MEASUREMENT

Measurement is the process in which we convert physical quantity into meaningful number. **Electrical measurements** are the methods, devices and calculations used to measure electrical quantities. Measurement of electrical quantities may be done to measure electrical parameters of a system. Using transducers, physical properties such as temperature, pressure, flow, force, and many others can be converted into electrical signals, which can then be conveniently measured and recorded. High-precision laboratory measurements of electrical quantities are used in experiments to determine fundamental physical properties such as the charge of the electron or the speed of light, and in the definition of the units for electrical measurements, with precision in some cases on the order of a few parts per million. Less precise measurements are required every day in industrial practice. Electrical measurements are a branch of the science of meteorology.

Measurable independent and semi-independent electrical quantities comprise:

- Voltage
- Electric current
- Electrical resistance and electrical conductance
- Electrical reactance and susceptance
- Magnetic flux
- Electrical charge by the means of electrometer
- Partial discharge measurement
- Magnetic field by the means of Hall sensor
- Electric field
- Electrical power by the means of electricity meter
- S-matrix by the means of network analyzer (electrical)
- Electrical power spectrum by the means of spectrum analyzer

Measurable dependent electrical quantities comprise:

- Inductance
- Capacitance
- Electrical impedance defined as vector sum of electrical resistance and electrical reactance
- Electrical admittance, the reciprocal of electrical impedance
- Phase between current and voltage and related power factor
- Electrical spectral density
- Electrical phase noise
- Electrical amplitude noise
- Transconductance
- Transimpedance
- Electrical power gain
- Voltage gain
- Current gain
- Frequency

Definition of Instruments:

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc. Generally instruments are classified into two categories in the form of absolute and secondary instrument.

Absolute instrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangent galvanometer.

Secondary instrument

This instrument determines the value of the quantity to be measured directly. Generally, these instruments are calibrated by comparing with another standard secondary instrument. Examples of such instruments are voltmeter, ammeter, and wattmeter etc. Practically secondary instruments are suitable for measurement.

- **Types of secondary instrument**

Indicating instrument

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

Recording instrument

This type of instrument records the magnitude of the quantity to be measured continuously over a specified period of time.

Integrating instrument

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

Electromechanical indicating instrument

For satisfactory operation electromechanical indicating instrument, three forces are necessary. They are

(a) Deflecting force

(b) Controlling force

(c)Damping force

Deflecting force

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.

Controlling force

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

Damping force

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation is quickly, a damping force is necessary. This force is produced by different systems.
(a) Air friction damping
(b) Fluid friction damping
(c) Eddy current damping

MEASURING DEVICES:

1. AMMETER:

An **ammeter** (from **Am**pere **Meter**) is a measuring instrument used to measure the current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the milliampere or micro-ampere range, are designated as *milliammeters* or *microammeters*. Early ammeters were laboratory instruments which relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems. It is generally represented by letter 'A' in a circle.

Types of Ammeter:
Moving Iron
Moving Coil
Dynamometer

Application: The majority of ammeters are either connected in series with the circuit carrying the current to be measured (for small fractional amperes), or have their shunt resistors connected similarly in series. In either case, the current passes through the meter or (mostly) through its shunt. Ammeters must not be connected directly across a voltage source since their internal resistance is very low and excess current would flow. Ammeters are designed for a low voltage drop across their terminals, much less than one volt; the extra circuit losses produced by the ammeter are called its "burden" on the measured circuit. Ordinary Weston-type meter movements can measure only milliamperes at most, because the springs and practical coils can carry only limited currents. To measure larger currents, a resistor called a *shunt* is placed in parallel with the meter. The resistances of shunts is in the integer to fractional milliohm range. Nearly all of the current flows through the shunt, and only a small fraction flows through the meter. This allows the meter to measure large currents. Traditionally, the meter used with a shunt has a full-scale deflection (FSD) of 50 mV, so shunts are typically designed to produce a voltage drop of 50 mV when carrying their full rated current.

