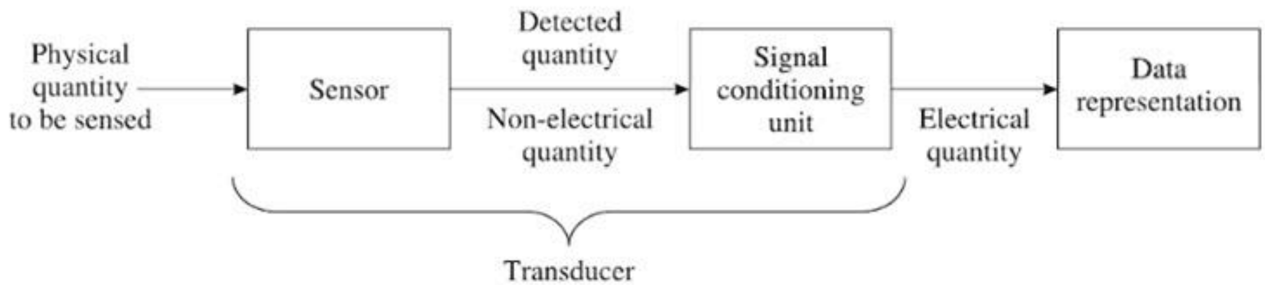
<u>**UNIT-1**</u>

Transducers:

Before understanding what a transducer is or diving into the different types of Transducers, consider the following setup of a measuring system. In this block diagram of a simple measuring system, there are three basic elements:

- Sensor
- Signal Conditioning Unit
- Data Representing Device



Sensor

A Sensor is a device that is used to detect changes in any physical quantity like Temperature, Speed, Flow, Level, Pressure, etc. Any changes in the input quantity will be detected by a Sensor and reflected as changes in output quantity.

Both the input and output quantities of a Sensor are Physical i.e. non-electrical in nature.

Signal Conditioning Unit

The non-electrical output quantity of the Sensor makes it inconvenient to further process it. Hence, the Signal Conditioning Unit is used to convert the physical output (or non-electrical output) of the sensor to an electrical quantity.

Some of the best known Signal conditioning units are:

- Analog to Digital Converters
- Amplifiers
- Filters
- Rectifiers
- Modulators

Data Representation Device

A Data representation device is used to present the measured output to the observer. This can be anything like

- A Scale
- An LCD Display
- A Signal Recorder

Transducer

In the above example, consider a Strain Gauge as the Sensor. Any changes in the strain will reflect as changes in its resistance. Now, in order to convert this change in resistance into equivalent voltages, you can use a simple Wheatstone Bridge circuit, which acts as the Signal Conditioning Unit.

The combination of Strain Gauge (Sensor) and Wheatstone Bridge (Signal Conditioning Unit) is Known as a Transducer.

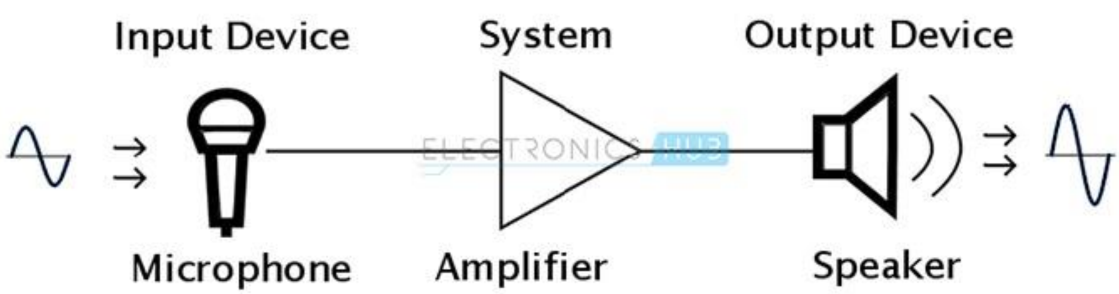
Generally speaking, a Transducer is a device that converts one form of energy into another by the principle of Transduction. Usually, a signal in one form of energy is converted to a signal in another form by a Transducer.

From the above example, a Transducer is a device that converts a Physical Quantity into an Electrical Quantity.

Sensors and Actuators

From the above definition, actually, both Sensors, devices that responds to a physical quantity with a signal and Actuators, devices that respond to signals with physical movement (or similar action) can be considered as Transducers.

For example, a Microphone is a Sensor, which converts sound waves into electrical signals and a Loudspeaker is an Actuator, which converts electrical signals into audio signals.



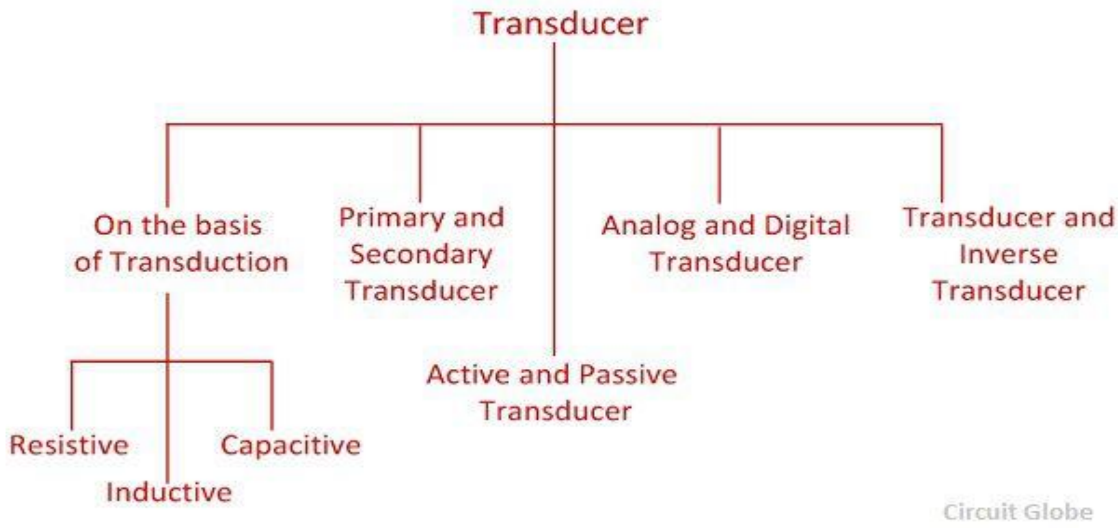
Both Microphone and Loudspeaker are Transducers in the sense that a microphone converts sound energy into electrical energy and a loud speaker converts electrical energy into sound energy.

Classification of Transducers

The transducer is of many types, and they can be classified by the following criteria.

1. **By transduction used.**
2. **as a primary and secondary transducer**
3. **as a passive and active transducer**
4. **as analogue and digital transducer**
5. **as the transducer and inverse transducer**

The transducer receives the measurand and gives a proportional amount of output signal. The output signal is sent to the conditioning device where the signal is attenuated, filtered, and modulated.



The input quantity is the non-electrical quantity, and the output electrical signal is in the form of the current, voltage or frequency.

1. Classification based on the Principle of Transduction

The transducer is classified by the transduction medium. The transduction medium may be resistive, inductive or capacitive depends on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

2. Primary and Secondary Transducer

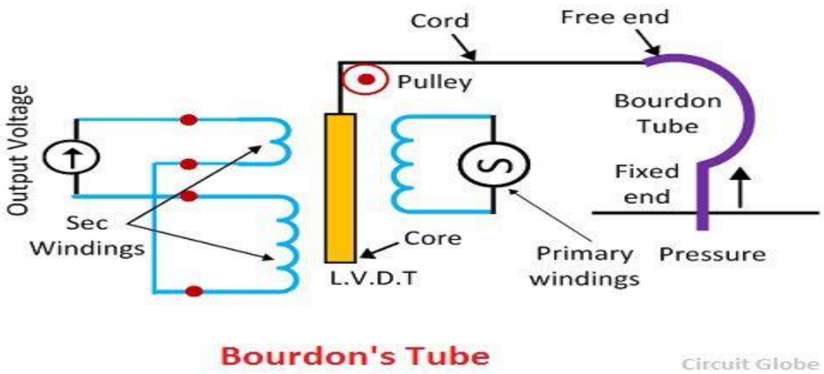
Primary Transducer – The transducer consists the mechanical as well as the electrical devices. The mechanical devices of the transducer change the physical input quantities into a mechanical signal. This mechanical device is known as the primary transducers.

Secondary Transducer – The secondary transducer converts the mechanical signal into an electrical signal. The magnitude of the output signal depends on the input mechanical signal.

Example of Primary and Secondary Transducer

Consider the Bourdon's Tube shown in the figure below. The tube act as a primary transducer. It detects the pressure and converts it into a displacement from its free end. The displacement of the free ends moves the core of the linear variable displacement transformer. The movement of the core induces the output voltage which is directly proportional to the displacement of the tube free end.

Thus, the two type of transduction occurs in the Bourdon's tube. First, the pressure is converted into a displacement and then it is converted into the voltage by the help of the L.V.D.T.



The Bourdon's Tube is the primary transducer, and the L.V.D.T is called the secondary transducer.

3. Passive and Active Transducer

The transducer is classified as the active and passive transducer.

