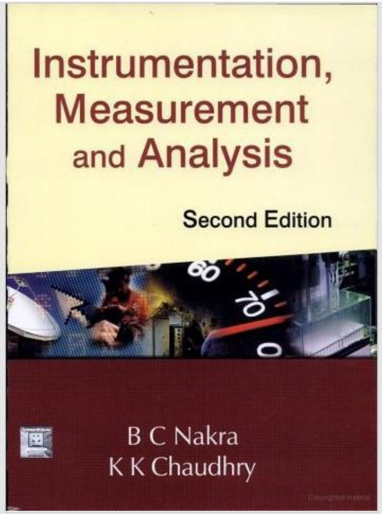


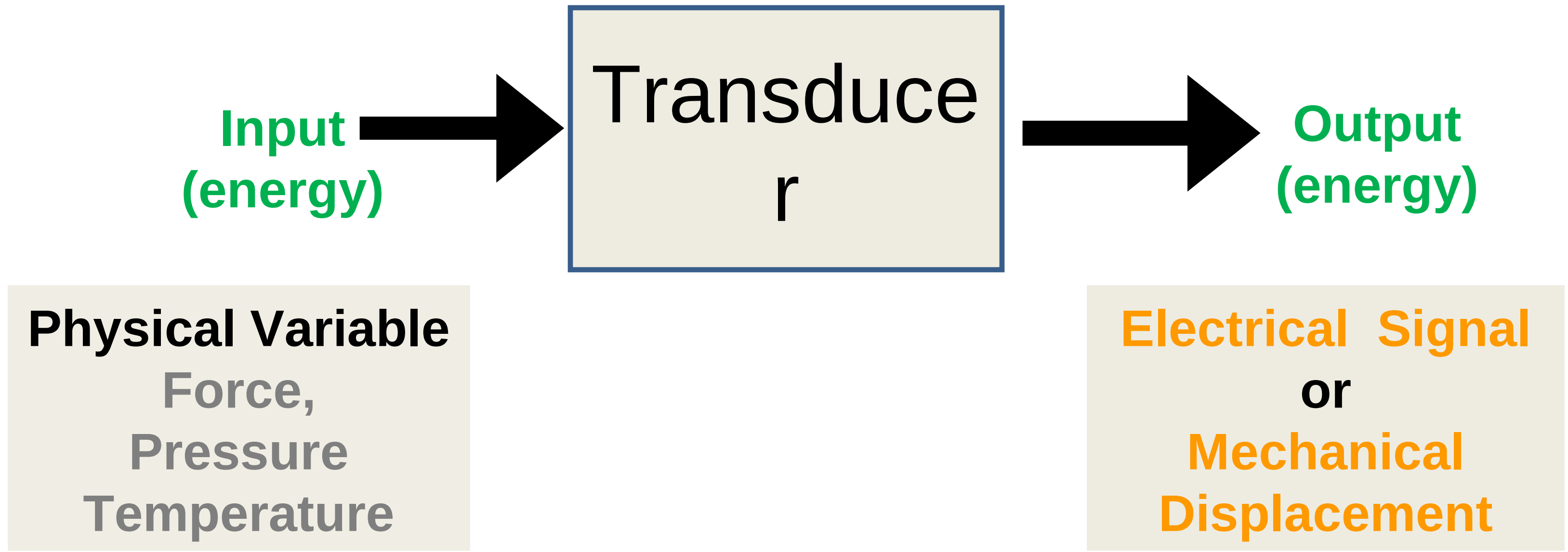
B.Sc. (Semester - 6)
Subject: Physics
Course: US06CPHY06
Instrumentation and Sensors
(Three Credit Course –3 Hours per week)
(Effective from June-2012)

UNIT – I CRO and Transducer Elements

Introduction to Cathode Ray Oscilloscope, Cathode Ray Tube, Deflection system in CRT, Analog Transducers, Electromechanical Type Transducer, Potentiometric resistance type, Inductive Type, Capacitive Type, Piezo-Electric Transducer, Dynamic Characteristics of Piezo-Electric Transducers, Resistance Strain Gauges, Unbounded Strain Gauge, Bonded Strain Gauge, Resistance Strain Gauge Bridges, Balanced Bridge, Unbalanced Bridge

What is a Transducer ?

Principle of Working:



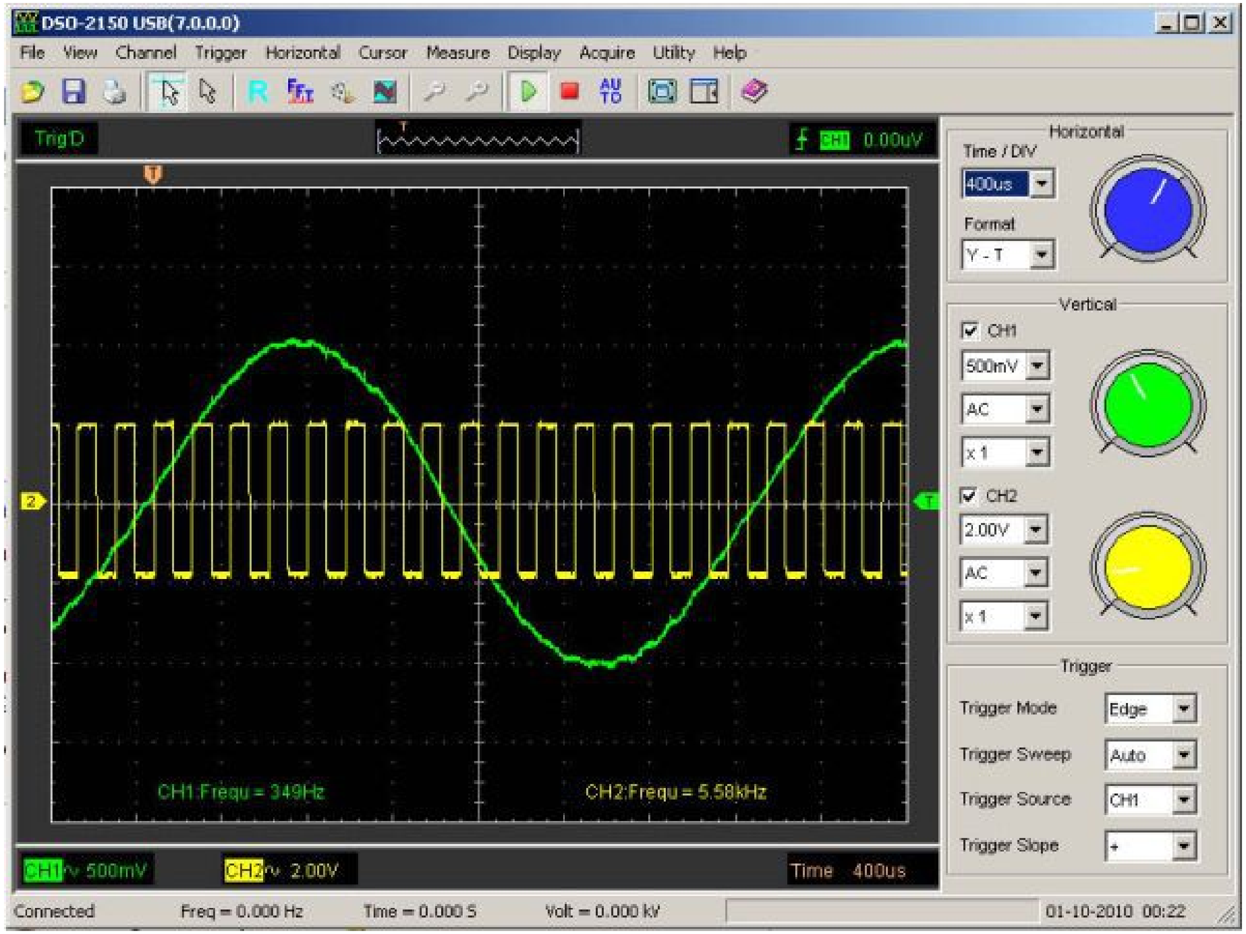
Advantage of electrical signal at the output:

1. Inertia and friction effects are absent, unlike in transducers with mechanical outputs.
2. Amplification can be obtained with relative ease.
3. Indication or recording, especially at a distance, is greatly facilitated.

Transducers Types: Classification

Analog : With variations of input, output changes continuously.

Digital : With variations of input, output changes non-continuously i.e. In a discrete manner.



Analog Transducers

Electro-Mechanical Transducers:

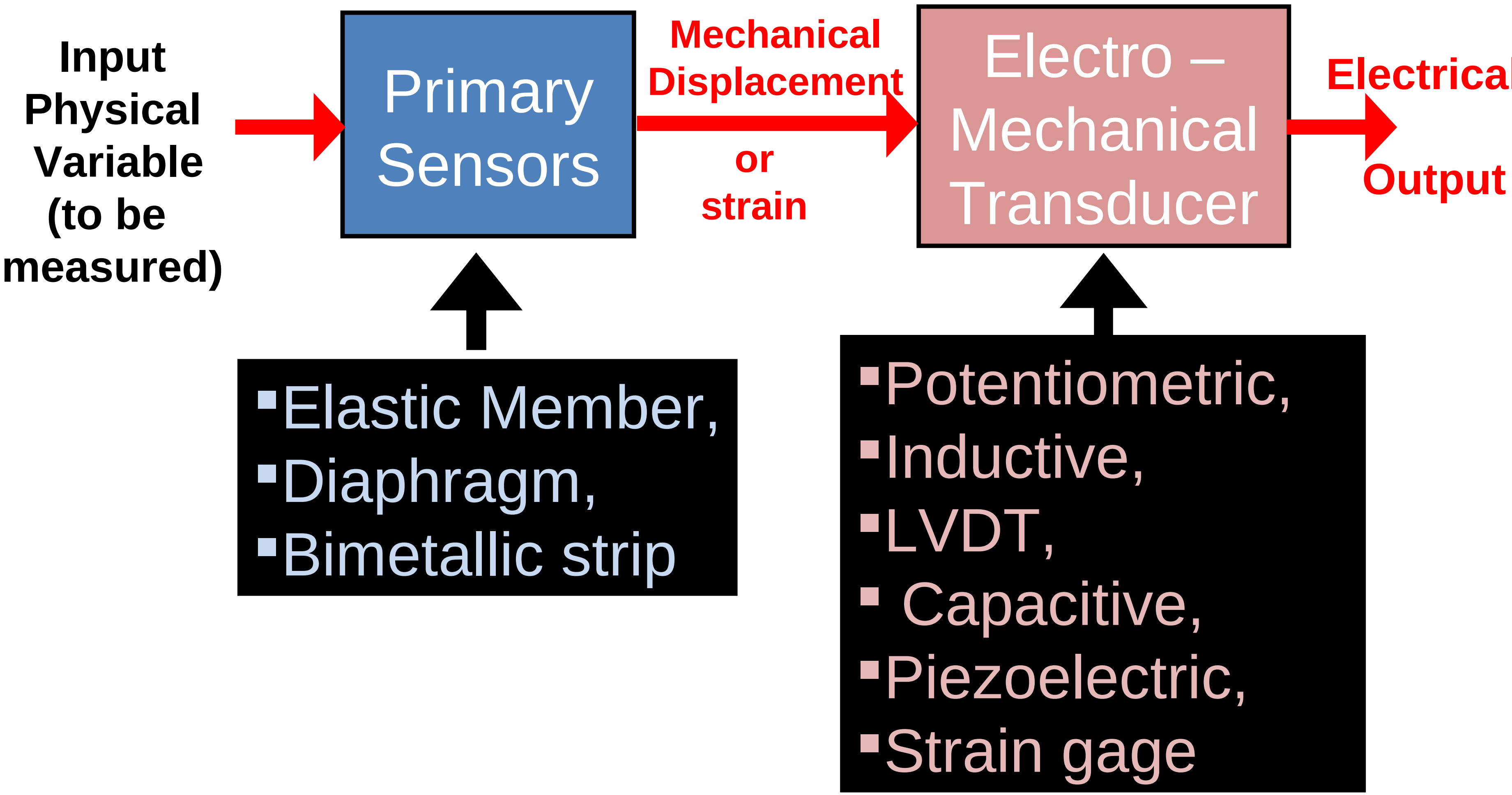
1.Potentiometric Resistance Type
2.Inductance Type
3.Capacitance Type
4.Piezo-electric Type
5.Resistance Srtain Gages
6.Ionization Type
7. Mechano-Electronical Type

