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## Guidelines for designing touch sensing applications

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### 1 Introduction

This application note describes the layout and mechanical design guidelines used for touch sensing applications.

Capacitive sensing interfaces provide many advantages compared to mechanical user interfaces. They:

- offer a modern look and feel
- are easy to clean
- are waterproof
- are robust

Capacitive sensing interfaces are more and more used in a wide range of applications.

The main difficulty designing such interfaces is to ensure that none of the items interfere with each other.

This document provides simple guidelines covering three main aspects:

1. Printed circuit board (PCB)
2. Overlay and panel materials
3. All other items in the capacitive sensor environment

Depending on which application you are designing, you may not need to refer to all of the contents of this document. You can go to the appropriate section after reading the common part which contains the main capacitive sensing guidelines. For example, if you are developing an application with only projected electrode, you should first read the main capacitive sensing guidelines and then go through the sections giving specific recommendations for projected electrode designs.

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## 2 Capacitive sensing technology in ST

STMicroelectronics offers different capacitive sensing technologies for STM8 and STM32 family products. These technologies are based on:

- The RC acquisition principle for STM8S and STM8L.
- The charge transfer acquisition principle for STM8L and STM32L.
- The surface ProxSense™ acquisition principle for STM8T14x.
- The projected ProxSense™ acquisition principle for STM8TL53xx.

*Note: ProxSense™ is a trademark of Azoteq.*

### 2.1 RC acquisition principle

The RC acquisition principle is based on the charging/discharging time measurement of an electrode capacitance through a resistor. When the electrode is touched, the charging/discharging time increases and the variation is used to detect the finger proximity. The RC acquisition principle is detailed in AN2927.

### 2.2 Charge transfer acquisition principle

The charge transfer acquisition principle uses the electrical properties of the capacitor charge (Q). The electrode capacitance is repeatedly charged and then discharged in a sampling capacitor until the voltage on the sampling capacitor reaches a given threshold. The number of transfers required to reach the threshold is a representation of the size of the electrode's capacitance. When the electrode is "touched", the charge stored on the electrode is higher and the number of cycles needed to charge the sampling capacitor decreases.

### 2.3 Surface ProxSense™ acquisition principle

The surface ProxSense™ acquisition principle is similar to the charge transfer one except that the acquisition is fully managed by a dedicated hardware IP providing improved performance. For more information, please refer to the application note AN2970.

### 2.4 Projected ProxSense™ acquisition principle

The projected ProxSense™ acquisition principle is a measurement of a charge transferred by a driven electrode to another one. Like the charge transfer, there is also a sampling capacitor which stores the charges coming from the electrodes which form a coupling capacitor with less capacitance than the sample one. When a finger approaches, the dielectric (between the two electrodes) is modified and so the capacitance also changes. As a consequence, the time taken to load the sample capacitor becomes different and this difference is used to detect if a finger is present or not.

## 2.5 Surface capacitance

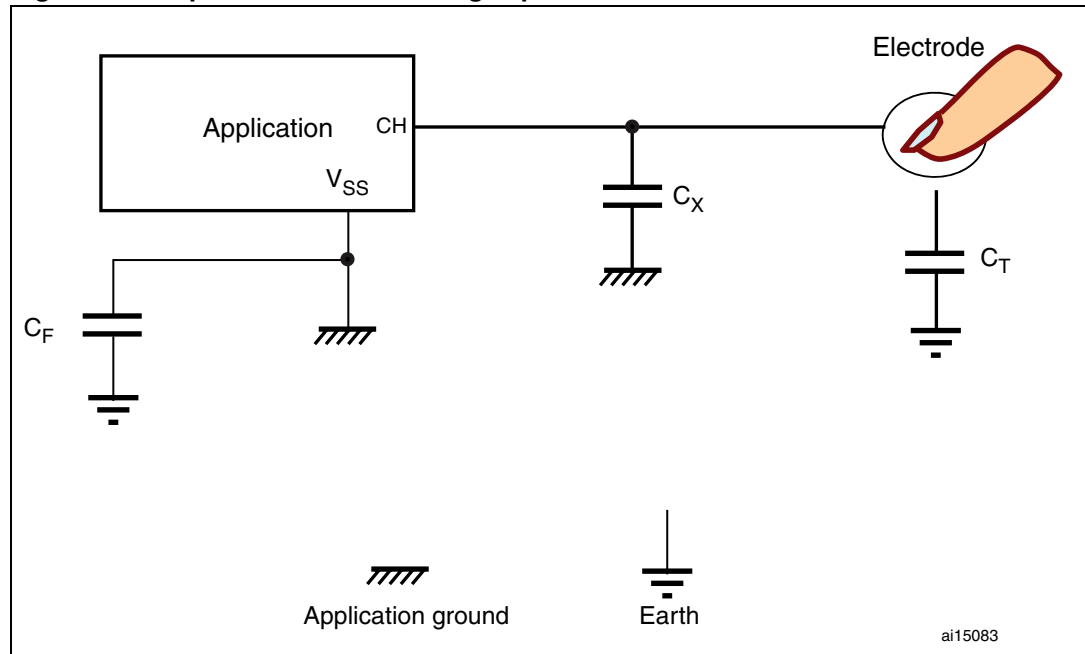
A capacitance is modified when a finger get close to a sensing electrode.

The return path goes either through:

- a capacitor to ground through the user's feet
- a capacitor between the user hand and the device
- a capacitor between the user's body and the application board through the air (like an antenna)

### Background

**Figure 1. Equivalent touch sensing capacitances**



$C_X$  is the parasitic capacitance of the electrode.

$C_X$  is composed of two capacitances: the first, refers to earth which is negligible and can be ignored and the second, refers to the application ground which is dependent on the PCB or the board layout. This latter parasitic capacitance includes the GPIO pad capacitance and the coupling between the electrode tracks and the application ground.

The PCB and board layout must be designed to minimize this parasitic capacitance.

$C_F$  is the feedback capacitance between earth and the application. Its influence is important in surface capacitance touch sensing applications, especially for applications which do not feature a direct connection to earth

$C_T$  is the capacitance created by a finger touch and it is the source of the useful signal. Its reference is earth and not the application ground.

The total capacitance measured is a combination of  $C_X$ ,  $C_F$  and  $C_T$  where only  $C_T$  is meaningful for the application. So we measure  $C_X$  plus  $C_T$  in parallel with  $C_F$  which is given by the formula:  $C_X + 1 / ((1 / C_T) + (1 / C_F))$ .

## 2.6 Projected capacitance

A capacitor is modified when the finger get close to a sensing electrode. The finger changes the dielectric properties.

The return path is on the sensor itself. The finger only modifies the capacitor dielectric element.



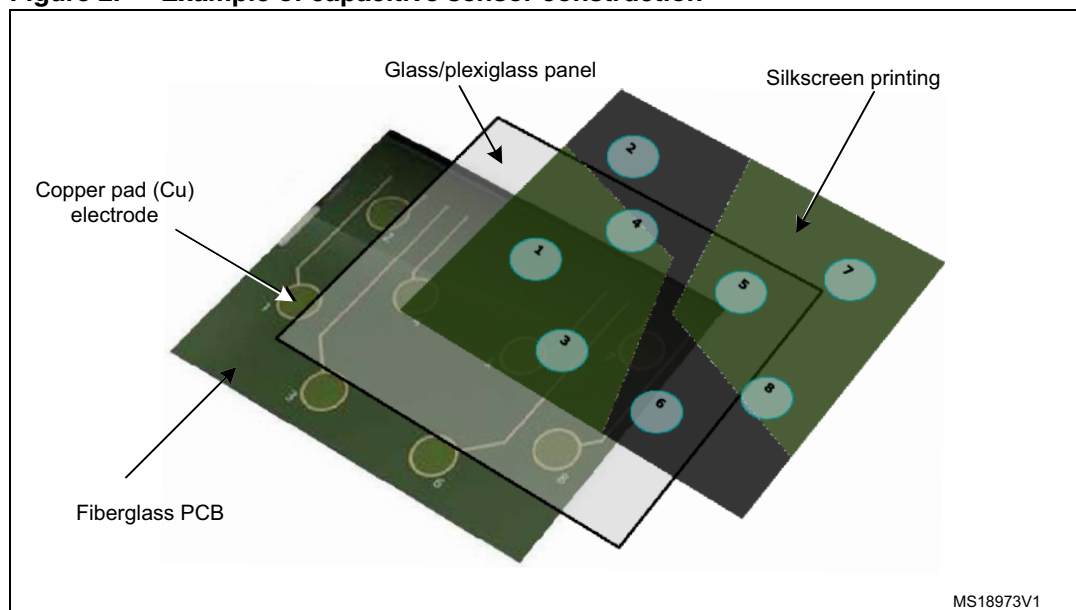
## 3 Main capacitive sensing guidelines

### 3.1 Overview

A surface or projected capacitive sensor is generally made up of the following different layers:

- A fiberglass PCB
- A set of electrodes made of a copper pad
- A panel made of glass, plexiglass, or any nonconductive material
- A silk screen printing

**Figure 2. Example of capacitive sensor construction**



### 3.2 Construction

#### 3.2.1 Substrates

The substrate is the base material carrying the electrodes.

A substrate can be chosen among any nonconducting material, in practice, PCB materials (e.g. FR4, CEM-1), acrylics like Polyethylene Terephthalate (PET), or Polycarbonate can be used. Glass is also an excellent material for this purpose.

In many cases, the substrate which is used in electronic application will also work well for capacitive sensing. Special care is required to avoid materials which can retain water contained in the atmosphere (e.g. hygroscopic material such as paper based). Unfortunately, this would modify  $\epsilon_R$  (relative permittivity) with environmental conditions.

It is not recommended to directly set the substrate against the front panel without gluing it by pressure or by bonding. Some moisture or air bubbles can appear between them and cause a change on the sensitivity. Indeed, if the substrate and the panel are closely linked together

this will avoid a varying sensitivity loss which is hard to predict (when the air bubbles are greater than 2 mm diameter). Hence the way used is to strongly glue them all mechanically or with a suitable bonding material.

It is possible to construct sensors that do not rely on a substrate. These are described in this document under separate sections ([Section 3.2.7](#), [Section 4.5.3](#) and [Chapter 5.4.1](#)).

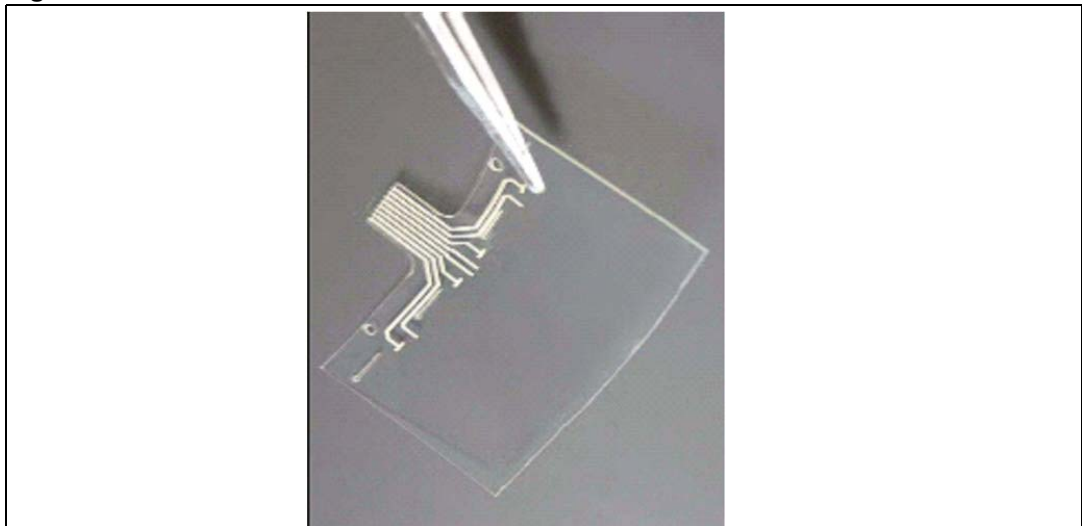
### 3.2.2 Electrode and interconnection materials

Generally, an electrode is made with the following materials: copper, carbon, silver ink, Orgacon™ or Indium Tin Oxide (ITO).

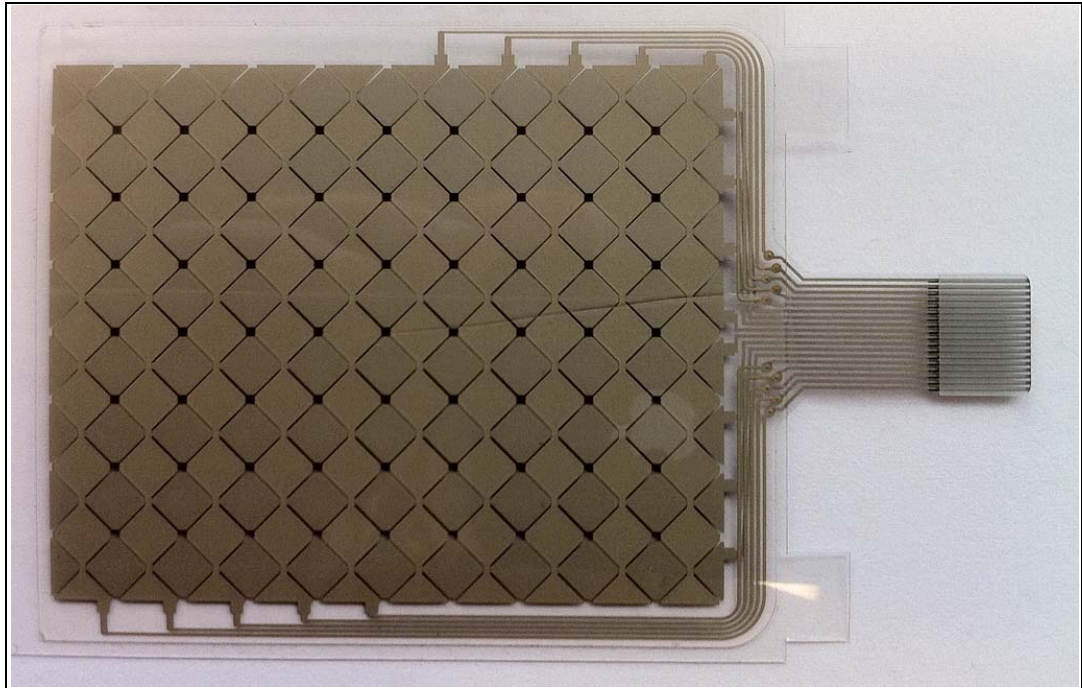
The resistance to electric current of a material is measured in ohm-meters ( $\Omega\text{m}$ ). The lower this degree of resistivity the better, as well as a good RC time constant. That's why interconnections will be made with low  $\Omega\text{m}$  material. e.g. a printed silver track at  $15.9\text{ n}\Omega\text{m}$  that is 100 mm long, 0.5 mm wide and 0.1 mm thick (so the area is  $0.05\text{ mm}^2$ ) will have a resistance of  $32\text{ }\mu\Omega$

About metal deposition, another well-known approach is to consider the  $\Omega/\square$  <sup>(a)</sup> of a material. For instance, you can compare silver and ITO (which is about 10 times greater) and deduce which material is well suited for the connections.

