Touch Sensors

Design Guide

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Appendix A

Getting Started

Start by reading the introductory sections in Section 1, paying particular attention to:

- Section 1.2 “Self-capacitance and Mutual-capacitance Type Sensors”
- Section 1.3 “Dimension Groups”
- Section 1.4 “Some Important Theory”

Next, read the general advice on sensor design in Section 2:

- Section 2.1 “Charge Transfer”
- Section 2.2 “Components”
- Section 2.3 “Materials”
- Section 2.4 “Nearby LEDs”
- Section 2.5 “Electrostatic Discharge Protection”

Now use the flow diagram below to determine which further sections in this design guide are relevant to your project.

Type of Sensor

What type of sensor are you designing (how many dimensions does it have; see Section 1.3)?

Key

The sensor has zero dimensions (a single point of contact)
Go to “Zero Dimensions” on page viii

Slider or wheel

The sensor has one dimension (linear movement along one axis)
Go to “One Dimension” on page ix

Touchscreen

Two-dimensional sensors are not covered by this guide. For information on designing two-dimensional sensors, please contact Atmel’s Touch Technology Division.

Zero Dimensions

Charge-transfer Technology

Which charge-transfer circuit technology does the sensor use?

- **One direct connection to the sensor controller chip (e.g. QTouch)**

  The circuit is a self-capacitance circuit (see Section 3)

  Location of Electrodes and Traces

  How are the electrodes located with respect to the related circuitry (traces, LEDs and other components)?

  - **The electrodes and traces are fabricated on the same plane of the substrate**

    The design is planar
    Read Section 3.2 “Planar Construction”

  - **The electrodes are located on the panel’s surface and the rest of the circuitry is on a separate circuit board**

    The design is non-planar
    Read Section 3.3 “Non-planar Construction”

- **Two connections (X transmit line and Y receive line) to the sensor controller chip (e.g. QMatrix)**

  The circuit is a mutual-capacitance circuit (see Section 4)

  Location of Electrodes and Traces

  How are the electrodes located with respect to the related circuitry (traces, LEDs and other components)?

  - **The electrodes and traces are fabricated on the same plane of the substrate**

    The design is planar
    Read Section 4.2 “Planar Construction”

  - **The electrodes are located on the panel’s surface and the rest of the circuitry is on a separate circuit board**

    The design is non-planar
    Read Section 4.3 “Non-Planar Construction”

One Dimension

Charge-transfer Technology

Which charge-transfer circuit technology does the sensor use?

One direct connection to the sensor controller chip (e.g. QTouch)

The circuit is a self-capacitance circuit (see Section 5.1)

Introduction and General Advice

Read Section 5.1 “Introduction”
Read Section 5.2 “General Advice”

Go To

Go to “One Dimension: Self-capacitance Sensors” on page x

Two connections (X transmit line and Y receive line) to the sensor controller chip (e.g. QMatrix)

The circuit is a mutual-capacitance circuit (see Section 6.1)

Introduction and General Advice

Read Section 6.1 “Introduction”
Read Section 6.2 “General Advice”

Go To

Go to “One Dimension: Mutual-capacitance Sensors” on page xi

One Dimension: Self-capacitance Sensors

Size of Slider/Wheel

What size slider or wheel and how many channels available (3 or more than 3?)

Small slider (21 – 26 mm long) with 3 channels

Use a spatially interpolated small slider or wheel
Read Section 5.3.2 “Small Slider Or Wheel”

Small wheel (12 – 20 mm diameter) with 3 channels

Use a spatially interpolated small slider or wheel
Read Section 5.3.2 “Small Slider Or Wheel”

Medium/large slider (20 – 60 mm long) with 3 channels

Use a spatially interpolated medium/large slider or wheel
Read Section 5.3.3 “Medium/Large Slider Or Wheel”

Note: If the slider is at the upper end of the scale, consider using more channels with a resistively interpolated slider, as this may be easier to construct
Read Section 5.4.2 “Medium/Large Slider Or Wheel”

Medium/large wheel (20 – 60 mm diameter) with 3 channels

Use a spatially interpolated medium/large slider or wheel
Read Section 5.3.3 “Medium/Large Slider Or Wheel”

Note: If the wheel is at the upper end of the scale, consider using more channels with a resistively interpolated wheel, as this may be easier to construct
Read Section 5.4.2 “Medium/Large Slider Or Wheel”

Large slider or more then 3 channels

Use a resistively interpolated medium/large slider or wheel
Read Section 5.4.2 “Medium/Large Slider Or Wheel”

Large wheel or more then 3 channels

Use a resistively interpolated medium/large slider or wheel
Read Section 5.4.2 “Medium/Large Slider Or Wheel”

One Dimension: Mutual-capacitance Sensors

Size of Slider/Wheel

? What size slider or wheel?

Small slider (n x 6 mm – n x 8 mm long, 5 – 50 mm high)

▶ Go to “One Dimension: Mutual-capacitance Sensors – Small Slider or Wheel” on page xii

Small wheel (15 – 21 mm circumference)

▶ Go to “One Dimension: Mutual-capacitance Sensors – Small Slider or Wheel” on page xii

Medium/large slider (n x 6 mm – n x 8 mm long, more than 50 mm high)

▶ Go to “One Dimension: Mutual-capacitance Sensors – Medium/Large Slider or Wheel” on page xiii

Medium/large wheel (more than 21 mm circumference)

▶ Go to “One Dimension: Mutual-capacitance Sensors – Medium/Large Slider or Wheel” on page xiii

