Position Sensing ..

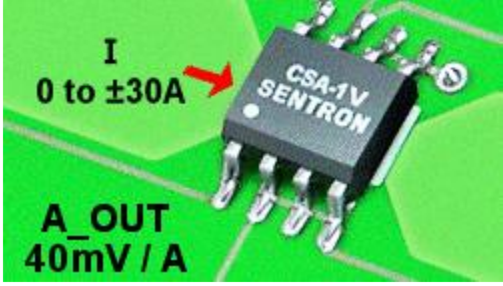
Do we need separate sensors?

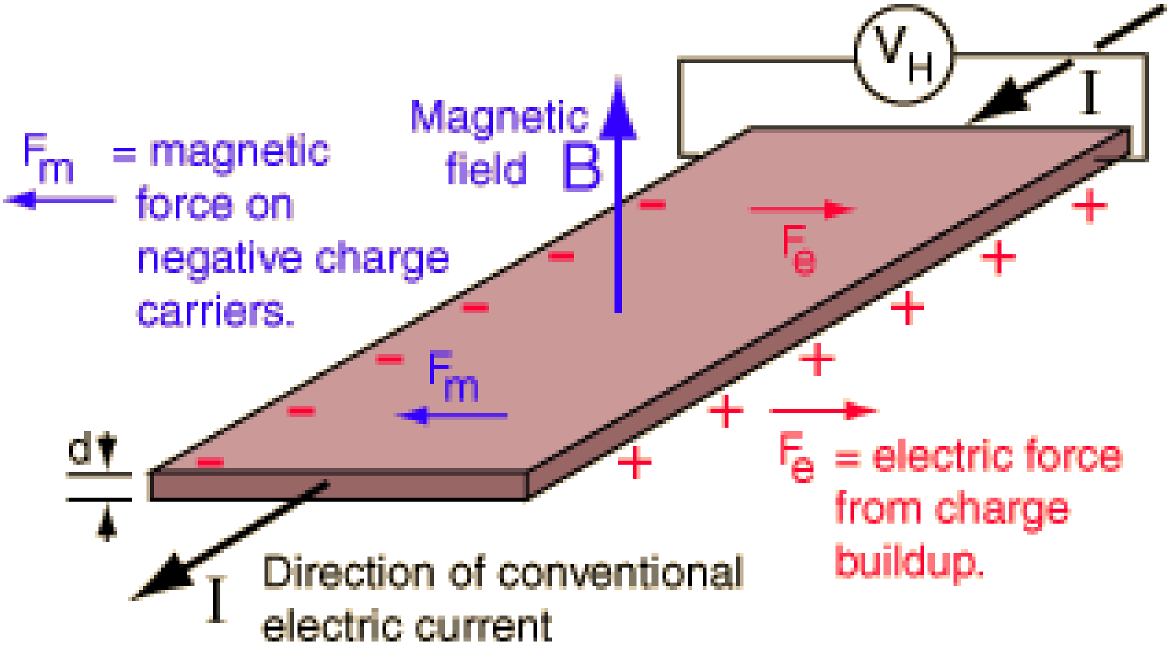
- The nature of the measured signal (e.g., steady, highly transient, periodic, narrow-band, broadband)
- The required frequency content of the processed signal (or the frequency range of interest)
- The signal-to-noise ratio (SNR) of the measurement
- Available processing capabilities (e.g., analog or digital processing, limitations of the digital processor, and interface, such as the speed of processing, sampling rate, and buffer size)
- Controller requirements and the nature of the plant (e.g., time constants, delays, complexity, hardware limitations)
- Required accuracy in the end objective (on which processing requirements and hardware costs will depend)

Our methods of direction sensing

- Magnetic compass
- Sextant + Chronometer
- Hall Probes
- Gyroscope – mechanical & optical
- Tilt Sensor
- Potentiometer (Angle Sensor)
- Piezo-resistive Sensors
- Magneto-resistive Sensors