**Figure 3. Clear ITO on PET with silver connections**



a. Pronounced "Ohms per square" and also called sheet resistance, if you know this constant (given by the manufacturer) and how many squares are put in series, you can deduce the overall resistance of the line.

**Figure 4. Silver printing on PET**

More and more applications need a flex PCB or FFC/FPC<sup>(a)</sup> to interconnect circuitry, it is suitable provided that the overall application is mechanically stable. Furthermore the FPC tracks will be part of the touch sensor. So if the flex moves a little bit, even a few micrometers, the capacitance to its surroundings will definitely change and might be significant, causing false touch detections or drops in sensitivity. Putting the flex in close proximity to a metal chassis or other signals, or on top of noisy circuitry, can cause problems as well (loss of sensitivity or spurious detection).

**Table 1. Potential application problems with flex PCB placement**

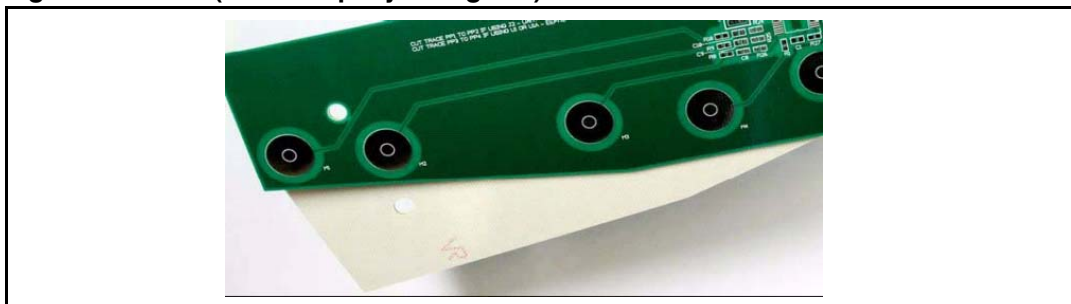
When the flex PCB is in close proximity to...	...the following can occur.
...the ground or to a metal chassis connected to the ground.	...the sensitivity is reduced.
... a floating metal object or to a floating metal chassis	... the object or the chassis conducts the touch to the electrode
... a source of noise	... the acquisition will be strongly perturbed and so the touchkey will become non-usable

a. FFC = Flat Flexible Conductor, FPC = Flexible Printed Circuit

Figure 5. Flexible PCB (FPC)



Figure 6. FR4 (2-sided epoxy-fiberglass)



### 3.2.3 Panel materials

You can choose the panel material which best suits your application. This panel material **MUST NOT** be conductive. The material characteristics impact the sensor performance, particularly the sensitivity.

#### Dielectric constant

The panel is the main item of the capacitor dielectric between the finger and the electrode. Its dielectric constant ( $\epsilon_R$ ) differentiates a material when it is placed in an electric field. The propagation of the electric field inside the material is given by this parameter. The higher the dielectric constant, the better the propagation.

Glass has a higher  $\epsilon_R$  than most plastics (see [Table 2: Dielectric constants of common materials used in a panel construction](#)). Higher numbers mean that the fields will propagate through more effectively. Thus a 5 mm panel with an  $\epsilon_R$  of 8 will perform similarly in sensitivity to a 2.5 mm panel with a relative epsilon of 4, all other factors being equal.

A plastic panel up to 10 mm thick is quite usable, depending on key spacing and size. The circuit sensitivity needs to be adjusted during development to compensate for panel thickness, dielectric constant and electrode size.

The thicker a given material is, the worse the SNR. For this reason, it is always better to try and reduce the thickness of the front panel material. Materials with high relative dielectric constants are also preferable for front panels as they help to increase SNR.

**Table 2. Dielectric constants of common materials used in a panel construction**

Material	$\epsilon_R$
Air	1.00059
Glass	4 to 10
Sapphire glass	9 to 11
Mica	4 to 8
Nylon	3
Plexiglass	3.4
Polyethylene	2.2
Polystyrene	2.56
Polyethylene terephthalate (PET)	3.7
FR4 (fiberglass + epoxy)	4.2
PMMA (Poly methyl methacrylate)	2.6 to 4
Typical PSA	2.0 - 3.0 (approx.)

### Sensitivity

A useful parameter to consider with panel material and thickness(t) is the electric field equivalent vacuum thickness  $T_V$ .

#### Equation 1

$$T_V = \frac{t}{\epsilon_R}$$

where t is the thickness of the dielectric.

$T_V$  is the thickness of vacuum with an electric field conduction equivalent to that of the material. The smaller it is, the easier the field can reach through. Panels with the same  $T_V$  make keys with identical sensitivity. This works for both directions of course and may be used to evaluate the touch sensitivity from the back side of the application.

For a panel built from a stack of different materials, it is possible to add the vacuum equivalent thickness of each layer:

#### Equation 2

$$T_{V(STACK)} = \sum V(layers)$$

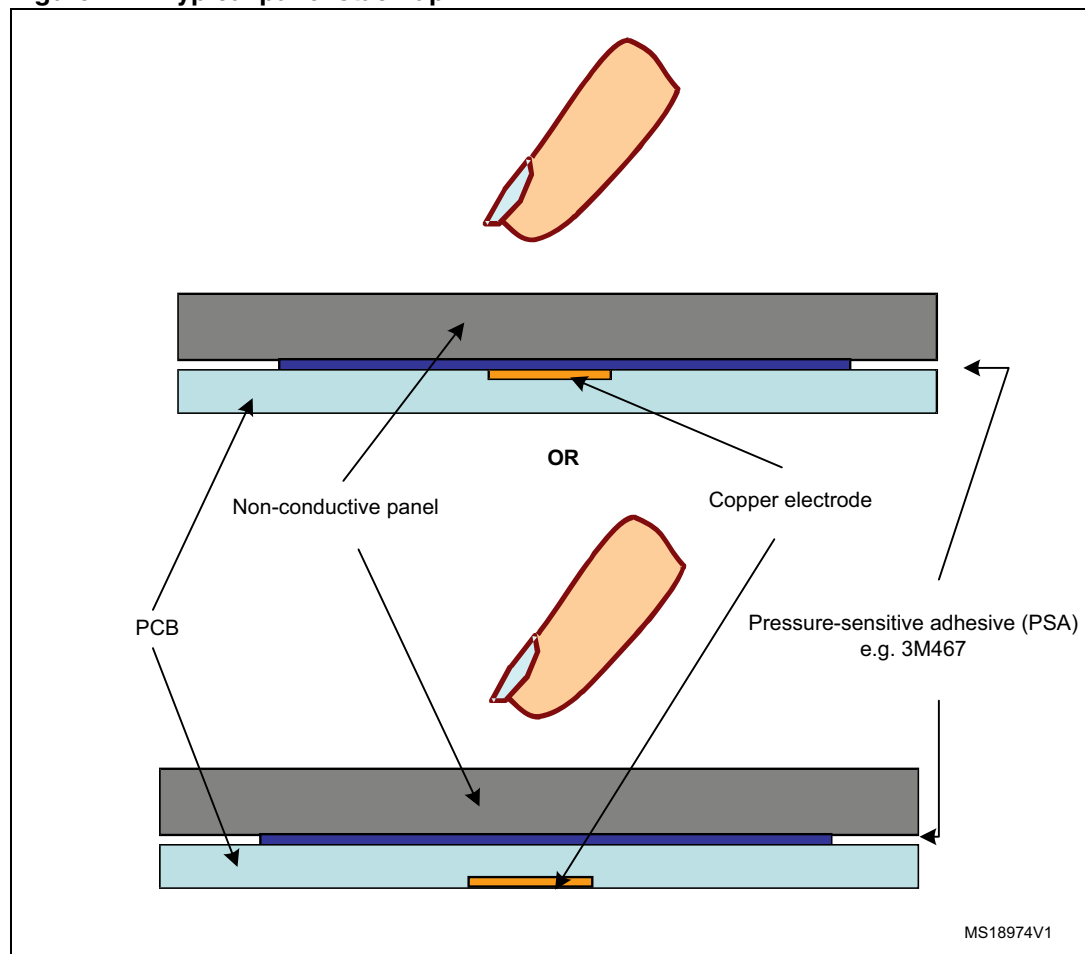
Each material has an influence on the sensitivity. So the equation can be used when, for example, the electrodes are on the bottom surface of the PCB substrate, then the thickness and  $\epsilon_R$  of the substrate will be also factors of the global sensitivity.

### 3.2.4 Mechanical construction and PCB to panel bonding

In order to ensure stable touch detection, the PCB must always be at the same place on the panel. The slightest variation, as small as 100 microns may lead to differences in the signal which can be detected. This must be avoided to ensure the integrity of the touch detection. The panel and other elements of the device must not be moved, or only as little as possible, by the user's finger. To avoid this kind of problem, glue, compression, co-convex surfaces can be used to mechanically stabilize the PCB and the panel very close together.

In the list of the different ways to achieve this we can put: heat staking plastic posts, screws, ultrasonic welding, spring clips, non-conductive foam rubber pressing from behind, etc.

**Figure 7. Typical panel stack-up**



Normal construction is to glue a sensor to a front panel with Pressure Sensitive Adhesive (PSA). 3M467 or 468 PSAs work very well.

### 3.2.5 Metal chassis

A metal chassis behind a touch sensor is a good path to the ground and tends to reduce the sensitivity of the touch response in case there is a significant area of overlap. Such a metallic surface must never be electrically floating as it makes the whole product unstable in terms of touch detection. This is also applicable for any conductive decorative feature close to the sensor.

Metal chassis and decorative items must be grounded or connected to the driven shield (see [Section 4.5.2: Driven shield](#)) if it is implemented.

Metallic paints can be an issue if they contain conductive particles. Low particle density paint is recommended.

### 3.2.6 Air gap

Due to its dielectric constant, air can be used as an isolator. An air gap reduces the touch sensitivity when it is in the touch side stack. However, in some conditions, air can be useful to reduce the ground loading in the nontouch side stack. Such ground loading can be due to the metal chassis or an LCD. For instance, when designing a touch-screen solution, an air gap of 0.5mm to 1mm between the LCD and the touch sensor is recommended. Air gaps also help to reduce the sensitivity of the back side of a portable device.

### 3.2.7 Transfer of an electrode from PCB to the front panel

It is possible to use a conducting cylinder or a compressed spring to achieve a transfer of an electrode from a PCB to the front panel. Please refer to [Section 4.5.3](#) or [Section 5.4.1](#) for further information.

### 3.3 Placing of LEDs close to sensors

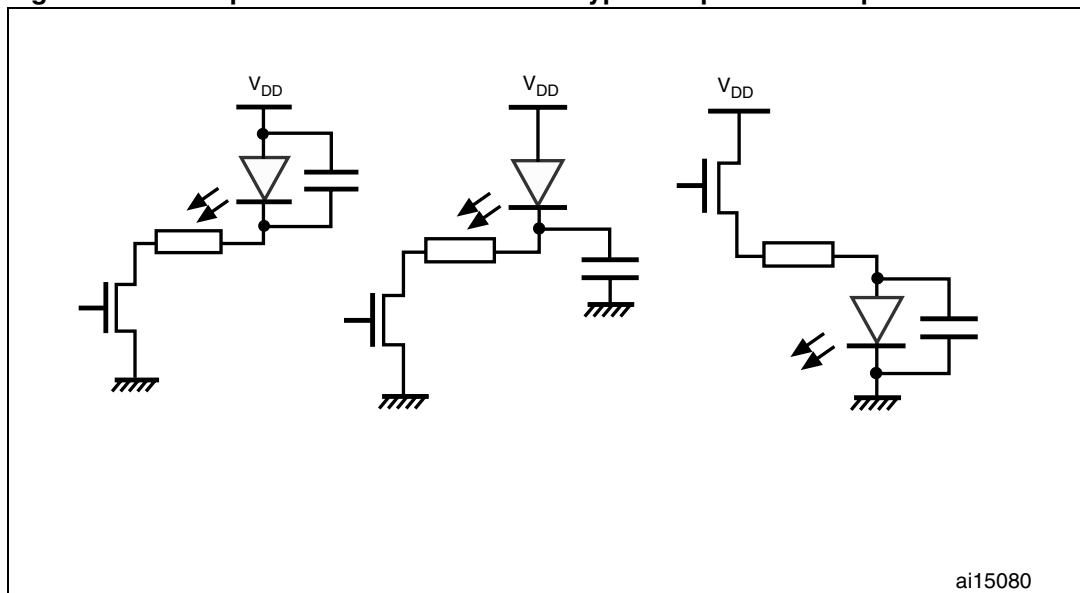
Light-emitting diodes (LEDs) are very often implemented near capacitive sensor buttons on application boards. The LEDs are very useful for showing that the button has been correctly touched. When designing applications boards with LEDs, the following considerations must be taken into account:

- LEDs change capacitance when switched on and off
- LED driver tracks can change impedance when switched on and off
- LED load current can affect the power rail

Both sides of the LEDs must always follow the low impedance path to ground (or power). Otherwise, the LEDs should be bypassed by a capacitor to suppress the high impedance (typically 10 nF).

The examples of bypass capacitors for the LEDs using a driver ([Figure 8](#)) can also be applied to transistors.

**Figure 8. Examples of cases where a LED bypass capacitor is required**





### 3.4 Power supply

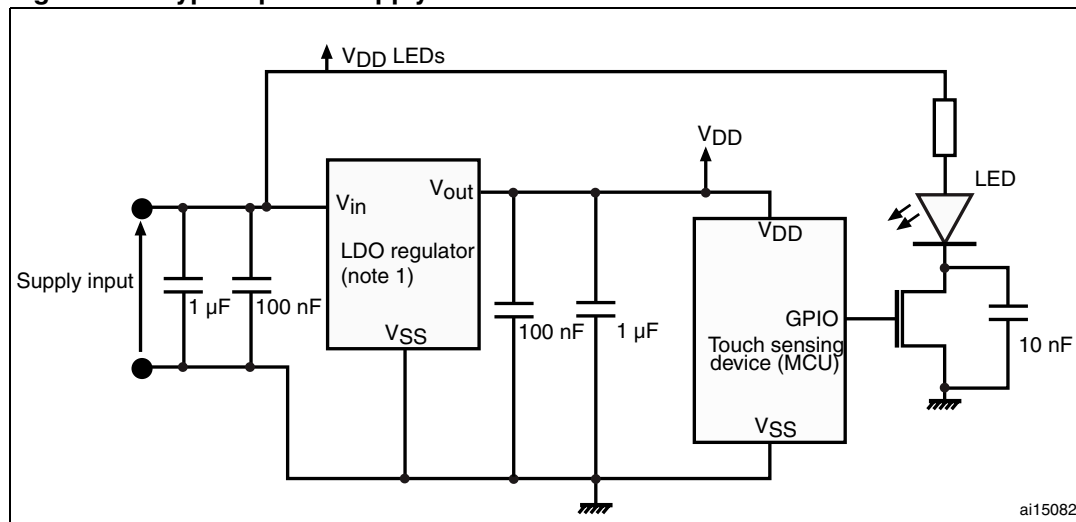
In order to reduce system costs, a regulator, which is fully dedicated to touch sensing, is already embedded in the devices of the STM8T family. For other devices without a touch sensing dedicated regulator, it is strongly recommended to use an external voltage regulator to power the device only.

