
**Guidelines to optimize proximity detection
with STM8T141 and STM8T143 capacitive sensors**

Introduction

The STM8T14x capacitive sensors open up a new dimension in capacitive sensing by detecting user proximity up to a few centimeters. This is a key feature for many end-applications such as personal navigation devices (PNDs) or stove tops which are equipped with backlighting that switches on as soon as a user is detected. Proximity detectors are also implemented in white goods, automotive devices, palm tops, and on any type of kitchen or office appliance where the display needs to be turned on to allow some parameters to be adjusted by the user.

To enhance their application appearance and ease-of-use, designers can choose to add proximity detection as an extra feature. Another motivation to add a proximity detection, in particular for portable devices, is energy saving. The product usually remains in sleep mode and only wakes up when it detects a user in its proximity.

One of the key features of capacitive sensors versus conventional proximity detectors (such as infrared light sensors), is the low power scheme. Capacitive sensors consumption is in the range of μA , versus mA for conventional sensors. Such a low power scheme is a fundamental characteristic for power sensitive applications.

The phenomenons described in this document exist in all capacitive sensing implementations. Because of the high sensitivity required by proximity detection, their impact seems amplified compared to touch sensors and therefore must be considered with great care.

A set of tools are provided to develop touch sensing applications based on STM8T141 and STM8T143. This includes :

- Hardware tools: STM8T141-EVAL, STM8T143-EVAL, ST-TSLINK, STM8T14X-SB
- PC application: STM-STUDIO, STVP

Table 1. Applicable products

Type	Applicable products
Microcontrollers	STM8T141, STM8T143

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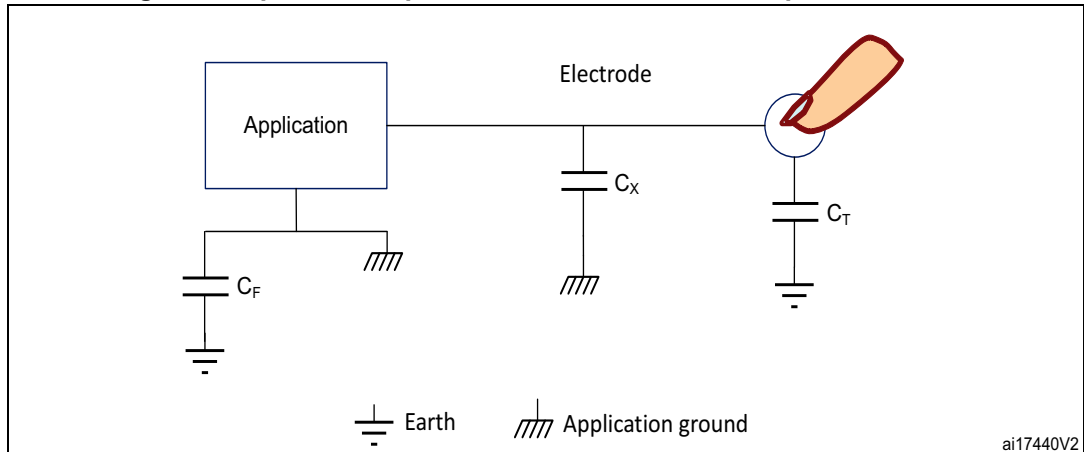
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1 Capacitive sensing overview

1.1 Capacitive sensing system equivalent circuit

To better understand the behavior of a proximity sensor, we need to consider [Figure 1](#) as the basic equivalent circuit of a single electrode sensor. It contains two signal references: ground and earth.

Figure 1. Equivalent capacitive circuit of a surface capacitive sensor



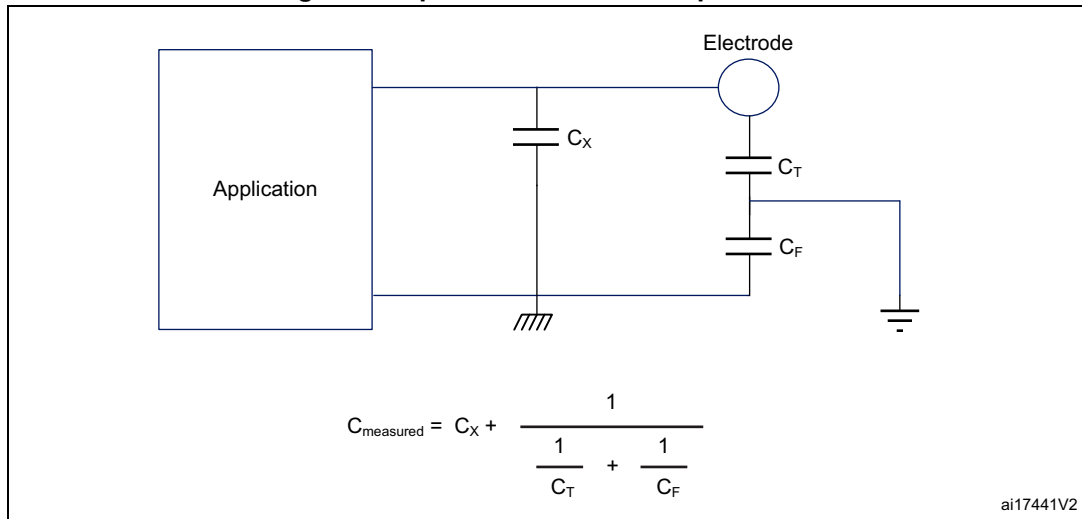
Ground is the application reference voltage, while earth represents the surrounding potential at the voltage of the user's body. Usually, this is the equipotential of the earth prong, the third terminal on power outlets.

In [Figure 1](#), C_T represents the capacitance created by a finger or a body proximity. This is the source of the useful signal and the variable part of the capacitance. It is referred to as the earth potential.

C_X represents the parasitic capacitance of the electrode. It is composed of all the capacitances between the electrodes and the application ground that are not impacted by the finger or body proximity. The sensing device input pin capacitance and the stray capacitance on the application PCB are the two elements of C_X .

C_F is the feedback capacitance between earth and the application ground. Its value varies greatly from one application to another and influences considerably the sensitivity of the capacitive sensor.

Figure 2. Equivalent measured capacitance



We can deduce from [Figure 2](#) the application measures not only C_T , but a combination of C_X , C_F and C_T (see [Equation 1](#)).

Equation 1

$$C_{\text{measured}} = (C_X + 1) / (1/C_T + 1/C_F)$$

The challenge in developing a capacitive sensing system is overcoming possible sensing errors coming from changes in C_X and C_F that are not created by a touch but, by a change in the application surroundings.

