Introduction to Sensors and Transducers

We are Analog World with Digital means of communication and control Mechanical objects with Electrical signals. This is because of devices like sensors and transducers, which help us in converting data or information from one domain to other.

Measurement is an important subsystem in any major system, whether it may be a mechanical system or an electronic system. A measurement system consists of sensors, actuators, transducers and signal processing devices. The use of these elements and devices is not limited to measuring systems.

These are also used in the systems which perform specific tasks, to communicate with the real world. The communication can be anything like reading the status of a signal from a switch or to trigger a particular output to light up an LED.

Sensor and Transducer Definitions

The sensor is an element that produces signals relating to the quantity that is being measured. A sensor is a device that detects changes and events in a physical stimulus and provides a corresponding output signal that can be measured and/or recorded. Here, the output signal can be any measurable signal and is generally an electrical quantity.

Sensors are devices that perform input function in a system as they 'sense' the changes in a quantity. The best example of a sensor is mercury thermometer. The measured temperature is converted to a readable value on the calibrated glass tube, based on the expansion and contraction of liquid mercury.

Actuators are devices that work opposite to sensors. A sensor converts a physical event into an electrical signal, whereas an actuator converts electrical signal into a physical event. When sensors are used at input of a system, actuators are used to perform output function in a system as they control an external device.

Transducers are the devices that convert energy in one form into another form. Generally, the energy is in the form of a signal. Transducer is a term collectively used for both sensors and actuators.

Criteria to Choose a Sensor

The following are certain features that are considered when choosing a sensor.

1. **Type of Sensing:** The parameter that is being sensed like temperature or pressure.
2. **Operating Principle:** The principle of operation of the sensor.
3. **Power Consumption:** The power consumed by the sensor will play an important role in defining the total power of the system.
4. **Accuracy:** The accuracy of the sensor is a key factor in selecting a sensor.

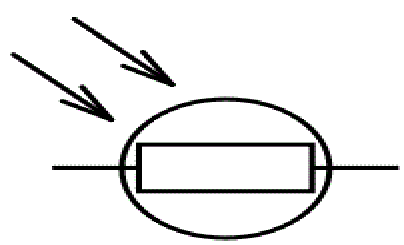
5. **Environmental Conditions:** The conditions in which the sensor is being used will be a factor in choosing the quality of a sensor.
6. **Cost:** Depending on the cost of application, a low-cost sensor or high cost sensor can be used.
7. **Resolution and Range:** The smallest value that can be sensed and the limit of measurement are important.
8. **Calibration and Repeatability:** Change of values with time and ability to repeat measurements under similar conditions.

Basic charecteristics of a Sensor or Transducer
The basic requirements of a sensor are:

1. **Range:** It indicates the limits of the input in which it can vary. In case of temperature measurement, a thermocouple can have a range of 25 – 2500C.
2. **Accuracy:** It is the degree of exactness between actual measurement and true value. Accuracy is expressed as percentage of full range output.
3. **Sensitivity:** Sensitivity is a relationship between input physical signal and output electrical signal. It is the ratio of change in output of the sensor to unit change in input value that causes change in output.
4. **Stability:** It is the ability of the sensor to produce the same output for constant input over a period of time.
5. **Repeatability:** It is the ability of the sensor to produce same output for different applications with same input value.
6. **Response Time:** It is the speed of change in output on a stepwise change in input.
7. **Linearity:** It is specified in terms of percentage of nonlinearity. Nonlinearity is an indication of deviation of curve of actual measurement from the curve of ideal measurement.
8. **Ruggedness:** It is a measure of the durability when the sensor is used under extreme operating conditions.
9. **Hysteresis:** The hysteresis is defined as the maximum difference in output at any measurable value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Hysteresis is a characteristic that a transducer has in being unable to repeat its functionality faithfully when used in the opposite direction of operation.

10. A **Light Dependent Resistor** (also known as a photoresistor or LDR) is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light-sensitive devices. They are also called as photoconductors, photoconductive cells or simply photocells.