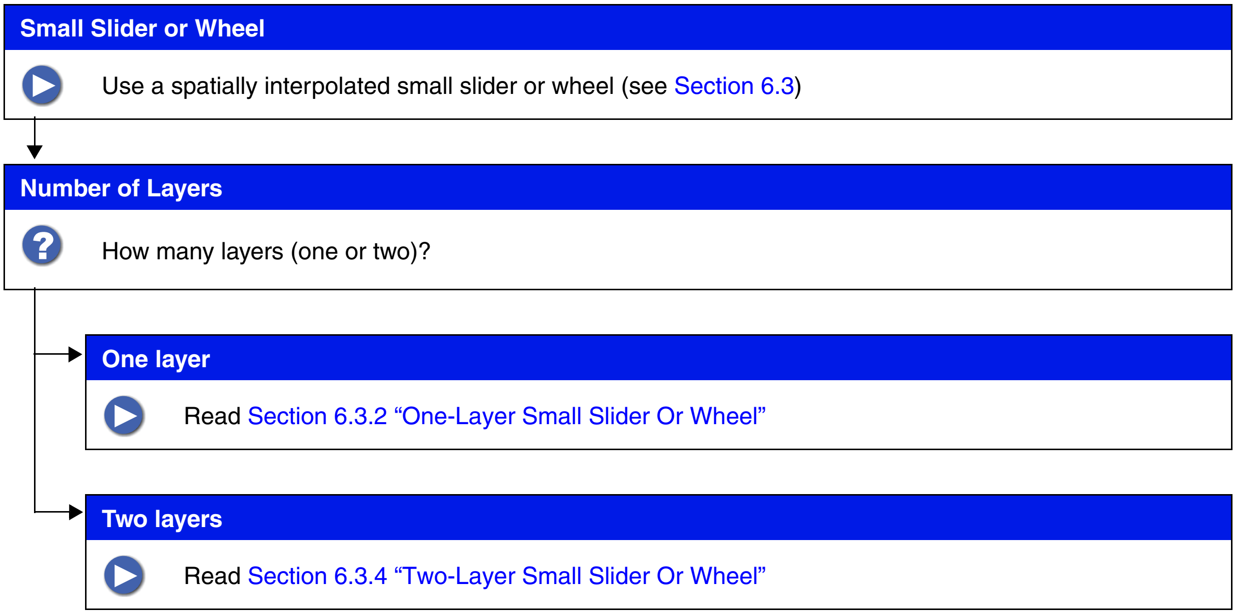
Large slider

▶ Go to “One Dimension: Mutual-capacitance Sensors – Large Slider or Wheel” on page xiv

Large wheel

▶ Go to “One Dimension: Mutual-capacitance Sensors – Large Slider or Wheel” on page xiv

One Dimension: Mutual-capacitance Sensors – Small Slider or Wheel



Small Slider or Wheel

Use a spatially interpolated small slider or wheel (see Section 6.3)

Number of Layers

How many layers (one or two)?

One layer

Read Section 6.3.2 “One-Layer Small Slider Or Wheel”

Two layers

Read Section 6.3.4 “Two-Layer Small Slider Or Wheel”

One Dimension: Mutual-capacitance Sensors – Medium/Large Slider or Wheel

Medium/Large slider or Wheel

Use a spatially interpolated medium/large slider or wheel (see Section 6.3)

Number of Layers

How many layers (one or two)?

One layer

Read Section 6.3.3 “One-Layer Medium/Large Slider Or Wheel”

Two layers

Add extra channels and use a resistively interpolated design
Read Section 6.4.3 “Two-Layer Medium/Large Slider Or Wheel” (see also Section 6.4.1)

One Dimension: Mutual-capacitance Sensors – Large Slider or Wheel

Large Slider or Wheel

▶ Add extra channels and use a resistively interpolated design (see Section 6.4)

Number of Layers

? How many layers (one or two)?

One layer

▶ Read Section 6.4.2 “One-Layer Medium/Large Slider Or Wheel” (see also Section 6.4.1)

Two layers

▶ Read Section 6.4.3 “Two-Layer Medium/Large Slider Or Wheel” (see also Section 6.4.1)

Section 1

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 implementating sensors for use with 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 for implementating sensors for use with QMatrix™ sensor controllers.

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

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

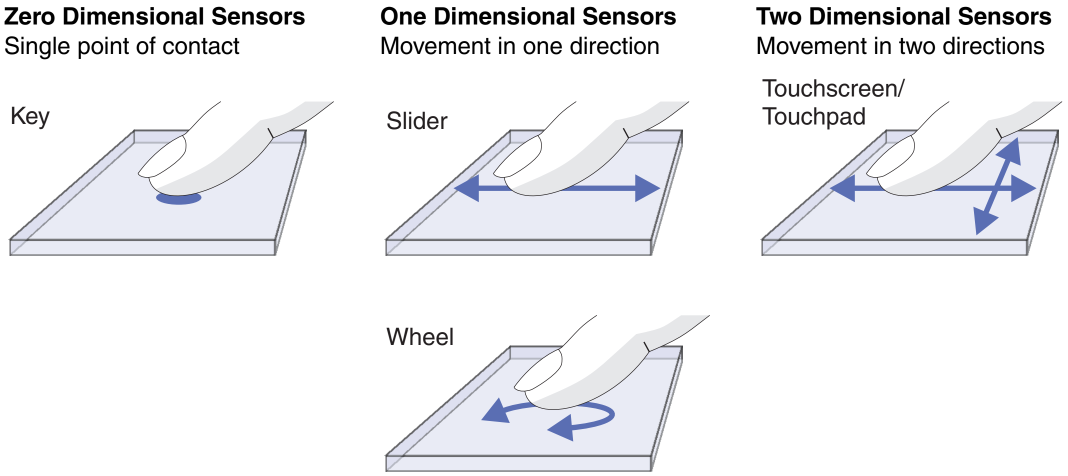
1.3 Dimension Groups

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 guide. For information on designing two-dimensional sensors, please contact Atmel's Touch Technology Division.

Figure 1-1. Sensor Dimensions



1.4 Some Important Theory

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

- **Cx:** 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)
- **Cp:** Any parasitic capacitance added in parallel with Cx
- **SNR:** Signal to noise ratio: a measure of the quality of the capacitive measurement

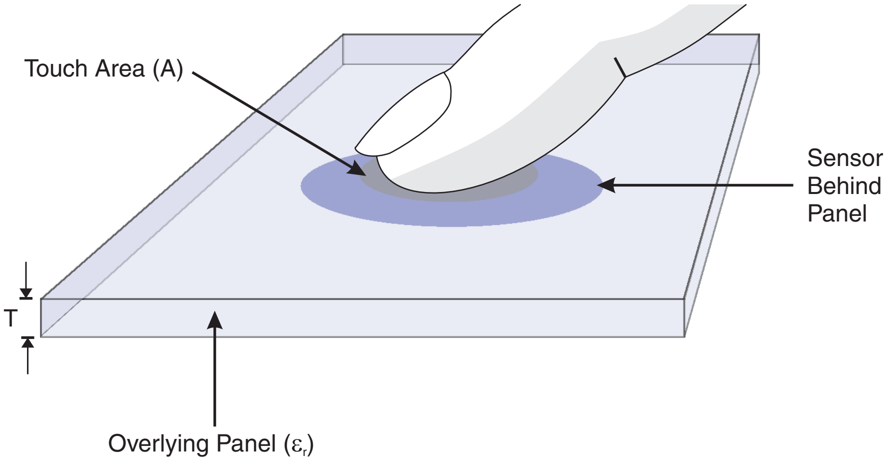
Capacitance (C) is defined in Equation 1-1.

Equation 1-1. Capacitance

$$C = \frac{\varepsilon_0 \times \varepsilon_r \times A}{T}$$

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

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

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

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

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.

