
EW
@ENGINEERINGWALLAH

Sinhgad College of Engineering, Pune – 41.

Department of Electronics &Telecommunication Engineering

UNIT 5

SENSORS

Sinhgad Institutes

Syllabus

Unit V Sensors [7L]

- Classification of a sensors, Active /Passive Sensors, Analog/Digital Sensors,
- Motion Sensors (LVDT, Accelerometer), Temperature Sensors (Thermocouple, Thermistor, RTD), Semiconductor Sensors(Gas Sensors),
- Optical Sensors (LDR), Mechanical Sensors (Strain Guage, Load Cell,Pressure sensors), Biosensors. (Working Principle and one application).

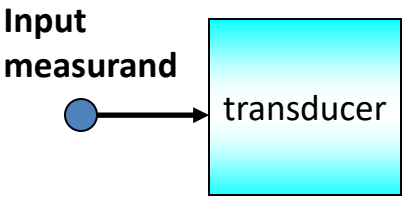
Basic Instrumentation System

Transducer:

- converts measurand into usable electrical energy
- capable of converting physical quantity into proportional electrical quantity such as voltage & current

Measurand:

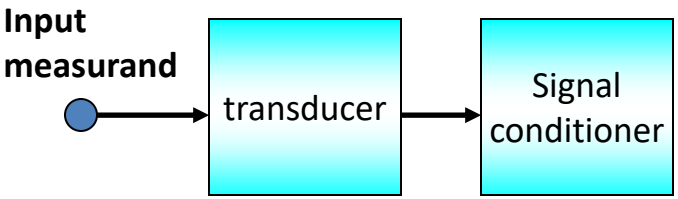
- i/p such as pressure, temperature ,displacement, force, acceleration etc



Basic Instrumentation System

Signal conditioner:

- process o/p of transducer
- makes it suitable for control, recording & display
- Its functions: amplification, filtering, modulation, analog to digital conversion



Basic Instrumentation System

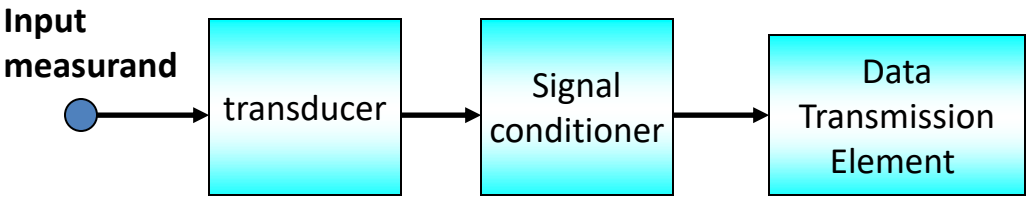
Data transmission and data presentation element:

Data transmission :

- provides transmission path required for sending signal from signal conditioner to rest of instrumentation system
- eg: electric cables, radio links, pneumatic pipes

data presentation element :

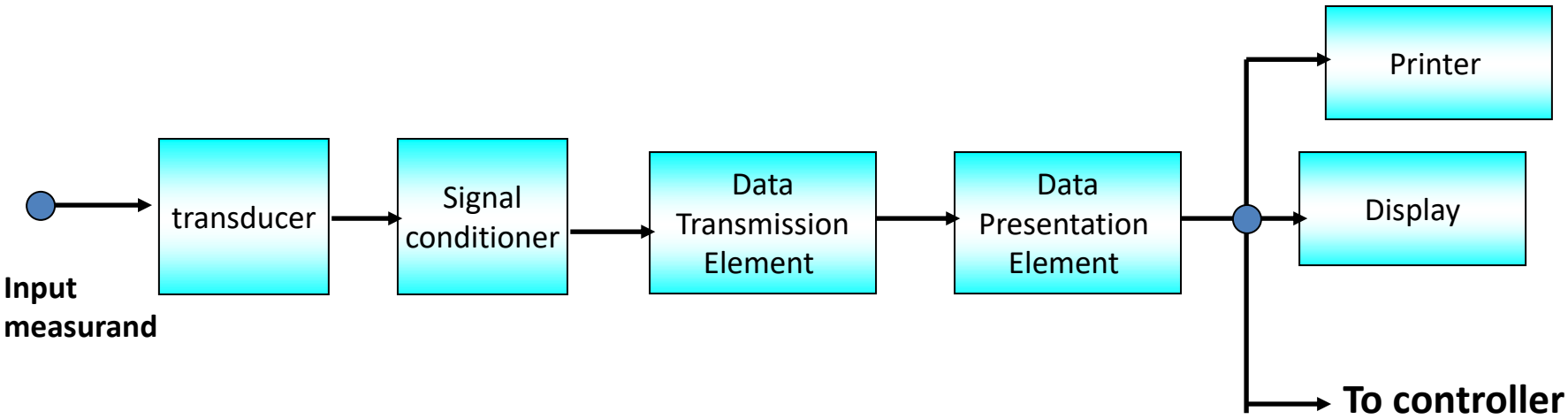
- Does fn such as amplification, demodulation, filtering etc



Basic Instrumentation System

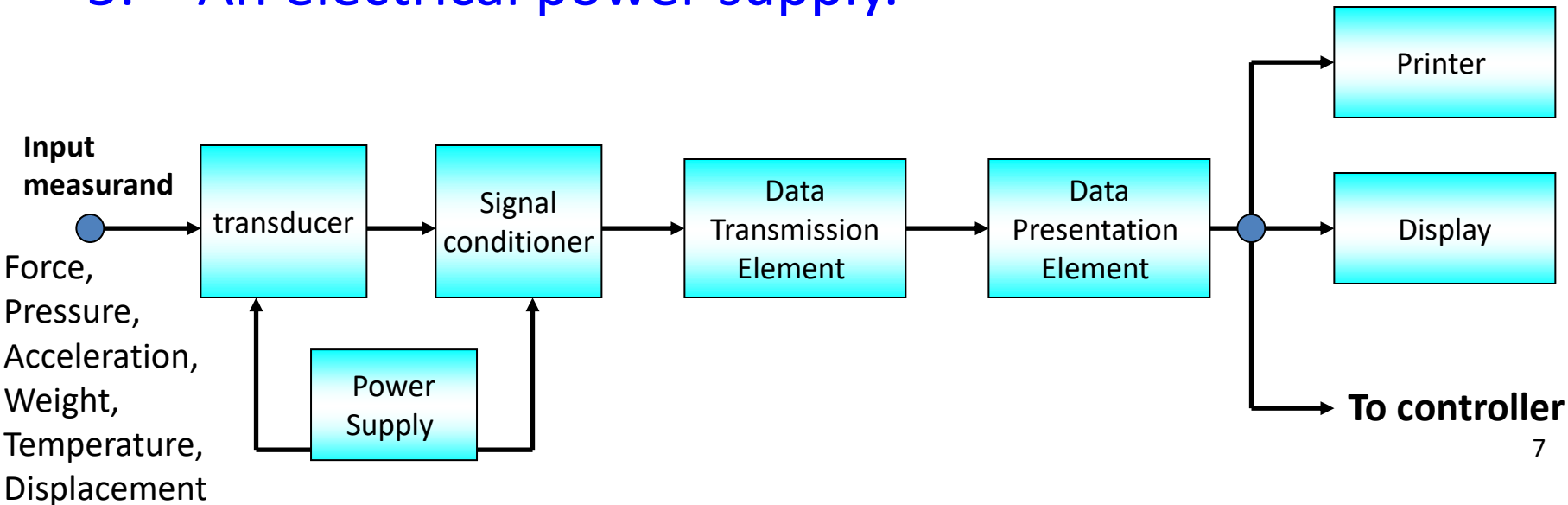
display or read out devices :

- read out devices; display value of measurand with help of analog meters



Block diagram of an instrumentation system

1. A transducer
2. A signal conditioner
3. Data transmission and data presentation element.
4. The display or read out devices
5. An electrical power supply.



What is a transducer ?

- device which converts a physical quantity to be measured into an equivalent electrical signal (voltage or current)

- physical quantity to be measured can be temperature, pressure, displacement, flow, vibration etc.

- electrical signal obtained from the transducer is then used to control the physical quantity automatically and to display the same.

Classification of transducer

- Depending on the quantity to be measured
- Depending on the principle of operation
- Depending on the application area
- Depending on whether an external source of excitation is required or not.

last criteria of classification gives rise

“active transducers” and “passive transducers”

Active transducer

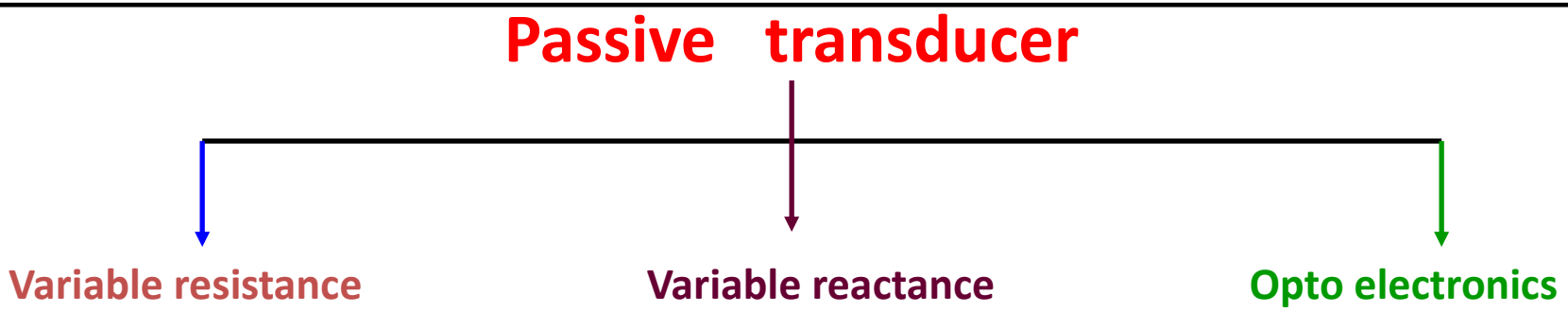
- do not need any external source of power for their operation
- also called as self generating type transducers.
- operate under the energy conversion principle
- Classification

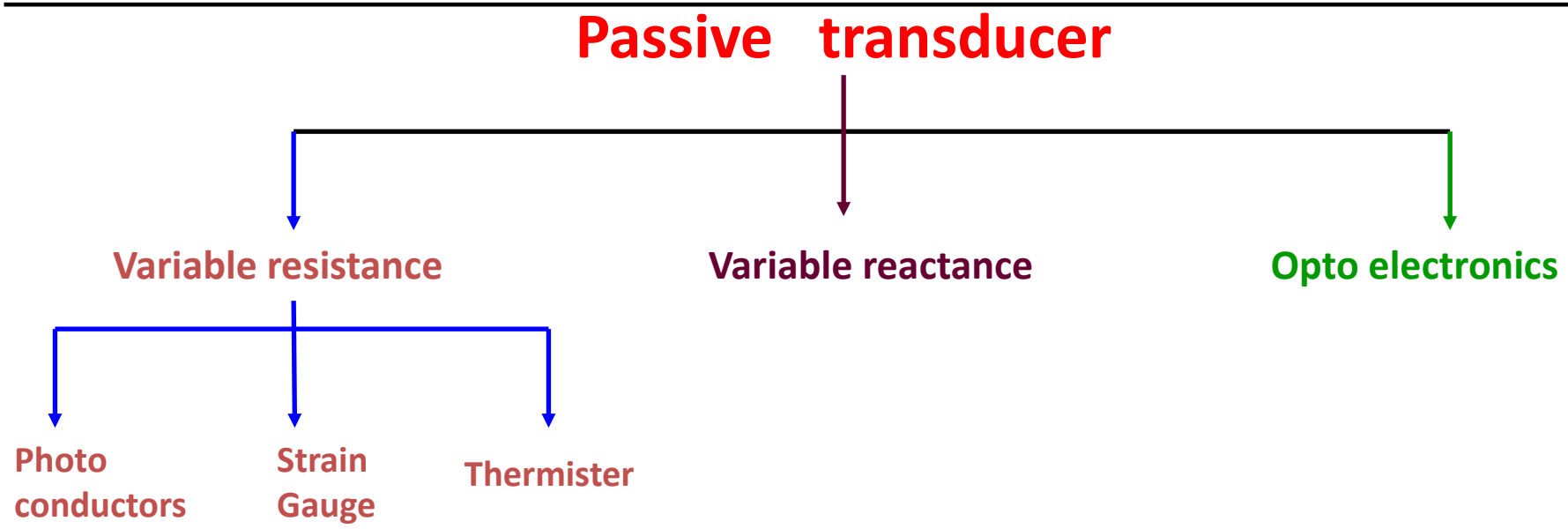
1. Photo voltaic
2. Thermo electric
3. Piezo electric
4. Electromagnetic.

