

Instrumentation

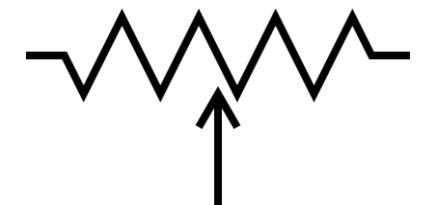
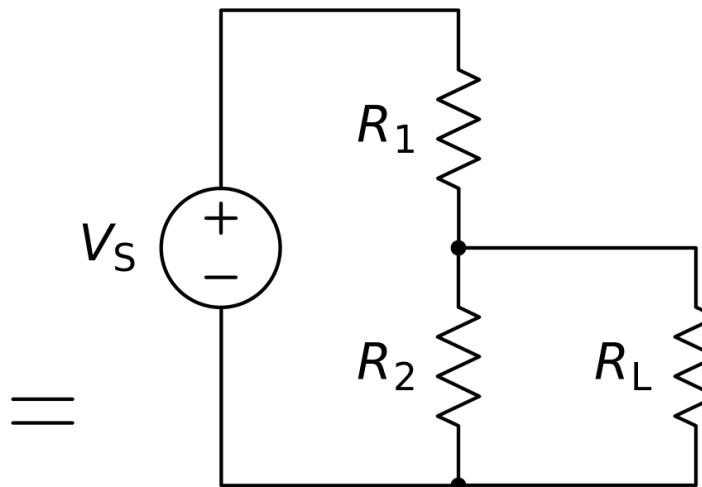
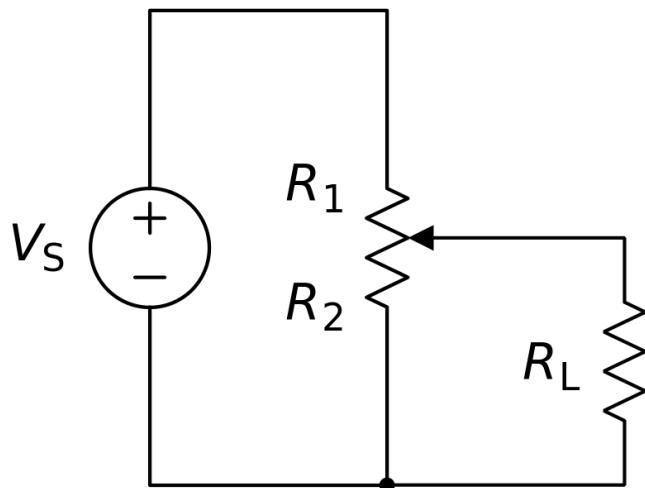
Displacement, Velocity and Acceleration Measurement

Course Instructor: Mohammad Reza Nayeri

Spring 2022

Potentiometer

- A **potentiometer** is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider.



$$V_L = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot V_s$$

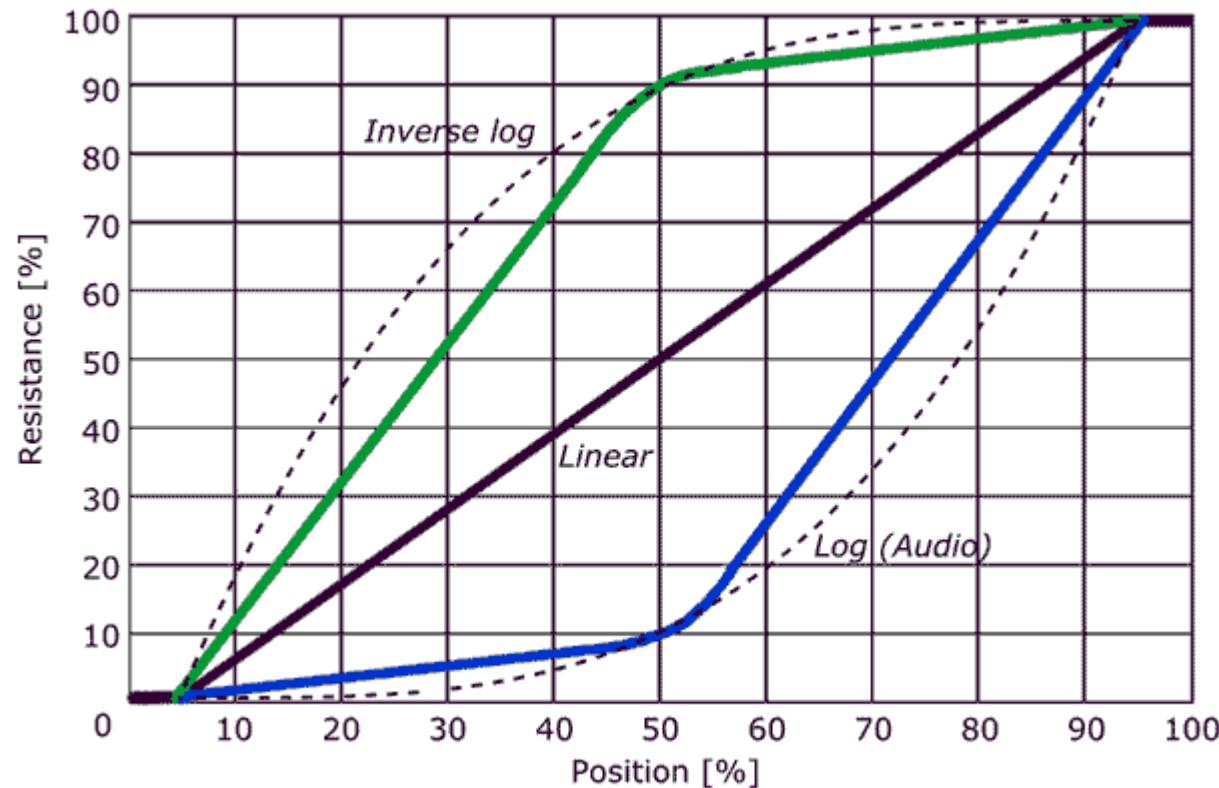
$$V_L = \frac{R_2}{R_1 + R_2} \cdot V_s$$

If R_L is large compared to the other resistances

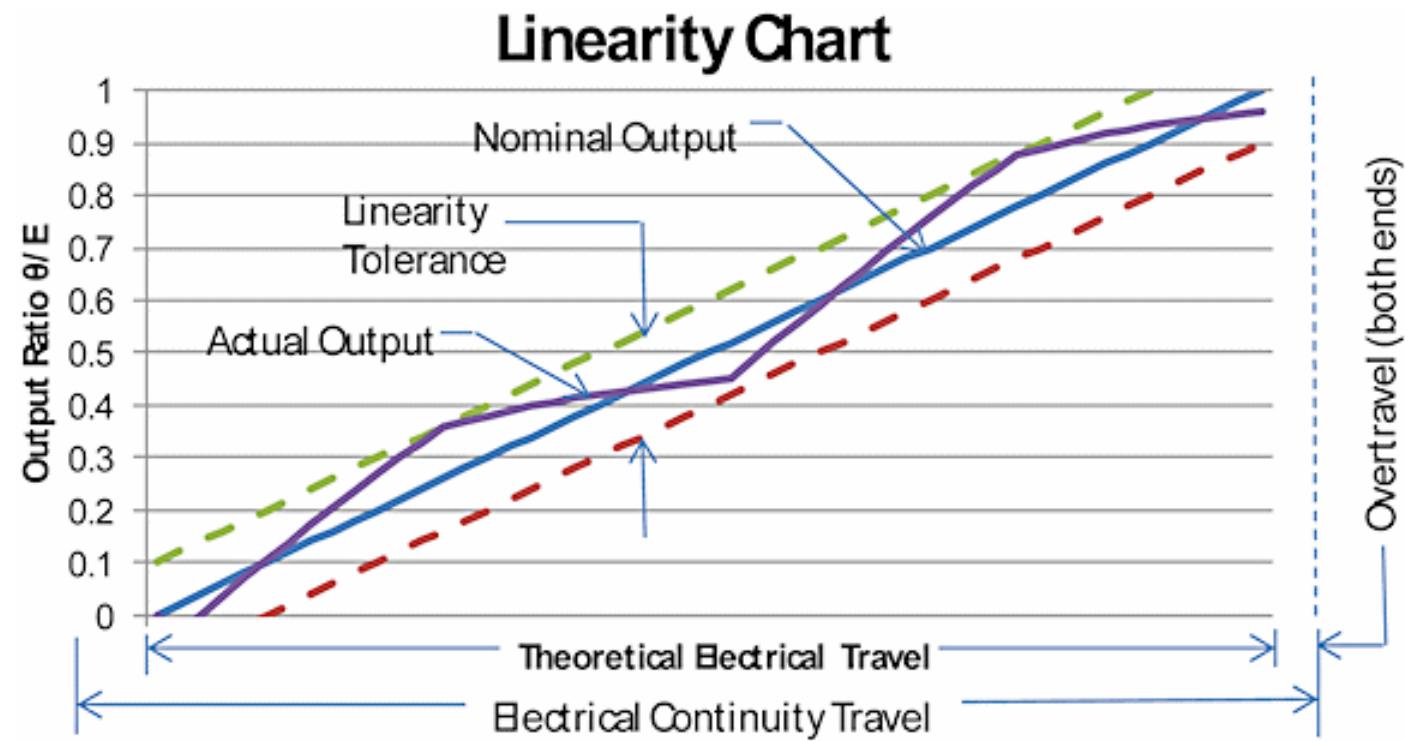
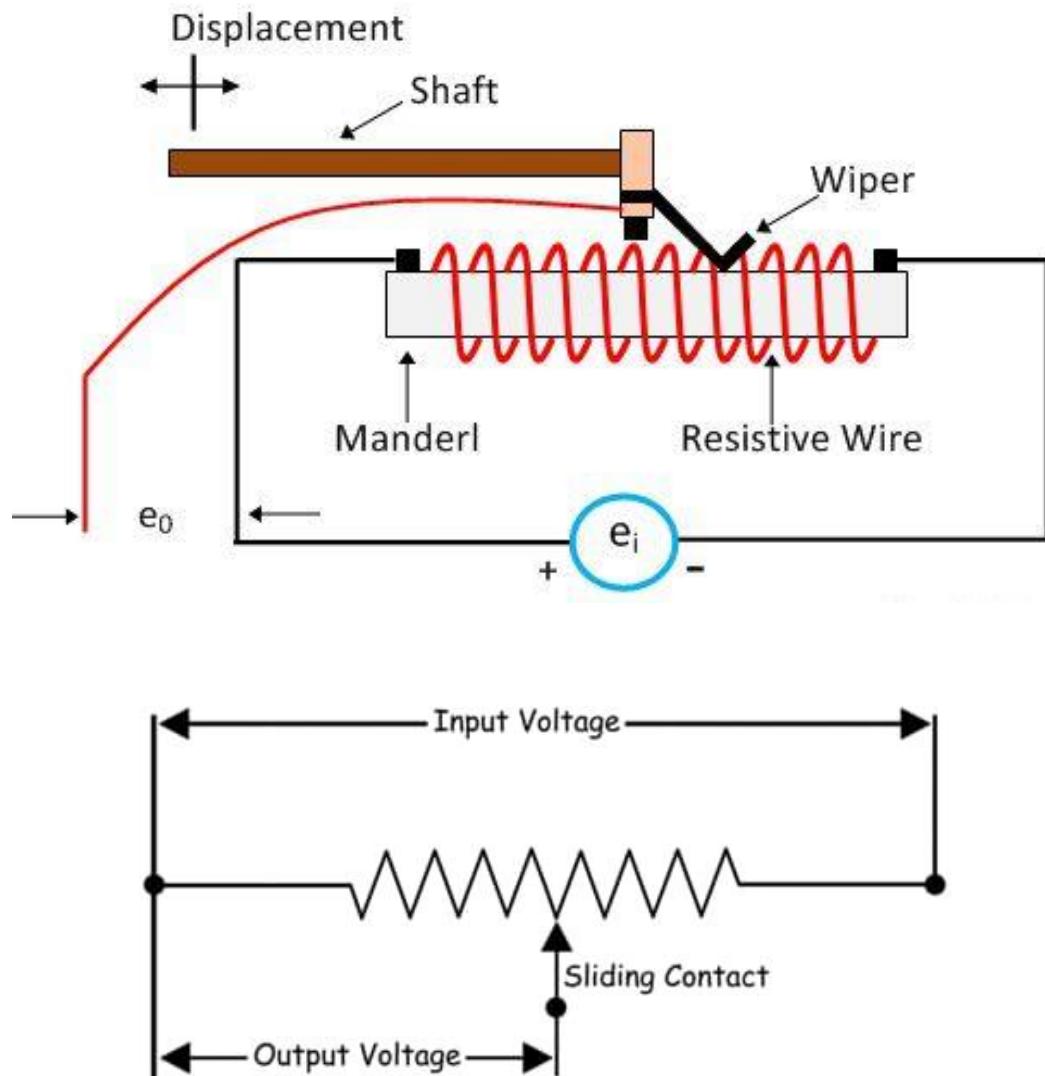
Potentiometer

Definition: *Taper* is the relation between the *position of the potentiometer* and the *resistance ratio*.

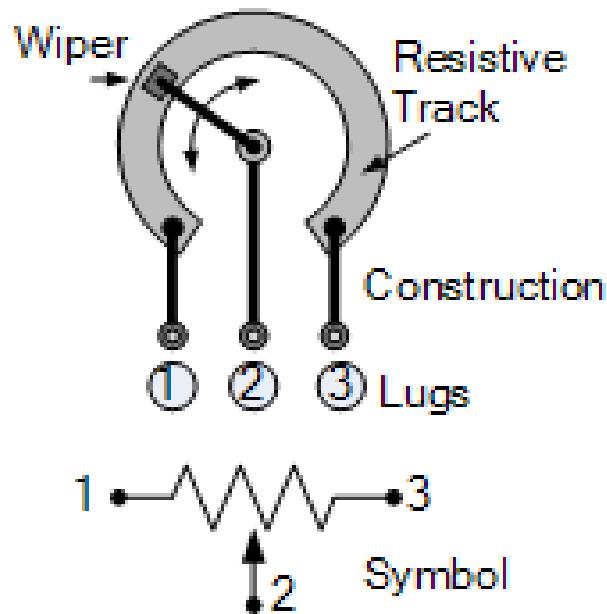
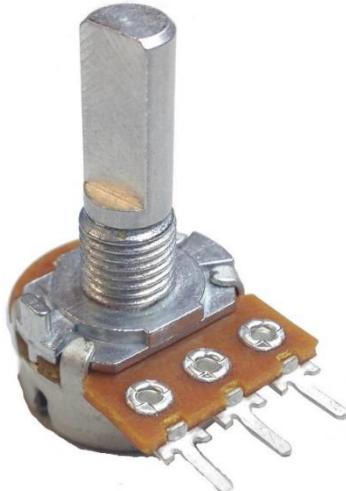
- **Linear taper**
- **Logarithmic (log) or Audio taper**
 - ✓ Mainly used for audio volume control
 - ✓ Because the human ear is sensitive to sound intensity in a logarithmic fashion
- **Inverse logarithmic (Anti-log) taper**
 - ✓ This taper are used, for example in audio controls which turn counterclockwise.



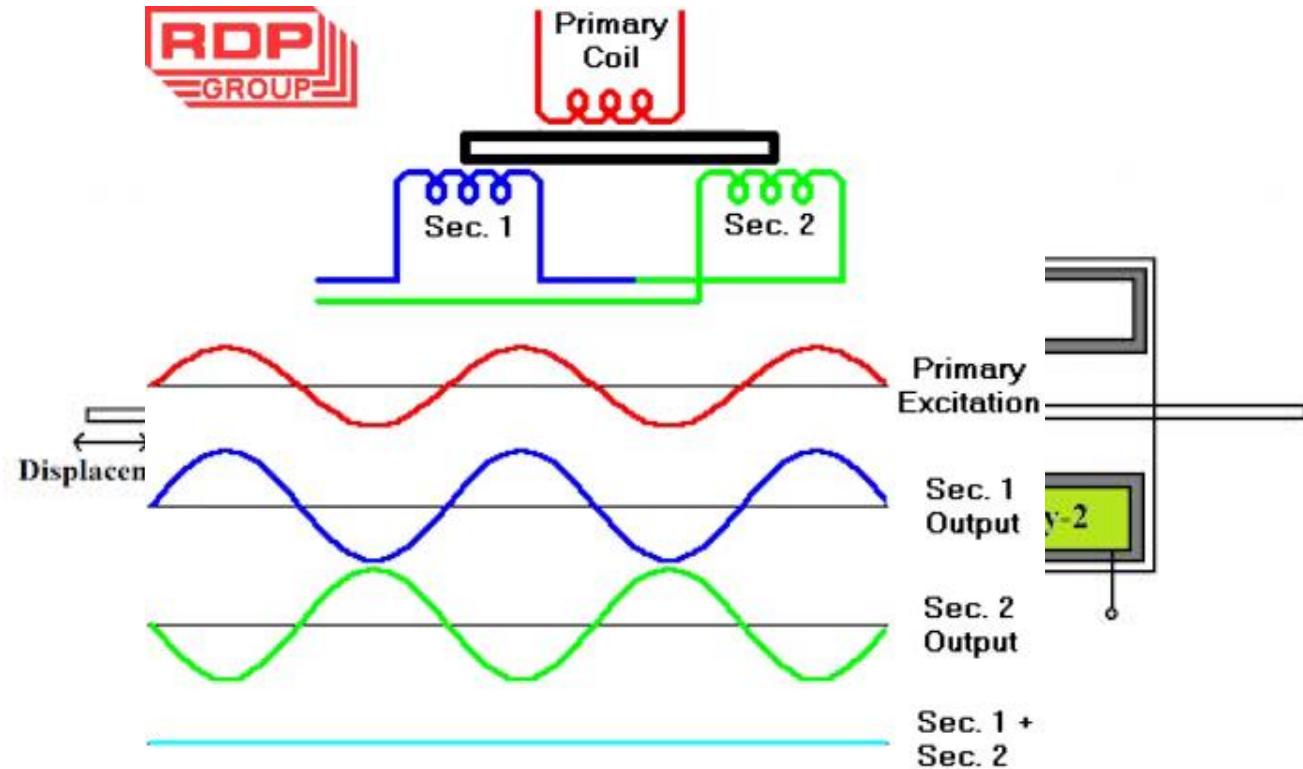
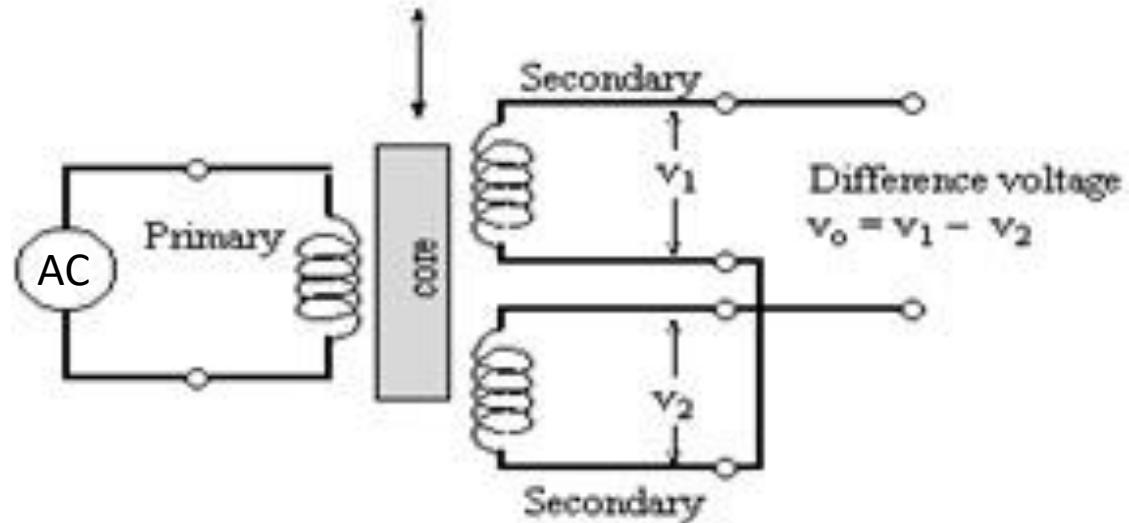
Linear Potentiometer



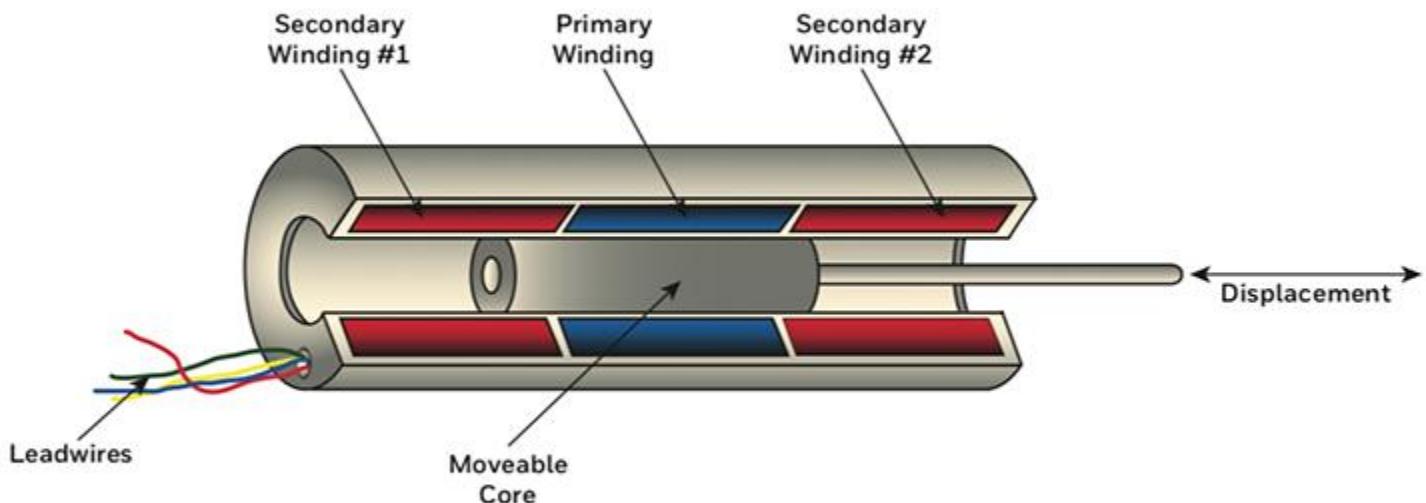
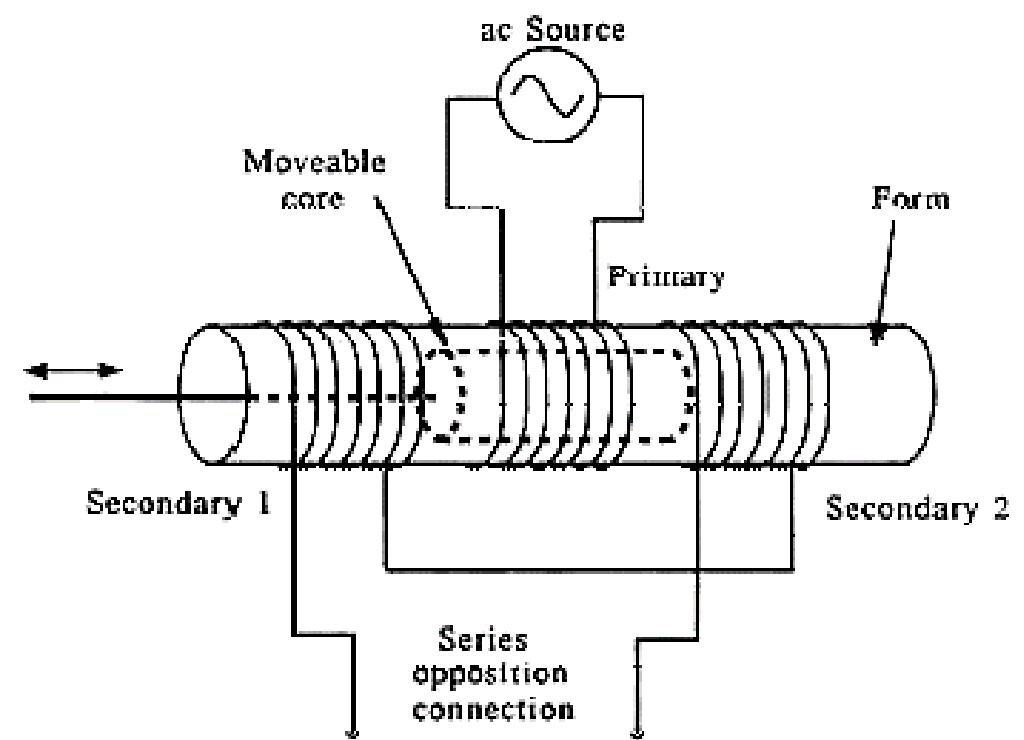
Rotary Potentiometer



Linear Differential Variable Transformer (LVDT)



Linear Differential Variable Transformer (LVDT)



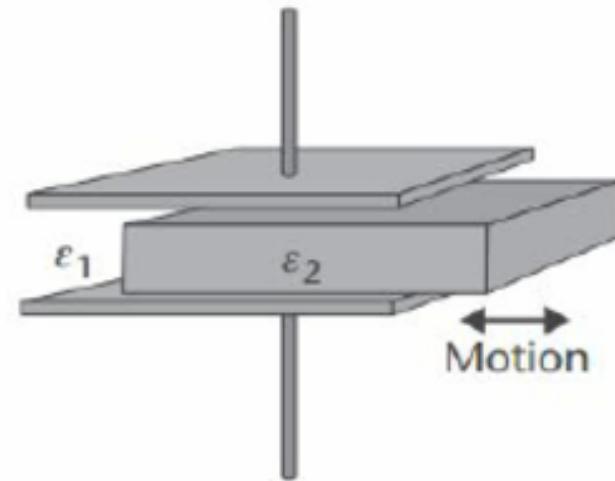
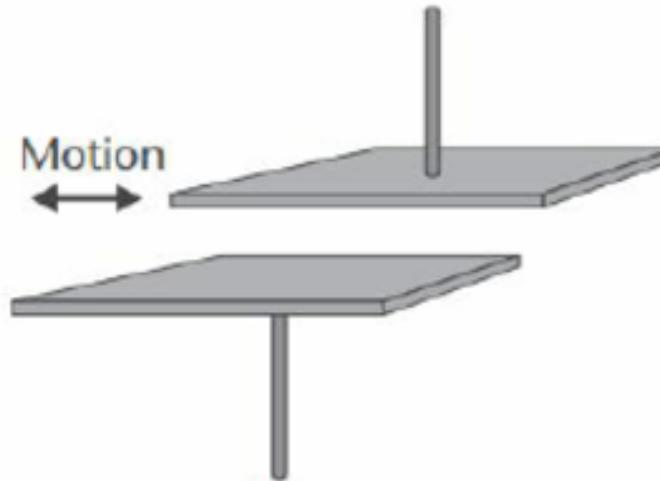
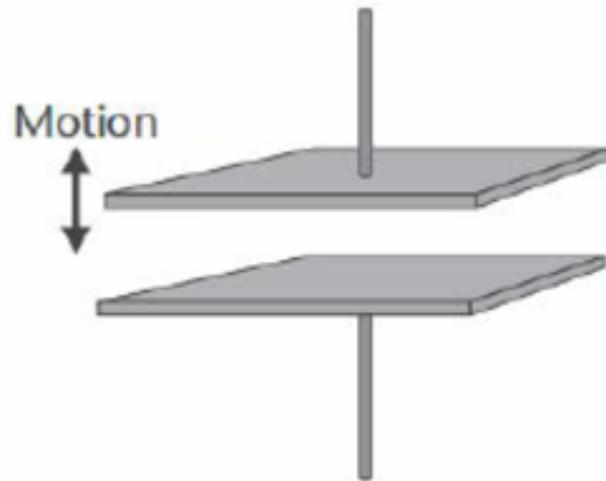