2. Voltmeter:

- A **voltmeter** is an instrument used for measuring electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.
- A voltmeter in a circuit diagram is represented by the letter *V* in a circle.
- Voltmeters are made in a wide range of styles. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a multimeter, are standard test instruments used in electrical and electronics work. Any measurement that

can be converted to a voltage can be displayed on a meter that is suitably calibrated; for example, pressure, temperature, flow or level in a chemical process plant.
- General purpose analog voltmeters may have an accuracy of a few percent of full scale, and are used with voltages from a fraction of a volt to several thousand volts. Digital meters can be made with high accuracy, typically better than 1%. Specially calibrated test instruments have higher accuracies, with laboratory instruments capable of measuring to accuracies of a few parts per million. Meters using amplifiers can measure tiny voltages of microvolts or less.

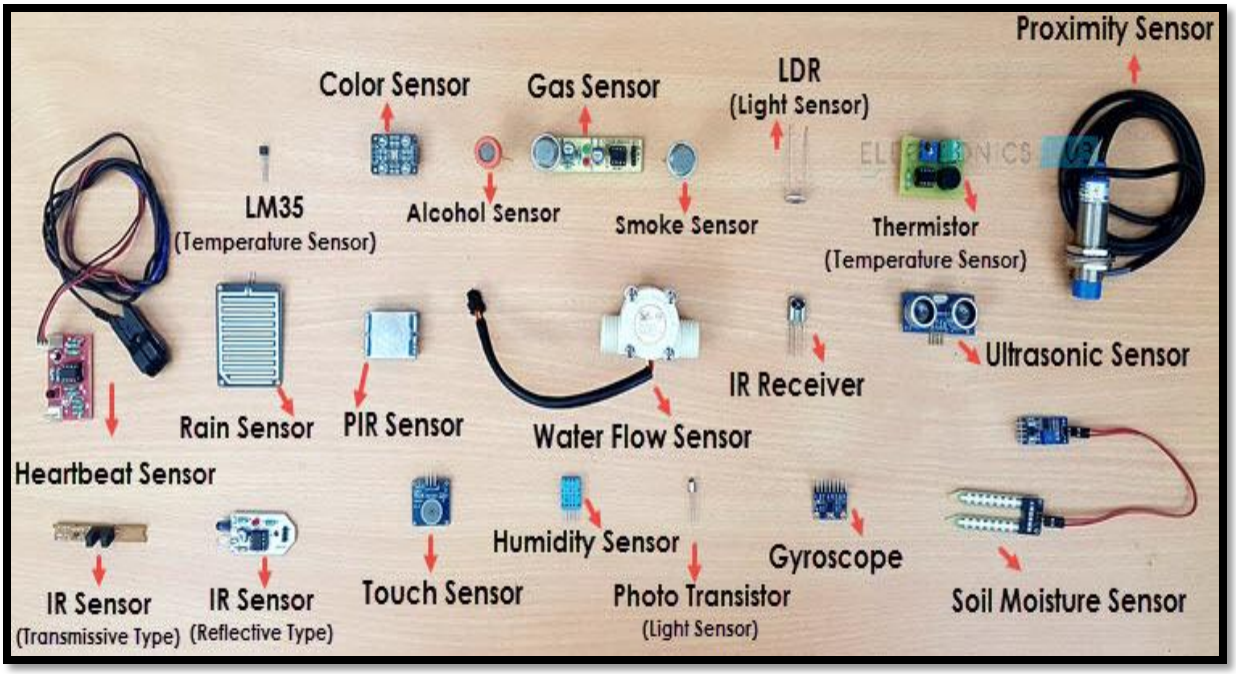
WATTMETER:

The **wattmeter** is an instrument for measuring the electric power (or the supply rate of electrical energy) in watts of any given circuit. Electromagnetic wattmeters are used for measurement of utility frequency and audio frequency power; other types are required for radio frequency measurements. The traditional analog wattmeter is an electrodynamics instrument. The device consists of a pair of fixed coils, known as *current coils*, and a movable coil known as the *potential coil*. The current coils are connected in series with the circuit, while the potential coil is connected in parallel. Also, on analog wattmeter's, the potential coil carries a needle that moves over a scale to indicate the measurement. A current flowing through the current coil generates an electromagnetic field around the coil. The strength of this field is proportional to the line current and in phase with it. The potential coil has, as a general rule, a high-value resistor connected in series with it to reduce the current that flows through it. The result of this arrangement is that on a DC circuit, the deflection of the needle is proportional to *both* the current (I) *and* the voltage (V), thus conforming to the equation $P=VI$. For AC power, current and voltage may not be in phase, owing to the delaying effects of circuit inductance or capacitance. On an AC circuit the deflection is proportional to the average instantaneous product of voltage and current, thus measuring active power, $P=VI \cos \varphi$. Here, $\cos\varphi$ represents the power factor which shows that the power transmitted may be less than the apparent power obtained by multiplying the readings of a voltmeter and ammeter in the same circuit.

ELECTRICAL SENSOR:

What is a Sensor?

There are numerous definitions as to what a sensor is but I would like to define a Sensor as an input device which provides an output (signal) with respect to a specific physical quantity (input). The term “input device” in the definition of a Sensor means that it is part of a bigger system which provides input to a main control system (like a Processor or a Microcontroller). Another unique definition of a Sensor is as follows: It is a device that converts signals from one energy domain to electrical domain. The definition of the Sensor can be understood if we take an example in to consideration.



The simplest example of a sensor is an LDR or a Light Dependent Resistor. It is a device, whose resistance varies according to intensity of light it is subjected to. When the light falling on an LDR is more, its resistance becomes very less and when the light is less, well, the resistance of the LDR becomes very high. We can connect this LDR in a voltage divider (along with other resistor) and check the voltage drop across the LDR. This voltage can be calibrated to the amount of light falling on the LDR. Now that we have seen what a sensor is, we will proceed further with the classification of Sensors.

Classification of Sensors:

There are several classifications of sensors made by different authors and experts. Some are very simple and some are very complex. The following classification of sensors may already be used by an expert in the subject but this is a very simple classification of sensors. In the first classification of the sensors, they are divided in to Active and Passive. Active Sensors are those

which require an external excitation signal or a power signal. Passive Sensors, on the other hand, do not require any external power signal and directly generates output response.
The other type of classification is based on the means of detection used in the sensor. Some of the means of detection are Electric, Biological, and Chemical, Radioactive etc. The next classification is based on conversion phenomenon i.e. the input and the output. Some of the common conversion phenomena are Photoelectric, Thermoelectric, Electrochemical, Electromagnetic, Thermo optic, etc. The final classification of the sensors is Analog and Digital Sensors. Analog Sensors produce an analog output i.e. a continuous output signal with respect to the quantity being measured. Digital Sensors, in contrast to Analog Sensors, work with discrete or digital data. The data in digital sensors, which is used for conversion and transmission, is digital in nature.

Different Types of Sensors

The following is a list of different types of sensors that are commonly used in various applications. All these sensors are used for measuring one of the physical properties like Temperature, Resistance, Capacitance, Conduction, Heat Transfer etc.

- Temperature Sensor
- Proximity Sensor
- Accelerometer
- IR Sensor (Infrared Sensor)
- Pressure Sensor
- Light Sensor
- Ultrasonic Sensor
- Smoke, Gas and Alcohol Sensor
- Touch Sensor
- Color Sensor
- Humidity Sensor
- Tilt Sensor
- Flow and Level Sensor

We will see about few of the above mentioned sensors in brief.