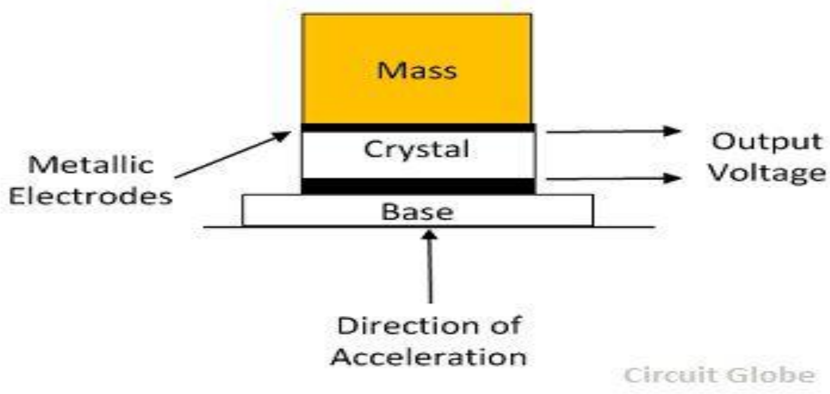
Passive Transducer – The transducer which requires the power from an external supply source is known as the passive transducer. They are also known as the external power transducer. The capacitive, resistive and inductive transducers are the example of the passive transducer.

Active Transducer – The transducer which does not require the external power source is known as the active transducer. Such type of transducer develops theirs owns voltage or current, hence known as a self-generating transducer. The output signal is obtained from the physical input quantity.

The physical quantity like velocity, temperature, force and the intensity of light is induced with the help of the transducer. The piezoelectric crystal, photo-voltaic cell, tacho generator, thermocouples, photovoltaic cell are the examples of the active transducers.

Examples – Consider the examples of a piezoelectric crystal. The crystal is sandwiched between the two metallic electrodes, and the entire sandwiched is fastened to the base. The mass is placed on the top of the sandwiched.

The piezo crystal has the special property because of which when the force is applied to the crystal, they induce the voltage. The base provides the acceleration due to which the voltage is generated. The mass applies on the crystals induces an output voltage. The output voltage is proportional to the acceleration.



The above mention transducer is known as the accelerometer which converts the acceleration into an electric voltage. This transducer does not require any auxiliary power source for the conversion of physical quantity into an electrical signal.

4. **Analog and Digital Transducer**

The transducer can also be classified by their output signals. The output signal of the transducer may be continuous or discrete.

Analog Transducer – The Analog transducer changes the input quantity into a continuous function. The strain gauge, L.V.D.T, thermocouple, thermistor are the examples of the analogue transducer.

Digital Transducer – These transducers convert an input quantity into a digital signal or in the form of the pulse. The digital signals work on high or low power.

5. Transducer and Inverse Transducer

Transducer – The device which converts the non-electrical quantity into an electric quantity is known as the transducer.

Inverse Transducer – The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer. The transducer has high electrical input and low non-electrical output.

Characteristics of Transducers

The performance characteristics of a Transducer are key in selecting the best suitable transducer for a particular design. So, it is very important to know the characteristics of transducers for proper selection.

Performance characteristics of transducers can be further classified into two types:

- Static Characteristics
- Dynamic Characteristics

Static Characteristics

The static characteristics of a transducer is a set of performance criteria that are established through static calibration i.e. description of the quality of measurement by essentially maintaining the measured quantities as constant values of varying very slowly.

Following is a list of some of the important static characteristics of transducers.

- Sensitivity
- Linearity
- Resolution
- Precision (Accuracy)
- Span and Range
- Threshold
- Drift
- Stability
- Responsiveness
- Repeatability
- Input Impedance and Output Impedance

Dynamic Characteristics

The dynamic characteristics of transducers relate to its performance when the measured quantity is a function of time i.e. it varies rapidly with respect to time.

While static characteristics relate to the performance of a transducer when the measured quantity is essentially constant, the dynamic characteristics relate to dynamic inputs, which means that they are dependent on its own parameters as well as the nature of the input signal.

The following are some dynamic characteristics that may be considered in selection of a transducer.

- Dynamic Error
- Fidelity
- Speed of Response
- Bandwidth

Overall, both static and dynamic characteristics of a Transducer determine its performance and indicate how effectively it can accept desired input signals and reject unwanted inputs.

Different Types of Transducers

Basically, the two different types of Transducers are Mechanical Transducers and Electrical Transducers. Mechanical Transducers are those which responds to changes in physical quantities or condition with mechanical quantity. If the physical quantity is converted to an electrical quantity, then the transducers are Electrical Transducers.

Mechanical Transducers

As mentioned earlier, mechanical transducers are a set of primary sensing elements that respond to changes in a physical quantity with a mechanical output. As an example, a Bimetallic Strip is a mechanical Transducer, which reacts to changes in temperature and responds with mechanical displacement. The mechanical transducers are differentiated from electrical transducers as their output signals are mechanical.

The output mechanical quantity can be anything like displacement, force (or torque), pressure and strain. For any measuring quantity, there can be both mechanical and electrical transducers.

For example, we have seen Bimetallic Strip, which is a mechanical transducer and is used to react to changes in temperature. In contrast, a Resistance Thermometer, also reacts to changes in temperature, but the response is a change in resistance of the element. Hence, it is an electrical transducer.

The following table shows a small list of mechanical transducers for measuring different quantities and responds with mechanical signal.

Quantity to be Measured	***Mechanical Transducer***	***Type of Output Signal (Mechanical)***
Temperature	Bimetallic Strip	Displacement and Force
	Fluid Expansion	Displacement and Force

Pressure	Ring Balance Manometer	Displacement
	Metallic Diaphragms	Displacement and Strain
	Capsules and Bellows	Displacement
	Membranes	Displacement
Force	Spring Balance	Displacement and Strain
	Hydraulic Load Cell	Pressure
	Column Load Cell	Displacement and Strain
Torque	Dynamometer	Force and Strain
	Gyroscope	Displacement
	Spiral Springs	Displacement
	Torsion Bar	Displacement and Strain
Flow Rate	Flow Obstruction Element	Strain and Pressure
	Pitot Tube	Pressure
Liquid Level	Manometer	Displacement
	Float Elements	Displacement, Force and Strain

Electrical Transducers

As mentioned earlier, electrical transducers are those that respond to changes in physical quantities with electrical outputs. Electrical Transducers are further divided into Passive Electrical Transducers and Active Electrical Transducers.

The following table lists out a few electrical transducers (both passive and active).

Resistive Transducers	Resistance Thermometers
	Resistive Displacement Transducers

		Resistive Strain Transducers
		Resistive Pressure Transducers
		Resistive Moisture Transducers
		Capacitive Moisture Transducers
Passive Electrical Transducers	Capacitive Transducers	Capacitive Displacement Transducers
		Capacitive Thickness Transducers
		Inductive Displacement Transducers
	Inductive Transducers	Inductive Thickness Transducers
		Eddy-Current Inductive Transducers
		Moving core Inductive Transducers
		Photoconductive Transducers
	Photoelectric Transducers	Photoemissive Transducers
		Photovoltaic Force Transducers
		Piezoelectric Strain Transducers
		Piezoelectric Acceleration Transducers
Active Electrical Transducers	Piezoelectric Transducers	Piezoelectric Pressure Transducers
		Piezoelectric Torque Transducers
		Piezoelectric Force Transducers
		Magnetostrictive Acceleration Transducers
	Magnetostrictive Transducers	Magnetostrictive Force Transducers
		Magnetostrictive Torsion Transducers

Tachometers

Electrodynamic Pressure Transducers

Electromechanical Transducers

Electrodynamic Vibration Transducers

Electromagnetic Flowmeters

Ionization Vacuum Gauge

Ionization Displacement Transducers

Nuclear Radiation Transducers

Ionization Transducers

Radioactive Vacuum Gauge

Radioactive Level Gauge

Radioactive Thickness Gauge

Electrochemical Transducers

Hall-Effect Transducers

Thermoelectric Transducers

Applications of Transducers

Electromagnetic

- Antennas
- Hall-Effect Sensors
- Disk Read and Write Heads
- Magnetic Cartridges

Electromechanical

- Accelerometers
- Pressure Sensors
- Galvanometers
- LVDT
- Load Cells
- Potentiometers
- MEMS

- Linear and Rotary Motors
- Air Flow Sensors

Electrochemical

- Hydrogen Sensors
- Oxygen Sensors
- pH Meters

Electroacoustic

- Speakers (Loudspeakers, earphones)
- Microphones
- Ultrasonic Transceivers
- Piezoelectric Crystals
- Sonar
- Tactile Transducers

Photoelectric

- LED
- Photodiodes
- Photovoltaic Cells
- Laser Diodes
- Photoresistors (LDR)
- Phototransistors
- Incandescent and Fluorescent Lamps

Thermoelectric

- Thermistors
- Thermocouples
- RTD (Resistance Temperature Detectors)

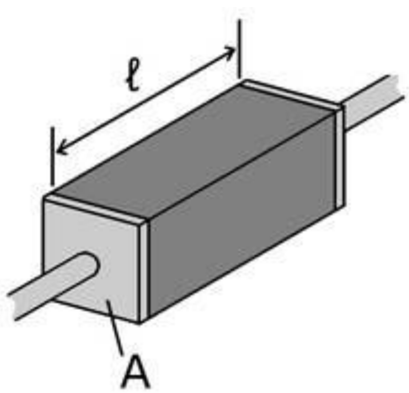
Radioacoustic

- Radio Transmitters and Receivers
- G-M Tube (Geiger-Muller Tube)

<u>ELECTRICAL TRANSDUCERS: RESISTIVE TRANSDUCERS</u>

Introduction

- The electrical measurements are used for measurement of electrical quantities but its use in measurement of non electrical quantities is growing. In the measurement of non electrical quantities a detector is used which usually converts the physical quantity in displacement. The displacement actuates an electric transducer, gives an output which is electrical in nature. The electrical quantity so produced is measured by standard methods used for electrical measurements. The resultant electrical output gives the magnitude of the physical quantity being measured. The advantages and limitations of electric measurements have been presented in Lesson 3.
- The electrical signal could be a voltage, current or frequency. The production of these signals is based upon the resistive, inductive or capacitive effects. These phenomena may be combined with appropriate primary sensing elements / detectors to produce different types of transducers.
- **16.2 Resistive Transducers**
- The resistive transducers or resistive sensors are also called as variable resistance transducers. The variable resistance transducers are one of the most commonly used types of transducers. They can be used for measuring various physical quantities, such as, temperature, pressure, displacement, force, vibrations etc. These transducers are usually used as the secondary transducers, where the output from the primary mechanical transducer acts as the input for the variable resistance transducer. The output obtained from it is calibrated against the input quantity and it directly gives the value of the input.
- The variable resistance transducer elements work on the principle that the resistance of the conductor is directly proportional to the length of the conductor and inversely proportional to the area of the conductor.