Potentiometer vs LVDT

Position Sensor Technology	Potentiometer	AC-LVDT
Range in inches (mm)	0.12-20 (3-500)	0.02-20 (0.5-500)
Resolution	Good	Excellent
Repeatability	Good	Excellent
Non-linearity	Good	Good
Temp Characteristics	Fair	Very Good
Dynamic Response	Fair	Good
Vibration/Shock Sensitivity	Poor	Excellent
Mechanical Overload	Poor	Excellent
Life & Reliability	Fair	Excellent
Installed Cost	Low	High

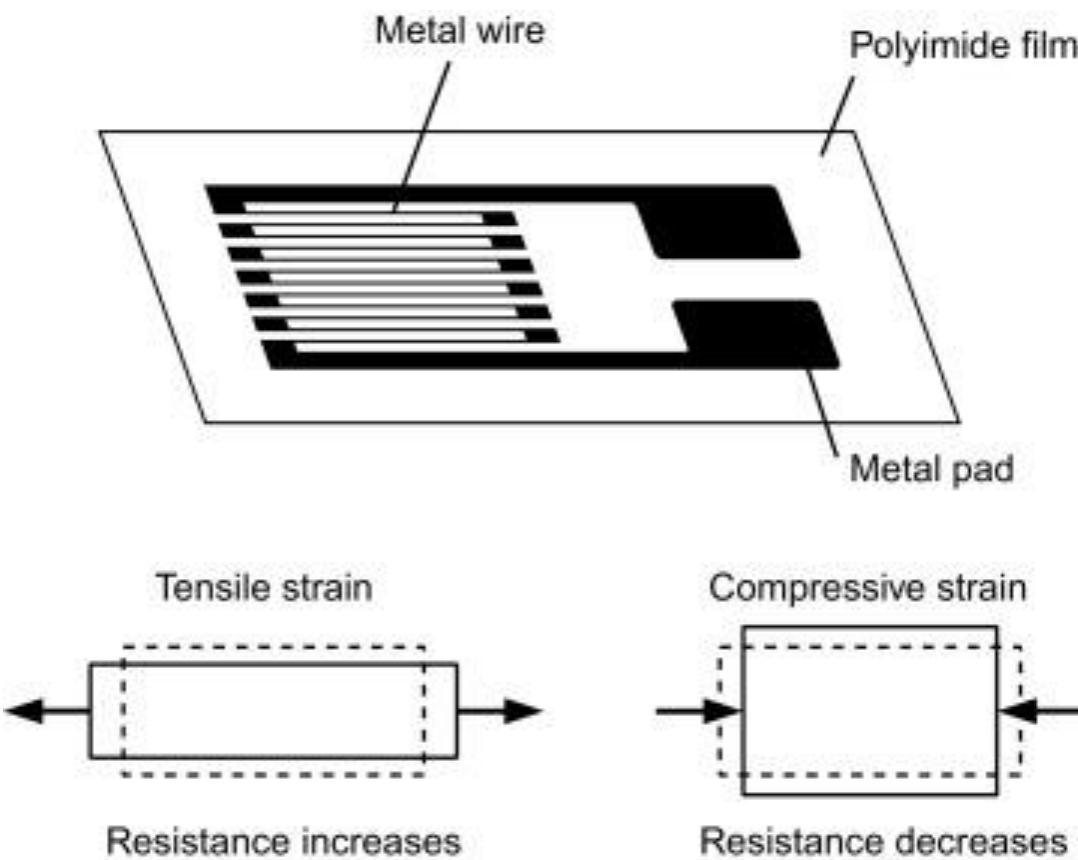
Capacitive Displacement Sensors

Linear or Non-linear ??!



$$C = \varepsilon \frac{A}{d}$$

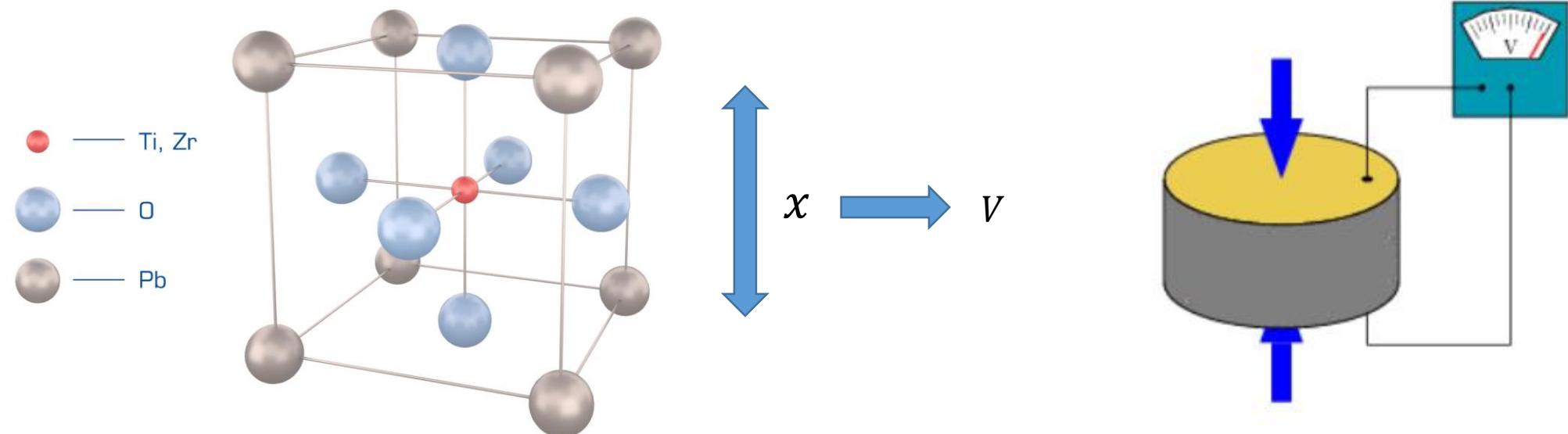
Strain gauge Displacement Sensors



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

Piezoelectric Displacement Sensors

- **Piezoelectricity** is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress.



Ultrasonic Distance Sensor

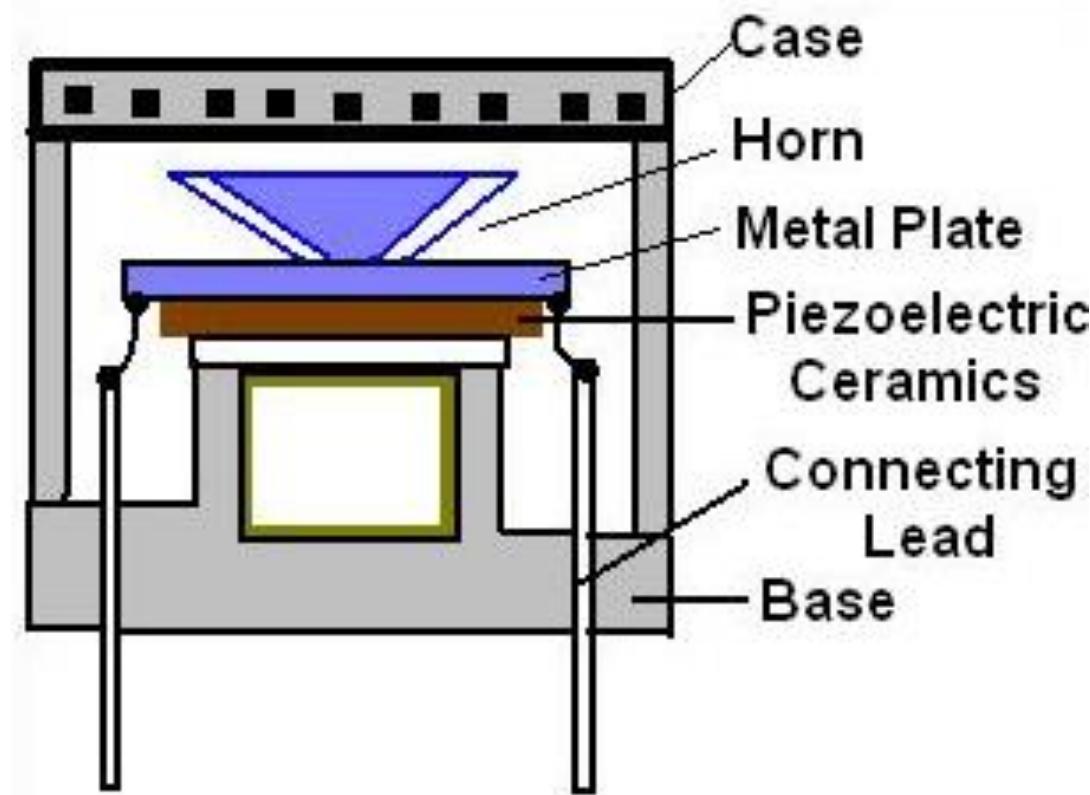
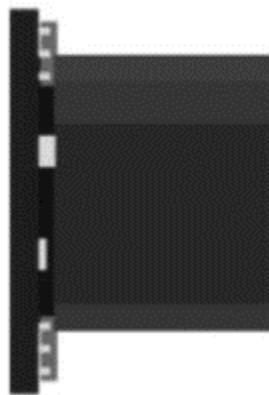


Diagram source: www.electronics-tutorials.ws

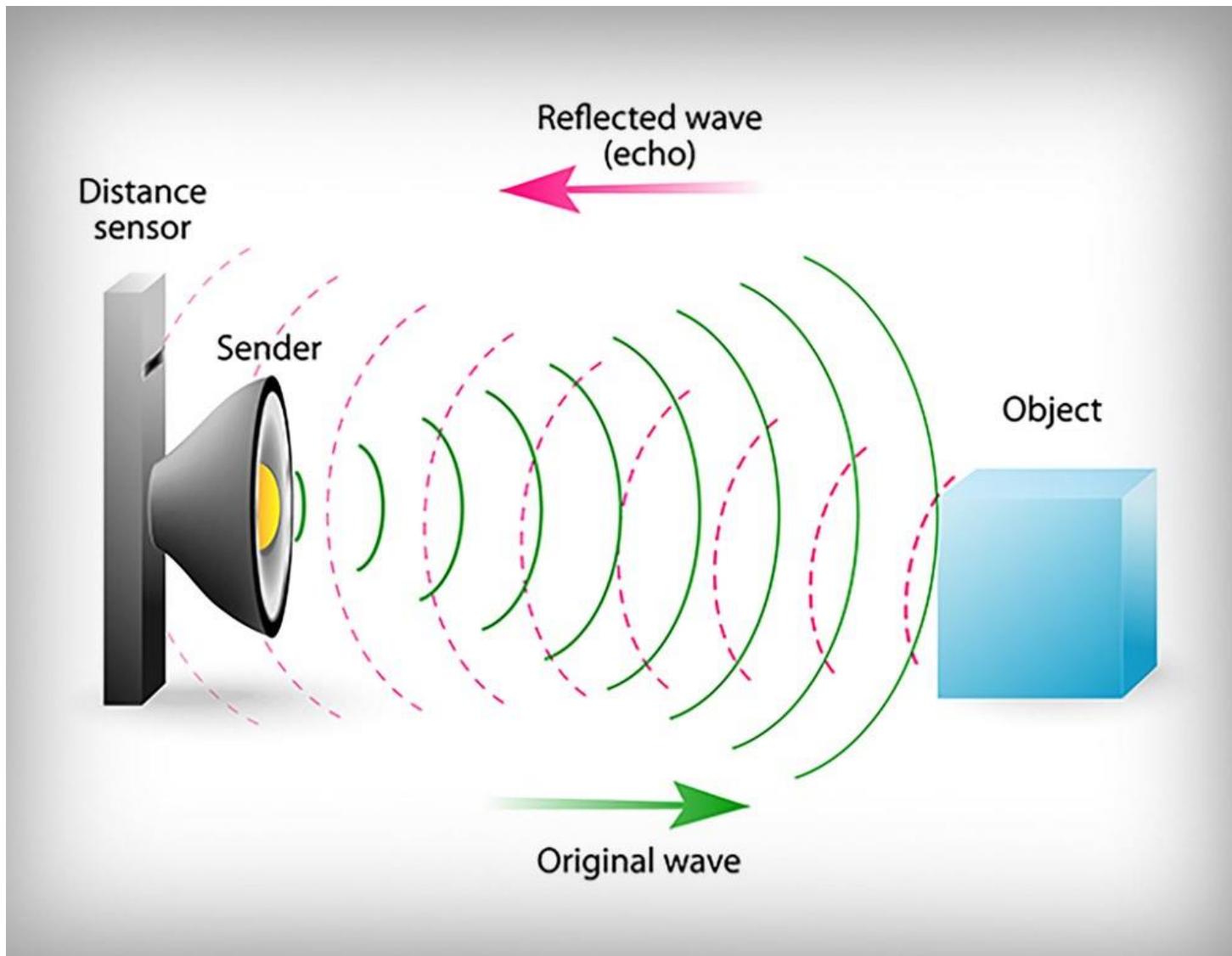
Ultrasonic Distance Sensor

Transmit



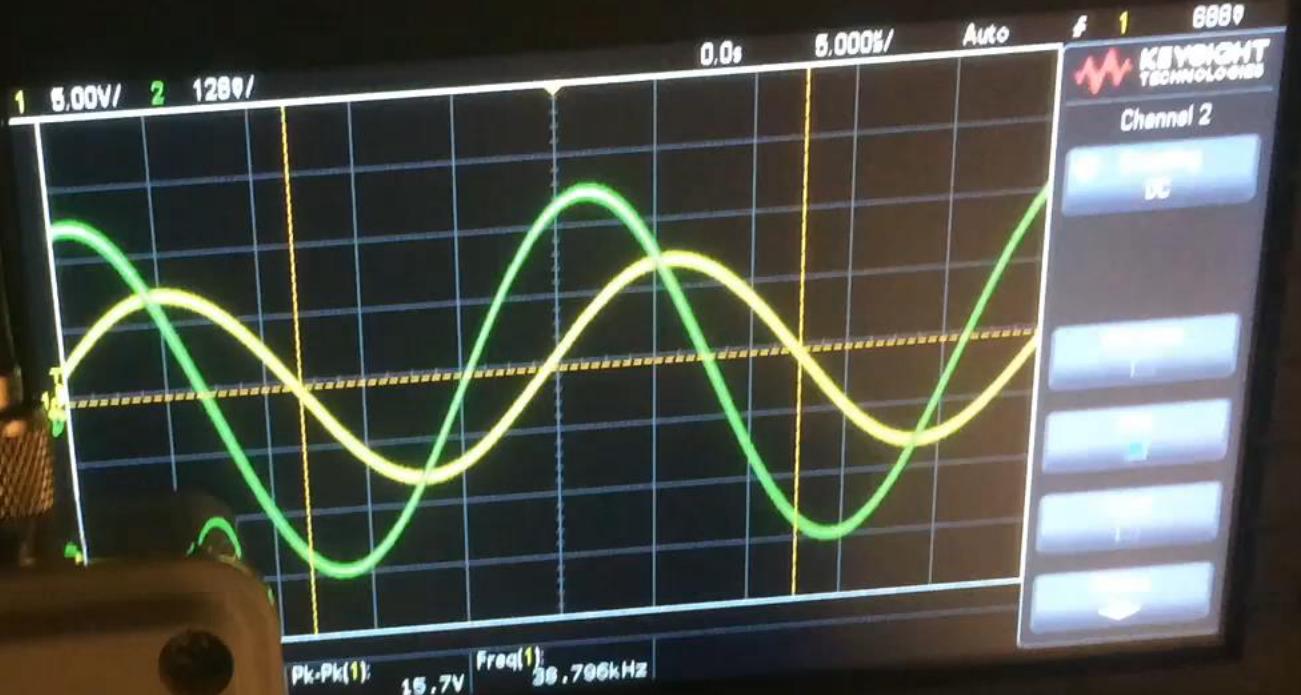
Sensor

Ultrasonic Distance Sensor



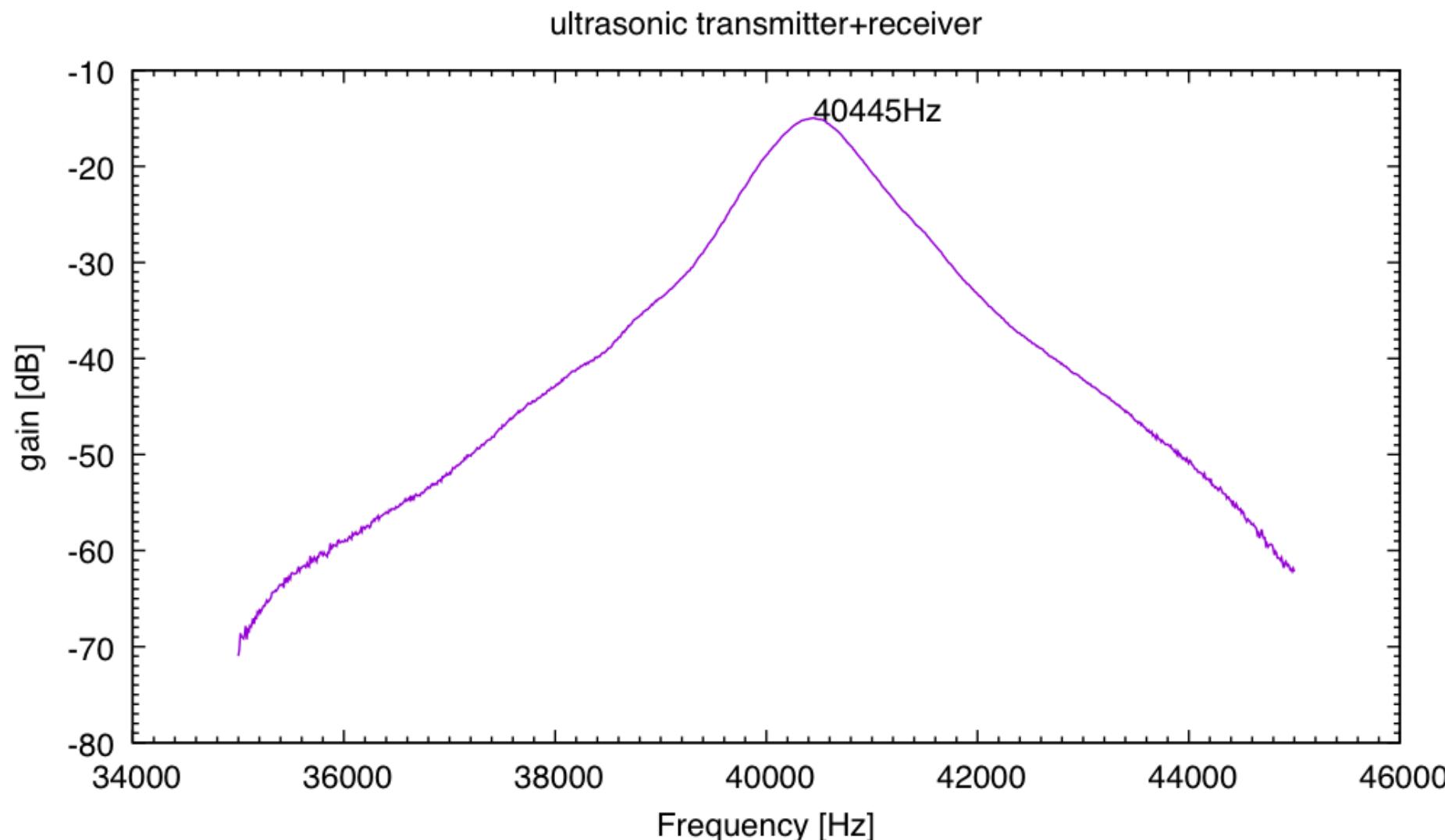
KEYSIGHT EDUX1002A

AUTO Scale

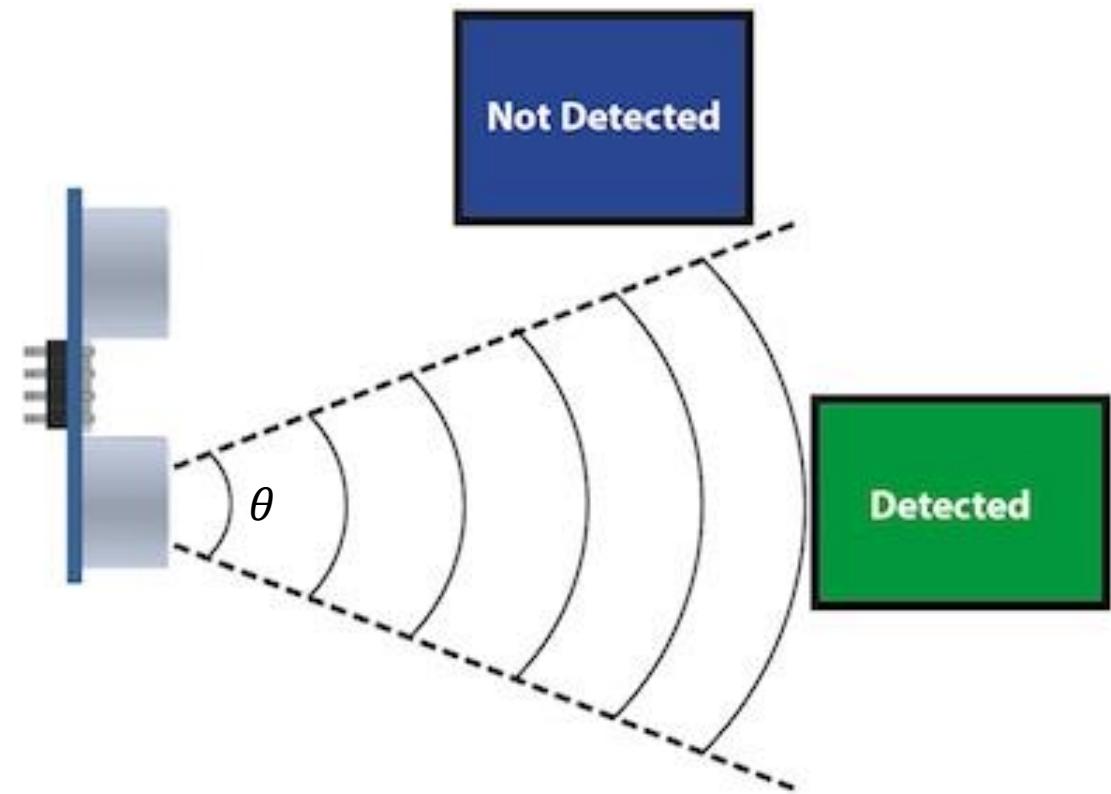
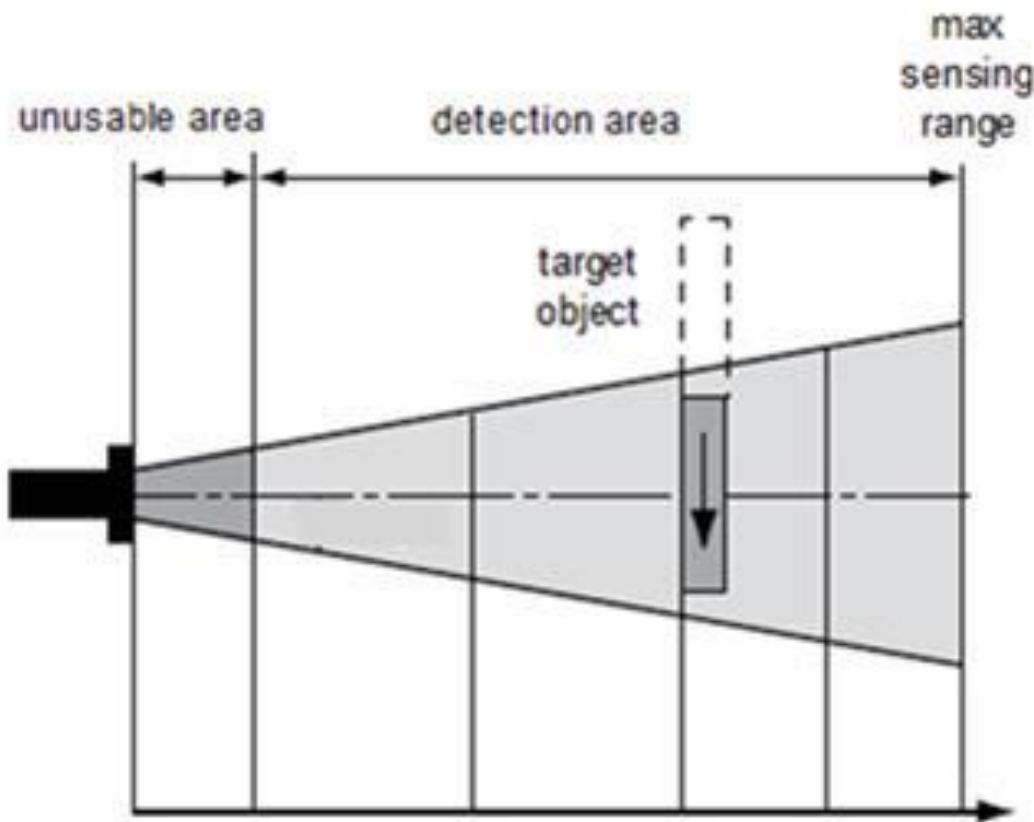


