AN2869
Application note

Guidelines for designing touch sensing applications

1 Introduction

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

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

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

Capacitive sensing interfaces are used more and more 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 concerning three main aspects:

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

Contents

List of tables

List of figures

2 Capacitive sensing technology in ST

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

- The RC acquisition principle for STM8S and STM8L. It is implemented as a firmware library.
- The charge transfer acquisition principle for STM8L. It is implemented as a firmware library to drive a dedicated hardware IP.
- The ProxSense™ acquisition principle for STM8T. It is implemented by a hardware IP.

Note: ProxSense™ is a trademark of Azoteq.

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 increase and the variation is used to detect the finger proximity. The RC acquisition principle is detailed in AN2927: RC acquisition principle for touch sensing applications.

The charge transfer and ProxSense acquisition principles use 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 cycle number to charge the sampling capacitor decreases.

The ProxSense aquisition principle is described in AN2970: Principles of capacitive and touch sensing techniques

3 Capacitive sensor construction

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

- A fiberglass PCB
- A sensor electrode made of a copper pad (also called a copper spot)
- A panel made of glass, plexiglass, or any nonconductive material
- A silk screen printing

Figure 1. Example of capacitive sensor construction

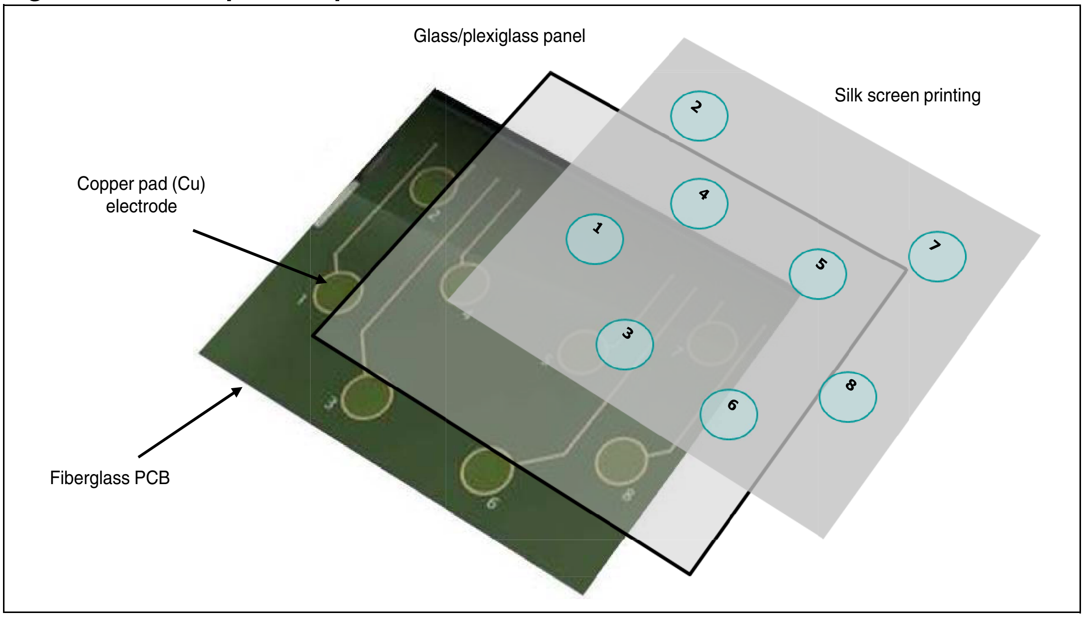
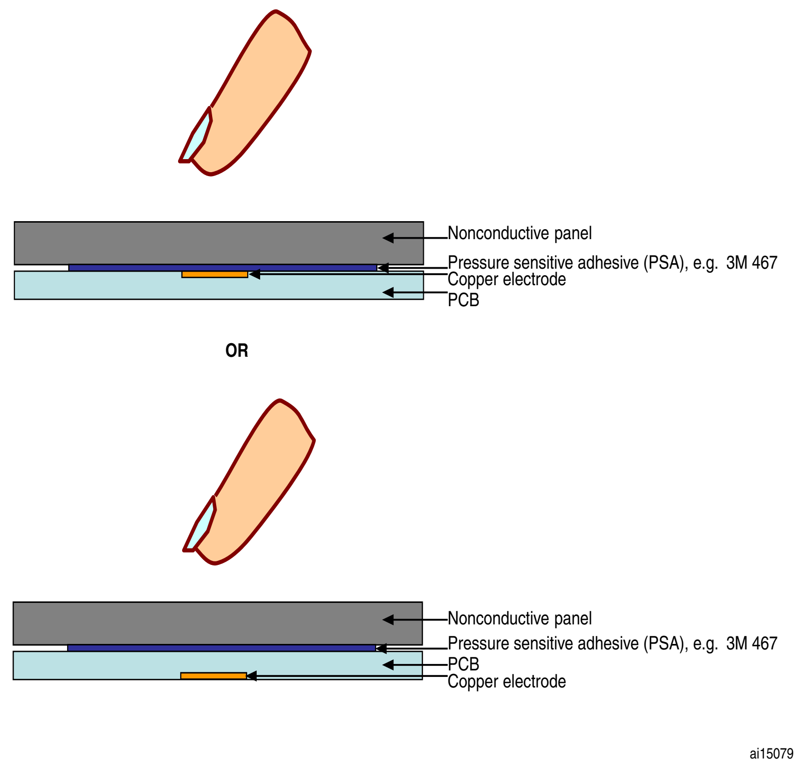


Figure 2. Typical panel stack-up



3.1 Sensor electrode

Usually, the sensor electrode is made of copper as part of a PCB or a flexible PCB, but it can be made of any conductive material. Transparent electrodes can easily be made using Indium Tin Oxide (ITO), which is commonly used for touchscreens and LCD.

