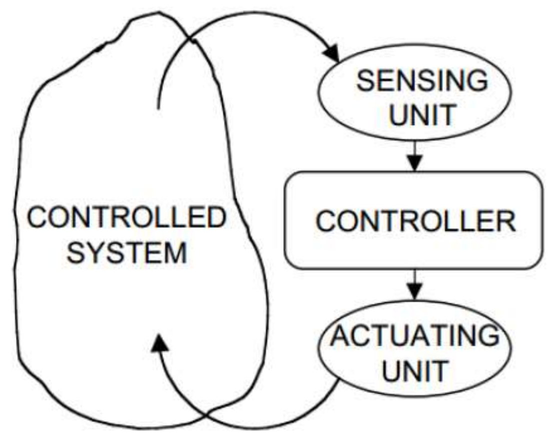
Sensors

Sensors

- Sensors and actuators are two critical components of every closed loop control system. Such a system is also called a mechatronics system.
- A sensing unit can be as simple as a single sensor or can consist of additional components such as filters, amplifiers, modulators, and other signal conditioners.
- The controller accepts the information from the sensing unit, makes decisions based on the control algorithm, and outputs commands to the actuating unit.
- The actuating unit consists of an actuator and optionally a power supply and a coupling mechanism.



Sensors

- ➢Sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).
- ➢The term transducer is often used synonymously with sensors.
- ➢However, ideally, a sensor is a device that responds to a change in the physical phenomenon.
- ➢On the other hand, a transducer is a device that converts one form of energy into another form of energy.
- ➢Sensors are transducers when they sense one form of energy input and output in a different form of energy.
- ➢For example, a thermocouple responds to a temperature change (thermal energy) and outputs a proportional change in electromotive force (electrical energy). Therefore, a thermocouple can be called a sensor and or transducer.

Sensors and Actuators

Sensors

According to the Instrument Society of America, sensor can be defined as

"A device which provides a usable output in response to a specified measurand."

Here, the output is usually an 'electrical quantity' and measurand is a 'physical quantity, property or condition which is to be measured'.

Transducer

It is defined **as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output** by using a transduction principle.

Sensors Specifications

Various specifications of a sensor/transducer system are:

Range	Hysteresis
Span	Resolution
Error	Stability
Accuracy	Dead band/time
Sensitivity	Repeatability
Nonlinearity	Response time

Sensors Specifications

- Range:

  The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25-225°C.

- Span

  The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

- Error

  Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2 mm.

- Sensitivity
  - Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a sensitivity of 41 μV/C

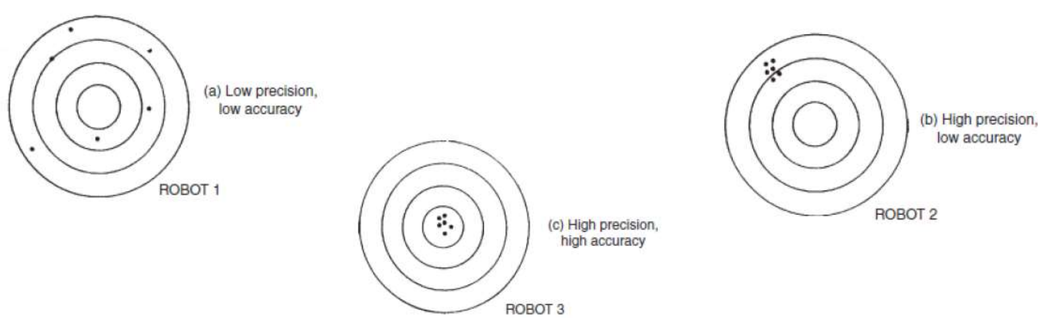
Sensors Specifications

- Accuracy

  The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full–scale deflection.

- Precision:

  describes an instrument s degree of freedom from random errors If an instrument is said to be a high precision instrument, then the spread of readings will be very small



Sensors Specifications

- Resolution

  Resolution is the smallest detectable incremental change of the output signal. Resolution can be expressed either as a proportion of the full-scale reading or in absolute terms.

  Example: if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2 mm.

- Stability

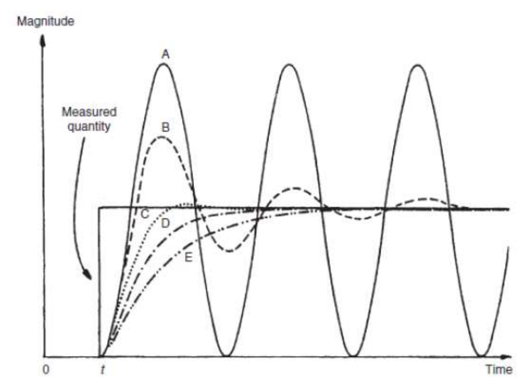
  Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term 'drift' is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

- Dead band/time
  - The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

Sensors Specifications

- Repeatability
  - It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

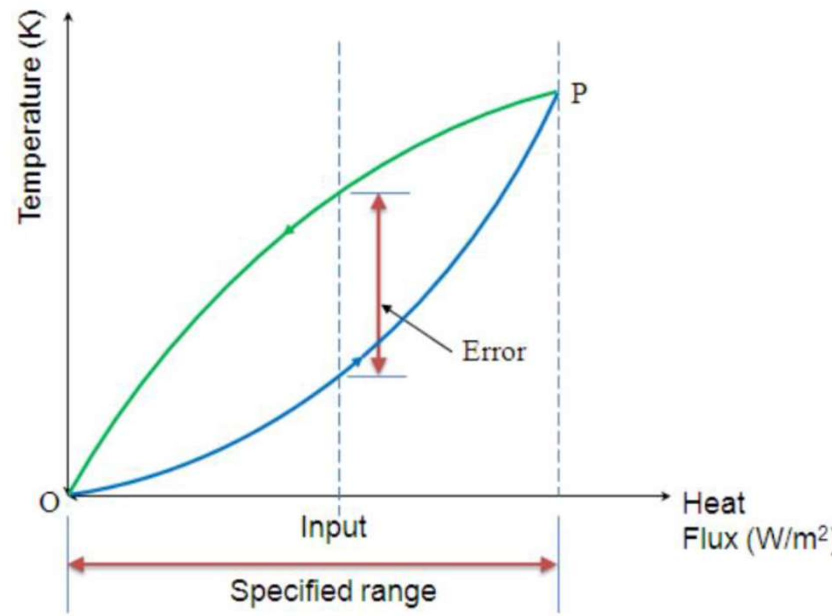
- Response time
  - Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.



Sensors Specifications

- Hysteresis

  The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.