Frekvens:
28.770
steps:
100

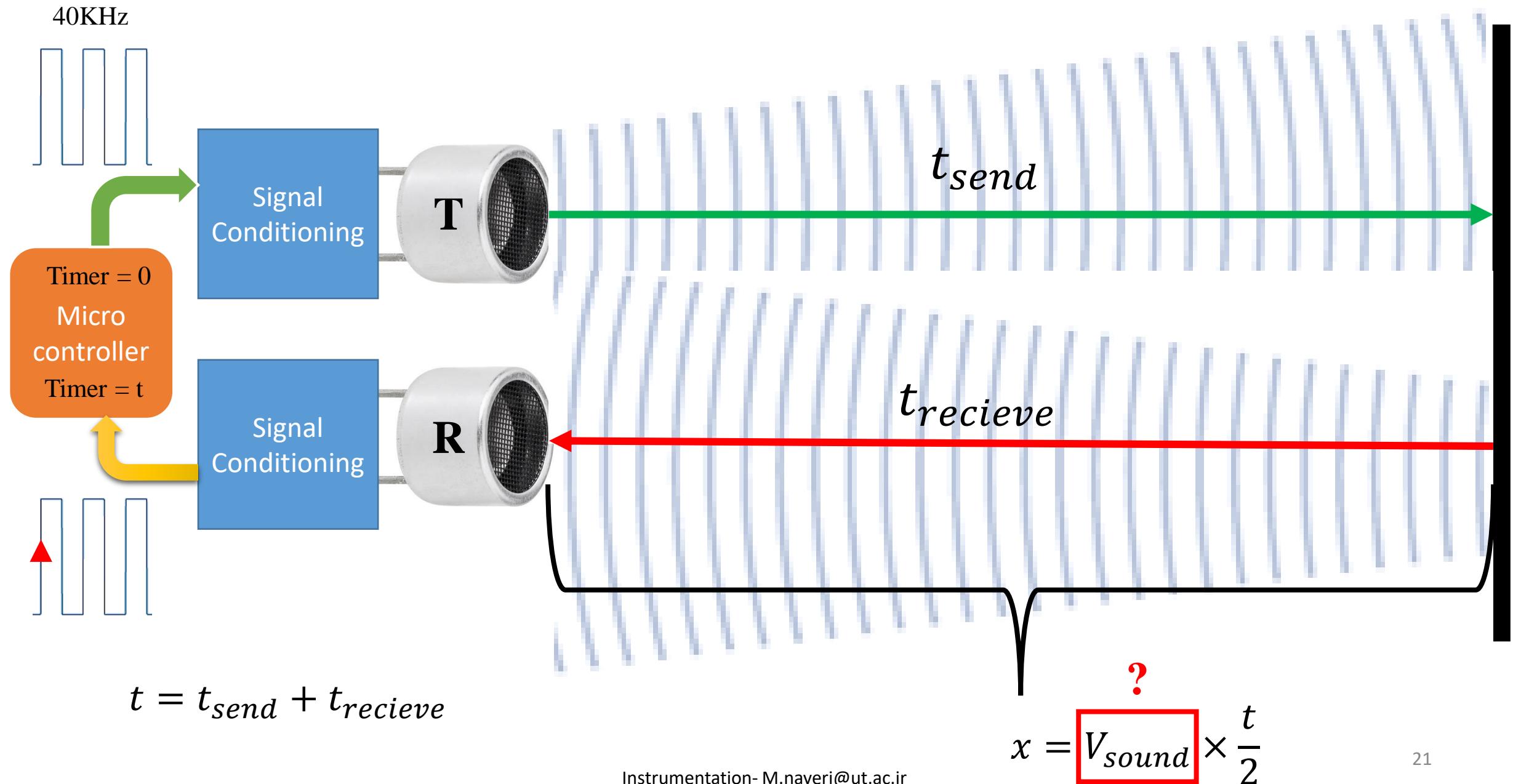
Ultrasonic Distance Sensor



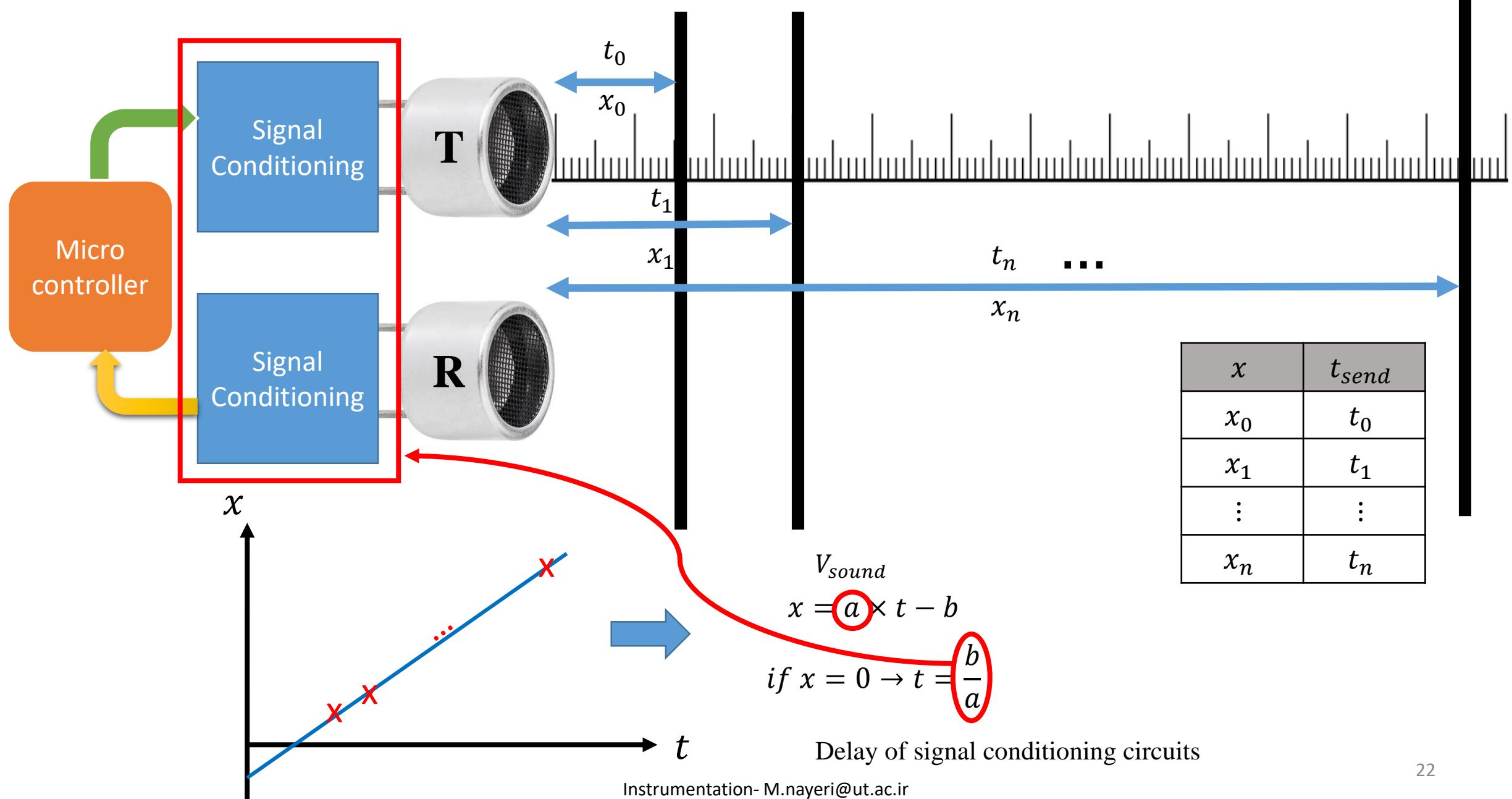
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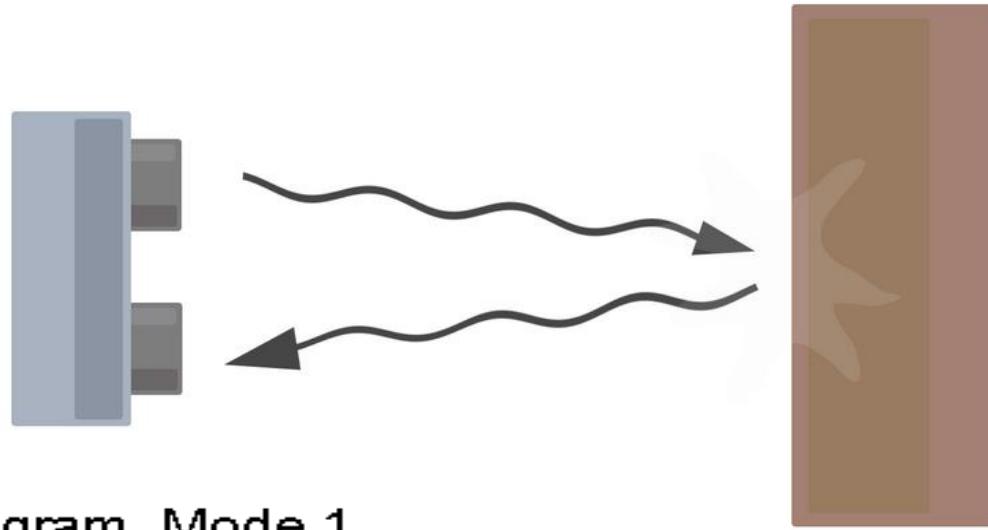
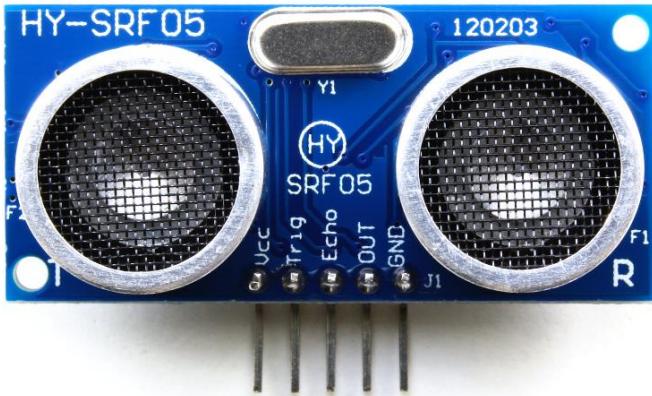
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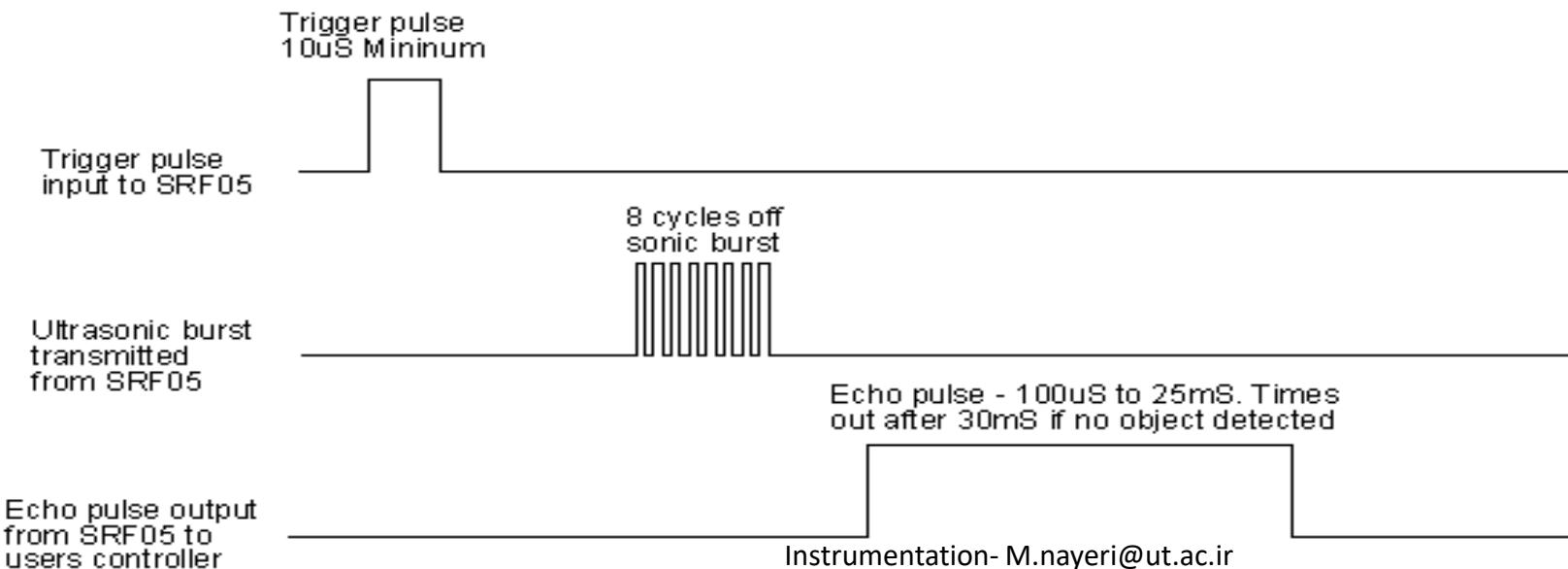
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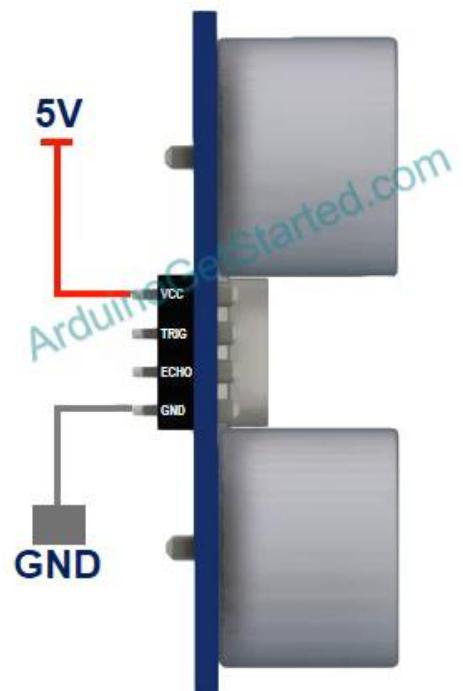
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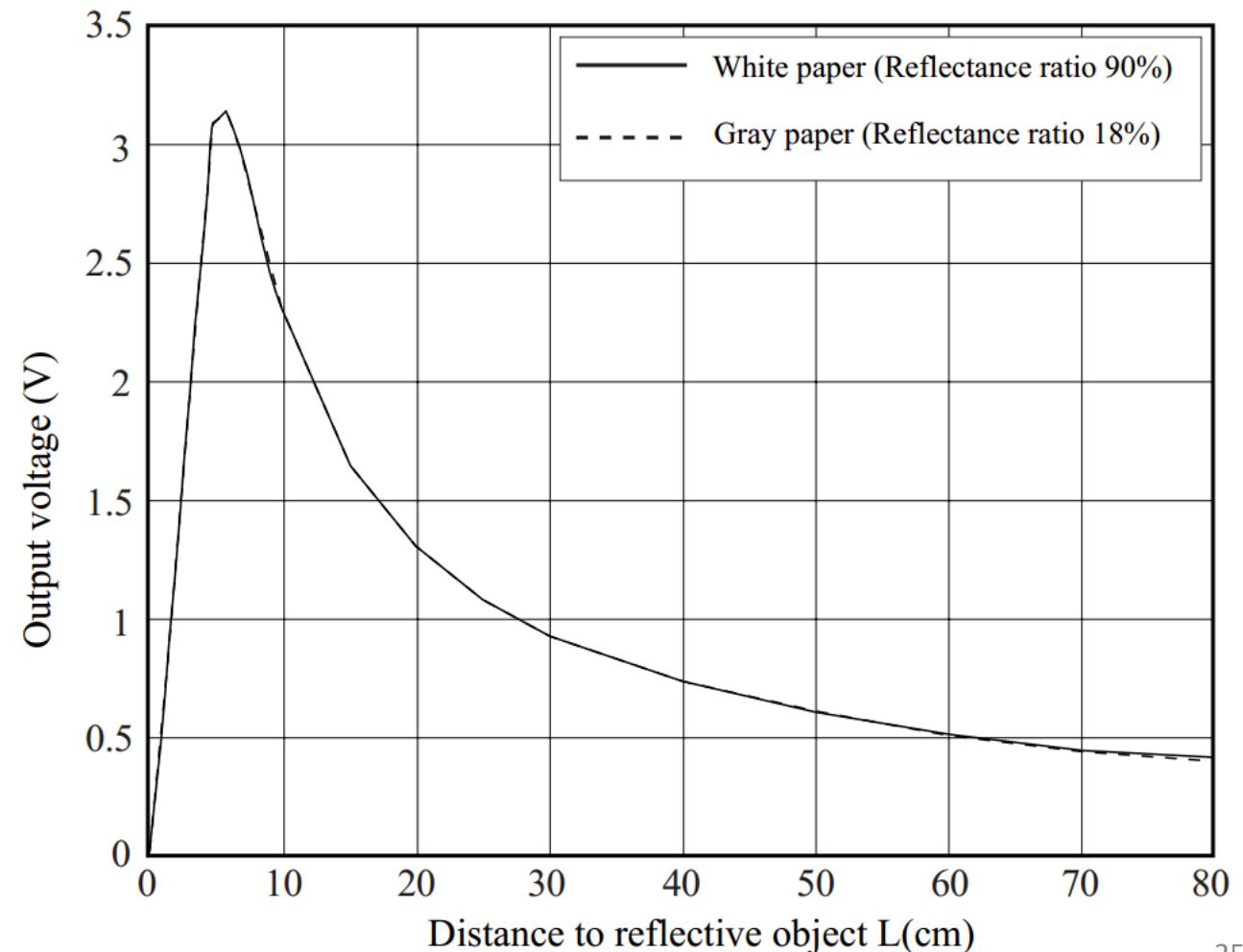
SRF05 Timing Diagram, Mode 1



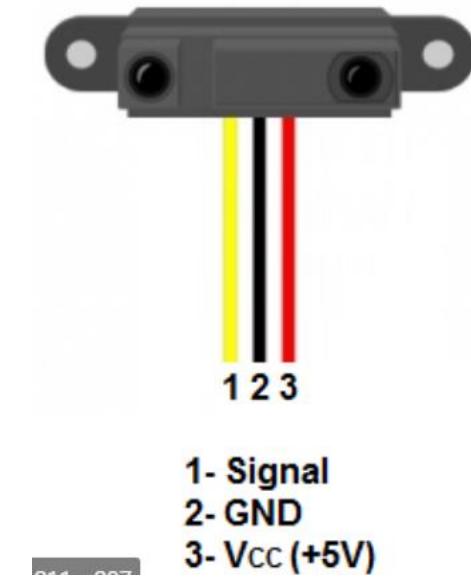
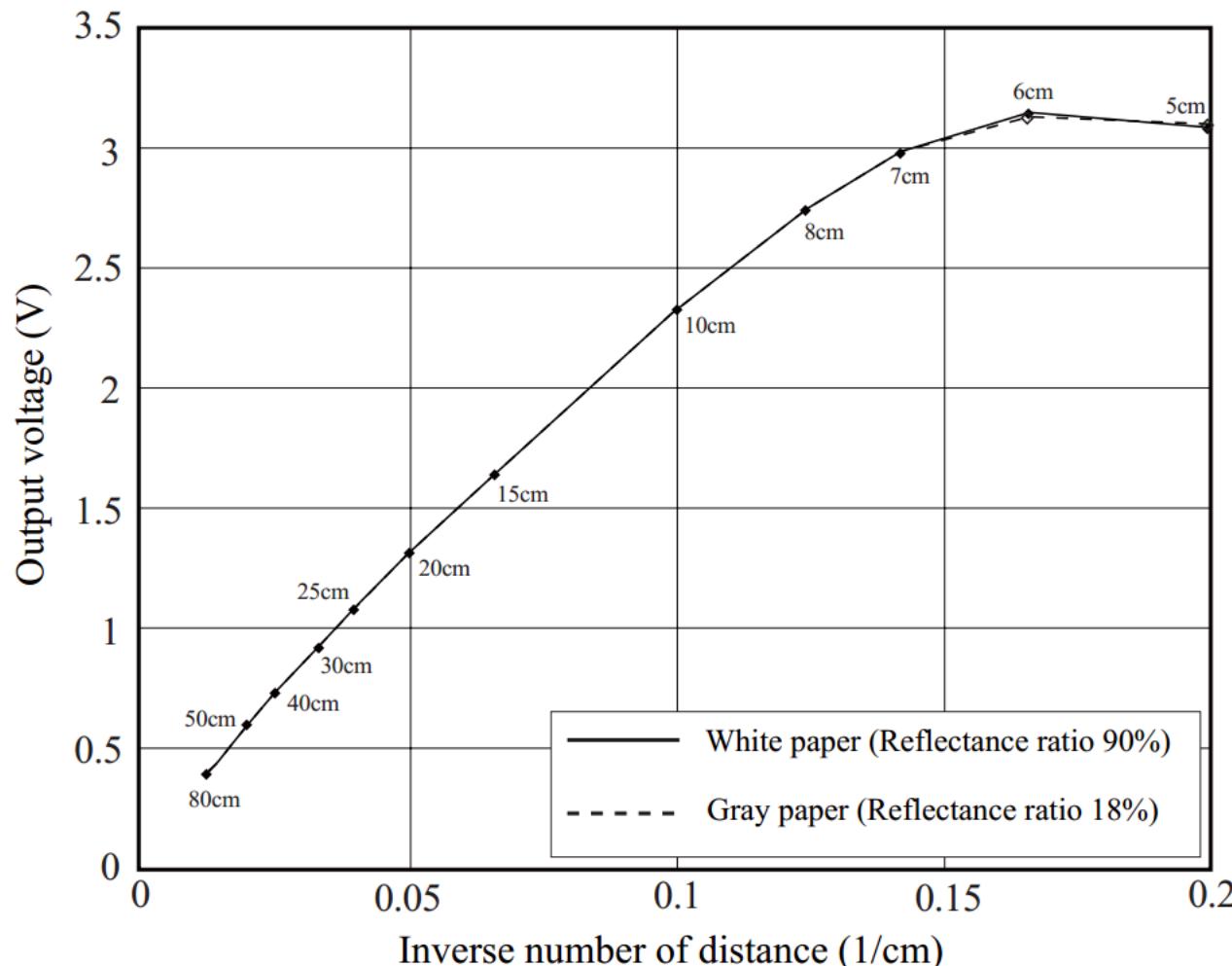
Ultrasonic Distance Sensor



Optical Distance Sensor



Optical Distance Sensor



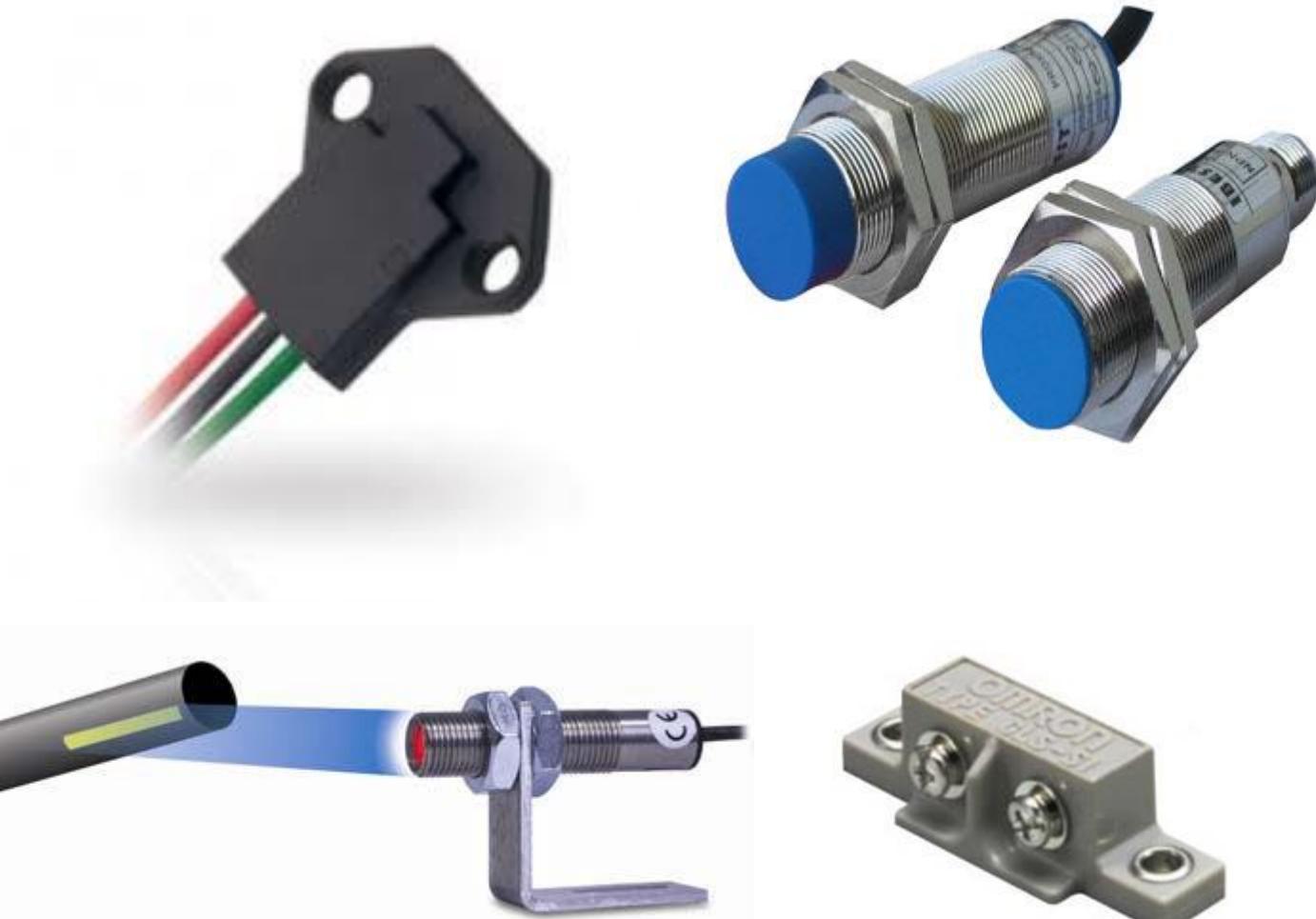
Optical Distance Sensor

Sharp GP2YXX Analog Distance Sensor



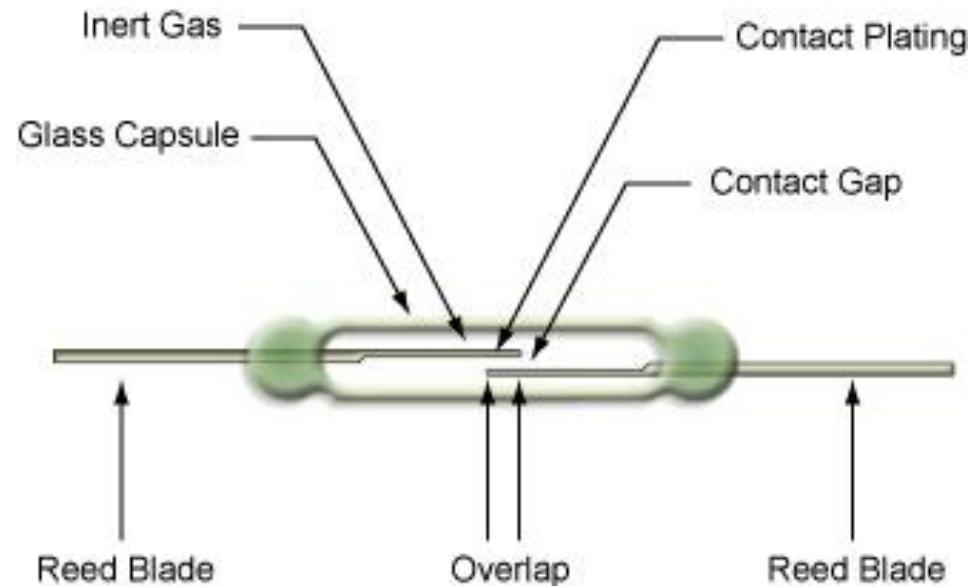
Proximity Sensors

- Magnetic
- Inductive
- Capacitive
- Optical
- Ultrasonic



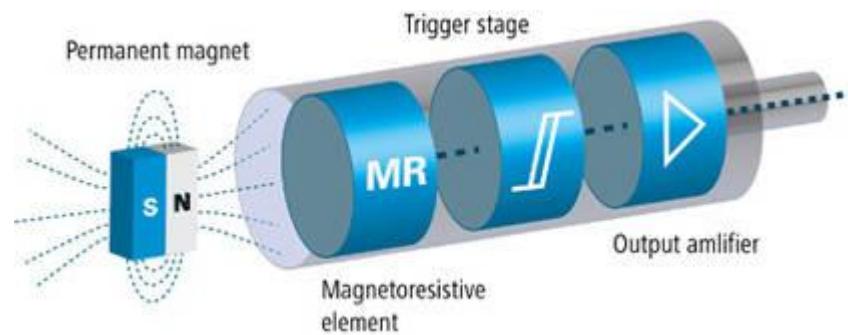
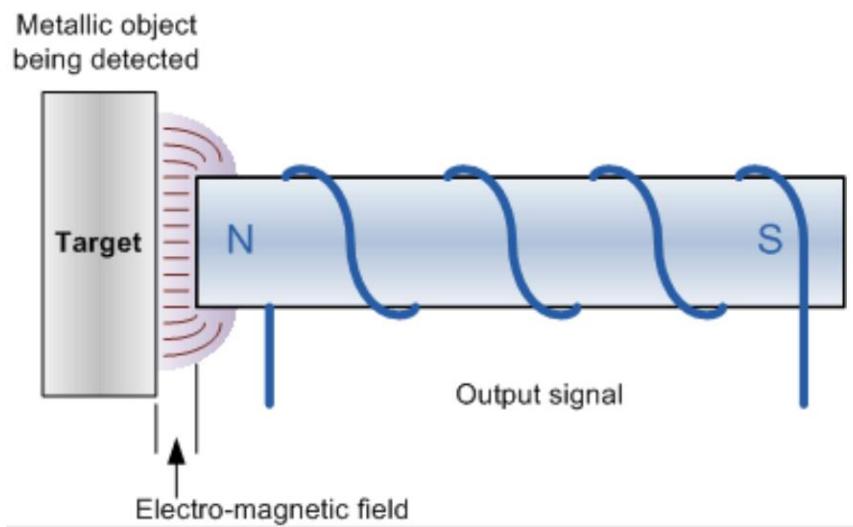
Magnetic Proximity Sensor