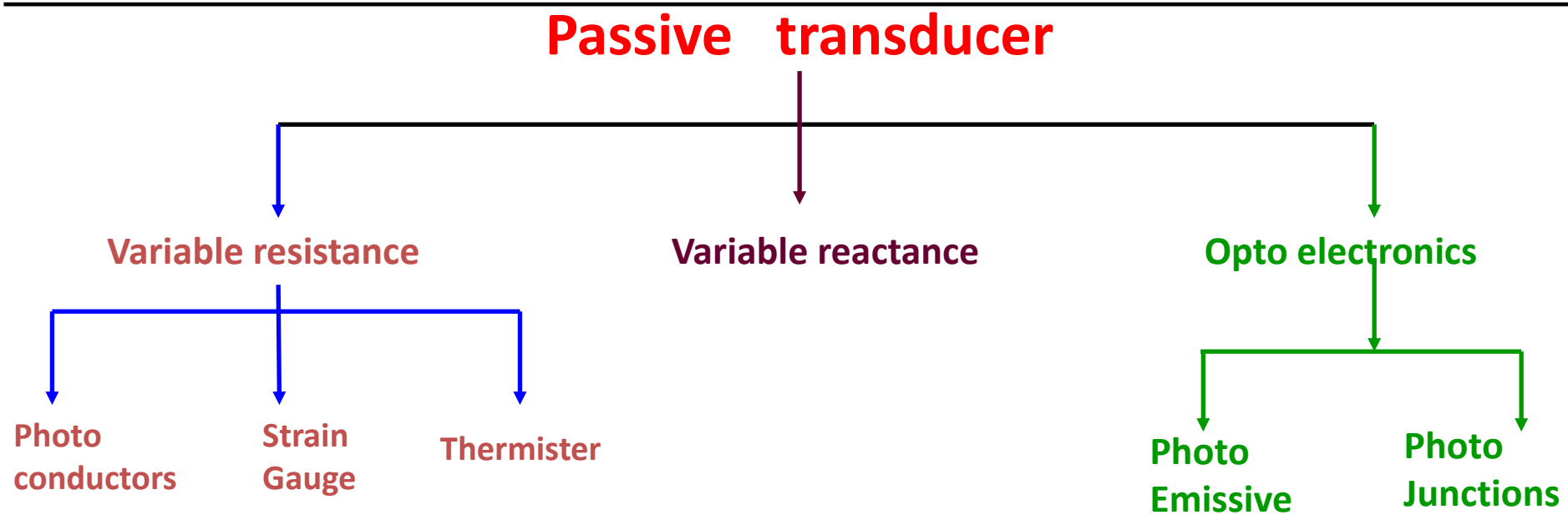
Passive transducer

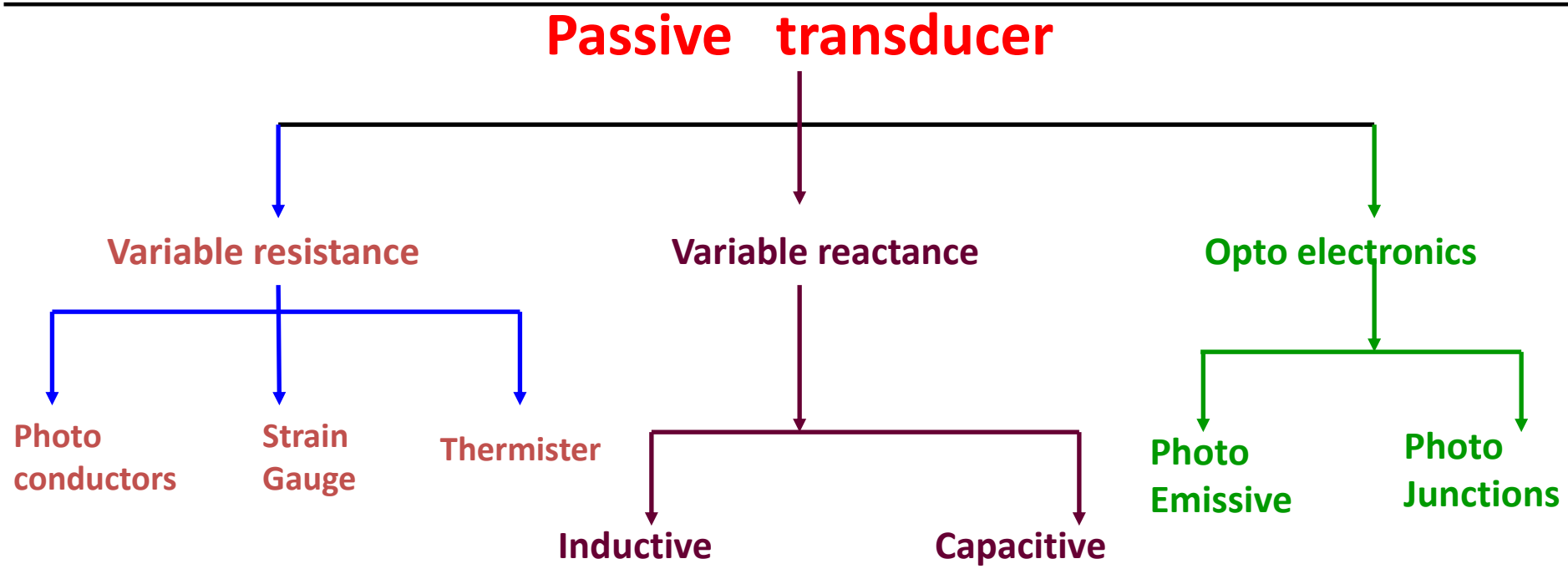
- need external power supply for their operation. So they are not " self generating" transducers
- depends upon the change in an electrical parameter
- also known as externally power driven transducers

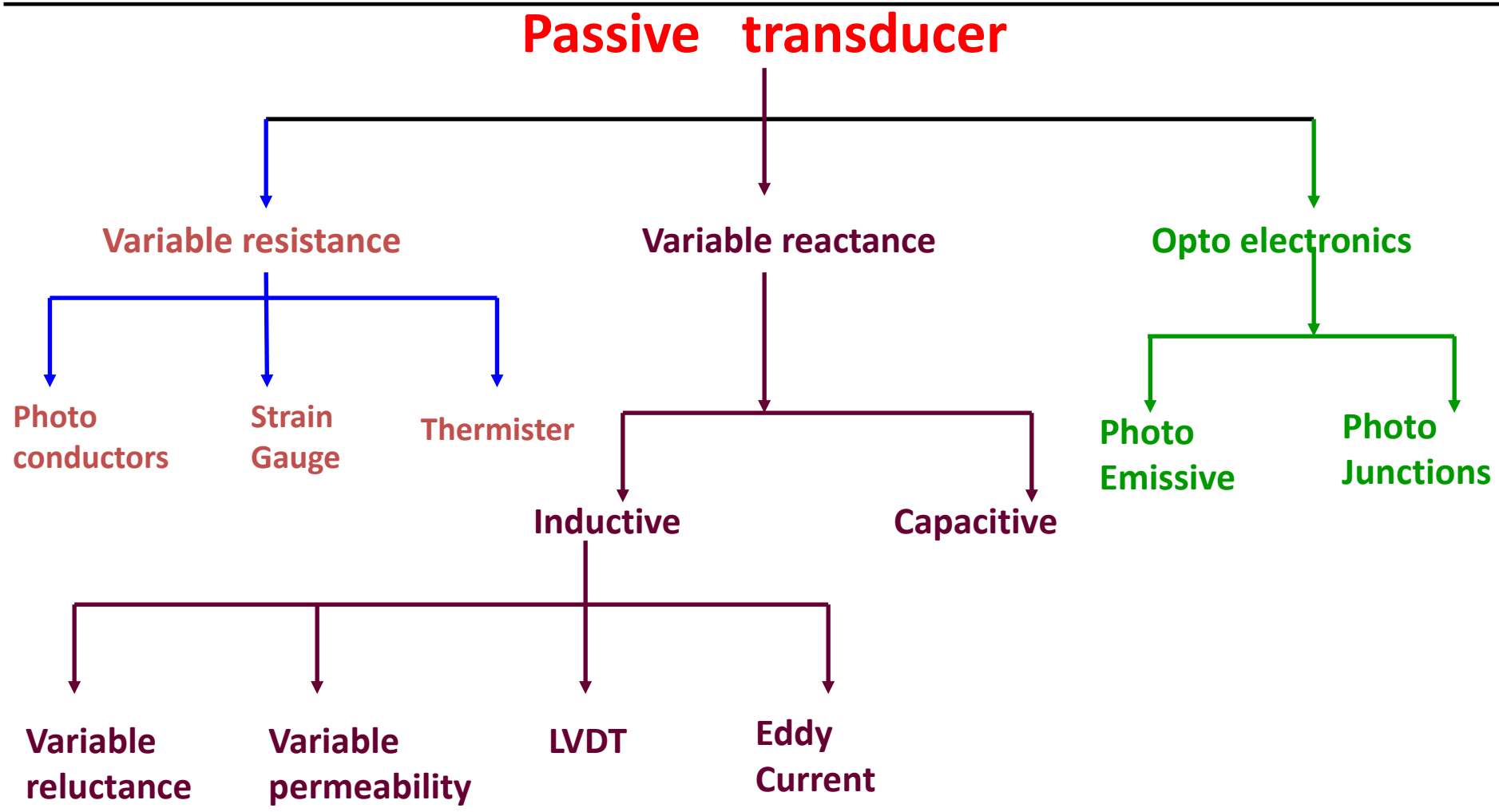
Classification

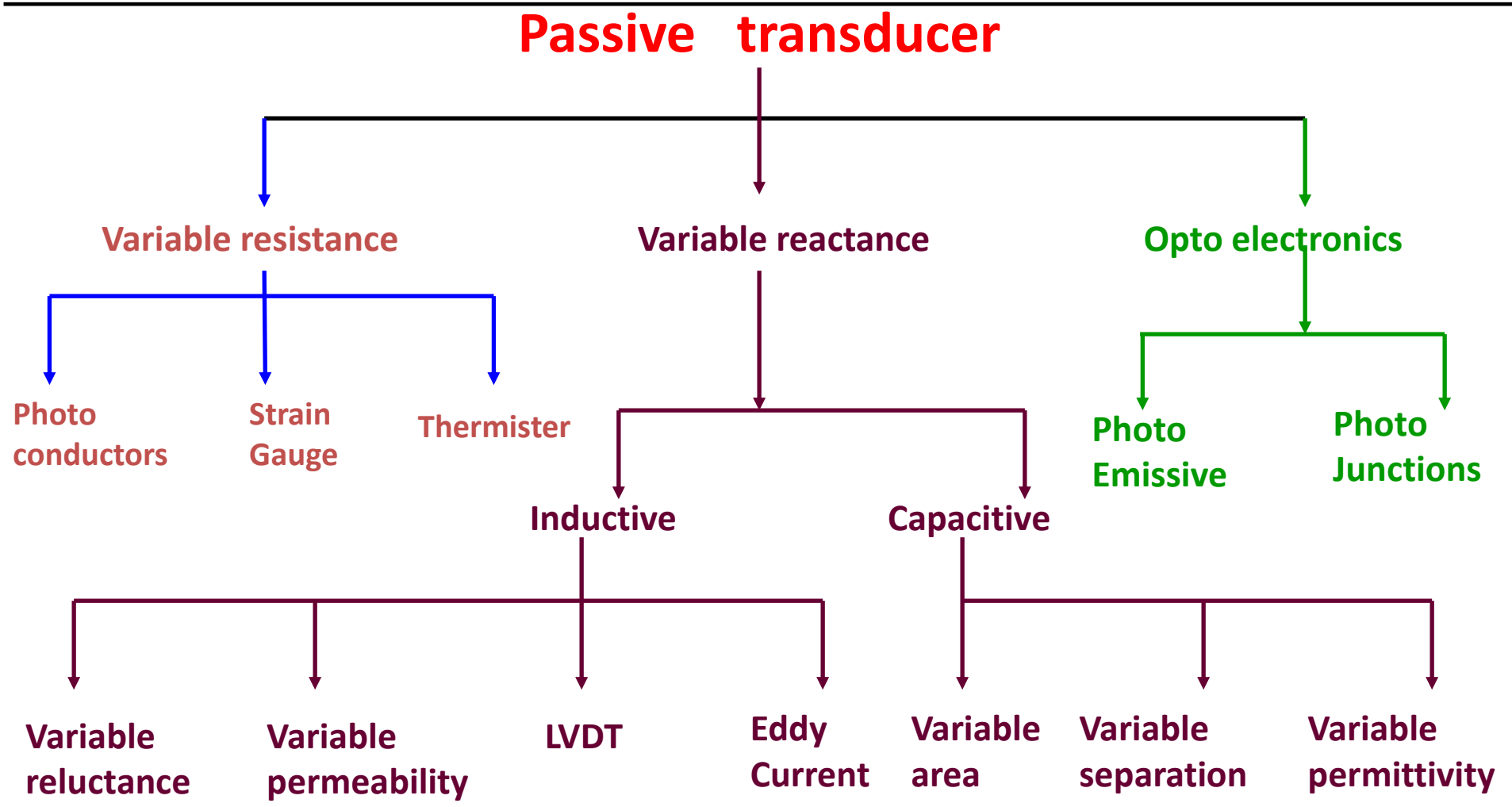

Passive transducer
Variable resistance
Variable reactance
Opto electronics


Passive transducer
Variable resistance
Variable reactance
Opto electronics
Photo conductors
Strain Gauge
Thermister


Passive transducer
Variable resistance
Variable reactance
Opto electronics
Photo conductors
Strain Gauge
Thermister
Photo Emissive
Photo Junctions

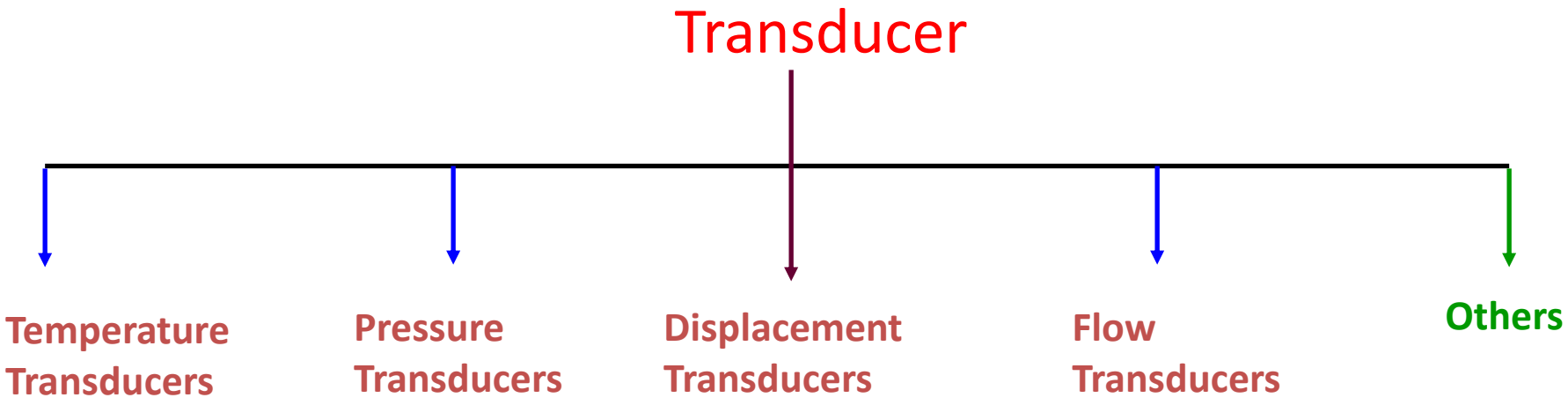

Passive transducer
Variable resistance
Variable reactance
Opto electronics
Photo conductors
Strain Gauge
Thermister
Inductive
Capacitive
Photo Emissive
Photo Junctions


Passive transducer
Variable resistance
Variable reactance
Opto electronics
Photo conductors
Strain Gauge
Thermister
Inductive
Capacitive
Photo Emissive
Photo Junctions
Variable reluctance
Variable permeability
LVDT
Eddy Current


Passive transducer
Variable resistance
Variable reactance
Opto electronics
Photo conductors
Strain Gauge
Thermister
Inductive
Capacitive
Photo Emissive
Photo Junctions
Variable reluctance
Variable permeability
LVDT
Eddy Current
Variable area
Variable separation
Variable permittivity

Parameter	Active Sensor	Passive Sensor
Definition	They produce electrical parameter such as voltage or current proportional to the physical parameter under measurement.	They produce change in the electrical parameter such as inductance, resistance or capacitance in response to the physical parameter under measurement.
Generation Capability	They are self generating type transducers.	They are not self generating type transducers.
Additional Energy Source	They do not require any external source or power for their operation	They require an external source of power for their operation.
Design	Simple	Complicated
Resolution	Low	High
Cost	Low	High
Examples	thermocouple, photocell, piezoelectric transducers.	Thermistor, LDR, LVDT, Phototransistor.