Temperature Sensor

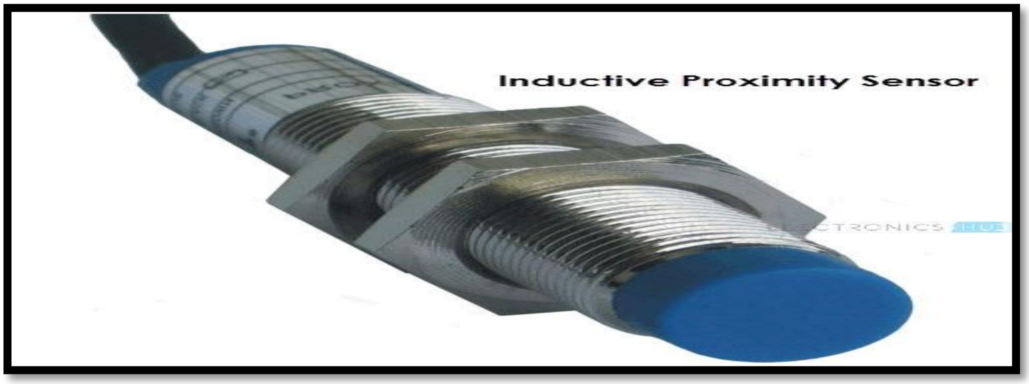
One of the most common and most popular sensors is the Temperature Sensor. A Temperature Sensor, as the name suggests, senses the temperature i.e. it measures the changes in the temperature.

LM35 - Temperature Sensor IC   10KΩ NTC Thermistor

In a Temperature Sensor, the changes in the Temperature correspond to change in its physical property like resistance or voltage. There are different types of Temperature Sensors like Temperature Sensor ICs (like LM35), Thermostats, Thermocouples, RTD (Resistive

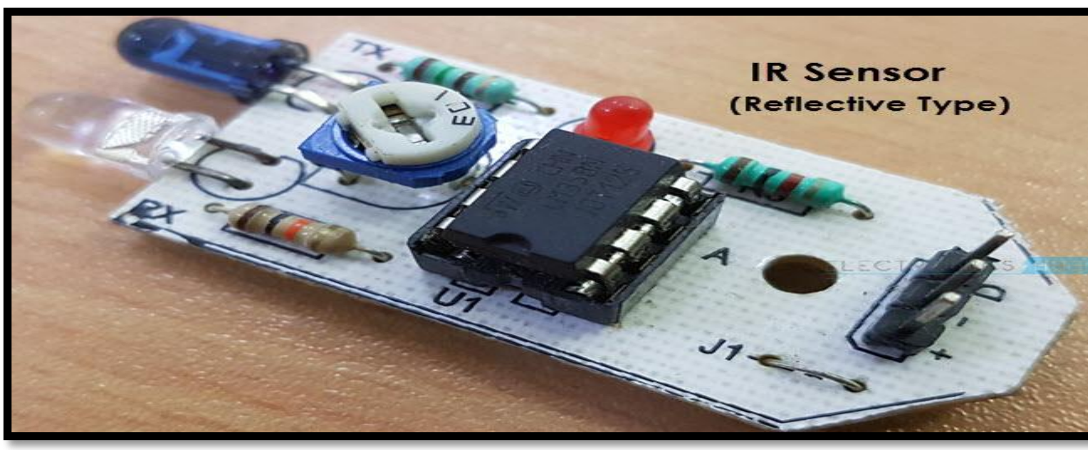
Temperature Devices), etc. Temperature Sensors are used everywhere like computers, mobile phones, automobiles, air conditioning systems, industries etc.

Proximity Sensors:
A Proximity Sensor is a non-contact type sensor that detects the presence of an object. Proximity Sensors can be implemented using different techniques like Optical (like Infrared or Laser), Ultrasonic, Hall Effect, Capacitive, etc.



Some of the applications of Proximity Sensors are Mobile Phones, Cars (Parking Sensors), industries (object alignment), Ground Proximity in Aircrafts, etc.

