

Touch Sensors

Design Guide







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Introduction To Sensor Design

1.1 Introduction

The process for designing products that use touch controls is a complex process with many decisions to be made, such as what materials will be used in their construction and how the mechanical and electrical requirements will be met. Key to this process is the design of the actual sensors (specifically keys, sliders, wheels and touchscreens) that form the interface with the user.

Sensor design is often considered a “black art”; the distributed nature of the electric fields between the sensor and its electrical environment can make simple “lumped element” approximations of sensor behavior misleading at best. Nevertheless, by following a few essential rules, it is possible to produce a resilient design that ensures that the sensors will operate in a reliable and consistent manner.

This design guide describes the rules that can be used to create sensor patterns on PCBs or other conductive material, such as Indium Tin Oxide (ITO). There are, of course, many possible configurations for such sensors, and this guide cannot be exhaustive; however, it will aid in the initial selection and construction of sensors for touch-enabled products, and should provide an excellent starting point.

You should also refer to QTAN0032, *Designing Products with Atmel Capacitive Touchscreen ICs* for an overview on designing capacitive touchscreens.

1.2 Self-capacitance and Mutual-capacitance Type Sensors

Atmel® touch controllers allow for two families of sensors, each using one of two charge-transfer capacitive measurement styles:

■ Self-capacitance type sensors

A self-capacitance type sensor has only one direct connection to the sensor controller. These sensors tend to emit electric fields in all directions, and as such are quite non-directional. They can work with and without an overlying panel, although a panel is always recommended for electrostatic discharge (ESD) reasons ⁽¹⁾. This type of sensor is suitable for implementing keys using QTouch™ sensor controllers.

■ Mutual-capacitance type sensors

A mutual-capacitance type sensor has two connections to two parts of the sensor: an X (transmit) electrode, and a Y (receive) electrode. The mutual capacitance from X to Y is measured by the sensor controller. Because of the close-coupled nature of the fields with this type of sensor, it is only suitable for use when bonded to an overlying panel so that no significant air gaps or bubbles are present; the overlying panel forms an essential conduit for the field from X to Y. This type of sensor is suitable for implementation with QMatrix™ sensor controllers.

Background information on Atmel’s capacitive sensing methods can be found at www.atmel.com.

1. Direct contact with the sensor carries an elevated risk of ESD damage for the control chip.

1.3 Dimension Groups

In addition to the self- and mutual-capacitance types described in [Section 1.2](#), sensors can also be split into three groups, depending on the number of dimensions they use (see [Figure 1-1](#)):

- **Zero-dimensional sensors**

A zero-dimensional sensor is one that represents a single point of contact. The typical implementation of a zero-dimensional sensor is a key.

- **One-dimensional sensors**

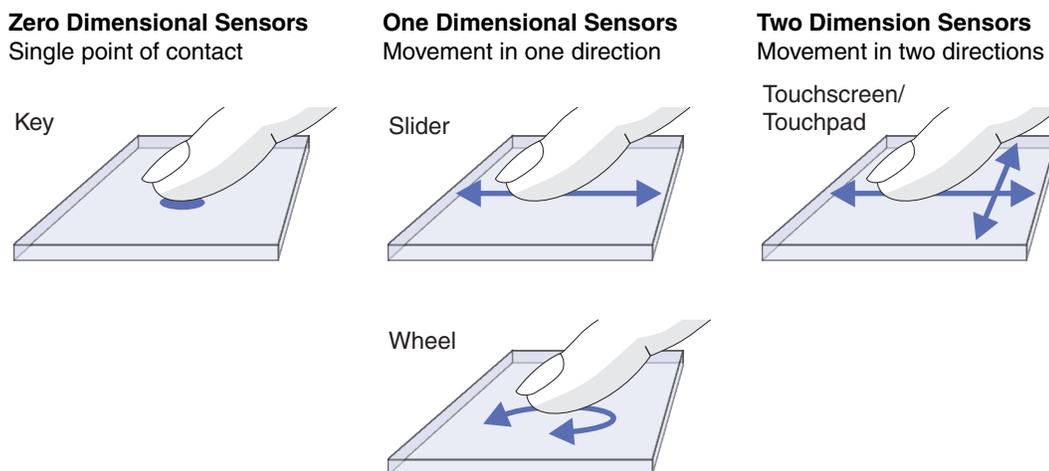
A one-dimensional sensor is one that detects the linear movement of a finger during touch (that is, along a single axis). Typical implementations of one-dimensional sensors are sliders and wheels.

- **Two-dimensional sensors**

A two-dimensional sensor is one that detects the movement of a finger during touch along two axes. Typical implementations of two-dimensional sensors are touchscreens and touchpads.

When considering the design of a sensor, you will need to consider both the sensor type and the dimension group, making six possible combinations in total. The combinations for zero-dimensional and one-dimensional sensors are discussed individually in [Section 3](#) to [Section 6](#); two-dimensional sensors are not covered by this version of the guide. For information on designing two-dimensional sensors, see the full version of this guide (available under a non-disclosure agreement only).

Figure 1-1. Sensor Dimensions



1.4 Some Important Theory

You will need to be aware of the following terms when reading this document:

- **C_x**: The electrode's natural capacitance, separate from any parasitic capacitance
- ϵ_r : The relative dielectric constant of the overlying panel material (see [Figure 1-2](#) on page 1-3)
- ϵ_0 : The capacitance per meter of free space, defined as 8.85×10^{-12} F/m
- **T**: The thickness of the overlying panel in meters (see [Figure 1-2](#))
- **A**: The area of the touched region in square meters (see [Figure 1-2](#))
- **C_p**: Any parasitic capacitance added in parallel with C_x
- **SNR**: Signal to noise ratio: a measure of the quality of the capacitive measurement

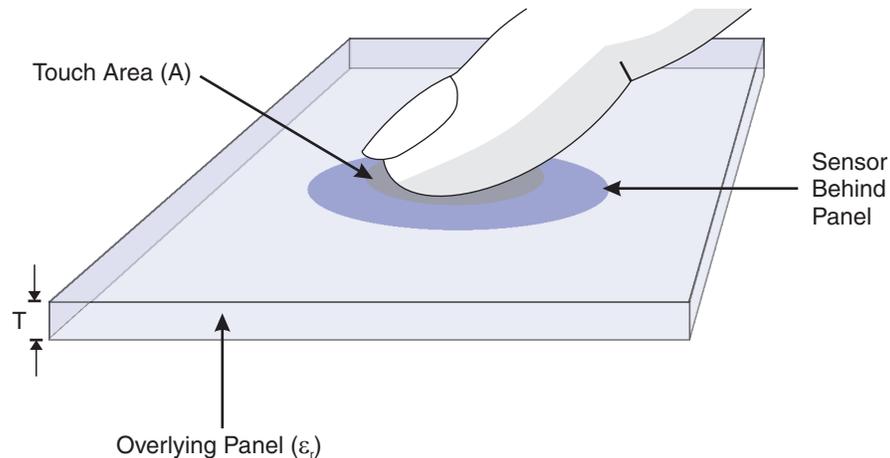
Capacitance (C) is defined in [Equation 1-1](#).

Equation 1-1. Capacitance

$$C = \frac{\epsilon_0 \times \epsilon_r \times A}{T}$$

It should therefore be clear that thinner panels and higher dielectric constant materials yield higher capacitance change during touch and hence a higher gain and a better SNR. [Section 2.3.3 “Front Panel Materials”](#) on [page 2-5](#) discusses the thickness of the panel and its effect on the SNR.

Figure 1-2. Touchscreen Panel



In the context of capacitive sensors, SNR is defined as in [Equation 1-2](#).⁽¹⁾ See [Figure 1-3](#) for definitions of the touch signal levels.

Equation 1-2. SNR

$$\text{SNR(dB)} = 20\text{Log}(\text{TouchStrength} / \text{NoiseTouched}_{\text{RMS100}})$$

$$\text{TouchStrength} = \text{SignalTouched}_{\text{AVG100}} - \text{SignalUntouched}_{\text{AVG100}}$$

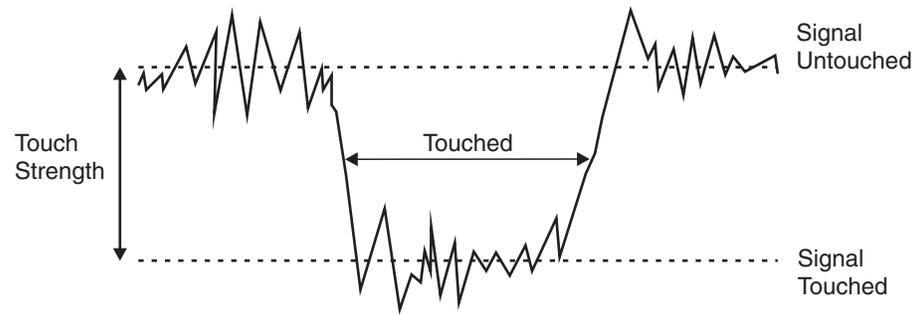
$$\text{NoiseTouched}_{\text{RMS100}} = \sqrt{\frac{\sum_{n=0}^{n=99} (\text{Signal}[n] - \text{SignalTouched}_{\text{AVG100}})^2}{100}}$$

where:

- AVG100 means the simple numeric average of 100 data points, typically taken evenly spaced over a period of 2 seconds.
- RMS100 means the root-mean-square of 100 data points, typically taken evenly spaced over a period of 2 seconds, using the AVG100 figure as a baseline.

1. Note that this definition uses the RMS noise present during touch, as this is the worst case.

Figure 1-3. Touch Signal Levels





2.1 Charge Transfer

Atmel's capacitive sensors work on a principle called charge transfer. This uses a switched capacitor technique to assess relative changes in a sensor's capacitance as it is touched.

Charge transfer works by applying a voltage pulse to series connection of the unknown capacitance C_x and a charge integrator capacitor C_s . By repeating the pulse multiple times, a high resolution measurement system is realized that can detect changes in capacitance of just a few femtofarads ⁽¹⁾.

In order to obtain stable and repeatable results, it is important that the voltage pulse is allowed to settle properly and hence transfer all the charge into C_x and C_s (see [Figure 2-2 on page 2-2](#)).

Because C_x and C_s are normally connected with some amount of series resistance, the RC time constants so formed will tend to slow down this settling process.

It is therefore important that when designing a capacitive touch system that the amount of series resistance is kept in mind in combination with the size of C_x (the sensor's capacitance).

Series resistance is normally deliberately introduced to improve electromagnetic interference (EMI) and ESD behavior (see the device datasheets for recommended series resistors). For some designs, significant extra resistance can be introduced because of the resistivity of the tracks connecting the sensor, or the resistivity of the electrode material itself. This is normally only true for designs using material like Indium Tin Oxide (ITO), Orgacon™ ⁽²⁾ or Carbon with high Ω/sq values. However, there are situations where adding deliberate extra series resistance can be beneficial, most notably in designs with difficult ESD conditions or where emissions must be controlled to very low levels. A 10 k Ω series resistor can be a good choice. In either case, RC time constants can degrade the charge-transfer process so some precautions must be taken.

For all designs, it is good practice to measure the settling time of the charge-transfer pulses to make sure they are fast enough to work reliably. This can be done by observing the pulses using an oscilloscope and coupling the scope probe to the sensor electrode capacitively ⁽³⁾ using a small coin on top of the overlying panel, or using a small piece of copper tape instead (see [Figure 2-1 on page 2-2](#)). The charge pulses should have substantially flat tops, that is the voltage has settled before the pulse ends (see [Figure 2-2 on page 2-2](#)).

1. One femtofarad is 1/1000 of a picofarad.

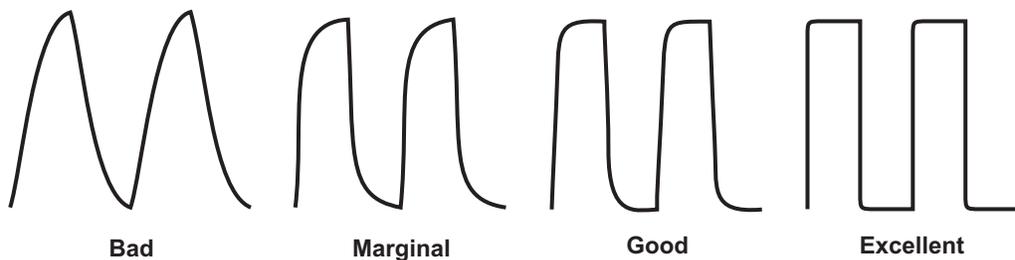
2. Orgacon™ is a trademark of Agfa-Gevaert Group. Orgacon is a printable conductive ink using a PEDOT polymer base. Care should be taken when assessing this material's suitability for sensor construction due to the high starting resistivity and the fact that this resistivity is known to increase over life depending on its exposure to UV, heat and moisture (and any other oxidising substance). Consult Agfa before making any design decisions.

3. Probing the sensor directly will add the capacitance of the probe and so give an unrealistic wave shape.

Figure 2-1. Measuring the Charge-transfer Pulses



Figure 2-2. Good and Bad Charge Pulses



As a rule, the overall RC time constant of each sensor should be reduced as far as possible, while trying to preserve at least a 1 kΩ series resistor close to the sensor chip. A good rule-of-thumb is given in [Equation 2-3](#).

Equation 2-3. Rule Of Thumb for RC Time Constant

$$R_{series_total} * (C_x + C_p) \leq 5 * T_{charge}^{(1)}$$

Where:

- R_{series_total} is the total series connection from the sensor chip’s pin to the farthest point on the sensor.
- $C_x + C_p$ represents the total capacitance that the sensor chip detects for the sensor (that is, the sensor itself plus any parasitic capacitance). Measuring this can be done for a first order approximation using a commercial capacitance bridge. A more practical approach is to measure the pulse shapes as described above.
- T_{charge} varies somewhat from sensor chip to sensor chip, but a good estimate is 1 μs for zero- and one-dimensional sensors, and 2 μs for two-dimensional sensors.

The “Marginal” example in [Figure 2-2](#) represents about 3 time constants; the “Good” example represents about 5 time constants.

1. The factor of 5 ensures that each charge-transfer pulse settles to better than 99 percent, leaving just 1 percent of charge subject to 2nd order effects like the R_{series} value, chip output drive strength, etc.

2.2 Components

2.2.1 Cs Capacitor

Charge transfer uses an integration capacitor (Cs) to measure changes in Cx. The Cs capacitor accumulates charge over a number of charge transfer pulses. Ultimately, the voltage on Cs is used as the basis of the measurement. Clearly then, the stability of Cs is important to obtain a consistent and repeatable measurement. In general, you can easily achieve this by making sure that Cs is an X7R or X5R type of capacitor. If possible, use a COG type, as these have the highest stability. In practice, though, this limits Cs to around 1 nF, and often Cs needs to be higher – sometimes as much as 100 nF. In this case, use an X7R or X5R type capacitor.

All Atmel capacitive sense chips use drift compensation methods to correct for slow-rate thermal changes in Cs. Faster rate changes are not possible to compensate for in this way, and for this reason you should never try to use Y5R type capacitors; they are simply too unstable.

A short-term change in Cs that can sometimes be observed on sensors using elevated gain is an effect known as dielectric absorption. This is a complex physical mechanism whereby charge becomes "trapped" in discontinuities in the dielectric lattice of the capacitor. This manifests itself as changes in the value of Cs that are a function of the previous voltage history on the capacitor. Dielectric absorption is rarely observed in practice, but every now and then it can disrupt a project, causing shifts in the background reading as the sensor chip exits from sleep mode⁽¹⁾. Note that this effect can appear only in sleep modes; it is never seen in a continuous run mode. If this kind of effect is suspected, try changing to another brand of capacitor for Cs. Some modern Hi-K ultra-small X5R capacitors (for example, 0201 size) have been shown to demonstrate such behavior. However, it has not been seen by Atmel as a significant effect for 0402, 0603, 0805 sized components.

2.2.2 Series Resistors

The series resistors are non critical and have no special characteristics. 10 percent, or better, tolerance is fine, and generally 200 ppm/°C is more than stable enough.

2.2.3 Voltage Regulator

Use a good quality linear regulated supply for Vdd to the sensor chip. Remember that long term shifts in Vdd are compensated for by the internal drift algorithms, but short-term shifts or spikes on Vdd can be problematic. Refer to the sensor chip's datasheet for advice on regulator types.

2.2.4 Component Placement

All passive components associated with the capacitive sensor should be placed as close to the control chip as is physically possible. Avoid compromises in layout in this regard; placing such components closer to the chip is always better.

1. That is, some period of no charge-discharge activity on Cs, which causes it to change value slightly.



2.3 Materials

2.3.1 Substrates

The substrate is the base material carrying the electrodes.

Almost any insulating material can be used as a substrate, but low-loss substrates are generally preferable, such as PCB materials (FR4, CEM-1, Polyamide and Kapton to name a few), acrylics like Polyethylene Terephthalate (PET) or Polycarbonate. Glass is also an excellent material.

Generally, if the substrate under consideration is commonly used for electronic assemblies, then it will also work well for capacitive sensing. Just be careful to avoid materials that are strongly hydroscopic, such as those that are paper based, as this can cause ϵ_r to change substantially with environmental conditions.

When considering the stack of materials that make up the front panel and the sensor substrate, you are always advised to glue the substrate to the front panel using pressure-sensitive or optically clear adhesive, or another suitable bonding agent. Small (less than 1 mm diameter) or infrequent air bubbles in the adhesive are generally acceptable, but large (greater than 2 mm diameter) or frequent bubbles can cause drops in sensitivity and unit-to-unit variances that are not desirable for mass production.

It is never recommended to simply push the substrate up against the front panel, as it is hard to achieve consistent sensor performance from unit to unit. Furthermore, moisture can become trapped between the two layers causing shifts in sensitivity, and optically it is very easy to end up with unsightly Newton rings ⁽¹⁾.

It is possible to construct sensors that do not rely on a substrate. These are described in this document under separate sections.

2.3.2 Electrode and Interconnection Materials

Common electrode materials include copper, carbon, silver ink, Orgacon™ and ITO.

The lower the Ω/sq resistivity of the material the better. Less than 1 $\text{k}\Omega/\text{sq}$ is preferred ⁽²⁾ as it makes control of any RC time constants much easier.

Interconnections are usually formed from low Ω/sq material because they tend to be long and thin in nature. Remember that a printed silver track at 1 $\text{k}\Omega/\text{sq}$ that is 100 mm long and 0.5 mm wide will have a resistance of 200 Ω .

