Displacement, Proximity and Position sensors

Position means the determination of the object's coordinates (linear or angular) with respect to a selected reference. Displacement means moving from one position to another for a specific distance or angle. In other words, a displacement is measured when an object is referenced to its own prior position rather than to another reference.
A critical distance is measured by proximity sensors. In effect, a proximity sensor is a threshold version of a position detector.

3.Capacitive Displacement Sensors

Capacitive sensors use the electrical property of "capacitance" to make measurements. The relation between the charge in plates and the voltage across a capacitor is named as Capacitance. The capacitance is a property that exists between any two conductive surfaces within some reasonable proximity.

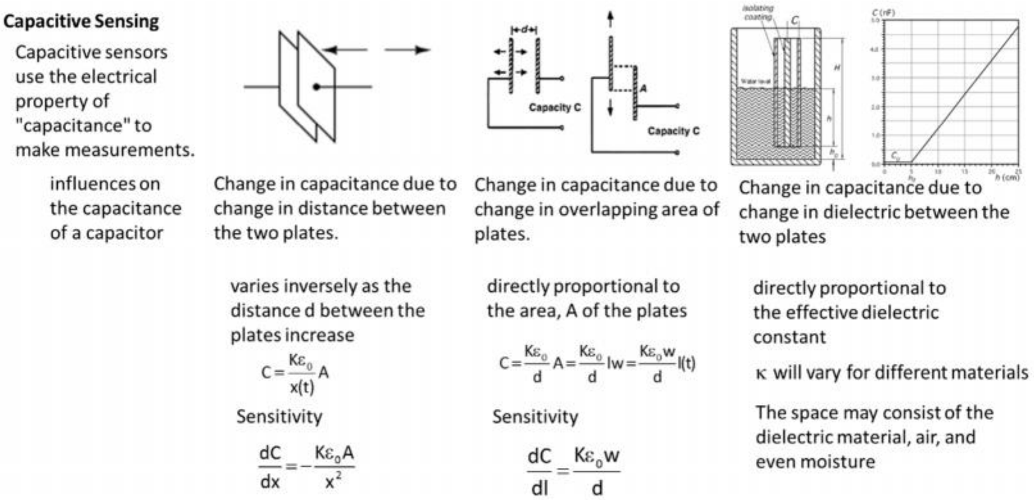
A change in plate distance, plate area or of the dielectric material between plates influences the capacitance of a capacitor.

The signal processing circuits consist of AC lattice networks (capacitive bridge). They have to be operated with a high carrier frequency (0.5 ... 1 MHz) because of small capacitances

Changes in the distance between the surfaces changes the capacitance. It is this change of capacitance that capacitive sensors use to indicate changes in position of a target.
The basic sensing element of a typical displacement sensor consists of two simple electrodes with capacitance C. The capacitance is a function of the distance d (cm) between the electrodes of a structure, the surface area A (cm^2)) of the electrodes, and the permittivity ε (8.85×10^{-12} F m for air) of the dielectric between the electrodes; therefore:

$$C = C(d, A, \varepsilon)$$

There are three basic methods for realizing a capacitive displacement sensor: by varying d, A, or ε.



Transducers Using Change in Area of Plates: Examining the equation for capacitance, it is found that the capacitance is directly proportional to the area, A of the plates. Thus, the capacitance changes linearly with change in area of plates. Hence this type of capacitive transducer is useful for measurement of moderate to large displacements say from 1 mm to several cm. The area changes linearly with displacement and also the capacitance.

$C = \frac{K\varepsilon_0}{d} A = \frac{K\varepsilon_0}{d} lw = \frac{K\varepsilon_0 w}{d} l(t)$ and the sensistivity $\frac{dC}{dl} = \frac{K\varepsilon_0 w}{d}$ sensitivity is constant so the sensor is linear sensor.

Transducers Using Change in Distance between Plates: One plate is fixed and the displacement to be measured is applied to the other plate which is movable. Since, the capacitance, C, varies inversely as the distance d, between the plates the response of this transducer is not linear.

$C=\frac{K\varepsilon_0}{x(t)}A$ and the sensistivity $\frac{dC}{dx}=-\frac{K\varepsilon_0 A}{x^2}$ sensitivity is a nonlinear function so the sensor is nonlinear(only approximately linear over a small range of displacement.). Thus this transducer is useful only for measurement of extremely small displacements.

