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 are used in many applications, simple or more complex. These interfaces consist of sensing elements made from conductive elements, such as copper, connected to the touch sensing controller device.

The physical design of the printed circuit board is important and must comply with certain general guidelines that are applicable to all types of applications.

This document provides simple guidelines concerning three main layout aspects:

1. printed circuit board (PCB),
2. overlay materials,
3. all another elements not related to PCB or touch sensing such as the chassis or LEDs.

Contents

2 PCB general guideline

When designing printed circuit boards (PCB) for a capacitive sensing application, it is important to take into account more than just the circuit that is involved directly with the sensing. The entire circuit affects the capacitance of the sensor elements and their traces. Most often, PCB elements have a negative effect on sensitivity. Hardware elements such as capacitors, connectors, resistors, LEDs, etc. add parasitic capacitance to the connected touch sensing buttons. Traces, even those not involved with sensing, can couple with sensing elements and further decrease application performance.

These reasons and many others explain why the entire board layout must be carefully examined and optimized when designing capacitive sensing applications.

2.1 Board area

For capacitive sensing, only the area covered by the sensing elements and by the trace are important. It is good practice to keep this area small by reducing the distance between the controller device and the sensors to a minimum. Centering the device among the sensor elements is one way to ensure an optimized board area.

2.2 Ground plane

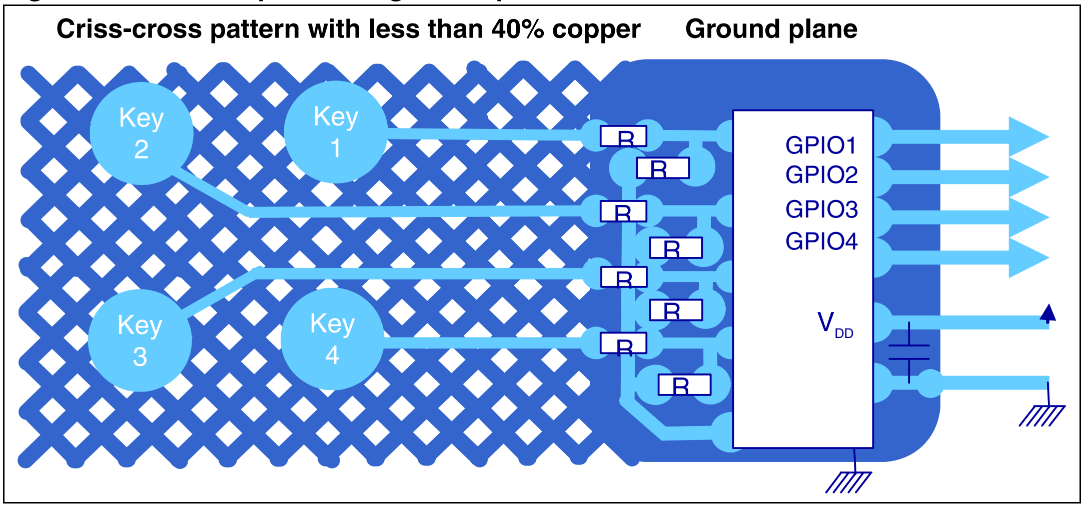
It is not recommended to run sensor tracks over any power plane.

Ground or power floods below sensor tracks increase parasitic capacitance to the ground and reduce sensitivity.

When a ground plane is placed under a sensor, the plane must use a criss-cross pattern with less than 40% copper (*Figure 1*) and placed on the furthest layer to help reduce parasitic capacitance to ground while maintaining a good shielding effect. See also *Section 3.1.4: Button-ground clearance on page 9*.

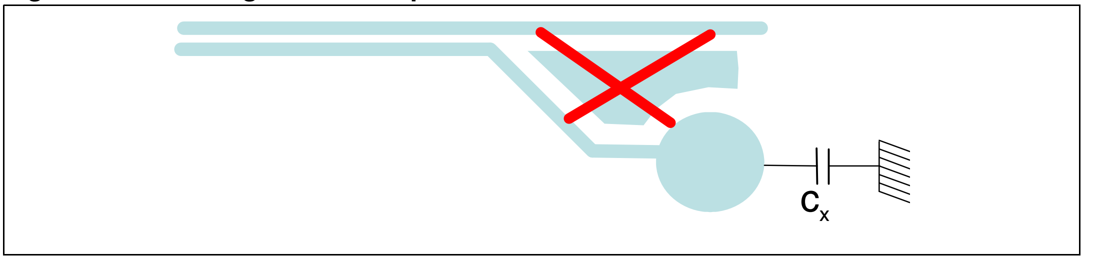
In noisy environments, the most sensitive area may require a ground plane.