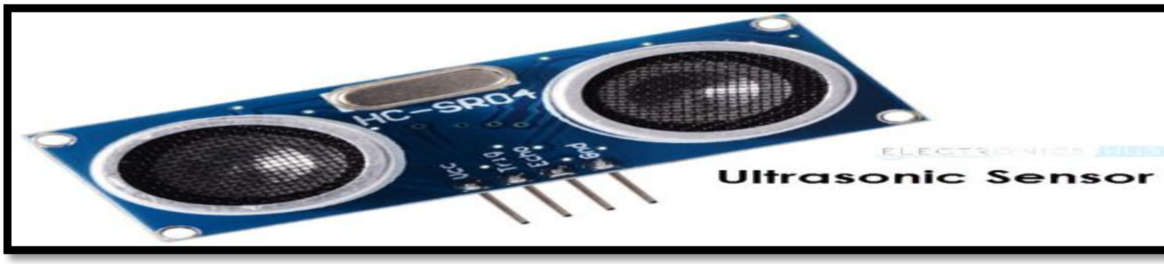
Infrared Sensor (IR Sensor)
IR Sensors or Infrared Sensor are light based sensor that are used in various applications like Proximity and Object Detection. IR Sensors are used as proximity sensors in almost all mobile phones.



There are two types of Infrared or IR Sensors: Transmissive Type and Reflective Type. In Transmissive Type IR Sensor, the IR Transmitter (usually an IR LED) and the IR Detector (usually a Photo Diode) are positioned facing each other so that when an object passes between them, the sensor detects the object. The other type of IR Sensor is a Reflective Type IR Sensor. In this, the transmitter and the detector are positioned adjacent to each other facing the object. When an object comes in front of the sensor, the sensor detects the object.
Different applications where IR Sensor is implemented are Mobile Phones, Robots, Industrial assembly, automobiles etc.

Ultrasonic Sensor:

An Ultrasonic Sensor is a non-contact type device that can be used to measure distance as well as velocity of an object. An Ultrasonic Sensor works based on the properties of the sound waves with frequency greater than that of the human audible range.

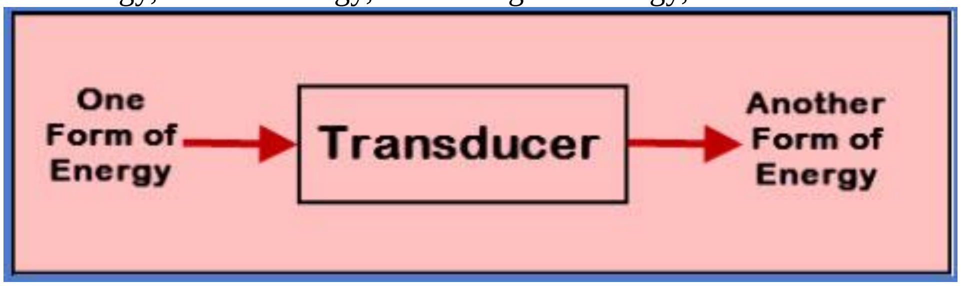


Using the time of flight of the sound wave, an Ultrasonic Sensor can measure the distance of the object (similar to SONAR). The Doppler Shift property of the sound wave is used to measure the velocity of an object.

TRANSDUCER

What is a Transducer?

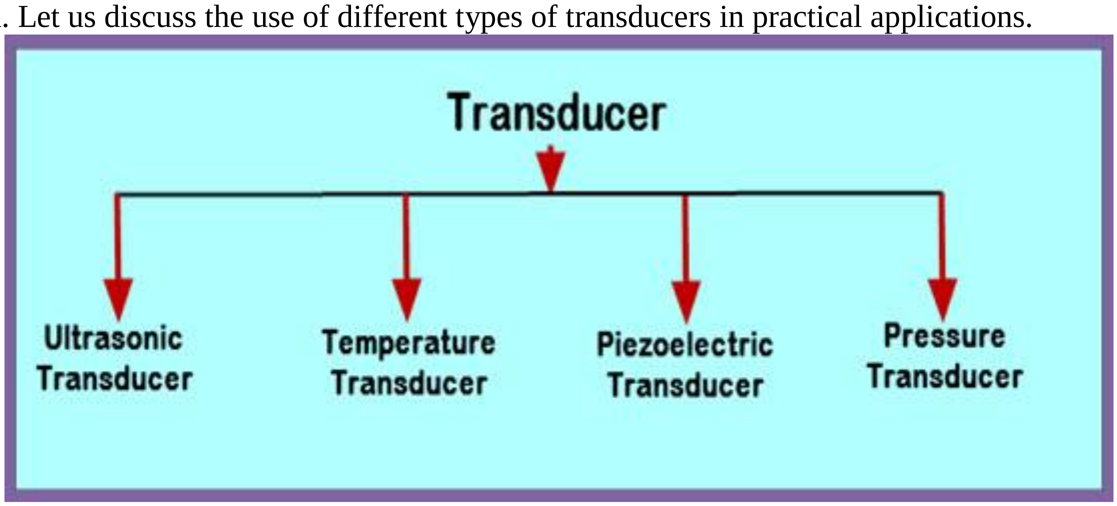
A transducer is an electrical device which is used to convert one form of energy into another form and also convert non-electrical quantity into electrical quantity. In general, these devices deal with different types of energies such as mechanical, electrical energy, light energy, chemical energy, thermal energy, acoustic energy, electromagnetic energy, and so on.