3.1.1 Sensor size

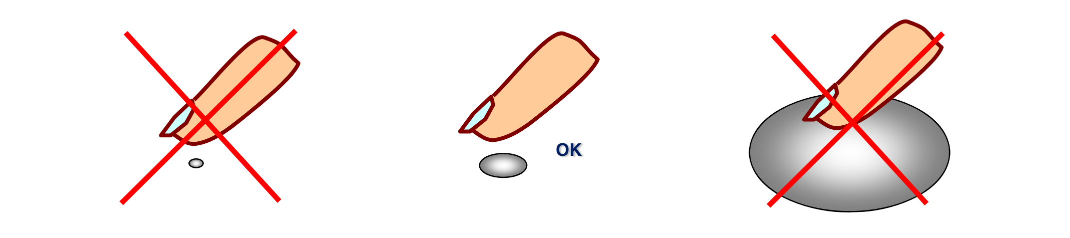
For key sensors, two parameters must be taken into account when choosing the sensor size:

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

Regarding object size (see *Figure 3*), it is recommended to design a sensor in the same range as the object to be detected. In most cases, it is a finger.

Regarding panel thickness, the touchkey must be at least four time 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. There are sensitivity issues if dimensions lower than these values are used.

Figure 3. Sensor size



As shown in *Equation 1*, 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 this can involve a false touch, where a touch is detected without a finger, because the sensor is too sensitive. The false touch can be triggered by noise when the capacitance created by the finger touch (C_T) is in the same range as the parasitic capacitance of the electrode (C_X). Refer to *Section 3.4: 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 1

$$C_T = \frac{\varepsilon_R \varepsilon_0 A}{d}$$

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)

ε_R is the dielectric permitivity constant

ε_0 is the vaccuum permitivity

3.1.2 Sensor shape

The sensor can be any shape, however it is recommended to use round or oval as these shapes are the simpliest. 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 keys can be customized by the drawing on the panel.

3.2 LEDs and sensors

3.2.1 Protection against parasitic effects

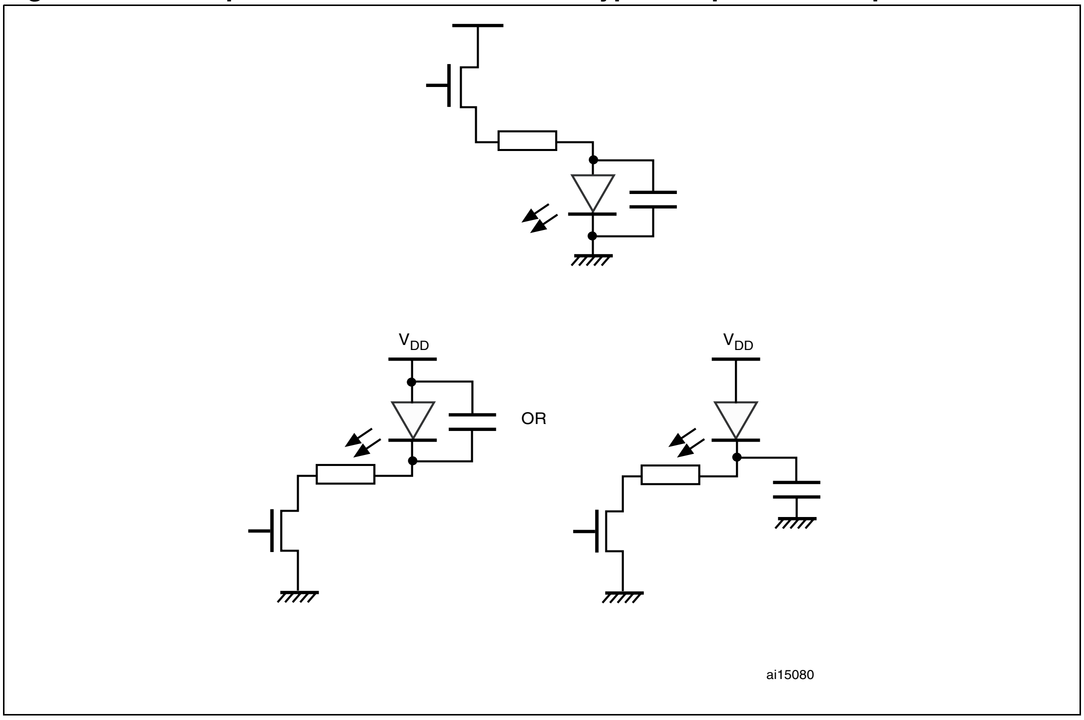
Light-emitting diodes (LEDs) are very often implemented near capacitive sensor buttons on application boards. These lightings are very useful to show that the button is correctly touched. When designing applications boards with LEDs, the following considerations must be taken into account:

- LED's change capacitance when switched on and off
- LED's driver tracks can change impedance when switched on and off
- LED's 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 4*) can also be applied to transistors.