Figure 1. Ground plane design examples



Keep any floating metal away from the sensor signals (*Figure 2*) to prevent sensing field re-radiation and to reduce unwanted effects.

Figure 2. Floating metal example



2.3 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 sensibility.
- The implementation is useful:
  - “LOAD” signal can be used by the RC software library for driving the shield
  - A dedicated pin can also be used to drive the shield, as seen in STM8T products
- Driven shield is useful for certain applications where shielding may be required to:
  - Protect the touch electrodes from the noise source
  - Remove the touch sensibility from a cable or track which are placed between the electrode and the sensing device
  - Increase performance when a moving metal part is close to the sensing device

Figure 3. RC library

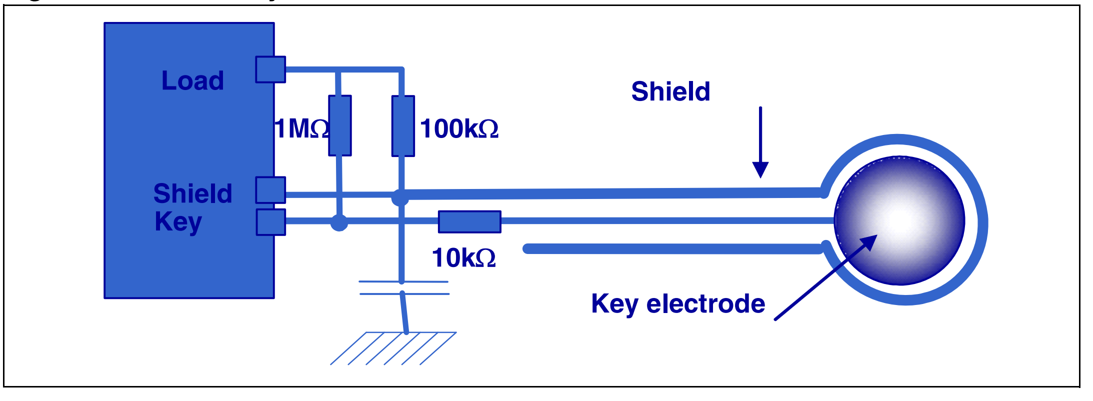
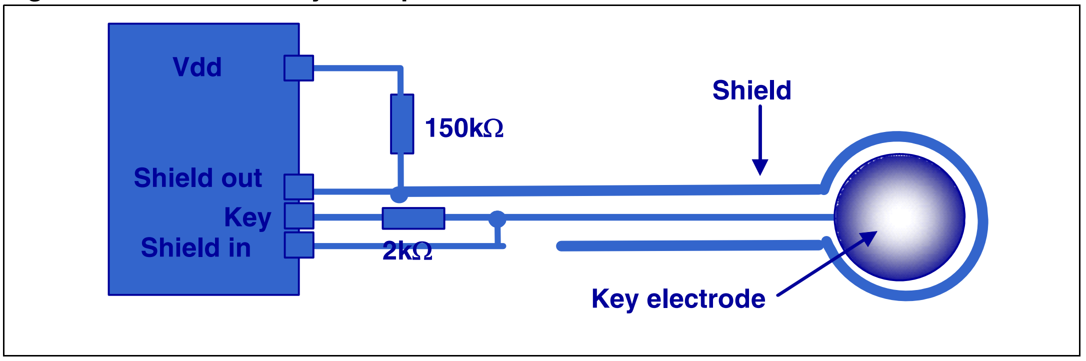


Figure 4. STM8T family example



2.4 Communication line isolation

Do not run capacitive sensing traces close to high-frequency communication lines, such as an I²C or SPI master. The frequency in communication lines can impact the performance of the capacitive sensors.

