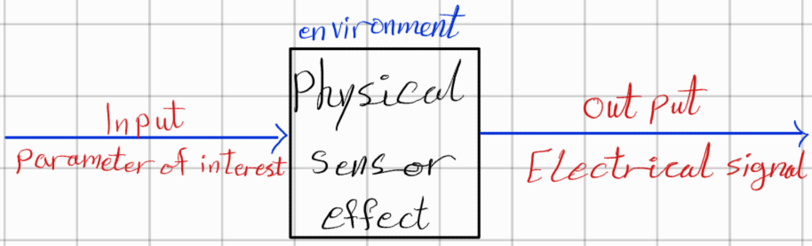
Sensor Definition: Transform parameters of interest into electrical signal which can be displayed, stored, or further processed for applications in science & technology.



Physics of sensors:

Dimentional Metrology

Bragg's Law: Crystalised solids produce surprising patterns of reflected X-rays. These crystals at certain wave length and incidence angels produce intense peak of reflected radiation (also the case for opticals)

Snell's Law: Reflected and refracted rays of light at an optical inter-face are related to the angle of incidence. (Fiber-optic strain law are based on this law)

Villari effect: based on the magnetic susceptibility of the material when subjected to a mechanical stress.

Poisson effect: A material deforms in a direction perpendicular to an applied stress.
→ partially responsible for the response of a strain gauge.

Kinematics:

Bernoulli's equation: Conservation of energy in a fluid predicts a relationship between pressure & velocity of the fluid.
→ A Pitot tube uses this effect to measure air speed of an aircraft.

Coriolis effect: A body moving relative to a rotating frame of reference experiences a force relative to the frame.
→ A Coriolis gyrometer detects disturbing torque moments acting detrimental on a moving automobile.

Doppler effect: The frequency received from a wave source (e.g., sound or light) depends on the speed of the source.
→ A LASER Doppler velocimeter uses the frequency shift of LASER light reflected by moving bodies, e.g., machinery components or moving automobiles.

Galvanomagnetic Thomson effect (Gauss effect): The resistance of a conductor increases when magnetized.
→ This effect is used to determine lateral or rotational motions of moving components in machines.

Gyroscopic effect: A body rotating about one axis resists rotation about other axes.
→ A navigation gyroscope uses this effect to track the orientation of a body with the aid of a gimbal-mounted flywheel that maintains constant orientation in space.

Hall effect: A voltage is generated perpendicular to current flow in a magnetic field.
→ A Hall effect proximity sensor detects when a magnetic field changed due the motion of a metallic object.

Dynamics:

Lorentz's law: There is a force on a charged particle moving in an electric and magnetic field.
→ The Lorentz force is the basic effect for the operation of motors and generators.

Newton's law: Acceleration of an object is proportional to force acting on the object.
→ This law is essential for acceleration sensors.

Piezoelectric effect: Charge is displaces across a crystal when it is strained.
→ A Piezoelectric pressure sensor measures charge polarization across a piezoelectric crystal due to the force of a diaphragm applied to pressure.

Temperature:

Joule's (first) law: Heat it produced by current flowing through a resistor.
→ The design of a hot-wire anemometer is based on this principle.

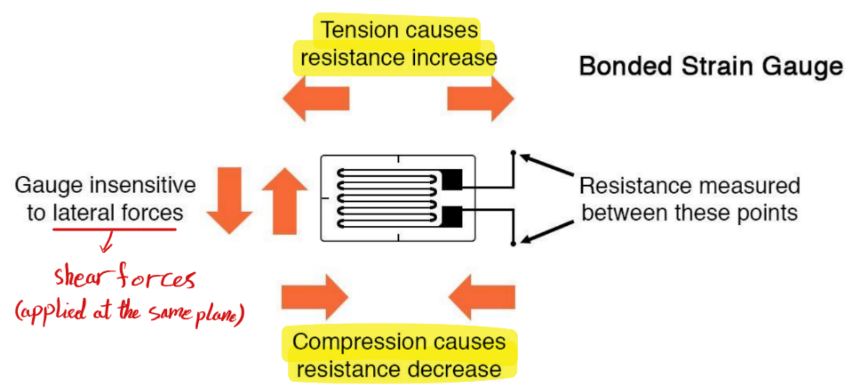
Seebeck effect: Dissimilar metals in contact result in a voltage difference across the junction that depends on temperature.
→ Principle of a thermocouple.