Reed Relay



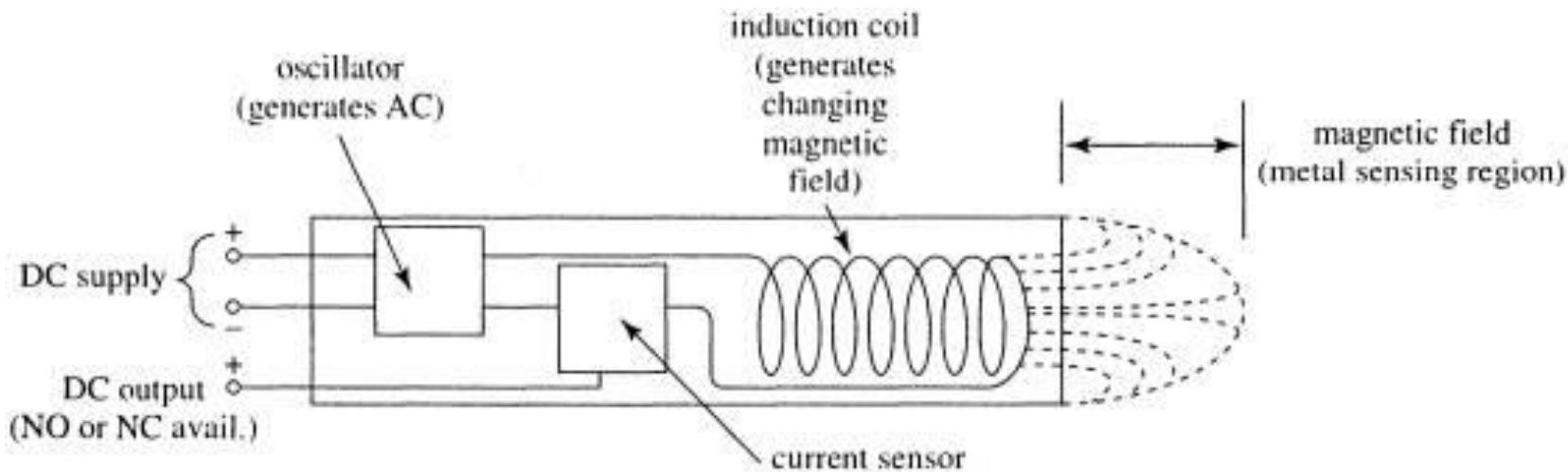
- ✓ Detects Magnetic objects without physical contact

Magnetic Proximity Sensor



- ✓ Detects Magnetic objects without physical contact

Inductive Proximity Sensor



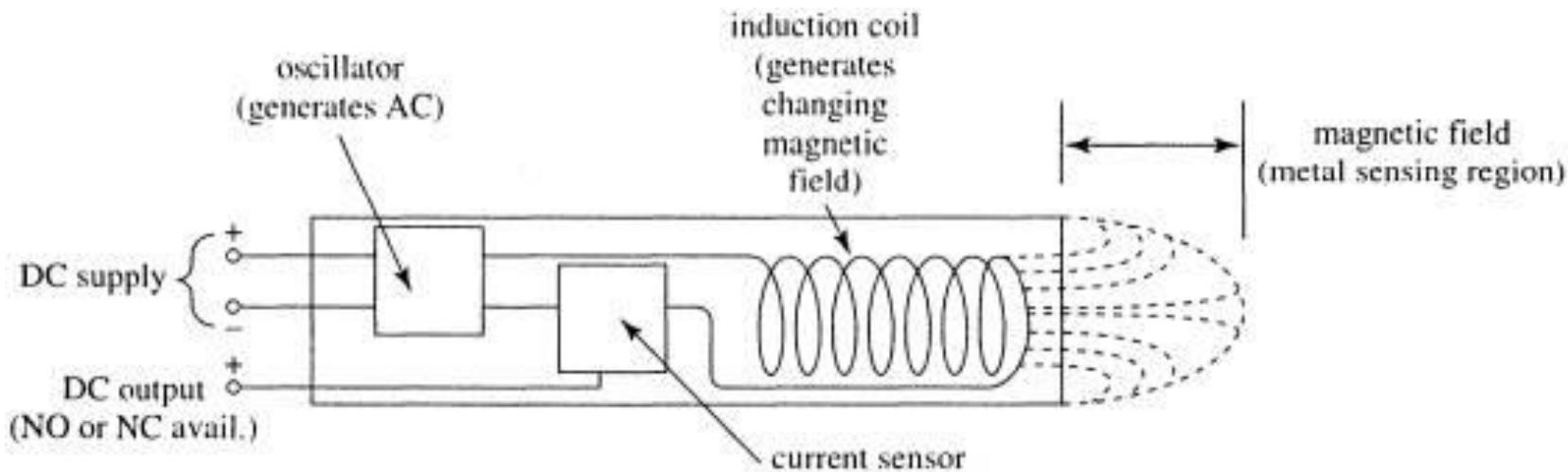
- ✓ Detects Metallic objects without physical contact

Operating distance depends on:

- Coil's size
- Target's shape, size, material



Inductive Proximity Sensor



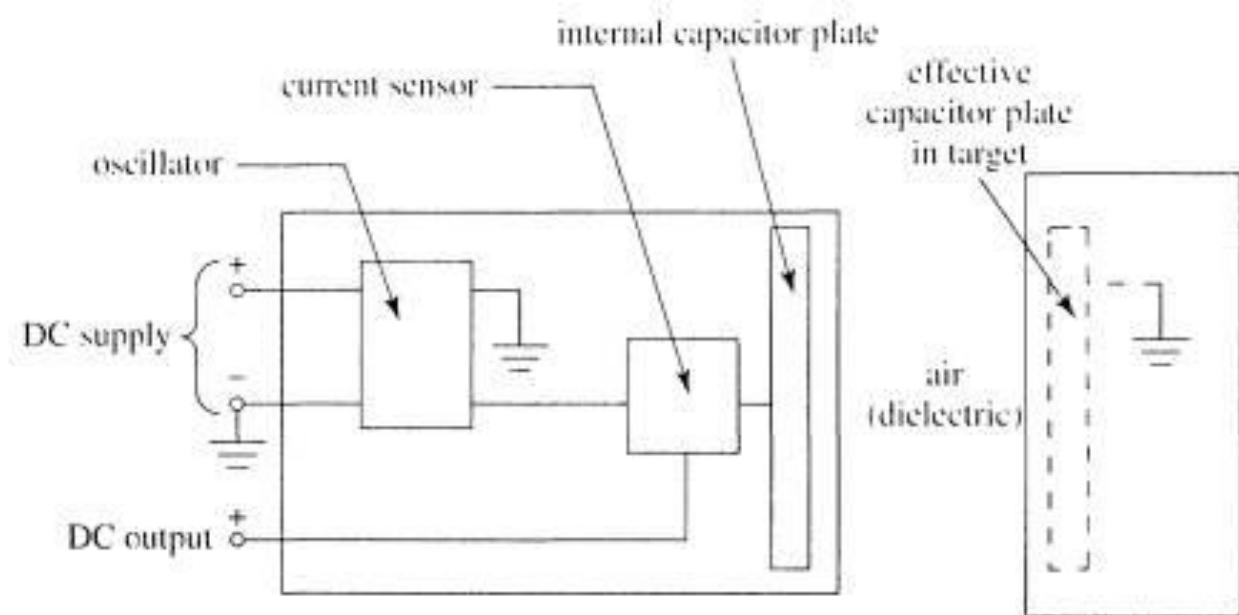
- ✓ Detects Metallic objects without physical contact

Operating distance depends on:

- Coil's size
- Target's shape, size, material



Capacitive Proximity Sensor



Detects metallic objects as well as non-metallic objects(liquid, plastic, wooden material etc)

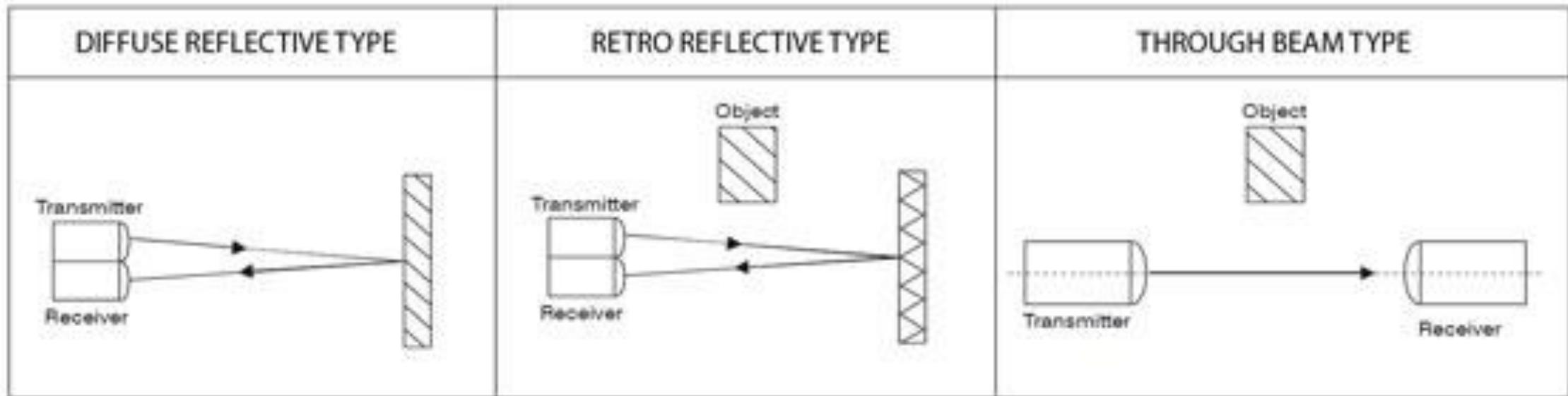
- ✓ Uses variation of capacitance between sensor and object

Optical Proximity Sensor

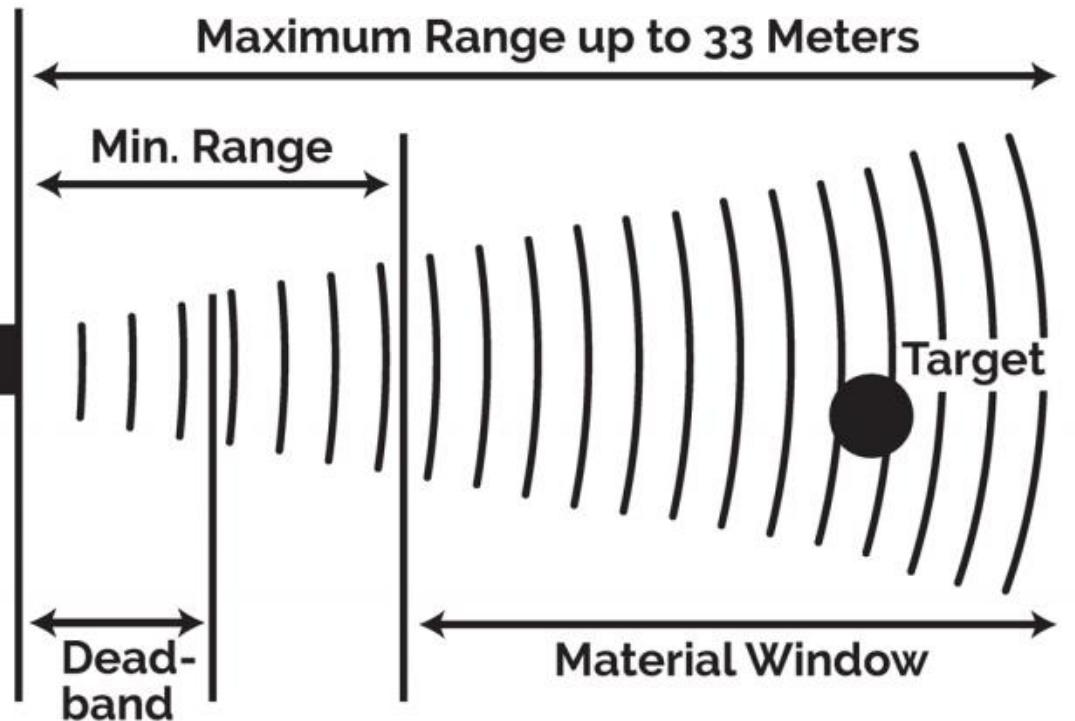
- Senses any object within 10 meters range
- Uses an LED in either infrared or visible light spectrum to transmit
- Phototransistor detects the light generated
- Generally light sources pulse the infra-red light on and off at a fixed frequency.
- Sensor detects object when it disrupts light beam



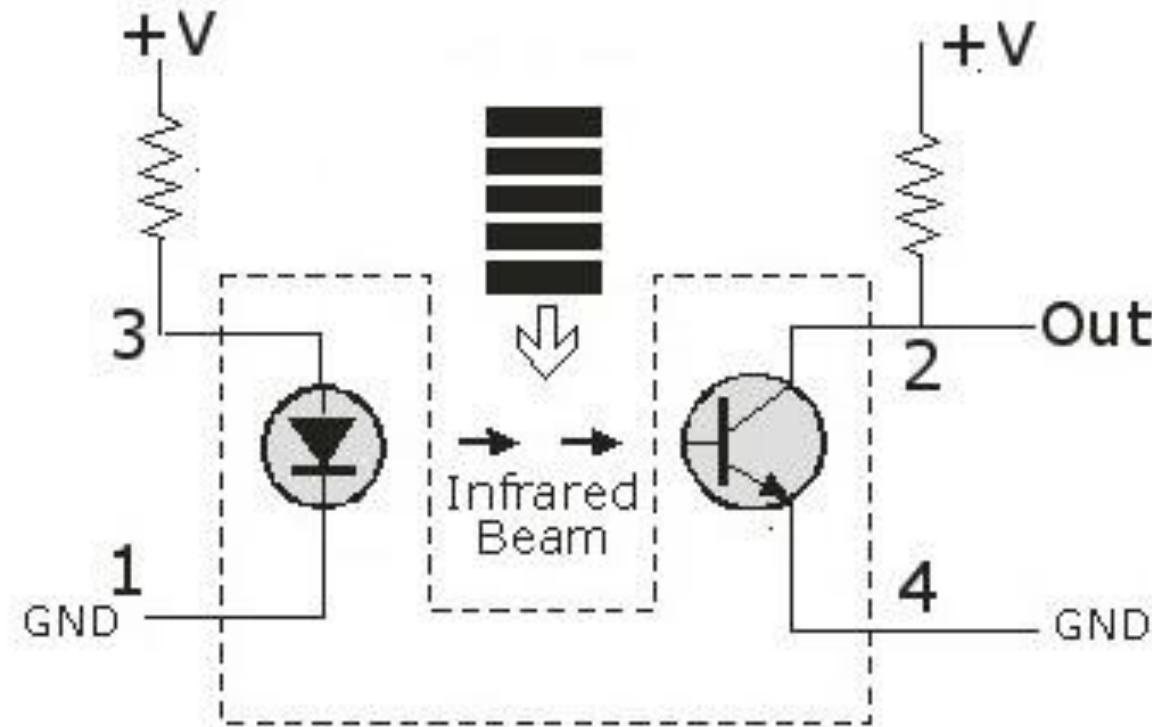
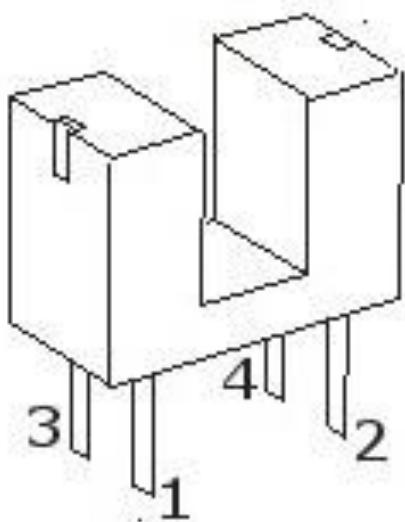
Optical Proximity Sensor



Ultrasonic Proximity Sensor



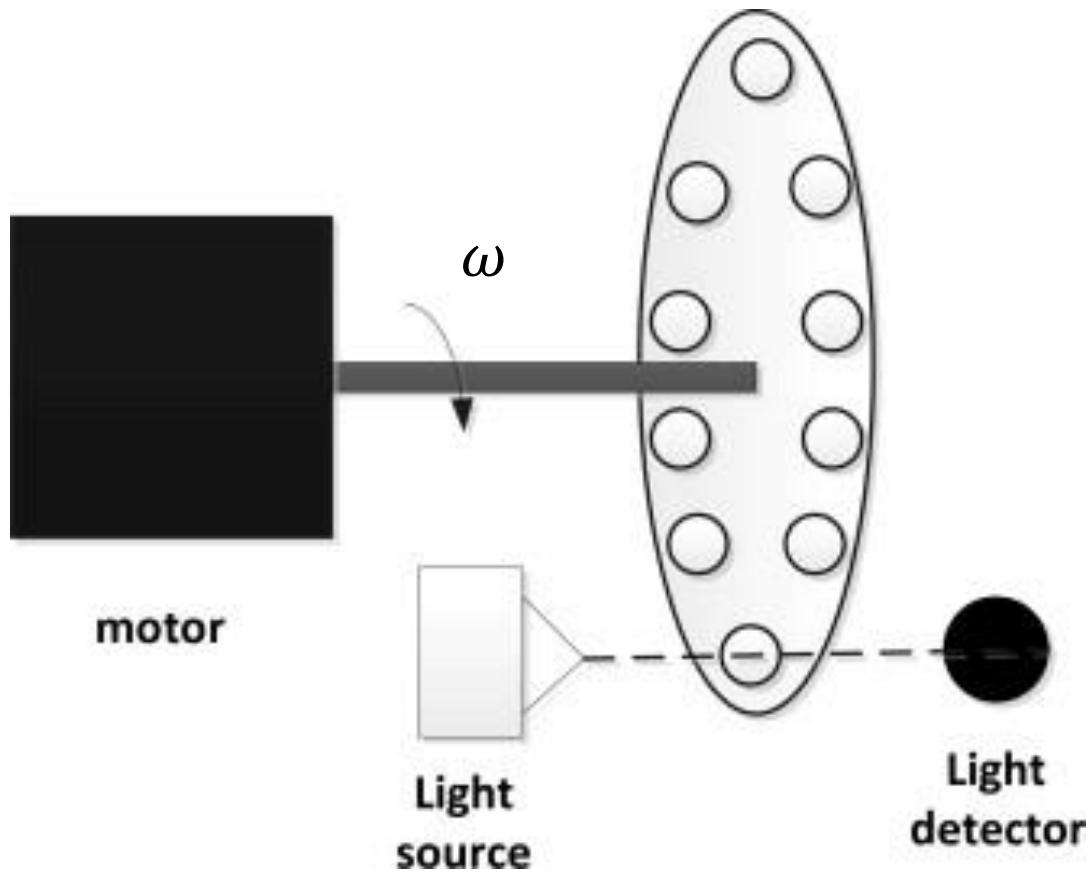
Optocounter





Optocounter

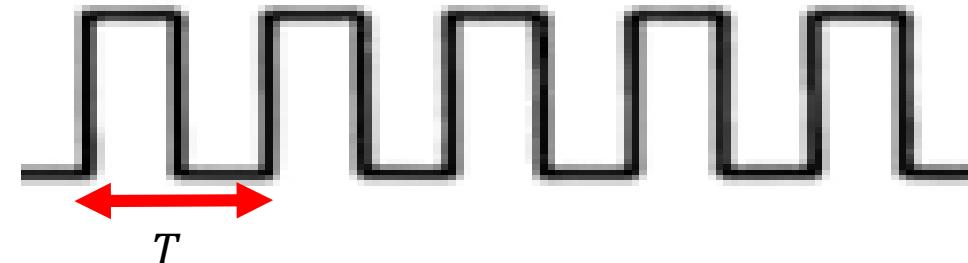
Number of Holes: n



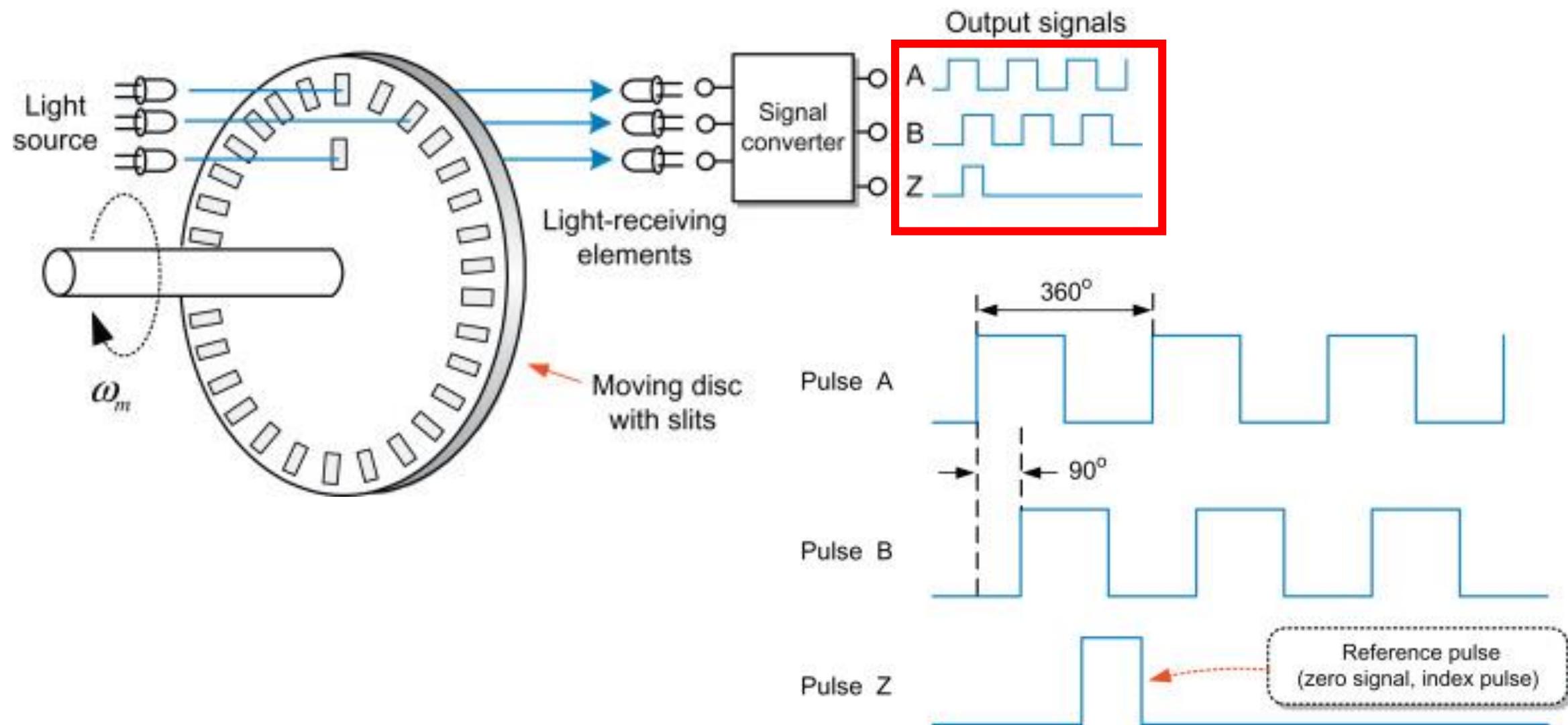
One Revolution Time = nT

$$\rightarrow \text{Revolutions Per Second (RPS)} = \frac{1}{nT}$$

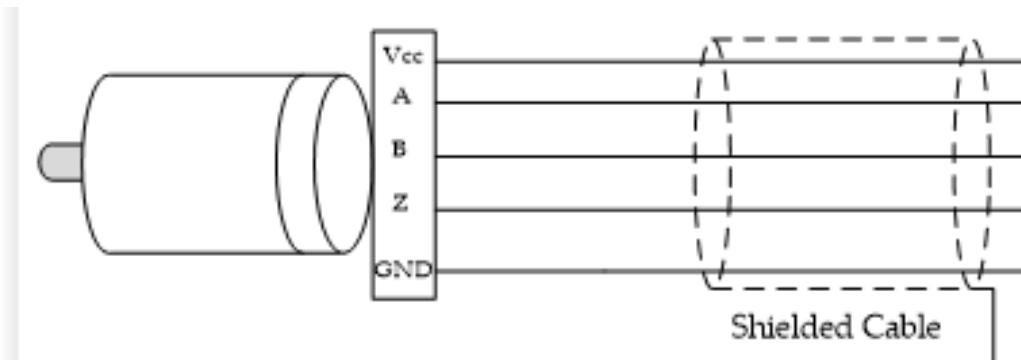
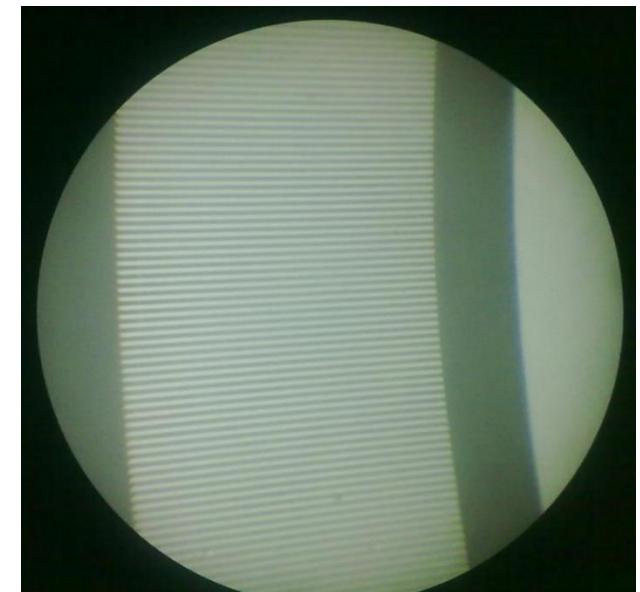
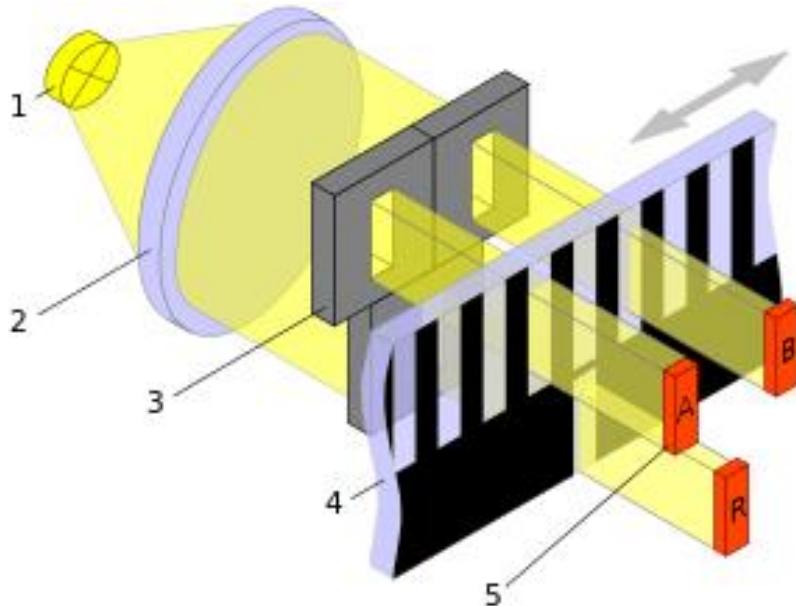
$$\text{Revolutions Per Minute (RPM)} = \frac{60}{nT} = \frac{60f}{n}$$