All the sensors include a means of compensating slow changes in the surroundings but, they cannot automatically compensate for a fast signal change and report a false spurious detection if the change is in the same direction as the touch/proximity. For this reason, it is recommended to recalibrate the device if the application detects changes in the environment (for example, when the USB cable is plugged/unplugged or the application door is closed).

Improving the capacitive sensing system sensitivity can be achieved by:

- Minimizing the C_F effect, also known as improving the application grounding.
- Minimizing the C_X value. This value is impacted by the electrode and the overall application design. It can be improved by using an active shield.

1.2 Capacitive sensing acquisition method

The principle of charge transfer is to charge the electrode capacitance (C_X) using a stable power supply. When C_X is fully charged, part of the accumulated charge is transferred from C_X to an external sampling capacitance, referred to as C_S . The transfer cycle is repeated until the voltage across the sampling capacitor C_S reaches the end of acquisition reference voltage (V_{TRIP}). The change in the electrode capacitance is detected by measuring the number of transfer cycles composing a burst (see [Figure 2](#)).

Throughout this document the following naming conventions apply:

- The charge transfer period ($t_{TRANSFER}$) refers to the charging of C_X and the subsequent transfer of the charge to C_S .
- The burst cycle duration (t_{BURST}) is the time required to charge C_S to V_{TRIP} .
- The sampling period ($t_{SAMPLING}$) is the acquisition rate.

2 Factors influencing proximity sensitivity

The following factors influence proximity sensitivity:

- Capacitive system ground
 - A battery supplied portable system versus a well-grounded system offer different system sensitivity
- Electrode (C_X)
 - Size: a bigger the electrode size increases the coupling between the user and the electrode and thus improves the sensitivity.
 - Shape: the shape of the electrode is directly linked to the detection area expected for the application.
 - Ground and supply proximity to sensor and tracks.
 - Route and distance between electrodes and proximity sensor.
- Sampling capacitor (C_S)
 - Increasing the C_S capacitor increases the resolution of the C_X measurement.
- Panel
 - Materials and thickness can modify the sensitivity. The better the dielectric value, the better the sensitivity of the sensors (glass is better than plastic).
 - Avoid air gaps between the sensor and the overlay material. For example, use a spring with a conductive surface pressing against the overlay where big air gaps exist or attach the touch pad directly to an overlay using non-conductive glue/double-sided tape.
- Power supply
 - Variation in the power supply level can disrupt the sensor measurement and cause unwanted proximity detection.
- Temperature
 - Temperature variations have an effect on the proximity sensor measurement

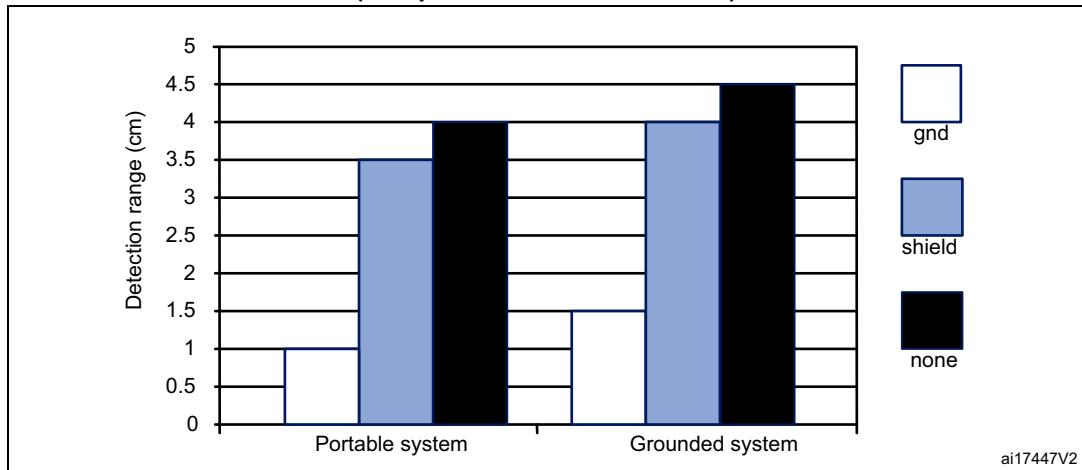
Special care should be taken of the above factors to ensure stability of the sensor systems.

Increasing the sensitivity of the sensor excessively (by increasing the electrode size or the C_S) can cause an unstable sensor system and trigger unwanted proximity detection.

3 Capacitive system ground

Having a battery supplied portable system versus a wire-grounded system affects the sensitivity of the sensor. This is illustrated in [Figure 3](#) which shows the difference in detection range between grounded and ungrounded proximity sensors. Three different electrode designs are considered (see [Section 4: Proximity sensing electrode design](#) for more details).

Figure 3. Detection range comparison between portable and grounded system (test performed on STM8T141)



3.1 Connected applications

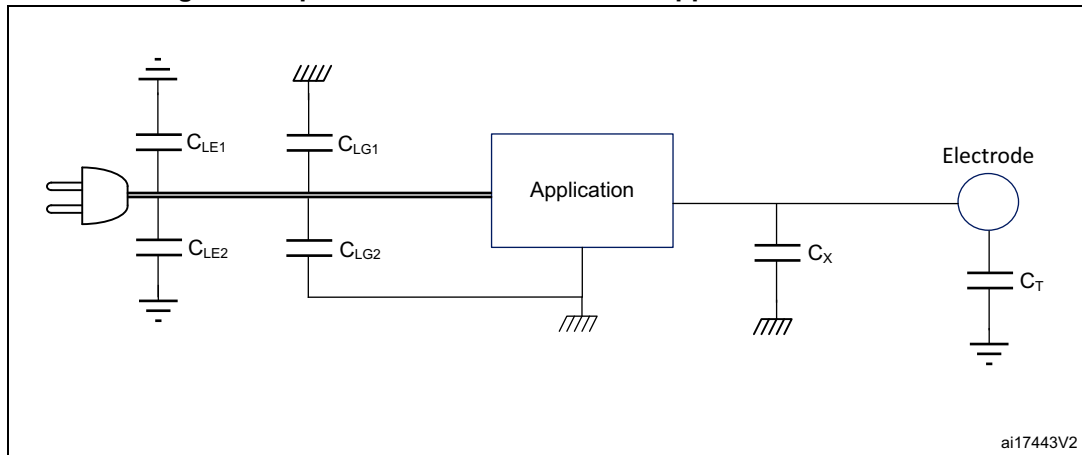
From a capacitive sensing point of view, connected applications form two groups.