Hall Effect

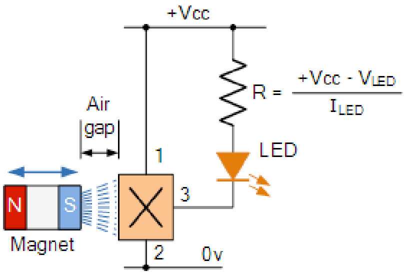


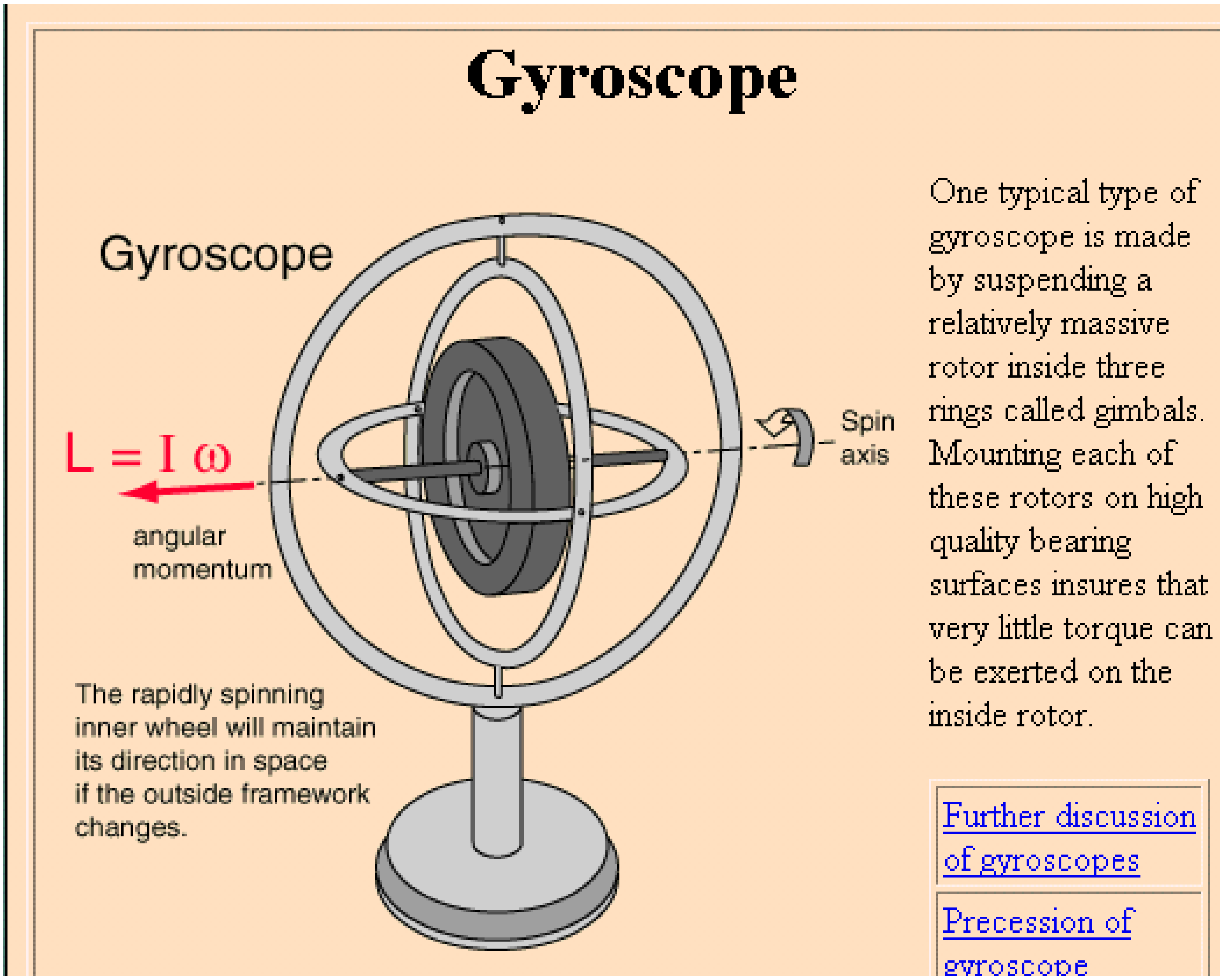


If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor as illustrated. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor.

The Hall voltage is given by

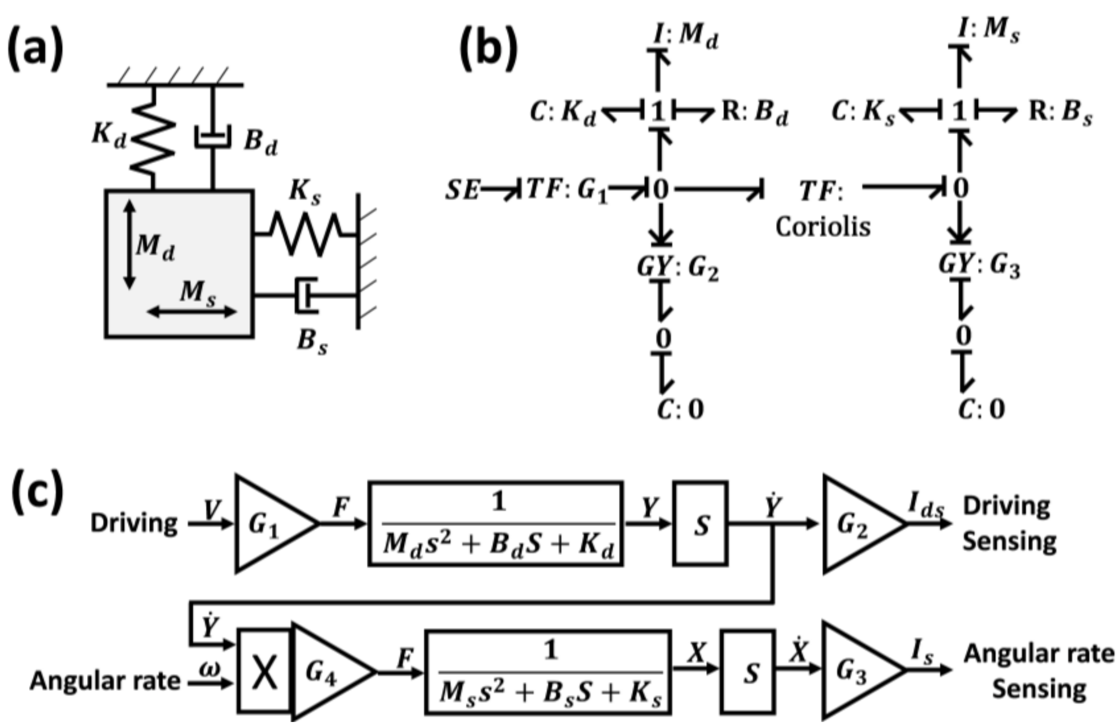
V_H = R_H I B /d; R_H= Hall Coefficient





Gyroscope, also called a gyro, is a device that uses rotation to produce a stable direction in space.

A MEMS based Gyroscope

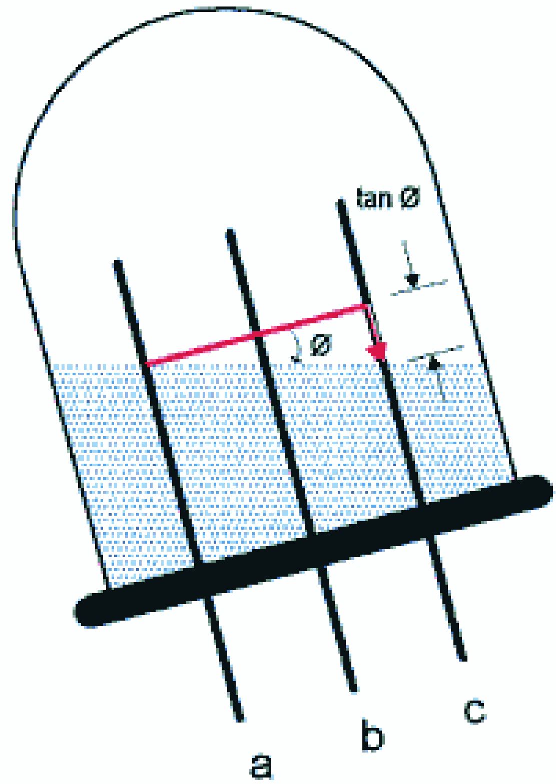


$$\frac{I_{\mathrm{ds}}}{V} = \frac{(G_1 G_2)s}{M_d s^2 + B_d s + K_d}, \quad (1)$$

$$\frac{I_{\mathrm{s}}}{\omega} = \frac{(G_1 G_3 G_4)s^2}{M_d M_s s^4 + (M_d B_s + M_s B_d)s^3 + (M_d K_s + M_s K_d + B_d B_s)s^2 + (B_d K_s + B_s K_d)s + K_d K_s}, \quad (2)$$

System Modeling of a MEMS Vibratory Gyroscope and Integration to Circuit Simulation
Hyukjin J. Kwon , Seyeong Seok and Geunbae Lim – Sensors, MDPI, 2017

Tilt Sensor



As the sensor tilts, the surface of the fluid remains level due to gravity. The fluid is electrically conductive, and the conductivity between the two electrodes is proportional to the length of electrode immersed in the fluid. At the angle shown, for example, the conductivity between pins a and b would be greater than that between b and c.

