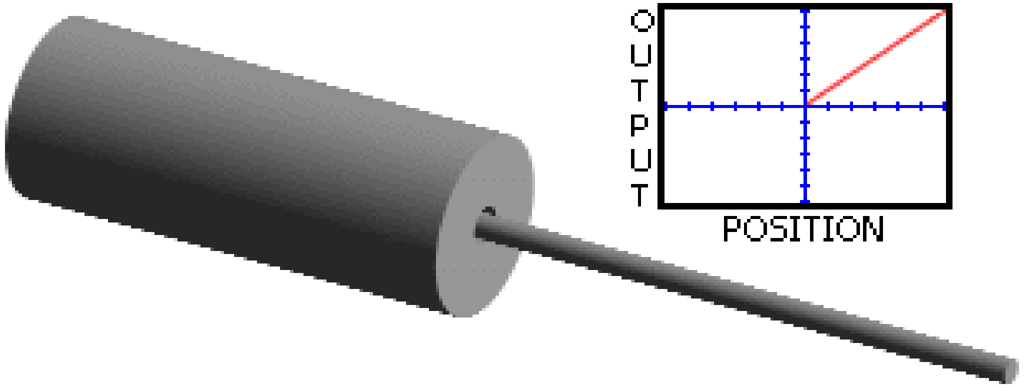


LVDT



- Primary coil
  - Energized with constant A/C
- Two identical secondary coils
  - Symmetrically distributed
  - Connected in opposition
- Ferromagnetic core

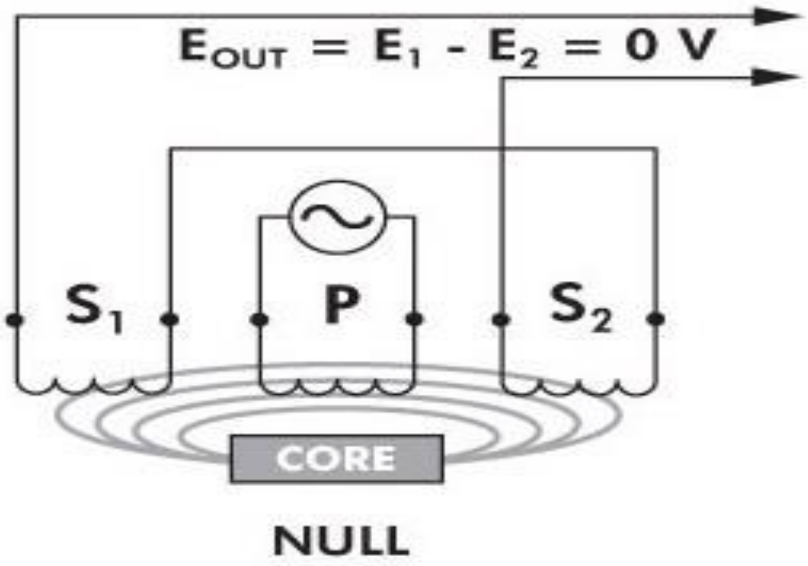


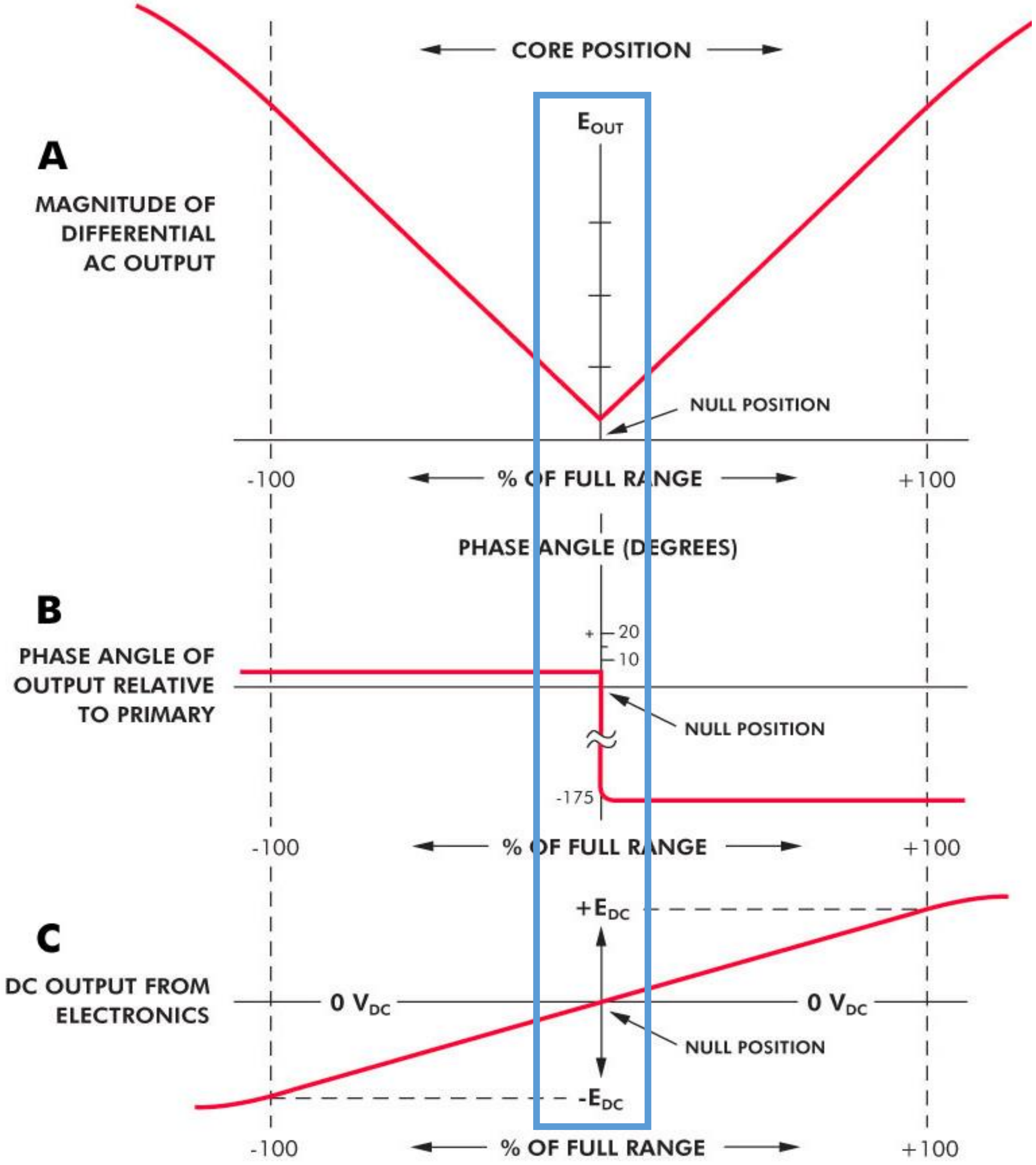


How LVDT works?

1.If core is centered between S1 and S2

- Equal flux from each secondary coil
- Voltage E1 = E2





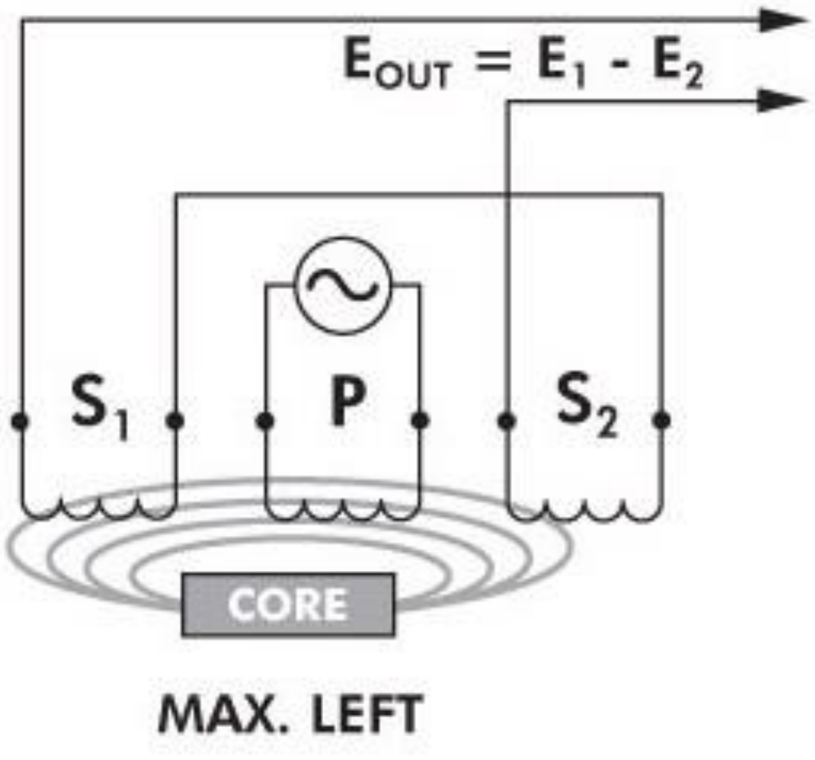
2.If core is closer to S1

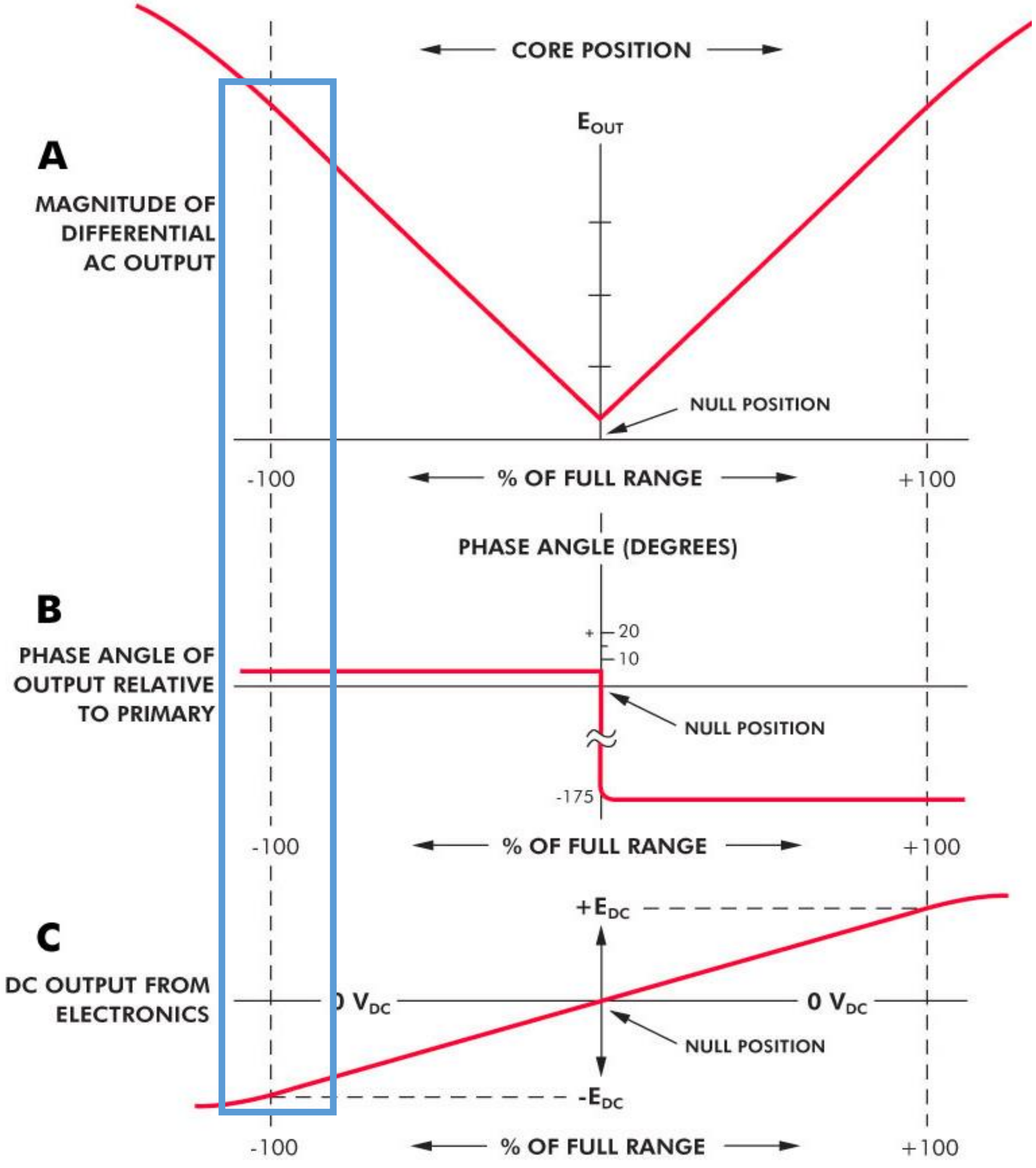
Greater flux at S1

Voltage E1 increases,

Voltage E2 decreases

E_{out}=E1 – E2





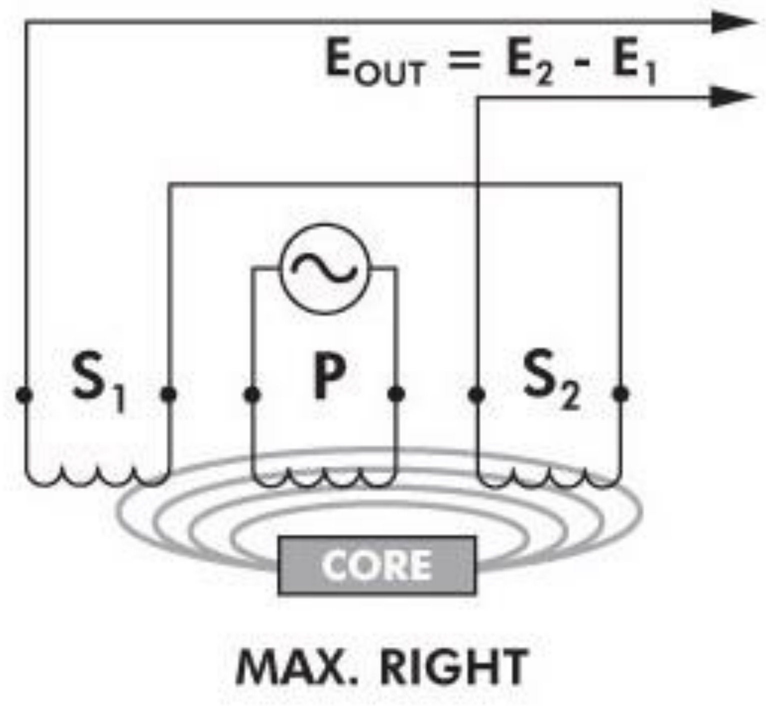
3. If core is closer to S2

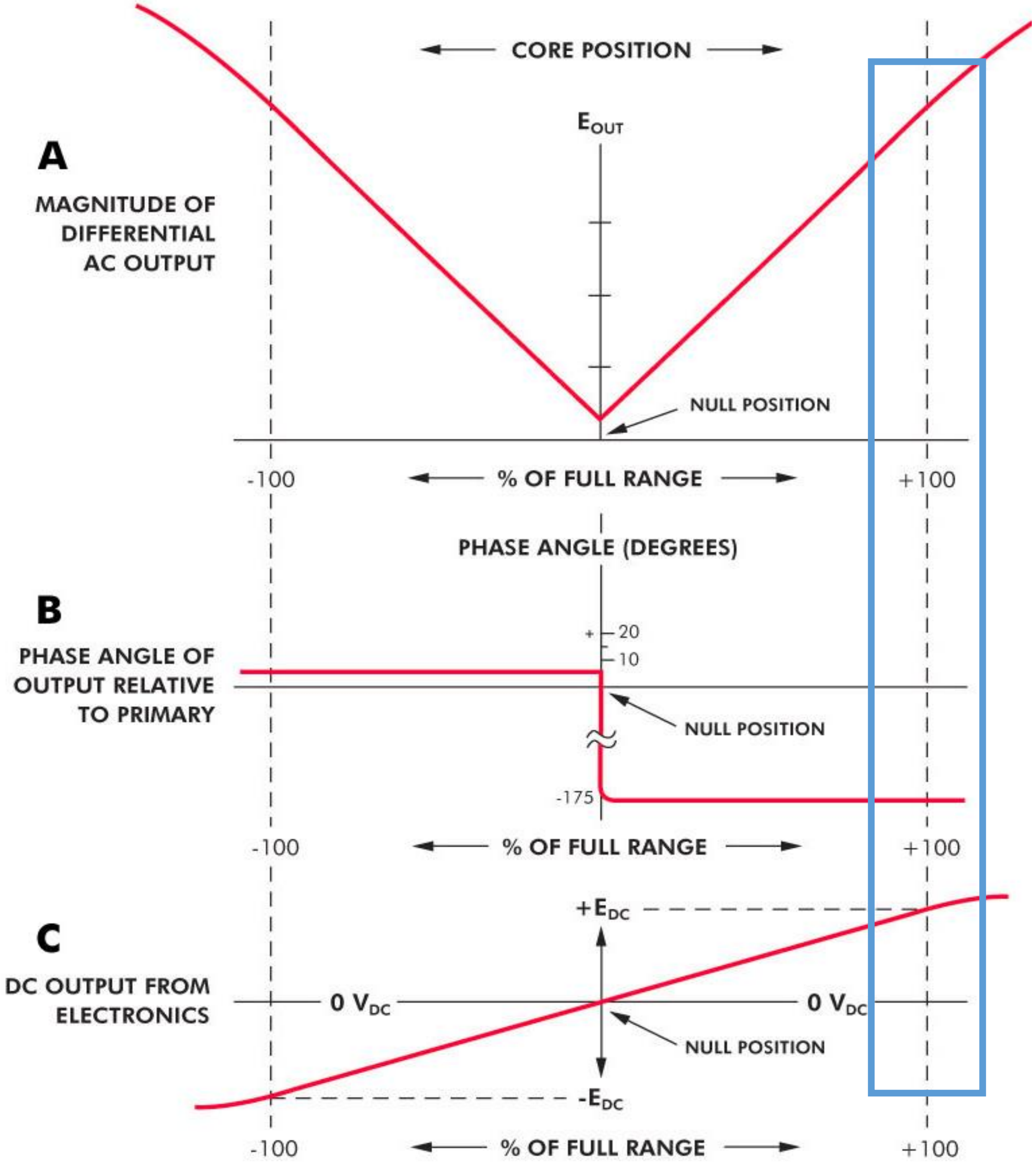
Greater flux at S2

Voltage E2 increases,

Voltage E1 decreases

E_{out}=E2 – E1





Advantages of LVDT-

1. **High Range** - The LVDTs have a very high range for measurement of displacement. they can used for measurement of displacements ranging from ***0.25 mm to 250 mm***

2. **No Frictional Losses** - As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.

3. **High Input and High Sensitivity -** The output of LVDT is so high that it doesn't need any amplification. The transducer possesses ***a high sensitivity*** which is typically about ***40V/mm.***

4. **Low Hysteresis** - LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
5. **Low Power Consumption** - The power is about ***1W*** which is very as compared to other transducers.
6. **Direct Conversion to Electrical Signals** - They convert the linear displacement to electrical voltage which are easy

Disadvantages of LVDT-

1. LVDT is ***sensitive to stray magnetic fields*** so they always require a setup to protect them from stray magnetic fields.

2. They are ***affected by vibrations and temperature***.

Applications of LVDT-

1. They are used in applications where ***displacements ranging from fraction of mm to few cm*** are to be measured.

2. The LVDT acting as a ***primary transducer converts the displacement to electrical signal directly***.

3. They can also ***acts as the secondary transducers***.

E.g. the Bourbon tube which acts as a primary transducer and covert pressure into linear displacement. Then LVDT coverts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.

Encoders

Digital Optical Encoders types

1. Absolute Digital Optical Encoders

2. Incremental Digital Optical Encoders

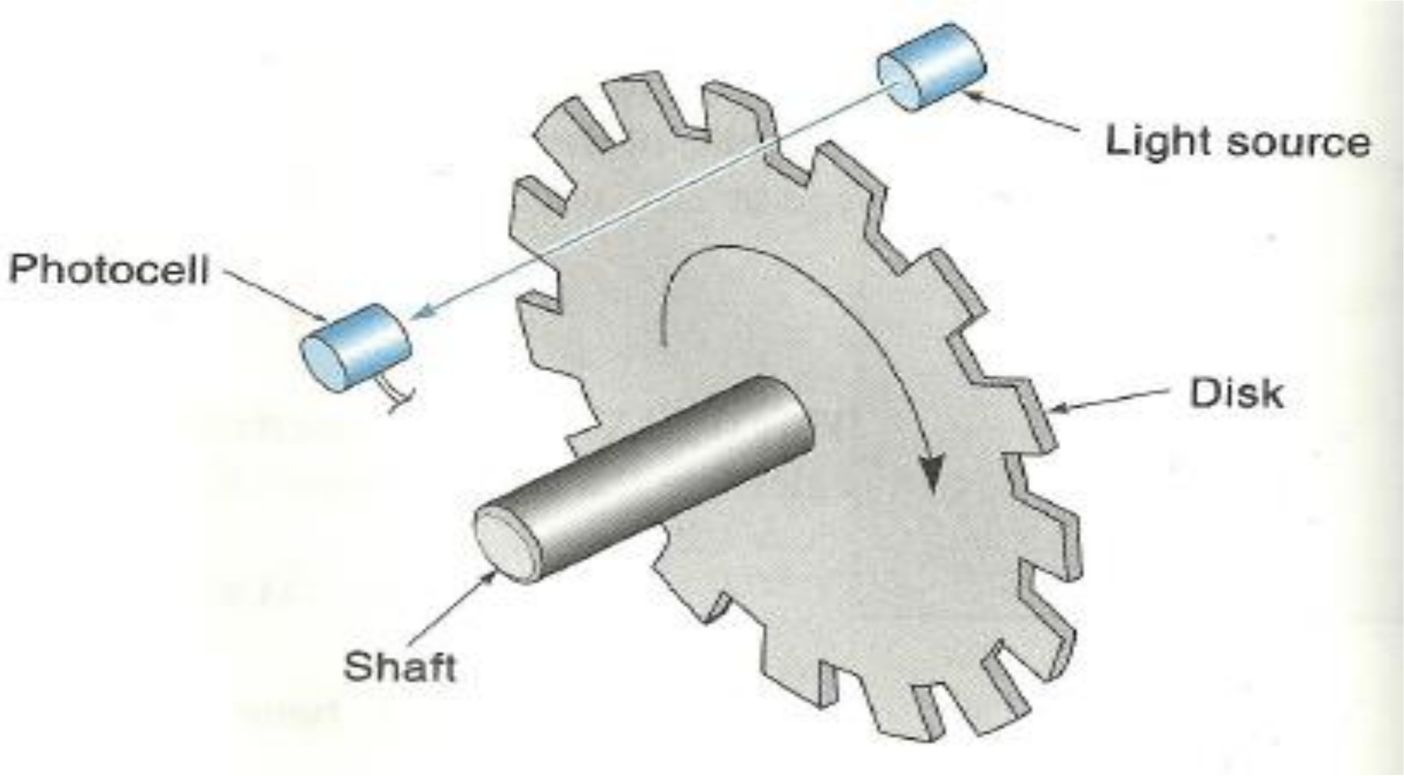
Digital Optical Encoders

✓Produces ***angular position data directly in digital form***, eliminating any need for ADC

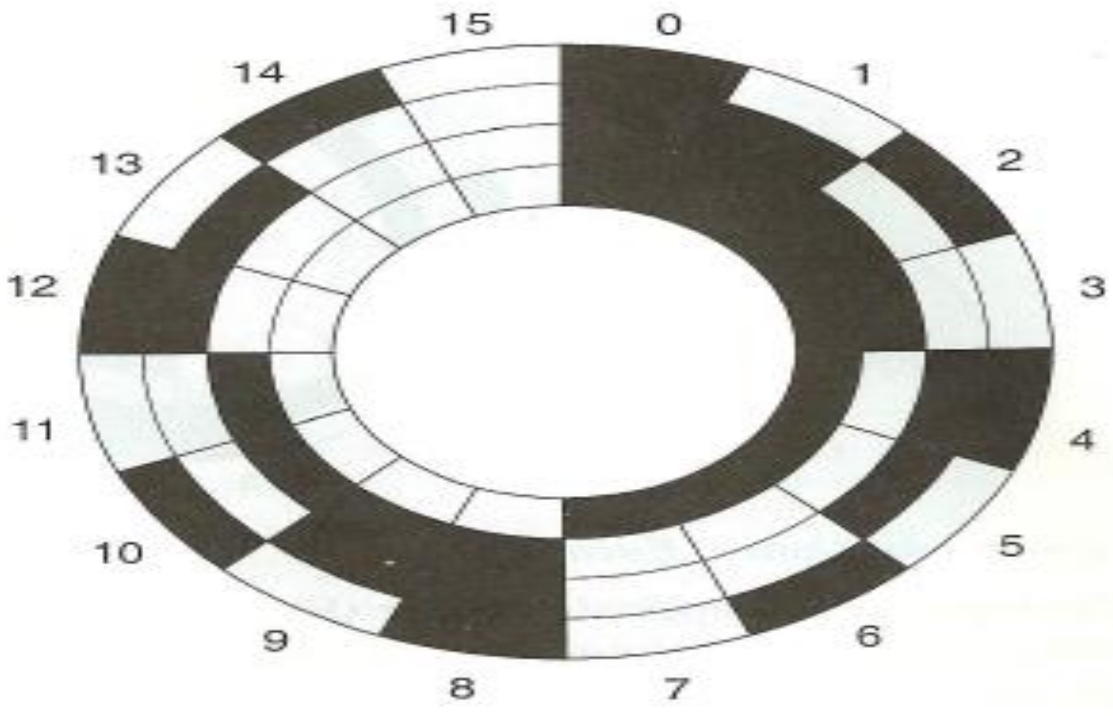
✓The design is comprised of a ***"code disk"*** attached to a shaft

✓A light source and photocell arrangement are mounted so that the slots pass the light beam as the disk rotates

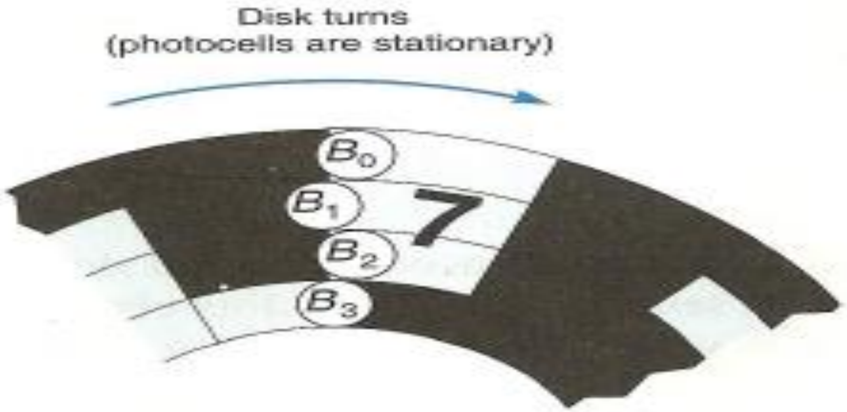
✓***The angle of the shaft is deduced from the output of the photocell***



Absolute Encoder



(Note: Light areas cause a 1 output)



8	5	7	
0	1	1	B_0
0	0	1	B_1
0	1	1	B_2
1	0	0	B_3

Erroneous state

Absolute Encoder

- ✓Uses a glass disk marked off with a pattern of concentric tracks
- ✓A separate light beam is sent through each track to individual photo-sensors
- ✓Each photo-sensor contributes 1 bit to the output digital word
- ✓Advantage of this encoder is that the ***output is in straightforward digital form***

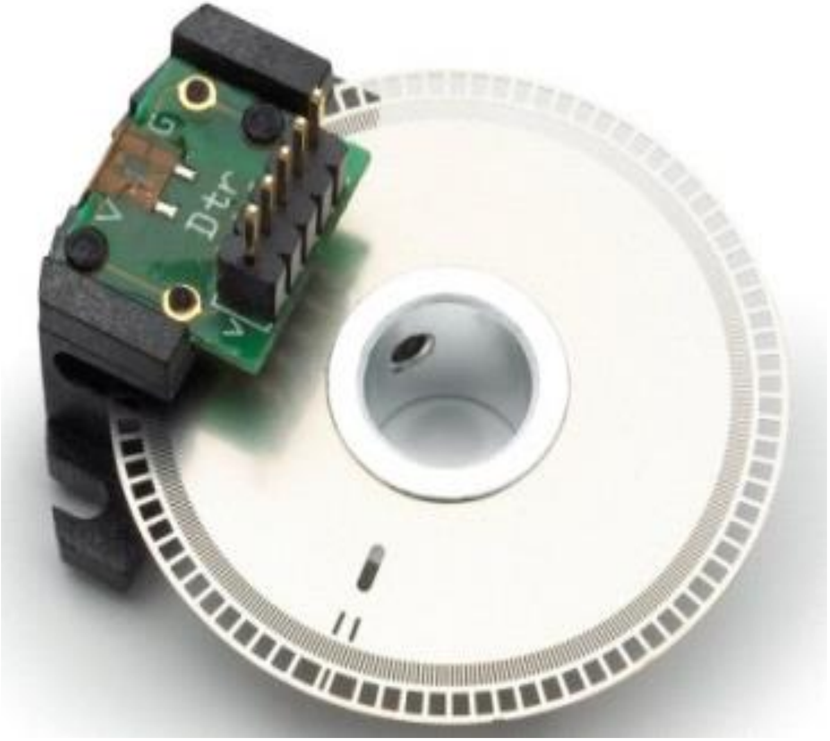
Incremental Encoder

- ✓Has only one track of equally spaced slots

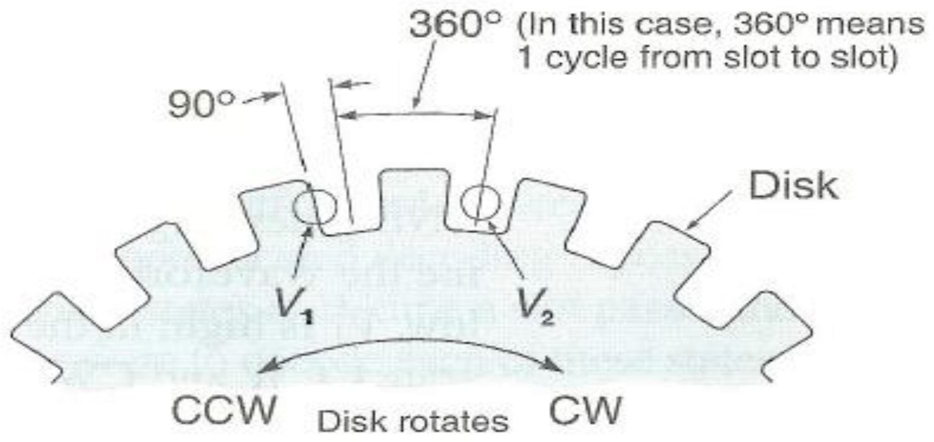
- ✓***Position is determined by counting the number of slots that pass a photo-sensor***, where ***each slot represents a known angle***