Classification based on quantity to be measured



Analog or Digital transducer

Analog Transducers:

- analog form Output ;function of time
- Examples thermocouple, LVDT, strain gauge etc.

Digital Transducers :

- digital form output ; digital pulses discrete in time.

Primary and Secondary transducer

- Some transducers contain the mechanical as well as electrical devices
- mechanical device converts the physical quantity to be measured into a mechanical signal
- Such mechanical devices are called as the primary transducers
- electrical device then converts this mechanical signal into a corresponding electrical signal
- Such electrical devices are known as the secondary transducers

Characteristics (Parameters) of a transducer

- **Ruggedness:** Ability to withstand overloads; must have high degree of ruggedness
- **Linearity :**o/p & i/p relationship should be linear
- **Repeatability :**ability to produce same o/p when i/p is applied again & again
- **Accuracy, Precision and resolution:** closeness of actual o/p produced by a transducer to ideal or true value measured

Characteristics (Parameters) of a transducer

- **High stability & reliability:** should not be affected by temperature, vibrations etc
- **Speed of response:** quick o/p ; as high as possible
- **Sensitivity :** o/p produced per unit change in i/p; should be as high as possible
- **Dynamic Range** :operating range should be as high as possible for wider applications
- **Physical size:** small size, proper shape , minimum volume

Selection of a transducer

- **Operating range:** should be as per requirement of application; should provide good resolution
- **sensitivity :**should be high ,to produce sufficient o/p for even small change in quantity to be measured
- **Frequency response :**should be flat over entire frequency range of operation
- **Environmental considerations:** fit to work in provided environment, with good reliability

Selection of a transducer

- **Usage & ruggedness:** no wear & tear over its expected life span
- **Measurand c/s:** it's the quantity to be measured, transducer selected to measure temperature should be sensitive to only changes in temperature
- **Electrical c/s:** type of excitation, type of o/p impedance , necessity of amplification
- **Mechanical c/s:** shape, size& dimensions , mounting & mechanical strength of transducer

Selection of a transducer

- **Cost& availability:** cost effective & readily available in market, no frequent repairs & maintenance
- **compatibility:** should be compatible with measuring system
- **Accuracy:** high accuracy to minimize all errors due to repeatability & calibration problems
- **Time span:** span over which transducer work reliably

MOTION SENSOR

MOTION SENSOR

- Displacement means change in the position of a body with respect to some reference point
- Displacement can be linear or rotational

L V D Ts

&

ACCELEROMETER

Linear **V**ariable **D**ifferential **T**ransformer

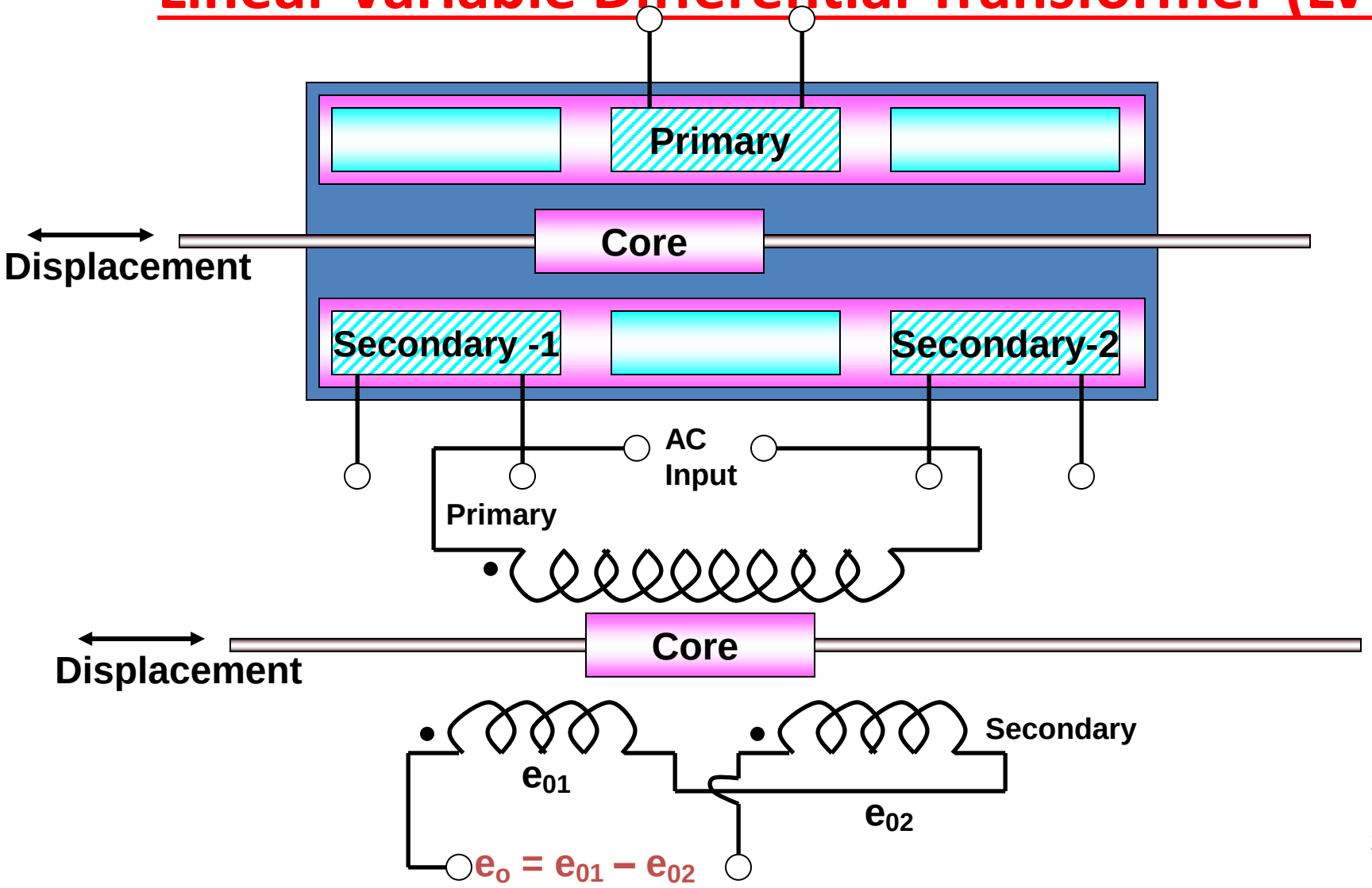
Transformer: AC Input / AC Output

Differential: Natural Null Point in Middle

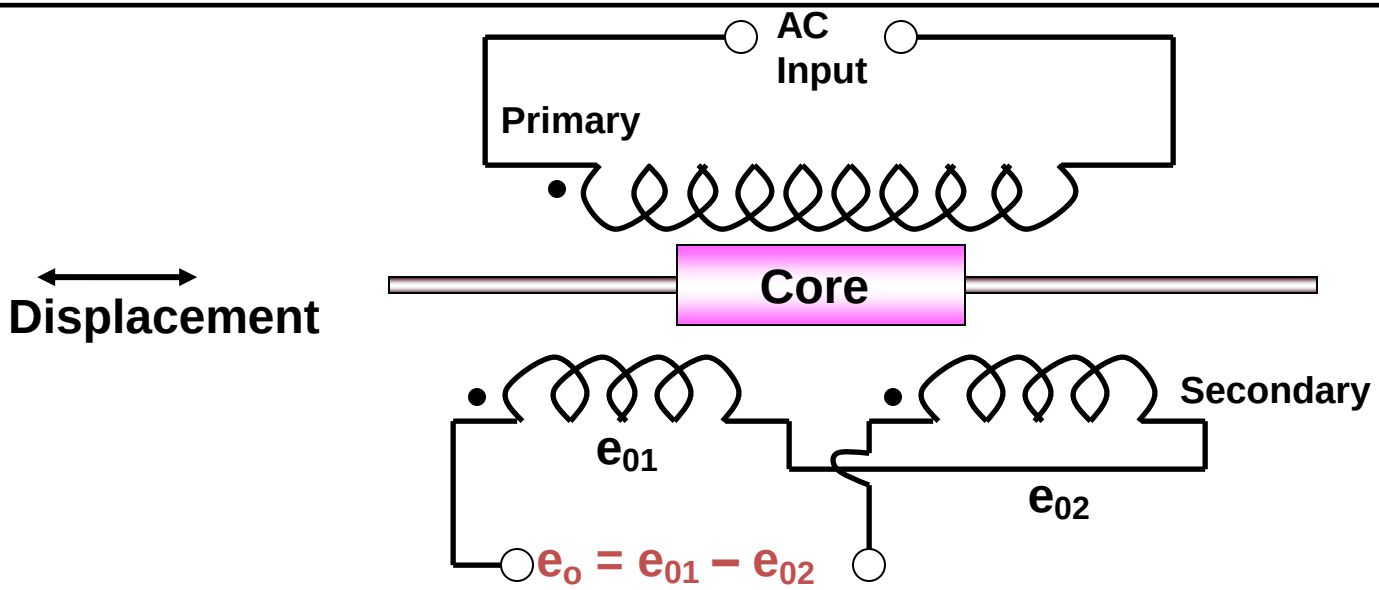
Variable: Movable Core, Fixed Coil

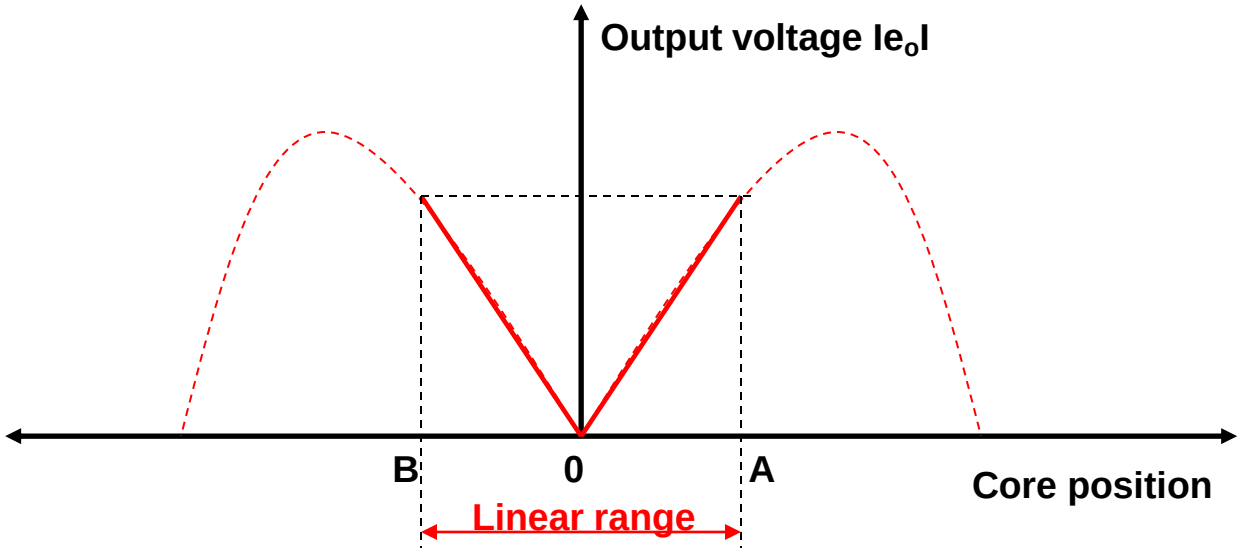
Linear: Measures Linear Position

Linear Variable Differential Transformer (LVDT)