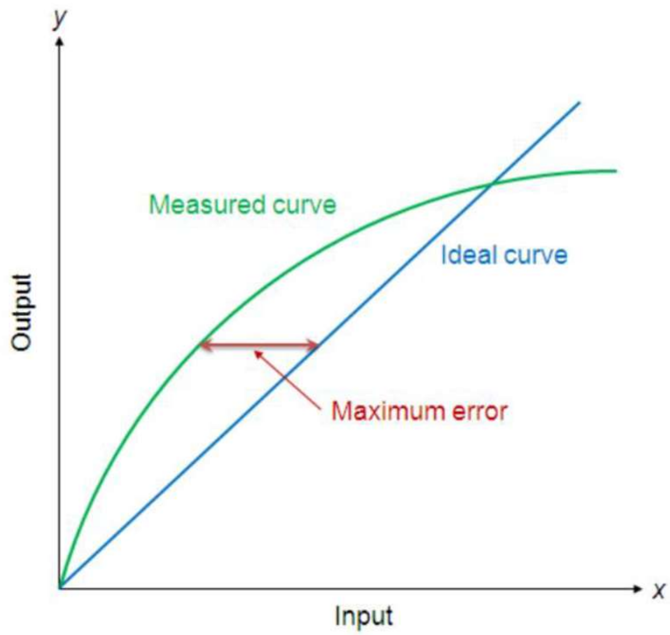


Sensors Specifications

- Nonlinearity
  - The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve.
  - Linearity is often specified in terms of percentage of nonlinearity, which is defined as:

$$\text{Nonlinearity (\%)} = \frac{\text{Maximum deviation in input}}{\text{Maximum full scale input}}$$

  - The static nonlinearity is dependent upon environmental factors, including temperature, vibration, acoustic noise level, and humidity.
  - Therefore it is important to know under what conditions the specification is valid input



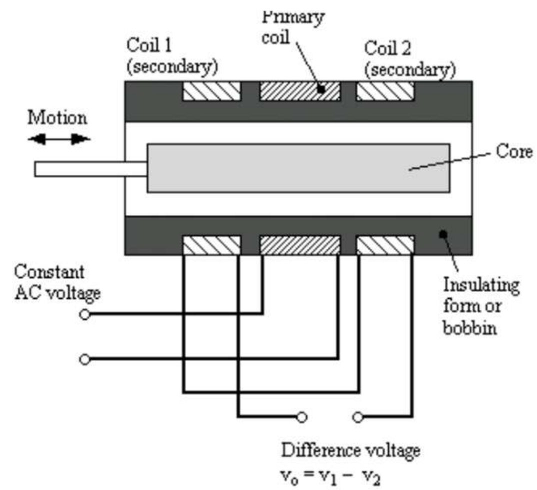
Commonly Detectable Phenomena

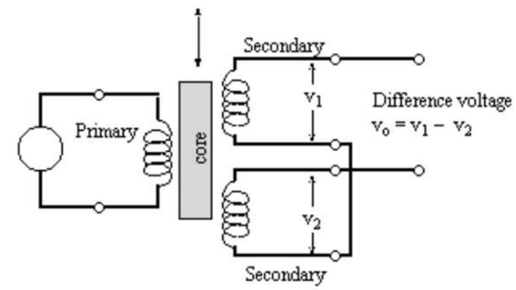
- Biological
- Chemical
- Electric
- Electromagnetic
- Heat/Temperature
- Magnetic
- Mechanical motion (displacement, velocity, acceleration, etc.)
- Optical
- Radioactivity

Displacement Measurements

Linear variable differential transformer (LVDT)

- Secondary coils are connected in series in such a way that their outputs oppose each other.
- A magnetic core attached to the element of which displacement is to be monitored is placed inside the insulated tube.
- Due to an alternating voltage input to the primary coil, alternating electromagnetic forces (emfs) are generated in secondary coils.
- When the magnetic core is centrally placed with its half portion in each of the secondary coil regions then the resultant voltage is zero.
- Linear variable differential transformer (LVDT) is a primary transducer used for measurement of linear displacement with an input range of about ±2 to ±400 mm in general.
- It has non-linearity error ±0.25% of full range.



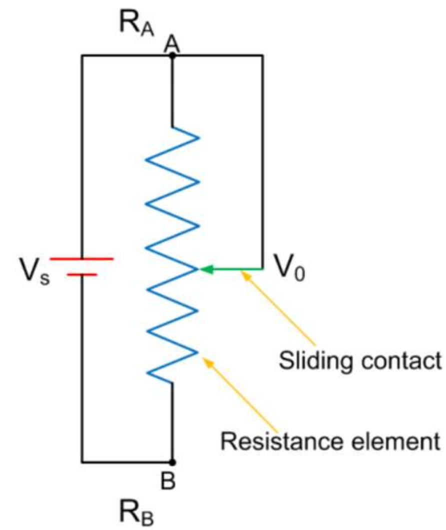


Applications:

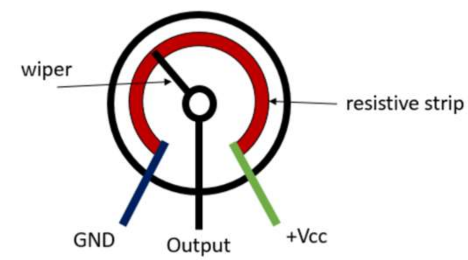
- Measurement of spool position in a wide range of servo valve applications,
- To provide displacement feedback for hydraulic cylinders,

Potentiometers

- The potentiometer is also called as ‘pots’
- The potentiometer is the electrical type of transducer or sensor and it is of resistive type because it works on the principle of change of resistance of the wire with its length.
- The resistance of the wire is directly proportional to the length of the wire, thus as the length of the wire changes the resistance of the wire also changes.



Application:
- The object of whose displacement is to be measured is connected to the slider by using , for example, a rotating shaft (for angular displacement)

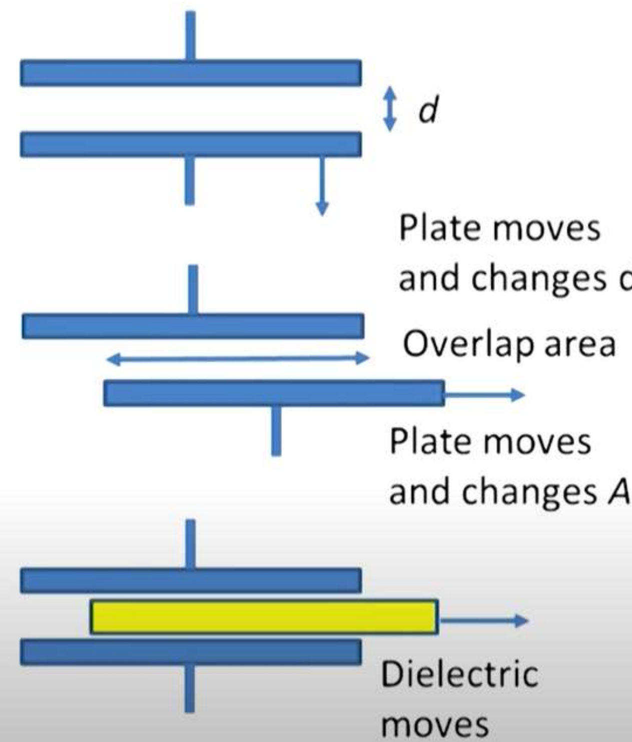


•Commonly used in circuits for various purposes like to control volume in audio circuits, to regulate the speed of the motor in a fan, as light dimmer, etc.

