Transducers

Course Title: Electrical Drives and Instrumentation
Course No.: EEE 2421

Reference

A Course in Electrical & Electronics Measurement & Instrumentation

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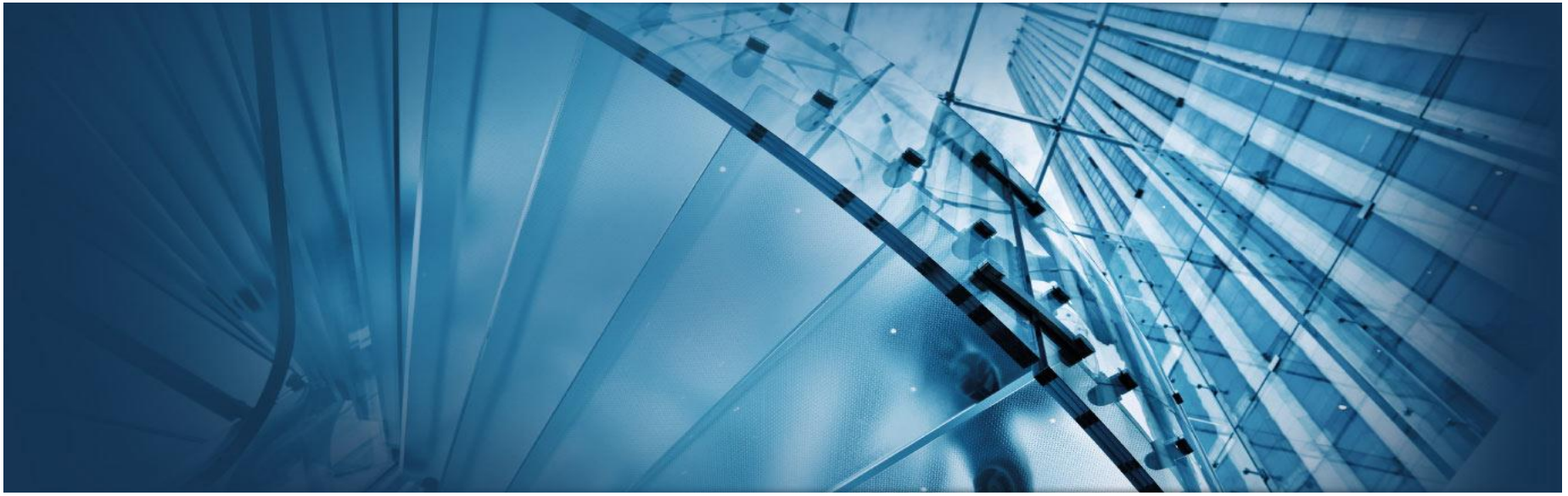
Chapter 25

BASIC DEFINITIONS

- **Instrumentation** is a technology of measurement and control of process variables which serves sciences, engineering etc.
- **Measurement** is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.
- **Instrument** is a device for determining the value or magnitude of a quantity or variable.