Stefan-Boltzmann law: The heat radiated from a black body is proportional to the fourth power of its temperature.
→ Principle for the design of a temperature-sensing pyrometer.

Resistive Sensors: A resistor is a passive two terminal electrical component that implements electrical resistance as a circuit element. Its resistance is defined by:

$$R = \rho \frac{L}{A}$$

ρ: resistivity of the conductor material
L: length of the conductor material
A: cross-section of the conductor material



Gauge Factor (GF)

$$GF = \frac{dR/R_G}{\varepsilon}$$

dR: change in resistance caused by strain
R_G: resistance of the undeformed gauge
ε: strain

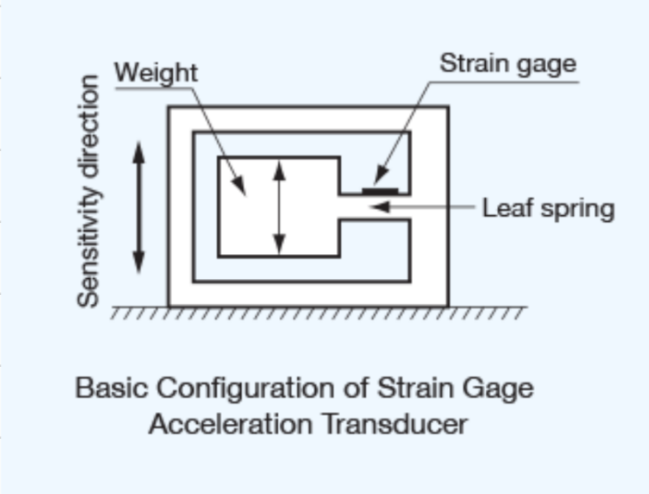
A typical GF for a metallic foil gauge is little over 2.

Choosing Strain gauges with:

Lower value: Less sensitive to variation of the isolating resistance, and electromagnatic interferences.
drawback: due to ohm's law, low resistance → low output voltage.

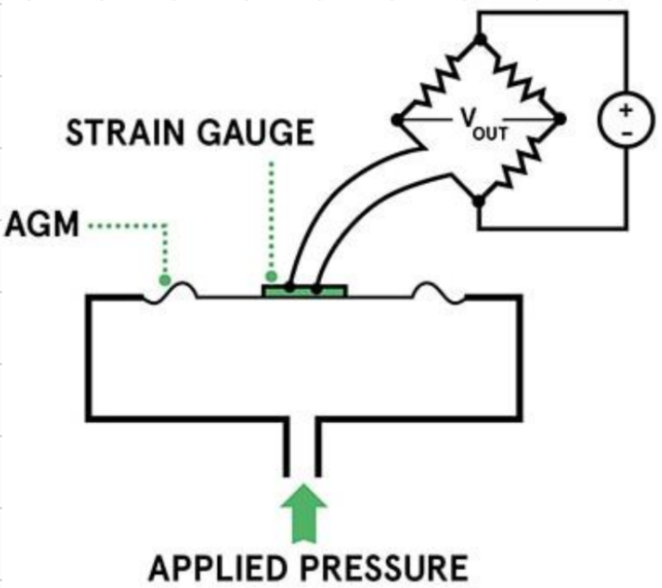
Higher value: less self-heating, less sensitive to the resistance of the connection lines.

Example of strain gauge to sense acceleration



Basic Configuration of Strain Gage Acceleration Transducer

Strain Gauge to sense pressure



Capacitive sensors:

A capacitor consists of two parallel conducting plates separated by a small gap. The capacitance is defined by:

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

A → area of the plates

d → distance between the plates

ε_0 → electric const.

ε_r → dielectric const. of the material

Eample for capacitive sensors based on spacing changes:

* Distance sensors (for distance < sensor diameter)
* Acceleration sensors
* Pressure Sensors

Capacitive pressure sensor: uses a pressure sensitive diaphram as one electrode, whereas the other electrode is fixed.

Inductive sensor: based on Faraday's law of induction.

Lenz's Law states: $U(t) = -L * \frac{di}{dt}$

Most important advantage of the inductive proximity sensor:

It doesn't require physical contact.

