Instrumentation

Displacement, Velocity and Acceleration Measurement

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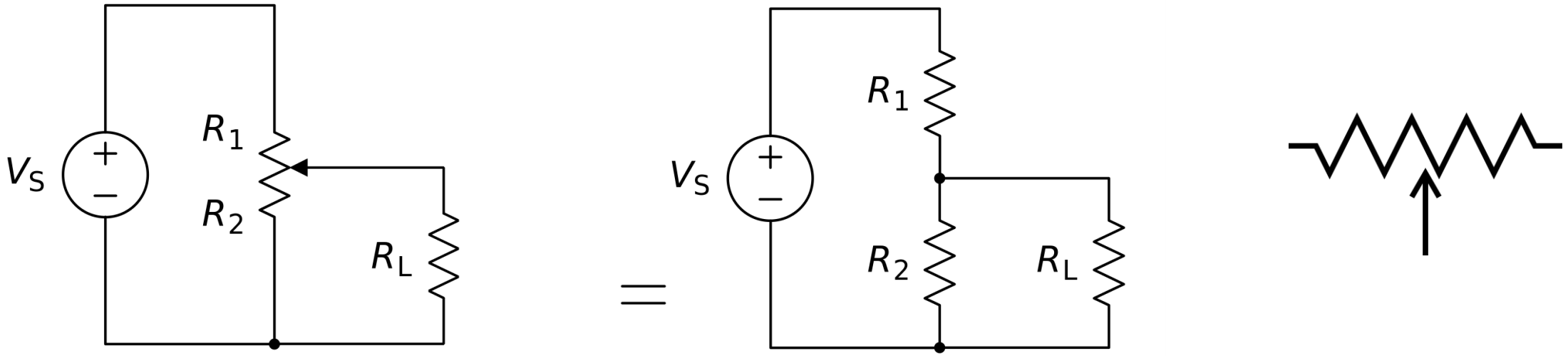
Spring 2022

Potentiometer

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



$$V_{\mathrm{L}} = \frac{R_2 R_{\mathrm{L}}}{R_1 R_{\mathrm{L}} + R_2 R_{\mathrm{L}} + R_1 R_2} \cdot V_s$$

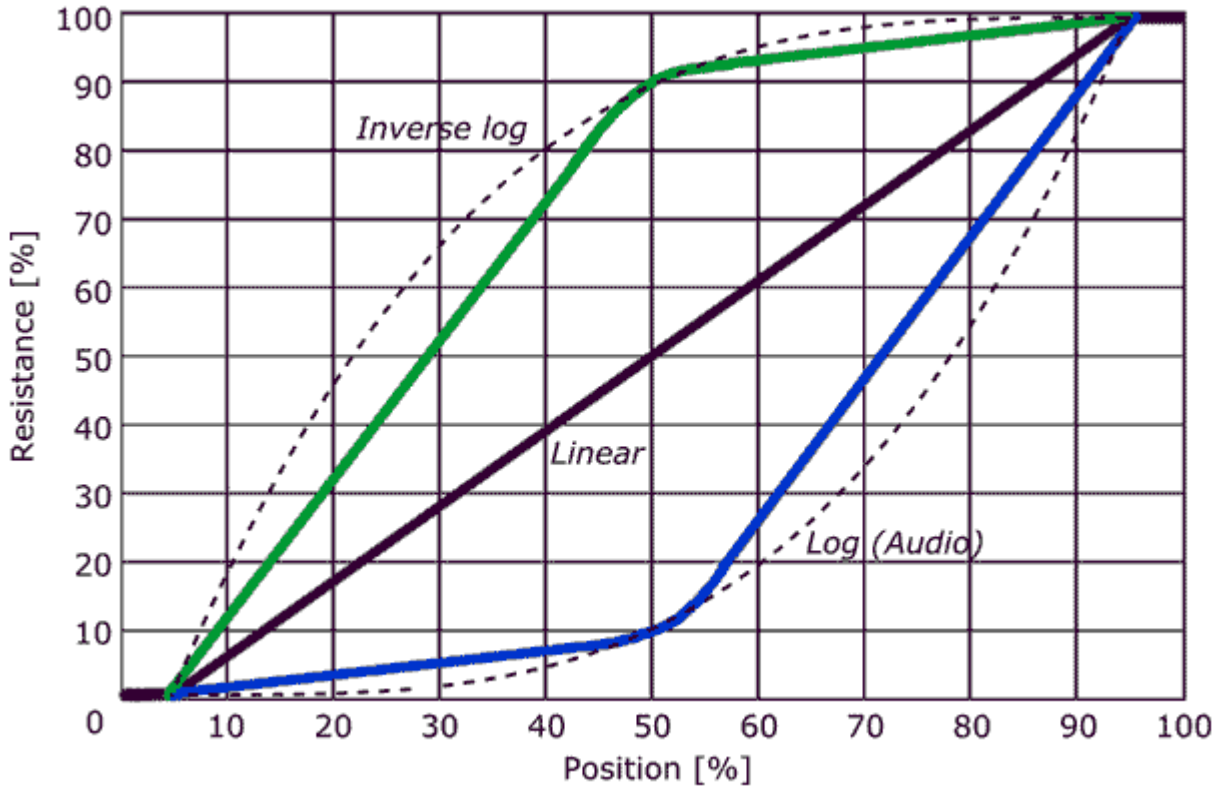
$$V_{\mathrm{L}} = \frac{R_2}{R_1 + R_2} \cdot V_s$$

If R_L is large compared to the other resistances

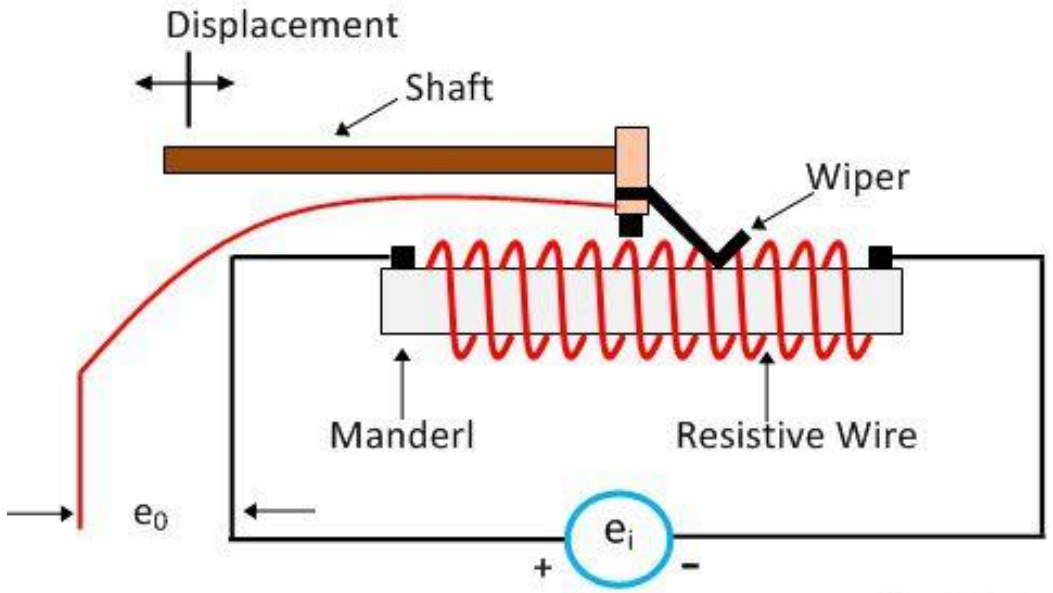
Potentiometer

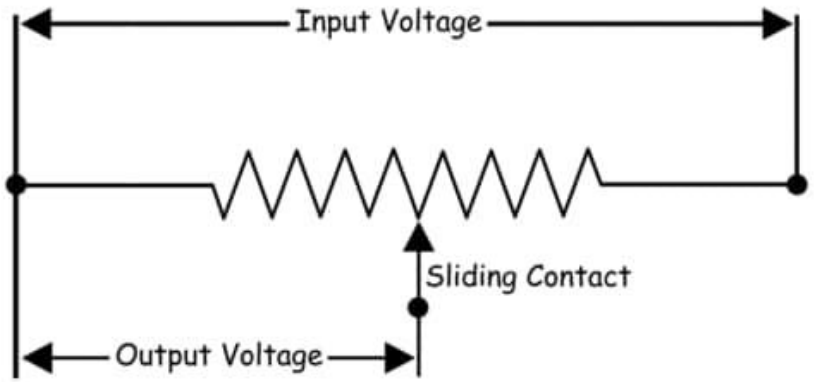
Definition: *Taper* is the relation between the *position of the potentiometer* and the *resistance ratio*.

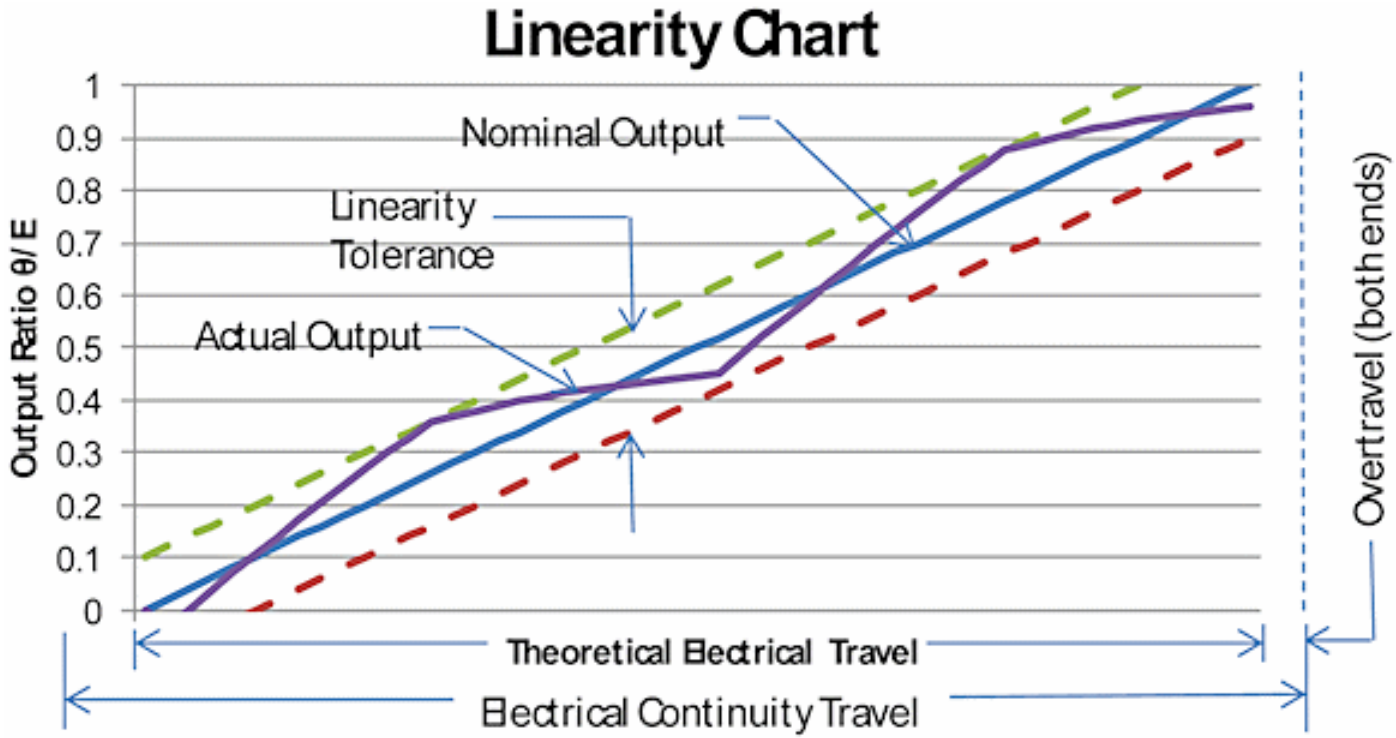
- **Linear taper**
- **Logarithmic (log) or Audio taper**
  - ✓ Mainly used for audio volume control
  - ✓ Because the human ear is sensitive to sound intensity in a logarithmic fashion
- **Inverse logarithmic (Anti-log) taper**
  - ✓ This taper are used, for example in audio controls which turn counterclockwise.



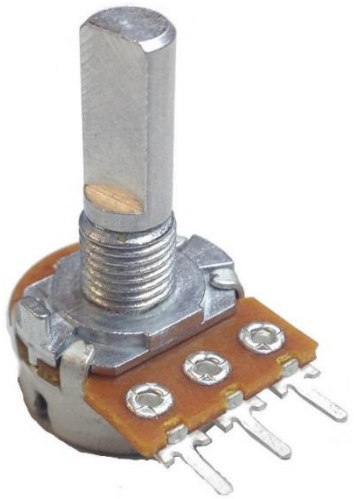
Linear Potentiometer

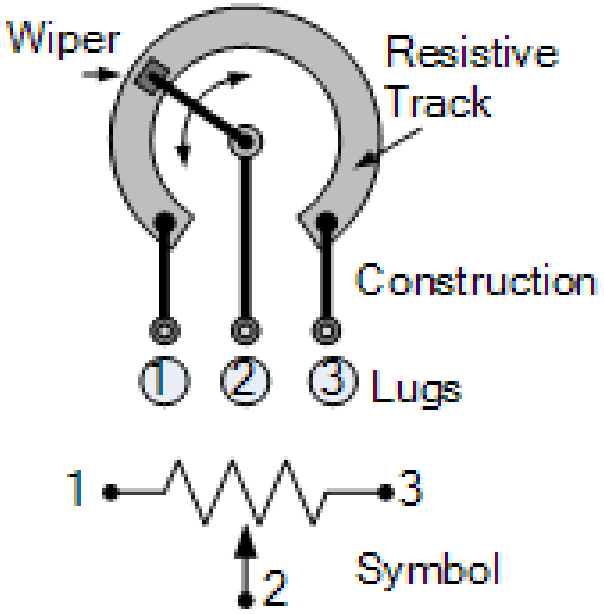




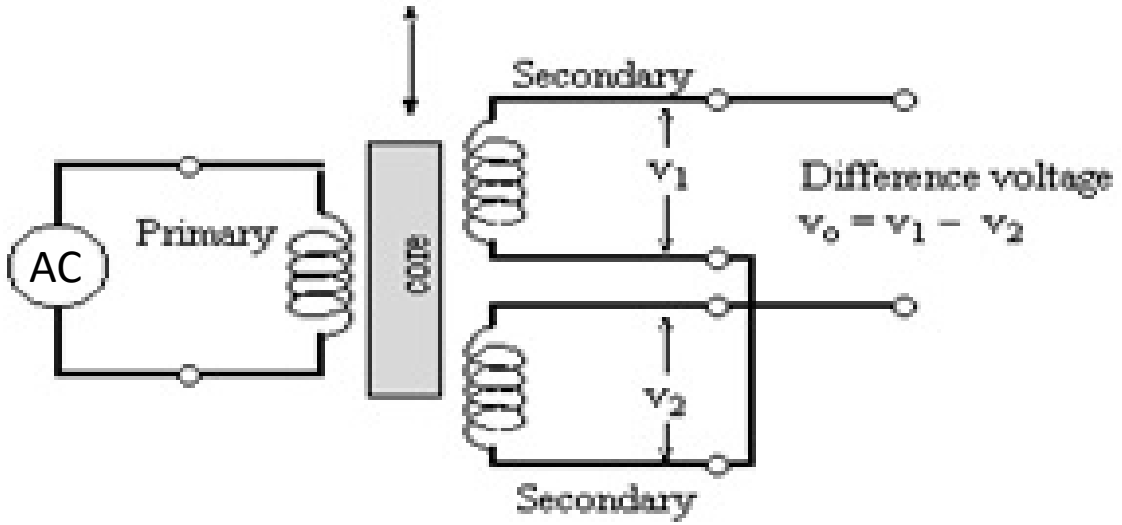


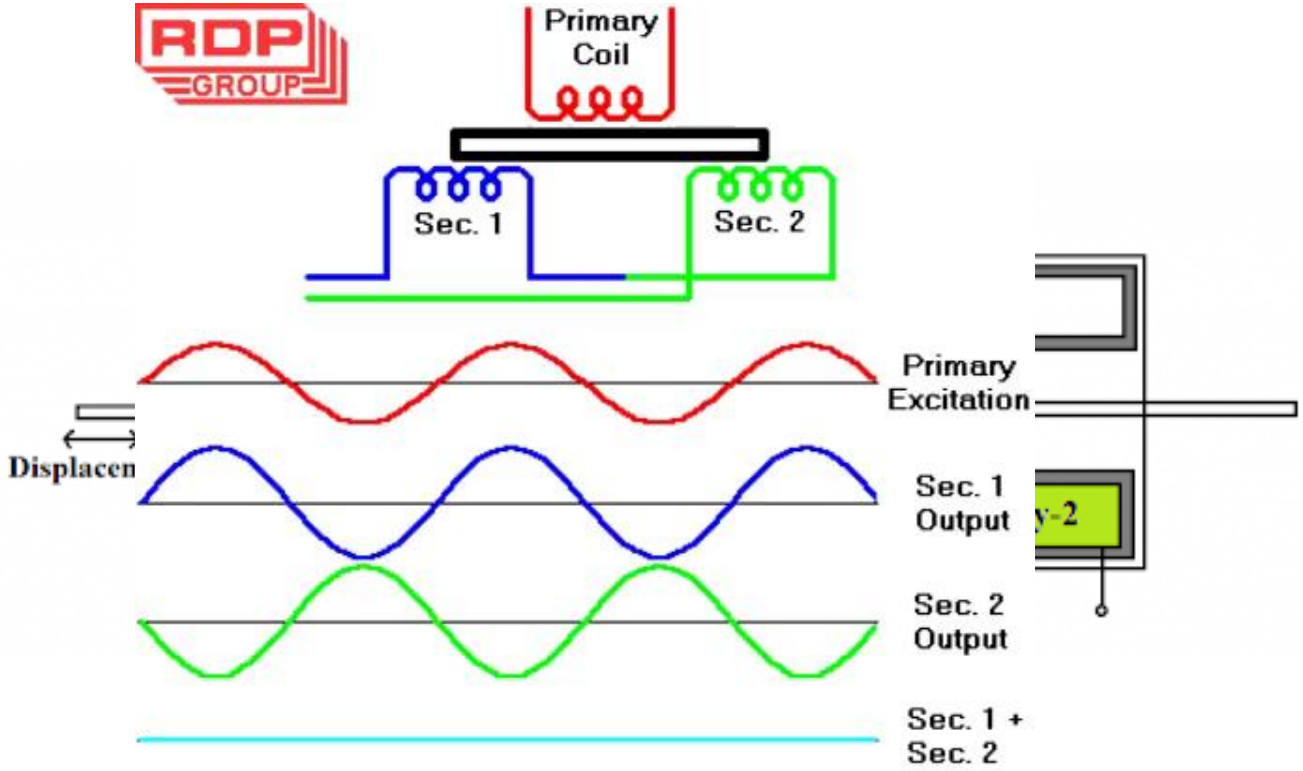
Rotary Potentiometer





Linear Differential Variable Transformer (LVDT)





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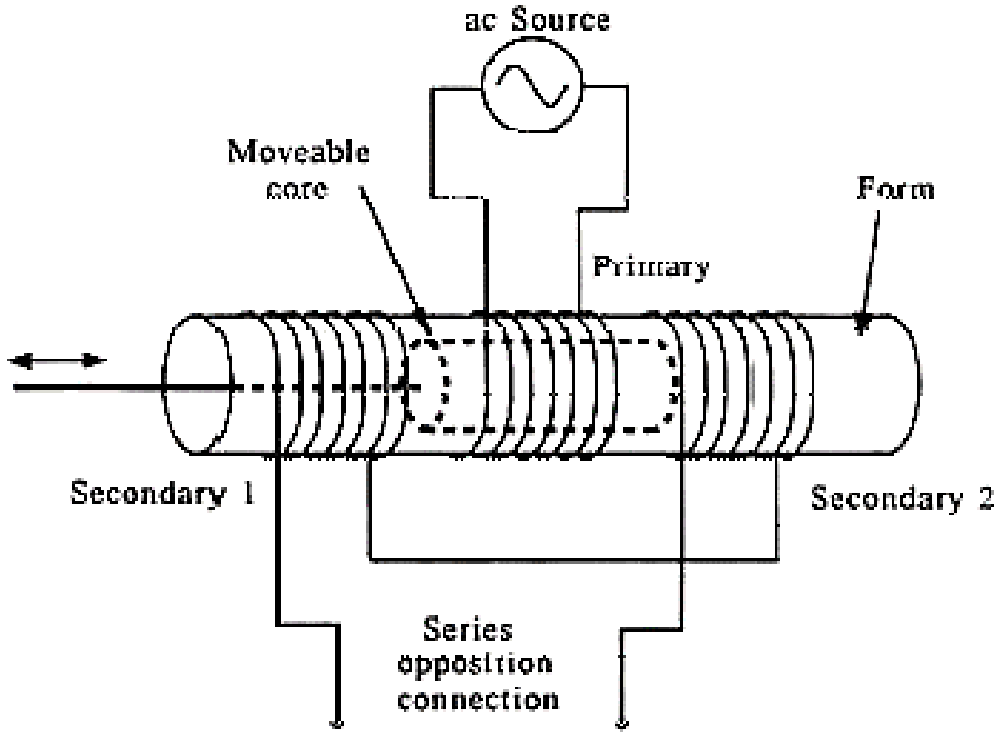
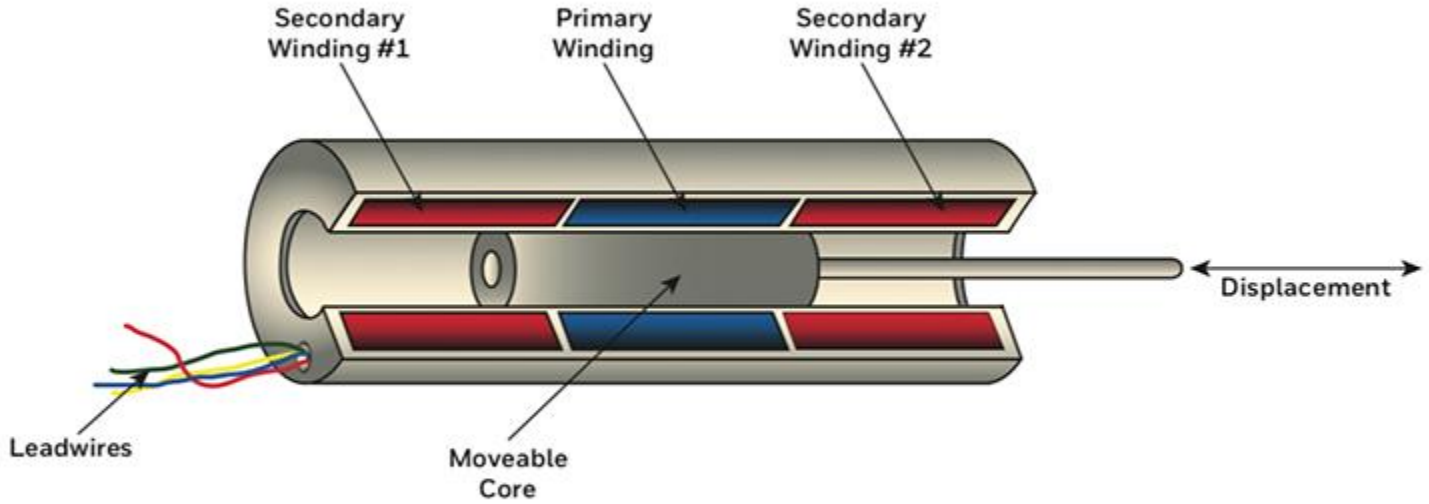


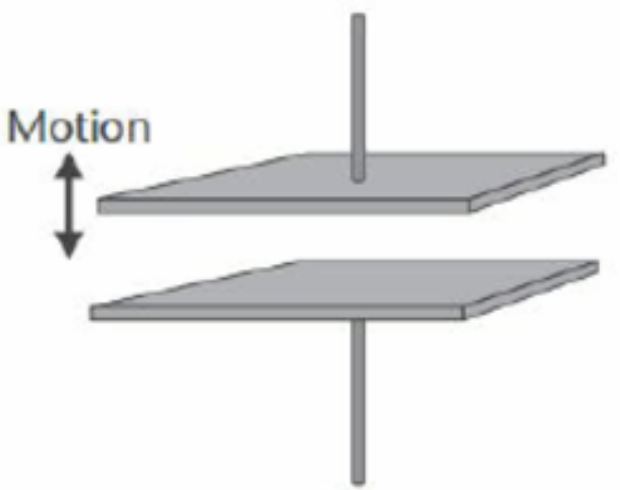


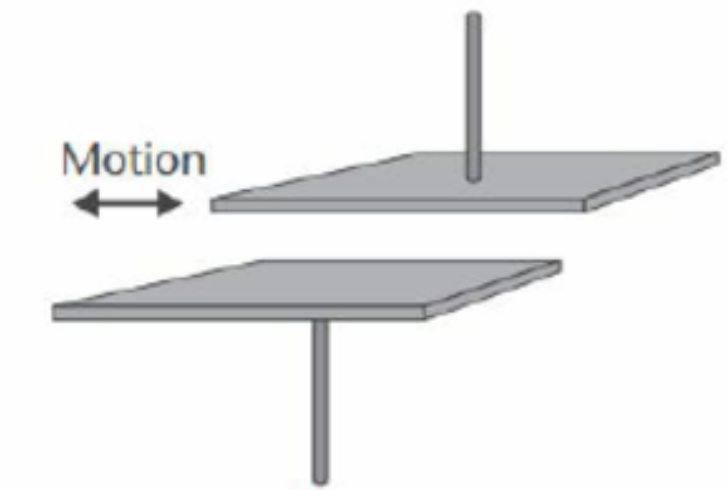
Potentiometer vs LVDT

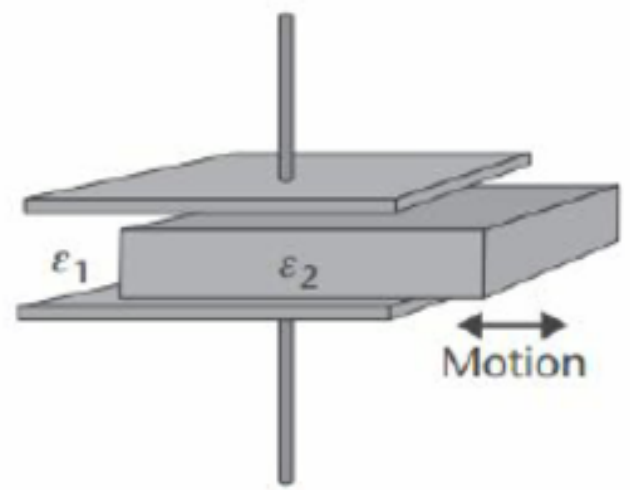
Position Sensor Technology	Potentiometer	AC-LVDT
Range in inches (mm)	0.12-20 (3-500)	0.02-20 (0.5-500)
Resolution	Good	Excellent
Repeatability	Good	Excellent
Non-linearity	Good	Good
Temp Character-istics	Fair	Very Good
Dynamic Response	Fair	Good
Vibration/Shock Sensitivity	Poor	Excellent
Mechanical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

Capacitive Displacement Sensors

Linear or Non-linear ??!