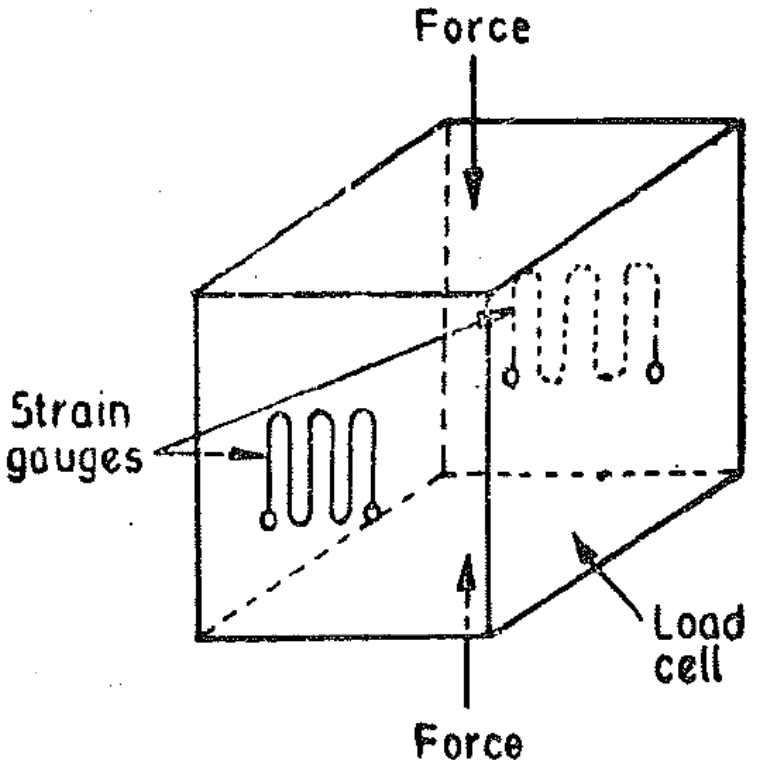


Transducers

- The input quantity for most instrumentation systems is a **non-electrical quantity.**
- In order to use electrical methods and techniques for measurement, manipulation or control, the **non-electrical quantity** is generally **converted into** an **electrical form** by a device called a "**transducers**".
- Transducer a device which convert one form of energy to another form.

Transducer Stage

1. Detector or Primary Transducer
2. Secondary Transducer



Electrical Transducers

- In order to measure non-electrical quantities a detector is used which usually converts the physical quantity into a displacement. This displacements actuates an electrical transducer, which acting as a secondary transducer, gives an output that is electrical in nature.
- The electrical quantity so produced is measured by standards methods used for electrical measurements.
- The result (electrical output) gives the magnitude of the physical quantity or condition being measured.

Advantages of Electrical Transducers

The reason for transforming a physical phenomenon into electrical form are numerous. The advantages of converting physical quantities into analogous electrical quantities are:

- Electrical **amplification** and **attenuation** can be done easily.
- The **mass-inertia effects** are minimized.
- The effects of **friction** are minimized.
- The electrical or electronic systems can be controlled with a **very small power level.**
- The electrical output can be easily used, transmitted and processed for the **purpose of measurement**.
- **Telemetry** (remote indication or recording e.g. aerospace) is used in almost all sophisticated measurement systems.
- **Miniaturization** on account of use of IC's (integrated circuit).

Electrical Transducer Types

- Primary Transducer
- Secondary Transducer

- Active Transducer
- Passive Transducer

- Analogue Transducer
- Digital Transducer

Resistance Thermometers

- The resistance of a conductor changes when its temperature is changed. This property is utilized for **measurement of temperature.**

- The variation of resistance R with temperature T (^{o}k) can be represented by the following relationship for most of the metals as:

$$R=R_0(1+\alpha_1 T+ \alpha_2 T^2+...+ \alpha_n T^n+.....)$$

Where, R_0=resistance at temperature T=0

and α_1, α_2, α_n are constants (resistance temperature co-efficient).

- Platinum is especially suited for this purpose, as it can withstand high temperatures while maintaining excellent stability.

Resistance Thermometers…

The requirements of a conductor material to be used in **RTDs (Resistance Temperature Detector)** are:

1. The change in resistance of material per unit change in temperature should be as large as possible.
2. The material should have a high value of resistivity so that minimum volume of material is used for the construction of RTD.
3. The resistance of material should have a continuous and stable relationship with temperature.