If it is necessary to cross communication lines with sensor pins, ensure the intersection is orthogonal, as shown in *Figure 6* and *Figure 5*.

Figure 5. Same-layer processing of sensing and communication lines

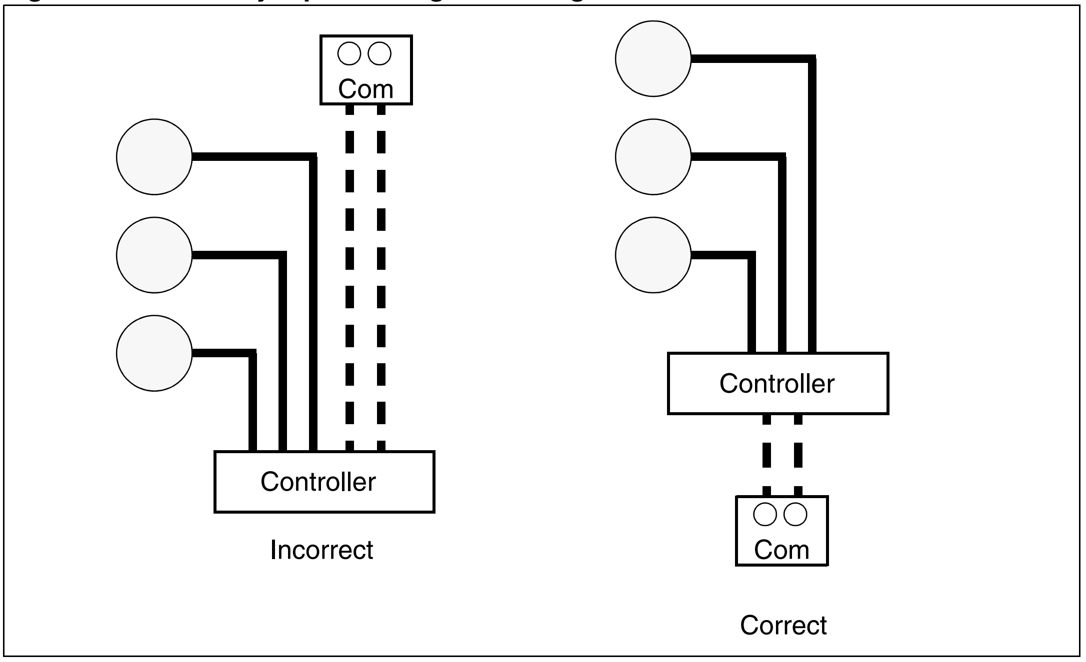
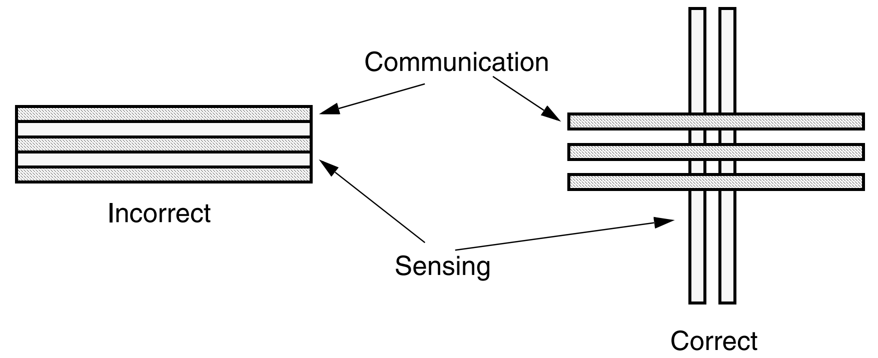


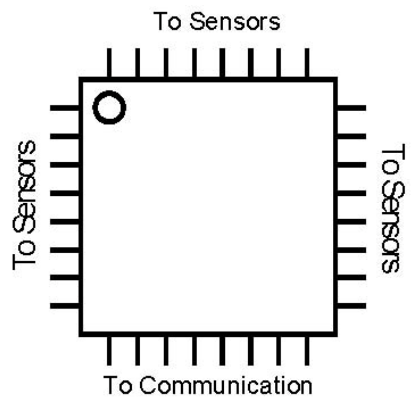
Figure 6. Multi-layer processing of sensing and communication lines



An effective method for reducing the interaction between communication and sensor traces is to select pins mapped on the same side of the package for the touch sensing controller.