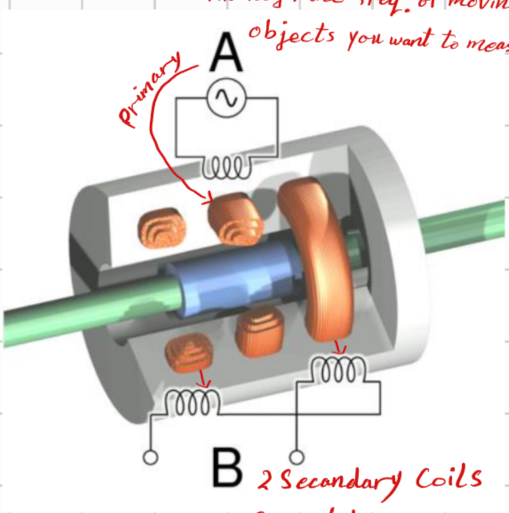
$$\underset{\text{In Henry (SI unit)}}{L} = \underset{\text{Permeability of free space } 4\pi \cdot 10^{-7} H/m}{\mu_0} * \underset{\text{Permeability of the core material}}{\mu_r} * \underset{\text{num. of turns}}{N^2} * \frac{\overset{\text{cross-section of the coil}}{A}}{\underset{\text{Length of the coil}}{l}}$$

Linear Variable Differential Transformer (LVDT):
An electromechanical sensor used to measure linear displacement.

Rotary Variable Differential Transformer (RVDT):
Same concept as LVDT except that it's rotary displacement.

Main advantage: LVDT & RVDT doesn't require an electrical contact between the moving part and the coil assembly, making these sensors very reliable.

Frequency of A should be at least x10 high the freq. of moving objects you want to measure.



2 Secondary Coils Connected in series (generating an AC ouput voltage which indicates the displacement).

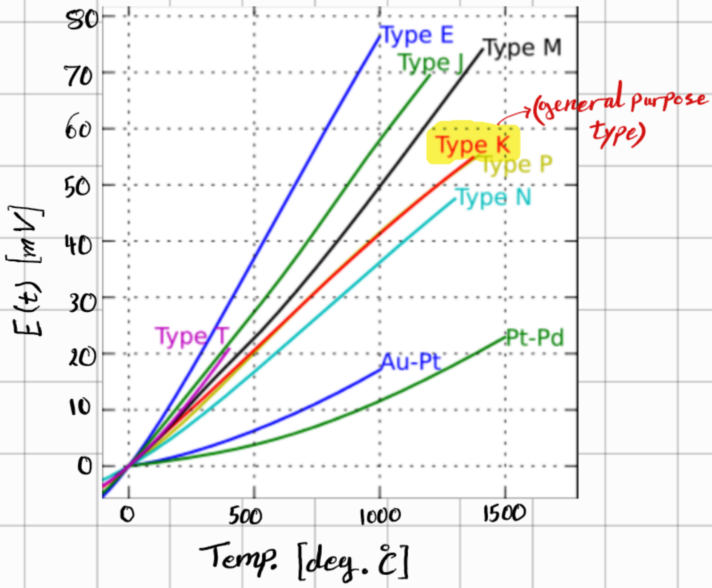
Inductive proximity Sensors:
detects ferrous target without Contact by creating an electromagnatic field.

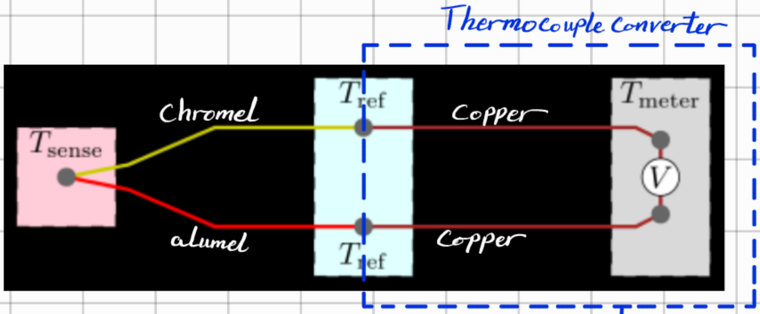
Typical characteristics	Capacitive proximity sensor	Inductive proximity sensor
Range	0.1-60mm	3-60mm
Speed	Up to 5kHz	Up to 50Hz
Diameter	3-40mm	12-60mm
Sensitive to	Most materials (conductive and isolating)	Ferrous materials, less sensitive to non-ferrous metals

Thermocouple: Consists of two diff. electrical conductors generating a temp.-dependant voltage in microvolt range as a result of thermoelectric effect (seeback eff.)