Opto-Electrical Transducers:

1.Photo-emissive Type
2. Photo-conductive Type
3. Photo-voltaic Type.

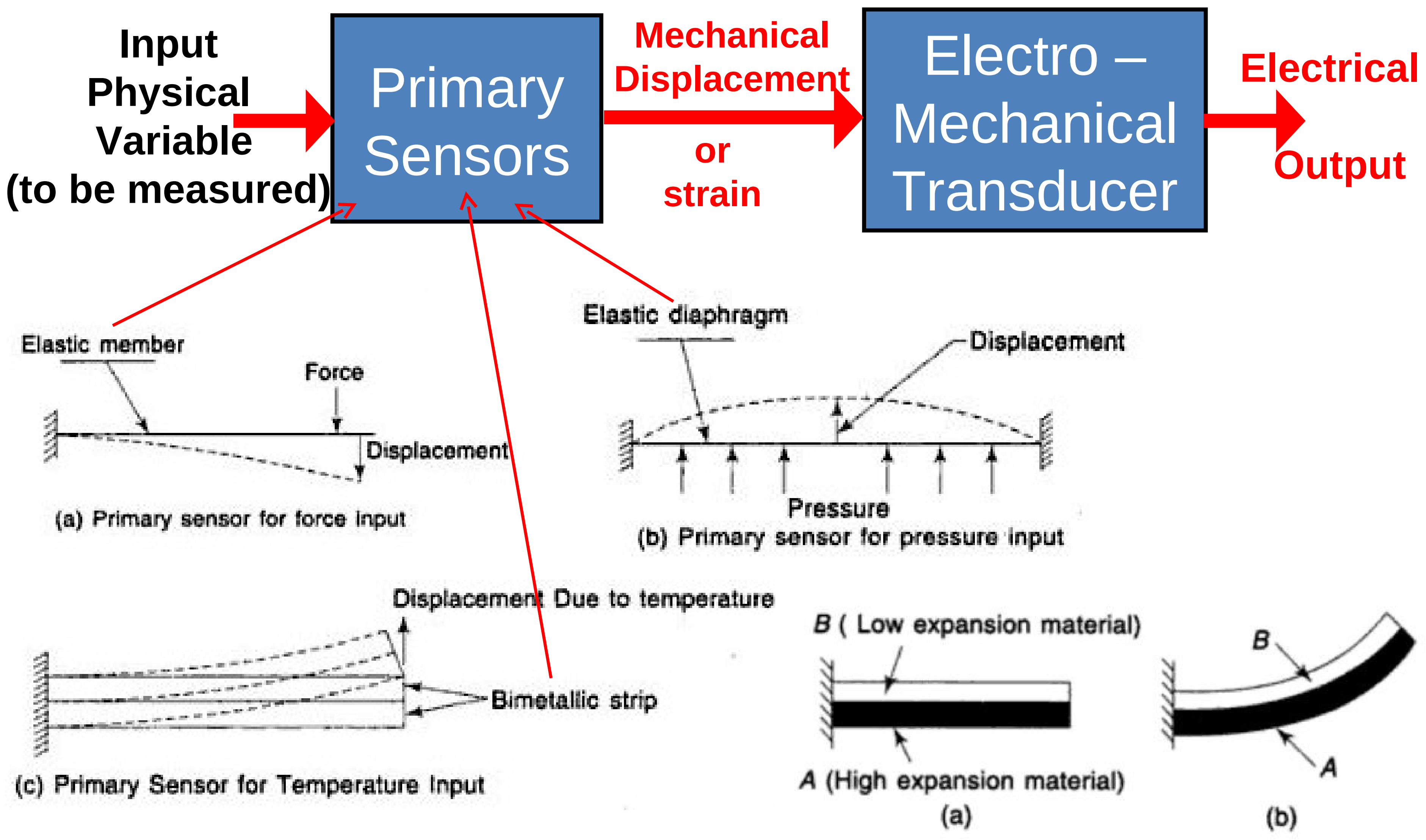
Electromechanical Transducers

Principle of Measurements



Electromechanical Transducers

Primary Sensors for Displacements



Selection criterion for Motion Transducers:

Since displacement or motion is input to an EMT, they are called as

"Motion Transducers"

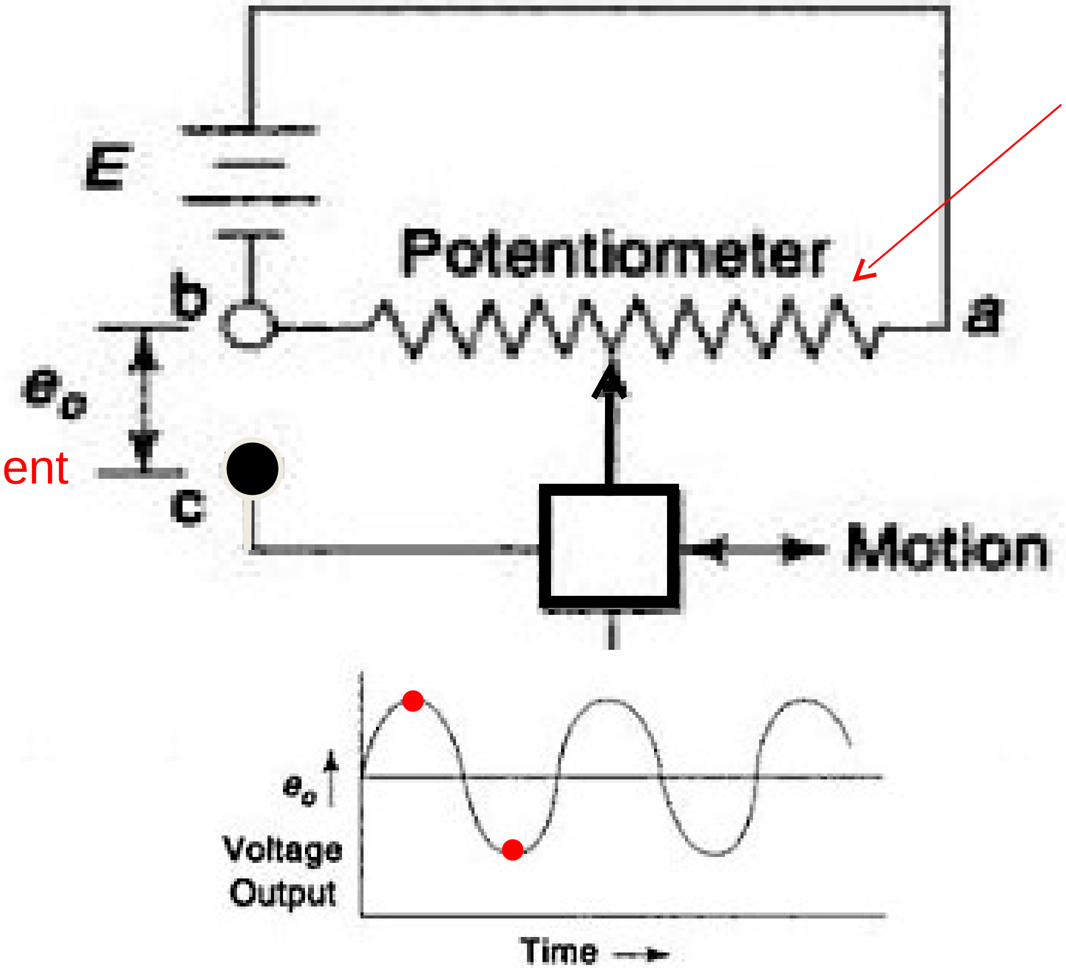
1. Magnitude of Motion: small/medium/ large?
2. Input-Output Relation: to displacement x / (dx/dt) / (d^2x/dt^2)?
3. Static / Dynamic Characteristics: of motion to be measured.
4. Attachment /Proximity Type: to moving object
5. Self-generating /external source type: to energies the Trans.
6. Type of Associated Circuit: Simple or complicated.

