AN10832

PCF8883 and PCA8886 - capacitive proximity switch with auto-calibration

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Document information

Info	Content
Keywords	PCF8883; PCA8886; touch and proximity switch; auto-calibration
Abstract	This application note describes briefly important factors for the usage of the PCF8883 and PCA8886 sensor devices.

Revision history

Rev	Date	Description
v.6	20150116	corrected revision
v.5	20140314	revised revision
v.4	20120612	extended revision
v.3	20100908	corrected revision
v.2	20100819	extended revision
v.1	20090612	new application note, first revision

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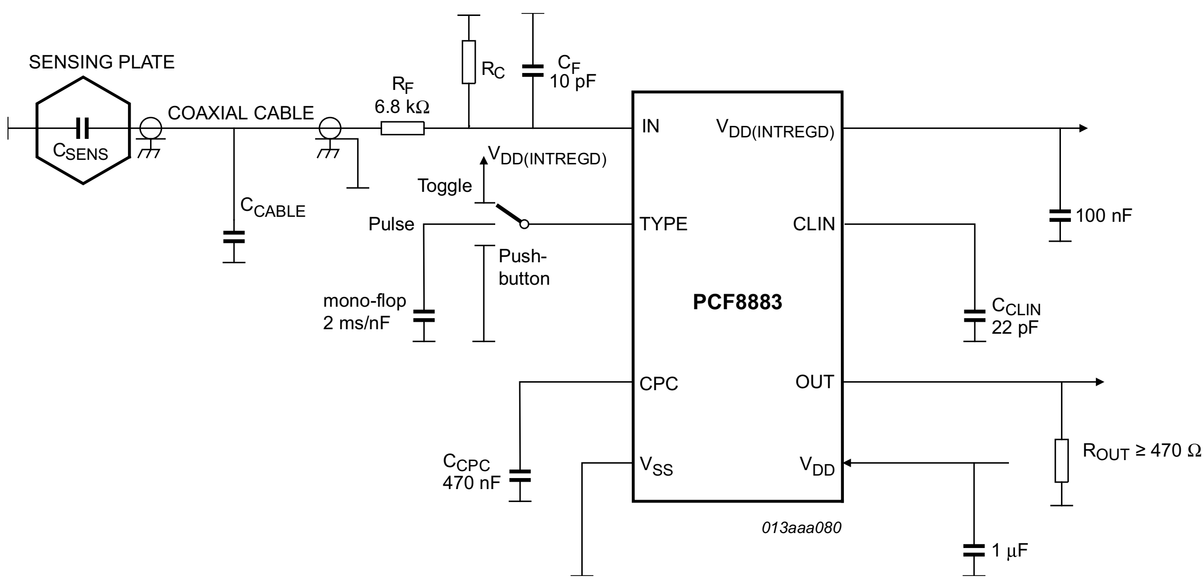
1. Introduction

NXP's capacitive switches use a patented digital technique (patent from Edisen) to detect a change of capacitance on the device input. In order to use this switch, the following must first be defined:

- mechanical outline and materials to be used
- the desired switching distance from the sensing plate and
- application specific optimal approach speed sensitivity

The following text explains the relationship between the product design and the electrical switching to be expected.



Coaxial cable needed for distant sensing plates in noisy environments.

Fig 1. Typical application circuit

2. Dimensioning of R_C, C_{CPC}, and C_{CLIN}

The adaption of the switch to a particular application usually requires to adjust several components because certain parameters can be influenced by one or more factors: sensor area, sensor environment, and triggering must be taken into account. These aspects are constitutive for the behavior of the switch.

The circuit has three parameters that influence the switching behavior. Below they are listed in order of their influence:

- Switch sensitivity (C_{CPC} capacitance between CPC and V_{SS})
- Calibration of the total capacitance on the sensor input (R_C between IN and V_{SS})
- Switching speed (C_{CLIN} between CLIN and V_{SS})

Once the sensing area is defined (geometry, material, distance from sensing plate to input), the typical values given in the data sheet for C_{CPC} and C_{CLIN} should be used as a starting point for tuning the sensitivity of the switch.