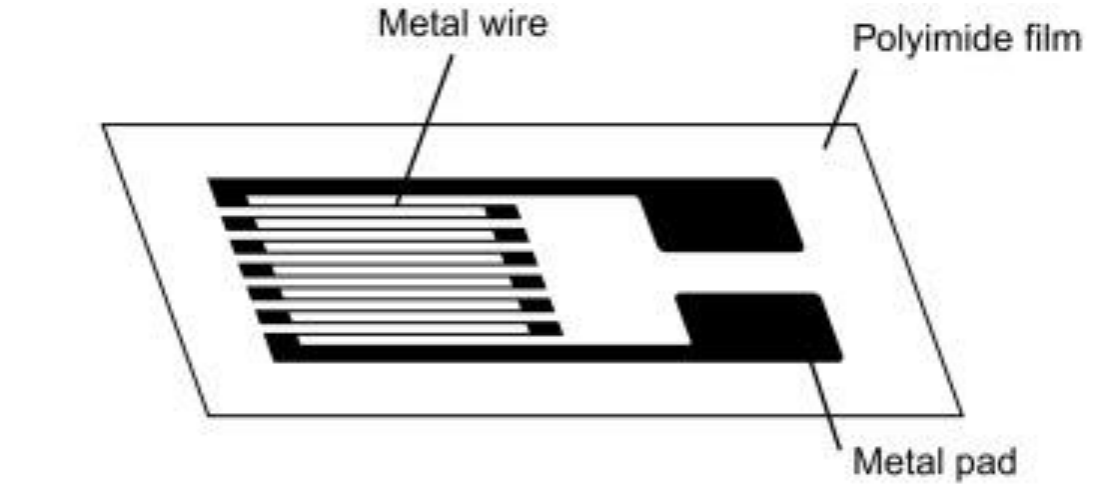


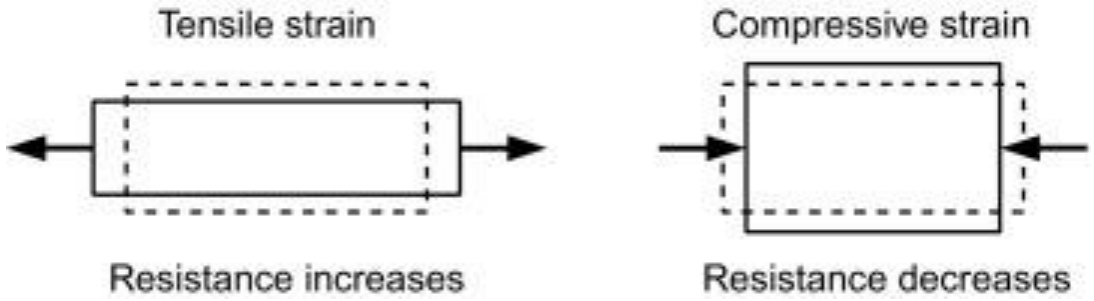




$$C = \varepsilon \frac{A}{d}$$

Strain gauge Displacement Sensors

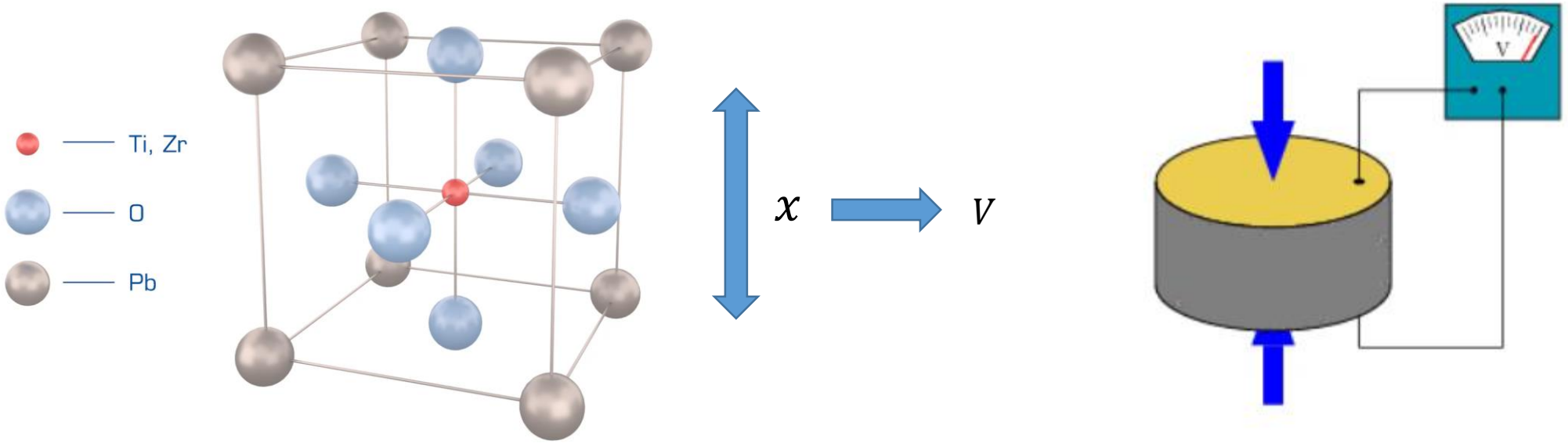




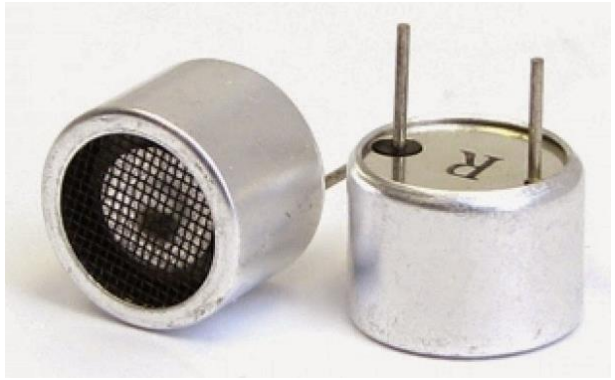
$$R = \rho \frac{L}{A}$$

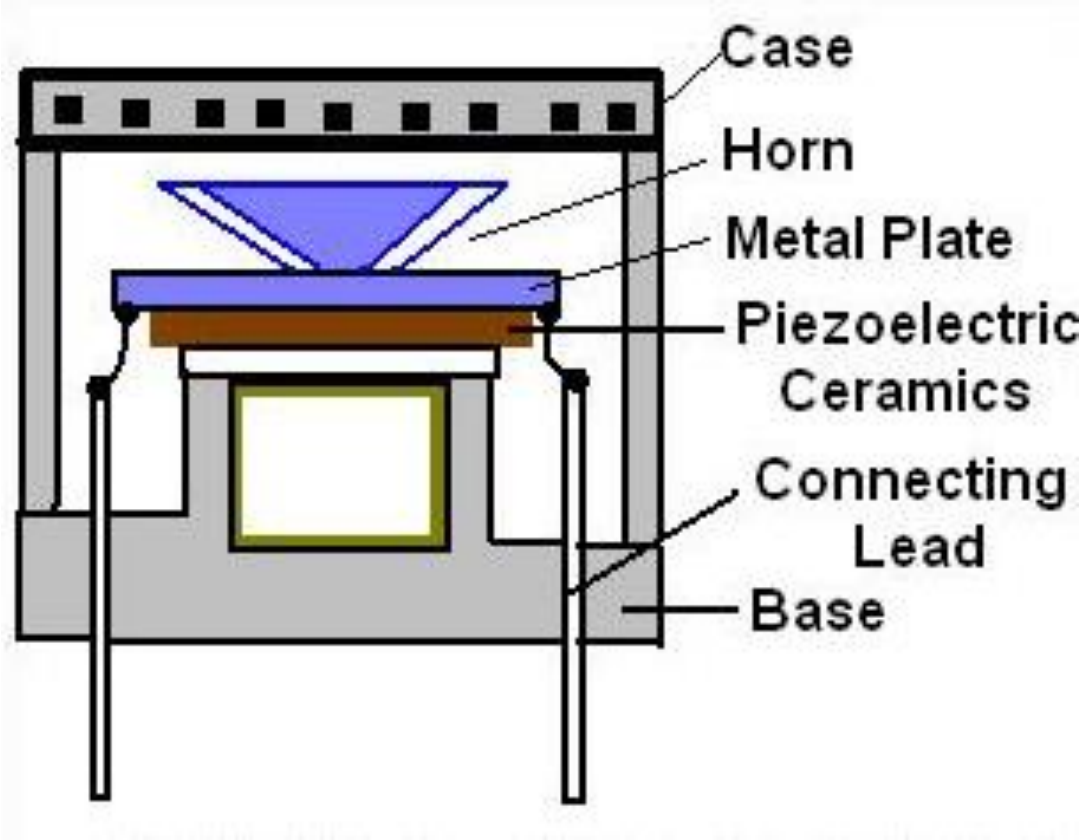
Piezoelectric Displacement Sensors

- **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.