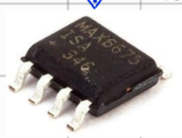
(diff. types covering temp. range from -200°C to 2300°C)

dis adv.: bad accurrcy





Integrated Circuit



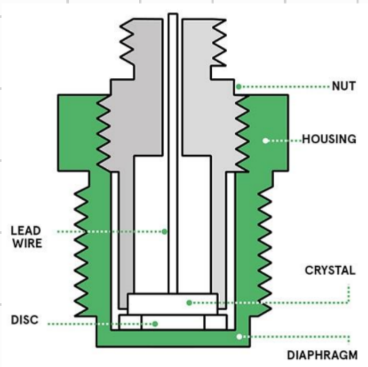
Piezoelectric Sensors: Some substances generate an electrical charge and an associated potential difference when they are subjected to mechanical stress or strain.

Can be used measure changes in:

- Pressure
- Acceleration
- Temperature
- Force

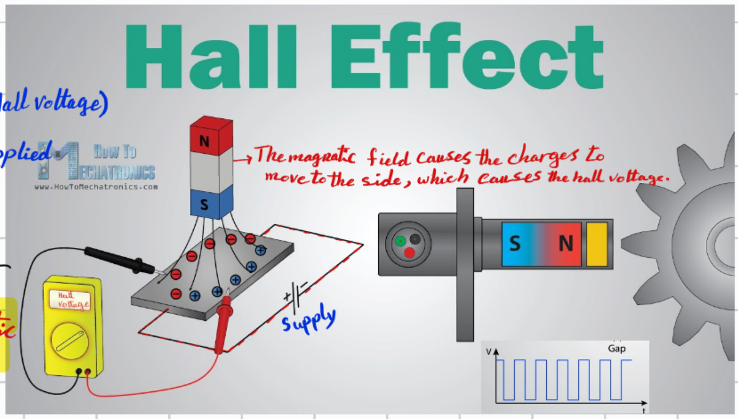
disadvantage: Cannot be used for purely static measurements, as a static force results in a fixed amount of charge.

Piezoelectric Pressure Sensors: Same as Capacitive & resistive strain gauge sensors, except that this one can hadle much higher pressure range.



Hall (Effect) Sensor:

Hall effect is the production of a voltage difference (Hall voltage) across the sides of an electrical conductor as a result to an applied magnatic field perpendicular to the current.



Compaired to inductive sensor, hall sensor has one major advantage: In inductive sensors we need an alternating magnatic field, where in Hall sensor we can detect static // as well.

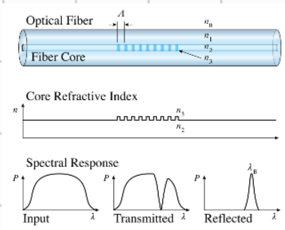
Adv. when used as electronic switches: cheaper, more reliable, and can operate at much higher freq. than a mech. switches.

Photo Diode: is a semiconductor converting light into an electrical current.

Photo Transistor: Consists of a bipolar transistor encased in a transparent case.

	Photo diode	Photo transistor
Symbol		
Output response	Fast	Slow
Sensitivity	Less	More
Biasing	Forward and reversed	Forward

Fiber Bragg Grating (FBG) Sensor:



disadv.: since FBG is sensitive strain & temp., we have to seperate them for an accurate output.