Electrically, the sensor is similar to a potentiometer, with resistance changing in proportion to tilt angle.

The sensor's angle range is a function of the volume of fluid, electrode spacing, and electrode height. Provided that the electrodes and container are tall enough not to be limiting factors, tilt measurement range is proportional to fluid volume.

Can you find out a Input-Output Relationship?

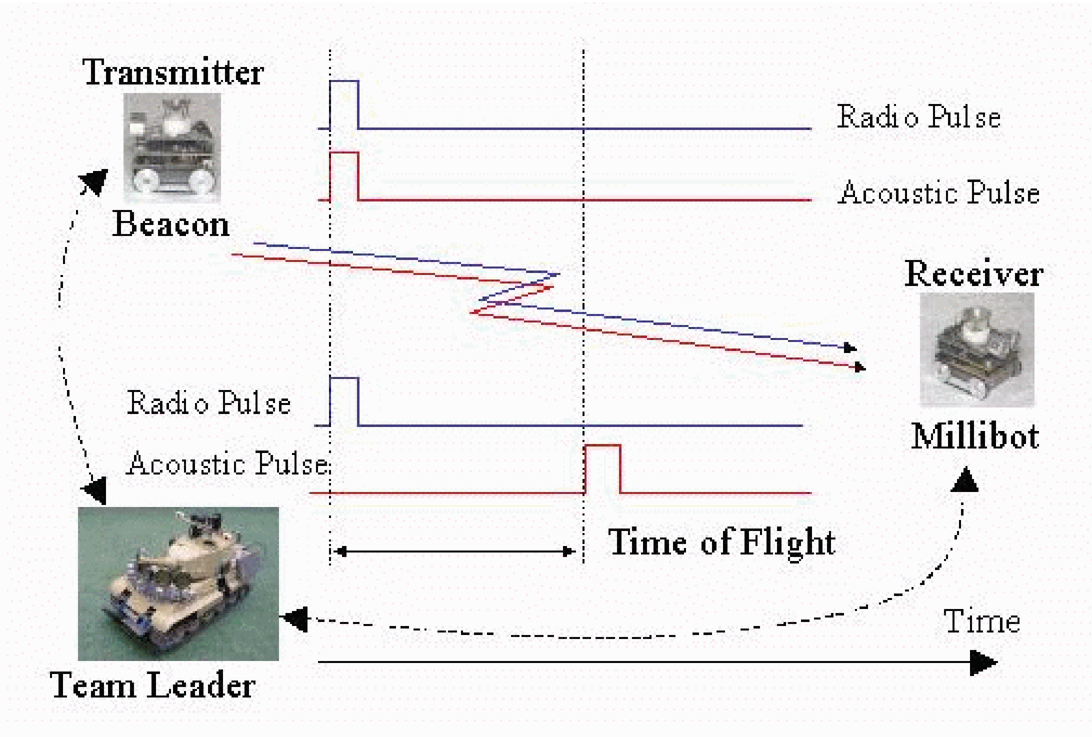
Our methods of distance sensing

- Radar
- Sonar

Long range

- Radio Beacon **1m to 100m**
- Linear Voltage Differential Transformer (LVDT) **.1mm to 1m**
- Capacitance based Sensors **1mm to 1μm**
- Potentiometer POD
- Optical Encoder
- ?