It is acceptable to use a flex PCB or FFC/FPC ⁽³⁾ to act as an interconnection, but make sure you are certain that it will be mechanically stable for the intended uses of the product. The traces running in the flex will be part of the touch sensor; so if the flex shifts even a fraction of a millimeter, the capacitance to its surroundings will definitely change and might be significant, causing false touches or drops in sensitivity. Running the flex in close proximity to a metal chassis or other signals, or over the top of noisy circuitry, can cause problems too.

-
1. The colorful diffraction effect that spreads out around the center of a spec of moisture, oil or other contaminant trapped as a thin film between the layers.
 2. As should be obvious, the Ω/sq rating choice is intimately coupled with the shape and size of the electrode. Long thin electrodes or traces build up resistance extremely quickly, even for relatively low resistivities.
 3. FFC = Flat Flexible Conductor, FPC = Flexible Printed Circuit



2.3.3 Front Panel Materials

Common front panel materials include glass, plexiglas, polycarbonate and PMMA. Remember that glass front panels may require an anti-shatter layer to pass drop and safety tests; this is often an extra PET film bonded to the glass. In general, the same rules apply to front panels as apply to substrates but, of course, a common requirement is to also offer excellent transparency and cosmetic quality.

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

Table 2-1. Relative Dielectric Constants for Materials

Material	Dielectric Constant (ϵ_r)
Vacuum	1 (by definition)
Air	1.00059
Glass	3.7 to 10
Sapphire Glass	9 to 11
Mica	4 to 8
Nylon	3
Silicon	11 to 12
Silicone Rubber	3.2 to 9.8
Silicone Moulding Compound	3.7
Paper	2
Plexiglass	3.4
Polycarbonate	2.9 to 3.0
Polyethylene	2.2 to 2.4
Polystyrene	2.56
PET (Polyethylene Terephthalate)	3.0
Pyrex Glass	4.3 to 5.0
Quartz	4.2 to 4.4
Rubber	3
FR4 (Glass Fiber + Epoxy)	4.2
PMMA (Polymethyl Methacrylate)	2.6 to 4
Typical PSA (Pressure Sensitive Adhesive)	2.5 – 2.7

A useful metric when dealing with panels of different thicknesses and materials is the sensitivity factor (S), given by [Equation 2-4](#).

Equation 2-4. Sensitivity Factor (S)

$$S = \epsilon_r / t$$

where:

- t is the thickness of the layer in question
- ϵ_r is the dielectric constant of the layer in question

In the case of a stack of materials, the combined ϵ_r for the whole stack is given in [Equation 2-5](#).

Equation 2-5. Dielectric Constant (ϵ_r) for a Stack of Materials

$$1/S_{STACK} = \text{Sum}(1/S_{LAYER}[n])$$

where:

- n is the number of layers
- Sum is the sum of all terms

As can be seen, very thick panels will greatly reduce the sensitivity factor. If you need to use materials that are thicker than what is considered normal practice (for example, if you need to sense through a 20 mm glass panel or a 10 mm acrylic panel), then be very careful about anything that increases parasitic loading to the rear of the sensor. More on this in later sections.

When designing a decorated front panel, be aware that some paints and finishes can be substantially conductive (refer to QTAN0021, *Materials and Coatings Selection for Atmel Capacitive-touch Panels*, for more information).

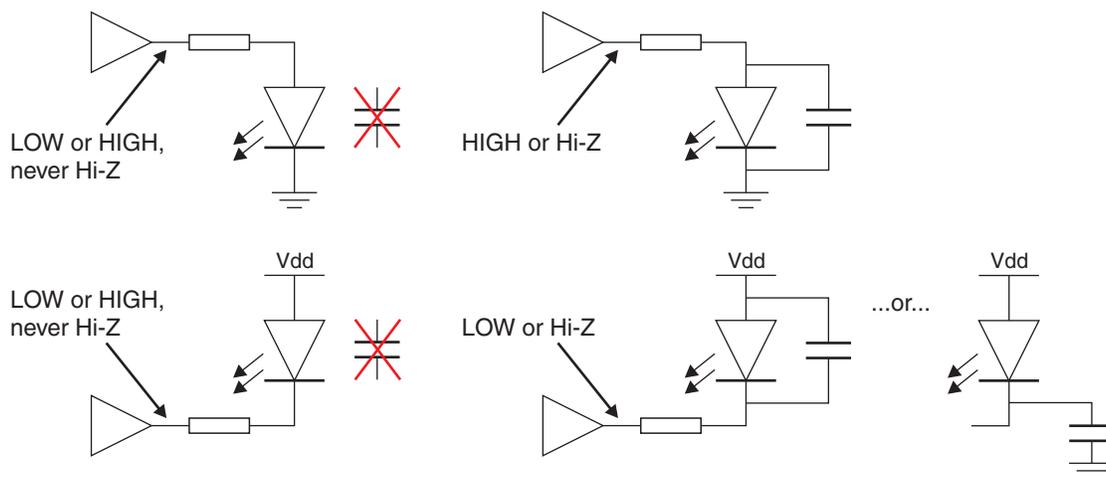
2.4 Nearby LEDs

If LEDs are close (that is, less than 4 mm away) to capacitive sensors, you must give some consideration to their change in capacitance between on and off states (and the possible change of the LED driver's output impedance too). It is also necessary to consider the changes in the nature of their drive circuitry.

As a general rule, LEDs that are judged as close must be bypassed with a capacitor that has a typical value of 1 nF⁽¹⁾ if either end of the LED changes to a non-low impedance state at any point. This is particularly important for LEDs that are pulled down or up to switch on, but are allowed to float when off.

Note that the bypass capacitor does not need to be physically close to the LED itself. Even if the capacitor is several centimeters away from the LED, it will still serve its purpose. This may aid layouts that are tight for space around the sensors.

Figure 2-3. LED Circuits



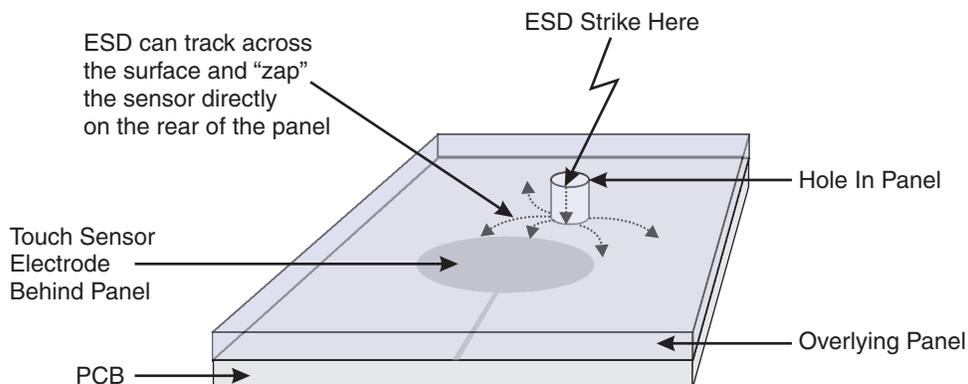
1. Non critical value. The idea is to simply provide a constant low impedance path as seen by the sensor, on both ends of the LED. Low means less than 1 k Ω at 100 kHz

2.5 Electrostatic Discharge Protection

In general, Atmel capacitive sensors do not need extra ESD protection on their electrodes or traces. Normally, the touch sensor is located behind a dielectric panel that has a breakdown potential of tens of kilovolts per mm of thickness.

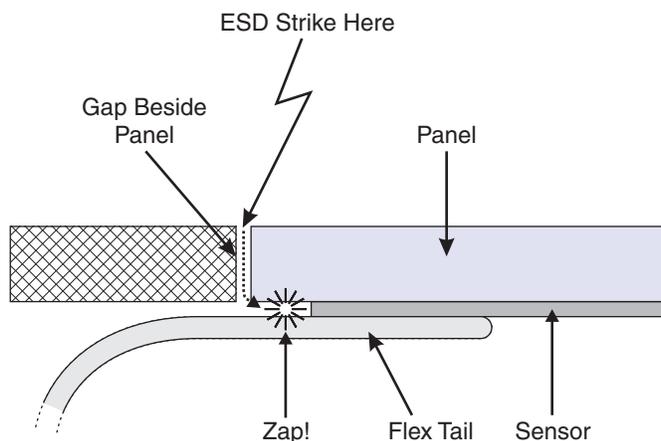
The single greatest threat from ESD tends to occur where there is a gap or hole in the panel, particularly at the edge of the panel. In these situations an effect known as "creepage" can allow ESD to track across an insulating surface and connect directly with the sensor or interconnecting tracks (Figure 2-4).

Figure 2-4. Effect of ESD Creepage



Places to watch for ESD creepage also include regions where flex circuits or tails pass close to a panel gap (see Figure 2-5).

Figure 2-5. Effect of ESD Creepage On a Flex Tail



Under extreme circumstances⁽¹⁾, where extra ESD protection must be added, consider placing very low capacitance (1 pF or less) varistors or transient suppressor devices near to the control chip.

If the creepage path is "broken" before the ESD meets the sensor, then this will block the creepage; for example, if there is adhesive on the surface around and overlapping the electrode. Generally, creepage occurs only on insulating uniform non-dissipative surfaces. This is a complex field of study that should be considered but probably not over-analyzed; simple precautions usually suffice.

1. These include direct contact sensors or situations where such gaps are unavoidable.

Self-capacitance Zero-dimensional Sensors

3.1 Introduction

This section describes how you design zero-dimensional sensors using a self-capacitance implementation (see [Section 1.2](#) and [Section 1.3](#)). These styles of sensors are typically used to implement keys for use with QTouch sensor controllers.

The guidelines for constructing a self-capacitance sensor depend on whether the construction is planar (that is, the electrodes that form the sensor and the traces are on the same insulating substrate) or non-planar (that is, the electrodes are on the inner surface of the panel and separated from the main circuit board). These two types of construction are discussed in the following sections.

3.2 Planar Construction

With planar construction, both the electrodes and the traces for the sensor are fabricated on the same plane of the insulating substrate (for example, a PCB or Flex PCB).

3.2.1 Electrode Shapes

An electrode is simply the patch of conductive material on the substrate that forms the sensor. Common shapes are filled discs, squares and rectangles (see [Figure 3-1](#)).

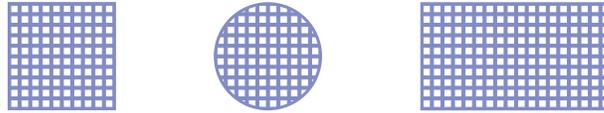
Figure 3-1. Common Electrode Shapes



The size of the electrode should be approximately the size of the object being sensed; for a finger touch this generally means discs approximately 8 to 10 mm in diameter. Larger areas will work but will show reduced sensitivity for finger touches.

It is also possible to use a hatched pattern (such as a 50 percent mesh fill) for the electrode, if desired ⁽¹⁾ (see [Figure 3-2](#)). This tends to reduce the natural capacitance of the key, but also equally reduces the area interacting with the touch, and so there is some drop in sensitivity.

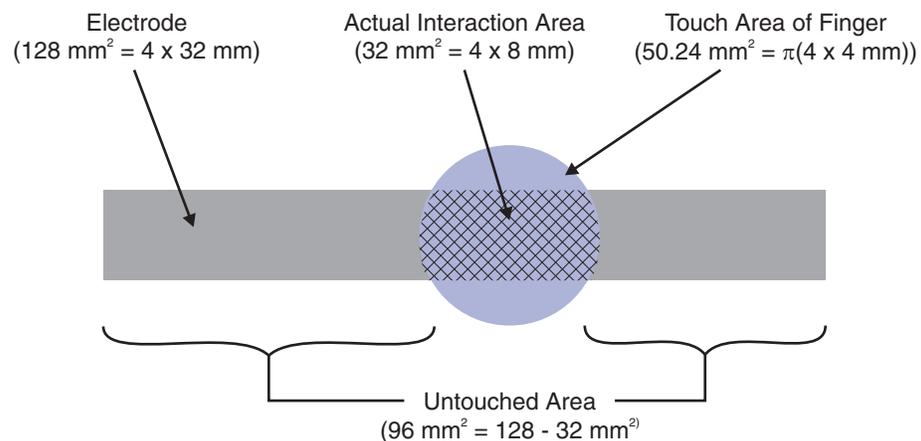
1. A mesh pattern may have some advantages for aesthetic or optical reasons.

Figure 3-2. Electrodes with 50 Percent Mesh Fills

In general, the electrode shape and size should be a close match to the object being sensed (or slightly larger). For example, if the electrode will be detecting touches from a finger, then the electrode should be either a circle or square 8 to 10 mm wide. If the electrode is larger than it needs to be, then the extra area will reduce the sensitivity (assuming that there is some nearby loading behind the sensor).

For example, consider an 8 mm diameter fingertip (see [Figure 3-3](#)) with a maximum effective touch area (a rough circle) of approximately 50 mm². If you make the electrode 4 mm by 32 mm (that is, half the width and four times the length of the finger touch), then only 32 mm² (4 x 8 mm) of the electrode's entire area of 128 mm² (4 x 32 mm) is actually covered by the touch. Thus, only a quarter of the electrode's area is "useful" at any one time. Although it is true that the electrode is touch-sensitive along its whole length, the sensitivity is compromised if there is ground loading near the sensor.⁽¹⁾ Think of the non-touched surface area as diluting the capacitance change caused by the touching object.

In reality, it may be perfectly viable to make this 4 x 32 mm electrode and get it to work well, but in order to do so you will have to increase the overall gain of the system due to the narrowness of the electrode.

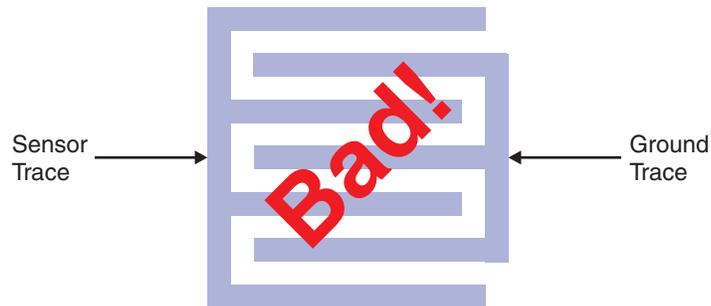
Figure 3-3. Effective Interaction Area of an 8 mm Finger On a 4 x 32 mm Electrode

1. Which in many cases there will be, particularly for small devices that have few internal empty voids.

Self-capacitance Zero-dimensional Sensors

Electrodes that are implemented by interdigitating the sensor electrode with ground (Figure 3-4) can also be considered a “waste” of capacitance and degrade SNR; plain and simple electrodes are almost always better.

Figure 3-4. Interdigitating Electrodes Result in a Poor SNR



Remember that with self-capacitance sensors, the sensitivity comes from the area of the electrode that is interacting with the touching object, and nowhere else. Therefore, electrodes with exotic shapes are not recommended (for example, long, thin electrodes or electrodes with complex “pointy” boundaries).

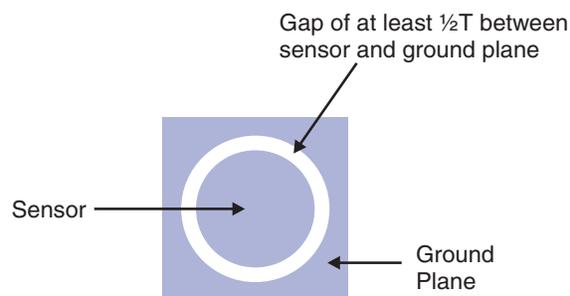
3.2.2 Ground Loading

This style of sensor is highly sensitive to ground loading because such loading adds directly to C_x , thus reducing the sensor’s gain. Any signal or power rail that runs under, or close to, the electrode will reduce its gain. Note that ground in this context is anything that looks like an AC ground from the electrode’s point of view and therefore encompasses just about any circuit element or feature that is nearby.

Always avoid flooding planes under self-capacitance type electrodes and indeed, avoid running *any* traces under the sensors where possible. Where a flood plane is absolutely required behind a sensor (perhaps to stop reverse side touch sensitivity), and if the flood plane is on a layer that is a reasonable distance away (perhaps the back face of a 1.6 mm FR4 PCB), then the trade-off between sensitivity loss and the desired operation may be acceptable. In this case, always consider using a 50 percent mesh flood rather than a solid one, as this will reduce the parasitic loading.

It can be beneficial to place hatched or solid ground floods on the same layer as the electrodes, and near to the electrodes themselves, ideally stopping the ground flood at about $\frac{1}{2}T$ away⁽¹⁾ (see Figure 3-5). The ground flood can also be on layers further down in the stack, if this is more convenient, but the upper layer is preferred as it tends to offer superior shielding.

Figure 3-5. A Ground Flood Near To a Sensor



1. It is acceptable to stop closer, but some loss of sensitivity will be observed. Experimentation will be required to reach the best compromise.

For small battery-powered devices, the addition of this ground plane can greatly aid the free-space return path⁽¹⁾ of the product and so actually make the sensor more sensitive overall. It also helps to control stray interfering fields, and fields from the sensor itself, making the sensor more immune to noise and more focused in terms of its sensitive region.

One down-side to this ground plane is that it offers a very easy path for water droplets to bridge and cause capacitive changes that look very much like a normal touch. Therefore, for applications where moisture sensitivity is a concern, it is best to avoid this ground plane method.

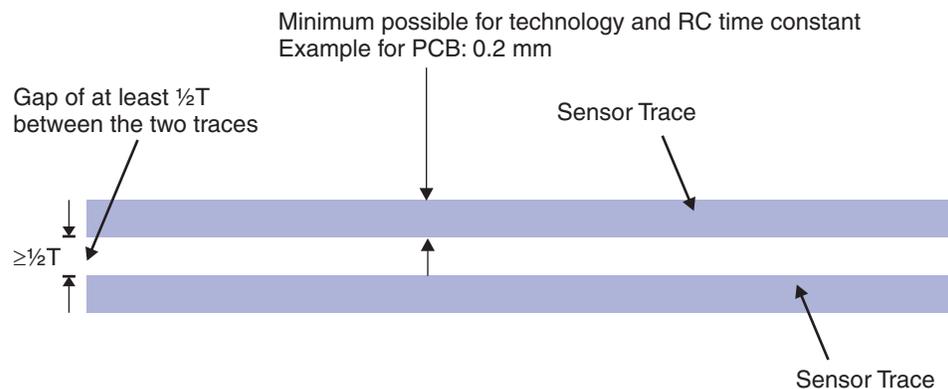
3.2.3 Interconnection

This type of sensor should be connected to the controller using conductive traces that are as thin as possible, while observing RC time constant effects. Interconnections that are shorter than 150 mm are recommended. Longer traces can couple noise and add parasitic capacitance that reduces sensitivity.