- ✓Requires an initial reference point, which may come from a second sensor

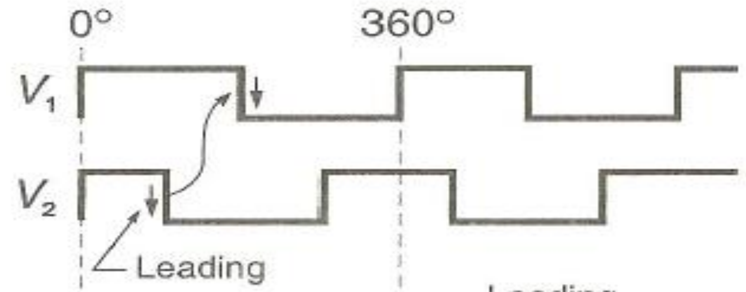
- ✓To track position, the controller must know the direction the disk is turning as well as the number of slots passed



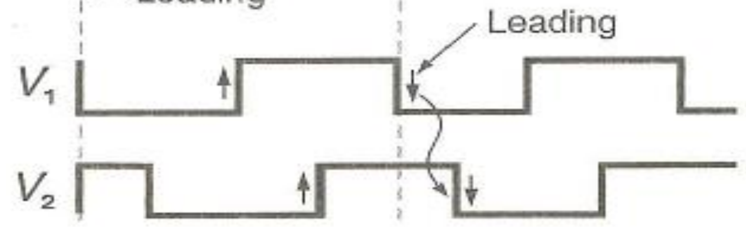
(a) Two-photosensor arrangement to determine direction

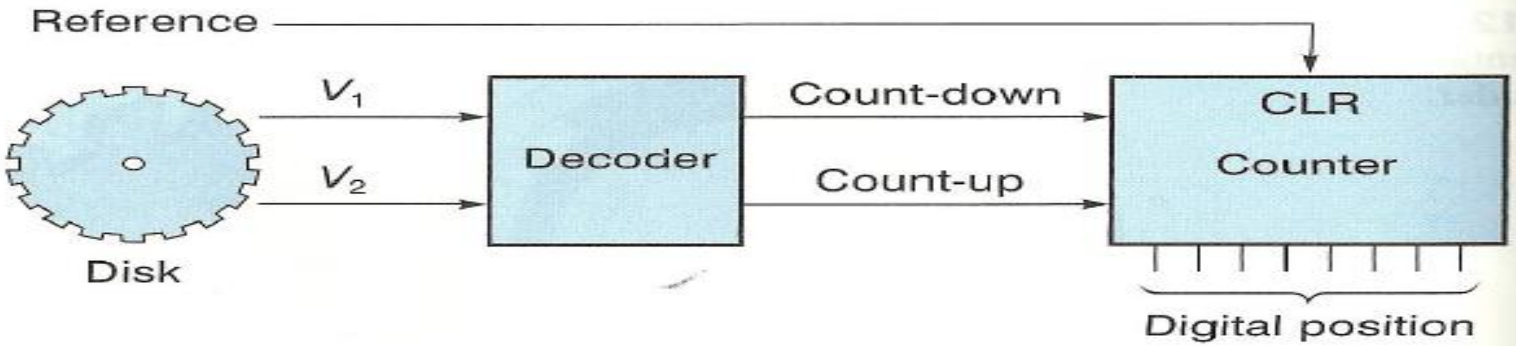


(b) CCW—Photocell waveforms for counterclockwise

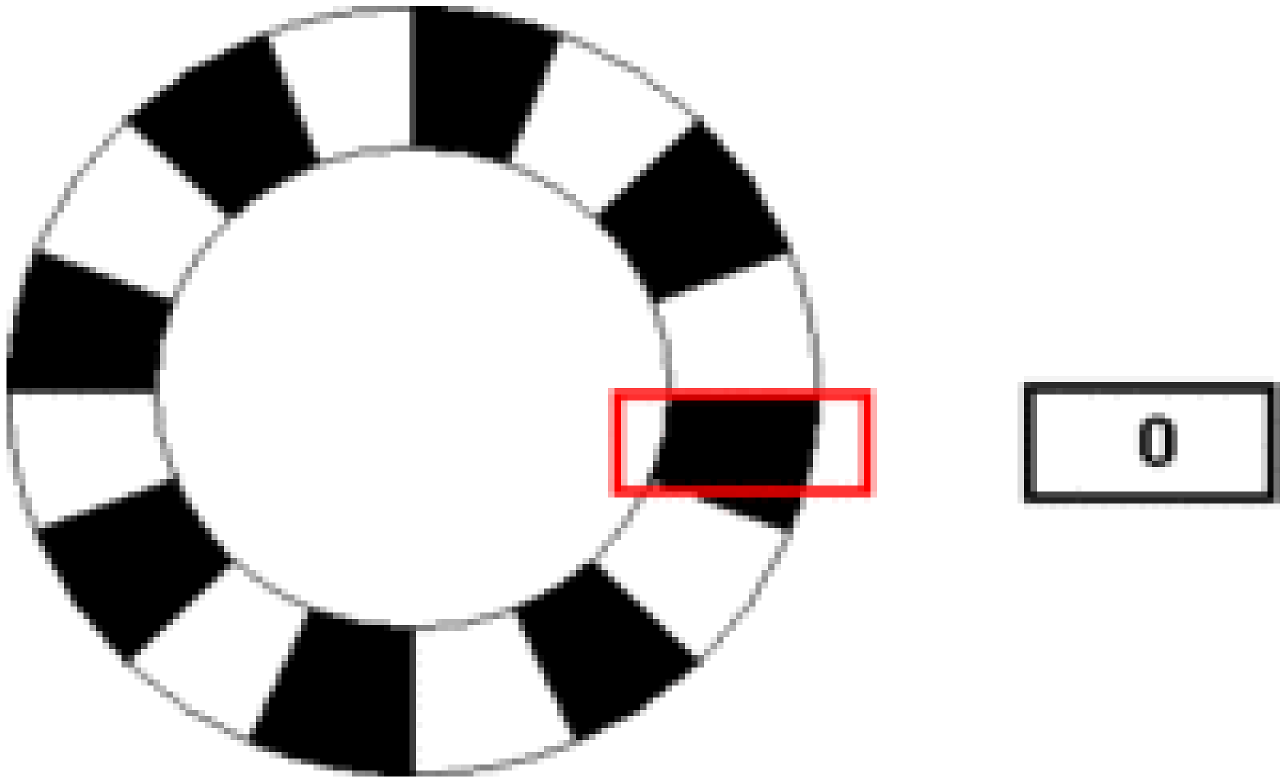


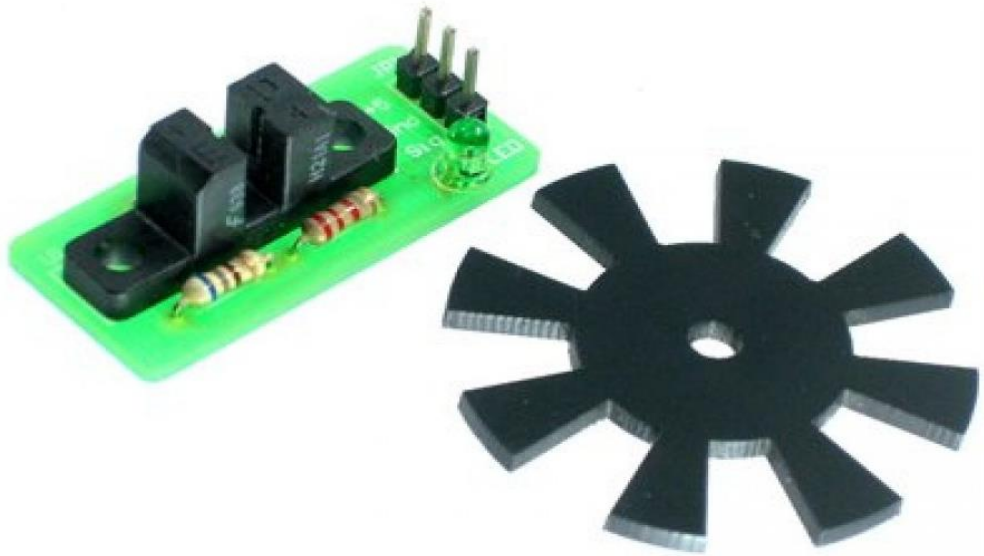
(c) CW—Photocell waveforms for clockwise



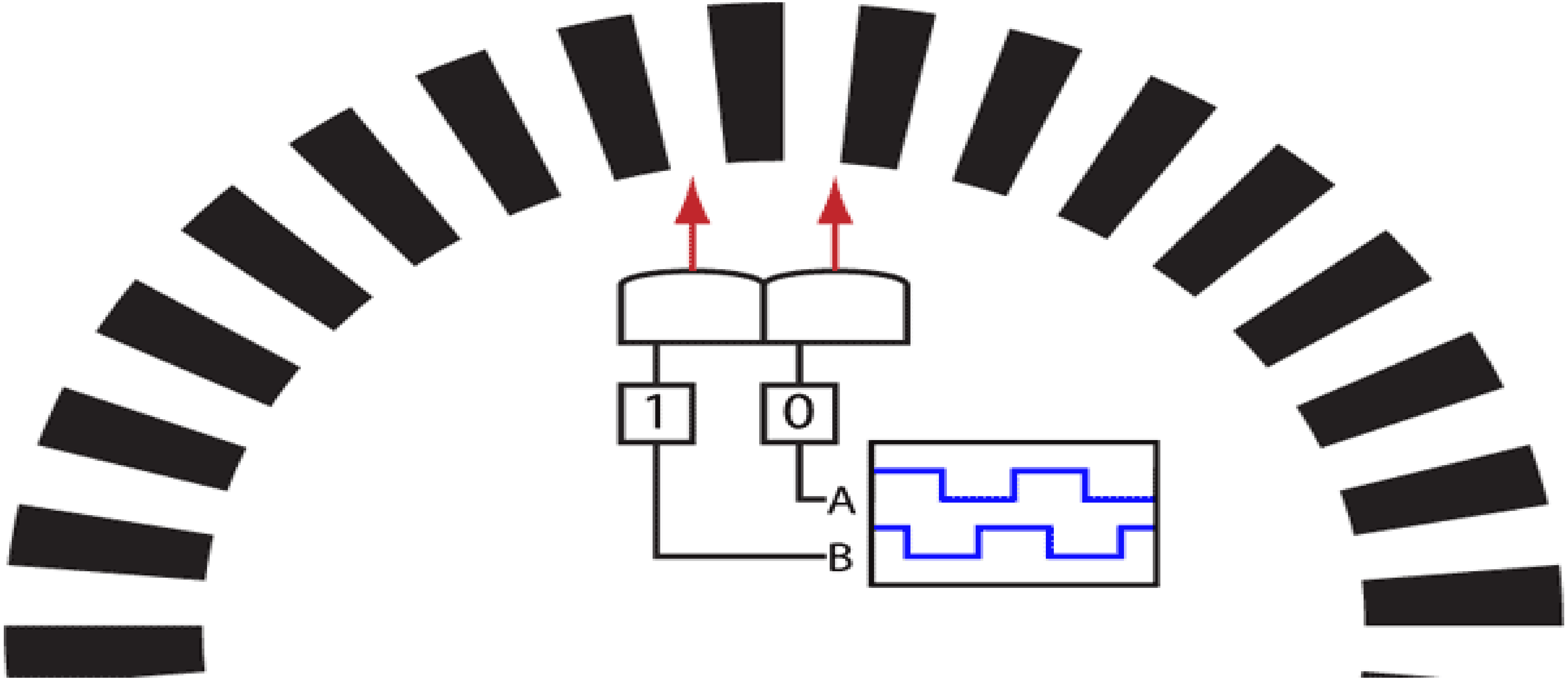


Simple Rotary Encoder

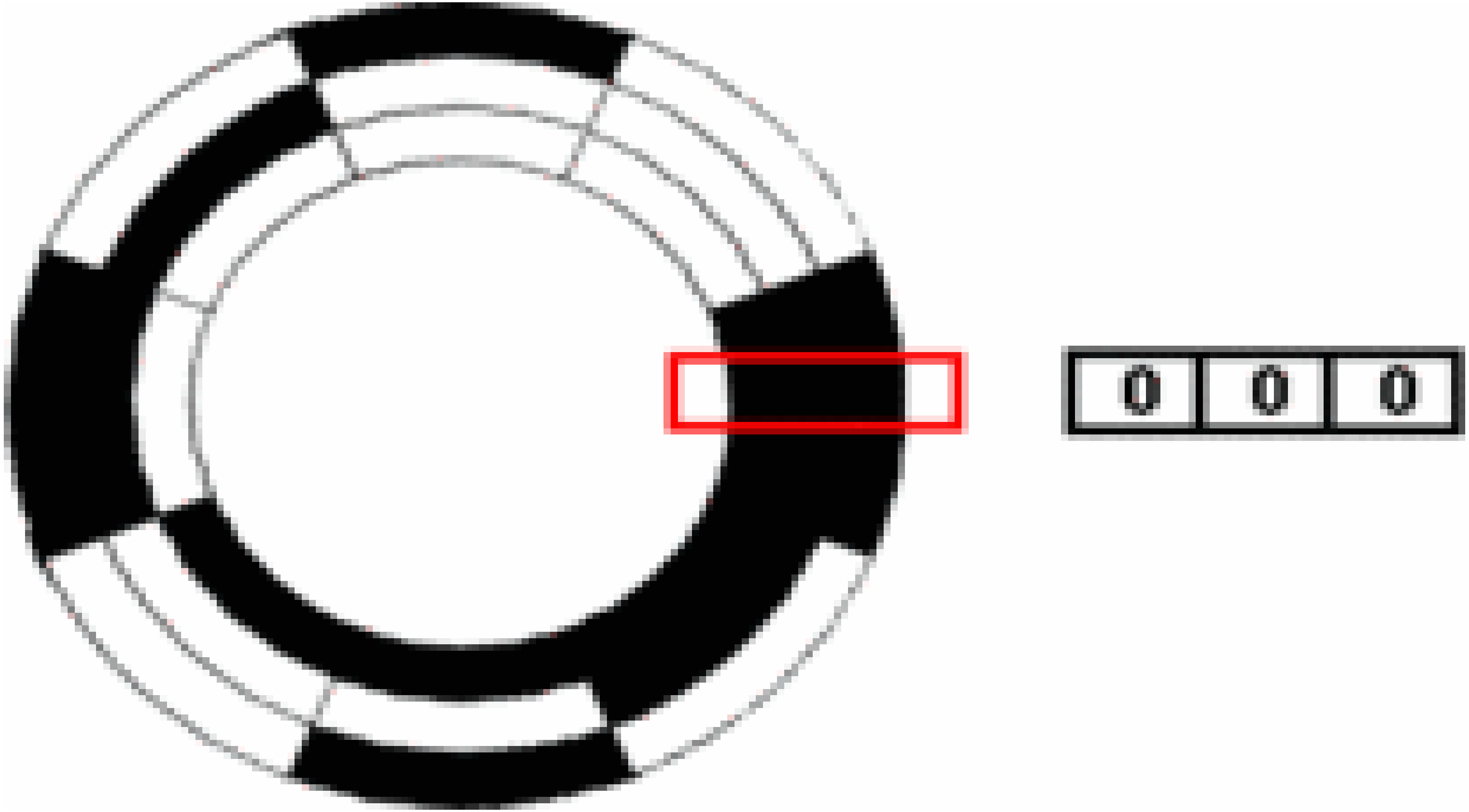




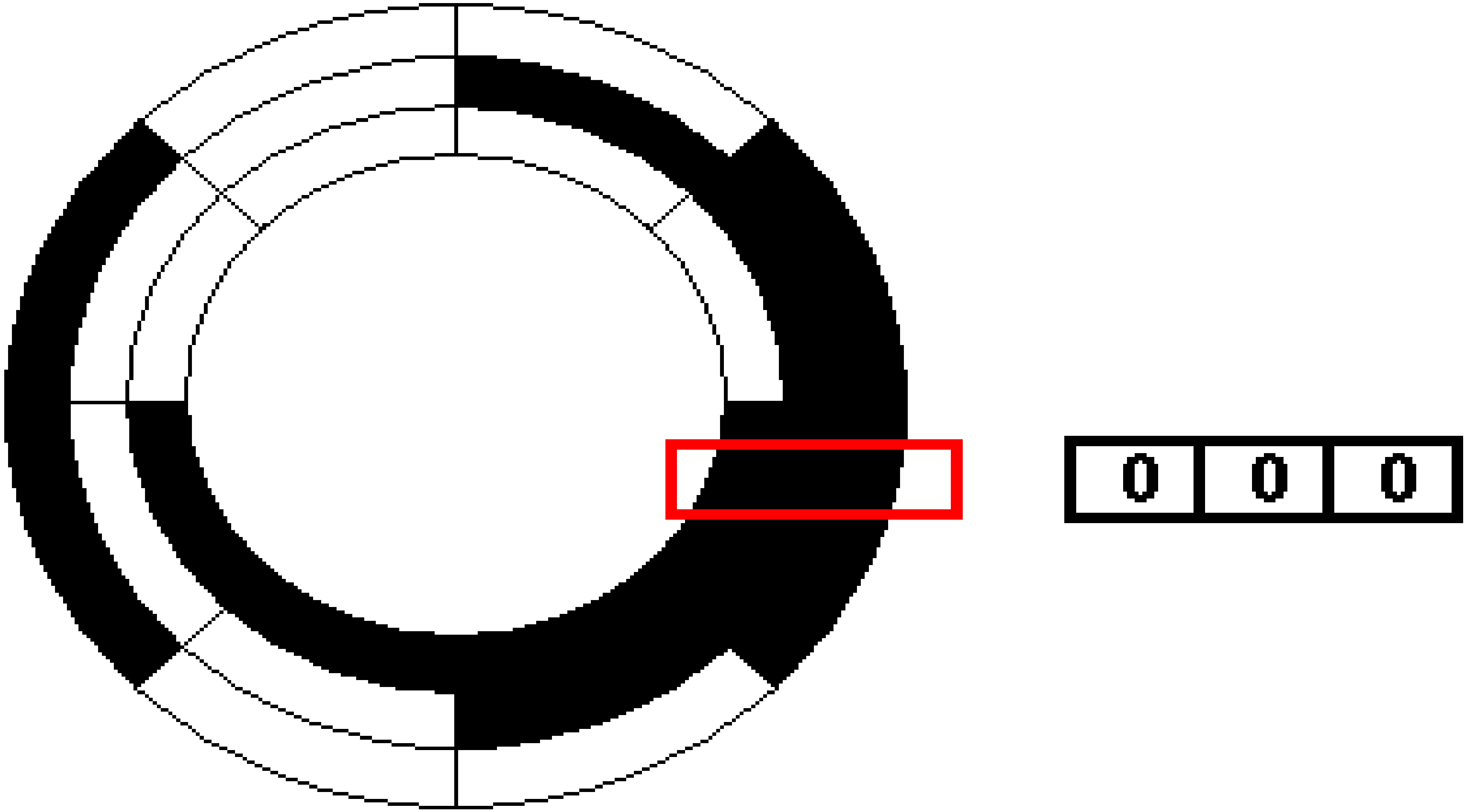
Quadrature Encoder



Binary Encoder



Grey Code Encoder



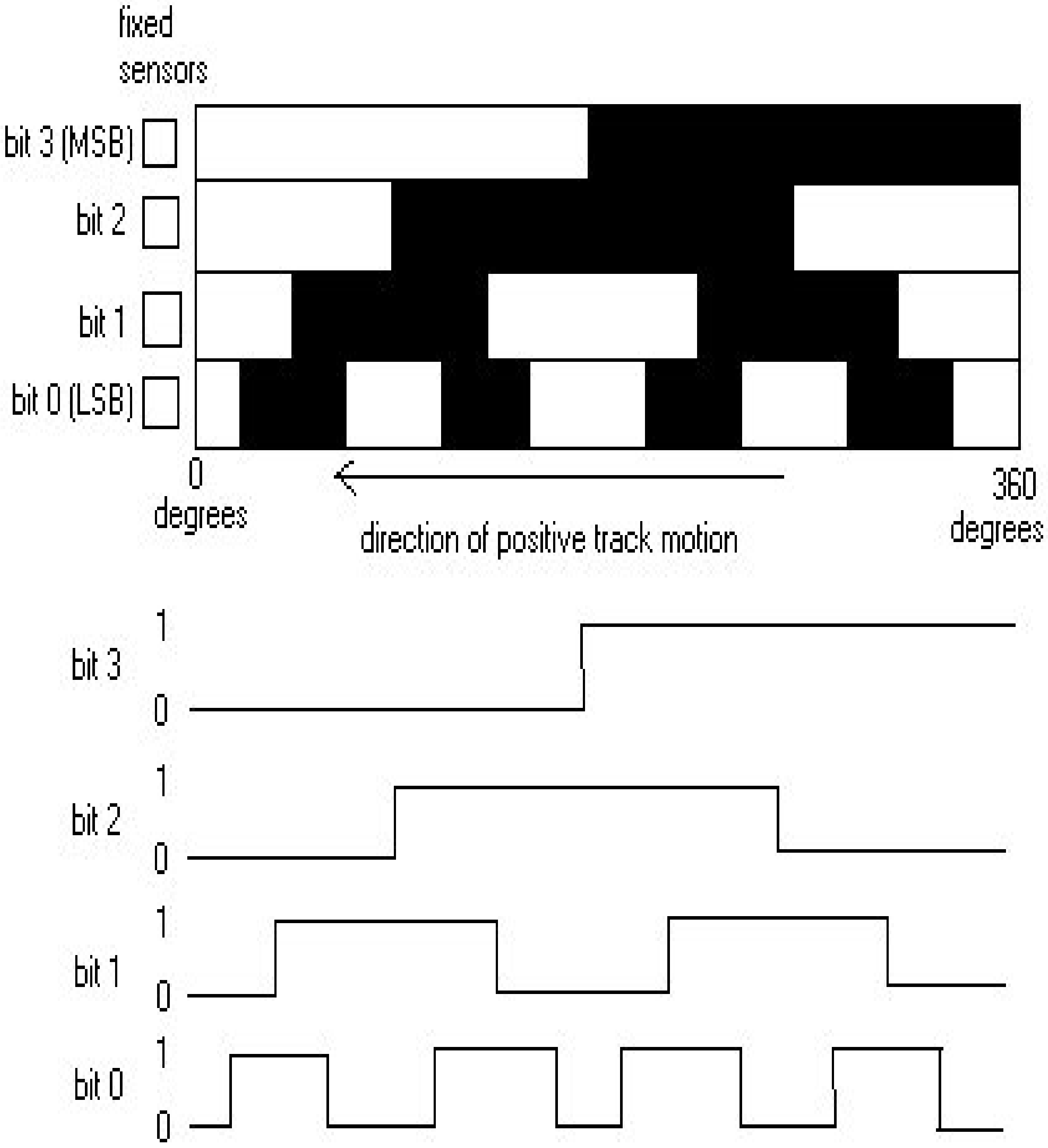


Fig 2. 4-Bit gray code absolute encoder disk track patterns

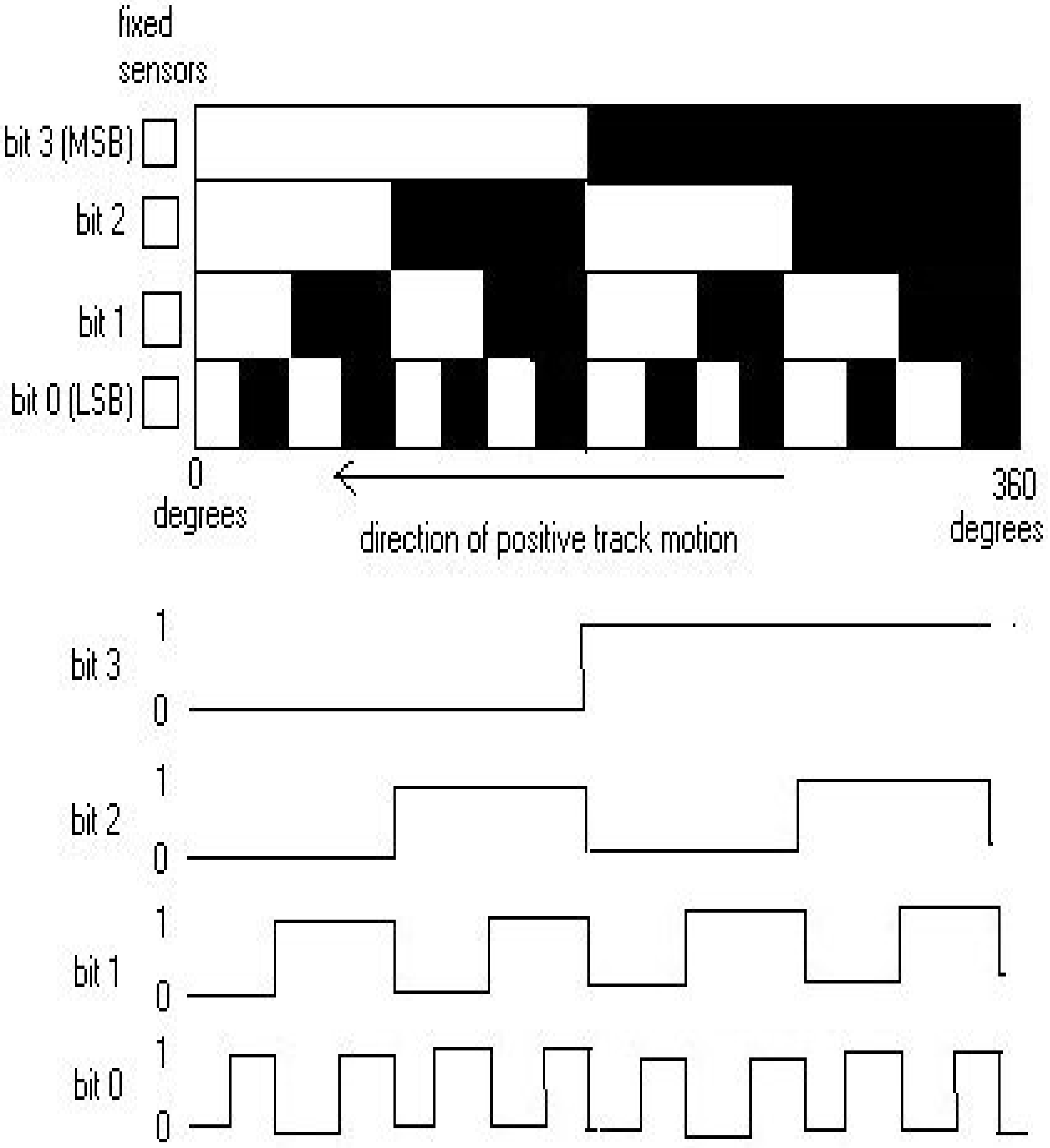


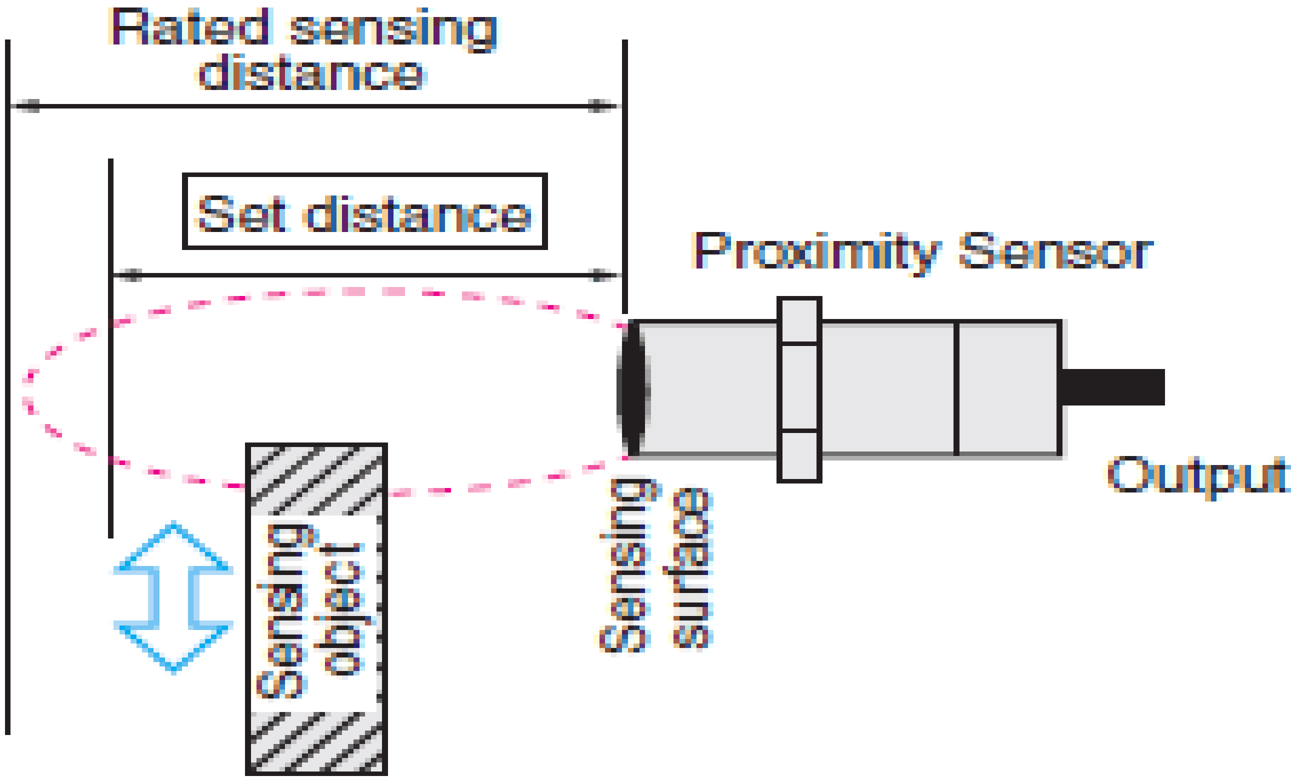
Fig 3 4-Bit binary code absolute encoder disk track patterns