Capacitive Displacement sensor

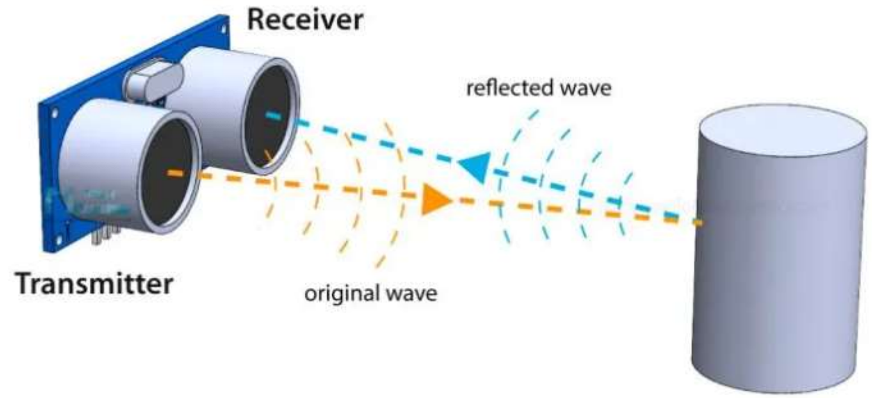
Capacitive Elements

- The capacitance C of a parallel plate capacitor is given by $C = \frac{\varepsilon_r \varepsilon_0 A}{d}$
- ε_r is relative permittivity of the dielectric between the plates
- ε_0 is a constant called permittivity of free space
- *A* is the area of overlap between the two plates
- *d* is plate separation.



Ultrasonic Sensor

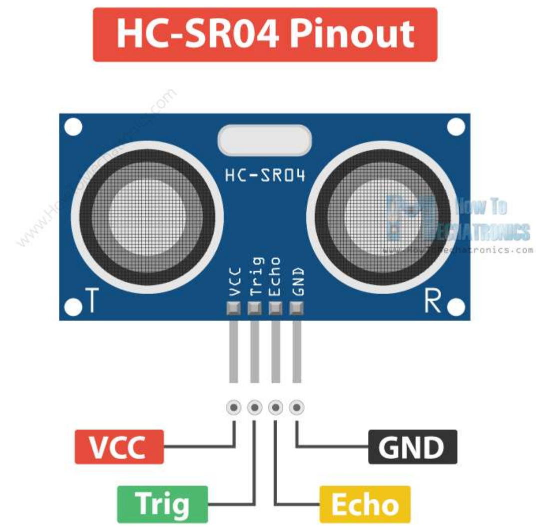
- It emits an ultrasound at 40KHz which travels through the air and if there is an object or obstacle on its path It will bounce back to the module.
- Considering the travel time and the speed of the sound you can calculate the distance.



Ultrasonic pin out and specification

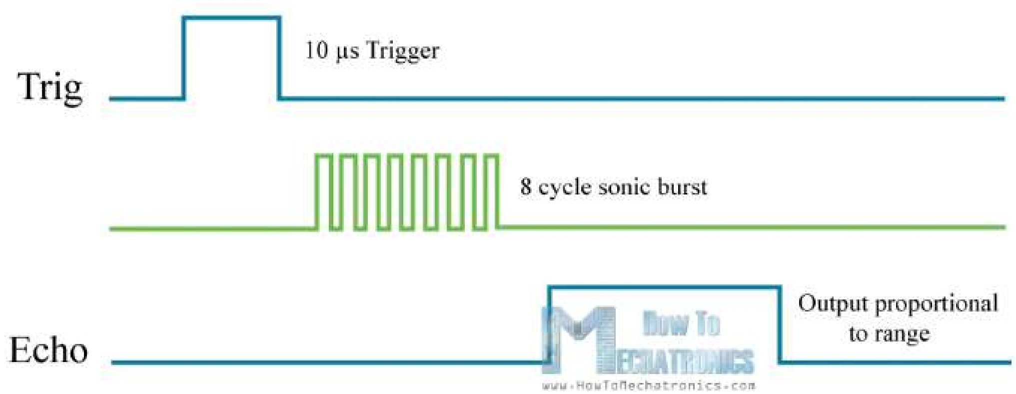
Datasheet: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf

Operating Voltage	5V DC
Operating Current	15mA
Operating Frequency	40KHz
Min Range	2cm / 1 inch
Max Range	400cm / 13 feet
Accuracy	3mm
Measuring Angle	<15°
Dimension	45 x 20 x 15mm



Ultrasonic Sensor Operation

- In order to generate the ultrasound, we need to set the Trig pin on a High State for 10 µs.
- That will send out an 8-cycle ultrasonic burst which will travel at the speed of sound.
- The Echo pins goes high right away after that 8-cycle ultrasonic burst is sent, and it starts listening or waiting for that wave to be reflected from an object.
- If there is no object or reflected pulse, the Echo pin will time-out after 38ms and get back to low state.
- If we receive a reflected pulse, the Echo pin will go down sooner than those 38ms.



Strain Gauges

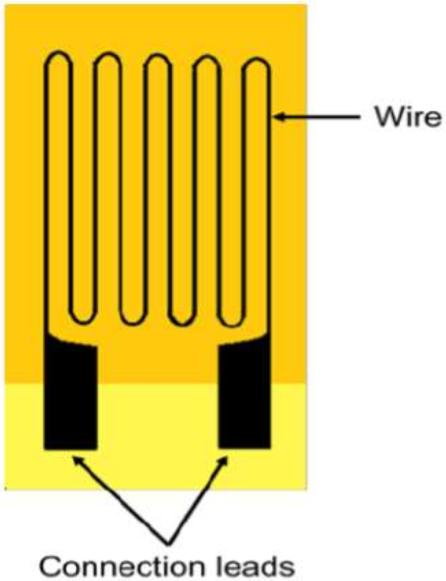
- The strain of an element is a ratio of change in length in the direction of applied load to the original length of an element.
- Resistance strain gauge is a transducer that exhibits the change in electric resistance when it is stretched or strained.
- The resistance of metal sample is:

  $R=\rho l/A$
- where ρ, l and A are density, length and cross-sectional area, respectively.
- When this metal sample is stressed by the application of a Force F,
- The material elongates by some amount Δl and change in resistance is:

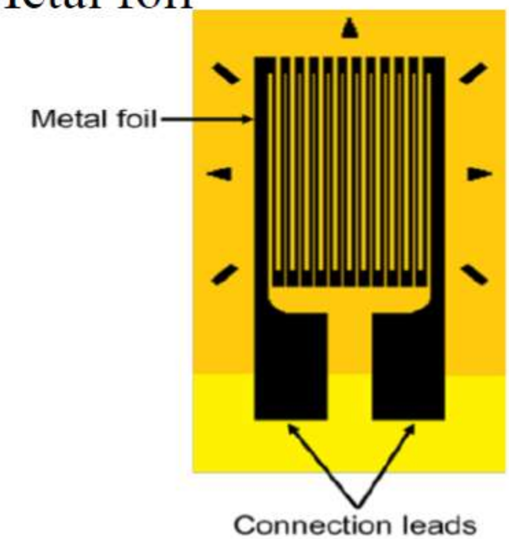
  $\Delta R=2R\ \Delta l/l$

Strain Gauges

- Wire



- Metal foil



Application:

- Strain gauges are primarily used as sensors for machine tools and safety in automotive.