Note that interconnecting traces are touch sensitive and simply form an extension to the sensor itself. It is good practice to run sensor traces on a PCB or substrate layer that is farthest from touch, while the sensor is on a layer closest to touch.

Traces from neighboring sensors should be spaced as far apart as practically possible. A good rule of thumb is to space adjacent traces so that the gap between them is at least half the panel thickness ($T/2$) – see [Figure 3-6](#).⁽²⁾

Figure 3-6. Spacing of Adjacent Traces



It is important to note that interconnecting traces should not be run over ground or power planes where possible, especially when the separation to the plane is small (for example, when the traces and the ground or power plane are on adjacent layers of a multilayer PCB). Doing so can quickly desensitize the key. If sensor traces must run close to other foreign signals, avoid tracking them in parallel in order to reduce the coupling. Where they cross, cross them at 90° for the same reason.

Running interconnections as part of a cable loom is not a good idea in any circumstances. However, running sensor traces inside a low capacitance coaxial cable can be done as a last resort, but expect low sensitivity keys.

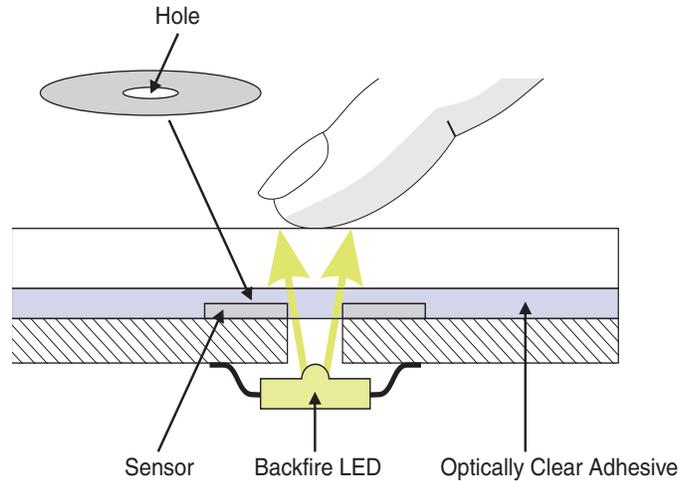
1. The implied return path between the person touching the product and the product itself via “free-space” (that is, the current returns via the capacitance that couples the product to the person’s body).
2. Assuming that these sensor traces are driven from the same chip.

3.2.4 Illumination Effects

LEDs that are very close to the sensor should be bypassed as described in [Section 2.4 “Nearby LEDs” on page 2-6](#).

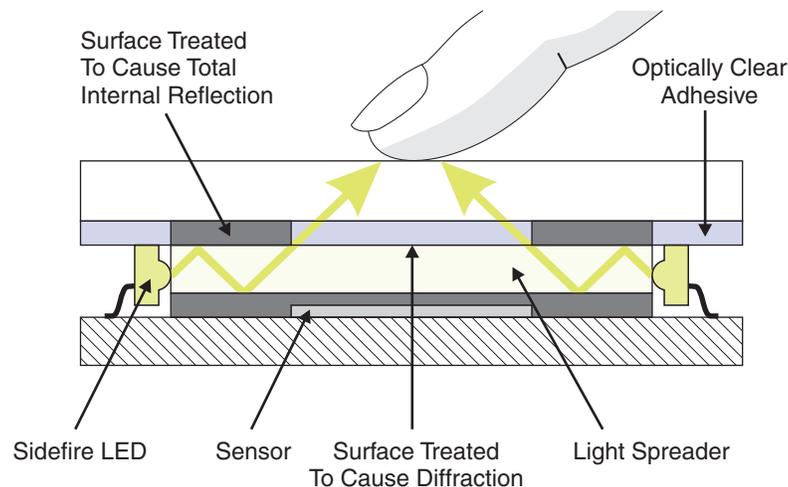
Backlighting can be achieved by using transparent sensor materials or by making a small hole in the sensor itself to allow light to shine through from behind (see [Figure 3-7 on page 3-5](#)). Remember to keep the hole small: the larger the hole, the more sensitivity will be lost. Remember, too, that the LED looks like a ground load – and a constant one if you have remembered to bypass it – and this will further reduce sensitivity.

Figure 3-7. Backlighting Using an LED



Another common method of backlighting is to use a light spreader sheet with side illumination and controlled light leakage areas above the keys (see [Figure 3-8](#)). This can yield very thin illuminated structures.

Figure 3-8. Backlighting Using Side Illumination and Light Spreader Sheet

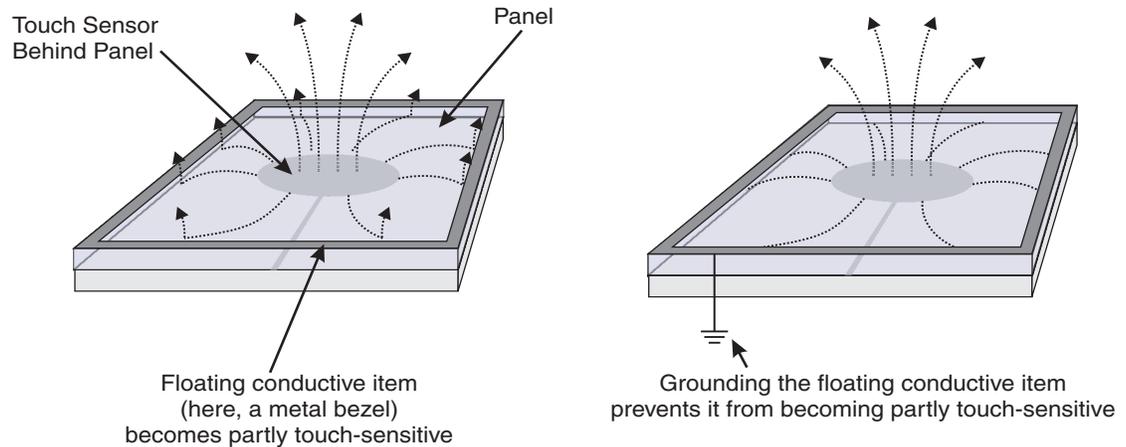


Electroluminescent lamps have also been successfully used with Atmel’s capacitive sensors, but this is a much more complex topic and is beyond the scope of this document.

3.2.5 Floating Conductive Items

Regions of floating metal, or any other conductor, that are in close proximity to sensors of this type (that is, nearer than 10 mm edge to edge) can tend to re-radiate the sensor's electric field and so become touch-sensitive themselves. Always ground nearby conductive regions.

Figure 3-9. The Effect of a Floating Conductive Item



Remember that any type of conductive item can cause this effect. Examples of such items include decorative logos created using metallic paints or foils, paints with a high carbon black content, and paints containing metallic particles.

3.2.6 Conductive Paints

Refer to QTAN0021, *Materials and Coatings Selection for Atmel Capacitive-touch Control Panels* (available under a non-disclosure agreement only), for details of selecting conductive paints and coatings.

3.3 Non-planar Construction

The underlying principle of a non-planar construction method is to form the electrodes on the inner surface of the touch panel, with the rest of the touch sensing circuitry on the main capacitive touch circuit board and remote from the electrodes.

This non-planar approach can be desirable in that it offers several advantages:

- It allows for more flexibility and creativity in product shape and size, as the touch sensing circuitry does not need to be placed on the under surface of a sloping or curved front panel.
- The physical separation of the sensor and the front panel allows LEDs to be easily incorporated in the product.
- It can aid in the assembly and testing of the product, as the sensor assembly and the circuit assembly are built and tested as separate items.

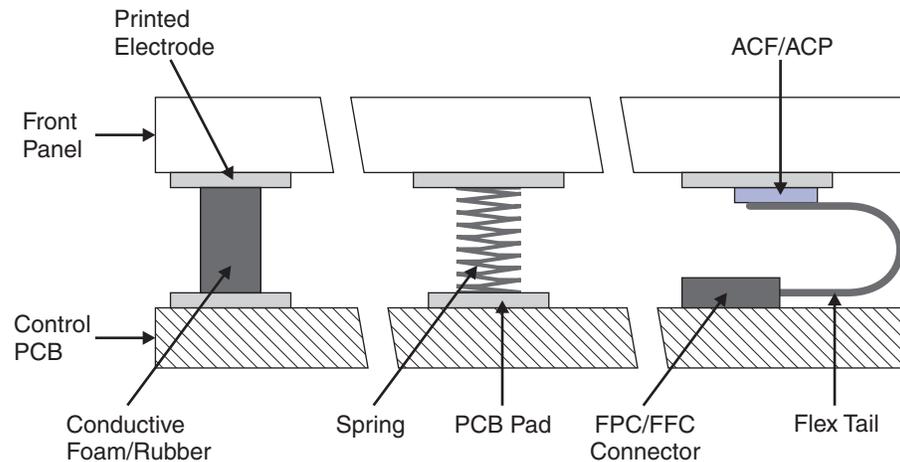
The rules for the interconnecting traces are identical to those already described in [Section 3.2.3 “Interconnection” on page 3-4](#). However, the methods for interconnection are tightly coupled with the method of construction, and so careful consideration must be given as to how the two halves of the circuit will be connected together.

3.3.1 Printed Electrode Method

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 [Section 3.2.1 “Electrode Shapes” on page 3-1](#), and the materials are as described in [Section 2.3.2 “Electrode and Interconnection Materials” on page 2-4](#). The sensors can be connected using spring contacts ⁽¹⁾, conductive foam or rubber, or a flex tail attached using ACF/ACP ⁽²⁾ (see [Figure 3-10](#)).

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

Figure 3-10. Printed Electrode Method Showing Several Connection Methods



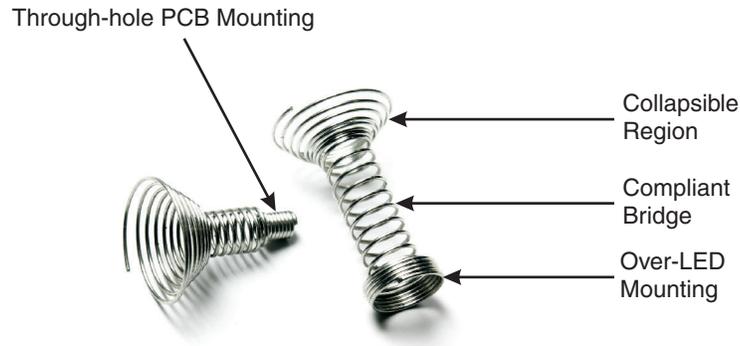
3.3.2 Philipp Spring™ Method

A subtle but important derivative of the method in [Section 3.3.1](#) is to use a spring connection to the control PCB, but with no printed electrode on the panel surface.

One such spring is Atmel’s patented Philipp spring product (see [Figure 3-11 on page 3-8](#)). This has an increasing diameter at its upper end, which means that as the spring collapses under pressure the coils of the spring form a tight, flat spiral that is a very good approximation to a disc electrode (see [Figure 3-12 on page 3-8](#)).

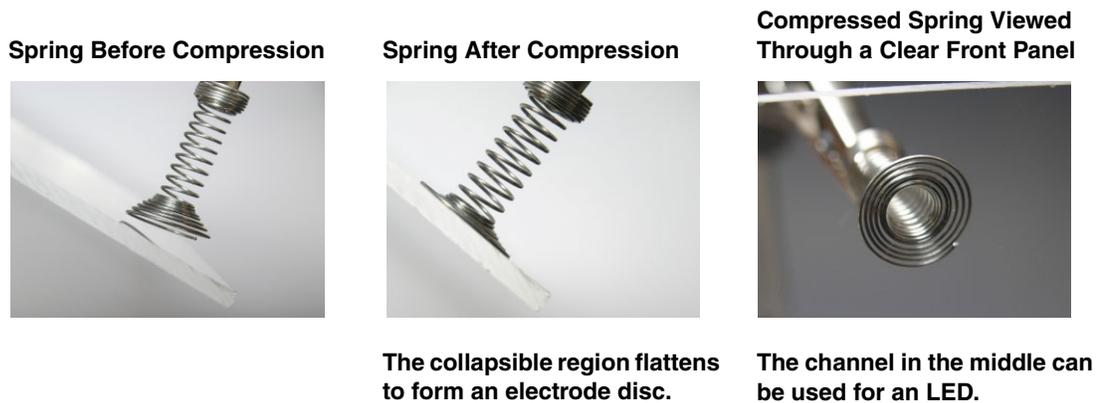
1. Check for life expectancy of these spring tails especially where vibration may be present that can scratch off the sensor material. The dissimilar metals may also cause premature ohmic failure of the contact due to oxidation. It is advisable to “crimp” or solder the spring to the control PCB to give a gas tight joint for these reasons. Also consider drop test survival issues when using springs.
2. ACF/ACP = Anisotropic Conductive Film/Anisotropic Conductive Paste. This is a means of electrically joining and bonding two circuits together with a formulation of “glue” that is full of tiny silver or gold particles. The particles are spaced so that they do not contact their neighbors but will contact any circuit placed in the “Z” axis when heated and pressed together.

Figure 3-11. Philipp Spring Products



Using a conventional spring may also work, but it tends to result in low sensitivity keys and a poor SNR, due to the low surface area of the top of the spring

Figure 3-12. Compressing a Philipp Spring Product

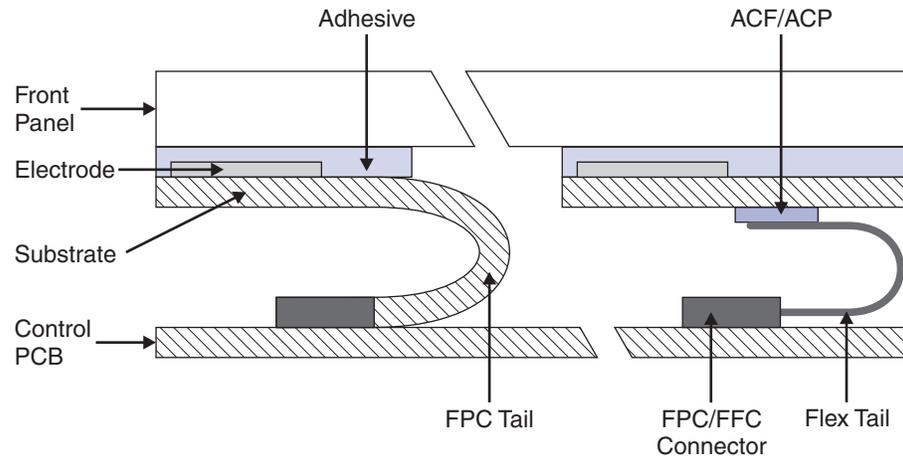


Make sure that when the spring is placed under compression that it still contacts properly on the PCB contact pad. It has been known for a spring to spread out and overlap a nearby track or ground region, causing loss of sensitivity or an intermittent fault. In addition, remember that the pad is just as much part of the electrode structure as the spring itself. You should therefore minimize the area of the contact pad to avoid building up C_x that is not touchable, and keep ground planes away from this pad to reduce the parasitic capacitance (C_p).

3.3.3 Secondary Substrate Method

Another option is to form the electrodes on a secondary PCB, flex, or similar substrate. This can then be bonded to the front panel and interconnected to the control chip by a separate flex tail using an ACF/ACP connection, or by a tail formed from an extension to the substrate itself. Board-to-board connectors are also possible.

Figure 3-13. Secondary Substrate Method



3.3.4 Ground Loading

Unlike with the planar approach, this style of sensor is less sensitive to ground loading. The reason for this is that the ground loads (for example, from internal chassis components and other circuits) tend to be further away from the electrodes and therefore do not desensitize the electrodes so much.

3.3.5 Illumination Effects

A non-planar approach to sensor construction means that there tends to be a physical separation between the sensor and front panel. This has the side benefit that it allows LEDs to be incorporated in the design more easily.

For example, using Philipp spring products as electrode extensions allows an LED to be axially mounted inside the spring itself (see [Figure 3-14 on page 3-9](#)), thus giving a good centralized illumination of the touch graphic on the panel above it.

Figure 3-14. Using LEDs with Philipp Spring Products



Another popular method of providing illumination is in the form of a light spreader or light guides, as described for planar construction in [Section 3.2.4 “Illumination Effects” on page 3-5](#).

The general rules for LEDs are described in [Section 2.4 “Nearby LEDs” on page 2-6](#).

3.3.6 Floating Conductive Items

The considerations for the use of floating conductive items described in [Section 3.2.5 “Floating Conductive Items” on page 3-6](#) apply.

3.3.7 Conductive Paints

The considerations for the use of conductive paints described in [Section 3.2.6 “Conductive Paints” on page 3-6](#) apply.

Mutual-capacitance Zero-dimensional Sensors

4.1 Introduction

This section describes how you design zero-dimensional sensors using a mutual-capacitance implementation (see [Section 1.2](#) and [Section 1.3](#)). These styles of sensors are typically used to implement keys for use with QMatrix sensor controllers.

As with a self-capacitance zero-dimensional type sensor, the guidelines for constructing a mutual-capacitance sensor depend on whether the construction is planar or non-planar. The guidelines for these two types of construction are discussed in the following sections.

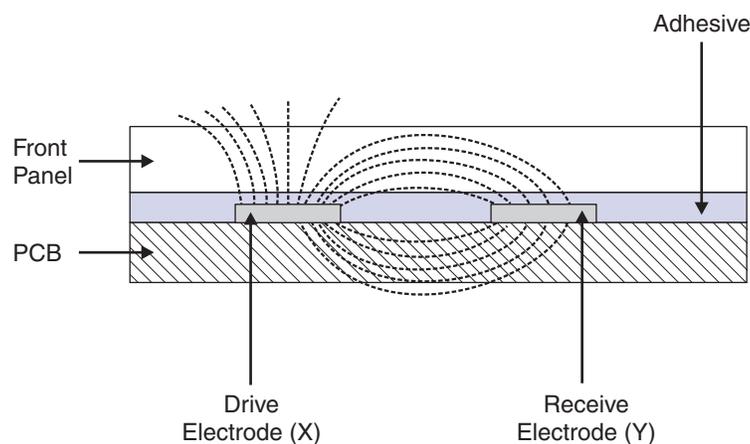
4.2 Planar Construction

4.2.1 Introduction

With planar construction, both the electrodes and the traces for the sensor are fabricated on the same plane of the insulating substrate (for example, a PCB or Flex PCB).

