Velocity and Motion sensors (1)

- **Many sensors is now under operation to monitor linear and angular velocity and detect motion however the most used are**

- **Encoders, Tacho-generators Pyroelectic sensors**

Both incremental and absolute encoders

Is used to measure angular velocity :

1-Variable reluctance

2-Ac generator

It is based on pyroelectrical materials that produces charge in respond to heat flow

Velocity and Motion sensors (2)

Tacho-generator:

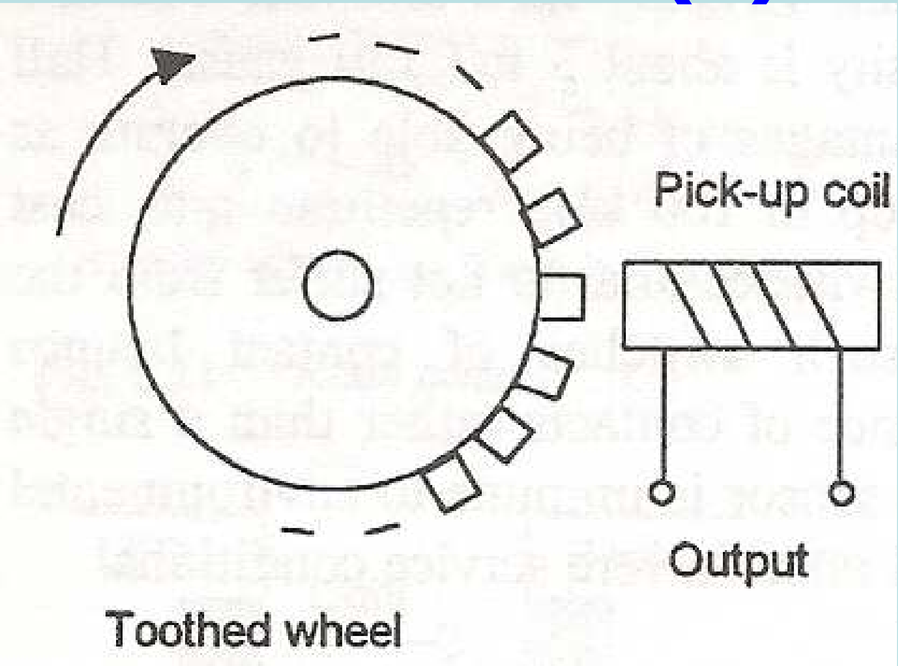
Is used to measure angular velocity

Can be of two types: variable reluctance or ac generator

The variable reluctance one consist of toothed wheel of ferromagnetic material which is attached to the rotating shaft. As the wheel rotates, the air-gap between the coil and the Ferro-magnet changes. Thus the flux linked by the a pickup coil changes. This result in alternating emf in the coil. If the coil has n teeth and rotates with angular velocity w, then the flux and the induced voltage is given by

$$\Phi = \Phi_0 + \Phi_a \cos n\omega t$$

Φ_0 is the mean value of the flux



$$e = -N\frac{d\Phi}{dt} = -N\frac{d}{dt}(\Phi_0 + \Phi_a \cos n\omega t)$$
$$= N\Phi_a n\omega \sin n\omega t$$

$$e = E_{max} \sin \omega t$$

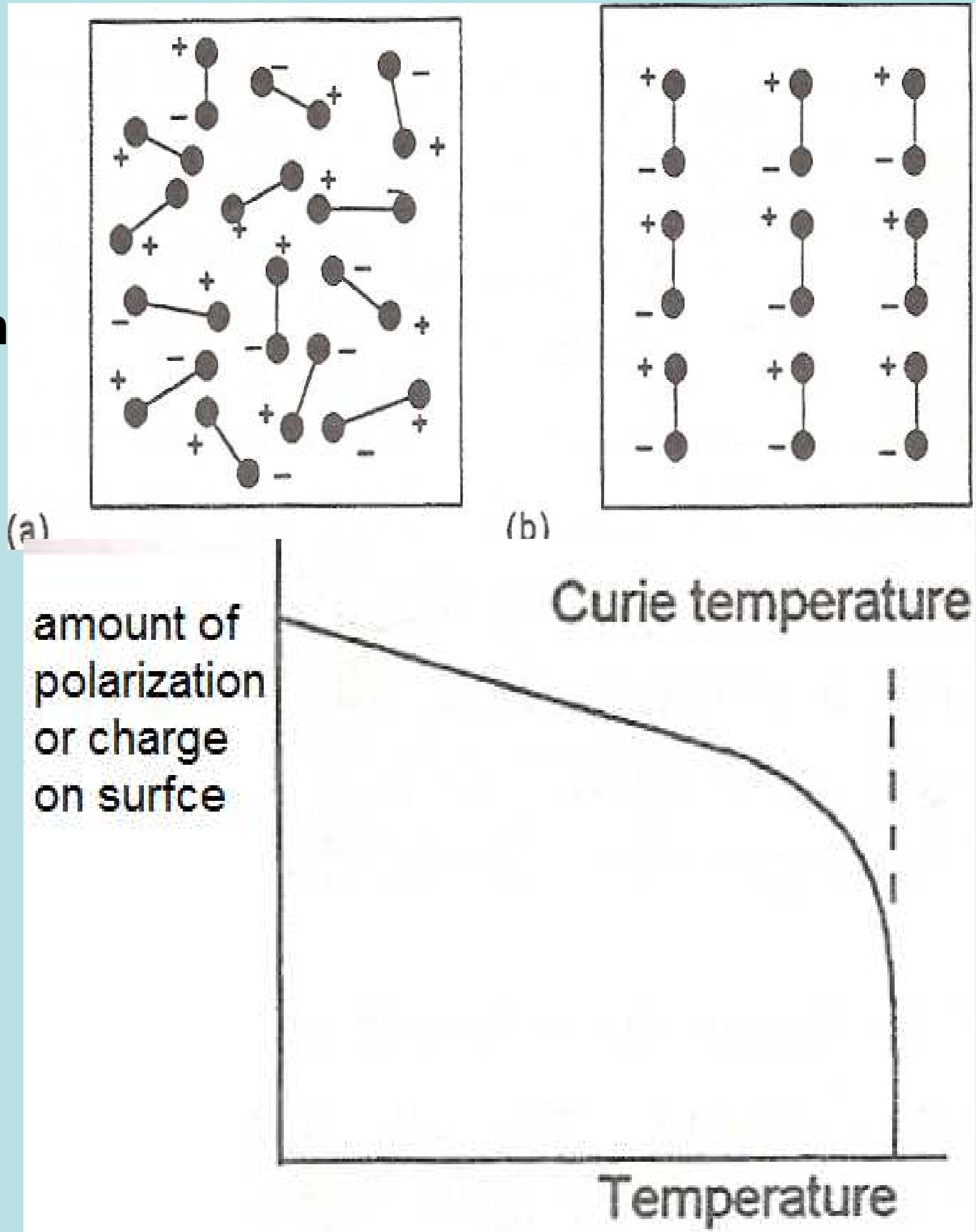
E_{max} is measure of the angular velocity. A pulse shaping circuit can be use to transform the output into sequence of pulses which can be counted