- In particular, they are employed for force measurement in machine tools, hydraulic or pneumatic press and as impact sensors in aerospace vehicles.

Strain Gauges

- $R_2/R_1 = R_x/R_3$

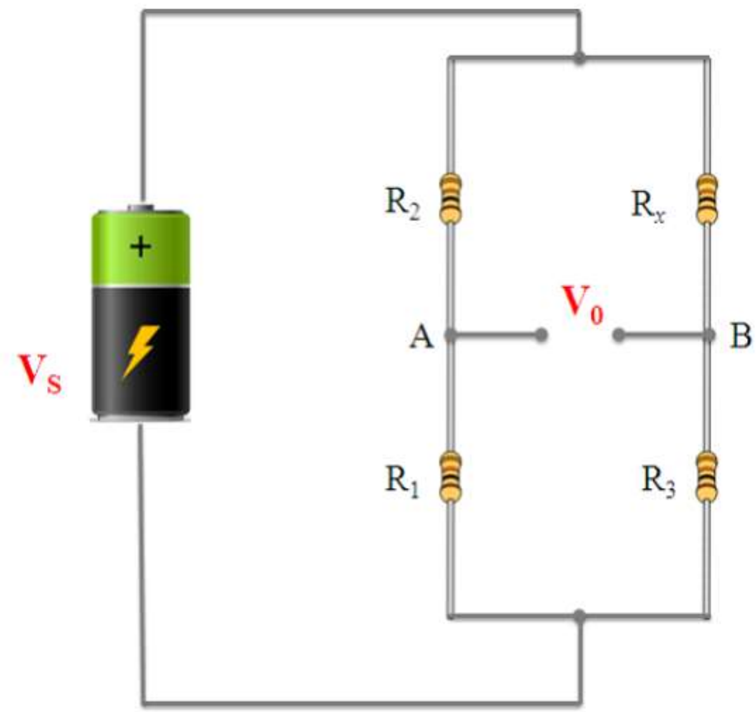
where

R_x is resistance of strain gauge element,

R_2 is balancing/adjustable resistor,

R_1 and R_3 are known constant value resistors.

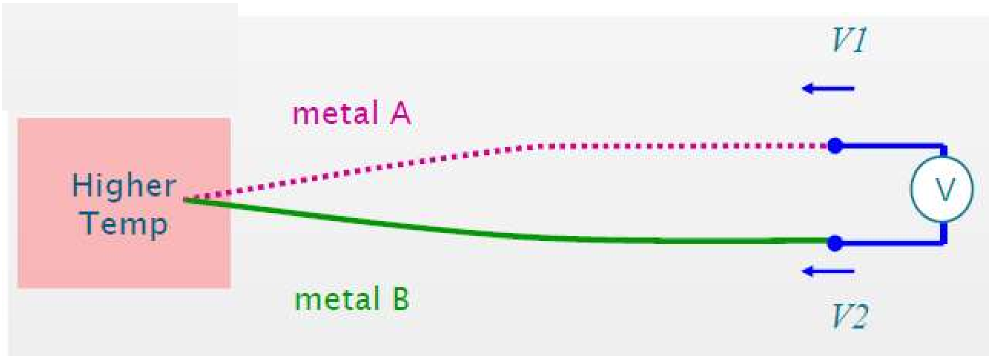
The measured deformation or displacement by the stain gauge is calibrated against change in resistance of adjustable resistor R_2 which makes the voltage across nodes A and B equal to zero.



Temperature Measurements

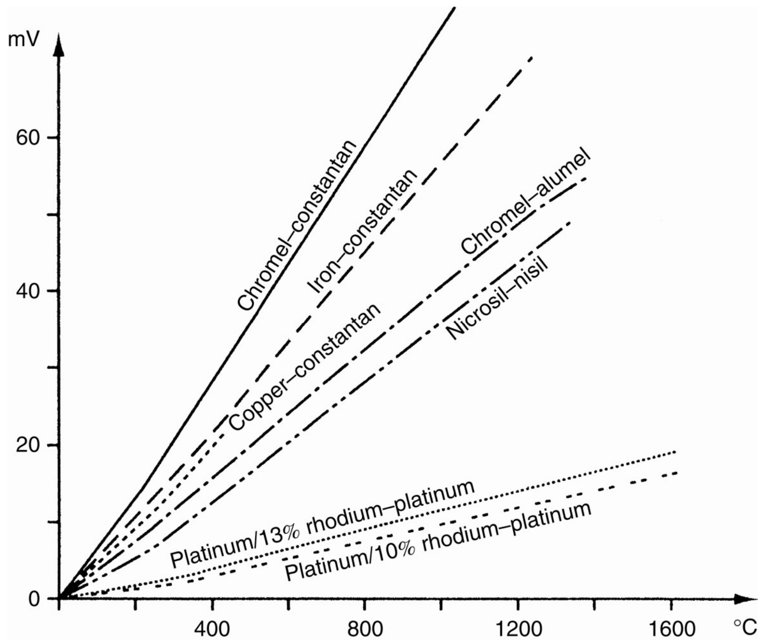
Thermocouples

- If a voltmeter is used to replace one junction, voltage reading = difference between the contact potential at the **sensing junction** and the net contact potential at the voltmeter.



- Because they are different materials and have different Seebeck coefficients, the voltage at the two reference points are also different.

Standard Thermocouples

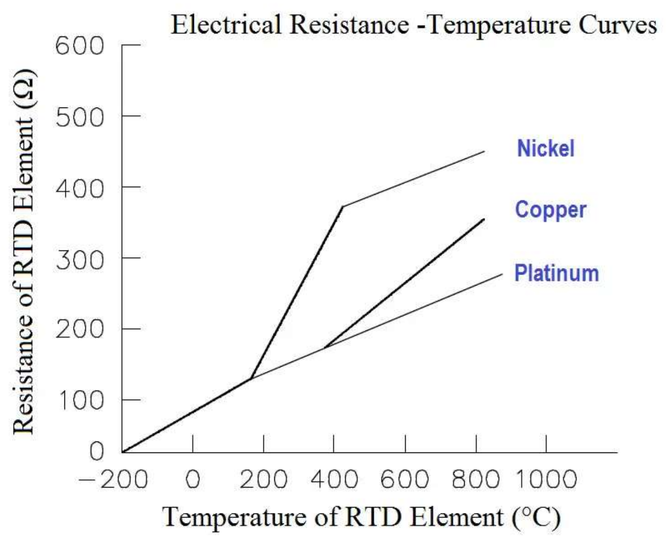


The e.m.f. temperature characteristics for some standard thermocouple materials.