Field propagation relies heavily on the overlying panel as most of the coupling field flow is horizontal (see [Figure 4-1](#)). It is important to make sure that the sensor is firmly laminated to the panel with adhesive, and that air bubbles are avoided during lamination; bubbles that are too large or too numerous can give rise to significant unit-to-unit variation.

Figure 4-1. Field Flow



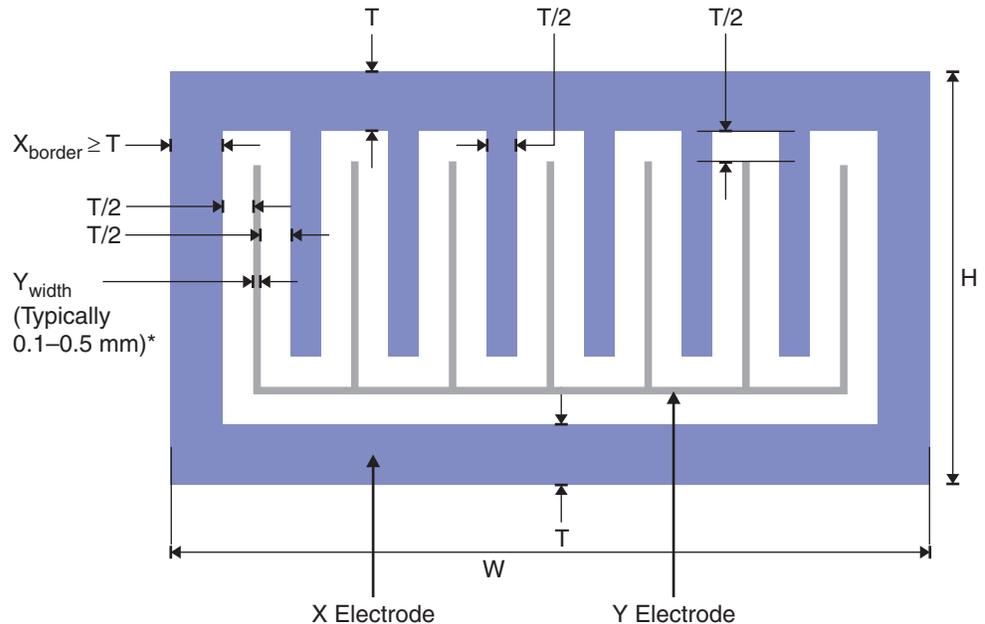
The X and Y electrodes are designed to optimize the distribution of the electric field that is coupling through the overlying panel. This maximizes touch sensitivity, as the touching object (typically a finger) has the maximum opportunity to disrupt this field coupling and cause a touch to be detected.

4.2.2 X and Y Electrodes

4.2.2.1 Interdigitating the X and Y Electrodes

The X and Y electrodes are generally interdigitated, that is they form interlocking “fingers”. Typically the X electrode surrounds the Y electrode, as it helps to contain the field between the two (see [Figure 4-2](#)).

Figure 4-2. Interdigitated X and Y Electrodes



T = Front panel thickness

* Y_{width} is related to electrode conductivity. Keep Y line worst case resistance in line with RC time constants rules (this is very important, for example, for ITO)

4.2.2.2 Width of Y Electrodes

The Y electrodes should use the thinnest trace possible (say, 0.1 to 0.5 mm) for the Y fingers, as this minimizes the possibility of noise coupling to the sensor during touch. Although past advice has suggested Y trace widths as a function of T , extensive field testing has shown that a better SNR is achieved using thinner traces.

4.2.2.3 Width of X Electrodes

For the X electrodes, wider electrodes are generally preferred as they tend to act as partial shields for the Y traces. They also help maximize the free space coupling of small battery-powered products.

The width of the X fingers for the X electrodes should be calculated from thickness of the overlying panel (T). Generally, the function $T/2$ is used, as shown in [Figure 4-2](#).

4.2.2.4 Spacing Between the Electrodes

As with the width of the X fingers, the spacing between the X and Y electrodes should be calculated from thickness of the overlying panel (T). Again, the function $T/2$ is generally used, as shown in [Figure 4-2](#).

4.2.2.5 Coupling Length

The goal with this interdigitated design is to optimize SNR by maximizing the coupling length⁽¹⁾ between the X and Y electrodes within the confines of the space allocated for the key. The coupling length is determined by a combination of the number of X and Y fingers, their individual widths, and the spacing between them; several thin fingers means a longer coupling length than a few wide ones, which results in a better SNR.

4.2.2.6 Calculations for the X Electrode

Given the widths of the Y and X traces, you will need to calculate the number of X fingers (X_{fingers}) that will fit in the digitated electrode, allowing for a border at least T wide. Note that any unallocated width remaining after the number of fingers has been calculated must be added to the border, so the width of the border (X_{border}) must also be calculated.

Equation 4-6 gives the equations that can be used to calculate X_{fingers} and X_{border} (see Figure 4-2 for definitions).

Equation 4-6. Calculation for X_{fingers} and X_{border}

$$X_{\text{fingers}} = \lfloor (W - 3T - Y_{\text{width}}) / (1.5T + Y_{\text{width}}) \rfloor$$

$$X_{\text{border}} = (W - T - Y_{\text{width}} - X_{\text{fingers}}(1.5T + Y_{\text{width}})) / 2$$

Where:

- $\lfloor \dots \rfloor$ is the FLOOR operator, defined as the largest integer not greater than the number; that is, round down to the nearest integer. For example, $\lfloor 6.6 \rfloor$ is 6.

4.2.2.7 Example Calculation

If the following measurements are used:

$$\begin{aligned} T &= 0.5 \text{ mm} \\ W &= 10 \text{ mm} \\ H &= 8 \text{ mm} \\ Y_{\text{width}} &= 0.1 \text{ mm} \end{aligned}$$

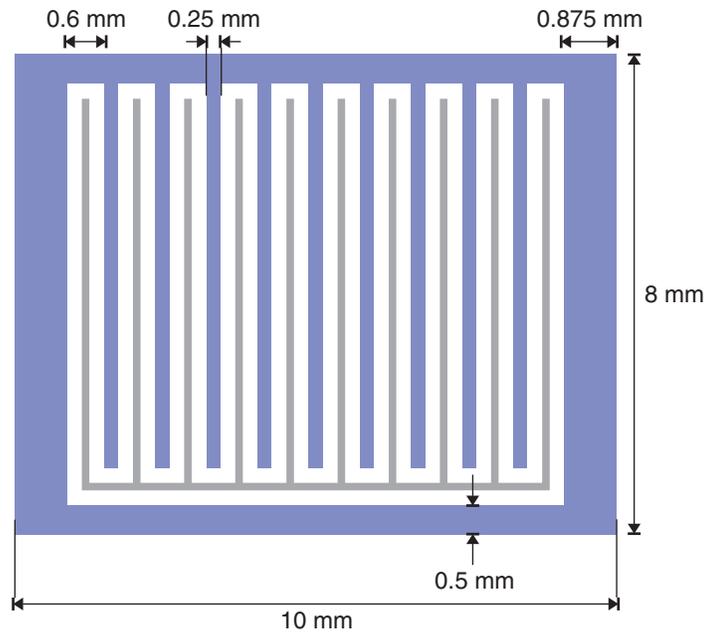
then the calculations using Equation 4-6 is as follows:

$$\begin{aligned} X_{\text{fingers}} &= \lfloor (10 - 1.5 - 0.1) / (0.75 + 0.1) \rfloor \\ &= \lfloor 8.4 / 0.85 \rfloor \\ &= \lfloor 9.88 \rfloor \\ &= 9 \end{aligned}$$

$$\begin{aligned} X_{\text{border}} &= (10 - 0.5 - 0.1 - 9 \times (0.75 + 0.1)) / 2 \\ &= (9.4 - 7.65) / 2 \\ &= 0.875 \text{ mm} \end{aligned}$$

This results in the pattern shown in Figure 4-3 on page 4-4.

1. That is, the total length of the facing edge between the X and Y electrodes.

Figure 4-3. Results of Example Calculation

4.2.2.8 Designs Resulting In Low Interdigitation

As has already been stated, designs that result in a very small number of fingers should be avoided, as such designs result in a poor SNR.

For example, if the following measurements are used in [Equation 4-6](#):

$$\begin{aligned} T &= 1.5 \text{ mm} \\ W &= 8 \text{ mm} \\ H &= 8 \text{ mm} \\ Y_{\text{width}} &= 0.1 \text{ mm} \end{aligned}$$

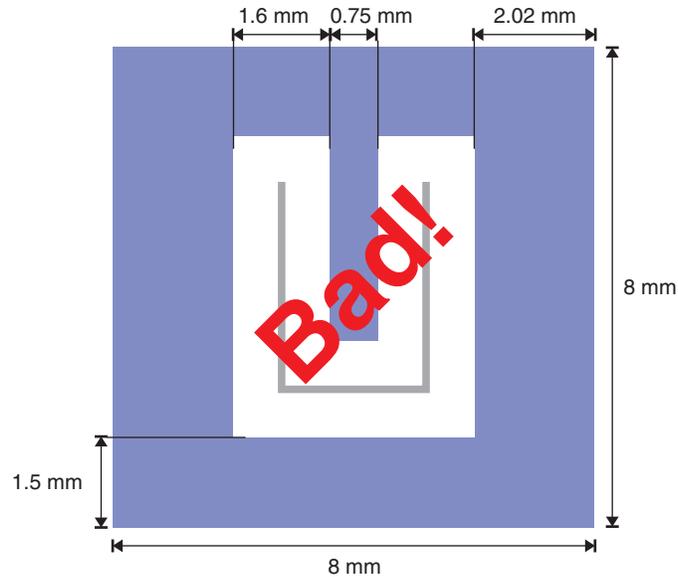
then the calculation is as follows:

$$\begin{aligned} X_{\text{fingers}} &= \lfloor (8 - 4.5 - 0.1) / (2.25 + 0.1) \rfloor \\ &= \lfloor 3.4 / 2.35 \rfloor \\ &= \lfloor 1.45 \rfloor \\ &= 1 \end{aligned}$$

$$\begin{aligned} X_{\text{border}} &= (8 - 1.5 - 0.1 - 1 \times (2.25 + 0.1)) / 2 \\ &= (6.4 - 2.35) / 2 \\ &= 2.02 \text{ mm} \end{aligned}$$

This results in the pattern shown in [Figure 4-4](#).

Figure 4-4. Example Resulting In Low Interdigitation



Due to the key size and panel thickness, the resulting key is far from ideal and has a lack of interdigitation – there is only one X finger! Such a low degree of interdigitation leads to very low key C_x and a lack of sensitivity. It also tends to render the design more susceptible to C_p on the Y line⁽¹⁾. Hence small keys with relatively long interconnections and thick panels are a bad combination.

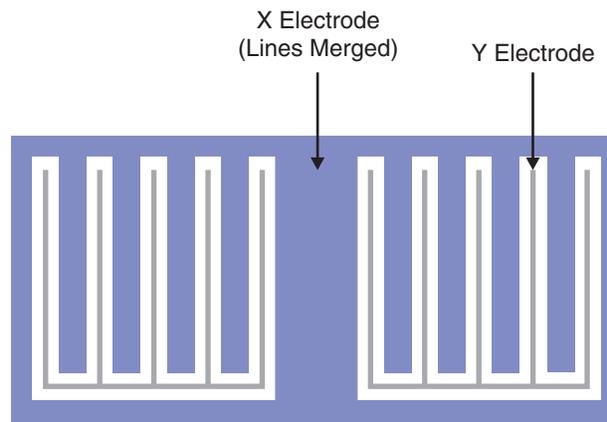
As can be seen from this example, designs with smaller keys and thicker panels make effective interdigitation very hard when following the guidelines. In such cases, it is better to break the guidelines by closing the gaps slightly ($0.75 \times T/2$ minimum) and thinning down the X regions.

See also [Section 3.2.2 “Ground Loading”](#) on page 3-3 for suggested compromises.

4.2.2.9 Merging X Regions

For keys that share the same X line, the X regions can be merged, as shown in [Figure 4-5](#).

Figure 4-5. Merged X Regions



1. The ratio of C_x to C_{py} is important as the maximum QMatrix terminal voltage that can be accumulated is directly proportional to this ratio. If the ratio is too small, it may be impossible to achieve acceptable key performance.

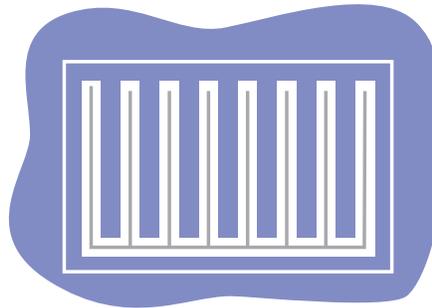
4.2.3 Ground Loading

One big advantage of a mutual-capacitance sensor is that because the coupling capacitance from X to Y is being measured, any parasitic effects on X or Y are not so acute as they are with a self-capacitance electrode.

Placing a ground plane in close proximity to the non-touch side of such a sensor should still be avoided because it will desensitize the key. However, the overall effect is far less dramatic than for a self-capacitance sensor.

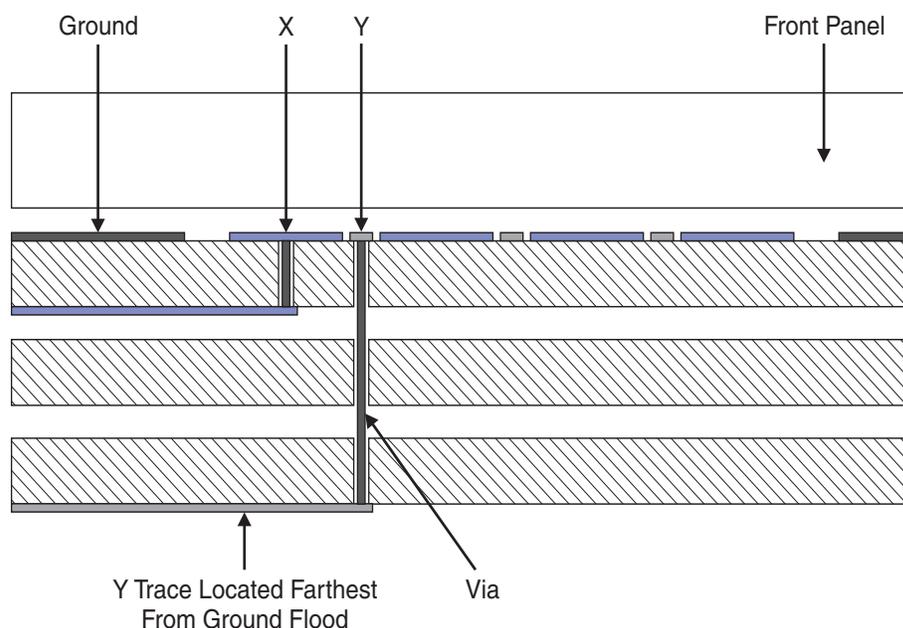
Bringing ground floods or traces close to the X element of the sensor has little or no effect on sensitivity. This is beneficial in most cases as it helps to shield X and Y traces on the layers below from interference from strong electromagnetic fields nearby. The ground flood can be made very close to X. Another benefit is that the ground flood helps to improve the overall free-space return path, which is particularly important for small battery powered devices.

Figure 4-6. Ground Flood Around X



Bringing ground floods or traces close to Y adds parasitic capacitance (C_p) and can cause loss of sensitivity. Keep this in mind when flooding around keys; the interconnecting Y traces on layers below the flood will suffer some additional C_p loading. Try to keep the Y interconnections to the layer farthest from the flood (see [Figure 4-7](#)). Be careful when adding ground floods on thin PCBs or FPCBs, as the C_p build-up on Y could be substantial due to the reduced separation between layers.

Figure 4-7. Cross-section of a Multi-layer PCB



4.2.4 Interconnection

4.2.4.1 X Routing

X routing is fairly trivial as long as RC time constant rules are observed. Nearby foreign signals that have large kHz frequency⁽¹⁾ switching transients should be routed well away from X traces as they can disturb the charge transfer. Examples of circuits to consider include D-class amplifier signals, LCD or LED drive signals.

X routing is not touch sensitive, and so X traces can be routed with ease on any layer of a PCB, including the side nearest to touch. However, X routing must also take the Y routing into account.

4.2.4.2 Y Routing

Y routing must be more carefully considered, due to Cp build-up and the need to avoid an effect called false key detection. Y routing is only very weakly touch sensitive, so it is good practice to run Y traces on a layer that is far from touch.

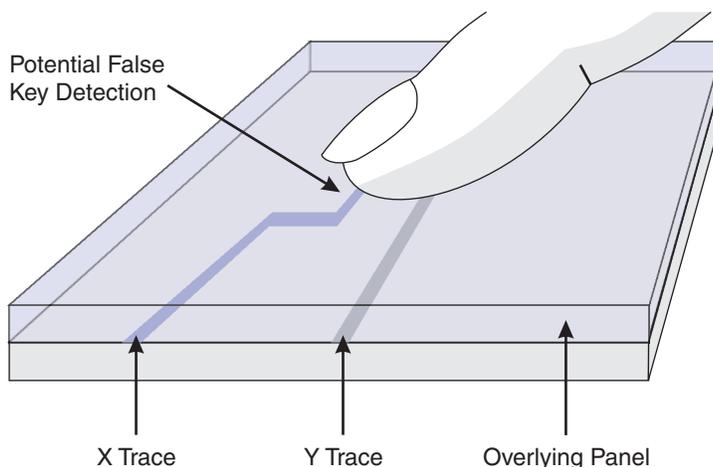
The first factor, Cp build-up, is easily dealt with by avoiding routing Y traces over or close to ground planes (or other power planes).

The second factor, false keys, relates to the interaction of the Y traces with the X traces. Remember that anywhere where X and Y get close (less than 10 mm), and the field between them is allowed to be influenced by touch, you have a potential key or at least a touch sensitive zone that you do not expect (see [Figure 4.2.4.3](#)).

