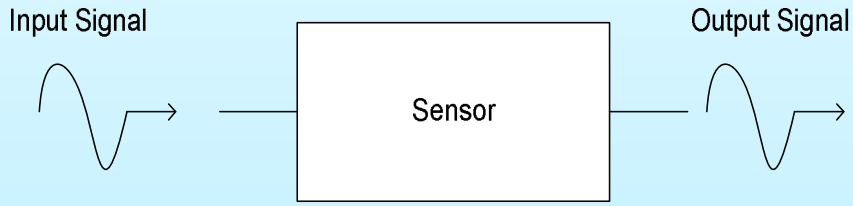
TRANSDUCERS & SENSORS

Sensors ?

- **American National Standards Institute**
  - A device which provides a usable output in response to a specified measurand



- A sensor acquires a physical quantity and converts it into a signal suitable for processing ***(e.g. optical, electrical, mechanical)***
- ***Nowadays common sensors convert measurement of physical phenomena into an electrical signal***
- Active element of a sensor is called a transducer

Transducer ?

A device which converts one form of energy to another

When input is a physical quantity and output electrical → Sensor

When input is electrical and output a physical quantity → Actuator

Sensors

Physical parameter

↓

Electrical Output

Actuators

Electrical Input

↓

Physical Output

e.g. Piezoelectric:

Force -> voltage

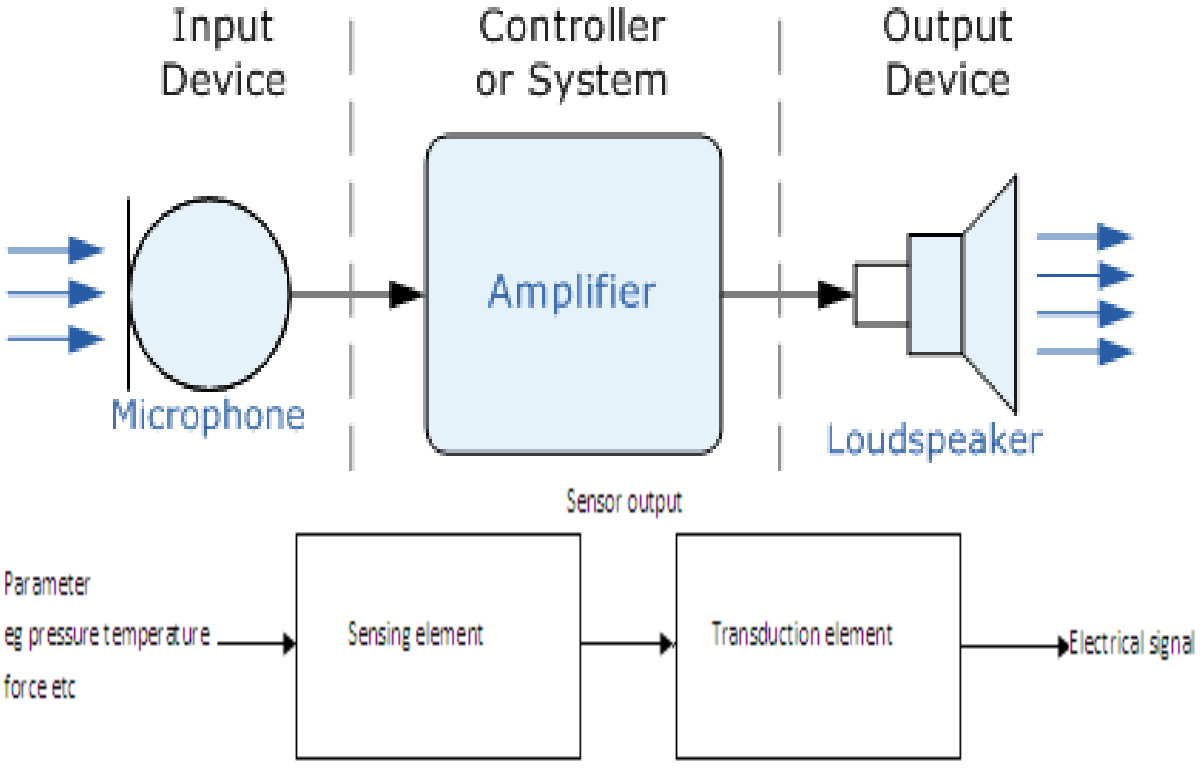
Voltage-> Force

=> Ultrasound!

Microphone, Loud Speaker

Introduction of Transducers

- Transducers convert one form of energy into another
- Sensors/Actuators are input/output transducers
- Sensors can be *passive* (e.g. change in resistance) or *active* (output is a voltage or current level)
- Sensors can be *analog* (e.g. thermocouples) or *digital* (e.g. digital tachometer)



- ***Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.***
- ***The sensing element is called as the sensor. It is device producing measurable response to change in physical conditions.***
- ***The transduction element convert the sensor output to suitable electrical form.***

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.
II. Analog and digital transducers.
III. On the basis of transduction principle used.
IV. Primary and secondary transducer
V. Transducers and inverse transducers.