Resistance Temperature Detector RTD

- RTD, resistance temperature detector, is a passive temperature sensing device that operates on the principle that the resistance of a metal changes as the temperature changes.
- Can be manufactured from different metals, like Platinum, Copper and Nickel

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



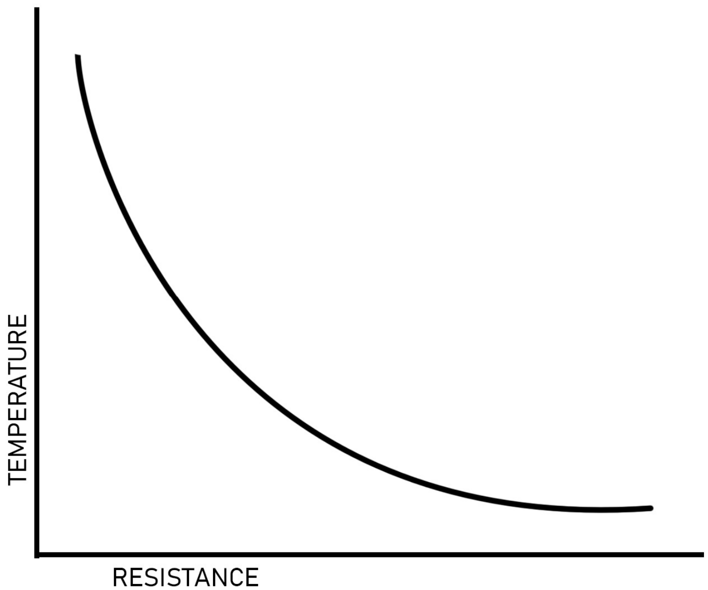
Thermistors

- A **thermistor** is a semiconductor device, available in probes of different shapes and sizes, whose resistance changes exponentially with temperature. Its resistance temperature relationship is usually expressed in the form

$$R = R_0 \, e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$$

  - where *T*0 is a reference temperature,
  - *R*0is the resistance at the reference temperature,
  - β is a calibration constant called the **characteristic temperature** of the material.

- •A well-calibrated thermistor can be accurate to within 0.01 C or better, which is better than typical RTD accuracies.
- However, thermistors have much narrower operating ranges than RTDs.



Sensor type	Thermistor	RTD	Thermocouple
Temperature Range (typical)	-100 to 325°C	-200 to 650°C	200 to 1750°C
Accuracy (typical)	0.05 to 1.5°C	0.1 to 1°C	0.5 to 5°C
Long-term stability @ 100°C	0.2°C/year	0.05°C/year	Variable
Linearity	Exponential	Fairly linear	Non-linear
Power required	Constant voltage or current	Constant voltage or current	Self-powered
Response time	Fast 0.12 to 10s	Generally slow 1 to 50s	Fast 0.10 to 10s
Susceptibility to electrical noise	Rarely susceptible High resistance only	Rarely susceptible	Susceptible / Cold junction compensation
Cost	Low to moderate	High	Low

Radiation Pyrometer

- Radiant energy emitted from a body increases with temperature, is used in measuring temperatures particularly in the higher ranges.
- Situation:
    - Relatively higher temperatures (700 –3000OC)
    - Not possible to contact the hot material

- Types of Pyrometers:
    - Total radiation pyrometer: Total radiant energy from a heated body is measured.
    - Selective (or partial) radiation pyrometer: Specular radiant intensity of the radiant energy from heated body at a given wavelength is measured.

Acceleration measurement

Accelerometer

- An accelerometer is an electronic sensor that measures the acceleration forces acting on an object, in order to determine the object's position in space and monitor the object's movement
- Measured in m/s^2 or in g; g=9.8 m/s^2

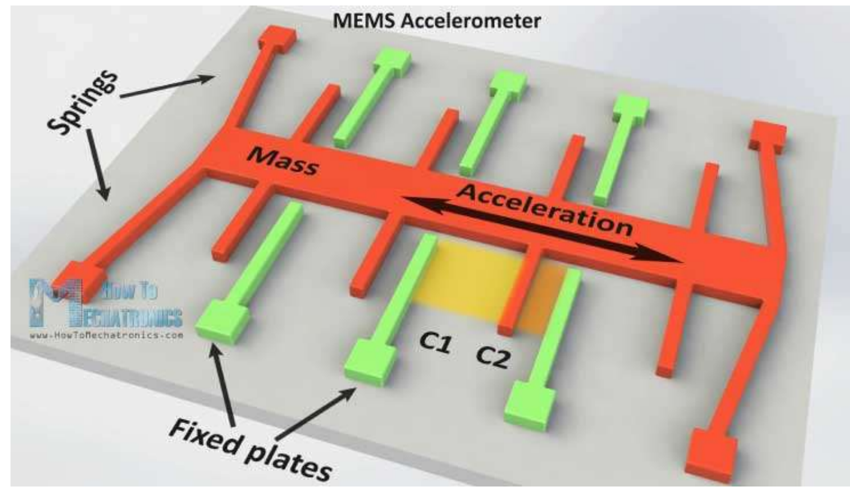
- There two common types of accelerometer:
  - Microelectromechanical (MEMS)

  - Piezoelectric accelerometer

MEMS Accelerometer

- It has a mass attached to a spring which is confined to move along one direction and fixed outer plates.

- When an acceleration in a particular direction will be applied the mass will move and the capacitance between the plates and the mass will change. This change in capacitance will be measured, processed and it will correspond to a particular acceleration value.

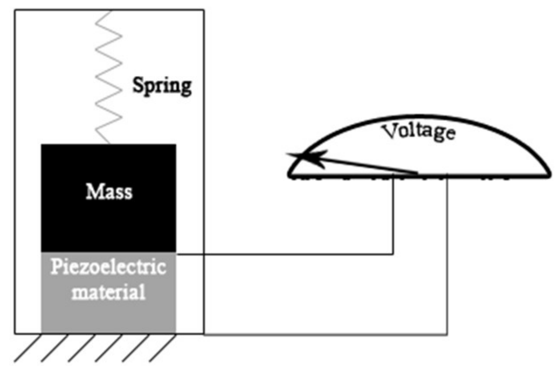


Piezoelectric Accelerometer

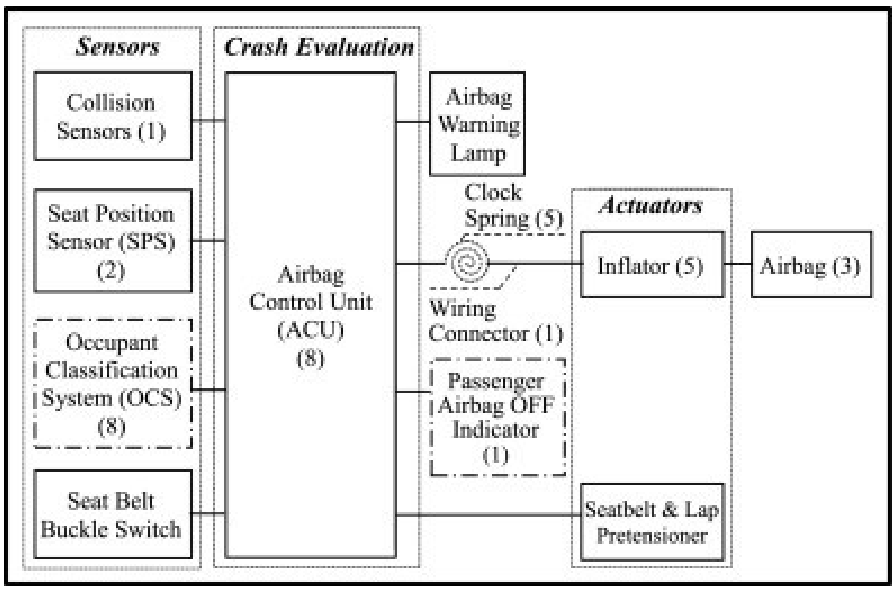
- a piezoelectric material can produce electricity when subjected to mechanical stress.