4.2.4.3 Avoiding False Key Detection

False key detection can occur wherever there is an interaction of the Y traces with the X traces. Remember that anywhere where X and Y get close (less than 10 mm), and the field between them is allowed to be influenced by touch, you have a potential key or at least a touch sensitive zone that you do not expect (see [Figure 4.2.4.3](#)).

Figure 4-8. Potential False Key



1. High kHz to hundreds of kHz in particular.

To avoid false keys, use any of the following tricks:

- Cross the X and Y traces as little as possible and then only at 90° (see [Figure 4-9.a](#)).
- If the X and Y traces must run parallel to each other for a distance, separate the traces with a ground trace. Where possible, use a ground trace that is twice as wide as the track-to-track gap (see [Figure 4-9.b](#)).
- Consider routing the X traces behind ground planes⁽¹⁾. This means that the field between the X and Y traces is minimized, even if the Y traces run close to the X traces adjacent to the ground flood (see [Figure 4-9.c](#)).
- Route the Y traces completely behind⁽²⁾ the X traces if needed, or route the X and Y traces well apart so they do not interact (see [Figure 4-9.d](#)).

In addition, keep to the following general guidelines:

- Keep the X and Y traces thin where possible.
- Route the Y traces farthest from touch where possible.
- Generally, keep all the X traces together and all the Y traces together. This way the number of potential false keys is substantially reduced.

Figure 4-9.a. 90° Crossing (Best)

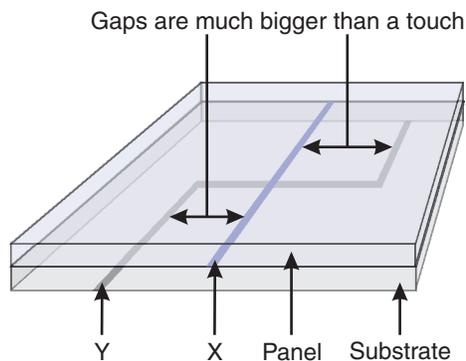


Figure 4-9.b. Separating ground Trace

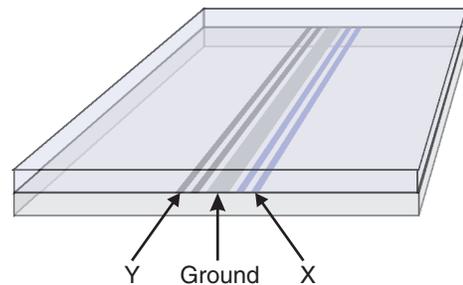


Figure 4-9.c. X Under Ground Trace

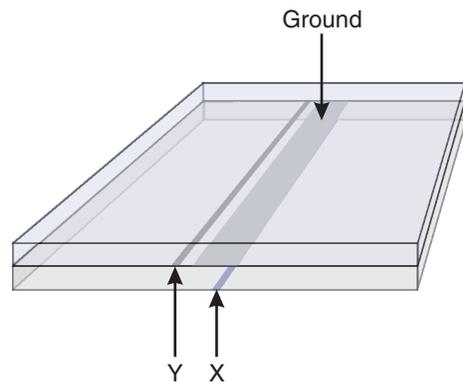
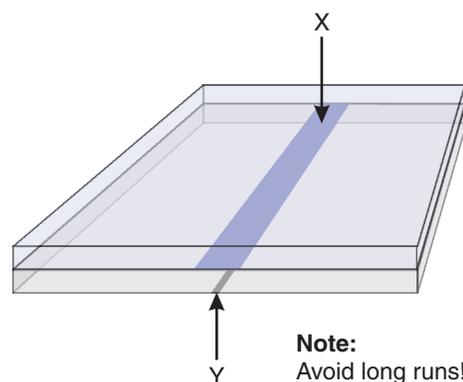


Figure 4-9.d. Y Under X



1. Watch out for time constants.
2. Behind from the point of view of touch.

4.2.5 Illumination Effects

With the planar construction of mutual-capacitance type electrodes it is fine to make holes in the X portion of the electrode to allow light to shine through, much as described in [Section 3.2.4 “Illumination Effects” on page 3-5](#). The rules for LEDs are described in [Section 2.4 “Nearby LEDs” on page 2-6](#).

Try not to remove too much of the X area or you risk making a dead spot in the key.

Transparent electrode materials also work well with this type of sensor if you take care to meet RC time constant constraints (see [Section 2.1 “Charge Transfer” on page 2-1](#)).

4.2.6 Floating Conductive Items

Mutual-capacitance type sensors are much less sensitive to floating metal as self-capacitance types. The reason for this is that the measured field is localized between X and Y. However, it is still good practice to avoid such risks, as described in [Section 3.2.5 “Floating Conductive Items” on page 3-6](#).

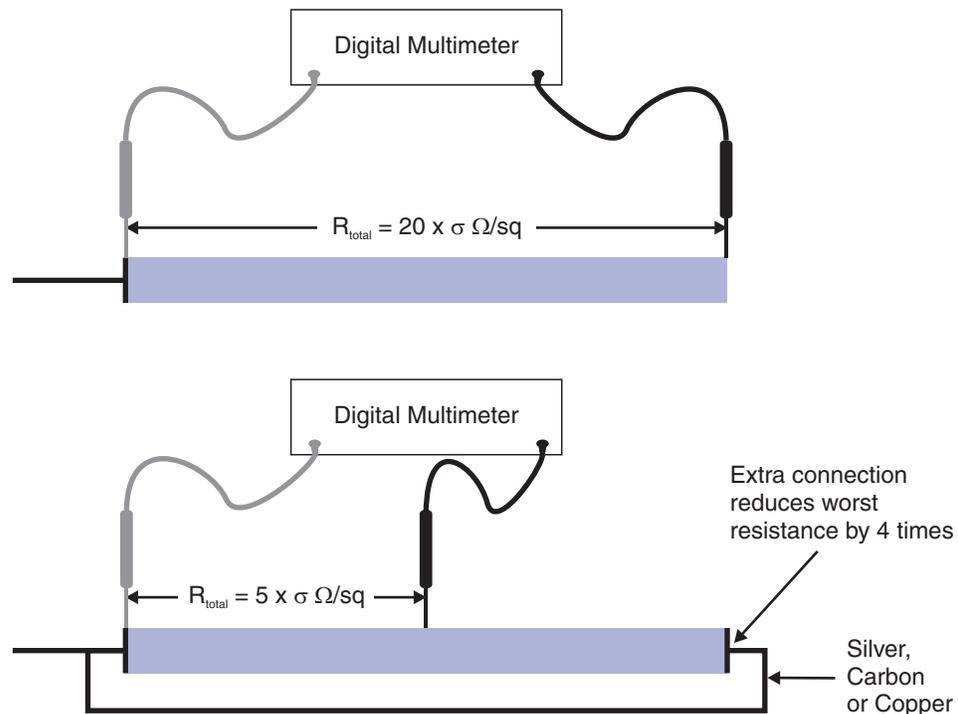
4.2.7 Conductive Paints

The considerations for the use of conductive paints described in [Section 3.2.6 “Conductive Paints” on page 3-6](#) apply.

4.2.8 Transparent Y Electrodes

Transparent Y electrodes can end up with significant series resistance if made from materials like ITO or Orgacon. This can be a problem due to excessive RC delay. Consider using printed silver or carbon tracks or copper traces to add more than one connection point, if possible, to lower the resistance (see [Figure 4-9 on page 4-9](#)). Selective use of silver or copper over the top of the electrode (outside the required transparent area, of course) is possible.

Figure 4-9. Lowering Resistance with Extra Silver, Carbon or Copper Traces



4.3 Non-Planar Construction

4.3.1 Introduction

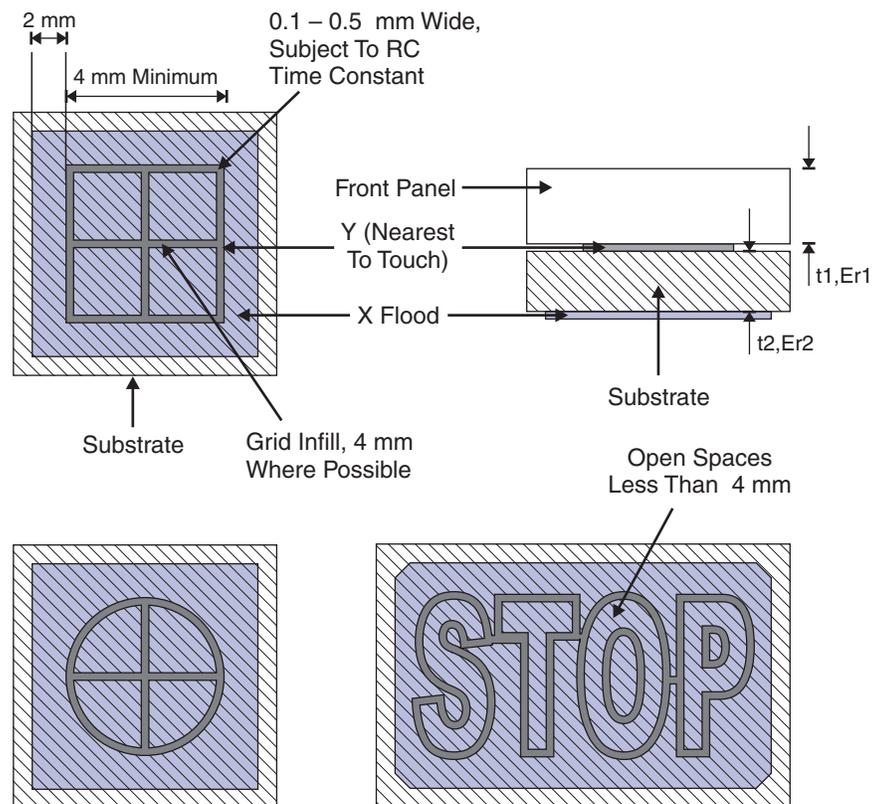
It is often desirable to form electrodes on the inner surface of a panel that is not part of the main capacitive touch circuit board. This technique can be used with a mutual-capacitance type sensor, typically using a spring as part of the sensor (see [Section 4.3.3 “Spring Method” on page 4-12](#)), although other methods are possible (see [Section 4.3.2](#) and [Section 4.3.4 on page 4-12](#)). The overlying panel has little effect on the field distribution until a touch is made, at which point a percentage of the field is deflected through the panel vertically.

The methods for interconnection are tightly coupled with the method of construction. The rules for the interconnecting traces are identical to those already described in [Section 4.2.4 “Interconnection” on page 4-7](#). However, some of the constraints can be relaxed because the substrate used to route the traces is no longer near to touch.

4.3.2 Flooded-X Two-layer Method

The flooded-X two-layer method distributes the X and Y electrodes across two layers of a substrate. This style has some great advantages in terms of sensitivity for small keys, and has some good intrinsic noise rejecting capabilities. Another useful property is that because the X electrode completely shields the Y electrode from behind, the sensor is not touch-sensitive from behind. The field behavior is similar to that mentioned above.

Figure 4-10. Flooded-X Two-layer Method



With the flooded-X two-layer method the X and Y electrodes are designed to overlap each other, with the Y electrode nearest to touch. The X electrode must be separated some distance below the Y electrode and be larger and of a solid fill (that is, flooded).

The Y electrode should be thin, typically between 0.1 mm and 0.5 mm, keeping in mind constraints caused by electrode material resistance build-up, of course. The X electrode should be the same basic shape as the Y electrode but bigger by around 2 mm on all sides.

The Y electrode can be more or less any shape – it can even be the outline shape of the key’s graphic, which opens up some interesting possibilities for illumination. Just make sure that the largest open gaps are not larger than 4 mm, or there will be dead spots in the key sensitivity for normal touch sizes. As a guide, make the Y electrode a simple outline shape, such as a box, and then fill out the bounded region with a grid of lines with a pitch of approximately 4 mm. Keys less than 4 x 4 mm are generally too small.

Ideally the X to Y layer separation should meet [Equation 4-7](#).

Equation 4-7. X To Y Layer Separation

$$2 \leq (S_{YtoXStack} / S_{TouchToXStack}) \leq 12$$

where:

- S is the sensitivity factor for the various material stacks, as defined in [Section 2.3.3 “Front Panel Materials” on page 2-5](#).

One important thing to realize is that the sensor does not suddenly stop working outside these limits. If you make the ratio 5, for example, you can expect to get a lower SNR. This may or may not be acceptable, depending on the system constraints. The SNR degrades approximately in proportion to this ratio. If you make the ratio lower than 2, then one potential side effect is that the field coupling between X and Y starts to rely more heavily on the overlying panel to propagate, and this can render the key more sensitive to moisture effects ⁽¹⁾.

For example, with the stack shown in [Figure 4-10 on page 4-10](#):

$$S_{YToXStack} = \epsilon_{r2} / t_2$$

$$S_{TouchToXStack} = \frac{1}{\left(\frac{t_1}{\epsilon_{r1}} + \frac{t_2}{\epsilon_{r2}} \right)}$$

Do not route any tracks in the region directly above the X flood – other than the Y electrode, of course. Tracks can be placed directly behind the X flood so long as those signals are not excessively noisy ⁽²⁾. Y traces connecting the Y electrode can use a via and escape down and away underneath the X flood. Alternatively, the trace can simply exit on the same layer as the electrode itself, routed directly away from any nearby X regions or traces.

1. QMatrix measurements have the useful property that placing an isolated water drop so that it couples between X and Y, actually increases the coupling; the opposite to a normal touch. This is known as anti-touch. As a result, QMatrix has a natural moisture rejecting property. However, if the overlying panel plays a significant role in the coupling between X and Y, introducing a water bead will have a proportionately larger anti-touch effect. If this anti-touch is compensated for by the controller chip (either over some period of time or immediately with a calibrate command) and then the anti-touch is removed (perhaps by wiping the panel), the sensor will jump towards touch and can cause a stuck key. It is therefore desirable to reduce the moisture sensitivity by controlling the stack as outlined.
2. There are no hard rules on this. Proceed with caution and expect some iteration in your design process if you route highly active signals behind the X flood.

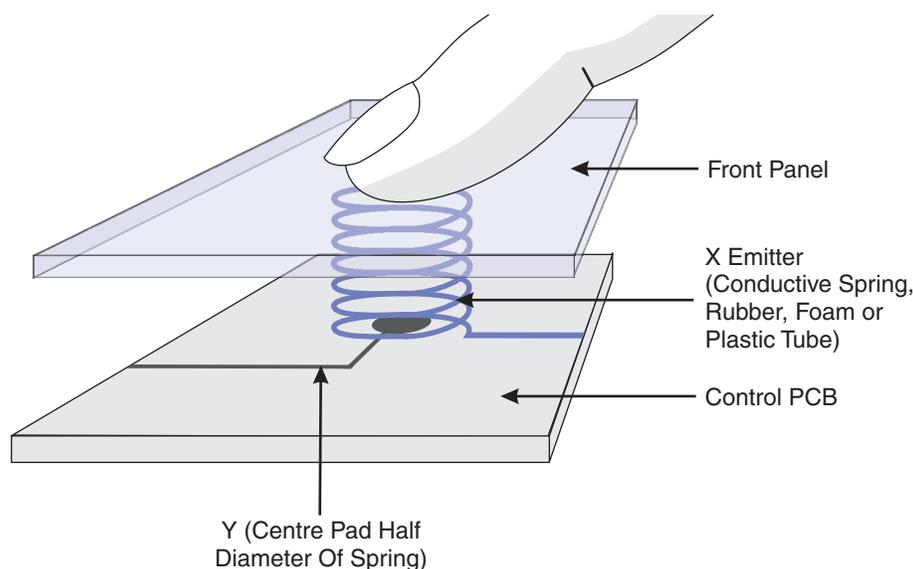
4.3.3 Spring Method

A useful method for transferring the touch-sensitive region of a mutual-capacitance sensor, is to use a conductive spring or hollow conductive tube to act as an X emitter, with the Y electrode placed centrally on the substrate below the panel inside the X electrode (see [Figure 4-11](#)).

The spring should have an inner diameter of 8 to 10 mm. The Y electrode should be a circular pad with a diameter of half the spring's inner diameter.

The compressed length of the spring, and hence the distance from the inside of the panel to the front of the PCB, should be less than 1 spring inner diameter. The pitch of the coils of the spring is not vitally important, but generally try to have the gaps approximately the same size as the diameter of the spring wire when the spring is compressed to its final position.

Figure 4-11. Using a Spring In a Mutual-capacitance Type Sensor



Neighboring coils can be arranged next to each other, ideally with a minimum center-to-center distance of $1.5 \times$ spring outer diameter⁽¹⁾.

4.3.4 Adapting the Planar Construction For Distribution Across Two Layers

For completeness, it is worth noting that the planar construction detailed in [Section 4.2 on page 4-1](#) can be distributed across two layers if desired; it may, for example, make the layout and interconnections easier. Generally, try to keep the Y layer nearest to touch and avoid separating the Y and X layers vertically by more than 10 percent of the X to Y gap.

4.3.5 Ground Loading

A non-planar construction method tends to have less potential for signal loss from nearby ground loads, and so is generally far less sensitive than a planar design. Flooded-X style sensors are particularly good in this regard because the X drive has a low impedance. This means that it can be loaded with relatively high amounts of parasitic capacitance before the RC time constant becomes a concern.

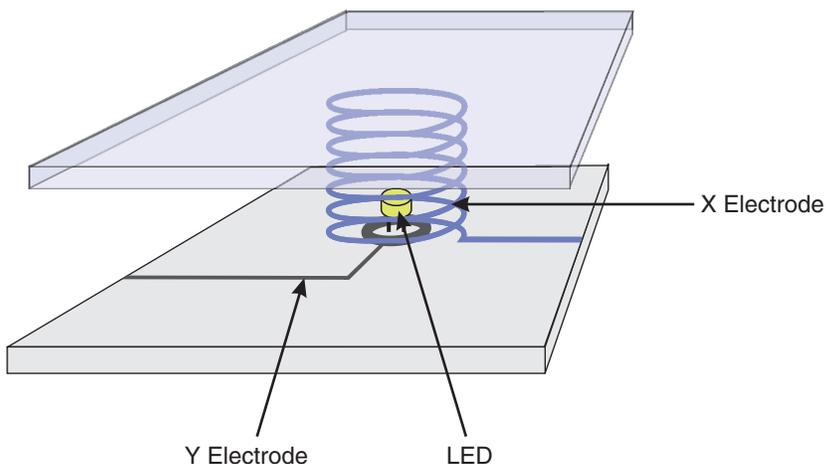
Generally, the considerations of [Section 4.2.3 “Ground Loading” on page 4-6](#) will apply.