Group one consists of applications where the ground is directly connected to earth. With this kind of connection, the C_F capacitor is shorted, and therefore has no impact on the touch/proximity sensor sensitivity. This is the best case scenario, but mostly reserved to some home appliances and white goods applications.

Group two consists of plugged applications with no earth connection. In this case the C_F capacitance is a combination of several capacitances as shown in [Figure 4](#). This group includes most consumer products, for example USB powered devices.

The big advantage of the connected applications is the stability of the C_F capacitor. Since the value is fixed, it cannot be misinterpreted as a touch or device proximity.

Figure 4. Equivalent connected to earth application schematic



C_{LE1} and C_{LE2} are the capacitances between the power lines and earth. They are both intrinsic to the power network. They usually have relatively high values and are seen as a short from a touch sense capacitance measurement.

C_{LG1} and C_{LG2} are the capacitances between the power lines and the application ground. The values of these capacitances depend on the power supply design of the application. For example, they may include the capacitance between the primary and secondary coils of a transformer.

In most cases, C_{LE} and C_{LG} are high enough to be seen as a short by the touch sensing system. However, in some specific designs it is possible to improve the sensitivity by adding a physical capacitor across the power supply.

On plugged devices, C_{LE1} and C_{LE2} capacitances in series with C_{LG1} and C_{LG2} capacitances, are the main components of the feedback capacitance C_F .

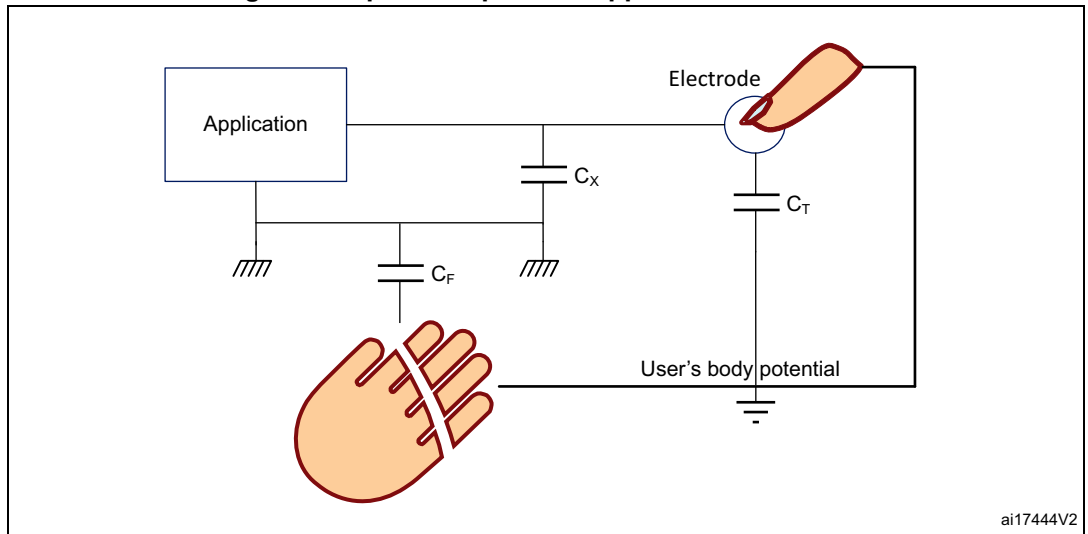
3.2 Portable applications

In portable configuration, it helps to consider the user's potential as a reference point instead of the earth potential. In this case, C_F is the capacitance between the user's body and the application ground, see [Figure 5: Equivalent portable application schematic](#).

The user's potential includes some stray capacitances like the one between the user's hand and the battery.

If a portable system is not moved, C_F stays relatively fixed. Therefore, in normal operation, while a user approaches the electrode, C_T changes and is detected as an activation. Note that the further the module is removed from earth, the weaker the coupling between the module and earth (yielding a smaller C_F capacitance). Because C_T and C_F are in series, a small C_F decreases the effect of C_T , and the system becomes less sensitive. The variable nature of both parameters C_T and C_F adds one more complication to the design of portable applications.

Figure 5. Equivalent portable application schematic



4 Proximity sensing electrode design

Each application has its specific proximity detection requirement. The design of the proximity sensing electrode is the result of the performance target requirement integrating application constraints.

To help proximity sensor integrators, the following chapters provide experimental results that can be used as guidelines to design the proximity sensing electrodes.

These tests have been performed on STM8T141 or STM8T143. The absolute performance values like the detection distance, depend on the detection threshold setting or system gain that are specific to the application.

4.1 Ring, spiral, plain electrode design

The performance results presented in this application note were measured using electrodes with basic shapes. The differences between these electrodes were obtained by changing only one parameter at a time in order to clearly show each parameter impact.

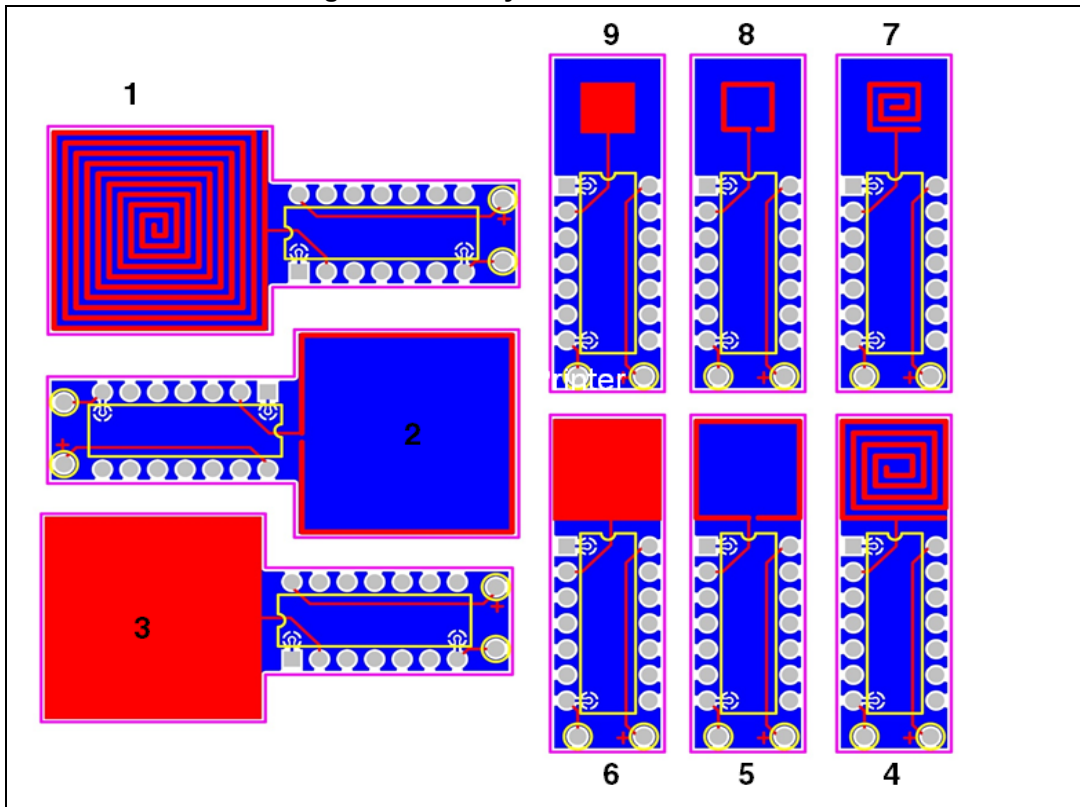
The differences between electrodes highlight the influence of:

- Electrode size with 5 mm, 10 mm, and 20 mm electrodes.
- Electrode shape with plain, spiral, and loop electrodes.
- Backside influences with grounded or non conductive electrode backside layers.

The PCB layouts used for these tests are shown in [Figure 6](#).

- Electrodes 1, 4 and 7 include square spiral electrode shape
- Electrodes 2, 5 and 8 include square loop electrode
- Electrodes 3, 6 and 9 include full plain square electrode

Figure 6. PCB layout of test electrodes



Characteristics of electrodes 1 to 9 are summarized in [Table 2](#).

Table 2. Electrode descriptions and characteristics

Electrodes	Description (shape, size, plane)	Conductive area	Cx
1	Spiral, 400mm ² , no plane	218mm ²	1,27pF
	Spiral, 400mm ² , ground plane		10,98pF 0,75pF
2	Loop, 400mm ² , no plane	40mm ²	1,1pF
	Loop, 400mm ² , ground plane		3,98pF 0,32pF
3	Plain, 400mm ² , no plane	400mm ²	1,57pF
	Plain, 400mm ² , ground plane		11,62pF 0,75pF
4	Spiral, 100mm ² , no plane	57,5mm ²	0,87pF
	Spiral, 100mm ² , ground plane		3,84pF 0,27pF
5	Loop, 100mm ² , no plane	20mm ²	0,85pF
	Loop, 100mm ² , ground plane		2,5pF 0,26pF

Table 2. Electrode descriptions and characteristics

Electrodes	Description (shape, size, plane)	Conductive area	C _x
6	Plain, 100mm ² , no plane Plain, 100mm ² , ground plane	100mm ²	0,84pF 4pF 0,32pF
7	Spiral, 25mm ² , no plane Spiral, 25mm ² ground plane	16,5mm ²	(1)
8	Loop, 25mm ² , no plane Loop, 25mm ² , ground plane	10mm ²	(1)
9	Plain, 25mm ² , no plane Plain, 25mm ² , ground plane	25mm ²	(1)

1. For the smallest electrode, C_x values are not relevant due to their very low values.

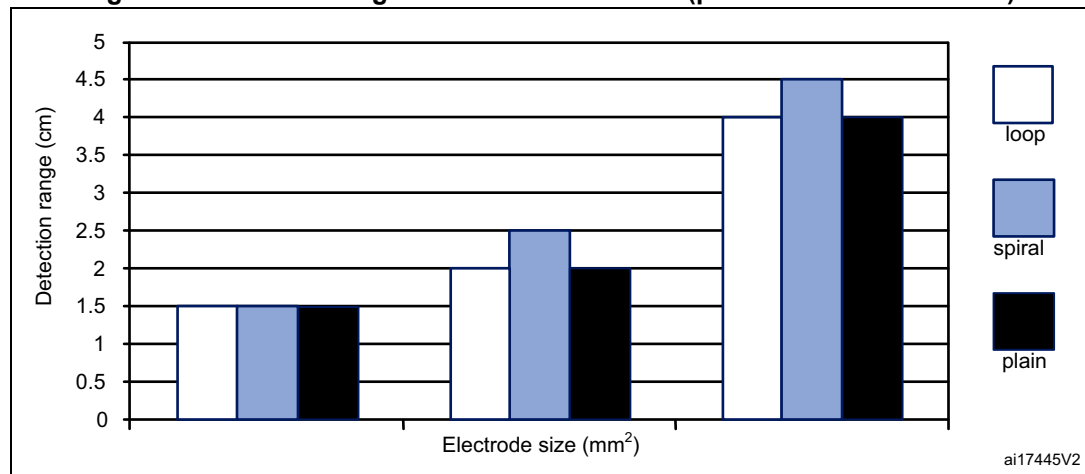
4.1.1 Electrode surface size influence

The size of the electrode significantly impacts the detection range. Theoretically, increasing the size of the electrode has two important effects:

- It increases the 'useful' capacitance (C_T) by increasing the coupling between the user close by and the electrode. This in turn improves the sensitivity.
- It also increases the parasitic capacitance (C_X) between the electrode and ground and consequently reduces the sensitivity.

(Figure 7) shows the influence of the sensing electrode size for a loop, spiral and plain pattern.

Figure 7. Detection range versus electrode size (performed on STM8T141)



In conclusion, electrodes with the largest conductive area (for each kind of electrodes) have the best sensitivity. Generally, increasing the size of the electrode is increasing the system sensitivity. However care should be taken, since increasing the electrode surface size is also increasing the noise susceptibility.

