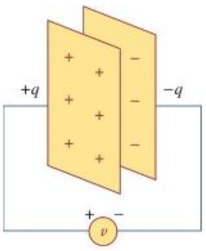
MEE303 Sensor Systems

W05
Displacement Sensing

Capacitive displacement Sensing

Capacitive Sensing

A capacitor is an electronic component that stores electric charge (and electric energy).



$$q = Cv$$

The relation between the charge in plates and the voltage across a capacitor is named as **capacitance** given as a capacity term showing capacitor functionality:

C also depends on the medium in which the plates are immersed

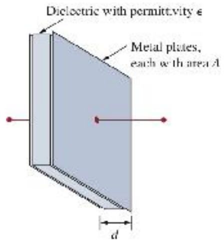
Its value depends on the shapes and relative position of the plates.

$$C = \kappa\varepsilon_0 G(A, d)$$

$$\varepsilon_0 = 8.854\times10^{-12}\,(F/m)$$

©:The dielectric constant indicates how easily a material can become polarized by imposition of an electric field on an insulator.

A simple version of a capacitor is the parallel-plate capacitor; it consists of two conducting plates separated by an insulating material, called *a dielectric*.

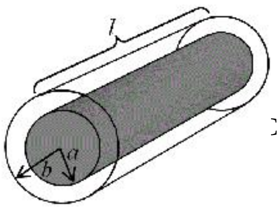


$$C = \frac{\varepsilon A}{d}$$

$$\varepsilon = \kappa\varepsilon_0$$

$$\varepsilon_0 = 8.854\times10^{-12}\,(F/m)$$

A cylindrical capacitor consists of two coaxial cylinders of radii a and b and length L. For the case when L>>b, we can calculate capacitance from the following formula:



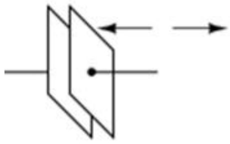
$$C = \frac{L}{2k\ln\left(\frac{b}{a}\right)} = \frac{2\pi\varepsilon_0 L}{\ln\left(\frac{b}{a}\right)}$$

Capacitive displacement Sensing

Capacitive Sensing

Capacitive sensors use the electrical property of "capacitance" to make measurements.

influences on the capacitance of a capacitor



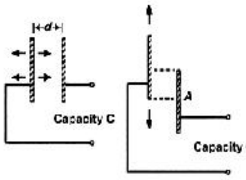
Change in capacitance due to change in distance between the two plates.

varies inversely as the distance d between the plates increase

$$C = \frac{K\varepsilon_0}{x(t)} A$$

Sensitivity

$$\frac{dC}{dx} = -\frac{K\varepsilon_0 A}{x^2}$$



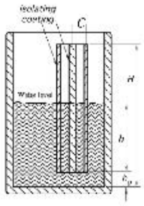
Change in capacitance due to change in overlapping area of plates.

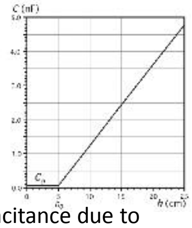
directly proportional to the area, A of the plates

$$C = \frac{K\varepsilon_0}{d} A = \frac{K\varepsilon_0}{d} lw = \frac{K\varepsilon_0 w}{d} l(t)$$

Sensitivity

$$\frac{dC}{dl} = \frac{K\varepsilon_0 w}{d}$$





Change in capacitance due to change in dielectric between the two plates

directly proportional to the effective dielectric constant

κ will vary for different materials

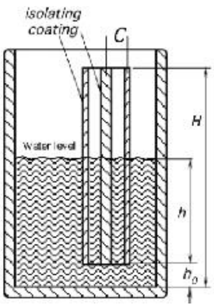
The space may consist of the dielectric material, air, and even moisture

Capacitive displacement Sensing

Capacitive Sensing

a capacitive water-level sensor

The sensor is fabricated in a form of a coaxial capacitor where the surface of each conductor is coated with a thin isolating layer.