1. This helps to keep cross-coupling between keys to a manageable level. Using continuous tube type X electrodes will relax this requirement.

4.3.6 Illumination Effects

The issues for illumination are very similar to those presented in [Section 3.3.5 “Illumination Effects” on page 3-9](#). When considering the use of LEDs in the centre of spring-based sensors, the Y disc electrode can be opened to make way for an LED (see [Figure 4-12 on page 4-13](#)). In this case it may be necessary to increase the diameter of the Y electrode slightly while ensuring that the surrounding ring has the greatest width as possible.

Figure 4-12. Using an LED With a Spring In a Mutual-capacitance Type Sensor



4.3.7 Floating Conductive Items

The considerations for the use of floating conductive items described in [Section 4.2.6 “Floating Conductive Items” on page 4-9](#) apply.

4.3.8 Conductive Paints

The considerations for the use of conductive paints described in [Section 3.2.6 “Conductive Paints” on page 3-6](#) apply.



Self-capacitance One-dimensional Sensors

5.1 Introduction

This section describes how you design one-dimensional sensors using a self-capacitance implementation (see [Section 1.2](#) and [Section 1.3](#)). These styles of sensors are typically used to implement sliders or wheels for use with QTouch sensor controllers. Note that three active channels are used in all the cases described in this section.

This type of sensor is normally only used with planar type construction methods. For construction ideas see [Section 3.3.1 “Printed Electrode Method” on page 3-7](#) and [Section 3.3.3 “Secondary Substrate Method” on page 3-9](#).

Two types of sensor can be considered:

- **Spatially interpolated**

This type uses the shape of the electrodes to spatially interpolate the electric fields above the sensor.

- **Resistively interpolated**

This type uses physical resistors to electrically interpolate the electrodes. This type of sensor allows for a simpler electrode design. It also allows larger sensors to be constructed.

This section discusses both types of sensors.

5.2 General Advice

5.2.1 Ground Loading

One of the most important things to keep in mind with sliders and wheels is that they work best when they have well-balanced sensitivities across all channels. Avoid ground loading underneath sliders and wheels, as uneven or excessive ground loading underneath the sensors will render them useless. Moderate or even ground loading may work, but the resolution of the output is reduced.

Generally speaking, avoid running any foreign traces or components underneath slider or wheel sensors.

5.2.2 Interconnection

The following guidelines should be followed when designing the traces for slider and wheel sensors:

- Always run all three channel connections together as a group and keep them well away from noisy sources and ground loads.
- Keep the traces as short and thin as possible and space the traces with a gap equal to the track width.
- When routing traces from the electrodes, use a via, if possible, for each electrode to route the traces down to the non-touch side of the board, and then run the traces away on this layer.

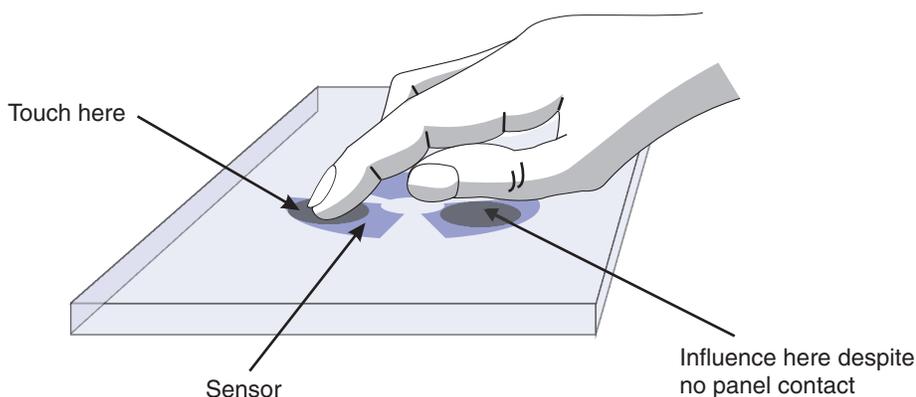
Self-capacitance One-dimensional Sensors

If this is not possible, and the connecting traces have to be routed on the same layer as the electrodes themselves, always escape the traces as quickly as possible out of the touch area; then regroup the three traces for their path to the sensor chip. It can be useful in some cases to run a thin ground trace alongside these escaping traces to desensitize them to touch. Note that some experimentation is usually necessary.

5.2.3 Hand Shadow Effect

When a sensor is particularly large in proportion to a hand, it is possible for a false touch to be detected from the hand as it is held over the sensor, rather than from the user's finger. This is known as the hand shadow effect (see [Figure 5-1](#)).

Figure 5-1. Hand Shadow Effect



This effect presents a particular problem for large sliders or wheels that use the self-capacitance style of electrode. These electrodes are generally scanned so that all the channels are measured at the same time, which makes all the channels equally touch sensitive.

5.2.4 Floating Conductive Items

The considerations for the use of floating conductive items described in [Section 3.2.5 "Floating Conductive Items"](#) on [page 3-6](#) apply.

5.2.5 Conductive Paints

The considerations for the use of conductive paints described in [Section 3.2.6 "Conductive Paints"](#) on [page 3-6](#) apply.

Note that wheels and sliders, in particular, can be badly affected by conductive paints and finishes. The reason for this is that the calculation of the touch position relies on the difference in signal between the various channels, and the conductive paint has a tendency to make the channels cross-couple together. The result is a considerable degradation of the resolution of the sensor.

5.3 Typical Spatially Interpolated Method

5.3.1 Introduction

A spatially interpolated wheel or slider sensor uses three electrodes, all directly connected to the sensor chip. The form of the electrodes depends on the overall size of the slider or wheel.

Note that the designs shown in this section use the method of “two plus two half” electrodes so that they are compatible with the spatially interpolated slider technique described in [Section 5.4 “Typical Resistively Interpolated Method” on page 5-6](#) from an algorithmic point of view. This means that the same sensor chip can drive either electrode style.

Note also that here and elsewhere in this guide, the order of the channels is determined by the chip used and, in the case of a wheel, by the rotation of the wheel.

5.3.2 Small Slider Or Wheel

In the context of this document, a small slider is between 21 and 26 mm long and a small wheel is between 12 and 20 mm diameter.

Note that because the slider or wheel is small in comparison with a typical finger, the linearity and usable range on the sensor are compromised in favor of simple electrode geometries. A small slider uses simple rectangular electrodes (see [Figure 5-2](#)) and a small wheel uses simple wedge-shaped electrodes (see [Figure 5-3 on page 5-4](#)).

This design relies on both the touching finger and the front panel to interpolate the channels. Expect these smaller electrodes to have low sensitivity and plan for front panels of 1.5 mm acrylic or less.

Figure 5-2. Small Slider (Spatially Interpolated)

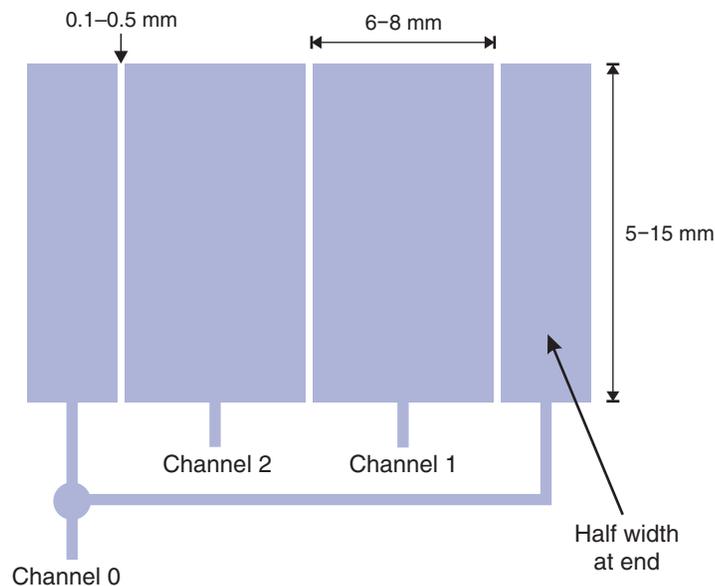
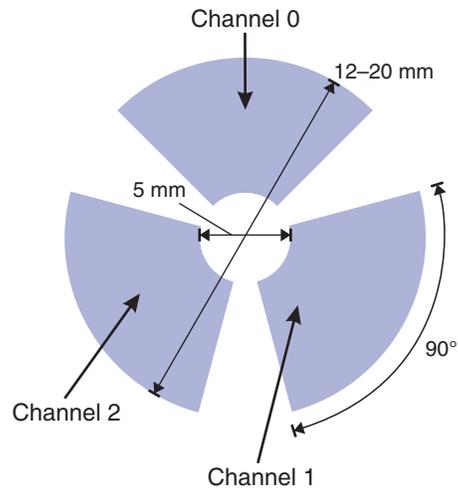


Figure 5-3. Small Wheel (Spatially Interpolated)



5.3.3 Medium/Large Slider Or Wheel

In the context of this document, a medium/large slider is between 26 and 60 mm long and a medium/large wheel is between 20 and 60 mm diameter.

A medium/large slider or wheel uses toothed electrodes (see [Figure 5-4 on page 5-5](#) and [Figure 5-5 on page 5-5](#)) to interpolate the capacitive change spatially as a finger moves across the sensor (that is, along the longitudinal axis of a slider or the radial axis of a wheel). Some transverse variation of the reported position is inevitable ⁽¹⁾, but is reduced by making the segments narrow (towards the 3 mm size).

Note that there are some alternative methods of construction that are very similar to the method shown here, but with some subtle changes in segment lengths and tooth gapping. These methods are normally an attempt to optimize the intrinsic linearity of the slider or wheel. However, it is often more practical to perform this linearization in software rather than trying many iterations of the electrode pattern during development ⁽²⁾.

1. That is, for a wheel, a movement “in to out” or “out to in” results in a small change in the reported angle. For a slider, this change happens when moving at 90° to the normal slide direction.
2. A software linearization using a look up table, or perhaps piecewise-linear-interpolation is fundamentally not as good as correcting the underlying electrode pattern because the non-linearity is locally corrected at the expense of the resolution achievable.

Figure 5-4. Medium/Large Slider (Spatially Interpolated)

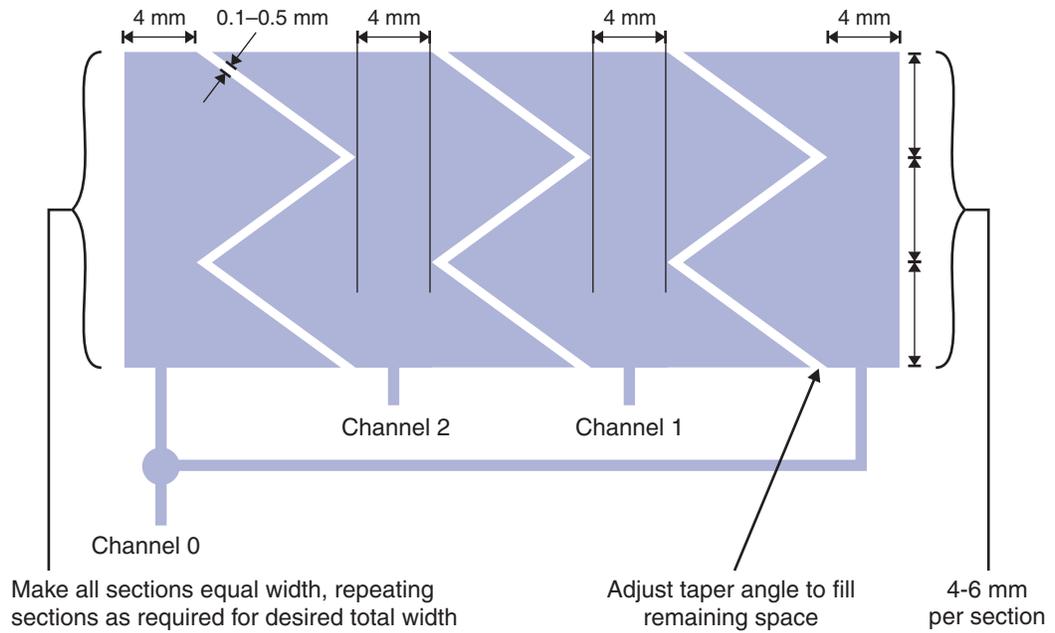
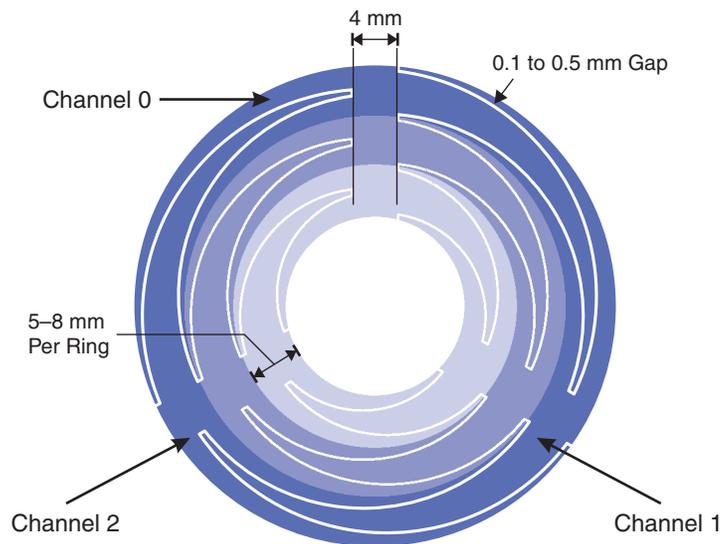


Figure 5-5. Medium/Large Wheel (Spatially Interpolated)



Note: Make all the rings equal width, repeating rings as required for desired total diameter. Where a choice exists, use the largest number of rings to achieve the desired diameter. Rings are shown in different colours for clarity, but are electrically connected where they meet.

5.4 Typical Resistively Interpolated Method

5.4.1 Medium/Large Slider Or Wheel

This sensor uses more than three electrodes in total, with only three of them directly connected to the sensor chip. The rest of the electrodes are connected using resistors to provide an electrical interpolating effect.

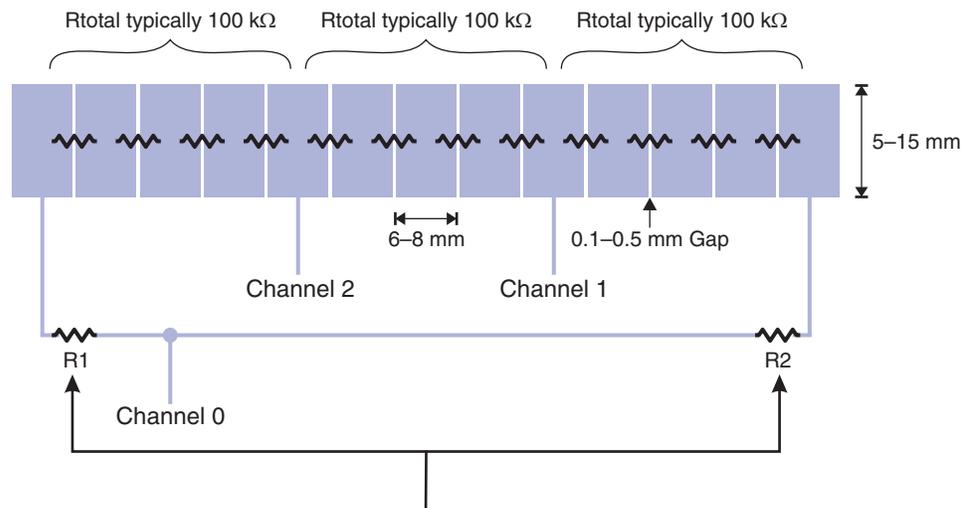
This arrangement can be useful for constructing large sliders out of simple rectangular segments (see [Figure 5-6](#)), or large wheels out of simple wedge-shaped segments ([Figure 5-7 on page 5-7](#)); these segments are not only simple to draw, but they also work better when the taper angle of the more conventional design yields unfeasibly sharp and slender structures.

The resistors can be physical components soldered to the PCB, preferably on the non touch side. They can also be printed (for example, carbon), in which case they can be located on the touch side of the PCB.

It is also possible to make such a slider from a completely resistive carbon strip, with the connection points making a full width contact across the strip and the two ends joined as already described (that is, the continuous equivalent of the “lumped” example shown in [Figure 5-6](#)).

Note that typically, extending a slider too far in length leads to poor SNR and also worsens any problems caused by the hand shadow effect (see [Section 5.2.3 “Hand Shadow Effect” on page 5-2](#)).

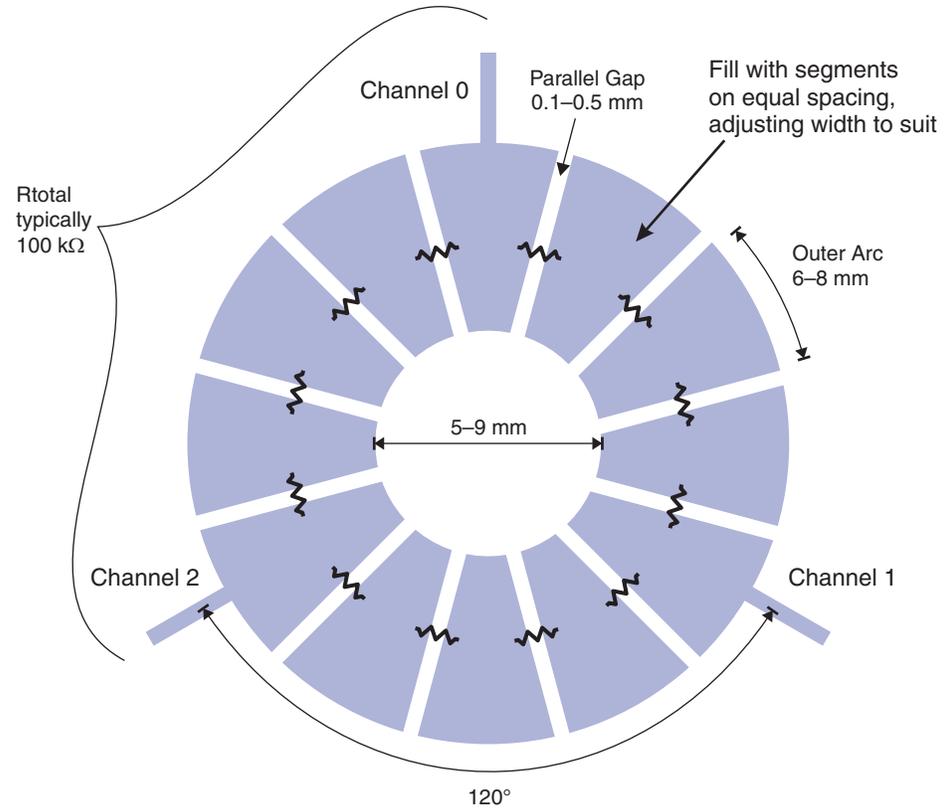
Figure 5-6. Medium/Large Slider (Resistively Interpolated)



Resistors R1 and R2 form a “dead band” at the each end to stop end wrap-around. Make them approximately 5 percent of R_{total} to achieve a 5 percent band at each end. Note that not all Atmel slider chips need these.