Radio Beacon + Ultrasonic

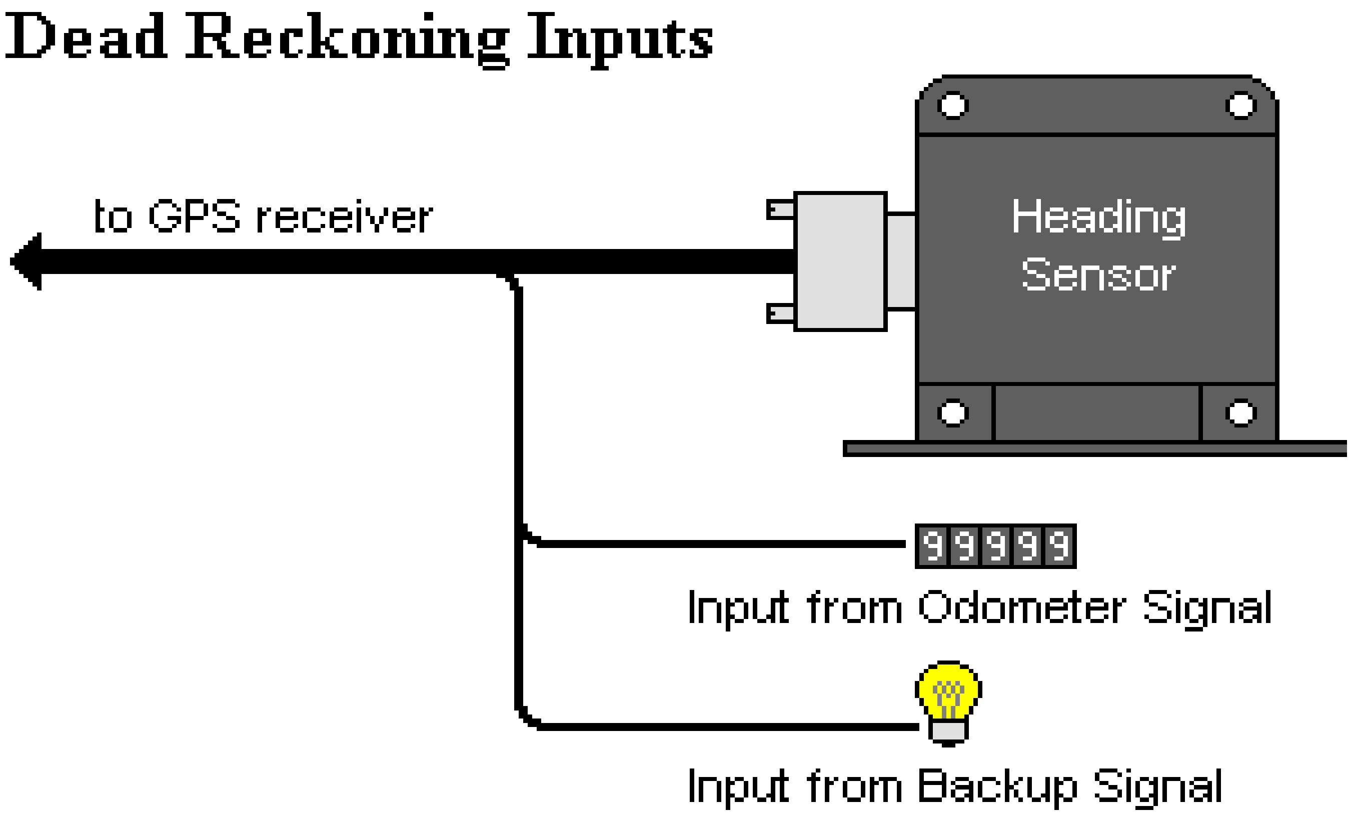


Periodically, each beacon simultaneously emits a radio frequency (RF) pulse and an ultrasonic pulse.

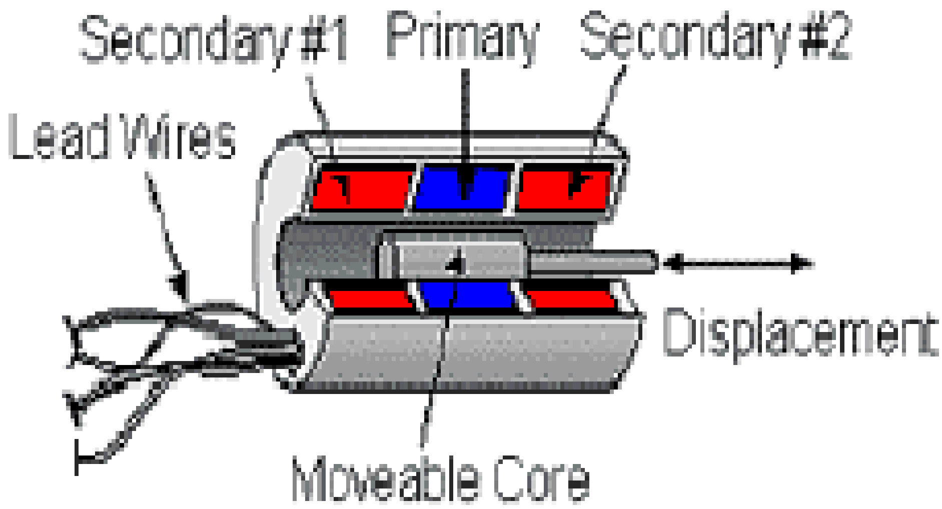
The RF pulse, traveling at the speed of light (3´108 m/s), arrives at all receivers almost instantaneously. The ultrasonic pulse, on the other hand, traveling only at 343 m/s (assuming 20°C air temperature) arrives at the receiver delayed by a time proportional to its distance to the beacon.

Each Millibot measures this delay, using the RF pulse for synchronization, and converts it to a distance measurement by multiplying with the speed of sound.

