Capacitive pressure sensors

What are capacitive pressure sensors?

- Capacitive pressure sensors measure pressure by detecting changes in electrical capacitance caused by the movement of a diaphragm.

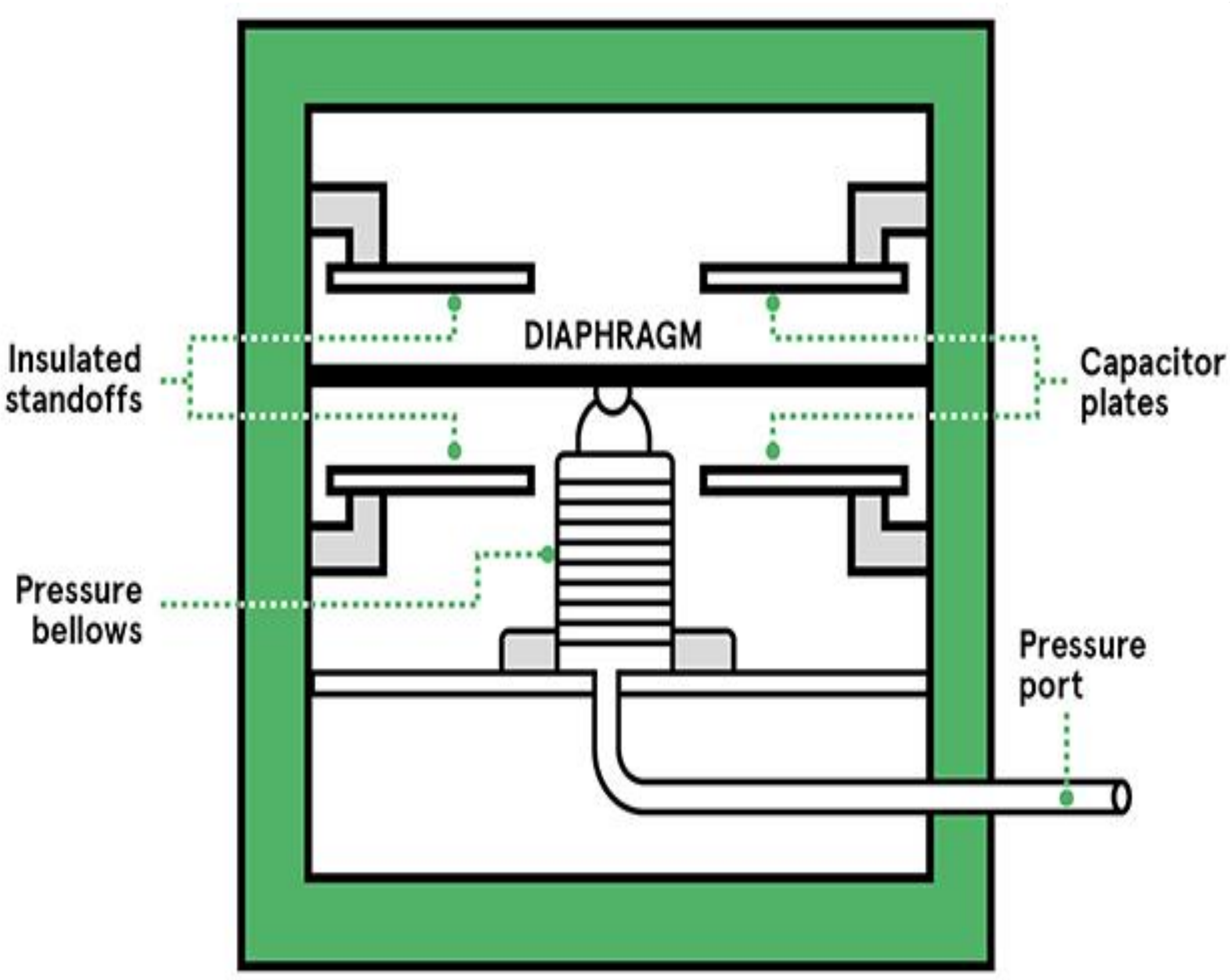
Working principle

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

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

where:

- εr is the dielectric constant of the material between the plates (this is 1 for a vacuum)
- ε0 is the electric constant (equal to 8.854x1012 F/m),
- A is the area of the plates
- d is the distance between the plates


Insulated
standoffs
DIAPHRAGM
Capacitor
plates
Pressure
bellows
Pressure
port

- Changing any of the variables will cause a corresponding change in the capacitance.
- The easiest one to **control is the spacing.** This can be done by **making one or both of the plates a diaphragm that is deflected by changes in pressure.**
- Typically, one electrode is a pressure sensitive diaphragm and the other is fixed.
- An easy way of measuring the **change in capacitance is to make it part of a tuned circuit**, typically consisting of the capacitive sensor plus an inductor. This can either change the frequency of an oscillator or the AC coupling of a resonant circuit.