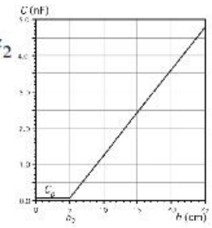


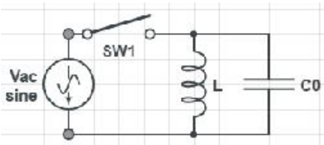
The sensor is immersed in a water tank. When the level increases, water fills more and more space between the sensor's coaxial conductors, thus changing the sensor's capacitance

The total capacitance of the coaxial sensor is

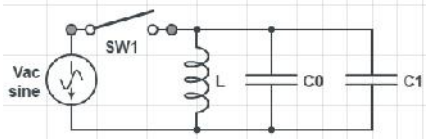
$$C_h = C_1 + C_2 = \varepsilon_0 G_1 + \varepsilon_0 \kappa G_2$$

$$C_h = \frac{2\pi\varepsilon_0}{\ln(b/a)}[H - h(1-\kappa)]$$

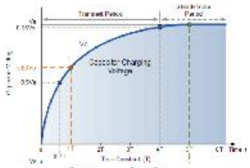


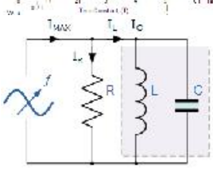


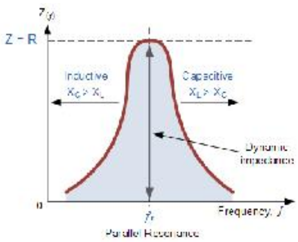
$$C_0 = C_1 = \frac{2\pi\varepsilon_0}{\ln(b/a)} H$$



$$C_2 = \frac{2\pi\varepsilon_0\kappa}{\ln(b/a)} h$$





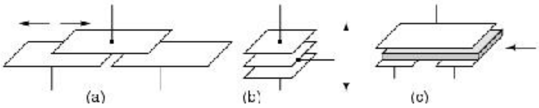


$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ (Hz)}$$

Capacitive displacement Sensing

Capacitive Sensing

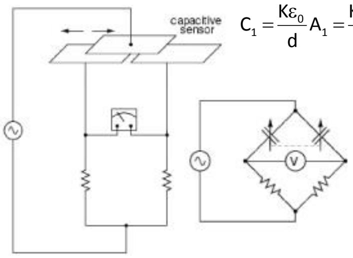
Transducers with greater sensitivity and immunity to changes in other variables can be obtained by way of differential design, much like the concept behind the LVDT



Differential capacitive transducer varies capacitance ratio by changing: (a) area of overlap, (b) distance between plates, (c) dielectric between plates

the differential devices shown in the above illustration have three wire connections rather than two: one wire for each of the "end" plates and one for the "common" plate. As the capacitance between one of the "end" plates and the "common" plate changes, the capacitance between the other "end" plate and the "common" plate is such to change in the opposite direction.

high power supply frequencies (in the megahertz range!)

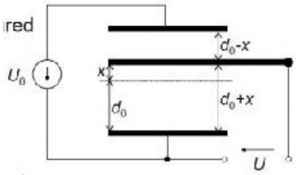


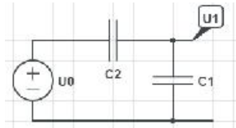
$$C_1 = \frac{K\varepsilon_0}{d} A_1 = \frac{K\varepsilon_0 w}{d}(l+x) \qquad C_2 = \frac{K\varepsilon_0 w}{d}(l-x)$$

$$X_{C_1} = \frac{1}{2\pi f C_1} = \frac{d}{2\pi f \kappa \varepsilon_0 (l+x)}$$

$$X_{C_2} = \frac{d}{2\pi f \kappa \varepsilon_0 (l-x)}$$

red





$$C_1 = \frac{K\varepsilon_0}{d+x} A \qquad C_2 = \frac{K\varepsilon_0}{d-x} A$$

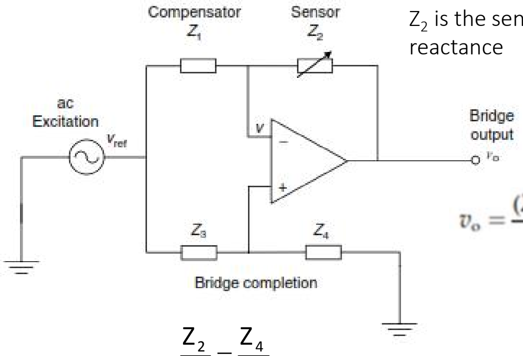
$$U_1 = U_0 \left(\frac{1/C_1}{\frac{1}{C_1} + \frac{1}{C_2}} \right)$$

Linear i/o relationship $\quad U_1 = \frac{U_0}{2}\left(1 + \frac{x}{d}\right)$

Capacitive displacement Sensing

Capacitive Sensing Bridge

Sensing change in capacitance and compensate a change in capacitance, which is not caused by a change in measurand