GPS+DR by automobiles

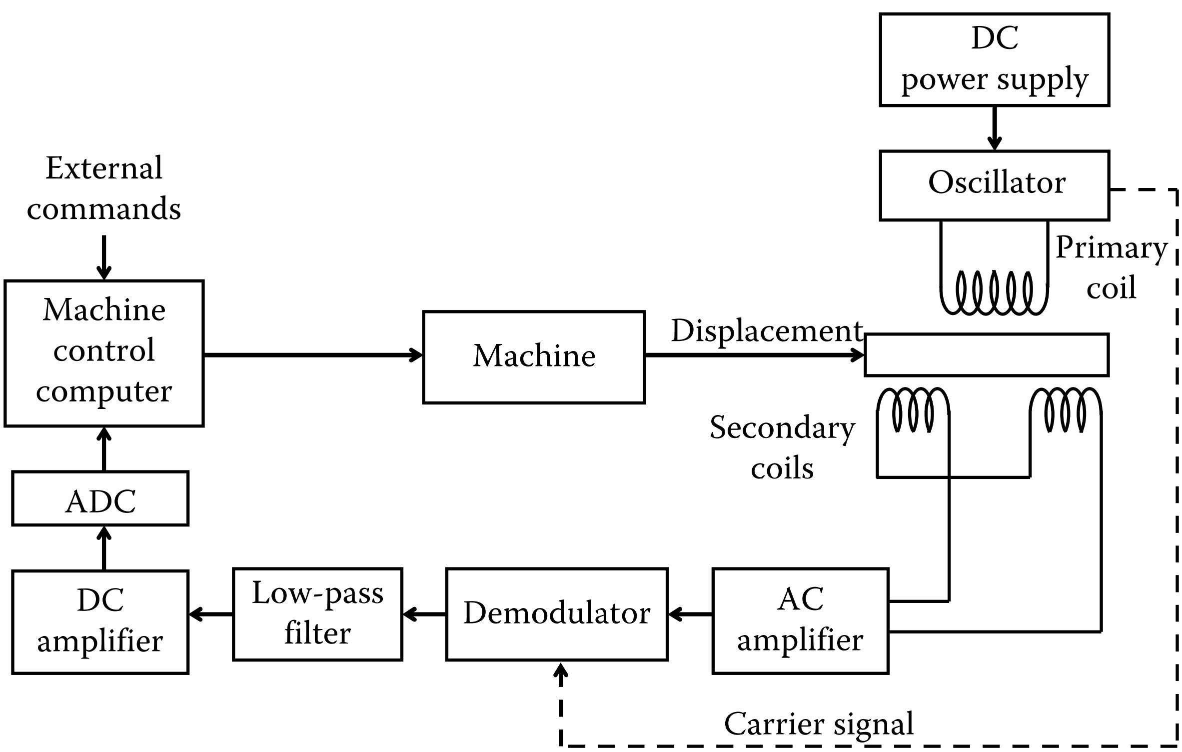


LVDT Construction

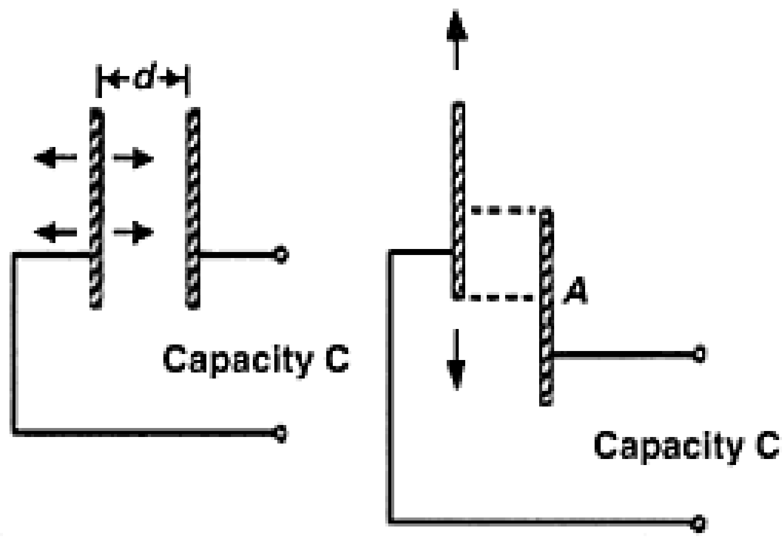


- Primary coil and 2 symmetric secondary coils
- Coils are Encapsulated in Metal/Epoxy Ferromagnetic Core

How is it used?



Capacitance based Sensor



Consider two parallel steel plates with a gap between them. When a voltage is applied to one of the plates, the difference between the charges stored on the surfaces of the plates will cause an electric field to exist between them.

This is a parallel-plate capacitor. Capacitance describes how the space between the two conductors affects an electric field between them, and refers to the capacity of the two plates to hold this charge. A large capacitance can hold more charge than a small one.

The basic operation of a capacitive position measurement sensor can be deduced from the familiar equation for a parallel-plate capacitor:

$$C = \epsilon_0 \epsilon_r \frac{A}{x}$$

where:

ε_0 = absolute permittivity of free space (8.85×10^{-12})

ε_r = relative permittivity (dielectric constant) of medium in gap between plates

A = plate common surface area

x = plate separation (displacement)

There are three ways to change the capacitance of the parallel-plate system:

Variation of the distance between the plates (*x*)

Variation of the shared area of the plates (*A*)

Variation of the dielectric constant (r)

The electronics continuously change the voltage on the sensor surface. This is the excitation voltage. The amount of current required to change the voltage is detected by the electronics and indicates the amount of capacitance between sensor and target.

Various ways of using Capacitance Sensor

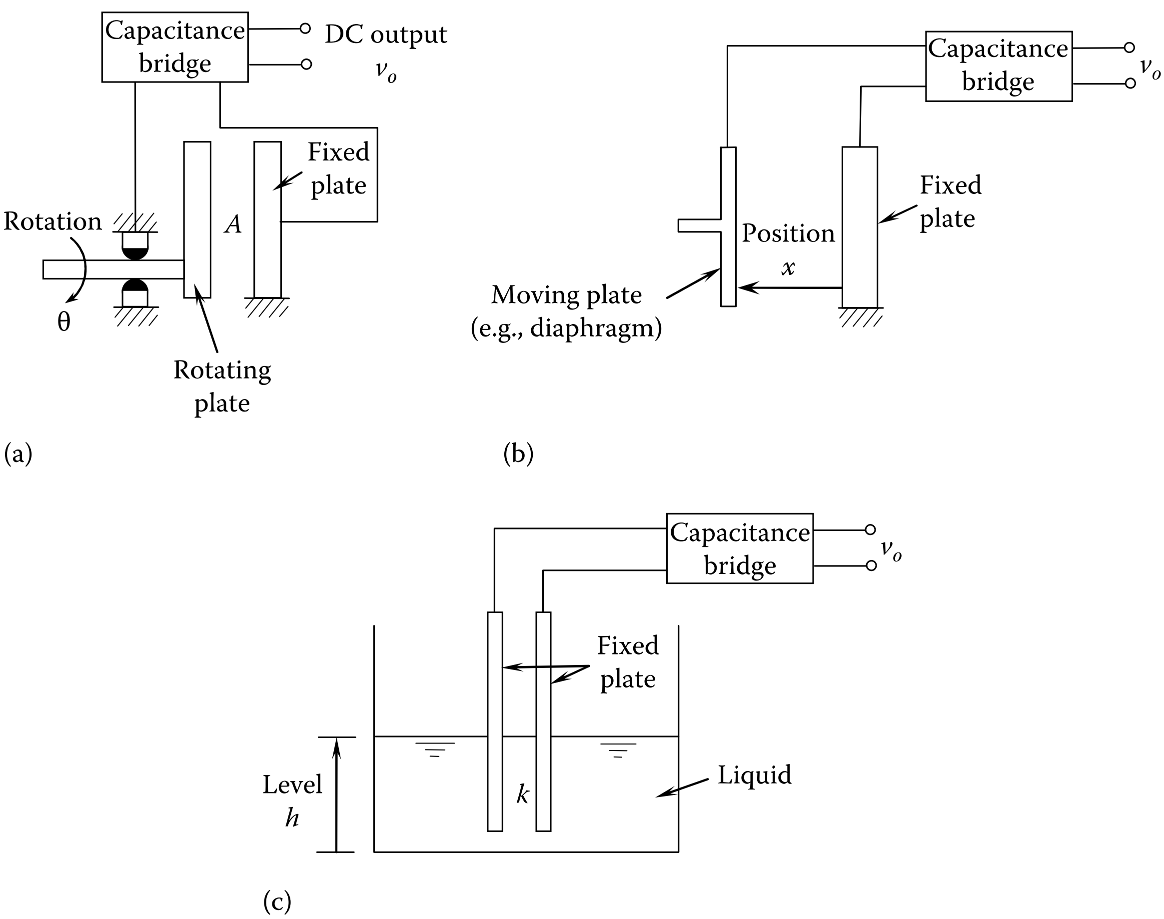
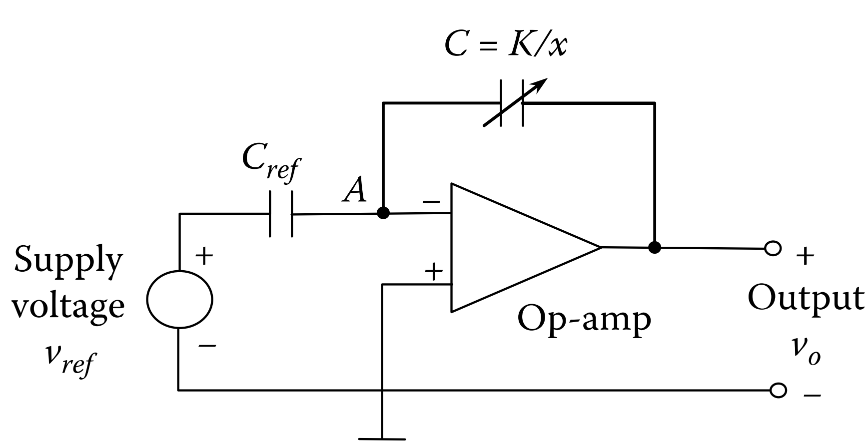