Velocity and Motion sensors (3)

Pyroelectric sensors:

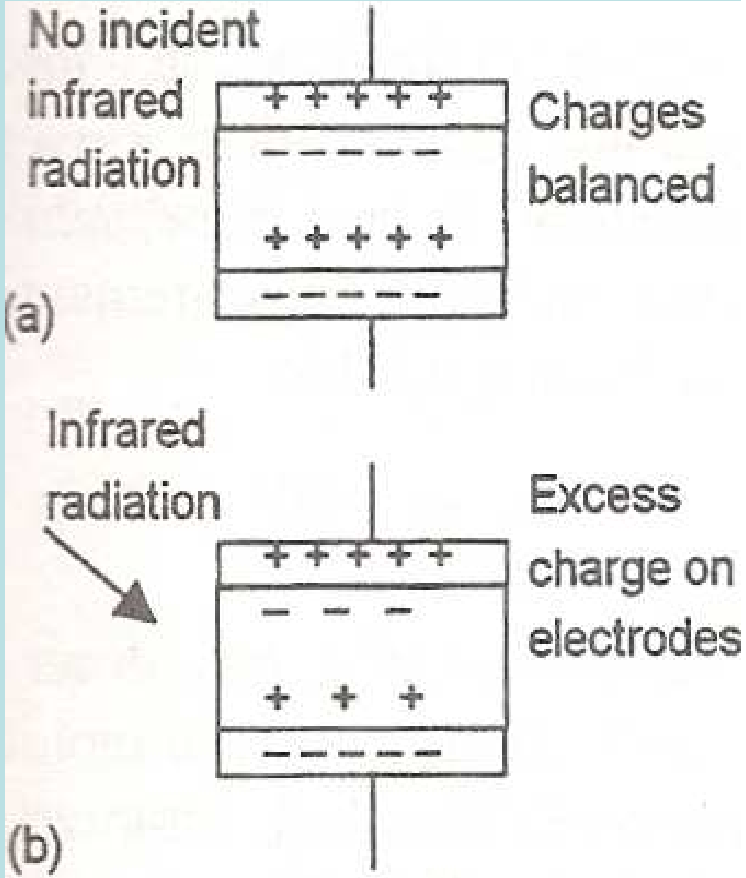
Pyroelectric materials such as lithium are crystalline material which generate charge in response to heat flow. When such material are heated to a temperature just below Curie temperature (610^{0}C for lithium tantalate) in an electric field and the material cooled while remaining in the field, it becomes polarized.

When the pyroelectric material is exposed to infrared radiation, its temperature rises and this reduces the amount of polarization in the material.



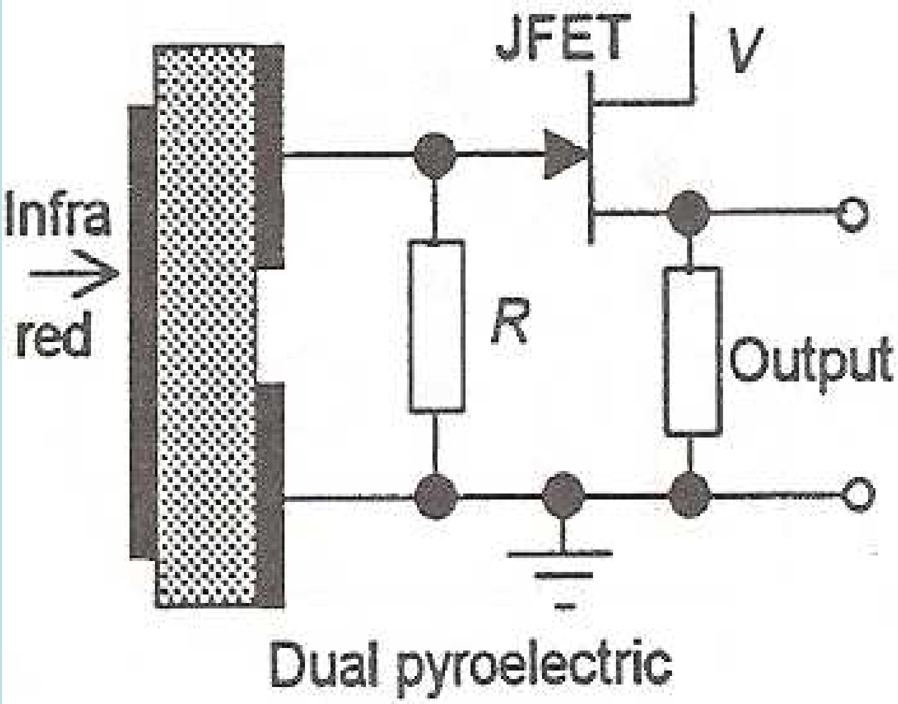
Velocity and Motion sensors (4)

A pyroelectric sensor consists of a polarized pyroelectric crystal with thin metal film electrodes on opposite sides. If infra red radiation is incident on the crystal and changes it is temperature, the polarization in the crystal is reduced and consequently that is a reduction in the charge at the surfaces of the crystal. Therefore is an excess of charge on the metal electrodes over that needed to balance the charge on the crystal surfaces. These changes leak away through the measurement circuit until the charge on the crystal once again balanced by the electrodes



Velocity and Motion sensors (5)

To detect the motion of human or other heat source, the sensing element has to distinguish between general back ground heat radiation and that given by a moving heat source. One arrangement is shown in the Fig. it consist of a single front electrode and two separate back electrodes.



When the heat source moves from one electrode to the other, the resulting current through the resistance alternates, typically a moving human body gives an alternating current of the order of 10^{-12} A, which required very large resistance (50 G ohm) to produce 50 mV so normally a JEFT is included in the circuit as a voltage follower.

Force sensors

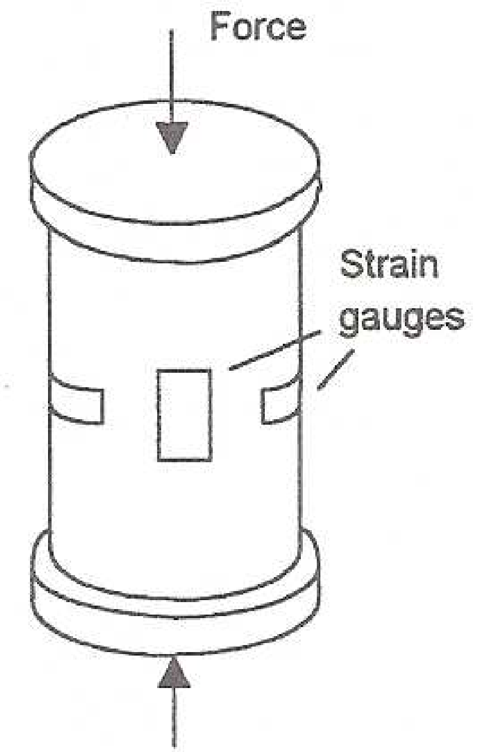
Normally forces are measured by measuring the displacements that made.