Figure 7 shows a device with a 32-pin QFN package using this type of isolation. Communication and addressing pins are assigned to one side, while sensing is achieved on the other.

Figure 7. Port isolation for communication and sensor pins



2.5 Use of LEDs

LEDs are very often implemented near capacitive sensors buttons on application boards. These diodes are very useful to ensure that the button is correctly touched. When designing applications boards with LEDs, the following considerations must be taken into account:

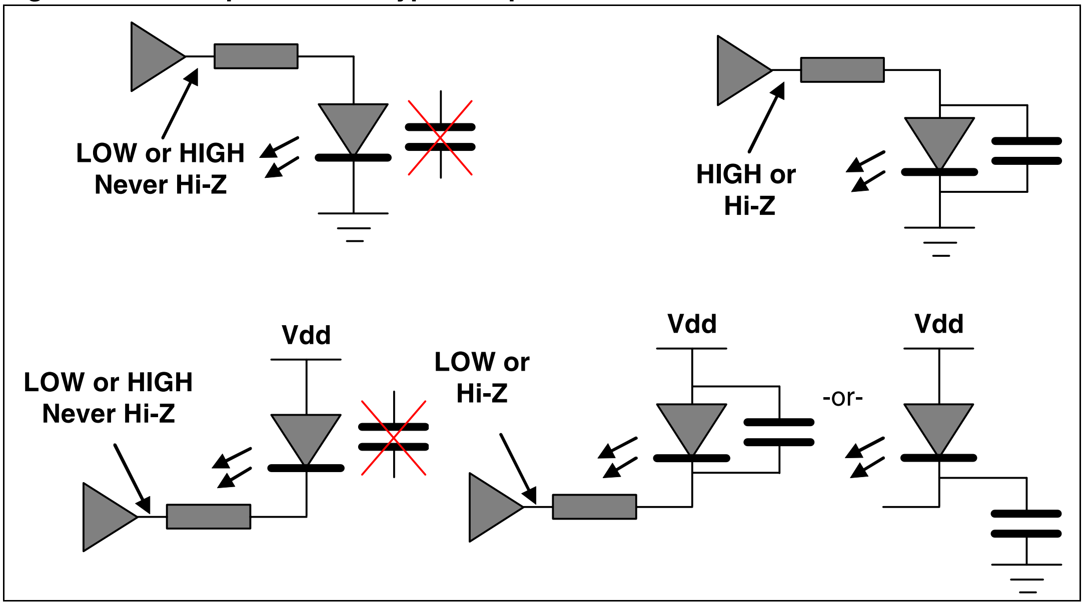
- LEDs change capacitance when switched on and off
- LED driver tracks can change impedance when switched on and off
- LED load current can affect the power rail

If the LEDs are close to the sensors and very often activated, it is recommended to bypass the LED or its driver track with a capacitor (less than 1nF).

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

The examples of bypass capacitors for the LED using a driver shown in *Figure 8* can also be applied to transistors.

Figure 8. Examples of LED bypass capacitors



2.6 Voltage regulator

It is strongly recommended to use a voltage regulator for the power supply of the device. The voltage regulator should be placed as far as possible from the sensor trace and the sensing device.

The voltage regulator also acts as a filter against conductive noise coming from the power supply.