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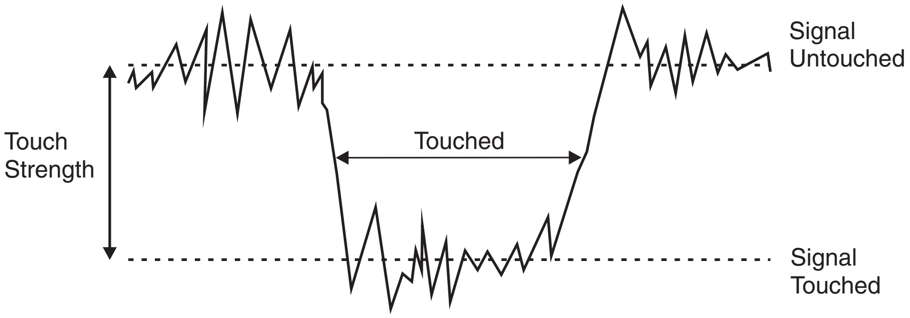
1. Note that this definition uses the RMS noise present during touch, as this is the worst case.

Figure 1-3. Touch Signal Levels



Section 2

General Advice

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 Cx and a charge integrator capacitor Cs. 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 Cx and Cs (see Figure 2-2 on page 2-2).

Because Cx and Cs 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 Cx (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 resitivity 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 kΩ 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).

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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

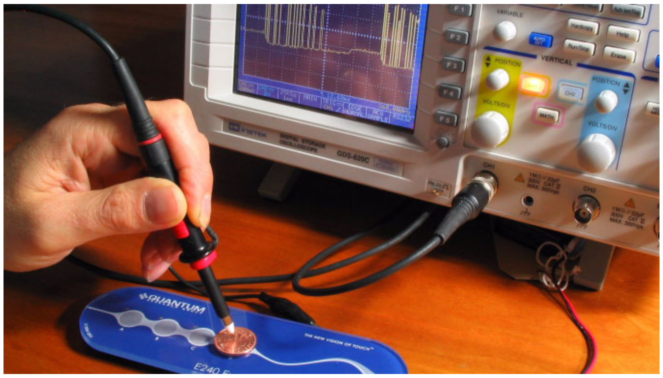
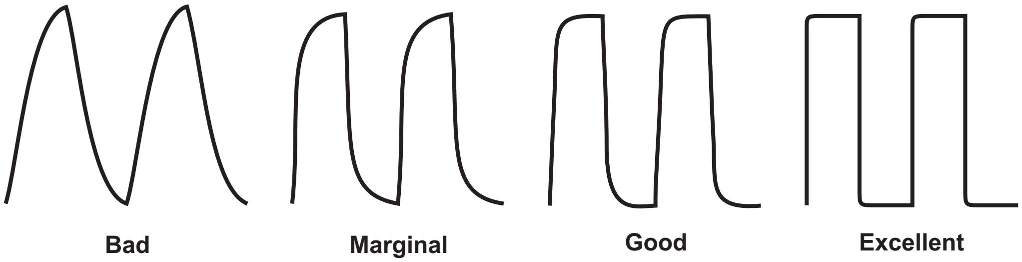


Figure 2-2. Good and Bad Charge Pulses



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

Rseries_total * (Cx + Cp) <= Tcharge / 5 (1)

Where:

- Rseries_total is the total series connection from the sensor chip's pin to the farthest point on the sensor.
- Cx + Cp 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.
- Tcharge 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.

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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 second order effects, such as the Rseries value, chip output drive strength, and so on..

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 senor 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 (such as the Cs reference capacitors and associated resistors) should be placed as close to the control chip as is physically possible to assist with EMC compliance. Avoid compromises in layout in this regard; placing such components closer to the chip is always better.

If these parts are placed far from the chip, serious noise problems and instabilities can arise. A common mistake is to place the series resistors at the actual key locations instead of at the chip. The trace length from the chip to the passive components is just as important as the distance from the chip to the actual key.

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

Placing the passive components close to the chip, whilst having a long set of tracks to the chip from the key, negates the desired result, as long tracks act as RF antennas. The series resistor acts to reduce RF coupling both in and out of the sensor circuit. However, the circuit cannot perform this function on RF signals coupled into the chip on a long trace between the chip and the resistor.

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 kΩ/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 kΩ/sq that is 100 mm long and 0.5 mm wide will have a resistance of 200 kΩ.

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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.

It is acceptable to use a flex PCB or FFC/FPC [1] 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.

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 panel thickness and its dielectric constant (ε_r) play a large part in determining the strength of electric field at the surface of the control panel. If the metal electrodes are on the inside surface of the substrate, then the thickness and ε_r of the substrate are also factors.

Glass has a higher ε_r than most plastics (see Table 2-1). Higher numbers mean that the fields will propagate through more effectively. Thus a 5 mm panel with an ε_r of 8 will perform similarly in sensitivity to a 2.5 mm panel with an epsilon of 4, all other factors being equal.

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

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

Table 2-1. 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
Plexiglas	3.4
Polycarbonate	2.9 to 3.0
Polyethylene	2.2 to 2.4
Polystyrene	2.56
PET (Polyethylene Terephthalate)	3

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[1] FFC = Flat Flexible Conductor, FPC = Flexible Printed Circuit

Table 2-1. Relative Dielectric Constants for Materials (Continued)

Material	Dielectric Constant (ε_r)
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 to 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)

$$S = \varepsilon_r / t$$

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

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

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).

2.3.4 PCB to Panel Bonding

Good contact between the substrate and the panel is essential for reliable performance. An unreliable interface which can change by even 100 microns after being touched by a finger can cause unacceptable signal fluctuations. Adhesives or compression mechanisms can be used to reliably overcome these problems. Non-adhesive solutions can for example involve the use of co-convex surfaces that are placed under preloaded pressure when clamped together, to ensure complete surface mating.

Various methods have been used to mechanically clamp electrode substrates to panels, including heat staking plastic posts, screws, ultrasonic welding, spring clips, non-conductive foam rubber pressing from behind, etc.

The most common form of electrode is a filled circle or rectangle of copper on a PCB, corresponding loosely in shape to the key graphic. The PCB is then usually glued with an industrial adhesive such as a two-sided acrylic sheet to the inside of the operator panel. (1)

2.4 Nearby LEDs

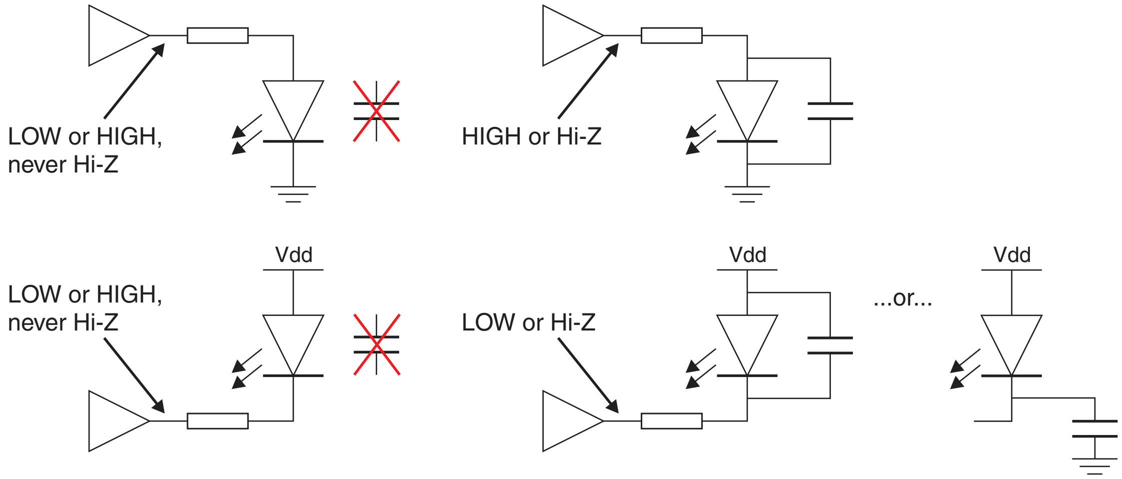
If LEDs are close (that is, less than 4 mm away) to capacitive sensors, you must give some consideration to their change in capacitance between on and off states (and the possible change of the LED driver's output impedance too). It is also necessary to consider the changes in the nature of their drive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