The sensor design for medium/large wheels is essentially the same as that for sliders, but with the electrode segments wrapped into a complete ring (see [Figure 5-7 on page 5-7](#)). Unlike the design for the medium/large slider, this design does not attempt to introduce any dead bands, thus allowing continuous operation across the 0° – 360° boundary.

Figure 5-7. Medium/Large Wheel (Resistively Interpolated)





Mutual-capacitance One-dimensional Sensors

6.1 Introduction

This section describes how you design one-dimensional sensors using a mutual-capacitance implementation (see [Section 1.2](#) and [Section 1.3](#)). These styles of sensors are typically used to implement sliders or wheels for use with QMatrix sensor controllers.

As with self-capacitance one-dimensional sensors, two types of sensors can be considered: spatially interpolated and resistively interpolated (see [Section 5.1 on page 5-1](#)).

6.2 General Advice

6.2.1 QMatrix Channels

Because QMatrix generally has fewer channel restrictions than QTouch, it is very common to make sliders and wheels from 4 or more channels along a common Y line. In fact many chips are structured to allow up to 8 channels for slider or wheel use.

6.2.2 Ground Loading

One-layer sensors are quite resilient to ground loading in the same way as described in [Section 4.2.3 “Ground Loading” on page 4-6](#). However, with one-dimensional sensors that are designed to output a touch coordinate with moderate to high resolution, degrading SNR by introducing ground loading near the sensor will directly compromise the resolution achievable. This can manifest itself as jitter in the reported touch coordinate and is not desirable.

Flooded-X style sensors (see [Section 4.3.2 “Flooded-X Two-layer Method” on page 4-10](#)) are particularly good at resisting ground loading from behind because the X drive is low impedance and so can be “loaded” with very high amounts of parasitic capacitance before the RC time constant becomes a concern.

Generally, the considerations of [Section 4.2.3 “Ground Loading” on page 4-6](#) still apply.

6.2.3 Floating Conductive Items

The considerations for the use of floating conductive items described in [Section 4.2.6 “Floating Conductive Items” on page 4-9](#) apply.

6.2.4 Conductive Paints

The considerations for the use of conductive paints described in [Section 3.2.6 “Conductive Paints” on page 3-6](#) apply.

6.3 Typical Spatially Interpolated Method

6.3.1 Introduction

This method uses an array of keys directly adjacent to each other.

6.3.2 One-Layer Small Slider Or Wheel

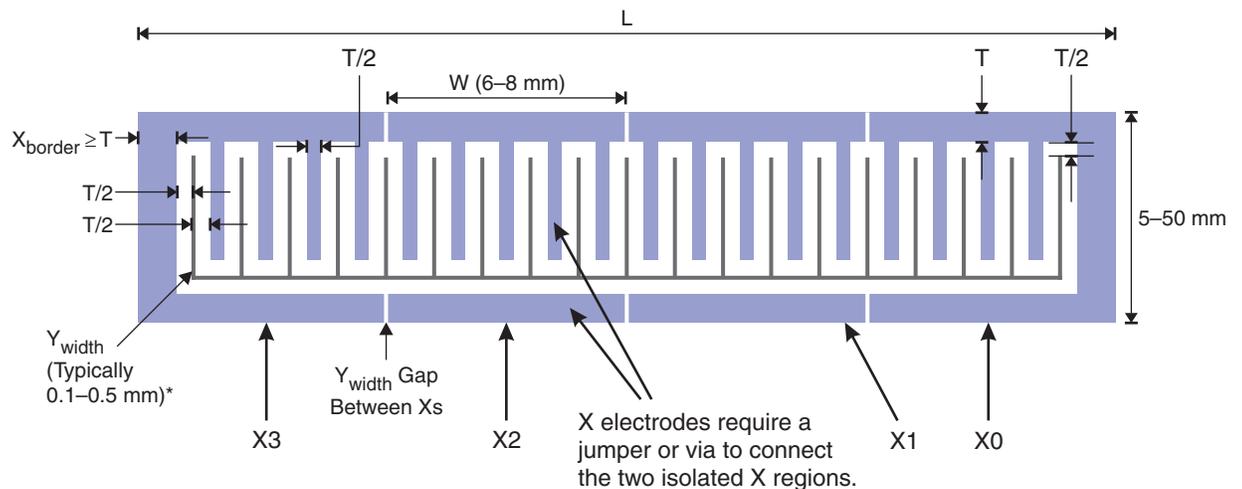
6.3.2.1 Slider

There are numerous ways to construct a spatially interpolated slider, but the most basic form is to use an array of keys as shown in [Figure 6-1 on page 6-2](#). It is suitable for sliders that are approximately $n \times 6$ mm to $n \times 8$ mm in length, where n is the number of keys used. For larger sliders use a resistively interpolated design (see [Section 6.4 “Typical Resistively Interpolated Method” on page 6-10](#)).

From [Figure 6-1](#) it can be seen that the slider can be treated as one large “super key” of interdigitated X and Y fingers for design purposes. There is no border between the keys, only at either end of the slider. Instead, an “extra” Y finger is inserted between each key.

Note: This method by its nature has the electrodes arranged on a single layer, which means that Y electrode cuts through the X electrodes. Jumpers or vias are therefore required to connect the isolated X regions to the interdigitated X regions.

Figure 6-1. One-layer Small Slider (Spatially Interpolated)



Given the widths of the Y and X traces, you will need to calculate the number of X fingers ($X_{fingers}$) that will fit in the slider, allowing for end borders of at least T wide. Any unallocated width remaining after the number of fingers has been calculated is added to the end of the slider, so the width of the end borders (X_{border}) must also be calculated.

To design the slider:

1. Decide on the length of your slider (L).
2. Apply the rules in [Section 4.2.2 “X and Y Electrodes” on page 4-2](#) and use [Equation 6-8](#) to calculate X_{fingers} and X_{border} for the whole slider (see [Figure 6-1](#) for definitions).

Equation 6-8. Calculation for X_{fingers} and X_{border} For a Slider

$$X_{\text{nominalfingers}} = \lfloor (L - 3T - Y_{\text{width}}) / (1.5T + Y_{\text{width}}) \rfloor$$

$$X_{\text{fingers}} = ((\lfloor (X_{\text{nominalfingers}} + 2) / \text{keys} \rfloor) \times \text{keys}) + 2$$

$$X_{\text{border}} = (L - X_{\text{fingers}} \times (1.5T + Y_{\text{width}}) - T - Y_{\text{width}}) / 2$$

Where:

- $\lfloor \dots \rfloor$ is the FLOOR operator, defined as the largest integer not greater than the number; that is, round down to the nearest integer. For example, $\lfloor 6.6 \rfloor$ is 6.

3. Check that the width (W) of each key in the slider is between 6 and 8 mm:

$$W = ((X_{\text{fingers}} + 2) / \text{keys}) \times (1.5T + Y_{\text{width}}) - Y_{\text{width}}$$

If W is < 6 mm, then consider doing one of the following:

- Break the slider into fewer keys
- Make the slider a little longer

If W is > 8 mm, then consider doing one of the following:

- Break the slider into more keys (if the controller supports more keys)
- Make slider a little shorter
- Use a resistively interpolated design to artificially break the slider into smaller pieces (see [Section 6.4.2 “One-Layer Medium/Large Slider Or Wheel” on page 6-10](#))

4. Determine where the gaps between the keys occur by calculating the number of X fingers in each key.

For the inner keys this is equal to $(X_{\text{fingers}} + 2) / \text{keys}$. However, there is one less X finger in each of the end keys, because the X fingers at the end of the slider are merged into the borders. For example, in [Figure 6-1 on page 6-2](#) the number of X fingers in the four keys is: 4, 5, 5, 4.

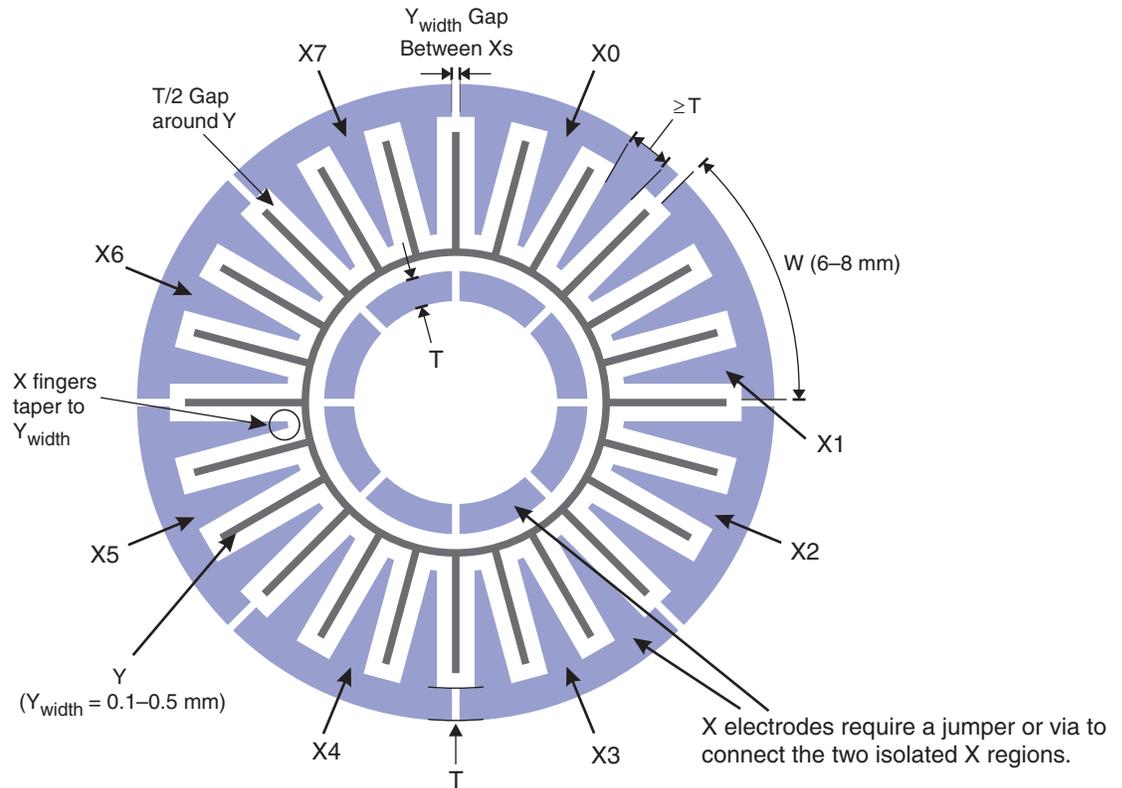
Note that the outer two keys, of course, have slightly more X to Y coupling because they do not have a shared Y finger at the ends; this is normal.

6.3.2.2 Wheel

The sensor design for a wheel is essentially the same as that for the slider, but the array of keys are arranged in a circular form (see [Figure 6-2](#)) and there is no end border. This design can be used for wheels from 15 mm to 21 mm in diameter that are constructed with at least 6 keys. Note that the X fingers taper to Y_{width} or slightly greater (not sharp points), and this tapering determines the inner diameter of the wheel.

As with the slider, you will need to calculate the number of X fingers for the wheel. However, as there is no end border, X_{border} is not calculated and any unallocated width remaining after the number of fingers has been calculated is distributed equally across the X fingers.

Figure 6-2. One-layer Small Wheel (Spatially Interpolated)



To design the wheel:

1. Decide on the diameter (D) of the wheel (15 mm to 21 mm).
2. Check that the outer arc (W) of each key in the wheel is between 6 and 8 mm:

$$W = (\pi D / \text{keys}) - Y_{width}$$

If W is < 6 mm, then consider doing one of the following:

- Break the wheel into fewer keys
- Make the diameter of the wheel larger

If W is > 8 mm, then consider doing one of the following:

- Break the wheel into more keys (if the controller supports more keys)
- Make the diameter of the wheel smaller
- Use a resistively interpolated design to artificially break the wheel into smaller pieces (see [Section 6.4 “Typical Resistively Interpolated Method”](#) on page 6-10)

Mutual-capacitance One-dimensional Sensors

3. Apply the rules in [Section 4.2.2 “X and Y Electrodes”](#) on page 4-2 and use [Equation 6-9](#) to calculate X_{fingers} (see [Figure 6-2](#) for definitions).

Equation 6-9. Calculation for X_{fingers} For a Wheel

$$X_{\text{nominalfingers}} = \lfloor \pi D / (2T + Y_{\text{width}}) \rfloor$$

$$X_{\text{fingers}} = (\lfloor X_{\text{nominalfingers}} / \text{keys} \rfloor) \times \text{keys}$$

Where:

- $\lfloor \dots \rfloor$ is the FLOOR operator, defined as the largest integer not greater than the number; that is, round down to the nearest integer. For example, $\lfloor 6.6 \rfloor$ is 6.

4. Determine where the gaps between the keys occur by calculating the number of X fingers in each key ($X_{\text{fingers}} / \text{keys}$).

You can now draw the wheel. Note that the X fingers taper to Y_{width} or slightly greater (not sharp points), and this tapering will determine the inner diameter of the wheel.

6.3.3 One-Layer Medium/Large Slider Or Wheel

Spatially interpolating a one-layer interdigitated key array to make a longer slider or a large wheel is not a good way to increase slider length or wheel diameter. While it is possible to design sliders and wheels in this way, the complexity of doing so makes the use of a resistively interpolated slider or wheel much more favorable.

See [Section 6.4.2 “One-Layer Medium/Large Slider Or Wheel”](#) on page 6-10 or [Section 6.4.3 “Two-Layer Medium/Large Slider Or Wheel”](#) on page 6-11 for more information on designing a resistively interpolated slider or wheel.

6.3.4 Two-Layer Small Slider Or Wheel

6.3.4.1 Introduction

This sensor style uses a Flooded X design (see [Section 4.3.2 “Flooded-X Two-layer Method” on page 4-10](#)) and can operate with 3 or more channels. The basic layout rules listed in [Section 4.3.2](#) still apply, as do the layer separation rules.

6.3.4.2 Slider

When designing a slider, if the height of the X electrodes are 8 mm or less, then a single Y trace can be used, as in [Figure 6-3](#). However, as the slider gets taller, more Y “stripes” must be added to keep the maximum separation to 4 mm (see [Figure 6-4](#)).

Figure 6-3. Two-layer Small Slider: Single Y Trace (Spatially Interpolated)

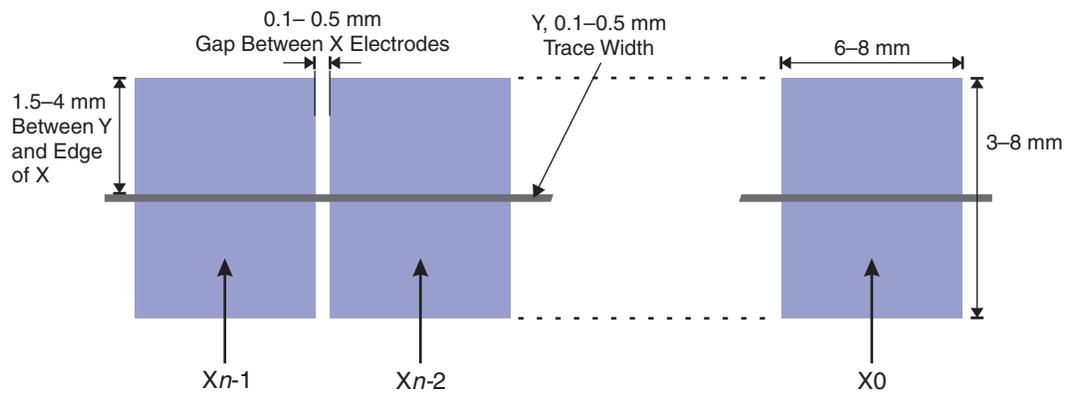
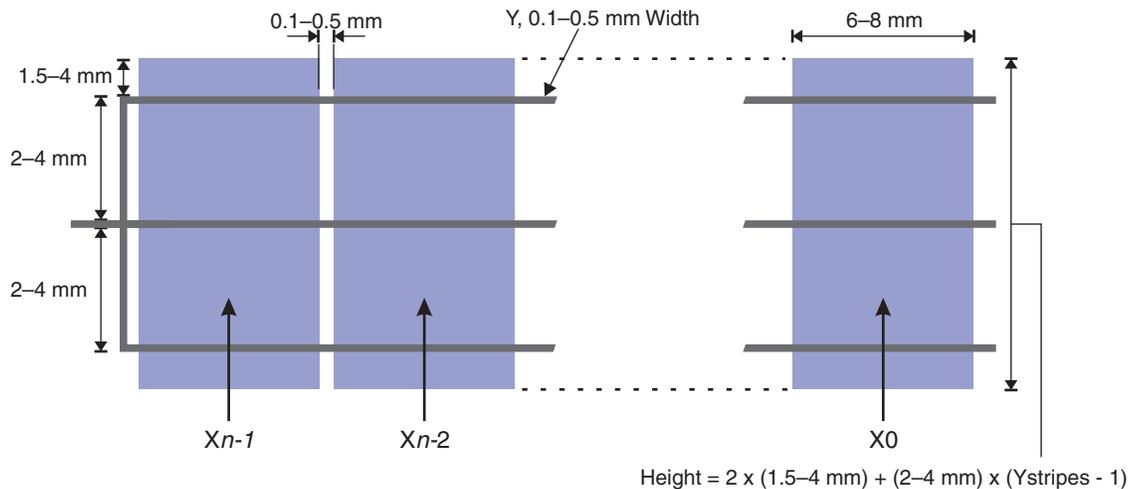


