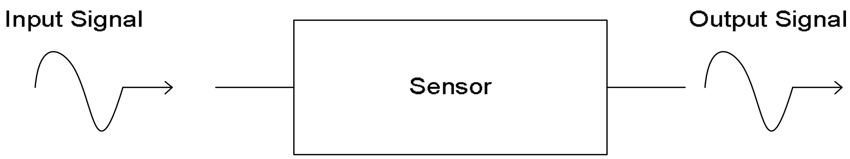
Intro to Sensors

Overview

- Sensors?
- Commonly Detectable Phenomenon
- Physical Principles – How Sensors Work?
- Need for Sensors
- Choosing a Sensor
- Examples

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

<u>e.g. Piezoelectric</u>:

Force -> voltage

Voltage-> Force

=> Ultrasound!

Microphone, Loud Speaker

Commonly Detectable Phenomena

- Biological
- Chemical
- Electric
- Electromagnetic
- Heat/Temperature
- Magnetic
- Mechanical motion (displacement, velocity, acceleration, etc.)
- Optical
- Radioactivity

Common Conversion Methods

- Physical
  - thermo-electric, thermo-elastic, thermo-magnetic, thermo-optic
  - photo-electric, photo-elastic, photo-magnetic,
  - electro-elastic, electro-magnetic
  - magneto-electric
- Chemical
  - chemical transport, physical transformation, electro-chemical
- Biological
  - biological transformation, physical transformation

Commonly Measured Quantities

Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Physical Principles: Examples

- **Amperes’s Law**
  - A current carrying conductor in a magnetic field experiences a force (e.g. galvanometer)
- **Curie-Weiss Law**
  - There is a transition temperature at which ferromagnetic materials exhibit paramagnetic behavior
- **Faraday’s Law of Induction**
  - A coil resist a change in magnetic field by generating an opposing voltage/current (e.g. transformer)
- **Photoconductive Effect**
  - When light strikes certain semiconductor materials, the resistance of the material decreases (e.g. photoresistor)

Choosing a Sensor

Environmental Factors	Economic Factors	Sensor Characteristics
Temperature range	Cost	Sensitivity
Humidity effects	Availability	Range
Corrosion	Lifetime	Stability
Size		Repeatability
Overrange protection		Linearity
Susceptibility to EM interferences		Error
Ruggedness		Response time
Power consumption		Frequency response
Self-test capability		