Bragg wavelength λ_B shifts by $d\lambda$:

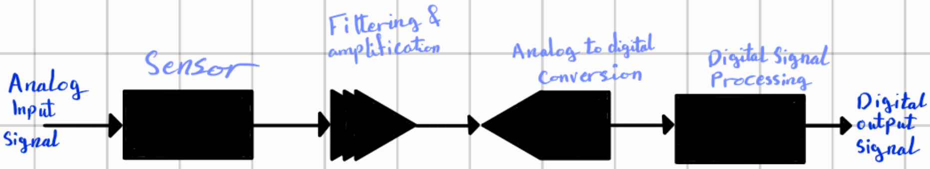
strain (mech. & temp included) → temp. change

$$\frac{d\lambda}{\lambda_B} = C_S * \varepsilon + C_T * dT$$

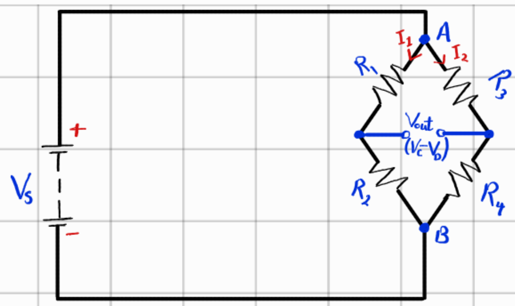
C_S ↓ Coeff. Strain

C_T ↓ Coeff. for change of the refractive

Sensor electronis (typical Signal chain):



Wheatstone Bridge (used in most sensors)

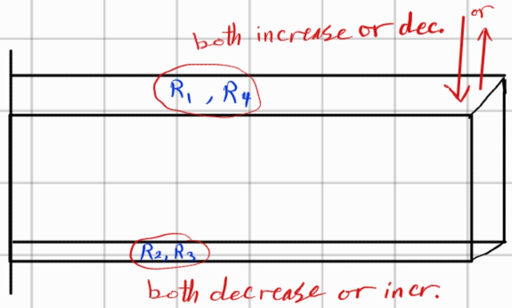


$$V_{out} = V_s * \frac{R_2}{R_1 + R_2} - V_s * \frac{R_4}{R_3 + R_4}$$

Balanced bridge:

$V_{out} = 0$

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$



For typical full bridge: $R_1 = R_2 = R_3 = R_4$

$$\boxed{\frac{V_{out}}{V_s} = \frac{dR}{R}}$$

Adv. of wheatstone bridge:

I) For a balanced bridge ($V_{out} = 0$), a high amplification for the output voltage can be used to get a high resolution of the measurement.

II) A symmetrical bridge compensates thermal influences electrically.

III) A symmetrical bridge compensates unwanted mechanical strain orthogonally to the measuring direction electricall.

Sensitivity of Diff. strain Gauge Bridges:

For example, gauge factor $GF = 2$

Full bridge (4 active strain gauges): 1 mV/V per 500 $\mu m/m$

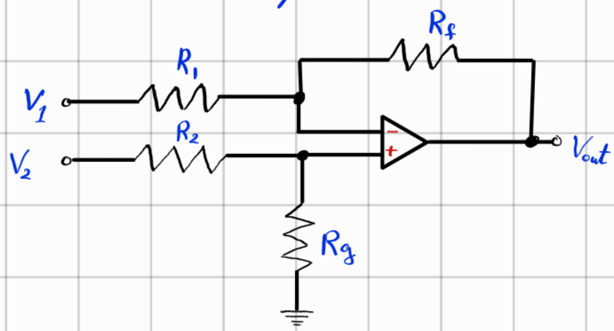
Half bridge (2 active strain gauges): 1 mV/V per 1000 $\mu m/m$

Quarted bridge (1 active strain gauge): 1 mV/V per 2000 $\mu m/m$

(but no temperature compensation)

Differential amplifier: Low differential voltages have to be amplified.

$$\boxed{V_{out} = (V_2 - V_1) * \frac{R_f}{R_1} \quad , \quad \text{if } R_f/R_1 = R_g/R_2}$$

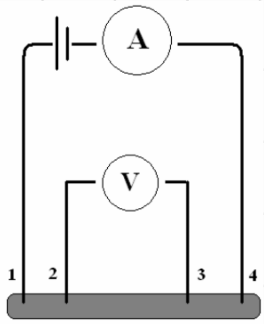


Instrumentation Amplifier:

$$\boxed{A = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}}$$

Four-Terminal sensing (Kelvin connection):

By the use of separate pairs of current-carrying and voltagesensing cables, a voltage drop in combined lines because of the line resistance can be avoided.



Kelvin connections are typically used to measure the voltage drop at a current sensing (shunt) resistor. As shunt resistors are typically very small (mOhms), an accurate layout is necessary.

A way of measuring current flow precisely