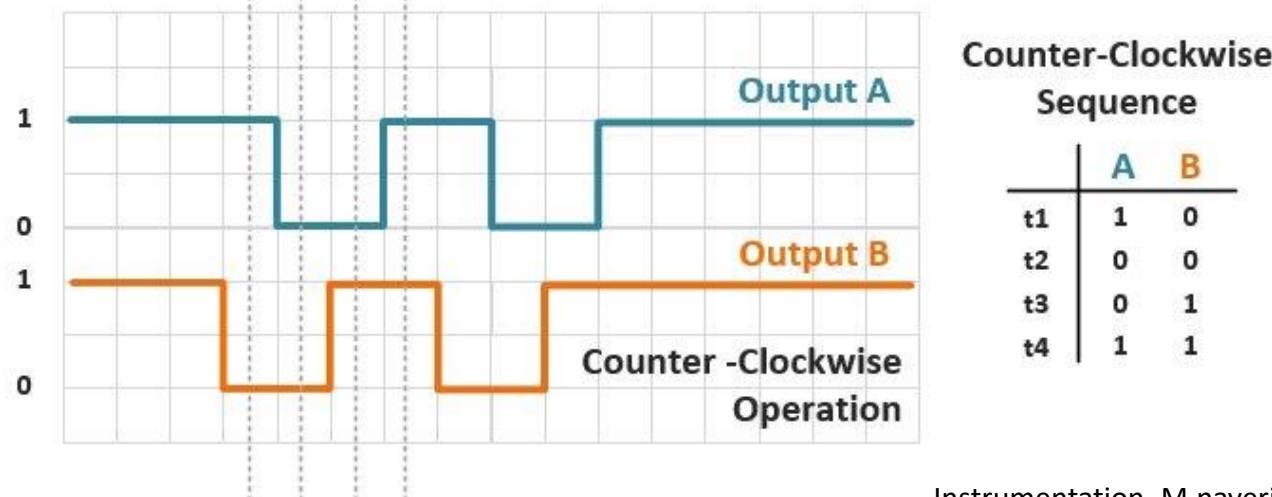
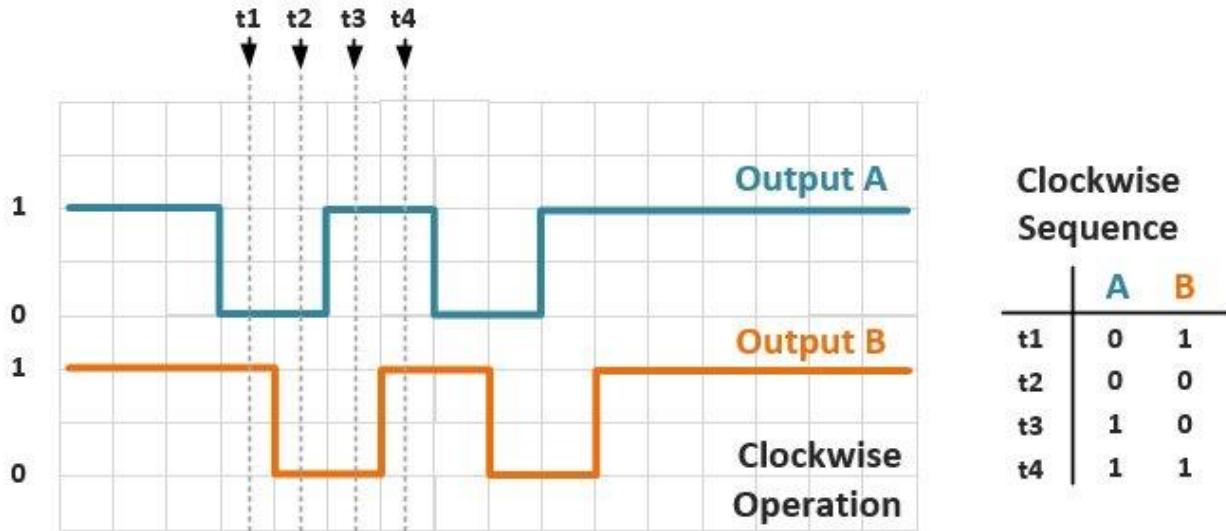
Incremental Encoder

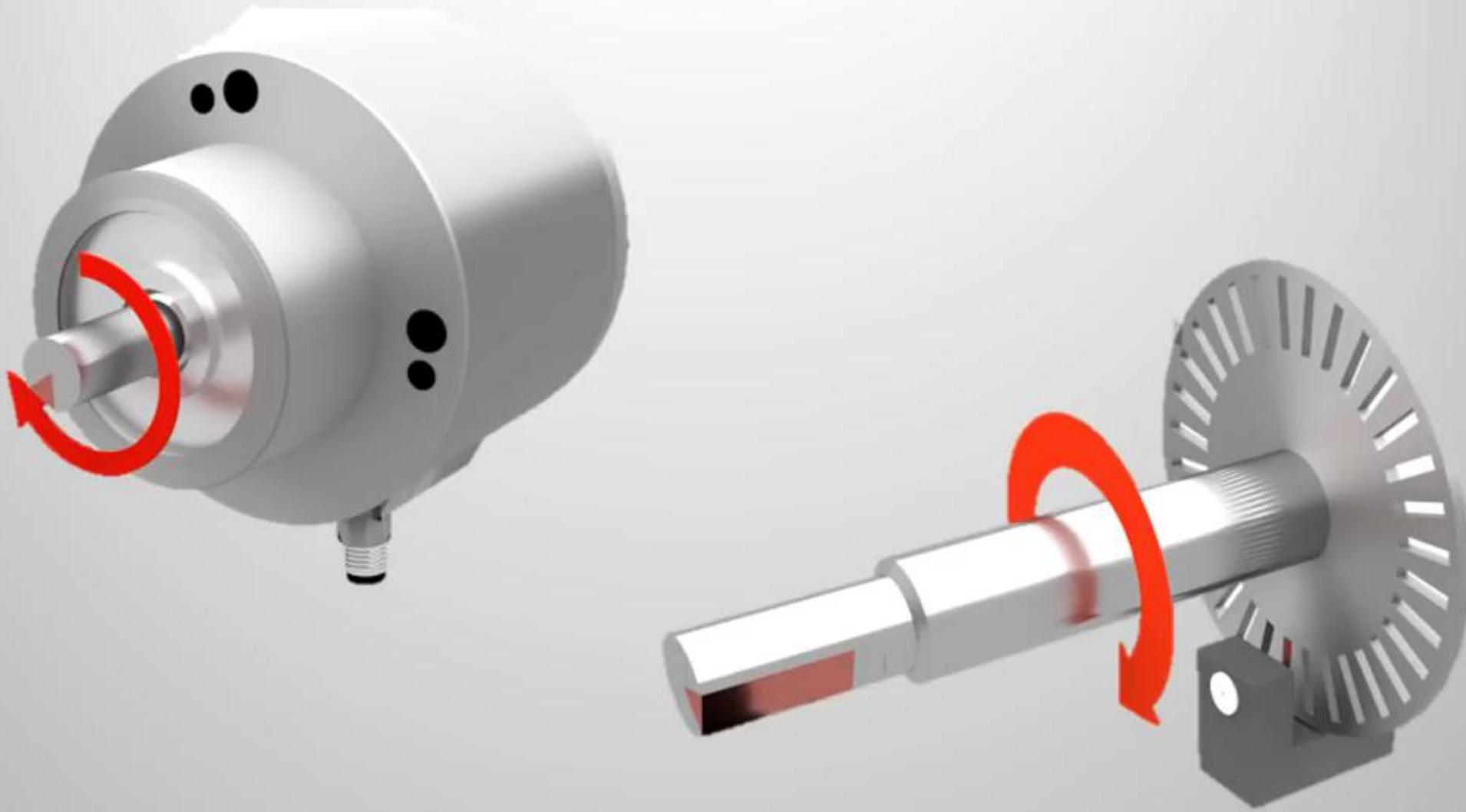


Incremental Encoder

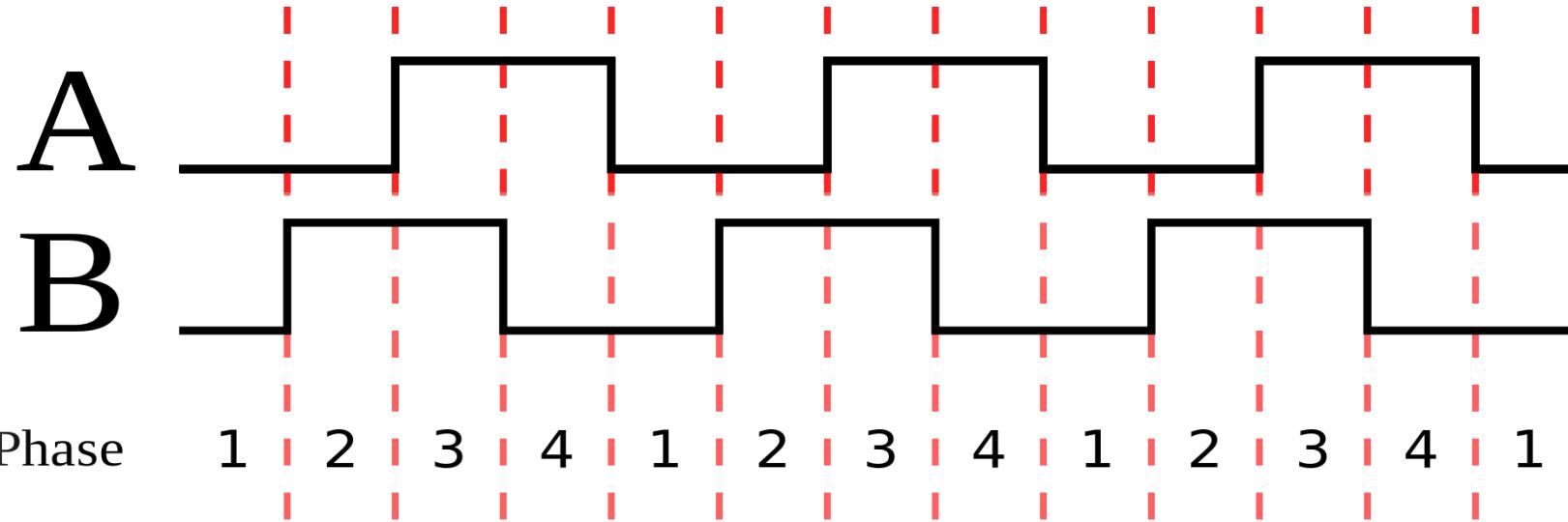


Incremental Encoder





Incremental Encoder



Number of Holes: n

$$\text{Rising Edge Interrupt on } A: \quad \pm \frac{360}{n}$$

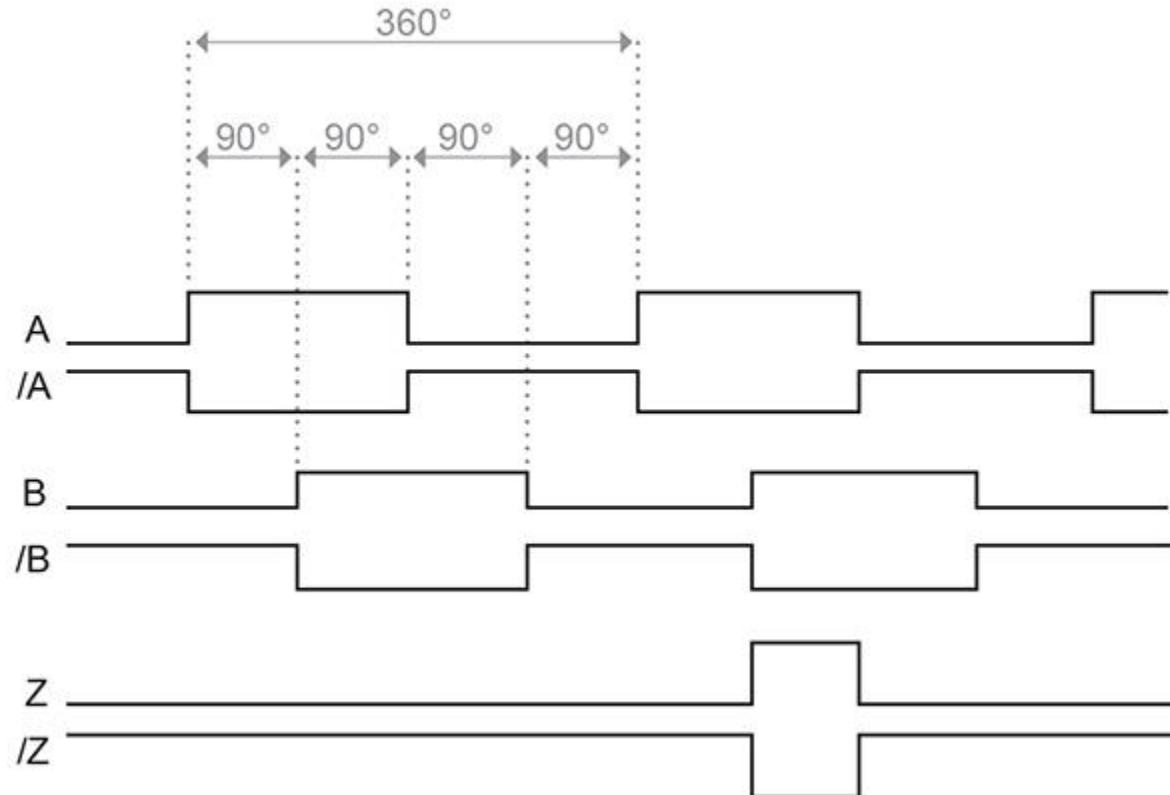
$$\text{Rising and Falling Edge Interrupt on } A: \quad \pm \frac{360}{2n}$$

$$\text{Rising and Falling Edge Interrupt on } A \text{ and } B: \quad \pm \frac{360}{4n}$$

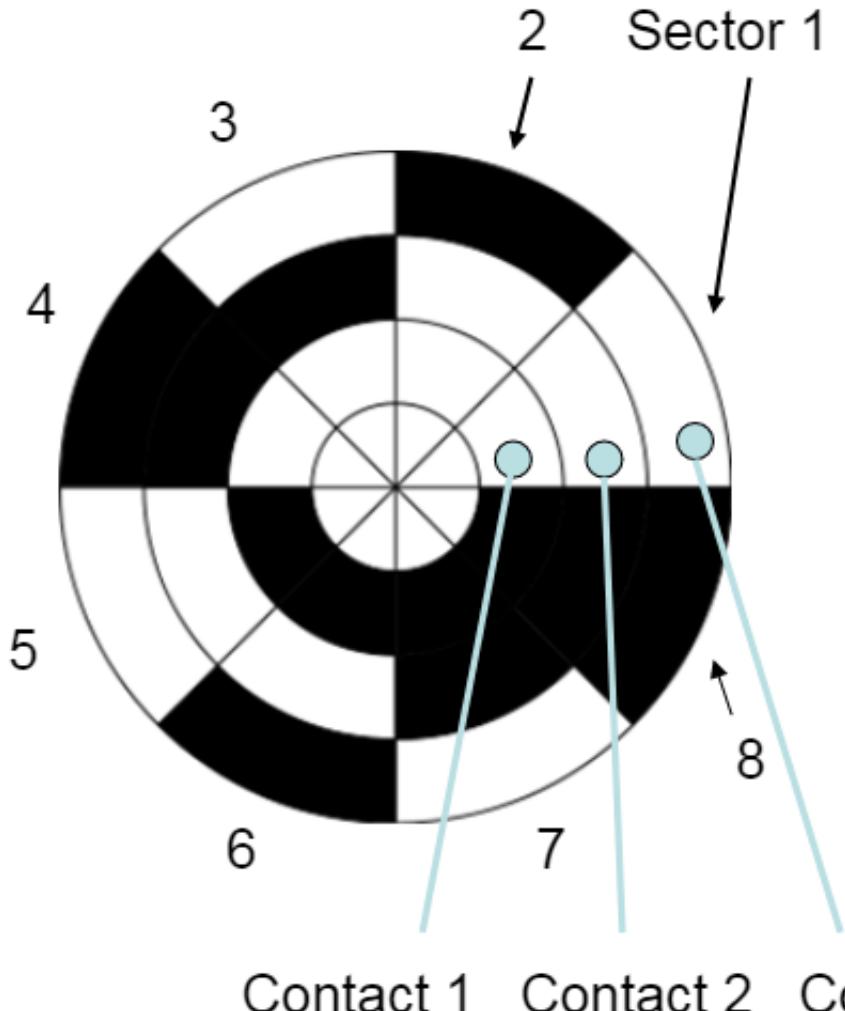
Incremental Encoder

Differential RS-422 signaling is typically preferred:

- ✓ When the encoder will output high frequencies.
- ✓ When the encoder be located far away from the encoder interface.
- ✓ When the encoder signals may be subjected to electric fields or common-mode voltages.
- ✓ When the interface must be able to detect connectivity problems between encoder and interface.

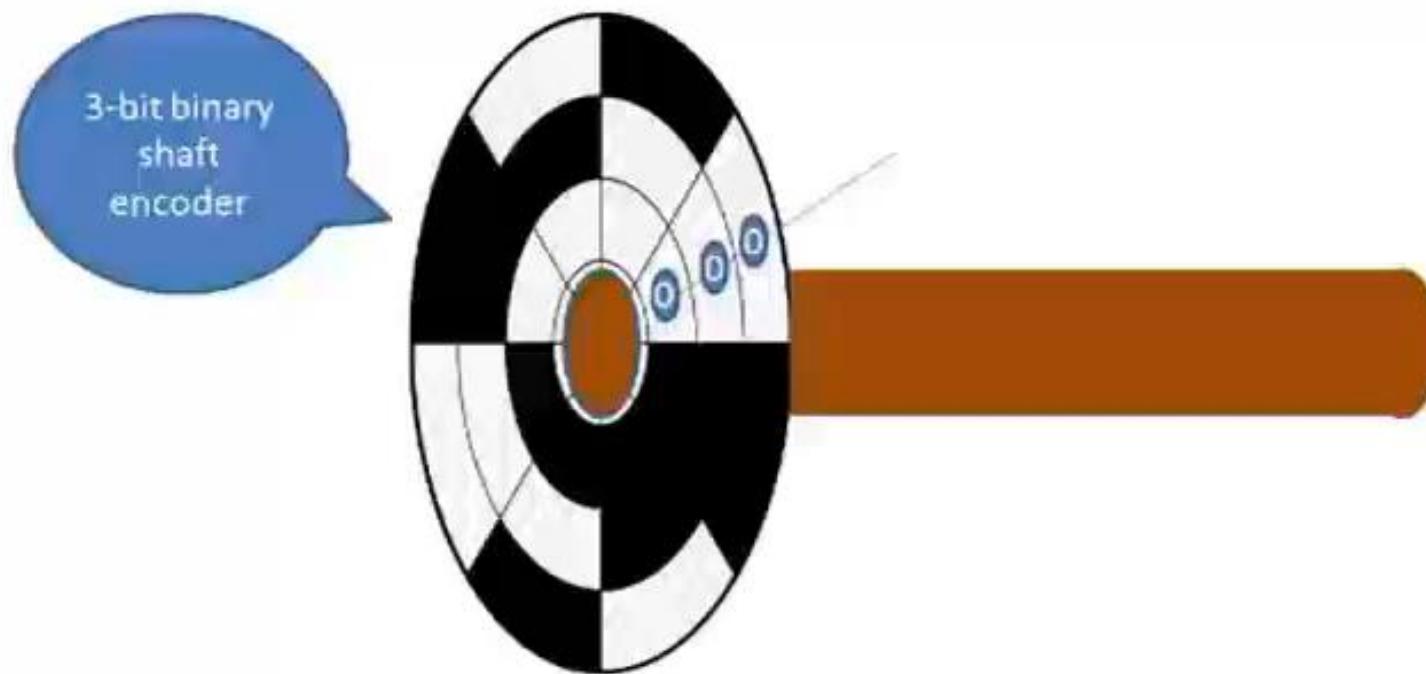


Absolute Encoder

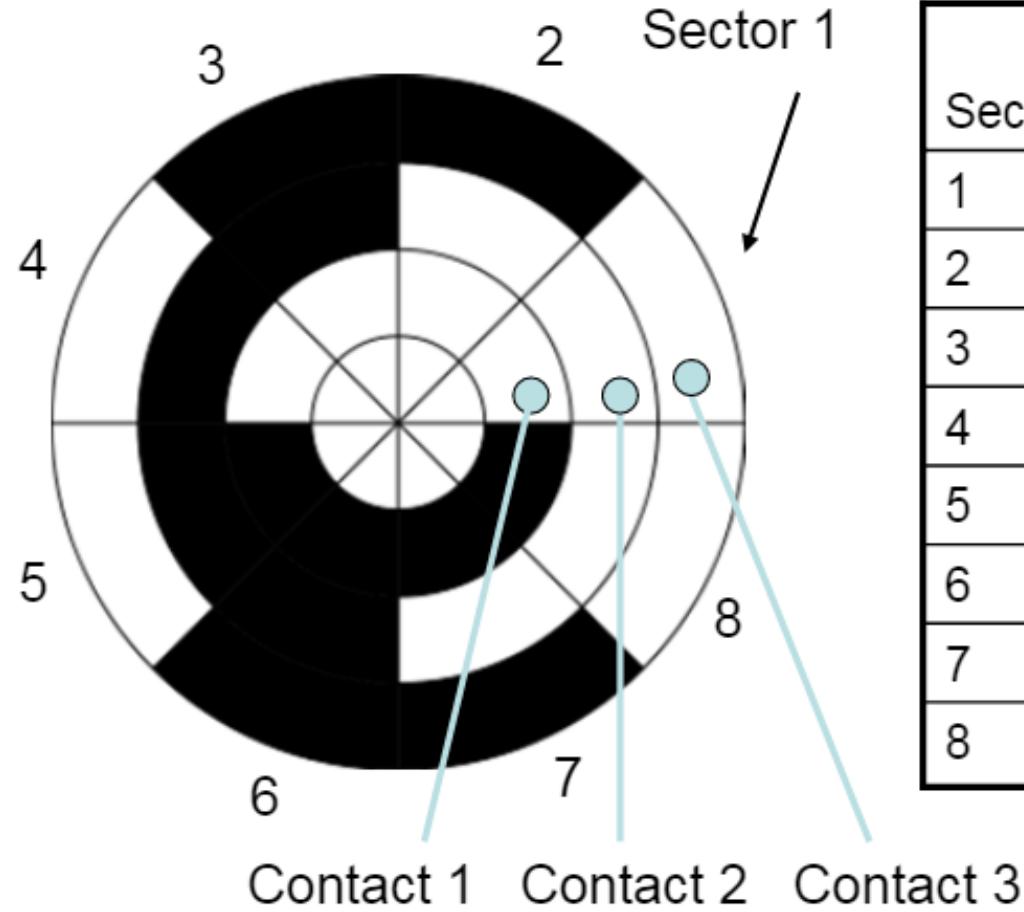


Sector	Contact 1	Contact 2	Contact 3	Angle
1	off	off	off	0° - 45°
2	off	off	ON	45° - 90°
3	off	ON	off	90° - 135°
4	off	ON	ON	135° - 180°
5	ON	off	off	180° - 225°
6	ON	off	ON	225° - 270°
7	ON	ON	off	270° - 315°
8	ON	ON	ON	315° - 360°