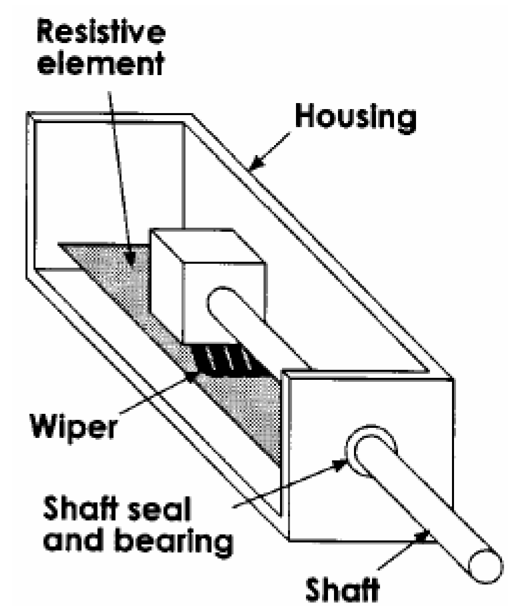
Need for Sensors

- 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

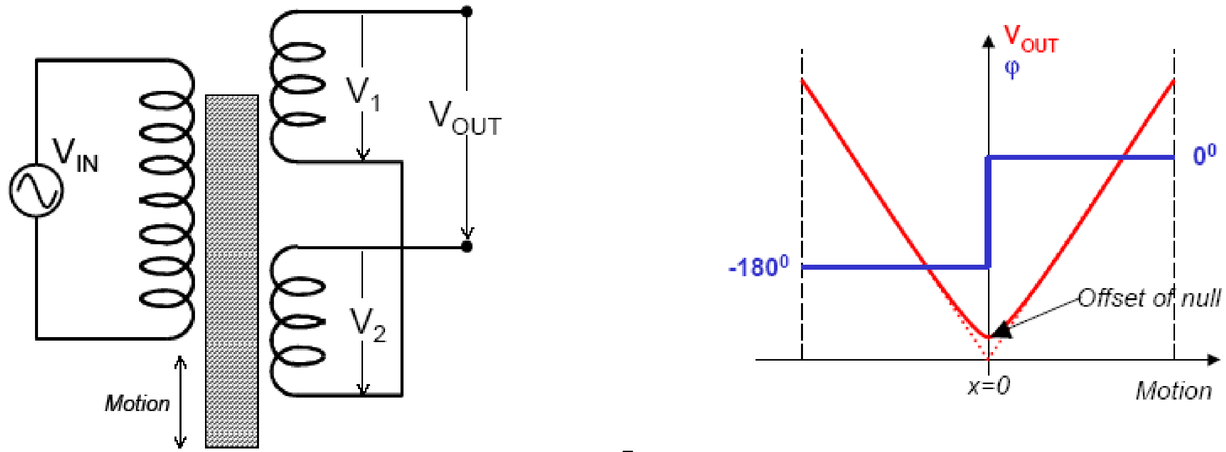
Motion Sensors

- 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.