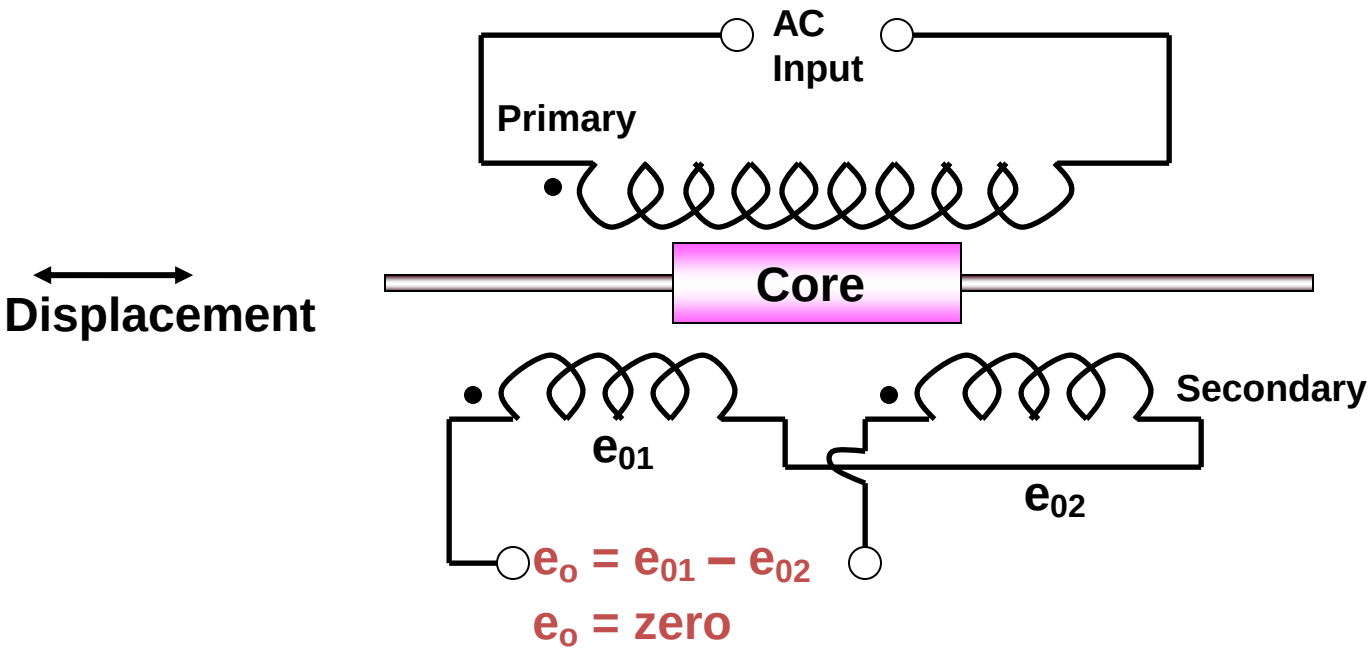


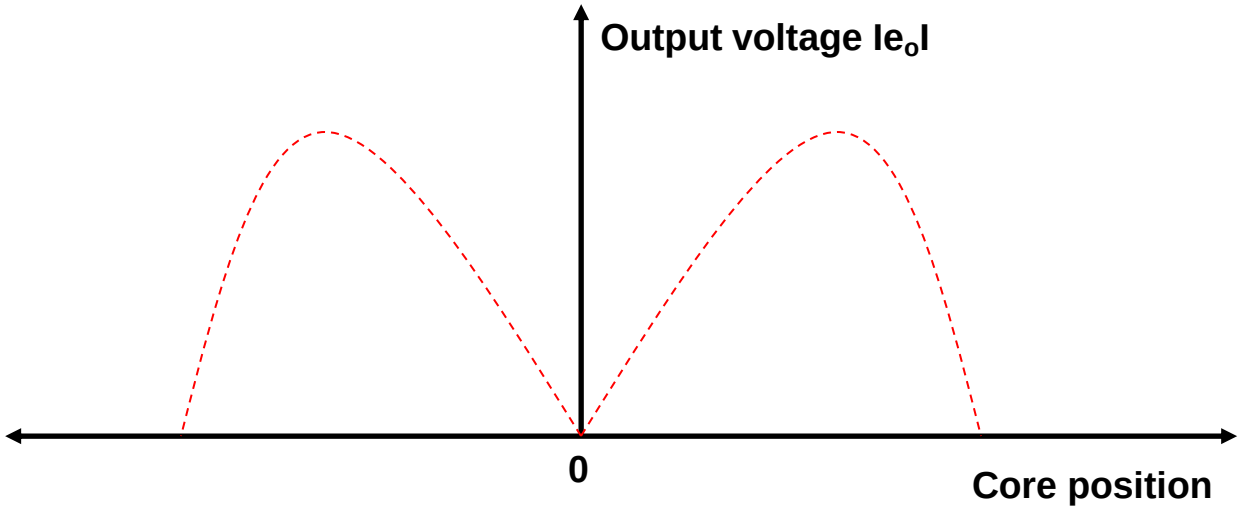
(LVDT)

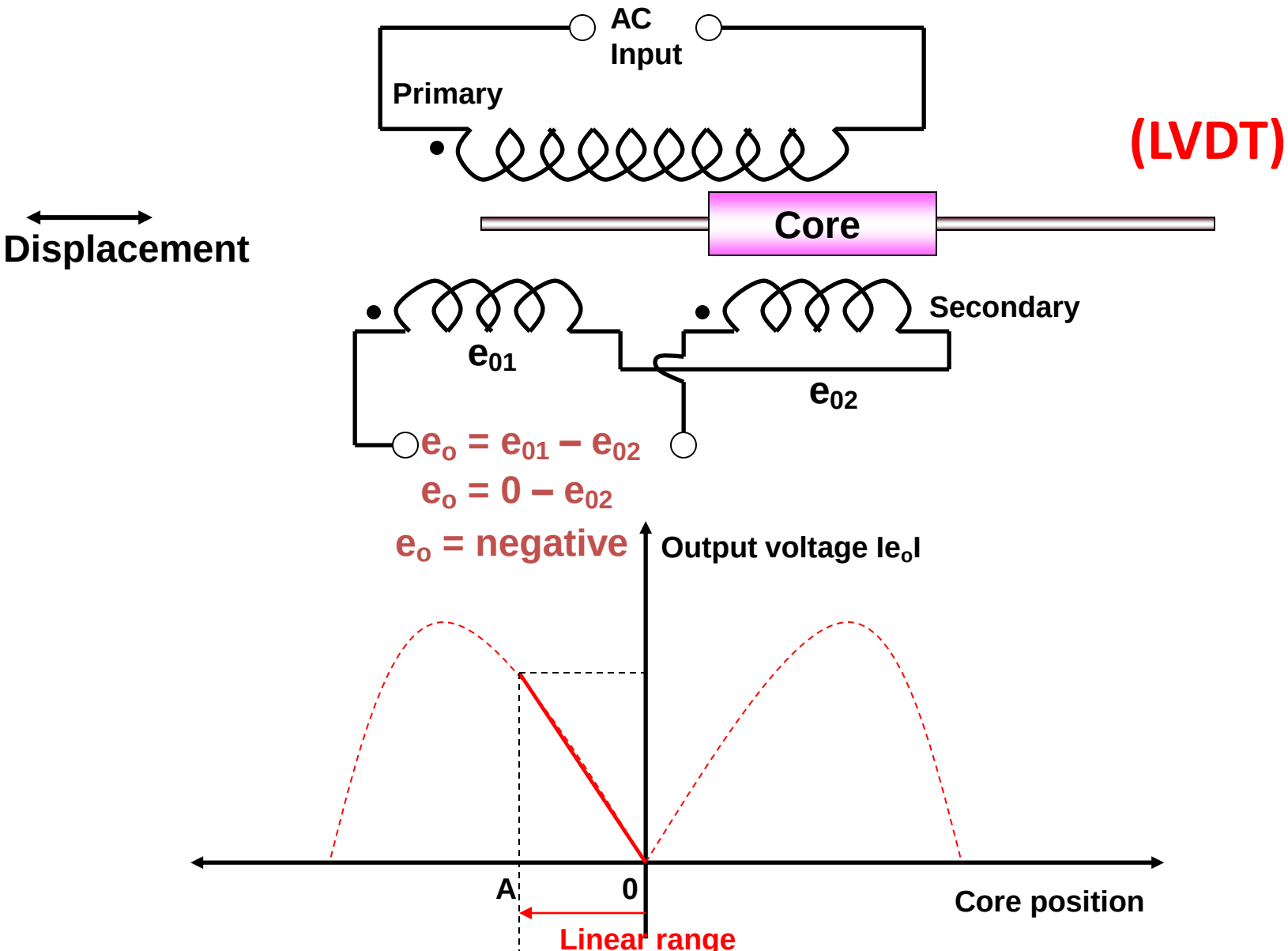

AC
Input
Primary
Displacement
Core
Secondary
e_{01}
e_{02}
$e_o = e_{01} - e_{02}$


Output voltage $|e_o|$
B
0
A
Core position
Linear range

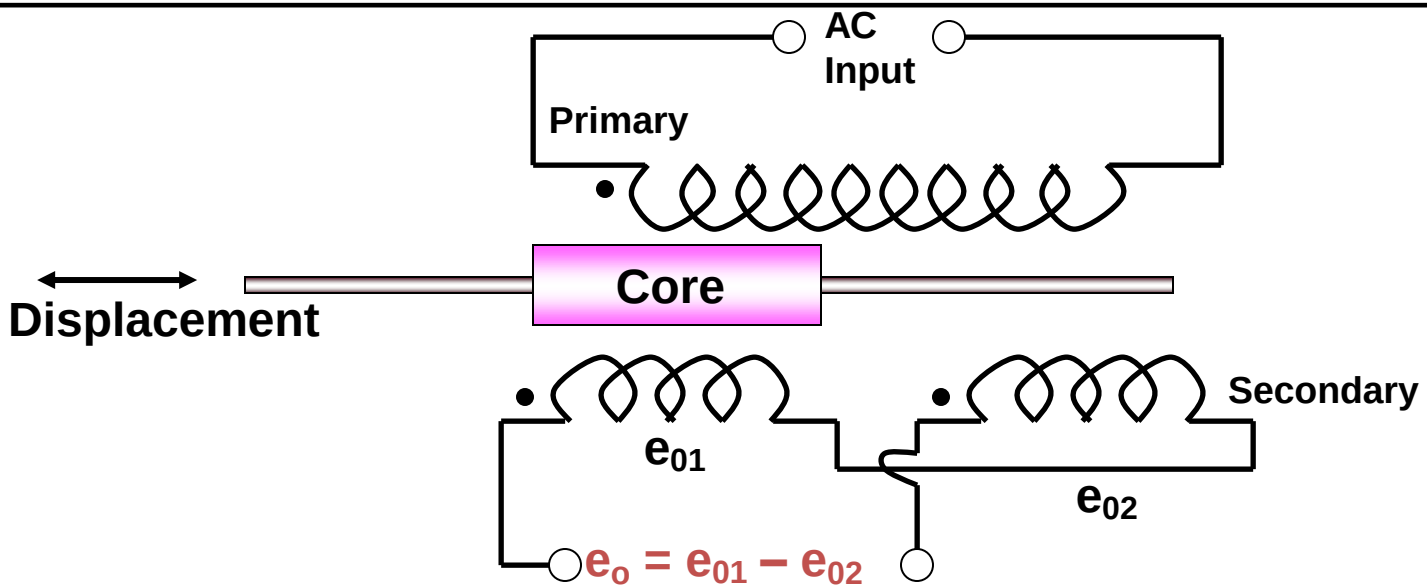
(LVDT)


AC
Input
Primary
Displacement
Core
Secondary
e_{01}
e_{02}
$e_o = e_{01} - e_{02}$
e_o = zero


Output voltage $|e_o|$
0
Core position


AC
Input
Primary
(LVDT)
Displacement
Core
Secondary
e_{01}
e_{02}
$e_o = e_{01} - e_{02}$
$e_o = 0 - e_{02}$
e_o = negative
Output voltage $|e_o|$
A
0
Core position
Linear range

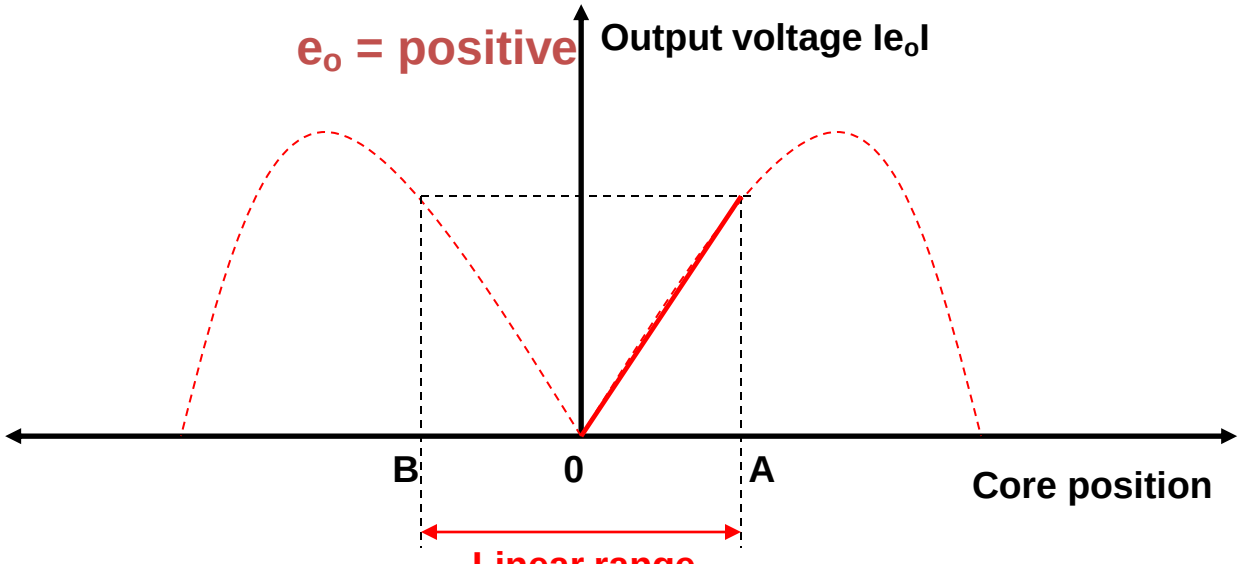
(LVDT)