Strain gauge

(Up 10 10 MN).

Nonlinearity error ± 0.03%, repeatability error ± 0.02%

Spring



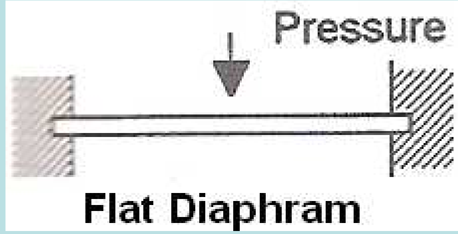
A very commonly used form of force measuring transducer is based on the use of electrical resistance strain gauges. So to measure the force, the strain produced in some member when stretched, compressed or bent by the application of the force should be monitored.

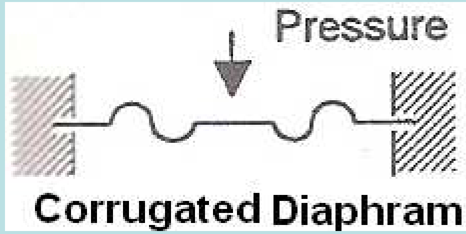
Signal conditioning circuit to eliminate the effect of temperature is normally used.

Fluid pressure sensors (1)

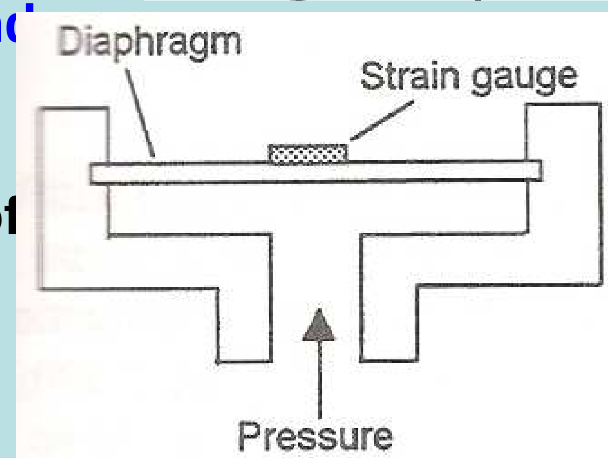
Types of fluid pressure measurement:

- **Absolute pressure**: relative to vacuum pressure (=0)
- **Differential pressure**: pressure difference
- **Gauge pressure**: relative to the barometric pressure





Methods: involve the monitoring of the elastic deformation of diaphragms, capsules, bellows and tubes



Diaphragms: When there is a difference in pressure between the two sides, then the centre of the diaphragm becomes displaced. Two types of diaphragms normally used; flat and corrugated. The corrugation result in greater sensitivity.

Strain gauges are used with diaphragm movement to measure the pressure. Specially designed strain gauge consisting of four strain gauges with two measuring the strain in a circumferential direction while two measure strain in a radial direction is often used

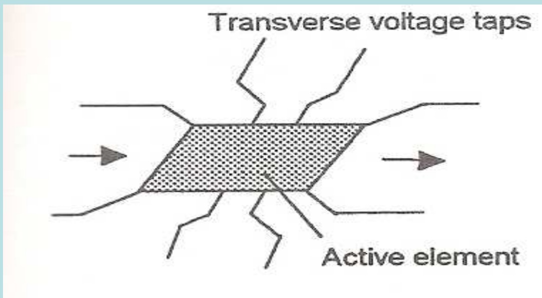
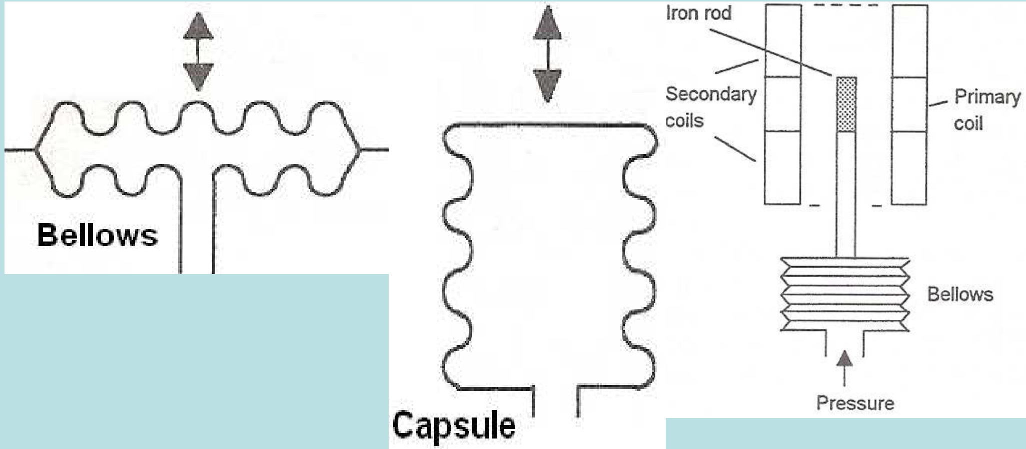


Fig. 2.36 Pressure sensor element

Fluid pressure sensors (2)

Capsules: can be constructed as two corrugated diaphragms

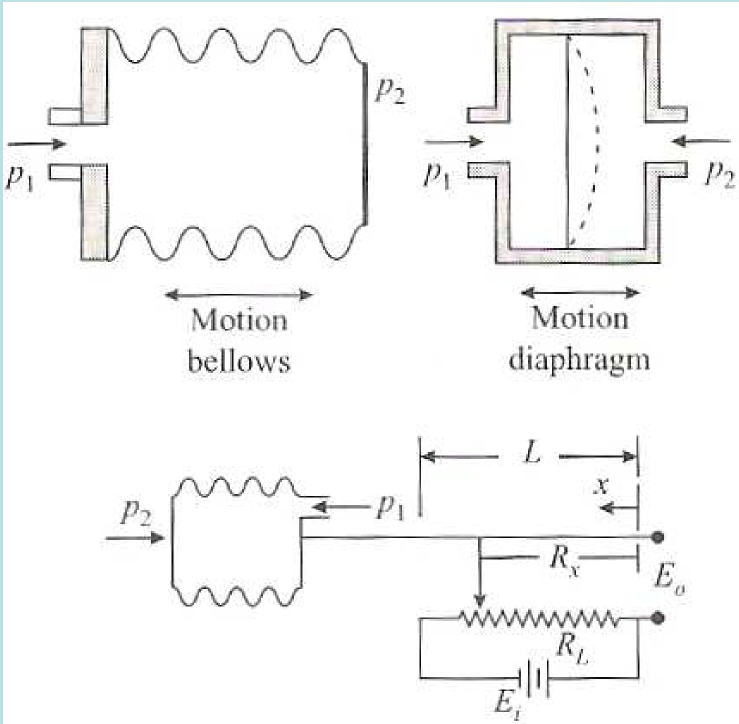
Bellows: is a stack of capsules which result into more sensitivity