Decimal code	Rotation range (deg.)	Binary code	Gray code
0	0-22.5	0000	0000
1	22.5-45	0001	0001
2	45-67.5	0010	0011
3	67.5-90	0011	0010
4	90-112.5	0100	0110
5	112.5-135	0101	0111
6	135-157.5	0110	0101
7	15.75-180	0111	0100
8	180-202.5	1000	1100
9	202.5-225	1001	1101
10	225-247.5	1010	1111
11	247.5-270	1011	1110
12	270-292.5	1100	1010
13	292.5-315	1101	1011
14	315-337.5	1110	1001
15	337.5-360	1111	1000

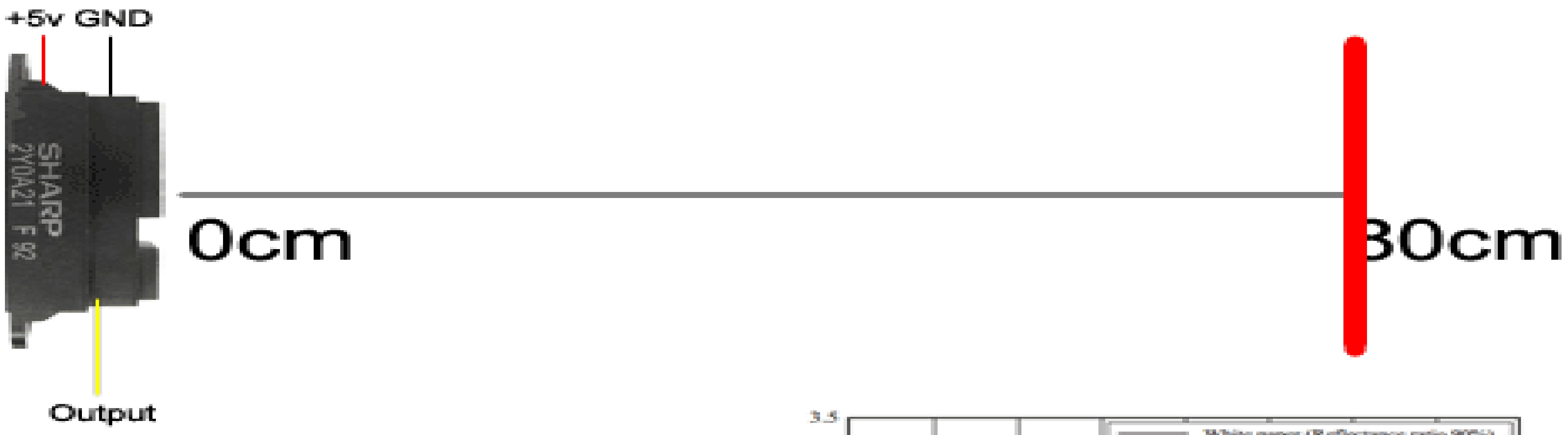
Table 1. 4-Bit gray and natural binary codes

Proximity sensors

- Proximity sensors types:
  - Optical
  - Inductive
  - Capacitive

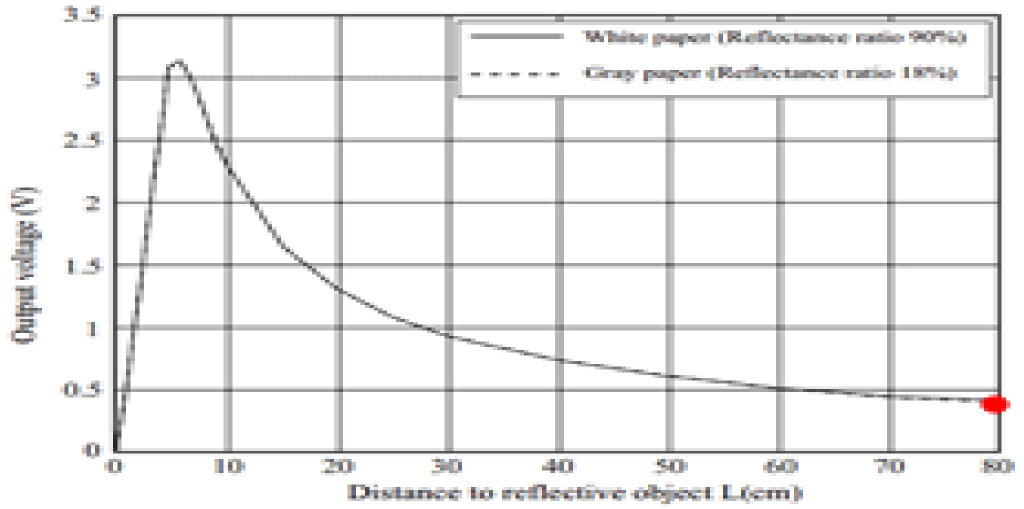


Proximity sensors

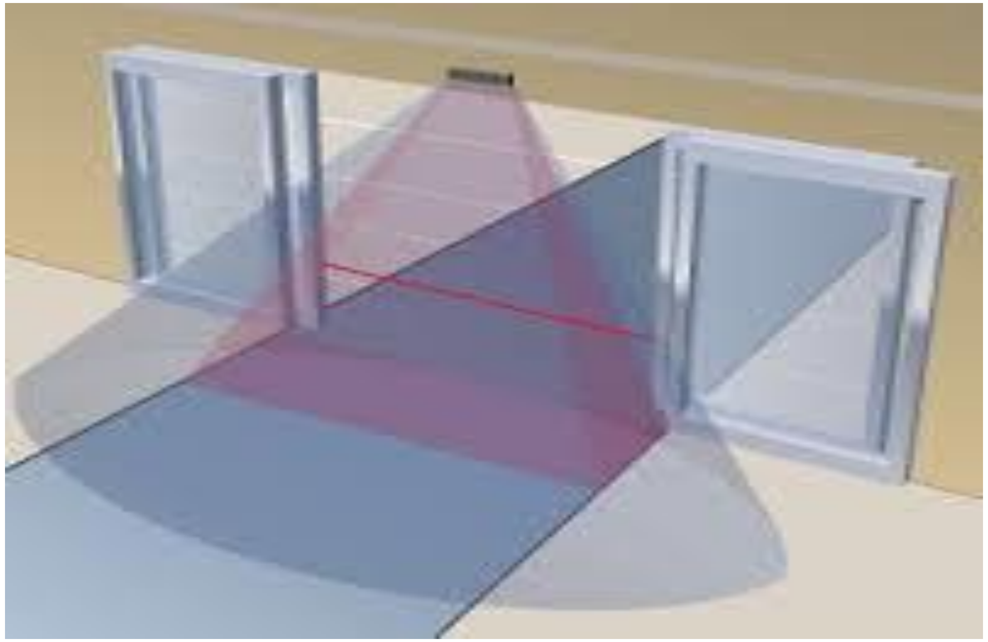


Output Voltage

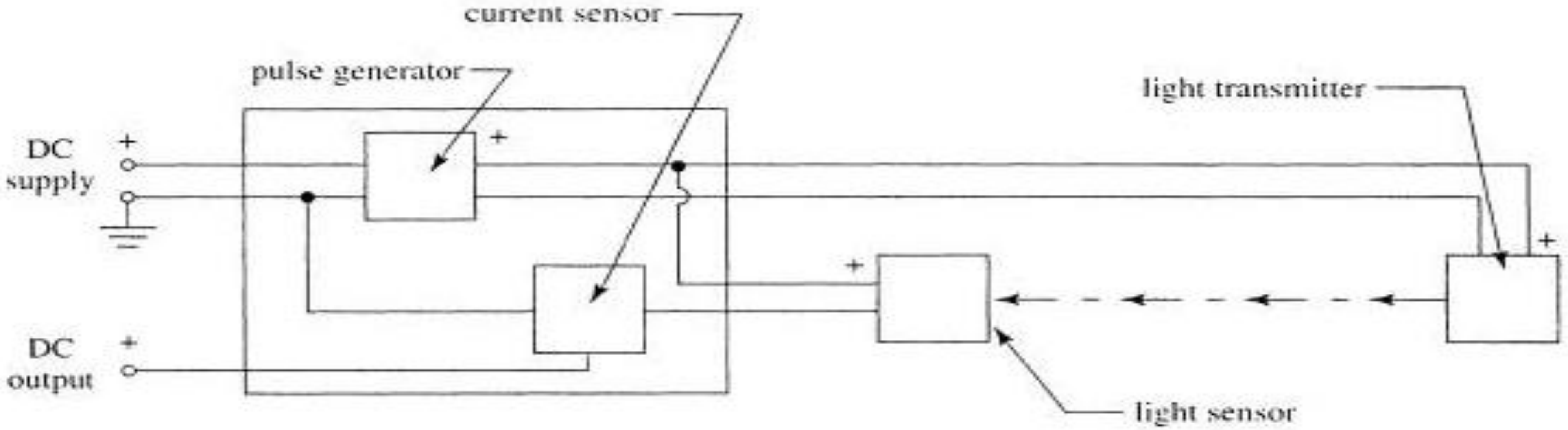
+0.44v

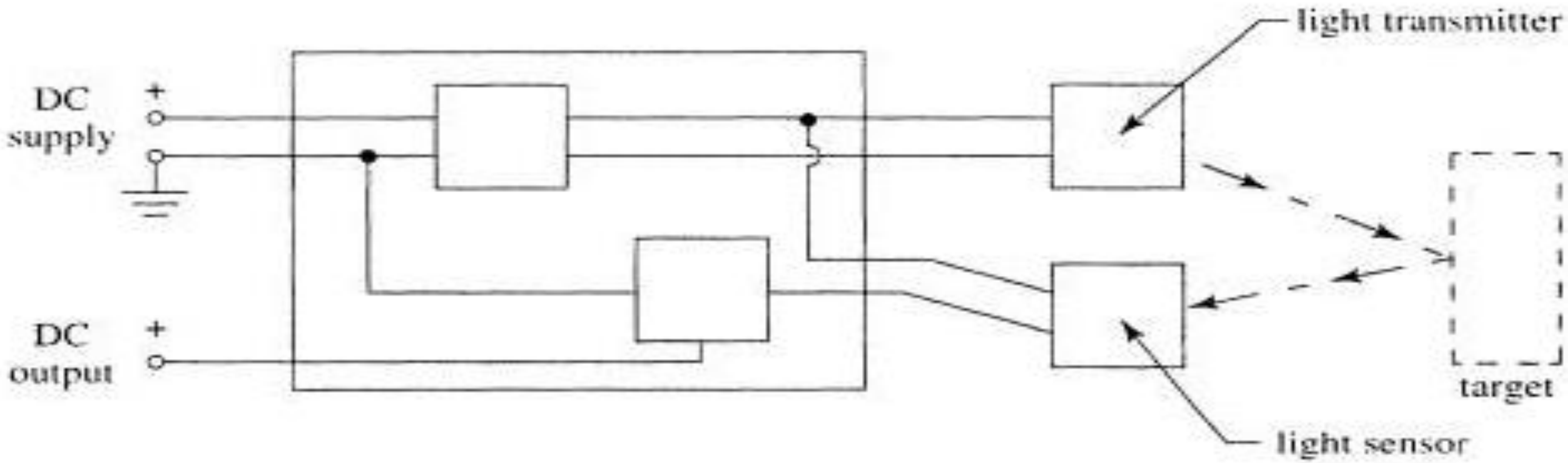


Application of Proximity sensors



Optical Proximity Sensors

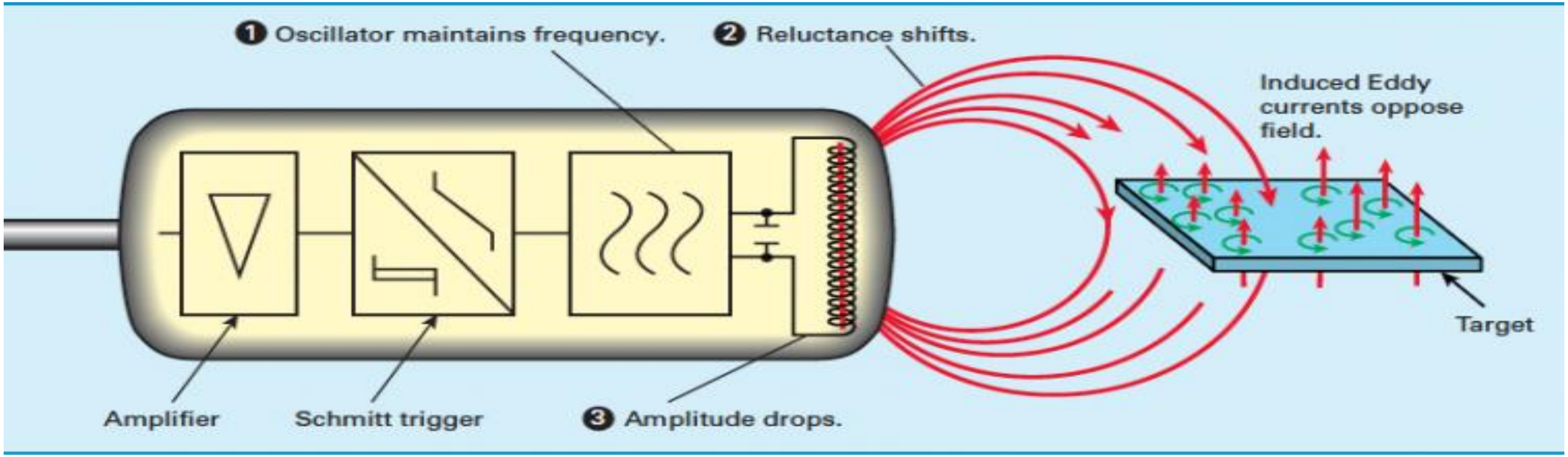




Inductive Proximity sensors

✓The ***coil generates a magnetic field*** that extends out the face of the sensor.

✓If a metal object moves into the field, ***change the reluctance of magnetic circuit system oscillation frequency, eddy currents are induced in the object***, causing the ***magnitude of the coil oscillations to be reduced.***



Inductive Proximity sensors

✓A sturdy self-contained device that can detect the presence of all metals at relatively close range (under an inch)

Advantages

1. They are very accurate compared to other technologies.

2. Have high switching rate.

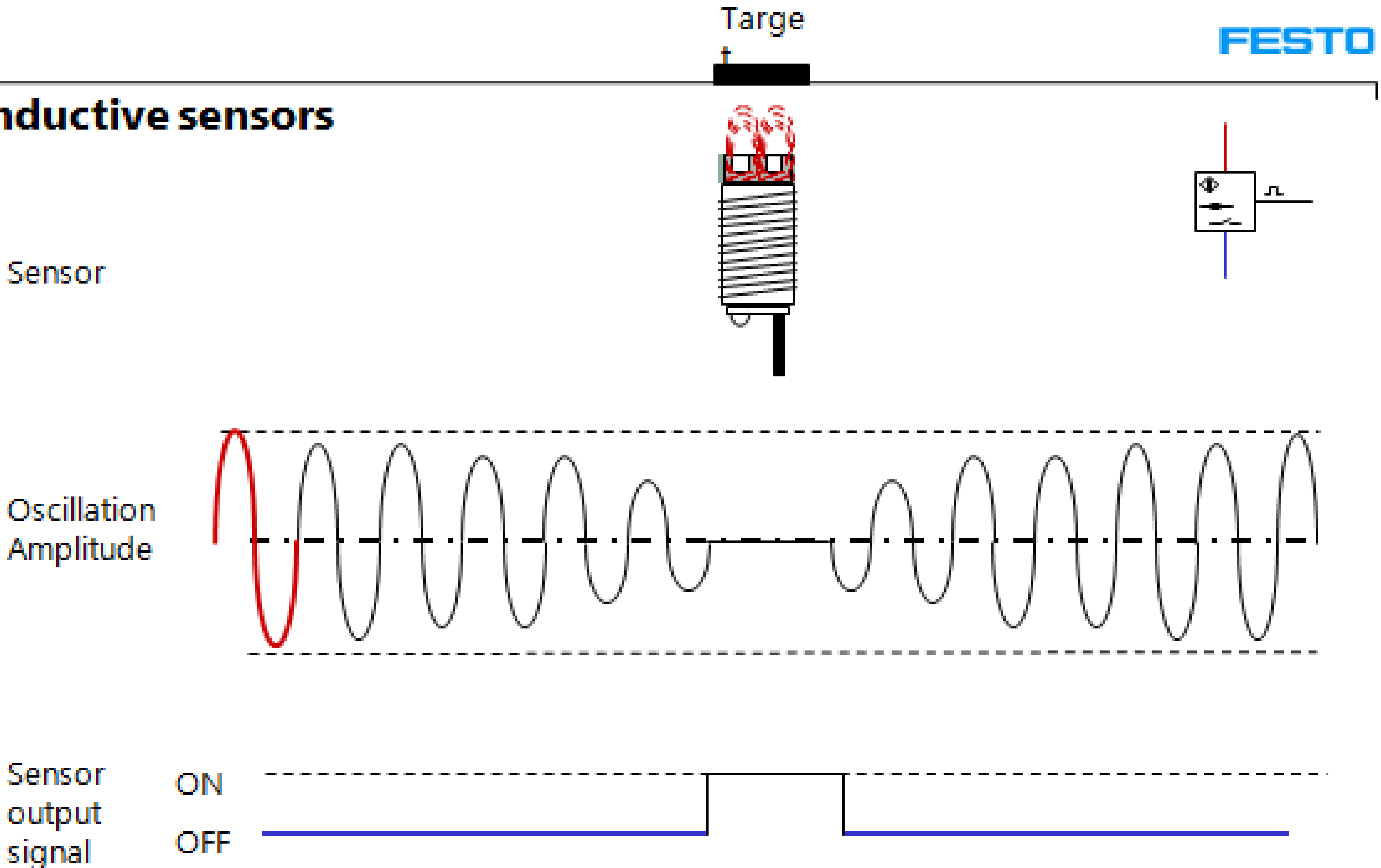
3. Can work in harsh environmental conditions.