If changes in capacitance of the LED and associated drive circuit couple to a touch sensor electrode, it is possible to cause detection instability or touch keys that stick either on or off when the LED changes state.

As a general rule, LEDs that are judged as close must be bypassed with a capacitor that has a typical value of 1 nF (2) 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



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1. One example of acrylic bonding sheet includes 3M type 467MP, although there are other suppliers and types which may prove more suitable.
2. 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 kΩ at 100 kHz

Any LED terminal already connected full time to either Vdd or ground, even if through a limiting resistor, does not need such bypassing. LEDs that are constantly driven (for example, just for constant backlighting) do not normally require bypassing so long as these LEDs are driven before the control chip is given a chance to calibrate itself on power-up. Multiplexed LEDs usually require bypassing on one terminal but since multiplex lines drive two or more LEDs, the number of bypass capacitors need not be one per LED; only one capacitor per common drive line is needed.

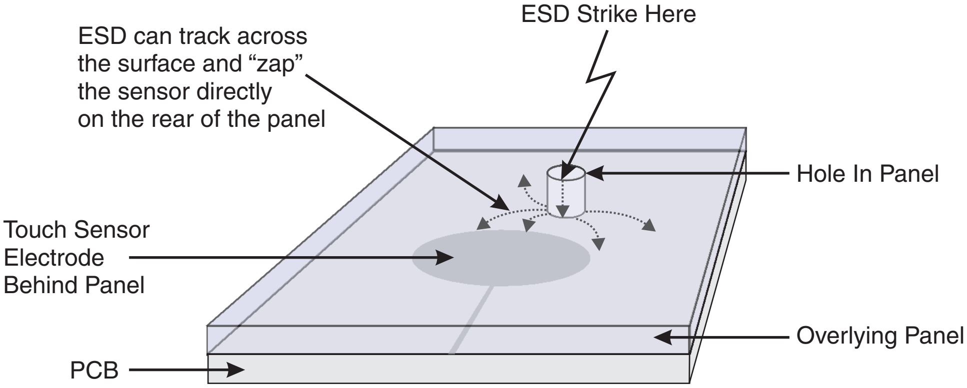
Other kinds of signal traces that change impedance can also cause false detections. Any nearby trace that switches between “floating” and “clamped” states will usually cause a slight apparent capacitance change and should be bypassed. Push-pull driven traces, so long as they are never three state, do not require bypassing.

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.

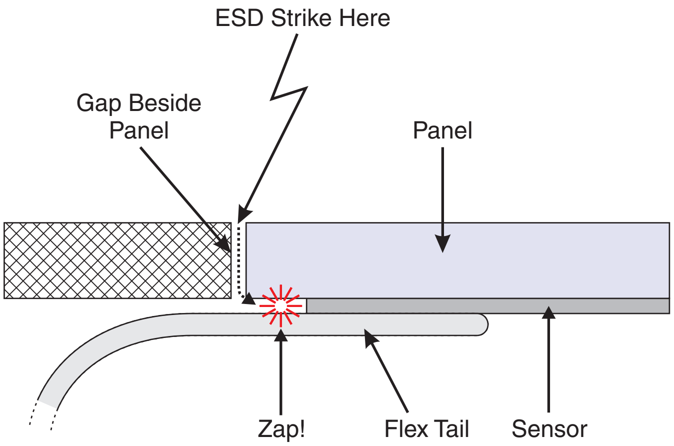
The single greatest threat from ESD tends to occur where there is a gap or hole in the panel, particularly at the edge of the panel. In these situations an effect known as "creepage" can allow ESD to track across an insulating surface and connect directly with the sensor or interconnecting tracks (Figure 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-dissapative surfaces. This is a complex field of study that should be considered but probably not over-analyzed; simple precautions usually suffice.

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

Section 3

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.

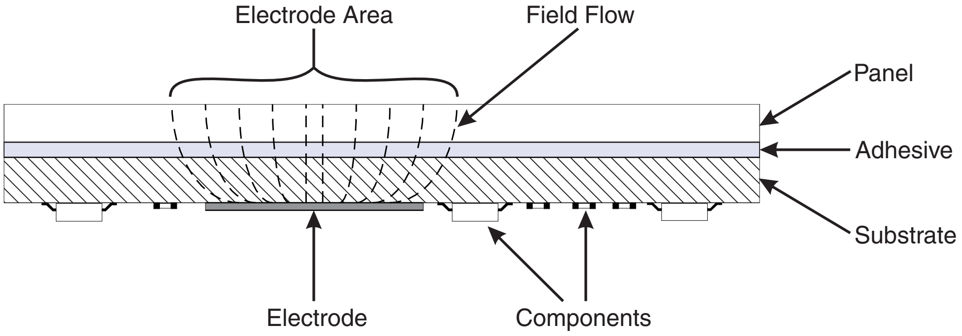
3.2 Planar Construction

3.2.1 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).

What is interesting about this type of construction is that the PCB can be one-sided, with both the components and electrodes on the side *away* from the user's finger. The electrode "back-fires" its electric field through the PCB, the adhesive layer, and the panel. Atmel's QT devices are unique in having a sufficient signal range to detect through thick panel construction, and yet remain highly reliable and sensitive (10 mm is a common stack thickness for QT sensor circuits). This results in a very low-cost touch panel.

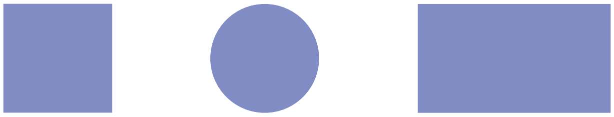
Figure 3-1. "Back-firing" Sandwich-style Touch Panel



3.2.2 Electrode Shapes

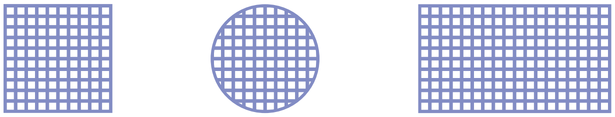
An electrode is simply the patch of conductive material on the substrate that forms the sensor. Common shapes are filled discs, squares and rectangles (see Figure 3-2).