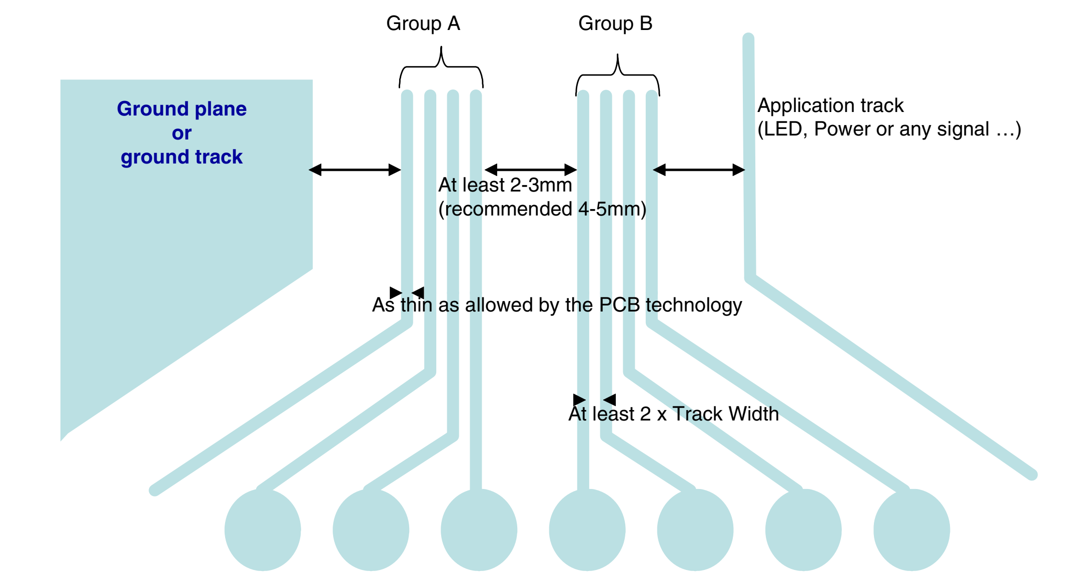
3 Electrode and element design

The goal of a good PCB layout is to minimize the effect of (non-sensing) elements that do not contain conductive materials, such as copper, that may affect the sensitivity of buttons, slider and touch pads.

When designing the PCB, the following recommendations should be taken into account:

- Run tracks to electrodes over short distances (less than 100mm if possible)
- Use tracks as thin as allowed by the selected PCB technology
- Keep the resistive load as close as possible to the controller
- For touchkeys, space adjacent key tracks so that gap is at least twice the track width

Figure 9. Sensing element definition



Sensing elements

The goal of PCB layout should be to minimize the interactions between elements or, if they cannot be minimized, 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.

Traces belonging to the same pin group can be close together as shown in *Figure 9*.

The following sections describe the most obvious factors and provide guidelines for designing a good board layout.

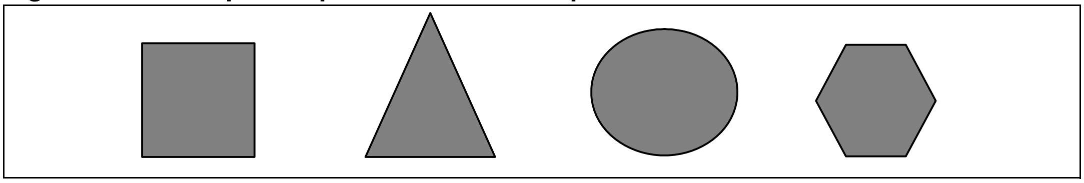
3.1 Surface capacitance buttons

A surface capacitance button consists of a single-ended copper electrode connected to the device. It does not have to be highly sensitive as it needs only to determine the presence or absence of a finger.

3.1.1 Shape

All types of shapes can be used for capacitive touch sensing. *Figure 10* shows examples of possible shapes. Different shapes do not affect sensing characteristics, but concern board esthetics only.

Figure 10. Examples of possible button shapes



3.1.2 Size

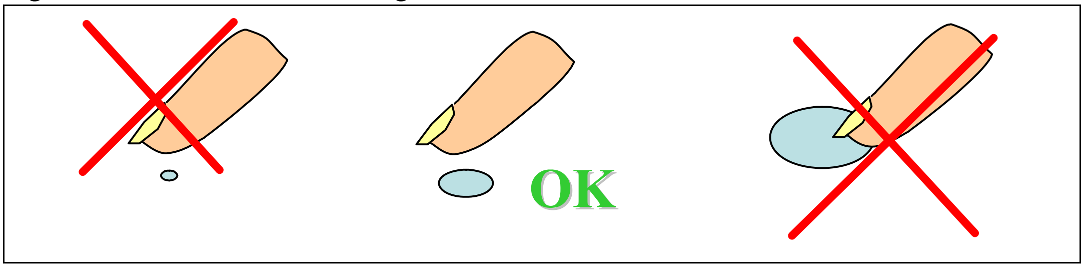
All things being equal, larger buttons are typically better. Two buttons connected to the device with identical traces will have different sensitivities if they are different in size.