Bellows and capsules can be combined with LVDT to give a pressure sensor with an electrical output

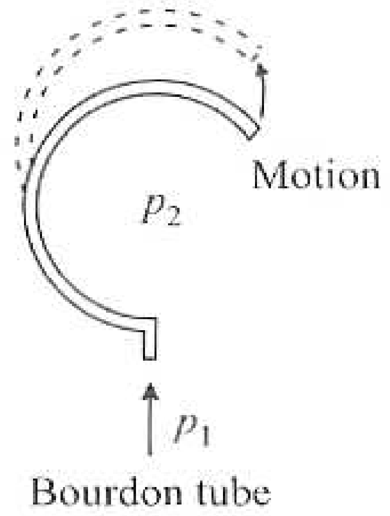
Diaphragms, bellows, and capsules are made of such material as stainless steel, phosphor, bronze, and nickel; with rubber and nylon also being used for some diaphragms

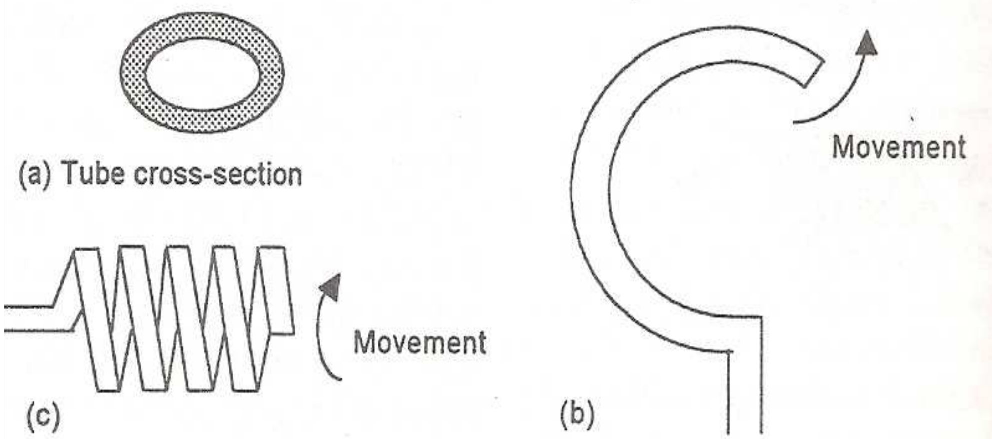
Pressure in the range of 10^3 – to – 10^8 Pa can be monitored with such sensor

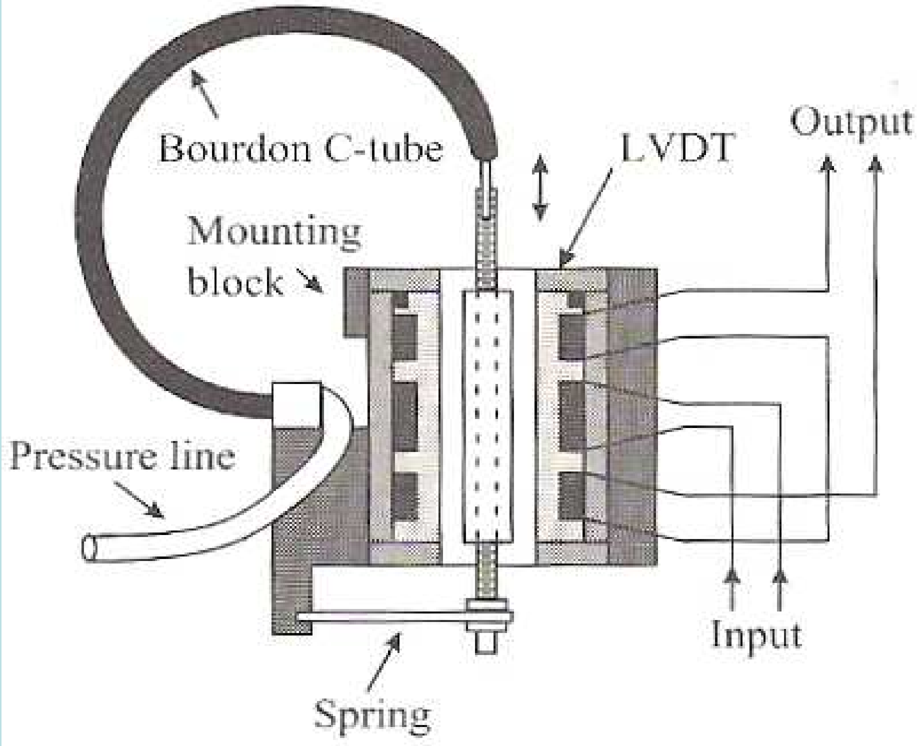


Fluid pressure sensors (3)

Tubes: has an elliptical cross section. Increasing the pressure causes it tends to a more circular cross section. When such tubes is in form of a C-shaped tube, the C opens up to some extent when the pressure in the tube increases. A helical form of such a tube gives greater sensitivity. They are used for pressures in the range 10^3 to 10^8 Pa







Piezoelectric sensors (1)

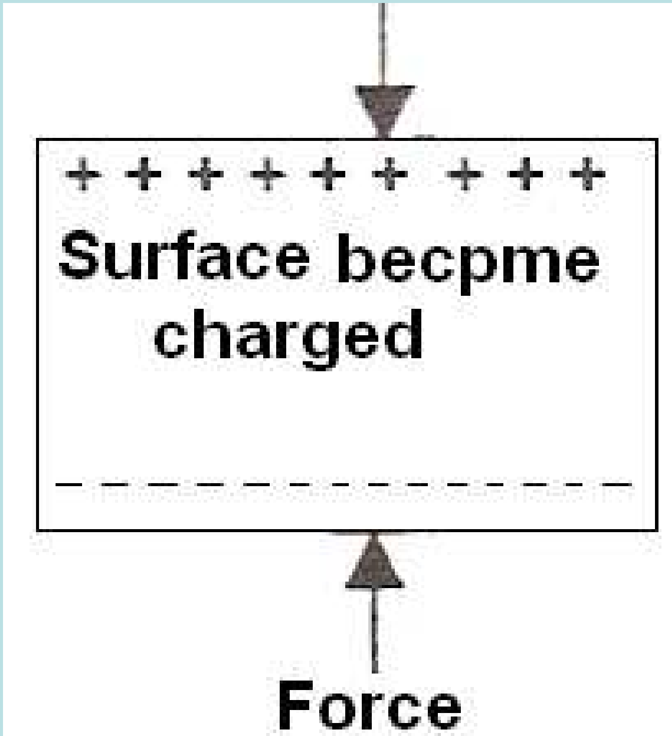
Piezoelectric materials when stretched or compressed generate electric charges with one face of the material becoming positively charged and the opposite face negatively charged