Figure 3-2. Common Electrode Shapes



It is also possible to use a hatched pattern (such as a 50 percent mesh fill) for the electrode, if desired [1] (see Figure 3-3). 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.

Figure 3-3. Electrodes with 50 Percent Mesh Fills



It is a common mistake to assume that the electrode shape and the graphic key symbol on the panel should be the same. In fact, it is often better to make the electrodes larger than the graphic especially with small key sizes since key sensitivity falls off at the edges; an oversize electrode not only compensates for this but also allows for off-center touch with good response. Generally, it is a good idea to make the electrode shape extend 2–3 mm beyond the graphic symbol. Of course, this is not always possible, for example on a densely spaced panel. As a rule, the electrode shape should have a *minimum* dimension of at least 4 times the panel thickness for reliable operation.

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).

---

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

3.2.3 Ground Loading

This style of sensor is highly sensitive to ground loading because such loading adds directly to Cx, 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.

Note that traces from other sensing channels of the same chip can act as ground, depending on the device.

Some QT devices only burst (acquire) a single channel at a time; when a channel is not bursting, it is clamped to ground. Thus, two electrodes placed together that do not parallel burst will act as field shapers against each other, since one will be at ground potential while the other acquires. If a trace leading to key 1, say, is routed past key 2, then key 2 "sees" a ground trace next to it during its burst.

Other QT devices use "parallel bursts" where several keys burst at the same time; the signals on these traces are at a similar potential during bursts, making them "self-shielding" and hence non-grounding and non-interfering with respect to each other.

Electrodes when not acquiring are held at ground potential, and therefore act as a ground plane on neighboring acquiring electrodes and diminish sensitivity overall, particularly at the edges. While these effects can be overcome by increasing the value of Cs, it is still helpful to understand why these effects happen, even if they cannot be improved due to panel design constraints.

Sometimes it is desirable to shield an electrode on its rear side to prevent false detection from moving parts to the rear, or to prevent interference from high voltage AC signals (such as from electroluminescent backlighting or driver circuitry). Either an active shield with a solid metal plane behind the electrodes or a rear ground plane can be used. If a ground plane is used, the ground should be connected directly to the chip's Vss pin to provide a clean ground having no relative voltage spikes on it. Also, the electrode and ground plane should be separated by the maximum distance of air or thickness of insulator 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.

Electrodes will propagate fields into the panel material and laterally around the key area as well. These fields will drop off gradually with distance from the edge of the key; sometimes this can result in key detection some distance away from the key itself. It can therefore 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 ½T 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.

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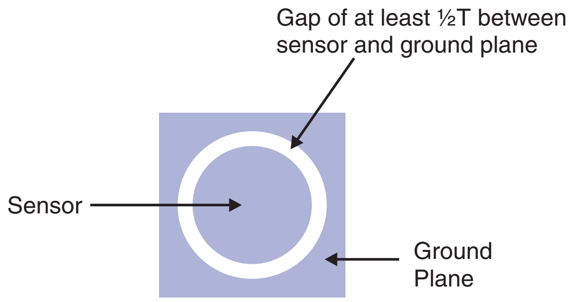
1. It is acceptable to stop closer, but some loss of sensitivity will be observed. Experimentation will be required to reach the best compromise.

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



While the ground flood shown in Figure 3-5 is is an effective approach, it should be remembered that ground areas near the key also increase the capacitive loading (Cx), thereby also reducing sensitivity to touch. Although this effect can be compensated by increasing the sample capacitor Cs, an overall decrease in signal-to-noise ratio (SNR) and an increase in power consumption will occur.

A compromise is to place a ground ring around the electrode with a 3–5 mm gap. The electric fields will terminate sharply across this gap yet capacitive loading on the key will be minimized. A ground plane near an electrode will cause the key to be less sensitive near its edges, since the field lines are shunted away from the panel surface. The width of the ground plane also matters: a thin ground track next to an electrode will have less of an effect than a wide ground pour.

For small battery-powered devices, the addition of a 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.

Note that, in any case, ground planes or tracks should only be used to define a key area as a last resort for a specific purpose. Key fields will naturally decay with distance from an electrode edge, and this drop in field strength is usually enough to define a key boundary.

3.2.4 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.

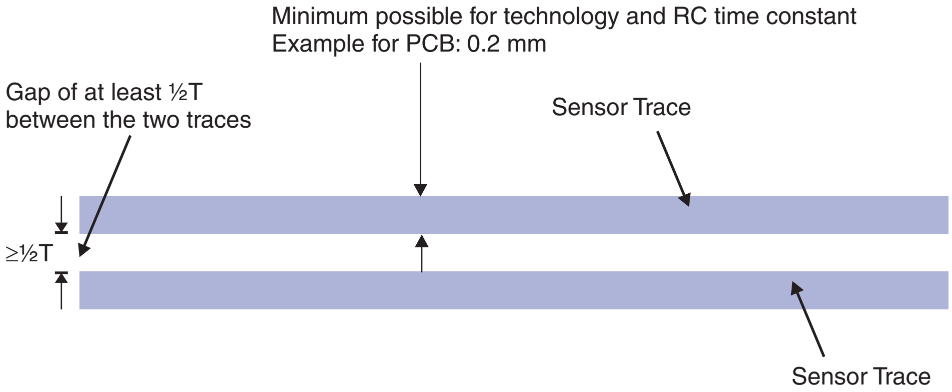
Note that interconnecting traces are touch sensitive and simply form an extension to the sensor itself. It is good practice to run sensor traces on a PCB or substrate layer that is farthest from touch, while the sensor is on a layer closest to touch.

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)

---

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.

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.

3.2.5 Illumination Effects

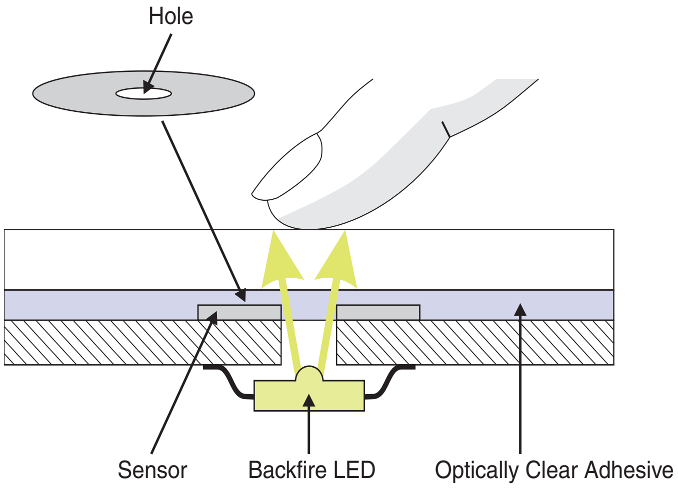
LEDs that are very close to the sensor should be bypassed as described in Section 2.4 “Nearby LEDs” on page 2-7.