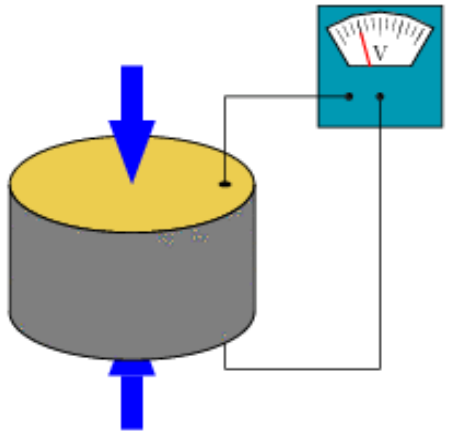
ACTIVE AND PASSIVE TRANSDUCERS

Active transducers :

These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.



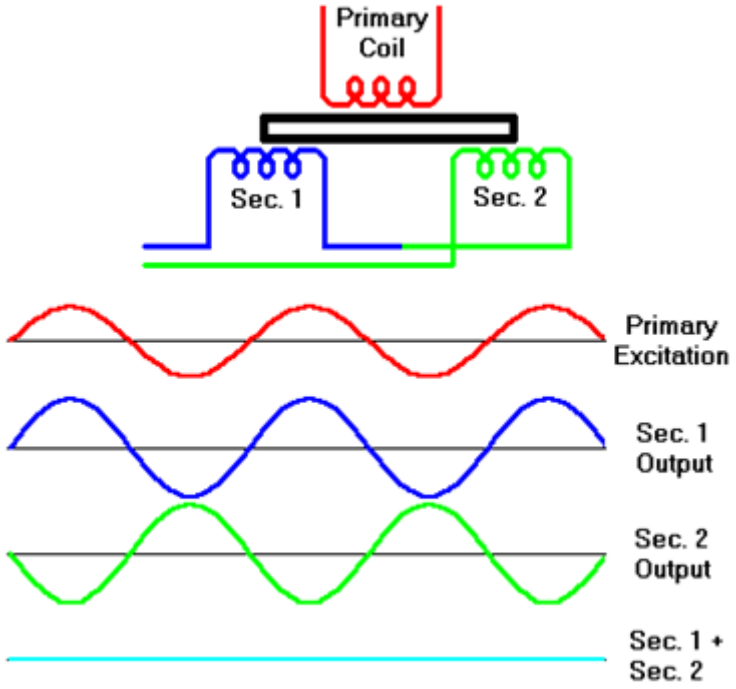
Piezoelectric Transducer

Passive Transducers :

I. These transducers need external source of power for their operation. So they are not self generating type transducers.

II. A DC power supply or an audio frequency generator is used as an external power source.

III. These transducers produce the output signal in the form of variation in resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.



CHARACTERISTICS OF TRANSDUCERS

1. Linearity
2. Repeatability
3. Accuracy
4. High stability and reliability
5. Speed of response
6. Sensitivity
7. Small size

Transducer types

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR), Photodiode, Phototransistor, Solar Cell	Lights & Lamps, LED's & Displays, Fiber Optics
Temperature	Thermocouple, Thermistor, Thermostat, Resistive temperature detectors (RTD)	Heater, Fan, Peltier Elements
Force/Pressure	Strain Gauge, Pressure Switch, Load Cells	Lifts & Jacks, Electromagnetic, Vibration
Position	Potentiometer, Encoders, Reflective/Slotted Opto-switch, LVDT	Motor, Solenoid, Panel Meters
Speed	Tacho-generator, Reflective/Slotted Opto-coupler, Doppler Effect Sensors	AC and DC Motors, Stepper Motor, Brake
Sound	Carbon Microphone, Piezo-electric Crystal	Bell, Buzzer, Loudspeaker

Need for Sensors

- Sensors are pervasive. ***They are embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.***

- Without the use of sensors, there would be no automation !!
  - ***Imagine having to manually fill Poland Spring bottles***