The net charge q on a surface is proportional to the amount x by which the charges have been displaced:

$$q=kx=SF;$$

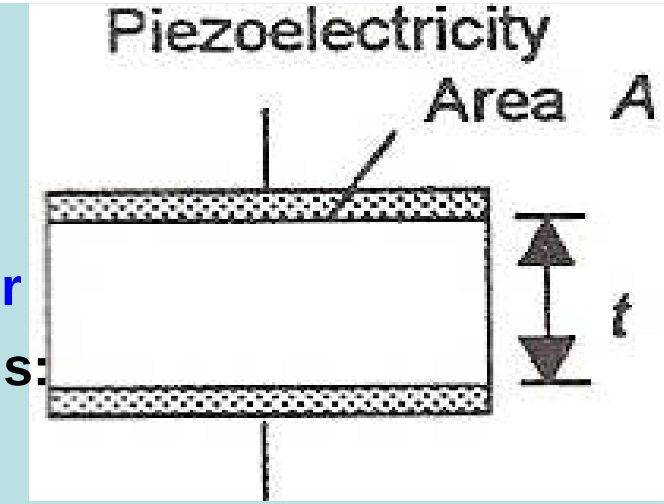
where k and S are constants. S called the charge sensitivity.

Quartz has a charge sensitivity of 2.2 pC/N, Barium Titanate of 130 pC/N and Lead Zirconate of 265pC/N



Piezoelectric sensors (2)

- Metal electrodes are deposited on opposite faces as shown to form piezoelectric capacitor



The capacitance of the above piezoelectric chip is:

$C = \varepsilon_0 \varepsilon_r A / t$ **And since**

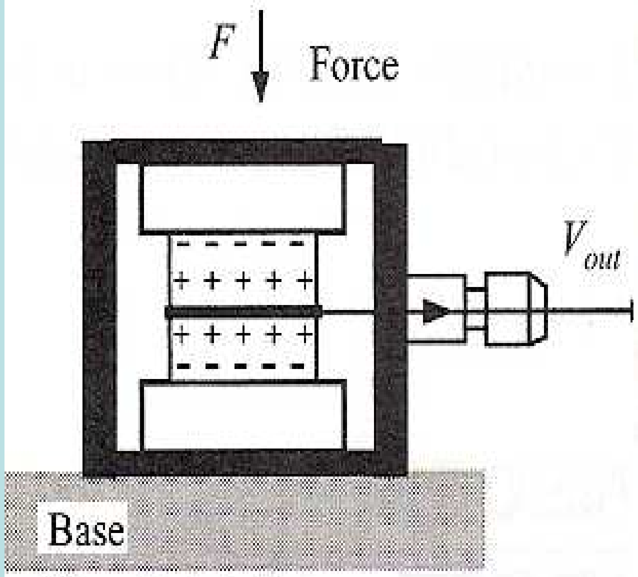
$C = q/V$ **we have** $V = q/C = SF\,t/\varepsilon_0\varepsilon_r A = (s/\varepsilon_0\varepsilon_r)(F/A).t = t.\,S_v.P$

Where P is the applied pressure F/A, S_v is the voltage sensitivity factor

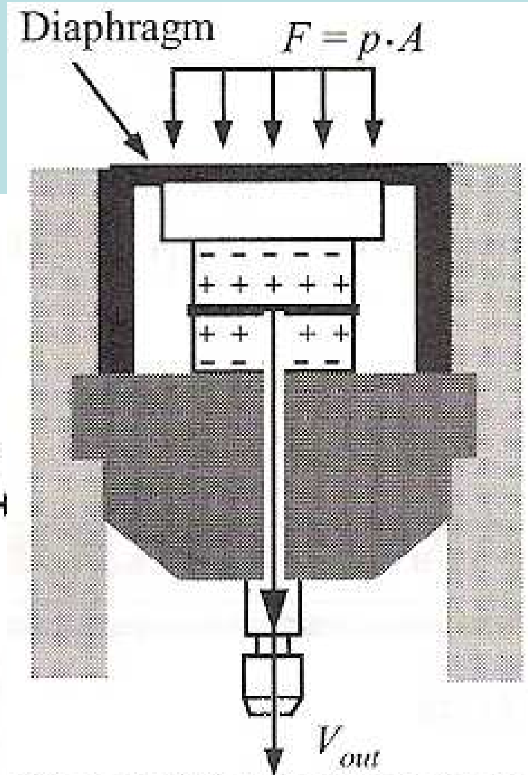
Voltage is proportional to the applied pressure.

The voltage sensitivity for quartz is about 0.011 V/m Pa

The piezoelectric sensors are used for measurement of (force, pressure and acceleration)



Piezoelectric force sensor

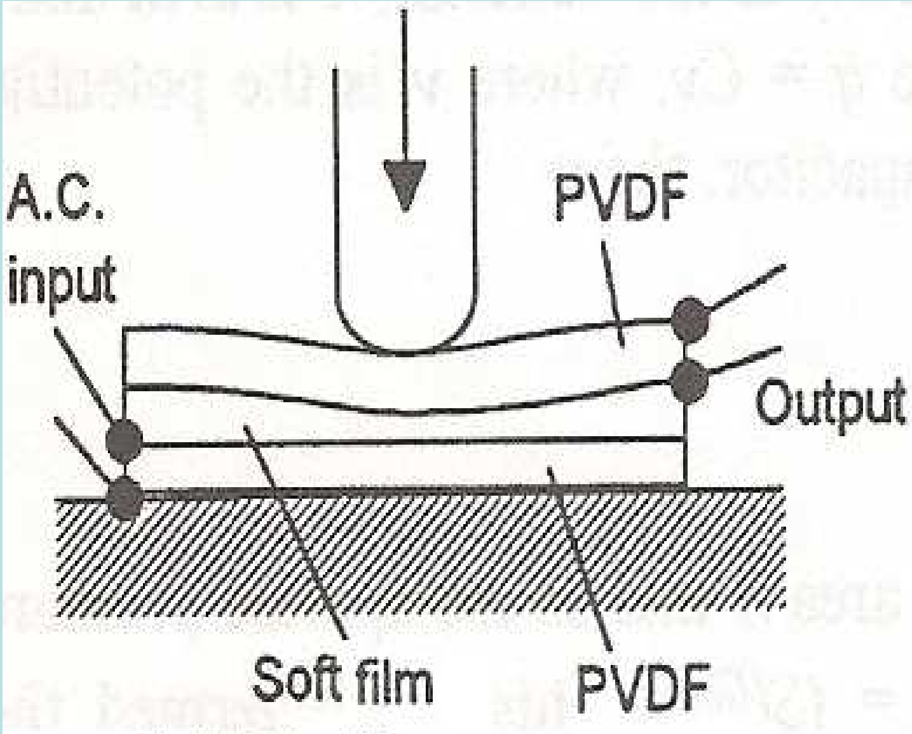


Piezoelectric pressure sensor

Fluid pressure sensors (3-Tactile)

Is a particular form of pressure sensor, is used on the finger tip's of robotic hands to determine when a hand has come into contact with an object. They are also used for touch display screens where a physical contact has to be sensed. One form uses piezoelectric poly-vinylidene fluoride (PVDF) film.

