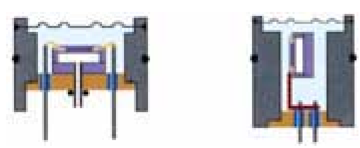
Chapter 2 How do sensor technologies work?

1. Fig 2.1 Linear potentiometer - Linear displacement; the wiper moves over a linear resistive substrate. The output voltage is determined with a voltage divider calculation, just that the values for R_1 and R_2 change with wiper displacement.

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}$$

2. Fig 2.1 Single turn potentiometer - Same as linear except the displacement is rotational. Limited to less than single revolution of the wiper.
3. Fig 2.1 Multi-turn potentiometer - Same as single turn potentiometer, but usually capable of 10 turns rotation.
4. Fig 2.2 Strain gage pressure sensor - implemented using a diaphragm to create a displacement with pressure. The displacement is sensed and measured with a wire, foil, or piezoresistive strain guage. Pressure changes create a displacement of the diaphragm which stretches or deforms the strain gauge causing a change in the gauge's resistance. Changes in resistance can then be measured similar to a potentiometer.

   Piezoresistive OEM Pressure Transducer.

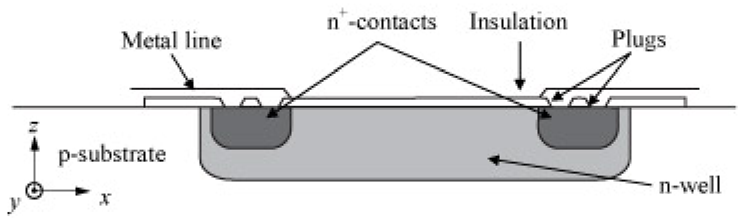
   

   http://www.sensorland.com/HowPage004.html
5. Fig 2.3 Wire and foil strain gage - The wire or foil resistance chages because of changes in the diameter, length and/or resistivity of the sensor. R=Resistance, ρ = resitivity (ohms·meter), L=length (meters) and A is cross-sectional area.

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

   http://www.efunda.com/designstandards/sensors/strain_gages/strain_gage_theory.cfm

6. Fig 2.4 Semiconductor strain gage - Piezoresistive effect varies with strain. Very sensitive, but also temperature sensitive. Changes in the crystalline structure vary with physical deformation.



Schematic cross-section of the basic elements of a silicon n-well piezoresistor.

http://en.wikipedia.org/wiki/Piezoresistive_effect

7. Fig 2.5 Silicone-elastic strain gage - Narrow silicone-rubber tube (0.5mm inside diameter) from 3 to 25 cm in length. Filled with mercury or an electrolyte or conductive paste. As the tube stretches, the diameter of the tube decreases and length increases, causing the resistance to increase.

http://www.nymc.edu/fhp/centers/syncope/SPG.htm

8. Fig 2.6 Inductive displacement sensors -

$$L=\frac{\mu_o N^2 A}{l}$$

inductance equals permeability (μ_0) * N(number of turns)^2 * A(cross-sectional area) divided by l (length of the coil).

   1. Self inductance varies either by changing the diameter of a coil (cross-sectional area), changing the length of a coil or changing the permeability of the coil (with a metal plunger).
   2. Mutual inductance - changing the distance between two coils or the permeability between two coils with a plunger
   3. Differential transformer - coupling between a single transmitting coil and opposing receiving coils varies by changing coupling permeability when moving a plunger within

coupling region between coils

Inductance of a solenoid [ed

A solenoid is a long, thin coil, i.e. a coil whose length is much greater than the diameter. Under these conditions, and without any magnetic material used, the magnetic flux density B within the coil is practically constant and is given by

$$B = \mu_0 N i / l$$

where μ_0 is the permeability of free space, N the number of turns, i the current and l the length of the coil. Ignoring end effects the magnetic flux through the coil is obtained by multiplying the flux density B by the cross-section area A and the number of turns N:

$$\Phi = \mu_0 N^2 i A / l,$$

from which it follows that the inductance of a solenoid is given by:

$$L = \mu_0 N^2 A / l.$$

This, and the inductance of more complicated shapes, can be derived from Maxwell's equations. For rigid air-core coils, inductance is a function of coil geometry and number of turns, and is independent of current.