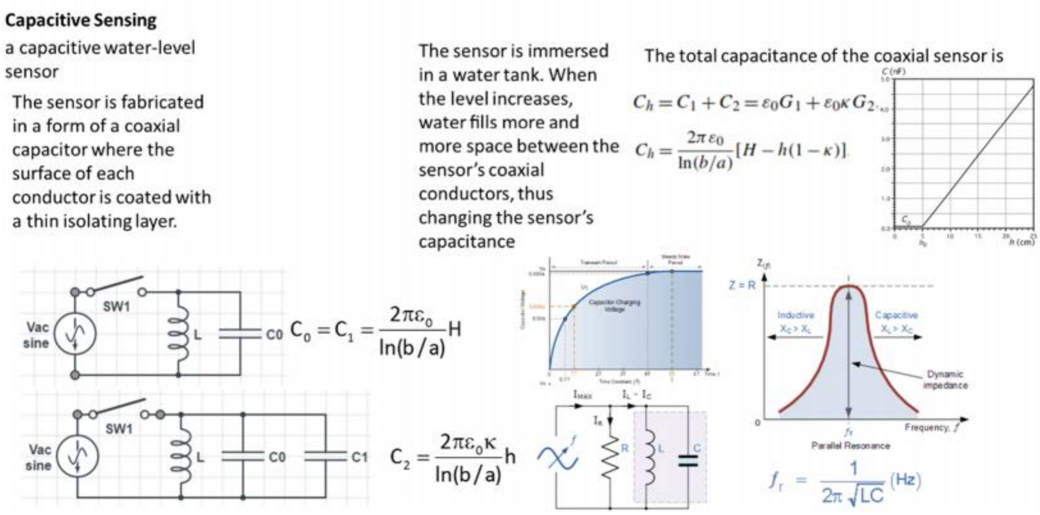
Transducers Using Change in dielectric constant between Plates: If the area (A) of and the distance (d) between the plates of a capacitor remain constant, capacitance will vary only as a function of the dielectric constant (e) of the substance filling the gap between the plates.

The value of dielectric constant is initially set by design in the choice of dielectric material used to make the capacitor. Many factors will cause the κ to change, and this change in κ will vary for different materials.

The major factors that will cause a change in κ are moisture, voltage, frequency, and temperature. The dielectric constant of a process material can change due to variations in temperature, moisture, humidity, material bulk density, and particle size etc. The κ in the basic formula is the effective dielectric constant of the total space between the electrodes. This space may consist of the dielectric material, air, and even moisture, if present.

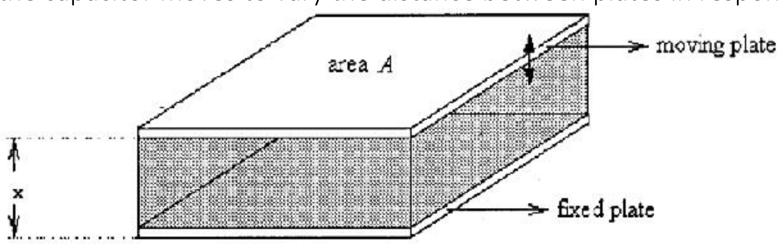
Physical variables, such as, displacement, force or pressure can cause the movement of dielectric material in the capacitor plates, resulting in changes in the effective dielectric constant, which in turn will change the capacitance.

$C=\frac{\varepsilon_0 A}{d}\kappa(x)=\frac{dC}{dx}=\frac{dC}{d\kappa}\frac{d\kappa}{dx}=\frac{\varepsilon_0 A}{d}\frac{d\kappa}{dx}$ and the sensistivity $\frac{dC}{dx}=\frac{dC}{d\kappa}\frac{d\kappa}{dx}=\frac{\varepsilon_0 A}{d}\frac{d\kappa}{dx}$ sensitivity is constant so the sensor is linear sensor.



2.1 Variable Distance Displacement Sensors

A capacitor displacement sensor, made from two flat coplanar plates with a variable distance x apart :One of the plates of the capacitor moves to vary the distance between plates in response to changes in a physical variable.



$$C(x)=\varepsilon A/x=\varepsilon_r\varepsilon_0 A/x$$

ε= the dielectric constant or permittivity

ε_r= the relative dielectric constant (in air and vacuum ε≈ 1)

ε_0= 8.854188 × 10–12 F/m :the dielectric constant of vacuum

x= the distance of the plates in m

A= the effective area of the plates in m

The sensitivity of capacitance to changes in plate separation is:

$$dC/dx=-\varepsilon_r\varepsilon_0 A/x^2$$

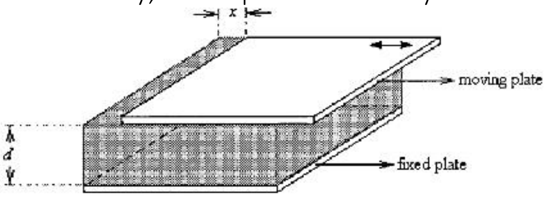
The outputs of these transducers are nonlinear with respect to distance x having a hyperbolic transfer function characteristic. Nevertheless, it follows that the percent change in C is proportional to the percent change in x. This can be expressed as:

$$dC/C = -dx/x$$

Appropriate signal processing must be employed for linearization.