Absolute Encoder

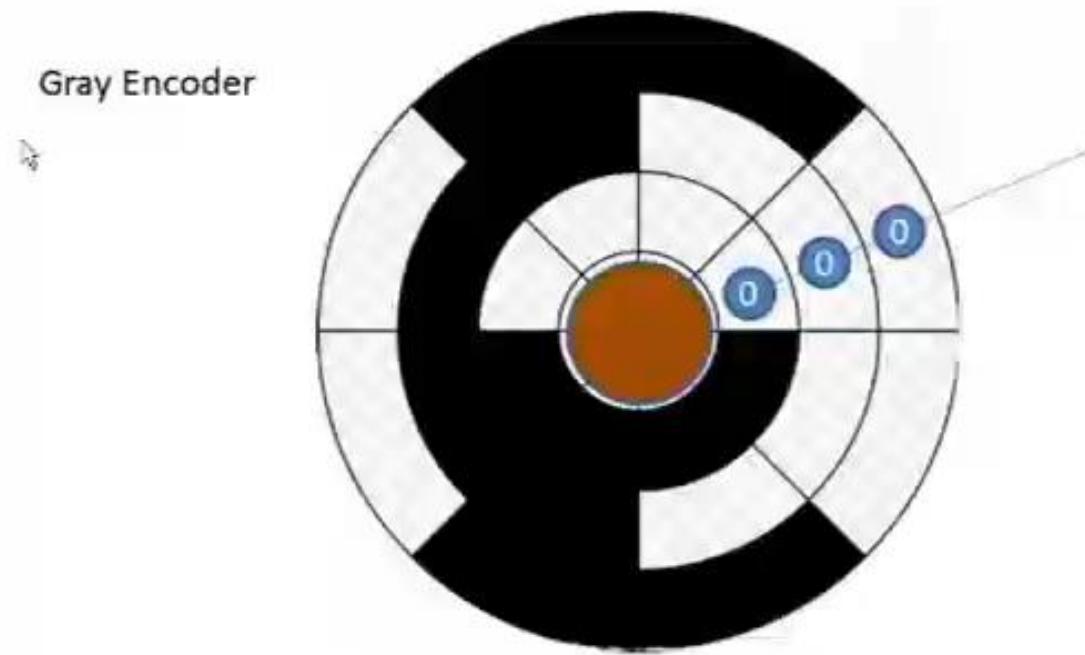


Absolute Encoder

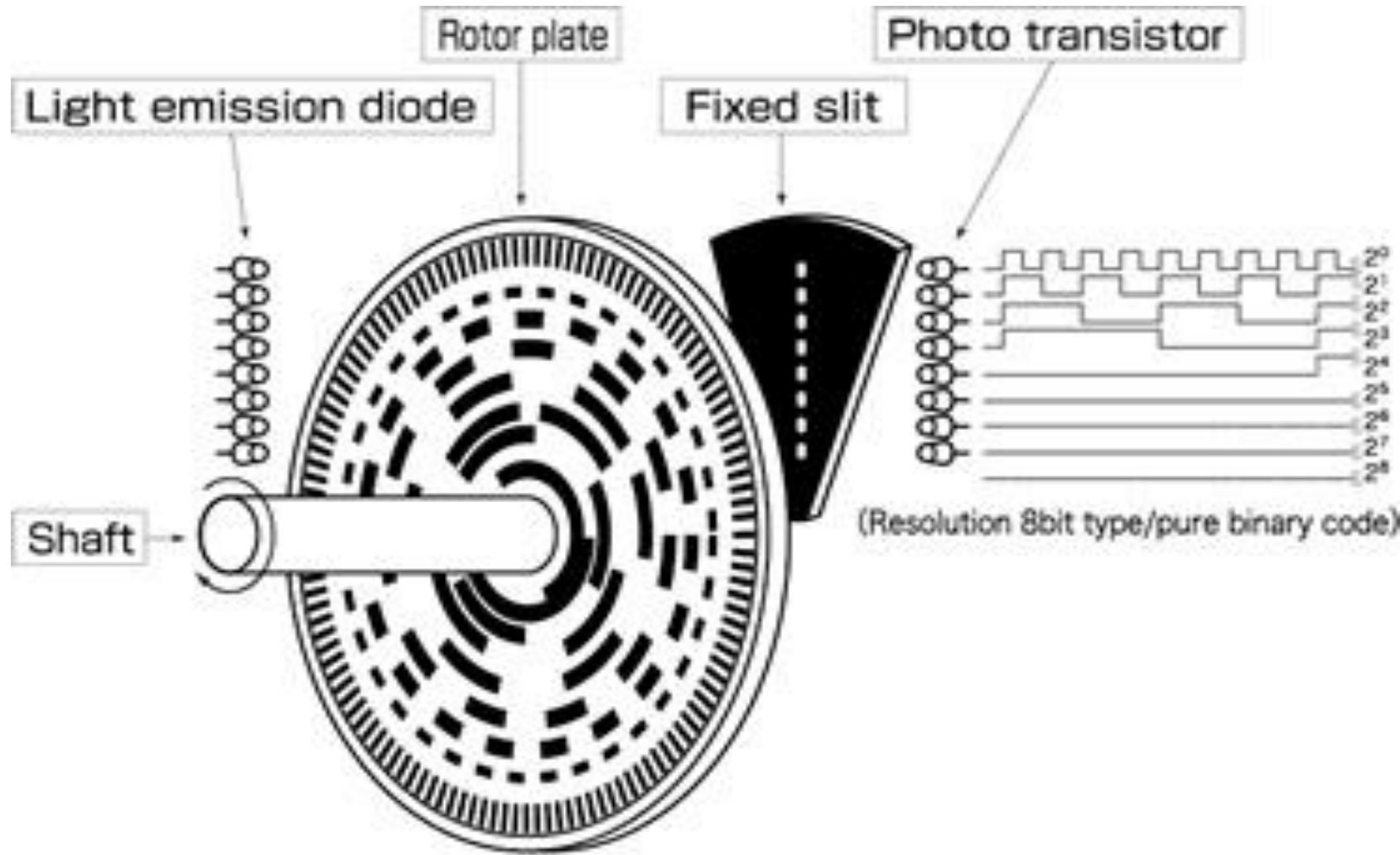
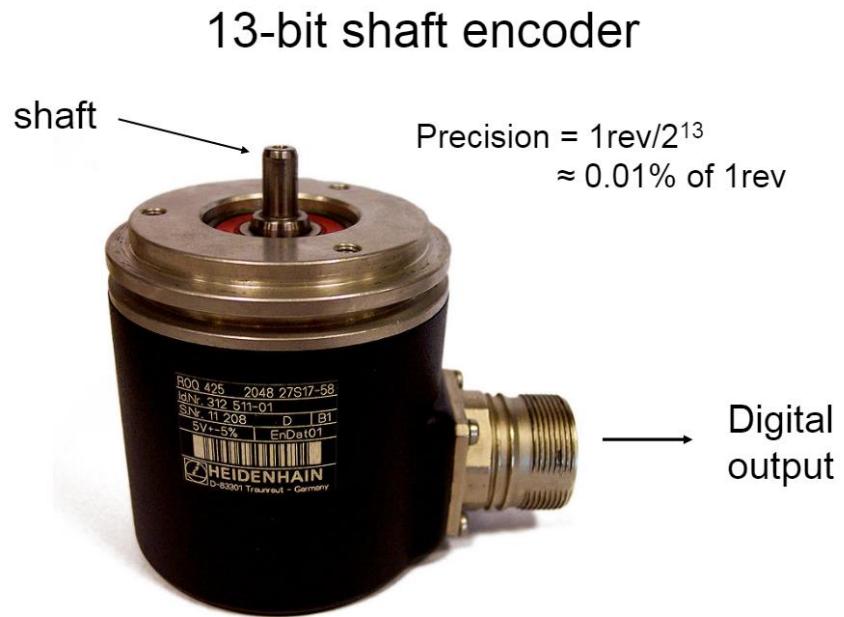


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4	off	ON	off	135° - 180°
5	ON	ON	off	180° - 225°
6	ON	ON	ON	225° - 270°
7	ON	off	ON	270° - 315°
8	ON	off	off	315° - 360°

Absolute Encoder

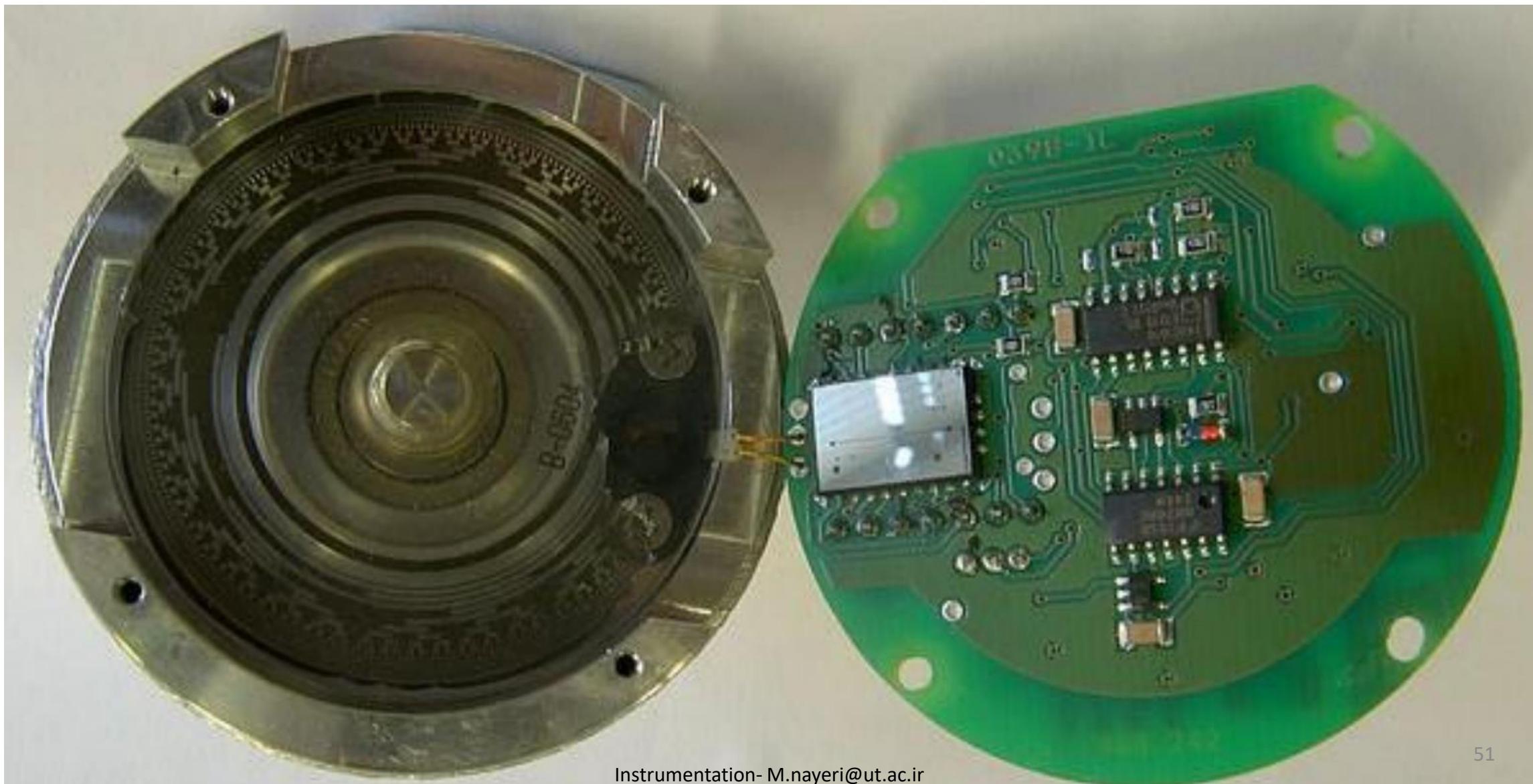


Absolute Encoder

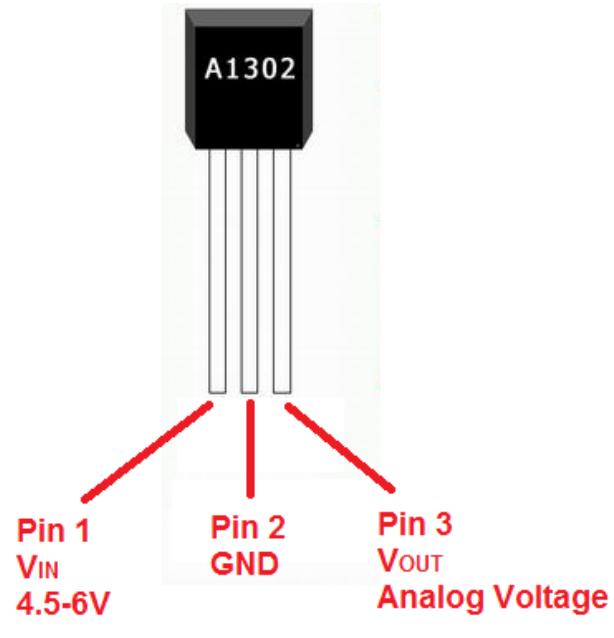


Absolute Encoder Simplified Structure

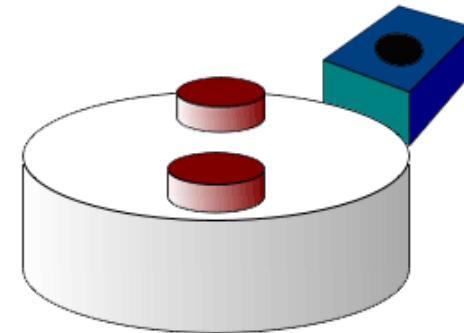
Absolute Encoder



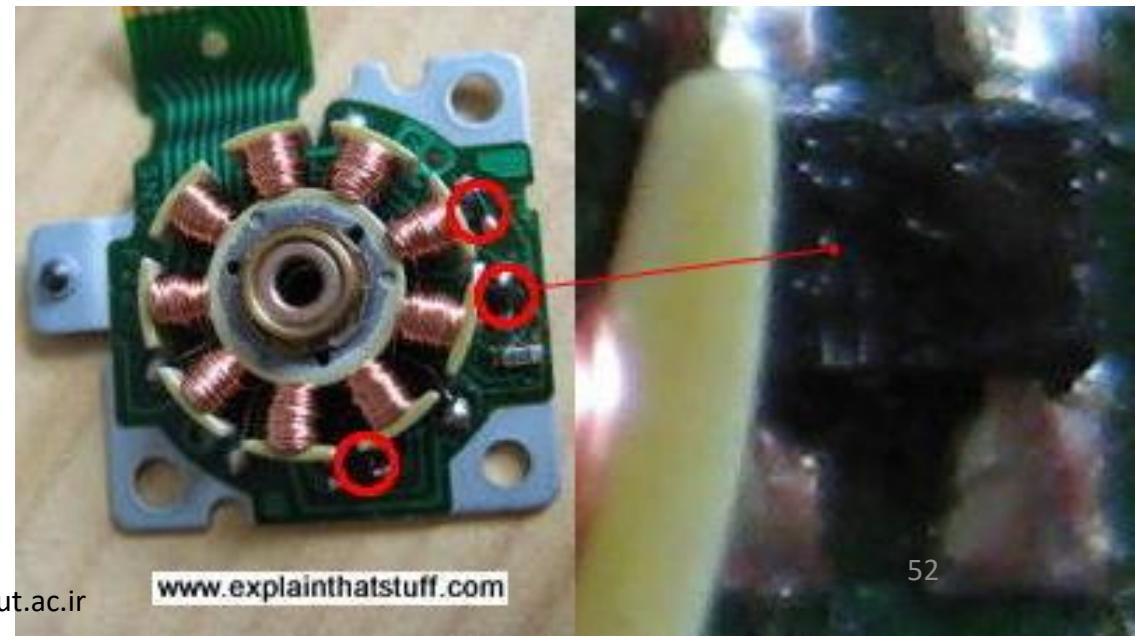
Hall Effect Sensors

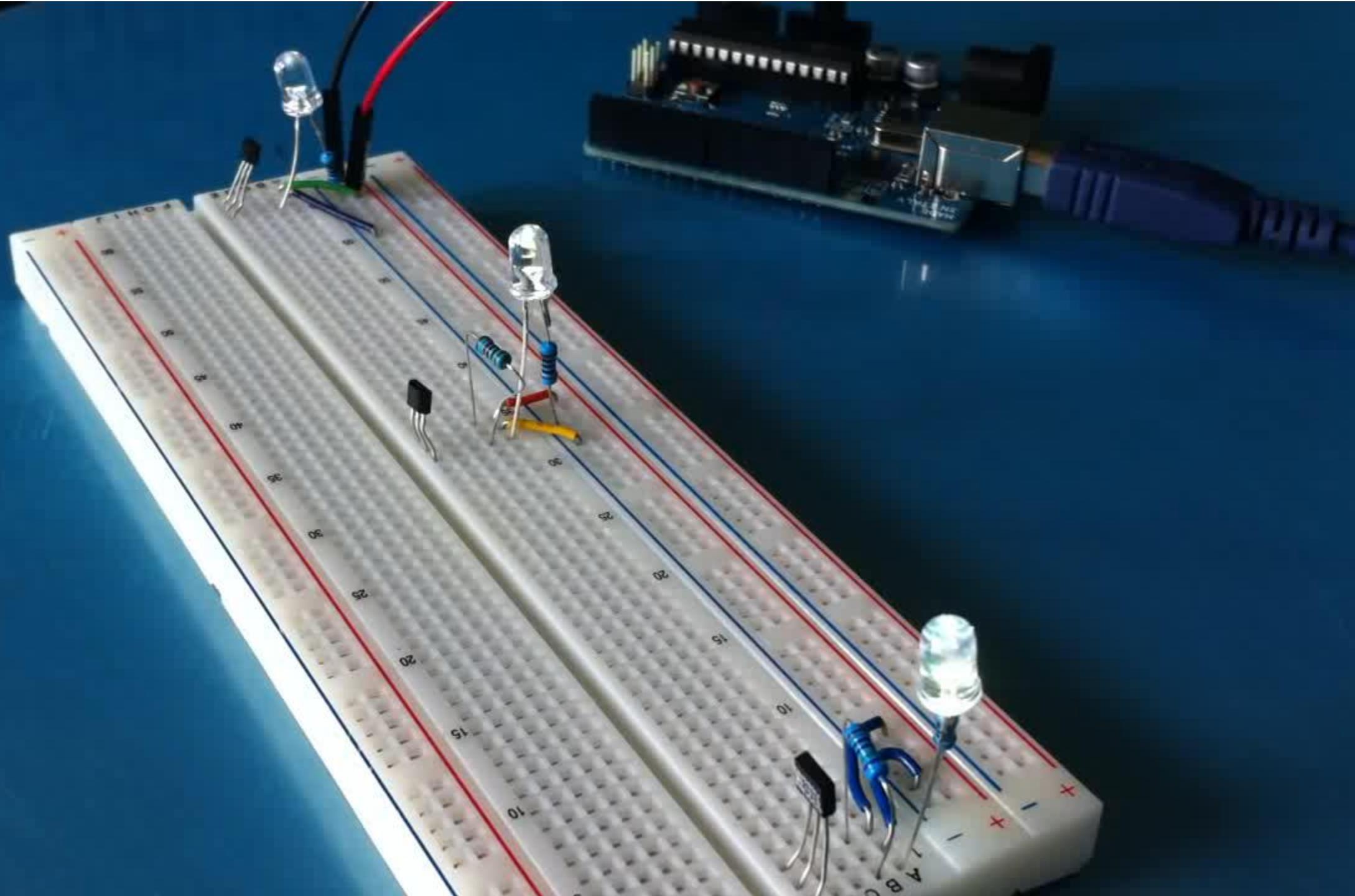


Analog



Digital

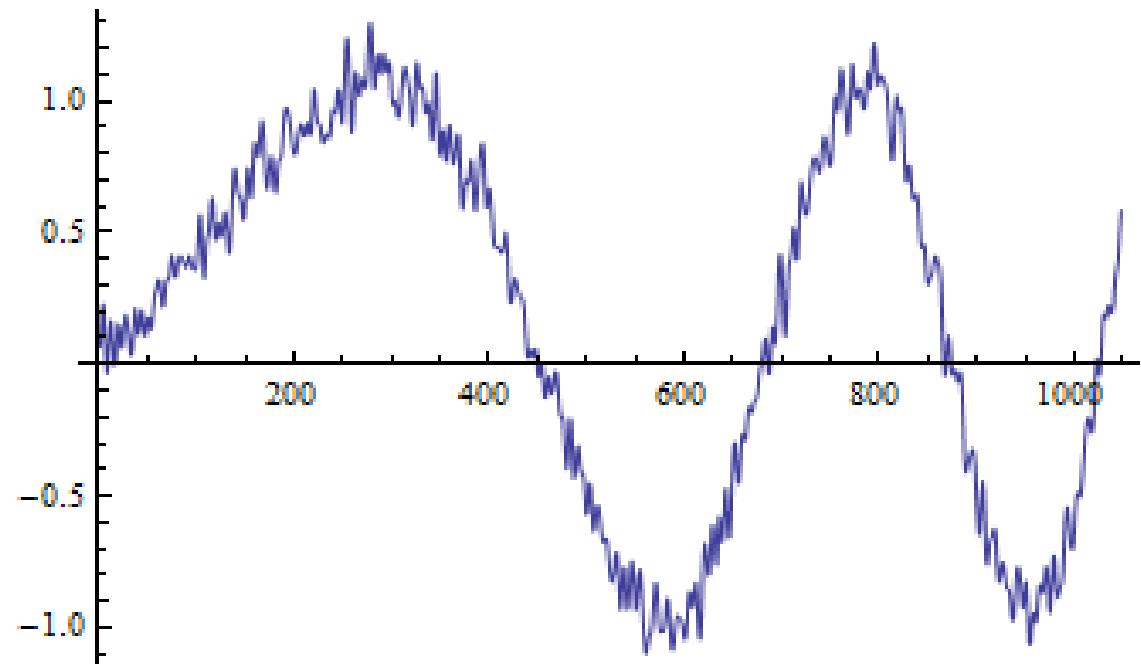




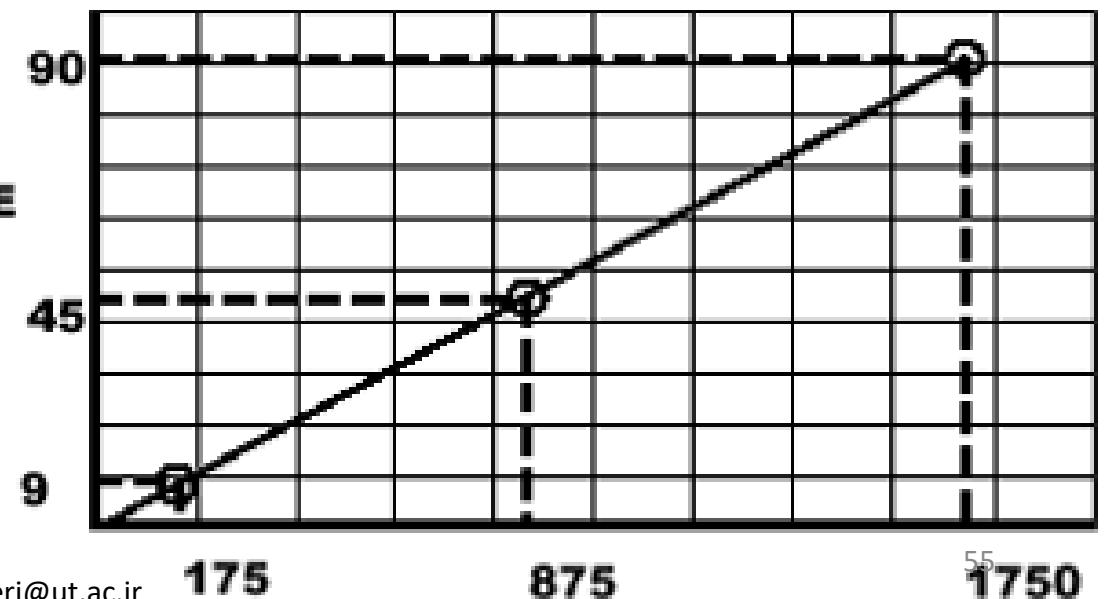
Magnetic Encoder



Tachometer (Tachogenerator)