Resistance Thermometers…

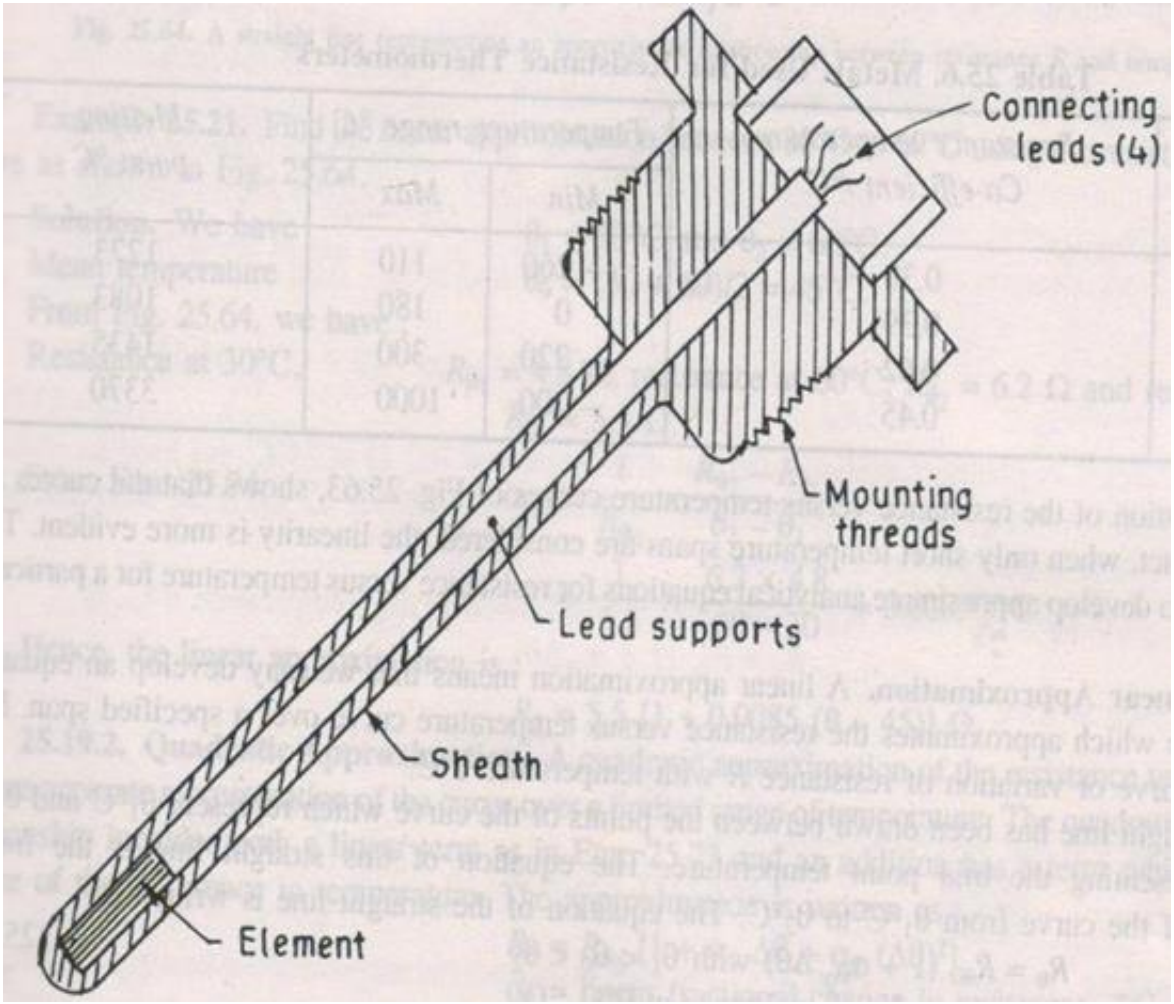


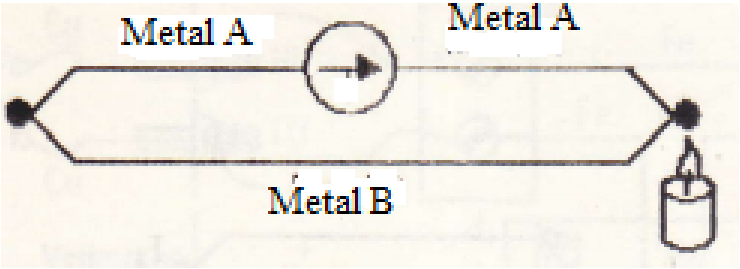
Fig. Industrial Platinum resistance thermometer

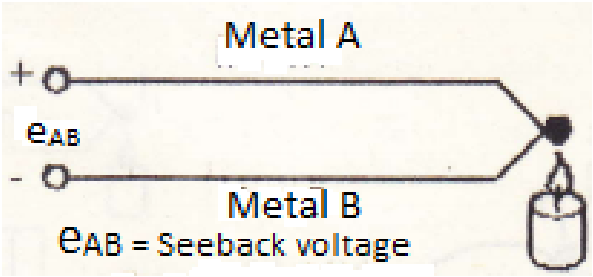
Thermocouples

- When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the thermoelectric circuit. Thomas Seeback made this discovery (hence, the name Seeback Effect) in 1821 (Fig. 1).
- If this circuit is broken at the center, the net open circuit voltage (the Seeback voltage) is a function of the junction temperature and the composition of the two metals (Fig.2). All dissimilar metals exhibit this effect. For small changes in temperature the Seeback voltage is linearly proportional to temperature:

$$e_{AB} = \alpha T$$

- Where, α the Seeback co-efficient, is the constant of proportionality. (For real world thermocouples, α is not constant but varies with temperature)
- Examples: Copper-Constantan thermocouple, Iron-Constantan thermocouple etc.