A very small button have low surface area and therefore will have a lower touch capacitance (C_T) and possibly a very poor sensitivity.

Making buttons larger has not been shown to improve C_T.

However, increasing the button surface in order to be similar to the item to be sensed (finger, thumb, etc.) will increase the C_T observed.

Figure 11. Button size and finger size



For finger sensing, buttons with a diameter of at least 0.4 inches (10 mm) are recommended. Smaller buttons can work, but performance is diminished.

Large buttons are more sensitive, however the upper limit of the button size is set by the effective area of the conductive object.

3.1.3 Button-button spacing

Buttons can be adjacent without any problem but when the pitch is small and buttons are very close together, there may be unwanted interaction between buttons.

3.1.4 Button-ground clearance

When possible, the ground plane should be not placed on the same layer of the board as the sensing elements.

Placing the ground too close to the sensing elements adds capacitance and affects the measurements used to detect finger presence.

3.2 Sliders

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

It can be composed of a set of 5 or 8 elements, depending on the required size and resolution.

Sliders use differential capacitance changes between adjacent capacitive elements to determine the central (center of mass) position of a conductive object with greater resolution.

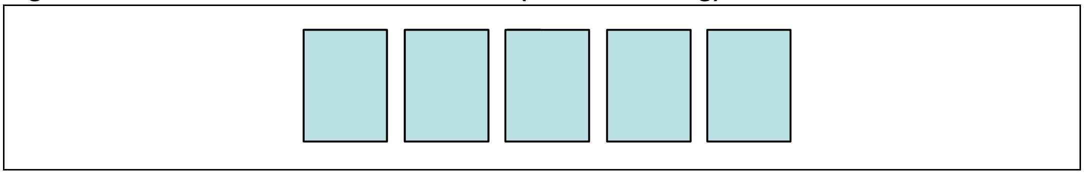
3.2.1 Slider size and layout

There are various possible designs for sliders.

The size and targeted application tend to dictate the slider layout.

To ensure that a conductive object couples to more than one element, each element must be small enough so that the finger overlaps its outside edge. However, it must also be large enough to function (sense) through the application overlay.

Figure 12. Small slider with 5 elements (20-50 mm long)



For medium or large sliders, to create more overlap between slider elements, which provides better differential change between elements, a sawtooth pattern can be used.

We also could use a set of 8 elements in order to have a better resolution.

Figure 13. Medium/large slider (40-60mm long)

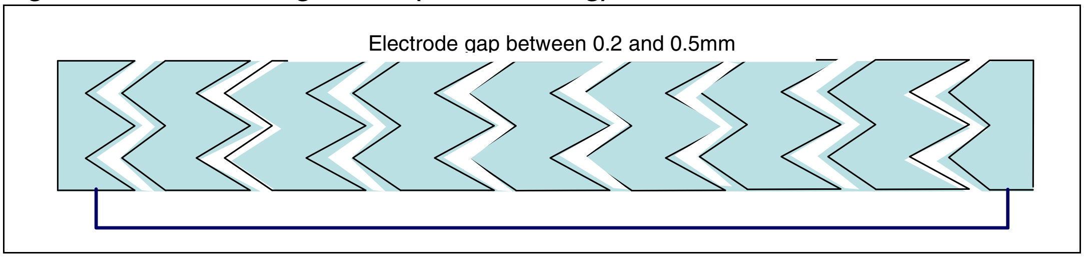
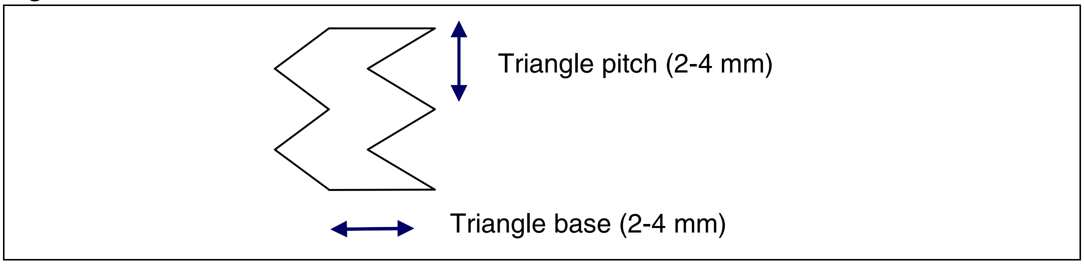