CONSTRUCTION

- The **diaphragm can be** constructed from a variety of materials, such as **plastic, glass, silicon or ceramic**, to suit different applications.
- The **capacitance** of the sensor is typically around **50 to 100 pF**, with the change being a few pico farads.
- The **stiffness and strength of the material** can be chosen to **provide a range of sensitivities and operating pressures.**
- To get a **large signal, the sensor may need to be fairly large,** which can limit the frequency range of operation.
- However, **smaller diaphragms are more sensitive** and have a faster response time.

- **A large thin diaphragm may be sensitive to noise** from vibration (after all, the same basic principle is used to make **condenser microphones) particularly at low pressures.**
- **Thicker diaphragms are used in high-pressure sensors** and to ensure mechanical strength. Sensors with full-scale **pressure up to 5,000 psi** can readily be constructed by controlling the diaphragm thickness.
- The structure also needs to have **low hysteresis to ensure accuracy and repeatability** of measurements.
- Because the diaphragm itself is the sensing element, there are no issues with extra components being bonded to the diaphragm, so **capacitive sensors are able to operate at higher temperatures than some other types of sensor.**

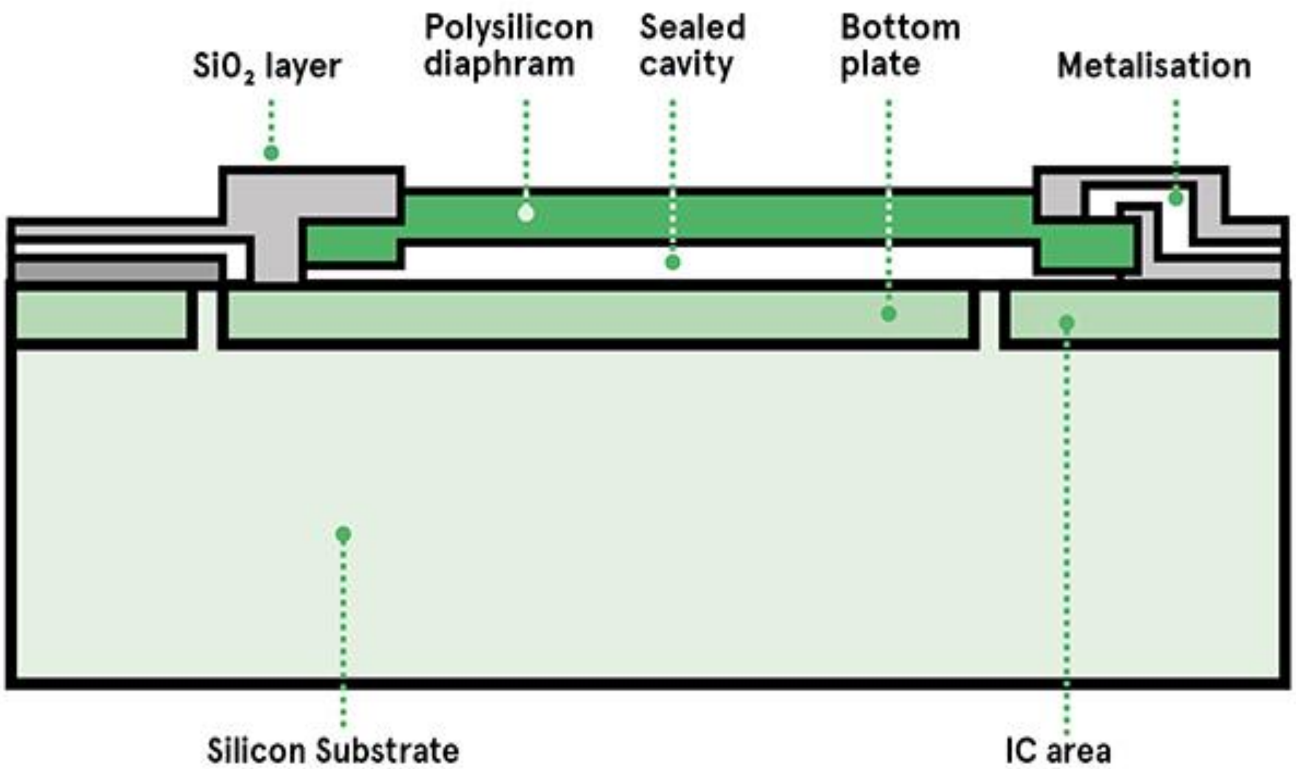
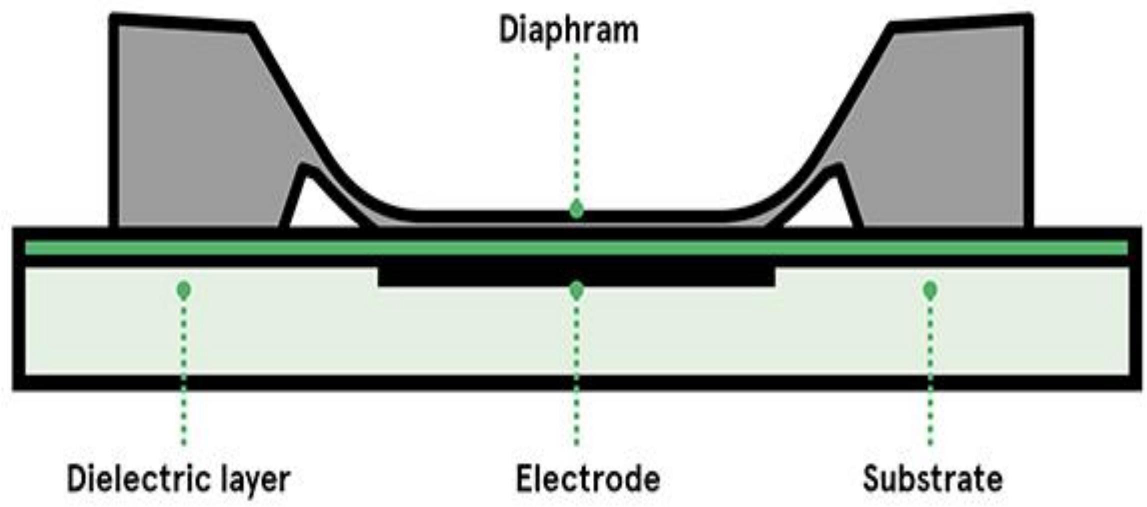


