A device to which change or converts physical quantity to a more easily measurable quantity

Transducer Basic Requirements:
- Ruggedness
- Linearity
- Repeatability
- High Signal to Noise Ratio
- High stability and reliability
Sensor

A device which senses and detects the physical quantity of measurand and converts to electrical form.

Example of sensors:

Mechanical : Bourdon tube pressure meter.

Electrical : Potentiometer

Optical : Photon counter

Chemical : Thermocouples

*All sensors are transducers but not all transducers are sensors
Actuator

A device that senses and detects the electrical quantity and converts to physical form.

Example of actuator:

• Valve in heat exchanger system

• Motor speed control where the motor is driving the conveyor belt

• Magnetic relays that turn on/off of the fans

• Compressor in a control air conditioning
Transducers

- Transducer - is a device which converts the quantity being measured into an optical, mechanical or electrical signal.

- The energy conversion process is referred to as transduction.

- Transducers are of fundamental important for any application that is not purely electronic in nature (i.e. EVERY application) must rely on a transducer at some point.

- Transducer elements – most transducers consist of a sensing element and a conversion or control element.

- The relationship between the measurand and transducer output signal is usually obtained by calibration test.
Transducer

- There are two further distinctions that can be made with regards to transducers:
  - Passive Transducers operate without the need for an external power source (that is: additionally to the power being converted.)
  - Active transducers must draw power from an external power source in order to work.
Variable Conversion Element

A device that converts \textit{analogue signals to digital form} or vice versa.

Example of converters:

ADC -- Analogue to digital converter

DAC -- Digital to analogue converter
Transducer

- Resistance transducers
- Resistance strain gauge
- Resistance temperature transducer
- Photo-emisive cell
- Capacitive transducer
- Inductive transducer
- Linear variable differential transformer
- Piezos-electric transducer
- Electromagnetic transducers
- thermoelectric transducer
- Photoelectric cell
a) Electrical transducers

- Exhibit many of the ideal characteristics
- High sensitivity and useful for remote sensing.
- Can be classified into:
  - Variable control – parameter types, which relies on an external excitation voltage e.g. resistance, capacitance.
  - Self generating types, which produces an output voltage in response to the measurand input and their effects are reversible e.g. electromagnetic, thermoelectric, piezoelectric.
Resistance transducers

**Potentiometers** – the excitation voltage maybe AC or DC and output voltage is proportional to the input motion.

- The wiper displacement can be rotary, translational or both. Electrical device which has a user-adjustable resistance.

- Usually, this is a three-terminal resistor with a sliding contact in the center (the wiper). If all three terminals are used, it can act as a variable voltage divider.

- If only two terminals are used (one side and the wiper), it acts as a variable resistor. Such potentiometers suffer from the linked problems of resolution and electrical noise.

Schematic symbol for a potentiometer. The arrow represents the moving terminal, called the wiper.
• Construction of a wire-wound circular potentiometer.
  - The resistive element (1) which is trapezoidal, giving a non-linear relationship between resistance and turn angle.
  - The wiper (3) rotates with the axis (4), providing the changeable resistance between the wiper contact (6) and the fixed contacts (5) and (9).
  - The vertical position of the axis is fixed in the body (2) with the ring (7) (below) and the bolt (8) (above).
Potentiometer

The output voltage $v_0$ of the unloaded potentiometer circuit shown is determined as follows.

Let

$$R_1 = \frac{x_i}{x_T} R_T$$

Where: $x_i = \text{input displacement}$

$x_T = \text{maximum possible displacement}$

$R_T = \text{total resistance of the potentiometer}$

Then output voltage

$$v_0 = v \times \frac{R_1}{R_1 + (R_T - R_1)} = v \times \frac{R_1}{R_T} = v \times \frac{x_i}{x_T} \times \frac{R_T}{R_T} = v \times \frac{x_i}{x_T}$$

Maximum value of $v = \sqrt{P R_f}$

where $P = \text{maximum power dissipation}$

Resolution effects and circuit diagram of resistance potentiometer
b) Resistance strain gauges transducer

- Resistance strain gauges are transducers which exhibit a change in electrical resistance in response to mechanical strain.