They are made up of semiconductor materials that have high resistance. There are many different symbols used to indicate a photoresistor or LDR, one of the most commonly used symbol is shown in the figure.



The arrow indicates light falling on it.

Symbol of a Photoresistor (or LDR)

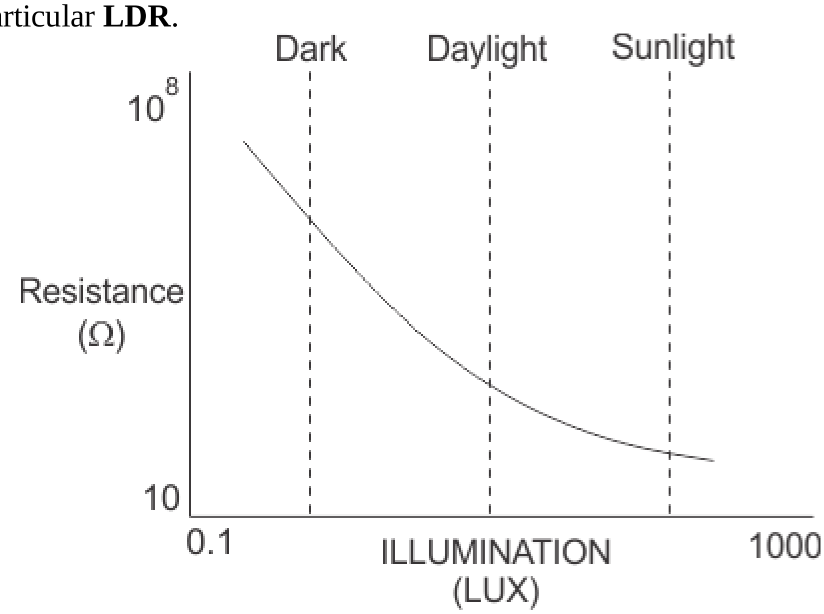
Photoresistors work based on the principle of photoconductivity. Photoconductivity is an optical phenomenon in which the material's conductivity is increased when light is absorbed by the material.

When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the bandgap of the semiconductor material to make the electrons jump from the valence band to the conduction band.

Hence when light having enough energy strikes on the device, more and more electrons are excited to the conduction band which results in many charge carriers. The result of this process is more and more current starts flowing through the device when the circuit is closed and hence it is said that the resistance of the device has been decreased.

Characteristics of Photoresistor (LDR)

Photoresistor LDR's are light-dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as 1012 Ω and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and the intensity of light is increased the current starts increasing. The figure below shows the resistance vs. illumination curve for a particular **LDR**.



Photocells or LDR's are nonlinear devices. Their sensitivity varies with the wavelength of light incident on them. Some photocells might not at all response to a certain range of wavelengths. Based on the material used different cells have different spectral response curves.

When light is incident on a photocell it usually takes about 8 to 12 ms for the change in resistance to take place, while it takes one or more seconds for the resistance to rise back again to its initial value after removal of light. This phenomenon is called a resistance
recovery rate. This property is used in audio compressors.

Also, **LDR**'s are less sensitive than photodiodes and phototransistors. (A photo diode and a photocell (LDR) are not the same, a photodiode is a pn junction semiconductor device that converts light to electricity, whereas a photocell is a passive device, there is no pn junction in this nor it "converts" light to electricity).

Types of Light Dependent Resistors (LDRs or Photoresistors)

Photoresistors (LDRs) can be categorized into two types depending on the materials used to construct them. The two types of photoresistors include:

1. **Intrinsic photoresistors** (Undoped semiconductor): These are made of pure semiconductor materials such as silicon or germanium. Electrons get excited from valance band to conduction band when photons of enough energy fall on it and the number charge carriers are increased.
2. **Extrinsic photoresistors**: These are semiconductor materials doped with impurities which are called dopants. These dopants create new energy bands above the valence band which is filled with electrons. Hence this reduces the bandgap and less energy is required in exciting them. Extrinsic photo resistors are generally used for long wavelengths.