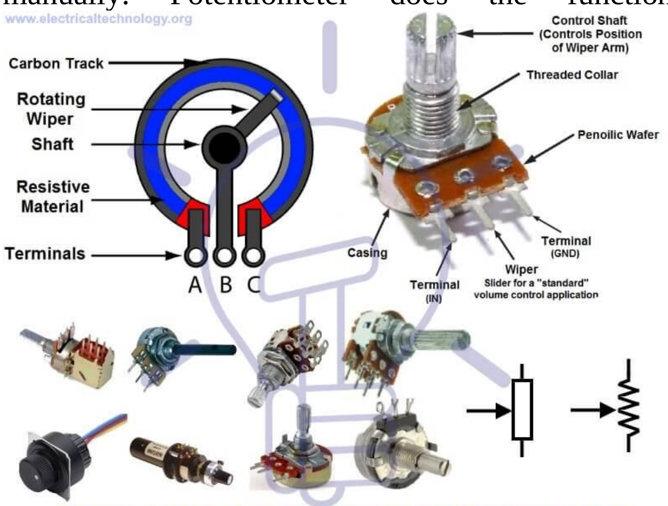


- **Fig. 16.1 Resistance element**

- Thus, if �L� is the length of the conductor (m) and �A� is its area (m^2) as shown in Fig.16.1, then its resistance �R� (ohms) is given by:
- $R = \rho L/A$
- Where �ρ� is called as resistivity of the material measured in �ohm-m� and it is constant for the given material.
- Some of the popular variable resistance transducers that are being used for various applications are as below:

Potentiometers:

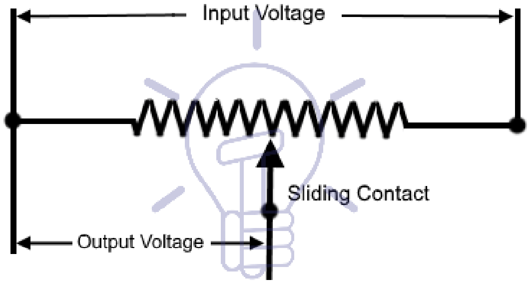
A potentiometer is also called as pot. It is variable resistor that has 3 terminals. Two fixed terminals and one variable terminal. In this device the current flow is controlled by varying the resistance manually. Potentiometer does the function of an adjustable voltage divider.



Construction, Types & Symbols of Potentiometer

How does a Potentiometer work?

Potentiometer is a passive component that works on moving the slider across the full length of the conductor. The input supply voltage is applied to the entire length of the resistor. The output voltage is measured as voltage drop between fixed and movable contact as seen in the figure below. The slider is adjusted manually over the resistive strip to change the resistance value from zero to a higher value. When the resistance changes, the current flowing through circuit changes. Hence according to Ohm's law, the resistive material also changes.



Working of Potentiometer

Assume that two batteries are connected in parallel through galvanometer. Negative ends of both batteries are connected together and similarly both positive ends are connected together. Since both batteries carry same electric potential, there will be no current flowing through galvanometer and its does not show deflection. The pot also works on the same phenomenon.

Types of Potentiometers:

1. Rotary Potentiometer
2. Linear Potentiometer

Rotary Potentiometer:

Adjustable supply voltage can be obtained using rotary potentiometer. A familiar example is volume controller of a radio transistor, in which the amplifier supply is supported by the rotary knob of the pot. The other applications are it is used when the end user needs smooth voltage control.

Linear Potentiometer:

It works same as the rotary potentiometer but the only difference is slider moves linearly on the resistor. The resistor ends are connected across the supply voltage. The two ends of the output circuit are connected to the sliding terminal and resistor terminal

Applications of Potentiometers:

1. Potentiometer as a Voltage Divider:
2. Audio Control
3. Television
4. Transducers
5. Pots as measuring devices:
6. Pots as tuners and calibrators
7. To compare the emf of a battery cell with a standard cell
8. To measure the internal resistance of a battery cell
9. To measure the voltage across a branch of a given circuit.

Strain Gauge:

A strain gauge is a passive transducer, that converts mechanical displacement into the change of resistance. A strain gauge sensor is a thin wafer-like device that can be attached to a variety of materials to measure applied strain. These are used as a fundamental sensor in many types of sensors like pressure sensors, load cells, torque sensors etc.

Strain Gauge Working Principle

The foil type strain gauges (Figure #1) are very common in which a resistive foil is mounted on a backing material. These are available in a variety of shapes and sizes for different applications. The resistance of the foil changes as the material to which the gauge is attached undergoes tension or compression due to change in its length and diameter.

This change in resistance is proportional to the applied strain. As this change in resistance is very small in magnitude so its effect can be only sensed by a Wheatstone bridge. This is the basic *strain gauge working principle*.

10.

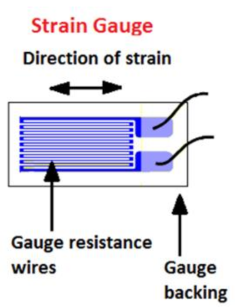


Figure #1

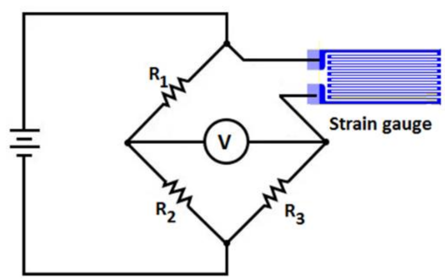


Figure #2

A circuit diagram is shown in Figure #2. In this circuit diagram, a strain gauge is connected into a Wheatstone bridge. This circuit is so designed that when no force is applied to the strain gauge, R1 is equal to R2 and the resistance of the strain gauge is equal to R3. In this condition the Wheatstone bridge is balanced and the voltmeter shows no deflection.

But when strain is applied to the strain gauge, the resistance of the strain gauge sensor changes, the Wheatstone bridge becomes unbalanced, a current flows through the voltmeter. Since the net change in the resistance is proportional to the applied strain, therefore, resultant current flow through the voltmeter is proportional to the applied strain. So, the voltmeter can be calibrated in terms of strain or force.

In the above circuit, we have used only one strain gauge. This is known as ‘quarter bridge’ circuit. We can also use two strain gauges or even four strain gauges in this circuit. Then this circuit is called ‘half bridge’ and ‘full bridge’ respectively. The full bridge circuit provides greater sensitivity and least temperature variation errors.

Gauge Factor of Strain Gauge

The gauge factor of strain gauge is defined as the unit change in resistance per unit change in length.

i.e. gauge factor $G_f = (\Delta R/R)/(\Delta l/l)$

where, R = nominal gauge resistance,

ΔR = change in resistance,

l = length of the specimen in an unstressed condition,

Δl = change in specimen length.

It can be proved mathematically,

Gauge factor, $G_f = 1 + 2v + (\Delta\rho/\rho)/(\Delta L/L)$

If the change in resistivity due to strain is almost negligible, then

gauge factor of strain gauge, $G_f = 1 + 2v$

Where, v is Poisson’s ratio. It may be defined as the ratio of strain in the lateral direction to the strain in the axial direction. The Poisson’s ratio for most metals lies in the range of 0 to 0.5 and this gives a gauge factor of 2 approximately.

Strain Gauge Transducer Types:

Strain Gauge Transducer Types are three types, namely

1.Wire Strain Gauges

2.Foil Strain Gauge

3.Semiconductor Strain Gauge

1.Wire Strain Gauges:

Wire Strain Gauges has three types namely,

1. Grid type
2. Rossette type
3. Torque type
4. Helical type

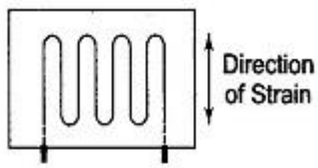


Fig. 13.6 Grid Type Strain Gauge

The grid arrangement of the wire element in a bonded strain gauge creates a problem not encountered in the use of unbonded strain gauges. To be useful as a strain gauge, the wire element must measure strain along one axis. Therefore complete and accurate analysis of strain in a rigid member is impossible, unless the direction and magnitude of stress are known. The measuring axis of a strain gauge is its longitudinal axis, which is parallel to the wire element, as shown in Fig. 13.6.

When a strain occurs in the member being measured, along the transverse axis of the gauge, it also affects the strain being measured parallel to the longitudinal axis. This introduces an error in the response of the gauge.

In most applications, some degree of strain is present along the transverse axis and the transverse sensitivity must be considered in the final gauge output. Transverse sensitivity cannot be completely eliminated, and in highly accurate measurements the resultant gauge error must be compensated for.

If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member's surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member. Figure 13.7 shows a three-element strain gauge, called a **Rossette gauge**, in which the angle between any two longitudinal gauge axes is 45°.