Fig: A cross section of capacitive sensor construction

Function

- The change in capacitance can be measured by connecting the sensor in a frequency-dependent circuit such as an oscillator or an LC tank circuit. In both cases, the resonant frequency of the circuit will change as the capacitance changes with pressure.
- An oscillator requires some extra electronic components and a power supply. A resonant LC circuit can be used as a passive sensor, without its own source of power.
- The dielectric constant of the material between the plates may change with pressure or temperature and this can also be a source of errors. The relative permittivity of air, and most other gasses, increases with pressure so this will slightly increase the capacitance change with pressure. Absolute pressure sensors, which have a vacuum between the plates, behave ideally in this respect.



- A more linear sensor can be constructed by using '**touch mode**' where the **diaphragm makes contact with the opposite plate (with a thin insulating layer in between)** throughout the normal operating range (as shown to the right).
- **The geometry of this structure results in a more linear output signal.**

DESIGN:

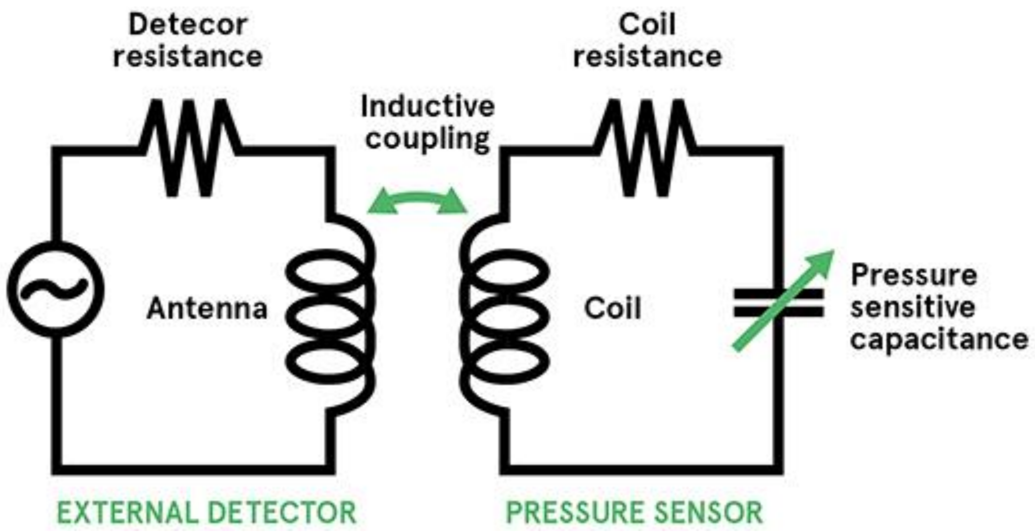


Fig: An external antenna in some passive sensors to stimulate the tuned circuit

Applications

- Capacitive pressure sensors are often used to **measure gas or liquid pressures in jet engines, car tyres, the human b**ody and many other places.
- But they can also be used as **tactile sensors in wearable devices** or to measure the pressure applied to a switch or keyboard.

Advantages:

- more robust
- able to cope with a larger over-pressure.
- suited to industrial environments.

- They can have **very low power consumption** because there is no DC current through the sensor element. **Current only flows when a signal is passed through the circuit** to measure the capacitance. Passive sensors, where an external reader provides a signal to the circuit, do not require a power supply – **these attributes make them ideal for low power applications such as remote or IoT sensors.**

- The sensors are **mechanically simple,** so they can be made rugged with stable output, making them suitable for use in harsh environments. Capacitive sensors are usually **tolerant of temporary over-pressure conditions.**

Disadvantages:

- On the other hand, capacitive sensors **have non-linear output,** although **this can be reduced in touch-mode devices**. However, this may come at the **cost of greater hysteresis.**
- Finally, **careful circuit design is required for the interface electronics** because of the high output impedance of the sensor and to minimise the effects of parasitic capacitance.


Thank you