2.1 R_C

This resistor is only necessary to unload the sensor input when the total capacitance of the sensor plate and - in case it is used - the capacitance of the coaxial cable is higher than 60 pF which is the upper limit of the input capacitance.

Check the switching by touching the sensor plate although the final application will use proximity sensing. Assuming that the default value of C_{CPC} (470 nF) is used, switching should occur. If not, the R_C resistance can be gradually reduced till switching occurs. The lowest value allowed is 20 kOhm.

Remark: According to the data sheet, the total capacitance on the input should be between 10 pF and 60 pF in order for the control loop to work correctly and reliably. In practice, it is normally impossible to measure this capacitance. Alternatively, the voltage on C_{CPC} can be measured. Ideally, the operating voltage on C_{CPC} should be $V_{DD(INTREGD)}/2$.
This measurement must be done with a high impedance probe (R_{in} > 5 GΩ) since this point has a high resistance[1]. The lower limit for R_C is approximately 20 kΩ. It should be noted, that the IC has an internal 50 kΩ resistor connected in parallel to R_C (pin IN to V_{SS}). When R_C is less than 20 kΩ, higher internal currents are flowing and the precision of the device is declining.

2.2 C_{CPC}

The sensitivity can be adjusted once the sensor switches reliably (see previous step). Touching the sensor plate is the least critical case and usually works with the value of C_{CPC} given in the data sheet (C_{CPC} = 470 nF, typical).

Adjustments are usually necessary when:

1. The sensor area is small and the triggering area is comparable or smaller. For example, if the sensor is used in a keyboard, the keys may have a small area. The area of a finger is comparable to the sensor area. The switch must be fine-tuned such that neighboring switches do not react.
2. The distance between the sensor plate and triggering object is larger than the sensor plate area (switching at a distance).
3. Switching through materials having different permittivity ε_r is desired.

The second point is actually a special case of the third point. The complexity is caused by the fact that the switching point is not solely defined by the sensing plate but also by the situation of the air (and its permittivity ε_r) between the plate and the triggering object. Since the nature of air can change slightly depending on conditions, the situation for

1. Measuring the voltage on the CPC capacitor is not usually possible since the impedance on pin CPC is too high for most oscilloscope probes. The problem can be solved by using a high impedance probe (a voltage follower for example).

   Alternatively, it is possible to use the following characteristic: On power-up, the internal capacitors are charged using 50 times the normal charging current in order to stabilize the control loop as quickly as possible. During this time, it is possible to measure the voltage at CPC correctly using a standard oscilloscope probe.

proximity switching is not as well defined as when the plate has to be touched. This makes it difficult to give a precise range for switching at a distance. Furthermore, the sampling of the sensor influences switching at a distance as well (see Section 2.3). The cases listed above can also occur in combination.

A larger value of C_{CPC} increases the sensitivity, which means:

- That the sensor area can be reduced
- The sensor reacts at a distance
- The range through materials with different permittivity is increased

Remark: C_{CPC} should be a high-quality foil or ceramic capacitor, for example an X7R type.

2.3 C_{CLIN}

C_{CLIN} defines the internal sampling frequency used to sample the signal on input pin IN. The sampling period is given by:

$$T(fk)[\mu s] = 300\mu s + C_{CLIN}[\mathrm{pF}] \times 33\mu s/\mathrm{pF} \quad (1)$$

The sensor reacts faster when the frequency is increased since the necessary number of comparisons is reached in less time. On the other hand, this also means that the sensor self calibrates to new environments more quickly with the result that a slow moving hand will no longer cause the sensor to switch: The sensor calibrates itself to the new environment (with the hand) more quickly than detecting the changes caused by the approaching hand. Another consequence of increasing the sampling frequency is that the sensor reacts to quick changes at a distance with higher sensitivity. This effect can be enhanced by increasing C_{CPC} or the sensing area.