Disadvantages

1. It can detect only metallic target.

2. Operating range may be limited.

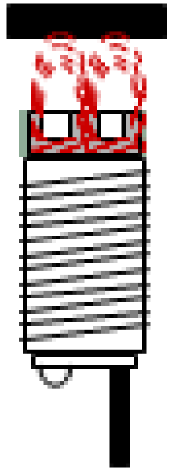
Inductive sensors

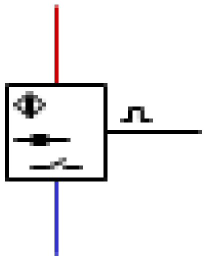


Inductive sensors

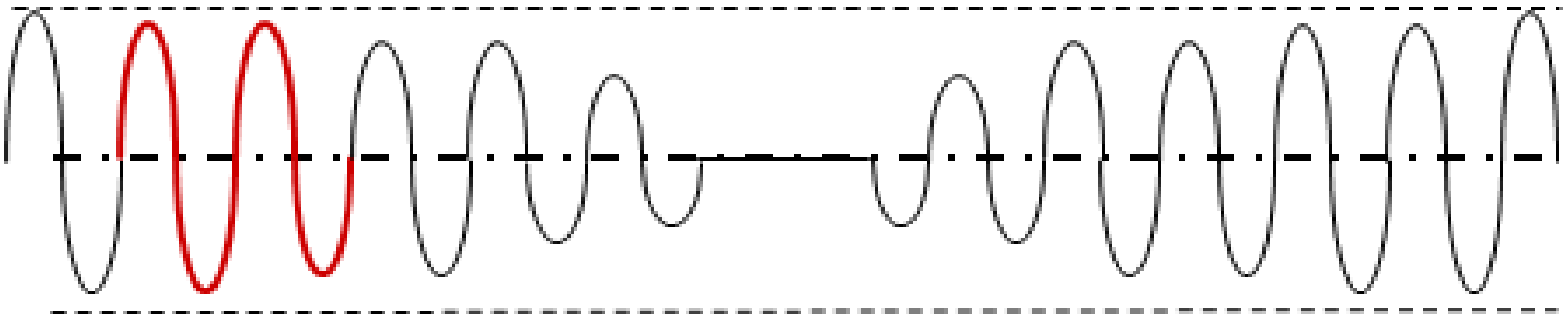
Target

Sensor





Oscillation Amplitude



Sensor output signal

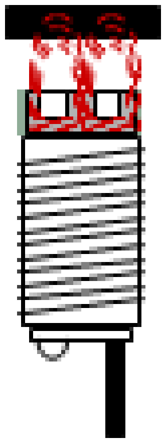
ON

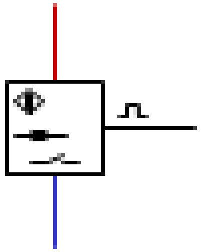
OFF

Target

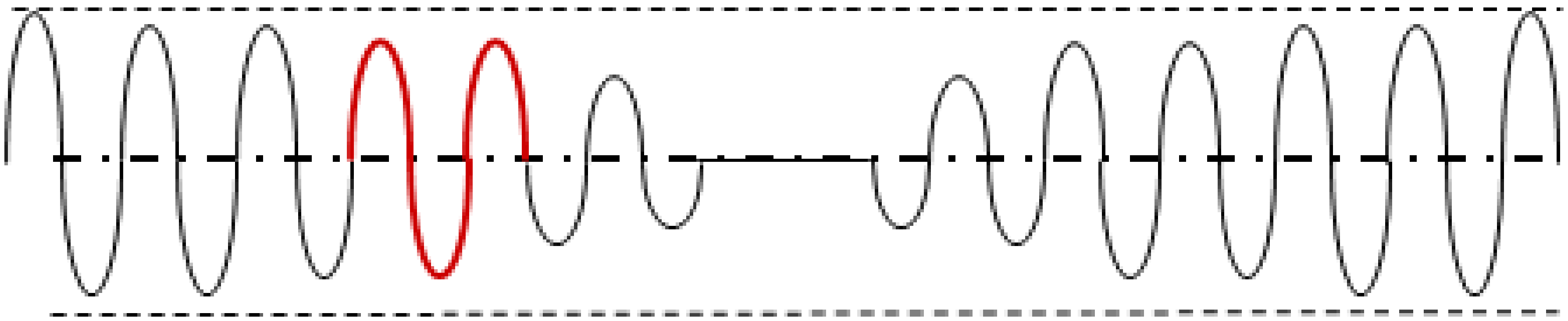
Inductive sensors

Sensor





Oscillation
Amplitude

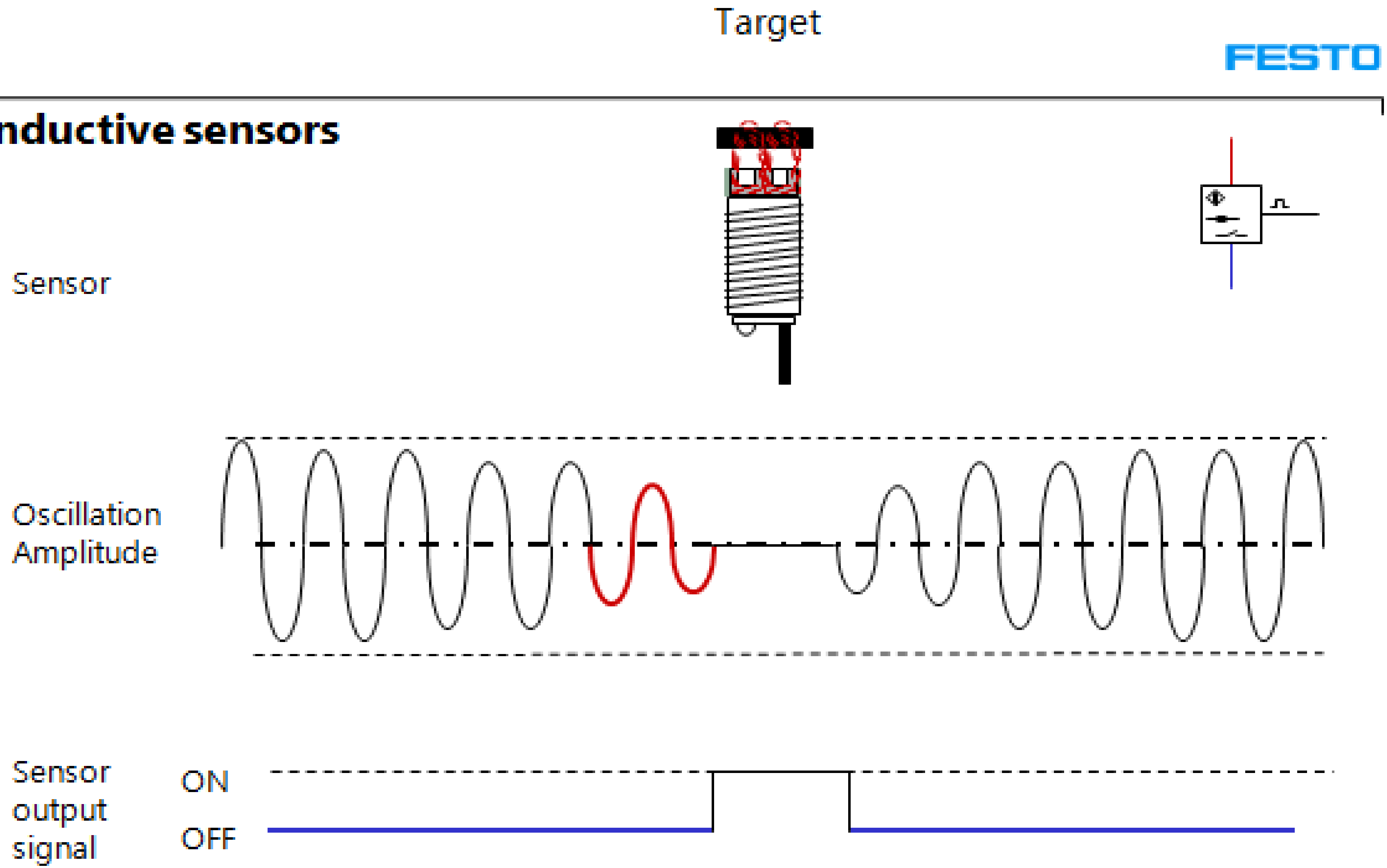


Sensor
output
signal

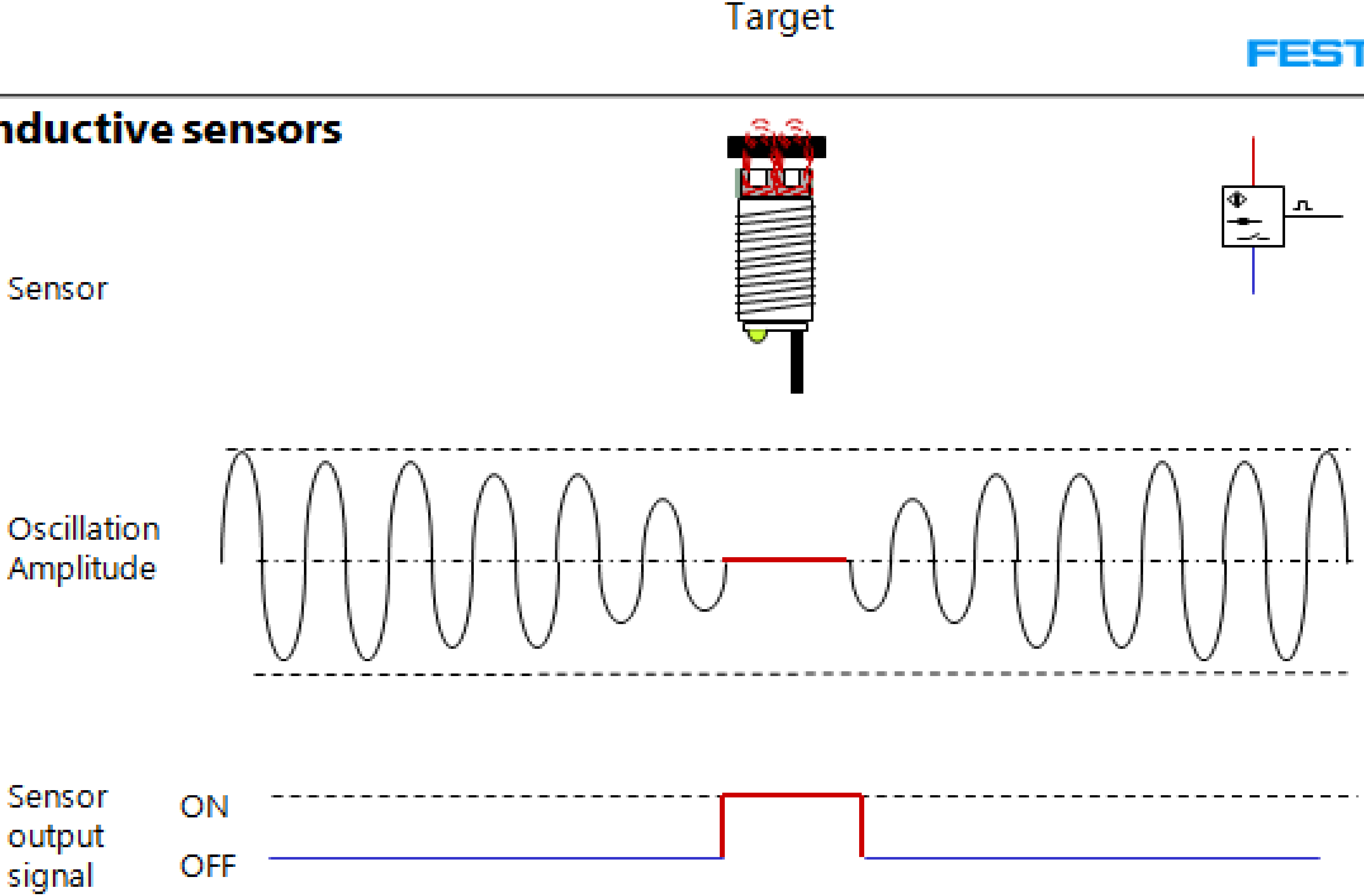
ON

OFF

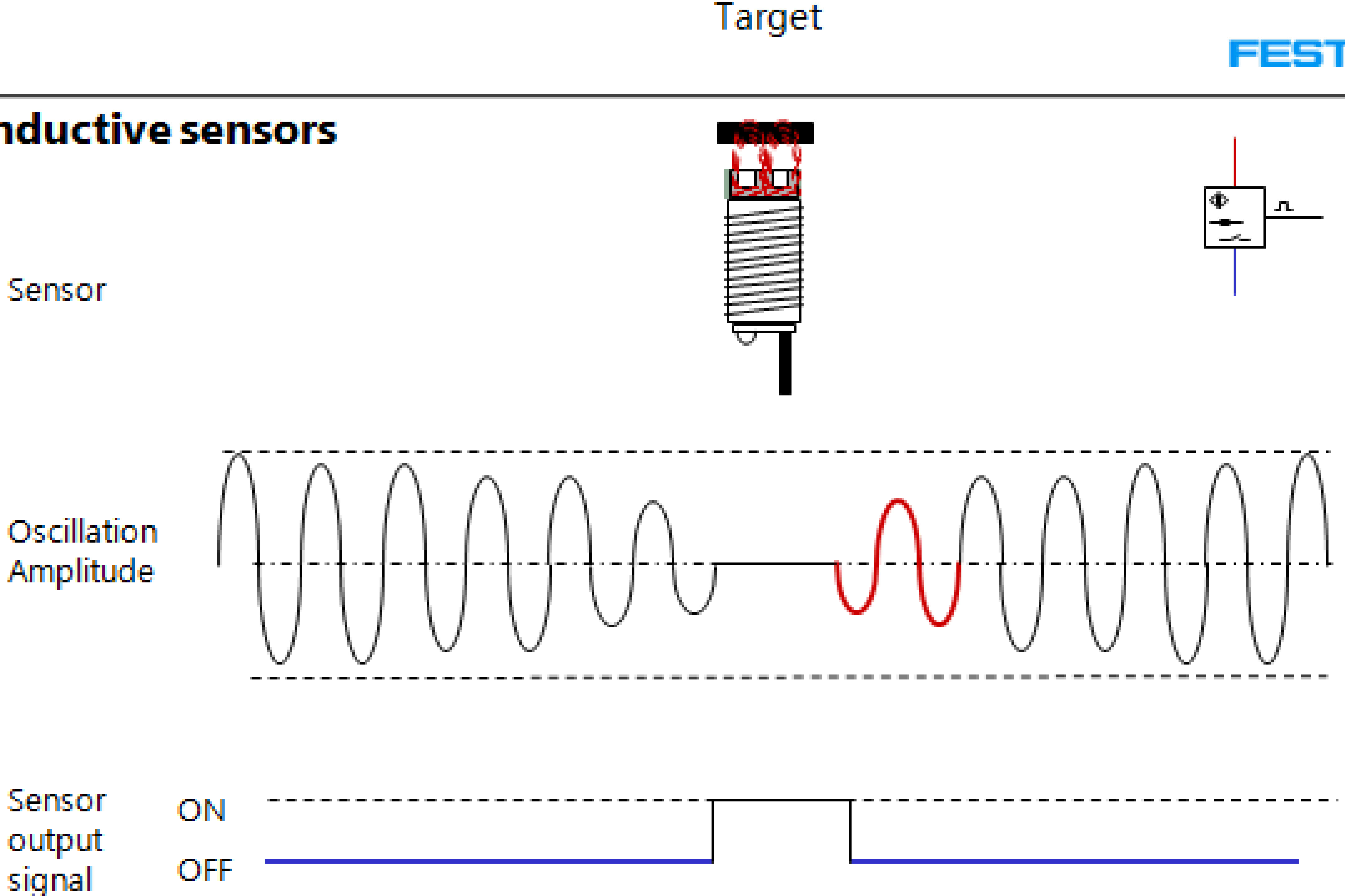
Inductive sensors



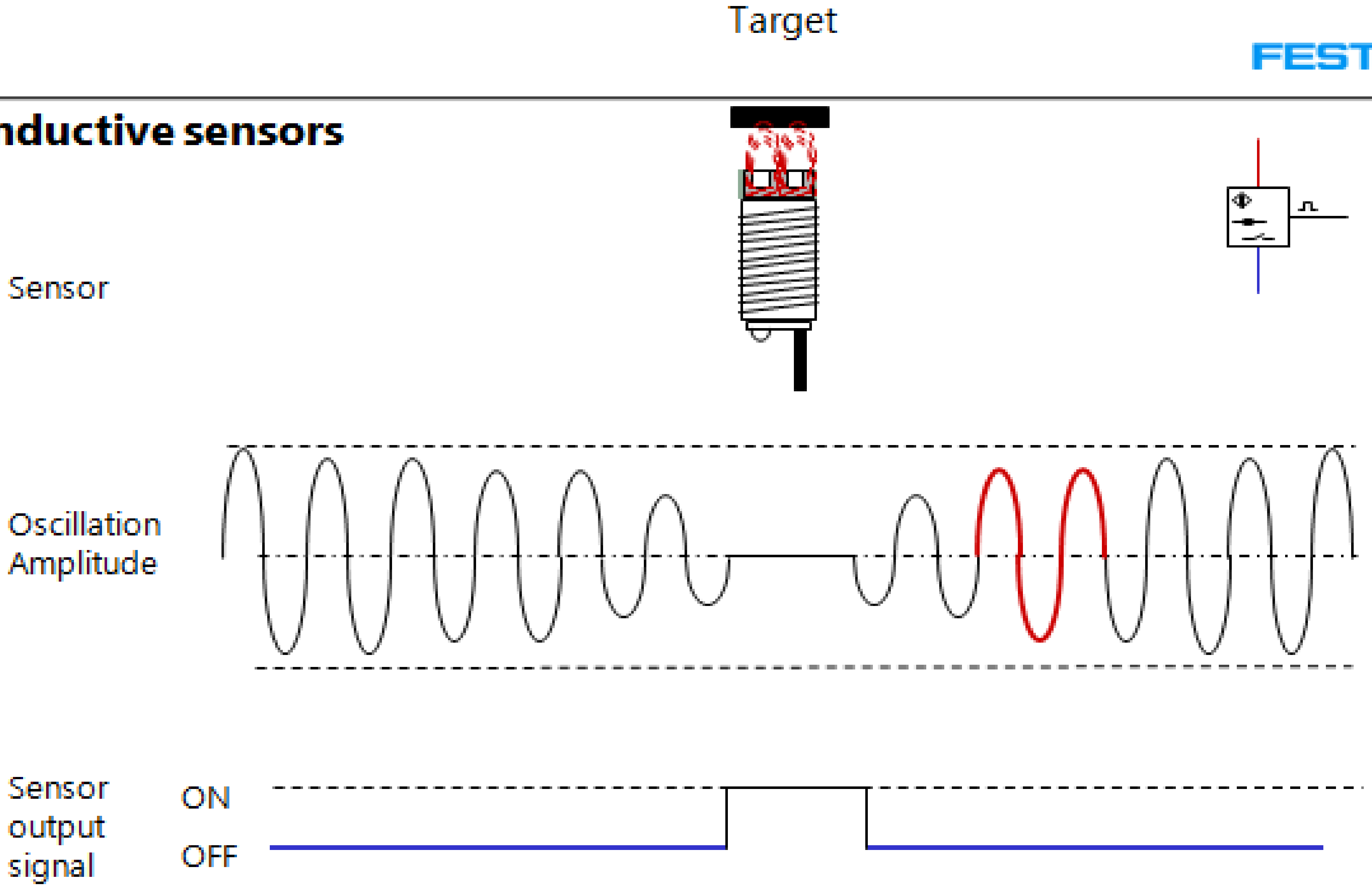
Inductive sensors



Inductive sensors



Inductive sensors

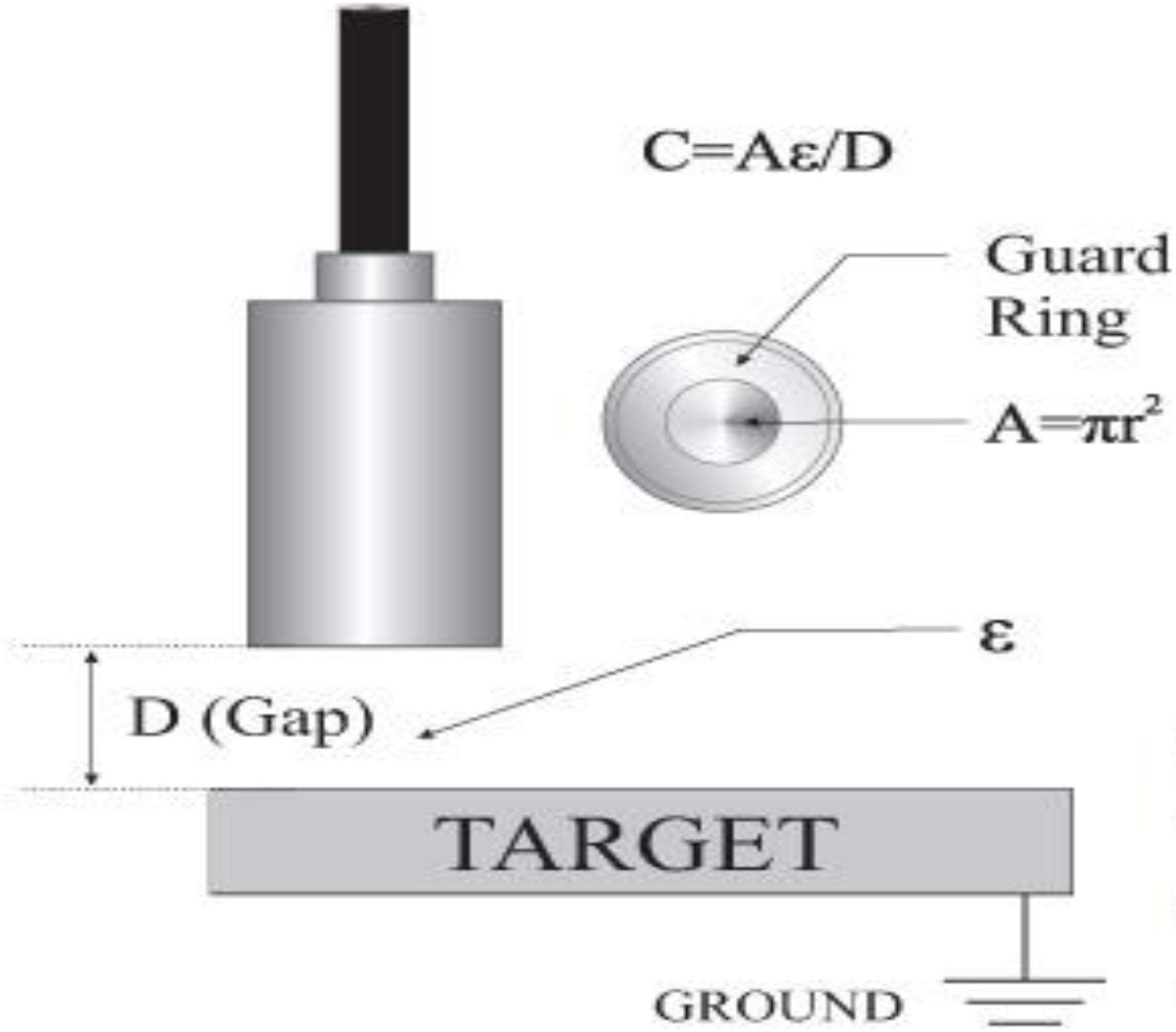


Capacitive Proximity sensors

- ✓ The ***sensing surface of the sensor's probe is the electrified plate***.
- ✓ The sensor electronics continually changes the ***voltage on the probe surface***
- ✓ The ***amount of current required change this voltage is measured*** which ***indicates the amount of capacitance distance between the probe and target***.
- ✓ Capacitive sensing is a noncontact technology suitable for detecting metals, nonmetals, solids, and liquids, although it is best suited for nonmetallic targets because of its characteristics and cost relative to inductive proximity sensors. In most applications with metallic targets, inductive sensing is preferred because it is both a reliable and a more affordable technology.

Capacitive Proximity sensors

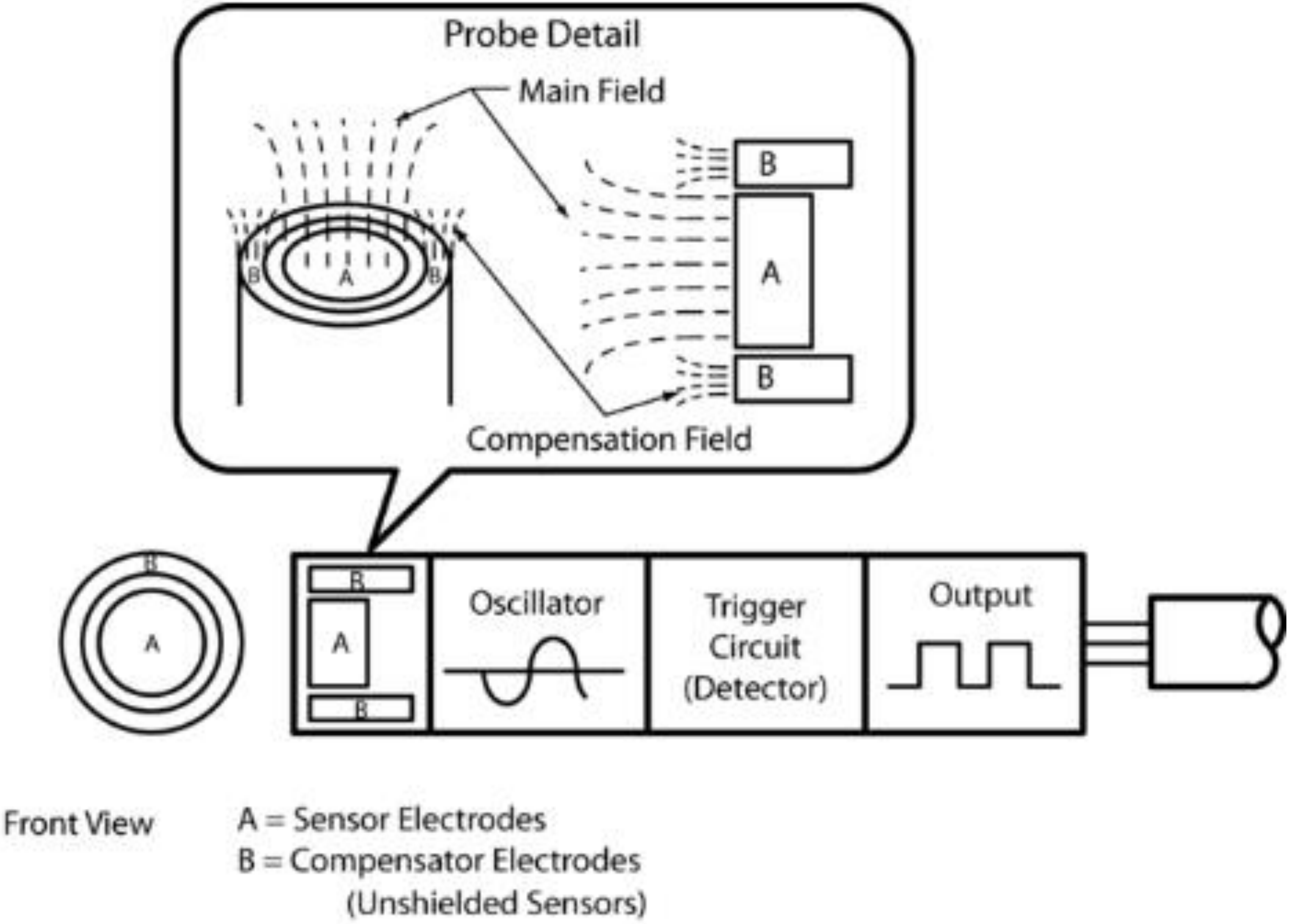
generate an electrostatic field



Dielectric Constants of Common Industrial Materials

Material	Constant	Material	Constant
Acetone	19.5	Perspex	3.2...3.5
Acrylic Resin	2.7...4.5	Petroleum	2.0...2.2
Air	1.000264	Phenol Resin	4...12
Alcohol	25.8	Polyacetal	3.6...3.7
Ammonia	15...25	Polyamide	5.0
Aniline	6.9	Polyester Resin	2.8...8.1
Aqueous Solutions	50...80	Polyethylene	2.3
Bakelite	3.6	Polypropylene	2.0...2.3
Benzene	2.3	Polystyrene	3.0
Carbon Dioxide	1.000985	Polyvinyl Chloride Resin	2.8...3.1
Carbon Tetrachloride	2.2	Porcelain	4.4...7

Where:
C=Capacitance
ε= Dielectric constant of the gap medium, typically air
D= Gap distance between the probe and grounded target
A= Probe sensing area



Capacitive sensor components

Working-

✓Capacitive proximity sensors are similar in size, shape, and concept to inductive proximity sensors. However, unlike inductive sensors which use induced magnetic fields to sense objects, capacitive proximity generate an electrostatic field and reacts to changes in capacitance caused when a target enters the electrostatic field.

✓When the target is outside the electrostatic field, the oscillator is inactive. As the target approaches, a capacitive coupling develops between the target and the capacitive probe.

✓When the capacitance reaches a specified threshold, the oscillator is activated, triggering the output circuit to switch states between ON and OFF

✓The ability of the sensor to detect the target is determined by the target's size, dielectric constant and distance from the sensor.

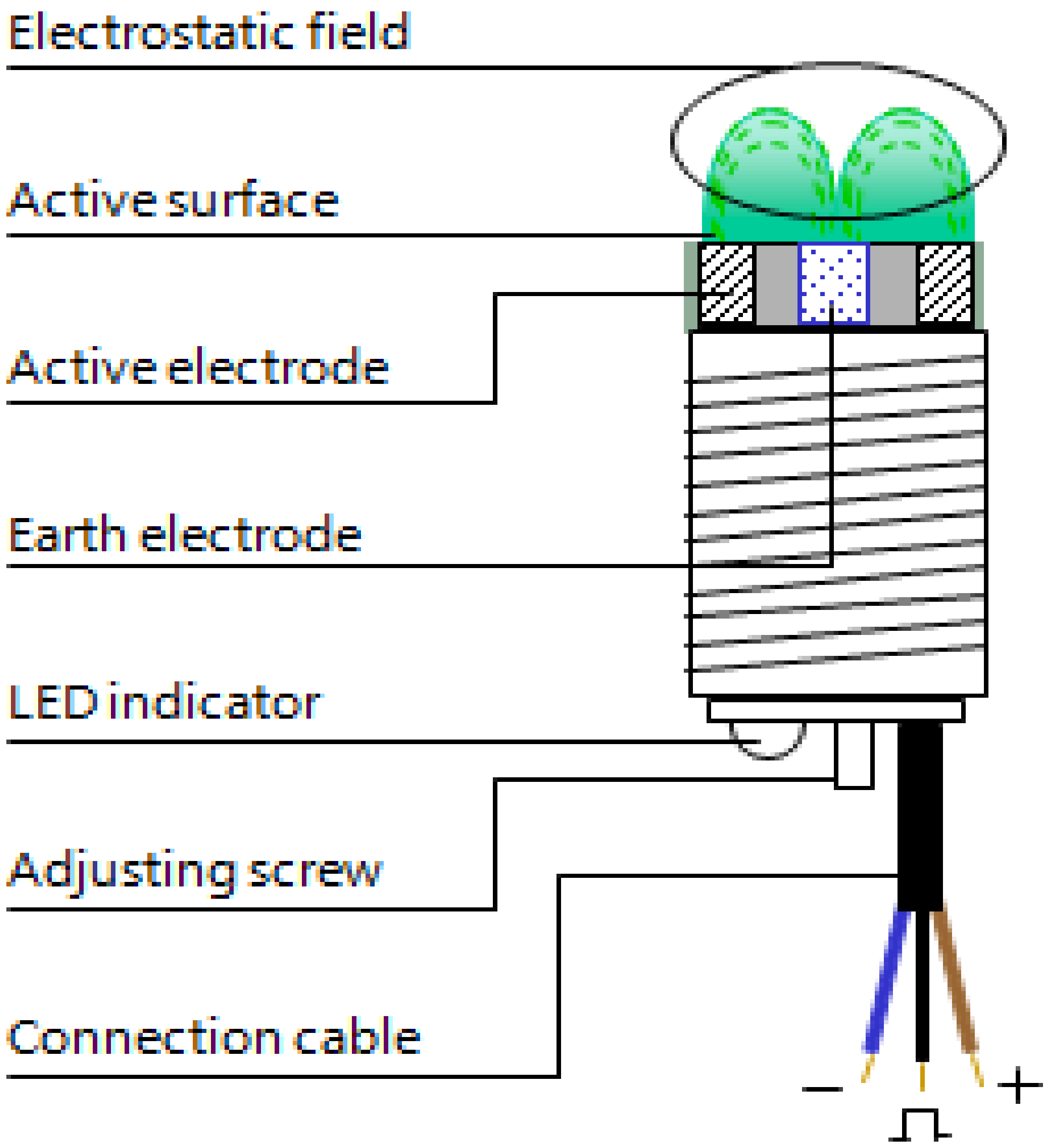
✓The larger the target's size, the stronger the capacitive coupling between the probe and the target.

✓Materials with higher dielectric constants are easier to detect than those with lower values.

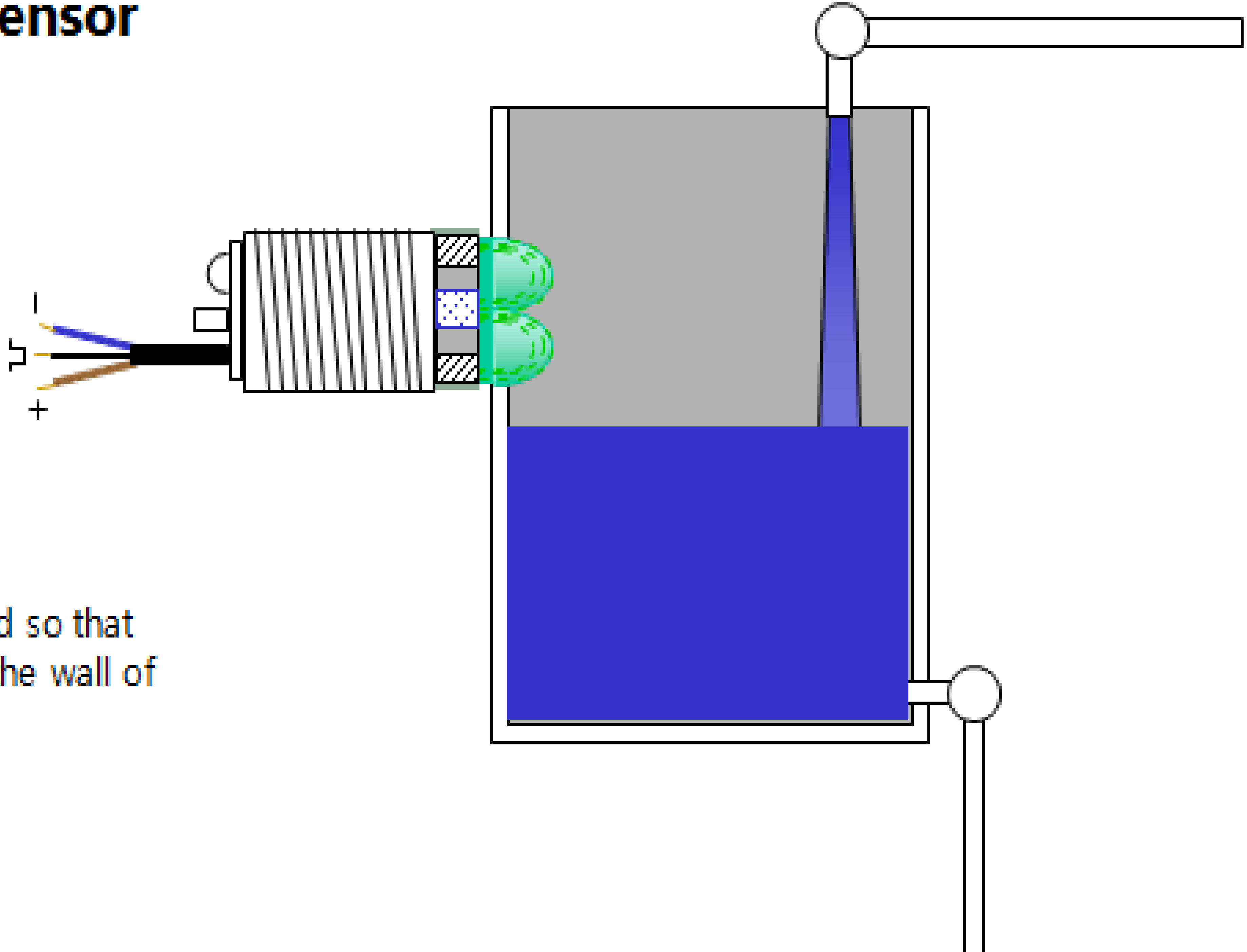
✓The shorter the distance between target and probe, the stronger the capacitive coupling between the probe and the target.

Capacitive sensor

Sensor is looking for a change in capacitance in the active field

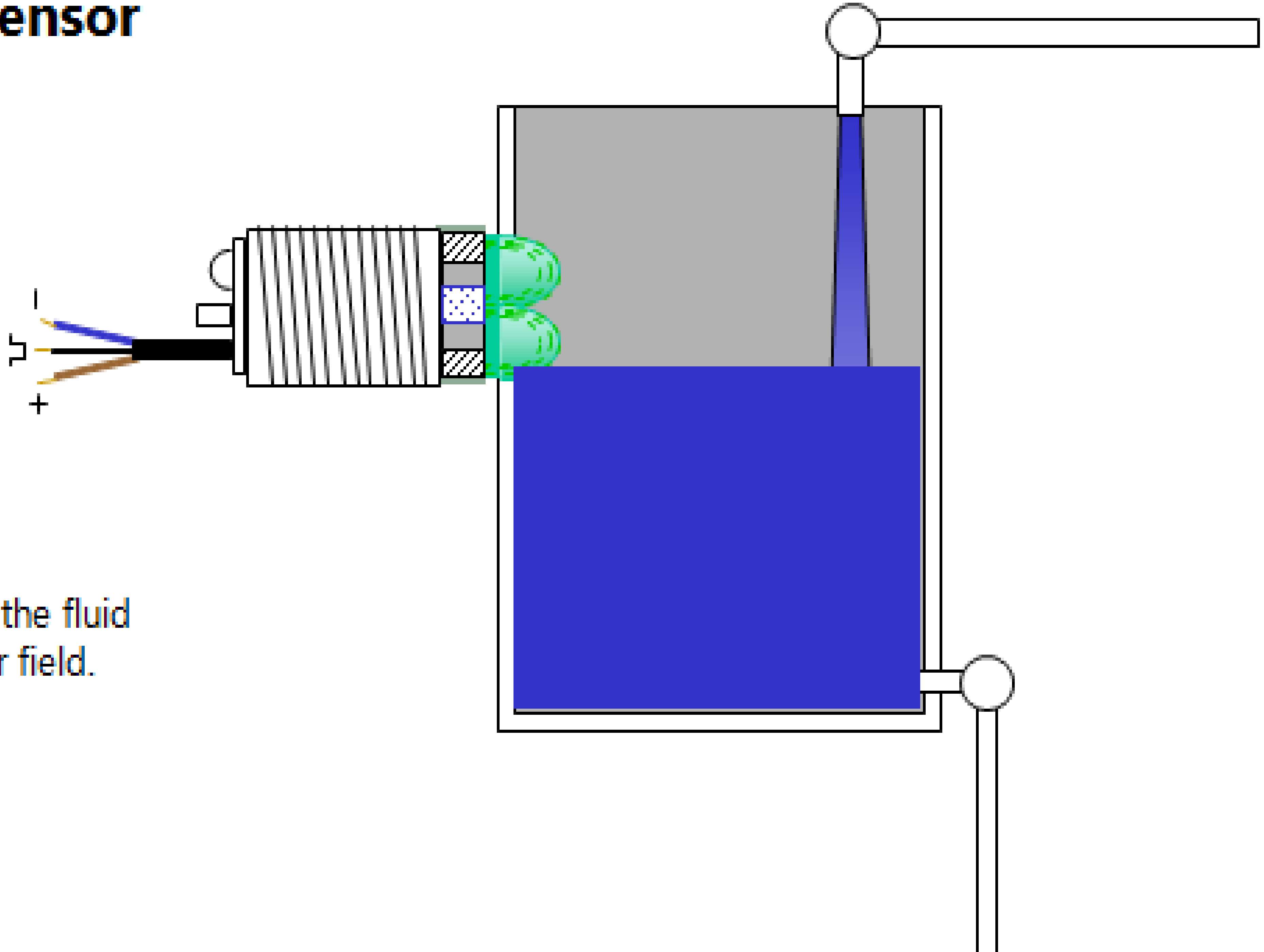


Capacitive sensor



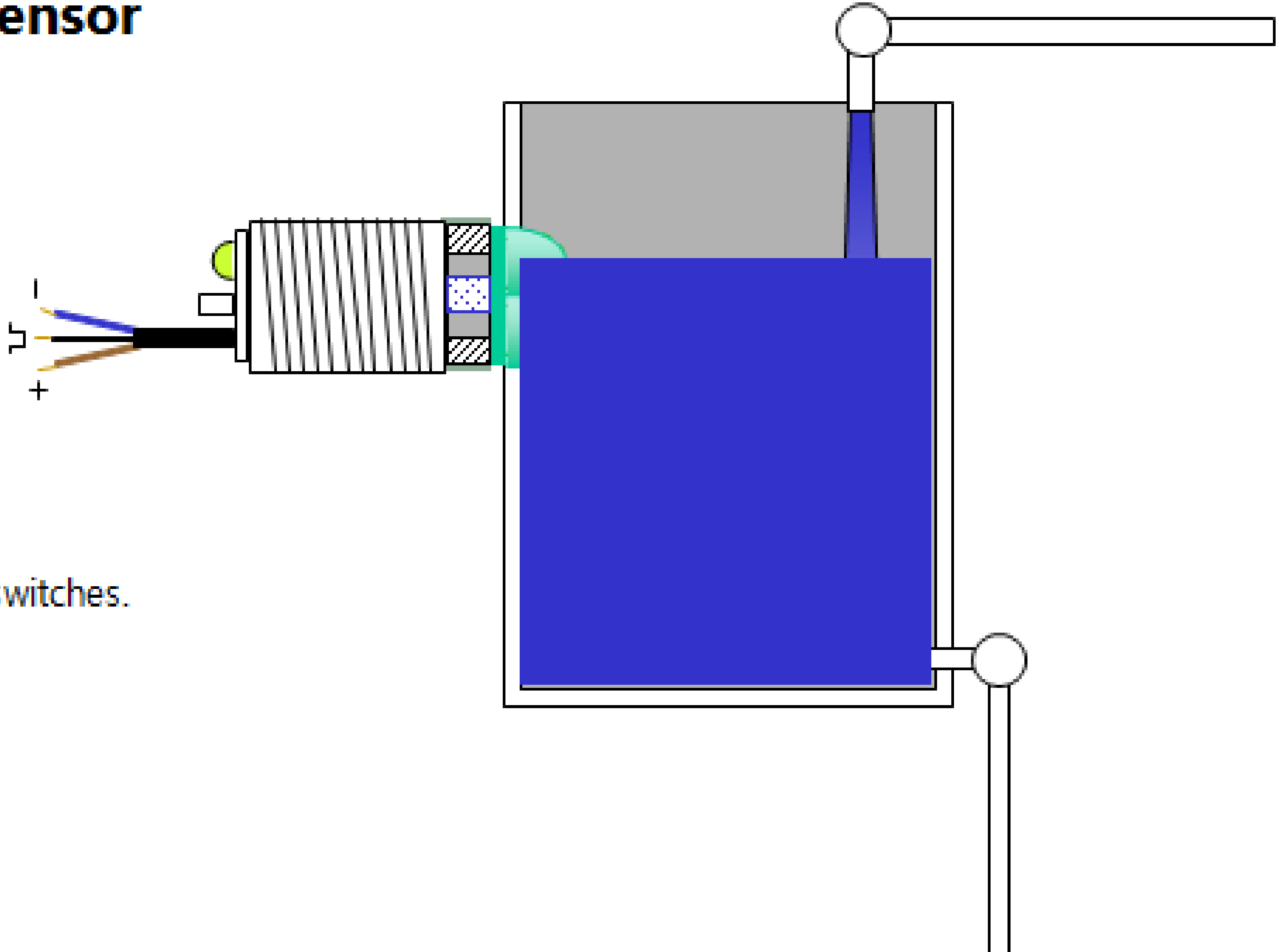
Sensor is adjusted so that it does not 'see' the wall of the vessel.