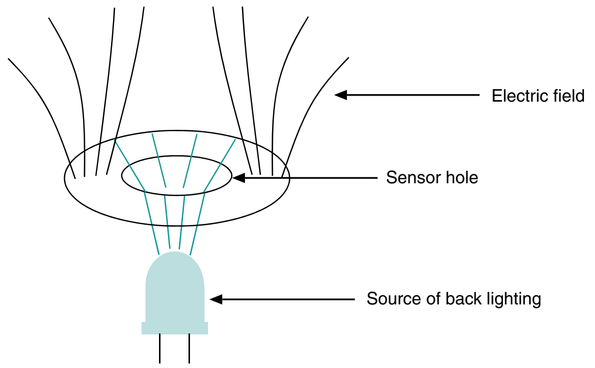
Figure 4. Examples of cases where a LEDs bypass capacitor is required



3.2.2 Sensor hole

In some cases, a hole needs to be inserted in the sensor electrode to create a back-lighting touchkey (see *Figure 5*). This is a very common solution which does not involve a sensitivity dip in the middle of the sensor electrode as the electric field tends to close over above the hole. As the sensor area decreases, there is a corresponding decrease in sensitivity.

Figure 5. Back-lighting touchkey



3.3 Power supply

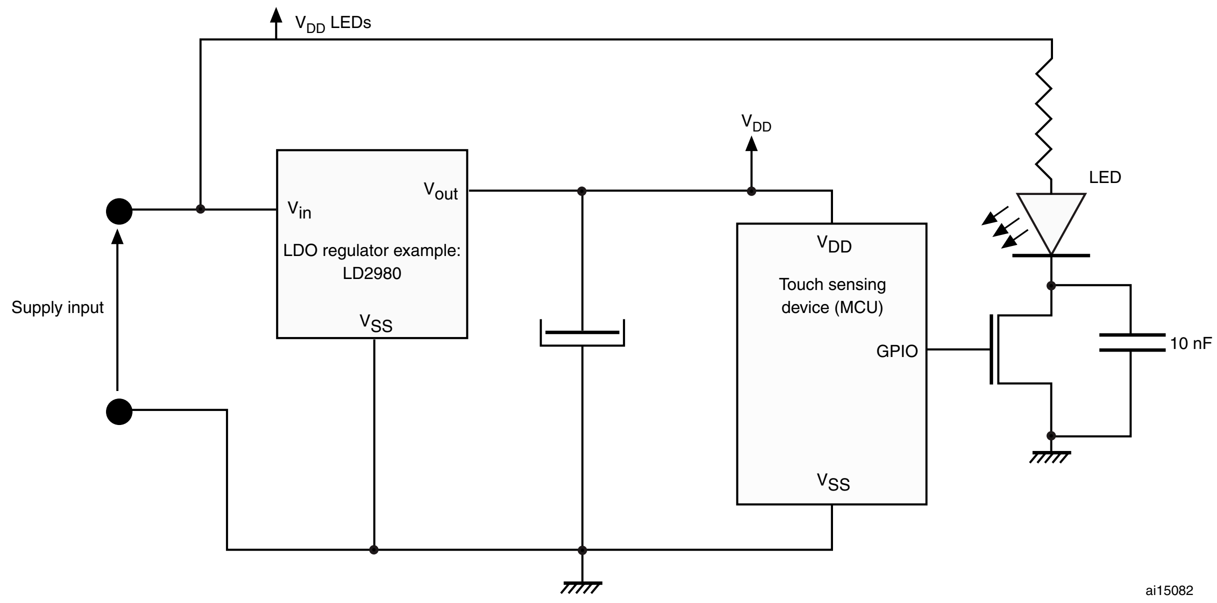
For devices without a touch sensing dedicated regulator, it is strongly recommended to use an external voltage regulator for the power supply of the device. In order to reduce system costs, a regulator, which is fully dedicated to touch sensing, is already embedded into the devices of the STM8T familly.

If the regulator is external, it must be choosen 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 ±10 mV peak to peak variation on V_{DD}, limits the resolution of a multikey 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 6*).

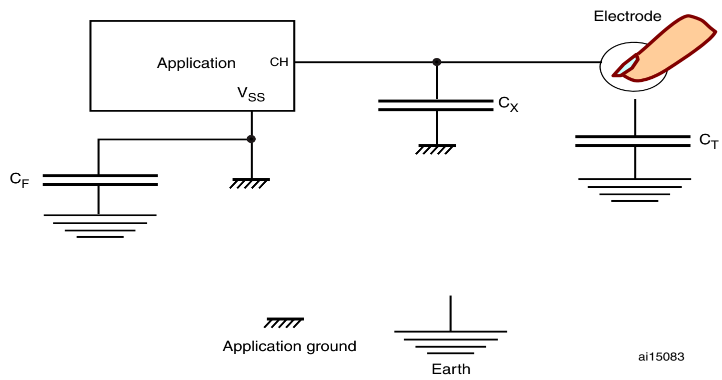
Figure 6. Typical power supply schematic



3.4 PCB and layout

3.4.1 Background

Figure 7. Equivalent touch sensing capacitances



C_X is the parasitic capacitance of the electrode and refers to the application ground.