To get the proper dimension of C_{CLIN} it is important to know the normal “approach speed” of the triggering object. A machine often moves more quickly than a human does; and a single finger could move more quickly than an entire hand.

It is also important to note that the power consumption of the device increases when increasing the sampling frequency.

3. Dimensioning of R_F and C_F

R_F and C_F are used to create a low-pass filter placed close to the sensor pin. This filter and the frequency characteristics are described in AN11157. Depending on the R_F, noise in the environment and the spectral characteristics the value of R_F can be adjusted from 0 Ω up to 10 kOhm without any significant impact on the sensitivity.

The value of C_F requires consideration of the total capacitive load on the sensor input and it can be increased as long as the voltage over C_{CPC} is kept around $V_{DD(INTREGD)}/2$.

4. Sensitivity and capacitance changes

Many factors can increase and decrease the sensitivity of the switch. The sensitivity is a function of:

- The approach speed of the triggering object
- The area of the sensor plate (or electrode) and the area of the triggering object
- The shape of the sensor plate and the triggering object
- The nature and thickness of the material between the electrodes
- The plate (or electrode) orientation
- The coupling between the sensor area, sensor triggering object, and the ground (earth)

The sensor area, the triggering object, and the dielectric material between them constitute a capacitor. The capacitance seen on the sensor input (IN) consists of all the desired capacitance and parasitic capacitance to be compensated by the control loop. In Figure 2, the capacitor connected to the hand (triggering object) is used to show that a capacitance exists between the hand and ground (earth). The ground can be the negative supply or the earth, depending on the situation.

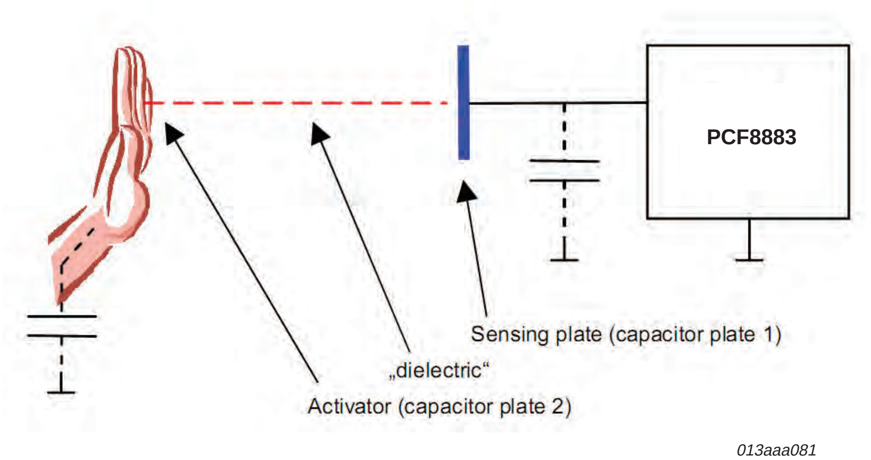


Fig 2. Typical example

The capacitance of a plate capacitor is given by:

$$C = \frac{A}{d} \times \varepsilon_0 \times \varepsilon_r \quad (2)$$

Whereas

C = capacitance in F

A = cross sectional area of plates in m^2

d = distance between sensing plate and activator in m

ε_0 = absolute permittivity of free space (8.85×10^{-12} F/m)

ε_r = relative permittivity of the material covering the sensor

This expression is valid for our example, but in practice, the plates are rarely identical and the distance and dielectric can change.

4.1 Capacitance changes

The voltage on the sensor input is compared to an internal reference at discrete points in time defined by the sampling frequency. The control loop continuously tries to maintain voltage equilibrium on C_{CPC} by either subtracting or adding charge to the capacitor. An up-down counter counts how often charge flows consecutively in one direction. In equilibrium, the counter is effectively continually reset since the charge flows first in one direction and then the other. The counter causes the output to switch when the counter has counted 64 times. The sensor reacts only to changes in capacitance. A finger that approaches the sensing plate continually changes the capacitance of the plate.