Advantages and Disadvantages of Thermocouples

Advantages:

- Thermocouples are cheaper than the resistance thermometers.
- Thermocouples follow the temperature changes with a small time lag and are suitable for recording rapid changes in temperature.
- Thermocouples are very convenient for measuring the temperature at one particular point in a piece of apparatus.

Disadvantages:

- They have a lower accuracy and hence cannot be used for precision work.
- To ensure long life of thermocouples, they should be protected in an open or closed-end metal protecting tube or well.
- The circuitry is very complex.

Comparison of Thermocouples, RTDs, and Thermistors

	RTD	Thermocouple	Thermistor
Temp. range	-260 to 850°C (-436 to 1562°F)	-270 to 1800°C (-454 to 3272°F)	-80 to 150°C (-112 to 302°F) (typical)
Sensor cost	Moderate	Low	Low
System cost	Moderate	High	Moderate
Stability	Best	Low	Moderate
Sensitivity	Moderate	Low	Best
Linearity	Best	Moderate	Poor
Specify for:	• General purpose sensing • Highest accuracy • Temperature averaging	• Highest temperatures	• Best sensitivity • Narrow ranges (e.g. medical) • Point sensing

Integrated circuit Temperature Transducers

- Each of the three temperature transducers i.e. RTD, Thermistors and Thermocouples have some significant limitations. For each of these transducers, electronic compensation circuits have to be used in order to overcome their shortcomings. Also, additional circuitry may be needed to increase their voltage or current outputs. Thus, it requires to combine the temperature sensing element with signal conditioning electronics to produce single monolithic integrated circuit package.
- Three integrated circuit (IC) package are:
  - LM 335 – it provides an output of 10 mV/ ^{0}k
  - LM 34 – it provides an output of 10 mV/ ^{0}F
  - AD 592 – it provides a current output of 1 μA/ ^{0}k

Piezo-electric Transducers

- A **piezo-electric material** is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges.
- The effect is reversible, i.e. conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is know as **piezo-electric effect**.
- Elements exhibiting piezo-electric qualities are called as **electro-resistive elements.**

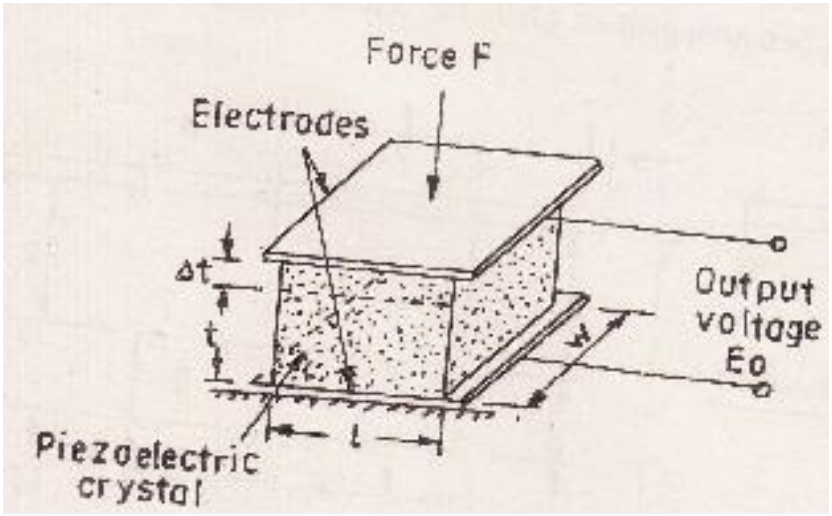


Fig. Piezo-electric crystal

Piezo-electric Transducers…

- Common piezo-electric materials include Rochelle salts, ammonium dihydrogen phosphate, lithium sulphate, dipotassium tartarate, potassium dihydrogen phosphate, quartz and ceramics A and B.
- The piezo-electric effect can be made to respond to mechanical deformations of the material in many different modes.
- The modes can be: thickness expansion, transverse expansion, thickness shear and face shear.
- The mode of motion effected depends on the shape of the body relative to the crystal axis and location of the electrodes.
- A piezo-electric element used for converting mechanical motion to electrical signals may be thought as **charge generator and a capacitor**.
- Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes. The voltage is E = Q/C.