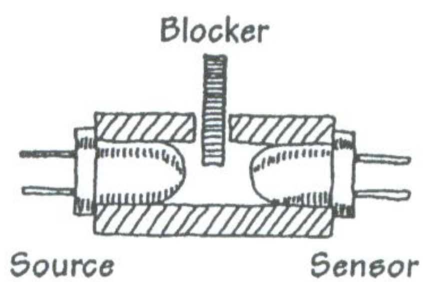


Potentiometer

Primary Secondary

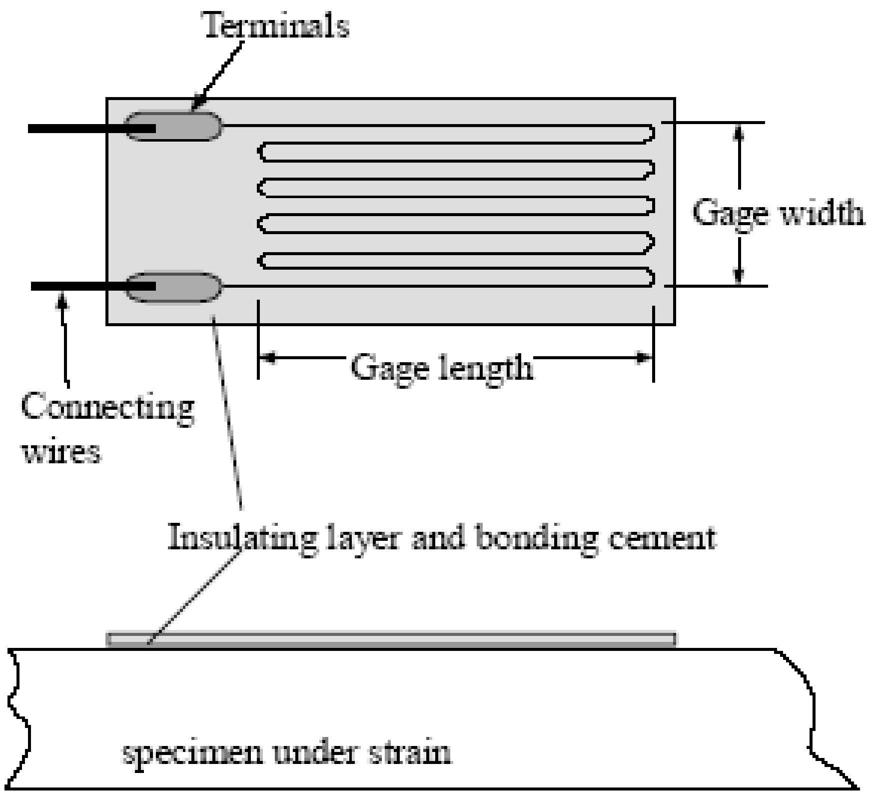


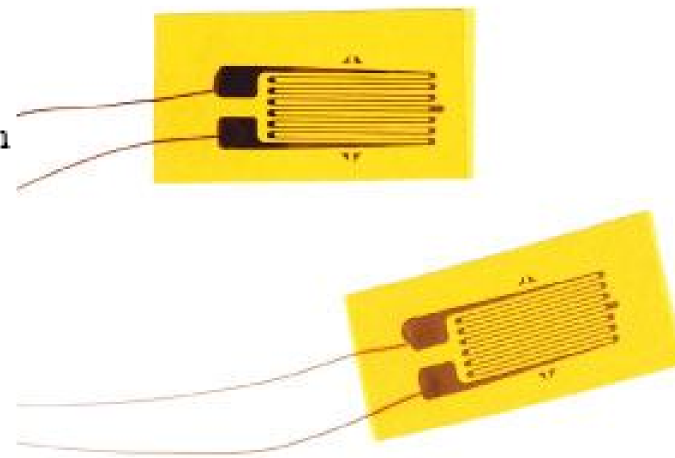
LVDT Displacement Sensor



Optoisolator

Strain Gauge: Motion, Stress, Pressure





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

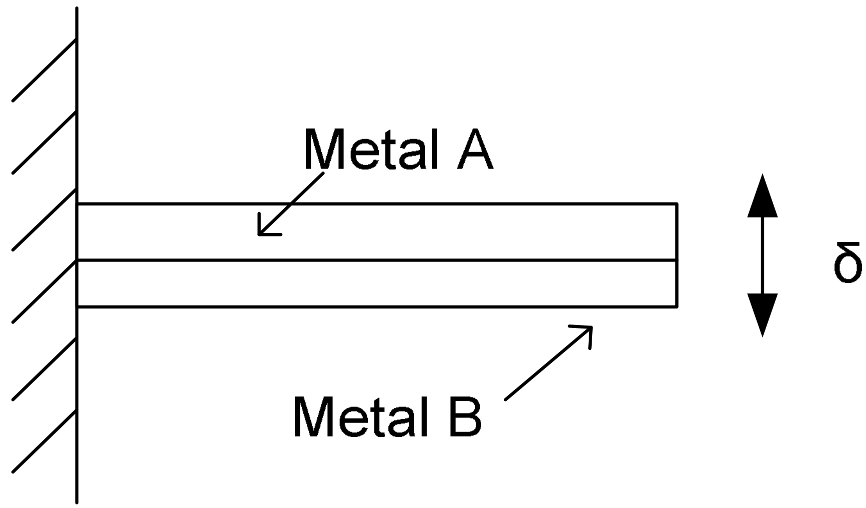
The resistance of the sensing element changes with applied strain

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

Temperature Sensor: Bimetallic Strip

- Bimetallic Strip

$$L = L_0[1 + \beta(T - T_0)]$$



- Application
  – Thermostat (makes or breaks electrical connection with deflection)

Temperature Sensor: RTD

- Resistance temperature device (RTD)

$$R = R_0[1+\alpha(T - T_0)]$$

$$R = R_0 e^{\gamma\left[\frac{1}{T}-\frac{1}{T_0}\right]}$$

Other Temperature Sensors

- Thermistor

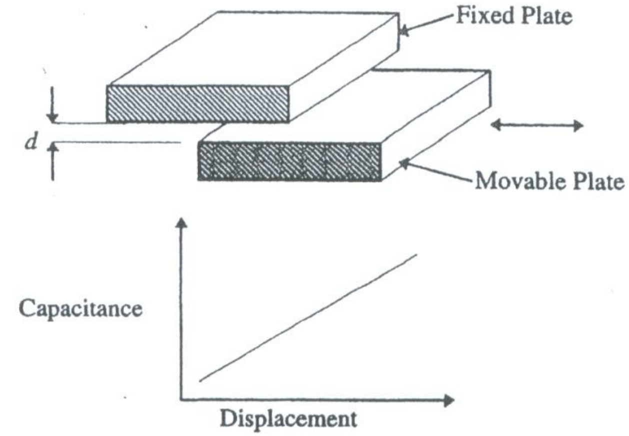
$$\underbrace{\text{Therm}}_{\text{Thermal}}\ \underbrace{\text{istor}}_{\text{Resistor}}$$

$$R \propto \exp\left(\frac{E_g}{2kT}\right)$$

- Thermocouple: Seeback effect to transform a temperature difference to a voltage difference