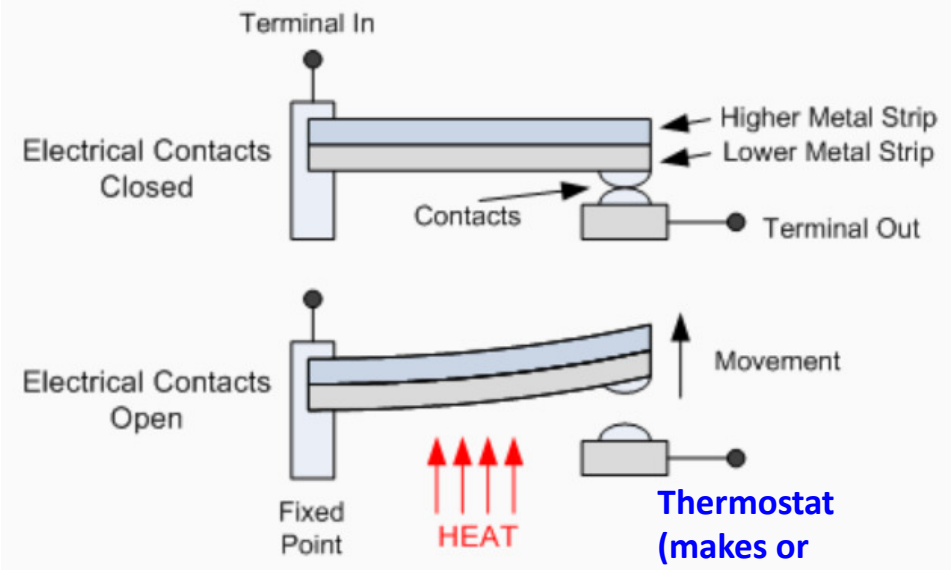
Technology can be used for measuring:

- **Often used in robots for obstacle avoidance**
- **Wind speed and direction (anemometer),**
- **Fullness of tank, and speed through air or water**
- **Measuring amount of liquid in tank, sensor measures distance to surface of fluid.**

Other applications include: alarms, non-destructive testing, and etc

Temperature Sensors

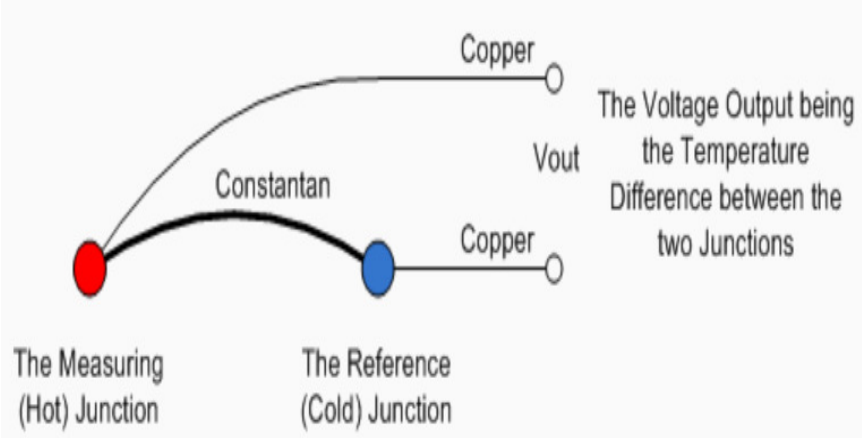
- Bimetallic switch (electro-mechanical) – used in thermostats. Can be "creep" or "snap" action.
- Thermistors (thermally sensitive resistors); Platinum Resistance Thermometer (PRT), very high accuracy.



Thermostat (makes or breaks electrical connection with deflection)

Thermocouples

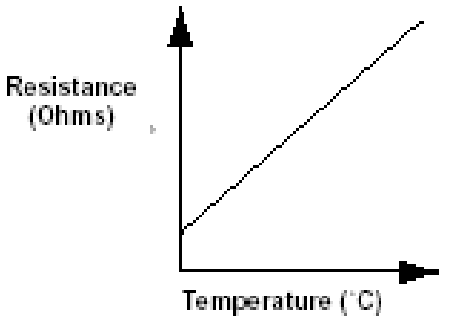
- **Two dissimilar metals induce voltage difference (few mV per 10K) – electro-thermal or Seebeck effect**
- **Use op-amp to process/amplify the voltage**
- **Absolute accuracy of 1K is difficult**



Resistance Temperature Detectors (RTDs)

- Wire wound and thin film devices.
- Nearly linear over a wide range of temperatures.
- Can be made small enough to have response times of a fraction of a second.
- Require an electrical current to produce a voltage drop across the sensor

RTD Resistance Vs Temperature (TCR) Curve



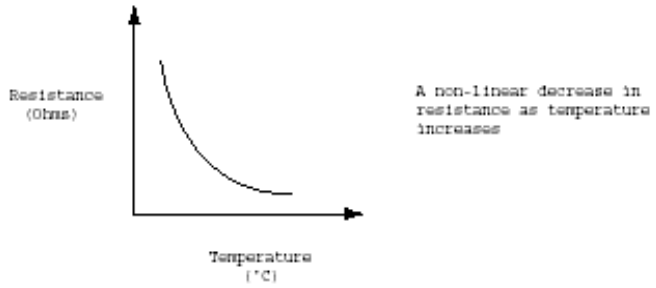
Thermistors

Therm istor

Thermal Resistor

- **A semiconductor used as a temperature sensor.**
- **Mixture of metal oxides pressed into a bead, wafer or other shape.**
- **Beads can be very small, less than 1 mm in some cases.**
- **The resistance decreases as temperature increases, negative temperature coefficient (NTC) thermistor.**