The voltage regulator must be chosen to provide a stable voltage without any ripple. The actual precision of the voltage is not important, but the noise rejection feature is critical. This voltage is used to drive  $C_X$  and is also used as a reference when measuring the sampling capacitor ( $C_S$ ). Any variation of this voltage may induce measurement variations which could generate a false touch or a missed touch. For instance, a  $\pm 10$  mV peak to peak variation on  $V_{DD}$ , limits the resolution of linear sensor or rotary sensor to 4 or 5 bits.

The voltage regulator should be placed as far as possible from the sensors and their tracks.

The voltage regulator also acts as a filter against noise coming from the power supply. So, it is recommended to power any switching components, such as LEDs, directly from  $V_{DD}$  and not from the regulated voltage (see [Figure 9](#)).

**Figure 9. Typical power supply schematic**



1. Typical voltage regulator LD2980 can be used.

## 4 Surface electrode design

### 4.1 Touchkey sensor

A touchkey can be either touched or untouched by the user. So the information that is managed by the microcontroller is a binary one (e.g. '0' for untouched and '1' for touched).

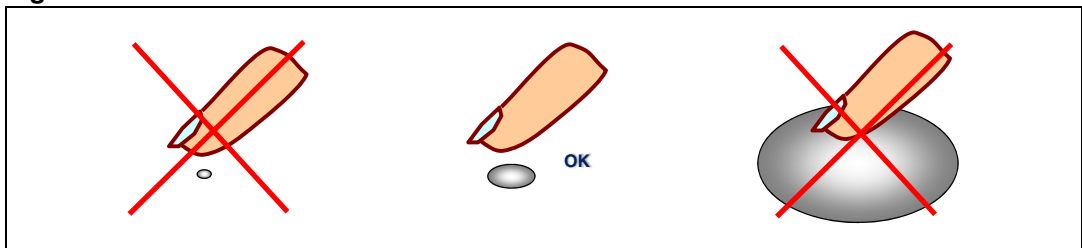
The sensor can be any shape, however it is recommended to use round or oval as these shapes are the simplest. The libraries and hardware cells automatically compensate for capacitance differences, but the acquisition time and processing parameters can be optimized if the electrodes have similar capacitance. For this reason, it is recommended to use the same shape for all electrodes. The touchkeys can be customized by the drawing on the panel.

When designing touchkey sensors, two parameters must be taken into account:

1. The object size to be detected
2. The panel thickness

Regarding object size (see [Figure 10](#)), it is recommended to design a sensor in the same range as the object to be detected. In most cases, it is a finger.

**Figure 10. Sensor size**



Regarding panel thickness, the touchkey must be at least four times as wide as the panel is thick. For example, a panel which is 1.5 mm thick and has no immediately adjacent ground layer, must have a touchkey which is at least 6 mm in diameter if the key is round, or have a 6 mm side if the key is square (see [Figure 11](#)). There are sensitivity issues if dimensions lower than these values are used.

**Figure 11. Recommended electrode size**



As shown in [Equation 3](#), a capacitor is used to detect the finger touch. The capacitor is proportional to the size of the electrode. Increasing the electrode area allows the capacitor to be maximized, but increasing the electrode size above the size of a finger touch only increases the parasitic capacitance and not the finger touch capacitance, resulting in lower relative sensitivity. Refer to [Section 4.5.4: PCB and layout](#). There is also a problem of relative sensitivity: when the electrode size is increased,  $C_T$  stops increasing while  $C_X$  keeps growing. This is because the parasitic capacitance is directly proportional to the electrode area.

**Equation 3**

$$C_T = \frac{\epsilon_R \epsilon_0 A}{d}$$

where:

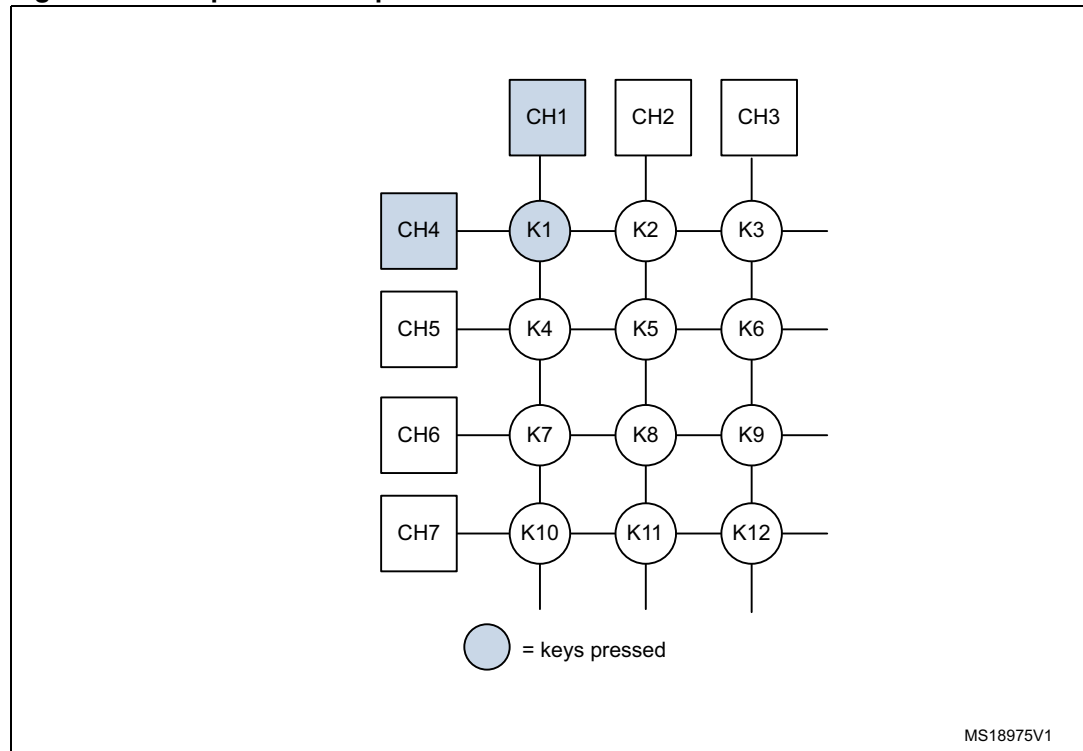
- $C_T$  is the finger touch
- $A$  is the area with regard to the electrode and the conductive object
- $d$  is the distance between the electrode and the conductive object (usually the panel thickness)
- $\epsilon_R$  is the dielectric constant or relative permittivity
- $\epsilon_0$  is the vacuum

## 4.2 Touchkey matrix sensor

To extend the number of touchkeys, it is possible to implement the touchkey using a matrix arrangement.

For further information please refer to AN3326.

**Figure 12. Simple matrix implementation**



Hardware recommendations:

- Touching one key may induce sufficient capacitance change on other channels
- Special care must be taken to avoid
  - Imbalanced electrodes
  - Columns and lines electrodes tracks too close in the user touchable area

## 4.3 Linear sensor

A linear sensor is a set of contiguous capacitive electrodes connected to the device and placed in a single line. Sliders are typically linear, running only along a single axis.

They can be made up of a set of electrodes, depending on the required size and resolution.

Linear sensors use differential capacitance changes between adjacent capacitive electrodes to determine the finger or conductive object position with greater resolution.

The size and targeted application tend to dictate the slider layout. However, some general rules apply to any kind of layout:

- To ensure that the conductive object couples to more than one element, each element must be small enough that the finger overlaps its outside edge. However, it must also be large enough to have correct sensitivity even through the application overlay.
- The extremities must be a half electrode and both should be connected so that the slider is well balanced (see [Figure 13](#)).

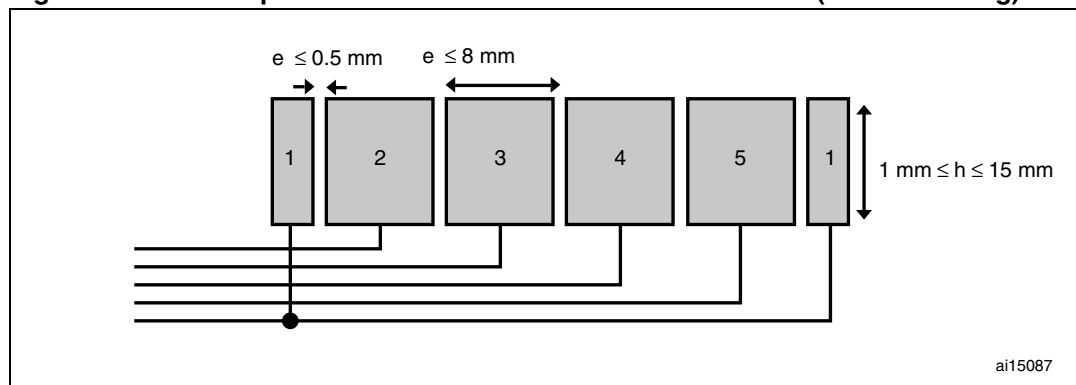
There are 2 kinds of linear sensors:

- Normal patterned linear sensors
- Interlaced patterned linear sensors

### 4.3.1 Normal patterned linear sensor

With a normal patterned linear sensor (see [Figure 13](#)), the linearity is limited due to the ratio square width versus finger touch area. To improve the linearity, to get a smoother transition between items and to increase the resolution, it is recommended to use an interlaced electrode with crisscross teeth as shown in [Figure 14](#).

**Figure 13. Normal patterned linear sensor with five electrodes (20-50 mm long)**



1. Legend:  $e$  is the gap between two sensor electrodes,  $h$  is the height of the sensor electrode, and  $w$  is the width of the sensor electrode.

The size of the square electrode and gap between electrodes are valid irrespective of the number of electrodes.

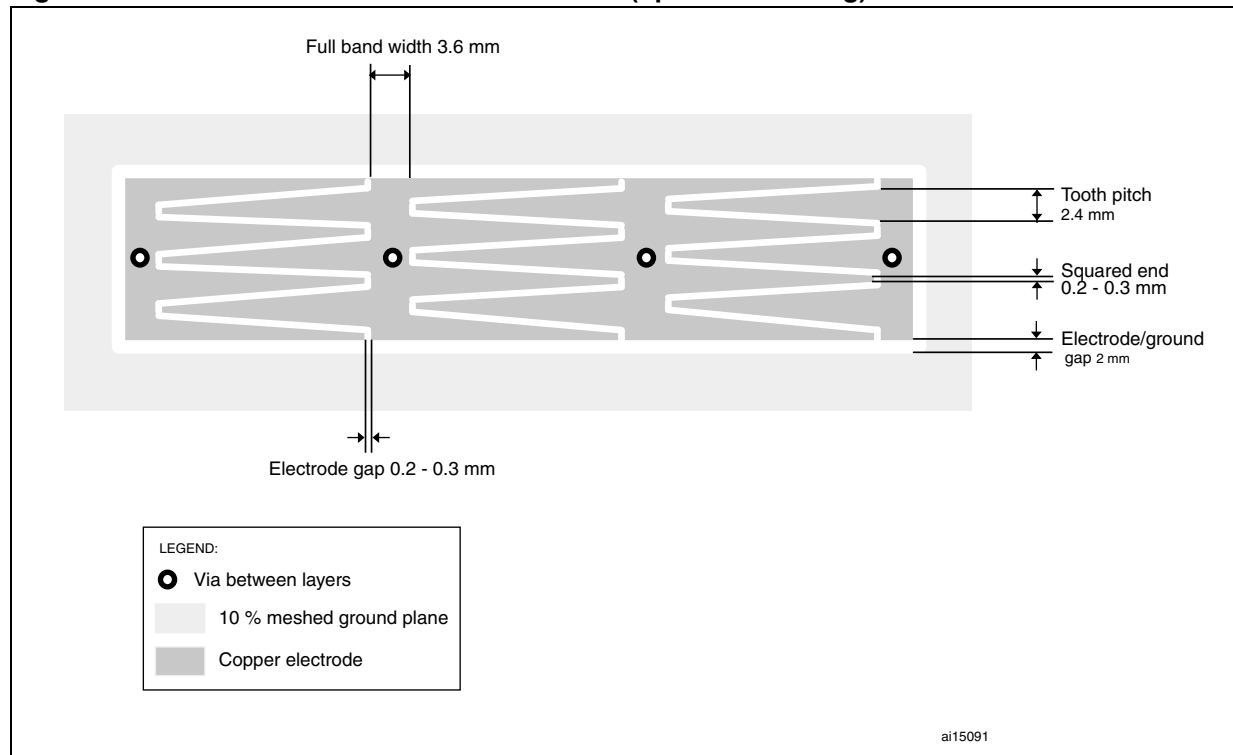
To get larger linear sensors, the number of electrodes can be increased to eight.

This solution is mainly used by RC acquisition principle.

### 4.3.2 Interlaced linear sensor

When using the charge transfer acquisition principle, it is possible to use only three elements thanks to the higher resolution achieved. This sensor type is not compatible with the RC acquisition principle due to the lower sensitivity supported.