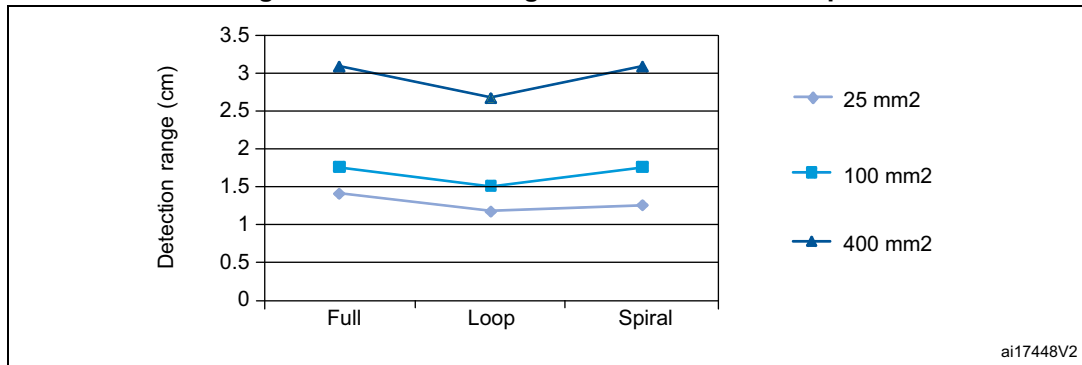
4.1.2 Electrode shape influence

The sensing electrode shape has also a direct influence on the sensor performance.

The detection volume is defined as all the points within a fixed distance from the electrode (in an homogenous dielectric environment). The shape of the sensing electrode will be driven by the detection volume that the designer wants to achieve: a square, round plane or a single wire design are options to consider to shape the detection volume.

Application constraints like mechanical environment will modify the sensing electrode field. A conductive object around the electrode tends to 'short' the electric field and consequently reduces significantly the detection distance in all directions. The detection distance is much smaller when the electrode is close to a metal object than away from it.

Figure 8. Detection range versus electrode shape

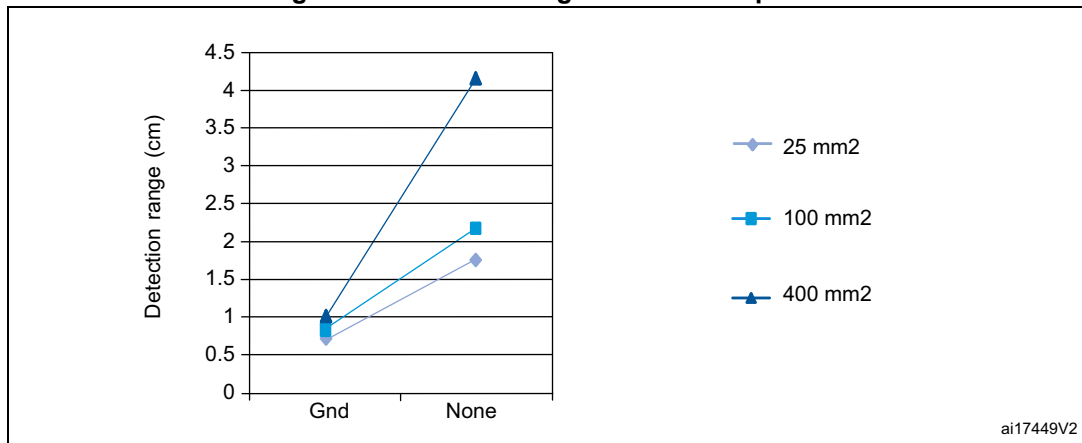


The loop electrode offers a lower sensitivity than plain or spiral electrodes. Considering the ratio copper surface versus detection distance, the loop electrode provides a higher relative sensitivity. The C_X capacitance is smaller, therefore the acquisition gain (C_S/C_X) is higher.

4.1.3 Influence of ground

This test is useful because in most of the applications, one or more GND planes can be found around the sensing electrode. (Figure 9) shows the influence of a GND plane placed on the back side of electrode 4, 5 and 6 of (Figure 6).

Figure 9. Detection range versus GND plane



The parasitic capacitance (C_X), created between the electrode and the ground, determines the sensitivity of the proximity detector. If the ground plane is too close to the electrode, it reduces significantly the detection distance.

The designer can also take advantage of a GND plane to obtain detection directivity. This GND field plane is also called “passive shield”.

Please refer to AN 3230 and 4010 for practical applications of passive shield.

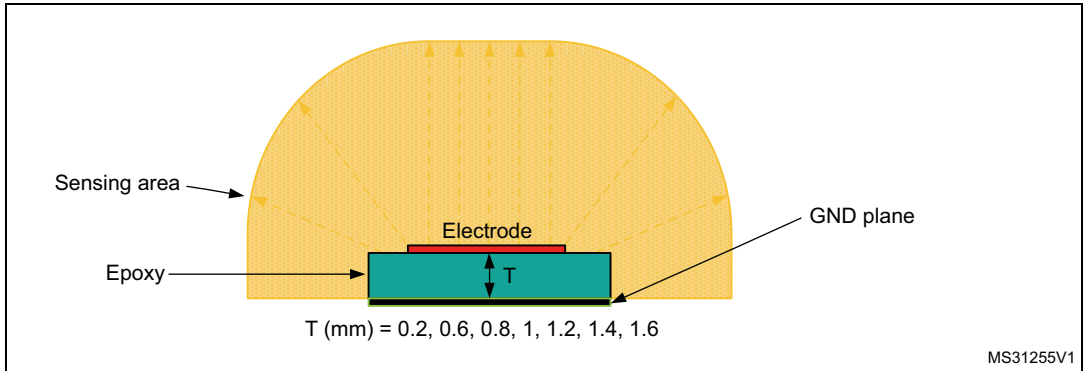
4.2 Proximity detection range versus electrode size

The objective of this test is to measure the influence of a ground plane on the back side of the sensing electrode, more accurately than in Chapter 4.1.3. This simulates some real case where sometimes the GND is very close to sensing electrode.

4.2.1 test description

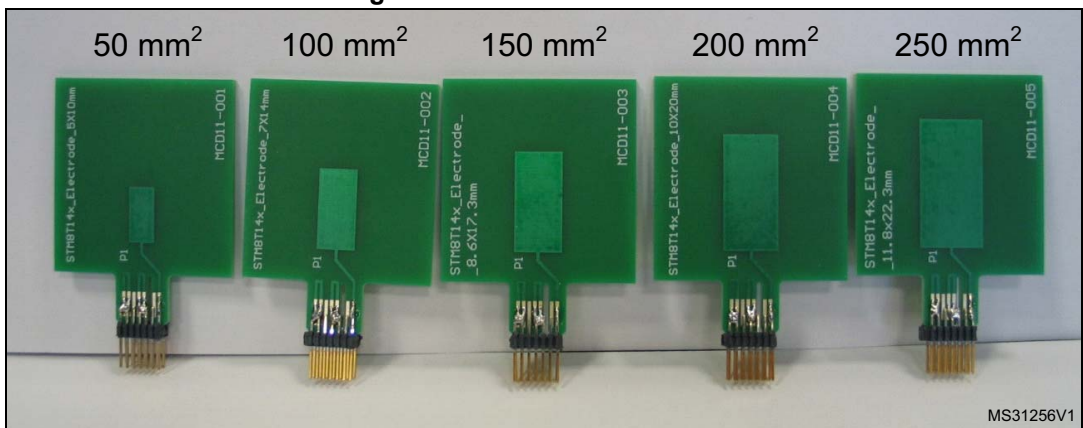
The dielectric thickness (T) between the electrode and GND plane varies from 0.2mm to 1.6mm (see [Figure 10.](#)).