Thermistor Resistance Vs Temperature Relationship (NTC)

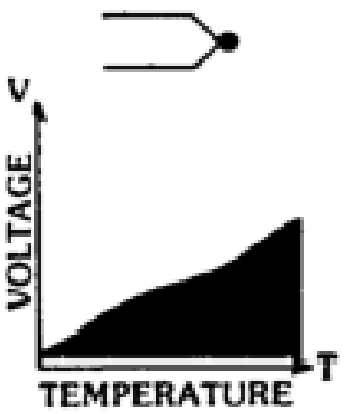
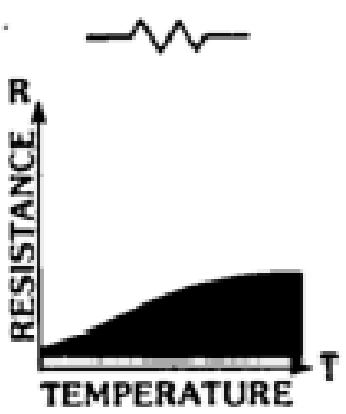
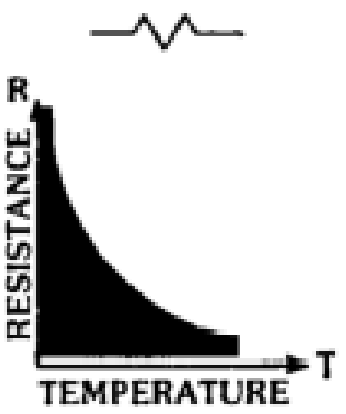
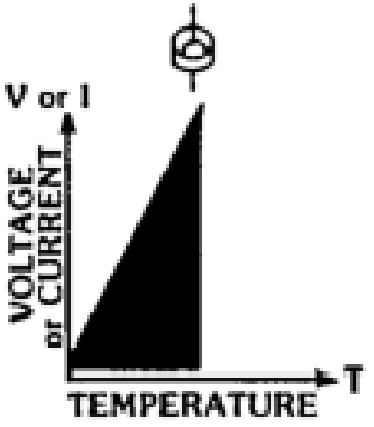


Thermistors are also used are for engine coolant, oil, and air temperature measurement in the transportation industry.

Thermocouple Sensor Colour Codes

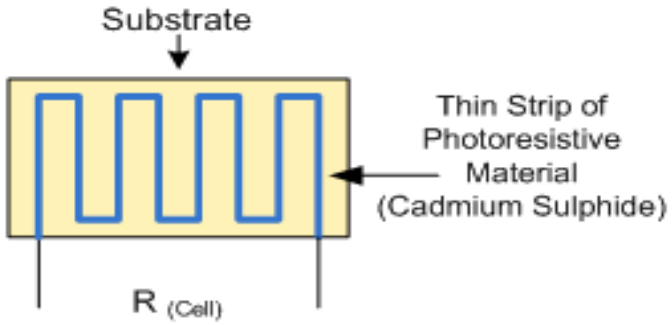
Extension and Compensating Leads

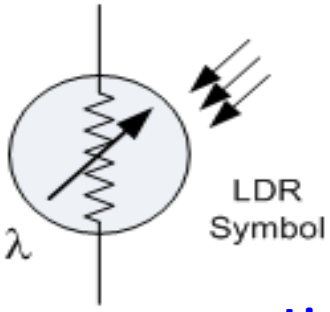
Code Type	Conductors (+/-)	Sensitivity	British BS 1843:1952
E	Nickel Chromium / Constantan	-200 to 900°C	
J	Iron / Constantan	0 to 750°C	
K	Nickel Chromium / Nickel Aluminium	-200 to 1250°C	
N	Nicrosil / Nisil	0 to 1250°C	
T	Copper / Constantan	-200 to 350°C	
U	Copper / Copper Nickel Compensating for "S" and "R"	0 to 1450°C	

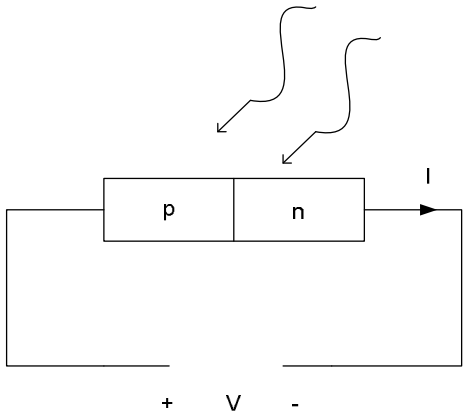
	Thermocouple	RTD	Thermistor	I.C. Sensor
				