Classified into
- i) Bonded
- ii) Unbonded

Strain rosettes are used to measure strain at different direction simultaneously

• The Wheatstone bridge
c) Resistance Temperature Transducers (RTD)

- Metals such as platinum, copper, tungsten exhibit small increase in resistance as the temperature rise.
- Positive temperature coefficient of Resistance depend upon the relationship:
  \[ R_1 = R_0 [1 + \alpha (\theta_1 - \theta_0)] \]

where
\[ \alpha = \text{temperature coefficient of resistance in } ^\circ\text{C}^{-1} \]
\[ R_0 = \text{resistance in ohms at the reference temperature } \theta_0 = 0 ^\circ\text{C} \]
Semiconductors - thermistors

- A **thermistor** is a type of **resistor** used to measure **temperature** changes, relying on the change in its **resistance** with changing temperature.

- Semiconductors such as thermistors which use oxides of manganese, chromium, nickel exhibit large non-linear resistance changes with temperature variations.

- Negative temperature coefficient of resistance. Normally made in the form of discs or small (1mm)
d) Photoconductive cells

- Uses light sensitive semiconductors material e.g. cadmium sulphide, lead sulphide, copper doped germanium.
- When these semiconductor materials are exposed to light, their electrical conductivity is increased.
- The resistance between the metal electrodes decreases as the intensity of the light increases.
Photoemissive cells

- When light strikes the cathode of the photo emissive cell

- Electrons are given sufficient energy to leave the cathode. The positive anode attract these electrons, producing current $I_p$ through a resistance $R_L$ and producing output voltage $v_o$,

$$v_o = I_p R_L$$

Also $I_p = K_t \varphi$,

$K_t =$ sensitivity ($A/\text{lm}$), $\varphi =$ illumination input (lumen)
f) Capacitive transducers

- The capacitance of a parallel plate capacitor is given by

\[ C = \varepsilon_0 \varepsilon_r \frac{A}{d} \text{ farads} \]

where

\[ C = \varepsilon_0 \varepsilon_r \frac{A}{d} \text{ farads} \]

\[ \varepsilon_0 = \text{permittivity of free space} = 8.854 \times 10^{-12} \text{ F/m} \]

\[ \varepsilon_r = \text{relative permittivity of the material between the plates} \]

\[ A = \text{overlapping or effective area between plates (m}^2\text{)} \]

\[ d = \text{distance between plates (m)} \]

- The capacitance can thus be varied by changing either \( \varepsilon_r \), \( A \) or \( d \).
Capacitive transducers

- First, what is capacitance? Any two metallic objects, positioned in space, can have voltage applied between them.
- Depending on their separation and orientation, the amount of charge that must be applied to the two elements to establish a certain voltage level varies.
- The capacitance is defined as the ratio of the charge to the voltage for a given physical situation. If the capacitance is large, more charge is needed to establish a given voltage difference.
Example of capacitive transducer

(a) Variable area

(b) Variable distance

(c) Variable permittivity
Example of capacitive transducer

- Variable distance capacitive transducers have an infinite resolution, making it most suitable for measuring small increments of displacement.

Important features of capacitive transducers

- Resolution infinite
- Accuracy $\pm 0.1\%$ of full scale
- Displacement ranges $25 \times 10^{-6}$ m to $10 \times 10^{-3}$ m
- Rise time less than $50 \mu$s
g) Inductive transducers

- Characteristics of inductive

**Inductive transducers** – The inductance of a coil wound a magnetic circuit is given by

\[ L = \frac{\mu_o \mu_r N^2 A}{l} \]

where
- \( \mu_o \) = permeability of free space
  = 4 \times 10^{-7} \text{ H/m}
- \( \mu_r \) = relative permeability
- \( N \) = number of turns of coil
- \( l \) = length of magnetic circuit \((\text{m})\)
- \( A \) = cross sectional area of magnetic circuit \((\text{m}^2)\)