Two layers of the film are used with a third layer of soft film which transmits vibrations separated them



PVDF tactile sensor

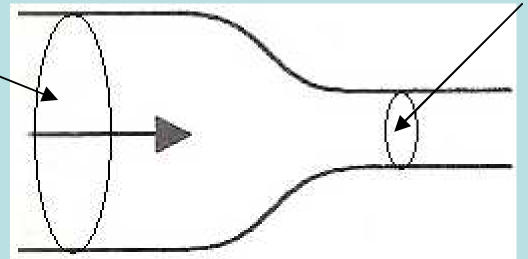
The lower film has ac voltage that causes mechanical vibration (reverse piezoelectric effect). The intermediate film transmits these vibrations to the upper film causing definite ac voltage to be produced, when the pressure is applied to the upper PVDF its vibrations are affected and the output voltage is changed.

Liquid flow sensors (1)

The measurement of the flow rate of liquids (quantity/s) is based on the measurement of the pressure drop occurring when the fluid flows through a construction

If the fluid density is *ρ*,
Bernoulli's equation gives:

$$\frac{v_1^2}{2g} + \frac{P_1}{\rho g} = \frac{v_2^2}{2g} + \frac{P_2}{\rho g}$$



The mass of the liquid passing per second through the tube prior to the construction must equal that passing through the tube at the construction, therefore:

$A_1V_1\,\rho = A_2V_2\,\rho$

But; $A_1V_1\,\rho = A_2V_2\,\rho$ ***=Q*** is the quantity of the liquid passing per second, hence

$$Q = \frac{A_2}{\sqrt{1-(A_2/A_1)^2}}\sqrt{\frac{2(P_1-P_2)}{\rho}}$$

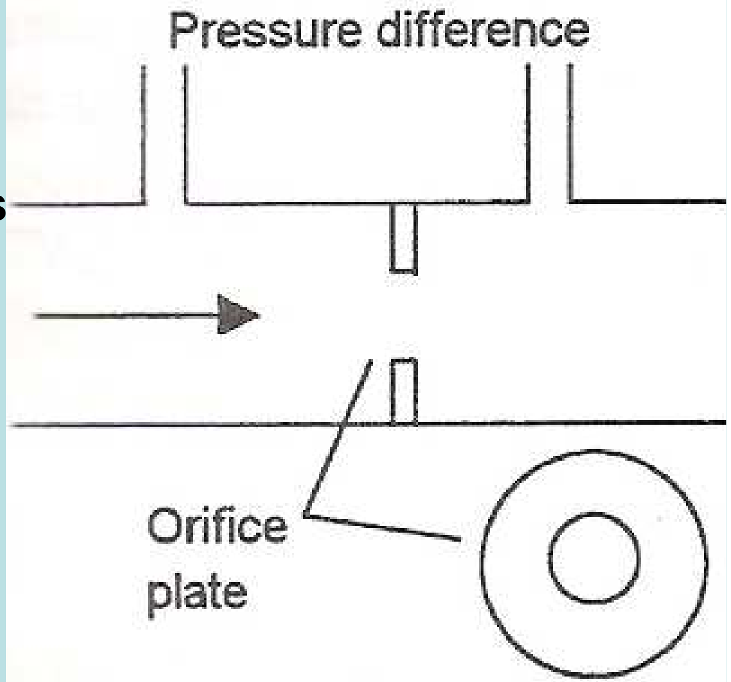
Measurement of pressure difference can be used to measure the rate of flow

Prove?

Liquid flow sensors (2)

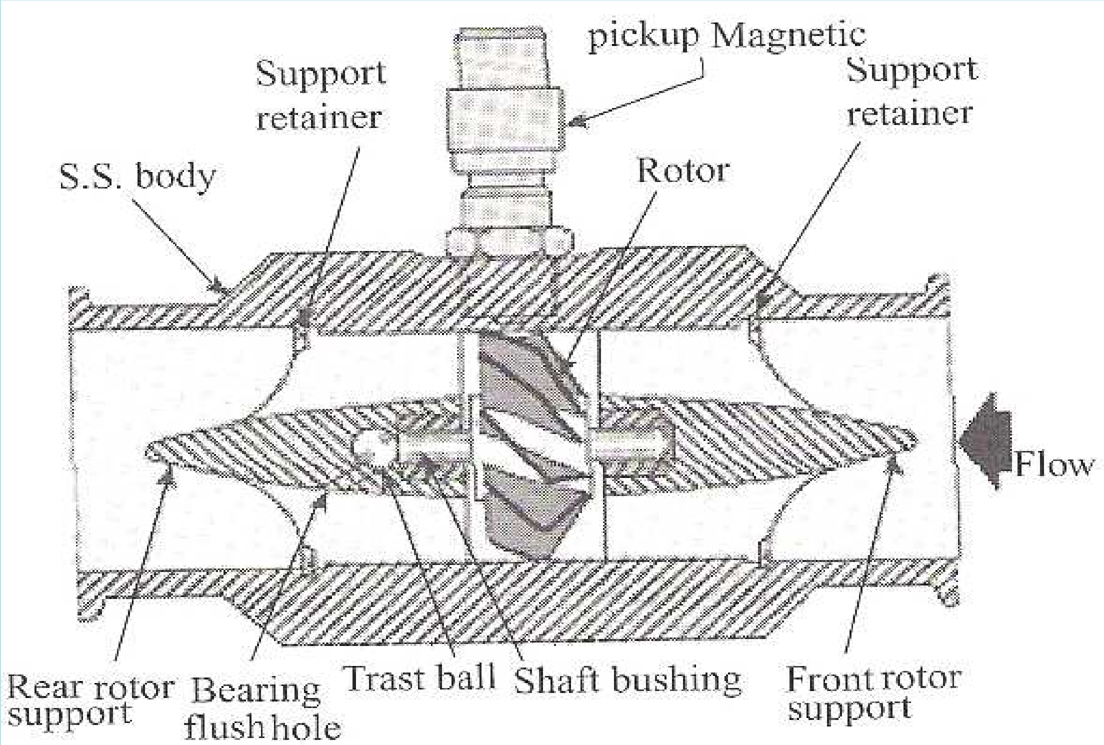
Orifice plate: is a disc with central hole, which is placed in the tube through which the fluid is passing. The pressure difference is measured between a point equal to the diameter of the tube upstream and a point equal to half the diameter downstream.