2.2 Variable Area Displacement Sensors

Alternatively, the displacements may be sensed by varying the surface area of the electrodes of a flat plate capacitor:



The sensor operates on the variation in the effective area between plates of a flat-plate capacitor. The transducer output is linear with respect to displacement x. This type of sensor is normally implemented as a rotating capacitor for measuring angular displacement.
The capacitance would be:

$$C = \varepsilon_r \varepsilon_0 \left(A - wx\right) / d$$

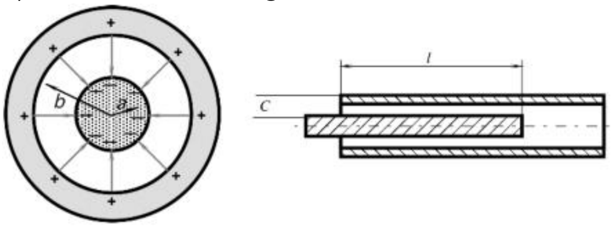
w= the width
w_x= the reduction in the area due to movement of the plate
the transducer output is linear with displacement x.

2.3 Variable Dielectric Displacement Sensors

The displacement may be sensed by the relative movement of the dielectric material between the plates

$$C = \varepsilon_0 \, w \left[\varepsilon_2 l - \left(\varepsilon_2 - \varepsilon_1\right) x\right]$$

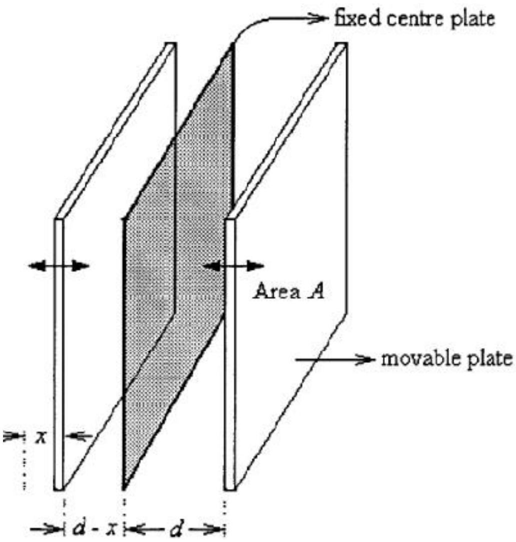
ε_1= the relative permittivity of the dielectric material
ε_2= the permittivity of the displacing material (e.g., liquid)
the output of the transducer is also linear. This type of transducer is predominantly used in the form of two concentric cylinders for measuring the level of fluids in tanks. A non conducting fluid forms the dielectric material.



$$C = \frac{2\pi \varepsilon_0 l}{\ln(b/a)}$$

2.4 Differential Capacitive Sensors

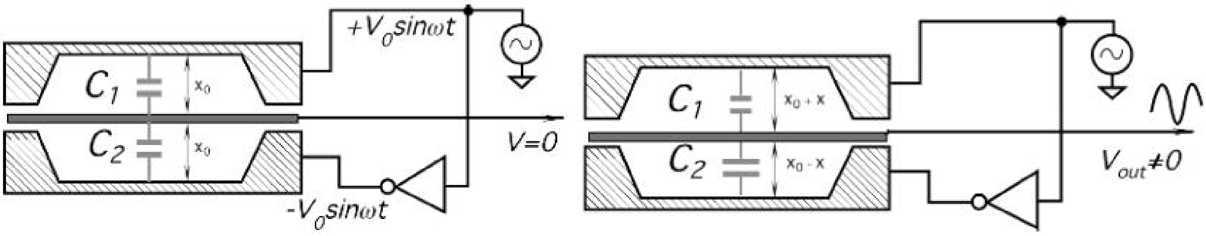
Some of the nonlinearity in capacitive sensors can be eliminated using differential capacitive arrangements. A differential capacitive sensor. They are essentially three terminal capacitors with one fixed center plate and two outer plates.