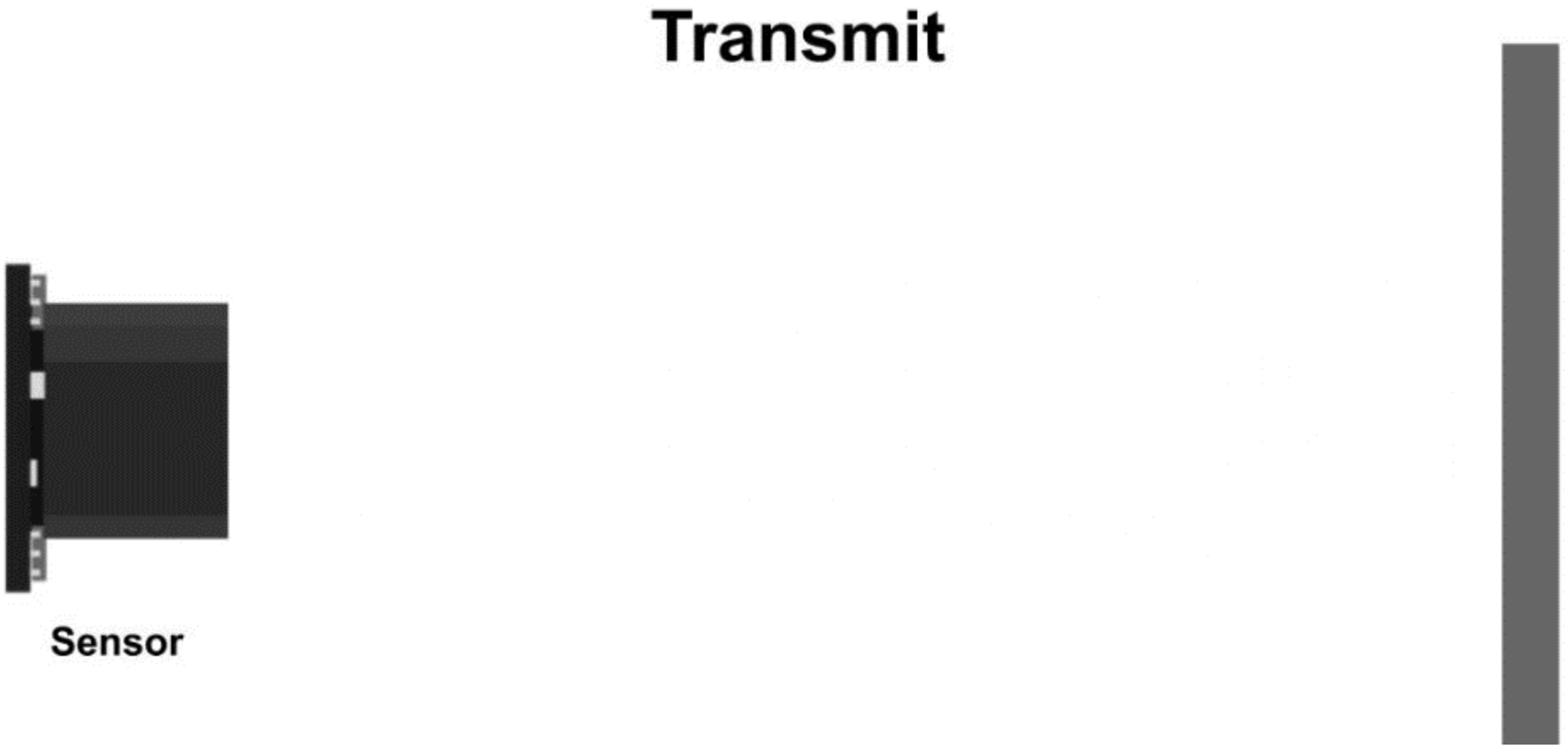


Ultrasonic Distance Sensor

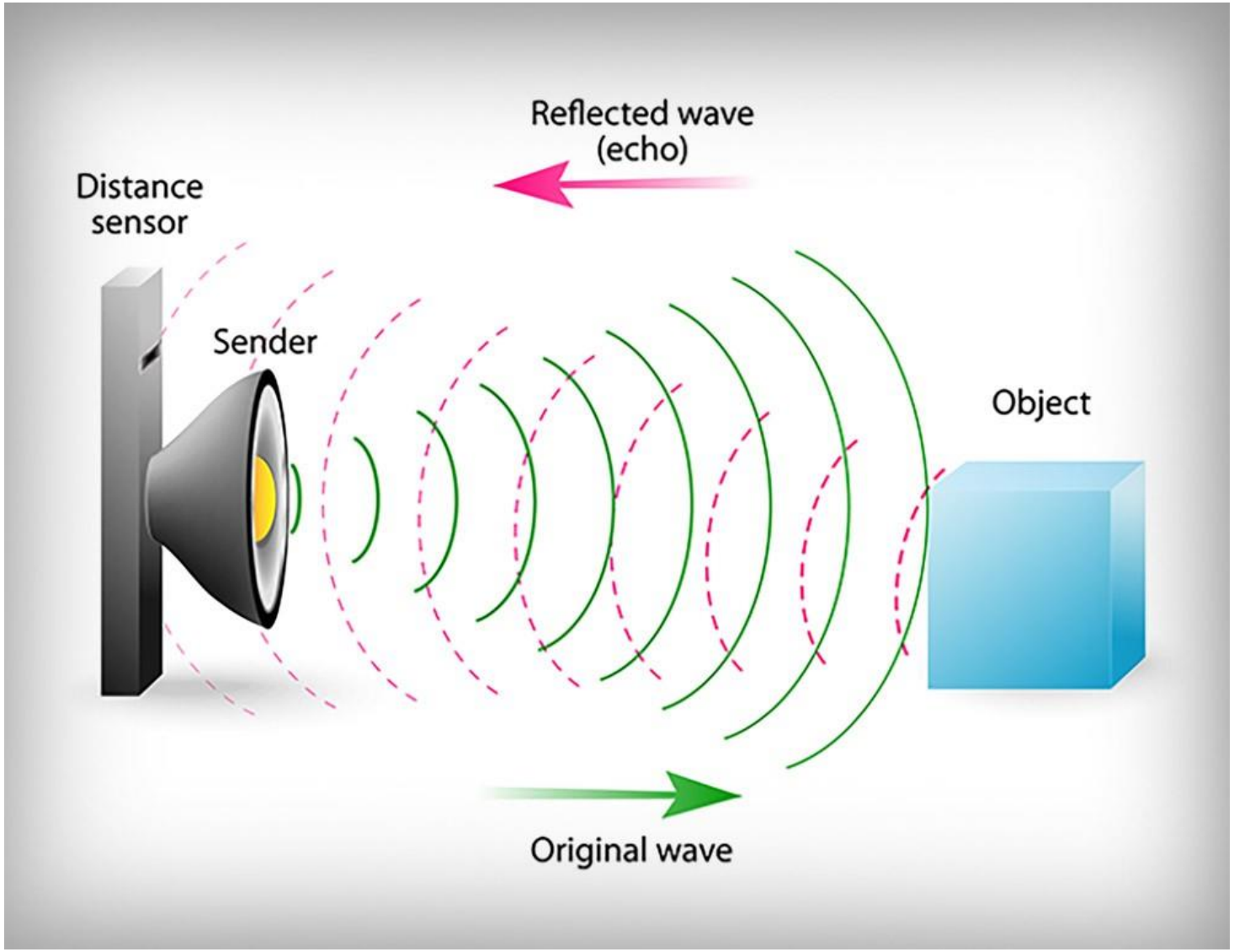


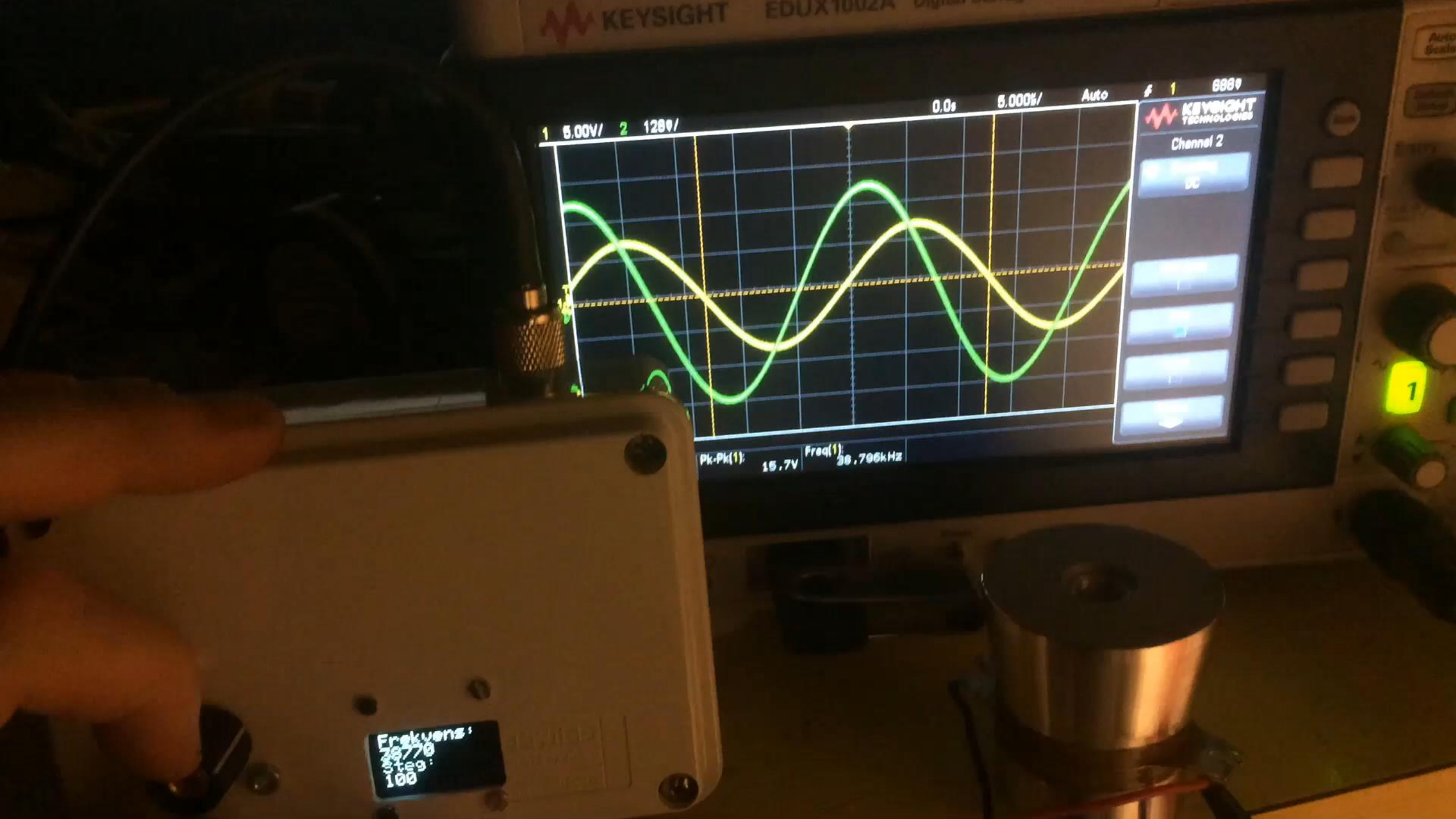


Ultrasonic Distance Sensor

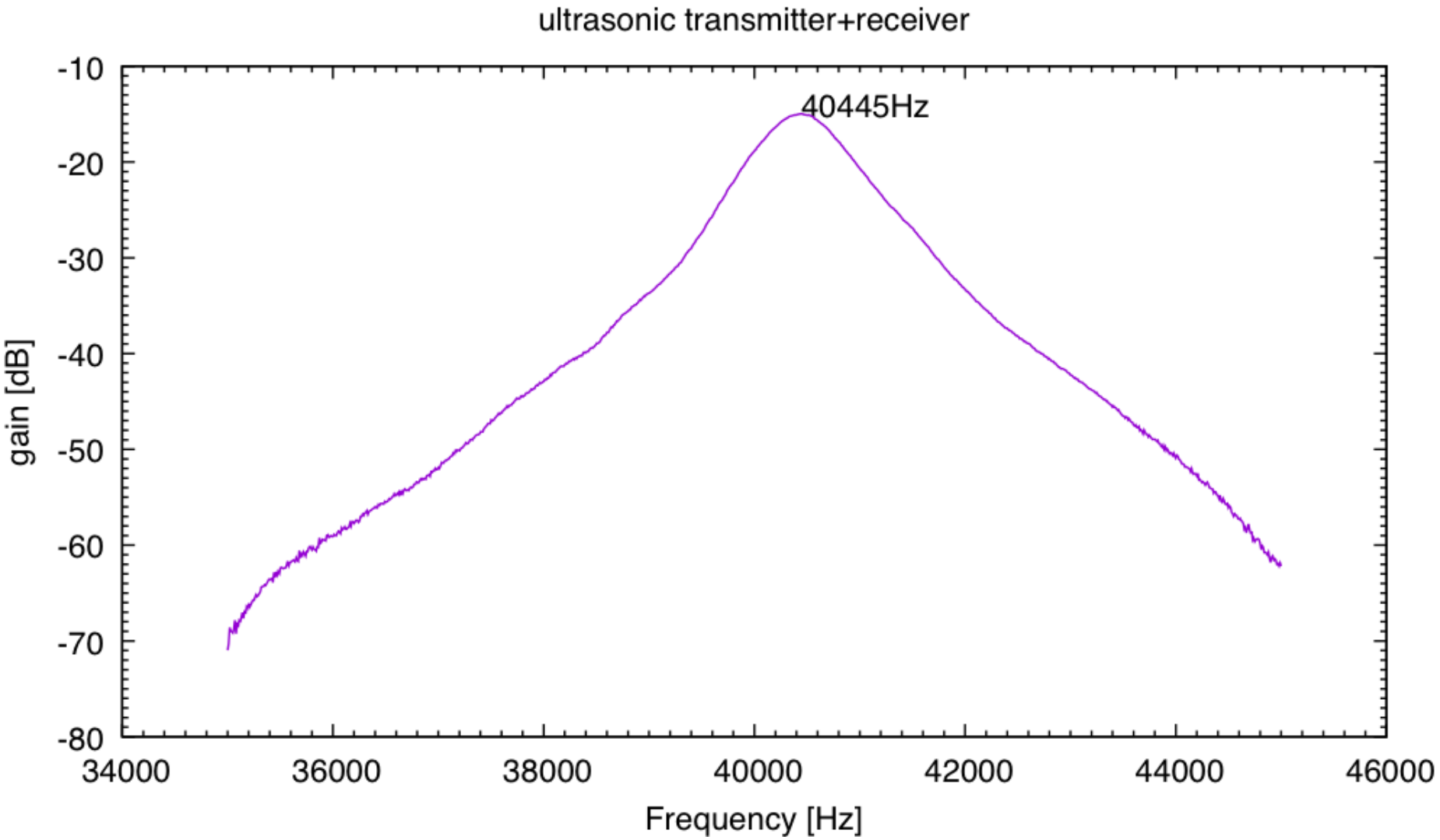


Ultrasonic Distance Sensor

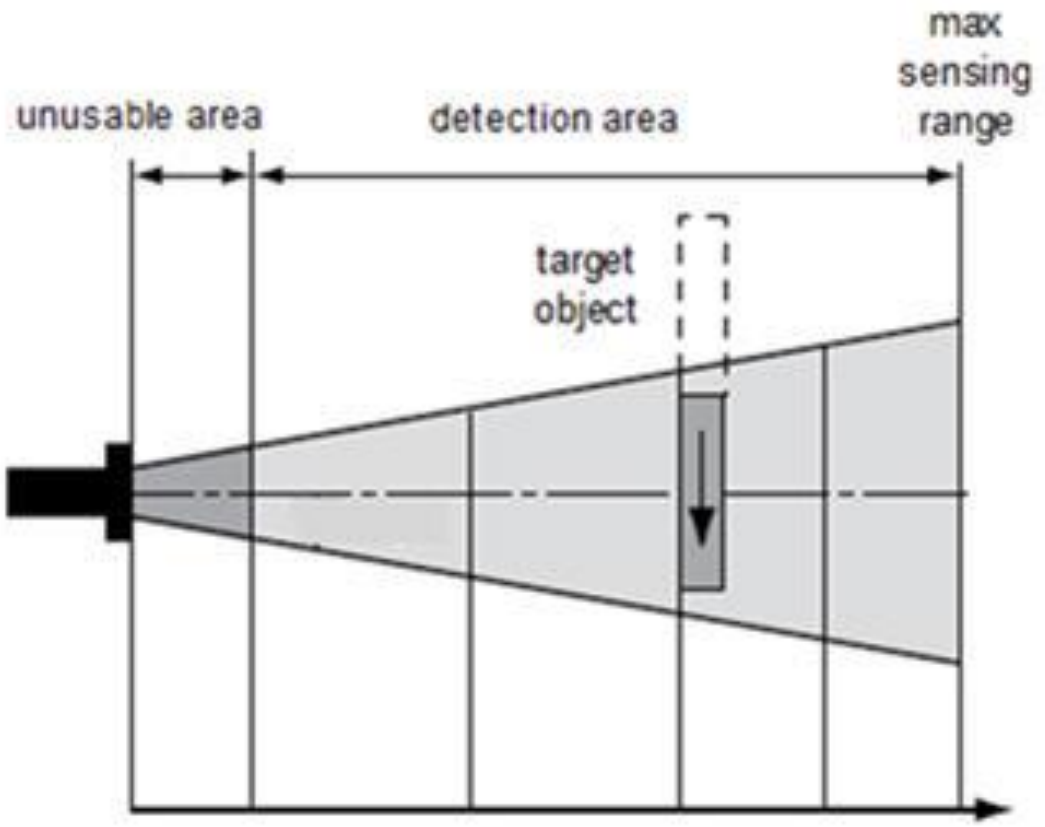


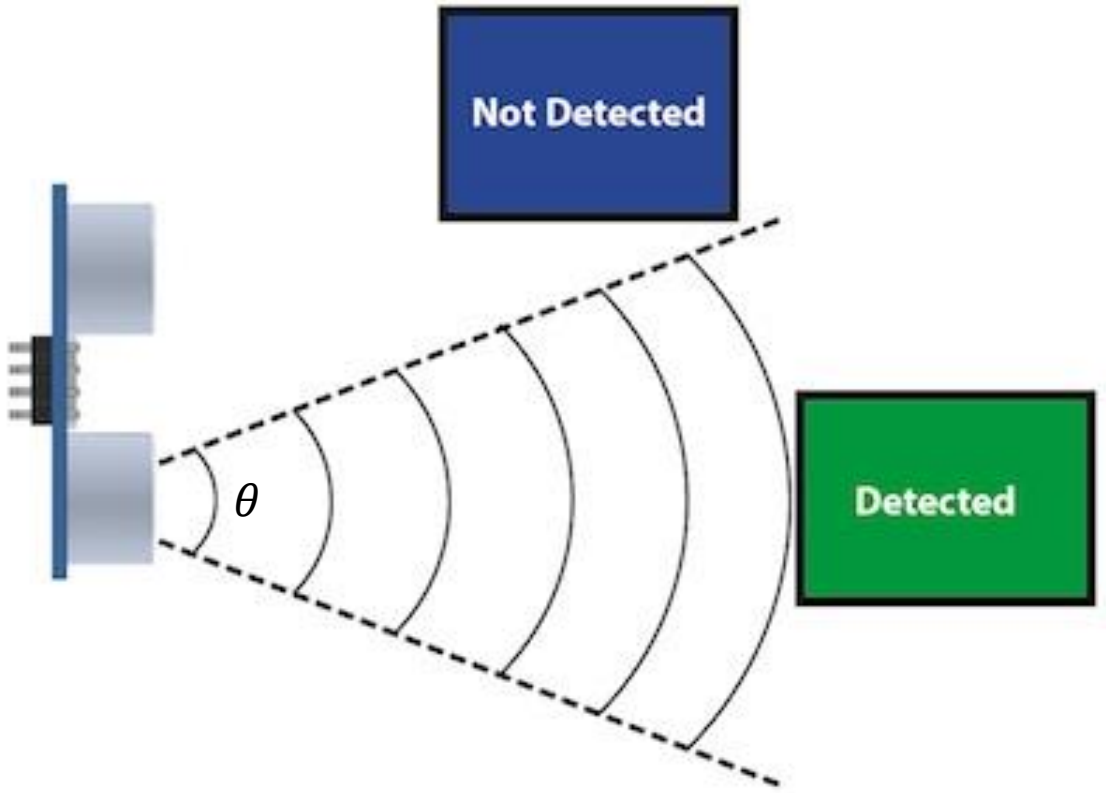

KEYSIGHT
1 5.00V/ 2 128V/
0.0s 5.000s/ Auto
Channel 2
DC
Pk-Pk(1) 15.7V
Freq(1) 38.796kHz
Frekvens:
38770
Steg:
100

Ultrasonic Distance Sensor

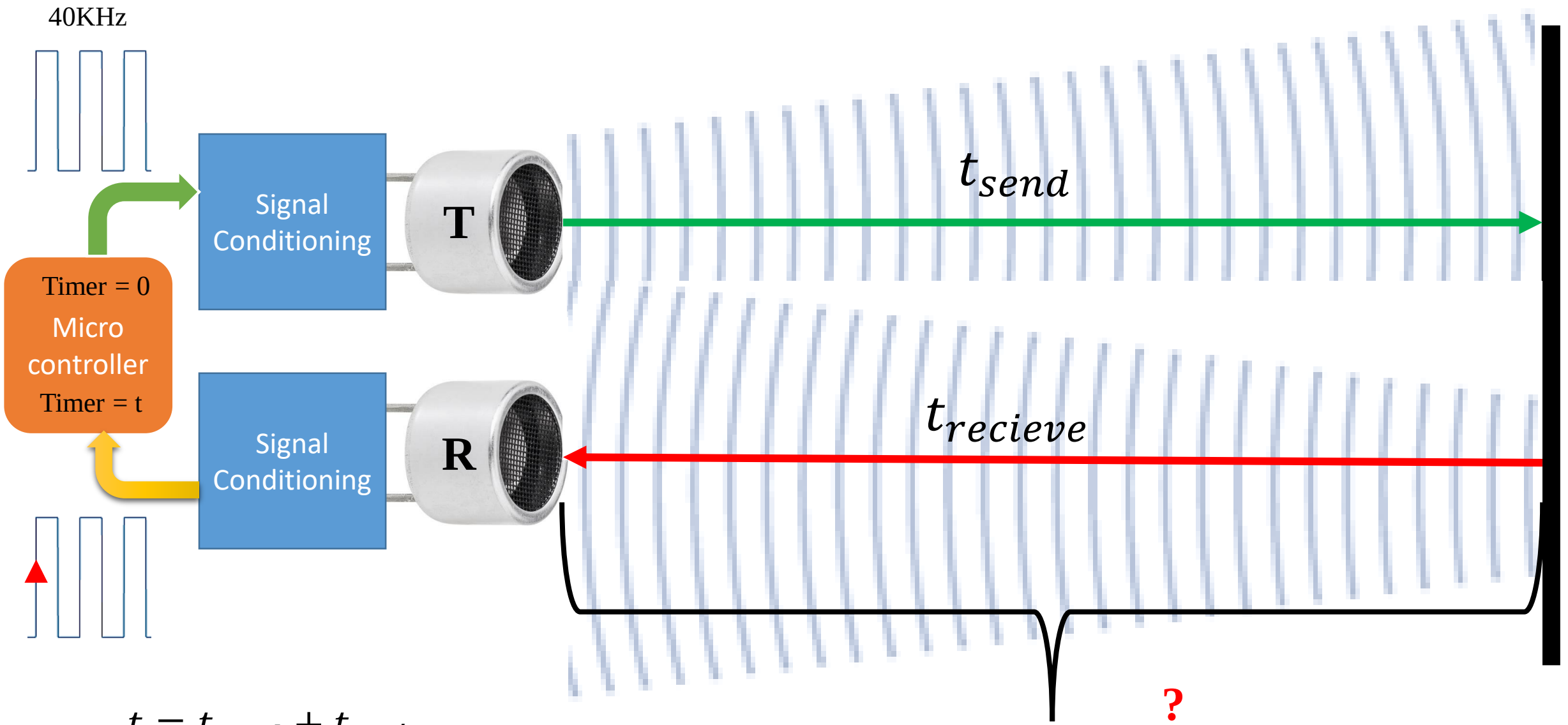


Ultrasonic Distance Sensor





Ultrasonic Distance Sensor

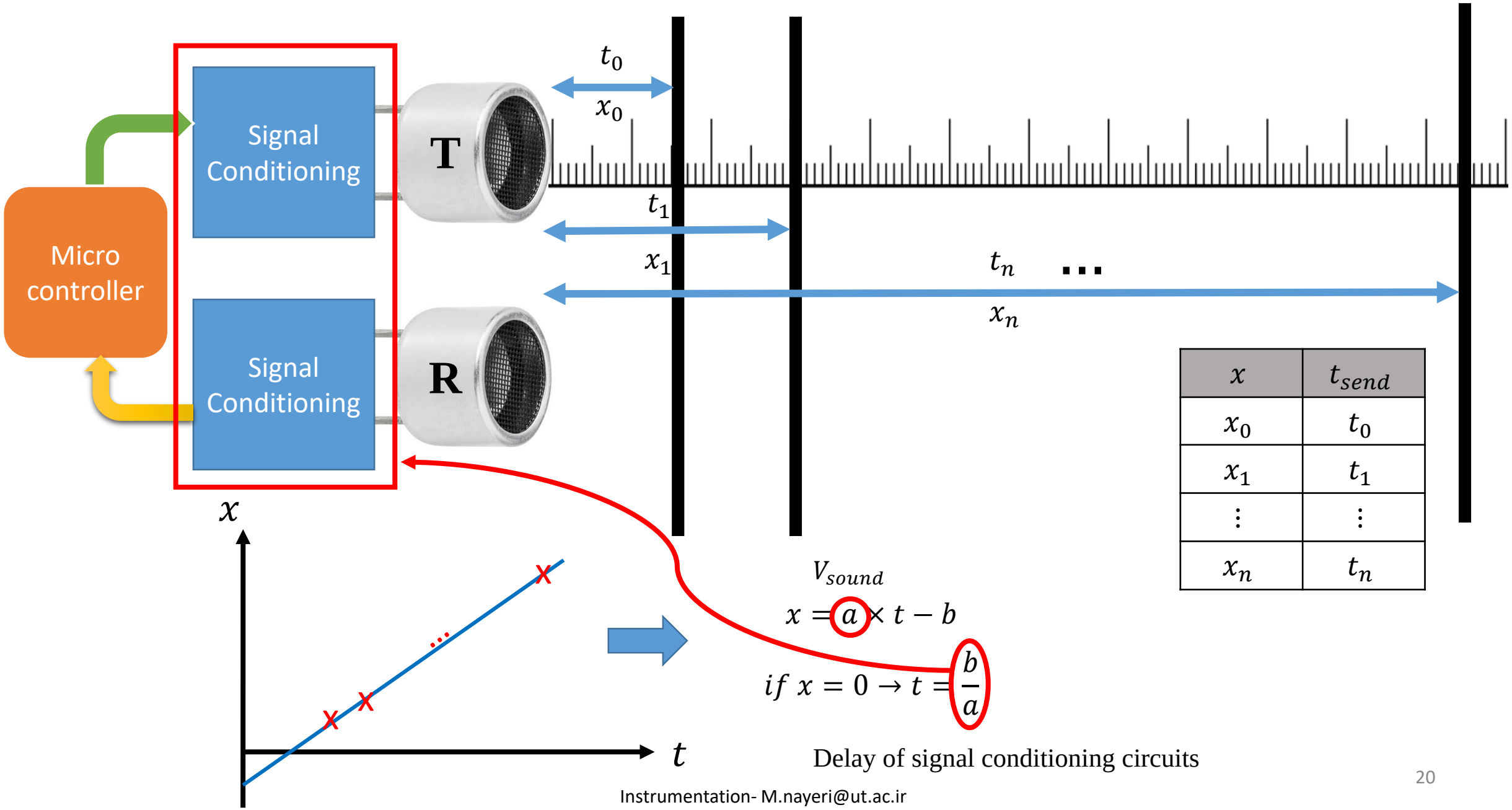


$$t = t_{send} + t_{recieve}$$

$$x = \boxed{V_{sound}} \times \frac{t}{2}$$

?

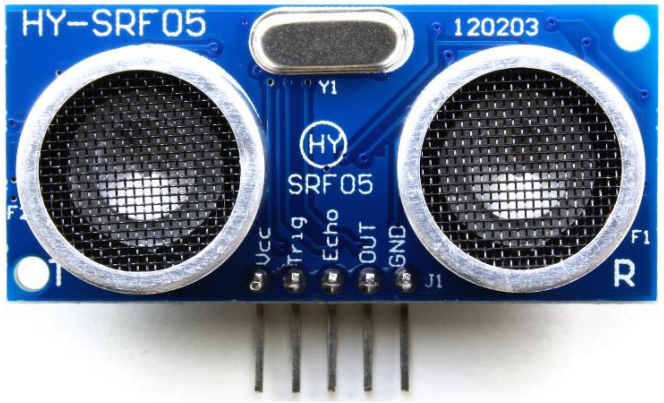
Ultrasonic Distance Sensor

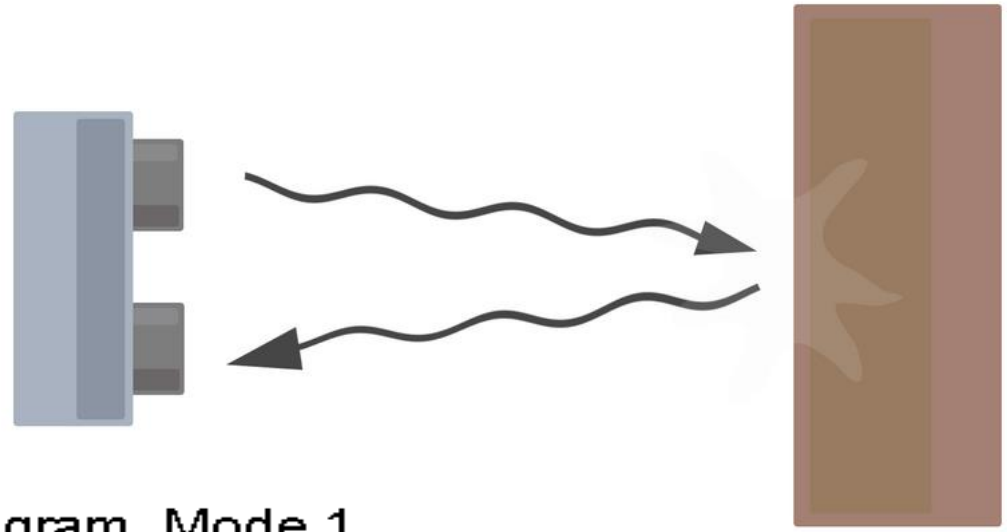


x	t_{send}
x_0	t_0
x_1	t_1
$\vdots$	$\vdots$
x_n	t_n

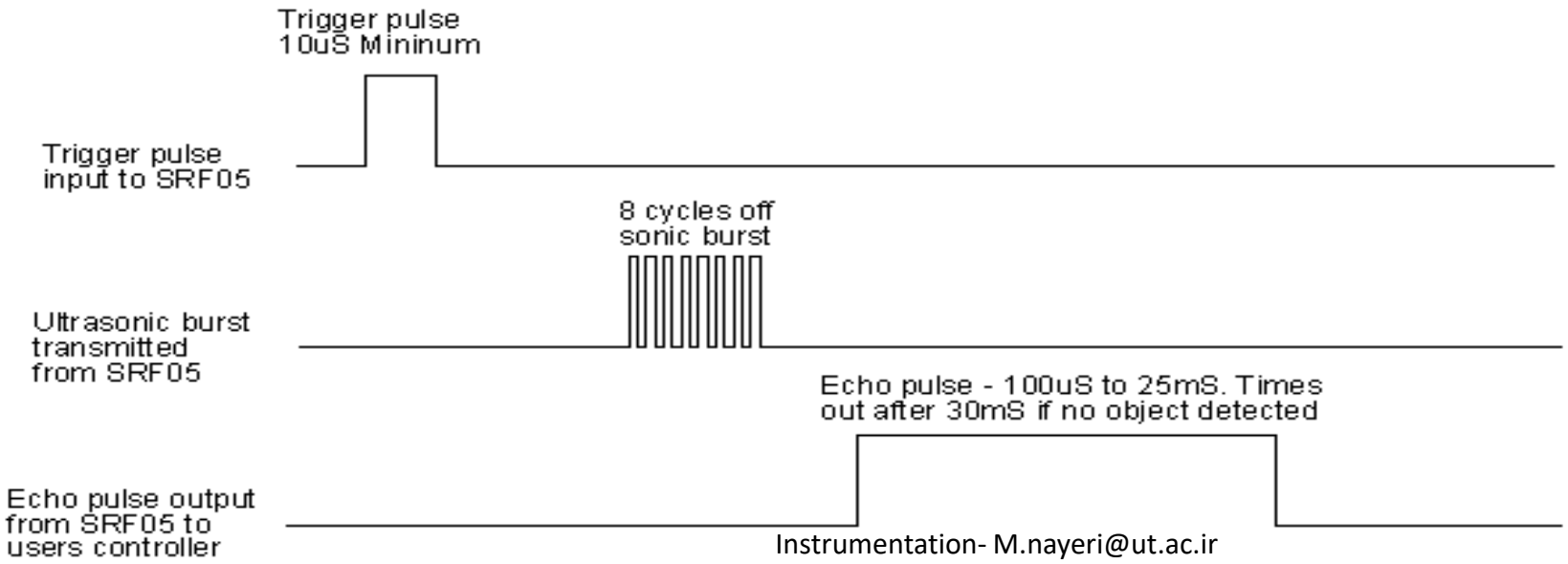
Delay of signal conditioning circuits

Ultrasonic Distance Sensor





SRF05 Timing Diagram, Mode 1



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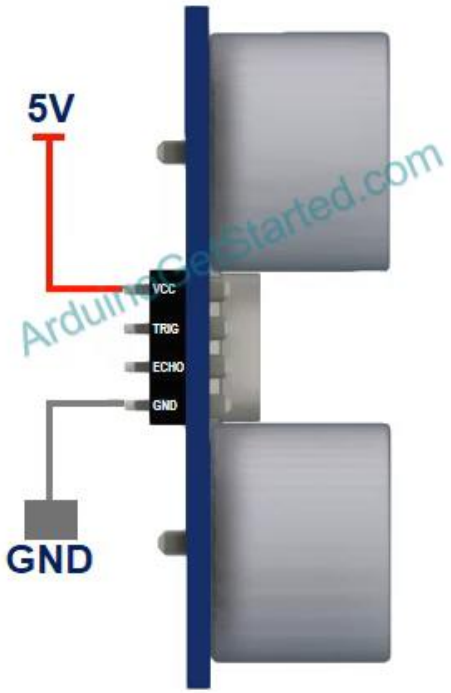
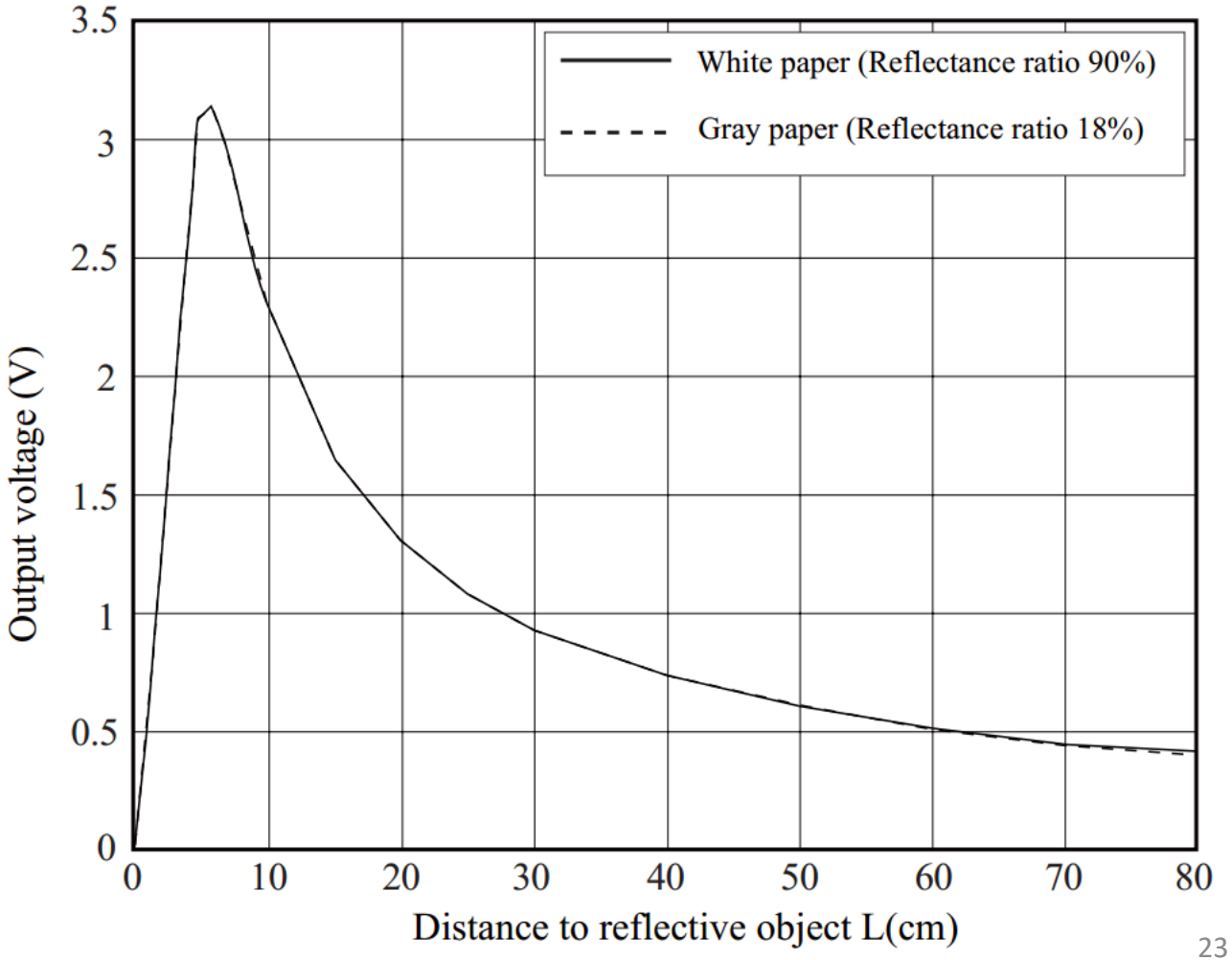
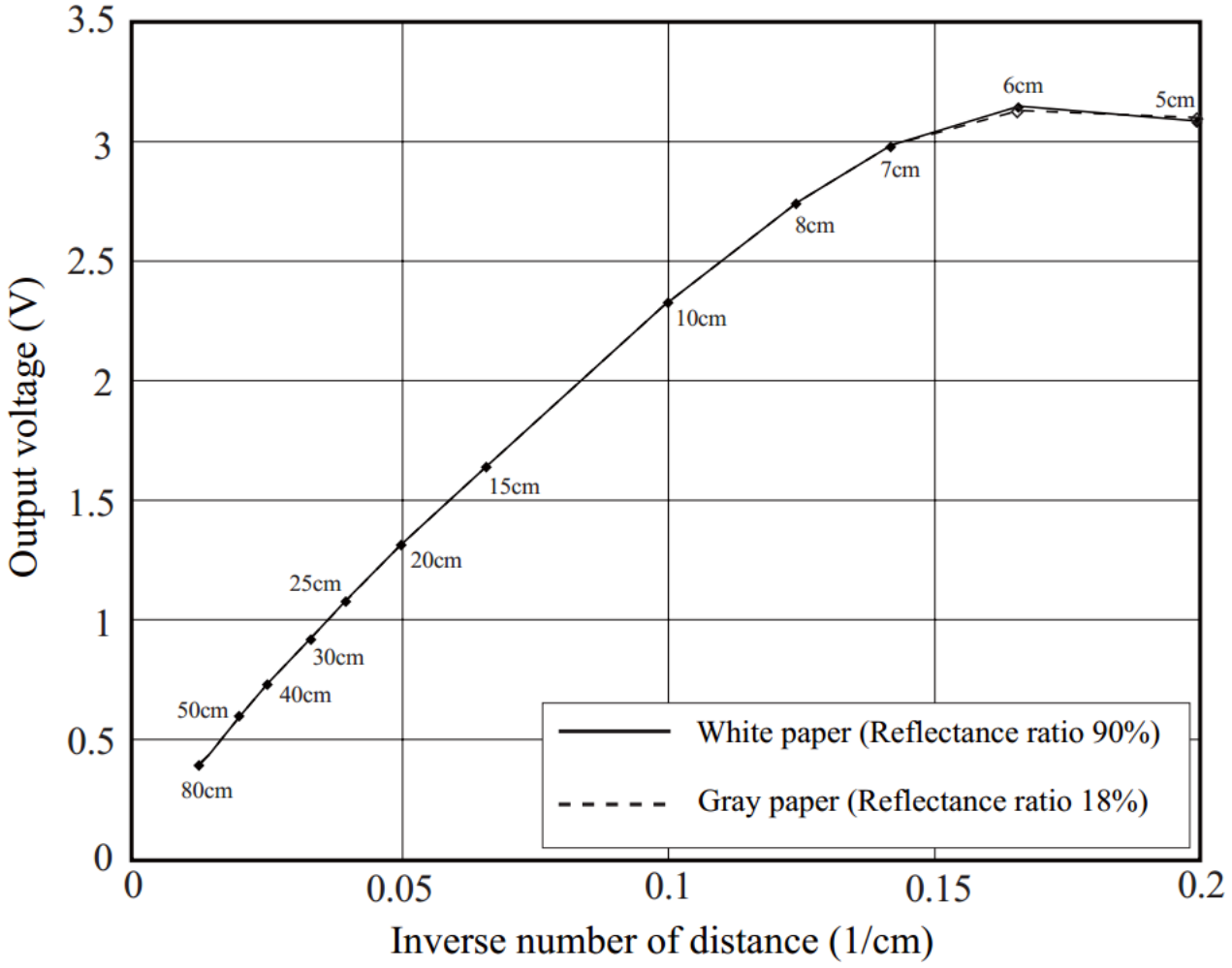
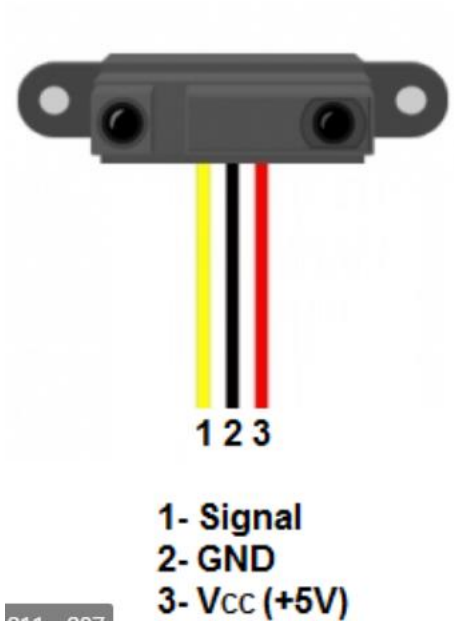