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement	☐ Most linear ☐ Highest output ☐ Inexpensive
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small ΔR ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating	☐ T <200°C ☐ Power supply required ☐ Slow ☐ Self-heating ☐ Limited configurations

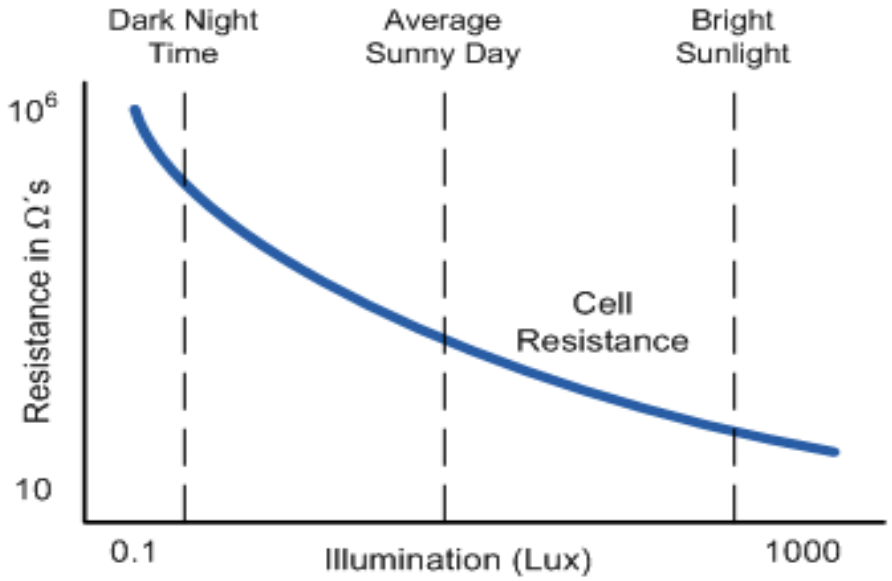
Light sensors: photoconductive cells

- **Light dependent resistor (LDR) cell**

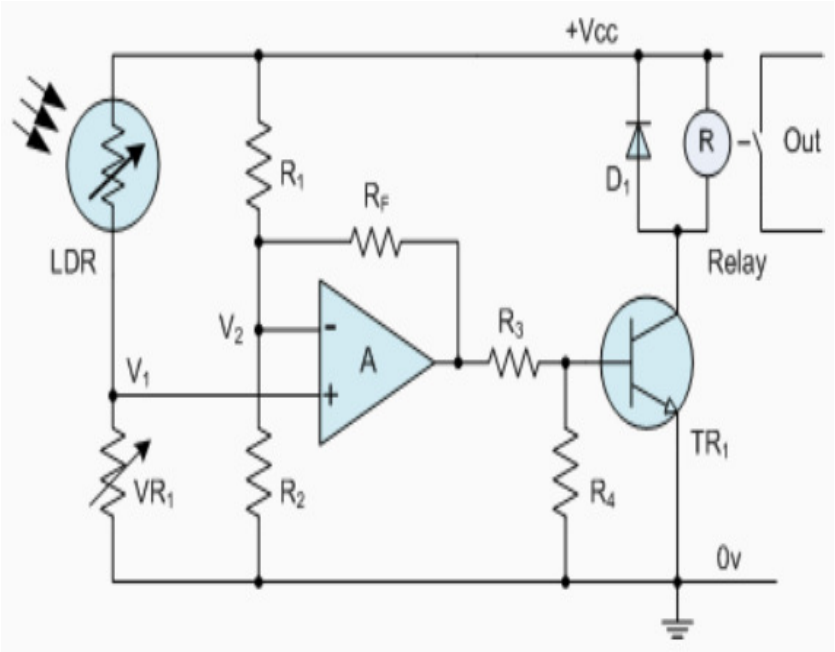






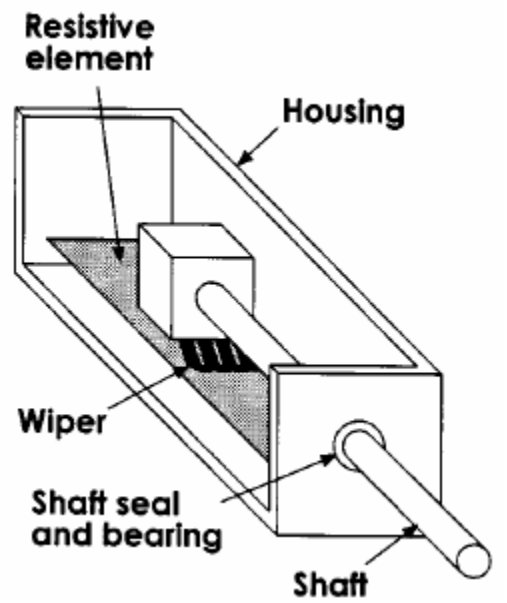


Light level sensitive switch



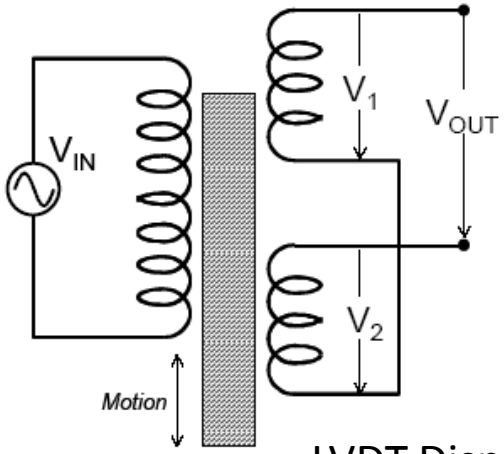
Motion Sensors

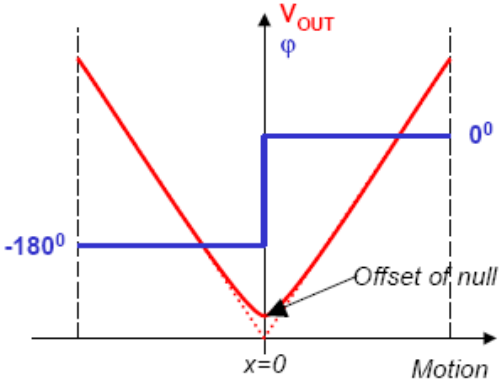
- Monitor location of various parts in a system
  - absolute/relative position
  - angular/relative displacement
  - proximity
  - acceleration
- Principle of operation
  - Magnetic, resistive, capacitance, inductive, eddy current, etc.