FIGURE 6.15
Schematic diagrams of capacitive sensors: (a) Capacitive rotation sensor; (b) capacitive displacement sensor; (c) capacitive liquid level sensor.

Distance Sensing

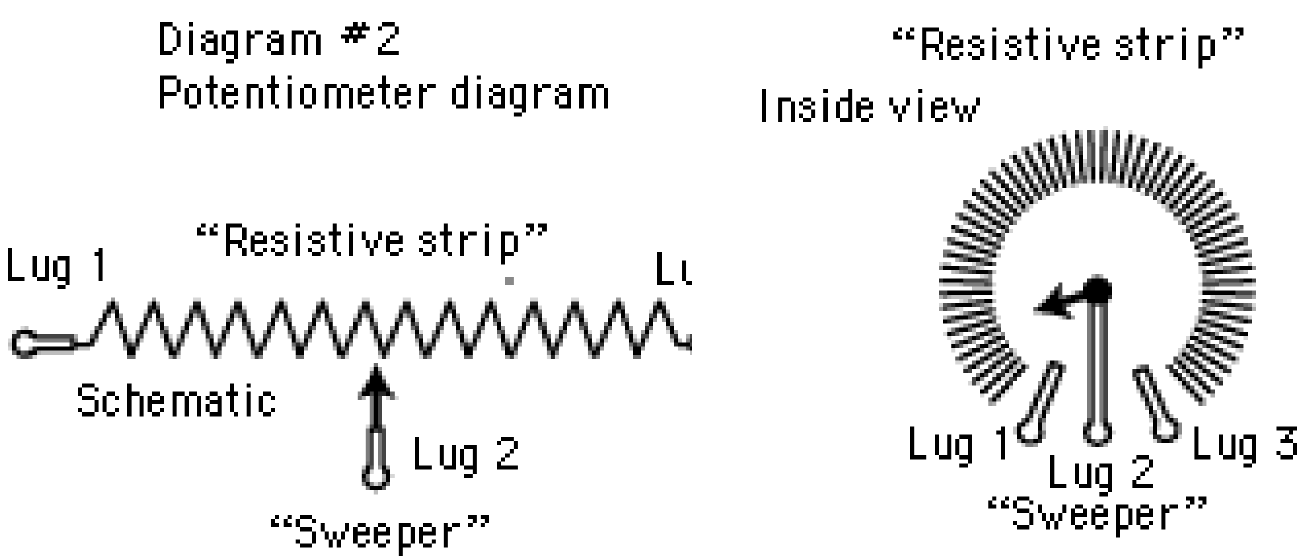
- In a simple capacitor, the voltage output is proportional to the reciprocal of the displacement: $V_0 = \frac{K}{x}$
- In order to linearize we can add an inverting amplifier so that: $V_0 = -\frac{V_{ref}\,C_{ref}}{K}x$



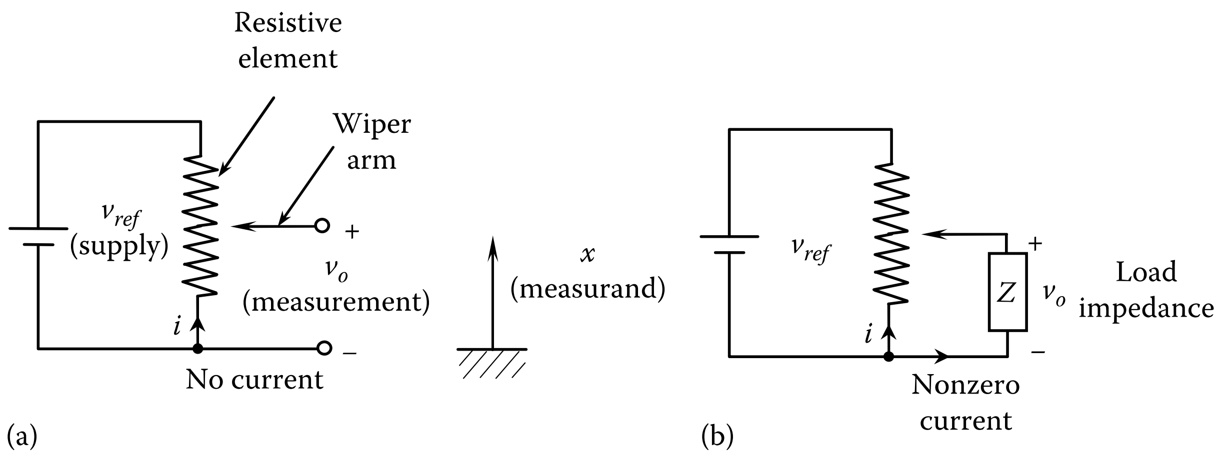
Potentiometer Pods

The potentiometer, or *pot*, is a displacement transducer.