Figure 10. Dielectric thickness



For each dielectric thickness, different electrode size from 50mm² to 250mm² have been tested (see [Figure 11.](#))

Figure 11. Test boards surfaces



4.2.2 Test results

Figure 12. Detection distance versus dielectric thickness

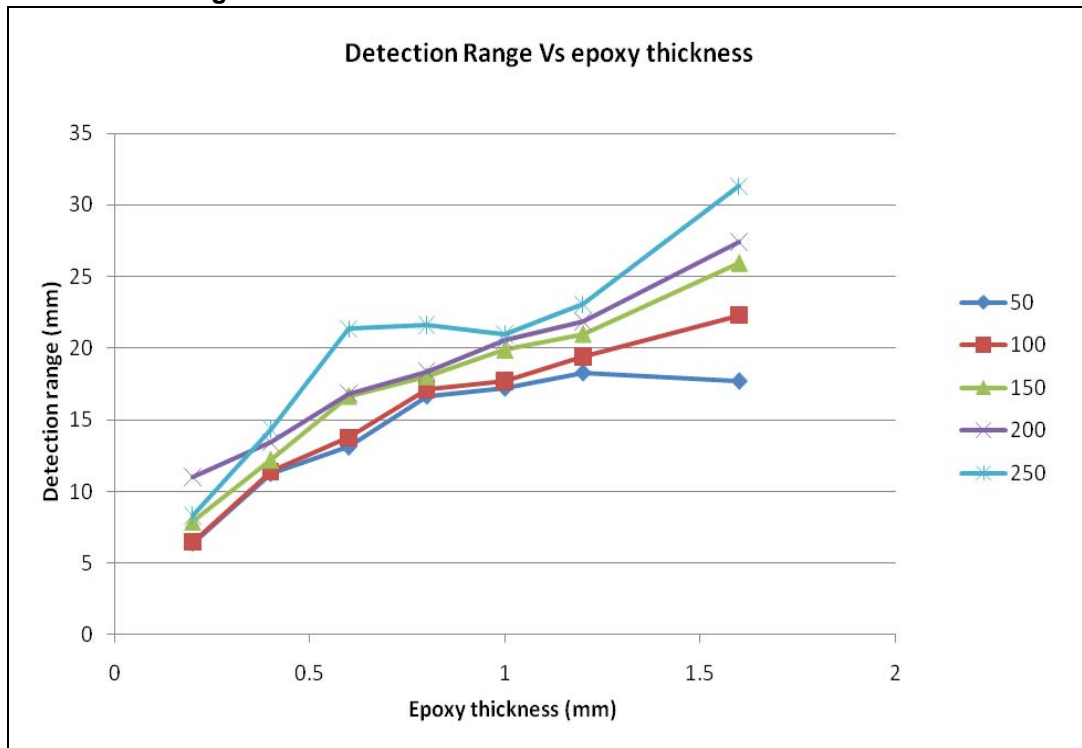
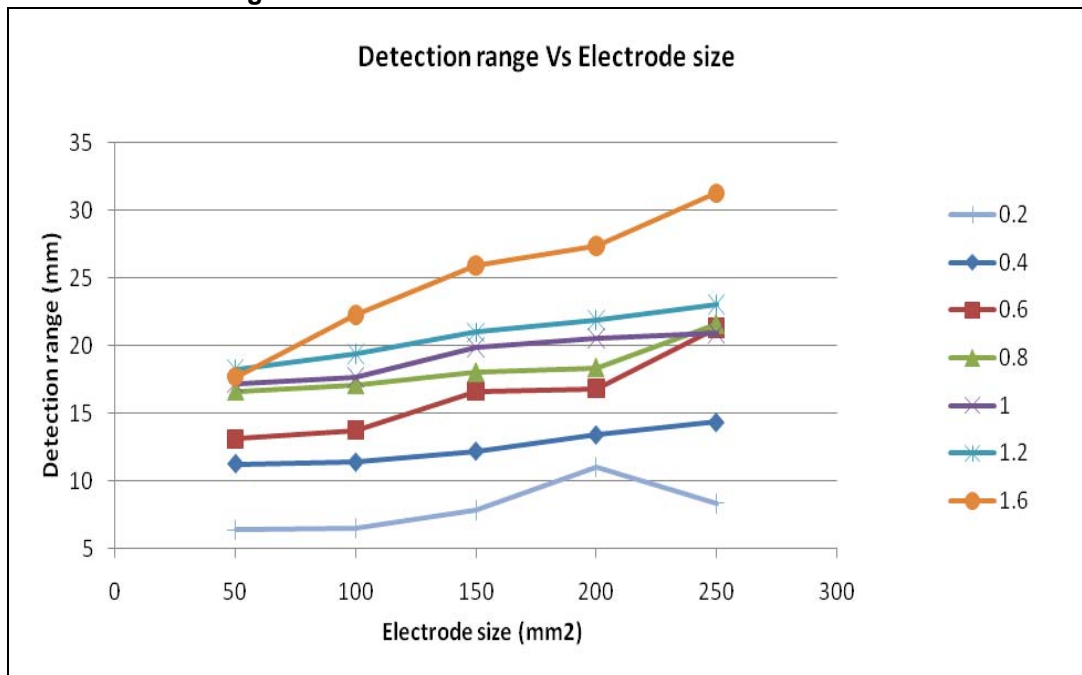


Figure 12. show that the detection distance is strongly influenced by the GND plane distance

Figure 13. Detection distance versus electrode size



[Figure 13](#). show that the surface size is not able to compensate the influence of the GND plane.

The size of the electrode is significantly impacting the detection range. Theoretically, increasing the size of the electrode has two important effects:

- It increases the ‘useful’ capacitance (C_T) by increasing the coupling between the close-by user and the electrode. This in turn improves the sensitivity.

It also increases the parasitic capacitance (C_X) between the electrode and the GND plane, and consequently reduces the sensitivity.