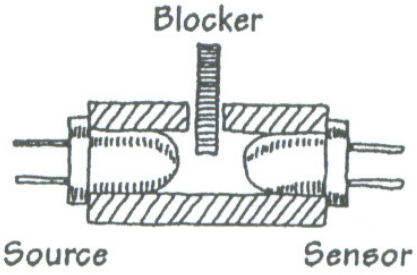
Potentiometer

Primary Secondary





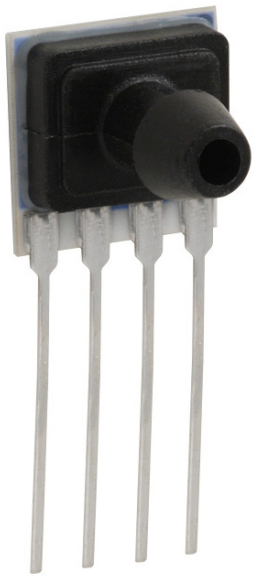
LVDT Displacement Sensor



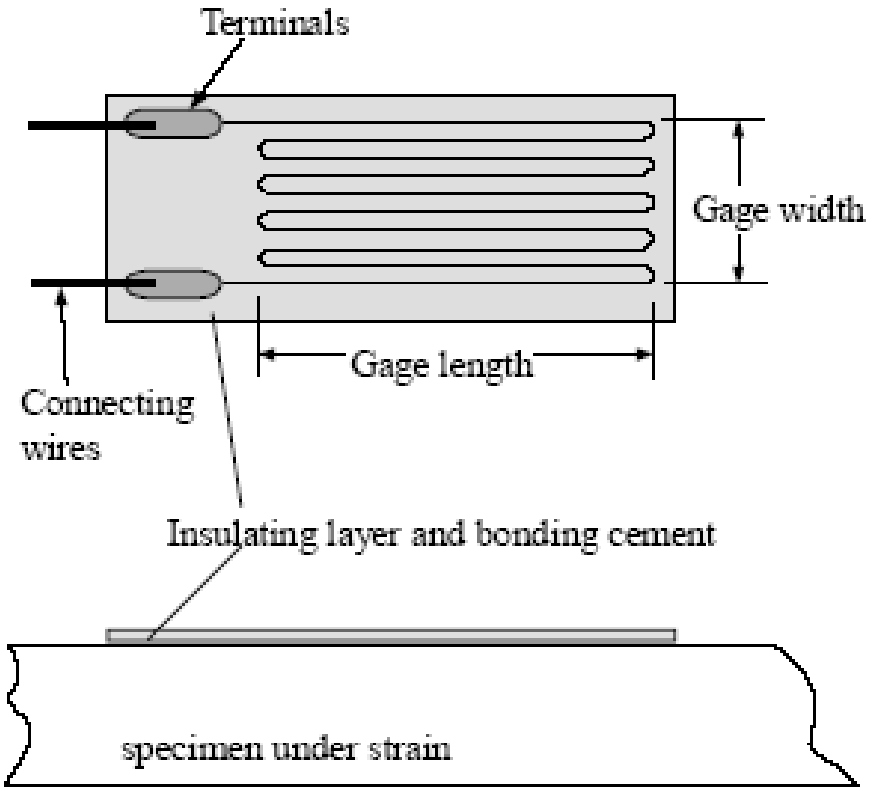
Optoisolator

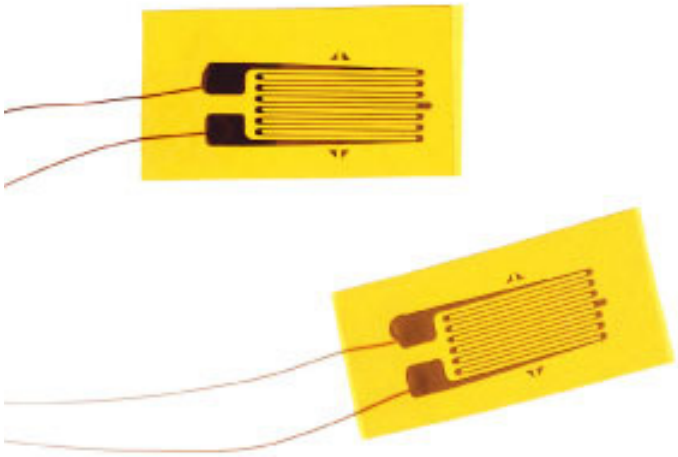
Pressure Sensors

- Used to detect pressure of fluids or gasses.
- Technologies (many)
  - Strain gage
  - Piezoresistive
  - Microelectromechanical systems (MEMS)
- Each sensor has a pressure range that it works in.
- Most have analog outputs that need amplification
  - Some have built-in amplifiers for direct connection into microcontroller



Strain Gauge: Motion, Stress, Pressure





Strain gauge is used to measure deflection, stress, pressure, etc.

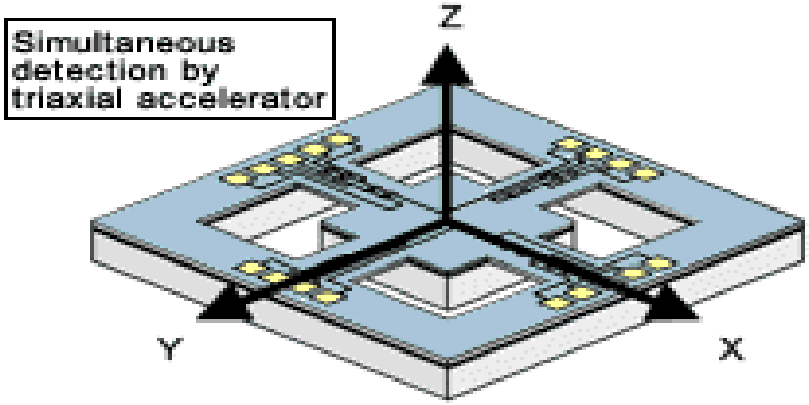
The resistance of the sensing element changes with applied strain