Figure 14. Sawtooth details



3.2.2 Spacing

Spacing slider elements with regard to the surrounding ground plane is the same as for buttons. A space of 0.020 inches (0.5 mm) between the slider element and the ground plane reduces the fringe capacitance between the two enough so that its impact on sensing is low.

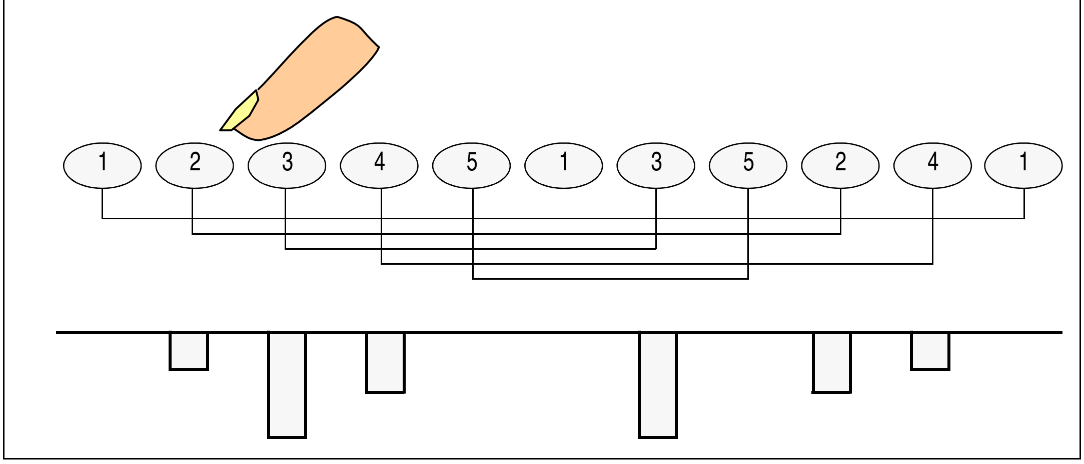
3.2.3 Diplexing

Diplexing elements normally provides a better resolution than with contiguous elements, but it is more sensitive to hand shadows.

The advantage of diplexing instead of using contiguous element depends on the slider application. Connecting two slider elements to a single pin increases the number of slider elements that can be sensed by the device. An example of a diplexed slider is shown in *Figure 15*. five is the minimum practical number of pins to use in a diplexed slider. *Table 1* shows some basic diplexing tables.

Figure 15 represents also the data collected by the device relative to finger position. The capacitance of both elements connected to the pin increases. Though changes in capacitance are detected in more than one place, there is only one location (of the two) at which all the adjacent elements have a higher capacitance than the baseline.

Figure 15. Basic example of a diplexed slider (10 electrodes)



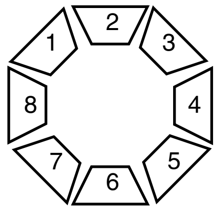
When a signal is detected on three consecutive channels, it means the finger is in that area.

Table 1. Common diplexing tables

Slider	Diplexing table
5 pins, 11 elements	1 2 3 4 5 1 3 5 2 4 1
8 pins, 17 elements	1 2 3 4 5 6 7 8 1 4 7 2 5 8 3 6 1

3.3 Wheel

Figure 16. Basic wheel example (8 electrodes)



Same as for the slider, the wheel is a set of contiguous capacitive objects (placed in a circle) connected to the controller pins. It consists of a set of 5 or 8 elements that can be interlaced, like the slider, or directly connected.

3.4 Capacitive sensing traces

Traces between the touch sensing controller and the sensors decrease the sensitivity of the sensors by increasing button capacitance and decreasing the signal. Trace length decreases sensitivity because it adds parallel capacitance to the sensing circuit that does not interact with the finger position, and therefore does not contribute to the signal. Trace length increases noise because the trace picks up noise from both in-circuit and external noise sources.