According to the capacitance equation above, the capacitance can also be changed by changing the area and the permittivity. In practice, the area and permittivity are more relevant for the sensitivity of the sensor.

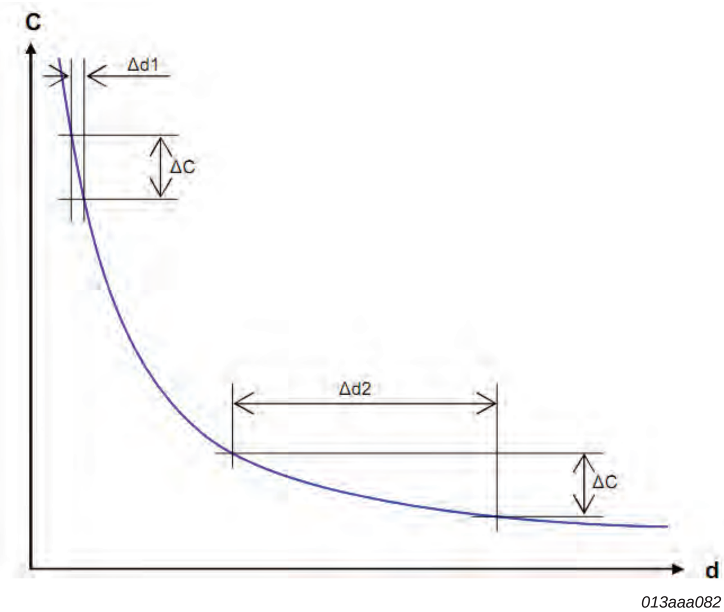
5. Approach speed and dynamics

The sensor compensates changes in static or slowly changing capacitance. The sensor first switches when it can no longer compensate the change in capacitance.

Figure 3 shows how the capacitance changes with respect to the distance. The same capacitance change ΔC can be produced close to the sensing plate ($\Delta d1$) or further away ($\Delta d2$).

A triggering object moving at a constant speed will cause a larger capacitance change nearer to the plate than one further away from it.

Please note that the sensor requires more than 63 consecutive increases (or decreases) in capacitance over a fixed period to cause a switch; hence it can be deduced that the switch distance increases with increasing approach speeds.



C = capacitance.

d = distance.

Fig 3. Capacitance change as function of the distance

6. Influence of the size and form of the capacitor plates (electrodes)

An open input pin on PCF8883 represents the worst possible sensing area and is not recommended. The easiest method to increase the sensitivity is to increase the sensing area. The capacitance equation, Equation 2, illustrates that the capacitance (C) is proportional to the cross sectional area of the sensing plate (A). In most cases, simply increasing the sensing area will lead to the desired result. When the sensing area is limited by the application then the value of C_{CPC} has to be increased to increase the sensitivity.

Increasing the size of the triggering object can also increase the sensitivity. Under certain conditions, this may be desired in order to optimize the switching characteristic for a particular application. For example, switching through a thick layer of material where the material itself influences the sensitivity (see Figure 4).

Figure 4 shows, that despite a large sensor area a fingertip may be unable to make the sensor switch whereas the whole hand does it because it cuts all of the sensor’s field lines. This simplified model can help to understand how to optimize the application.