**Figure 14. Interlaced slider with three elements (up to 60 mm long)**



1. The teeth of the interlaced slider must be perfectly regular.

## 4.4 Rotary sensor

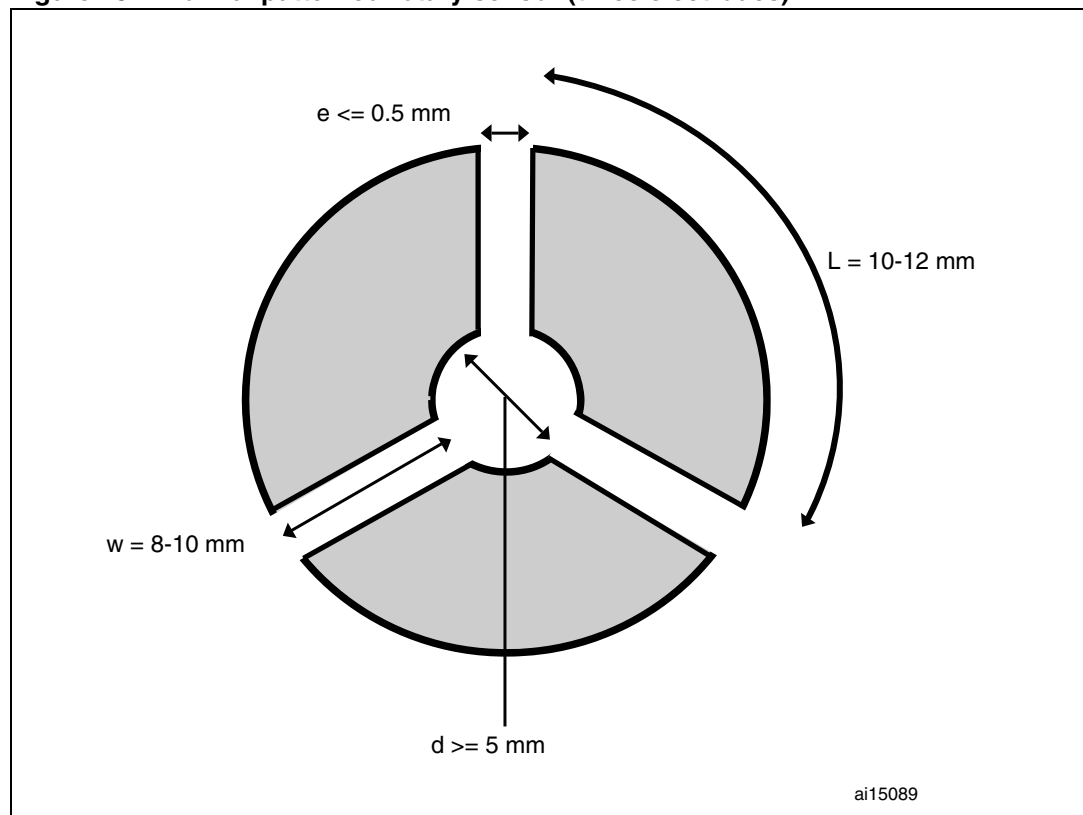
A rotary sensor is a set of contiguous capacitive electrodes (placed in a circle) connected to the controller pins. It consists of a set of three, five or eight electrodes that can be interlaced, like the slider.

There are three kinds of rotary sensors:

- Normal patterned rotary sensors
- Interlaced patterned rotary sensors
- Rotary sensor with central touchkey

### 4.4.1 Normal patterned rotary sensor

**Figure 15. Normal patterned rotary sensor (three electrodes)**



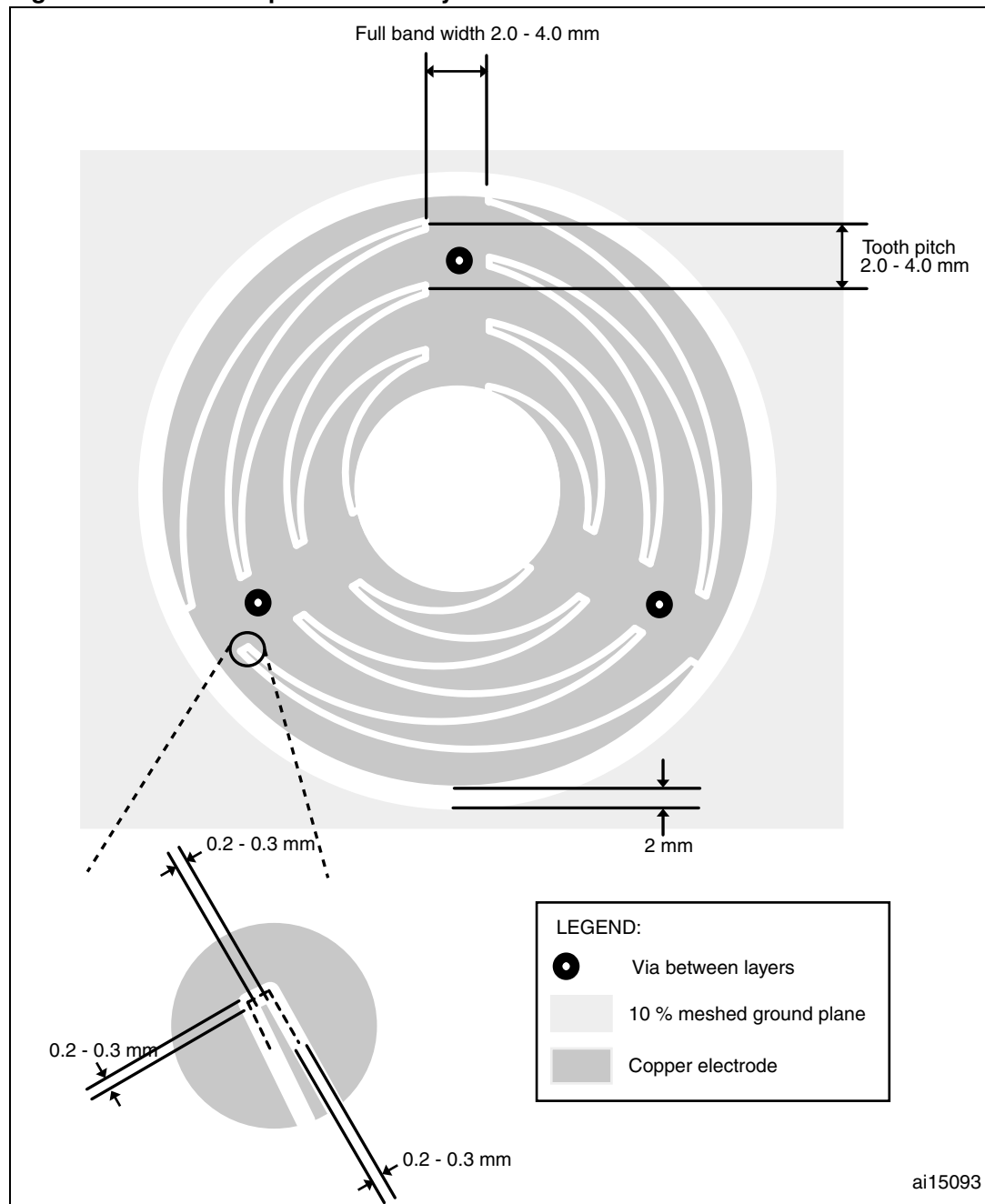
1. Legend:  $d$  is the diameter of the center,  $e$  is the gap between two sensor electrodes,  $w$  is the width of the sensor electrode,  $L$  is the length of the external perimeter of the sensor electrode.

The dimensions  $d$ ,  $e$ ,  $w$ , and  $L$  of the three-electrode scheme above, can also be applied for five and eight electrodes, thus giving a bigger rotor.

### 4.4.2 Interlaced patterned rotary sensors

The three-electrode wheel can be used for bigger rotary sensors with an interlaced pattern.

This allows a smoother transition and a higher sensitivity. To cover a large range of sizes, more teeth are added inside the wheel rather than increasing the size of an individual tooth.

**Figure 16. Interlaced patterned rotary sensor**

#### 4.4.3 Rotary sensor with central touchkey

It is possible to locate a touchkey in the centre of a rotary sensor. This touchkey has a lower sensitivity compared to other single keys. To reduce the loss of sensitivity induced by the center key on the rotary sensor, it is recommended to place the center key and rotary sensor electrodes on the same acquisition bank. The pattern of the central key must be as symmetrical as possible so that the loading effect on the rotary sensor is also symmetrical.

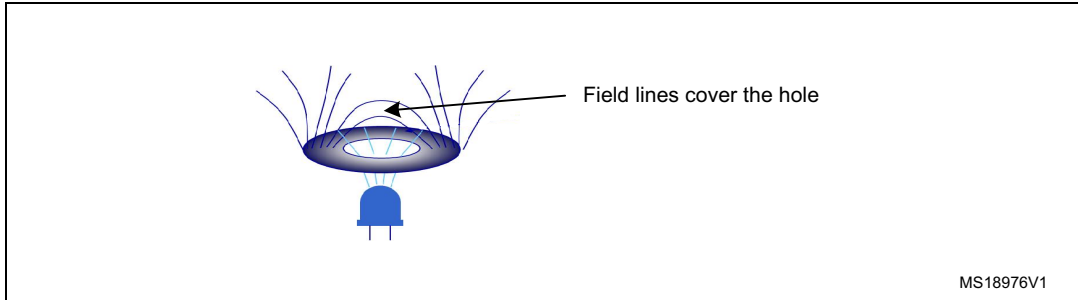


## 4.5 Specific recommendations

### 4.5.1 LEDs and sensors

In some cases, a hole needs to be inserted in the sensor electrode to create a back-lighting touchkey (see [Figure 17](#)). This is a very common solution which does not involve a sensitivity dip in the middle of the sensor electrode as the electric field tend to close over above the hole. As the sensor area decreases, there is a corresponding decrease in sensitivity.

**Figure 17. Back-lighting touchkey**

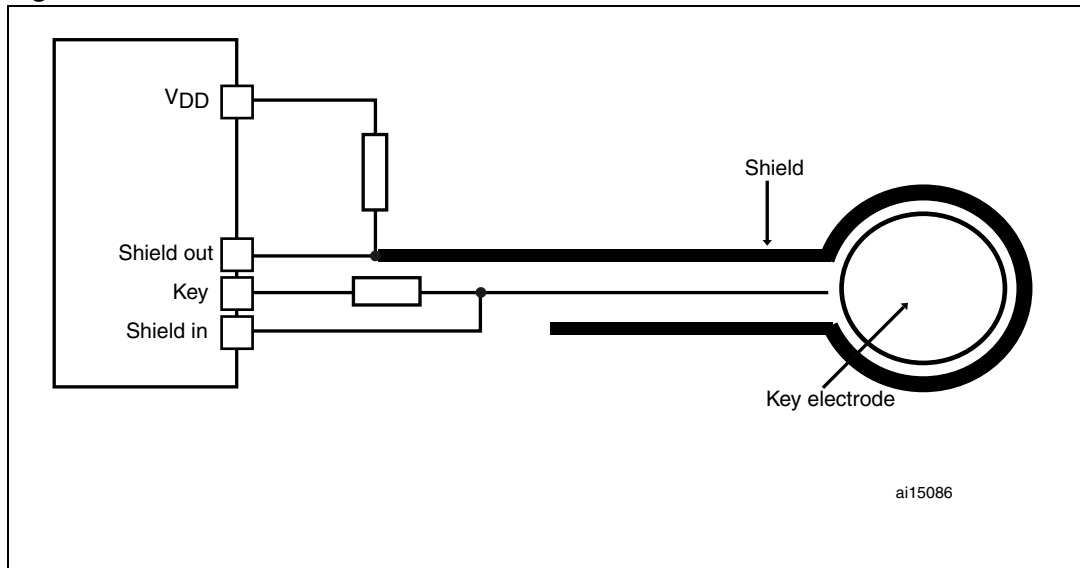


### 4.5.2 Driven shield

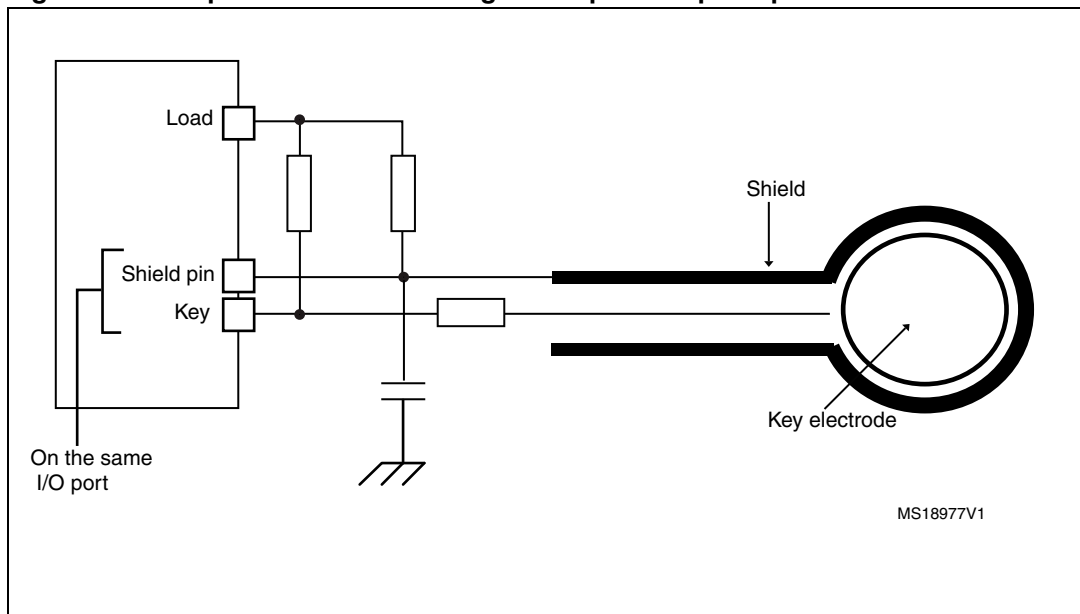
The principle of a driven shield is to drive the shield plane with the same signal as the electrode.

There are several advantages to using a driven shield instead of a grounded shield:

- The parasitic capacitance between the electrode and the shield no longer needs to be charged. This cancels the effect on the sensitivity.
- A driven shield is useful for certain applications where shielding may be required to:
  - Protect the touch electrodes from a noise source
  - Remove touch sensitivity from the cable or track between the electrode and the sensing MCU.
  - Increase system stability and performance when a moving metal part is close to the electrode.

**Figure 18. STM8T141 driven shield solution**

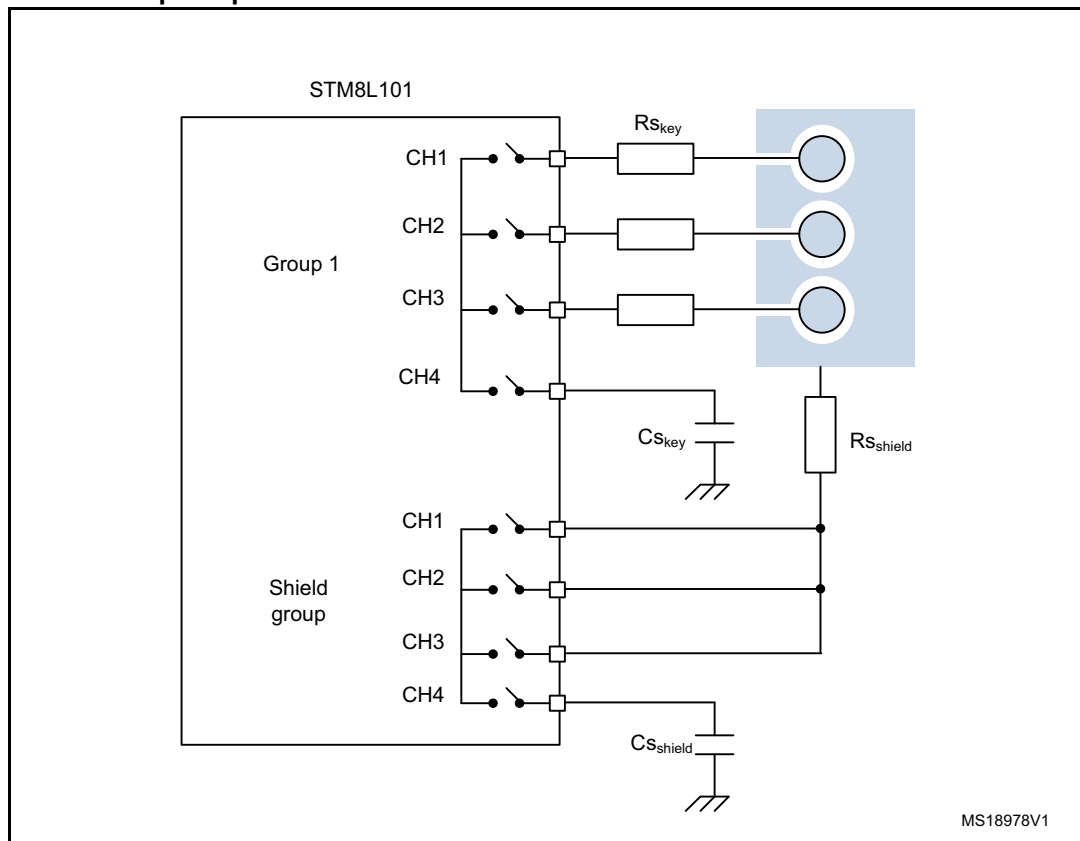
For more details on the STM8T141 shield implementation, please refer to AN2967.