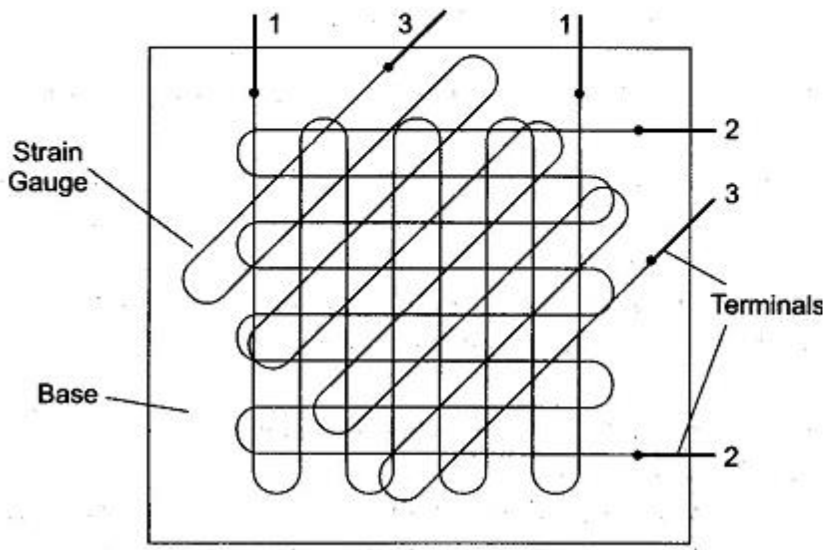


Fig. 13.7 Rossette Gauge

The 45° Rossette gauge is, in general, the most popular one. There are different shapes and sizes of Strain Gauge Transducer Types for various purposes.

Serving a similar, but not specialised, purpose are gauges with specially modified grid configurations, such as those shown in Figs. 13.8(a), (b) and (c).

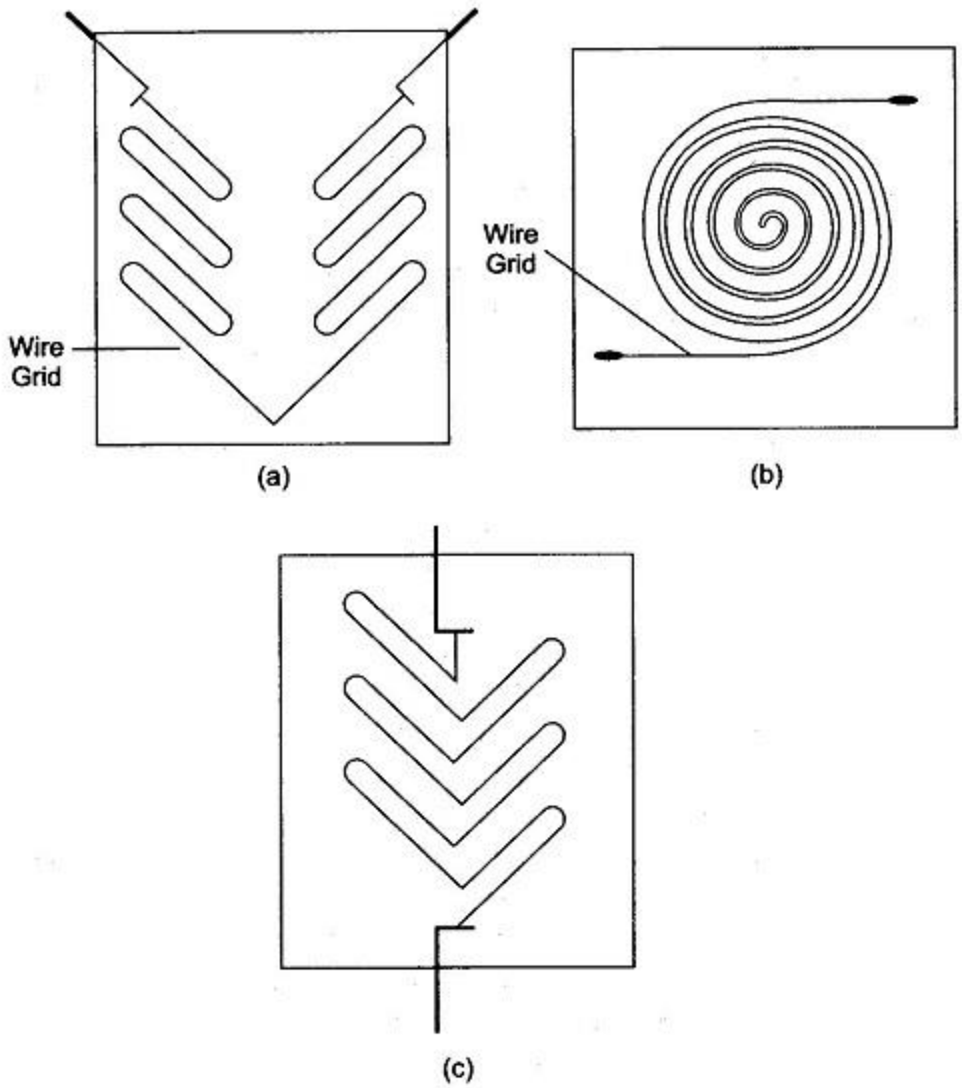


Fig. 13.8 (a) and (c) Torque Type Gauge (b) Helical Gauge

A measurement of this type would be useful at the cross-point of an X-shaped frame.

The latest in strain gauges is the etched foil strain gauge. This device uses the technique of PCB design. Its physical and electrical characteristics are superior to bonded wire strain gauges in almost every respect.

The size of strain gauges varies with application. They can be as small as 3 sq.mm. Usually they are larger, but not more than 2.5 mm long and 12.5 mm wide.

To obtain good results, it is desirable that a resistance wire strain gauge have the following characteristics.

1. The Strain Gauge Transducer Types should have a high value of gauge factor (a high value of gauge factor indicates a large change in resistance for particular strain, implying high sensitivity).
2. The resistance of the strain gauge should be as high as possible, since this minimises the effects of undesirable variations of resistance in the measurement circuit. Typical resistances of strain gauges are 120 Ω, 350 Ω and 1000 Ω.

A high resistance value results in lower sensitivity. Hence, in order to get high sensitivity, higher bridge voltages have to be used. The bridge voltage is limited by the maximum current carrying capacity of the wires, which is typically 30 mA.

3. The strain gauge should have a low resistance temperature coefficient. This is necessary to minimise errors on account of temperature variation, which affects the accuracy of measurements. (Temperature compensation is also used.).
4. The strain gauge should not have hysteresis effects in its response.
5. In order to maintain constancy of calibration over the entire range of the strain gauge, it should have linear characteristics, i.e. the variation in resistance should be a linear function of the strain.
6. Strain gauges are frequently used for dynamic measurements and hence their frequency response should be good. Linearity should be maintained within specified accuracy limits over the entire frequency range.
7. Leads used must be of materials which have low and stable resistivity and low resistance temperature coefficient.

Foil Strain Gauge

This class of strain gauges is an extension of the resistance wire strain gauge. The strain is sensed with the help of a metal foil. The metals and alloys used for the foil and wire are nichrome, constantan (Ni + Cu), isoelastic (Ni + Cr + Mo), nickel and platinum.

Foil gauges have a much greater dissipation capacity than wire wound gauges, on account of their larger surface area for the same volume. For this reason, they can be used for a higher operating temperature range. Also, the large surface area of foil gauges leads to better bonding.

Foil type Strain Gauge Transducer Types have similar characteristics to wire strain gauges. Their gauge factors are typically the same.

The advantage of foil type Strain Gauge Transducer Types is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier.

Etched foil gauge construction consists of first bonding a layer of strain sensitive material to a thin sheet of paper or bakelite. The portion of the metal to be used as the wire element is covered with appropriate masking material, and an etching solution is applied to the unit. The solution removes that portion of the metal which is not masked, leaving the desired grid structure intact.

This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, as shown in Fig. 13.9. This characteristics, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces.

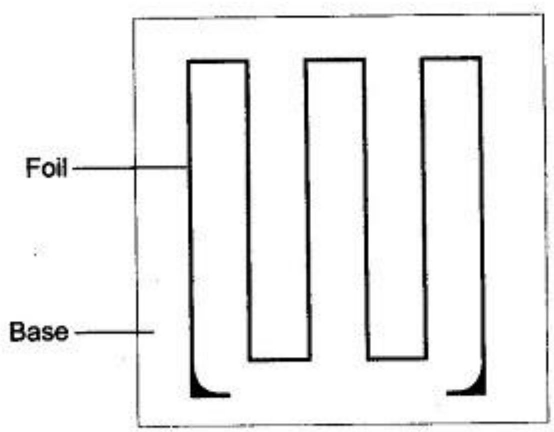


Fig. 13.9 Foil Type Strain Gauge

The longitudinal sensitivity of the foil gauge is approximately 5% greater than that of similar wire elements. The transverse strain sensitivity of this gauge is smaller 1/3 to 1/2 of similar wire gauges. The hysteresis of the foil gauge is also 1/3 to 1/2 of a wire strain gauge.

(The term hysteresis, as used in Strain Gauge Transducer Types, is defined as follows. If the resistance of a strain gauge is measured with no strain applied, and the gauge is then stressed to its maximum usable resistance value, the measured resistance, after the stress is removed, differs from the original value. The inability of the gauge element to resume the exact physical form it had before being elongated, produces the difference in resistance. This effect is called **hysteresis**.)

The resistance film formed is typically 0.2 mm thick. The resistance value of commercially available foil gauges is between 50 and 1000 Ω The resistance films are vacuum coated with ceramic film and deposited on a plastic backing for insulation.

Semiconductor Strain Gauge

To have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain.

Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials.

A typical strain gauge consists of a strain material and leads that are placed in a protective box, as shown in Fig. 13.10. Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as teflon.