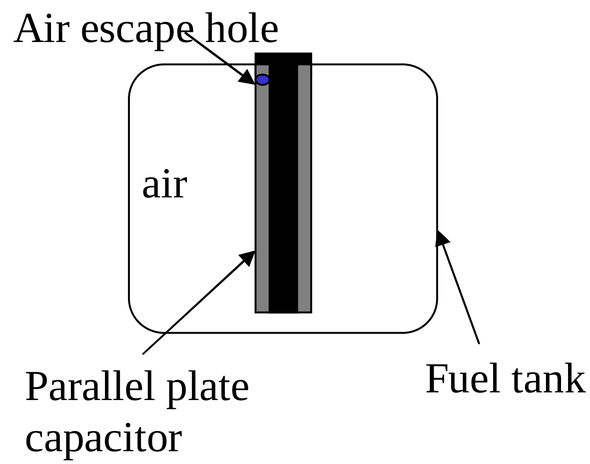
Capacitance Transducers—I

- Recall, capacitance of a parallel plate capacitor is:



$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

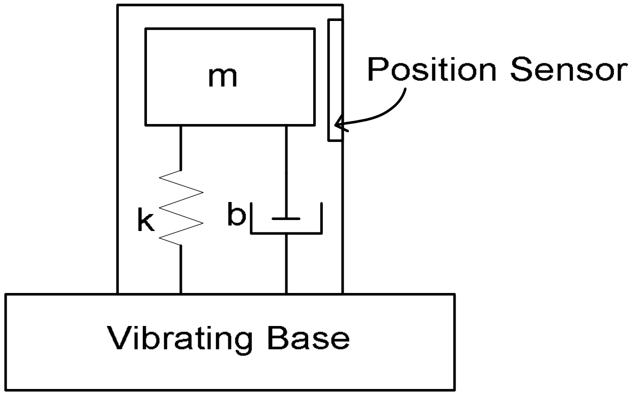
  - A: overlapping area of plates (m^2)
  - d: distance between the two plates of the capacitor (m)
  - ε_0: permittivity of air or free space 8.85pF/m
  - ε_r :dielectric constant



- The following variations can be utilized to make capacitance-based sensors.
  - Change distance between the parallel electrodes.
  - Change the overlapping area of the parallel electrodes.
  - Change the dielectric constant.