Potentiometric Resistance Transducers

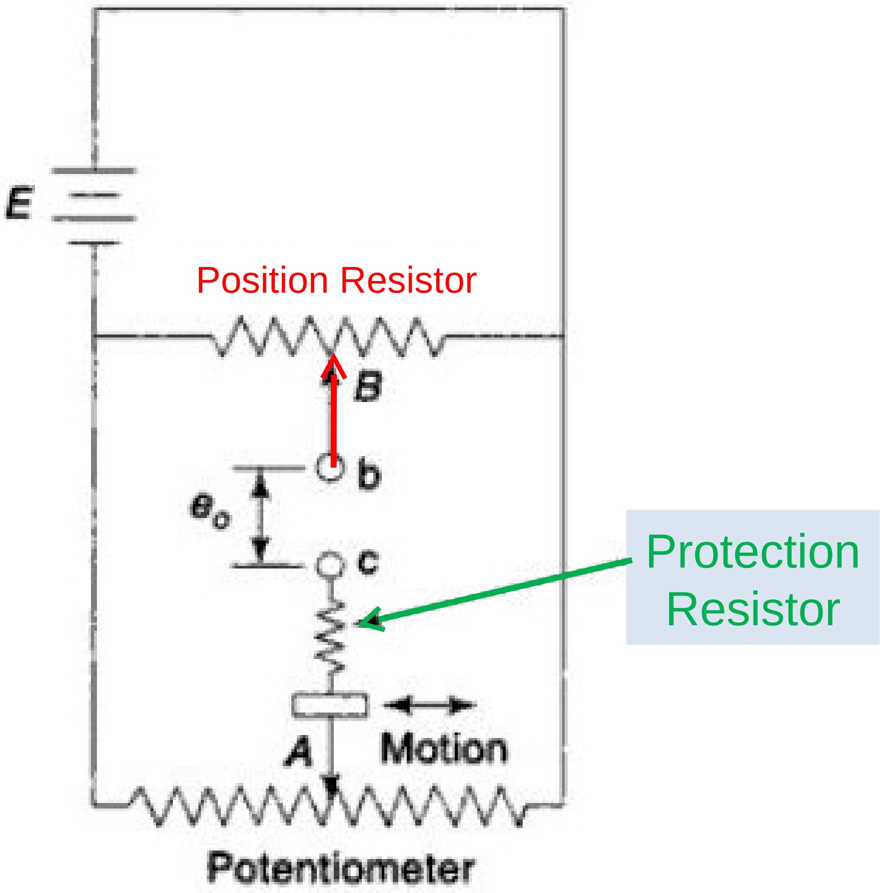
Linear/angular type

Output voltage

$e_0 \propto$ displacement



Modified Potentiometric Resistance Transducers



Position resistor at B is used to bring the initial value of e_0 to zero depending on the initial position of the moving point.

In case when the resistors are so placed that there is a short circuit across the battery, the movable contacts of the potentiometer may burn off. A ***Protection Resistor*** as shown in figure prevents this.

Inductive type Transducers

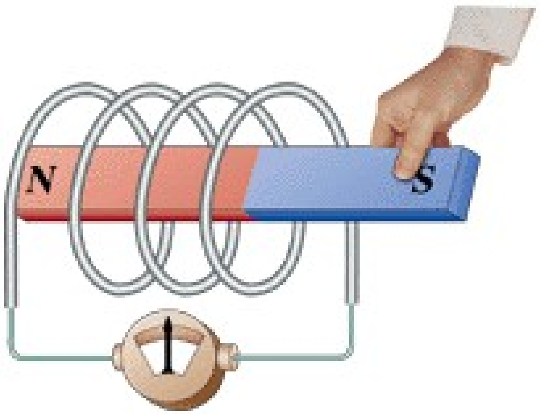
Principle of Operation:

The magnetic characteristics of an electric circuit changes

due to the motion of the

- Self-generating type:

In which a *voltage signal is generated in the transducer due to the relative motion of conductor and a magnetic field.*
e.g. electrodynamic, electromagnetic and eddy current type inductive transducers

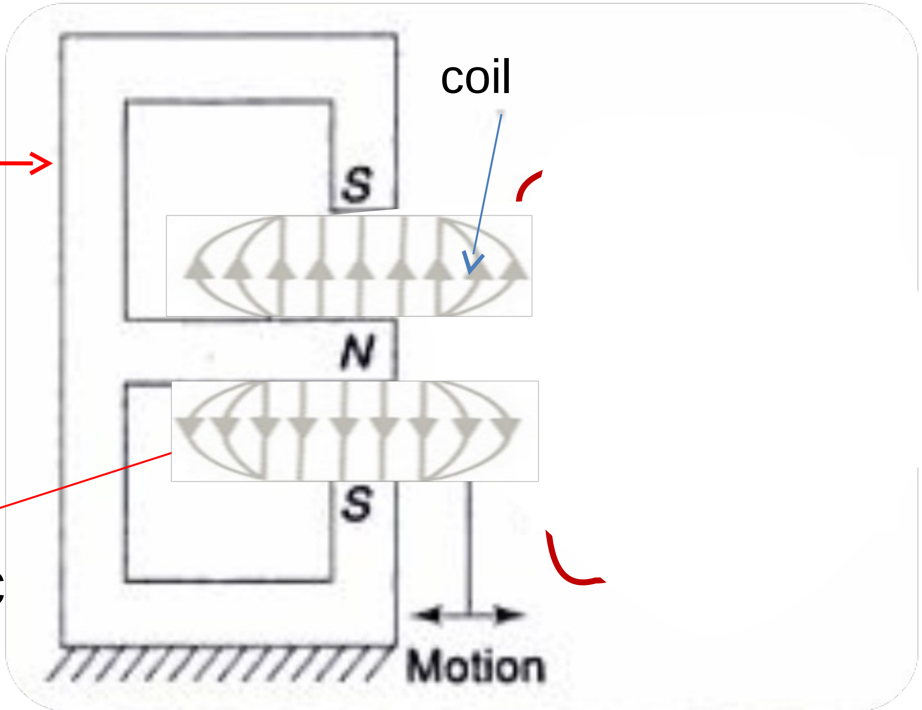


- Non-Self-generating type:

External source is needed to energize a coil/coils, the inductance of which would change due to the relative motion of conductor and a magnetic field.

Electrodynamic- Linear Motion

Fixed Magnet



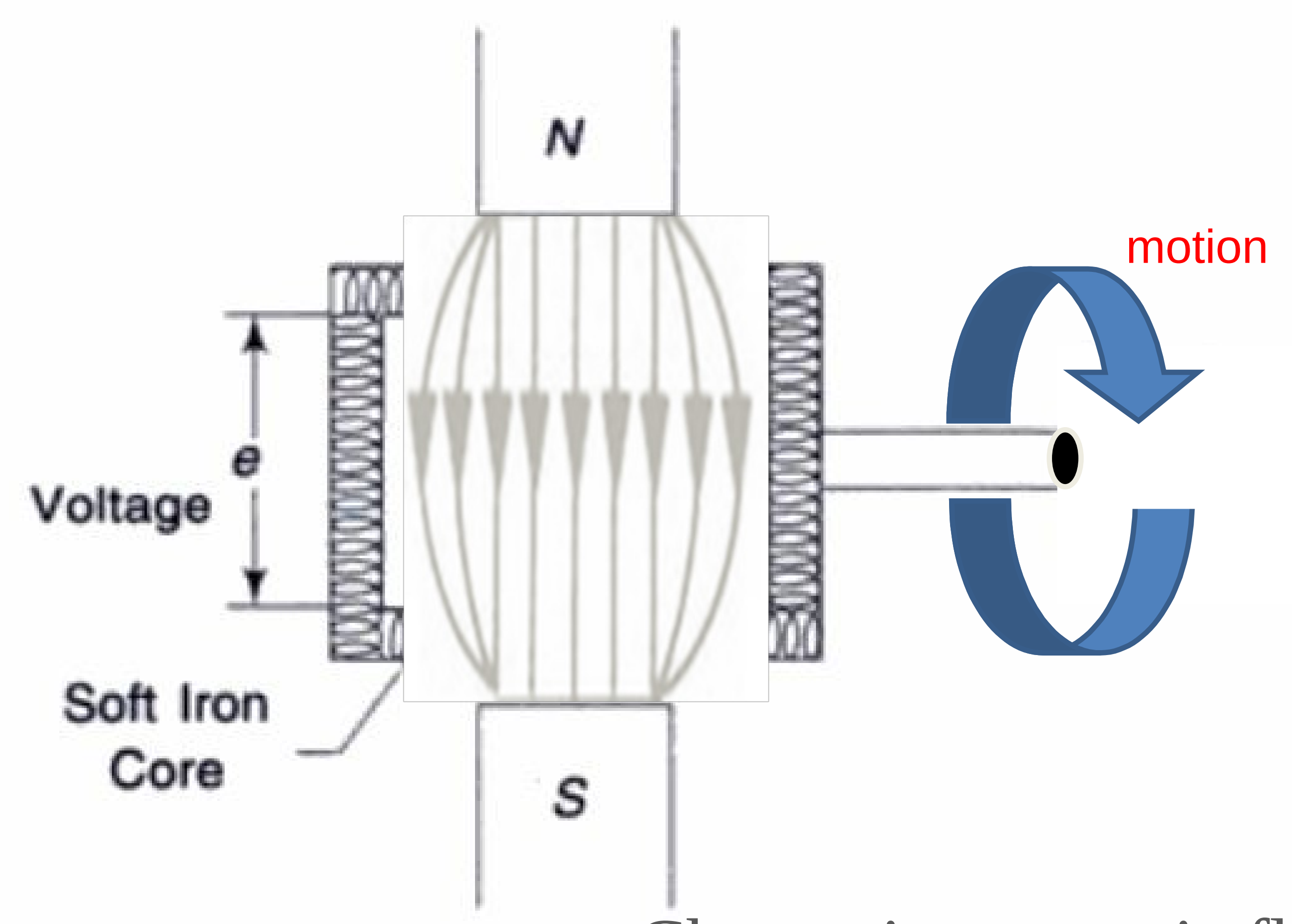
Non-Magnetic material

Change in magnetic flux

Induced voltage
e α $(d\varphi/dt)$
i.e. e α (d^2x/dt^2)