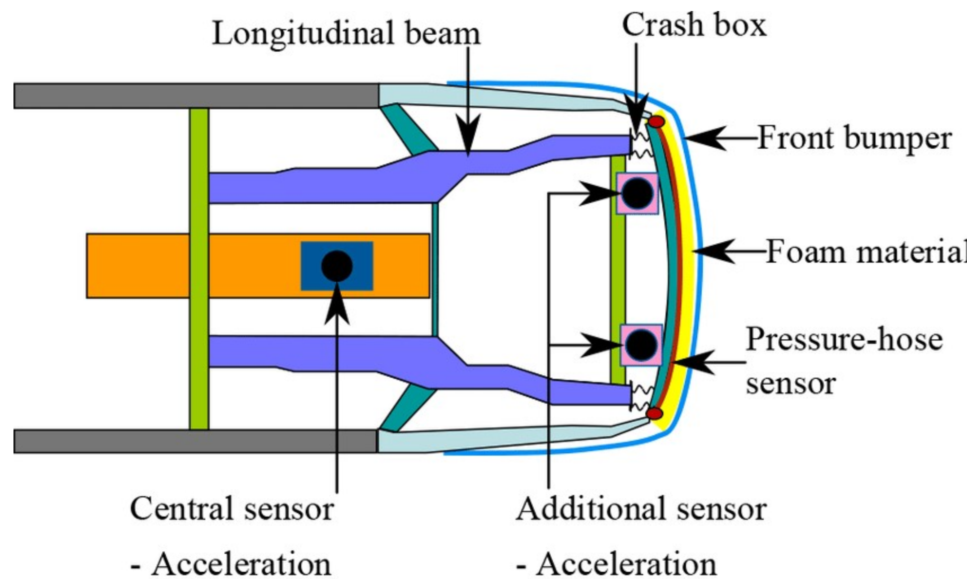
- In a piezoelectric accelerometer, a piezoelectric element is used to connect a known quantity of mass, commonly referred to as the proof mass, to the accelerometer body.

- When the sensor frame accelerates because of an external force, the piezoelectric element produce a charge output that can be measured to determine the input acceleration.



Crash Sensor for Airbag System



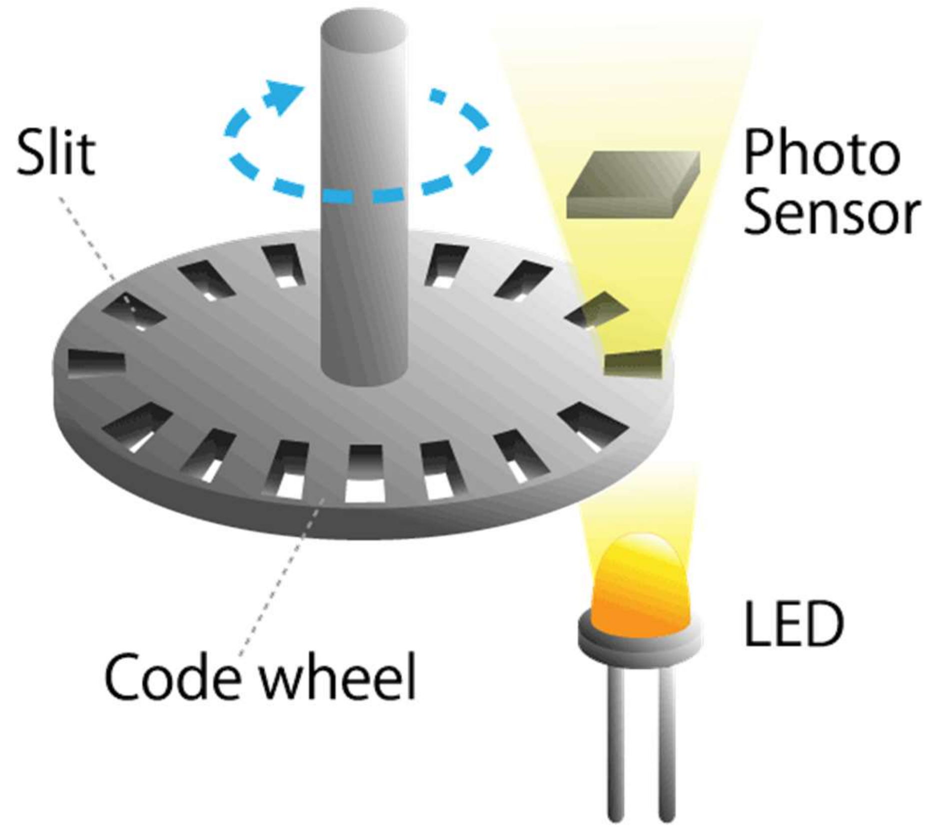


Speed Measurement

Optical Encoders

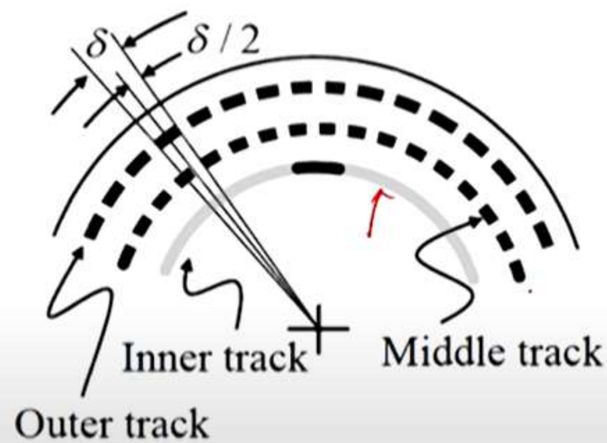
- The sensor uses a light sensor to detect whether light passes through a slit in the radial direction of a rotating disk called a code wheel attached to the motor shaft.

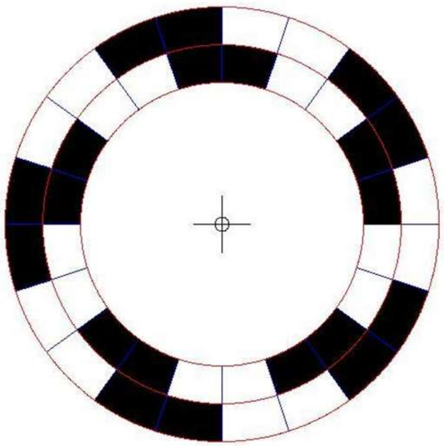
- The light pulse signal changes as it passes through the slit, and the amount of rotation of the motor shaft can be detected by counting the number of pulses.