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 3-6). This method allows for simple, low cost backlighting of the key area to back-illuminate a graphic symbol. Properly constructed, the result will be a very sensitive key even in the middle.

The width of the copper should be at least as wide as the panel is thick to provide adequate coupling; the electric field penetrates the panel material to “focus” inwards, while being terminated outwards from the ring by a ground plane. This method works well only if the panel material is thick enough (and with a high enough ε_r) to conduct the fields inwards. Remember to keep the hole small: the larger the hole, the more sensitivity will be lost. If the hole in the middle is too big and/or the panel has a low ε_r and/or is too thin, the fields in the middle will be weak and the key will not function as intended.

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.

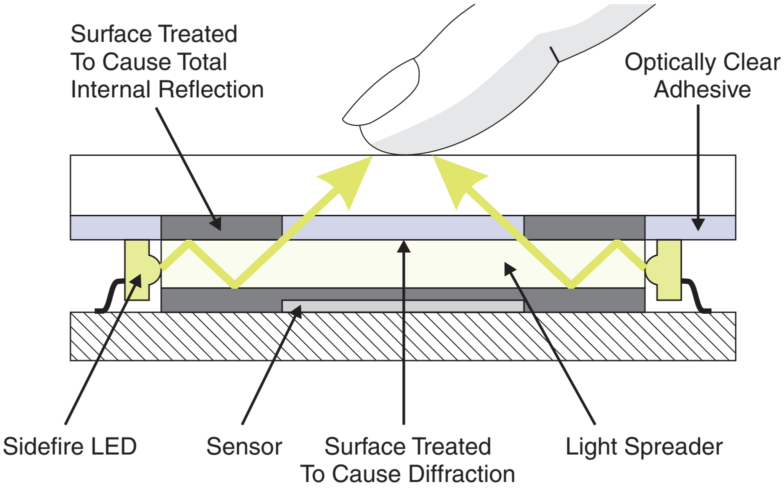
Figure 3-7. Backlighting Using an LED



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 on page 3-6). This can yield very thin illuminated structures.

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.

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

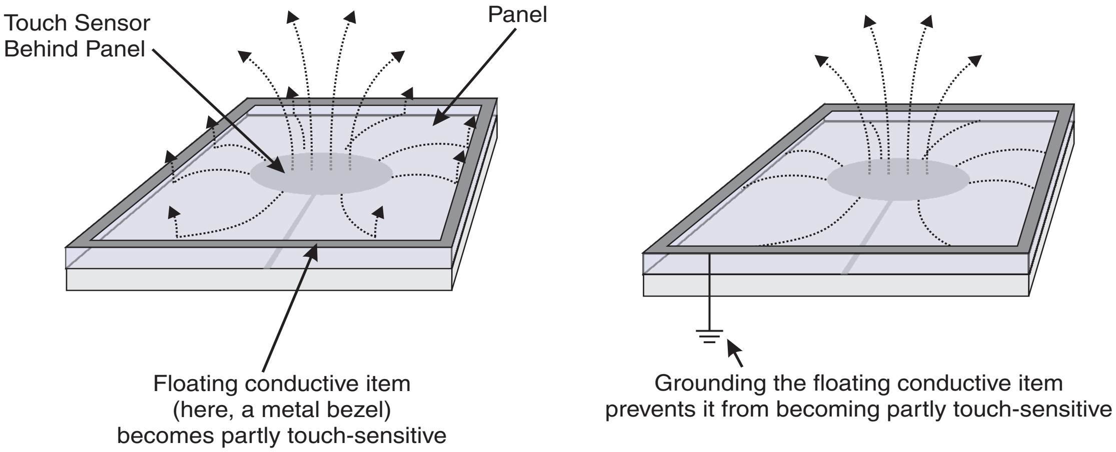


3.2.6 Floating Conductive Items

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. Usually this is undesirable, as it can cause strange behavior in key detection, depending on what the metal is contacting. Touching such nearby floating metal can also cause false key detection.

Always ground nearby conductive regions. This can be accomplished by a direct wire connection to power supply common, or by means of a 47 nF capacitor back to supply common.

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.

3.2.7 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.

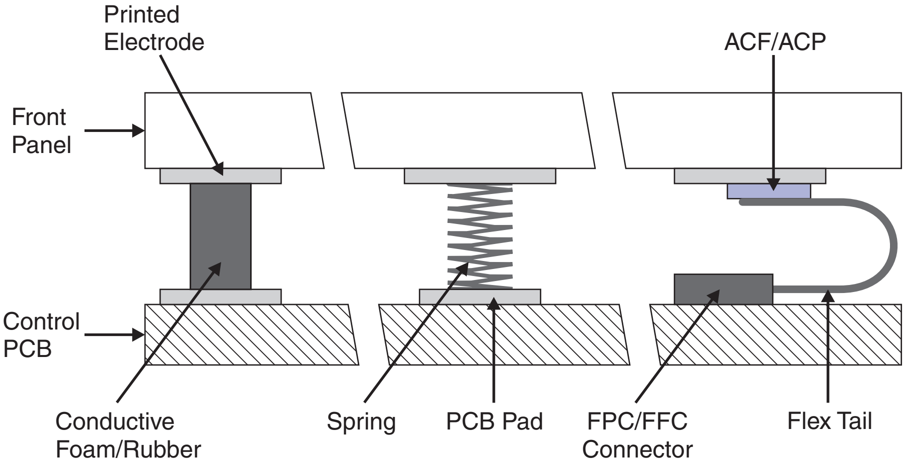
The rules for the interconnecting traces are identical to those already described in Section 3.2.4 “Interconnection” on page 3-4. However, the methods for interconnection are tightly coupled with the method of construction, and so careful consideration must be given as to how the two halves of the circuit 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 3.2.2 “Electrode Shapes” on page 3-2, 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

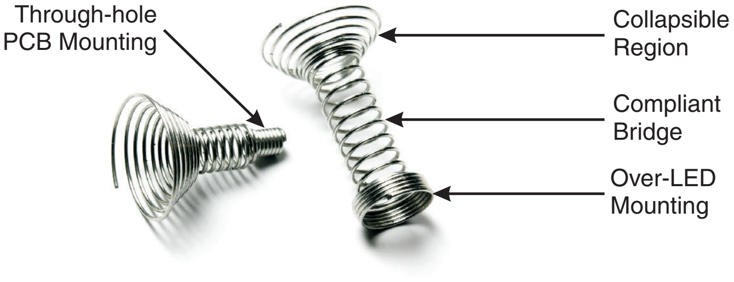


3.3.2 Philipp Spring™ Method

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.

Note that the spring is not intended to compress when touched; it is always maintained in a compressed state. The spring forms a static electrode that bridges the gap between the touch panel and the component PCB.