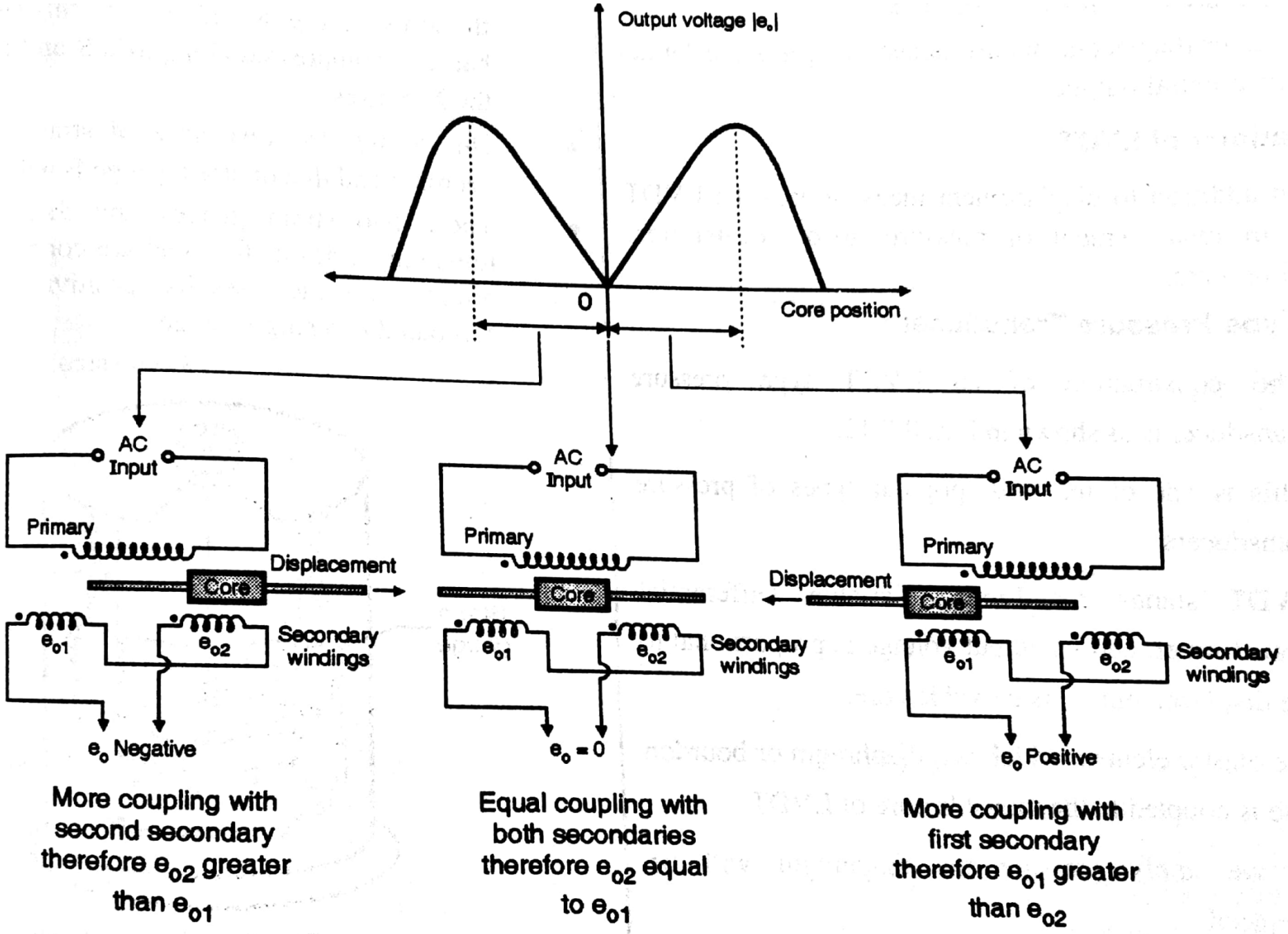


$e_o = e_{01} - e_{02}$

$e_o = e_{01} - 0$

e_o = positive





Operation of LVDT

Performance characteristics of LVDT

- Some of the important characteristics of LVDT are :

1. Null voltage
2. Resolution
3. Linearity
4. Sensitivity
5. Dynamic response

Advantages of LVDT

- Very fine resolution
- High accuracy
- Very good stability
- Linearity of transfer characteristics
- Ease of fabrication and installation
- Ability to operate at high temperature
- High sensitivity.

Advantages of LVDT

- Very fine resolution
- High accuracy
- Very good stability
- Linearity of transfer characteristics
- Ease of fabrication and installation
- Ability to operate at high temperature
- High sensitivity.

Disadvantages of LVDT

- LVDT is sensitivity to the external fields. To minimize this effect magnetic shielding is necessary
- Complicated circuitry is needed
- Larger displacements are required to get differential output

Application of LVDT

Measurement of

- Displacement
- Pressure
- Load
- Acceleration
- Force
- weight

Accelerometer

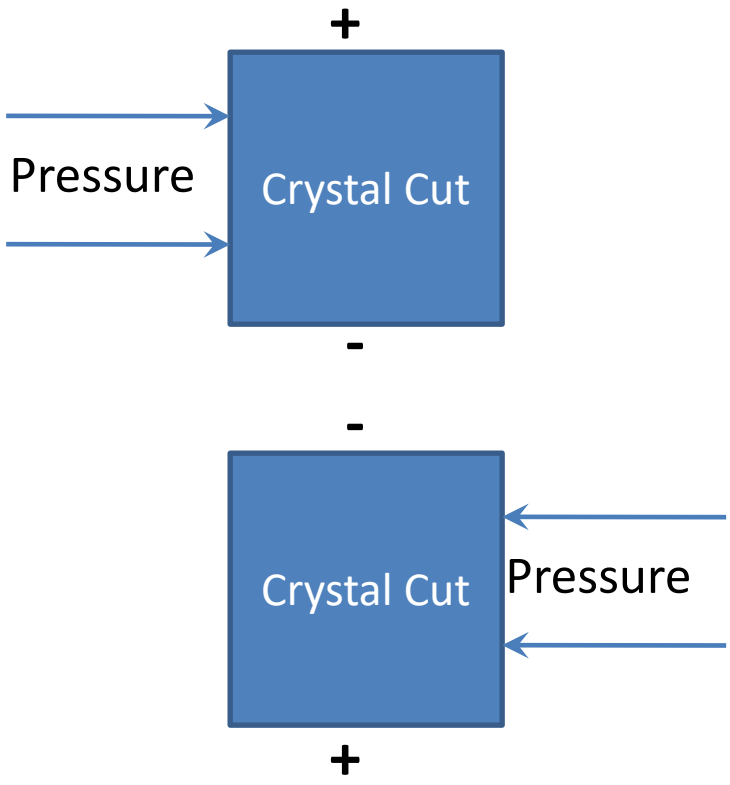
- Measures acceleration forces
- Electromechanical device
- Measures static as well as dynamic acceleration
- Static acceleration: angle of the object w.r.t earth
- Dynamic acceleration: movement of the object
- Application: Laptop, Cars

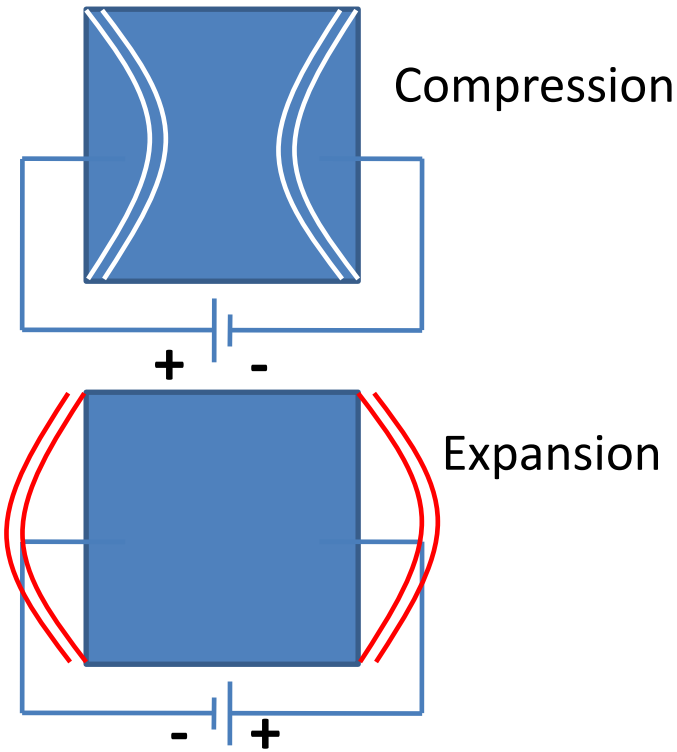
Accelerometer

- ✓ Piezoelectric Effect
- ✓ Capacitive effect

Piezo Electric Transducer

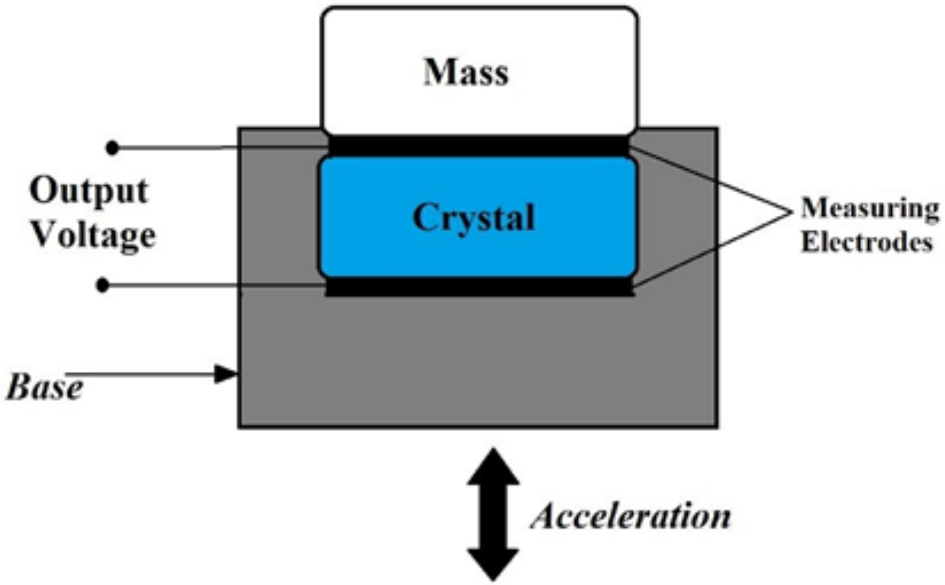
- **Basic Principle**: When piezo electric crystal is kept under pressure or mechanical stress it produces a potential difference across its opposite surfaces.





Accelerometer

Piezoelectric Accelerometer



Also called as Vibrating sensors

Accelerometer Applications

- Machine Monitoring
- Measure earthquake activity and aftershocks
- The depth of CPR Chest compression:
  Monitoring **chest compression** quality during **cardiopulmonary resuscitation**

Accelerometer Applications

- Inertial Navigation System (INS): Position, orientation and velocity of object in motion without the help of GPS
- Airbag shooting in cars
- Video games playstation for steering control
- Camcoder to make images stable

Temperature Transducer

Temperature transducers

When body is heated or cooled, various effects of heating or cooling effects include:

- Change in the physical or chemical state
- Change in the physical dimensions
- Change in the electrical properties
- Change in the intensity of total radiation emitted

1. Method based on change in resistance
2. Method based on generation of thermo emf.

Resistance type temperature sensor (RTD)

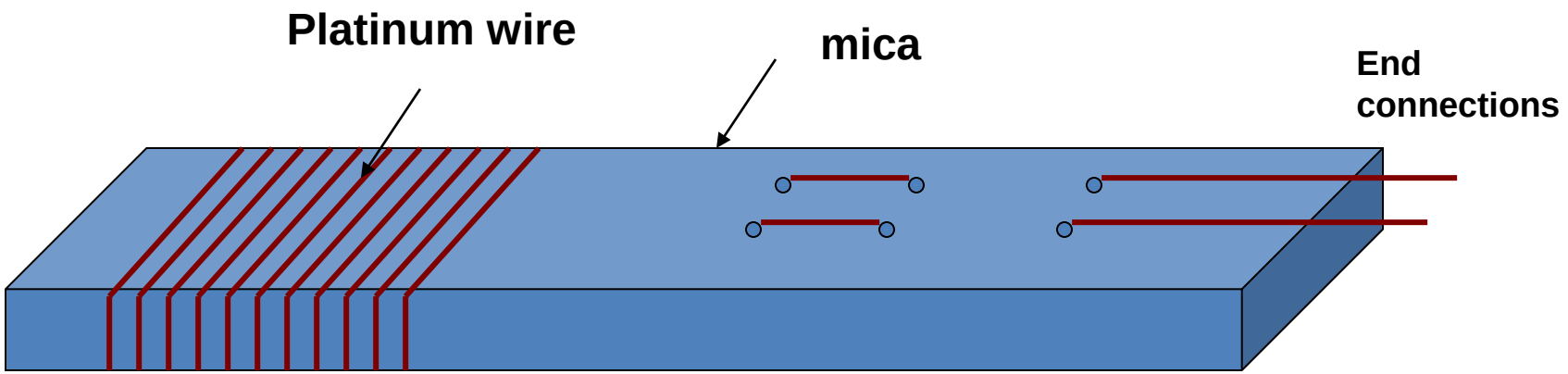
- resistance of metal increases with increase in temperature hence positive temperature coefficient
- semiconductor materials have a negative temperature coefficient i.e resistance decreases with increase in temperature.
- it is possible to convert the temperature variation into equivalent changes in resistance
- This is the principle operation of resistance type temperature sensors called as **resistance temperature detector (RTD)**

Resistance type temperature sensor (RTD)

Types of RTD

1. Platinum resistance thermometer (PRT)
2. Thermistor

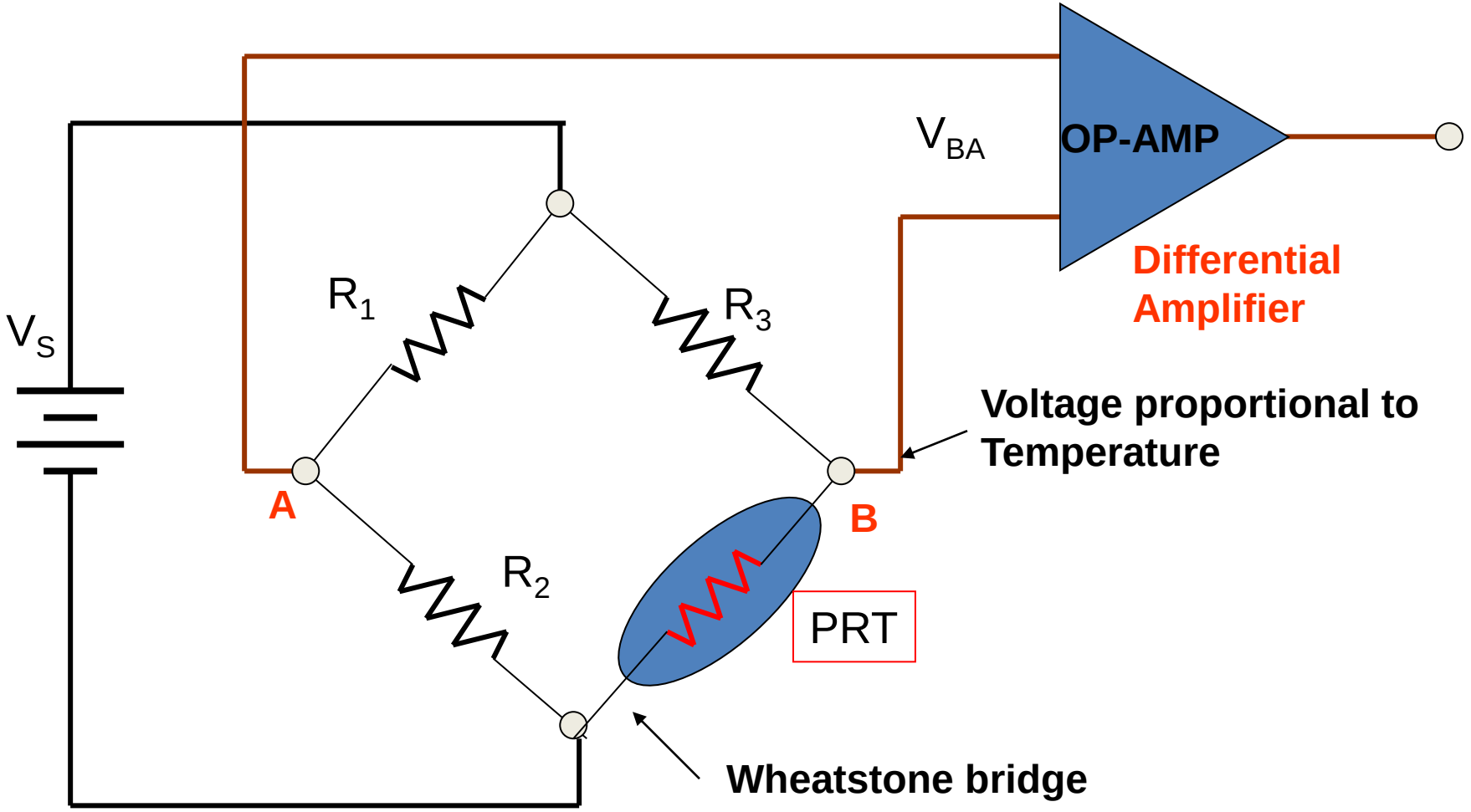
Construction of (PRT)