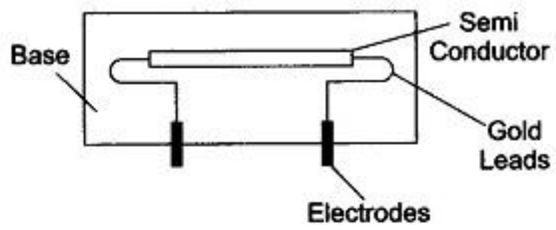


Fig. 13.10 Semiconductor Strain Gauge

Gold leads are generally used for making contacts. These strain gauges can be fabricated along with an IC Op Amp which can act as a pressure sensitive transducer. The large gauge factor is accompanied by a thermal rate of change of resistance approximately 50 times higher than that for resistive gauges. Hence, a semiconductor strain gauge is as stable as the metallic type, but has a much higher output.

Simple temperature compensation methods can be applied to semiconductor strain gauges, so that small values of strain, that is micro strains, can also be measured.

The gauge factor of this type of semiconductor strain gauge is 130 ± 10% for a unit of 350 Ω, 1″ long, 1/2″ wide and 0.005″ thick. The gauge factor is determined at room temperature at a tensile strain level of 1000 micro strain (1000 micro in/in. of length). The maximum operating tensile strain is ± 3000 micro strain, with a power dissipation of 0.1 W. The semiconductor strain gauge also has low hysteresis and is susceptible to regular methods of temperature compensation. The semiconductor strain gauge has proved itself to be a stable and practical device for operation with conventional indicating and recording systems, to measure small strains from 0.1-500 micro strain.

Advantages of Semiconductor Strain Gauge

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro
2. Hysteresis characteristics of semiconductor strain gauges are excellent, e. less than 0.05%.
3. Life in excess of 10 x 10^6 operations and a frequency response of 10^{12} HZ.
4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

Disadvantages of Semiconductor Strain Gauge

1. They are very sensitive to changes in temperature.
2. Linearity of semiconductor strain gauges is poor.
3. They are more expensive.

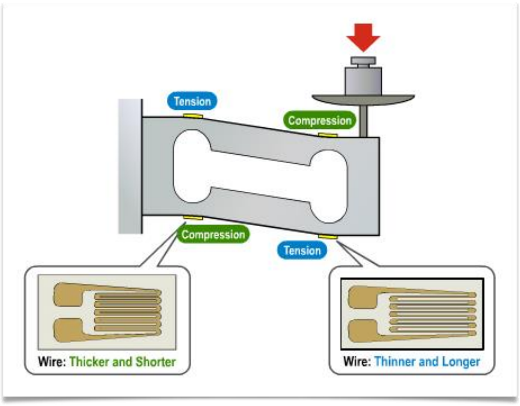
Strain Gauge Applications

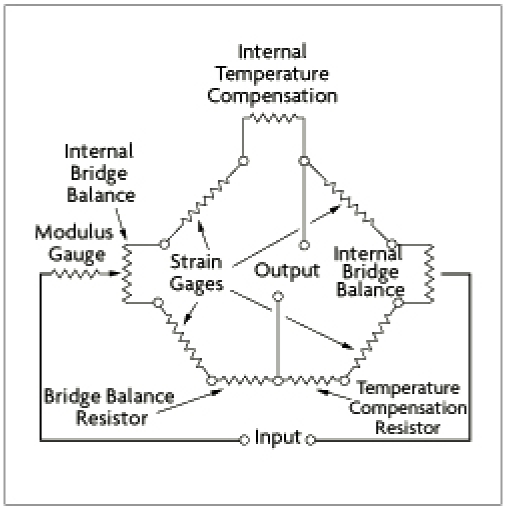
Strain gauges are used to determine or verify component or structure stresses, or by manufacturers of load cells, pressure and torque transducers, etc., where they utilize the physical parameter being measured to strain a part of the transducer in a linear way. It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.

Load cell, working, construction and Advantages

Load cells are used in different applications to measure force or weight. We can take the strain gauge and the **Wheatstone bridge** theories and use them to build a Load Cell. As the weight is placed above the line, the length of the line will decrease. this line will also be "fat," or stick out.

Theory:



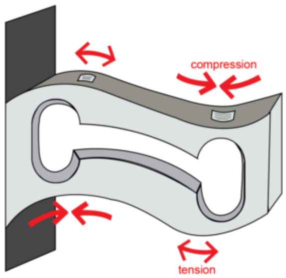


The Load Cell that we made has resistance values that represent our four strain gauges. Because in our Load Cell, all **strain gauge** resistances are the same. Using **Ohm's Law** we configure the drop voltage at points 1 and 2. Each branch contains 350Ω + 350Ω = 700Ω Resistance. The current flow in the branch and the branch voltage are divided by branch resistance

Construction and Operation:

Two strain gauges are placed opposite each other to respond proportionally to the change in length. Two other measuring devices are placed on the opposite side of the line and respond to changes in the line's protrusion.

Since a pair of strain gauges mounted on them the wire becomes shorter the wire diameter becomes larger and reduces their resistance. The other pair of strain gauges is positioned that will extend the cable, thereby reducing the diameter and increasing the wire resistance. If we hang the same weight from the bottom of the line, instead of pressing the line, we will place tension/stress on it. Line and strain gauges will act in the opposite direction but still in the same amount of stretching and pressing the cable. We can measure the wire strain to the Wheatstone Bridge configuration.



Advantages of Load cell:

- Inherently explosion proof
- Insensitive to temperature variations
- They do not contain fluids, therefore, there is no possibility of contamination of the process if the diaphragm breaks.
- The load cells of the voltage meter can be used for both expansion and compression.
- Strain gauge load cells are less costly so mostly used in the industry.

Hot Wire Anemometer

Definition: The Hot Wire Anemometer is a device used for measuring the velocity and direction of the fluid. This can be done by measuring the heat loss of the wire which is placed in the fluid stream. The wire is heated by electrical current.

The hot wire when placed in the stream of the fluid, in that case, the heat is transferred from wire to fluid, and hence the temperature of wire reduces. The resistance of wire measures the flow rate of the fluid.

The hot wire anemometer is used as a research tool in fluid mechanics. It works on the principle of transfer of heat from high temperature to low temperature.

Construction of Hot Wire Anemometer

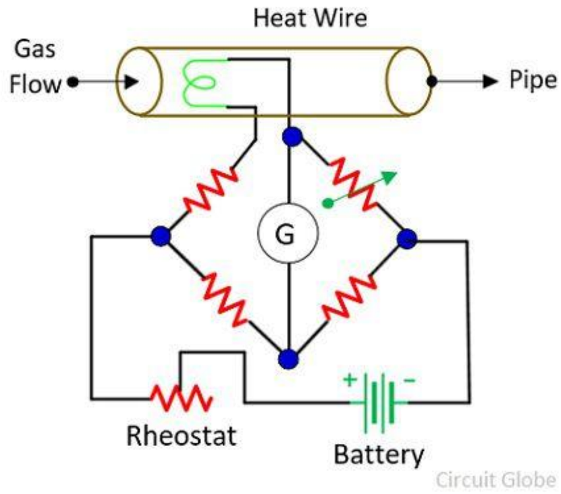
The hot wire anemometer consists two main parts.

1. Conducting wire
2. Wheat stone bridge.

The conducting wire is housed inside the ceramic body. The wires are taking out from the ceramic body and connecting to the Wheatstone bridge. The wheat stone bridge measures the variation of resistance.

1. Constant Current Method

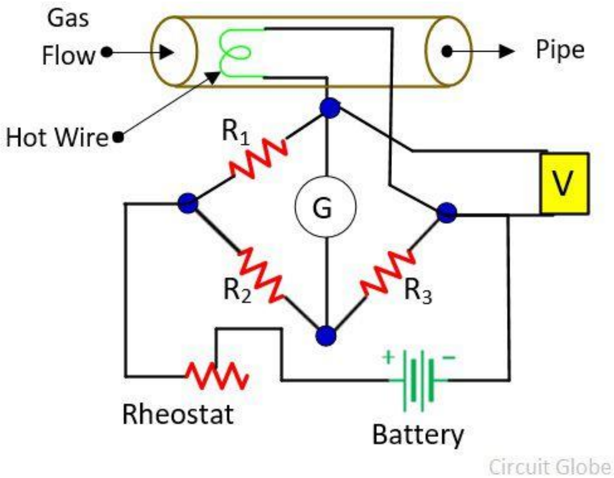
In the constant current method, the anemometer is placed in the stream of the fluid whose flow rate needs to be measured. The current of constant magnitude is passed through the wire. The Wheatstone bridge is also kept on the constant voltage.



When the wire is kept in the stream of liquid, in that case, the heat is transferred from the wire to the fluid. The heat is directly proportional to the resistance of the wire. If heat reduces, that means the resistance of wire also reduces. The Wheatstone bridge measures the variation in resistance which is equal to the flow rate of the liquid.