Uses of Piezo-electric Transducers

- The piezo-electric material are stable, high output, insensitivity to temperature variations, insensitivity to variations in humidity.
- The piezo-electric elements is confined primarily to **dynamic measurements.**
- **Ultrasonic generator elements** use piezo-electric material. Such elements are used in industrial cleansing apparatus and also in underwater detection system know as sonar.

Opto-Electronic Transducers

- The opto-electronic transducers include

1. Photo voltaic cell
2. Photo-diode
3. Photo-transistors
4. Etc.

Photovoltaic cell

- The photovoltaic cell/ PV cell or Solar cell, produces an electrical current when connected to a load. They are called photovoltaic cells because of their voltage generating characteristics. They convert EM energy into electrical energy. They are passive transducers i.e. they do not need an external source to power them.
- The cell is a diode, constructing a PN junction between doped semiconductors. Photons striking the cell pass through the thin P-doped upper layer and are absorbed by electrons in the lower N layer, causing formation of conduction electrons

and holes. The depletion region of PN junction then separates these conduction holes and electrons causing a difference of potential to develop across the junction.

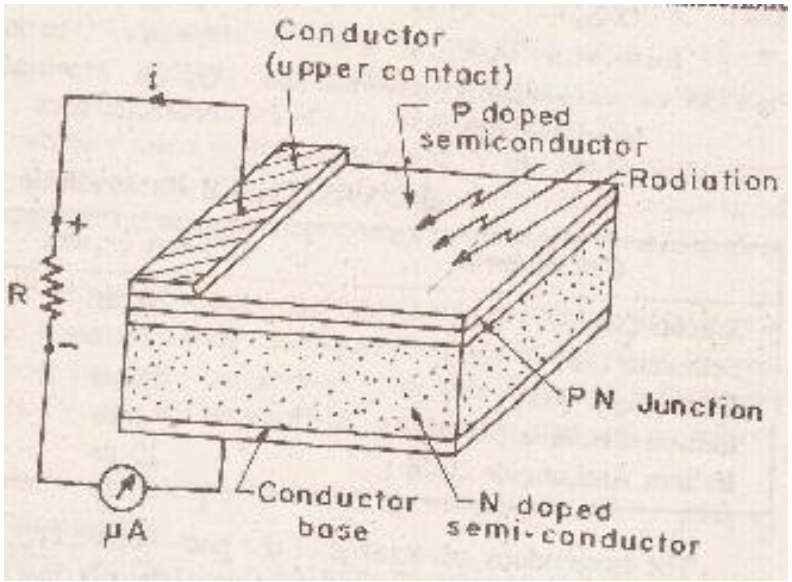


Fig. Photovoltaic cell

Photovoltaic cell…

- The open circuit voltage is given by:

$$E_0 = E_c \log_e (E_e)$$

- Where, E_c = calibration voltage; V, E_e = radiant incidence; W/m^2

- The **advantages of Photovoltaic** cells are-
  I. They can **generate voltage without any form of bias**
  II. It has extremely **fast response**
  III. They can operate at a temperature range of **-100 to 125 C**.

- Photovoltaic cells are **used** in-
  I. **Photographic exposure meters**
  II. **Space crafts** to supply electric energy

Photo-diode

- The photo-diode incorporates with a P and N type layer. The photo-diode is reverse biased. The reverse biased saturation current is dependent upon the intensity of the incident light. A reverse biased semiconductor diode passes only a small leakage current (around 1μA in Si) if the junction is not exposed to light. Under illumination, the current rises almost in direct proportion to the light intensity.