Operation of PRT

- Platinum wires are wound in form of spirals on insulating material like mica, ceramic
- This wire is in direct contact with gas or liquid whose temperature to be measured
- Gas or liquid should not be corrosive or conductive
- Resistance of platinum wire changes with change in temperature of gas or liquid

PRT resistance measurement



Advantages of PRT

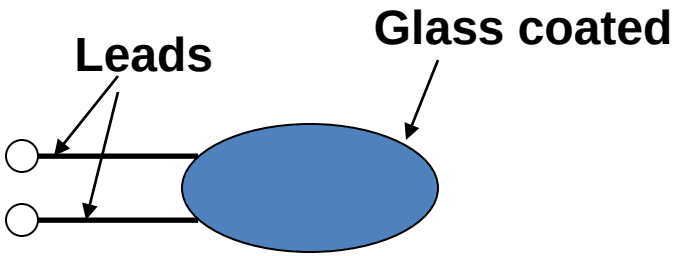
- used for measurement of small as well as large temperature difference.
- High accuracy
- High reproducibility i.e. characteristics remain unaltered
- Good dynamic response i.e. it responds very quickly to the changes in temperature
- Wide temperature range (- 200^0C to 650^0C)

Disadvantages of PRT

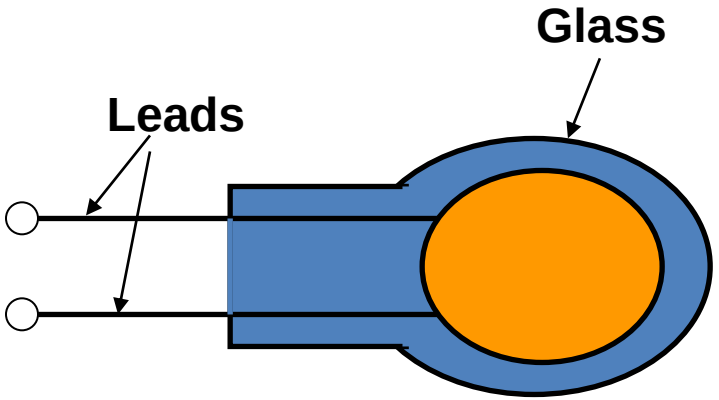
- Large size
- Sophisticated instrumentation is necessary for protection of resistance wire
- External DC power source is required
- High cost

Thermistors

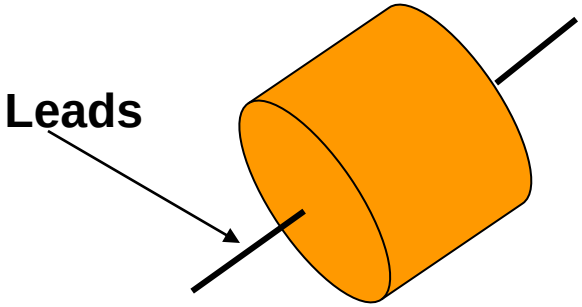
Construction of Thermistors



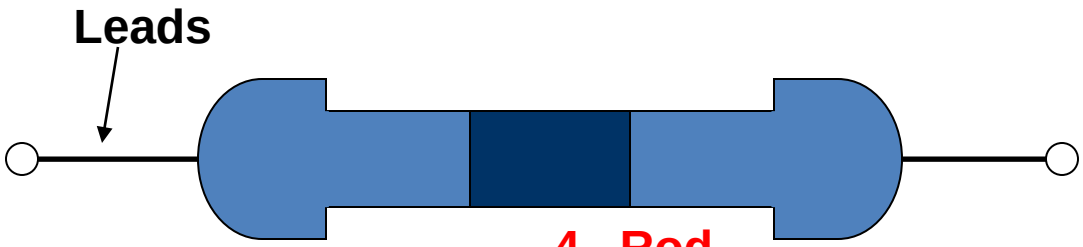
1. Bead



2. Probe



3. Disc



4. Rod

Materials used for Thermistors

- constructed by using the materials such as sintered mixtures of sulphides, selenides oxides of manganese, nickel, cobalt, iron, copper etc.

Thermistors

sensitive but highly *non-linear*

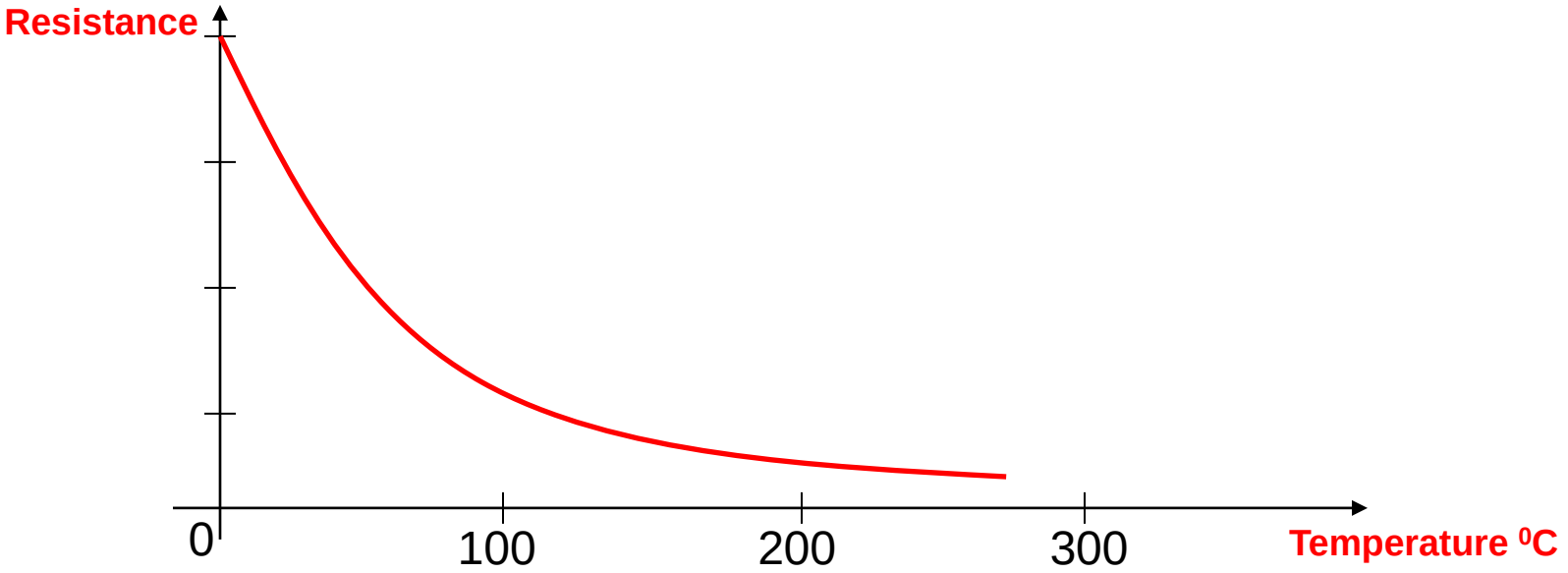
A typical disc thermistor

A threaded thermistor

Thermistors

- temperature dependent resistors (TDR)
- made of semiconductor materials which have a negative temperature coefficient of resistivity
- variation of resistance with change in temperature is nonlinear
- measure temperatures in the range of -100^0C to 300^0C
- Provides large change in resistance with small change in temperature

Thermistors



Thermistors

The resistance of a thermistor expressed as :

$$R_T = R_o \; Exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$$

R_T = Resistance at T ^{0} K

R_0 = Resistance at T_O^0 K

β = characteristics temperature

Thermistors

Advantages

-Small in size (0.5 mm in diameter)

-Large sensitivity to temperature changes

-Excellent long-term stability characteristics

Disadvantages

-Nonlinear

-Self heating

-Limited range

-need external power supply

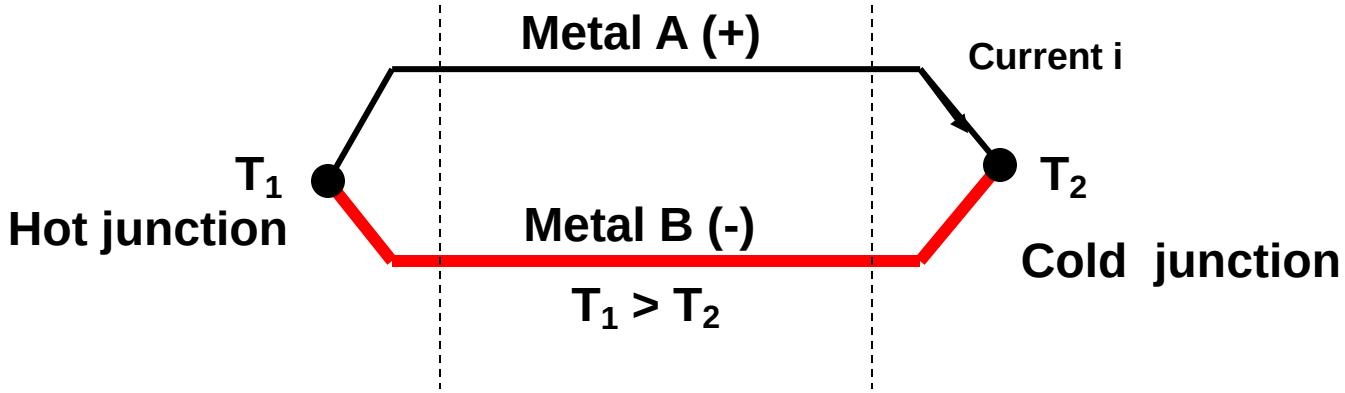
Applications of Thermistors

- As a temperature sensor with or without compensation
- In biomedical instrumentation
- In measuring the temperature distribution or temperature gradient

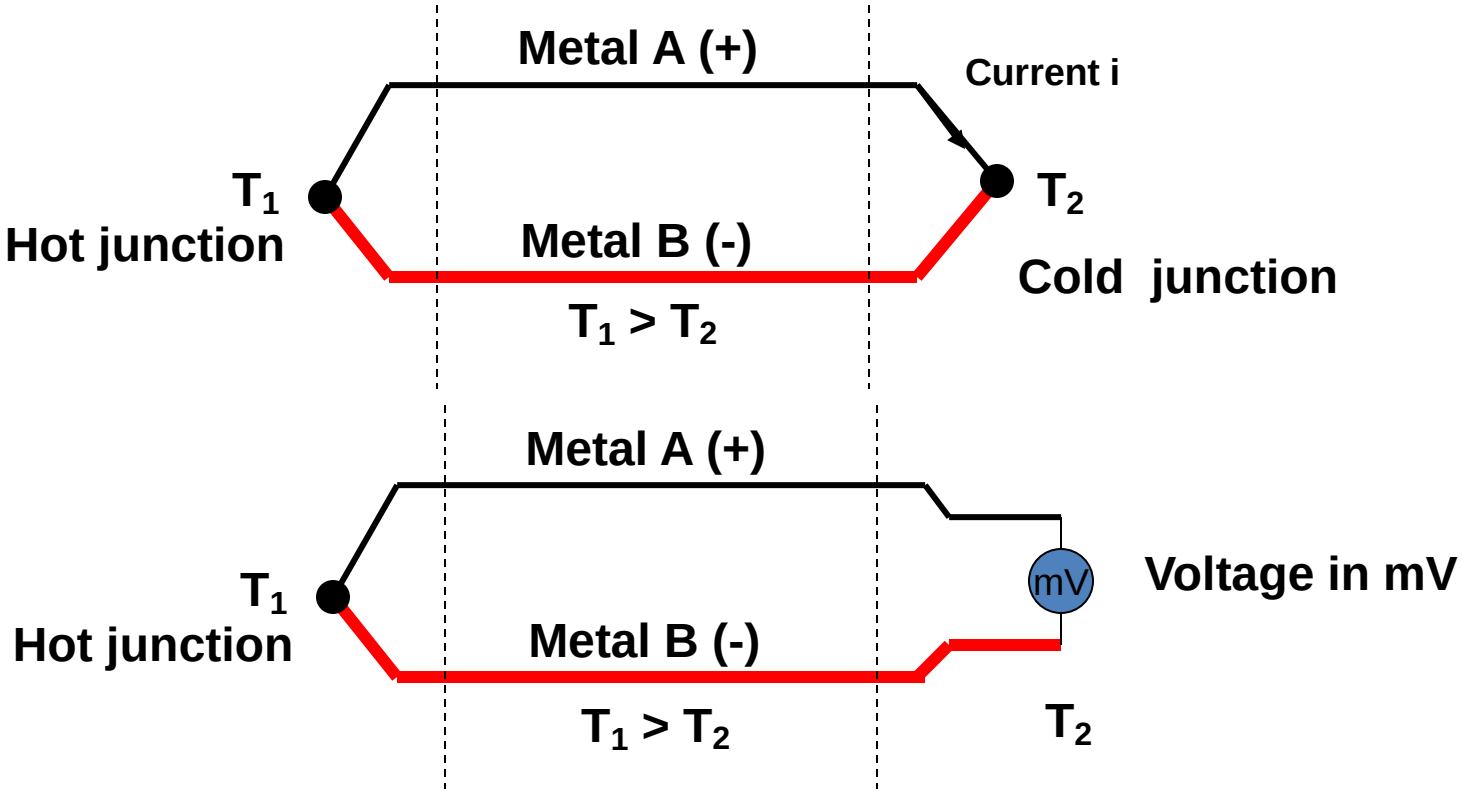
Thermocouple

Thermocouple

- operation of thermocouple is based on seeback effect
- current flows in a closed circuit made of two dissimilar metals if the junction of two metals are kept at different temperatures
- Due to this current flow, an emf proportional to the temperature difference is produced.