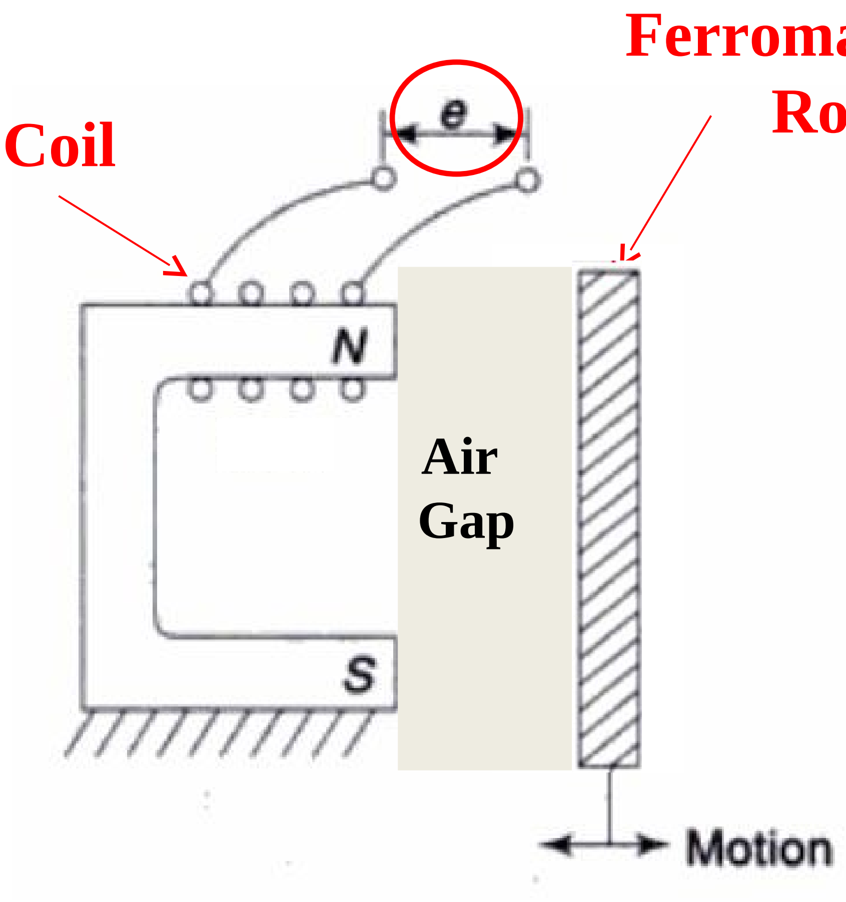
Attachment Type
Velocity transducer

Electrodynamic: Rotary Motion



- Change in magnetic flux
- Attachment Type
- Velocity transducer

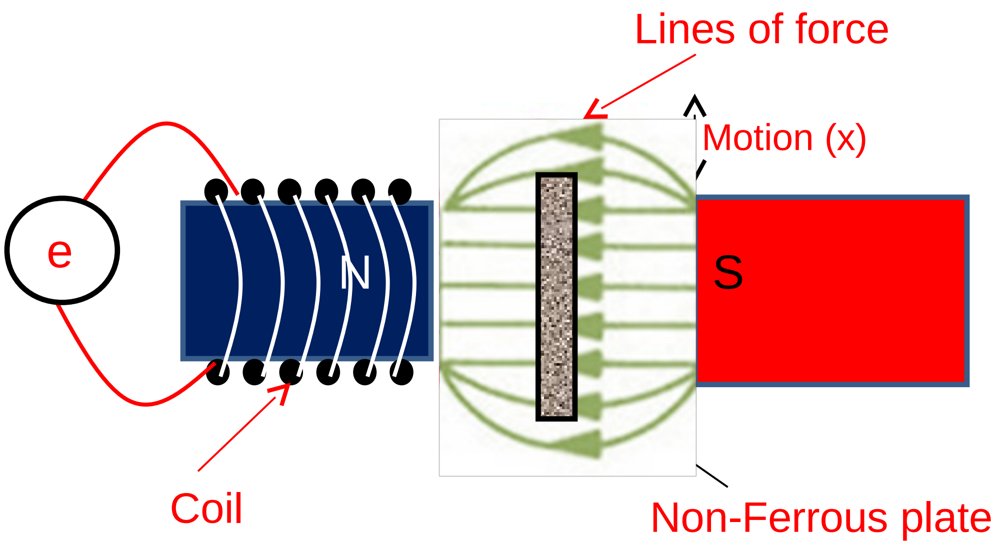
Electromagnetic Type:



- Change in air gap
- Change in magnetic flux
- Induced voltage
- Proximity Type
- Velocity transducer

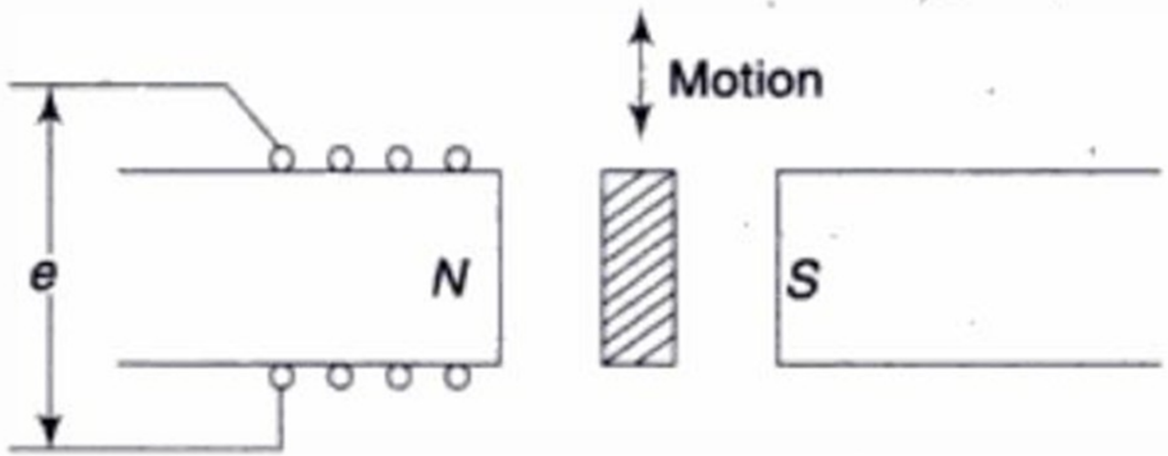
Limitation: linear for small motions

Eddy Current Type:



- The motion generates Eddy current i in the plate, which set-up a mag. field in the direction opposing the mag. field that generated them.
- The output voltage, e α (di/dt) i.e. e α (d^2x/dt^2)
- linear characteristics since gap remains constant

Eddy Current Type:

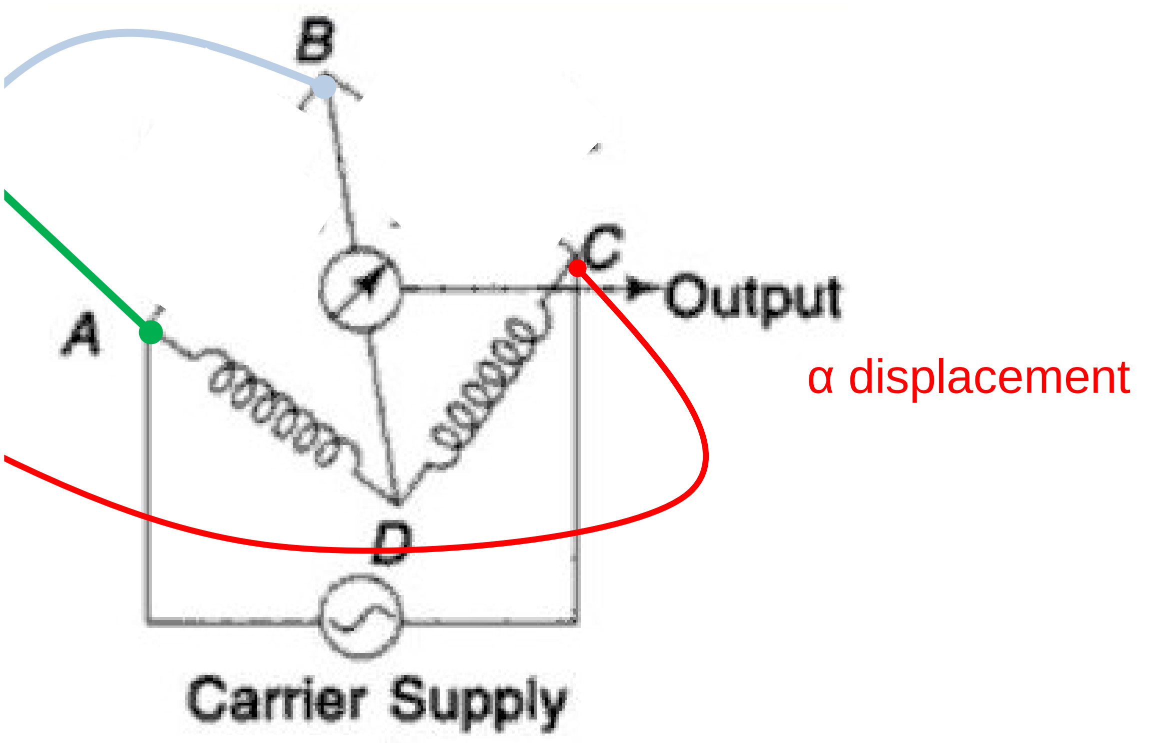


Non-Self generating Inductive Type:

Non-Self-generating type:

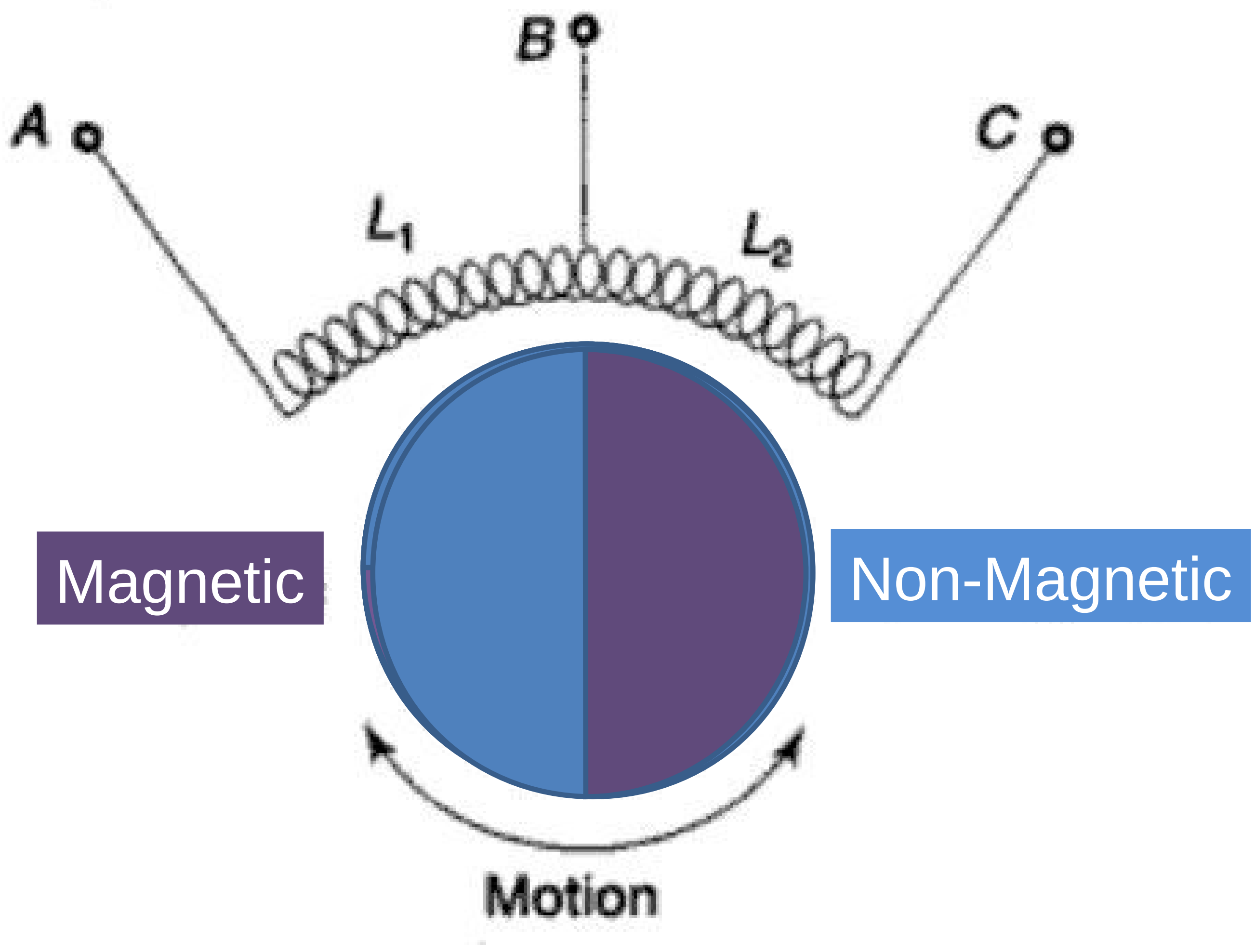
Principle: External source is needed to energize a coil/coils, the inductance of which would change due to the relative motion of conductor and a magnetic field.