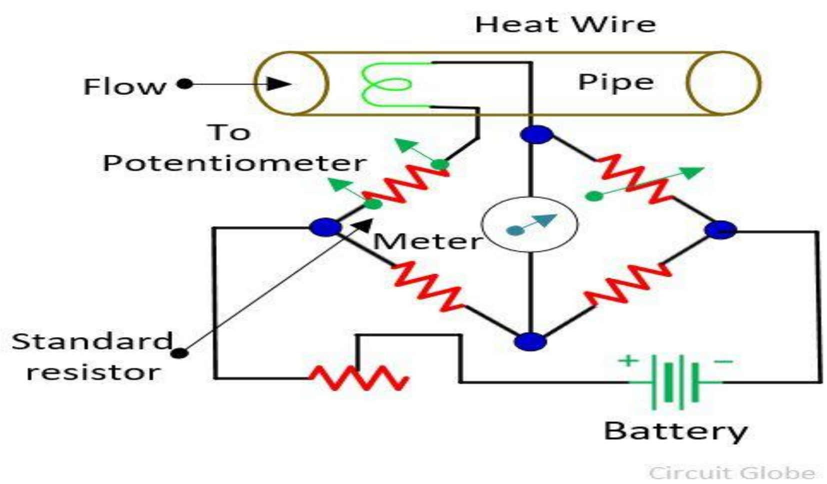
2. Constant Temperature Method

In this arrangement, the wire is heated by the electric current. The hot wire when placed in the fluid stream, the heat transfer from wire to the fluid. Thus, the temperature of the wire changes which also changes their resistance. It works on the principle that the temperature of the wire remains constant. The total current requires to bring the wire in the initial condition is equal to the flow rate of the gas.



Measurement of the rate of a fluid using a Hot Wire Instrument

In hot wire anemometer, the heat transferred electrically to the wire which is placed in the fluid stream. The Wheatstone bridge is used for measuring the temperature of wire regarding their resistance. The temperature of the wire remains constant for measuring the heating current. Thus, the bridge remains balanced.



The standard resistor is connected in series with the heating wire. The current across the wire is determined by knowing the voltage drop across the resistor. And the value of voltage drop is determined by the potentiometer.

The equation determines the heat loss from the heated wire $= a(vp + b)^{1/2} J/s$

Where, v – velocity of heat flow,
ρ – the density of fluid,

The a and b are the constants. Their value depends on the dimension and the physical properties of the fluid and wire.

Suppose I, is the current of the wire and the R is their resistance. In equilibrium condition,

Heat generated = Heat Lost

$$I^2R = a(vp + b)^{1/2}$$

$$v = \frac{\left(I^2R/_{a^2} - b\right)}{\rho}$$

The resistance and temperature of the instrument are kept constant for measuring the rate of the fluid by measuring the current I.

Photoresistor

Photoresistor is the combination of words "photon" (meaning light particles) and "resistor". True to its name, a photo-resistor is a device or we can say a resistor dependent on the light intensity. For this reason, they are also known as light dependent a.k.a. LDRs.

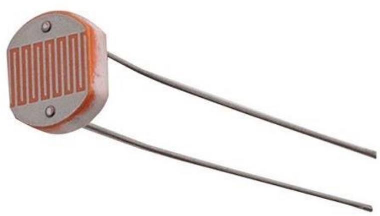
So to define a photo-resistor in a single line we can write it as:

"Photoresistor is a variable resistor whose resistance varies inversely with the intensity of light"

From our basic knowledge about the relationship between resistivity (ability to resist the flow of electrons) and conductivity (ability to allow the flow of electrons), we know that both are polar opposites of each other. Thus when we say that the resistance decreases when intensity of light increases, it simply implies that the conductance increases with increase in intensity of light falling on the photo-resistor or the LDR, owing to a property called photo-conductivity of the material.

Hence these Photoresistors are also known as photoconductive cells or just photocell.

The idea of Photoresistor developed when photoconductivity in Selenium was discovered by Willoughby Smith in 1873. Many variants of the photoconductive devices were then made.

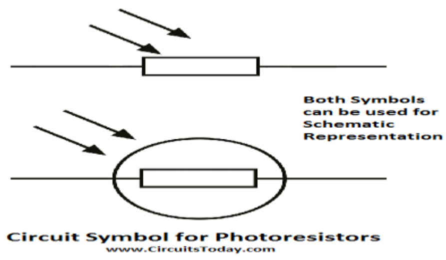


Photoresistor

Photoresistor Symbol

In order to represent a Photoresistor in a circuit diagram, the symbol chosen was that would indicate it to be a light dependent device along with the fact that it is a resistor.

While mostly the symbol used is shown in figure 2a (two arrows pointing to a resistor), some prefer to encase the resistor in a circle like that shown in figure 2b.



Photoresistors Circuit Symbol

Working principle of a Photoresistor

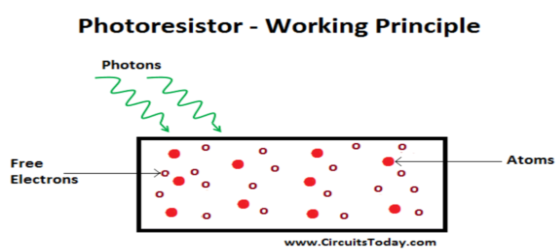
In order to understand the working principle of a Photoresistor, let's brush up a little about the valence electrons and the free electrons.

As we know valence electrons are those found in the outermost shell of an atom. Hence, these are loosely attached to the nucleus of the atom. This means that only some small amount of energy is needed to pull it out from the outer orbit.

Free electrons on the other hand are those which are not attached to the nucleus and hence free to move when an external energy like an electric field is applied. Thus when some energy makes the valence electron pull out from the outer orbit, it acts as a free electron; ready to move whenever an electric field is applied. The light energy is used to make valence electron a free electron.

This very basic principle is used in the Photoresistor. The light that falls on a photoconductive material is absorbed by it which in turn makes lots of free electrons from the valence electrons.

The figure below shows a pictorial representation of the same:



Photoresistor Working Principle

As the light energy falling on the photoconductive material increases, number of valence electrons that gain energy and leave the bonding with the nucleus increases. This leads to a large number of valence electrons jump to the conduction band, ready to move with an application of any external force like an electric field.

Thus, as the light intensity increases, the number of free electrons increases. This means the photoconductivity increases that imply a decrease in photo resistivity of the material.

Now that we have covered the working mechanism, we got an idea that a photoconductive material is used for the construction of a Photoresistor. According to the type of photoconductive material the Photoresistors are of two types. A brief introduction is given in the next section

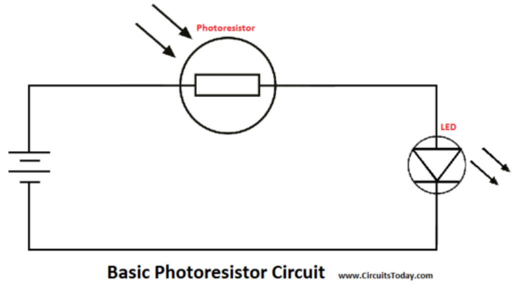
Types of Photoresistor

A Photoresistor is generally made of a semiconductor material that is used as resistive element without any PN junction. This essentially makes Photoresistor a passive device. The two types of Photoresistors are:

1. ***Intrinsic Photoresistor***: As we know, intrinsic is often referred for a semiconductor(in this case a photoconductive material) that is devoid of any doping. This means that the photoconductive material, used to build this Photoresistor involves excitation of charge carriers from the valence bands to the conduction band.
2. ***Extrinsic Photoresistor:*** Extrinsic Photoresistors have semiconductor material with some impurity or we can say they are doped, for better efficiency. The impurity dopants should be shallow and should not get ionised in the presence of light. The photoconductive material used for this Photoresistor involves excitation of charge carriers between an impurity and the valence band or conduction band.

Basic Photoresistor Circuit

The figure below shows a basic circuit diagram of a Photoresistor ciruit. It has a battery, a Photoresistor and a led. This setup helps understand the behaviour of Photoresistor when subjected to an electric field.



Basic Photoresistor Circuit

CASE 1: No light is present on the Photoresistor (say, you covered the Photoresistor completely)

There is no light energy for the Photoresistor to absorb; therefore no free electrons are generated. This means even if the Photoresistor is subjected to an electric field, there is no free electrons that would move and start the flow of current.

What does it mean? Yes, it means the opposition to the flow of current is high or we can say its resistance is very high.

Will the LED bulb get lit? Obviously NO, since no current is flowing through the circuit.
CASE 2: Light falls on the Photoresistor

This is an easy one for you to guess now right?

Here there are photons falling on the Photoresistor, therefore light energy needed to create free electrons is absorbed by it. Now, as the Photoresistor is connected to the battery, the free electrons start moving as they are now subjected to an electric field. Hence, we can say current starts flowing in the circuit.

So what does this imply about the resistance of the Photoresistor?

Yes you guessed it right; this implies that the resistance has decreased significantly allowing the flow of current in the circuit.

Thus the LED in this case would light up.

Next section lets you understand the common uses and applications of a Photoresistor.

Photoresistor – Uses & Applications

Automatic Street Lights: One of the prominent uses of Photoresistor that we experience in daily life is in the circuits of automatic street lights, as already hinted in the introductory paragraph. Here they are so used in a circuit that the street lights turn on as it starts getting dark and turns off in the morning.

Some of the Photoresistors are used in some of the consumer items like ***light meters in camera, light sensors*** like in robotic projects***, clock radios etc.***

They are also used ***to control the reduction in gain*** of dynamic compressors.

They are also considered as a ***good infra-red detector*** and hence find application in infrared astronomy.

Resistance Temperature Detector

A **Resistance Thermometer** or **Resistance Temperature Detector** is a device which used to determine the temperature by measuring the resistance of pure electrical wire. This wire is referred to as a temperature sensor. If we want to measure temperature with high accuracy, **RTD** is the only one solution in industries. It has good linear characteristics over a wide range of temperature.