**Figure 19. Simple driven shield using RC acquisition principle**

If the design is done by using the charge transfer acquisition principle, to have an efficient shield, its waveform must be similar to that of the touchkey. Here are some guidelines for achieving this (refer to [Figure 20](#) and [Figure 21](#)):

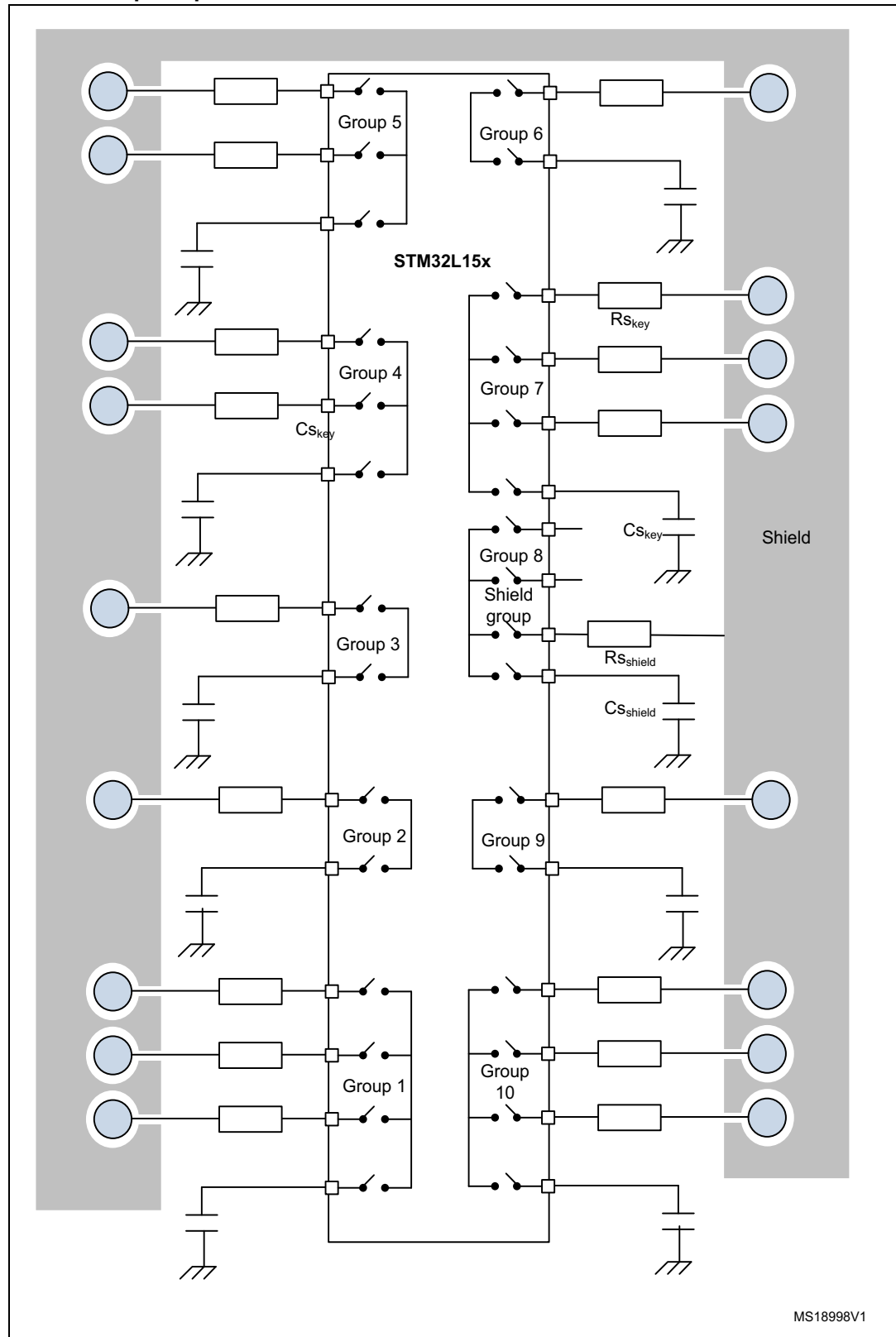
- The  $C_s/C_x$  of the shield should be in the same range as the  $C_s/C_x$  of the touchkeys
- Using  $C_{s_{shield}} = k.C_{s_{key}}$  <sup>(a)</sup> usually gives good results
- The  $C_s$  of the shield does not need to be a high grade capacitor. Any type should work.
- The noise/ESD protection resistor may be mandatory on the shield because it may be exposed to ESD. In order not to modify the pulse timings, the  $R_{s_{shield}}$  should be in the range of  $R_{s_{key}}/k$

**Figure 20. STM8L1xx driven shield example using the charge-transfer acquisition principle**



a.  $k = (\text{shield area})/(\text{electrode area})$

**Figure 21. STM32L driven shield example using the charge-transfer acquisition principle**



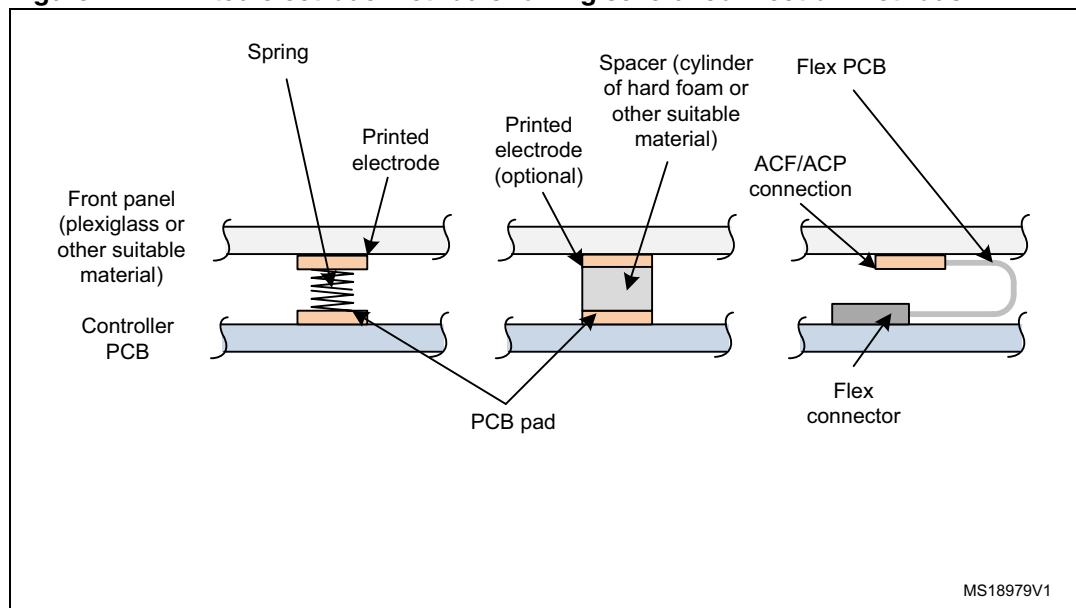
### 4.5.3 Using electrodes separated from the PCB

It is possible to use surface electrodes which create a sensitive area on the bottom surface of the panel and are not close to the PCB.

One option is to print an electrode array on the inner surface of the front panel. In this case the electrode shape rules are as described in [Chapter 4.1](#), and the materials are as described in [Chapter 3.2.2](#). The sensors can be connected using spring contacts, conductive foam or rubber, or a flex tail attached using ACF/ACP<sup>(a)</sup> (see [Figure 22](#)).

Remember that with this technique, the area where the interconnection is made is touch-sensitive too.

**Figure 22. Printed electrode method showing several connection methods**



a. ACF/ACP = Anisotropic Conductive Film/Anisotropic Conductive Paste.

**Figure 23. Spring and foam picture (both are not compressed)**



#### **4.5.4 PCB and layout**

##### **Sensor track length and width**

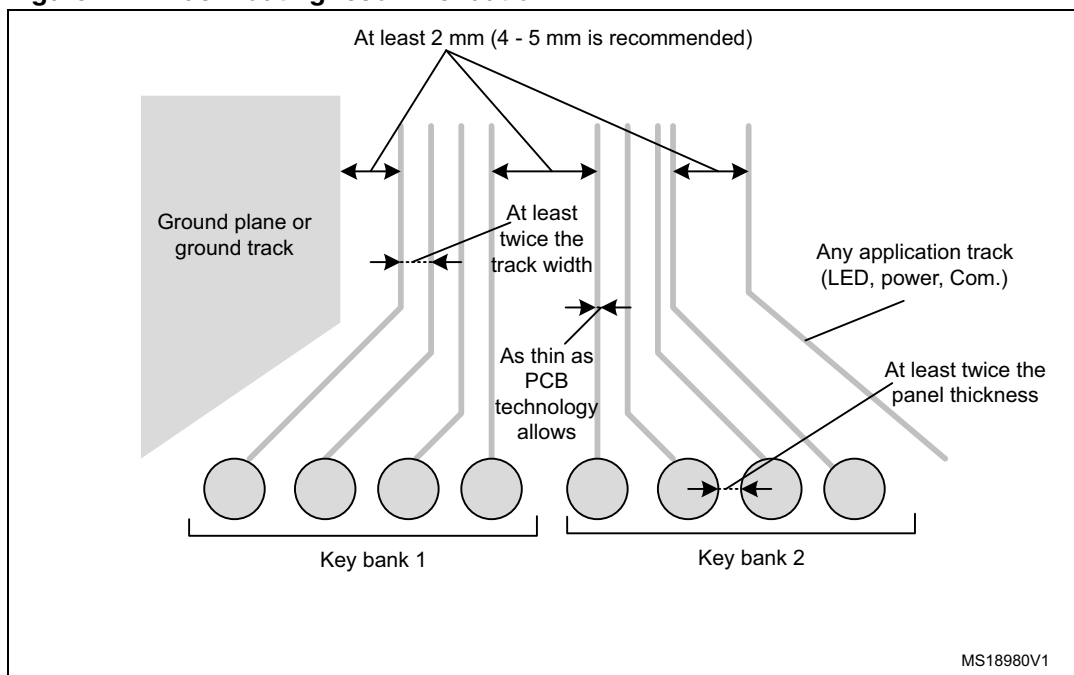
The parasitic capacitance of a track depends on its length and its width. Besides that, a long track can create an antenna effect which may couple noise. So, the main rule to keep in mind is the shorter and thinner the track is, the smaller the parasitic capacitance.

It is recommended to route the tracks as thin as the PCB technology allows and shorter than 10 cm for standard or flexible PCBs.

##### **Sensor track routing**

The main goal when laying out the PCB should be to minimize the interactions between elements or, if they cannot be minimized, to make them uniform for all capacitive elements.

Although the touch sensing controller algorithms, used to acquire touchkey, linear sensor and rotary sensor signals, take into account that the capacitance of each array is different, it is good practice to keep things as balanced as possible.

**Figure 24. Track routing recommendation**

### Electrode banks

We call an acquisition bank, a set of electrodes that are driven simultaneously during the acquisition.

This set of electrodes and tracks interact less with each other and can be routed closer. Typically, a spacing of two times the track width is sufficient.

For electrodes not belonging to the same bank, coupling must be avoided and a spacing of at least 2 mm is required and 4 to 5 mm is recommended (see [Figure 24](#)).

### Electrode spacing

To avoid cross detection on adjacent electrodes, it is recommended to keep a gap of at least twice the panel thickness between electrodes (see [Figure 24](#)).

### Interaction with other tracks

To avoid creating coupling with lines driving high frequency signals, it is recommended to cross the sensor tracks perpendicularly with the other tracks. This is especially true for communication lines, where it is forbidden to route them in parallel with the sensor tracks. To avoid such a configuration, the pins of the microcontroller must be selected and grouped by function. When it is possible, all the sensor pins are consecutively distributed on one or several sides of the microcontroller package (the pins are then used as GPIOs like the LED drivers and communication lines).

It is strongly recommended to dedicate the pins to be used as sensors and not to share them with other features. Sharing tracks produces parasitic capacitance due to re-routing of the sensor tracks, and impacts sensitivity.

### 4.5.5 Component placement

To reduce the sensor track lengths, it is recommended to place the microcontroller very close to the sensor electrodes. It is also recommended to center the microcontroller among the sensors to balance the parasitic capacitance and to put a ground layer above it.

The ESD protection resistors must also be placed as close as possible to the microcontroller to reduce the track length which could drive ESD disturbance directly to the microcontroller without protection. This ESD resistors must be selected according to the acquisition method recommendations.

### 4.5.6 Ground considerations

#### Ground plane

It is recommended to route the sensors and the ground on the same layer while the components and other tracks are routed on the other(s) layer(s).

When a multilayer PCB is used, both sides of the PCB are commonly grounded to improve immunity to noise. Nevertheless, the ground has an effect on the sensitivity of the sensor. The ground effect is to increase  $C_X$ , which reduces the sensitivity as the ratio  $C_T/C_X$  decreases. So, to balance between noise immunity and sensitivity, it is recommended to use partial grounding on both sides of the PCB through a 15% mesh on the sensor layer and a 10% copper mesh for the opposite side with the electrodes and tracks.

#### Ground around sensor

When the ground plane is on the same layer as the sensor, it surrounds the sensors. To avoid increasing  $C_X$ , it is recommended to keep a gap between the sensor and the ground.

This gap size must be at least 2 mm (4-5 mm recommended) and must also be respected with any noisy application track or power supply voltage.

There is two different cases:

- distance to GND and power supply voltage, shorter distance is possible, but impacts significantly the key sensitivity
- distance to noisy signal, the detection may completely stop working in case the distance is not respected

Special care must be taken to balance the ground around the sensors. This is particularly true for a rotary or linear sensor (see [Section 4.5.2: Driven shield](#)).