Optical Distance Sensor



Optical Distance Sensor





Optical Distance Sensor

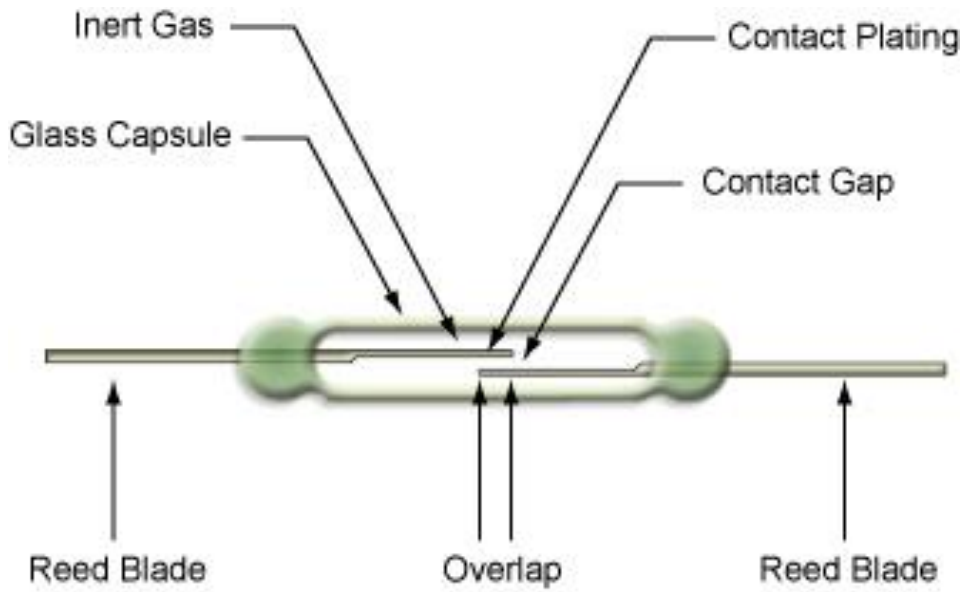
Sharp GP2YXX Analog Distance Sensor

Proximity Sensors

- Magnetic
- Inductive
- Capacitive
- Optical
- Ultrasonic

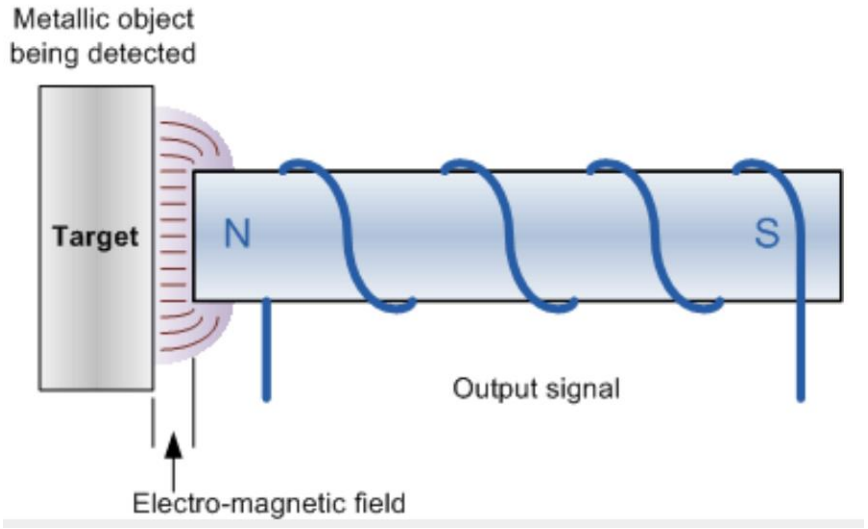
Magnetic Proximity Sensor

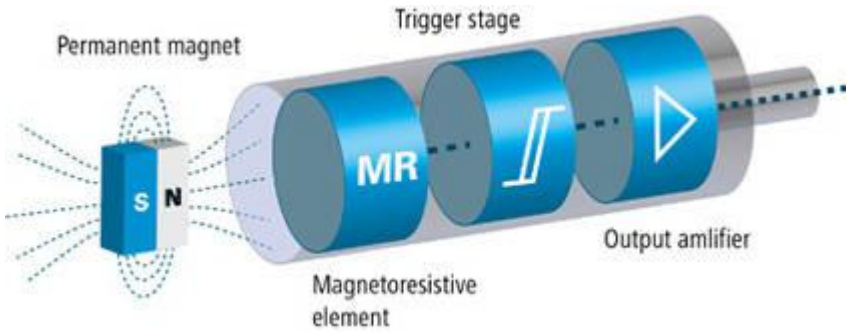
Reed Relay



- ✓ Detects Magnetic objects without physical contact

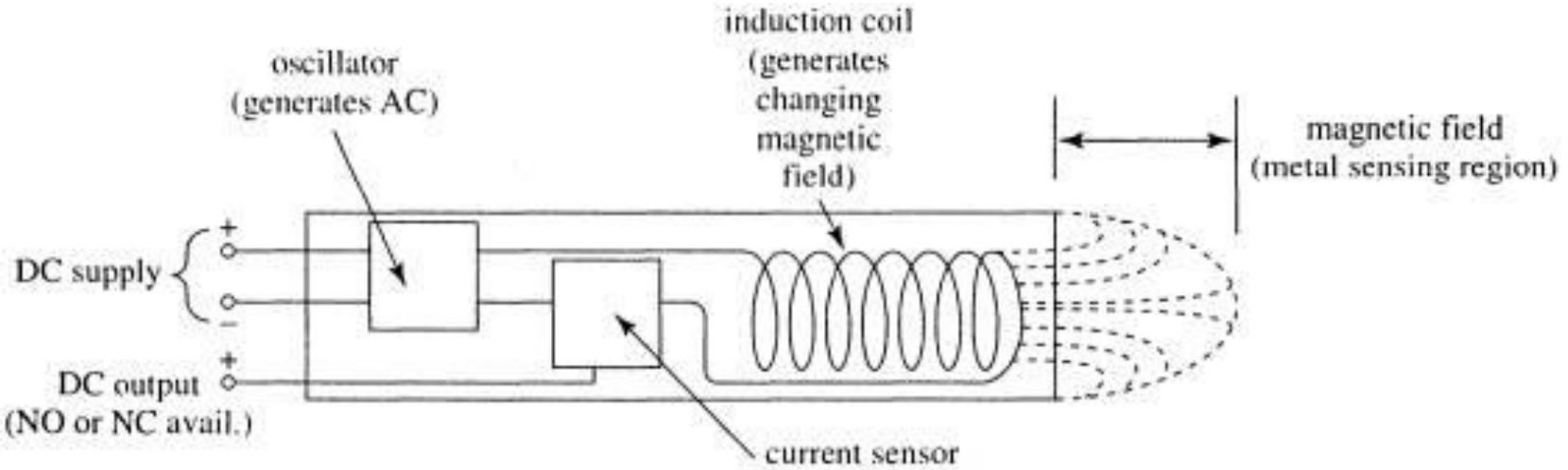
Magnetic Proximity Sensor





- ✓ Detects Magnetic objects without physical contact

Inductive Proximity Sensor

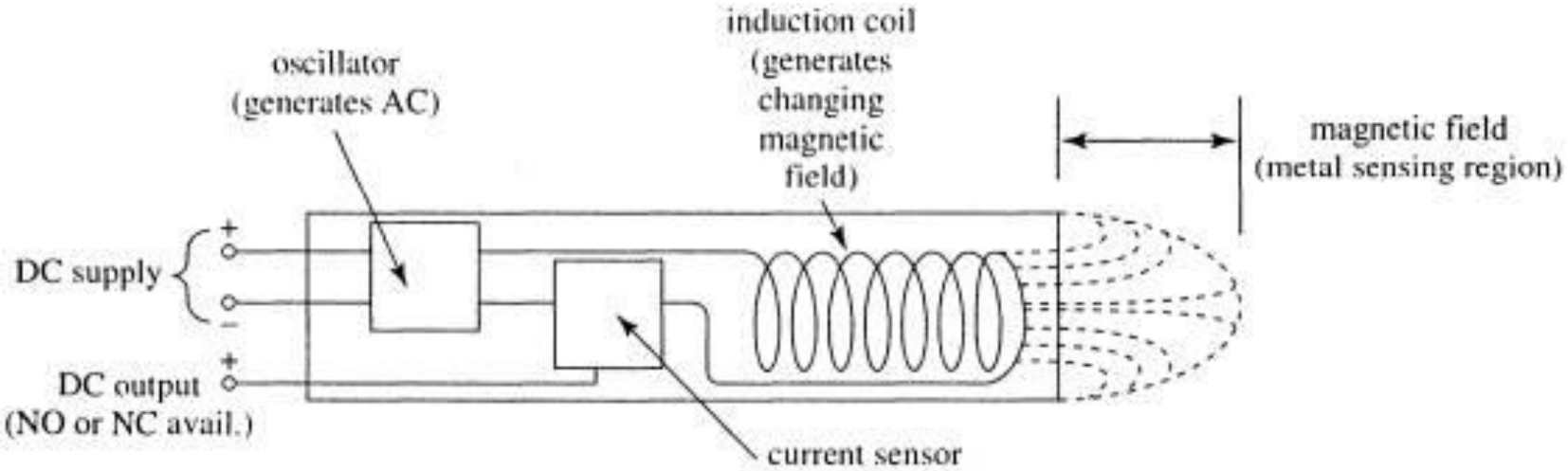


- ✓ Detects Metallic objects without physical contact

Operating distance depends on:

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

Inductive Proximity Sensor



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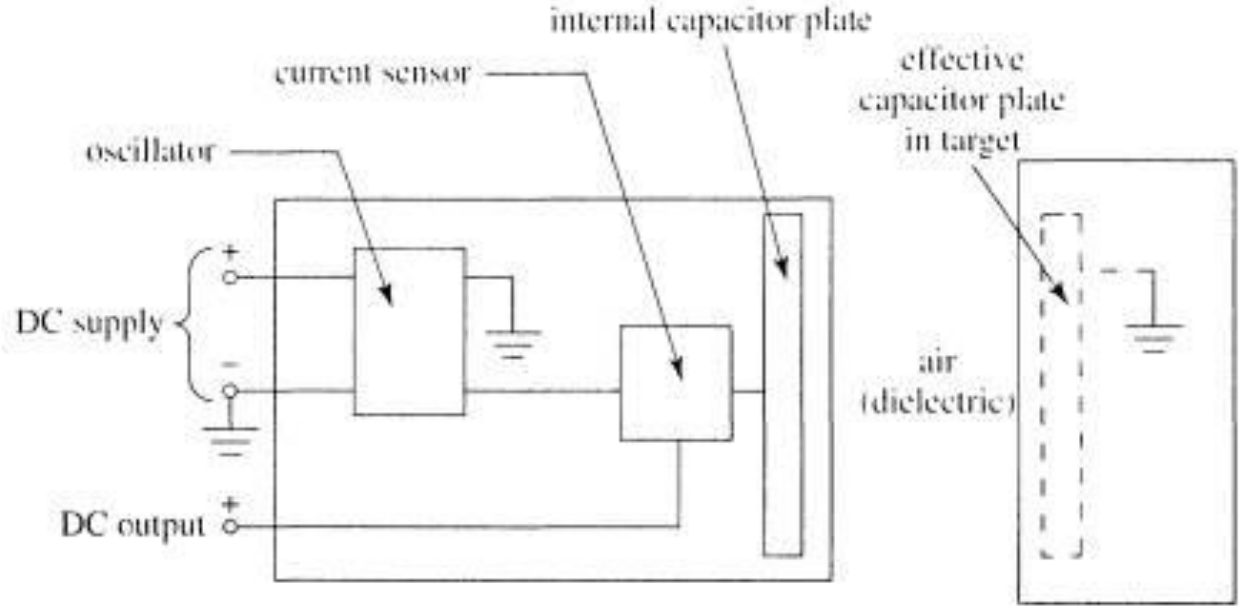
Capacitive Proximity Sensor



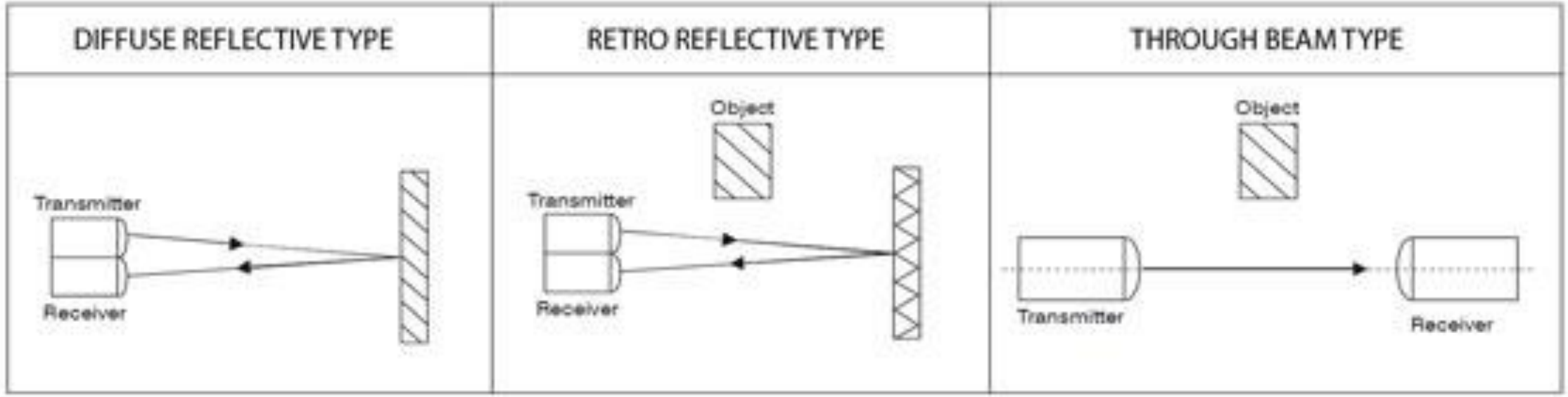
Detects metallic objects as well as non-metallic objects(liquid, plastic, wooden material etc)

✓ Uses variation of capacitance between sensor and object

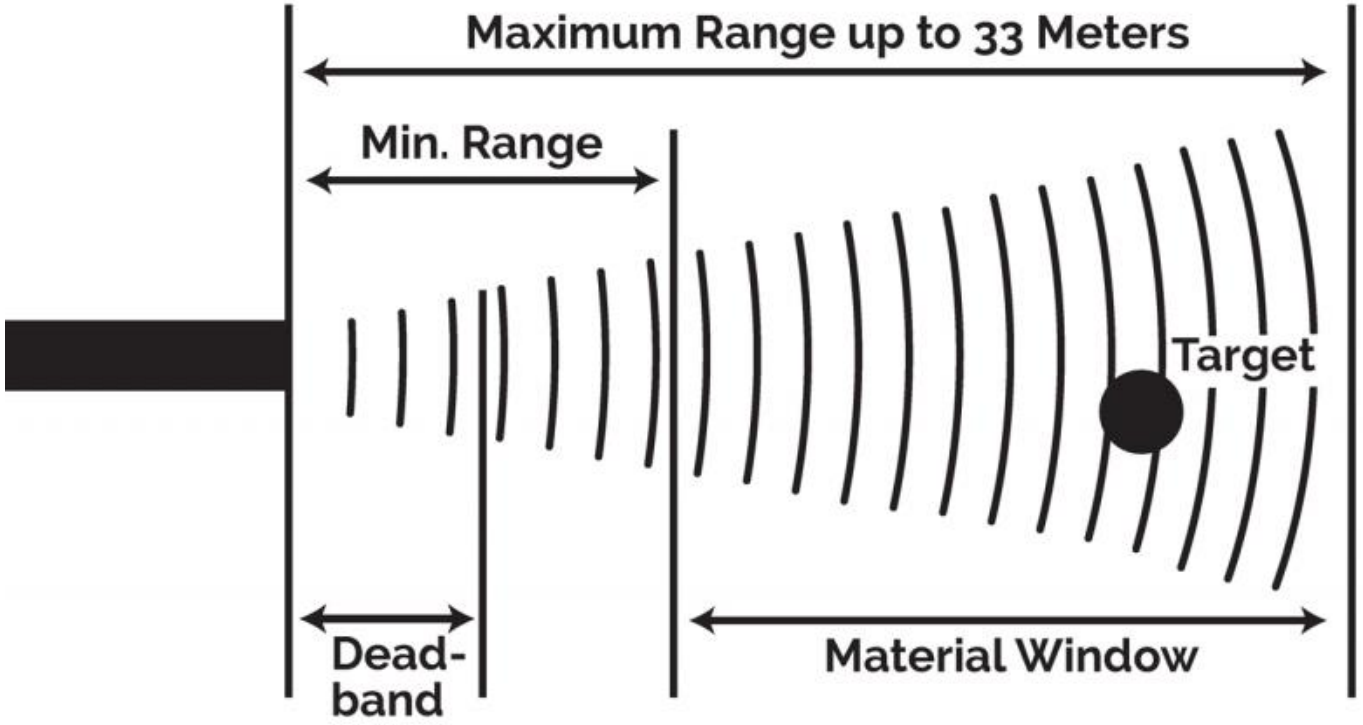
Optical Proximity Sensor

- 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

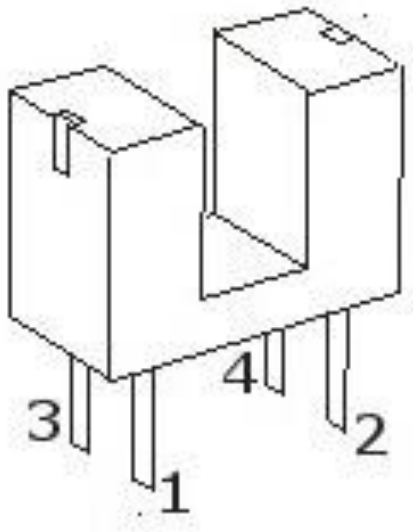
Optical Proximity Sensor

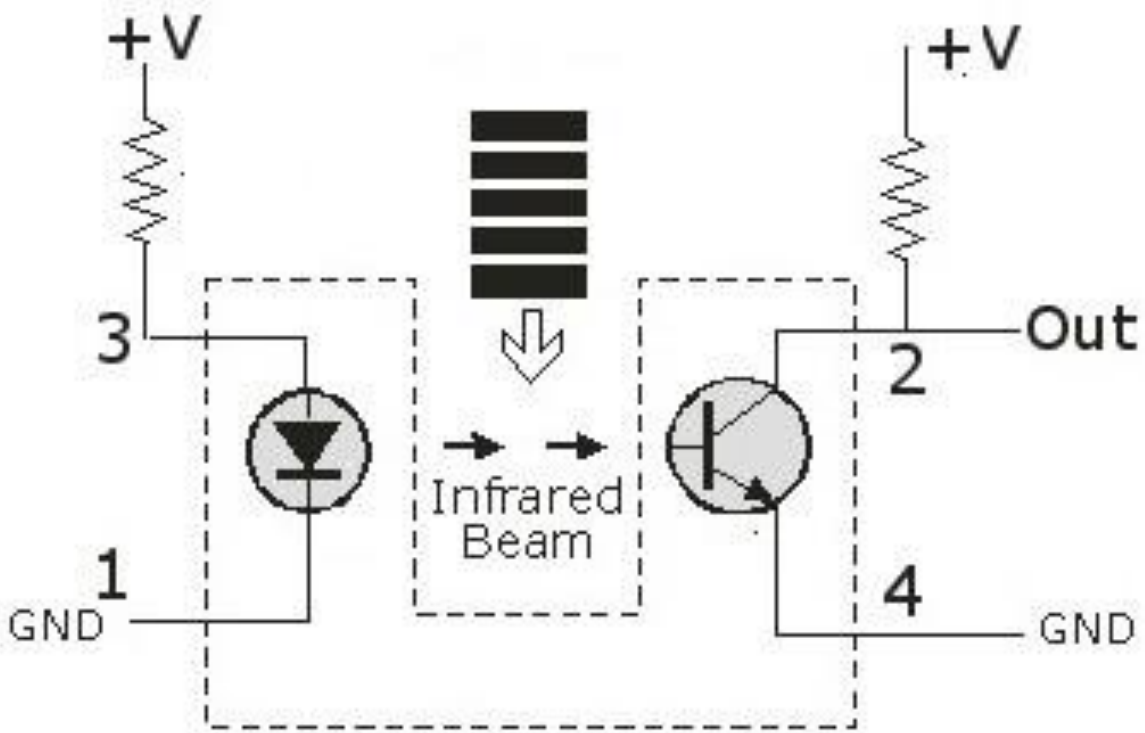


Ultrasonic Proximity Sensor



Optocounter

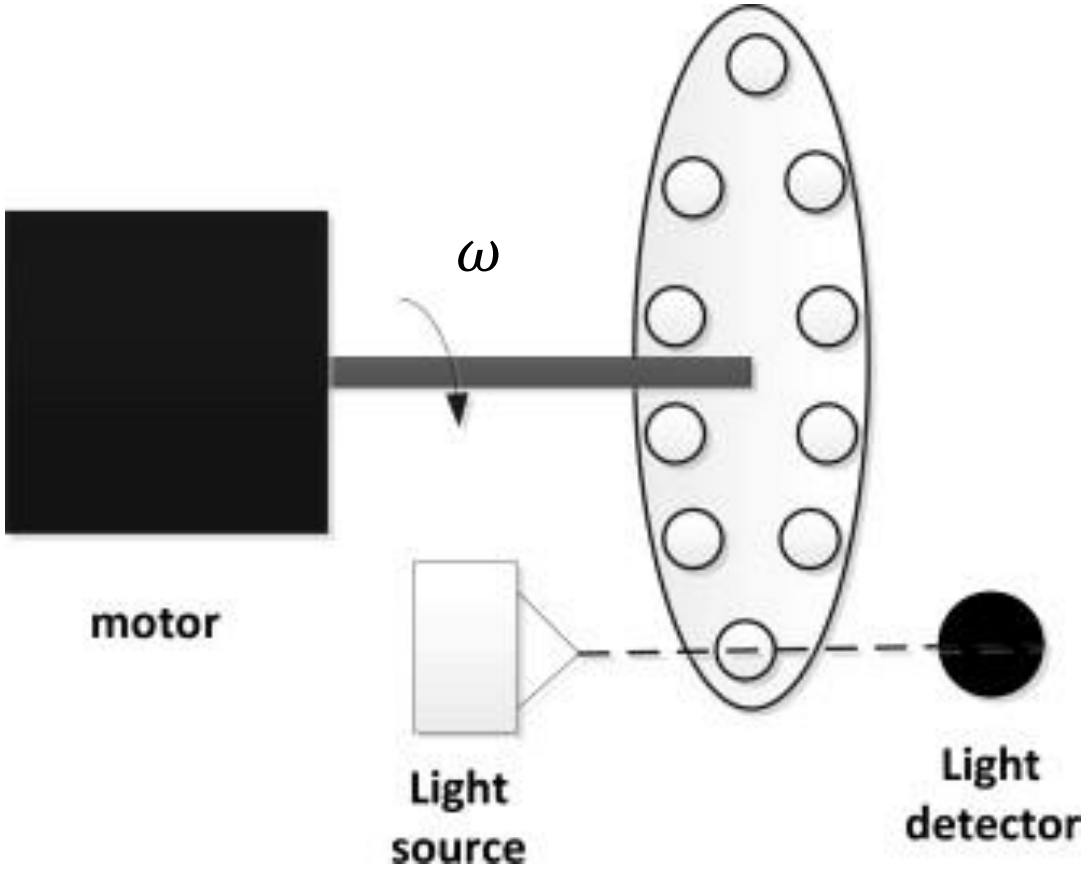





LM393
8AK
YH1518
FC-03
开关指示
电源指示

Optocounter

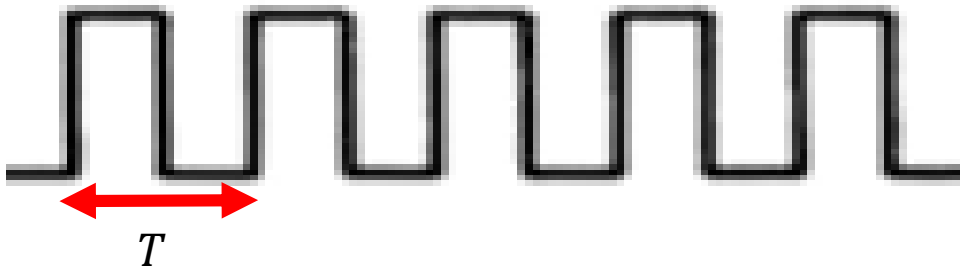
$Number\ of\ Holes: n$



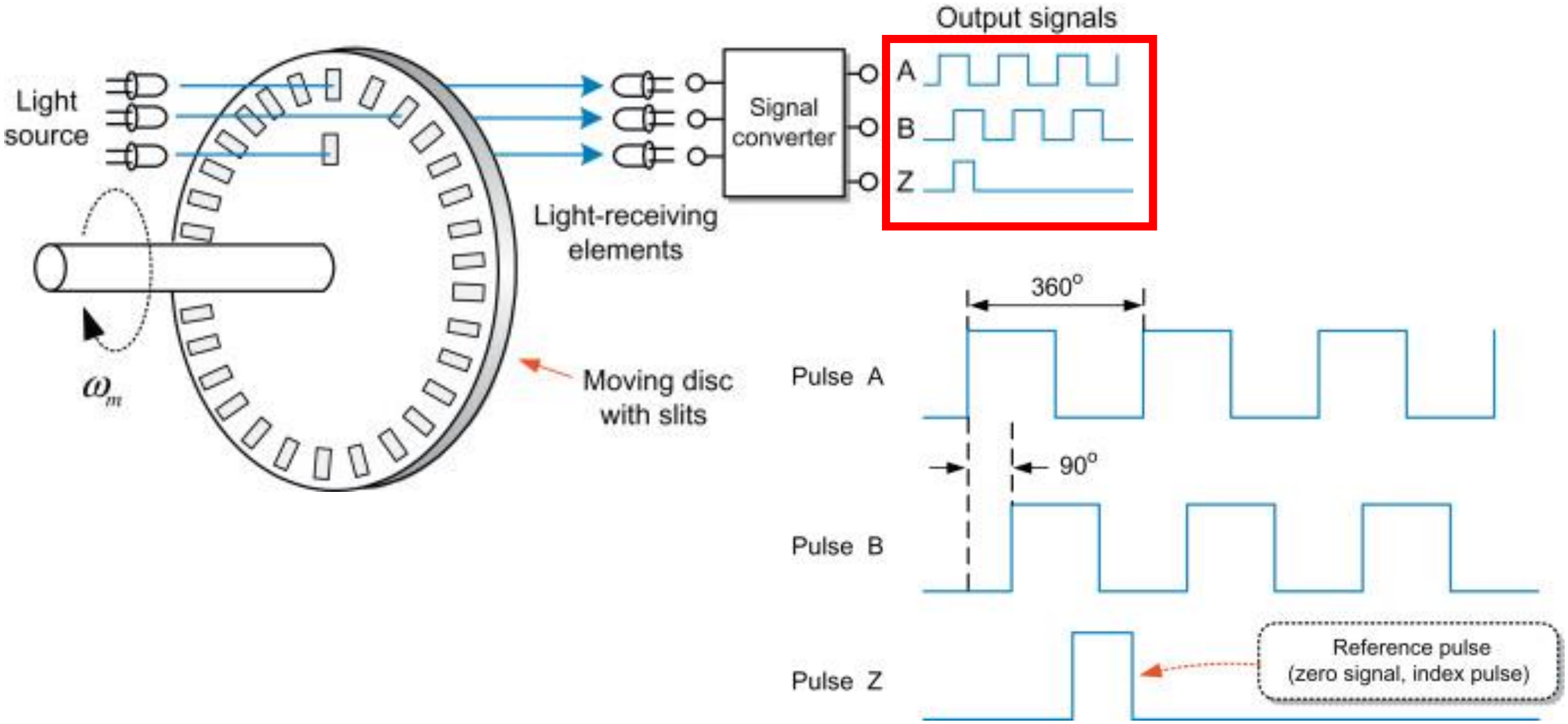
$$One\ Revolution\ Time = nT$$

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

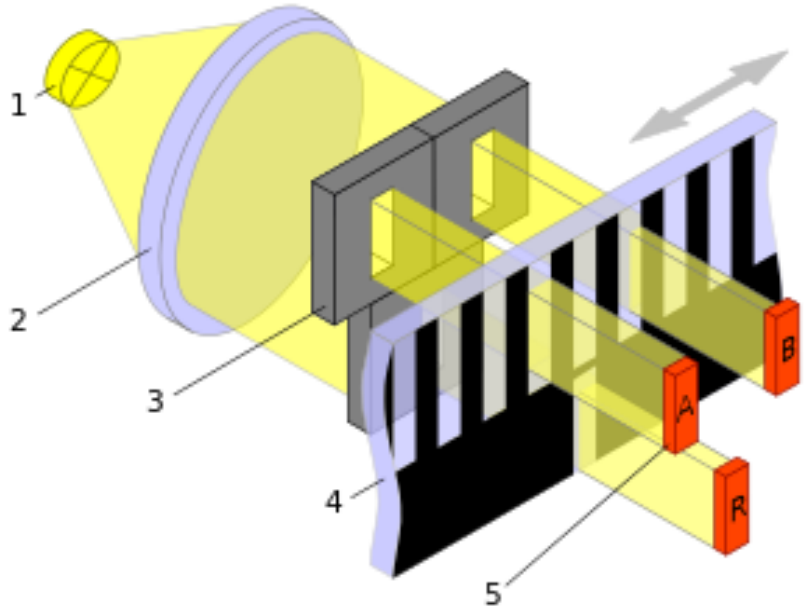
$$Revolutions\ Per\ Minute(RPM) = \frac{60}{nT} = \frac{60f}{n}$$