Temperature Sensors

Temperature Sensors can detect a change in physical quantity that corresponds to temperature change. The physical quantity can be anything like resistance or voltage. Electrical to thermal energy-based sensors use the heating effect of a current through a conductor. Thermal to electrical energy-based sensors will require a temperature difference to operate.

Resistive Sensors

Thermistors

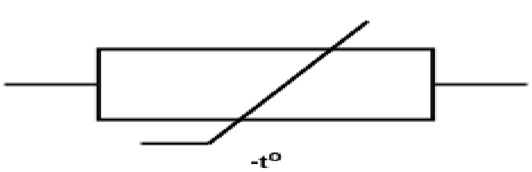
Thermistors are thermally sensitive resistors. In thermistors, the electrical resistance changes according to their temperature. They are made of a combination of two or three metal oxides with zinc oxide among one of them. This combination is inserted in a ceramic base which is an insulator.

Thermistors are available in two types based on temperature coefficient:

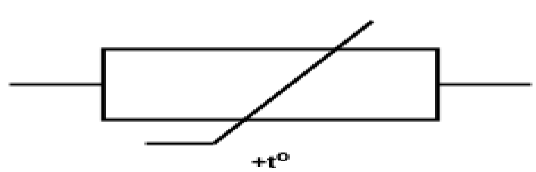
1) Positive temperature coefficient thermistors and
2) Negative temperature coefficient thermistors.

In case of **positive temperature** coefficient thermistors, resistance and temperature are directly proportional to each other i.e. the resistance increases as the temperature rises.

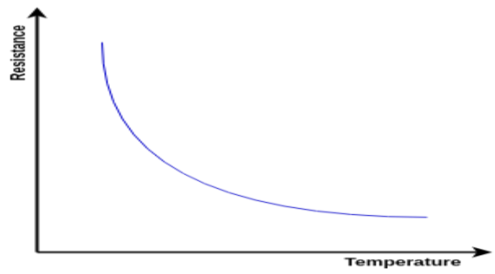
Negative temperature coefficient thermistors, resistance and temperature are inversely proportional to each other i.e. the resistance decreases as the temperature rises. Negative temperature coefficient thermistors provide a higher degree of sensitivity and are available in small configurations for rapid thermal response. NTC are made of ceramics and polymers. Materials like cobalt, nickel, iron, and copper oxides are used.