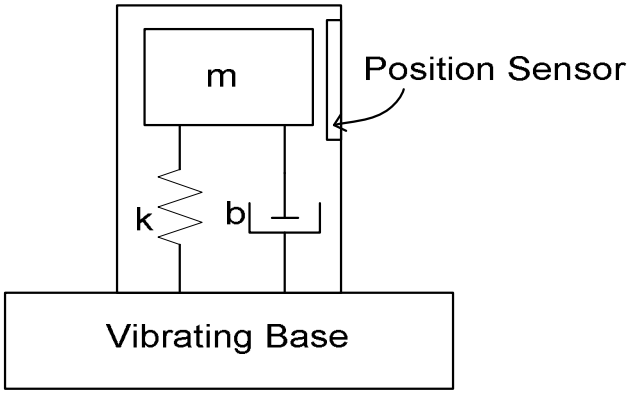
A Wheatstone bridge is used to measure small changes in the strain gauge resistance

Accelerometers

- Used to measure acceleration
  - Common SI units meters/second2 (m/s2) or popularly in terms of g-force (1 g is earth's gravity)
- At rest an acceleration will measure 1 g in the vertical direction
- They can come in 1, 2 or 3 axis configurations
  - With 3 axis it gives a vector of the accelerations direction (after accounting for gravity)

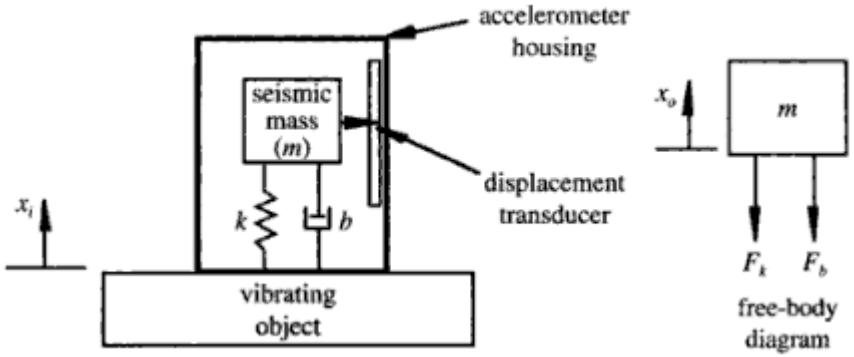
- Accelerometers are used to measure acceleration along one or more axis and are relatively insensitive to orthogonal directions
- Applications
  - Motion, vibration, blast, impact, shock wave
- Mathematical description is beyond the scope of this presentation.