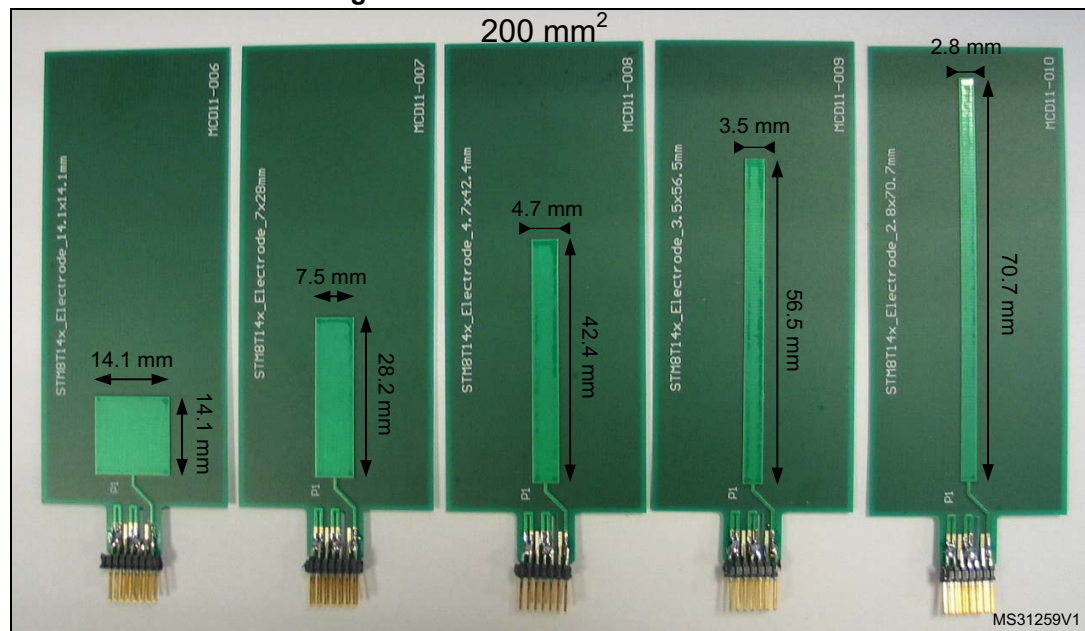
4.3 Proximity detection range versus electrode shape

The objective of this test is to measure the influence of the electrode form factor. For an electrode surface size of 200mm^2 , different form factors are tested. For all electrode shapes, different dielectric thickness have been evaluated.

4.3.1 Test description

Based on a 200mm^2 rectangle electrode, different width and length are tested according to [Figure 14](#). These test have been performed with a 0.8mm and 1.6mm dielectric thickness (T) between the electrode and the GND plane. In all test cases the whole electrode surface is covered by the test object.

Figure 14. Test boards form factors



For each dielectric thickness, different electrode size ranging from 50mm^2 to 250mm^2 have been tested (see [Figure 11](#).)

4.3.2 Test results

Figure 15. Detection distance versus electrode form factor

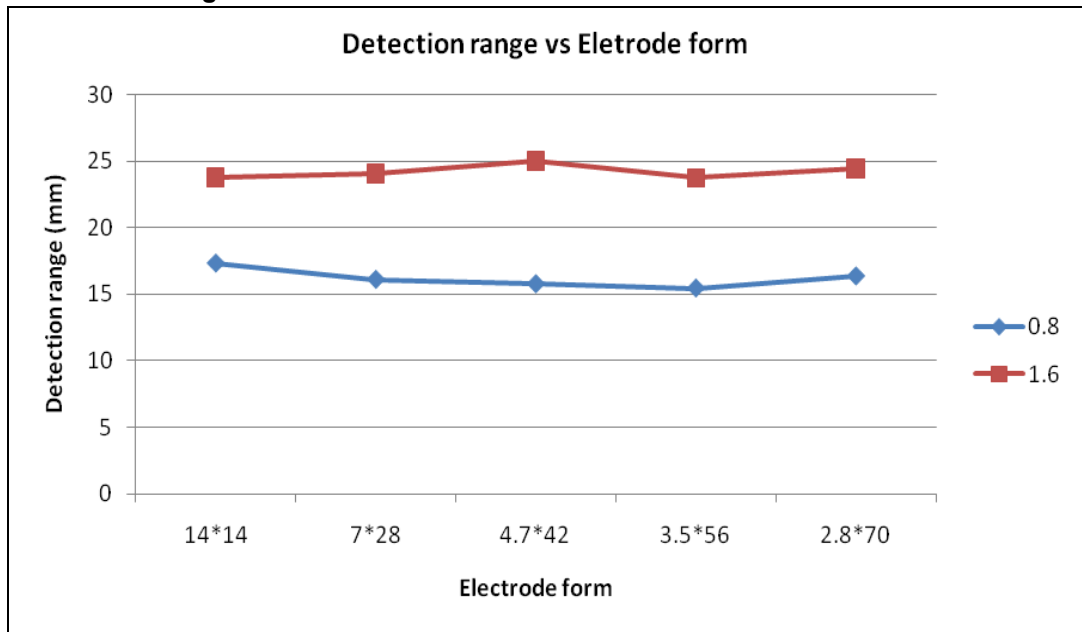


Figure 15. shows that the detection distance is not influenced by the length-over-width ratio when the whole electrode is covered with the test object. Obviously the 14.1mm x 14.1mm rectangle electrode will be easier to cover with a human hand than the 70.7mm x 2.8mm.

For all electrode shapes, the effect of the GND plane is similar.

5 Temperature effect

The temperature is an important parameter of the environment. This parameter has an impact on the sensor signal. The signal variation induced by the temperature drift is considered as a slow event and is compensated by the device “Environment Compensation System”. Please refer to the product specification for more information.