The response to physical variables is linear. In some versions, the central plate moves in response to physical variable with respect to two outer plates, and in the others, the central plate is fixed and outer plates are allowed to move

$$2\delta C = C_1 - C_2 = \varepsilon_r \varepsilon_0 lw / (d - \delta d) - \varepsilon_r \varepsilon_0 lw / (d + \delta d) = 2\varepsilon_r \varepsilon_0 lw \delta d / (d^2 + \delta d^2)$$
$$C_1 + C_2 = 2C = \varepsilon_r \varepsilon_0 lw / (d - \delta d) + \varepsilon_r \varepsilon_0 lw / (d + \delta d) = 2\varepsilon_r \varepsilon_0 lwd / (d^2 + \delta d^2)$$
$$\delta C / C = \delta d / d$$

In some versions, the central plate moves in response to physical variables with respect to the fixed plates. In others, the central plate is fixed and outer plates are allowed to move. The output from the center plate is zero at the central position and increases as it moves left or right. The range is equal to twice the separation d.



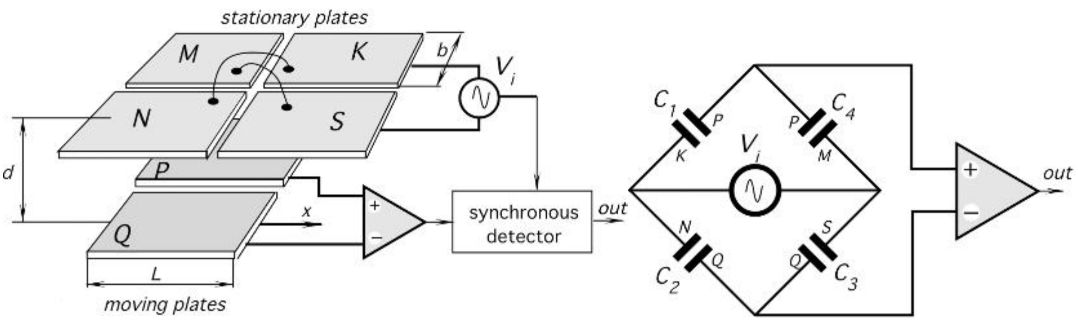
$$C_1 = \frac{\varepsilon A}{x_0 + x} \quad \text{and} \quad C_2 = \frac{\varepsilon A}{x_0 - x}$$

The amplitude of the output signals is:

$$V_{\text{out}} = V_0 \left(-\frac{x}{x_0 + x} + \frac{\Delta C}{C} \right)$$

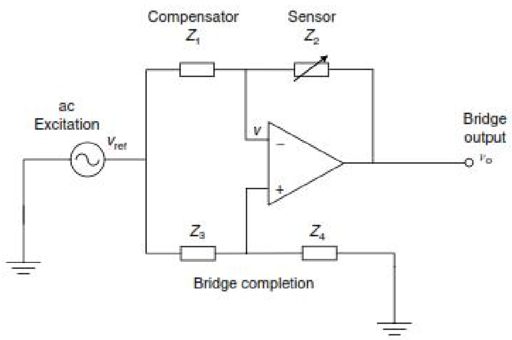
2.5 Parallel-plate capacitive bridge sensor

The sensor comprises two planar electrode sets that are parallel and adjacent to each other with a constant separation distance, d. The increase the capacitance, the spacing between the plate sets is relatively small. A stationary electrode set contains four rectangular elements, whereas a moving electrode set contains two rectangular elements. All six elements are of about the same size (a side dimension is b). The size of each plate can be as large as is mechanically practical when a large range of linearity is desired. The four electrodes of the stationary set are cross-connected electrically, thus forming a bridge-type capacitance network



2.5 Capacitive bridge sensor

Sensors that are based on the change in capacitance (reactance) require some means of measuring that change. Furthermore, a change in capacitance, which is not caused by a change in measurand (for example, due to change in humidity, temperature, and so on), causes errors and should be compensated for. Both these goals are accomplished using a capacitance bridge circuit.



In this circuit Z_2 is the sensor reactance and all other reactances are designed according to satisfy zero output condition in balance equation

$$\frac{Z_2}{Z_1}=\frac{Z_4}{Z_3}$$

Using the two assumptions for an op-amp:

- potentials at the negative and positive leads are equal
- the current through these leads is zero; we can write the current balance equation

$$\frac{v_{ref}-v}{Z_1}+\frac{v_o-v}{Z_2}=0,$$

$$\frac{v_{ref}-v}{Z_3}+\frac{0-v}{Z_4}=0,$$

v is the common voltage at the opamp leads. Next, eliminate v in Equation:

$$v_o=\frac{(Z_4/Z_3-Z_2/Z_1)}{1+Z_4/Z_3}v_{ref}.$$

Since all capacitors in thebridge are similarly affected by ambient changes, a balanced bridge will maintain that condition even under ambient changes, unless the sensor reactance Z_2 is changed because of the measurand itself. It follows that the ambient effects are compensated by the bridge circuit.