This can be written as

\[ L = \frac{N^2}{S} \]

Where \( S = l / (\mu_o \mu_r A) \) = magnetic reluctance of the inductive circuit
Inductive transducers
h) Linear Variable-Differential Transformer – LVDT

- Consist of a primary coil, two secondary coil and a movable magnetic core.
- When excitation voltage $V_p$ is applied to the primary winding, due to transformer action, voltages $V_{s1}$ and $V_{s2}$ are induced in the primary coils.

Cutaway view of an LVDT. Current is driven through the primary coil at $A$, causing an induction current to be generated through the secondary coils at $B$. 

Details of an l.v.d.t.
LVDT

- The amplitudes of these secondary voltages are dependent on the core displacement $x$. 

![Diagram](image_url)
i) Piezo-electric transducers

- **Piezoelectricity** is the ability of **crystals** and certain ceramic materials to generate a **voltage** in response to applied mechanical **stress**.

- When a force is applied across the faces of certain crystal materials—electrical charges (proportional to the applied force) of opposite polarity appear on the faces.

- These transducers are made from natural crystals such as quartz, Rochelle salt, Lithium sulphate or barium titanate.

- To enhance the response of the transducer charge amplifier is normally used.
J) Electromagnetic transducers

- Employs the generator principle of a coil moving in a magnetic field. The output voltage of the transducer is given as follows. Widely used as velocity transducers.

\[
\text{Output voltage } v_o = -N \frac{d\phi}{dt}
\]

- \(N\) = number of turns on coil
- \(\frac{d\phi}{dt}\) = rate of flux changes (Wb/s)

For the single conductor moving in a magnetic field,

Output voltage \(v_0 = Blv\)

- \(B\) = flux density (T), \(l\) = length of conductor (m), \(v\) = velocity of conductor perpendicular to flux direction (m/s)
k) Thermoelectric transducers (thermocouple)

- When two dissimilar metals or alloys are joined together at each end to form a thermocouple and the ends are at different temperatures, an emf will be developed causing a current to flow around the circuit.

- The emf is proportional to the temperature gradient.

- This is called the Seebeck effect. This transducer has an operating range from -250 °C to 2600 °C.
I) Photoelectric cells

- Make use of the voltaic effect, which is the production of the emf by light energy, incident on the junction of two dissimilar materials.
- The transducer is highly sensitive, good frequency response and can be used for wide range of light intensities.
Mechanical transducers

- Mechanical transducers –
  convert measurand into mechanical parameters eg displacement, pressure or force.
  Often used in cascade with electrical transducers.

a) Force-to-displacement transducers

Spring – is the simplest form of mechanical transducer

\[ F = \lambda \times x \]

\[ \lambda \] = spring stiffness (N/m) and sensitivity = i.e the stiffer the spring the smaller the sensitivity.

- Cantilever – the deflection, \( y \) caused by force \( F \), is

\[ y = k \times F \]

\( k \) = a constant depending on the material and dimensions of the cantilever.
b) Pressure-to-displacement transducers

i) **Diaphragms**-displacement, $x$ is proportional to the pressure difference.

$$x = k \left( p_1 - p_2 \right)$$

$k$ depend on material and dimensions.
Mechanical transducers

ii) Bourdon tubes – widely used in pressure gauges. The relationship between pressure, $p$ and deflection $\phi$ is;

- $\phi = k \ p$
Mechanical transducers

iii) **Bellows** – also known as pneumatic spring. The relationship between deflection, \( x \), Area A and stiffness \( \lambda \) can be composed.
c) Displacement to pressure transducers – Fapper – Nozzle

Control pressure $p_c$ varies with flapper movement, $x$ if supply pressure $p$ is constant.
Summary

- Types of transistors, and characteristics of transistor has been described.