Capacitive sensor



As the level rises the fluid affects the sensor field.

Capacitive sensor



Until the sensor switches.

Advantages

1. Detects metal and nonmetal, liquids and solids
2. Can “see through” certain materials (product boxes)
3. Solid-state, long life
4. Many mounting configurations

Disadvantages

1. Short (1 inch or less) sensing distance varies widely according to material being sensed
2. Very sensitive to environmental factors — humidity in coastal/water climates can affect sensing output
3. Not at all selective for its target — control of what comes close to the sensor is essential

Typical Applications-

1. Liquid level sensing

Sensing through a sight glass to watch liquid level, such as batter for food processing or ink for printing applications

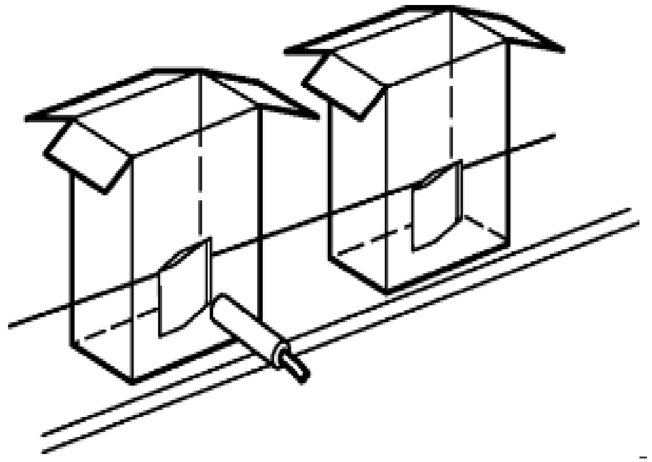
Insertion through sealed tubes into drums or holding tanks for chemicals or aqueous solutions

2. Product filling lines

Bottling applications, such as shampoo

Full-case detection to ensure that a container has the required number of products

Checking material levels, such as cereal in boxes



Product sensing through packaging

3. Plastic parts detection

Plastics on product packages, such as spouts on laundry detergent boxes

Plastic materials within a hopper

4. Pallet detection for materials handling

5. Irregularly shaped products

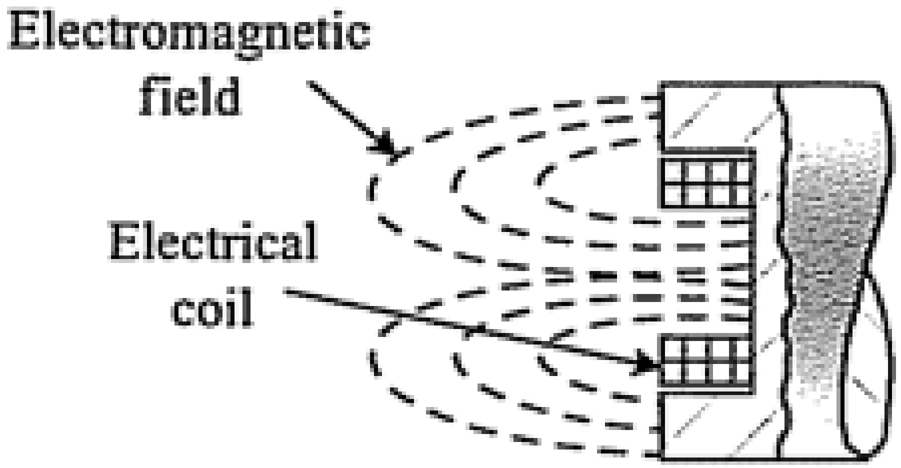
Objects randomly oriented on conveyor belt

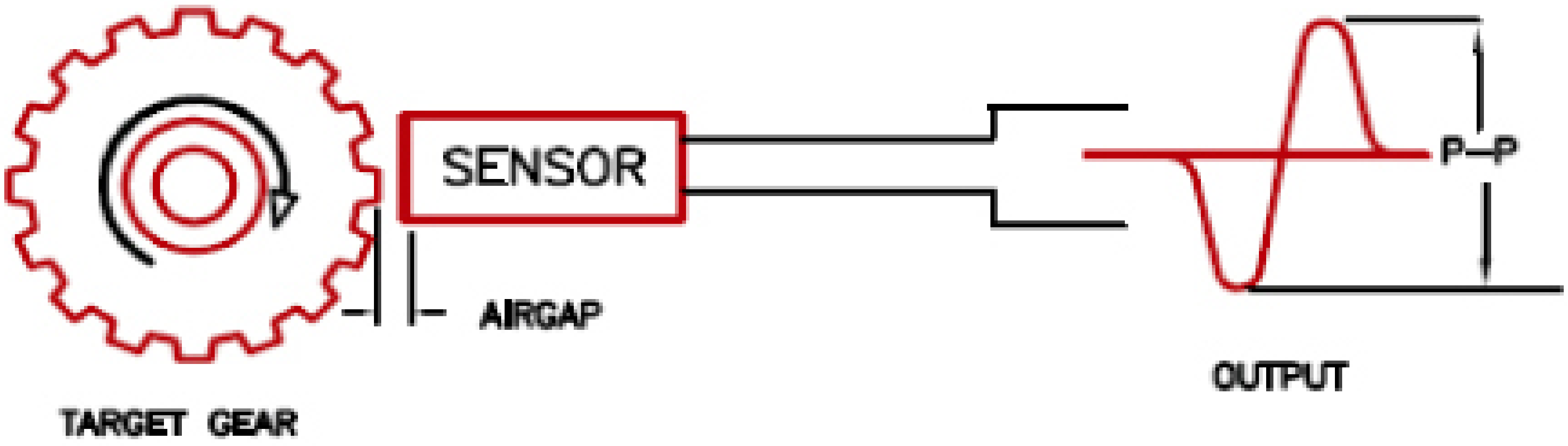
Highly textured objects

1. Motion Sensors- Variable Reluctance

- ✓ ***A magnet in the sensor creates a magnetic field***

- ✓ As a ***ferrous object moves*** by the sensor, the ***resulting change in the magnetic flux induces an emf in the pickup coil***





Working-

- ✓In its simplest form, a VR sensor consists of a ***coil of wire wound around a permanent-magnet armature.***
- ✓The target of the sensor is typically a gear or other toothed ring made from ferrous materials.
- ✓As the ring rotates in front of the sensor, ***the teeth concentrate the magnetic flux when they align with the magnetic poles***, but let the ***flux expand outward when the poles are over a gap between the teeth.***
- ✓ The ***change in flux density created by the change of reluctance at the poles induces an electrical voltage in the coil,*** creating the output from the sensor.

Reluctance- ***the ability of a material to pass a magnetic field, and is often likened to resistance in an electrical circuit.***

Ferrous materials possess a low reluctance as they help concentrate magnetic fields that easily pass through them.

Mathematically, the equation for reluctance looks much like Ohm's Law:

$$R = mmf/\Phi$$

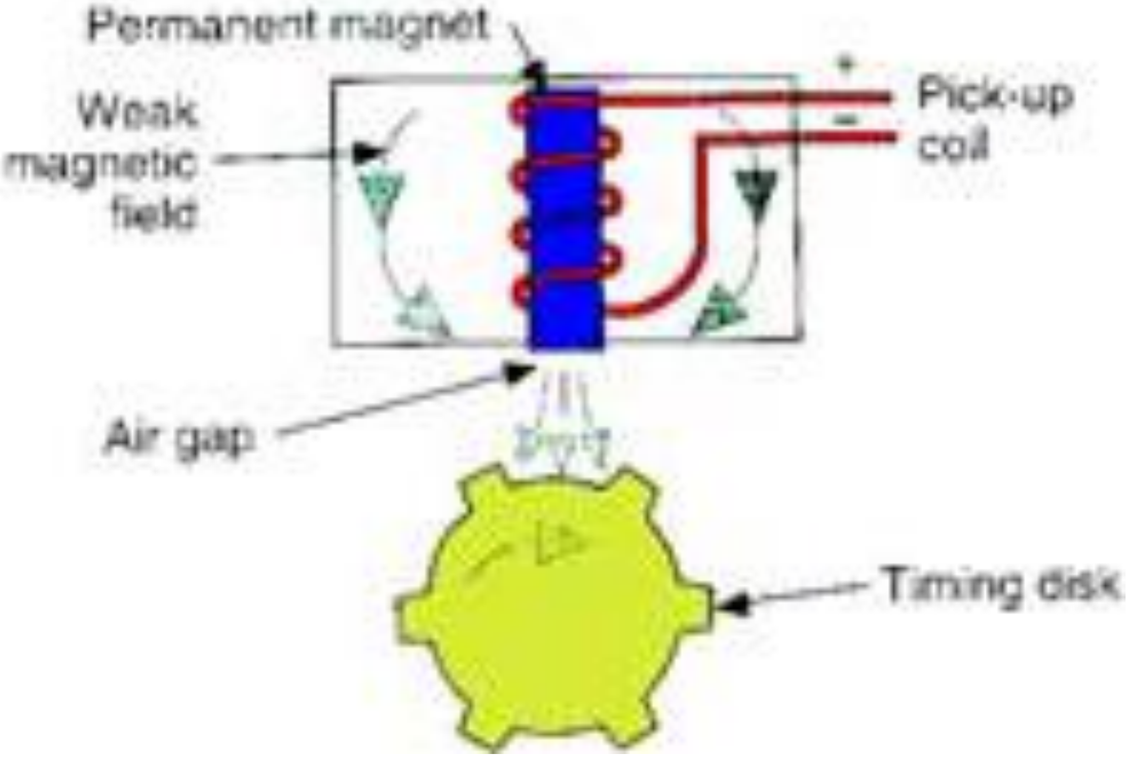
where R = value of reluctance,

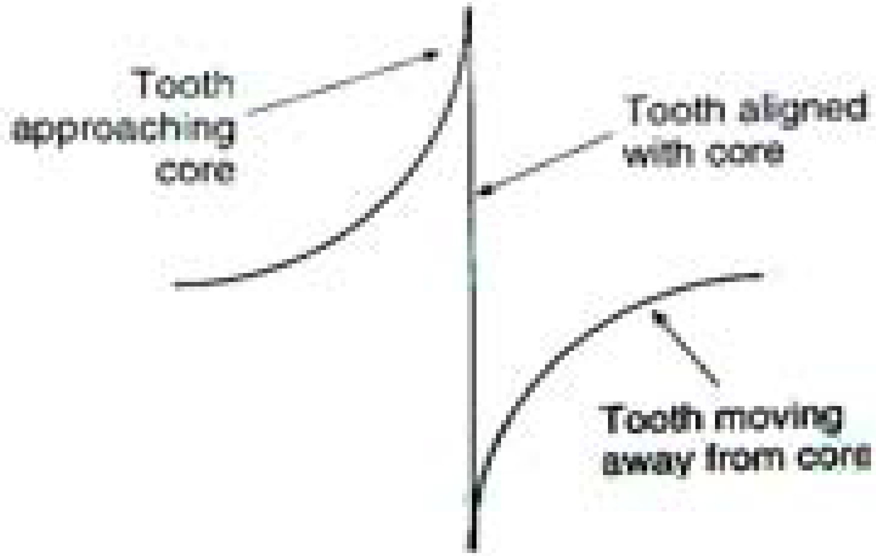
mmf = magnetomotive force in ampere-turns, and

Φ = intensity of the magnetic field in Webers.

✓**The frequency of the output is controlled by the speed of rotation and the number of teeth in the target.**

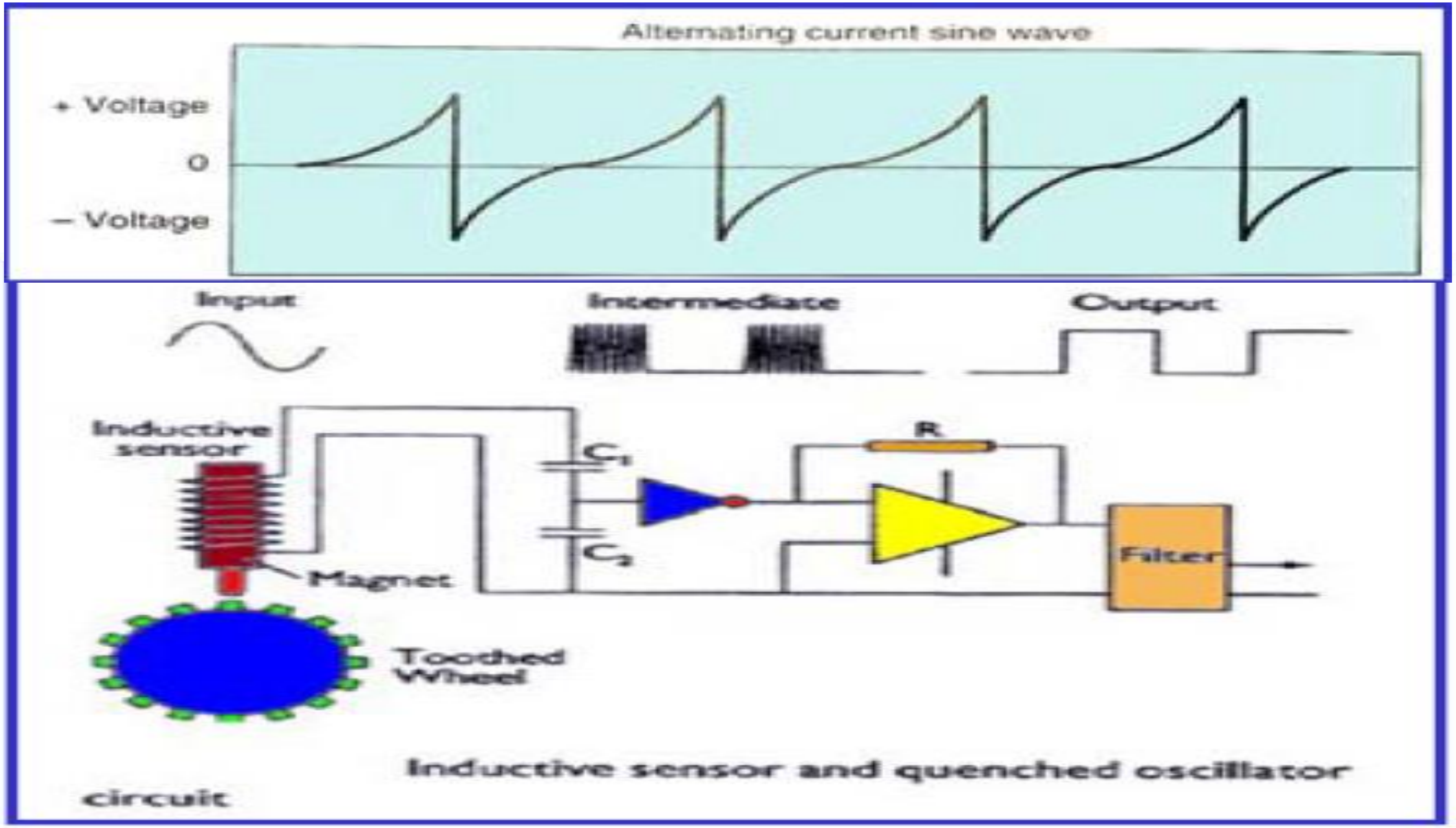
For example, a 100-tooth gear turning at 1,800 rpm generates an output frequency of 3,000 Hz.


Permanent magnet
Weak magnetic field
Pick-up coil
Air gap
Timing disk


Tooth approaching core
Tooth aligned with core
Tooth moving away from core

A common method of converting this signal into a useful signal for interfacing with other digital circuit is by using a ***Schmitt trigger circuit***.

• Another method is by using a ***quenched oscillator circuit*** as shown in the figure. This circuit has good resistance to interference



Inductive sensor and quenched oscillator circuit

Applications

- ***Used to measure speed and/or position of a moving metallic object***
- A VR sensor used as a simple proximity sensor ***can determine the position of a mechanical link in a piece of industrial equipment***.
- ***A Crankshaft position sensor*** (in an automobile engine) is used to provide the ***angular position of the crankshaft*** to the Engine control unit. ***The Engine control unit can then calculate engine speed*** (angular velocity).
- The ***Engine control unit or Transmission control unit*** (depending on the particular automobile) uses these sensors ***to determine when to shift from one gear to the next.***

Temperature measurement

1. ***EMF based***

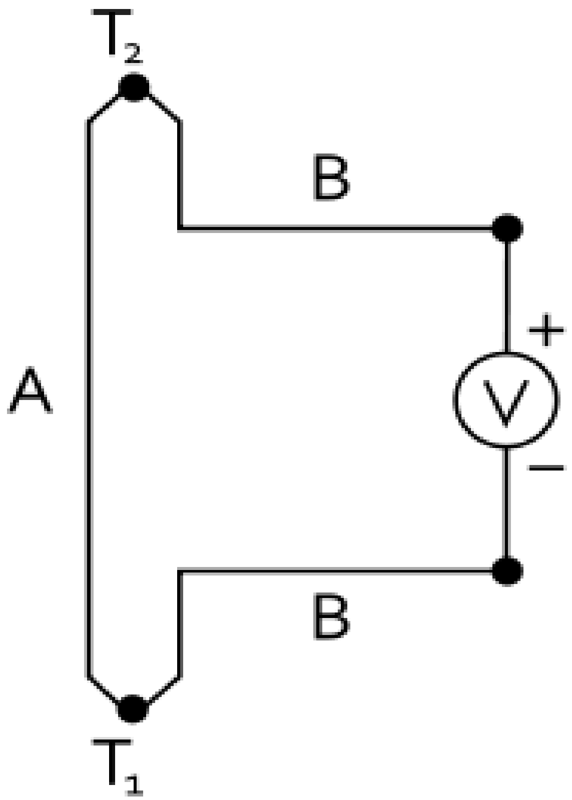
eg- Thermocouple

2. ***Resistance based***

eg- Resistance Temperature Detectors (RTD)

Thermocouples

- Based on the **<u>Seebeck effect</u>** – a phenomenon whereby a voltage that is almost proportional to temperature can be produced from a circuit consisting of two dissimilar metal wires
- The junctions at each end of the dissimilar metal wires produce a voltage
- One junction is called the hot junction (the junction on the probe) and the other junction is the cold junction (kept at some known reference temperature
- ***The actual difference between the junction voltages is known as Vnet, which is essentially the output voltage of this system.***



$$V_{net} = V_{hot} - V_{cold}$$

A thermocouple made from iron and constantan (an alloy) generates a voltage of approximately 35μV/°F

Construction of Thermocouples

- ✓At the tip of a ***grounded junction*** probe, the thermocouple wires are physically attached to the inside of the probe wall. This results in good heat transfer from the outside, through the probe wall to the thermocouple junction.

- ✓In an ***ungrounded probe*,** the thermocouple junction is detached from the probe wall. Response time is slower than the grounded style, but the ungrounded offers electrical isolation

- ✓The thermocouple in the ***exposed junction*** style protrudes out of the tip of the sheath and is exposed to the surrounding environment. This type offers the best response time, but is limited in use to dry, non-

Selection of Thermocouples

The following criteria are used in selecting a thermocouple:

- Temperature range
- Chemical resistance of the thermocouple or sheath material
- Abrasion and vibration resistance
- Installation requirements (may need to be compatible with existing equipment; existing holes may determine probe diameter)

Types of Thermocouple

- **Type B** – very poor below 50°C; reference junction temperature not important since voltage output is about the same from 0 to 42 °C

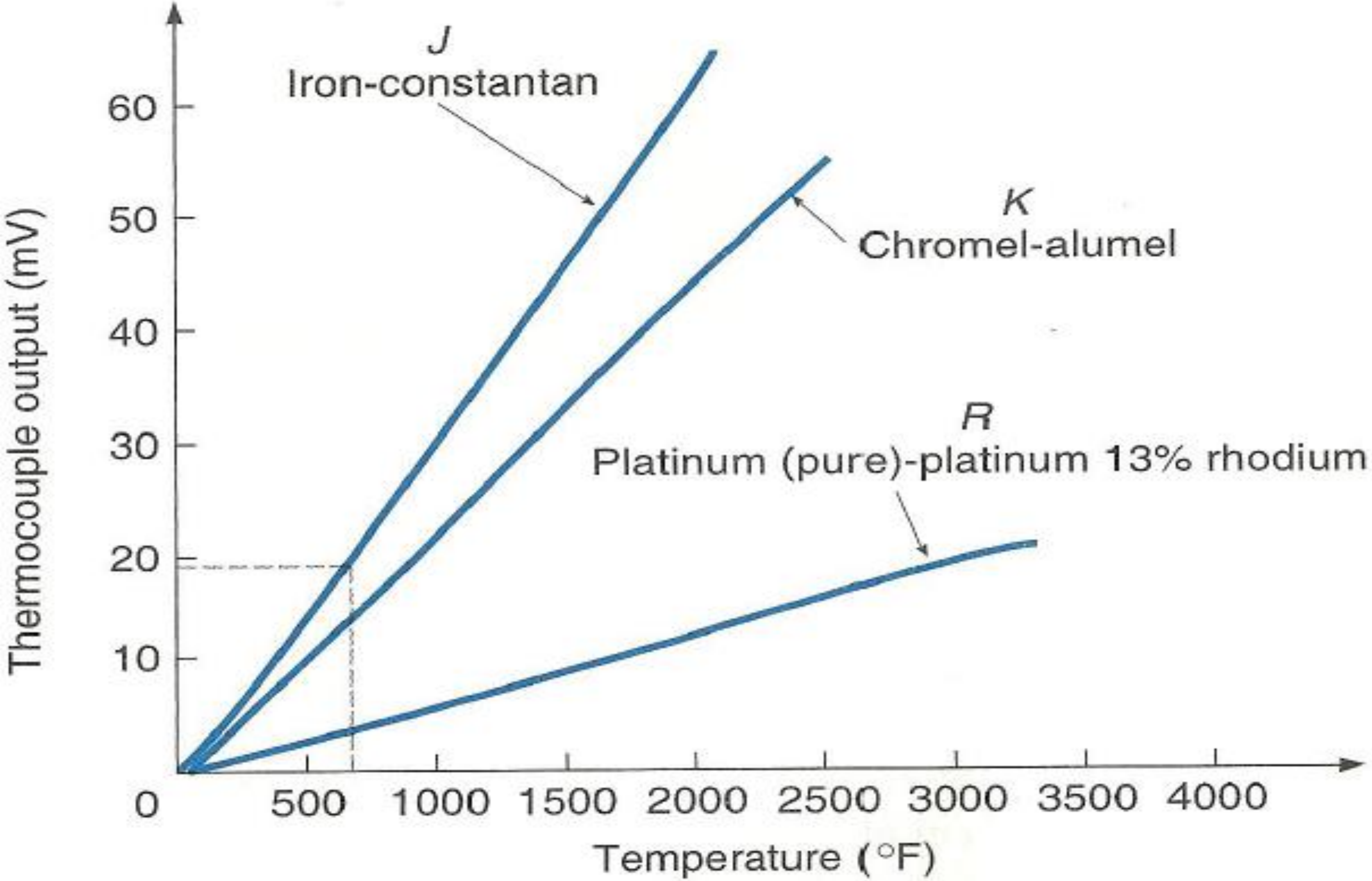
- **Type E** – good for low temperatures since dV/dT is high for low Temperatures

- **Type J** – cheap because one wire is iron; high sensitivity but also high uncertainty (iron impurities cause inaccuracy)

- **Type T** – good accuracy but low max temperature (400 °C); one lead is copper, making connections easier; watch for heat being conducted along the copper wire, changing your surface temp

- **Type K** – popular type since it has decent accuracy and a wide temperature range; some instability (drift) over time

- **Type N** – most stable over time when exposed to elevated temperatures for long periods


J
Iron-constantan
K
Chromel-alumel
R
Platinum (pure)-platinum 13% rhodium
Thermocouple output (mV)
60
50
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
Temperature (°F)

Properties of Thermocouple:

1 The temp and e.m.f relation should be linear and reproducible

2 It should be strong for withstand high temp.

4 It should maintain its calibration without drift for long period of time.

5 Cost should be reasonable

6 It should have long life

Advantages of Thermocouple:

1. Better response
2. Higher range of temp .measurements
3. Sensing element can be easily installed
4. Cheap
5. Very convenient for measuring the temp. at one particular point in a piece of appratus.

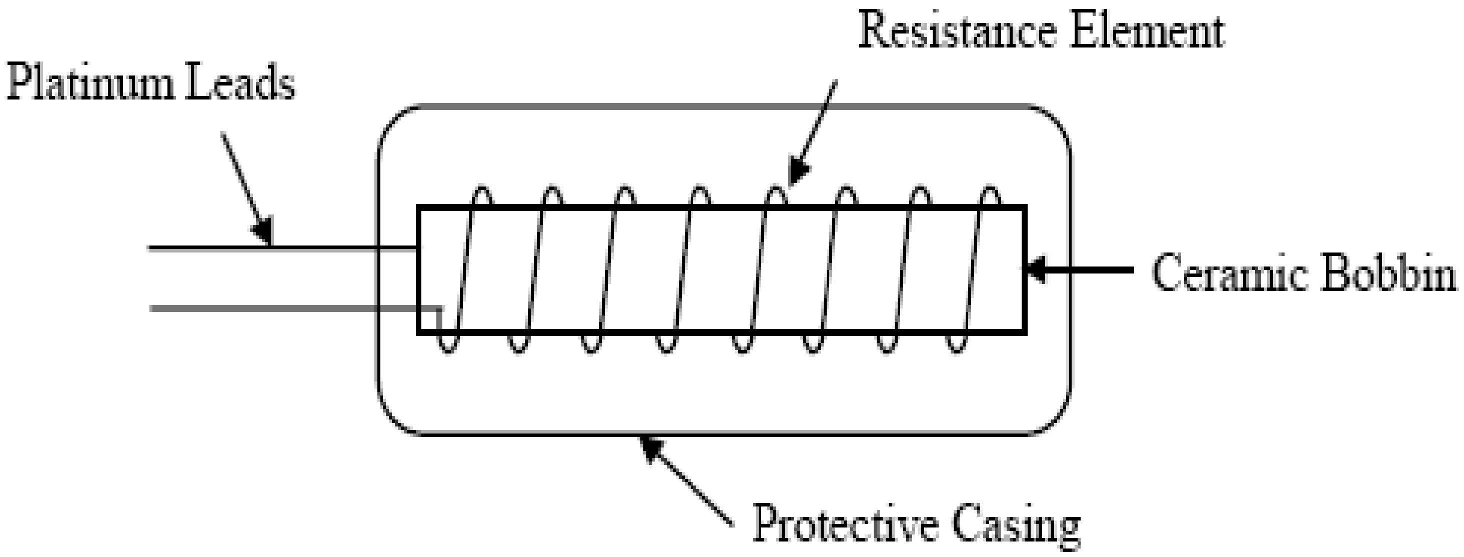
Disadvantages of Thermocouple:

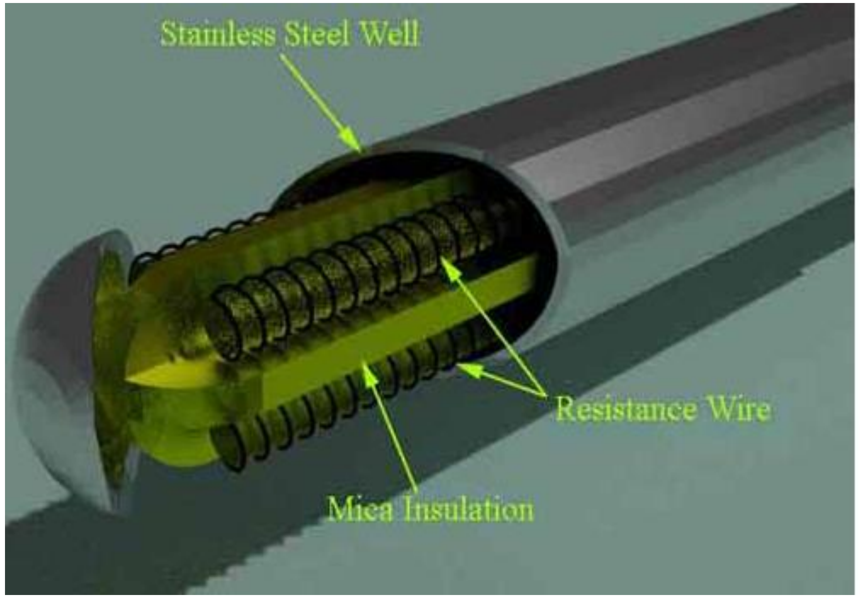
1. Low accuracy
2. Circuit is very complex
3. For long life they need to be amply protected.