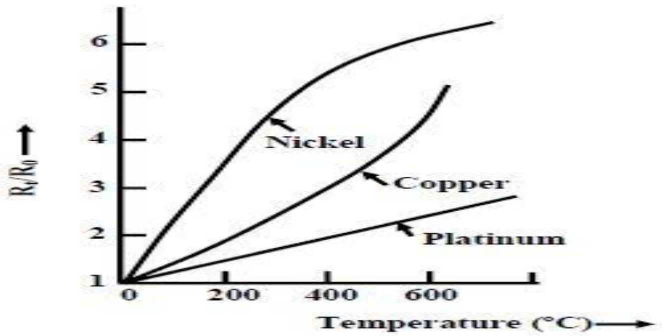
The variation of resistance of the metal with the variation of the temperature is given as,

$$R_t = R_0[1 + (t - t_0) + \beta(t - t_0)^2 + \cdots\cdots]$$

Where, R_t and R_0 are the resistance values at t^oC and $t_0{}^oC$ temperatures. α and β are the constants depends on the metals.

This expression is for huge range of temperature. For small range of temperature, the expression can be,

$$R_t = R_0[1 + (t - t_0)]$$



In **RTD** devices; Copper, Nickel and Platinum are widely used metals. These three metals are having different resistance variations with respective to the temperature variations. That is called resistance-temperature characteristics. Platinum has the temperature range of 650°C, and then the Copper and Nickel have 120°C and 300°C respectively. The figure-1 shows the resistance-temperature characteristics curve of the three different metals. For Platinum, its resistance changes by approximately 0.4 ohms per degree Celsius of temperature.

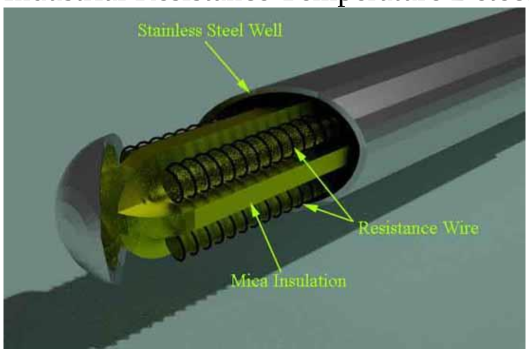
The purity of the platinum is checked by measuring R_{100} / R_0. Because, whatever the materials actually we are using for making the RTD that should be pure. If it will not pure, it will deviate from the conventional resistance-temperature graph. So, α and β values will change depending upon the metals.

Construction of Resistance Temperature Detector or RTD

The construction is typically such that the wire is wound on a form (in a coil) on notched mica cross frame to achieve small size, improving the thermal conductivity to decrease the response time and a high rate of heat transfer is obtained. In the industrial RTD's, the coil is protected by a stainless steel sheath or a protective tube.

So that, the physical strain is negligible as the wire expands and increase the length of wire with the temperature change. If the strain on the wire is increasing, then the tension increases. Due to that, the resistance of the wire will change which is undesirable.So, we don't want to change the resistance of wire by any other unwanted changes except the temperature changes.

This is also useful to RTD maintenance while the plant is in operation. Mica is placed in between the steel sheath and resistance wire for better electrical insulation. Due less strain in resistance wire, it should be carefully wound over mica sheet. The fig.2 shows the structural view of an Industrial Resistance Temperature Detector.



Signal Conditioning of RTD

We can get this RTD in market. But we must know the procedure how to use it and how to make the signal conditioning circuitry. So that, the lead wire errors and other calibration errors can be minimized. In this RTD, the change in resistance value is very small with respect to the temperature. So, the RTD value is measured by using a bridge circuit. By supplying the constant electric current to the bridge circuit and measuring the resulting voltage drop across the resistor, the RTD resistance can be calculated. Thereby, the temperature can be also determined. This temperature is determined by converting the RTD resistance value using a calibration expression. The different modules of RTD are shown in below figures.

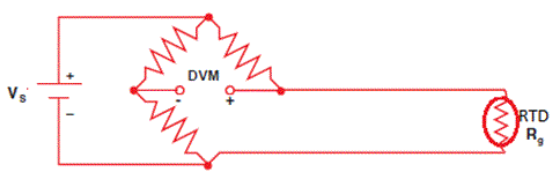


Fig.3. Two wires RTD Bridge

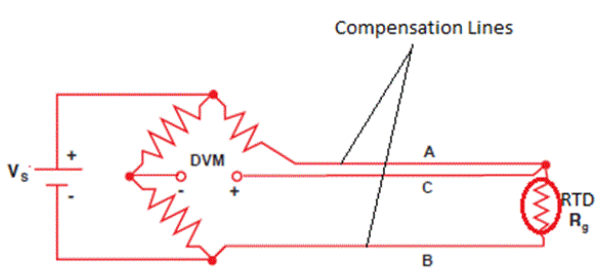
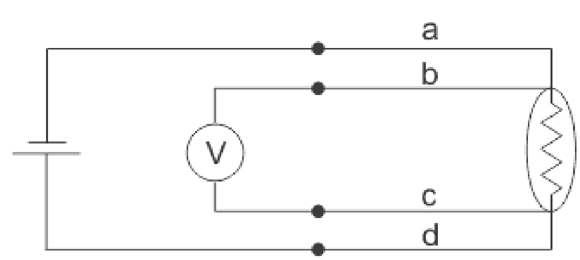


Fig.4. Three wires RTD Bridge



Four wires RTD Bridge

In two wires RTD Bridge, the dummy wire is absent. The output taken from the remaining two ends as shown in fig.3. But the extension wire resistances are very important to be considered, because the impedance of the extension wires may affect the temperature reading. This effect is minimizing in three wires RTD bridge circuit by connecting a dummy wire C. If wires A and B are matched properly in terms of length and cross section area, then their impedance effects will cancel because each wire is in opposite position. So that, the dummy wire C acts as a sense lead to measure the voltage drop across the RTD resistance and it carries no current. In these circuits, the output voltage is directly proportional to the temperature. So, we need one calibration equation to find the temperature.

Expressions for a Three Wires RTD Circuit

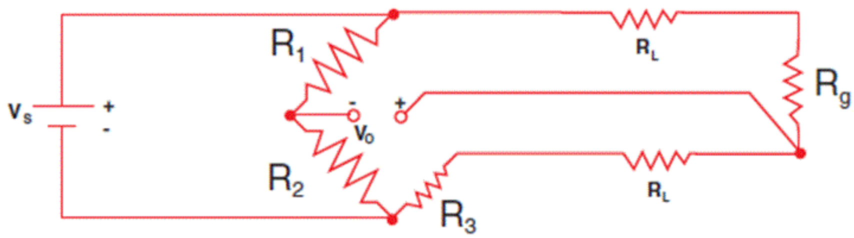


Fig.6. Circuitry view of three wires RTD Bridge

If we know the values of V_S and V_O, we can find R_g and then we can find the temperature value using calibration equation. Now, assume $R_1 = R_2$:

$$V_0 = V_S\left(\frac{R_3}{R_3+R_g}\right) - \left(\frac{V_S}{2}\right)$$

If $R_3 = R_g$; then $V_O = 0$ and the bridge is balanced. This can be done manually, but if we don't want to do a manual calculation, we can just solve the equation 3 to get the expression for R_g.

$$R_g = R_3\left(\frac{V_S-2V_O}{V_S+2V_O}\right)$$

This expression assumes, when the lead resistance $R_L = 0$. Suppose, if R_L is present in a situation, then the expression of R_g becomes,

$$R_g = R_3\left(\frac{V_S-2V_O}{V_S+2V_O}\right) - R_L\left(\frac{4V_O}{V_S+2V_O}\right)$$

So, there is an error in the RTD resistance value because of the R_L resistance. That is why we need to compensated the R_L resistance as we discussed already by connecting one dummy line 'C' as shown in fig.4.

Advantages

- Most stable over time
- Most accurate
- Most repeatable temperature measurement
- Very resistant to contamination/
- corrosion of the RTD element

Disadvantages of RTD

- **High cost**
- **Slowest response time**
- **Low sensitivity to small temperature changes**
- **Sensitive to vibration (strains the platinum element wire)**
- **Decalibration if used beyond sensor’s temperature ratings**
- **Somewhat fragile**

In the RTD resistance, there will be an I^2R power dissipation by the device itself that causes a slight heating effect. This is called as self-heating in RTD. This may also cause an erroneous reading. Thus, the electric current through the **RTD** resistance must be kept sufficiently low and constant to avoid self-heating.

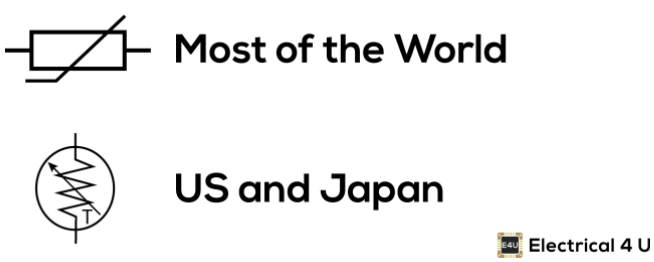
RTD Applications:

- **Air conditioning and refrigeration servicing**
- **Furnace servicing**
- **Foodservice processing**
- **Medical research**
- **Textile production**

Thermistor

A **thermistor** (or **thermal resistor**) is defined as a type of resistor whose electrical resistance varies with changes in temperature. Although all resistors’ resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.