Variable Inductance Type: Linear Motion

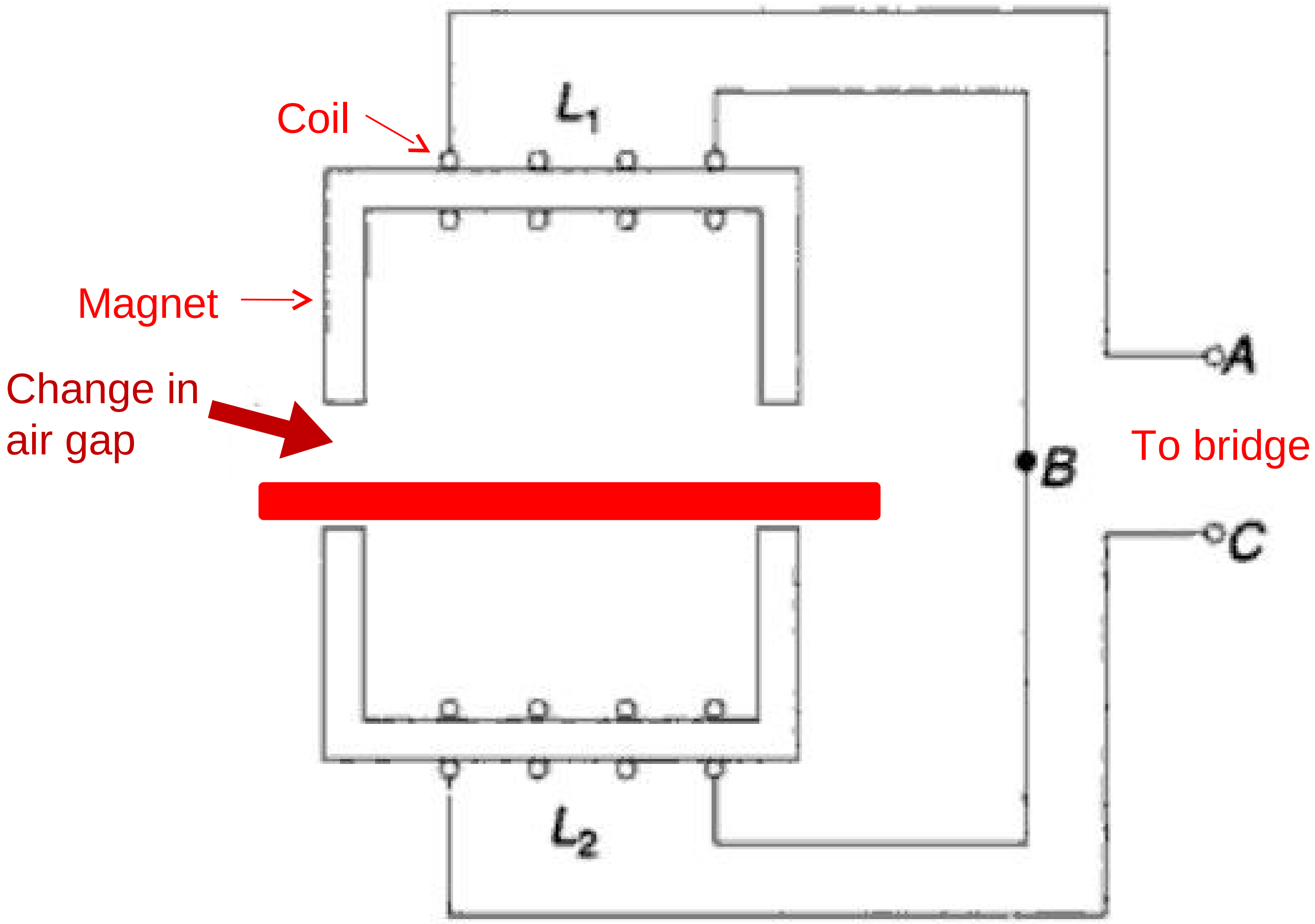


RELUCTANCE: the property of a magnetic circuit of opposing the passage of magnetic flux lines, equal to the ratio of the magnetomotive force to the magnetic flux