Resistance Temperature Detectors (RTD)

✓The *RTD*s use the phenomenon that the ***resistance of a metal changes with temperature.*** They are, however, linear over a wide range and most stable.

✓Typically***, a wire (usually a platinum wire) is wrapped around a ceramic or glass rod***





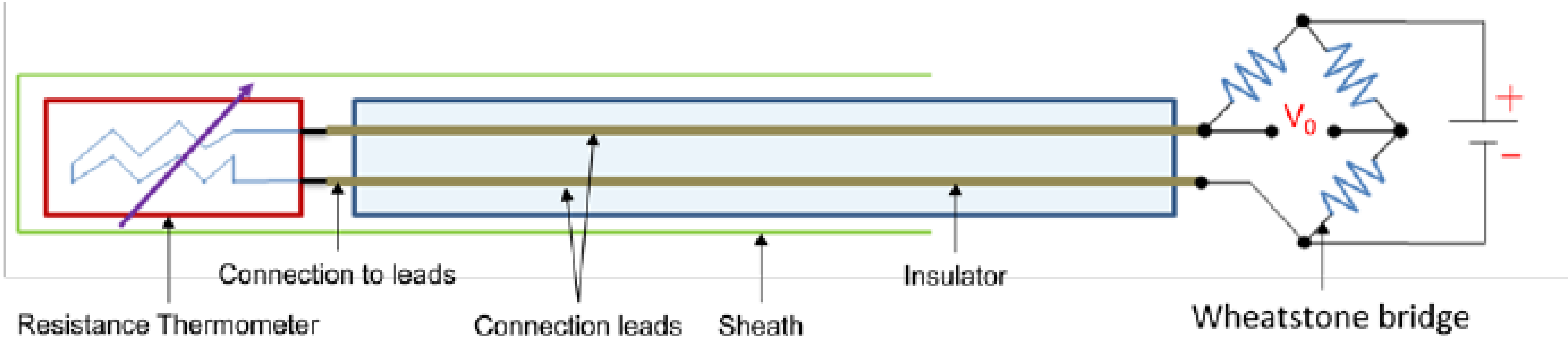


Figure 2.5.3 Construction of a Resistance temperature detector (RTD)

Construction of Resistance Temperature Detector or RTD

✓The construction is typically such that the wire is wound on a form (in a coil) on notched mica cross frame to achieve small size, improving the thermal conductivity to decrease the response time and a high rate of heat transfer is obtained.

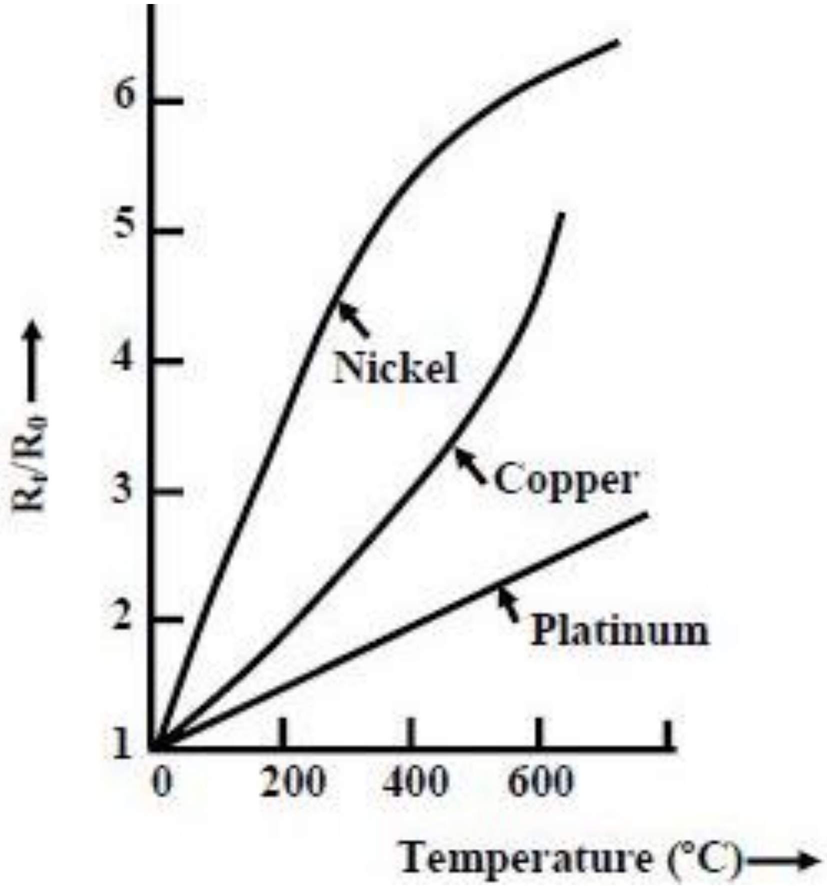
✓ In the industrial RTD's, the coil is protected by a stainless steel sheath or a protective tube. So that, the physical strain is negligible as the wire expands and increase the length of wire with the temperature change.

✓ If the strain on the wire is increasing, then the tension increases. Due to that, the resistance of the wire will change which is undesirable.So, we don't want to change the resistance of wire by any other unwanted changes except the temperature changes. This is also useful to RTD maintenance while the plant is in operation.

✓Mica is placed in between the steel sheath and resistance wire for better electrical insulation. Due less strain in resistance wire, it should be carefully wound over mica sheet

The relationship between temperature and resistance of conductors in the temperature range near 0°C can be calculated from the equation:

$$\boxed{R_t = R_0(1+\alpha\Delta t)}$$



Rt=the resistance of the conductor at temperature t (°C)

R_0 = the resistance at the reference temperature, usually 20°C

α = the temperature coefficient of resistance

ΔT = the difference between the operating and the reference temperature

✓***Platinum wire has a temperature coefficient of 0.0039 Ω/Ω/°C, which means that the resistance goes up 0.0039 Ω for <u>each ohm</u> of wire for each Celsius degree of temperature rise***

✓Therefore, a 100-platinum RTD has a resistance of 100 Ω at 0°C, and it has a positive temperature coefficient of 0.39 Ω/°C

Advantages of platinum as RTD

1. The temperature-resistance characteristics of pure platinum are stable over a wide range of temperatures.
2. It has high resistance to chemical attack and contamination
3. It forms the most easily reproducible type of temperature transducer with a high degree of accuracy .
4. It can have accuracy ± 0.01 ^{o}C up to 500 ^{o}C and ± 0.1 ^{o}C up to 1200 ^{o}C.
5. Linearity over a wide operating range

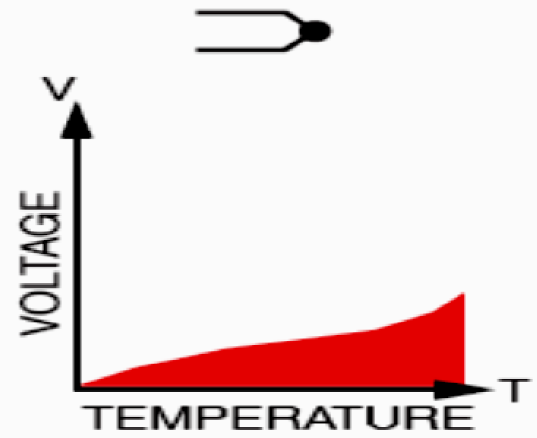
Limitations of RTD

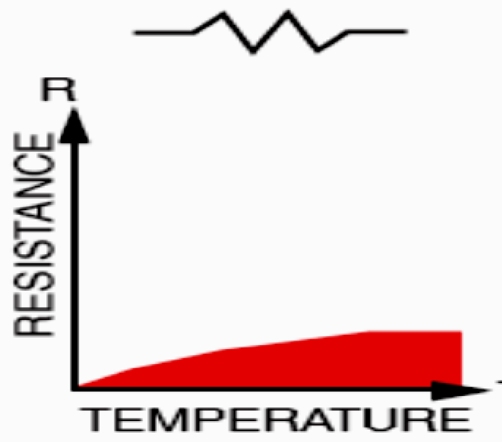
1. These are resistive devices, and accordingly they function by passing a current through a sensor.
2. Even though only a very small current is generally employed, it creates a certain amount of heat and thus can throw off the temperature reading.
3. This self heating in resistive sensors can be significant when dealing with a still fluid (i.e., one that is neither flowing nor agitated), because there is less carry-off of the heat generated.
4. This problem does not arise with thermocouples, which are essentially zero-current devices.
5. Low sensitivity
6. It can be affected by contact resistance, shock and vibration
7. No point sensing
8. Higher cost than other temperature transducers
9. Requires 3 or 4 wire for its operation and associated instrumentation to eliminate errors due to lead resistance

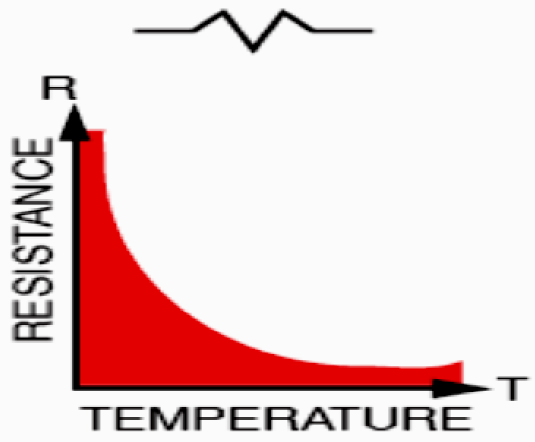
Applications of Resistance Temperature Detectors

1. Air conditioning and refrigeration servicing
2. Food Processing
3. Stoves and grills
4. Textile production
5. Plastics processing
6. Petrochemical processing
7. Micro electronics
8. Air, gas and liquid temperature measurement
9. Exhaust gas temperature measurement

Comparison

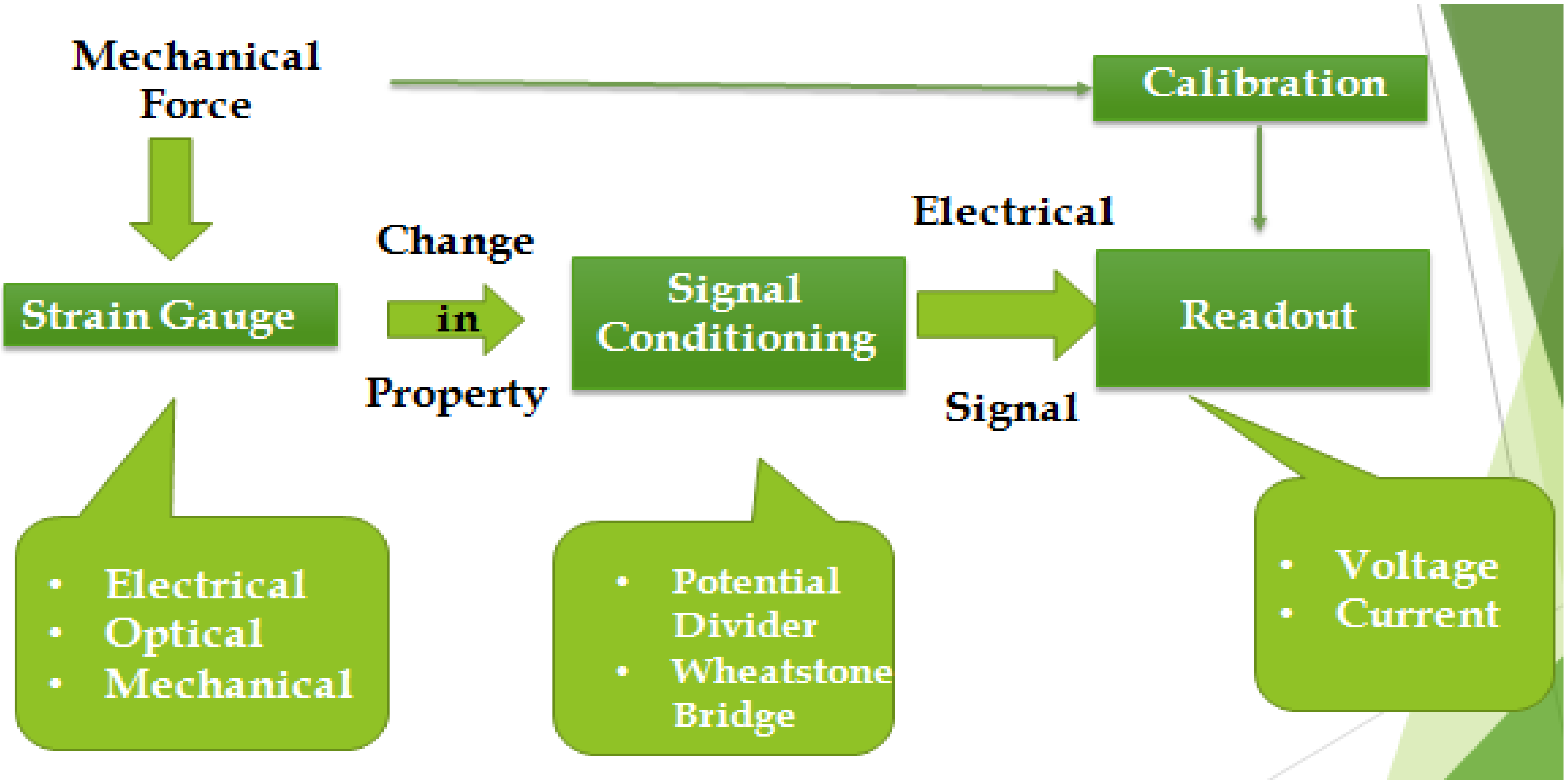






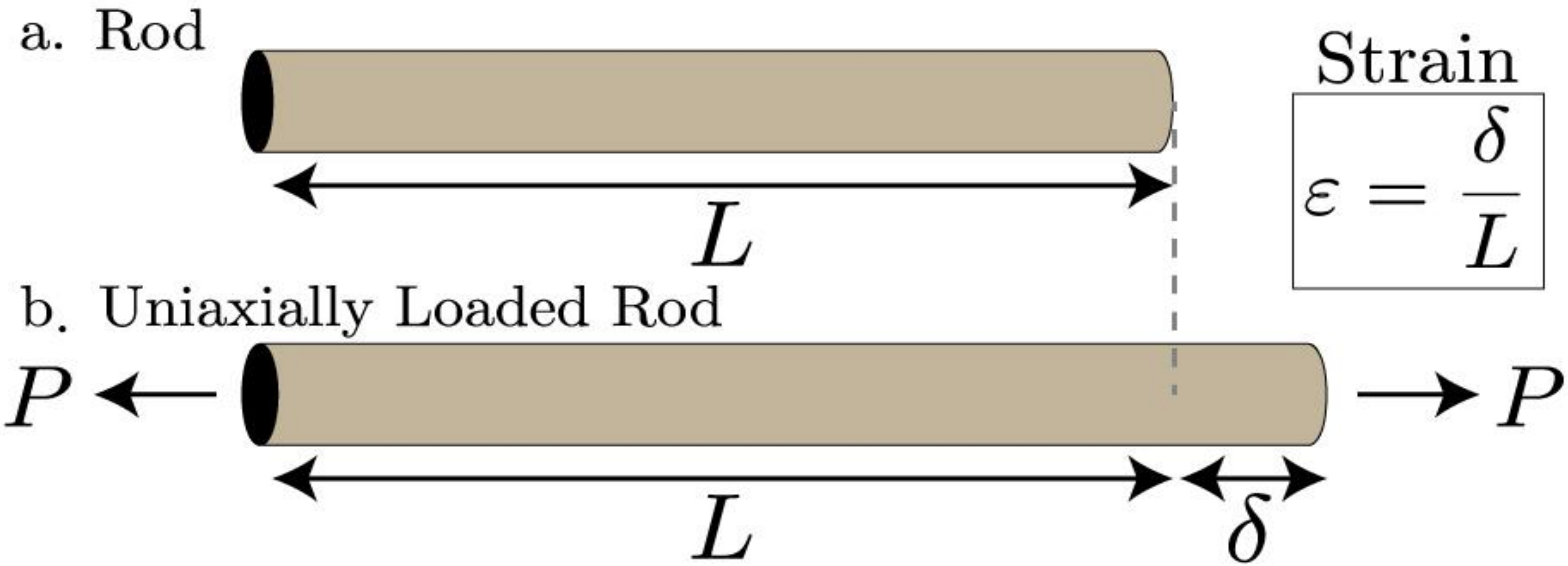
	Thermocouple	RTD	Thermistor
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small Δ R ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating

Force/Pressure Sensor



Force/Pressure Sensor

- ✓Stress measurement ***using strain***
- ✓Strain is change in length (dl) per unit length (l)
- ✓Strain gauge is primary sensing element used in pressure, force and position sensors

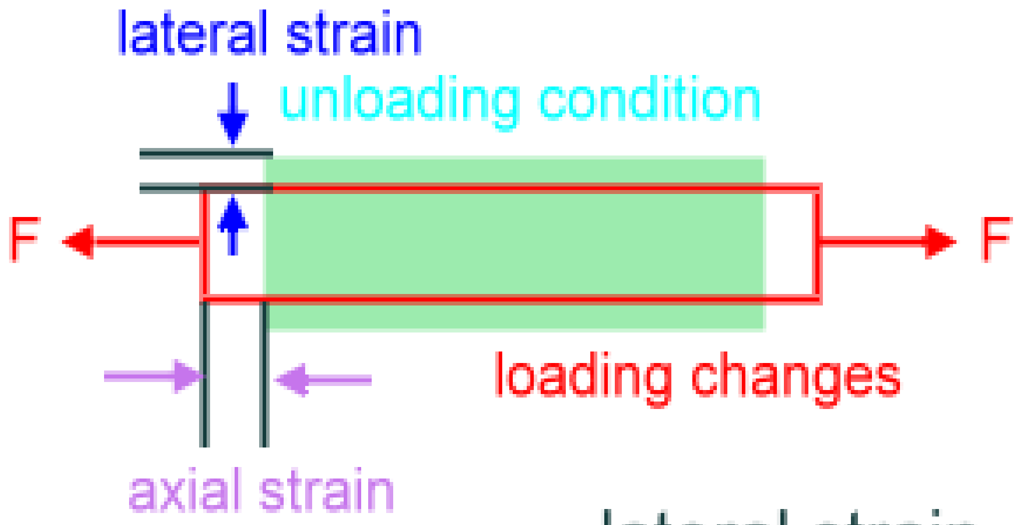


Young's Modulus or Modulus of Elasticity

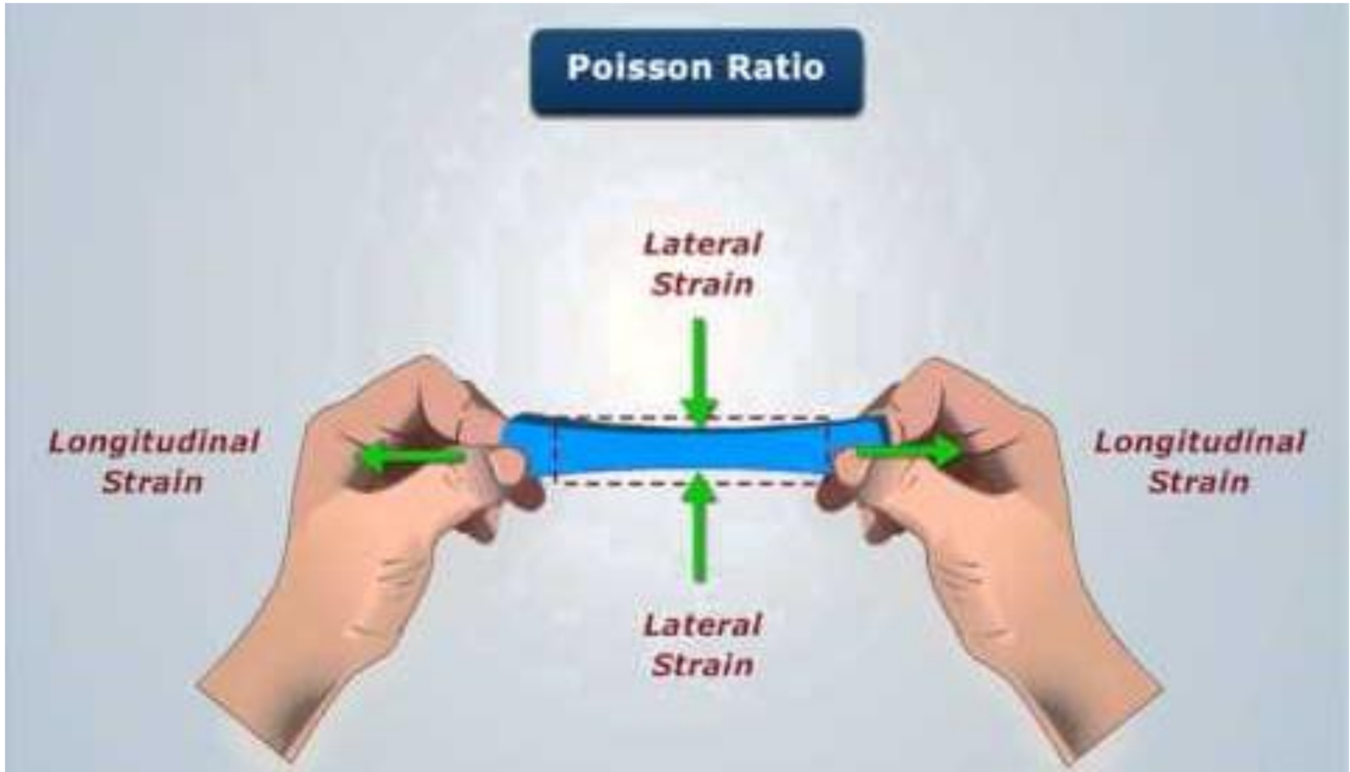
- ***Hooke's law***:- states that when a material is loaded within elastic limit, the stress is directly proportional to strain,

$$\sigma \propto \varepsilon \quad \text{or} \quad \sigma = E \times \varepsilon$$

$$\boxed{E = \frac{\sigma}{\varepsilon} = \frac{P \times l}{A \times \delta l}}$$



$$\text{Poisson Ratio} = \frac{\text{lateral strain}}{\text{axial strain}}$$

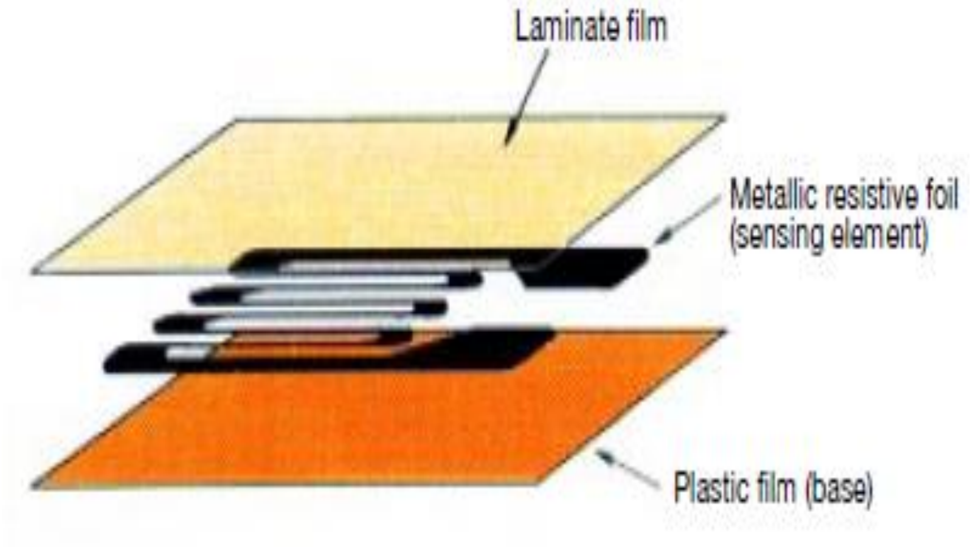


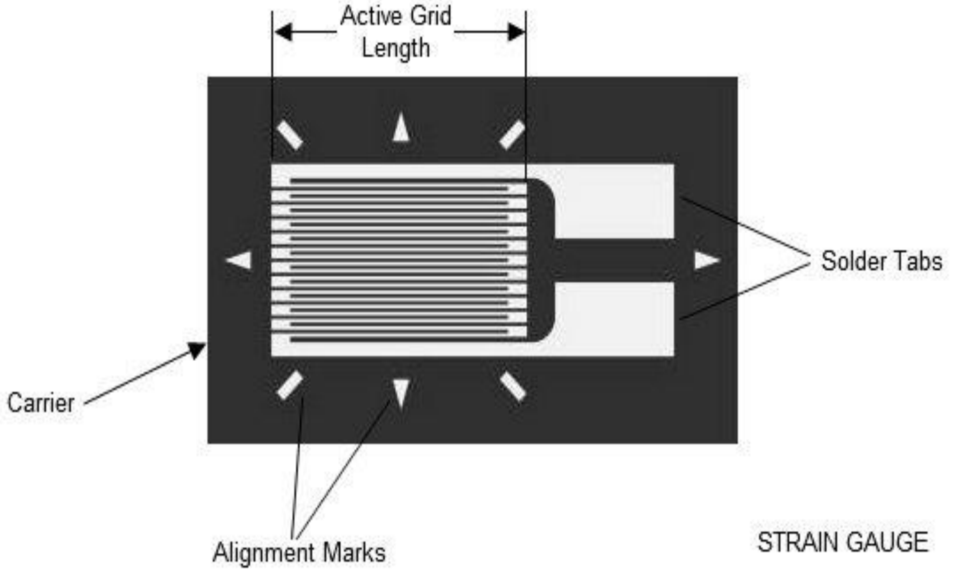
Strain Gauge

- ✓ Based on the ***variation of resistance of a conductor or semiconductor when subjected to a mechanical stress***.
- ✓ The electric resistance of a wire is having length l, cross section A, and resistivity ρ is:

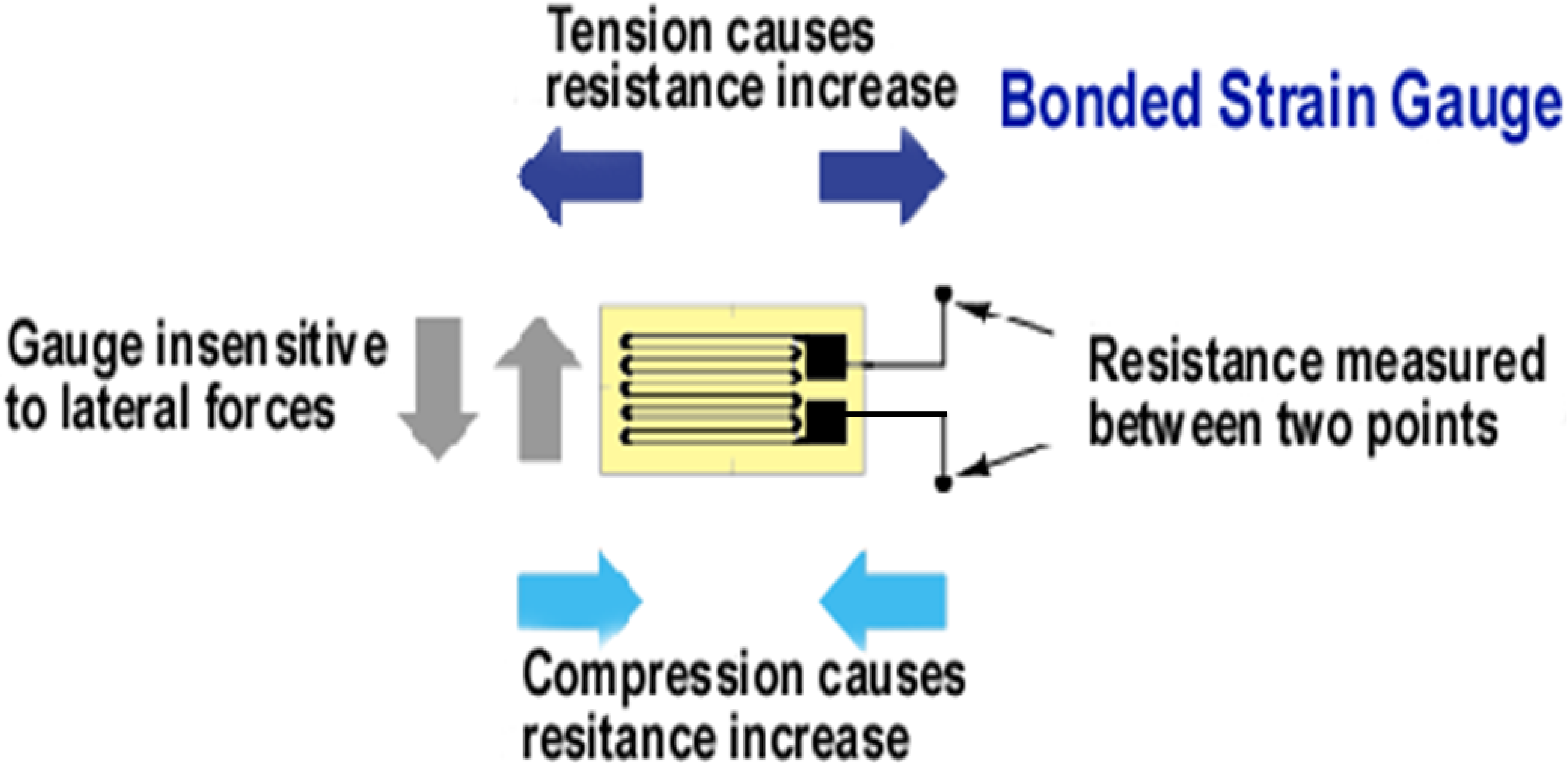
$$R = \rho \frac{l}{A}$$

- ✓ ***When the wire is stressed longitudinally, R undergoes a change.***
- ✓ ***Passing small amount of current*** through such wire will, thus, ***help measure voltage change.***
- ✓ The sensing element of the strain gauge is ***made of copper-nickel alloy foil***. The alloy foil has a rate of resistance change proportional to strain with a certain constant.