Thermistors act as a passive component in a circuit. They are an accurate, cheap, and robust way to measure temperature. While they do not work well in extremely hot or cold temperatures, they are the sensor of choice for many different applications. They are ideal when a precise temperature reading is required. The circuit symbol for a thermistor is shown below:



Uses of Thermistors

Thermistors have a variety of applications. They are widely used as a way to measure temperature as a thermistor thermometer in many different liquid and ambient air environments. Some of the most common uses of thermistors include:

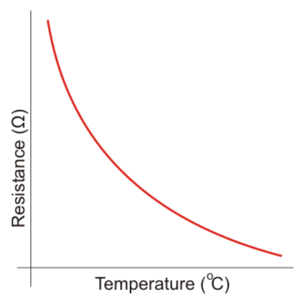
- Digital thermometers (thermostats)
- Automotive applications (to measure oil and coolant temperatures in cars & trucks)

- Household appliances (like microwaves, fridges, and ovens)
- Circuit protection (i.e. surge protection)
- Rechargeable batteries (ensure the correct battery temperature is maintained)
- To measure the thermal conductivity of electrical materials
- Useful in many basic electronic circuits (e.g. as part of a beginner Arduino starter kit)
- Temperature compensation (i.e. maintain resistance to compensate for effects caused by changes in temperature in another part of the circuit)
- Used in wheatstone bridge circuits

Thermistor Working

The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter. If we know the exact relationship between how changes in the temperature will affect the resistance of the thermistor – then by measuring the thermistor's resistance we can derive its temperature.

How much the resistance changes depends on the type of material used in the thermistor. The relationship between a thermistor's temperature and resistance is non-linear. A typical thermistor graph is shown below:



If we had a thermistor with the above temperature graph, we could simply line up the resistance measured by the ohmmeter with the temperature indicated on the graph. By drawing a horizontal line across from the resistance on the y-axis, and drawing a vertical line down from where this horizontal line intersects with the graph, we can hence derive the temperature of the thermistor.

Thermistor Types

There are two types of thermistors:

- Negative Temperature Coefficient (NTC) Thermistor
- Positive Temperature Coefficient (PTC) Thermistor

NTC Thermistor

In an NTC thermistor, when the temperature increases, resistance decreases. And when temperature decreases, resistance increases. Hence in an NTC thermistor temperature and resistance are inversely proportional. These are the most common type of themistor.

The relationship between resistance and temperature in an NTC thermistor is governed by the following expression:

$$R_T = R_0 e^{\beta(\frac{1}{T} - \frac{1}{T_0})} \qquad (1)$$

Where:

- R_T is the resistance at temperature T (K)
- R_0 is the resistance at temperature T_0 (K)
- T_0 is the reference temperature (normally 25ºC)
- β is a constant, its value is dependant on the characteristics of the material. The nominal value is taken as 4000.

If the value of β is high, then the resistor–temperature relationship will be very good. A higher value of β means a higher variation in resistance for the same rise in temperature – hence you have increased the sensitivity (and hence accuracy) of the thermistor.

From the expression (1), we can obtain the resistance temperature co-efficient. This is nothing but the expression for the sensitivity of the thermistor.

$$\alpha_T = \frac{1}{R_T}\frac{dR_T}{dT} = -\frac{\beta}{T^2} \qquad (2)$$

Above we can clearly see that the αT has a negative sign. This negative sign indicates the negative resistance-temperature characteristics of the NTC thermistor.

If β = 4000 K and T = 298 K, then the α_T = –0.0045/ºK. This is much higher than the sensitivity of platinum RTD. This would be able to measure the very small changes in the temperature. However, alternative forms of heavily doped thermistors are now available (at high cost) that have a positive temperature co-efficient. The expression (1) is such that it is not possible to make a linear approximation to the curve over even a small temperature range, and hence the thermistors is very definitely a non-linear sensor.

PTC Thermistor

A PTC thermistor has the reverse relationship between temperature and resistance. When temperature increases, the resistance increases. And when temperature decreases, resistance decreases. Hence in a PTC thermistor temperature and resistance are inversely proportional.

Although PTC thermistors are not as common as NTC thermistors, they are frequently used as a form of circuit protection. Similar to the function of fuses, PTC thermistors can act as current-limiting device.

When current passes through a device it will cause a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings then the device heats up. In a PTC thermistor, this heating up will also cause its resistance will increase. This creates a self-reinforcing effect that drives the resistance upwards, therefore limiting the current. In this way, it acts as a current limiting device – protecting the circuit.

Thermistor Characteristics

The relationship governing the characteristics of a thermistor is given below as:

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

Where:

- R_1 = resistance of the thermistor at absolute temperature T_1[^oK]
- R_2 = resistance of the thermistor at temperature T_2 [^oK]
- β = constant depending upon the material of the transducer

We can see in the equation above that the relationship between temperature and resistance is highly nonlinear. A standard NTC thermistor usually exhibits a negative thermal resistance temperature coefficient of about 0.05/^{o}C.

Thermistor Construction

To make a thermistor, two or more semiconductor powders made of metallic oxides are mixed with a binder to form a slurry. Small drops of this slurry are formed over the lead wires. For drying purpose, we have to put it into a sintering furnace. During this process, that slurry will shrink onto the lead wires to make an electrical connection. This processed metallic oxide is sealed by putting a glass coating on it. This glass coating gives a waterproof property to the thermistors – helping to improve their stability.

There are different shapes and sizes of thermistors available in the market. Smaller thermistors are in the form of beads of diameter from 0.15 millimeters to 1.5 millimeters. Thermistors may also be in the form of disks and washers made by pressing the thermistor material under high pressure into flat cylindrical shapes with diameter from 3 millimeters to 25 millimeters.

Types of Temperature Sensors

The typical size of a thermistor is 0.125mm to 1.5 mm. Commercially available thermistors have nominal values of 1K, 2K, 10K, 20K, 100K, etc. This value indicates the resistance value at a temperature of 25^{o}C.

Thermistors are available in different models: bead type, rod type, disc type, etc. The major advantages of thermistors are their small size and relatively low cost.

This size advantage means that the time constant of thermistors operated in sheaths is small, although the size reduction also decreases its heat dissipation capability and so makes the self-heating effect greater. This effect can permanently damage the thermistor.

To prevent this, thermistors have to be operated at low levels of electric current compared to resistance thermometer – resulting in lower measurement sensitivity.

Thermistor vs RTD

Resistance Temperature Detectors (also known as RTD sensors) are very similar to thermistors. Both RTDs and thermistors have varying resistance dependent on the temperature.
The main difference between the two is the type of material that they are made of. Thermistors are commonly made with ceramic or polymer materials while RTDs are made of pure metals. In terms of performance, thermistors win in almost all aspects.

Thermistors are more accurate, cheaper, and have faster response times than RTDs. The only real disadvantage of a thermistor vs an RTD is when it comes to temperature range. RTDs can measure temperature over a wider range than a thermistor.

Aside from this, there is no reason to use a thermistor over an RTD.

Carbon Microphone

The carbon microphone is not widely used these days, but it has been included here, more for the sake of interest and completeness.

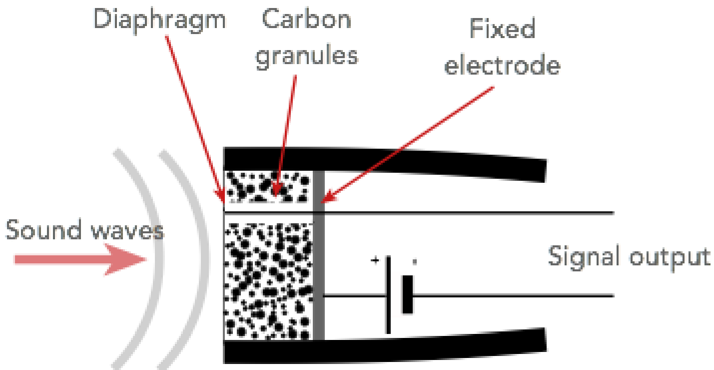
The carbon microphone was developed in the 1870s by Englishman David Edward Hughes. It was the first reliable form of microphone and it was widely used for many years before being supplanted by other types that gave much higher levels of performance.

Carbon microphone working

The basic concept behind the carbon microphone is the fact that when carbon granules are compressed their resistance decreases. This occurs because the granules come into better contact with each other when they are pushed together by the higher pressure.

The carbon microphone comprises carbon granules that are contained within a small contained that is covered with a thin metal diaphragm. A battery is also required to cause a current to flow through the microphone.

When sound waves strike the carbon microphone diaphragm it vibrates, exerting a varying pressure onto the carbon. These varying pressure levels are translated into varying levels of resistance, which in turn vary the current passing through the microphone.



Construction of a carbon microphone

The varying current can be passed through a transformer or a capacitor to enable it to be used within a telephone, or by some form of amplifier.

The frequency response of the carbon microphone, however, is limited to a narrow range, and the device produces significant electrical noise. Often the microphone would produce a form of crackling noise which could be eliminated by shaking it or giving it a small sharp knock. This would shake the carbon granules and enable them to produce a more steady current.

Carbon microphone applications

Carbon microphones were an ideal choice of microphone in the early days of the telephone. They were widely used in telephone applications because they gave a high output which meant no amplification was used.


Carbon microphones were used in telephones like this vintage British GPO 300 series telephone

As radio started to be used, the carbon microphone was initially used there as well – for broadcasting as well as communications purposes. However their use in broadcast applications soon came to end because of the drawbacks of noise and poor frequency response. Other types of microphone started to become available and their use was preferred because of the better fidelity that was available. The use of the carbon microphone persisted for many years for communications purposes as they gave a high output and they were robust. The poor frequency response was not an issue.

The carbon microphone was used for telephones up until the 1970s and 1980s, but even there it became possible to use other types of microphone more conveniently. Also the crackle and noise of the carbon microphone had always been an issue and when other types of microphone became available at a low cost they started t be used, despite the requirement for additional electronics needed.

Carbon microphones are now only used in a very few applications – typically only specialist applications. They are able to withstand high voltage spikes and this property lends itself to use in a small number of applications.

Carbon microphone advantages & disadvantages

Carbon microphone advantages

- High output
- Simple principle & construction
- Cheap and simple to manufacture

Carbon microphone disadvantages

- Very noisy - high background noise and on occasions it would crackle
- Poor frequency response
- Requires battery or other supply for operation