This active transducer consists of a uniform coil of wire or a film of high-resistive material—such as carbon, platinum, or conductive plastic—whose resistance is proportional to its length.
A constant voltage V_{ref} is applied across the coil (or film) using an external dc voltage supply. The transducer output signal V_o *(= K x)* is the dc voltage between the movable contact (wiper arm) sliding on the coil and one terminal of the coil. The slider displacement *x* is proportional to the output voltage:



How a Potentiometer is used?



Note: The linearity is lost for finite impedance as shown in Fig. (b).
You need either a Voltage Stabilizer or additional circuitry for increasing the output impedance artificially.

Limitations and Advantages of POT

- The force needed to move the slider (against friction and arm inertia) is provided by the displacement source. This mechanical loading distorts the measured signal itself.
- High-frequency (or highly transient) measurements are not feasible because of such factors as slider bounce, friction and inertia resistance, and induced voltages in the wiper arm and primary coil.
- Variations in the supply voltage cause error.
- Electrical loading error can be significant when the load resistance is low.
- Resolution is limited by the number of turns in the coil and by the coil uniformity. This will limit small-displacement measurements.

Limitations and Advantages of POT

- Wear-out and heating up (with associated oxidation) in the coil or film and slider contact cause accelerated degradation.

However, there are several advantages associated with potentiometer devices:

- They are relatively inexpensive.

- Potentiometers provide high-voltage (low-impedance) output signals, requiring no amplification in most applications.
- Transducer impedance can be varied simply by changing the coil resistance and supply voltage.

A Better Optical POT System

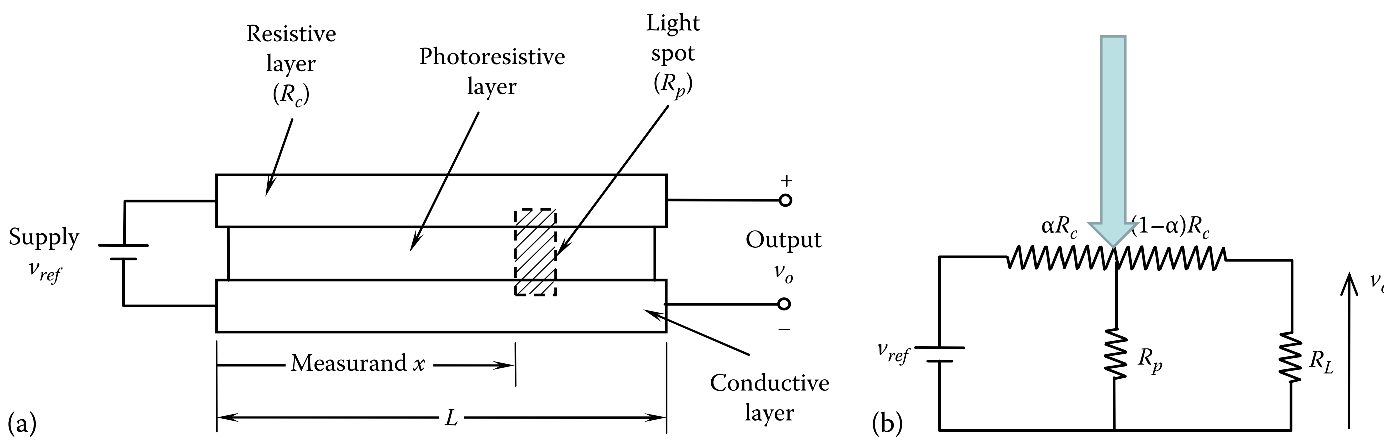


FIGURE 6.2
(a) An optical potentiometer; (b) equivalent circuit ($\alpha = x/L$).

The current balance at the junction of the three resistors gives:

$$\frac{v_{ref} - \left[(1-\alpha)R_c + R_L\right]v_o/R_L}{\alpha R_c} = \frac{v_o}{R_L} + \frac{\left[(1-\alpha)R_c + R_L\right]v_o/R_L}{R_p},$$

For high load resistance $R_c/R_L = 0$ and hence, the modified relationship may be written as:

$$\frac{v_o}{v_{ref}} = 1 \Big/ \left[\frac{x}{L}\frac{R_c}{R_p} + 1\right]$$

Optical Sensors

Fundamentals

- Most Optical Systems consist of three parts – a light source, a light sensor and the transmitting medium
- Many Auxiliaries: lenses, optical wave guides, mirrors, filters, polarizers, diaphragms and choppers
- For example: optical displacement sensor is designed in such a manner that a change in distance between two sensor parts, or one sensor and a moving object will result in change in transmission, reflection, absorption, scattering or diffraction of a beam of light

Major Light Emitters

- Thermal Light bulb – very cheap and easy to get optical source, wide optical spectrum, wide beam angle, slow – due to thermal operation the intensity can not change fast.
- LED: Light Emitting Diode – GaAs and GaN, narrow emission spectrum, electrically controllable intensity, moderately focused beam

Even Better Light Emitters

- Semiconductor Laser – more expensive device, similar to LED but physical operation varies, laser stimulation by injection of charged particles, controllable intensity, monocromatic with very narrow spectrum
- Solid State Laser: Much more expensive, Materials Nd^{3+} YAG (Yittrium Aluminium with Neodymium ion impurity), very narrow optical beam (nm level)

Light Emitters

Table 7.1 Overview of optical emitters and receivers, modulation types, and possible accessories

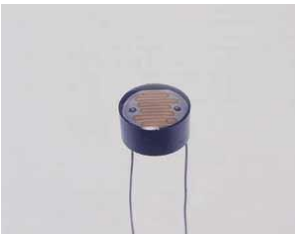
Emitters	Modulation	Receivers	Accessories
Light bulb	Transmission	Photoresistor	Lenses
(Gas) Laser	Reflection	Photovoltaic cell	Mirrors
Laser diode	Absorption	Photodiode	Reflectors
LED	Scattering	Phototransistor	Filters
	Refraction	PSD	Fibers
	Polarization	Line scan camera	Collimators
	Dispersion	Matrix camera	