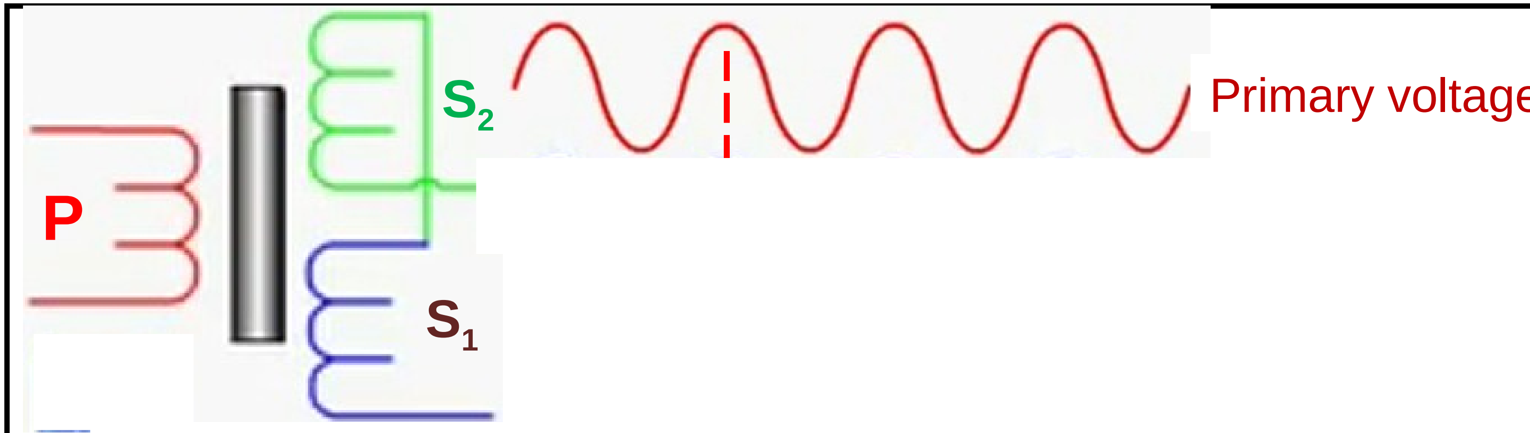
Variable Inductance Type: Rotary Motion



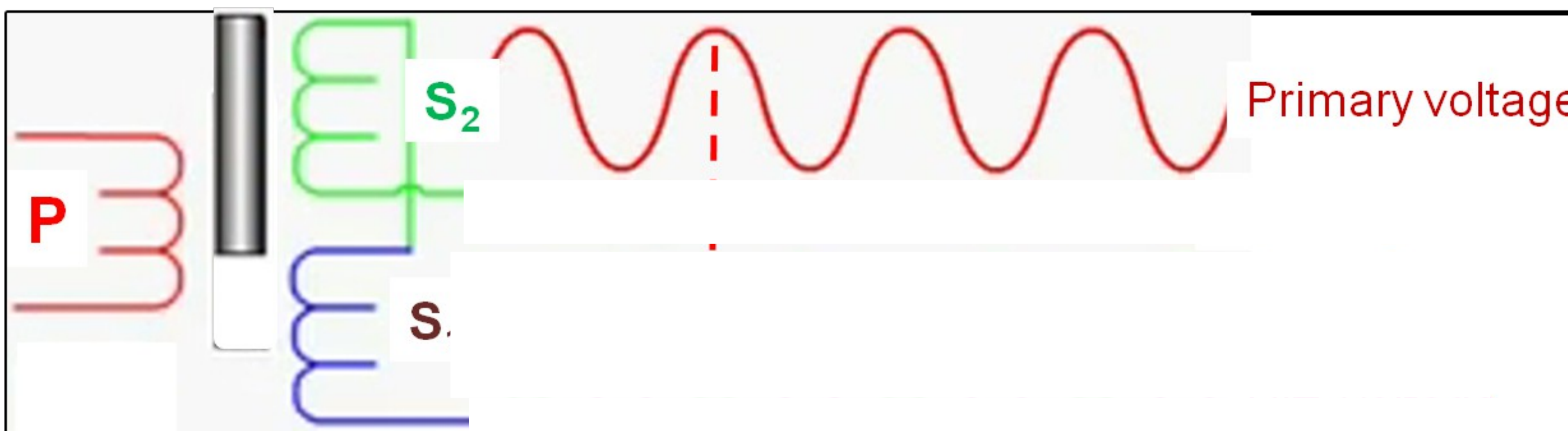
Proximity Type: Variable Inductance



LVDT : Linear Variable Diff. Transformer

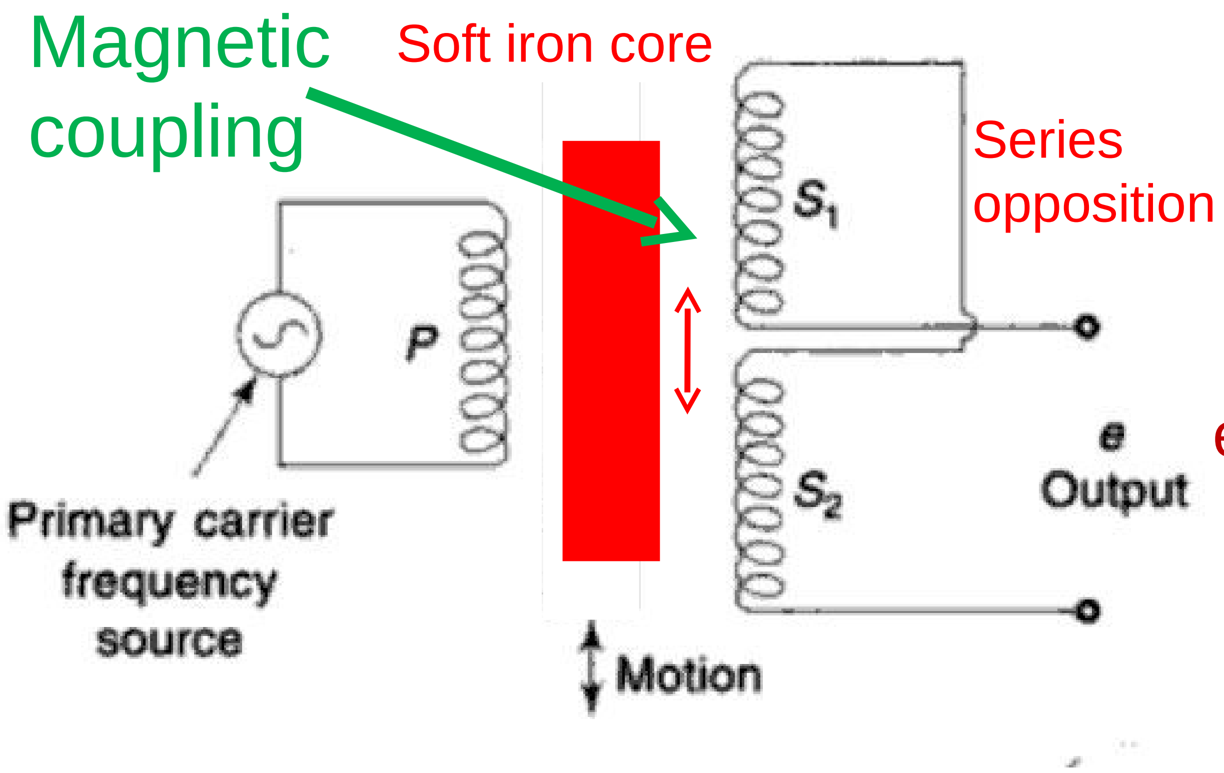


When the core is at the middle



When the core is at top end

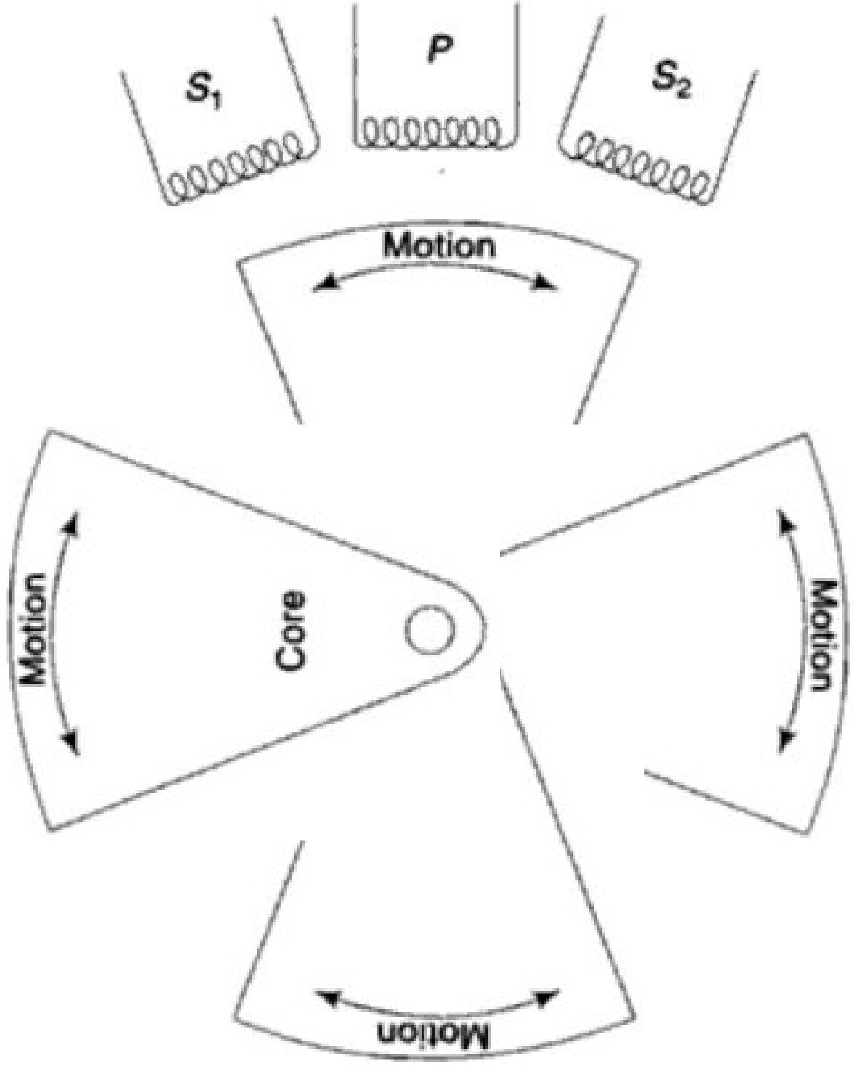
LVDT : Linear Variable Diff. Transducer



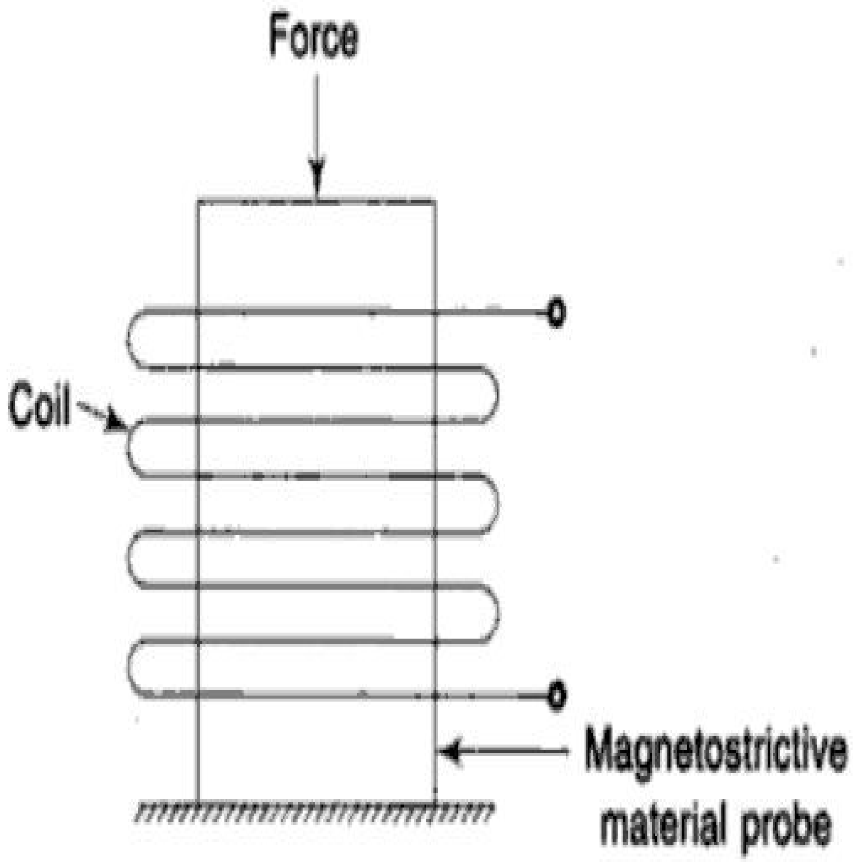
e α displacement

- Sensitive Transducer
- Linear over wide range

LVDT : Linear Variable Diff. Transducer
-ROTARY MOTION-



Magnetostrictive Type



Principle: For ferromagnetic materials, Magnetic Permeability Changes with Mechanical Stress

For Ni it increases with compression
And decreases with tension.

Hence L changes with compression or tension.

The magnitude and freq. of exciting current determines L.

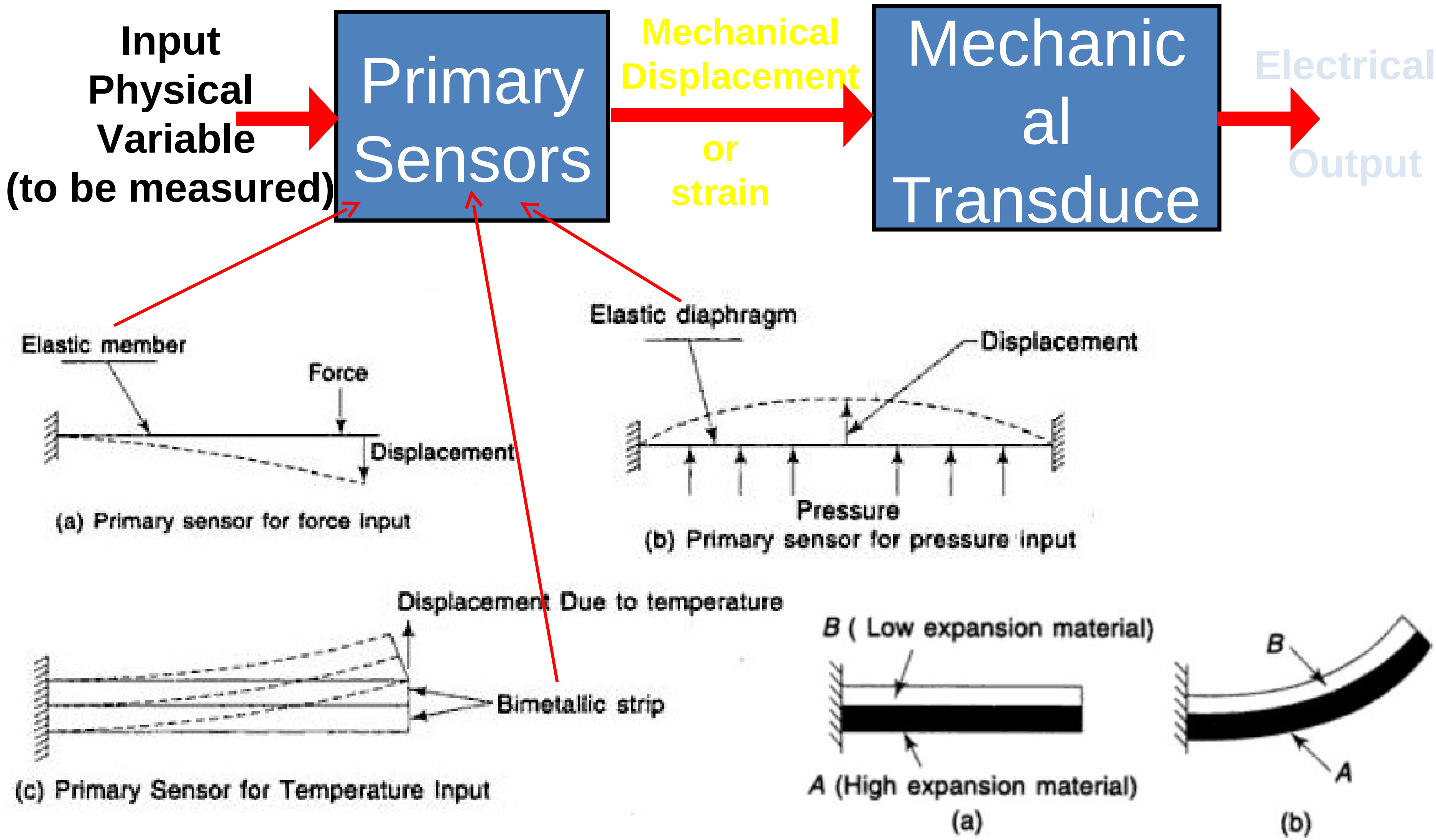
Force and motion can be measured.