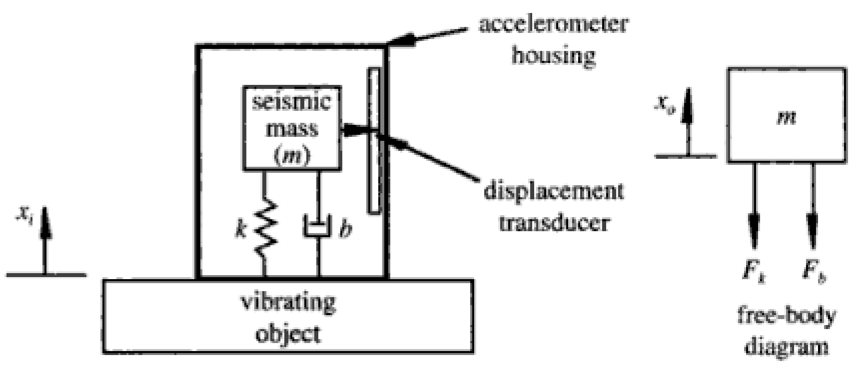
Accelerometer–I

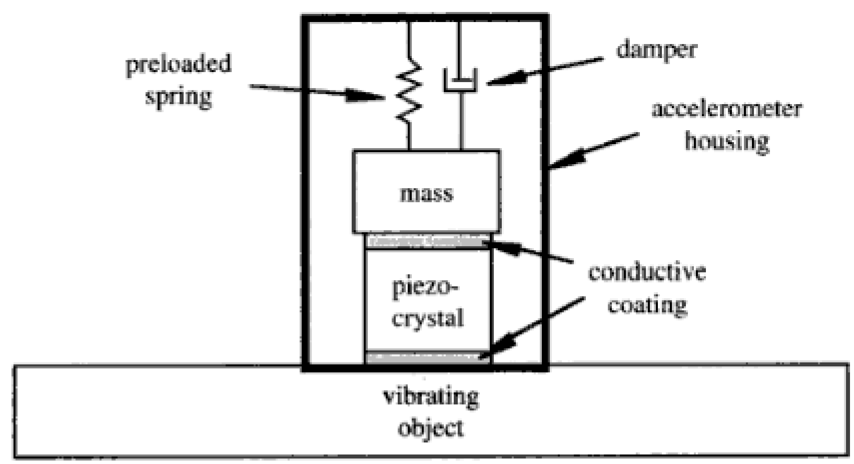
- Accelerometers are used to measure acceleration along one or more axis and are relatively insensitive to orthogonal directions
- Applications
  - Motion, vibration, blast, impact, shock wave
- Mathematical description is beyond the scope of this presentation.



Accelerometer–II

- 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





Accelerometer Applications

- Automotive: monitor vehicle tilt, roll, skid, impact, vibration, etc., to deploy safety devices (stability control, anti-lock breaking system, airbags, etc.) and to ensure comfortable ride (active suspension)
- Aerospace: inertial navigation, smart munitions, unmanned vehicles
- Sports/Gaming: monitor athlete performance and injury, joystick, tilt
- Personal electronics: cell phones, digital devices
- Security: motion and vibration detection
- Industrial: machinery health monitoring
- Robotics: self-balancing