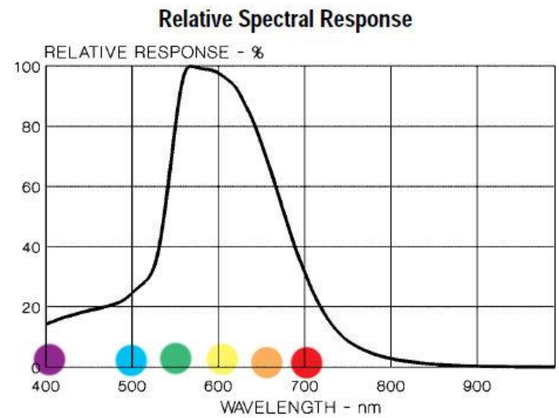
Light Sensors

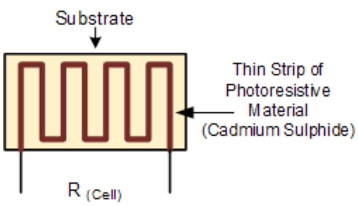
- Photoresistor: small, cheap; sensitive to visible and IR light, slow, no directional sensitivity
- Photodiode: Moderate directional sensitivity and faster response.
- Diode array: An array of Photodiodes – improved sensitivity
- Position Sensitive Diode (PSD): as photodiode, 1D and 2D position sensitive
- CCD: More sensitive, frame rate up to 1000/s
- CMOS: Higher Resolution but noise susceptible.

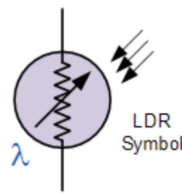
Light Dependent Resistors (LDR)

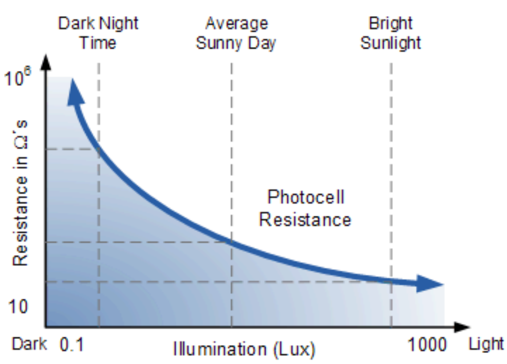
Photoresistor











An LDR has a resistance that varies according to the amount of visible light that falls on it.

The light falling on the brown zigzag lines on the sensor (usually Cadmium Sulphide), causes the resistance of the device to fall.

This is known as a negative co-efficient LDR.

There are some LDRs that work in the opposite way i.e. their resistance increases with light (called positive co-efficient).

Optical Reflective Detector

$$R_{LDR} = a(I)^{-b}$$

$$V_{out} = V_{in}\left(\frac{R_{LDR}}{R_{LDR} + R}\right)$$

Where I Intensity of light per unit area

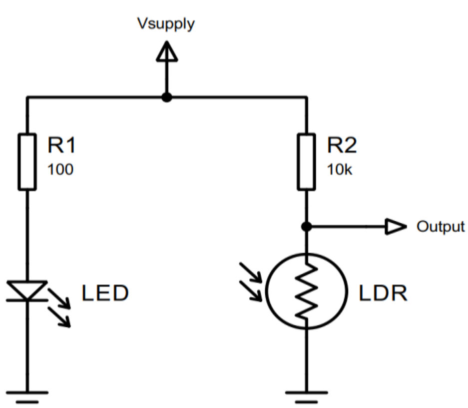
a Constant depends on material

b Constant depends on shape of the resistor

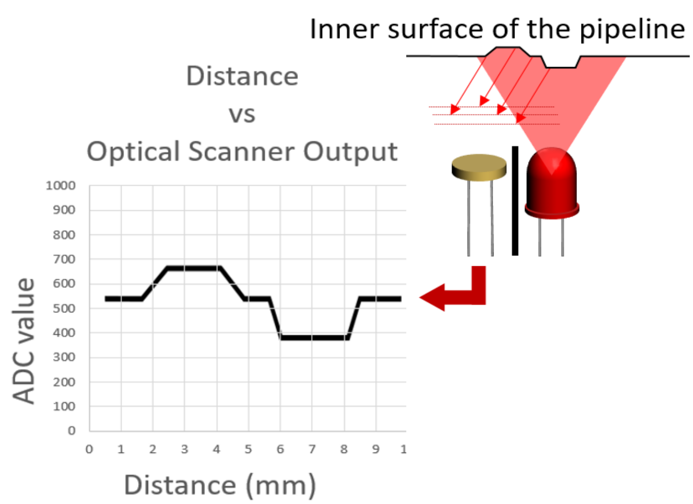
Where V_{in}

(Input voltage)

R Resistance of resistor R2



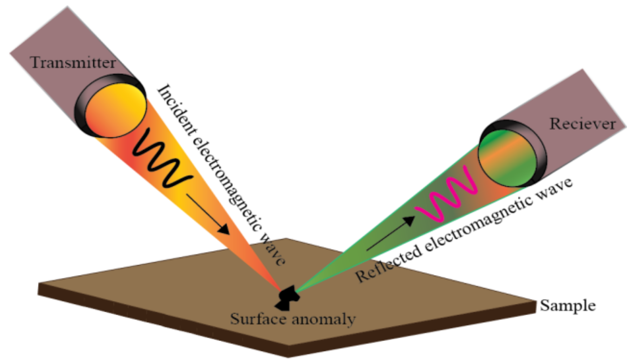
Optical Reflective Detector schematics



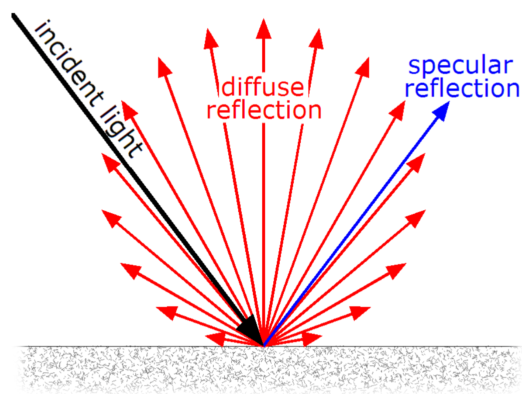
Output voltage variation of sensor

Sensing Mechanism

The intensity of reflected electromagnetic waves from the rough surface can be broadly summarized in the following relationship



$$\frac{I_s}{I_o} = \mathrm{k}\exp\left[-\left(\frac{4\pi R\cos\theta}{\lambda}\right)^2\right]$$



Where R RMS value of the surface roughness

k Material constant

θ Angle of incidence

λ Wavelength of light

I_s Intensity of specular reflectance

I_o Intensity of total reflectance (Specular + Diffuse)