Resonant freq. is high due to high mechanical impedance.

Since, physical properties of the material are changes individual calibration is Important.

Electromechanical Transducers

Primary Sensors for Displacements



Capacitive Type Transducers

- It is a Displacement sensitive transducer

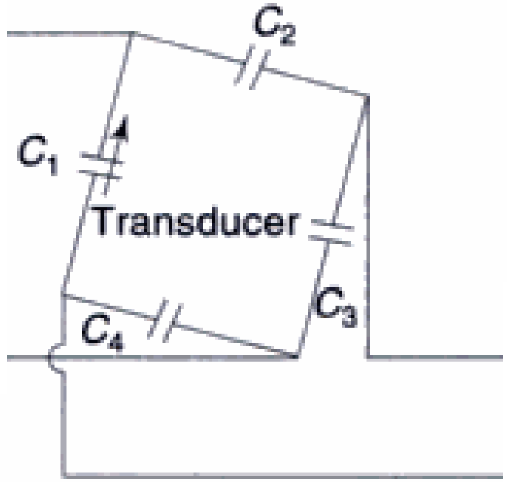
The capacitance ***C*** of a parallel plate capacitor is,

$$C = \frac{1}{3.6\pi} \varepsilon \frac{A}{d}$$

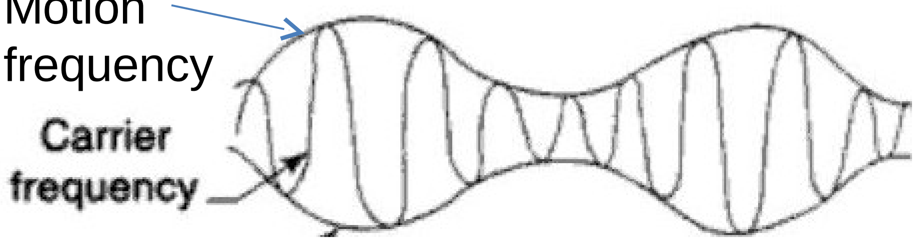
C is capacitance, µF
A is area of plates, cm^2
d is distance between plates, cm
ε is dielectric constant of the medium

Capacitive Type Transducers

Associated circuit for capacitive transducers

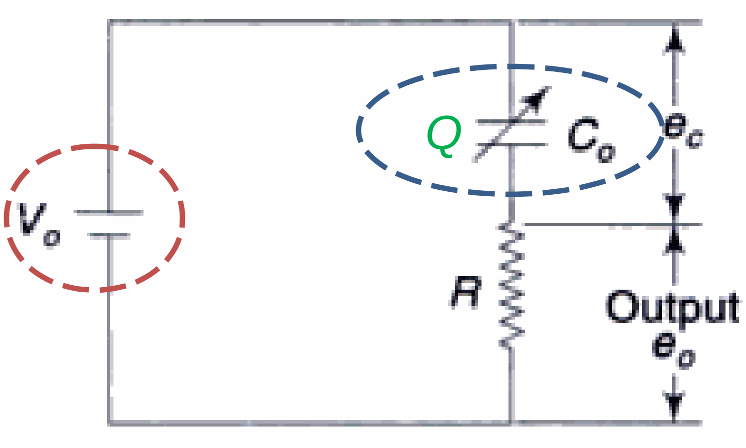


Motion frequency



Capacitive Type Transducers:

DC Type: Only for Dynamic Measurements



$$V_0 = e_c + e_o \quad .....(1)$$

$$and \;\; Q = C_0 V_o \quad .....(2)$$

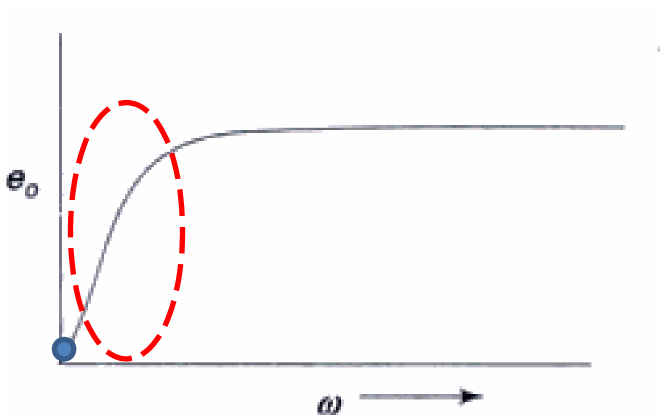
$$Also \;\; e_0 = V_0 - e_c \quad .....(3)$$

If motion is so fast that C_0 changes to C, but Q remains almost unchanged, then

$$e_c = Q / C \quad .....(4)$$

$$\frac{e_0}{V_0} = \frac{C - C_0}{C} = \frac{\Delta C}{C}$$

(prove)



Frequency response curve

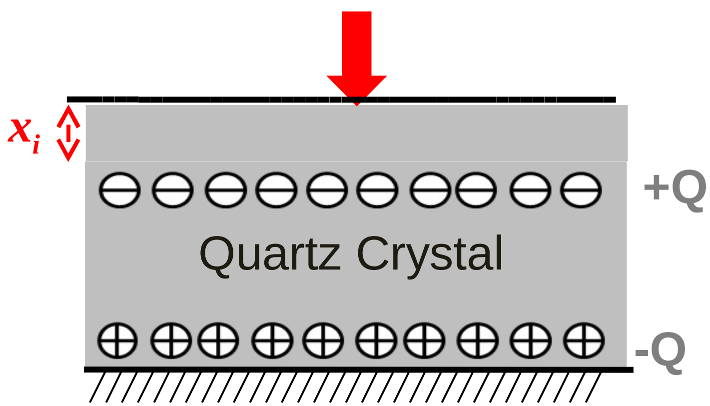
Example 4.1

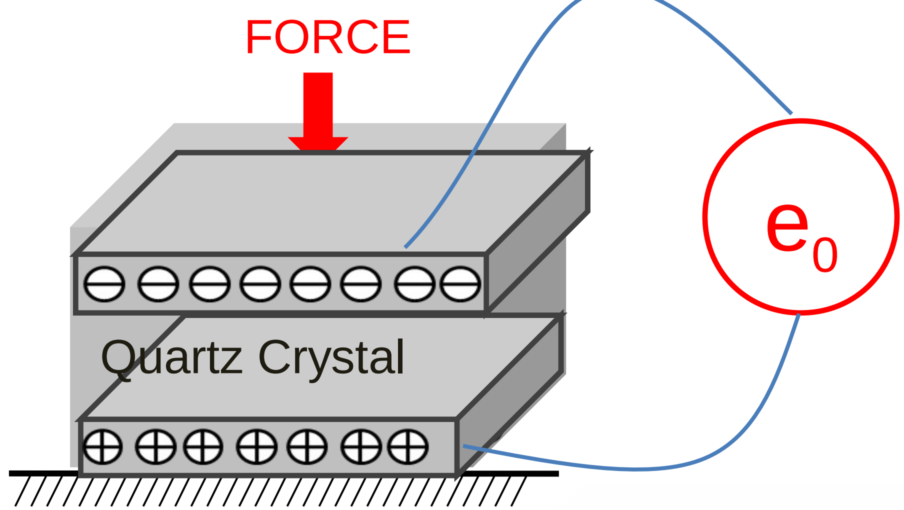
Problem 4.1

A capacitive transducer consists of two plates of diameter 2 cm each, separated by an air gap of 0.25 mm. Find the displacement sensitivity.

Solution

Piezo-electric Transducers: Piezoelectric Effect





Q α x_i

i.e. Q = K_1 x_i

K_1 is charge sensitivity constant

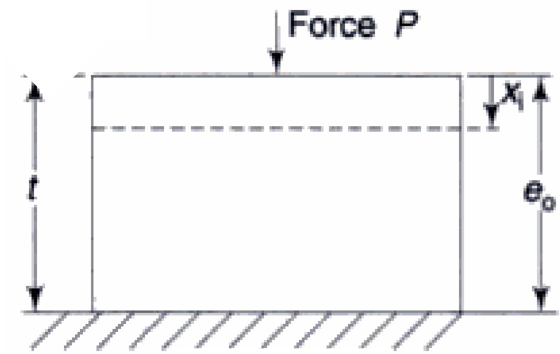
C = Q/e_0

i.e. e_0 = $K_1 x_i$/C

i.e. e_0 = K x_i

K is voltage sensitivity constant

Parallel Plate Capacitor



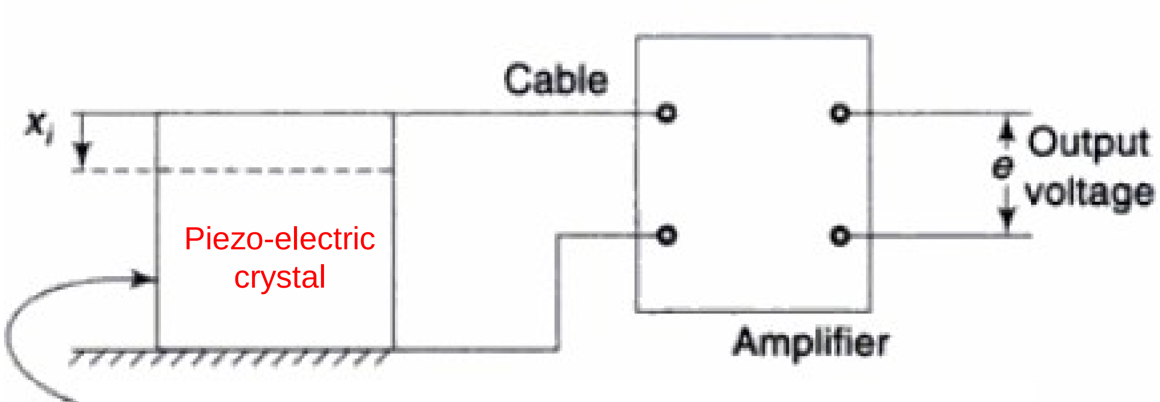
$$C = \frac{\varepsilon A}{3.6\pi t} \ \mu f$$