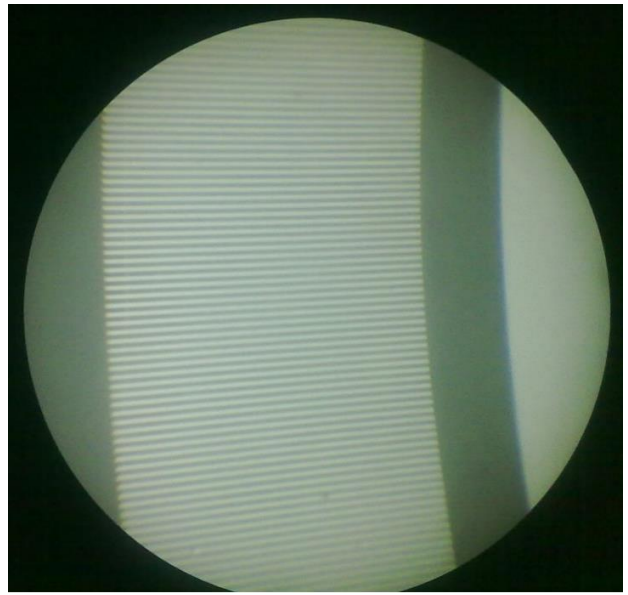


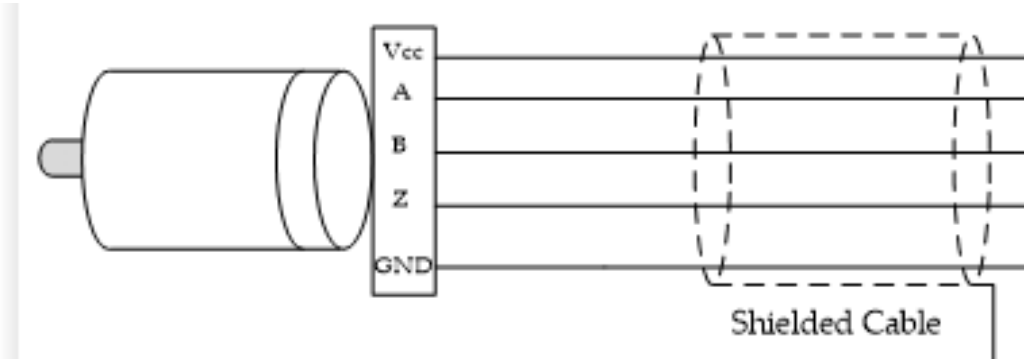
Incremental Encoder



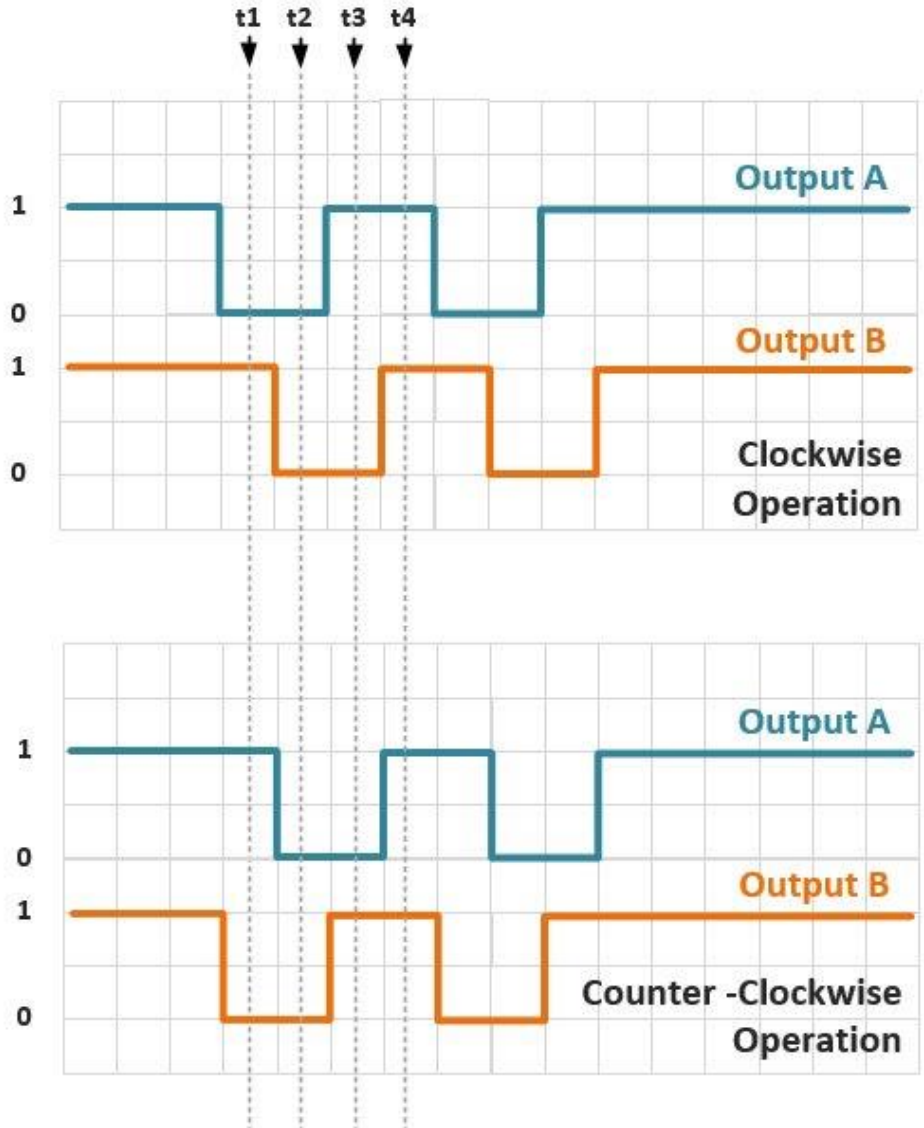
Incremental Encoder







Incremental Encoder

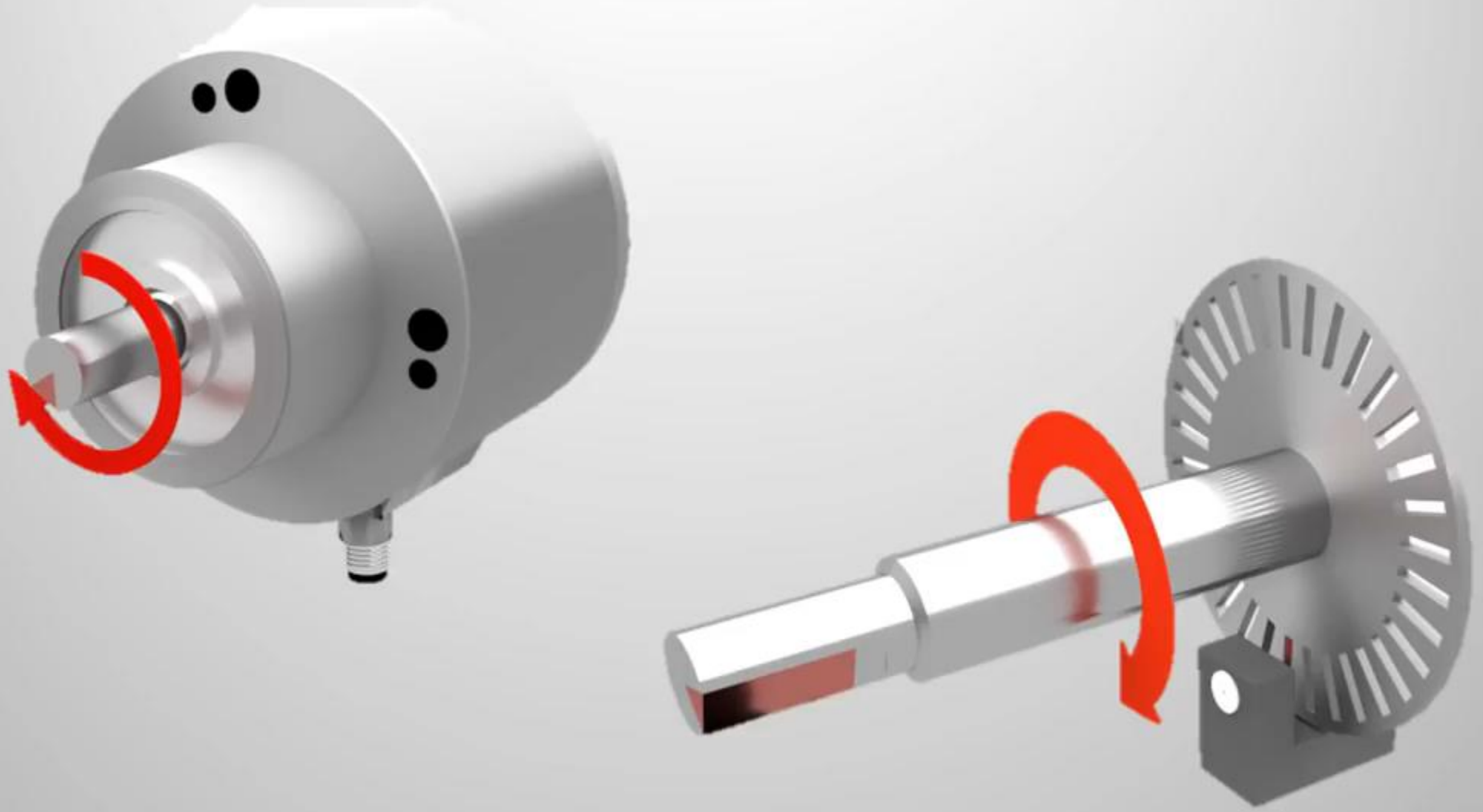


Clockwise Sequence

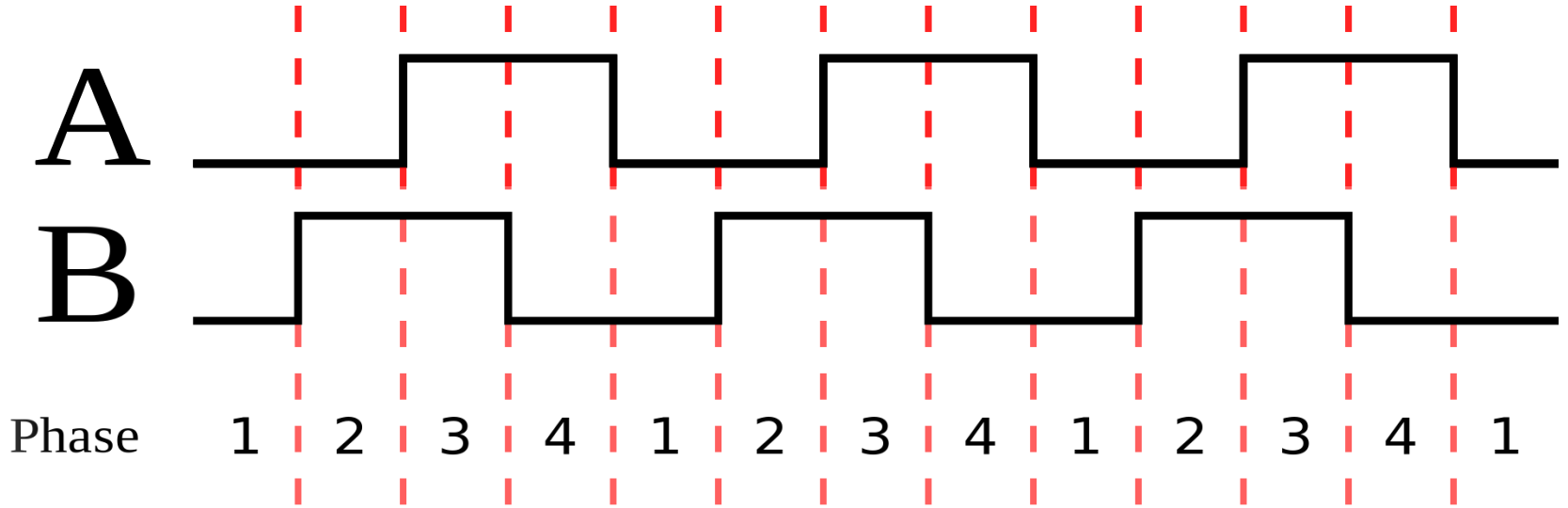
	A	B
t1	0	1
t2	0	0
t3	1	0
t4	1	1

Counter-Clockwise Sequence

	A	B
t1	1	0
t2	0	0
t3	0	1
t4	1	1



Incremental Encoder



$Number\ of\ Holes: n$

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

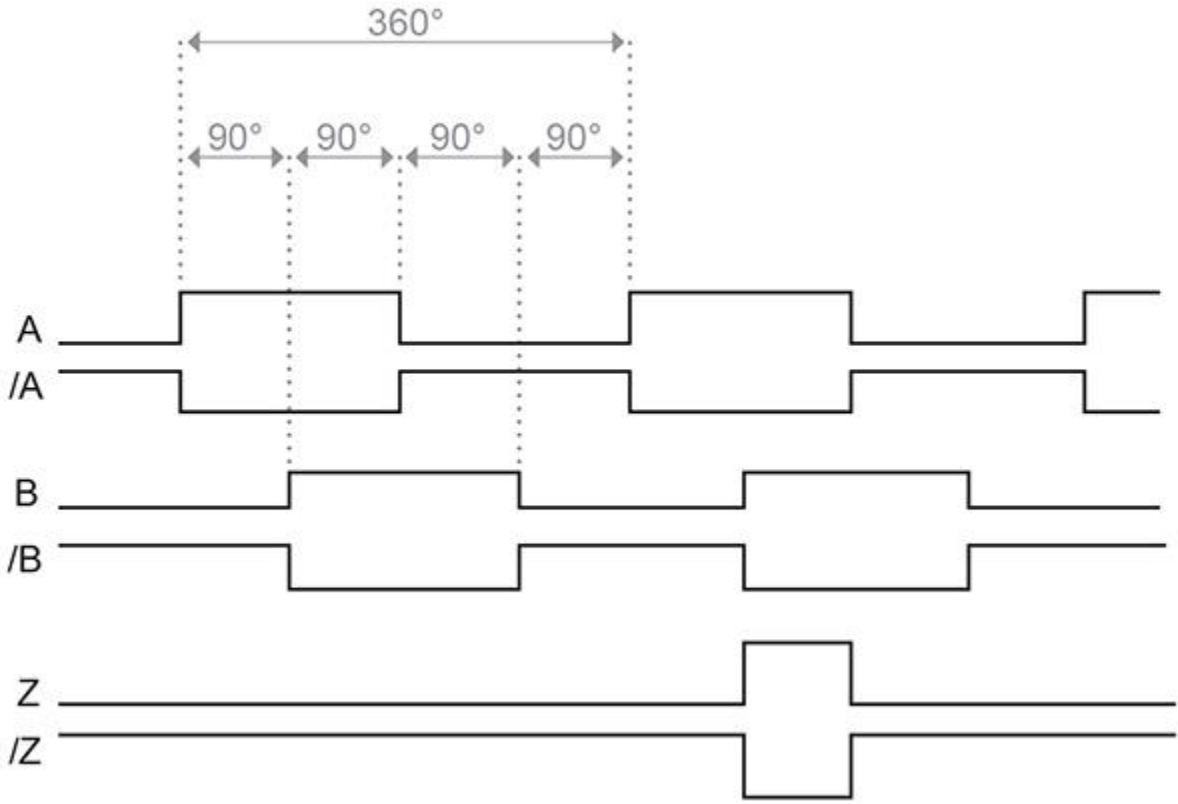
$Rising\ and\ Falling\ Edge\ Intrrupt\ on\ A: \quad \pm\frac{360}{2n}$

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

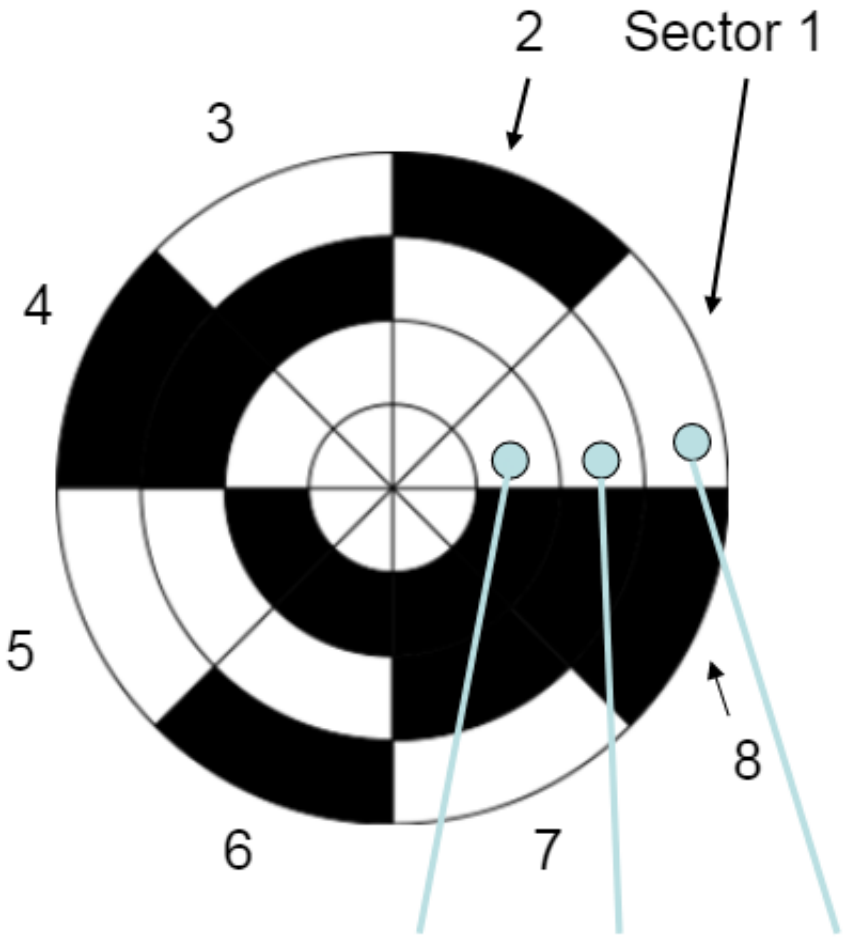
Incremental Encoder

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.

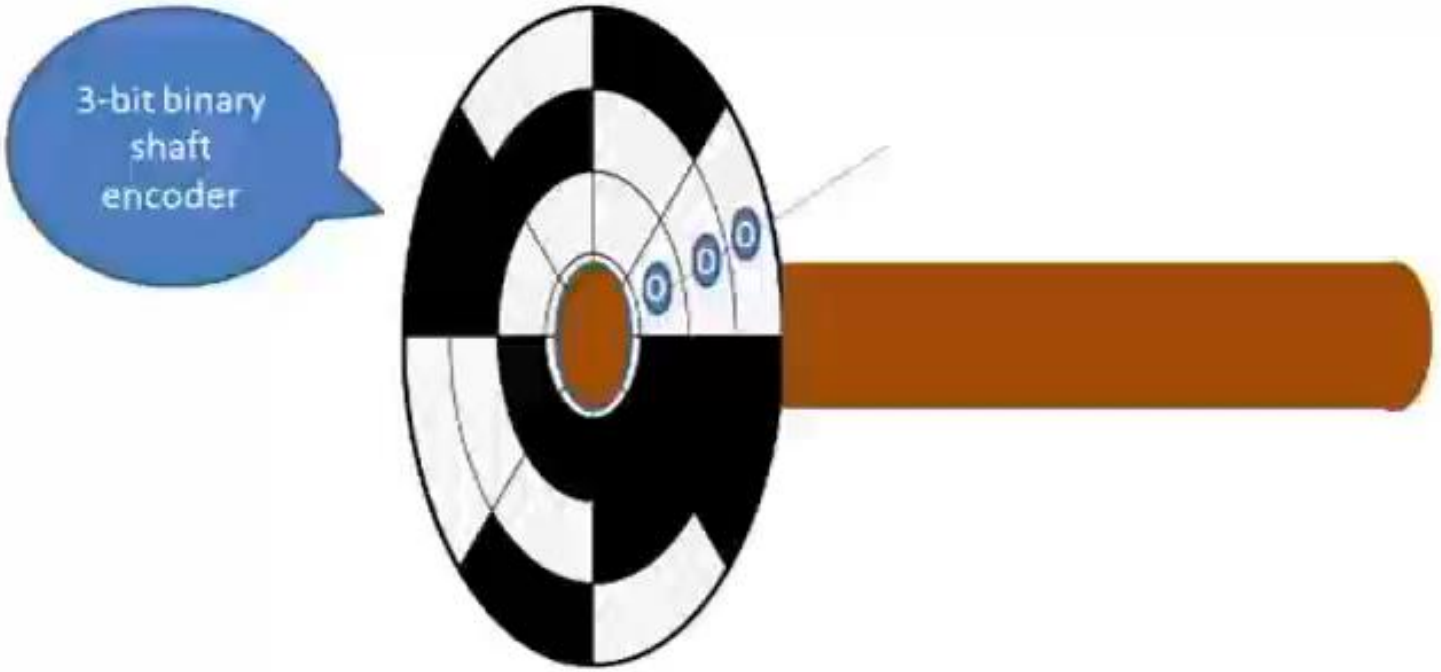


Absolute Encoder

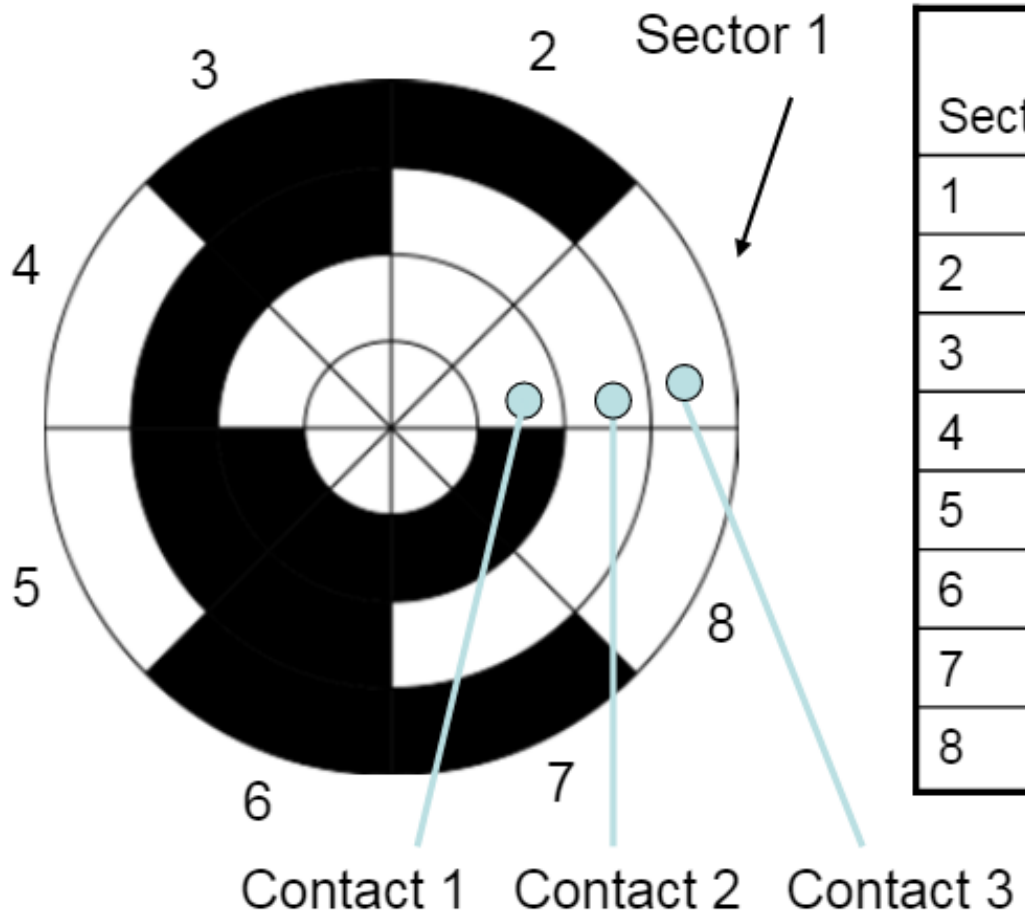


Sector	Con-tact 1	Con-tact 2	Con-tact 3	Angle
1	off	off	off	0° - 45°
2	off	off	ON	45° - 90°
3	off	ON	off	90° - 135°
4	off	ON	ON	135° - 180°
5	ON	off	off	180° - 225°
6	ON	off	ON	225° - 270°
7	ON	ON	off	270° - 315°
8	ON	ON	ON	315° - 360°