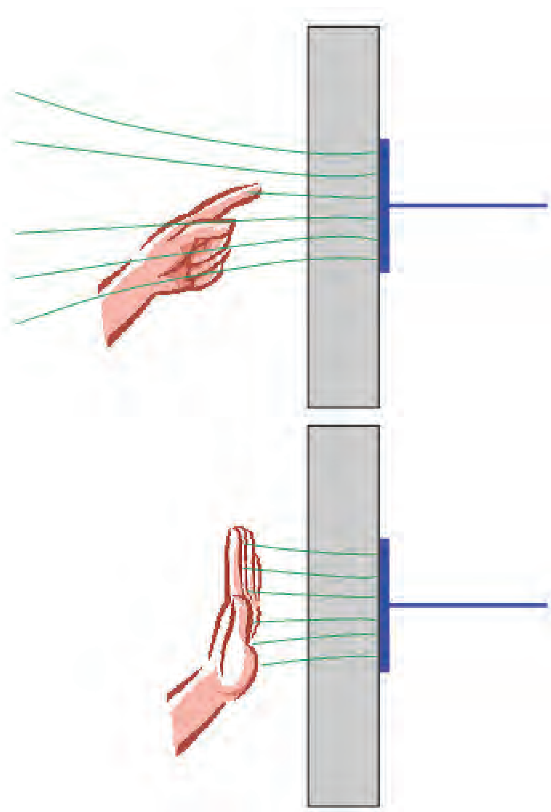


Fig 4. Influence of approaching objects

The minimal sensor area should not be smaller than the triggering object area. A larger sensing area is recommended. The sensor area or C_{CPC} must be increased in cases when switching has to take place through different layers (e.g. over distance, with differing permittivity).

Concerning the PCF8883, there is no limitation on form or design of the sensing area. The sensing area can take any form as long as the required sensitivity will be obtained. Oval or round areas are recommended, since they have the least edge effects.

7. Influence of thickness and nature of the dielectric

The dielectric encompasses everything between the sensing area and the triggering object area.

The thickness and nature of each dielectric influences the strength and flux of the electric field passing through. If different layers of material with different permittivity are used then all layers will influence the field and flux. The electric field will be refracted, diffracted, reflected and diminished depending on the exact materials and construction used. Another factor to be considered is the total thickness of the construction.

The range of permittivity ε_r for typical application materials are:

- Glass, ε_{rg}: 6 to 8
- Plastic, ε_{rp}: 2 to 4
- Conductive foam, ε_{rf}: 2 to 3
- Air, ε_{ra}: 1

7.1 Air gap

In the application shown in Figure 5, the sensor area is mounted behind 10 mm glass, a 0.3 mm air gap and 2 mm plastic.

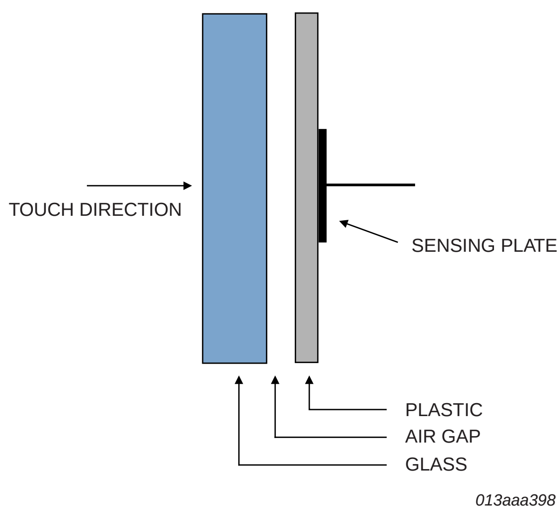


Fig 5. Application example containing an air gap

Materials having higher relative permittivity support higher sensitivity because the electrical field strength is proportional to the relative permittivity and inverse proportional to the thickness. The air gap above is an issue because the relative permittivity $\varepsilon_r = 1$ is low compared to plastic or glass.

The sensitivity is proportional to the capacity value of C_{SENS}. The total capacity is composed of the capacitors of the materials in series:

- Glass: C_g
- Plastic: C_p
- Conductive foam: C_f
- Air: C_a

And d_x is the thickness of the materials.