$$C = \frac{\varepsilon A}{1.31\times 10^{11}\, t} \ farad$$

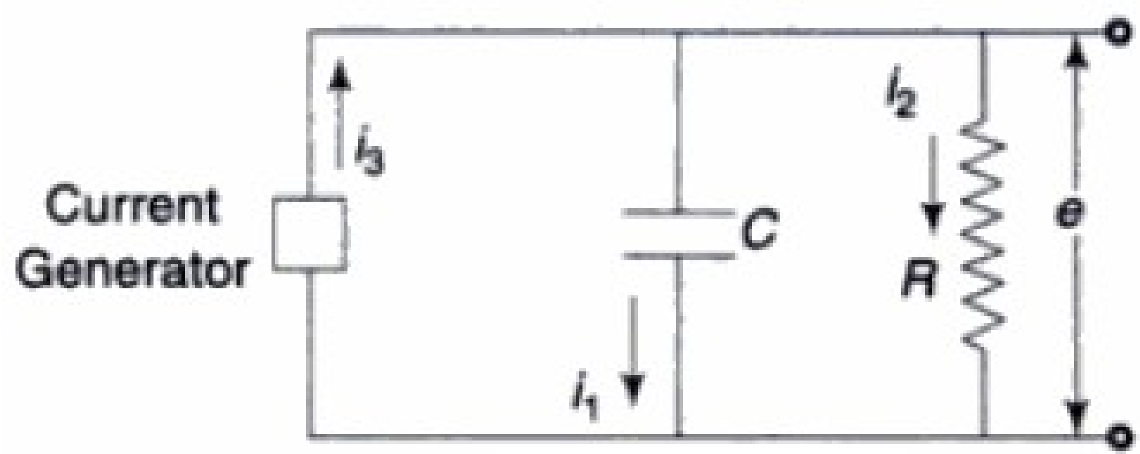
$$P = EA\frac{x_i}{t}$$

E is Young's modulus

Dynamic Characteristic of Piezo-electric Transducers



Piezo-electric crystal connected to amplifier



Equivalent Circuit

Here C is the effective capacitance given by,

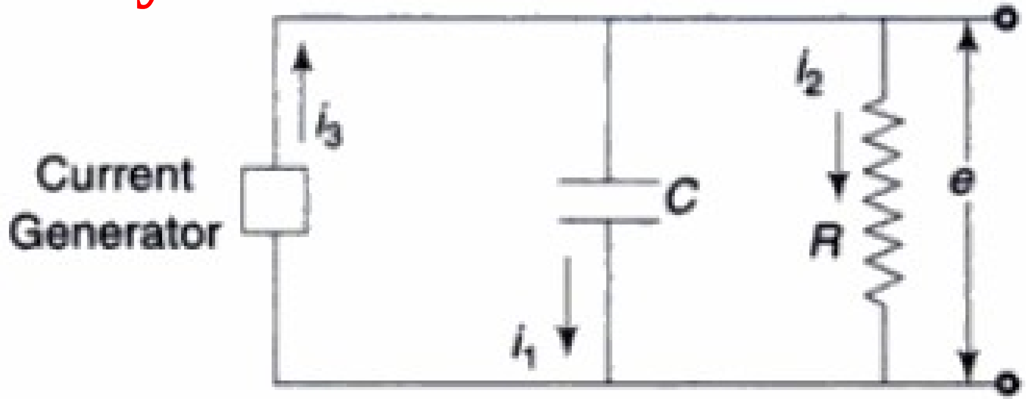
$$C = C_{crystal} + C_{cable} + C_{amplifier}$$

Also, **R** is effective resistance.

$$Since\ R_{leak} >> R_{amplifier}$$

$$R \approx R_{amplifier}$$

Dynamic Characteristic of Piezo-electric Transducers



$i_3 = dQ/dt = dK_1 x_i/dt$

$= K_1 D x_i$ where $D = (d/dt)$

$i_2 = e/R$

$i_1 = C(de/dt) = CDe$

KCL: $i_3 = i_1 + i_2$

KCL: $K_1 D x_i = CDe + e/R$.

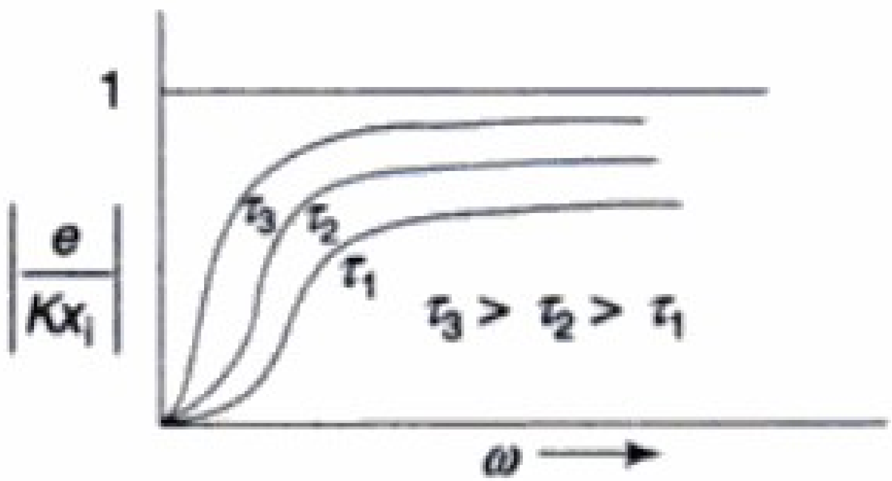
Using $K = K_1/C$, $(KC)Dx_i = CDe + e/R$

$(KCR)Dx_i = RCDe + e$

Let $RC = \tau$ = time constant of circuit, then $(K\tau)Dx_i = \tau De + e$

$(K\tau)Dx_i = e(\tau D + 1)$

If $x_i = 0$, ????



$$\left|\frac{e}{x_i}\right| = \frac{k\tau\omega}{\sqrt{1+\tau^2\omega^2}}$$

τ should be large (upto a limit).

Transient Response to Pulse Input

Pulse: $x_i = A$ for $0 < t <= T$ and $x_i = 0$, for $t > T$

For $t > T$, Putting $x_i = 0$, in $(K\tau)Dx_i = e(\tau D + 1)$

we get, $e(\tau D + 1) = 0$

Solution: $e = Be^{-t/\tau}$ …..(1)

Where B is const. depending on initial condition.

For $t = 0$, $e = Be^{-0/\tau} = Be^{0}$

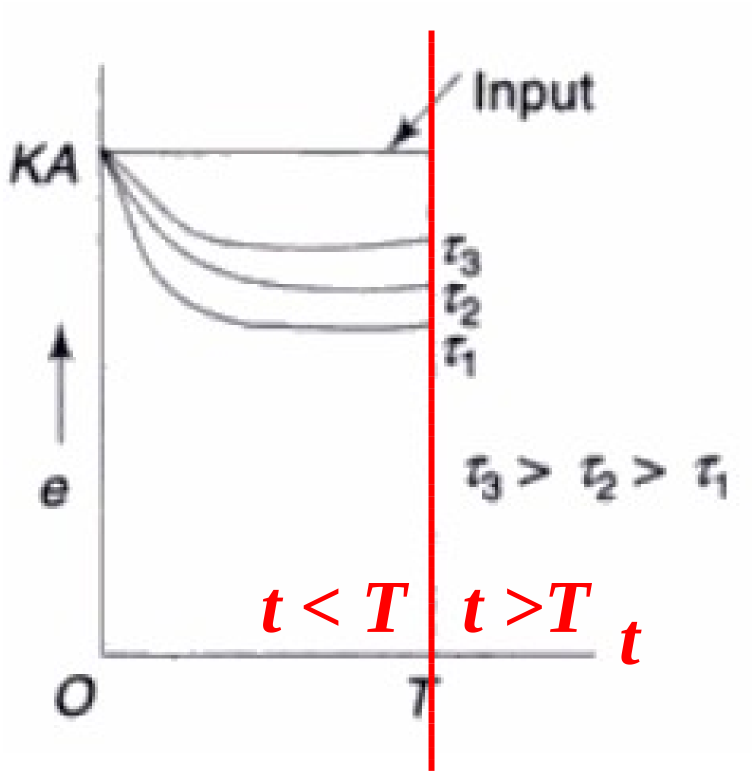
$e = B$ ….(2)

Also we have, $e = K x_i$.

For $t = 0$, $x_i = A$ and so

$e = KA$ …..(3). From (2)&(3),

$B = KA$. Hence (1) becomes $e = KA\, e^{-t/\tau}$



It can be seen that shape of output pulse (e) follows the Shape of input (x_i) for larger value of τ .

Properties of some Piezo-electric Materials

S.No.	Material	Charge sensitivity pC/N	Dieelectric constant ε	Young's modulus N/m^2
1.	Quartz	2.0	4.5	9×10^{10}
2.	Tourmaline	1.9	6.6	16×10^{10}
3.	Barium titanate	150	1380	12×10^{10}
4.	Lead zirconate titanate	265	1500	7.9×10^{10}

Problem 4.3

A piezo-electric transducer has the following characteristics:

Capacitance of crystal = 10^{-9} F

Capacitance of cable = 3×10^{-10} F

Charge constant of crystal = 4×10^{-6} C/cm

The oscilloscope used for read-out has a resistance of 1 MΩ in parallel with a capacitance of 10^{-10} F. Find the amplitude of the output voltage, as displayed on the oscilloscope, if the crystal is subjected to a harmonic deformation of amplitude 10^{-3} mm and frequency 200 Hz.

$$R = 10^6\ \Omega$$

$$C = 10^{-9} + 3 \times 10^{-10} + 10^{-10}\ \text{F} = 1.4 \times 10^{-9}\ \text{F}$$

$$\tau = RC = 1.4 \times 10^{-3}$$

$$K_1 = 4 \times 10^{-6}\ \text{coulomb/cm}$$

$$K = \frac{K_1}{C} = 2857\ \text{V/cm}$$

We have,

$$\left|\frac{e}{x_i}\right| = \frac{K\tau\omega}{\sqrt{1 + (\tau\omega)^2}}$$

Putting $\omega = 2\pi \times 200 = 1256.6$ *rad/s ,*

$x_i = 10^{-4}$ *cm and other values in above relation we get,*

$$e = 0.248\ V$$