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.

C_X is composed of two capacitances: the first, refers to earth which is neglible and can be ignored and the second, refers to the application ground which is dependent on the PCB or 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.

3.4.2 Sensor tracks

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 PCB. For flexible PCB, the track length should be limited to 5 cm.

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 signals, take into account that the capacitance of each array is different, it is a good practice to keep things as balanced as possible.

Electrode groups

We call a group of touch electrodes a set of keys that are driven simultaneously during the aquisition.

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.

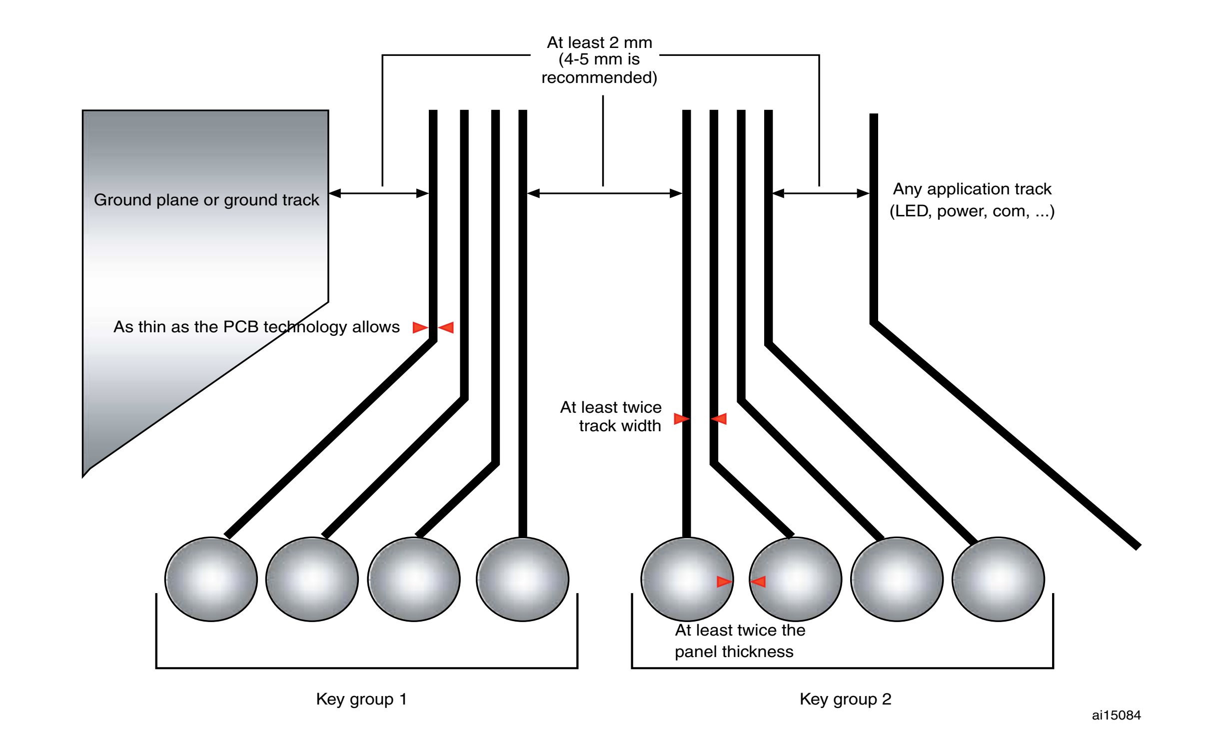
For keys not belonging to the same group, coupling must be avoided and a spacing of at least 2 mm is required and 4 to 5 mm is recommended (see *Figure 8*).

For example, with the STM8 RC aquisition library, a group is constituted off all the keys on the same GPIO port. With the charge transfer acquisition method, there are as many groups as sampling capacitors. A group is a set made of all the electrodes located on the same analog switch number.

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 8*).