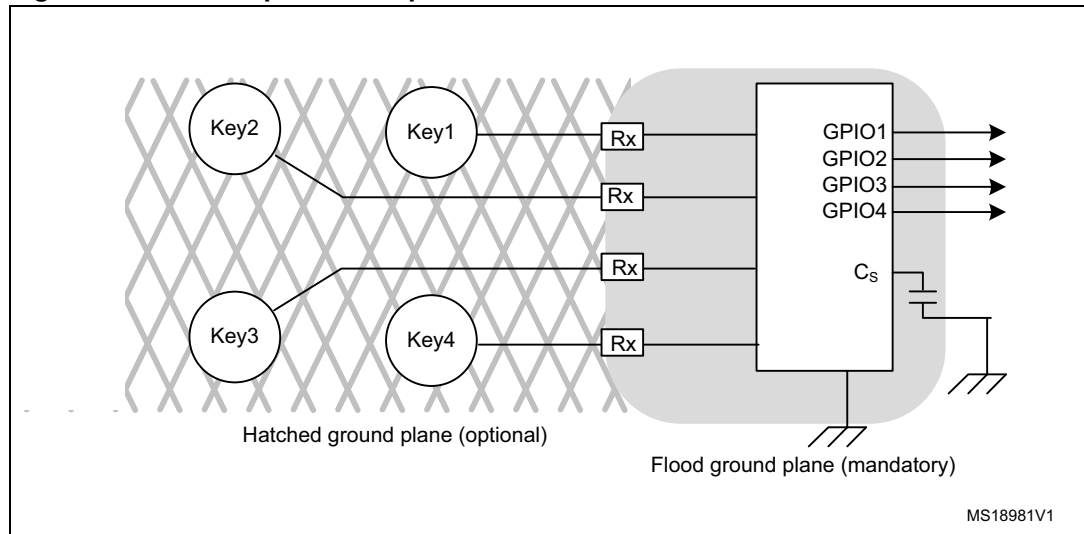
**Caution:** Floating planes must never be placed close to the sensors.

#### Ground plane example

A full ground plane is mandatory below the MCU up to serial resistors (see [Figure 25](#)).

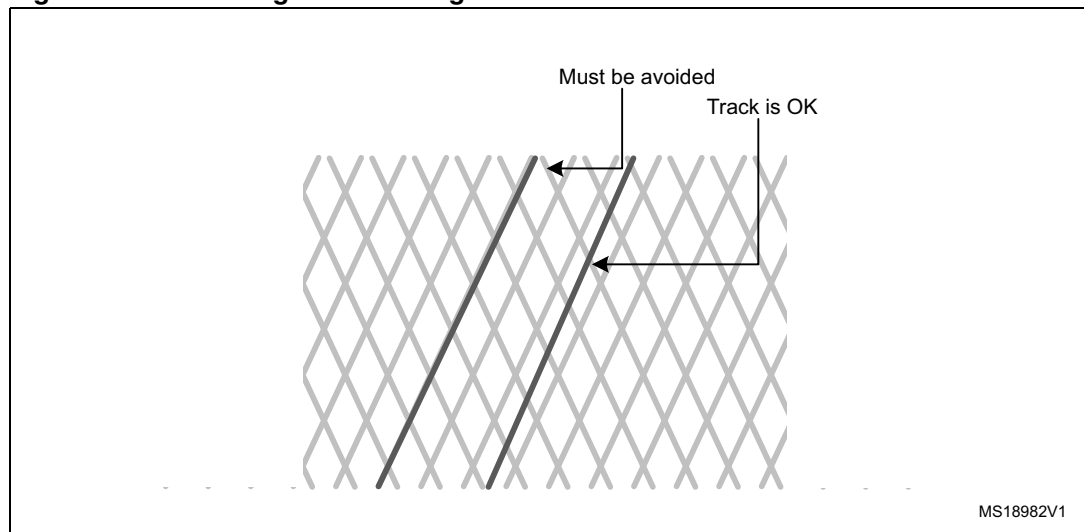
- It must cover the tracks between the MCU and the serial resistors
- In RC, it must also cover the load resistors
- In CT, it must cover the sampling capacitors



**Figure 25. Ground plane example****Hatched ground plane**

Here are some guidelines for satisfactorily designing an application with a hatched ground plane (see [Figure 26](#)):

- The signal track should cross the ground lines as little as possible
- The signal track should never follow the ground lines

**Figure 26. Hatched ground and signal tracks****4.5.7 Rotary and linear sensor recommendations**

Given that the sensitivity must be very high in order to be able to detect the position most accurately, neither the power plane nor any application signal should run under a rotary or linear sensor.

## 5 Projected electrode design

These kinds of electrodes are generally used to implement keys, rotary sensors or linear sensors for use with microcontrollers such as STM8TL53xx which embed a ProxSense interface.

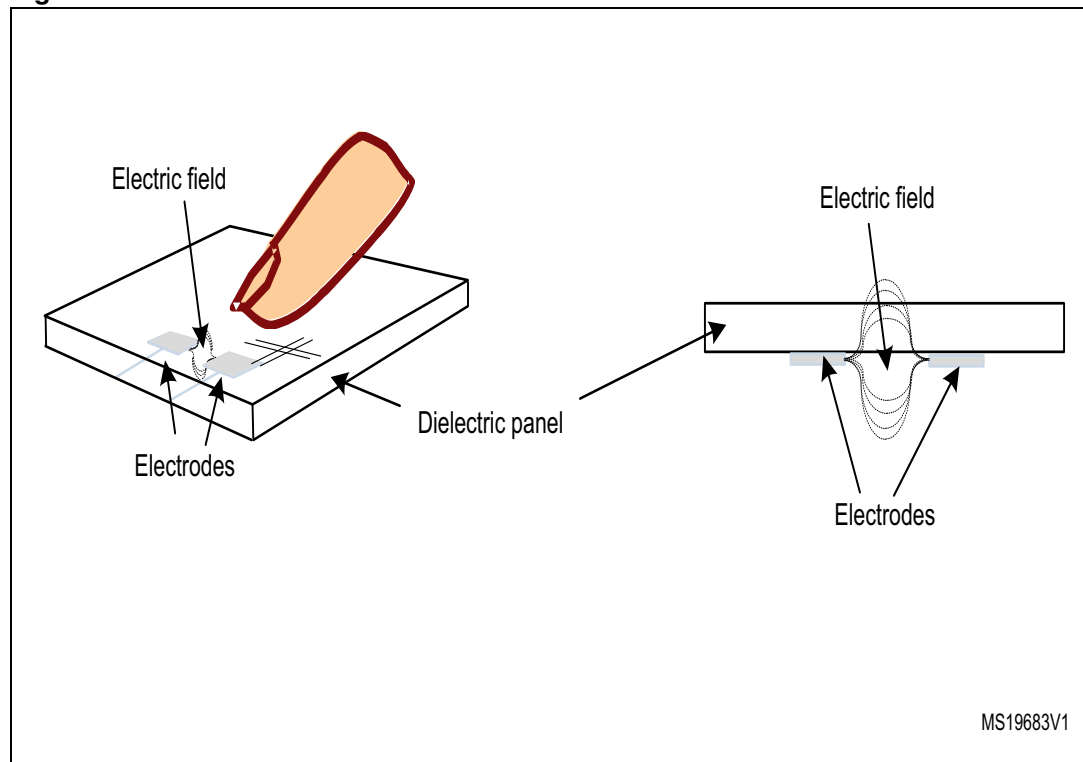
### 5.1 Touchkey sensor

A projected sensor is composed of 2 electrodes, one connected to a transmitter and the other to a receiver.

The touchkey sensor can be any shape, however it is recommended to use a square as this shape is the simplest. The touch sensing library and ProxSense™ IP automatically compensate for capacitance differences but, the acquisition time and processing parameters can be optimized if the electrodes have similar capacitance. For this reason, it is recommended to use the same shape for all electrodes.

An electric field surrounds the Tx and Rx electrodes (see [Figure 27](#)). This field is dependent on the permittivity  $\epsilon_R$  of both the front panel and the PCB. It should be not dependent on air bubbles or moisture which can be trapped between them because they must be sufficiently well bonded by the adhesive.

**Figure 27. Electric field between 2 surface electrodes**



1. The above figure shows only a simplified representation of the sensor, for specification details, refer to [Figure 28](#) thru [Figure 30](#)

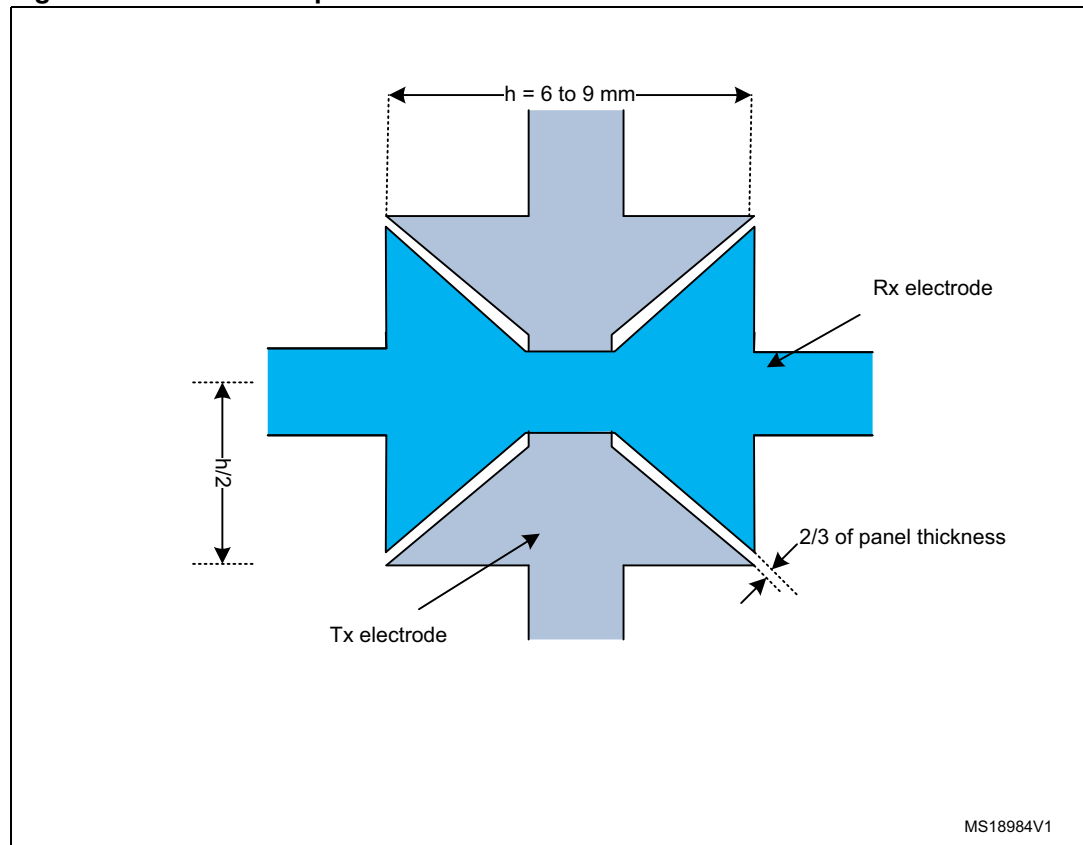
Hence the sensitivity is dependent on known materials and is optimized. This will ensure the disturbance caused by the user's finger is detected and measured with accuracy.

There are two types of implementation, with either symmetrical or asymmetrical Rx and Tx electrodes.

### 5.1.1 Symmetrical Rx and Tx electrodes - diamond type

In this implementation the Tx and Rx electrodes form a diamond with an isolating material between them (see [Figure 28](#)). It is possible to make this with one layer by using a bridge.

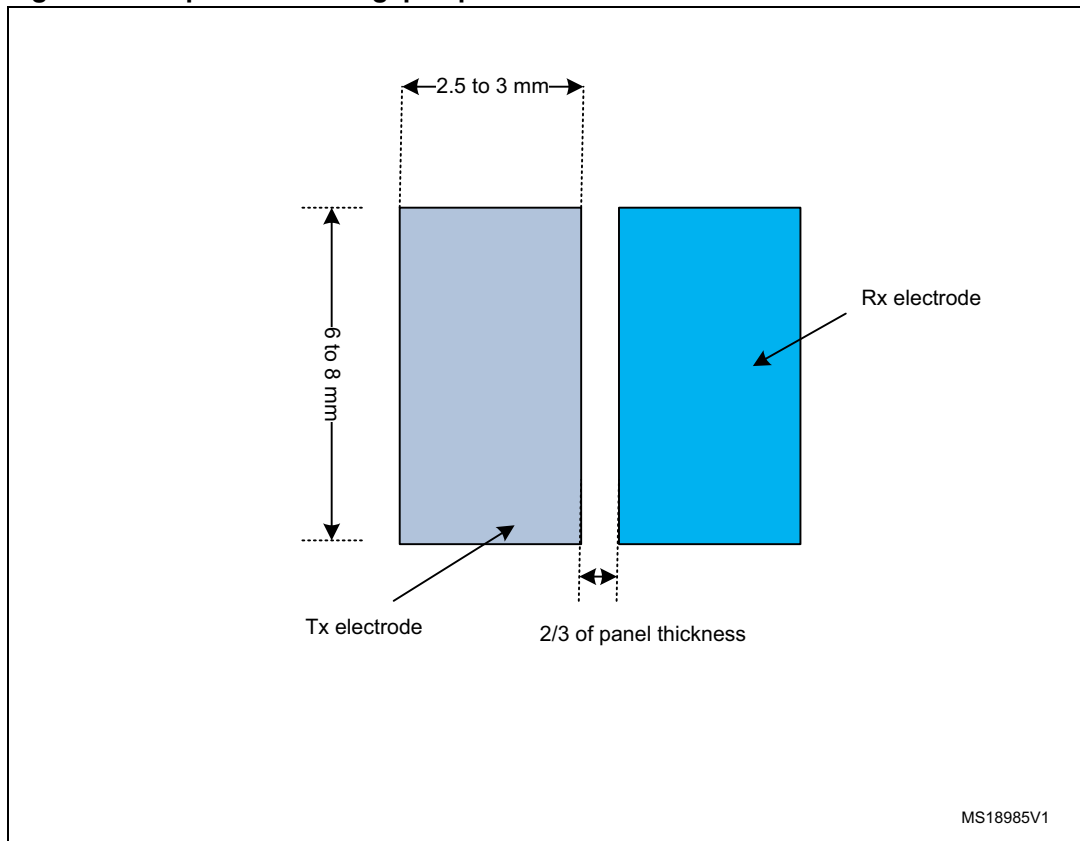
**Figure 28. Diamond implementation**



### 5.1.2 Symmetrical Rx and Tx - square with one gap

In this implementation the Tx and Rx electrodes form a square, in fact there are two rectangles face to face with an isolating material between them (see [Figure 29](#)).