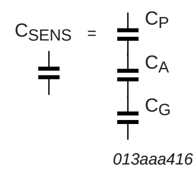


Fig 6. Total capacity as result of capacitors in series

$$C_p = \frac{A}{d_p} \times \varepsilon_0 \times \varepsilon_{rp} \quad (3)$$

$$C_a = \frac{A}{d_a} \times \varepsilon_0 \times \varepsilon_{ra} \quad (4)$$

$$C_g = \frac{A}{d_g} \times \varepsilon_0 \times \varepsilon_{rg} \quad (5)$$

Out of Equation 3 to Equation 5 C_{SENS} will be calculated with Equation 6:

$$C_{SENS} = \frac{C_p \times C_a \times C_g}{C_p \times C_a + C_p \times C_g + C_a \times C_g} \quad (6)$$

The total capacity is smaller than the smallest of the three capacities. Therefore air gaps should be avoided or minimized and the thickness of the material should be reduced to a minimum.

7.2 Conductive foam

By placing some conductive foam between the sensor plate and the glass, an air gap can be avoided (see Figure 7).

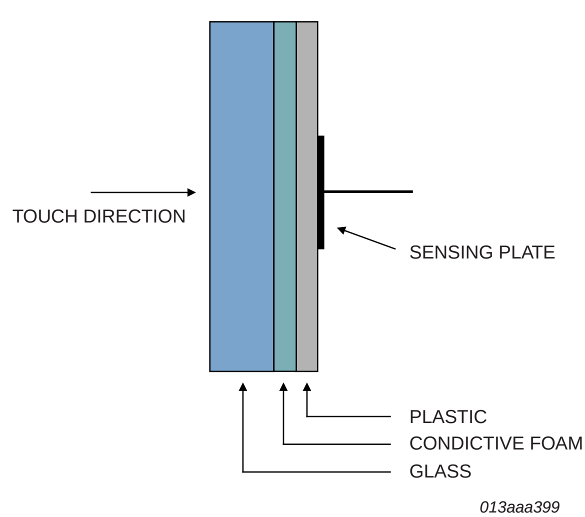


Fig 7. Application example with conductive foam

Compared with the example in Section 7.1, replacing the air gap with conductive foam will increase the sensitivity of the set-up.

8. Plate (electrode) orientation

A capacitance change that is high enough will cause any application to switch. The following rule always applies:

The more field lines that the triggering object cuts, the larger the generated capacitance change will be.

Figure 8 illustrates this effect. The approaching palm area triggers a switch faster than the side of the hand.

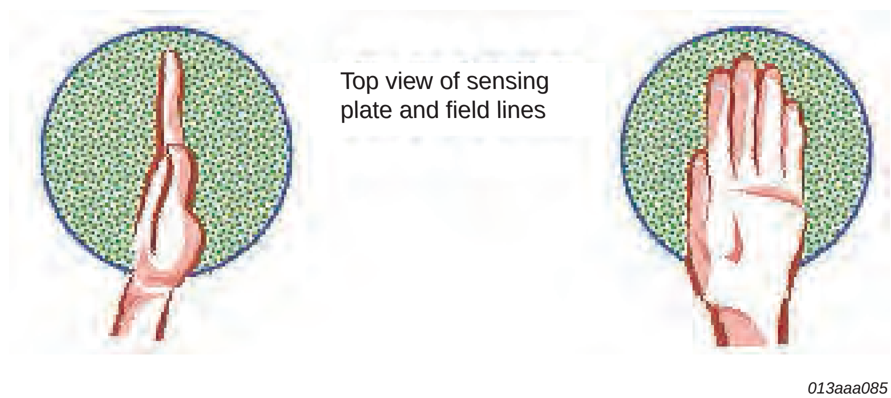


Fig 8. Trigger object area

9. Electrical environment

The presence of ground (earth) influences capacitive sensing. Figure 9 shows the expected field with and without neighboring grounds.