Helmet: Impact Detection

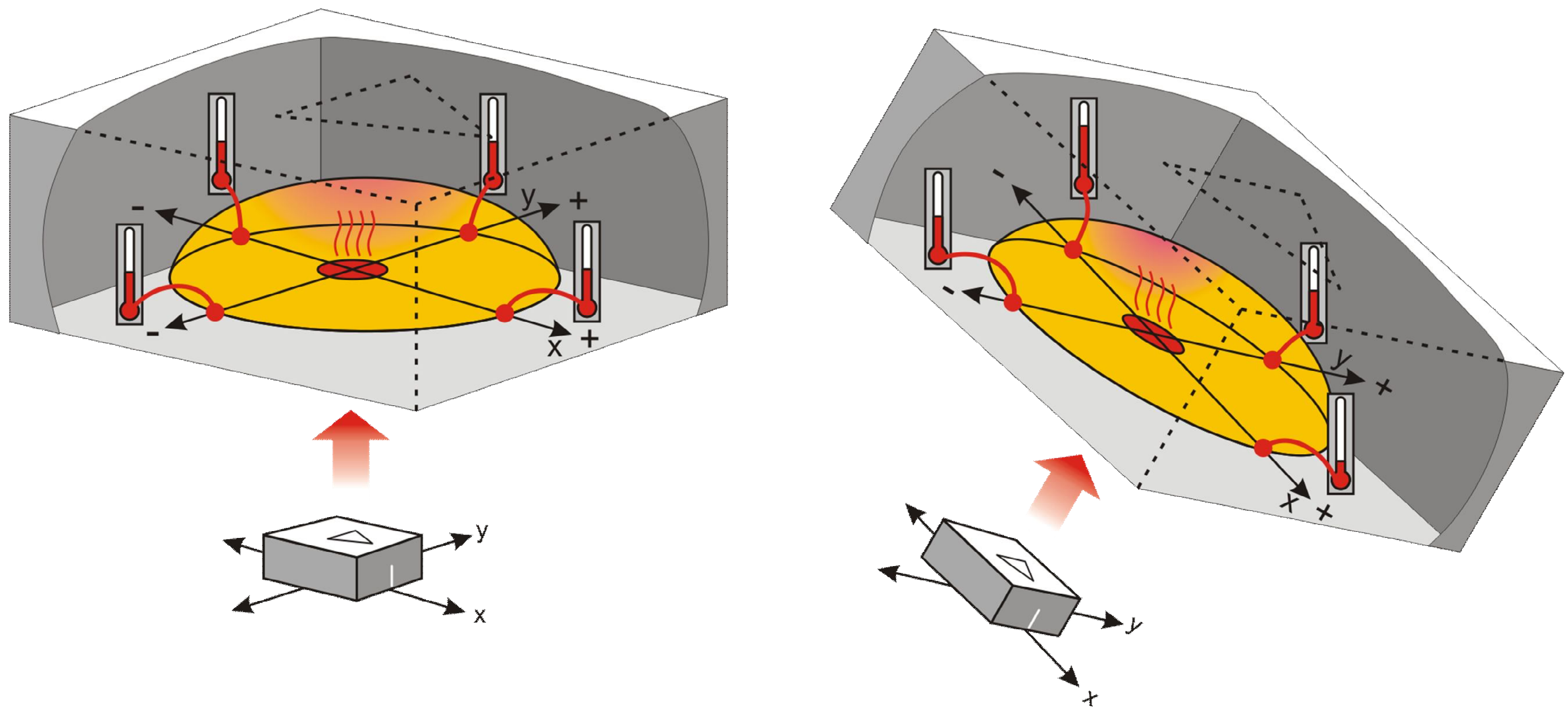
2 axis joystick

WII Nunchuk: 3 axis accelerometer

Segway

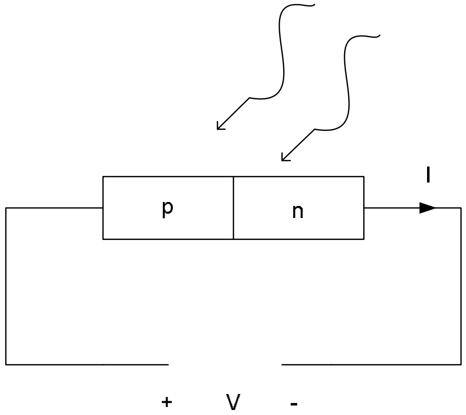
MX2125 Accelerometer: How it Works

- **A MEMS device consisting of**
  - **a chamber of gas with a heating element in the center**
  - **four temperature sensors around its edge**
- **Hold accelerometer level→hot gas pocket rises to the top-center of the accelerometer's chamber→all sensors measure same temperature**
- **Tilt the accelerometer→hot gas pocket collects closer to one or two temperature sensors→sensors closer to gas pocket measure higher temperature**
- **MX2125 electronics compares temperature measurements and outputs pulses (pulse duration encodes sensor o/p)**



Light Sensor

- Light sensors are used in cameras, infrared detectors, and ambient lighting applications
- Sensor is composed of photoconductor such as a photoresistor, photodiode, or phototransistor