Strain Gauge



Resistive Strain Gauge

Strain gauge is bonded to an object ,When subject to strain, its resistance R changes, the fractional change in resistance $\Delta R/R$ being proportional to the mechanical strain $\Delta L/L$.

Mechanical strain $\varepsilon_L = \Delta l/l$

Strain Gauge

Electrical strain $\Delta R/R = G.\Delta l/l$

Wheatstone Bridge

Electrical Output $E_o \propto \Delta R/R$

G is the gauge factor (Strain Factor)

Gauge Factor

The resistance R of a conductor of cross section area A, length L, made of material of resistivity ρ *is* $\boldsymbol{R = \rho \frac{L}{A}}$

Gauge Factor is Defined as $\boldsymbol{G = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon_L}}$

$$\boldsymbol{\Delta R = R.G.\varepsilon_L}$$

Where ΔR *being change in resistance due to axial Strain* ε_L *which is* $\frac{\Delta L}{L}$

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta A}{A}$$

Area A is geometric dimension of strain gauge,

$A = \frac{\pi}{4} D^2$*; where D Diameter*

$$\frac{\Delta A}{A} = 2\frac{\Delta D}{D}$$

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L} - 2\frac{\Delta D}{D}$$

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \varepsilon_L - 2\varepsilon_T \quad \text{Where } \varepsilon_L = \frac{\Delta L}{L}, \varepsilon_T = \frac{\Delta D}{D}$$

$$\frac{\Delta R/R}{\varepsilon_L} = \frac{\Delta\rho/\rho}{\varepsilon_L} + \frac{\varepsilon_L}{\varepsilon_L} - 2\frac{\varepsilon_T}{\varepsilon_L}$$

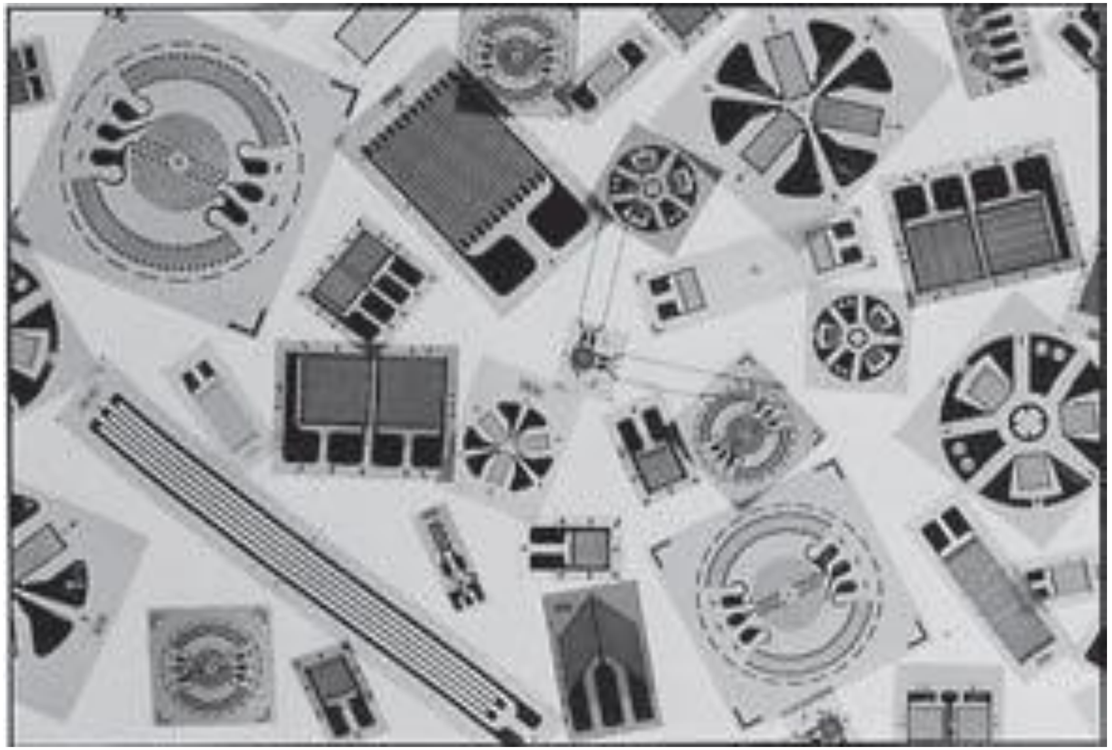
$$G = \frac{\frac{\Delta\rho}{\rho}}{\varepsilon_L} + 1 + 2\nu \approx \boldsymbol{1 + 2\nu} \qquad \text{Where } \nu = {}^{-\varepsilon_T}/_{\varepsilon_L}$$

Strain Gauge Type

a. **Mechanical S G**

b. **Optical S G**

c. **Electrical S G**

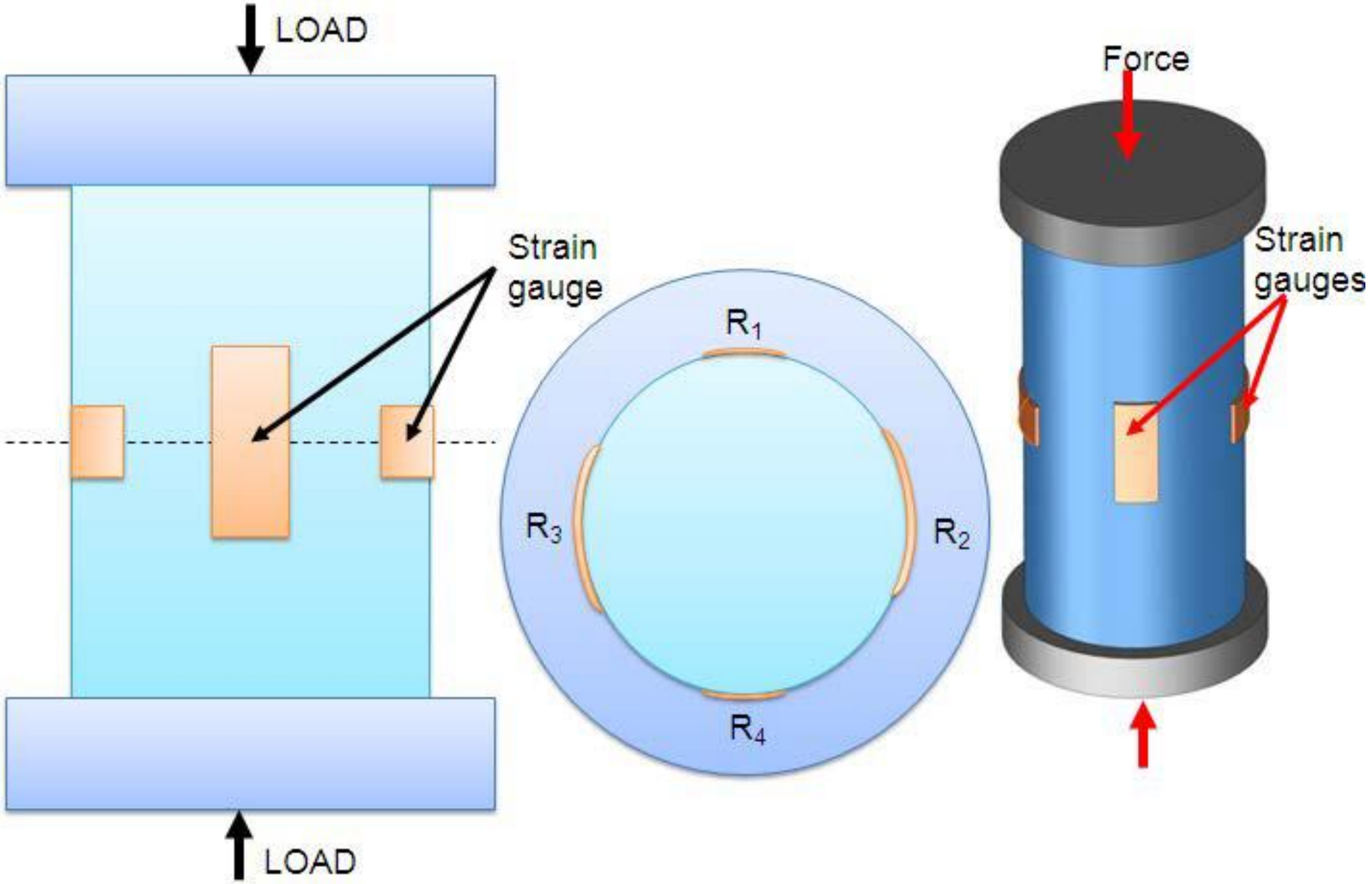


Selection Criterion

Operating Temperature, Nature of Strain, Stability Requirement

Types of electrical strain gauges

- Wire gauges
  i. Flat grid type
  ii. Wrap around type
  iii. Single wire gauge
  iv. Woven type
- Unbonded Strain gauges
- Foil gauges
- Semiconductor strain gauges
- Thin film gauges

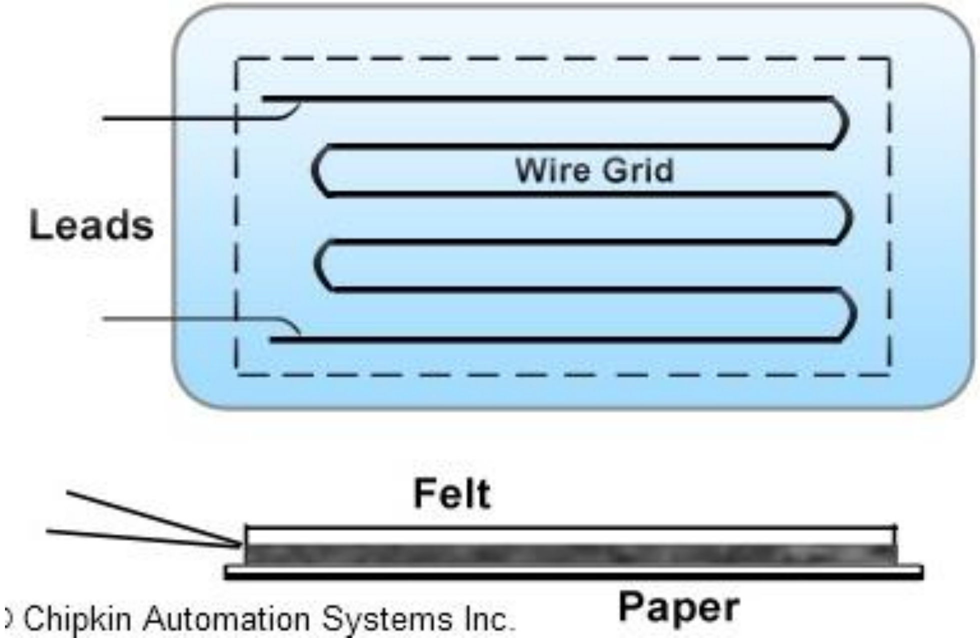


Bonded Wire Strain Gauge :

✓Consists of a ***strain sensitive conductor*** (wire) mounted on a small piece of paper or plastic backing.
✓This gauge is cemented to the surface of the structural member to be tested. The wire grid may be & flat type or wrap-around.

✓In the ***flat type*** after attaching the lead wires to the ends of the grids, a second piece of paper is cemented over the wire as cover.
✓In the ***wrap-around type***, the wire is wound around a cylindrical core in the form of a close wound helix. This core is then flattened & cemented between layers of paper for the purpose of protection and insulation.

✓Formerly only wrap-around gauges were available, but generally ***flat grid gauges are preferred as they are superior to wrap-around gauge*** in terms of hysterisis, creep, elevated temperature, performance, stability & current carrying capacity.



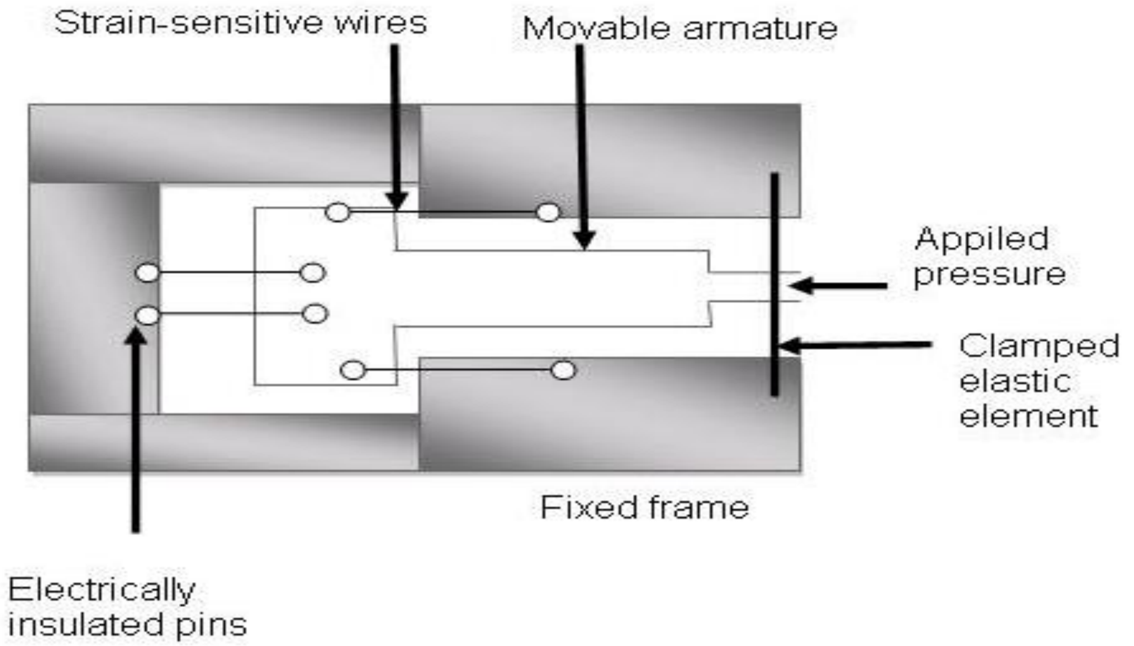
Un-bonded wire strain gauge :

The principal is based on the ***change in electrical resistance of a metallic wire due to the change in the tension of the wire***.

✓This type consists of a stationary frame and a movable platform.
✓Fine wire loops are wounded around the insulated pins with pretension. Relative motion between the platform and the frame increases the tension in two loops, while decreasing tension in the other two loops.

✓These four elements are connected approximately to a four arm **Wheat stone bridge**.

✓These type strain gauges are ***used for measurement of acceleration, pressure, force etc.***



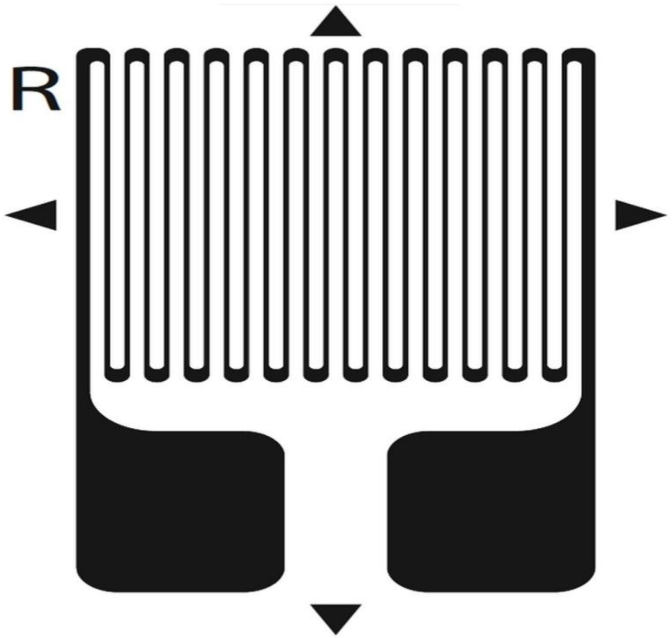
Foil Strain Gauges:

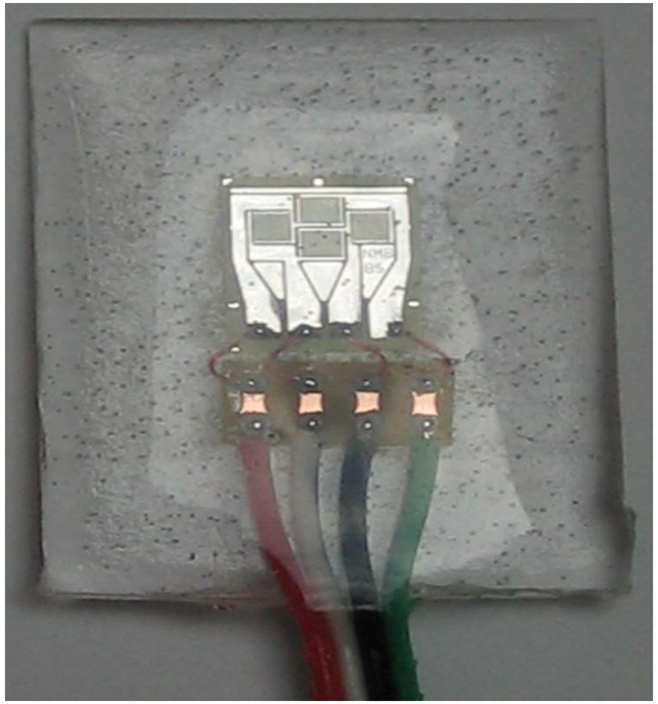
✓The foil type of strain gauges has a foil grid ***made up of thin strain sensitive foil***.

✓The ***width of the foil is very large as compared to the thickness*** (microns) so that larger area of the gauge is for cementing.

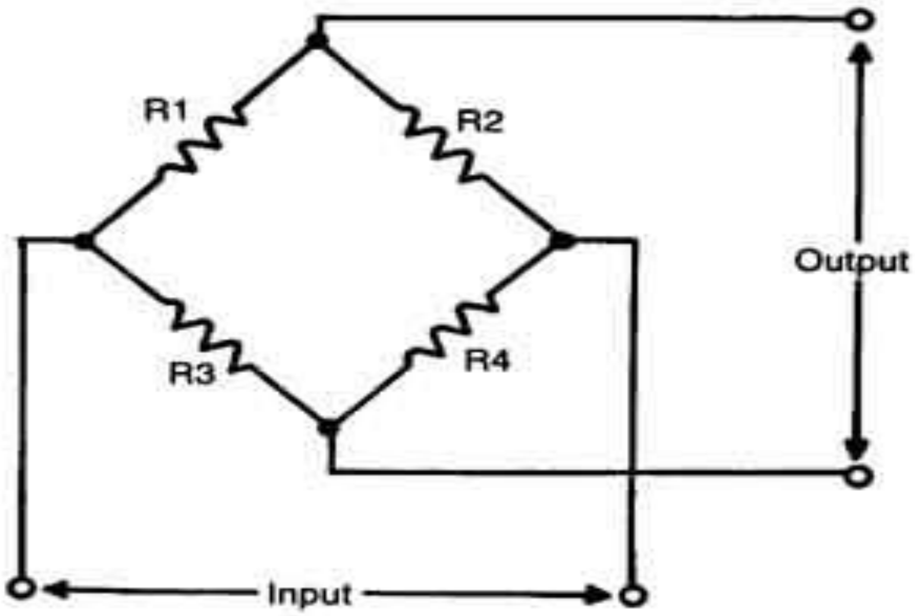
✓High heat dissipation capability

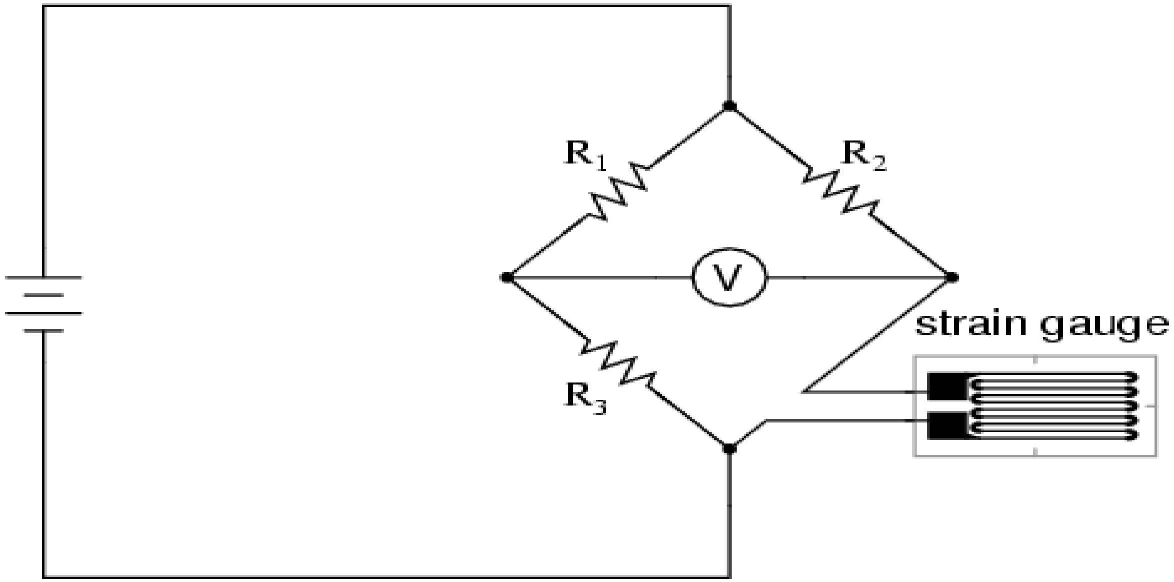
✓Better bonding properties



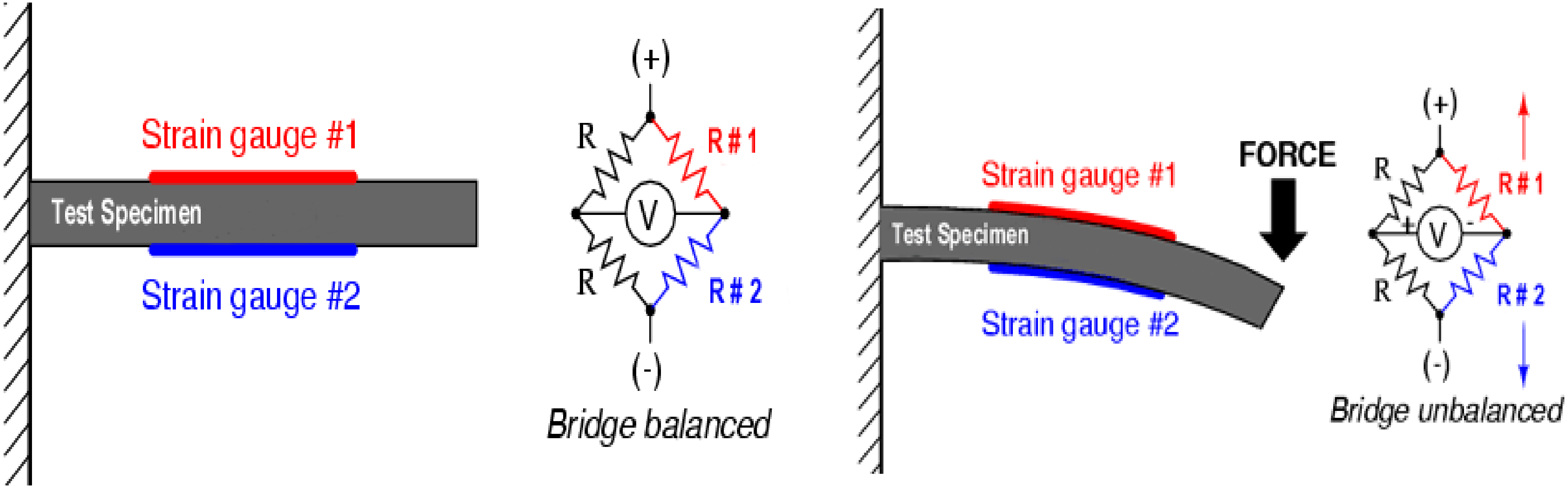


Strain Gauge Circuit





- ✓ ***The Wheatstone bridge is an electric circuit for detection of minute resistance changes.*** It is therefore used to measure resistance changes of a strain gauge.
- ✓ ***Strain gauge is connected in place of R4*** in the circuit. When the gauge bears strain and initiates a resistance change, ΔR, the bridge outputs a corresponding voltage.



✓With no force applied to the test specimen, both strain gauges have equal resistance and the bridge circuit is balanced.

✓However, when a downward force is applied to the free end of the specimen, it will bend downward, stretching gauge #1 and compressing gauge #2

Strain Gauge Circuit

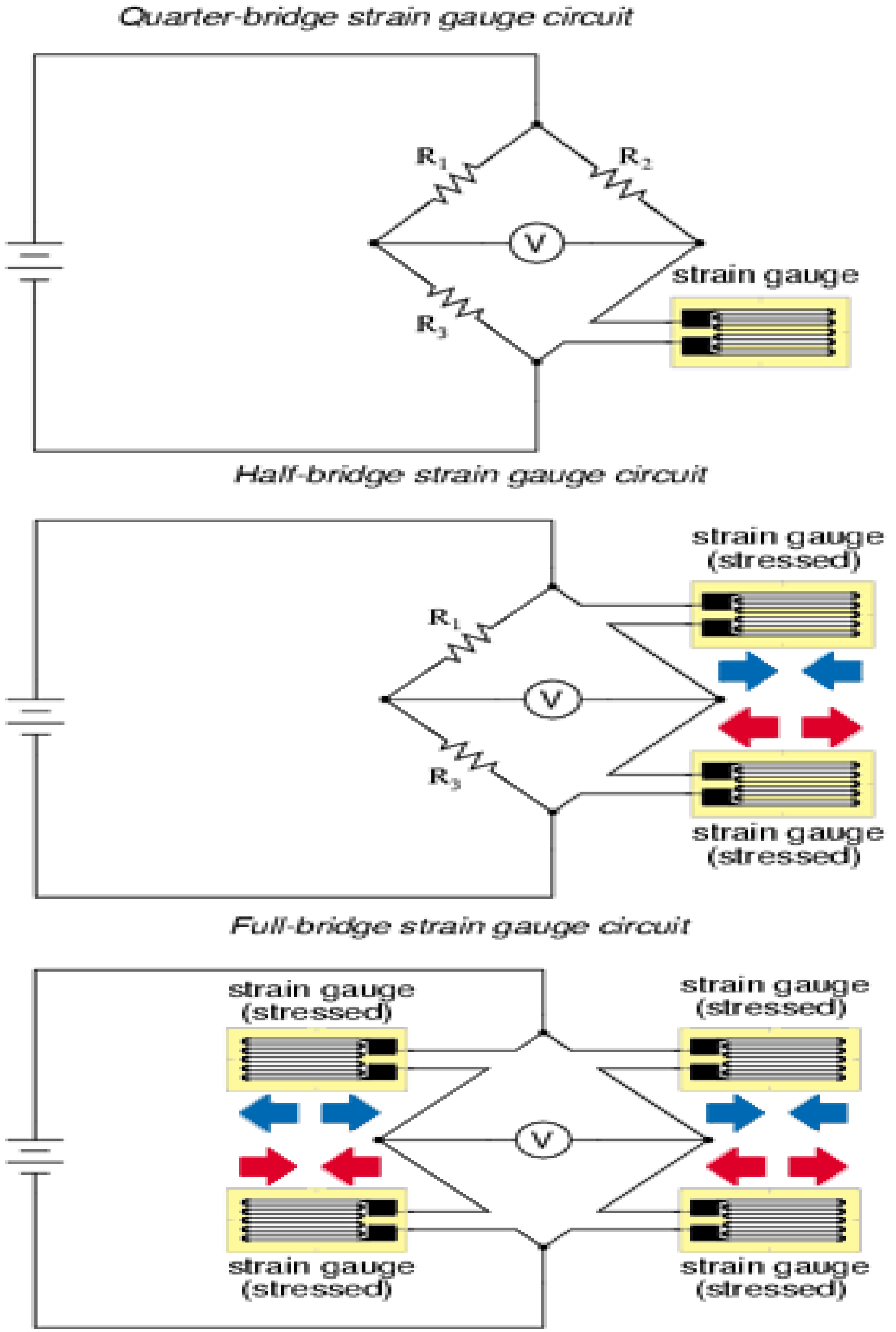
$$\text{Quarter Bridge}: \frac{V_{output}}{V_{input}} = \frac{1}{4} \times GF \times \varepsilon$$

$$\text{Half Bridge}: \frac{V_{output}}{V_{input}} = \frac{1}{2} \times GF \times \varepsilon$$

$$\text{Full Bridge}: \frac{V_{output}}{V_{input}} = GF \times \varepsilon$$

In above eqns :

$$GF = \frac{\Delta R / R}{\varepsilon} \qquad \varepsilon = \frac{\Delta l}{l}$$



Effect of Temperature on Output of Gauge

- ✓Ideally, we would like the resistance of the strain gauge to change only in response to applied strain.

- ✓However, strain gauge material, as well as the specimen material to which the gauge is applied, will also respond to changes in temperature.

- ✓Strain gauge manufacturers attempt to minimize sensitivity to temperature by processing the gauge material to compensate for the thermal expansion of the specimen material; compensated gauges reduce the thermal sensitivity, they do not totally remove it.