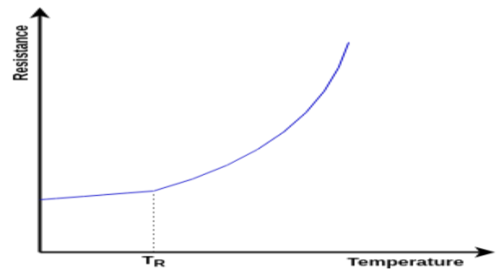
NTC Thermistor



PTC Thermistor



NTC Characteristics



PTC Characteristics

Applications of thermistors

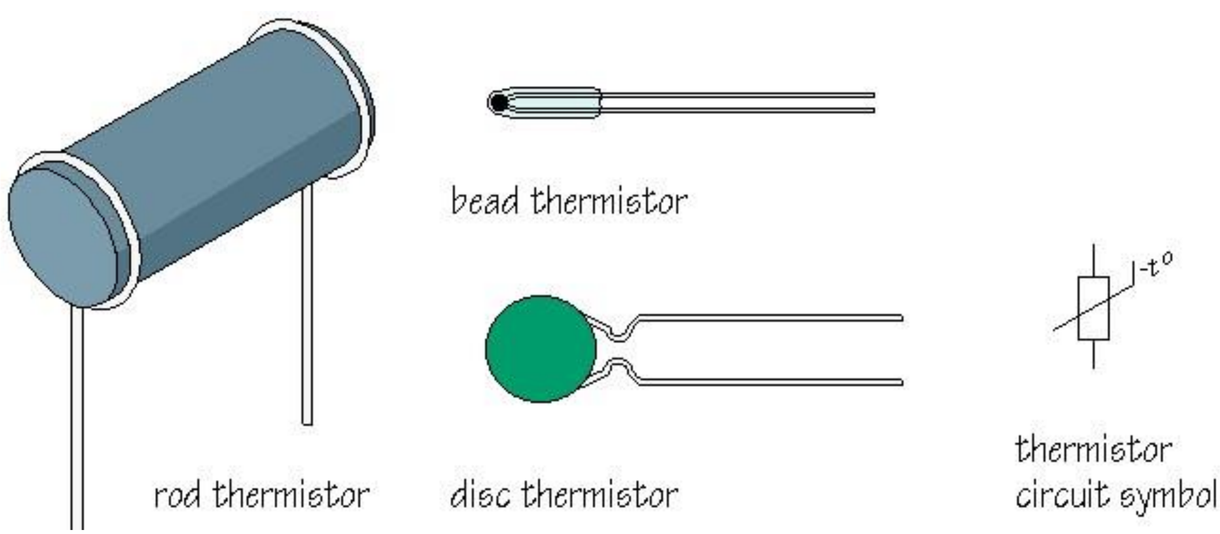
NTC Thermistor Application

- Digital Thermostats.
- Thermometers.
- Battery pack temperature monitors.
- In-rush-current limiting devices

PTC Thermistor Application

- Over-current protection
- In-rush-current protection

Thermistors are available that perform temperature measurement from -73 to 316°C (-100 to 600°F). It should be noted that many have limited ranges and cannot be used above 120°C (250°F).



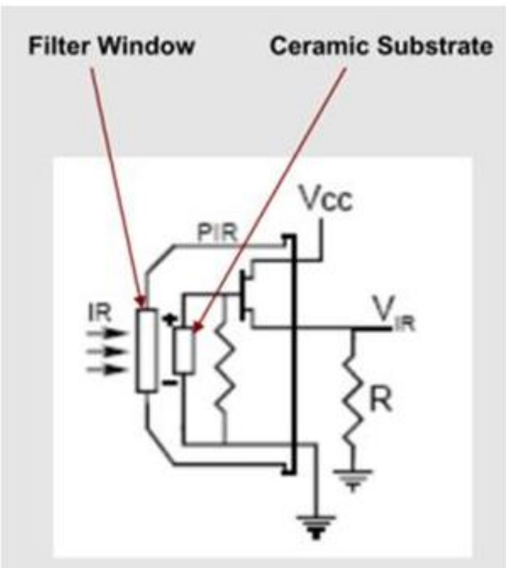
Motion Sensor

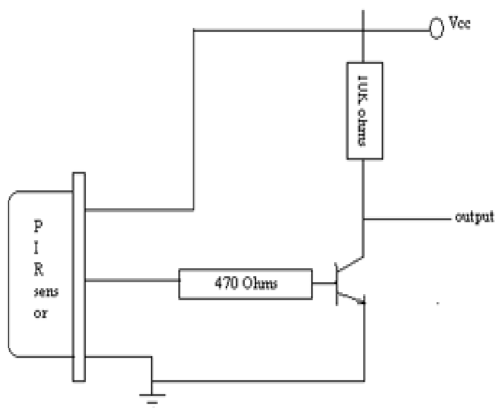
Active ultrasonic sensors and passive infrared sensors are the two most common motion sensor technologies, both of which are known for their accuracy and reliability.