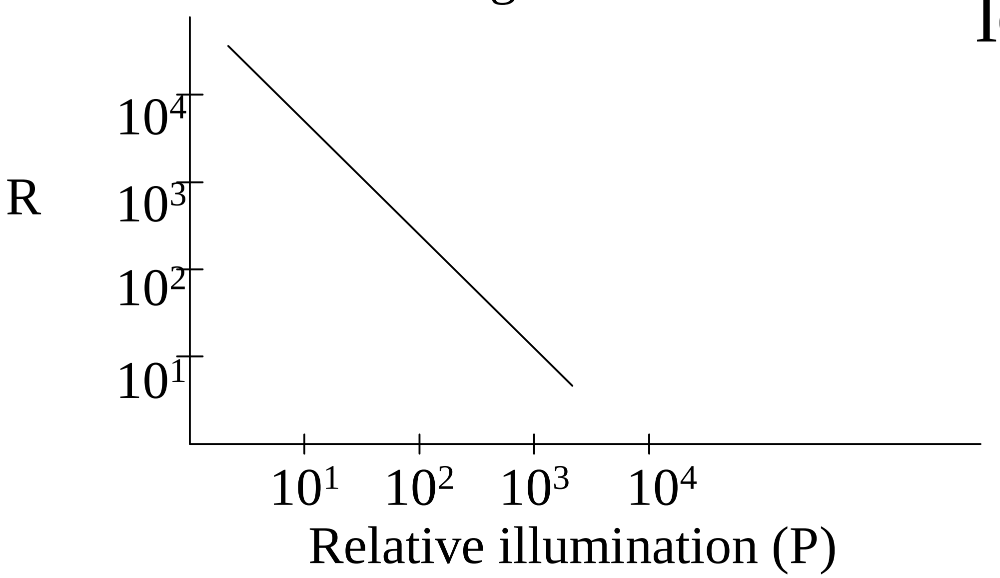


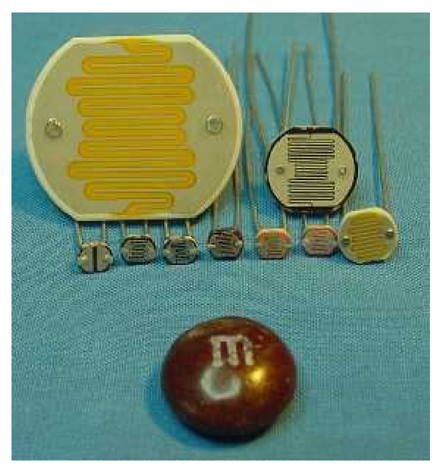
Photoresistors

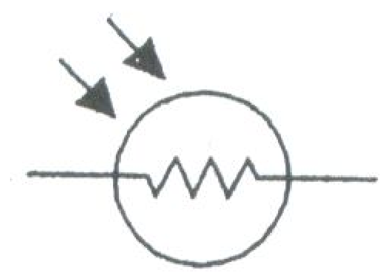
- Light sensitive variable resistors.
- Its resistance depends on the intensity of light incident upon it.
  - Under dark condition, resistance is quite high (MΩ: called dark resistance).
  - Under bright condition, resistance is lowered (few hundred Ω).
- Response time:
  - When a photoresistor is exposed to light, it takes a few milliseconds, before it lowers its resistance.
  - When a photoresistor experiences removal of light, it may take a few seconds to return to its dark resistance.

- Photoresisotrs exhibit a nonlinear characteristics for incident optical illumination versus the resulting resistance.

$$\log_{10} R = \alpha - \beta \log_{10} P$$





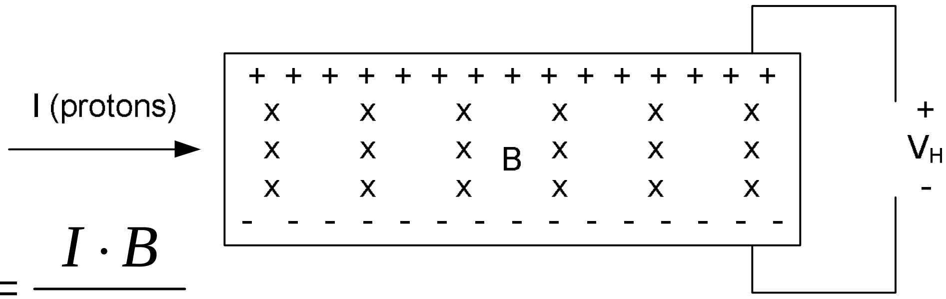


Symbol

Magnetic Field Sensor

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

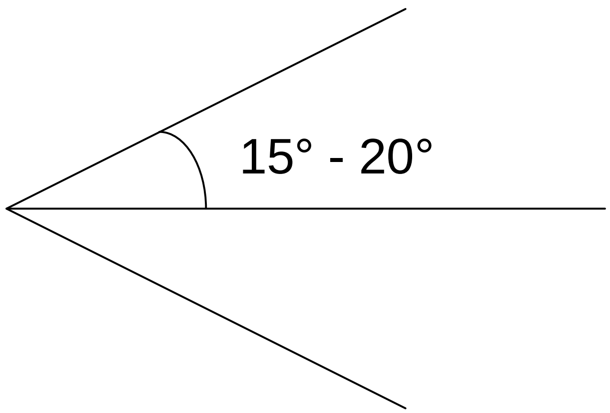
- Hall voltage is proportional to magnetic field



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

Ultrasonic Sensor

- Ultrasonic sensors are used for position measurements
- Sound waves emitted are in the range of 2-13 MHz
- **So**und **N**avigation **A**nd **R**anging (SONAR)
- **Ra**dio **D**ection **A**nd **R**anging (RADAR) – ELECTROMAGNETIC WAVES !!



Photogate

- Photogates are used in counting applications (e.g. finding period of period motion)
- Infrared transmitter and receiver at opposite ends of the sensor
- Time at which light is broken is recorded