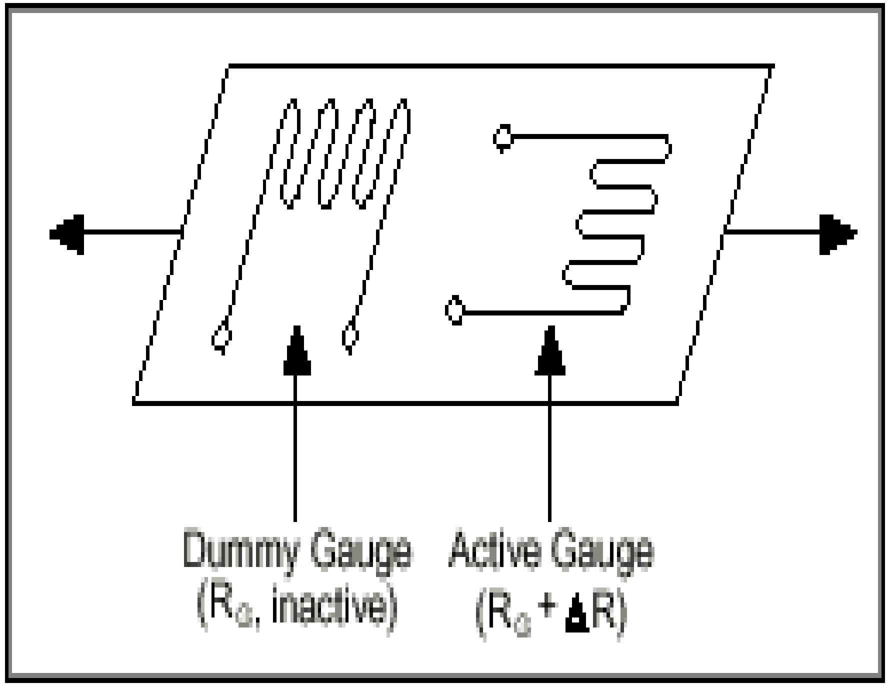
Temperature compensation

✓By using two gauges

✓One gauge is active, and a second gauge is placed transverse to the applied strain.

✓The strain has little effect on the second gauge, called the dummy gauge.

✓Because the temperature changes are identical in the two gauges, the ratio of their resistance does not change, the voltage does not change, and the effects of the temperature change are minimized.



Electromagnetic Flow sensor

- ✓Magnetic flow meters operate based upon Faraday's Law of electromagnetic induction, which states that a voltage will be induced in a conductor moving through a magnetic field.

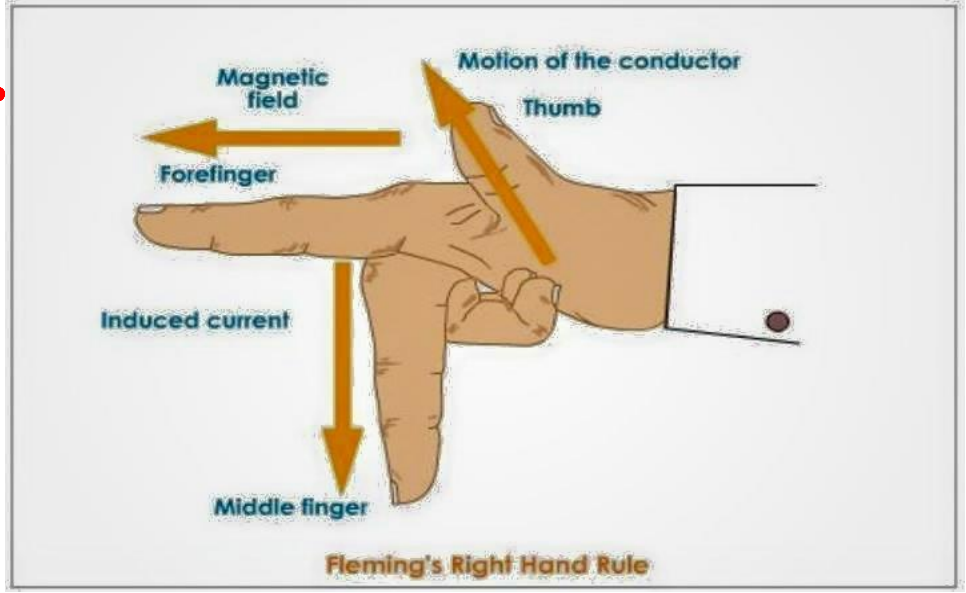
- ✓***Faraday's Law:*** ***E = k B D V***

  The magnitude of the **induced voltage E** is directly proportional to the **velocity of the conductor V**, **conductor width D**, and **the strength of the magnetic field B**.

- ✓Magnetic field coils are placed on opposite sides a pipe to generate a magnetic field.

Electromagnetic Flow sensor

- ✓As the liquid moves through the field with average velocity V, electrodes sense the induced voltage.
- ✓An insulating liner prevents the signal from shorting to the pipe wall.
- ✓The output voltage E is directly proportional to liquid velocity, resulting in the linear output of a magnetic flow meter.



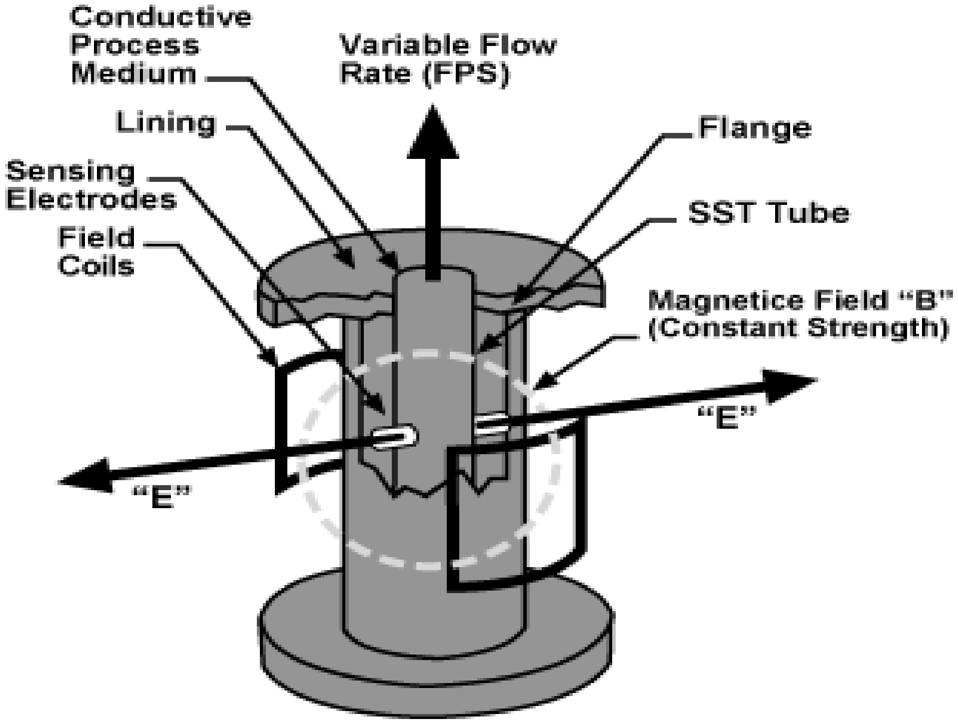


Figure 2.21 - The Magnetic Head Flow Meter

Advantages of Electromagnetic Flow Meter

(i) The obstruction to the flow is almost nil and therefore this type of meters can be used for measuring heavy suspensions, including mud, sewage and wood pulp.

ii) There is no pressure head loss in this type of flow meter other than that of the length of straight pipe which the meter occupies.

(iii) They are not very much affected by upstream flow disturbances.

(iv) They are practically unaffected by variation in density, viscosity, pressure and temperature.

(v) Electric power requirements can be low (15 or 20 W), particularly with pulsed DCtypes.

(vi) These meters can be used as bidirectional meters.

(vii) The meters are suitable for most acids, bases, water and aqueous solutions because the lining materials selected are not only good electrical insulators but also are corrosion resistant.

(viii) The meters are widely used for slurry services not only because they are obstruction less but also because some of the liners such as polyurethane, neoprene and rubber have good abrasion or erosion resistance.

(ix) They are capable of handling extremely low flows.

Disadvantages-

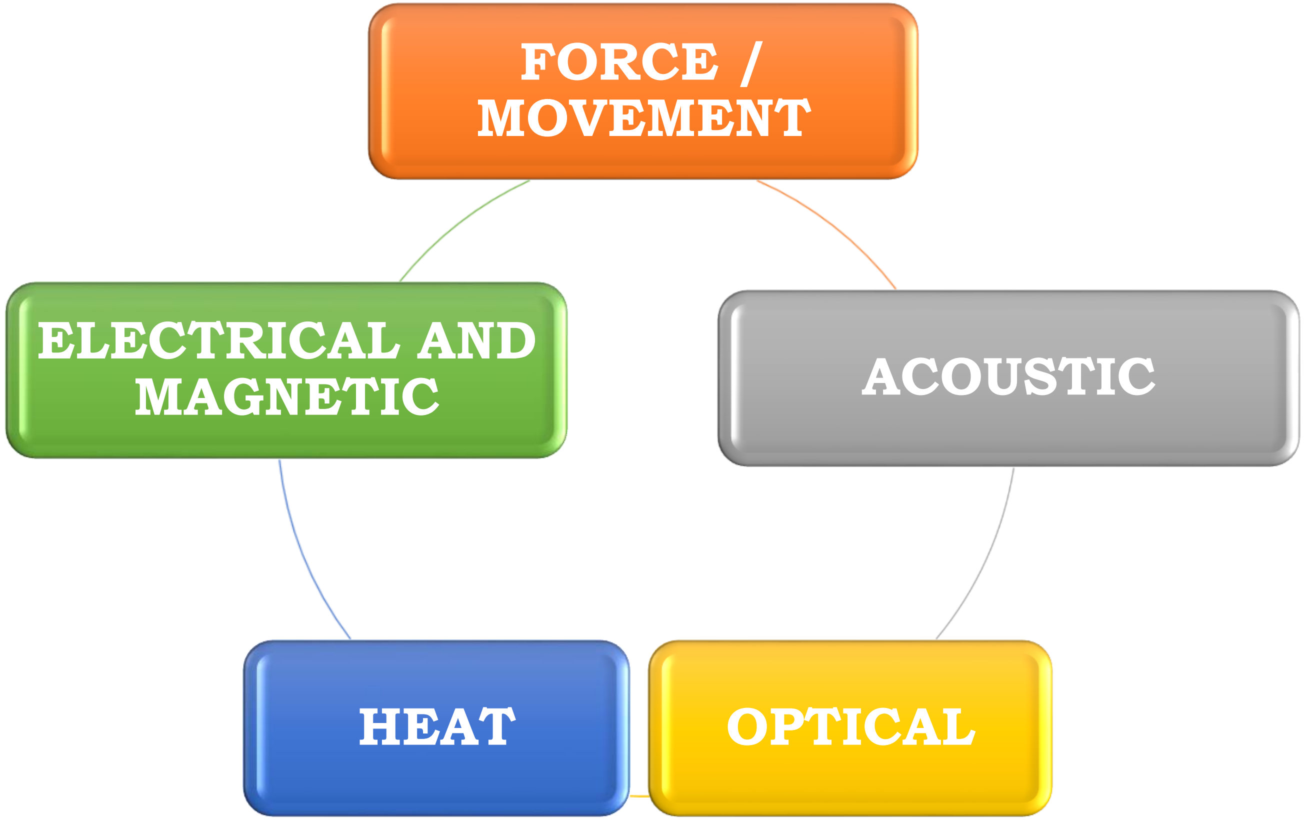
1. Operating cost is high particularly if heavy slurries are handled
2. Must be full at all times because velocity as analogues to volume flow rate
3. Limited to fluid having conductivity at least of order of 0.05μmho/cm

Applications

Fluids like sand water slurry,
coal powder, slurry, sewage, wood pulp, chemicals, water other than distilled water in large pipe lines, hot fluids, high viscous fluids specially in food processing industries, cryogenic fluids can be metered by the electromagnetic flow meter.

Actuator Types

converts an information signal from the control, into energy acting on the basic system.



Actuators

Movement:
electromagnetic

Torque:
electromagnetic

Movement:
pneumatic

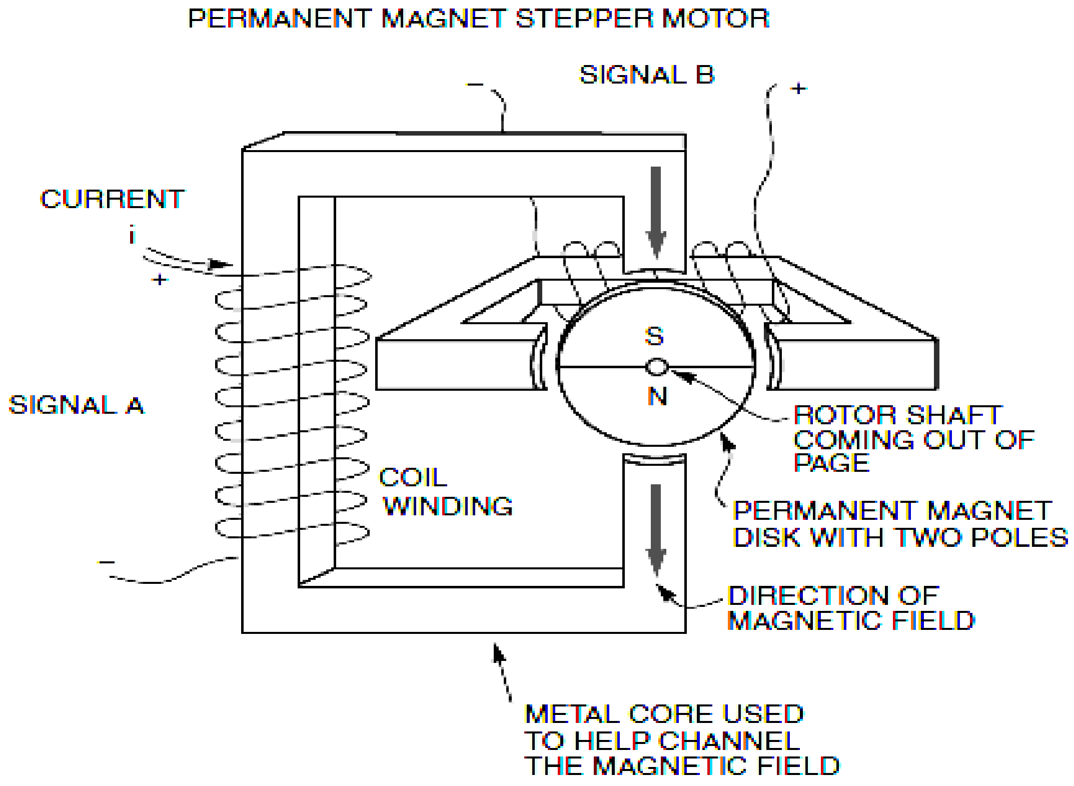
Light:
LED

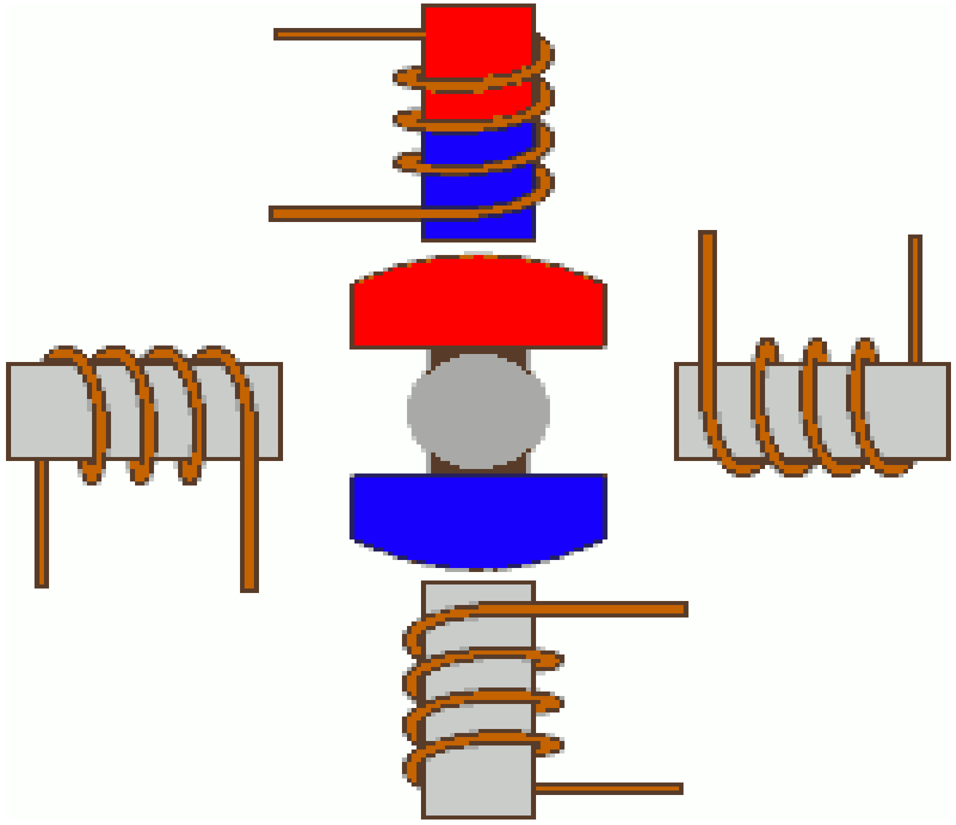
Current:
voltage

Sound:
electromagnetic

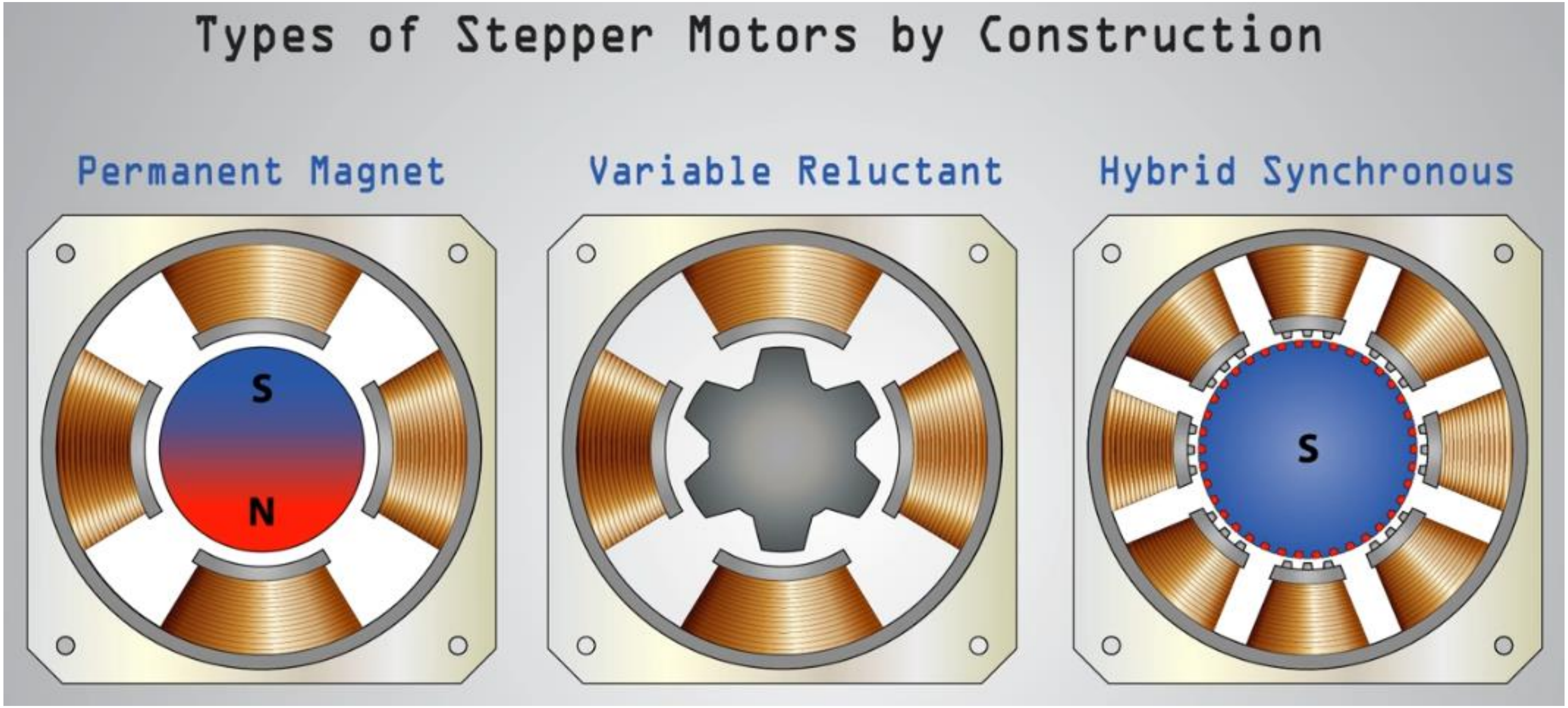
Stepper Motor

- Discrete Positioning device
- Moves one step at a time for each input
- Appropriate excitation in winding/s, makes the rotor attract towards the stator





Stepper Motor



Advantages

1. The ***rotation angle of the motor is proportional to the input pulse***.
2. The motor has ***full torque at standstill*** (*if the windings are energized*)
3. Precise positioning and repeatability of movement since good stepper motors have an ***accuracy of 3 – 5%*** of a step and this error is non cumulative from one step to the next.
4. Excellent ***response to starting/stopping/reversing***.
5. Very ***reliable since there are no contact brushes*** in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides ***open-loop control***, making the motor simpler and less costly to control.
7. It is possible to achieve ***very low speed synchronous rotation with a load*** that is directly coupled to the shaft.
8. A ***wide range of rotational speeds*** can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

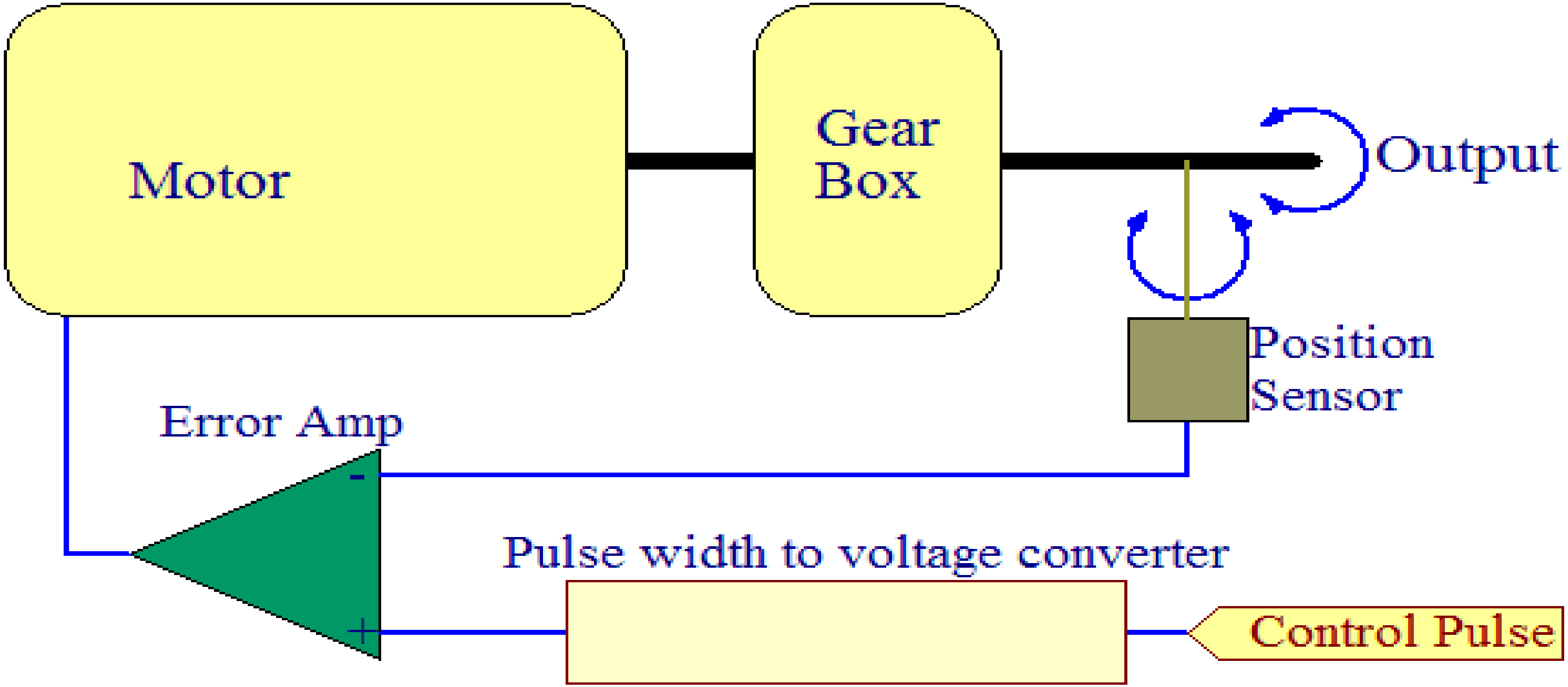
1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

Servo Motor

- ✓ *Precise control of* ***angular position, velocity and acceleration***
- ✓ Electric (DC/AC) motor driven using ***Pulse Width Modulation (PWM)***
- ✓ ***Closed looped control system***
- ✓ Basically DC motor (in some special cases it is AC motor)
- ✓ Servo unit consists - ***small DC motor, potentiometer, gear arrangement, an intelligent circuitry***

Servo Motor

- Servo mechanism consists of position sensor (potentiometer/encoder), gear mechanism and intelligent circuitry



Advantages:

1. If a heavy load is placed on the motor, the driver will increase the current to the motor coil as it attempts to rotate the motor. Basically, there is no out-of-step condition.
2. ***High-speed operation is possible***.

Disadvantages:

1. Since the servomotor tries to rotate according to the command pulses, but lags behind, it is ***not suitable for precision control of rotation.***
2. Higher cost.

3. When stopped, the motor’s rotor continues to move back and forth one pulse, so that it is not suitable if you need to prevent vibration

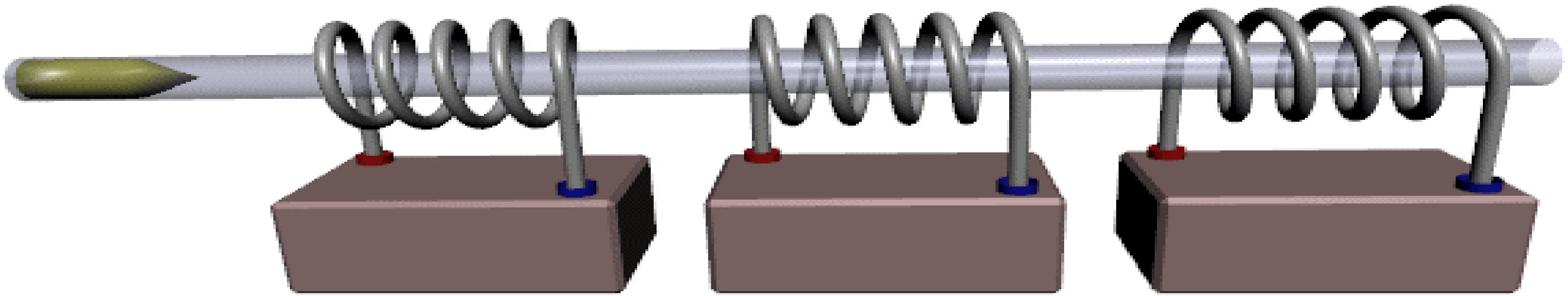
Applications of Servo Motors

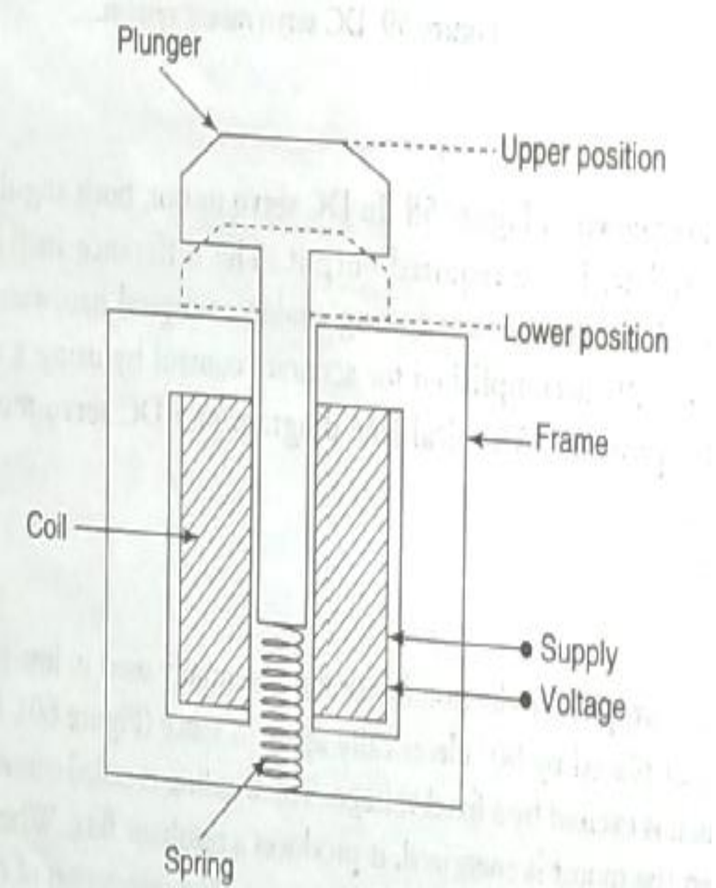
1. In Industries they are used in machine tools, packaging, factory automation, material handling, printing converting, assembly lines, and many other demanding applications robotics, CNC machinery or automated manufacturing.
2. They are also used in radio controlled airplanes to control the positioning and movement of elevators.
3. They are used in robots because of their smooth switching on and off and accurate positioning.
4. They are also used by aerospace industry to maintain hydraulic fluid in their hydraulic systems.
5. They are used in many radio controlled toys.
6. They are used in electronic devices such as DVDs or Blue ray Disc players to extend or replay the disc trays.
7. They are also being used in automobiles to maintain the speed of vehicles.

Solenoid Actuator

- Electromagnetic actuator
- Consist of a movable ferrite core that is activated by current flow
- When the coil is energized, a magnetic field is established that provides the ***force to push or pull the core***

- ***Provide large force over a short duration***
- Normally used as ***linear actuator***
- ***Application*** in- Room heating, gas flow, water flow etc





Working-

✓A solenoid is defined as a coil of wire commonly in the form of a long cylinder that when carrying a current resembles a bar magnet so that a moveable core (armature) is drawn into (pulled-in) the coil when a current flows.

✓ A more simple definition is that a solenoid is a coil and a moveable iron core used ***to convert electrical energy into mechanical energy.***

✓ Normally, the movement of the core compresses a spring.
✓ On power-off, the armature returns back to its normal
✓ The ***stroke of the armature varies from fraction of a mm to several mm depending on application.***

There are two main categories of solenoids:

Rotary – rotary motion of the armature
Linear – linear motion of the armature