Absolute Encoder

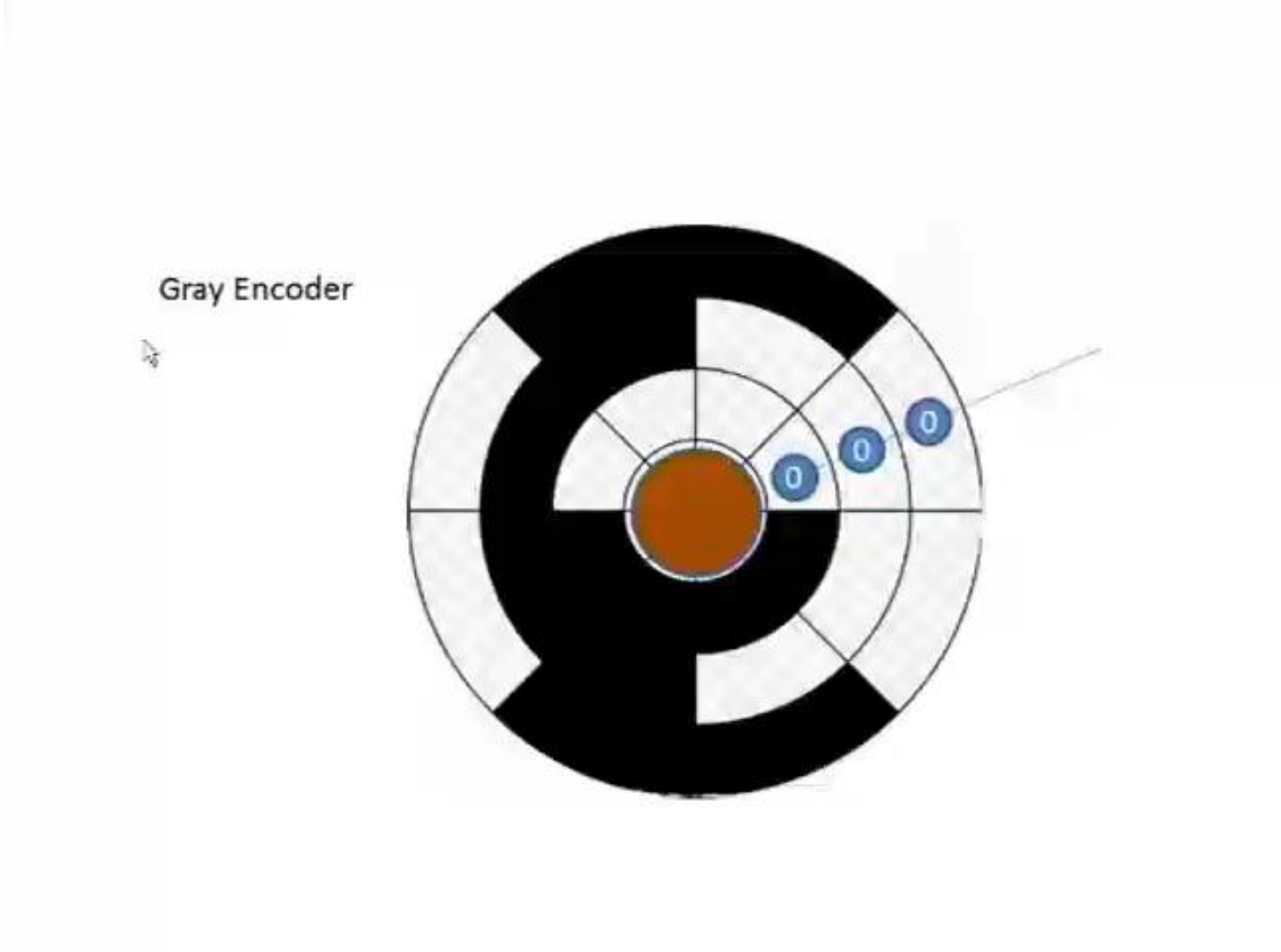


Absolute Encoder



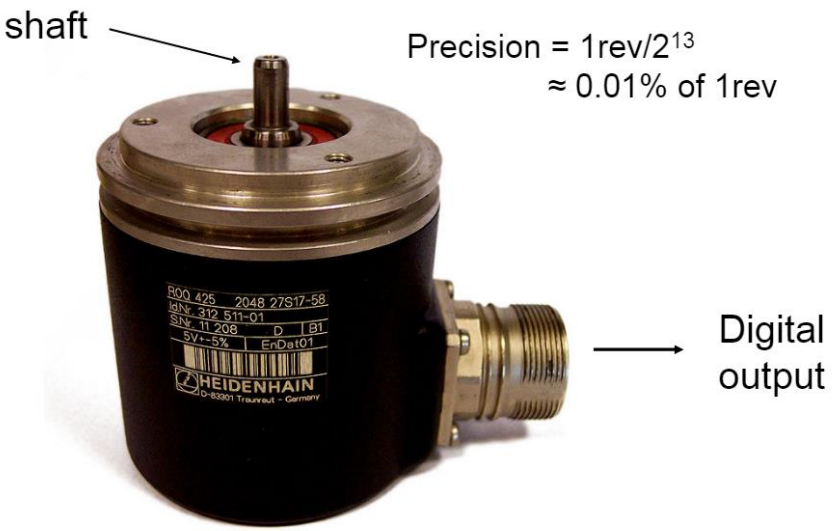
Sector	Con-tact 1	Con-tact 2	Con-tact 3	Angle
1	off	off	off	0° - 45°
2	off	off	ON	45° - 90°
3	off	ON	ON	90° - 135°
4	off	ON	off	135° - 180°
5	ON	ON	off	180° - 225°
6	ON	ON	ON	225° - 270°
7	ON	off	ON	270° - 315°
8	ON	off	off	315° - 360°

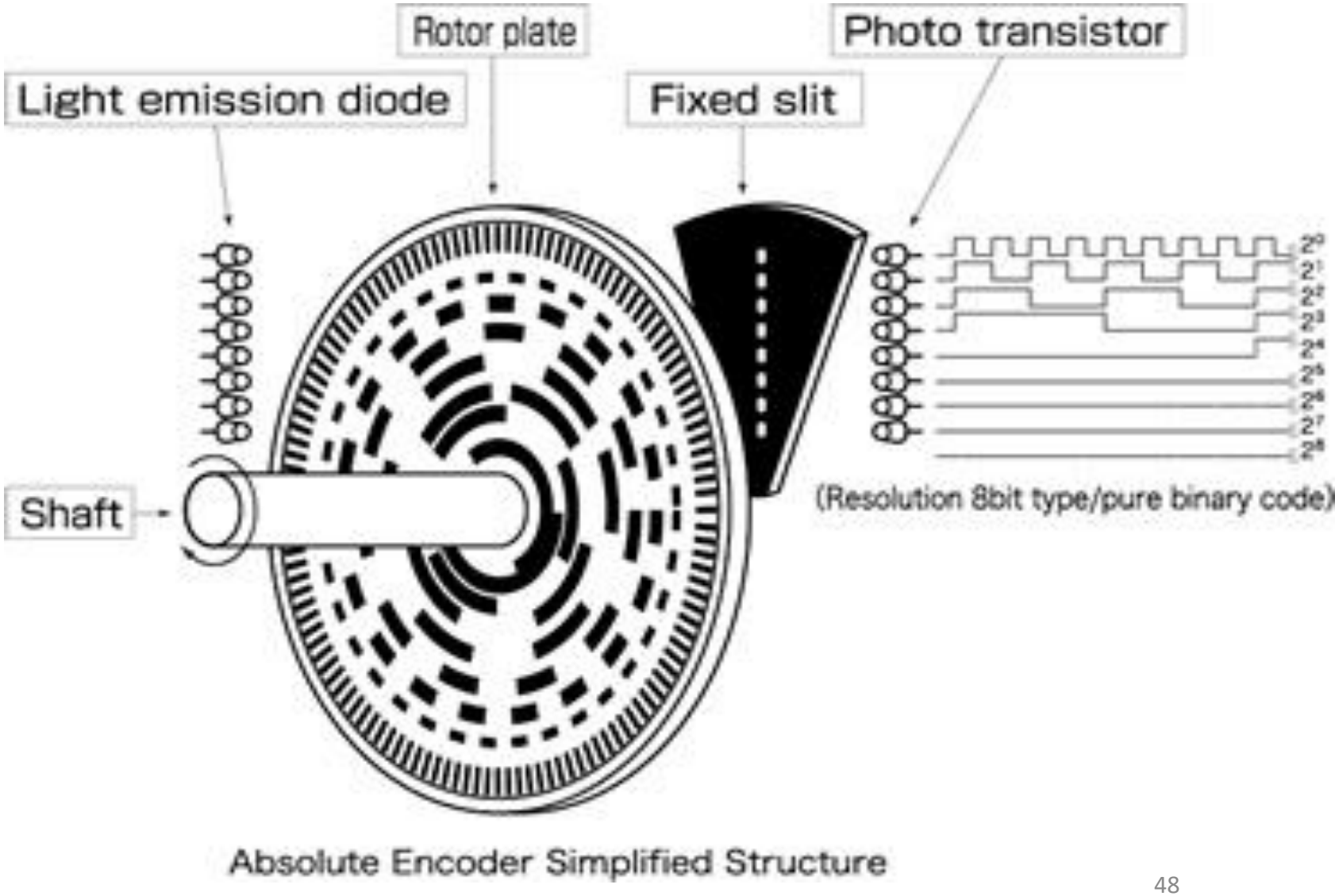
Absolute Encoder



Absolute Encoder

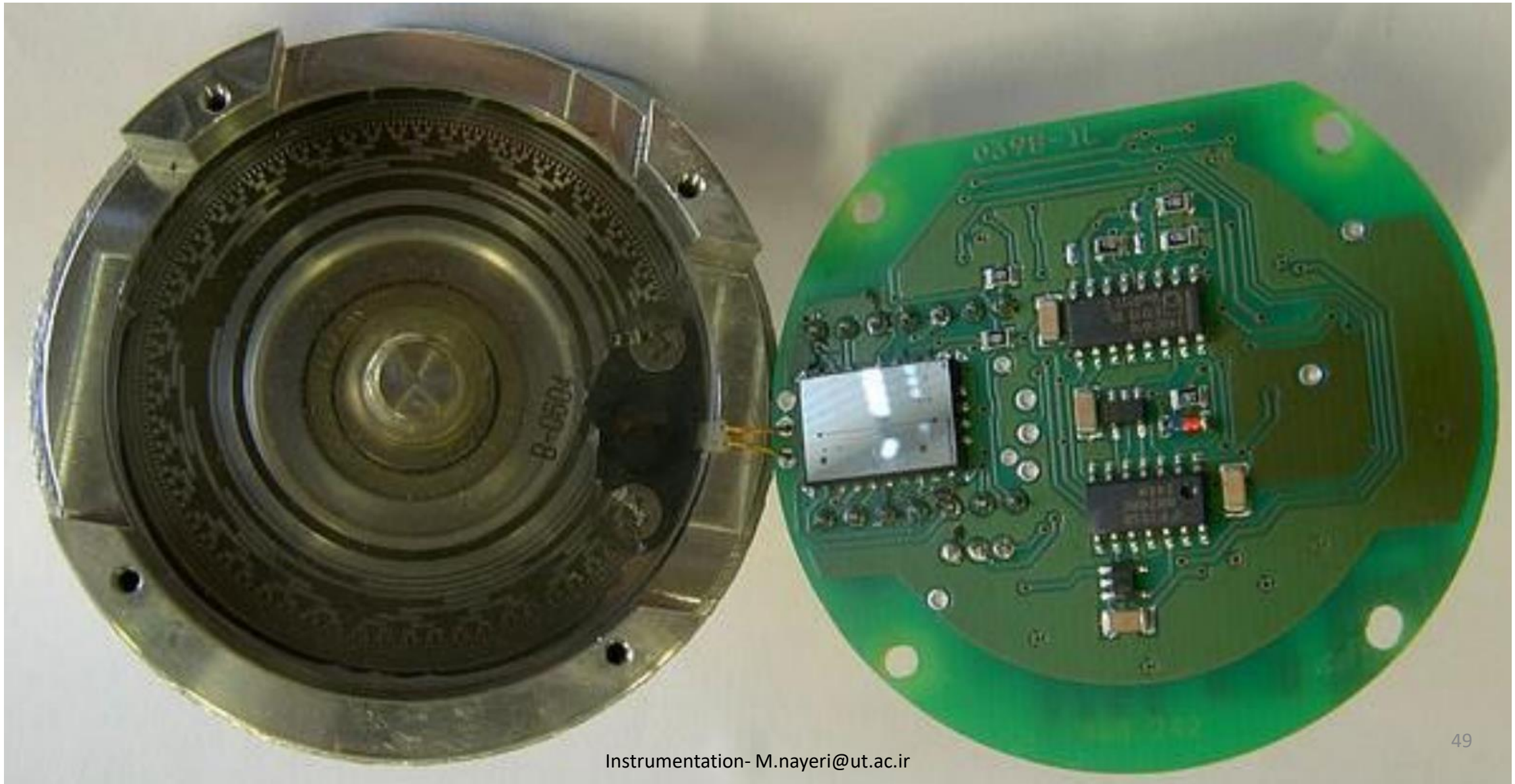
13-bit shaft encoder



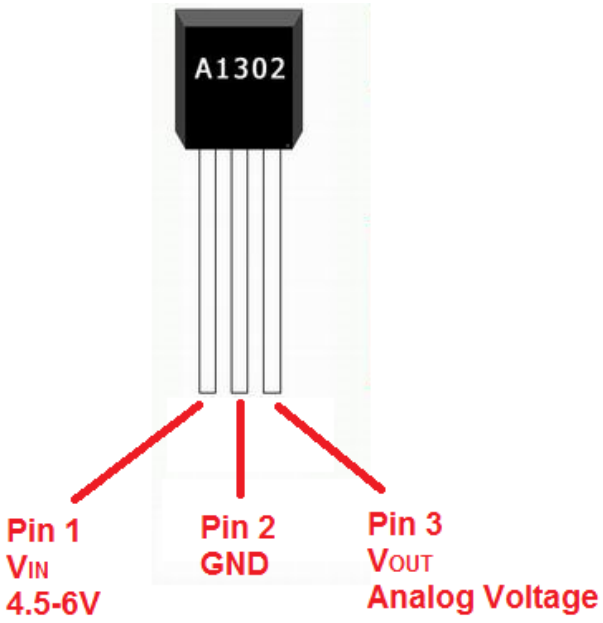


Absolute Encoder Simplified Structure

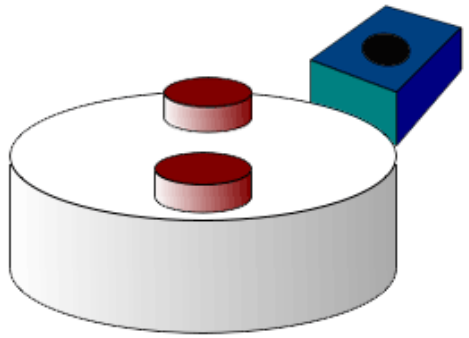
Absolute Encoder



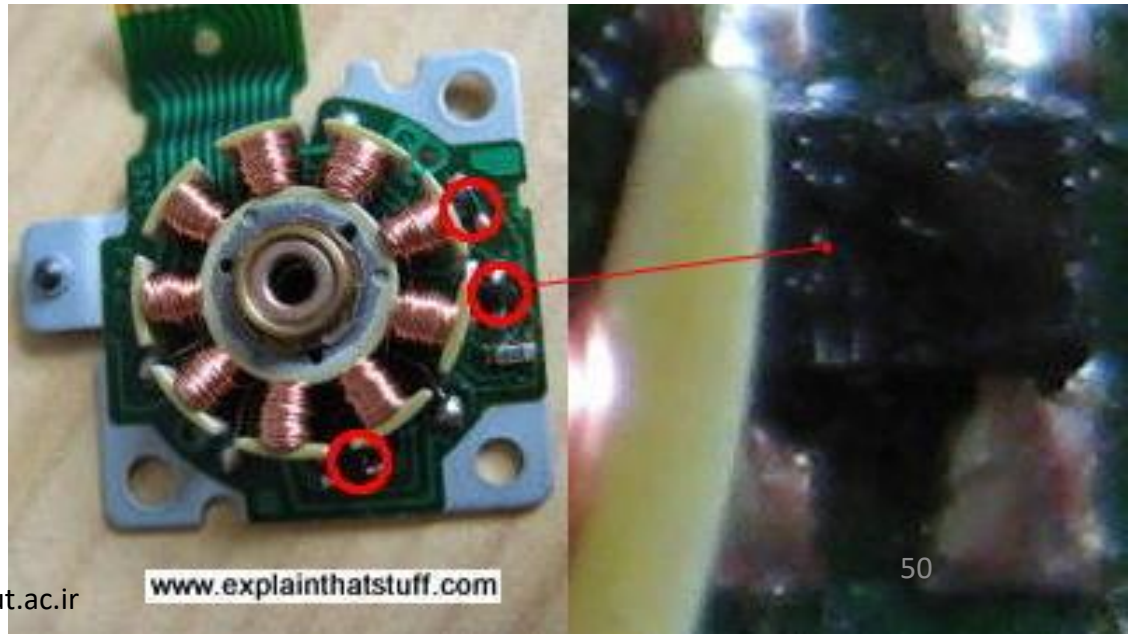
Hall Effect Sensors



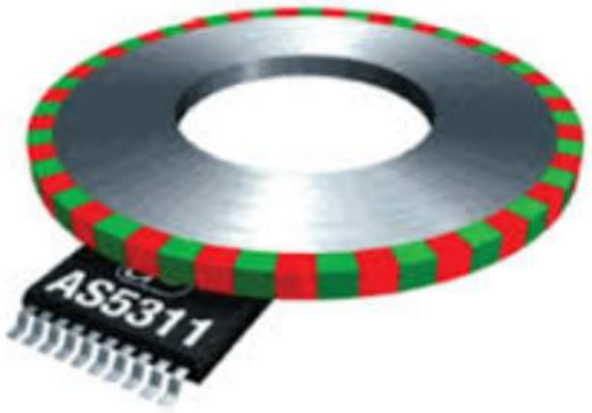
Analog



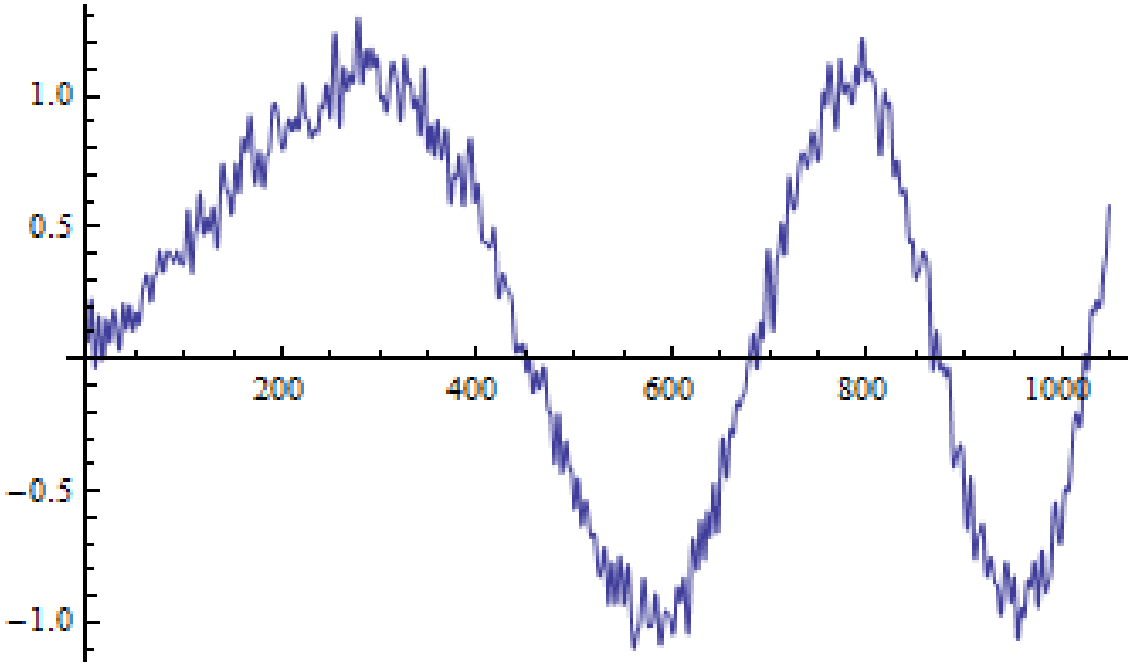
Digital

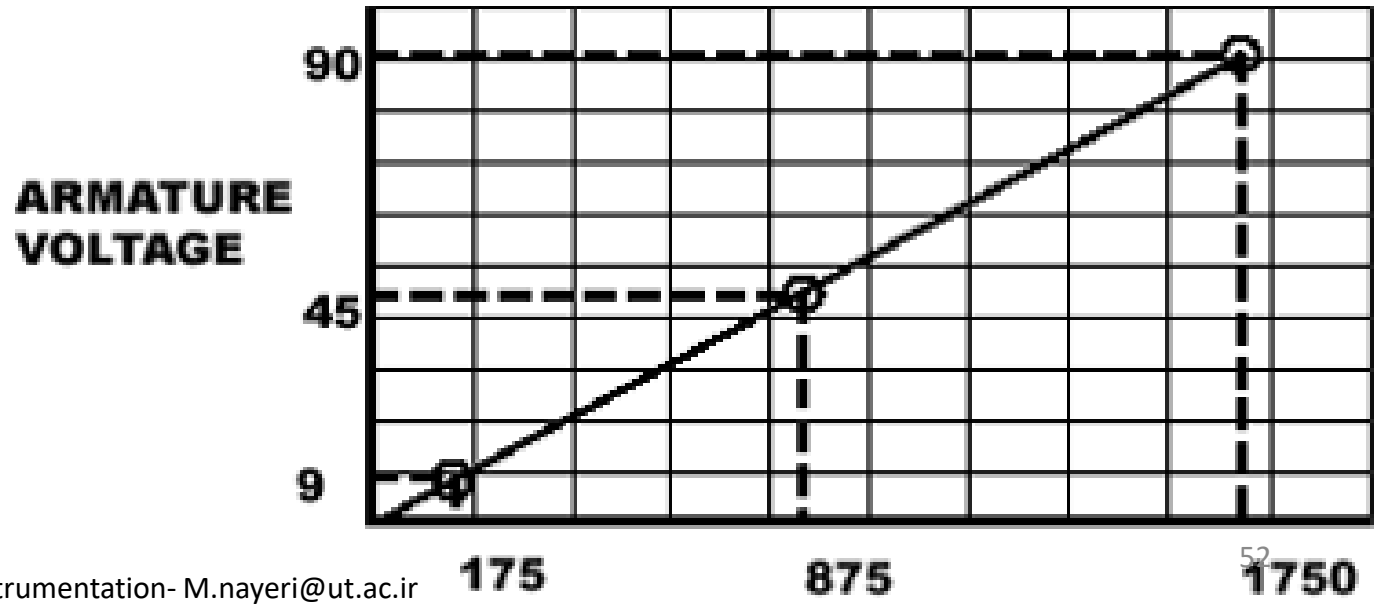


Magnetic Encoder



Tachometer (Tachogenerator)