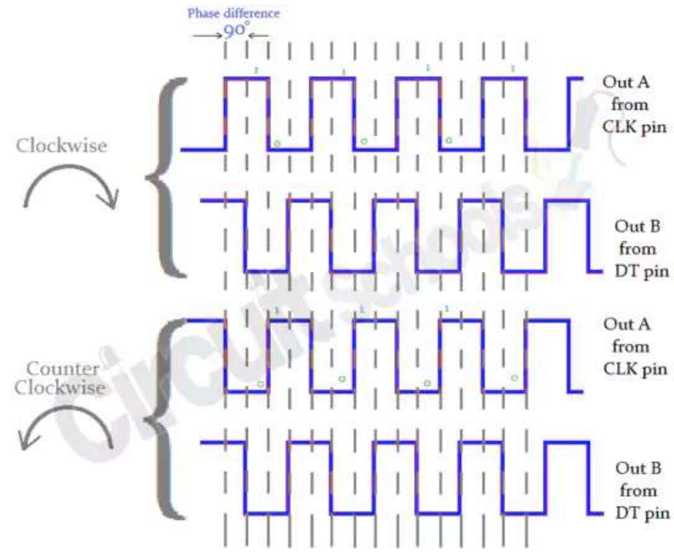


Incremental Encoder

- Actually, three concentric tracks with three sensors are used in incremental encoders where δ is the angle subtended by each hole.
- The inner track has one hole and it locates the home position of the disc.
- The middle and outer track have equally spaced holes around the periphery of the disc.
- Holes in the middle track are at an offset equal to half the width of a hole in comparison to outer track holes.







To compute the angular velocity ω, suppose that the count during a sample period T is n pulses. Hence, the average time for one pulse is T/n. If there are N windows on the disk, the average time for one revolution is NT/n. Hence ω (rad/s) = 2πn/NT.

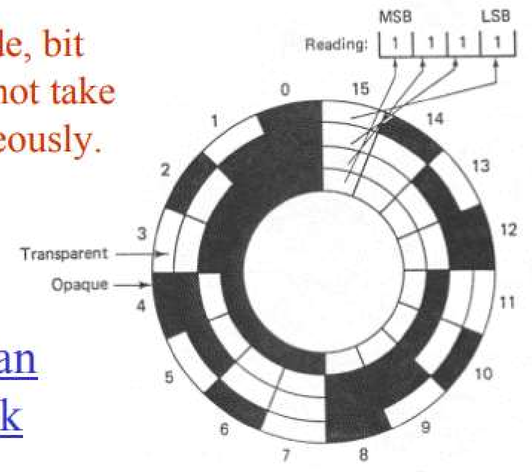
T: Pulse Period

N: Number of slits in the disk

n: Number of the counted pulses

Absolute Encoder

In Binary Code, bit switching may not take place simultaneously.



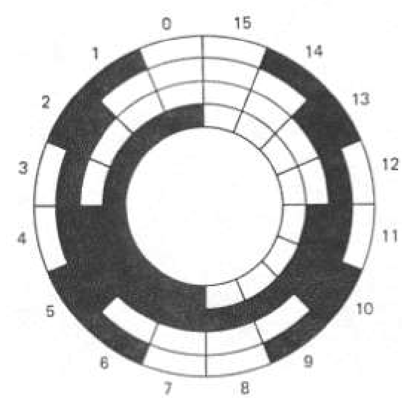
(a)

Schematic Diagram of an Absolute Encoder Disk Pattern

(a) Binary code

(b) Gray code

Absolute Encoders must be powered and monitored only when a reading is taken. Also, if a reading is missed, it will not affect the next reading.



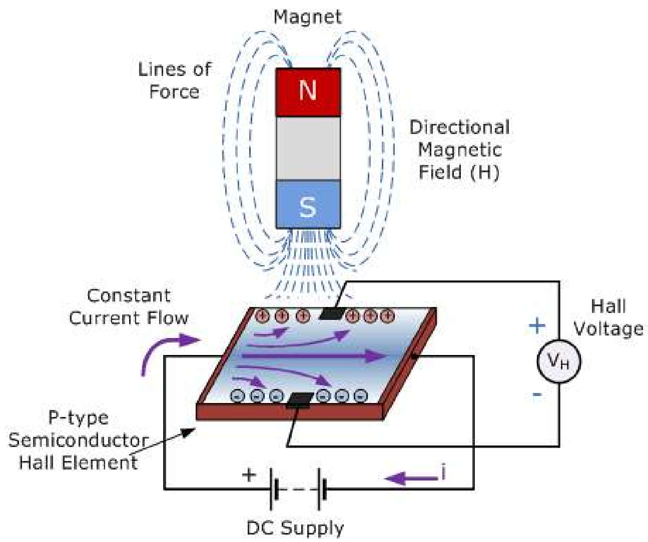
(b)

Ambiguities in bit switching can be avoided by using gray code. However, additional logic is needed to covert the gray-coded number to a corresponding binary number.

Hall Effect Sensor

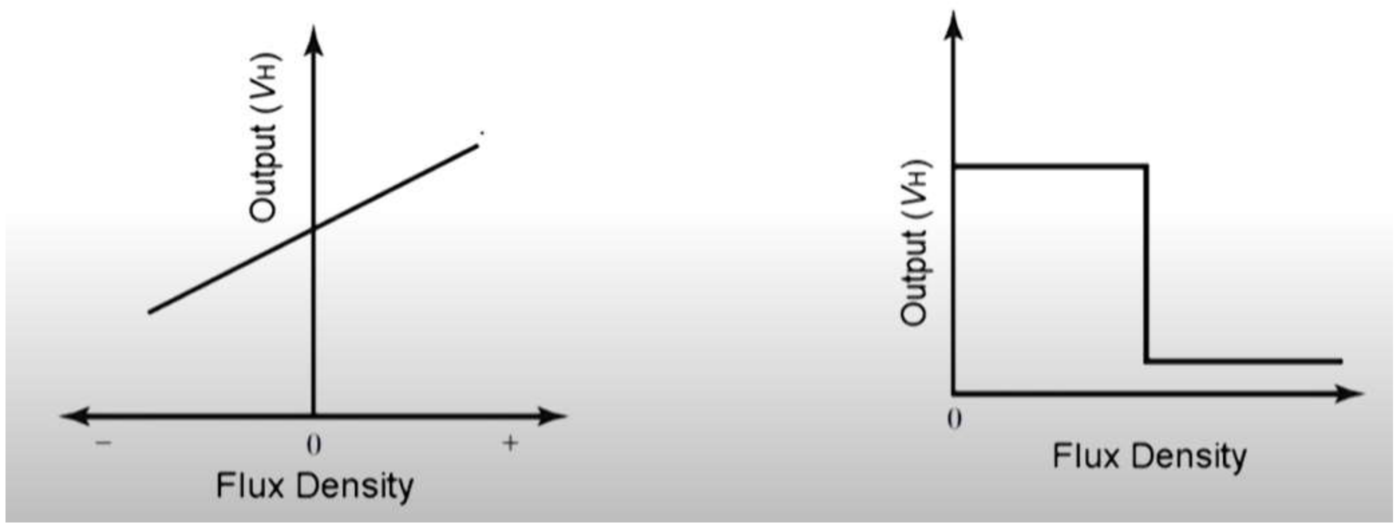
- When a beam of charged particles passes through a magnetic field, forces act on the particles and the beam is deflected from its straight line path (Hall effect).
- A current flowing in a conductor is like a beam of moving charges and thus can be deflected by a magnetic field.