**ARMATURE
VOLTAGE**



Synchro Generator

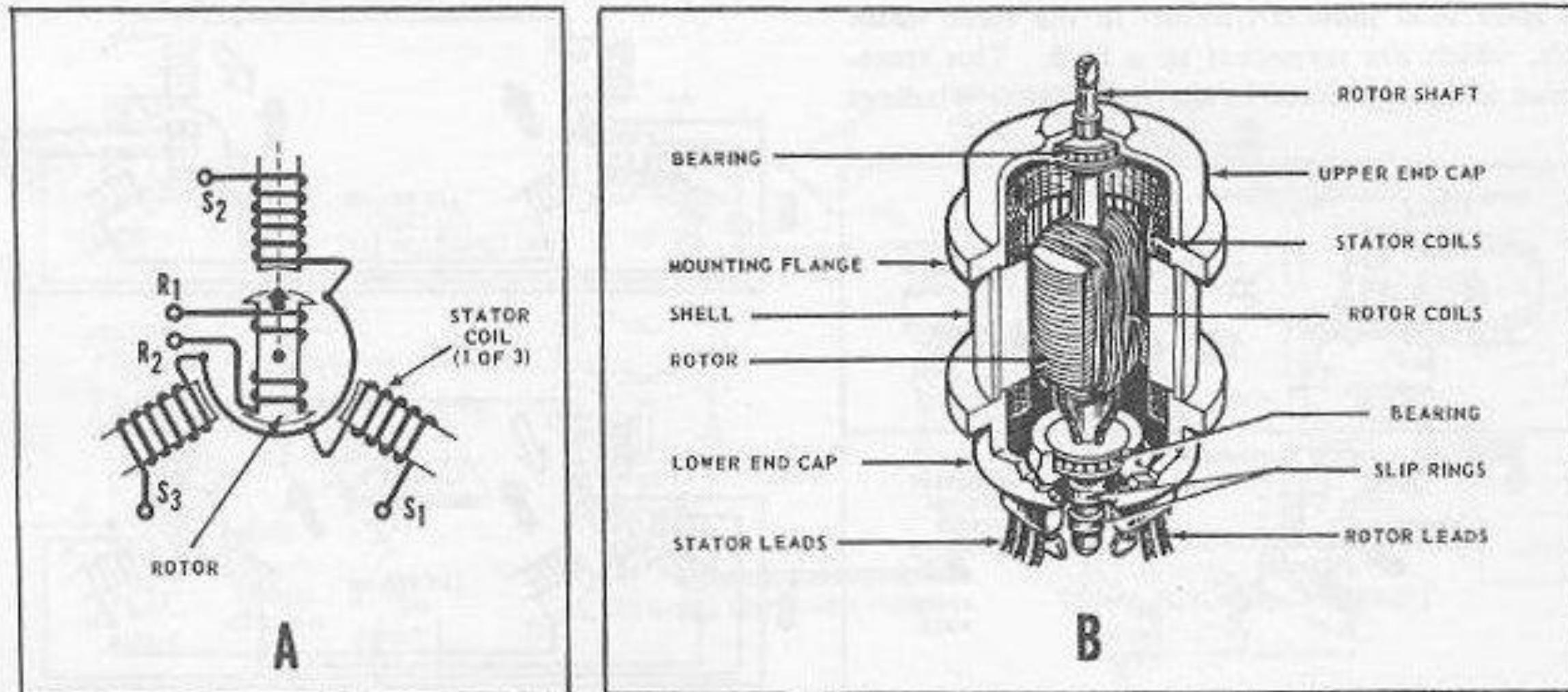
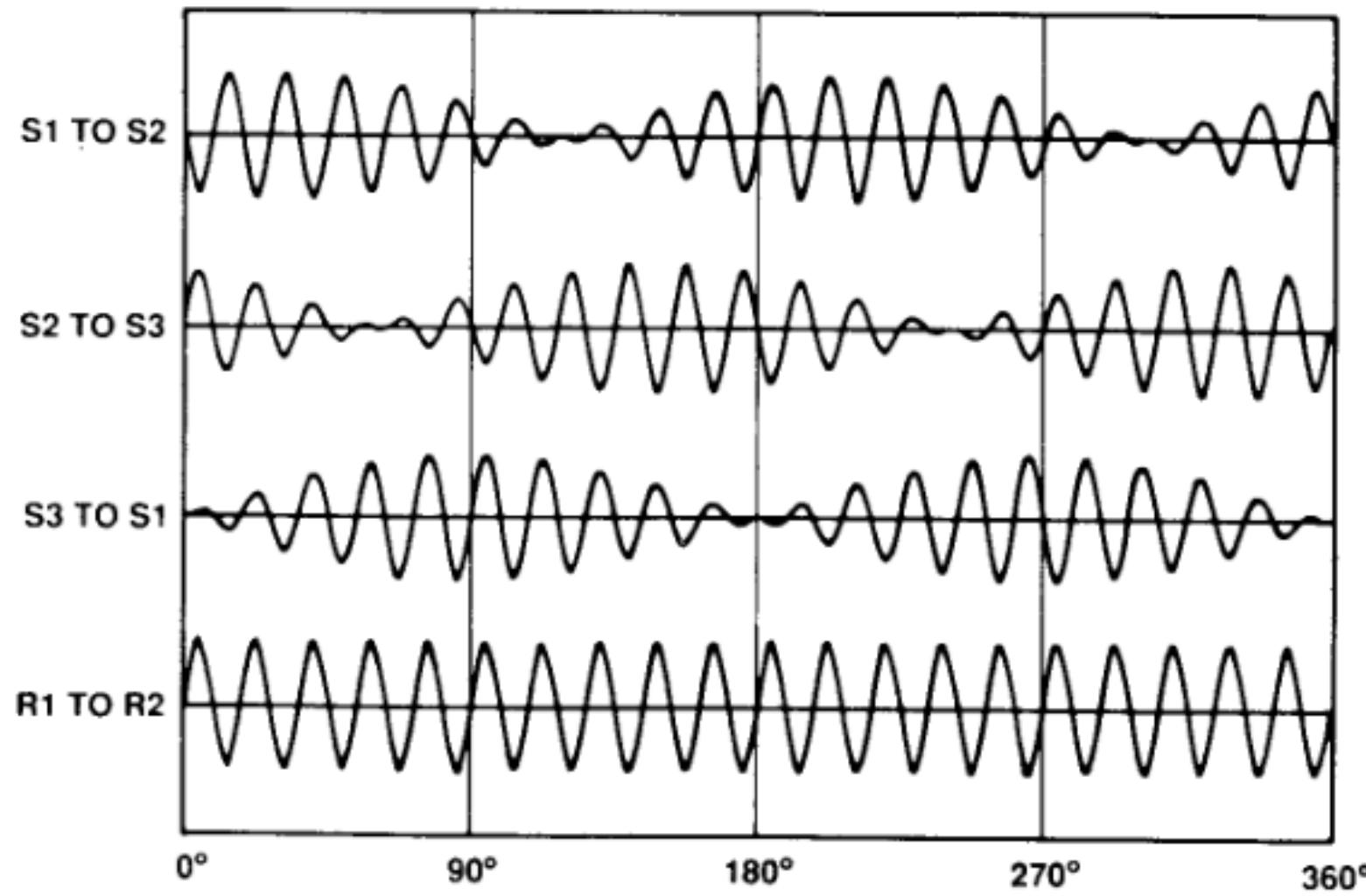
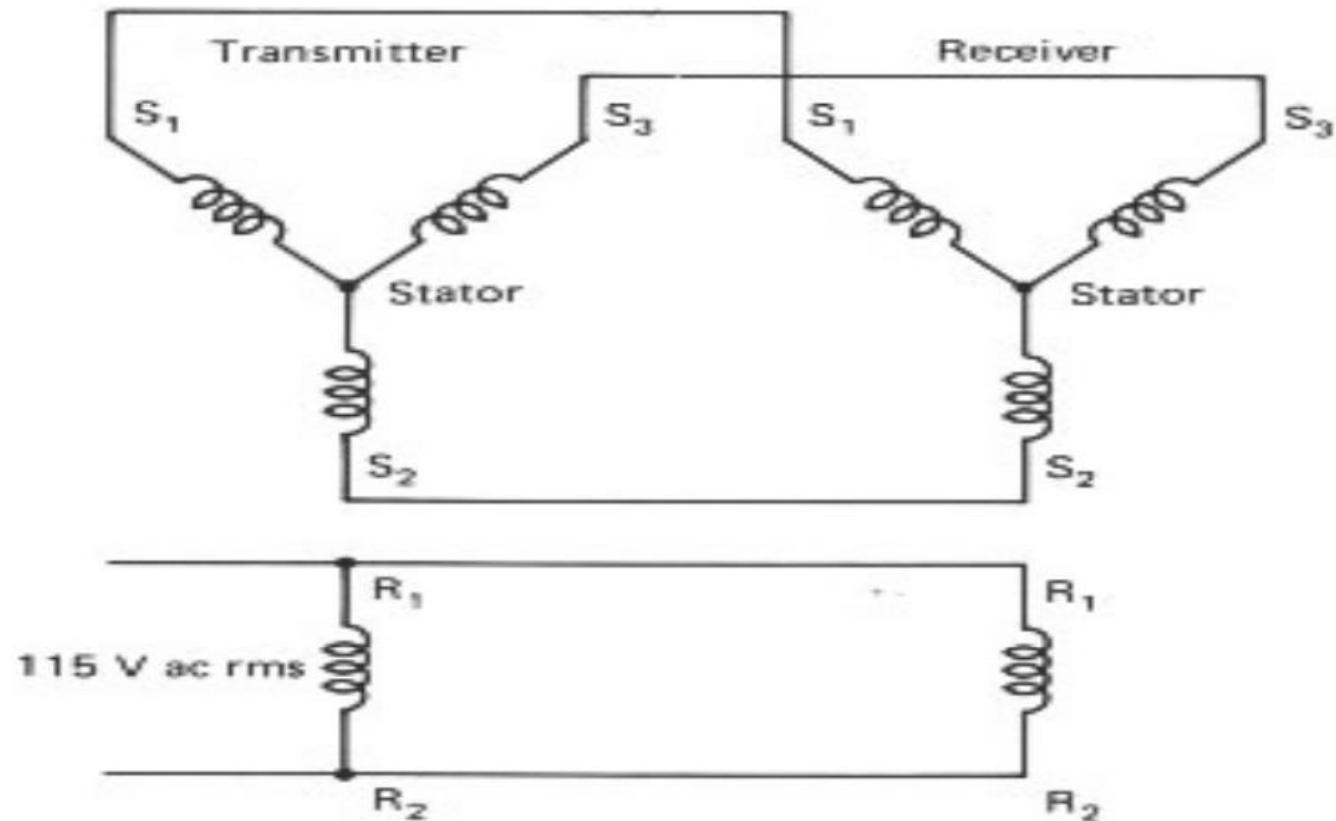
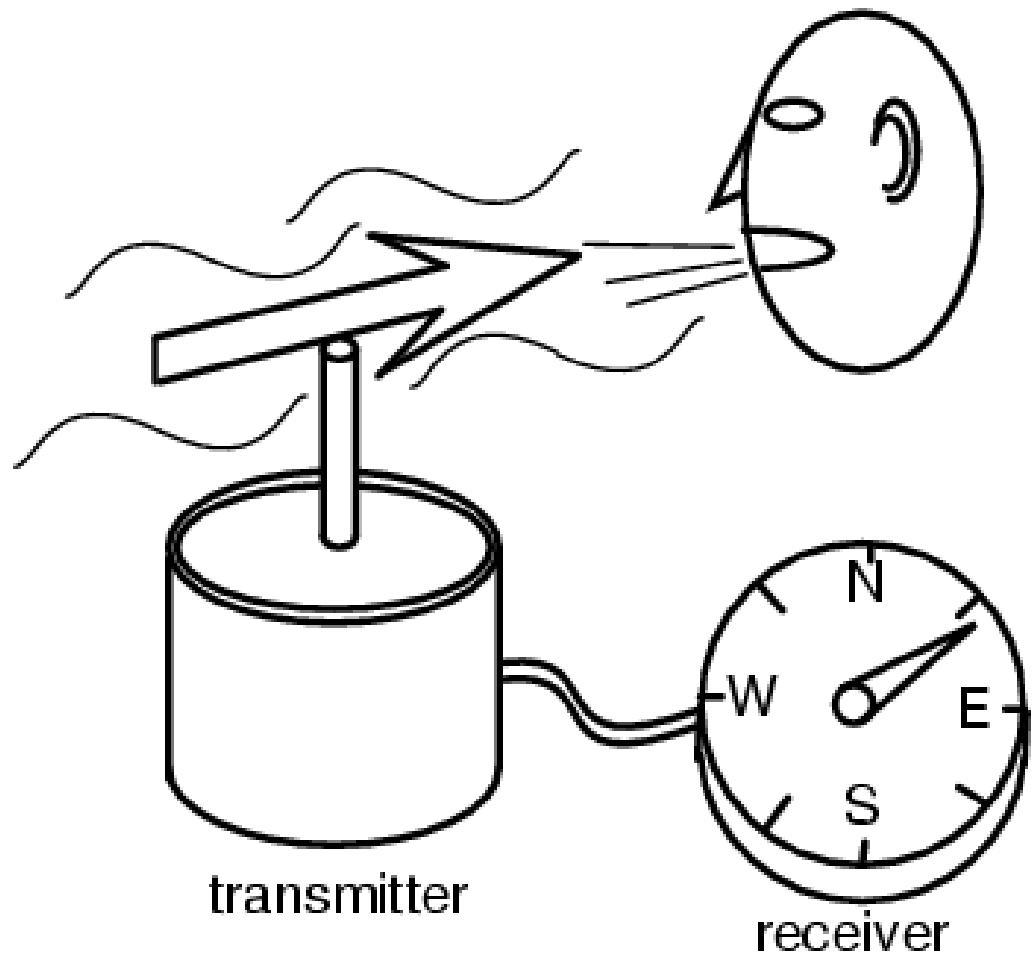


FIGURE 10B2.—Inside a synchro transmitter. A. Schematic representation. B. Construction.

Synchro Generator



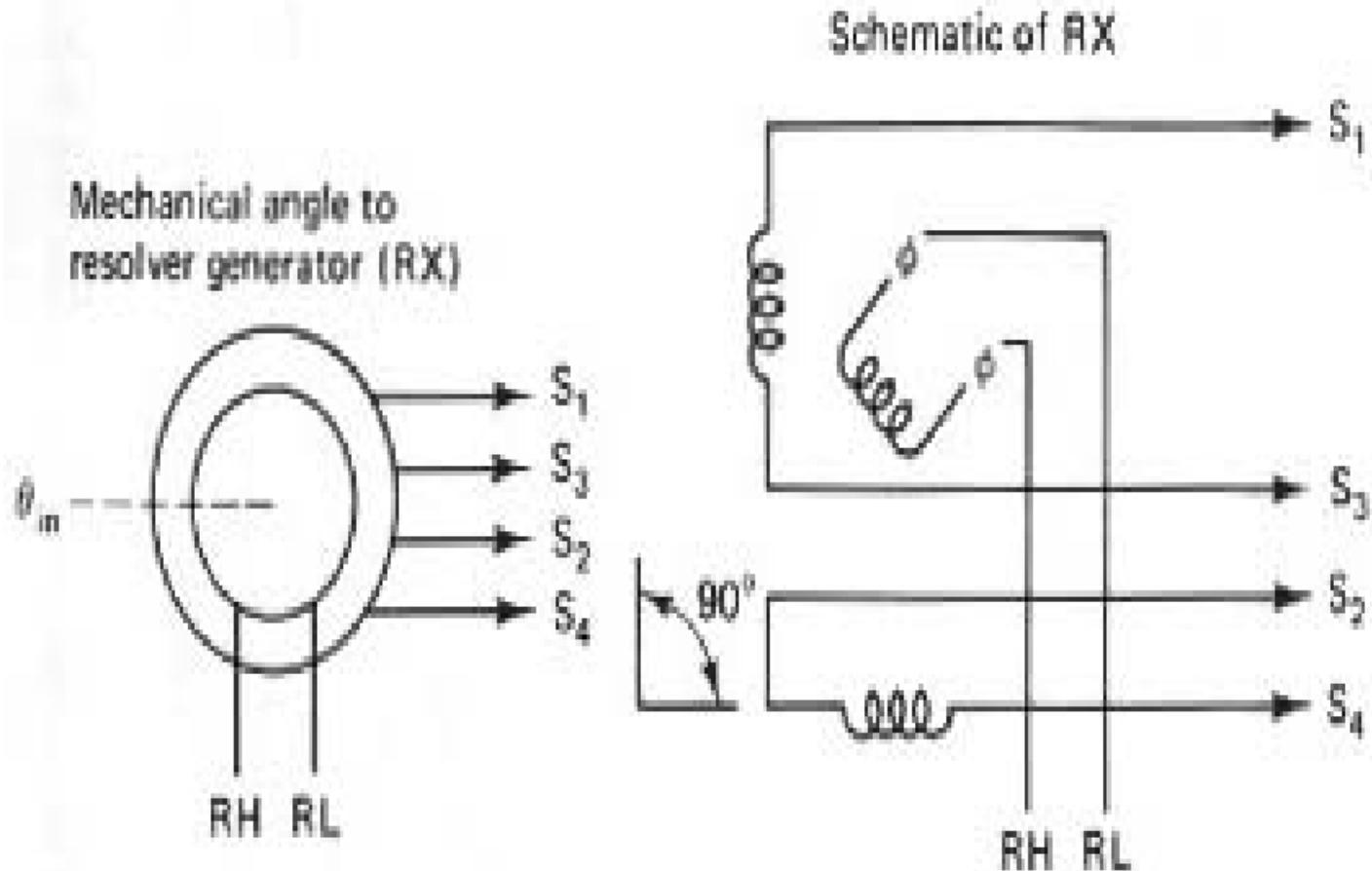
Synchro Generator



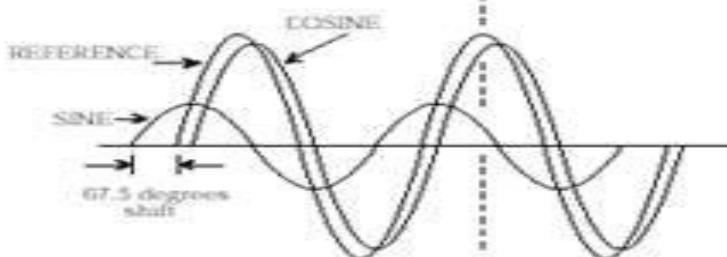
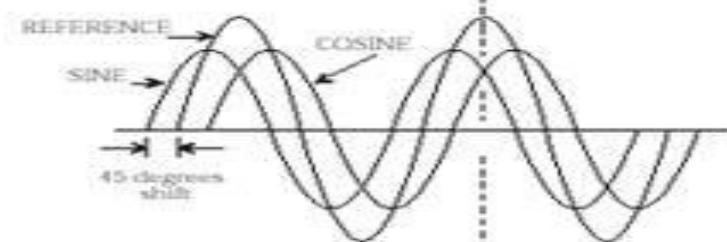
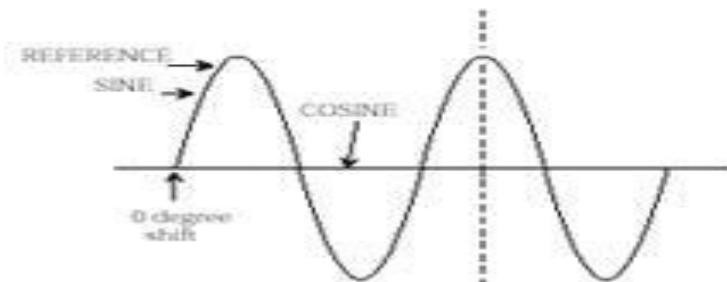
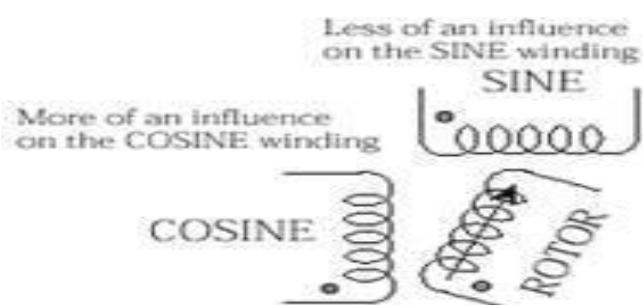
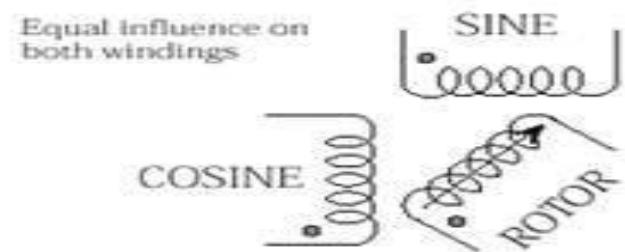
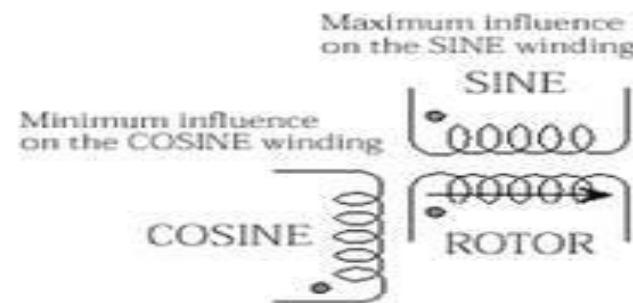
Synchro Generator



Resolver

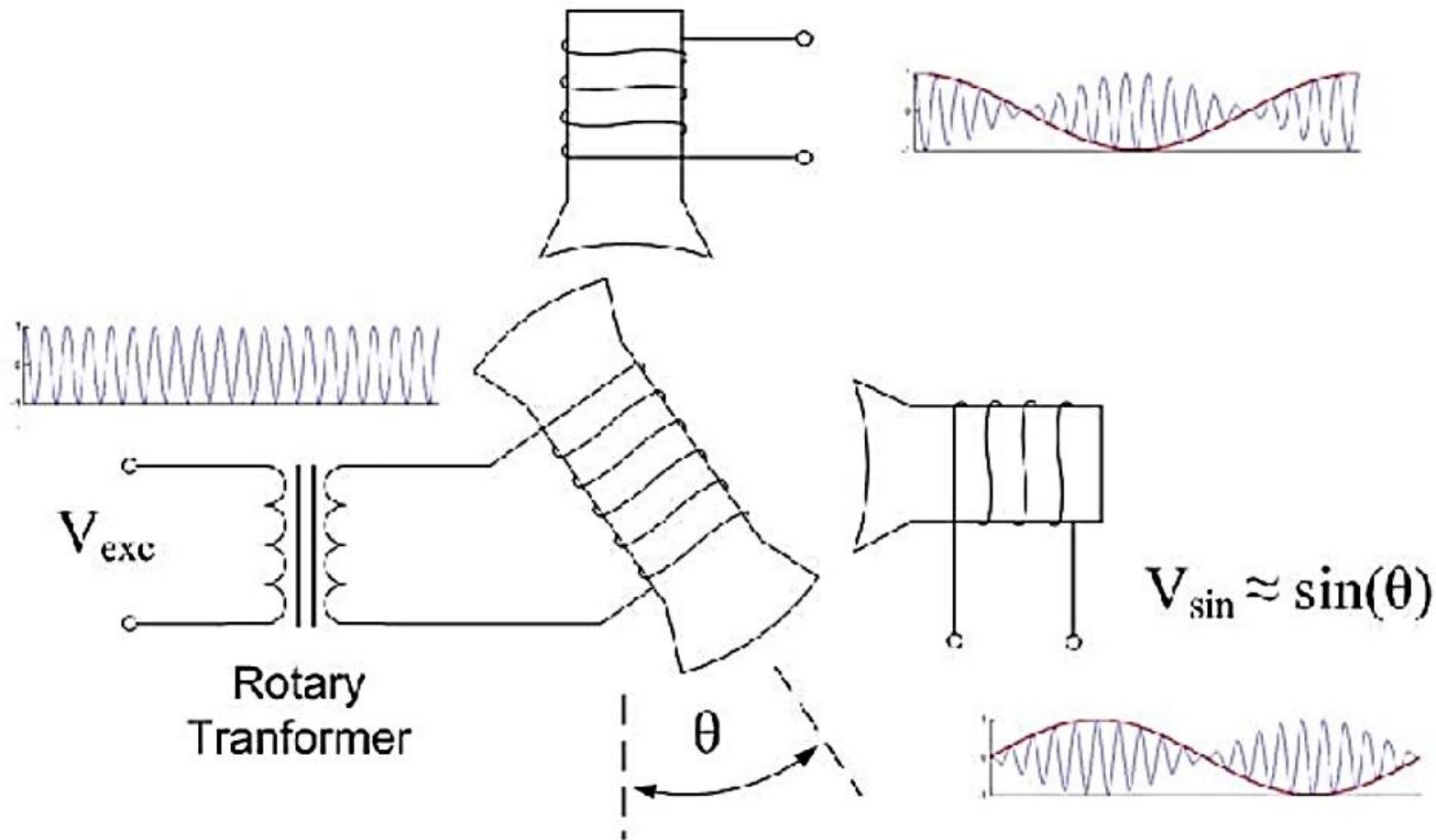


Resolver

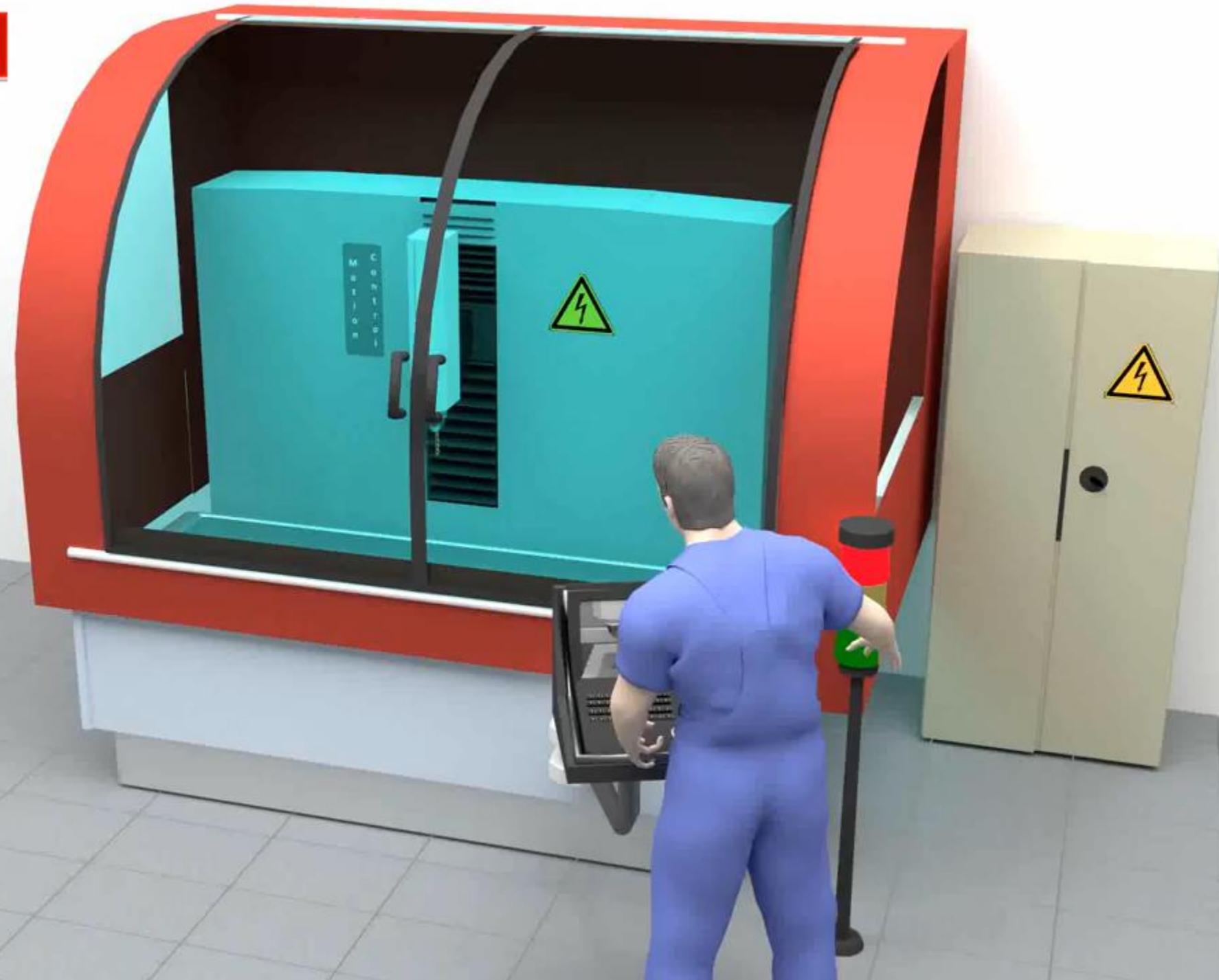


Resolver

$$V_{\cos} \approx \cos(\theta)$$

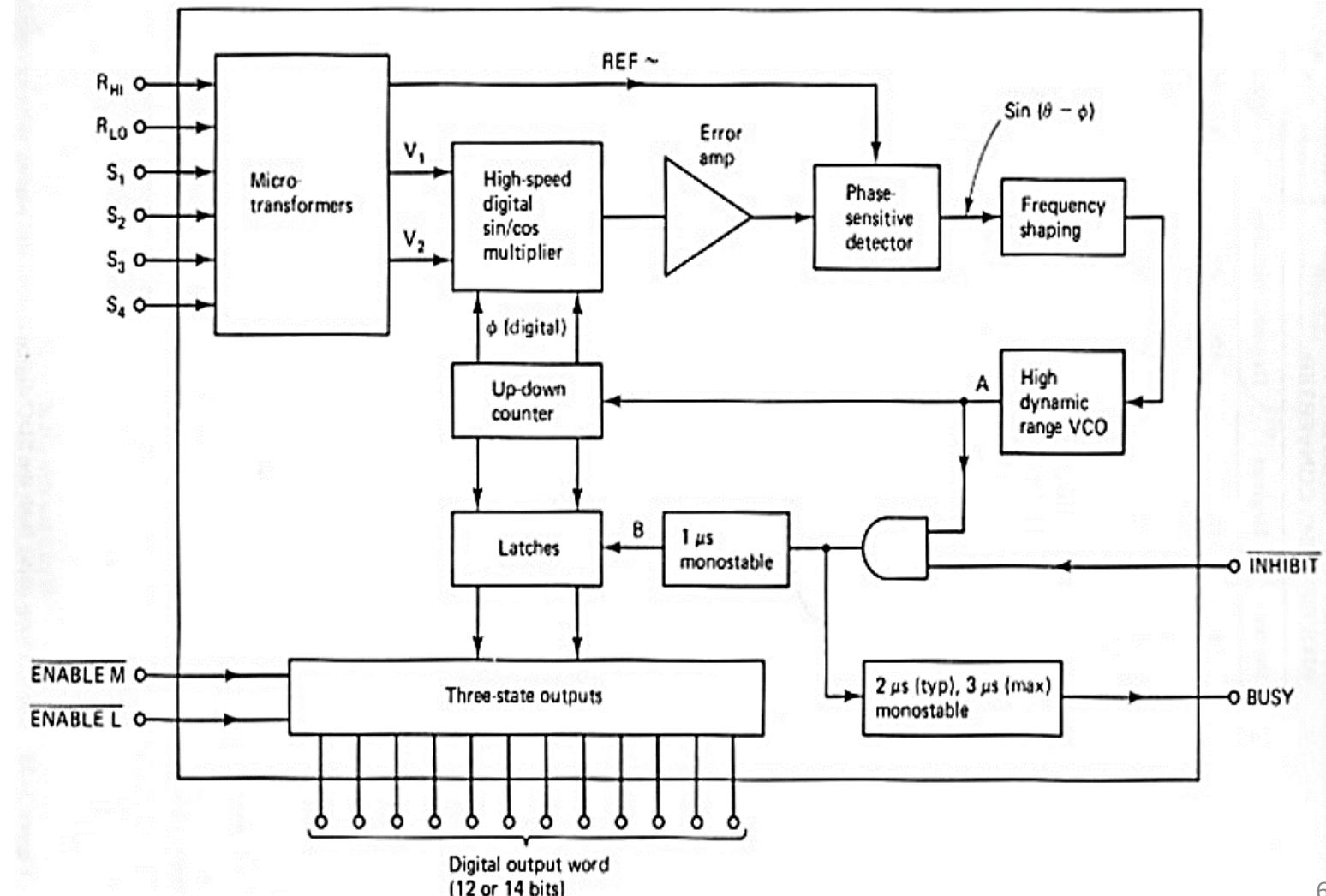


Introduction

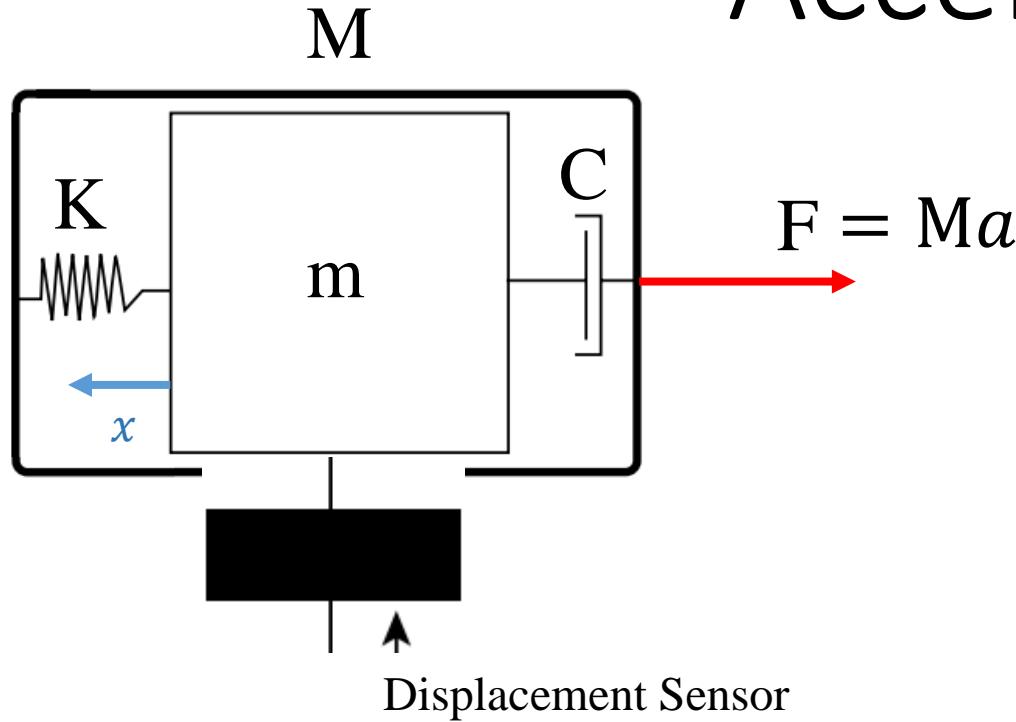


Synchro to Digital Converter (S/D)