3.4.1 Length

Shortening trace lengths from the device to the sensor reduces the risk for other design elements to couple to sensing traces. It is best to design traces between the touch sensing controller and the sensors as short as possible.

3.4.2 Width

Trace width adds to sensor capacitance by adding copper area to the system. It also increases coupling with elements on other layers by way of the increased copper area. So, whenever possible, traces should be kept small and away from the ground.

3.4.3 Placement

Placement of capacitive sense traces must minimize interaction with other design elements, including other capacitive sense traces, whenever possible.

Also, keeping traces on the side opposite of the user PCB decreases the impact of a finger on the traces, ensuring that all capacitive changes on the sensor pin is from the finger's (or other conducting object's) interaction with the active sensing area, and not from interaction between the finger and the trace.

3.4.4 Placement by group

Each pin on the touch sensing controller, which belongs to the same device port can be driven together by the software library and are mapped in the same group by software.

The trace of all pins in the same group can be close together with a minimum amount of space.

4 Overlay

It is rare that a design gives the end user access directly to the PCB. Rather, there is usually a material overlay across the surface of the PCB that protects the user from the circuit and the circuit from the environment.

Properties

Overlays in touch sensing applications MUST NOT be conductive. Metals and other conductive materials do not form the dielectric of the capacitor when placed between two conductive plates, such as the finger and the sensor.

The capacitance of a parallel plate capacitor is given in *Equation 1*.

Equation 1

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

The geometry of this simple system is captured in the ratio *A*/*d*. *A* is the area of the conductive plates, *d* is the distance between the plates, ε_R is the dielectric constant (permittivity) of the material between the sensors, and ε_0 is the permittivity of free space.

The geometry of the capacitive sensor is more complex than the parallel plate capacitor. The conductors in the sensor include the finger and PCB copper. In general, the geometry of this capacitive system is captured by the function f(*A*,*d*). *Equation 2* states the relation between geometry, the dielectric constant, and the system capacitance.

Equation 2

$$C = \varepsilon_R \varepsilon_0 f(A,d)$$

Like the parallel plate capacitor, the capacitance of the sensor is directly proportional to ε_R.

Different materials

Table 2 lists the dielectric constants of some common overlay materials. Materials with high dielectrics better propagate electrical fields, as with capacitive sensing applications.

Table 2. Dielectric constants of common materials

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

Table 2. Dielectric constants of common materials (continued)

Material	ε_R
Polyethylene Terephthalate (PET)	3.7
FR4 (fiberglass + epoxy)	4.2
PMMA (Poly methyl methacrylate)	2.6 to 4
Typical PSA (glue)	2.0 - 3.0 (approx.)

For a panel built from a stack of different materials, it is possible to have different sensitivities depending on the material of each layer.

For instance, a stack of plastic + glue + PCB will have a better sensitivity than a stack of plastic + air + PCB.

Air, with a dielectric of 1.0 is not well suited to capacitive sensing applications.

This is why air gaps between sensors and the overlay material are not recommended. Eliminating air gaps is also a good practice from a mechanical point of view.

Thickness

Overlay thickness is inversely proportional to sensitivity.

Wheels and sliders require a good sensitivity, so the overlay thickness must be small (approx. 1 mm).

Buttons can support a more important overlay thickness (up to 5mm).

5 Chassis

The chassis of a touch sensing application affects the sensitivity of capacitive sensors by interacting with the sensors and the traces between the controller and the sensors. A metal chassis can be a ground and will tend to make the application less sensitive.

The three most common chassis design elements that impact touch sensing are metal support structures, communication wires, and the plating of the overlay material on the sensing PCB.

Metal support structures must be kept away from sensing elements and traces whenever possible. Where support structures are necessary, non-metal structures are recommended. If metal is required for structure or decoration close to the sensor, it must be grounded.

The chassis can be also connected to the driven shield if it is implemented.

Communication cables must also be kept away from sensors and traces whenever possible.

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.

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

7 Revision history

Table 3. Document revision history

Date	Revision	Changes
02-Feb-2009	1	Initial release.