Simple, cheap, no moving par, widely used But, nonlinear, accuracy ±1.5% of Full range



Turbine meter:

It consist of a multi- bladed rotor that is supported centrally in the pipe, the flow result in a rotation of the rotor, the angular velocity being measured with a pick up magnetic coil. Expensive with accuracy of ± 0.3%



Light sensors

Photodiode:

Are semiconductor junction diode used in reverse bias to give very high resistance, so when light falls on the junction, the diode resistance drops and current in the circuit rises appreciably.

Photo-transistors:

The same idea as the photo diode. To increase current normally Darlington connection is used

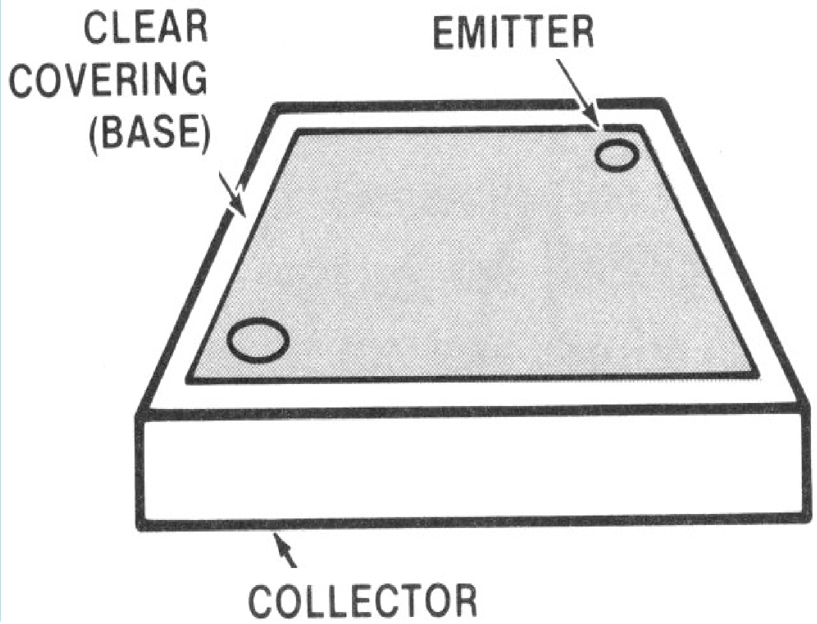
Photo-resistor:

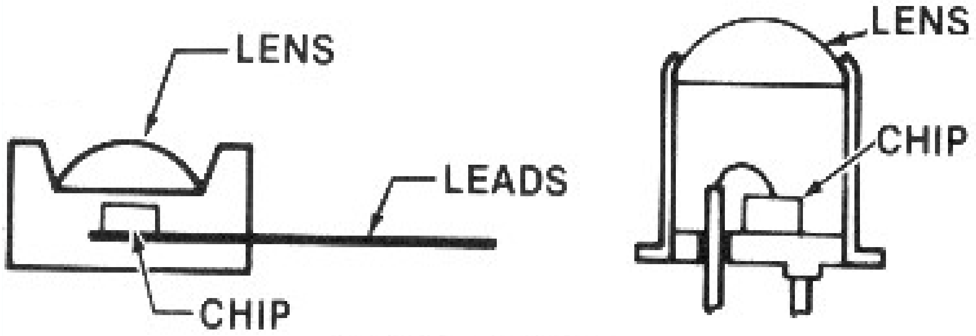
Has a resistance which depends on the intensity of light falling. It Decreases linearly as the intensity increases. Cadmium sulphide photo resistor is the most responsive to light having wave length 515 nm, and cadmium selinide 700 nm are used in automatic camera to determine exposure that will be most appropriate to take account of the varying light intensities across the image

Phototransistor

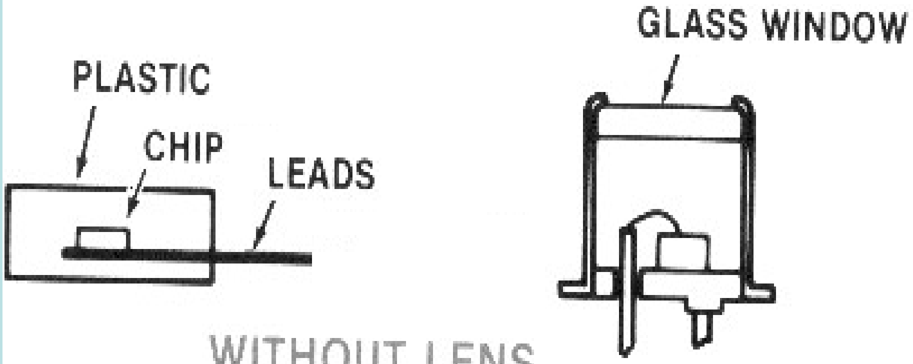
- **It is operation similar to traditional transistors**
- **A light sensitive collector base p-n junction controls the load current flow between the emitter and collector**

So, when light intensity increases, the junction resistance decreases, which result in more emitter-base current.
The level of the collector current depends on the quantity of base current which in turn depends on light intensity