Figure 8. Sensing element definition

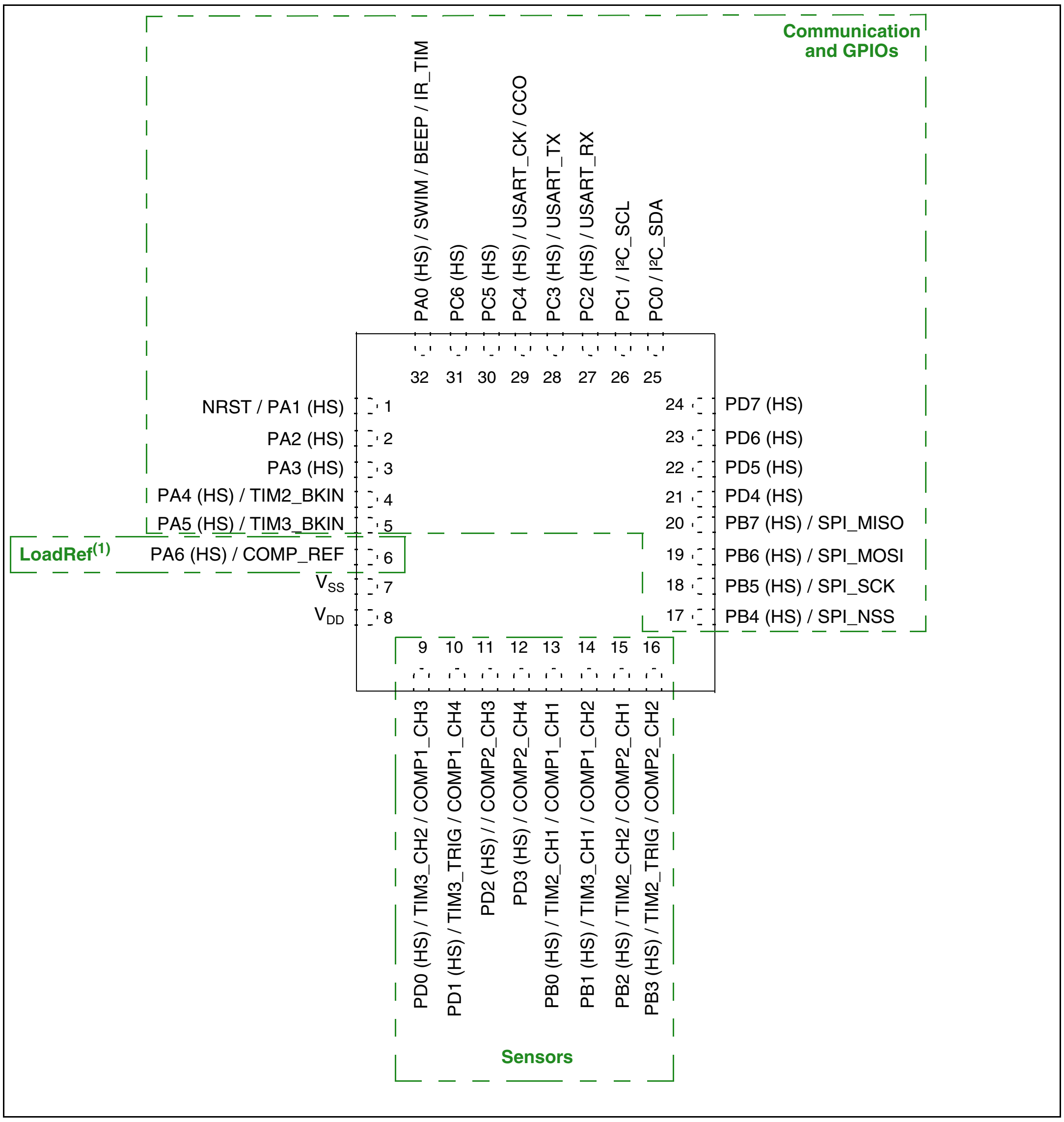


Interaction with other tracks

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 (see the STM8L101 example in *Figure 9*).

For general purpose microcontrollers used with the RC or the charge transfer firmware libraries, 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.

Figure 9. STM8L101/RC acquisition example for 8-channel application with USART communication



1. For an explanation of LoadRef, please see AN2970: Principles of capacitive and touch sensing techniques.

Component placement

To reduce the sensor track lengthes, 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.

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 resistances must be selected according to the acquisition method recommendations and the microcontroller specifications.

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 components.

Ground around sensor

The ground plane is on the same layer as the sensor, so 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.

Special care must be taken to balance the ground around the sensors. This is particularly true for a multikey sensor such as a slider and wheel (see *Section 3.5: Panel materials*).

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

3.5 Panel materials

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

3.5.1 Dielectric constant

The panel is the main item of the capacitor dielectric between the finger and the electrode. Its dielectric constant (ε_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.

Table 1. Dielectric constants of common materials used in a panel construction

Material	ε_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.)

3.5.2 Sensitivity

The sensitivity of an electrode depends on the materials of the panel and on the panel thickness. A sensitivity factor can be expressed as follows:

Equation 2

$$S = \frac{\varepsilon_R}{t}$$

where t is the thickness of the dielectric.

The higher S is, the better the sensitivity. So, it is recommended to avoid air gaps and to fill such gaps with a PSA which has a dielectric constant at least twice that of air. This factor can also be used to evaluate the sensitivity of the nontouch side of the application.

Equation 2 is valid for mono-component panels. For a panel composed of n-stacked materials the sensitivity expression is :

Equation 3

$$S_{stack} = \frac{1}{\sum_{n}^{i} \left(\frac{1}{Si}\right)}$$

Each material has an influence on the sensitivity.

3.5.3 Metal chassis

A metal chassis behind a touch sensor is a good path to the ground and tends to reduce the sentivity of the touch response in case there is a significant area of overlap. Such a metallic surface must never be electrically floating as it re-radiates the charge transfer bursts and potentially makes the whole product unstable to touch. 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: Driven shield*) if it is implemented.

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

3.5.4 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. Air gaps help reduce the sensitivity of the back side of a portable device.