Figure 3-11. Philipp Spring Products



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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 oxidisation. 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.

One such spring is Atmel’s patented Philipp spring product (see Figure 3-11 on page 3-8) (1). This has a conical section that interfaces with the panel, and a central compliant bridge section. The conical section collapses first under pressure, and the center bridge last. This “top-down” collapse of the spring under pressure causes the coils to form a tight, flat spiral that is a very good approximation to a disc electrode (see Figure 3-12 on page 3-9).

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


Spring Before Compression

Spring After Compression

The collapsible region flattens to form an electrode disc.

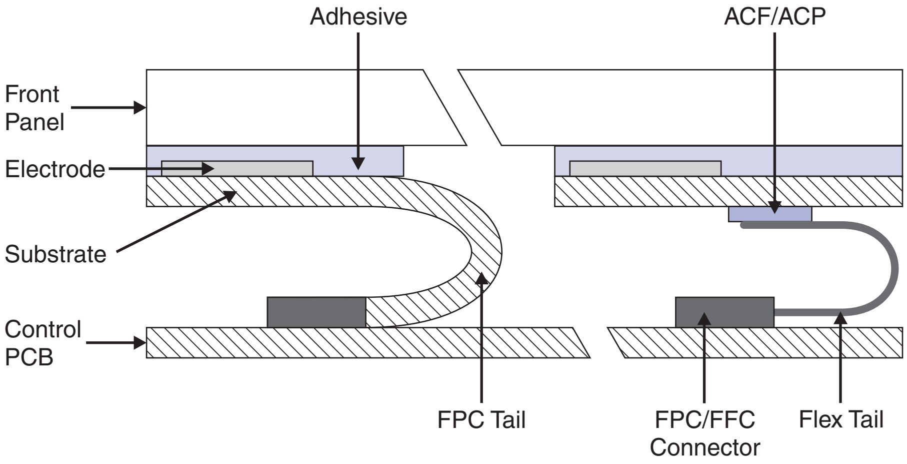
Compressed Spring Viewed Through a Clear Front Panel

The channel in the middle can be used for an LED.

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 Cx that is not touchable, and keep ground planes away from this pad to reduce the parasitic capacitance (Cp).

3.3.3 Secondary Substrate Method

Figure 3-13. Secondary Substrate Method



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1. The Philipp spring technology is available under license. Please consult Atmel for the licensing options on this technology. For advice on suitable sources of springs, contact Atmel’s Touch Technology Division.

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.

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 3-10), thus giving a good centralized illumination of the touch graphic on the panel above it.

Another popular method of providing illumination is in the form of a light spreader or light guides, as described for planar construction in Section 3.2.5 “Illumination Effects” on page 3-5.

The general rules for LEDs are described in Section 2.4 “Nearby LEDs” on page 2-7.

Figure 3-14. Using LEDs with Philipp Spring Products

3.3.6 Floating Conductive Items

The considerations for the use of floating conductive items described in Section 3.2.6 “Floating Conductive Items” on page 3-6 apply.

3.3.7 Conductive Paints

The considerations for the use of conductive paints described in Section 3.2.7 “Conductive Paints” on page 3-7 apply.

Section 4

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.

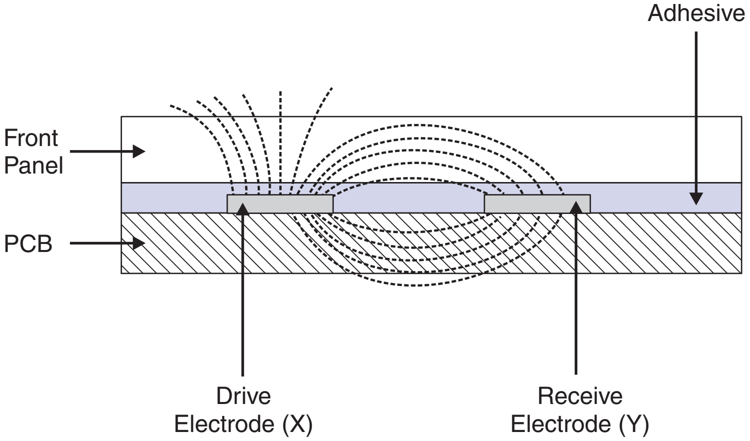
4.2 Planar Construction

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



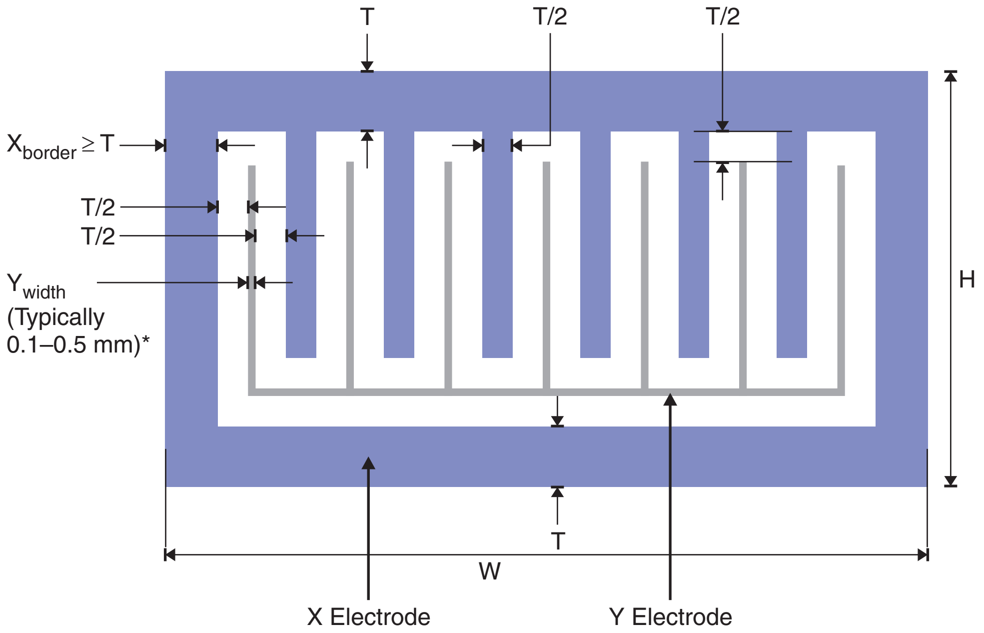
The X and Y electrodes are designed to optimize the distribution of the electric field that is coupling through the overlying panel. This maximizes touch sensitivity, as the touching object (typically a finger) has the maximum opportunity to disrupt this field coupling and cause a touch to be detected.