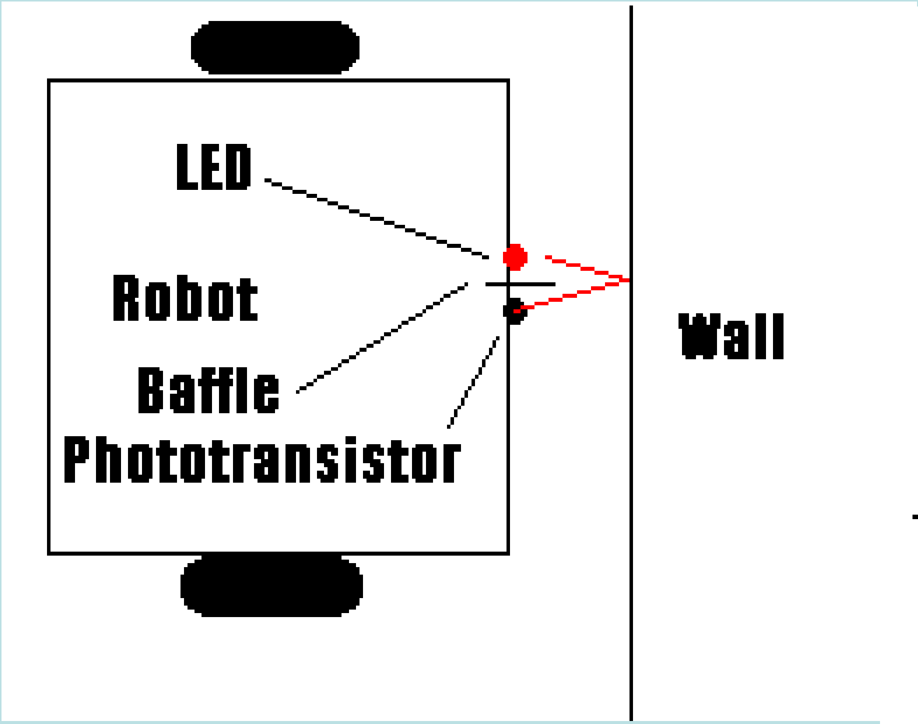
WITH LENS

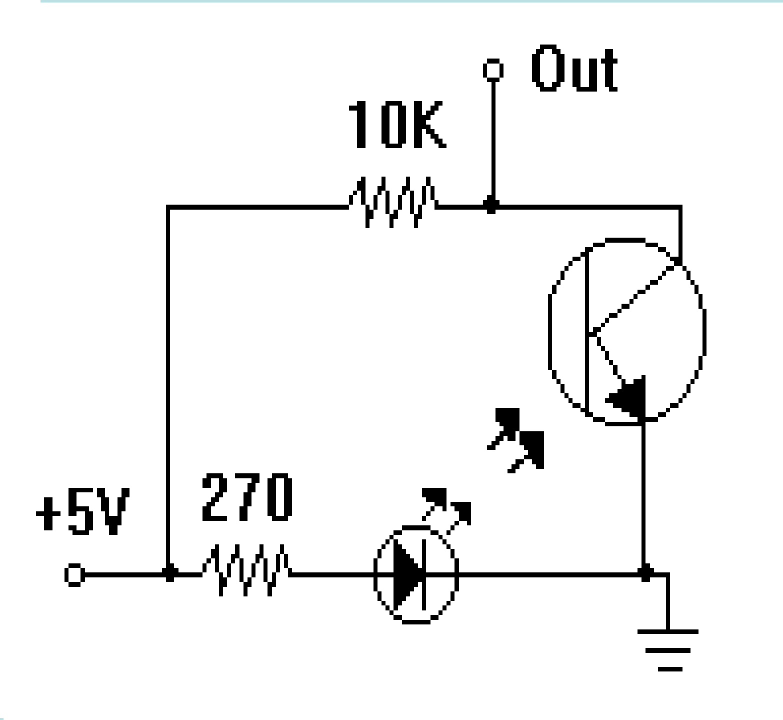


WITHOUT LENS

Example of phototransistor applications

Obstacle Avoidance





Tutorial-1

2 A copper–constantan thermocouple is to be used to measure temperatures between 0 and 200°C. The e.m.f. at 0°C is 0 mV, at 100°C it is 4.277 mV and at 200°C it is 9.286 mV. What will be the non-linearity error at 100°C as a percentage of the full range output if a linear relationship is assumed between e.m.f. and temperature over the full range?

3 A thermocouple element when taken from a liquid at 50°C and plunged into a liquid at 100° C at time $t = 0$ gave the following e.m.f. values. Determine the 95% response time.

Time (s)	0	20	40	60	80	100	120
e.m.f. (mV)	2.5	3.8	4.5	4.8	4.9	5.0	5.0

4 What is the non-linearity error, as a percentage of full range, produced when a 1 kΩ potentiometer has a load of 10 kΩ and is at one-third of its maximum displacement?

5 What will be the change in resistance of an electrical resistance strain gauge with a gauge factor of 2.1 and resistance 50 Ω if it is subject to a strain of 0.001?

6 You are offered a choice of an incremental shaft encoder or an absolute shaft encoder for the measurement of an angular displacement. What is the principal difference between the results that can be obtained by these methods?

7 A shaft encoder is to be used with a 50 mm radius tracking wheel to monitor linear displacement. If the encoder produces 256 pulses per revolution, what will be the number of pulses produced by a linear displacement of 200 mm?

8 A rotary variable differential transformer has a specification which includes the following information:

Ranges: ±30°, linearity error ±0.5% full range
±60°, linearity error ±2.0% full range
Sensitivity: 1.1 (mV/V input)/degree
Impedance: Primary 750 Ω, Secondary 2000 Ω

What will be (a) the error in a reading of 40° due to non-linearity when the RDVT is used on the ±60° range, and (b) the output voltage change that occurs per degree if there is an input voltage of 3 V?

9 What are the advantages and disadvantages of the plastic film type of potentiometer when compared with the wire-wound potentiometer?

10 A pressure sensor consisting of a diaphragm with strain gauges bonded to its surface has the following information in its specification:

Ranges: 0 to 1400 kPa, 0 to 35 000 kPa
Non-linearity error: ±0.15% of full range
Hysteresis error: ±0.05% of full range

What is the total error due to non-linearity and hysteresis for a reading of 1000 kPa on the 0 to 1400 kPa range?

11 The water level in an open vessel is to be monitored by a differential pressure cell responding to the difference in pressure between that at the base of the vessel and the atmosphere. Determine the range of differential pressures the cell will have to respond to if the water level can vary between zero height above the cell measurement point and 2 m above it.

12 An iron–constantan thermocouple is to be used to measure temperatures between 0 and 400°C. What will be the non-linearity error as a percentage of the full-scale reading at 100°C if a linear relationship is assumed between e.m.f. and temperature?

E.m.f. at 100°C = 5.268 mV; e.m.f. at 400°C = 21.846 mV

13 A platinum resistance temperature detector has a resistance of 100.00 Ω at 0°C, 138.50 Ω at 100°C and 175.83 Ω at 200°C. What will be the non-linearity error in °C at 100°C if the detector is assumed to have a linear relationship between 0 and 200°C?

14 A strain gauge pressure sensor has the following specification. Will it be suitable for the measurement of pressure of the order of 100 kPa to an accuracy of ±5 kPa in an environment where the temperature is reasonably constant at about 20°C?

Ranges: 2 to 70 MPa, 70 kPa to 1 MPa
Excitation: 10 V d.c. or a.c. (r.m.s.)
Full range output: 40 mV
Non-linearity and hysteresis errors: ±0.5 %
Temperature range: −54 to +120°C
Thermal shift zero: 0.030% full range output/°C
Thermal shift sensitivity: 0.030% full range output/°C

3 67.5 s
4 0.73%
5 0.105 Ω
6 Incremental – angle from some datum, not absolute; a
– unique identification of an angle
7 162
8 (a) ±1.2°, (b) 3.3 mV
9 See text
10 2.8 kPa
11 19.6 kPa
12 −0.89%
13 +1.54°C
14 Yes