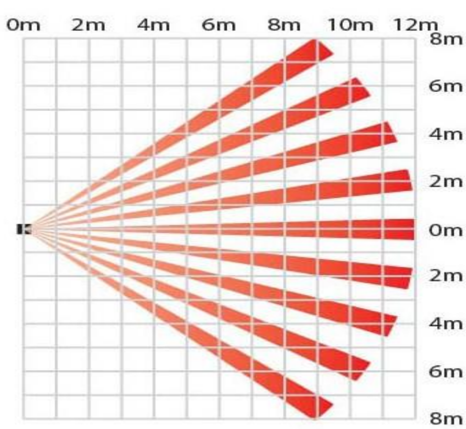
PIR Sensor

The PIR sensors are of two types:-
Thermal Infrared Sensors- Thermal Infrared sensors (IR Sensors) or Pyroelectric Infrared sensors (IR Sensors) use Infrared as the source of heat energy for the detection of objects and their sensitivity is independent of the wavelength. These sensors are slow with their detection time and responsiveness.
Quantum Infrared sensors- Quantum sensors detect photons and are dependent on the wavelength and are highly sensitive than those sensing heat. These sensors are fast in their detection time and responsiveness but require frequent cooling for precise measurement.

PIR sensor detects a human being moving around within approximately 10m from the sensor. This is an average value, as the actual detection range is between 5m and 12m.PIR are fundamentally made of a pyro electric sensor, which can detect levels of infrared radiation. For numerous essential projects or items that need to discover when an individual has left or entered the area. PIR sensors are incredible, they are flat control and minimal effort, have a wide lens range, and are simple to interface with.







Working Principle of PIR motion sensor

All the objects, living things having a temperature more than absolute zero emit infrared radiations in their surroundings. Warmer the object, more the infrared radiations are emitted.

The Passive Infrared sensor is a thermal infrared sensor (IR Sensor) which detects the motion of objects on reading these infrared radiations' variations in its nearby environment.

The sensor has two equal slots made up of Pyroelectric material that is very sensitive to Infrared. When the sensor is not active, both its slots sense the same amount of Infrared radiations coming from any object, door or wall, etc.

When a warm body comes in the range of the PIR motion sensor, it passes through both the slots one after the other. The moment it intercepts the first half of the sensor, a positive differential change is caused between the two halves. Similarly, when it leaves the detection area a negative differential change occurs between both the slots. These changes in the pulses are the indication to the sensor that there is some motion in its detecting zone.

Advantages of PIR Motion Sensors

1. PIR motion sensors can detect moving objects even in dark with great accuracy.
2. PIR sensors can detect the motion of objects without coming in contact with them.
3. They are very easy to install and do not require much wiring.
4. They reduce a lot of human efforts by making things to work automatically.
5. They consume very less energy and thus reduce electricity bills a lot.

Disadvantages of PIR Motion Sensors

1. PIR motion sensors are a bit costly and can not be afforded by a majority of people.
2. Passive Infrared Sensors sometimes behave abnormally during bad weather conditions.
3. PIR sensors sometimes become incapable of detecting a very slow-moving object.
4. Home security systems with PIR motion detectors sometimes trigger false alarms due to no reason.
5. PIR motion sensors have a very short detection range and thus sometimes it leads to a loophole in Burglar alarm systems because of incomplete coverage issue.

Applications

- Burglar Alarm Systems or Intrusion Detection System
- Automated Home Appliances
- Automated Doors
- Parking Areas
- Automated Lightings
- IR Thermometers
- Night Vision Cameras
- Gas Analyzers
- Moisture Analyzers
- Smoke and Fire Detectors

Gas Sensor

A gas sensor is a device which detects the presence or concentration of gases in the atmosphere. Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage. Based on this voltage value the type and concentration of the gas can be estimated.

The type of gas the sensor could detect depends on the sensing material present inside the sensor. Normally these sensors are available as modules with comparators as show. These comparators can be set for a particular threshold value of gas concentration. When the concentration of the gas exceeds this threshold, the digital pin goes high. The analog pin can be used to measure the concentration of the gas

Different Types of Gas sensors

Gas sensors are typically classified into various types based on the type of the sensing element it is built with. Below is the classification of the various types of gas sensors based on the sensing element that are generally used in various applications:

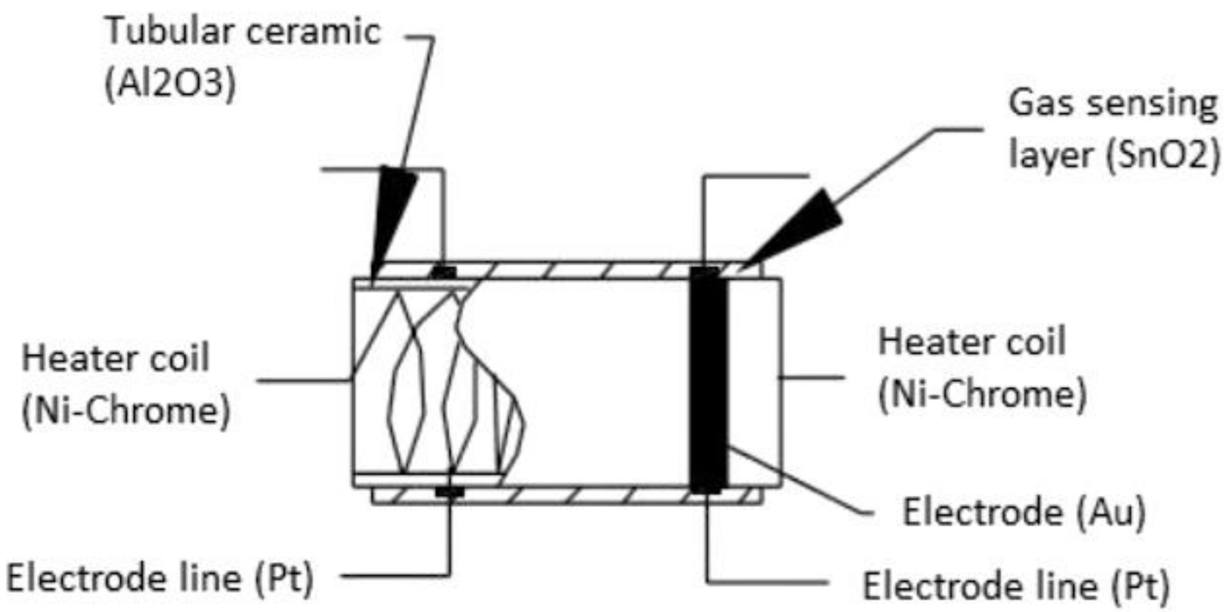
- **Metal Oxide based gas Sensor.**
- **Optical gas Sensor.**
- **Electrochemical gas Sensor.**
- **Capacitance-based gas Sensor.**
- **Calorimetric gas Sensor.**
- **Acoustic based gas Sensor.**

Gas Sensor Construction

Of all the above-listed types, the most commonly used gas sensor is the Metal oxide semiconductor-based gas sensor. All Gas sensors will consist of a sensing element which comprises of the following parts.

- Gas sensing layer
- Heater Coil
- Electrode line
- Tubular ceramic
- Electrode

The below image illustrates the parts present in a metal oxide gas sensor



The purpose of each of these elements is as below:

Gas sensing layer:
It is the main component in the sensor which can be used to sense the variation in the concentration of the gases and generate the change in electrical resistance. The gas sensing layer is basically a chemiresistor which changes its resistance value based on the concentration of gas in the environment. Here the sensing element is made up of a Tin Dioxide (SnO_2) which is, in general, has excess electrons (donor element). So whenever toxic gases are being detected the resistance of the element changes and the current flown through it varies which represents the change in concentration of the gases.

Heater coil:
The purpose of the heater coil is to burn-in the sensing element so that the sensitivity and efficiency of the sensing element increases. It is made of Nickel-Chromium which has a high melting point so that it can stay heated up without getting melted.

Electrode line:
As the sensing element produces a very small current when the gas is detected it is more important to maintain the efficiency of carrying those small currents. So, Platinum wires come into play where it helps in moving the electrons efficiently.

Electrode:
It is a junction where the output of the sensing layer is connected to the Electrode line. So that the output current can flow to the required terminal. An electrode here is made of Gold (Au–Aurum) which is a very good conductor.

Tubular ceramic:
In between the Heater coil and Gas sensing layer, the tubular ceramic exists which is made of Aluminum oxide (Al_2O_3). As it has high melting point, it helps in maintaining the burn-in (preheating) of the sensing layer which gives the high sensitivity for the sensing layer to get efficient output current.