http://en.wikipedia.org/wiki/Inductance

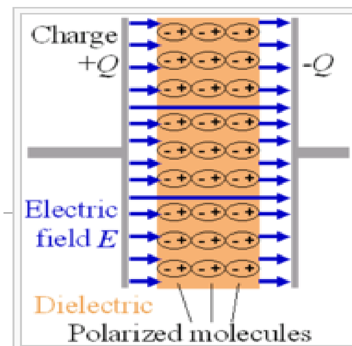
9. Fig 2.8 Capacitance sensor - The distance between plates is varied by sensor modality displacement. Alternatively, the cross-sectional area of the plates can also change or a combination of both.

$$C = \frac{\text{Area x Dielectric}}{\text{Gap}}$$

Capacitance is determined by Area, Gap, and Dielectric (the material in the gap). Capacitance increases when Area or Dielectric increase, and capacitance decreases when the Gap increases.

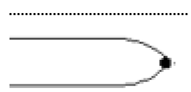
http://www.lionprecision.com/tech-library/technotes/cap-0020-sensor-theory.html

10. Fig 2.9 Piezoelectric sensor - Charge is developed by distortion of crystal lattice. Mechanical stress changes the charge separation of the individual atoms of the crystalline structure, creating a change in charge.
http://en.wikipedia.org/wiki/Piezoelectricity



Any spatially separated charge will result in an electric field, and therefore an electric potential. Shown here is a standard dielectric in a capacitor. In a piezoelectric device, mechanical stress is the cause for the charge separation in the individual atoms of the material, rather than an externally applied voltage.

11. Fig 2.12 Thermocouple sensor - An electromotive force (voltage) exists across a junction of two dissimilar metals (Seebeck effect). Peltier effect creates an emf due solely to the contact of two unlike metals and the junction temperature. Thomson effect is an emf due to temperature gradients along each single conductor. Thermelectric sensitivity α usually increases with temperature. Sensitivities range from 6.5 to 80 μV/ºC at 20ºC.



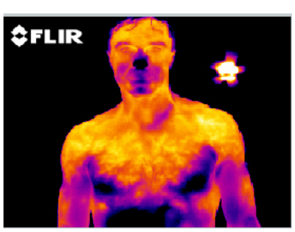
http://www.heise.com/products.cfm?doc_id=196

12. Fig 2.13 Thermistor sensor - resistance of the substrate decreases with increasing temperature. The change is -3 to -5% /ºC.

NTC thermistor, bead type, insulated wires

http://en.wikipedia.org/wiki/Thermistor

13. Fig 2.14 Thermography - Imaging using IR wavelengths. Fig 2.14(a) shows the maximum radiant energy wavelength. Fig 2.14(b) shows transmissivity for different materials suitable for an IR lens. Fig 2.14(c) shows the response for sensing materials used with IR wavelengths considered in the above two sections.



http://www.goinfrared.com/success/ir_image_list.asp?industry_id=1054

14. Fig 2.15 Radiation thermometer

Senses radiated IR by detecting emitted energy - determines internal or core body temperature of a human by measuring the magnitude of infared radiation emitted from the tympanic membrane and the surrounding ear canal. http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/eartherm.html

15. Fig 2.16 Fiber/semiconductor temperature probe - The semiconductor junction at the end of a fiber-optic probe absorbs light in a temperature sensitive manner.
16. Fig 2.17 Optical absorption - absorption amounts of a media is measured with a sample placed between a light source and a photo sensor.
17. Fig 2.19 LED light source - The semiconductor junction is doped such that passing a current through the junction causes holes and electron recombinations to emit light in a specific wavelength. Different materials and doping allow creation of different specific wavelengths.
18. Fig 2.20 Fiber Optics - According to Snell's Law, a ray is internally reflected for all angles of incidence greater than the critical angle. The critical angle is determined by the refractive index of the fiber material (n_1) and its coating (n_2). The critical angle is given by:

$$\sin\theta_{ic}=\frac{n_2}{n_1}$$

19. Fig 2.21 Photomultiplier - A photon strikes the photocathode coating and an electron is emitted. The electron is accelerated by high voltage which causes it to impact an electron multiplier. The electron multiplier consists of a series of plates (Dynodes). As an electron is accelerated and strikes a plate, more electrons are released. This happens in a cascade effect down through the photomultiplier until the released electrons strike the Anode plate, causing a current to flow which can be amplified.
20. Fig 2.22 Semiconductor photodetector - When a photon of sufficient energy strikes the semiconductor junction, it excites an electron thereby creating a mobile electron and a positively charged electron hole and produces a photocurrent. Photodiodes, phototransistors and photo avalanche devices exist which increase sensitivity and response to light.