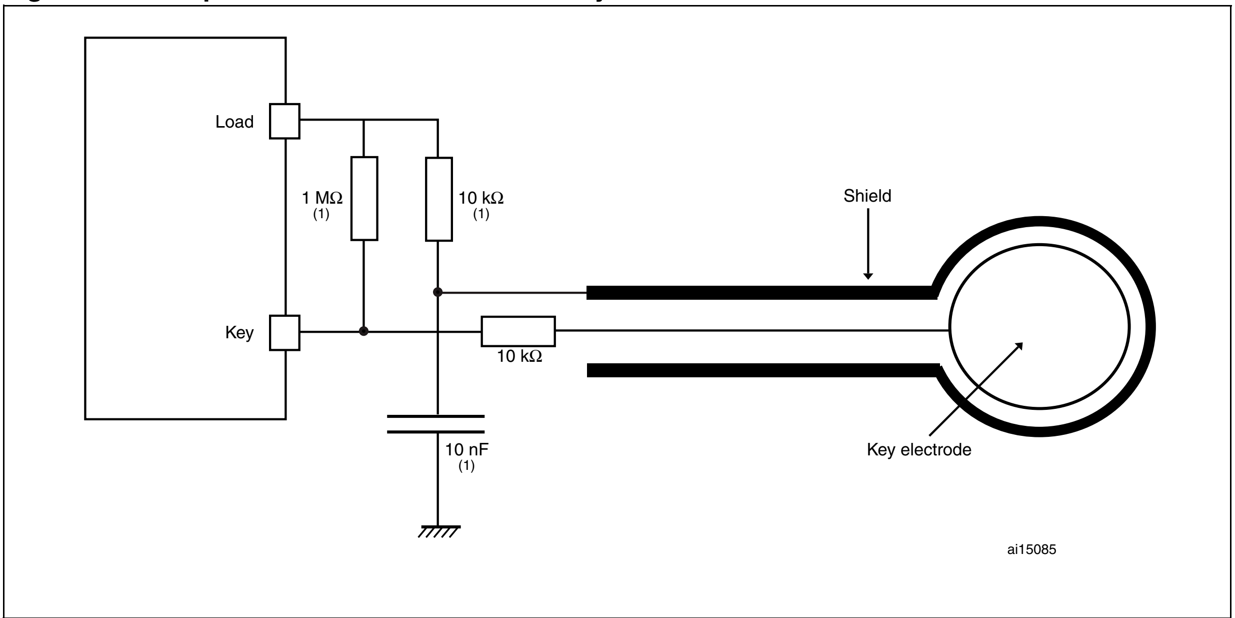
4 Driven shield

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

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

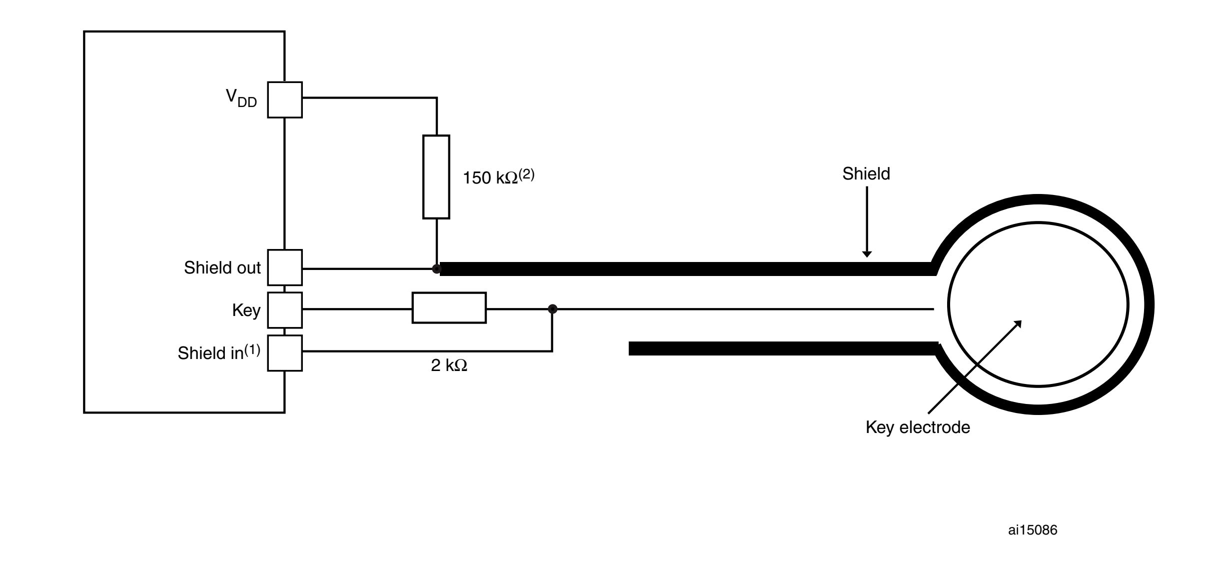
- The parasitic capacitance between the electrode and the shield no longer needs to be charged. This cancels the effect on the sensitivity.
- A driven shield is useful for certain applications where shielding may be required to:
  - Protect the touch electrodes from the noise source
  - Remove the touch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

Figure 10. Simple driven shield with RC library



1. The value of these components depends on the design.

Figure 11. STM8T family example



1. The shield pin is not available on all products.
2. The value of this component depends on the design.

For more details refer to AN2967: Implementation of driven shield.