Synchro Generator

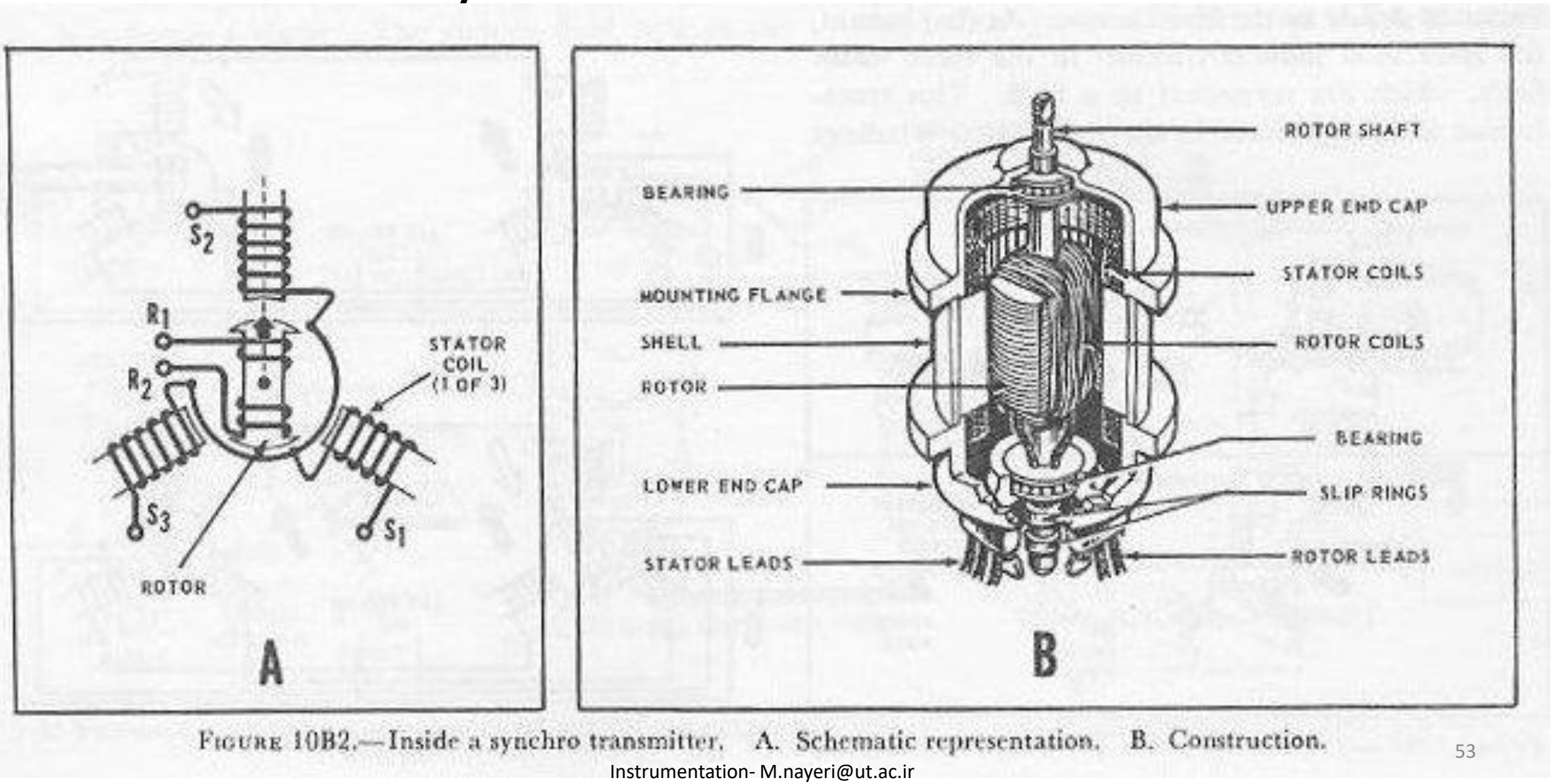
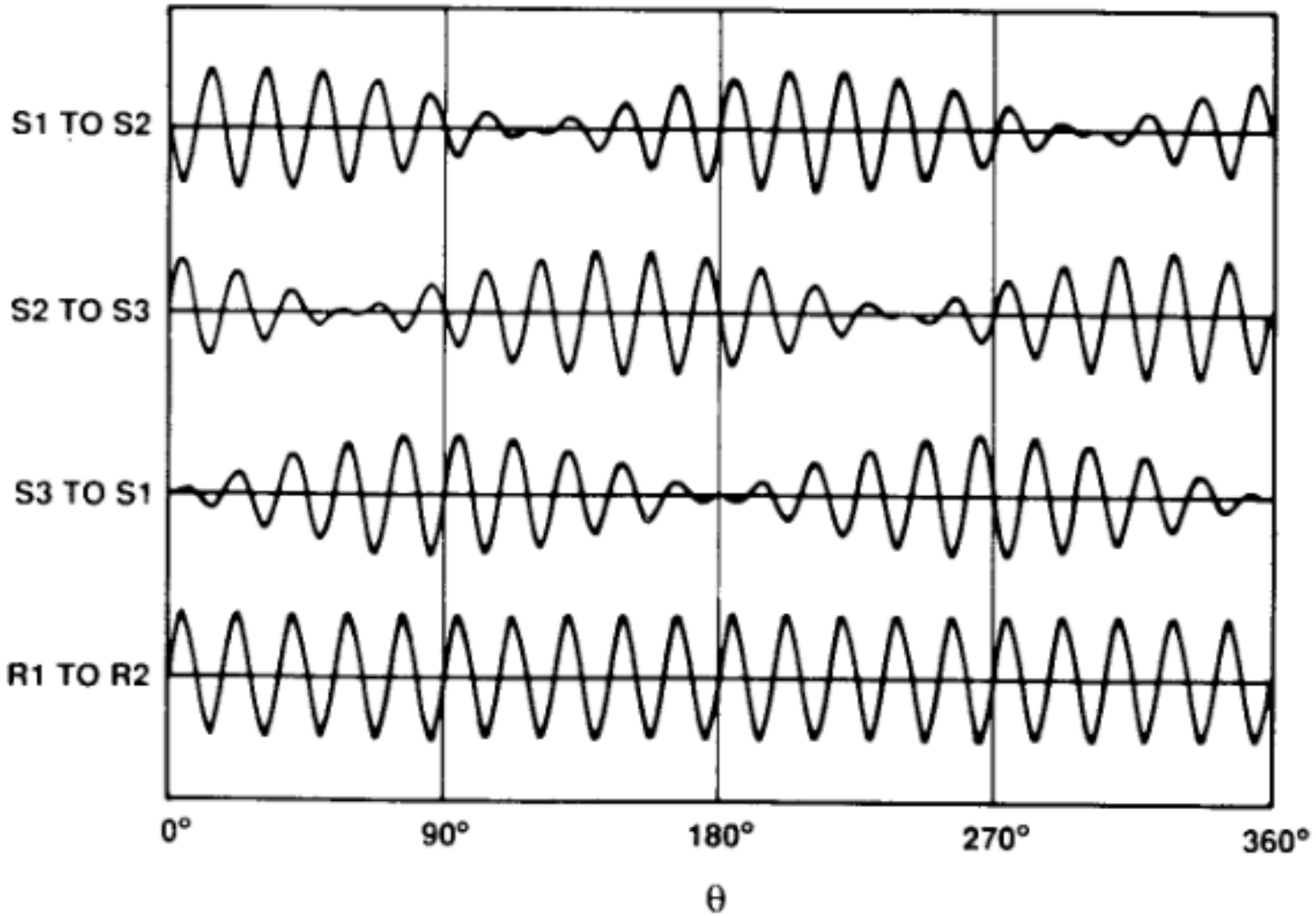
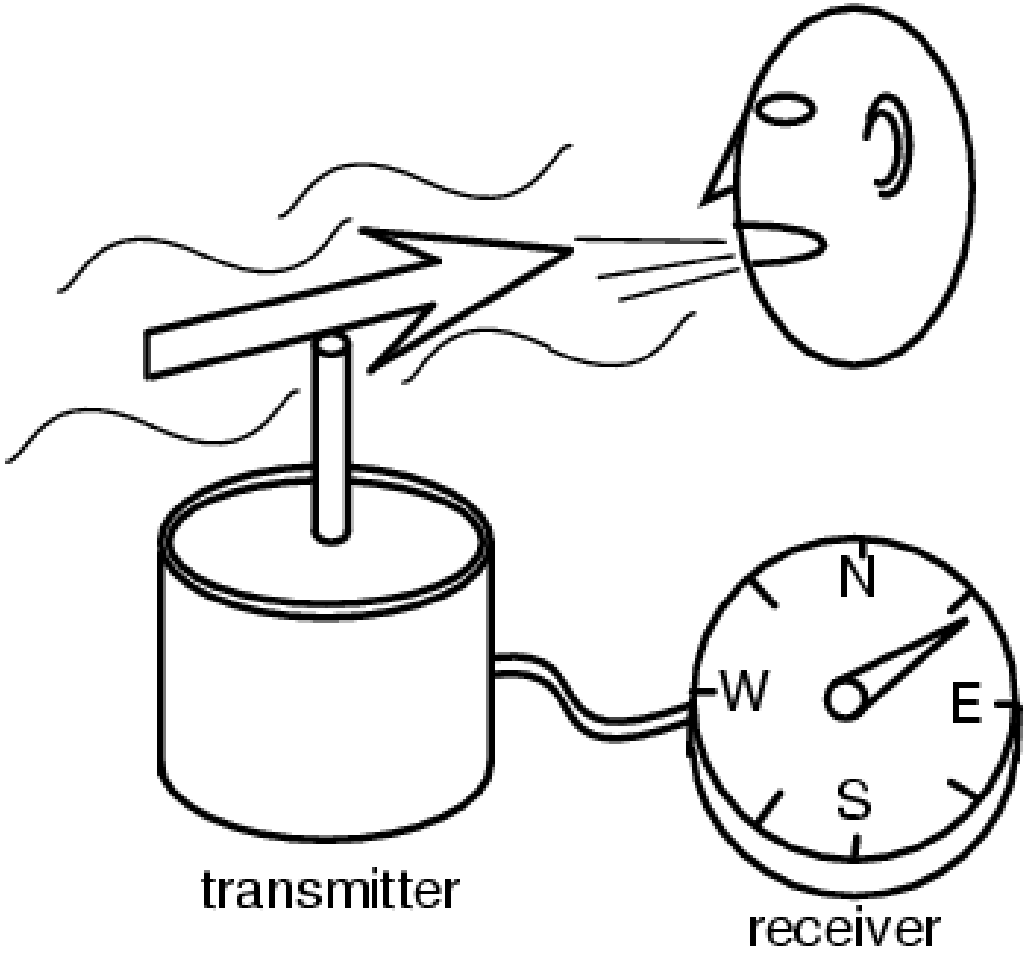


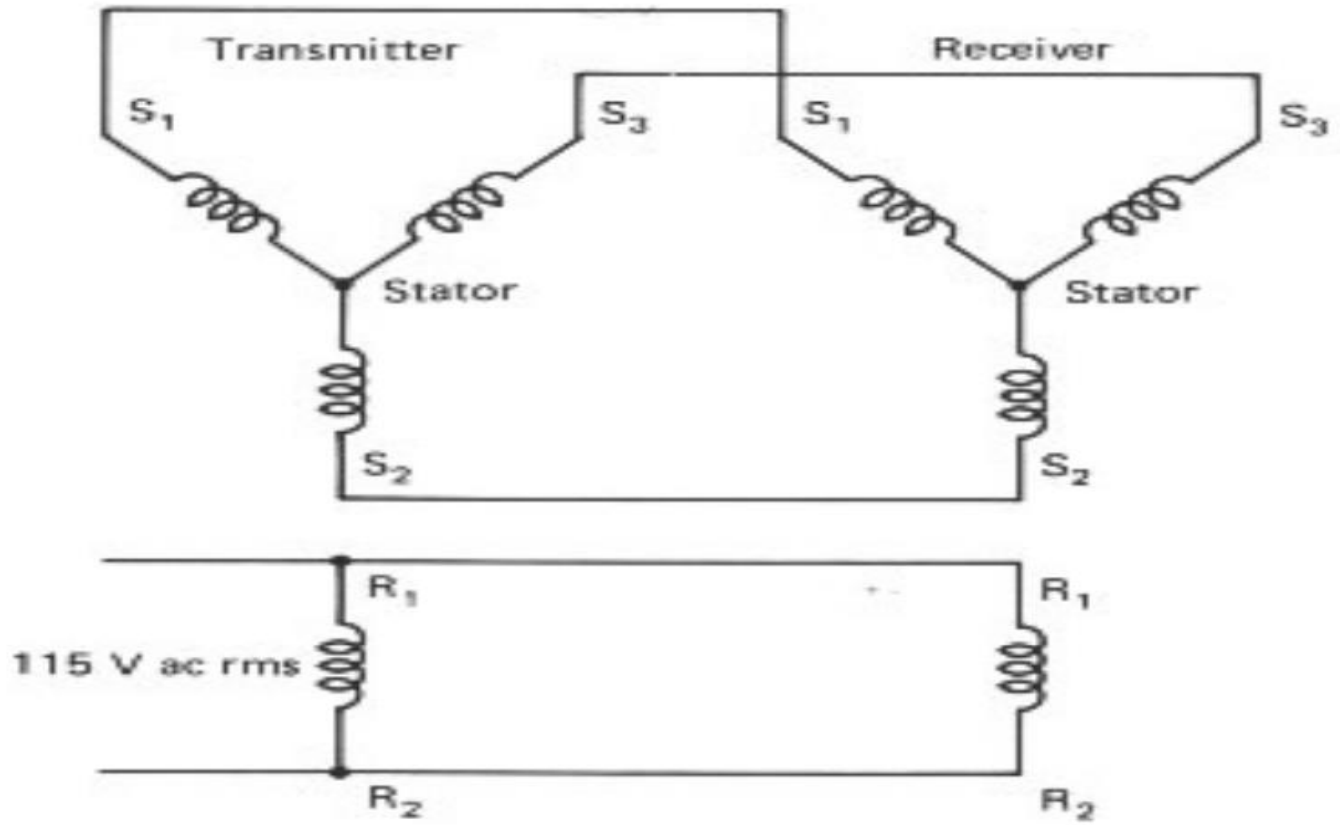
FIGURE 10B2.—Inside a synchro transmitter. A. Schematic representation. B. Construction.

Synchro Generator



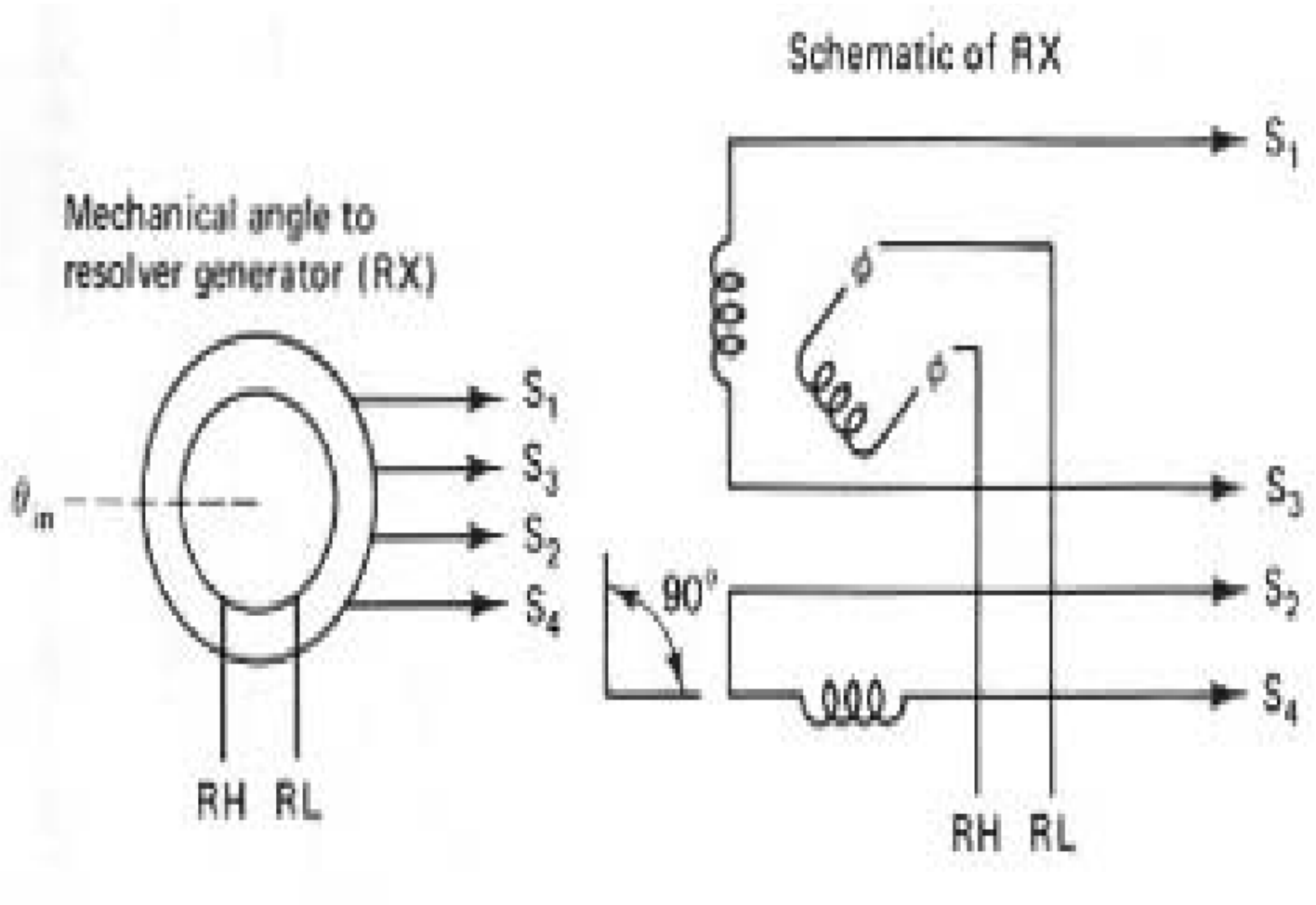
Synchro Generator



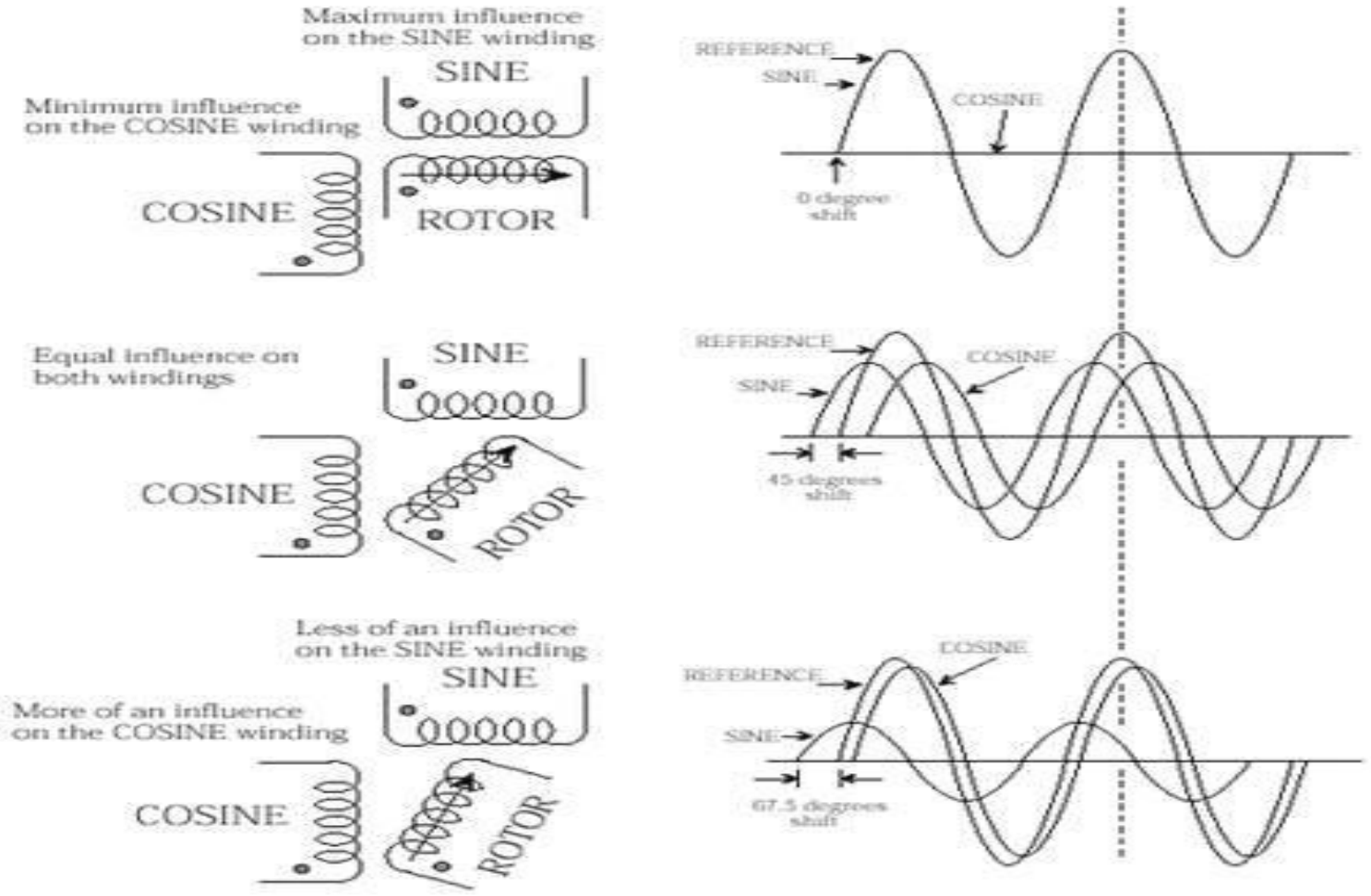


Synchro Generator

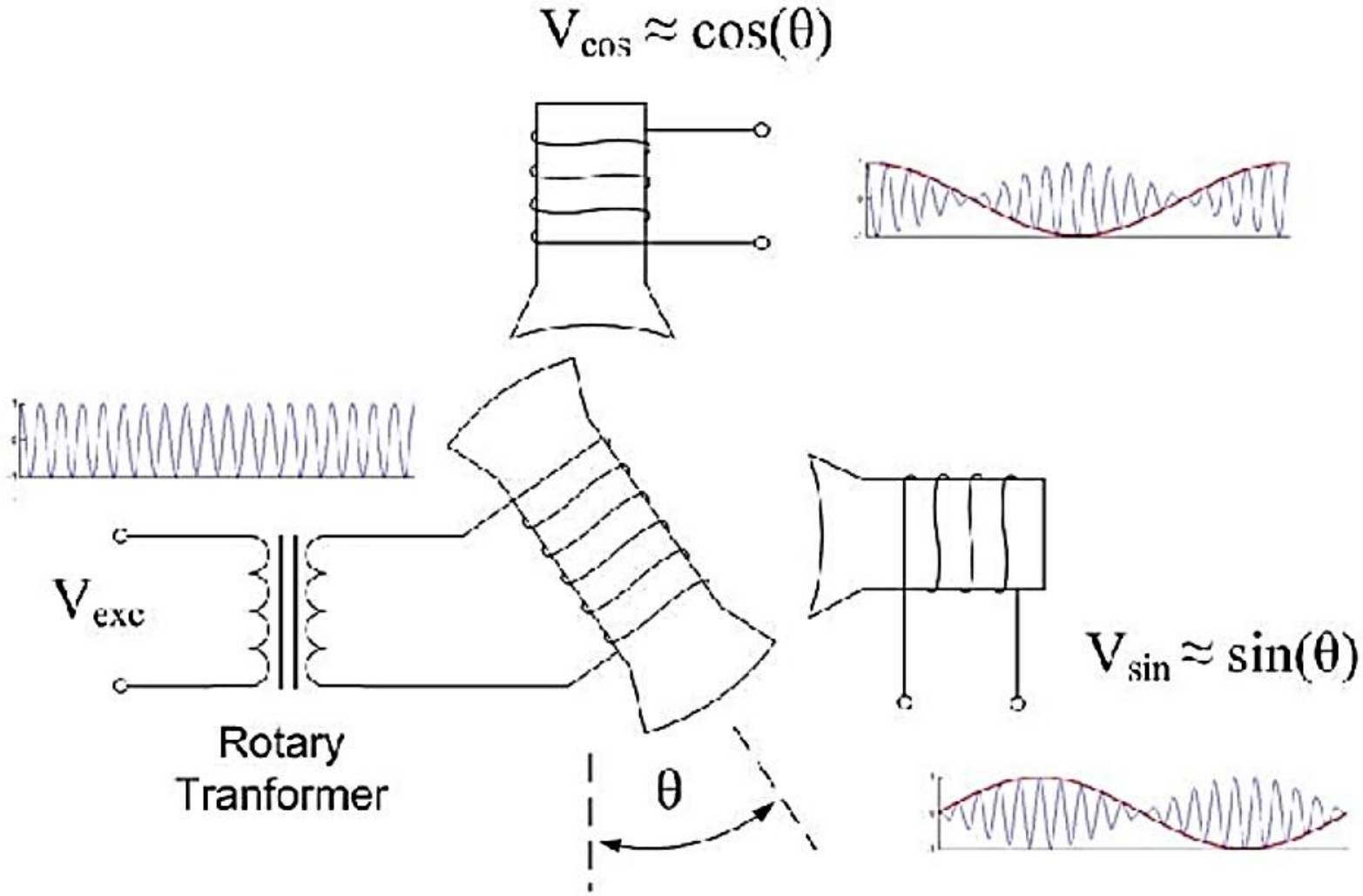
Resolver


Mechanical angle to
resolver generator (RX)
θ_m
S_1
S_3
S_2
S_4
RH RL
Schematic of RX
S_1
ϕ
ϕ
S_3
90°
S_2
S_4
RH RL