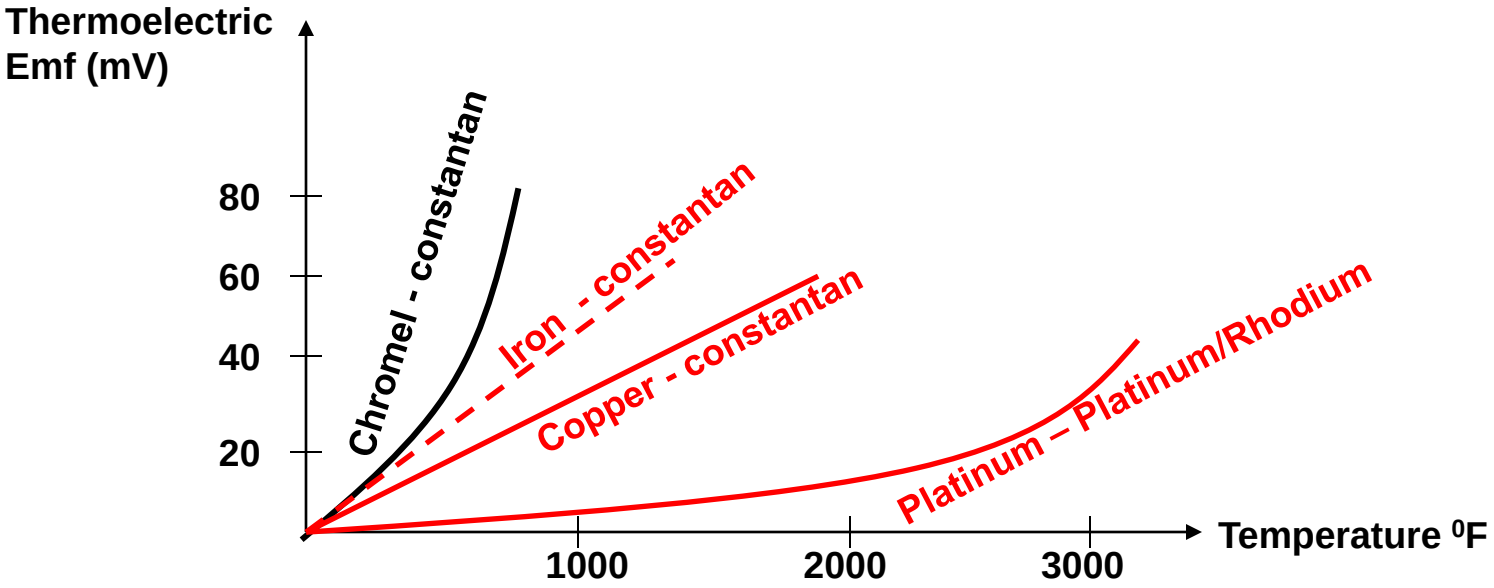
Thermocouple



Materials used for thermocouples

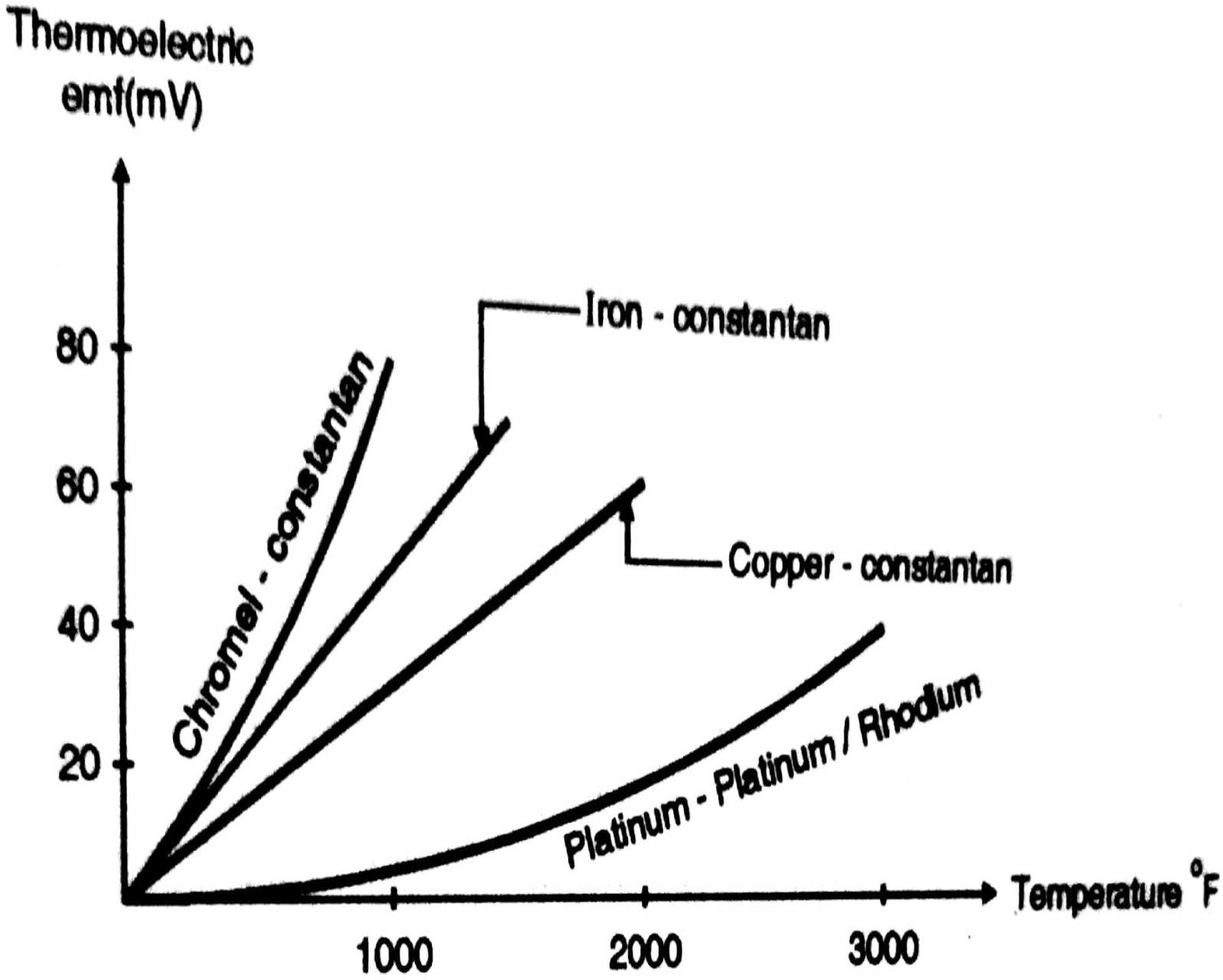
Different metals used for manufacturing:

1. Copper-constantan : $0 - 2000^0$ F
2. Iron – constantan : $0 - 1200^0$ F
3. Platinum – Platinum/ rhodium alloy : $0 - 3000^0$F
4. Chromel – Alumel alloy : $0 - 900^0$ F



Materials used for thermocouples

1. Copper-constantan : 0 – 2000^0 F
2. Iron – constantan : 0 – 1200^0 F
3. Platinum – Platinum/ rhodium alloy : 0 – 3000^0F
4. Chromel – Alumel alloy : 0 – 900^0 F


Thermoelectric emf(mV)
80
60
40
20
Chromel - constantan
Iron - constantan
Copper - constantan
Platinum - Platinum / Rhodium
Temperature °F
1000
2000
3000

Advantages of thermocouples

- Wide temperature range (-200^{0}C to 1100^0 C)
- External DC source is not required
- Good sensitivity i.e. small changes in temperature can be sensed.
- Fast dynamic response i.e. it responds quickly to any temperature changes.
- Less expensive and small in size.

Limitations of thermocouples

- temperature characteristics of thermocouple is slightly nonlinear
- Thermally generated emf is small. Hence amplification is required
- Cold junction compensation needs to be done for accurate measurement of temperature

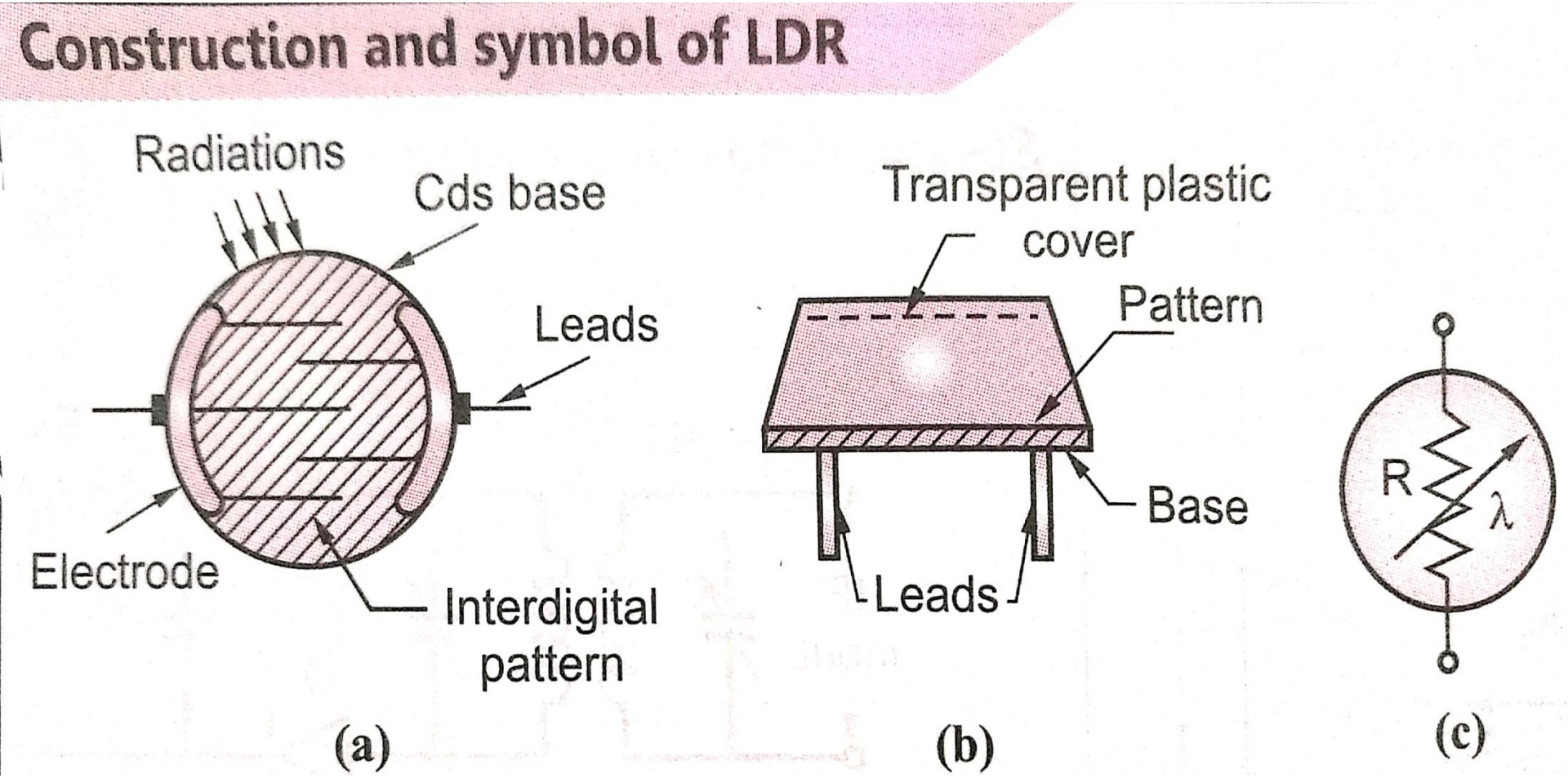
COMPARISON of TEMP. Transducers

Parameter	Thermocouple	RTD	Thremister
Principle of Operation	The temperature difference between cold and hot junction generate voltage which is proportional to the temperature difference	Resistance increases with Temperature	Resistance decreases with Temperature
Temp. Coefficient	Positive	Positive	Negative
Characteristics	Nonlinear	Linear	Nonlinear
Sensitivity	Medium	Medium	Medium
Speed of response	High	High	High over narrow temp range
Operating temp range	-270^0 C to $+2700^0$ C	-200^0 C to $+650^0$ C	-100^0 C to $+200^0$ C
Type of transducer	Active	Passive	Passive