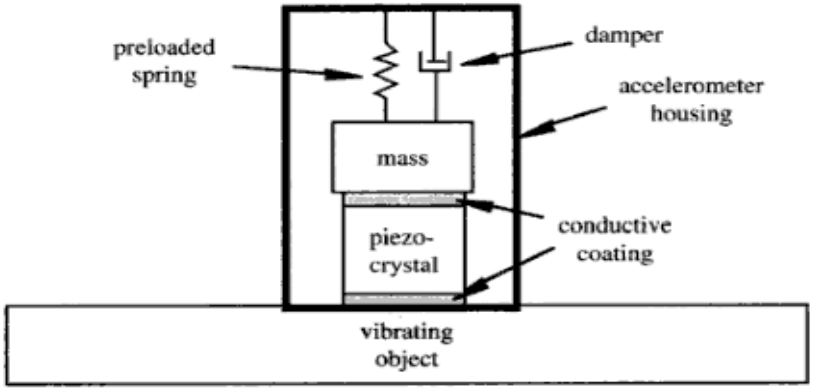




Accelerometer

- **Accelerometers are used to measure acceleration along one or more axis and are relatively insensitive to orthogonal directions**
- **Applications**
  - **Motion, vibration, blast, impact, shock wave**
- **Mathematical description is beyond the scope of this presentation.**
-
- **Electromechanical device to measure acceleration forces**
  - Static forces like gravity pulling at an object lying at a table
  - Dynamic forces caused by motion or vibration
- **How they work**
  - ***Seismic mass accelerometer: a seismic mass is connected to the object undergoing acceleration through a spring and a damper;***
  - ***Piezoelectric accelerometers: a microscopic crystal structure is mounted on a mass undergoing acceleration; the piezo crystal is stressed by acceleration forces thus producing a voltage***
  - ***Capacitive accelerometer: consists of two microstructures (micromachined features) forming a capacitor; acceleration forces move one of the structure causing a capacitance changes.***
  - ***Piezoresistive accelerometer: consists of a beam or micromachined feature whose resistance changes with acceleration***
  - ***Thermal accelerometer: tracks location of a heated mass during acceleration by temperature sensing***





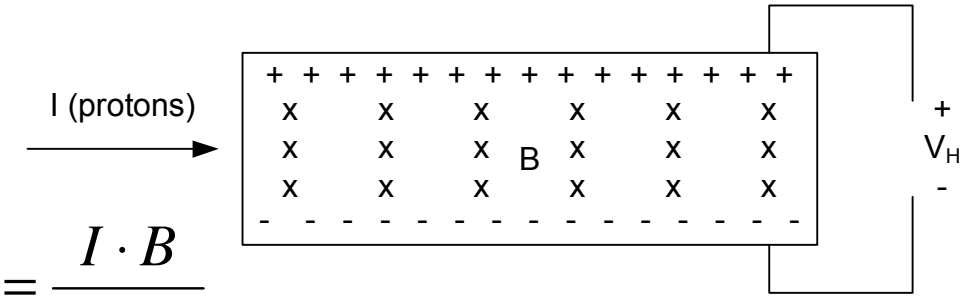
Accelerometers Applications

- ***Can be used to sense orientation, vibration and shocks.***
- Used in electronics like the Wii and iPhone for user input.
- Acceleration integrated once gives velocity, integrated a second time gives position.
  - The integration process is not precise and introduces error into the velocity and position.

Magnetic Field Sensor

- Magnetic Field sensors are used for power steering, security, and current measurements on transmission lines

- Hall voltage is proportional to magnetic field



$$V_H = \frac{I \cdot B}{n \cdot q \cdot t}$$

Applications

- IC Engine Electronic Ignition Systems
  - Used to determine position of cam shaft
- Brushless DC Motor Control
  - Sensors determine position of permanent magnet rotor
- Assembly Lines
  - Shaft position and velocity sensors
  - Contactless limit switches
- Current Sensing ICs
  - Electrically isolated alternative to shunt resistors

Implementation and Words of Warning

- Sensors may be affected by temperature variation. Some sensors incorporate circuitry to reduce this error.

- Sensors may be directional, in which case care must be taken with respect to orientations of sensor and magnet

- Some Hall Effect sensors detect presence of ferromagnetic materials, not magnetic fields