For instance, consider a mic we use in daily life in telephones, mobile phones, that converts the sound into electrical signals and then amplifies it into the preferred range. Then, alters the electrical signals into audio signals at the o/p of the loudspeaker. Nowadays, fluorescent bulbs are used for lighting, changes the electrical energy into light energy. The best examples of the transducer are mic, fluorescent bulb and speaker can be considered as a transducer. Likewise, there are different kinds of transducers used in electrical and electronic projects.

Transducer Types and Its Applications

There are a variety of transducer types like resistive, inductive and capacitive transducer, pressure transducer, piezoelectric transducer, ultrasonic transducer, temperature transducer, and so on. Let us discuss the use of different types of transducers in practical applications.

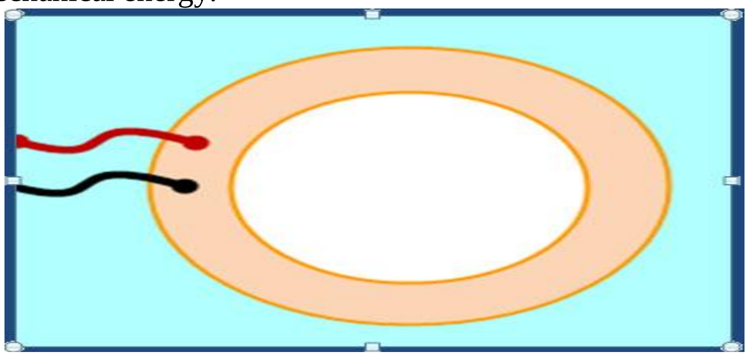


Transducer Types

Some transducer types like active transducer and passive transducers are based on whether a power source is required or not. Active transducer doesn't require any power source for their operations. These transducers work on the principle of energy conversion. They generate an electrical signal that is proportional to the i/p. The best example of this transducer is thermocouple. Whereas passive transducer requires an external power source for their operation. They generate an o/p in the form of capacitance, resistance. Than that has to be converted to an equivalent voltage or current signal. The best example of passive transducer is a photocell.

Piezoelectric Transducer

Piezoelectric transducer is a special kind of sensor, and the main function of this transducer is to convert mechanical energy into electrical energy. In the same way, electrical energy can be transformed into mechanical energy.

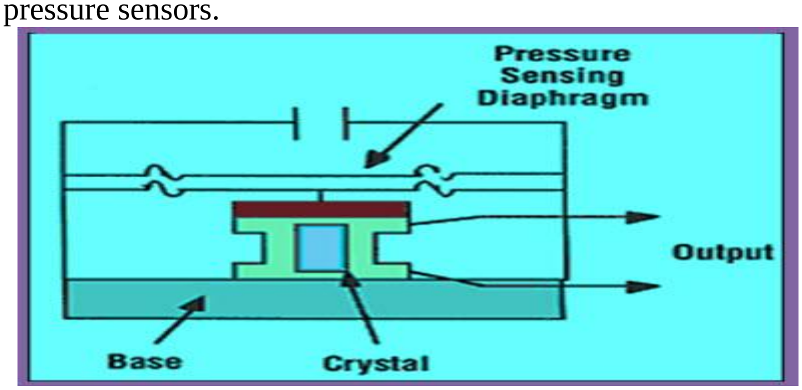


This transducer is mainly used to detect the sticks drummer impact in electronic drum pads and also used to detect the movement of the muscle, which can be named as acceleromyography.