Resolver

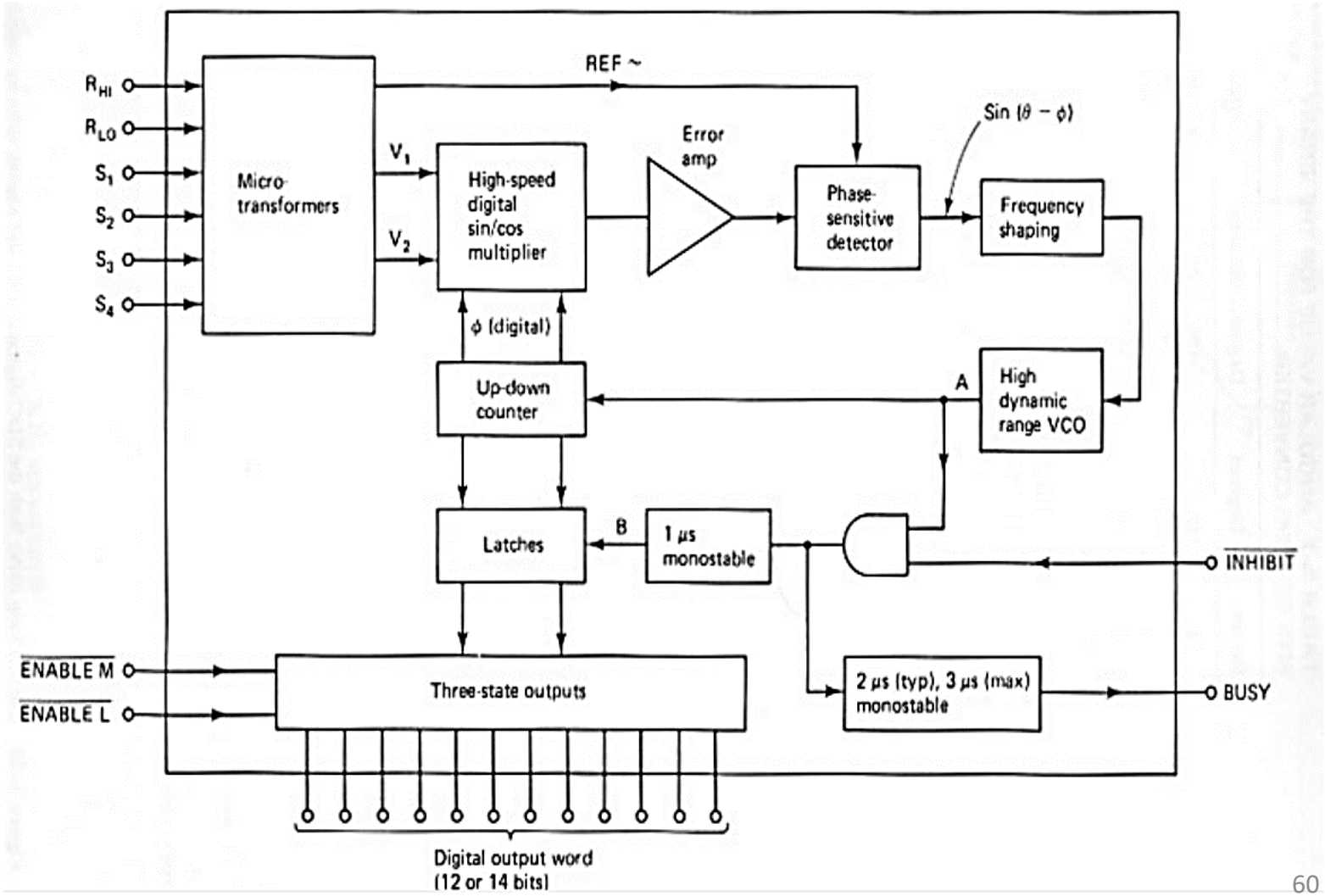

Maximum influence
on the SINE winding
SINE
Minimum influence
on the COSINE winding
COSINE
ROTOR
REFERENCE
SINE
COSINE
0 degree
shift
Equal influence on
both windings
SINE
COSINE
ROTOR
REFERENCE
SINE
COSINE
45 degrees
shift
Less of an influence
on the SINE winding
SINE
More of an influence
on the COSINE winding
COSINE
ROTOR
COSINE
REFERENCE
SINE
67.5 degrees
shift

Resolver

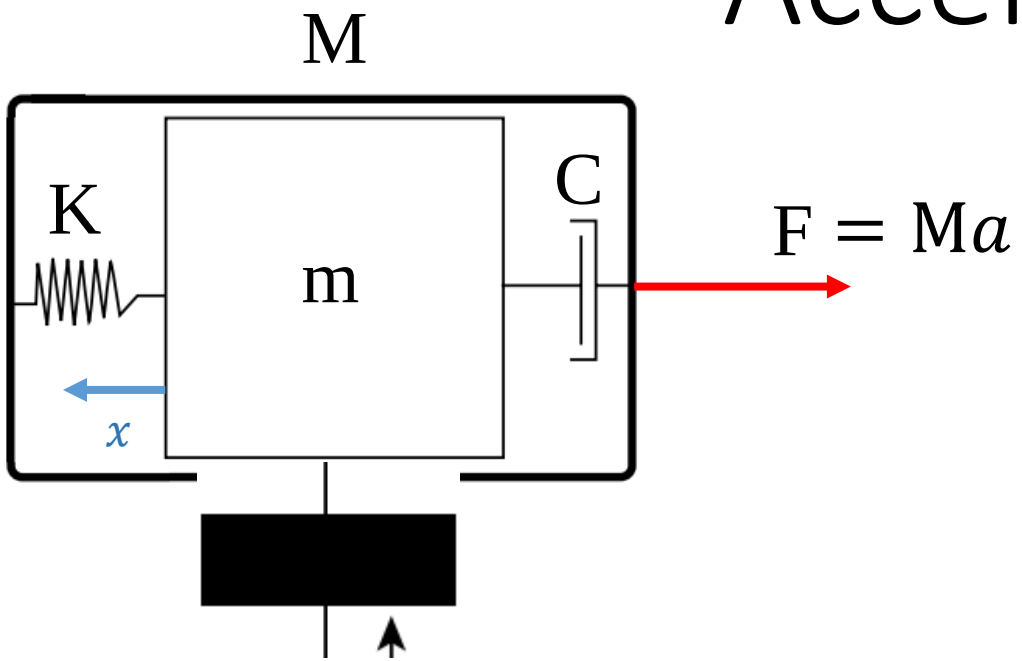

$V_{cos} \approx \cos(\theta)$
V_{exc}
Rotary
Tranformer
θ
$V_{sin} \approx \sin(\theta)$

Synchro to Digital Converter (S/D)

- SDC1740
- SDC1741
- SDC1742



Accelerometer



$$F = Ma$$

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

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

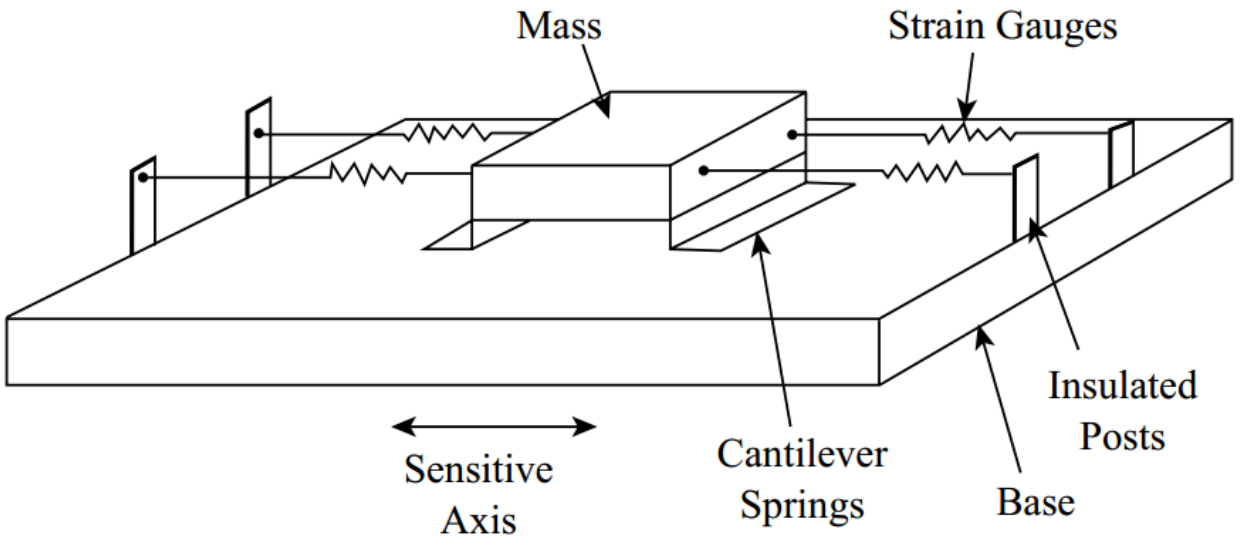
Sensitivity

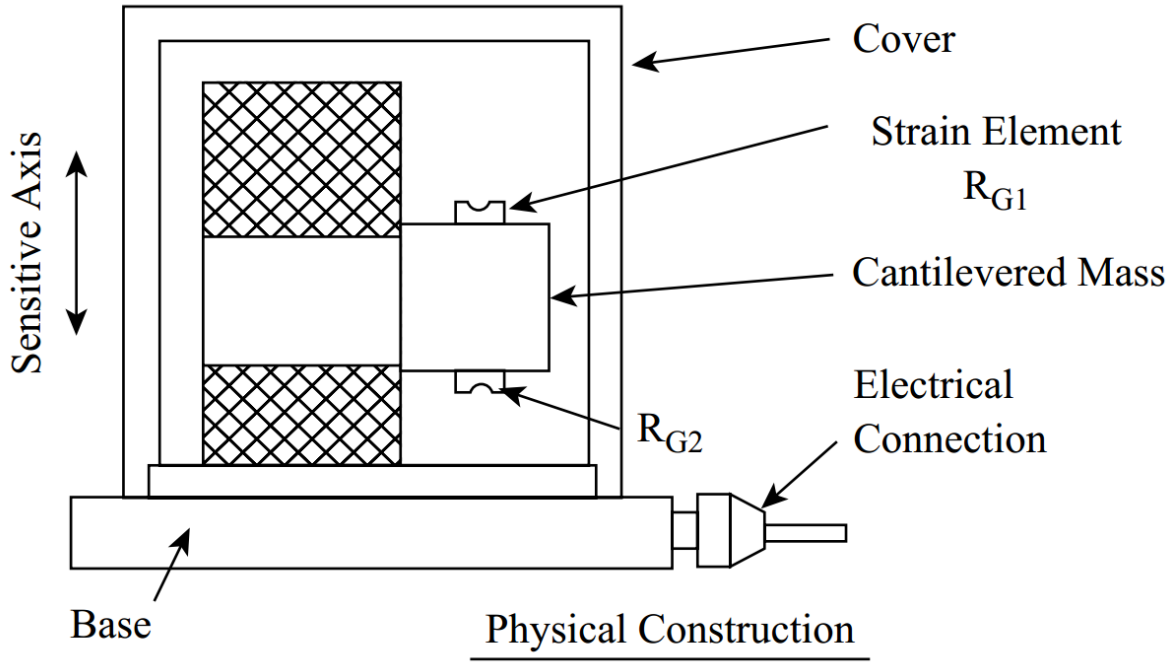
$$\frac{X(s)}{a(s)} = \frac{\frac{M}{k} \times \frac{k}{m}}{s^2 + \frac{c}{m}s + \frac{k}{m}}$$

ω_n^2

$2\xi\omega_n$

Strain Gauge Accelerometer





Capacitive Accelerometer

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

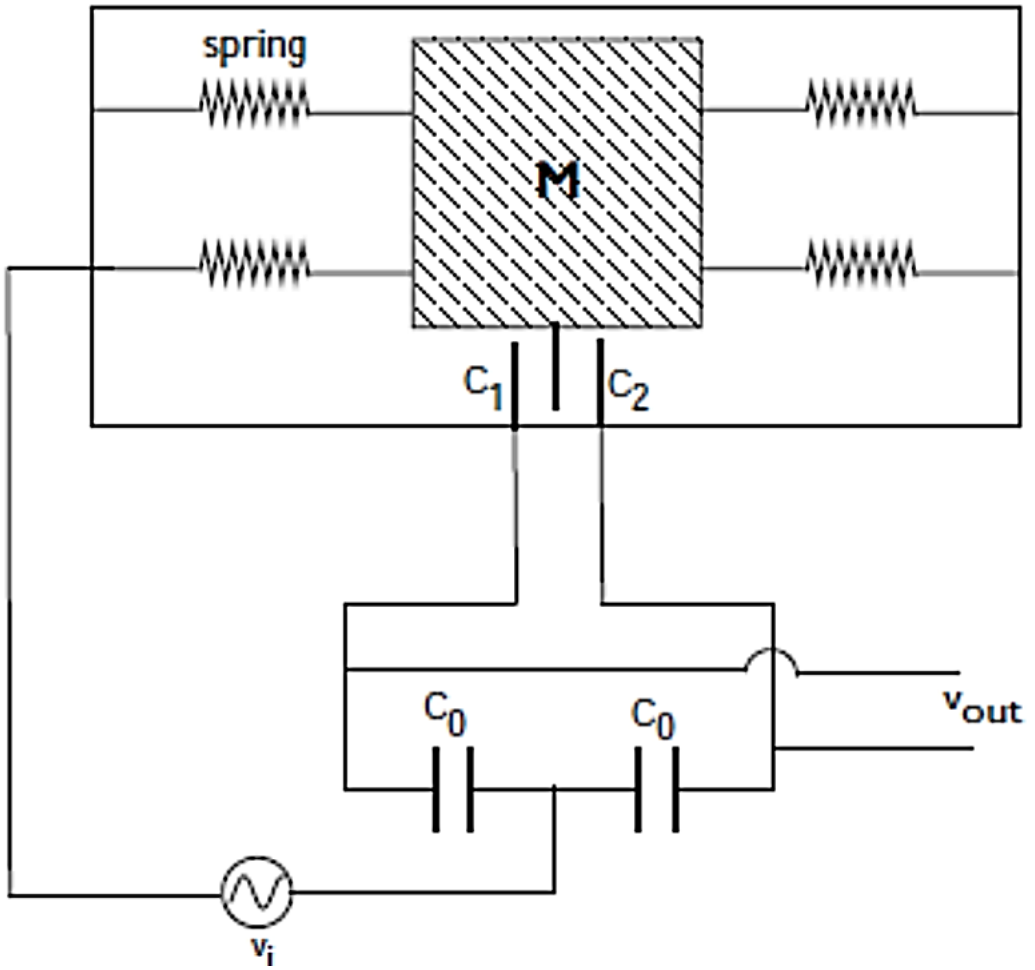
$$C_1 = \varepsilon \frac{S}{x_0 + x} = \varepsilon \frac{S}{x_0\left(1 + \frac{x}{x_0}\right)} = \frac{C_0}{1+\delta}$$

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

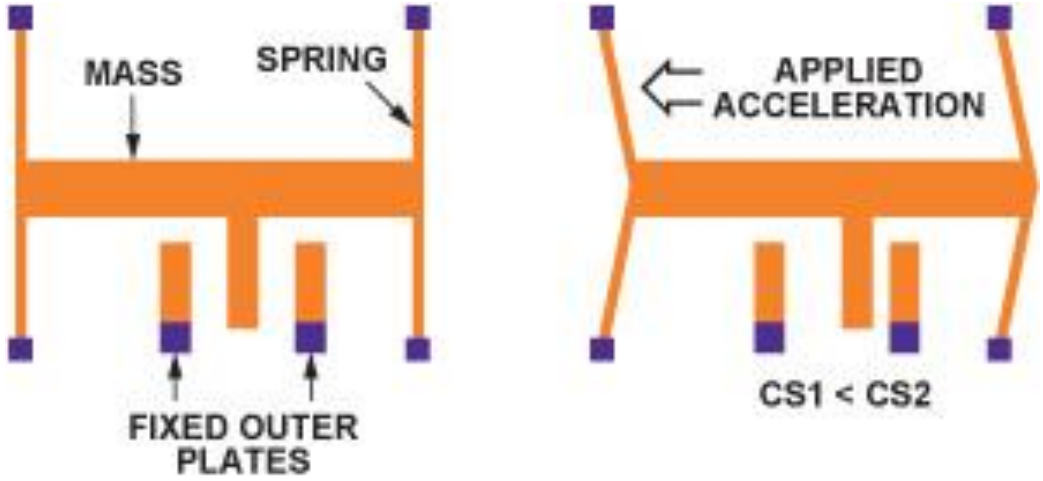
$$where\ \delta = \frac{x}{x_0}$$

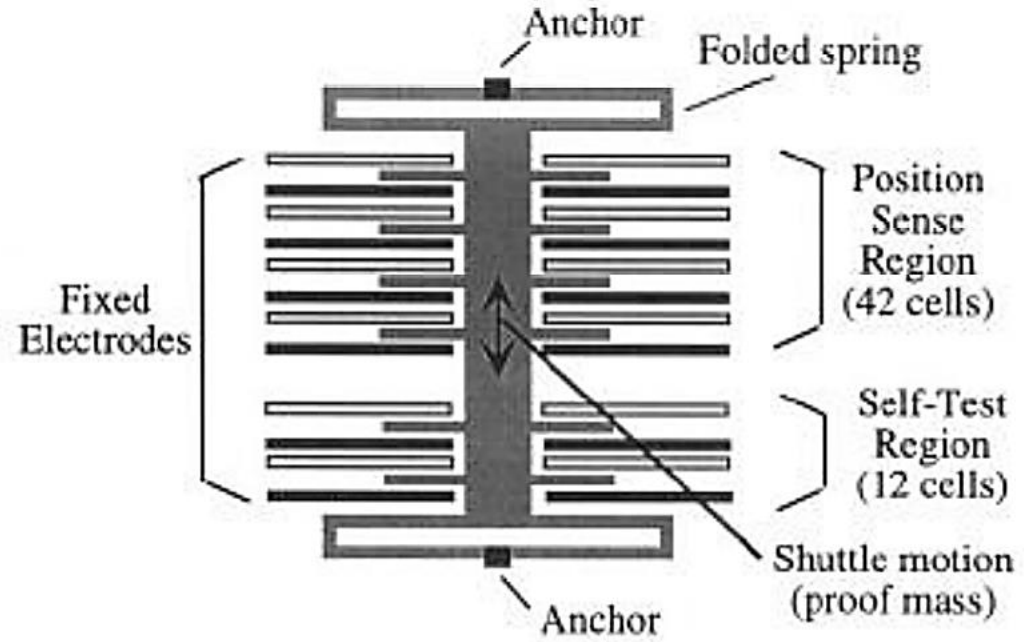
in a Wheatstone bridge: $if\ \delta \ll 1 \quad v_{out} = \frac{v_{in}}{2} \cdot \delta$???

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

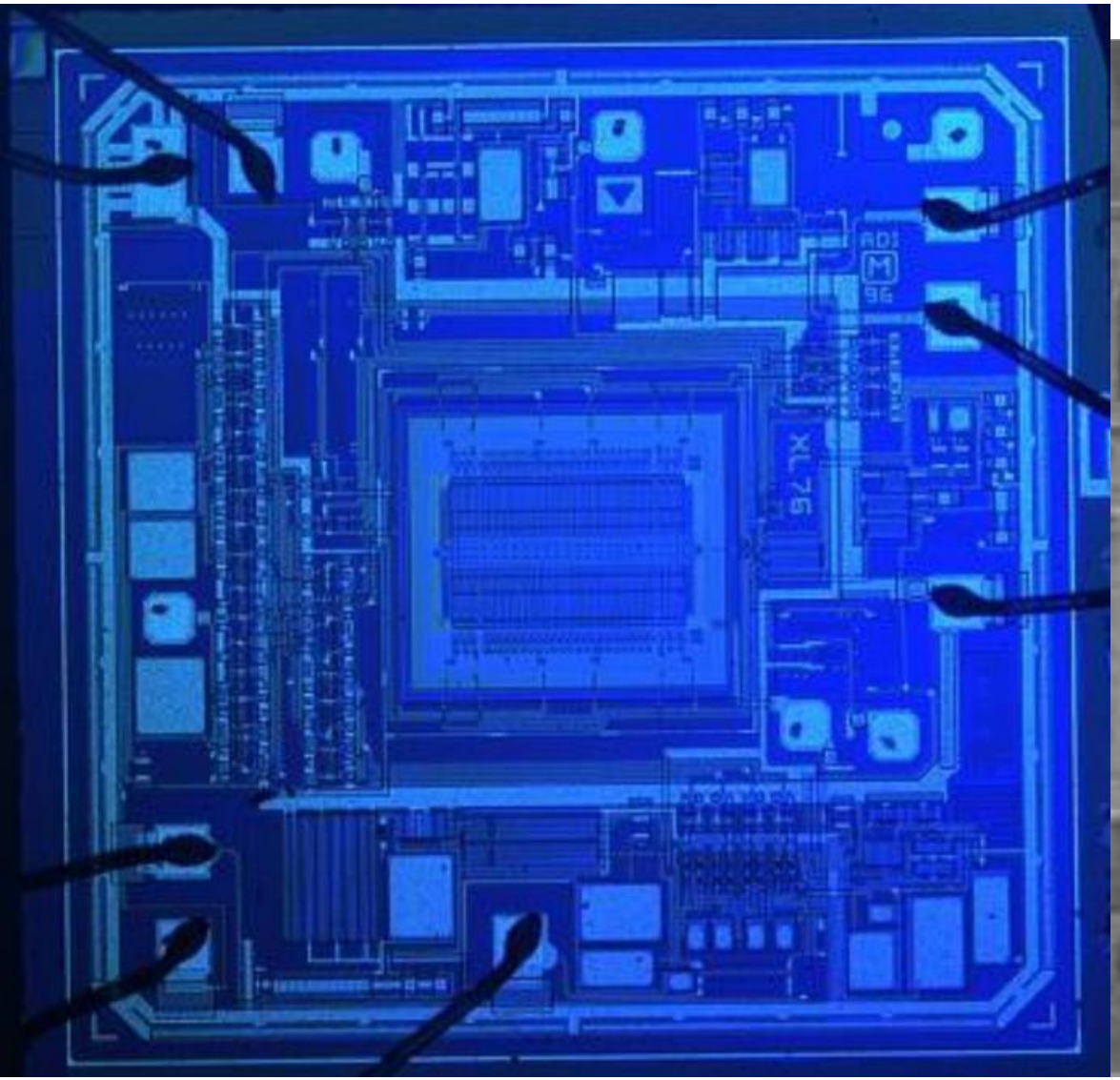


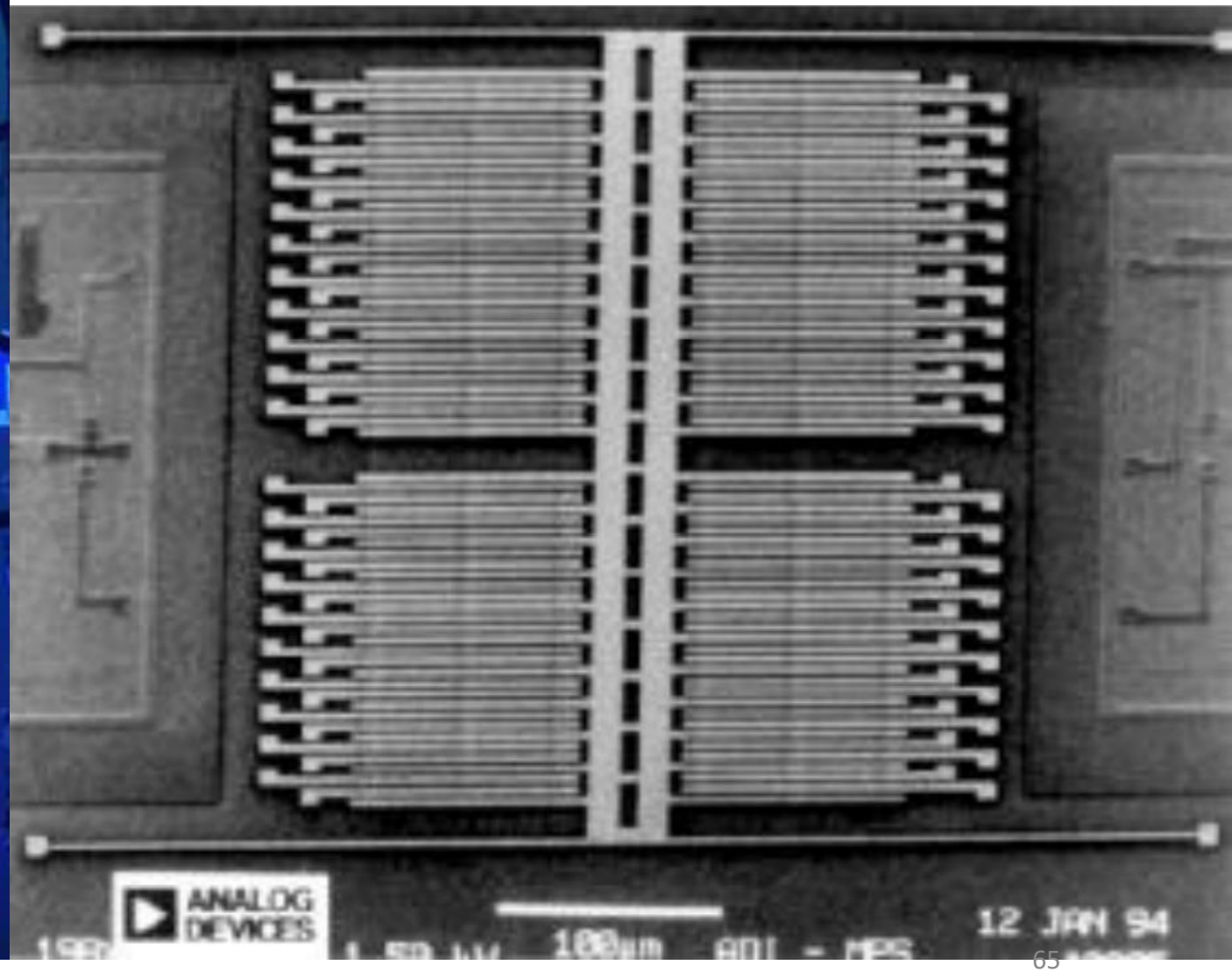
Capacitive Accelerometer





Capacitive Accelerometer





Linear Velocity

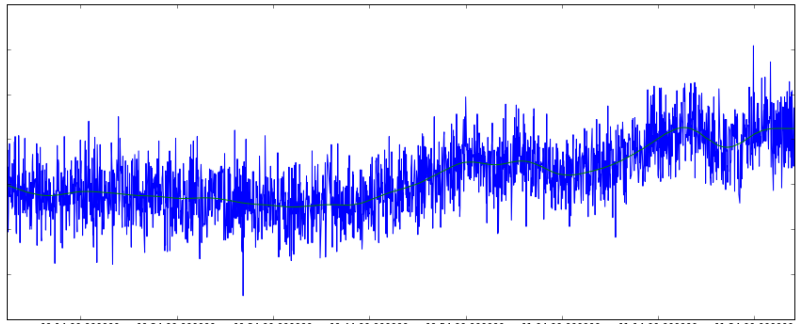
- **Derivation of linear displacement**

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

$Ultrasonic, Infrared, \ldots$

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

Noise



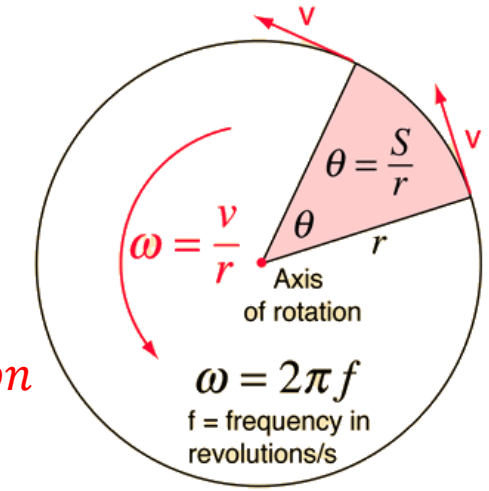
- **Use angular velocity measurement**

$Optocounter, Encoder, \ldots$

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

Sensor Fusion Methods

Mechanical limitation



- **Integration of acceleration**

$Acceleration\ sensor \rightarrow a \quad \Rightarrow \quad v = \int a.dt$

Initial Acceleration? → Bios