5 Multikeys

By combining several keys, we can design a “slider” or a “wheel” (see *Section 5.2: Sliders* and *Section 5.3: Wheel*). The goal of such sensors is not to provide a “0” or “1” signal, but, to extrapolate an intermediate position from the C_T variation on contiguous electrodes. A high number of relative positions can be extracted depending on the number of the electrodes and their sensitivity.

5.1 Special recommendations for multikeys

Given that the sensitivity must be very high in order to be able to extract the most accurate position, neither the power plane nor any application signal should run under a multikey sensor.

5.2 Sliders

A slider 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 elements, depending on the required size and resolution. When using the charge transfer acquisition principle, it is possible to use only three elements thanks to the higher resolution achieved.

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

5.2.1 Slider size and layout

There are various possible designs for sliders.

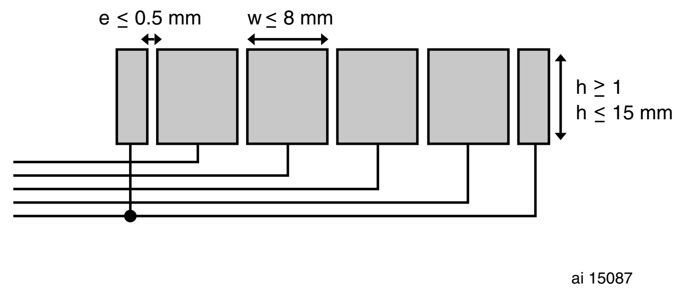
The size and targeted application tend to dictate the slider layout. However, some general rules apply to any kind of layout:

- 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 spot and both should be connected so that the slider is well balanced (see *Figure 12*).

There are different kinds of sliders:

- Normal patterned sliders
- Interlaced patterned sliders

Figure 12. Normal patterned slider with five elements (20-50 mm long)



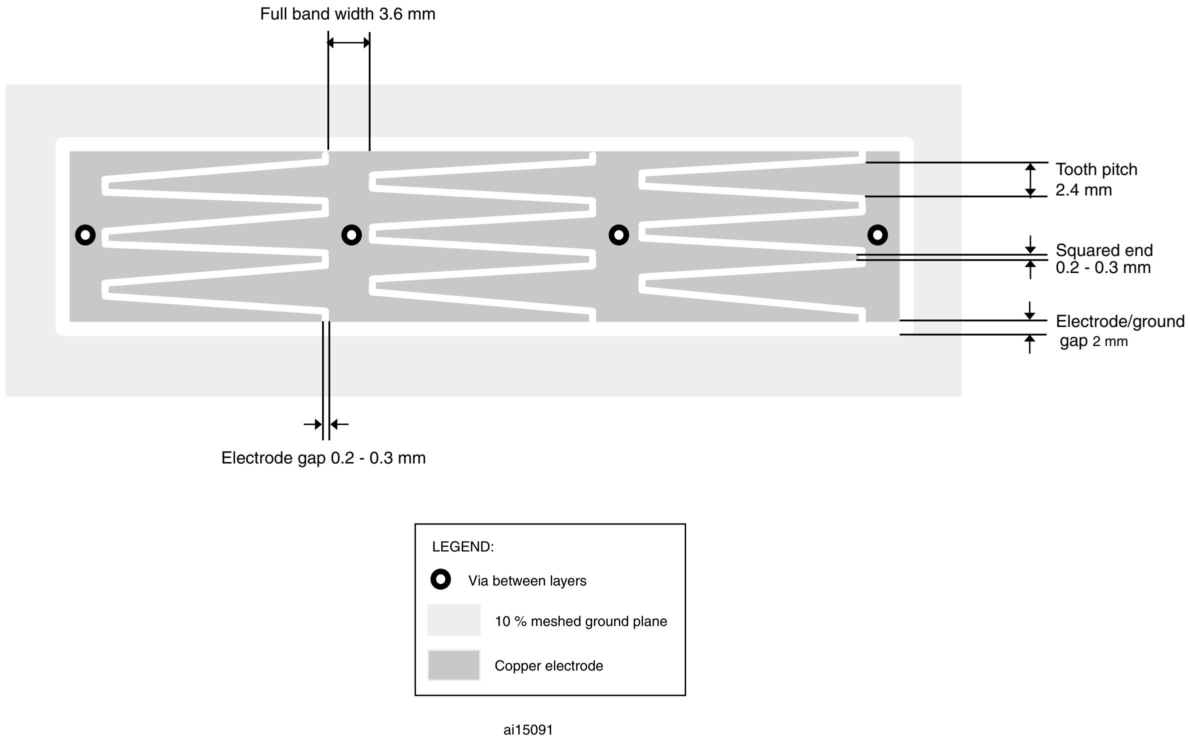
1. Legend: e is the gap between two sensor electrodes, h is the height of the sensor electrode, and w is the width of the sensor electrode.

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

To get larger sliders, the number of items can be increased to eight.