Mesh over the sensing element:
To protect the sensing elements and the setup, a metal mesh is used over it, which is also used to avoid/hold the dust particles entering into the mesh and prevent damaging the gas sensing layer from corrosive particles.

Gas Sensor Working

The ability of a Gas sensor to detect gases depends on the chemiresister to conduct current. The most used chemiresistor is Tin Dioxide (SnO_2) which is an n-type semiconductor that has free electrons (also called as donor). Normally the atmosphere will contain more oxygen than combustible gases. The oxygen particles attract the free electrons present in SnO_2 which pushes them to the surface of the SnO_2. As there are no free electrons available output current will be zero. The below gif shown the oxygen molecules (blue color) attracting the free electrons (black color) inside the SnO_2 and preventing it from having free electrons to conduct current

When the sensor is placed in the toxic or combustible gases environment, this reducing gas (orange color) reacts with the adsorbed oxygen particles and breaks the chemical bond between oxygen and free electrons thus releasing the free electrons. As the free electrons are back to its initial position they can now conduct current, this conduction will be proportional the amount of free electrons available in SnO_2, if the gas is highly toxic more free electrons will be available.

How to use a Gas sensor?

A basic gas sensor has 6 terminals in which 4 terminals (A, A, B, B) acts input or output and the remaining 2 terminals (H, H) are for heating the coil. Of these 4 terminals, 2 terminals from each side can be used as either input or output (these terminals are reversible as shown in the circuit diagram) and vice versa.

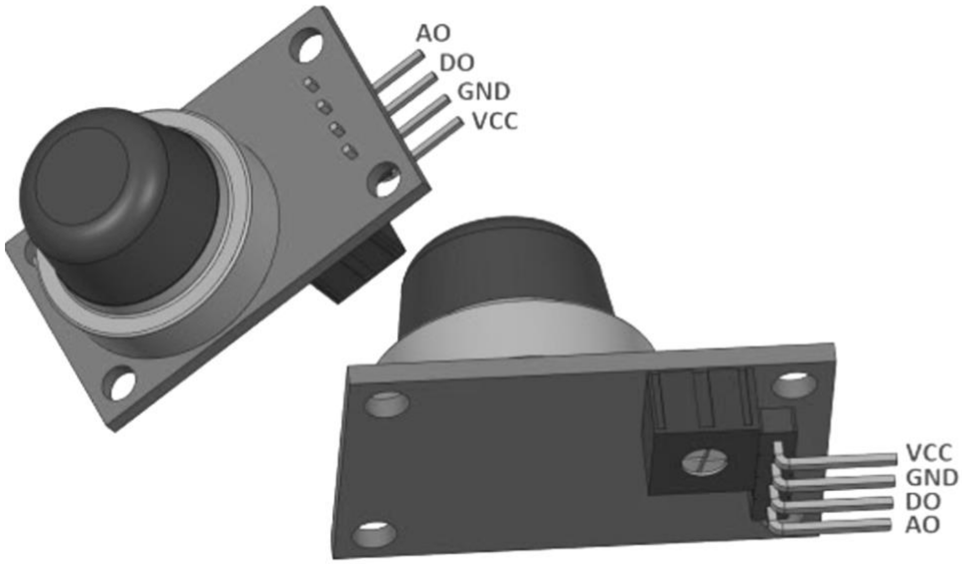
These sensors are normally available as modules (shown right), these modules consist of the gas sensor and a comparator IC. Now let's see the pin description of the gas sensor module which we will generally use with an Arduino. The gas sensor module basically consists of 4 terminals

Vcc – Power supply

GND – Power supply

Digital output – This pin gives an output either in logical high or logical low (0 or 1) that means it displays the presence of any toxic or combustible gases near the sensor.

Analog output – This pin gives an output continuous in voltage which varies based on the concentration of gas that is applied to the gas sensor.


AO
DO
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VCC
GND
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AO