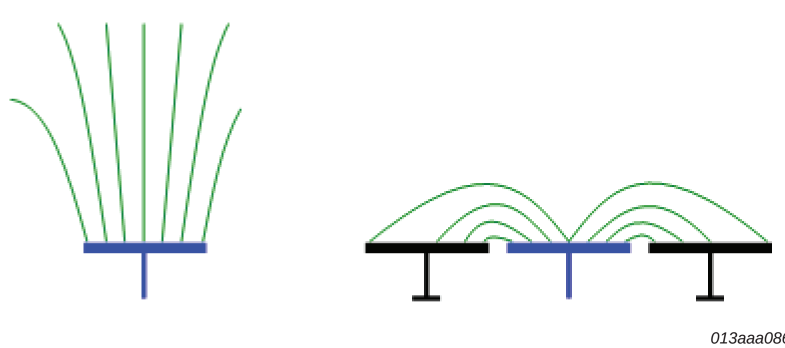
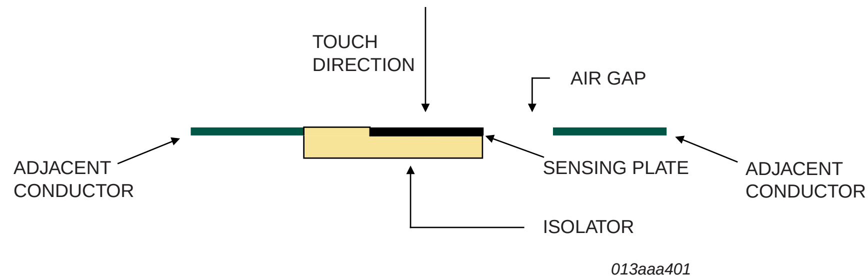


Fig 9. Influence of grounds

The electric field takes the shortest path to ground. As shown in Figure 9, the presence of the ground flattens the field and therefore shortens the switching distance and sensitivity in comparison to the example without a ground nearby.

Conductors next to the sensor plate have either to be isolated by an air gap or by isolating material, see Figure 10.

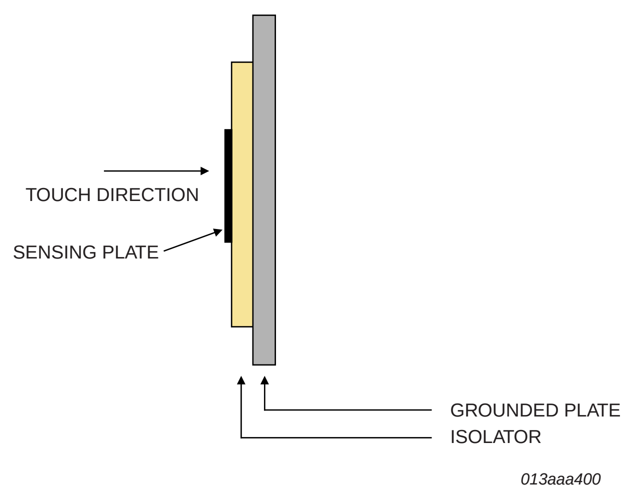


An isolation > 0.1 mm will be sufficient.

Fig 10. Isolating the sensing plate against adjacent conductors

A grounded plate placed underneath the sensor plate will shield signals from below, reduce any coupling, and give a defined sensor capacity, see Figure 11. Such a ground plate can easily be realized using a double sided or multilayer PCB.

However, the grounded plate and the sensing plate are building a capacitor, which may reduce the sensitivity.



An isolation > 0.2 mm will be sufficient.

Fig 11. Grounded plate under the sensor for shielding signals from below

10. The capacitive compromise

A capacitive switch is always a compromise. A non self-calibrated capacitive device must be initially calibrated and will only function with one set of materials and over a particular distance. Dirt, humidity, and changes in temperature can impair and prevent the correct function.

The self-calibrated switch, PCF8883, adjusts itself continuously to the environment. It will only switch when the capacitance changes more than 63 times consecutively in one direction.

Very slow changes will be neutralized by the self-calibration. Extremely quick changes are not registered because the device never reaches the required number of changes to switch. In other words, the disturbance is digitally filtered out.

Therefore, the switch must be optimized for the typical application requirements. The big advantage is that such things as dirt, humidity, ice or damage to the electrode do not affect this device.

Our experience is that the user intuitively and quickly adapts to the device behavior without having to understand any of the technical details.

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12. Figures

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