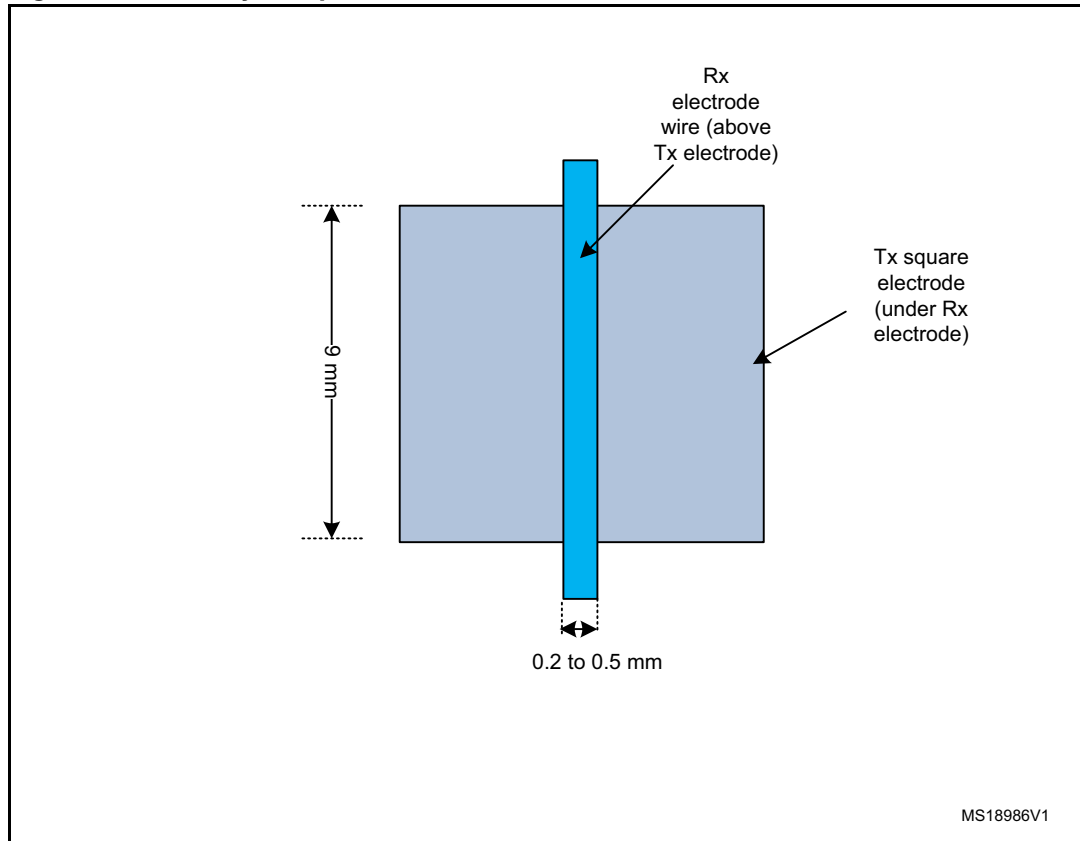
**Figure 29. Square with one gap implementation**



### 5.1.3 Asymmetrical Rx and Tx - Tx square with Rx wire

In this implementation the Tx electrode forms a square, and the Rx electrode is a wire which lies on the Tx square. There is an isolating material between them (see [Figure 30](#)). Obviously, this kind of touchkey is made of two layers.

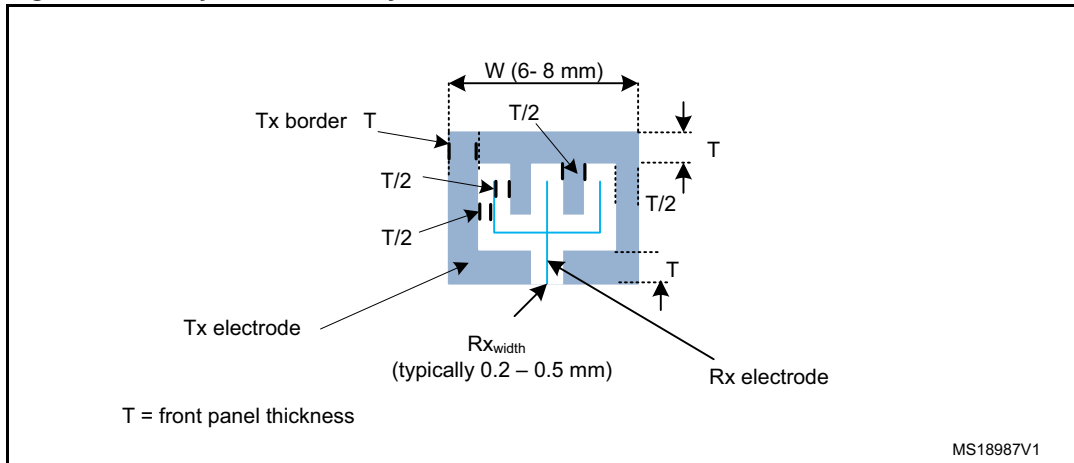
**Figure 30. Two-layer implementation**



#### 5.1.4 Asymmetrical Rx and Tx - interlacing teeth

The Tx and Rx electrodes are generally interlaced, that is they form interlocking “teeth”. Typically the Tx electrode surrounds the Rx electrode, as it helps to contain the field between the two (see [Figure 31](#)).

**Figure 31. Projected touchkey sensor**



##### Width of Rx electrodes

The Rx teeth have to be as thin as possible (i.e. 0.2 to 0.5 mm), this will reduce the SNR of the overall electrode. A suggestion could be to link the Tx and Rx width in a function but tests have always shown that the best is to have the thinner track for Rx to optimize noise limitation.

##### Width of Tx electrodes

In a different way, the Tx teeth have to be thicker than the Rx ones (see [Figure 31](#)). This also shields the electrode from the border. So the Tx tooth width can be equal to  $T/2$ , where  $T$  is the thickness of the panel; and the border of the electrodes is equal to  $T$ .

##### Spacing between the electrodes

Similarly, the spacing between the Tx and Rx electrodes can be a function of the thickness of the panel ( $T$ ). In practice,  $T/2$  is considered as a good choice (see [Figure 31](#)).

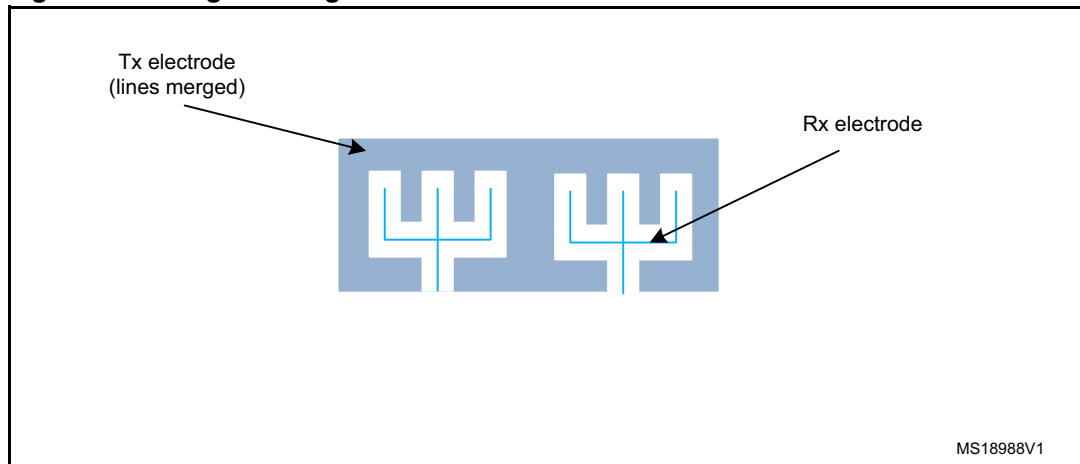
##### Coupling length

The purpose of this kind of design is to increase the coupling between Rx and Tx electrodes (by increasing the length between them) which will improve the SNR. This overall length will be defined by the number of teeth, their length and the spacing between each other. Obviously, all of the teeth are within the space allocated for the touchkey.

### Merging Tx regions

The Tx signal can be used by several touchkeys. In this case the Tx regions can be merged as shown in [Figure 32](#).

**Figure 32. Merged Tx regions**



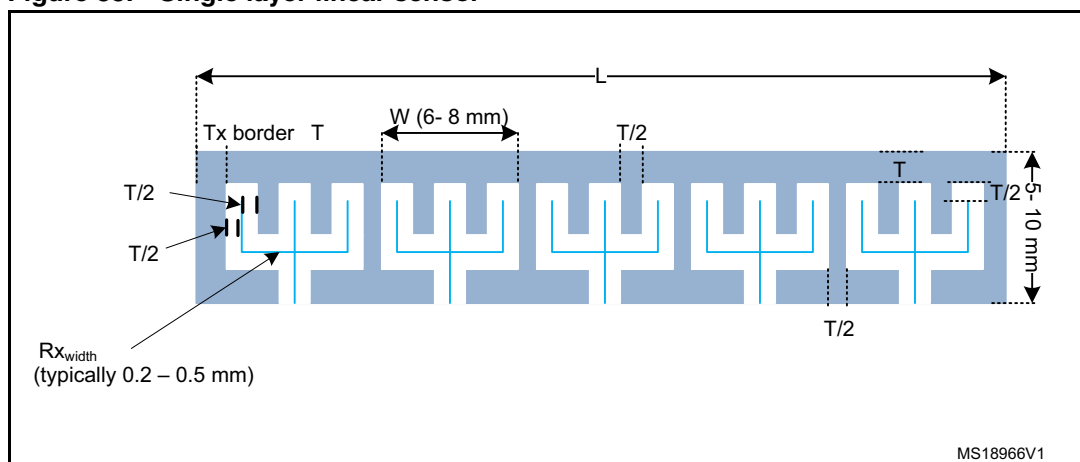
## 5.2 Linear sensor

To design a linear sensor with a projected technology, the most usual form used is an array of touchkeys as described in the previous chapter. You can see what it looks like in [Figure 33](#). This kind of slider is fine when each parcel is about 6 mm or 8 mm and it could have  $n$  parcels. So the overall length will be about  $n \times 6$  mm or  $n \times 8$  mm for instance.

The main differences between an set of touchkeys and a linear sensor is that there is no border between the parcel hence we can consider the linear sensor is a huge touchkey. In fact there are Rx teeth between each parcel.

Note that the Rx electrodes are cut to separate each parcel, therefore the Rx electrodes of each parcel are also separated and have to be connected externally with vias or in another way in order not to be isolated. You can see [Figure 33](#) for an illustration of this.

**Figure 33. Single layer linear sensor**



So now we have to calculate each variable shown in [Figure 33](#) as the number of Tx teeth ( $Tx_{teeth}$ ) and the width of the end borders ( $Tx_{border}$ ). In the same way as we did previously for the touchkey, the width of Rx and Tx tracks are given (between 0.1 mm and 0.5 mm for  $Rx_{width}$  and about  $T/2$  for  $Tx_{width}$ , where  $T$  is the thickness of the panel)

Here are the steps to follow when designing the slider:

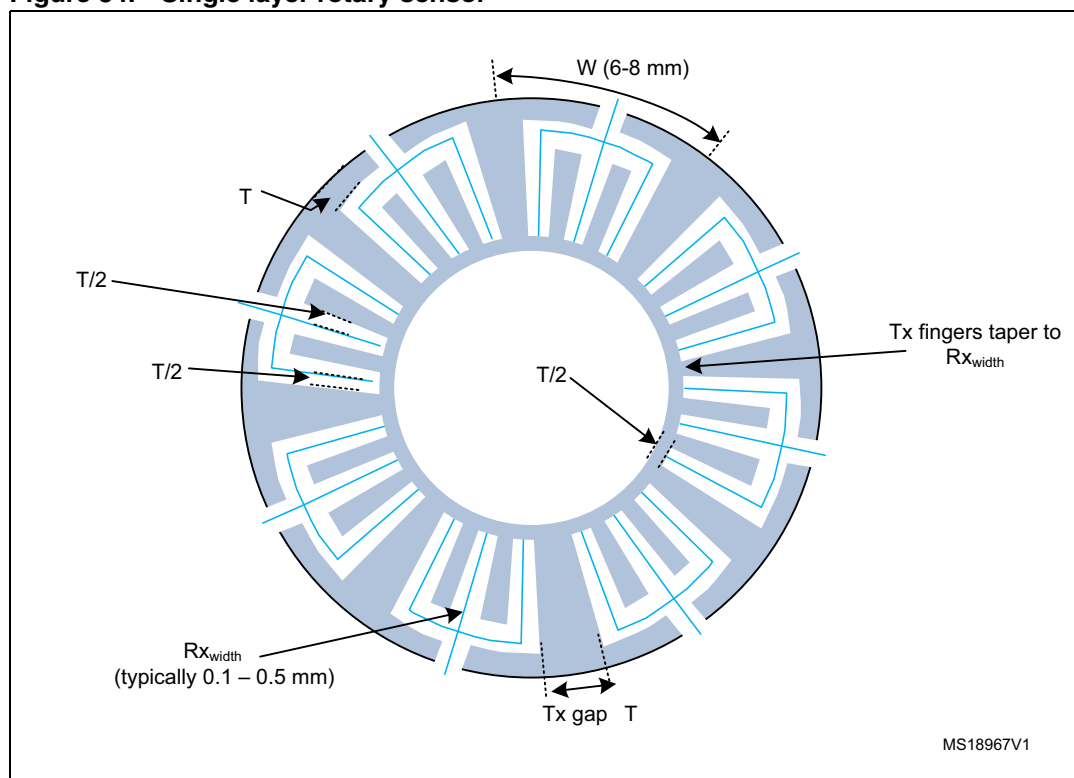
1. Fix the length of the slider and the number of keys (which will be  $L$  and  $K$ ).
2.  $Tx_{teeth}$  and  $Tx_{border}$  must be defined as shown in [Figure 33](#).

### 5.3 Rotary sensor

The design of rotary sensor with the projected technology is very similar to a linear sensor one. Obviously, the difference is the touchkeys are placed in a circle (see [Figure 34](#)), so there is no border as there is a loopback. With this you can design rotary sensors with a diameter of between 15 mm and 21 mm which is made of 6 keys minimum. You can see that the end of each Tx tooth is not a point but should be equal to Rx width at least, and this will set the size of the inner circle.

Now the number of Tx teeth have to be calculated as we did previously for the linear sensor. Don't forget there is no border so there is no need to calculate Tx border and the fractional part of the calculation is distributed equally between each of the Tx teeth.

**Figure 34. Single layer rotary sensor**



To design the rotary sensor:



1. Fix the diameter (D) of the rotary sensor (15 mm to 21 mm) and the number of keys (K > 6)
2. Verify the outer arc (W) of each key in the rotary sensor, it should be between 6 and 8 mm:

$$W_{II} = (IID / \text{keys}) - R_{x_{width}}$$

Check the length of W is < 6 mm, if this is the case you can:

- Modify the rotary sensor to have less keys
- Increase the size of the rotary sensor's diameter a few

Or check the length of W is > 8 mm, if this is the case you can:

- Modify the rotary sensor to have more keys (if the controller supports more keys)
- Decrease the size of the rotary sensor's diameter a few

3. Apply the rules in [Chapter 5.1.4](#) to calculate Tx fingers (see [Figure 34](#) for definitions).

Determine where the gaps between the keys occur by calculating the number of Tx teeth in each key ( $Tx_{teeth} / \text{keys}$ ).