Z_2 is the sensor reactance

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

zero output condition

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

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

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

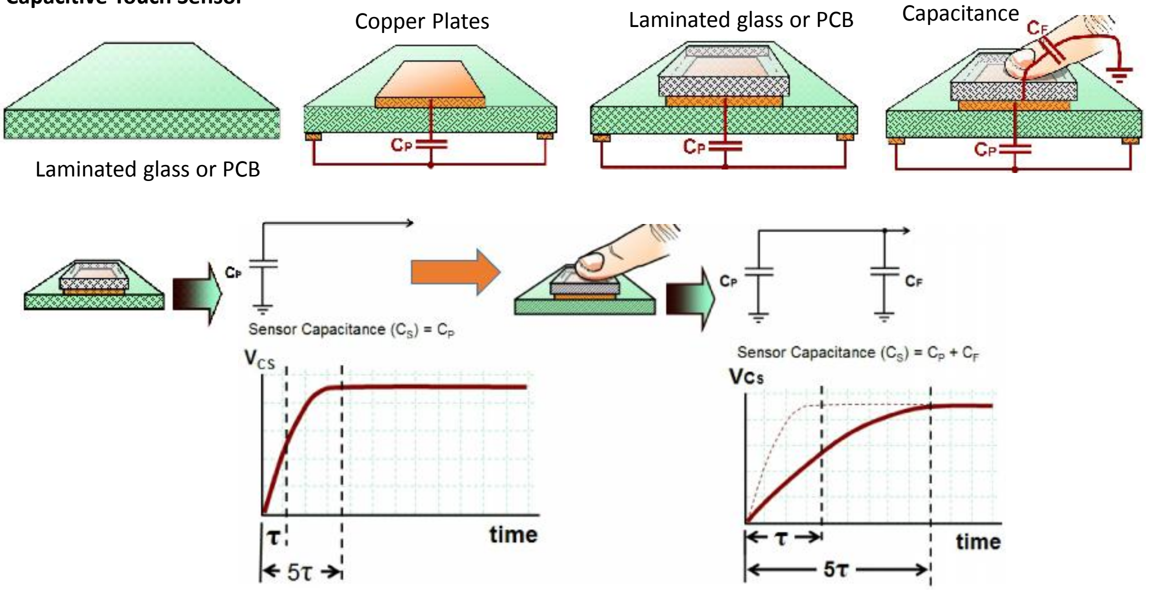
eliminate v in Equation

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

all capacitors in thebridge are similarly affected by ambient changes, a balanced bridge will maintain that condition even under ambient changes

Capacitive displacement Sensing

Capacitive Touch Sensor

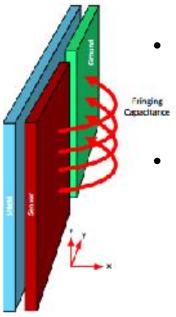


http://dkc1.digikey.com/US/en/TOD/Microchip/mTouch/mTouch.html

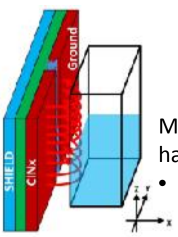
Capacitive displacement Sensing

Parallel Fingers Capacitive Sensor

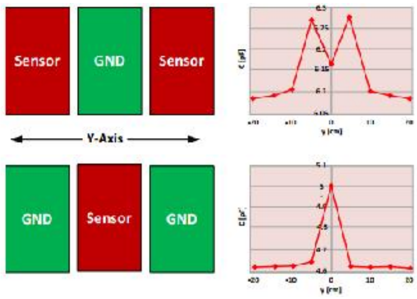
The parallel fingers (GND-sensor) topology works under the principle of fringing capacitance.



- The electric field lines are more dominant near the edges between the sensor and ground plates.
- High sensitivity along the z-axis of the sensors enables this topology to be implemented in liquid level sensing applications.

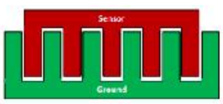


The capacitance calculations are not as straightforward as the simple parallel plate form but the sensitivity of the sensors increases as sensor size increases (non-linearly)



Multiple sensor and ground electrodes can be alternated to have a central ground or sensor symmetry.

- A central ground is required for a wide directivity along the width of the electrodes and gives the widest response.
- A central sensor electrode is required for high directivity along the width of the electrodes and provides the sharpest response.
- The comb configurationis comprised of both of these variants and very effective for wide and high directivity



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