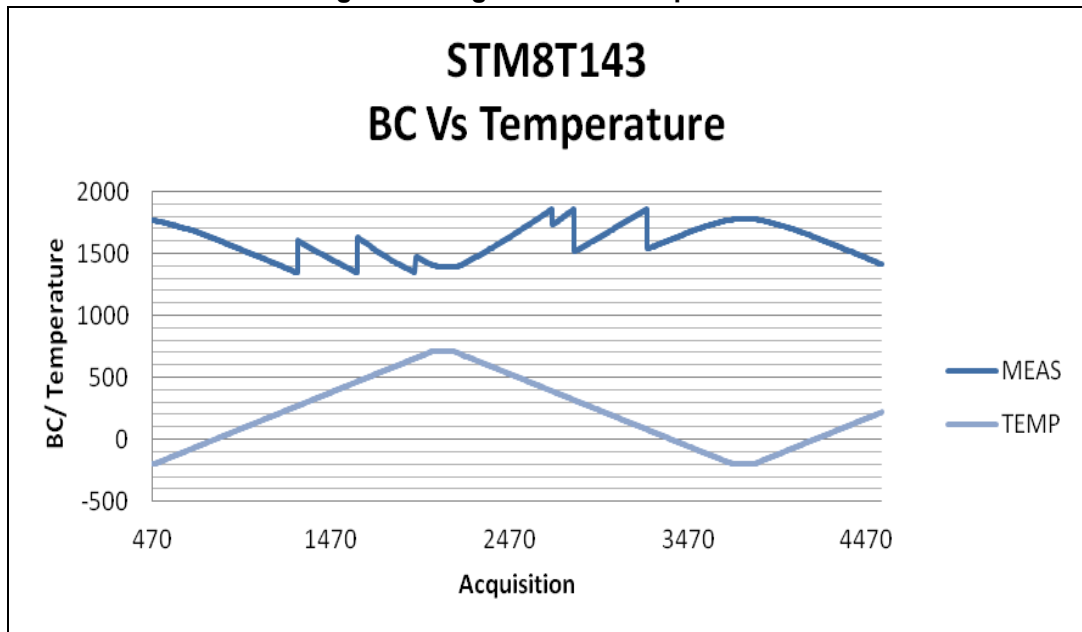
The influence of the temperature is different and specific to each system implementation. It is mainly related to the mechanical construction of the sensing electrode and the system gain.

5.0.1 Test description

The system is placed in an environment chambers (ESPEC PL-2K) and tested in the -40° to +90°C temperature range.

5.0.2 Test results

Figure 16. Signal versus temperature



Depending on the system sensitivity, the signal drift can be important.

6 Front Panel

Each material type is defined with a dielectric permittivity constant, known as epsilon (ϵ_r). The higher ϵ_r , the easier the electrical field is transmitted through the material.

If the proximity distance without any panel is t_{air0} , it becomes t_{air1} when a panel is inserted between the electrodes and the finger.

Equation 2 gives the formula at equivalent sensitivity tuning (same electrode, same C_S , and same threshold).

Equation 2

$$T_{air1} = T_{air0} - \Sigma(T/\epsilon_r)$$

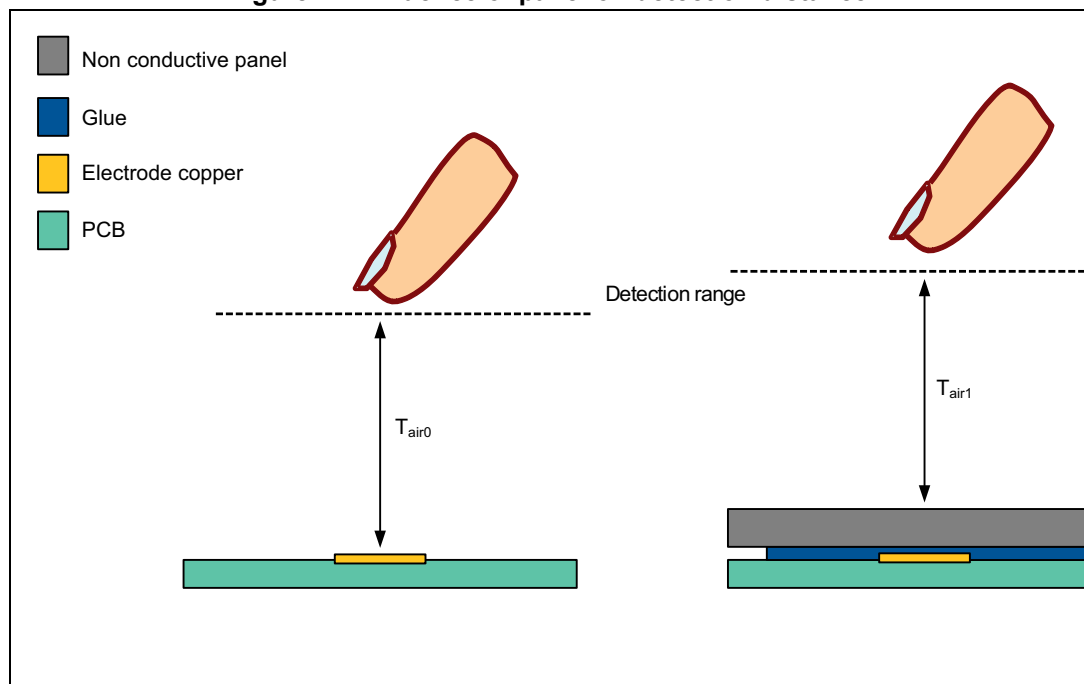
Example

If $T_{air0} = 5$ cm and we insert a 5 mm glass panel ($\epsilon_r = 10$) by gluing it to the electrode PCB with 0.5 mm of pressure sensitive adhesive ($\epsilon_r = 3$), then

$$T_{air1} = 5 - (0.5/10 + 0.05/3) = 4.93 \text{ mm.}$$

Note that the total distance between the finger and the electrode has increased due to the good dielectric performance of the glass panel.

Figure 17. Influence of panel on detection distance



7 Conclusion

This proximity sensor guideline gives some indications of which parameters to consider when developing a proximity application.

The deal is to find the best compromise between sensitivity, stability, and immunity to noise.

Depending on the application constraints, environmental change, board design constraints, and power supply, many considerations should be take into account, including:

- Define electrode design.
- Evaluate environmental constraints
- Use a shielding to bring detection directivity.
- Determine device internal parameters to optimize system performance and stability.

The best practice is to develop a prototyping device as similar as possible to the final design in order to be able to already integrate all system constraints during engineering phase.

8 Revision history

Table 3. Revision history

Date	Revision	Changes
03-Mar-2010	1	Initial release.
25-Jan-2013	2	Added Chapter 4.2: Proximity detection range versus electrode size , Chapter 4.3: Proximity detection range versus electrode shape , Chapter 5: Temperature effect . Removed figure in Chapter 1.2: Capacitive sensing acquisition method . Removed chapters: "Driven shield implementation", "sampling capacitor", "power supply variation influence". Changed some descriptions in Chapter 4: Proximity sensing electrode design . Updated document title. Updated Section : Introduction : development tools description. Updated Section 4: Proximity sensing electrode design
28-May-2013	3	Updated Table 1: Applicable products .

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