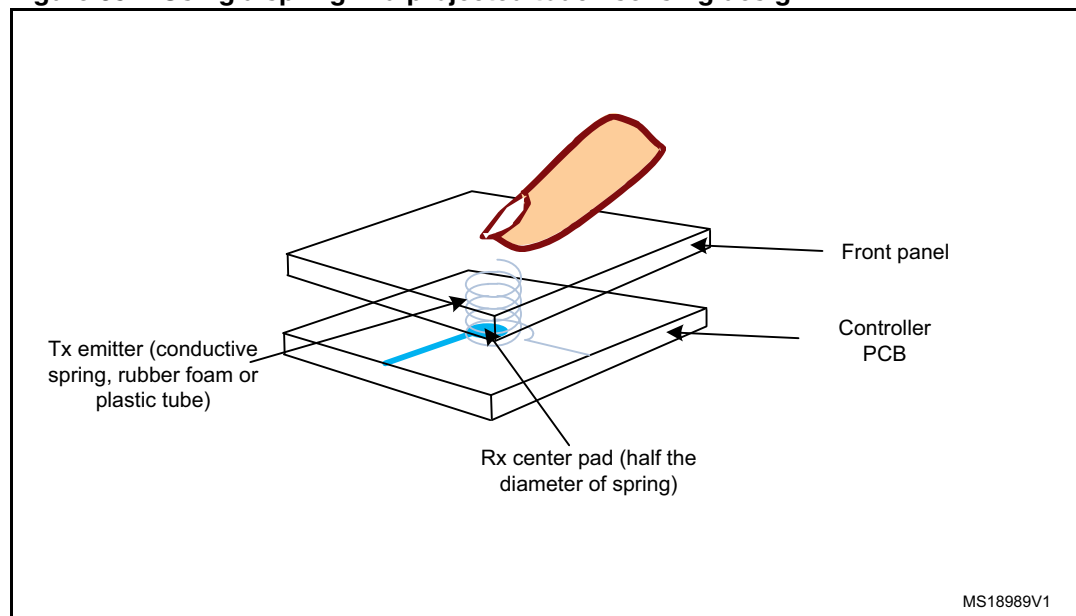
Now you have all of the elements to draw the rotary sensor.

## 5.4 Specific recommendations

### 5.4.1 Mounting electrodes separately from the PCB

It is possible to use a separated Tx electrode (if the panel is not directly in contact with the PCB) by using a spring or a hollow cylinder (both have to be conducting). These materials are connected to the Tx electrode and the Rx electrode still lies on the PCB (see [Figure 35](#)).

**Figure 35. Using a spring in a projected touch sensing design**

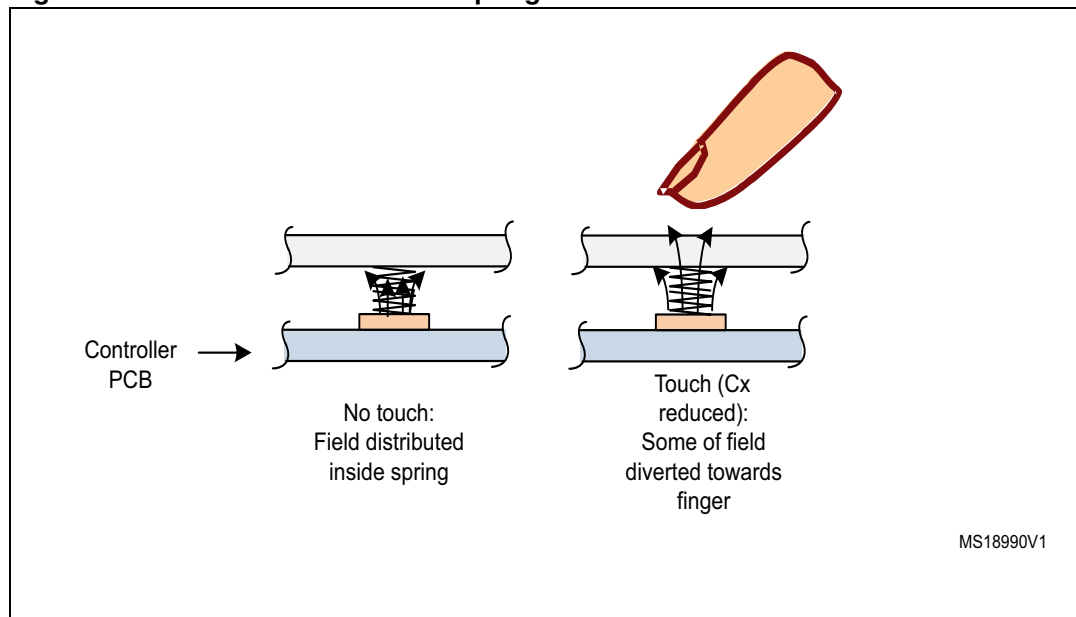


The diameter of the spring or the tube should be about 8 to 10 mm and the diameter of the circular Rx electrode should be half of this.

The height of the cylinder or the spring while it is compressed should be less than its diameter (which corresponds to the distance between the panel and the PCB). When a spring is used, you can check the gaps between the spring wire while it is compressed. The gaps should be the same size as the diameter of the spring wire itself.

If there are other touchkeys nearby which use the same technique, take care that the springs are not too close (approximately half of a spring diameter between the boundaries of each touchkey, or less if tubes are used instead).

**Figure 36. Effect of a touch with a spring**



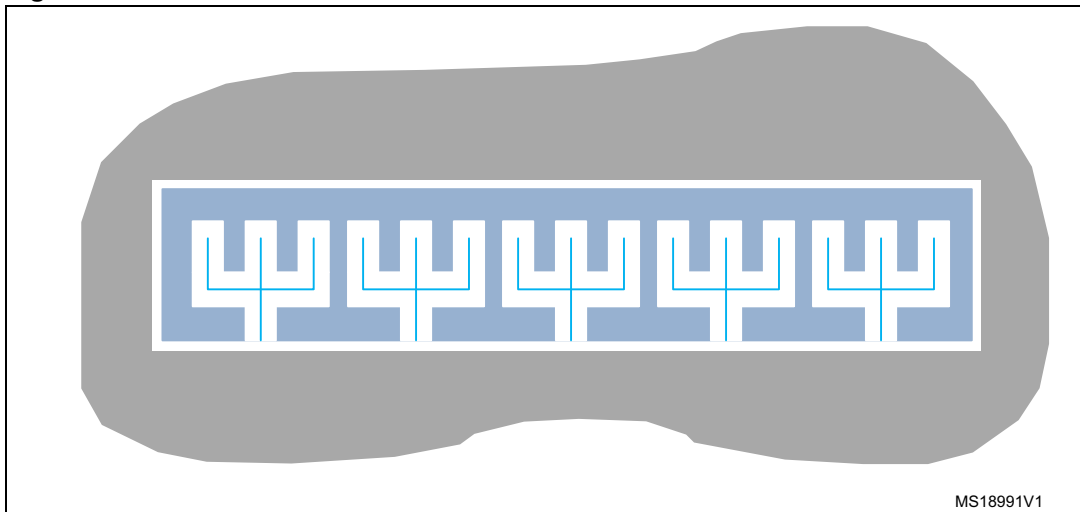
The purpose of the coil is not to be compressed when a touch occurs, but on the contrary it has to be maintained in a way that it is always stays compressed.

You can see in [Figure 36](#) how the electric field is impacted by an approaching finger. The resulting capacitance of the electrodes is decreased and therefore the touch is detected.

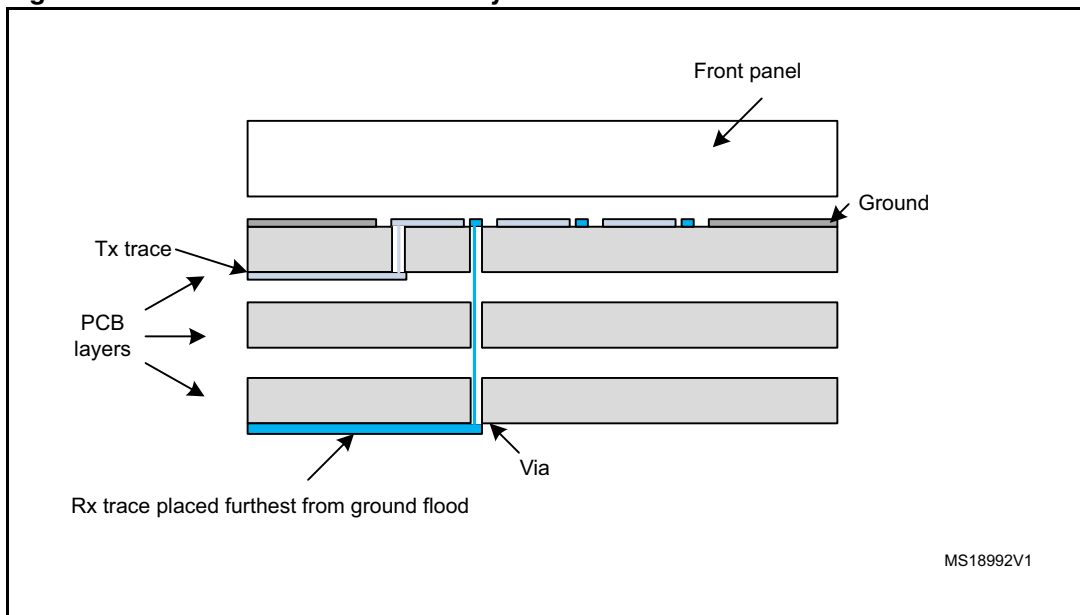
## 5.4.2 PCB and layout

### Background

One of the advantages of a projected sensor compared to a surface sensor is that its Tx and Rx signals are less sensitive to the external environment than the ones used with the surface sensor because they are coupled together. Rx is impacted by the ground in any case (but less than the surface sensor), but on the other hand Tx is shielded by the ground. So the sensor can be flooded as shown in [Figure 37](#).

**Figure 37. Ground floods around Tx**

The ground can shield it from external disturbance but reduces the sensitivity of Rx, so Rx should be as far as possible from the ground plane with Tx between them as shown in [Figure 38](#).

**Figure 38. Cross-section of a multi-layer PCB**

### Tx routing

To route the Tx signal efficiently the most important thing to respect and almost the only one is the RC time constant rule. But keep in mind that signals which switch rapidly (more than tens of kHz) such as high speed communication signals, LCD or LED drive signals must be routed far away from Tx.

The Tx track is less sensitive than the Rx track so it can be put on any layer of the PCB but Rx tracks should be considered when routing it to ensure a good design.

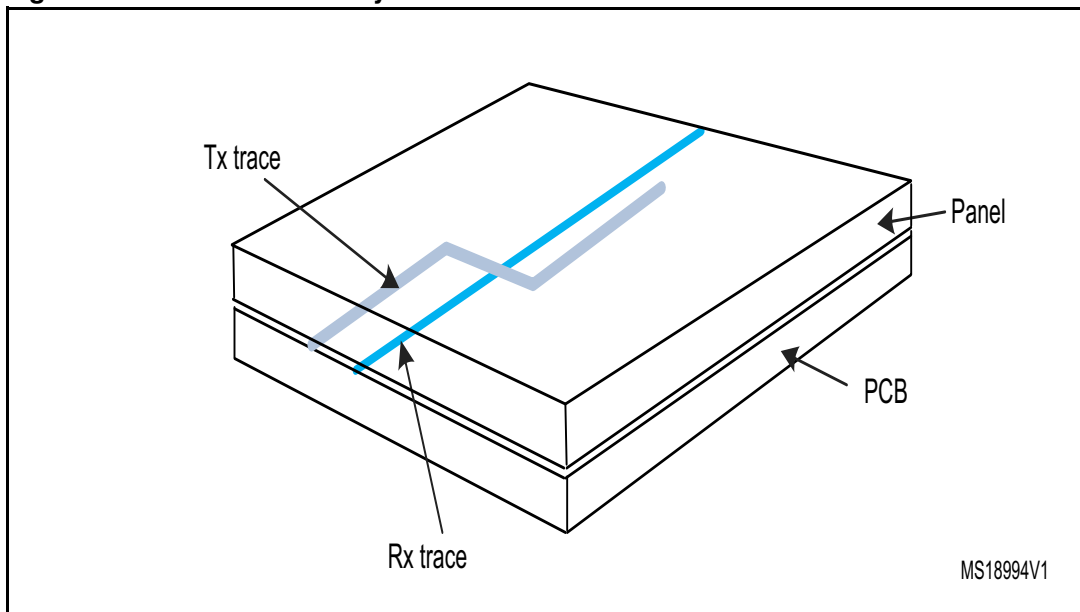
### Rx routing

On the other hand, the Rx track is very sensitive due to the capacitance of the sensor. A false detection may occur if some guidelines are not followed. The most obvious is to route it far from the sensor itself, e.g. on another layer.

Another one is to avoid placing ground near the Rx track which reduces the sensitivity.

Then when Rx and Tx are very close (about less than 10 mm) an electric field is also generated and a finger which roams here can generate a false touchkey detection (see [Figure 39](#)).

**Figure 39. Potential false key detection**



### Avoiding false key detection

Follow these recommendations to avoid false touchkey detection:

- The Tx and Rx tracks should never cross each other but if they do it must be with a right angle.
- When the Rx and Tx tracks go in the same direction and to places that are close together, it is better to separate them with a ground which has to be more than the twice the width of each signal track.
- To further reduce the coupling between the Tx and Rx tracks, the Tx signal can run under the ground, in this case even if Rx is near the ground, coupling should not happen .
- If the Rx track is behind the Tx track from a user point of view, the user cannot modify the electrical field. Obviously if Rx and Tx signals are too far apart, there will be no interaction.

Furthermore, you can consider these general guidelines:

- The Tx and Rx tracks must be as thin as possible.
- The Rx tracks must be as far as possible from the touchkey.
- When there are several touchkeys it is better to keep all the Tx tracks together and all the Rx tracks together which greatly reduces any false touchkey detection.

## 6 Conclusion

The layout and design of capacitive sensing boards usually present conflicts between all signals present on the application. This document should be used as a general guideline for resolving all issues. When the guideline recommendations cannot be followed, tests should be performed to validate the implementation and verify the sensitivity and robustness of the impacted channel.

In summary, the layout of a touch sensing application should reduce the ground coupling to a minimum and use short clean wires as far as possible from other potential interference sources.

## 7 Revision history

**Table 3. Document revision history**

Date	Revision	Changes
02-Feb-2009	1	Initial release.
23-Oct-2009	2	Document restructured and content reworked.
01-Apr-2010	3	Added that ProxSense™ is a trademark of Azoteq.
01-Apr-2011	4	Document restructured and content of all sections reworked. Added <a href="#">Section 5: Projected electrode design</a> .
17-Oct-2011	5	STM8TL53xx product name update

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