With a normal patterned slider, 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 used an interlaced item with crisscross teeth as shown in *Figure 13.*

Figure 13. Interlaced slider with three elements (up to 60 mm long)



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

5.3 Wheel

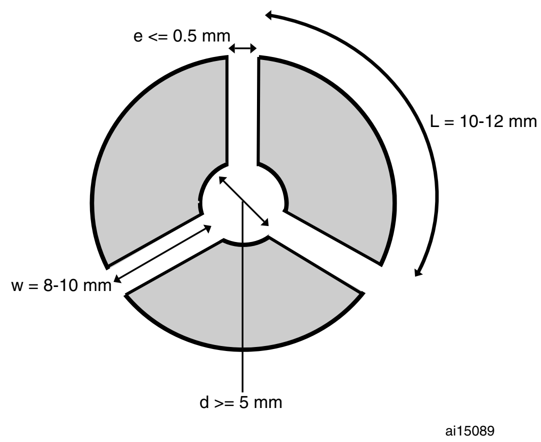
The wheel is a set of contiguous capacitive objects (placed in a circle) connected to the controller pins. It consists of a set of three, five or eight elements that can be interlaced, like the slider.

5.3.1 Wheel size and layout

There are two kinds of wheels:

- Normal patterned wheels
- Interlaced patterned wheels

Figure 14. Normal patterned wheel (three electrodes)

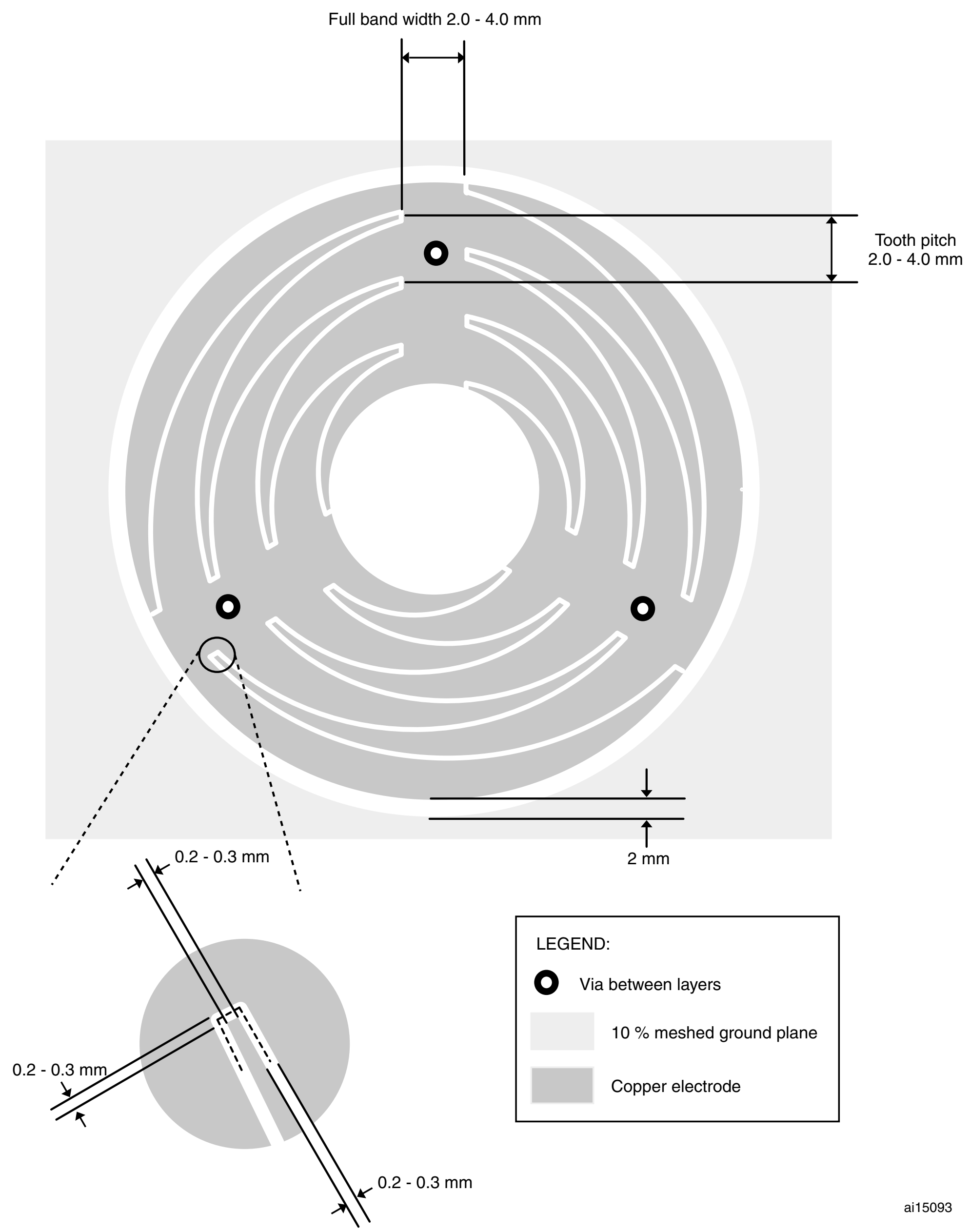


1. Legend: d is the diameter of the center, e is the gap between two sensor electrodes, w is the width of the sensor electrode, L is the length of the external perimeter of the sensor electrode.

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.

The three-electrode wheel can be used for bigger wheels 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 15. Interlaced patterned wheel



5.3.2 Central touchkey

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

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 2. 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.