The load of the engine can be determined by calculating diverse absolute pressure that can be done by using these transducers as the MAP sensor in fuel injection systems. This sensor can be used as knock sensor in automotive engine management systems for noticing knock of the engine.

Pressure Transducer

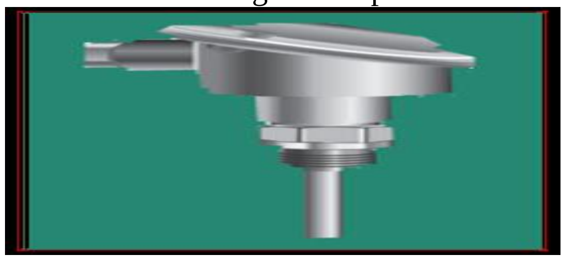
Pressure transducer is a special kind of sensor that alters the pressure forced into electrical signals. These transducers are also called as pressure indicators, manometers, piezometers, transmitters, and pressure sensors.



Pressure transducer is used to measure the pressure of the specific quantity like gas or liquid by changing the pressure into electrical energy. The different kinds of these transducers like an amplified voltage transducer, strain-gage base pressure transducer, millivolt (mv) pressure transducer, 4-20mA pressure transducer and pressure transducer. The applications of pressure transducer mainly involve in altitude sensing, pressure sensing, level or depth sensing, flow sensing and leak testing. These transducers can be used for generating an electrical power under the speed breakers on the highways or roads where the force of the vehicles can be converted into electrical energy.

Temperature Transducer:

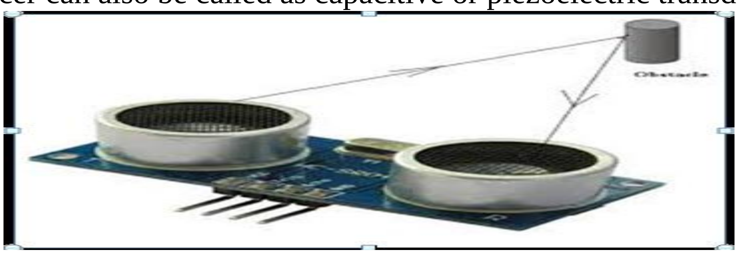
Temperature transducer is an electrical device that is used to convert the temperature of a device into another quantity like electrical energy or pressure or mechanical energy, then the quantity will be sent to the control device for controlling the temperature of the device.



Temperature transducer is used to measure the temperature of the air such that to control the temperature of several control systems like air-conditioning, heating, ventilation, and so on. Let us consider a practical example for temperature transducer that is used to control the temperature of any device based on necessity for different industrial applications. An Arduino based automatic fan speed regulator controlling of temperature and exhibiting measure of temperature on an LCD display.

Ultrasonic Transducer

The main function of the ultrasound transducer is to convert electrical signals to ultrasound waves. This transducer can also be called as capacitive or piezoelectric transducers.



This transducer can be used to measure the distance of the sound based on reflection. This measurement is based on a suitable method compared to the straight methods which use different measuring scales. The areas which are hard to find, such as pressure areas, very high temperature, using conventional methods the measurement of the distance is not a simple task. So, this transducer based measuring system can be used in this kind of zone.

Transducer Characteristics:

The characteristics of a transducer are given below that are determined by examining the o/p response of a transducer to a variety of i/p signals. Test conditions create definite operating conditions as closely as possible. The methods of computational and standard statistical can be applied to the test data.

Accuracy
Precision
Resolution
Sensitivity
Drift
Linearity
Conformance
Span
Hysteresis
Distortion

Noise