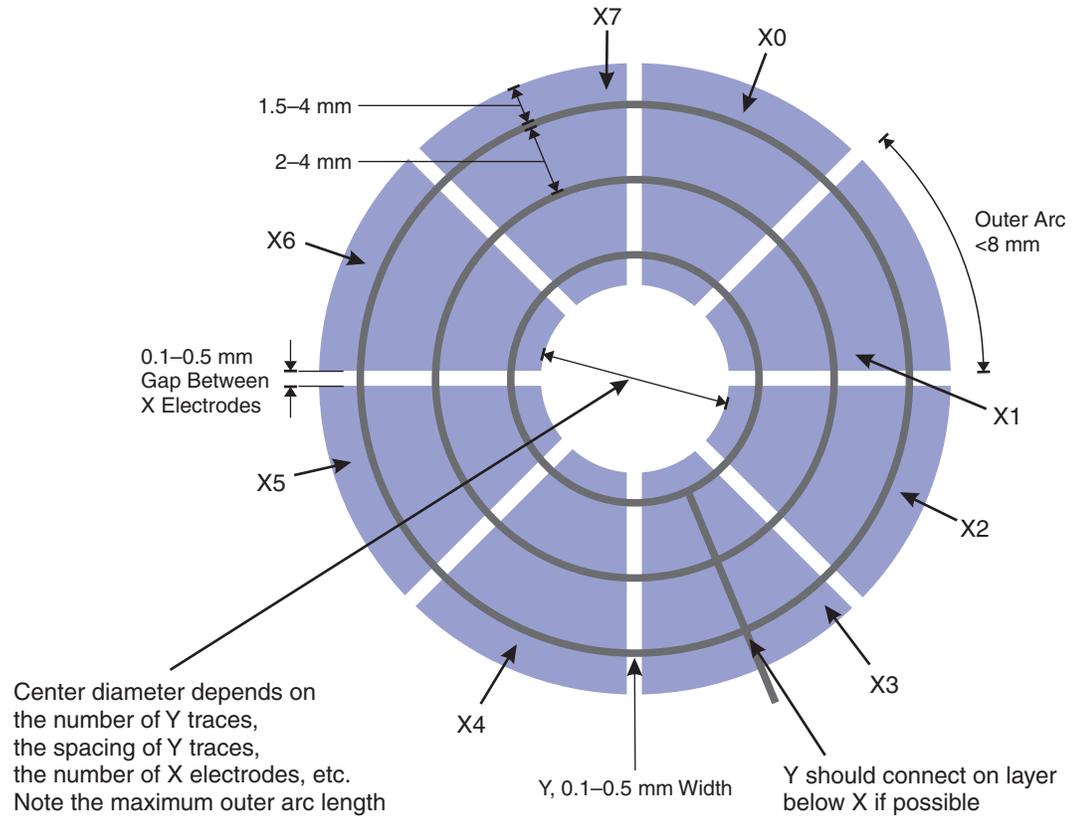
Figure 6-4. Two-layer Small Slider: Multiple Y Traces (Spatially Interpolated)



6.3.4.3 Wheel

To form a wheel, the design is simply wrapped around to form a circle, with the X segments becoming wedge shaped (see Figure 6-5). Note that, as with the Y “stripes” in the slider design, there should be as many Y “circles” as necessary to ensure a maximum gap of 4 mm between them.

Figure 6-5. Two-layer Small Wheel: Multiple Y Tracers (Spatially Interpolated)



6.3.5 Two-layer Medium/Large Slider Or Wheel

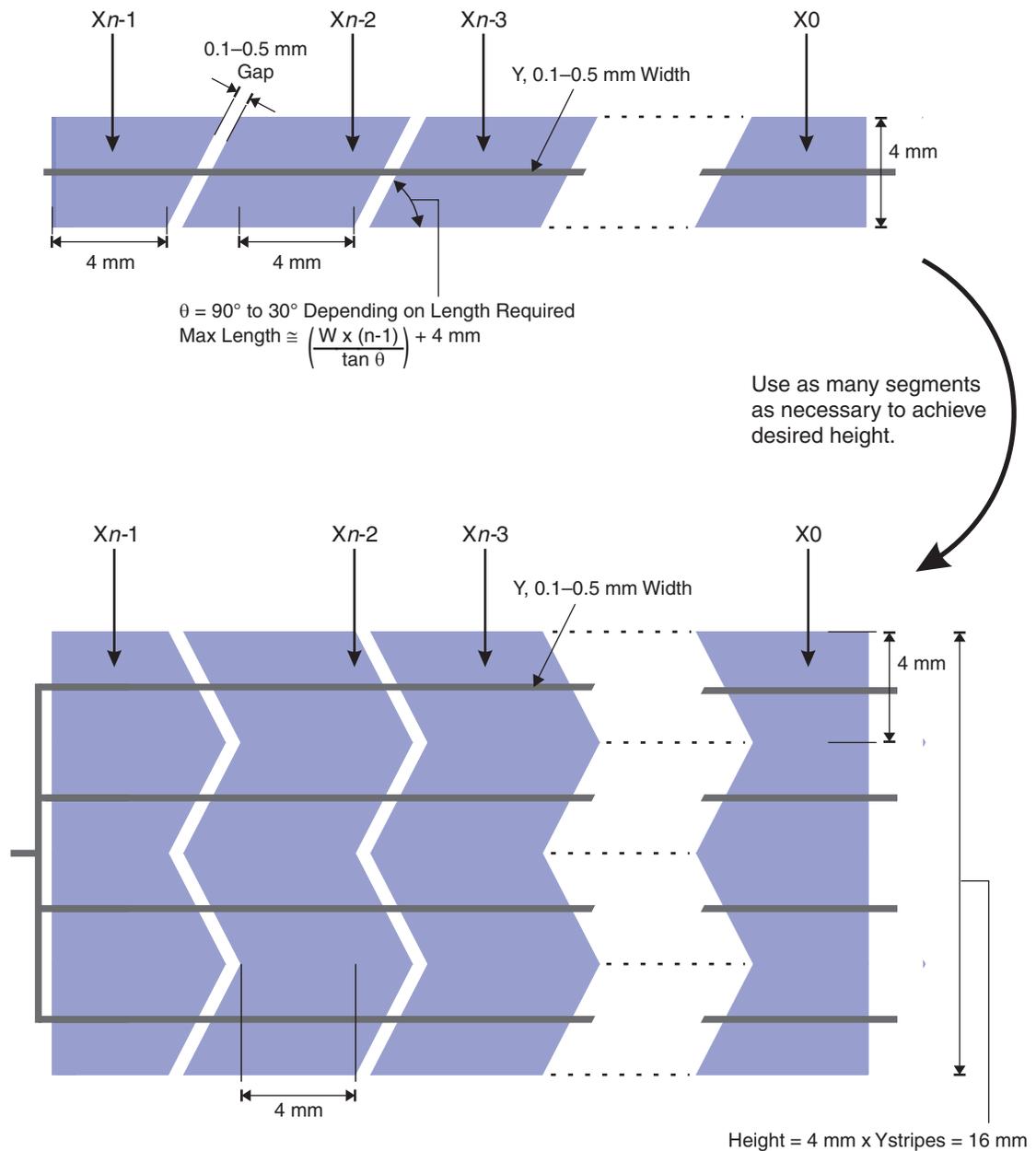
6.3.5.1 Introduction

When constructing two-layer medium/large sliders and wheels the electrodes are constructed from slanted “segments”.

6.3.5.2 Slider

For a slider, each “segment” is 4 mm high, and the slider is constructed from as many segments as is necessary to obtain the required height, as shown in Figure 6-6 on page 6-8. Note the way in which the direction of the slant of the “segments” alternates in Figure 6-6 to give a zigzag effect.

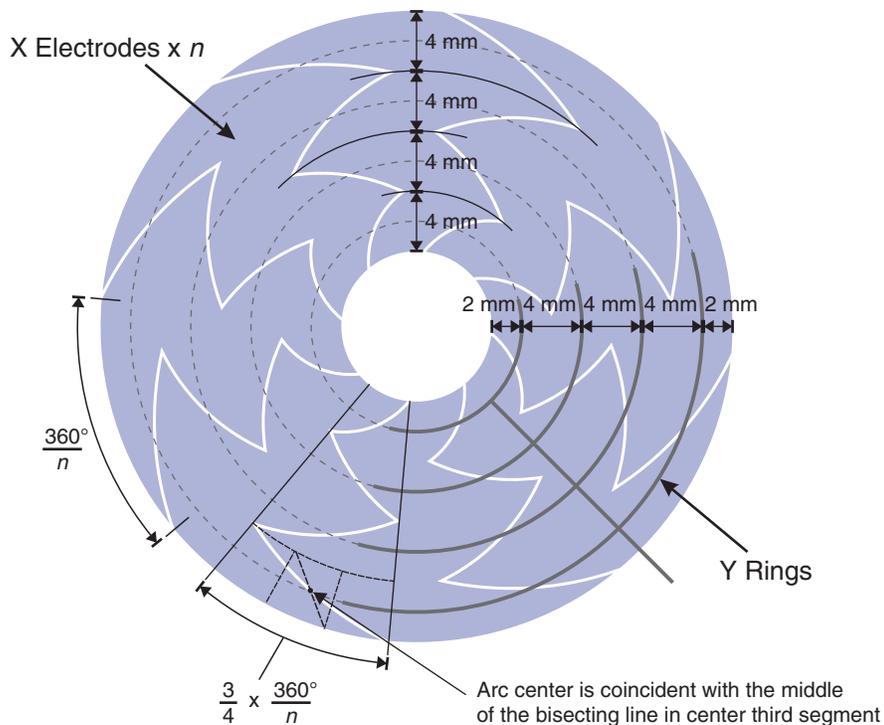
Figure 6-6. Two-layer Medium/Large Slider (Spatially Interpolated)



6.3.5.3 Wheel

To form a wheel, the design is wrapped around to form a circle, the X segments becoming curved tooth shapes (see Figure 6-7 on page 6-9).

Figure 6-7. Two-layer Medium/Large Wheel (Spatially Interpolated)



6.4 Typical Resistively Interpolated Method

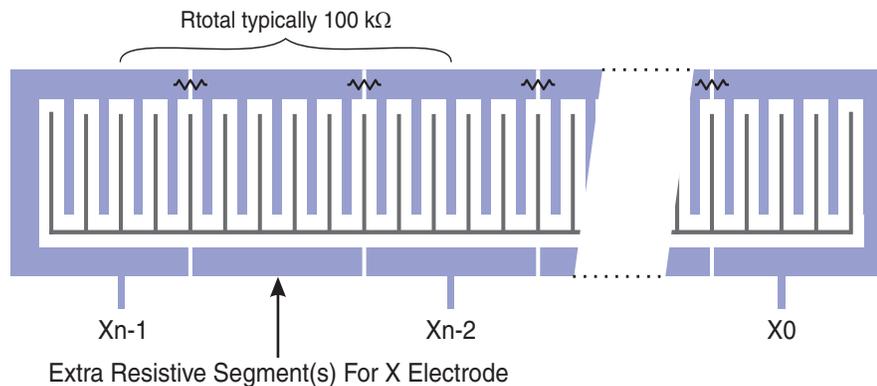
6.4.1 Introduction

This method uses an array of key segments connected by resistors. The advantage of this method is that each key (or channel) in the sensor is formed by one or more segments. This makes it possible to construct larger sliders and wheels than would be possible with the spatially interpolated method described in [Section 6.3 on page 6-2](#).

6.4.2 One-Layer Medium/Large Slider Or Wheel

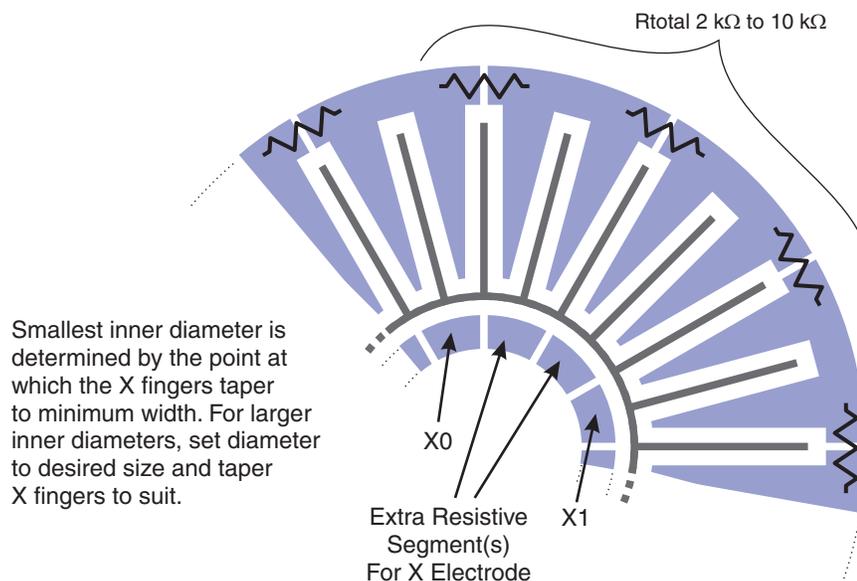
The basic design is the same as that shown in [Section 6.3.2 “One-Layer Small Slider Or Wheel” on page 6-2](#). However, to increase the length or diameter of the sensor, extra segments are created using resistive dividers on the X lines.

Figure 6-8. One-layer Medium/Large Slider (Resistively Interpolated)



For design rules, see [Figure 6-1 on page 6-2](#)

Figure 6-9. One-layer Medium/Large Wheel (Resistively Interpolated)

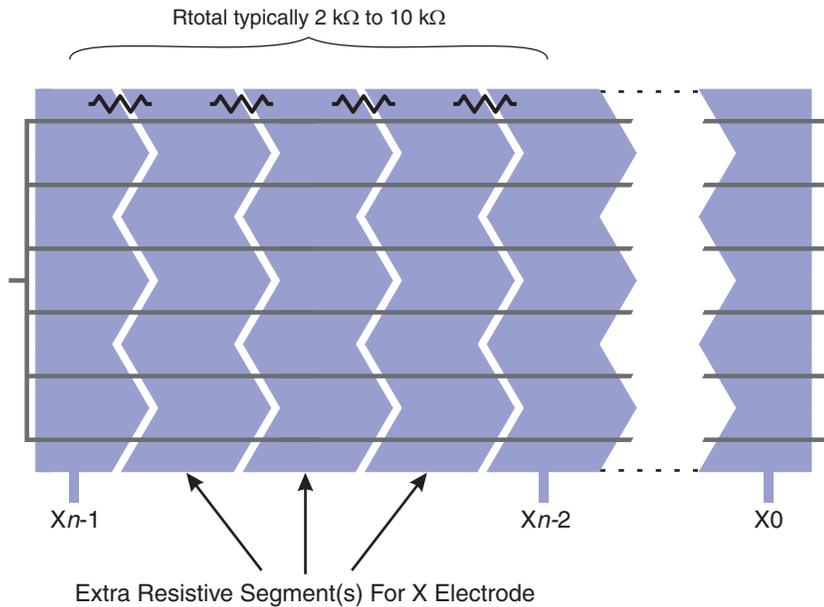


For design rules, see [Figure 6-2 on page 6-4](#)

6.4.3 Two-Layer Medium/Large Slider Or Wheel

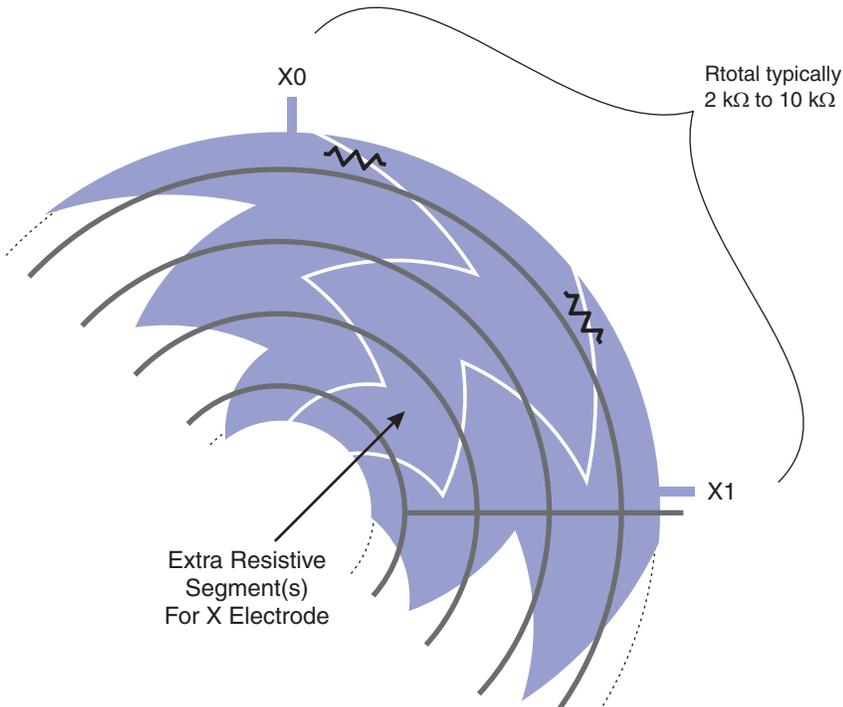
Creating larger sliders and wheels when using a flooded X design follows the same principles as in Section 6.3.5 “Two-layer Medium/Large Slider Or Wheel” on page 6-8, except that extra segments are introduced using resistive dividers on the X lines.

Figure 6-10. Two-layer Medium/Large Slider (Resistively Interpolated)



For design rules, see Figure 6-6 on page 6-8

Figure 6-11. Two-layer Medium/Large Wheel (Resistively Interpolated)



For design rules, see Figure 6-7 on page 6-9



Section 7

Two-dimensional Sensors

Two-dimensional sensors are not covered by this version of the guide. For information on designing two-dimensional sensors, see the full version of the guide (available under a non-disclosure agreement only).

Revision History

Revision No.	History
Revision A – December 2008	<ul style="list-style-type: none"><li data-bbox="824 268 1013 294">• Initial version
Revision B – January 2009	<ul style="list-style-type: none"><li data-bbox="824 317 1365 342">• Updates to advice on interdigitated electrodes.<li data-bbox="824 348 1484 403">• Additional advice added on PCB components, ESD protection, floating conductive items and conductive paint.





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