Hall Effect Sensor Principles



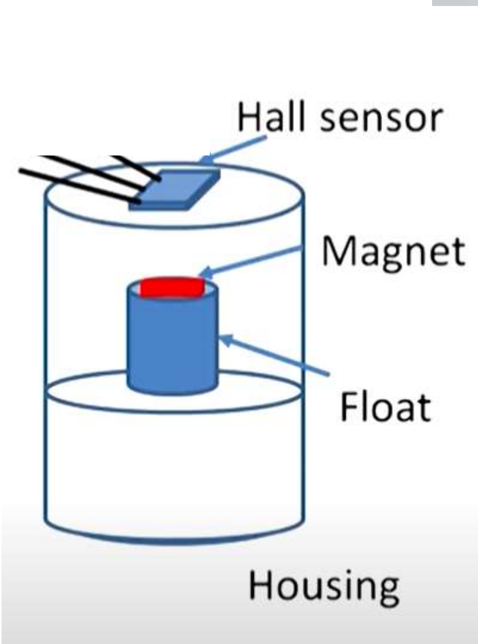
Hall Effect Sensor

- Types: linear, Threshold
  - Linear: used for position and displacement measurement
  - Threshold rotary speed measurement

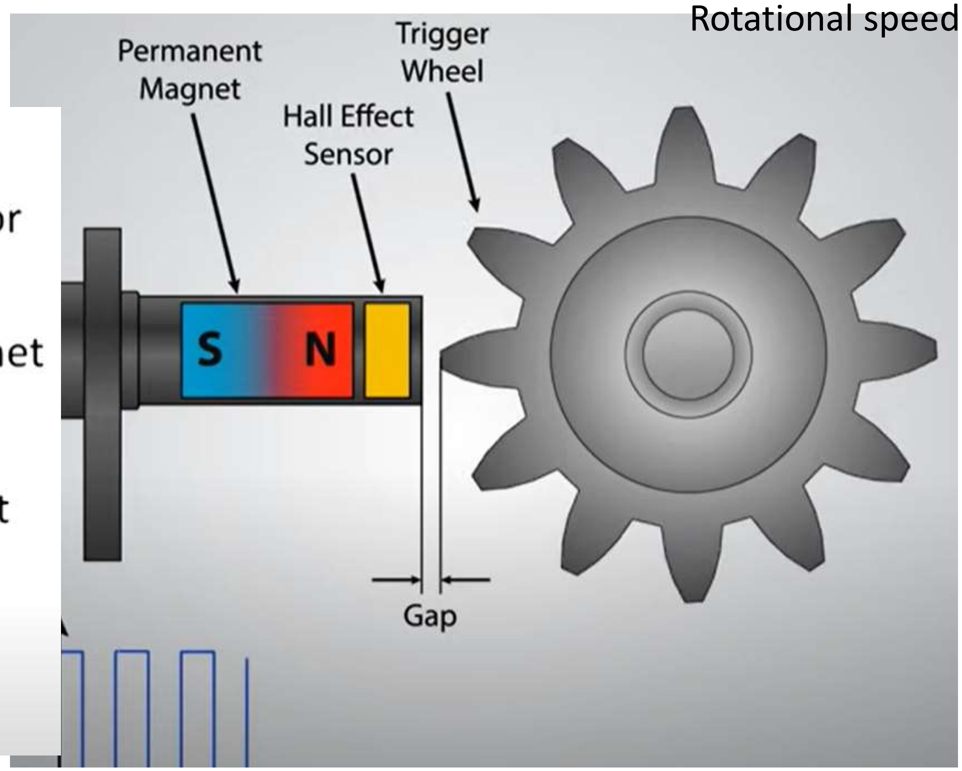


Hall Effect Sensor

Fluid level detection

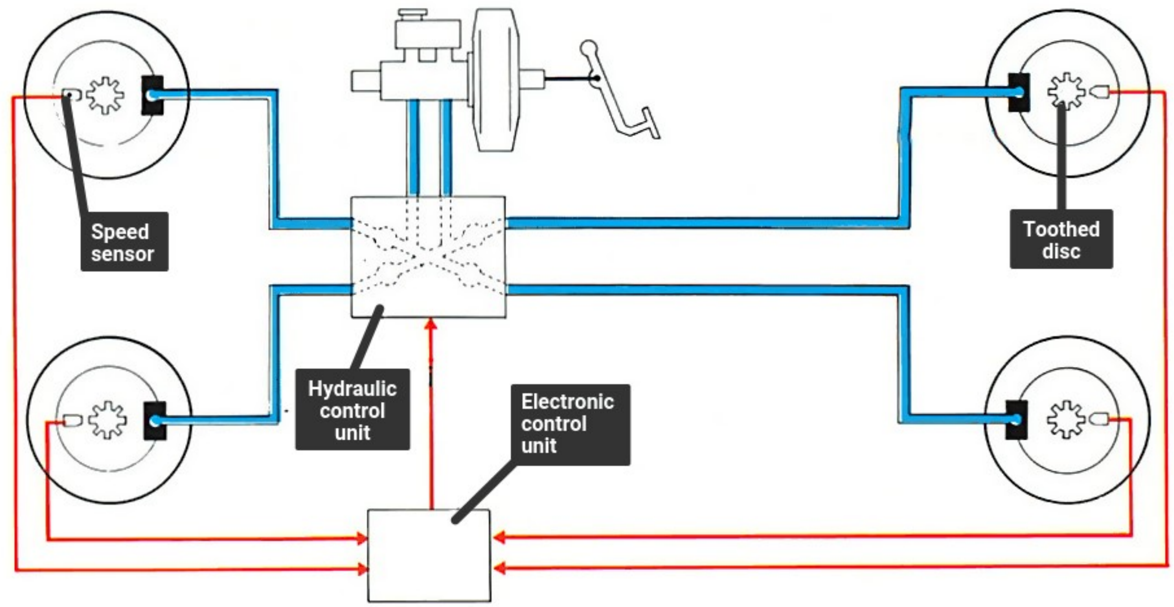


Rotational speed detection



Antilock Braking system

- Hall effect sensor is used to measure the wheels speed
- If one of the wheels is sliding ABS system is activated
- When an ABS works, the brakes are applied and released multiple times per second to prevent car sliding
- You'll stop faster, and you'll be able to steer while you stop. The ABS is maintaining the maximum braking to apply in the car system.



Camera and Computer vision systems

- Camera can be used for object detection using image processing and computer vision algorithms