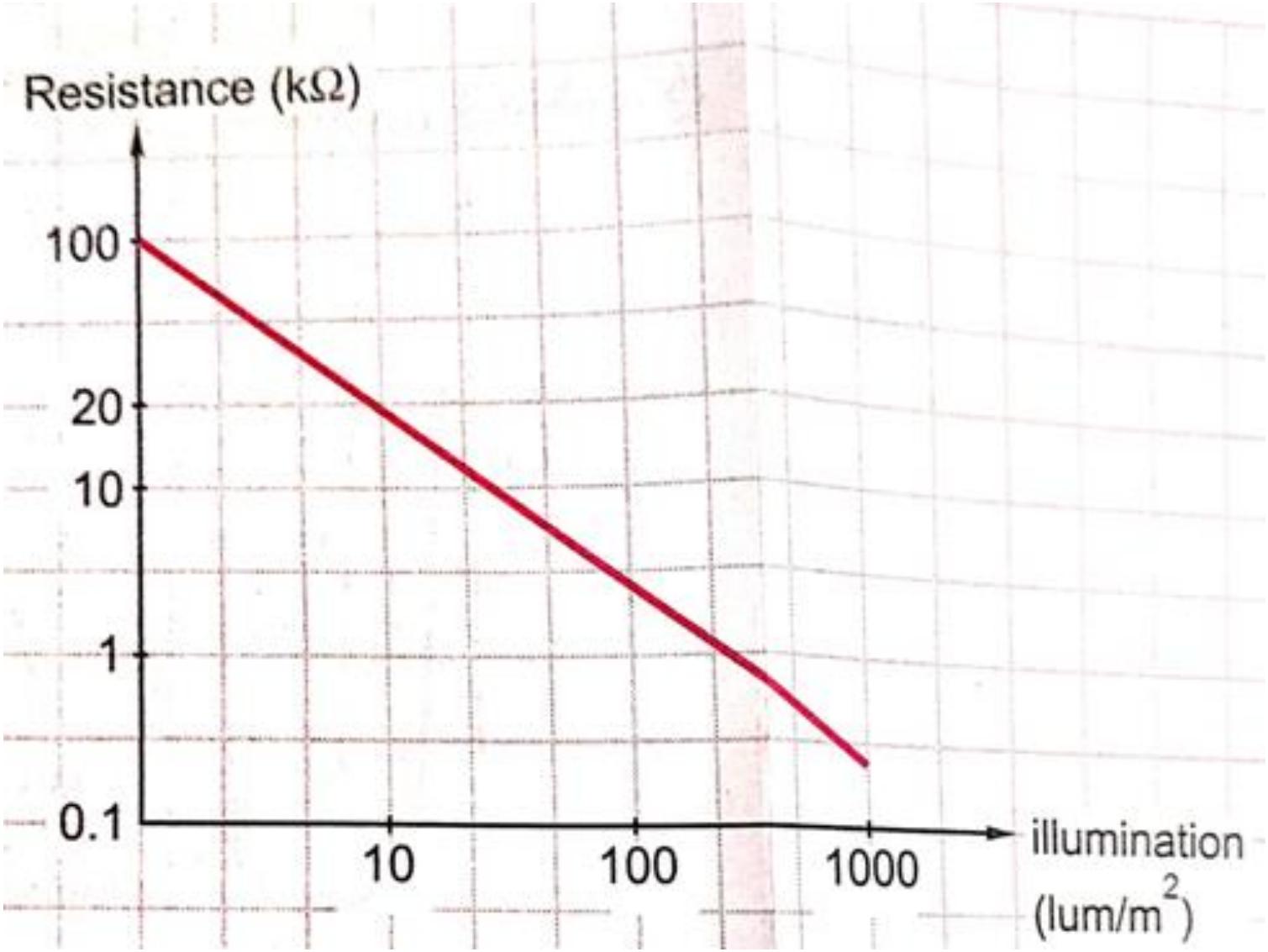
COMPARISON of TEMP. Transducers

Parameter	Thermocouple	RTD	Thremister
Accuracy	Moderate	High	Moderate
Size	Small	Large	Small
Cost	Low	High	Low
Material Used	Copper-Constantan Iron-Constantan Chromel-Alumel etc	Nickel, Platinum, Copper etc	Manganese, Nickel, Cobalt, Copper, Iron, Uranium
Compensation	Cold junction compensation is rewired	Not Required	Not Required
Applications	Suitable for applications which require wide temp range	Suitable for applications where speed of response and accuracy are more important	Suitable for applications where required temp range is small and sensitivity requirement is high

Optical Sensors (L.D.R.)



Characteristics of CdS LDR



Thermistors

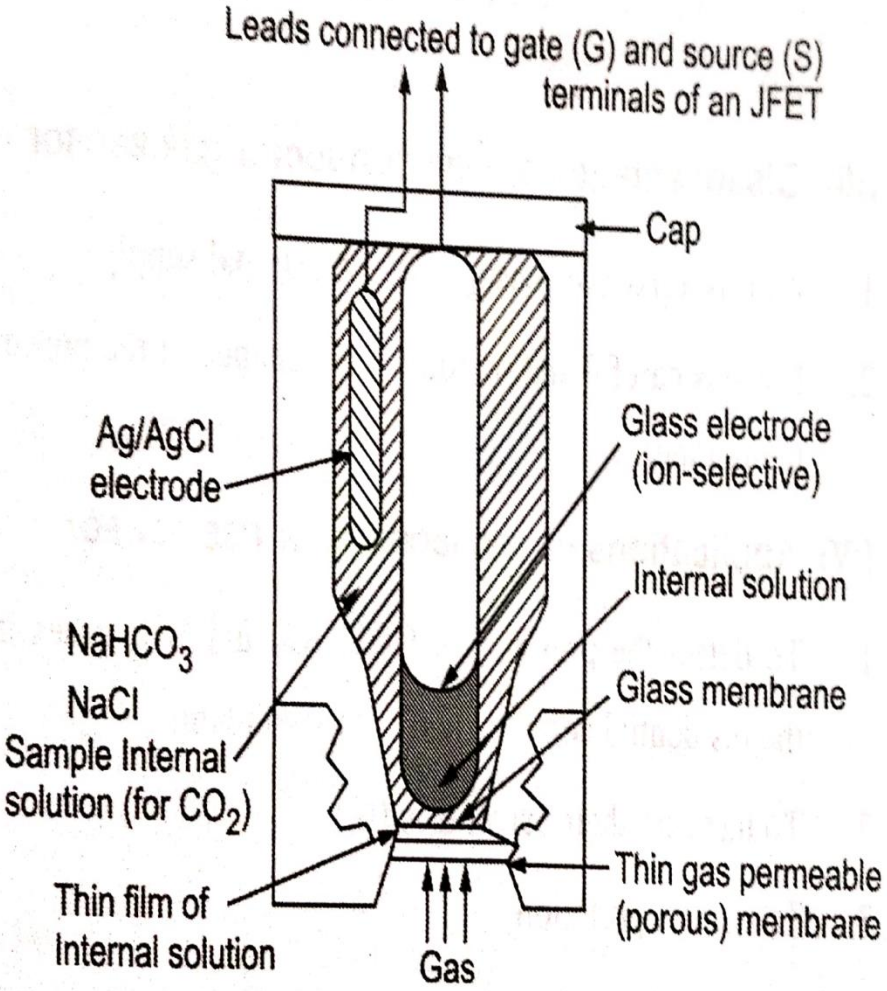
Thermal Resistor

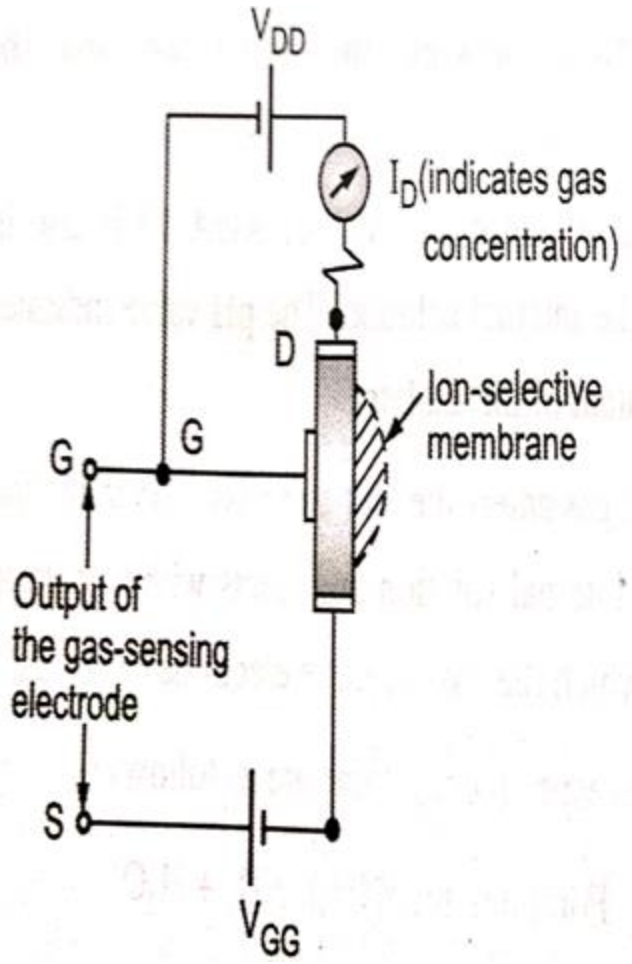
$$R \propto \exp\left(\frac{E_g}{2kT}\right)$$

Semiconductor Gas Sensor

- Used to detect combustible and toxic gases in hazardous atmosphere
- The absorption or desorption of the gas on the metal oxide changes either the conductivity or resistivity form known value.
- The electrical properties of semiconducting metal oxides have been successfully employed in gas sensing devices.

Semiconductor Gas Sensor





Gas Sensing Electrode

Ion Selective Semiconductor

Semiconductor Gas Sensor

- Sensors will have two, three or sometimes four electrodes.
- The electrodes are placed in contact with an electrolyte that is made from mineral acids or in some cases, organic substitute.
- The electrodes are very sensitive and give out electric current which is fed to the warning circuitry.

Semiconductor Gas Sensor

- The gas enters into the sensor through a membrane or thin film and reaches the electrode.
- Here it is either oxidized or reduced depending on the property of the gas.
- This electrochemical process results in an electric current that further goes to the external circuitry responsible for alarming.

Mechanical Transducer

- Flow measurement or rate of flow of measurement
- Flow velocity can be measured by inductive transducer
- But if it contains suspended solids such as sewage it has problems
- Measure flow of any material which is electrically conductive
- 2 saddle coils are placed opposite to each other
- When we energise this coil they produce magnetic field

Mechanical Transducer

- **Strain gauge**
  - * **Resistance wire Strain gauge**
    - * **Unbonded Resistance Wire Strain gauge**
    - * **Bonded Resistance Wire Strain gauge**
- **Load Cell**
- **Pressure Transducer**

Mechanical Transducer
Strain Gauge

- Stress: Measurement of how much internal pressure a material is under when a force acts on it
- Strain: It is what happens as a result of stress.

- Strain Gauge is a sensor whose resistance changes with applied force, Pressure, tension, weight etc

Mechanical Transducer
Strain Gauge

- Principle of Operation:
- Length of a wire increases on application force
- $R = \rho l/A$
- If l = Length of wire changes, resistance of wire changes
- This change in the resistance is measure and calibrated to give force reading
- Strain gauge factor =ratio of relative change in electrical resistance R to mechanical strain ε

Mechanical Transducer
Strain Gauge

Semiconductor strain gauge

Advantages:

- These gauges have high gauge factor and hence they can measure very small strains.
- Gauge factor (GF) or strain factor of a strain gauge is the ratio of relative change in electrical resistance R, to the mechanical strain ε.
- Very small size and long life
- Excellent frequency response

Mechanical Transducer
Strain Gauge

Semiconductor strain gauge

Disadvantages:

- These gauges are brittle and hence they cannot be used for measuring large strain.
- The gauge factor is not constant.
- These gauges have poor linearity.
- These gauges are very costly and are difficult to be bonded onto the structure under study.
- These gauges are sensitive to change in temperature.
- Expensive

Pressure Transducer

- force acting per unit area, at a given point or over a surface

classification

I. Gravitational pressure transducer

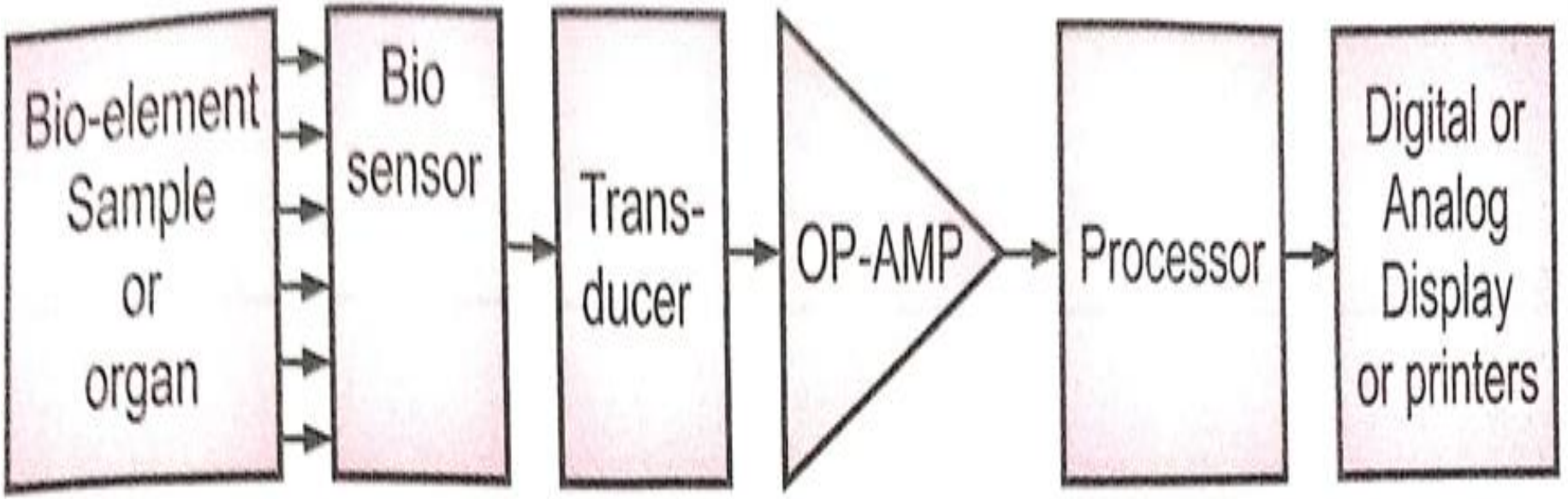
II. Elastic type pressure transducers

- Example of elastic transducers : Diaphragm, Capsule, Bellows or Bourdon Tubes
- convert the pressure into displacement or strain
- Then displacement or strain is measured with an appropriate electrical sensor

Pressure Transducer

- Diaphragm
- Capsule
- Bellows
- Bourdon Tube

Biosensor


Bio-element
Sample
or
organ
Bio
sensor
Trans-
ducer
OP-AMP
Processor
Digital or
Analog
Display
or printers

END OF UNIT 5