- SDC1740
- SDC1741
- SDC1742



Accelerometer

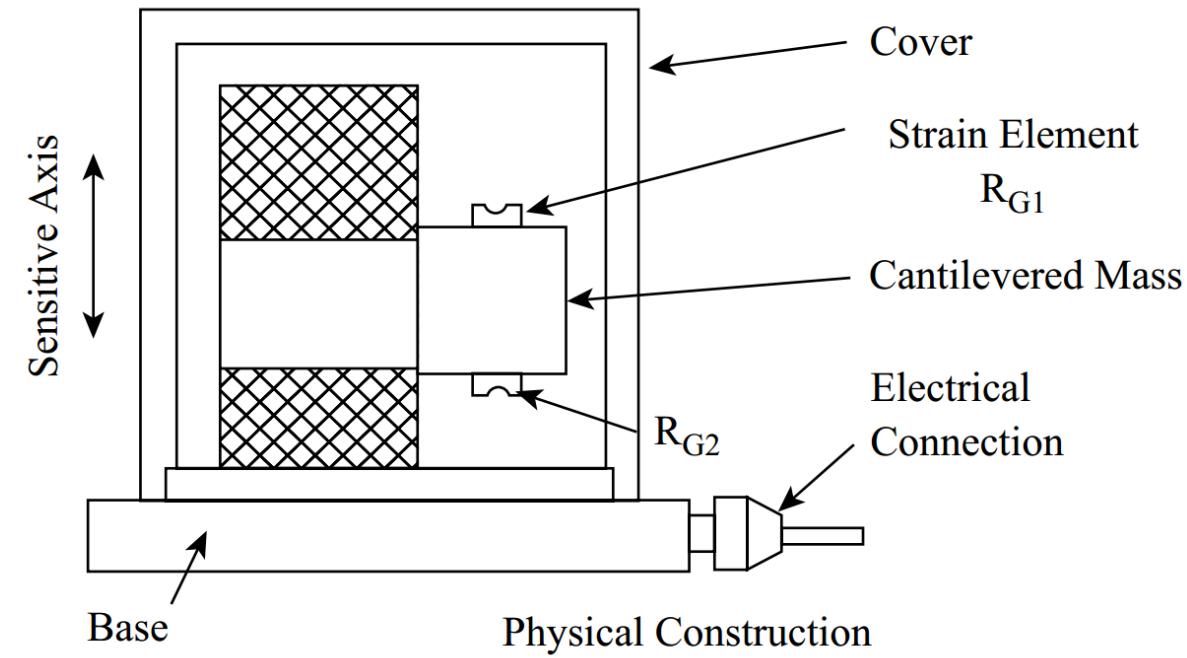
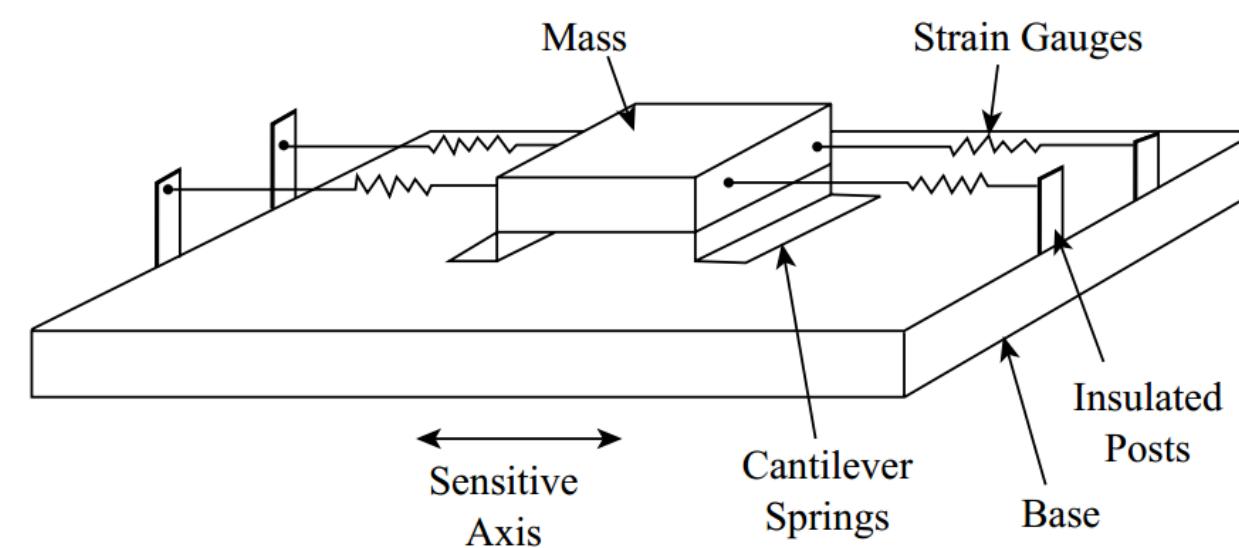


$$F - Kx - C\dot{x} = ma = m\ddot{x} \rightarrow Ma = m\ddot{x} + C\dot{x} + Kx \quad \text{Sensitivity}$$

$$\frac{X(s)}{a(s)} = \frac{M}{ms^2 + cs + k} \rightarrow$$

$$\frac{X(s)}{a(s)} = \frac{\frac{M}{k} \times \frac{k}{m} \omega_n^2}{s^2 + \frac{c}{m}s + \frac{k}{m}} \quad 2\xi\omega_n$$

Strain Gauge Accelerometer



Capacitive Accelerometer

$$C = \varepsilon \frac{A}{x}$$

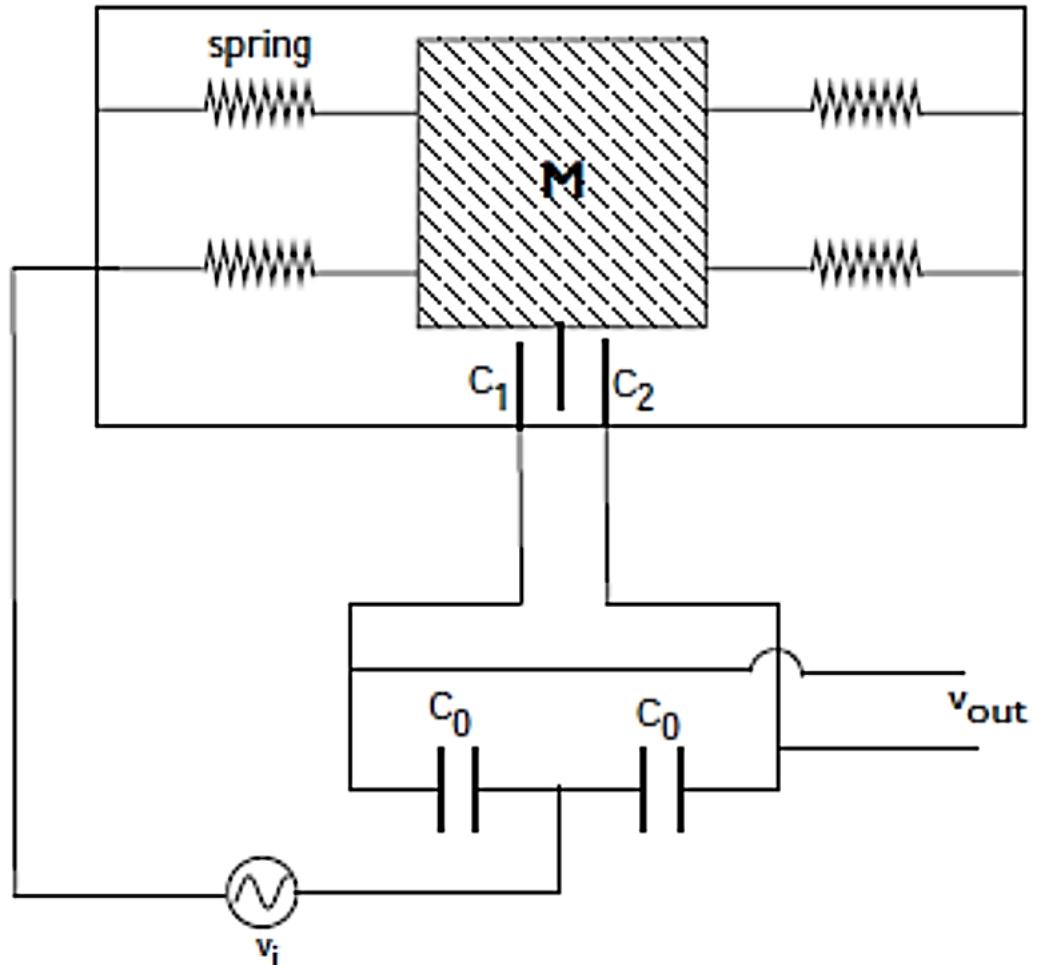
$$C_1 = \varepsilon \frac{S}{x_0 + x} = \varepsilon \frac{S}{x_0 \left(1 + \frac{x}{x_0}\right)} = \frac{C_0}{1 + \delta}$$

$$C_2 = \varepsilon \frac{S}{x_0 - x} = \varepsilon \frac{S}{x_0 \left(1 - \frac{x}{x_0}\right)} = \frac{C_0}{1 - \delta}$$

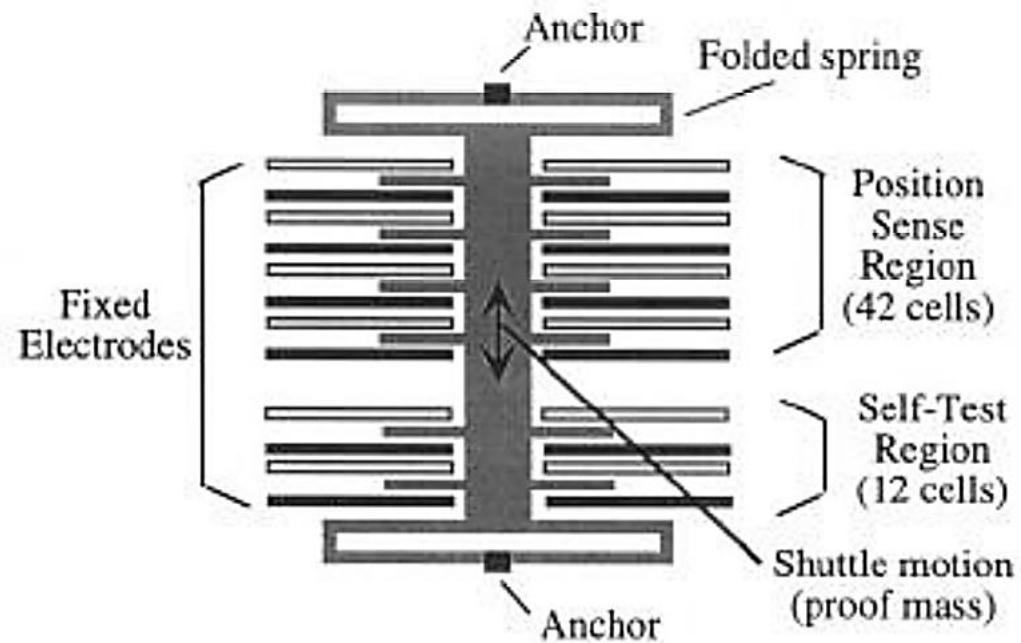
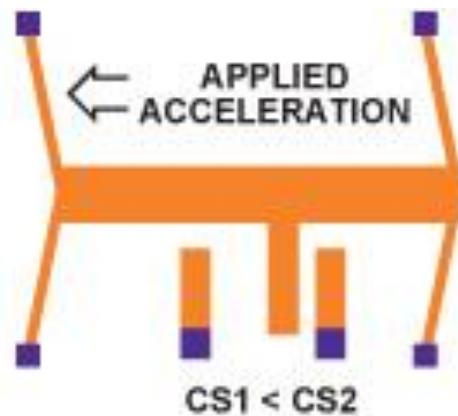
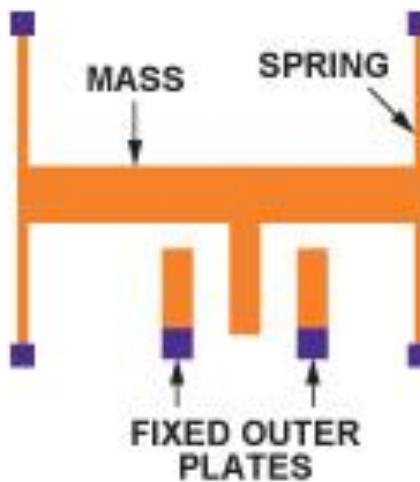
in a Wheatstone bridge: if $\delta \ll 1$ $v_{out} = \frac{v_{in}}{2} \cdot \delta$???

$$a = \frac{K}{M} \cdot x = \frac{K}{M} \cdot x_0 \cdot \delta = \frac{K}{M} \cdot x_0 \cdot 2 \cdot \frac{v_{out}}{v_{in}}$$

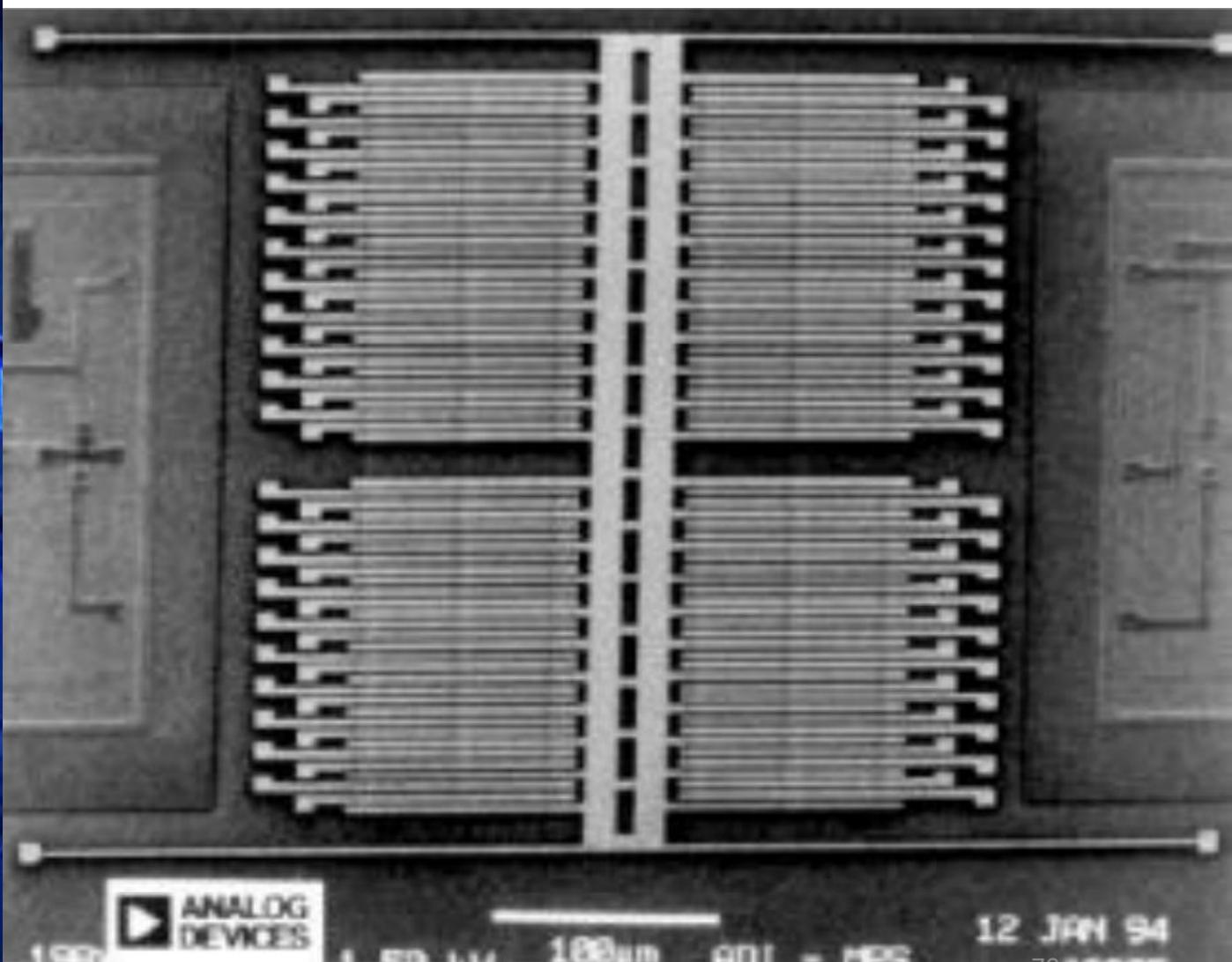
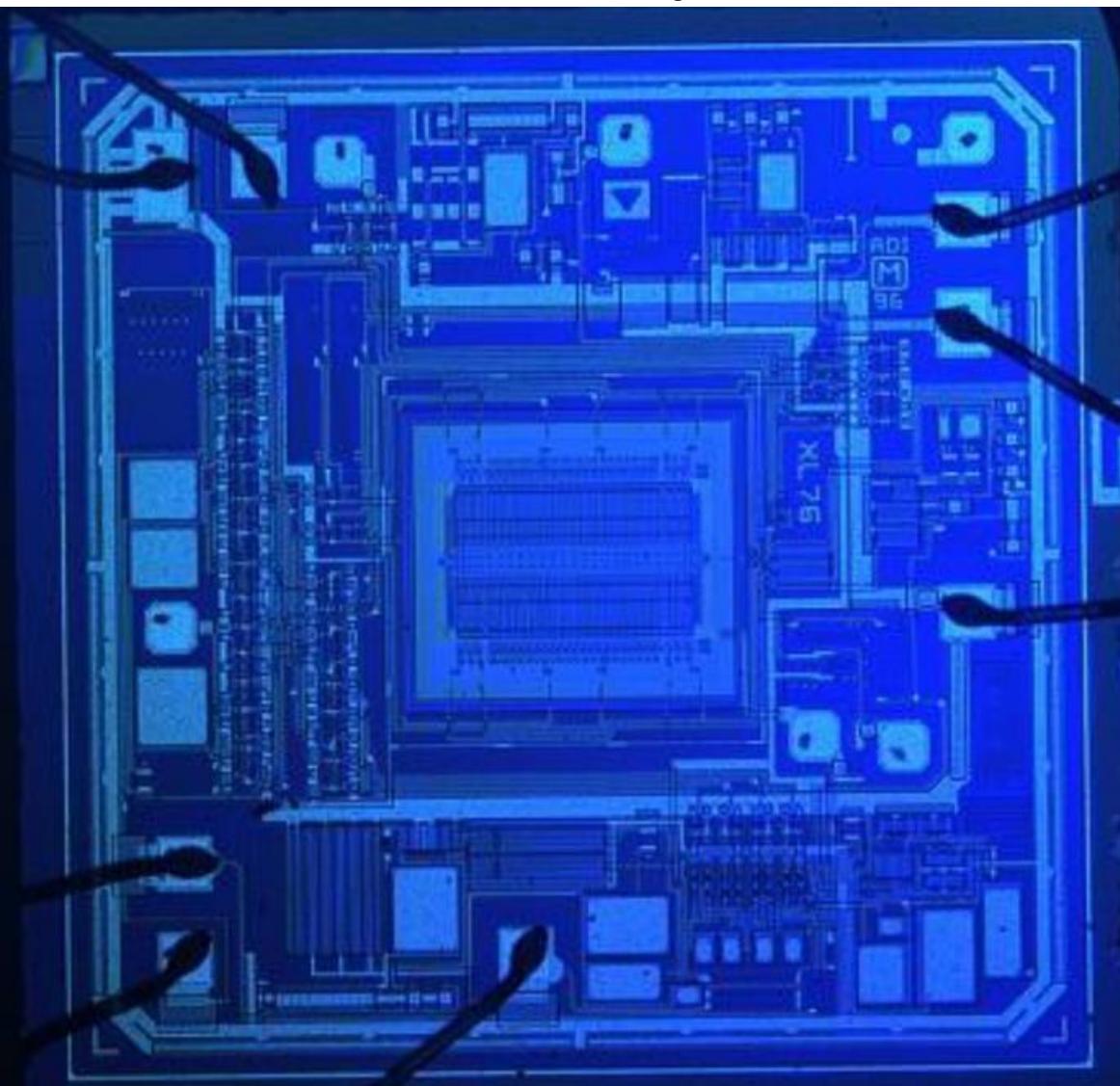
$$\text{where } \delta = \frac{x}{x_0}$$

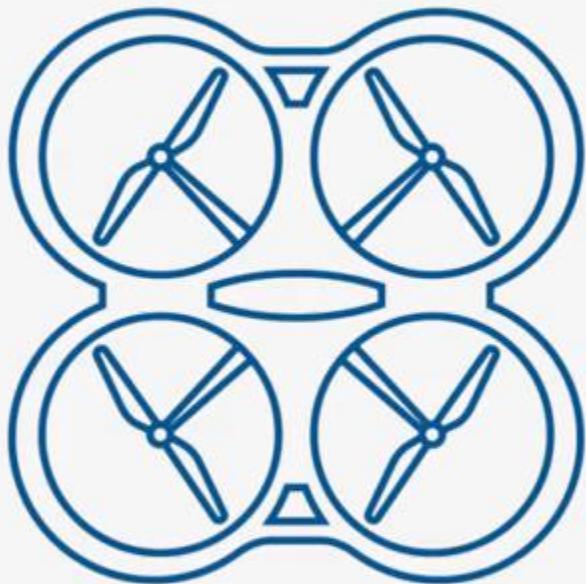
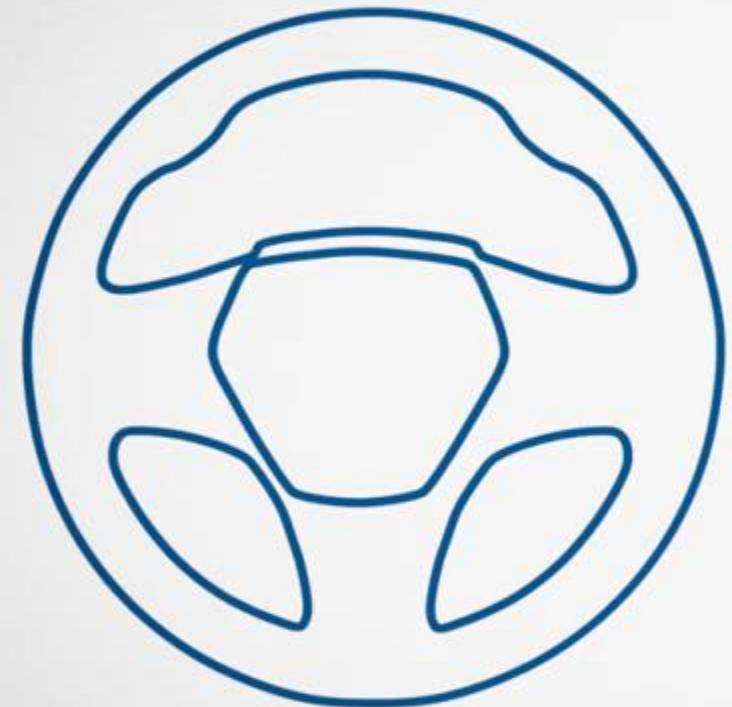


Capacitive Accelerometer



Capacitive Accelerometer





Linear Velocity

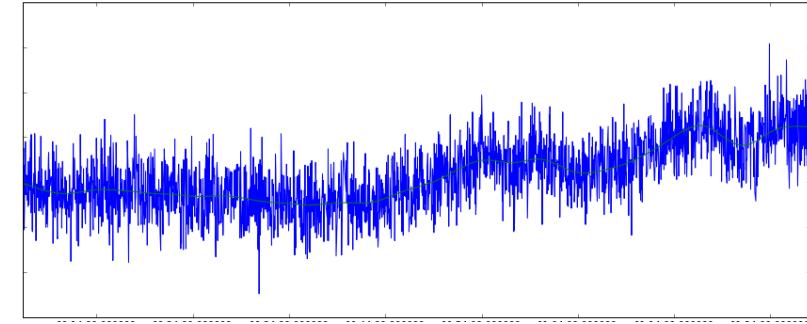
- Derivation of linear displacement

Linear Displacement sensor $\rightarrow x$ $\Rightarrow v = \frac{dx}{dt}$

Ultrasonic, Infrared, ...

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

Noise



- Use angular velocity measurement

Optocounter, Encoder, ...

$$S = r\theta \xrightarrow{d} \frac{d}{dt} v = r\omega$$

Sensor Fusion Methods

- Integration of acceleration

Acceleration sensor $\rightarrow a$ $\Rightarrow v = \int a \cdot dt$

Mechanical limitation

Initial Acceleration? \rightarrow Bios