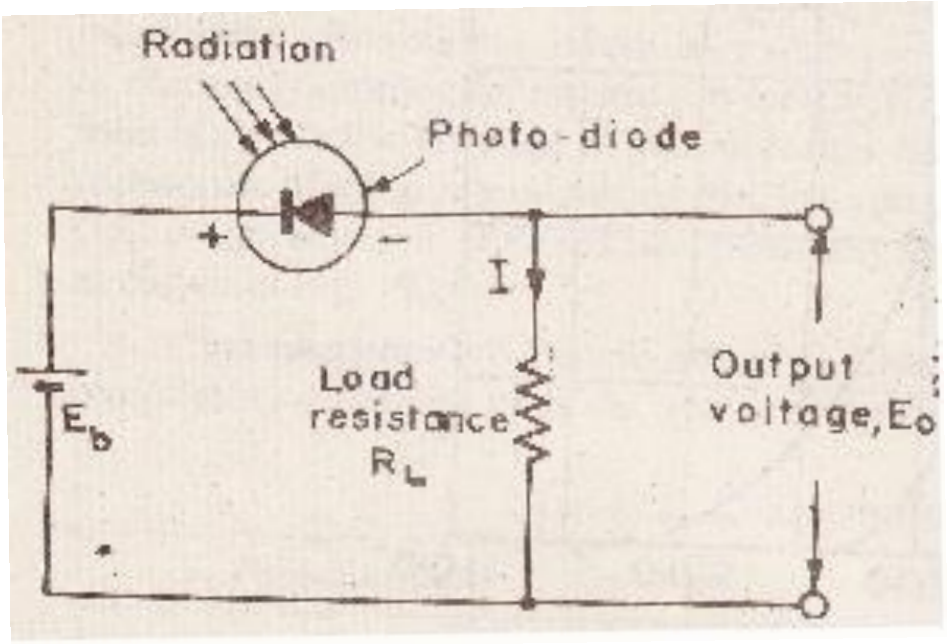


Fig. photo-diode circuit

Photo-diode…

- **Advantages**
  - It has **faster response time**
  - It has **better frequency response**
  - **Linear in characteristics**
  - **Better spectral response**
  - **Lower noise**
- **Disadvantages**
  - **Small active area**
  - Rapid **increase in dark current** with temperature
  - **Bias voltage** requirement
  - The **necessity of amplification** at illumination levels
- **Applications**
  - Used in **Cine film sound track readers**
  - Used as detectors of modulated light in **optical communication systems**
  - Used in **switching circuits**

Photo-transistors

- A photo-transistor is a normal transistor in which the envelope enclosing the junction is transparent to allow light to fall on the base-emitter junction. At any PN junction hole-electron pairs are generated when light falls on the junction, so that any light falling on the base-emitter junction, produces a current which is amplified by transistor action, making the device very sensitive.
- Illumination of the central region causes the release of electron hole pairs. This lowers the barrier potential across both junctions, causing an increase in the flow of electrons from left

hand region into the central region

and on to the right hand region.

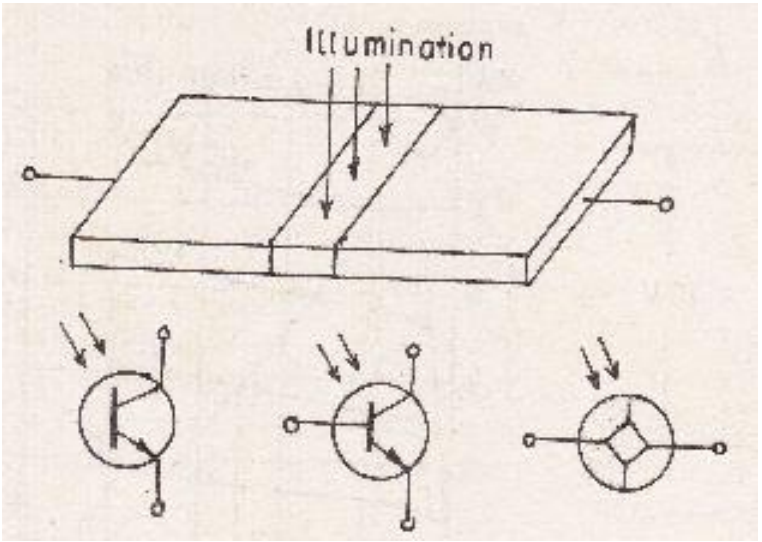


Fig. photo-transistor

Photo-transistors…

- **Advantages** of photo-transistors are-
  - Low power consumption
  - Small size
  - Immediate operation on switching ON
  - Low voltage operation
  - Long life
  - High gain

- Photo-transistors are **used** in-
  - Linear light meter
  - Operation of Relay
  - Modulated light
  - Shaft encoders
  - Digital circuits as a Switching devices


thank you!