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}

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

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

Where:

- $\lfloor ... \rfloor$ 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:

$T = 0.5$ mm
$W = 10$ mm
$H = 8$ mm
$Y_{width}=0.1$ mm

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

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

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

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

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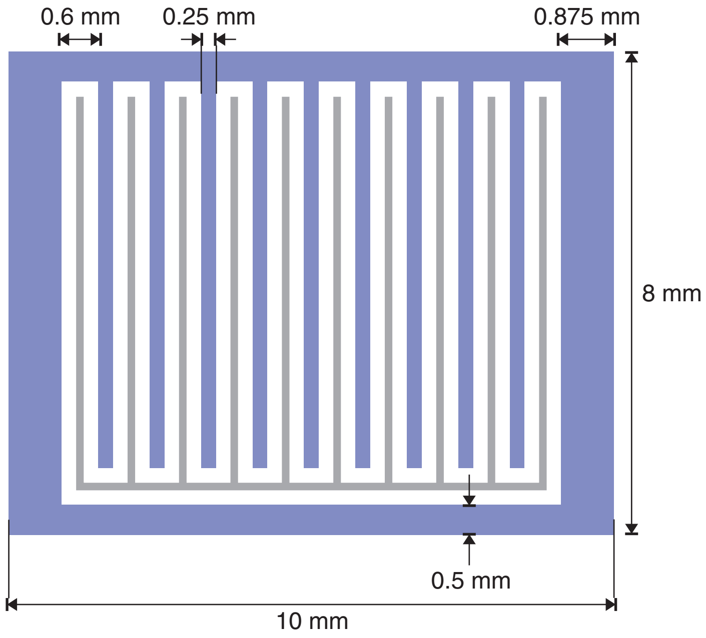
(1) That is, the total length of the facing edge between the X and Y electrodes.

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:

$T = 1.5$ mm
$W = 8$ mm
$H = 8$ mm
$Y_{width} = 0.1$ mm

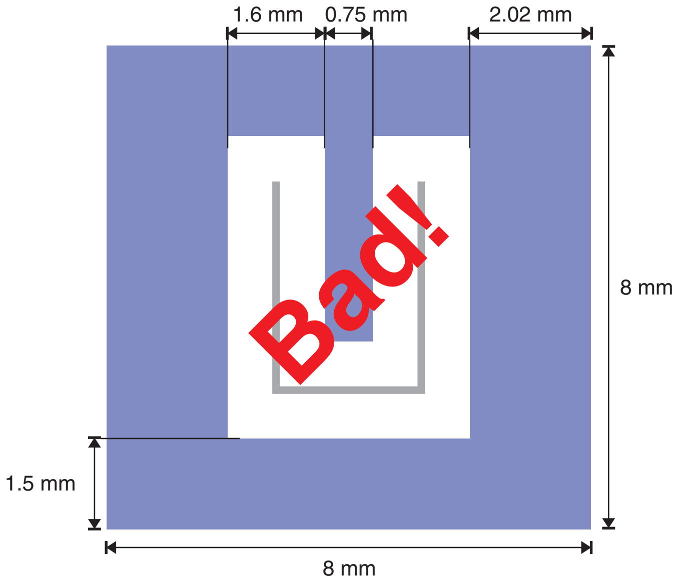
then the calculation is as follows:

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

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

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 Cx and a lack of sensitivity. It also tends to render the design more susceptible to Cp on the Y line (1). Hence small keys with relatively long interconnections and thick panels are a bad combination.

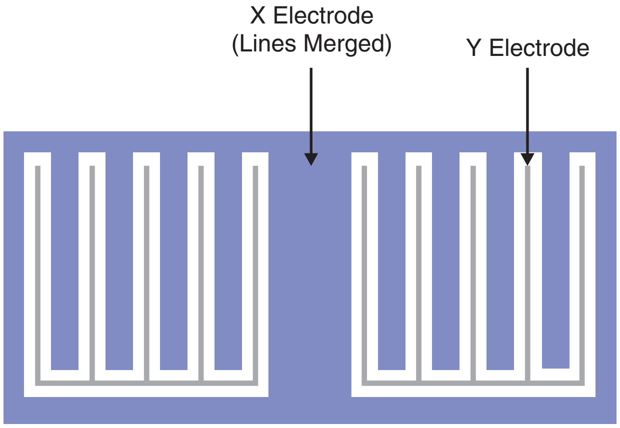
As can be seen from this example, designs with smaller keys and thicker panels make effective interdigitation very hard when following the guidelines. In such cases, it is better to break the guidelines by closing the gaps slightly (0.75 x T/2 minimum) and thinning down the X regions.

See also Section 3.2.3 "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



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1. The ratio of Cx to Cpy 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.

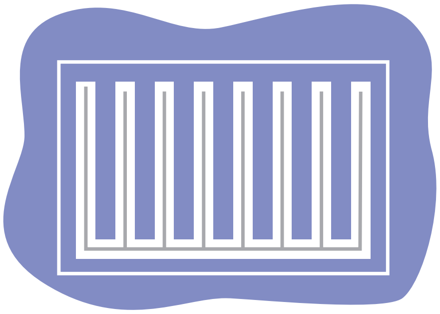
4.2.3 Ground Loading

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.

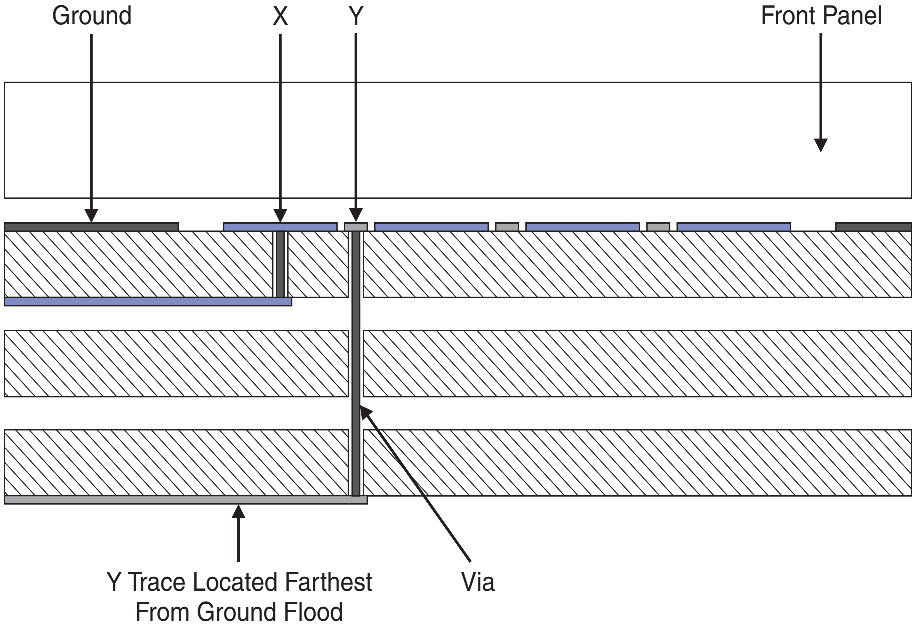
Bringing ground floods or traces close to the X element of the sensor has little or no effect on sensitivity. This is beneficial in most cases as it helps to shield X and Y traces on the layers below from interference from strong electromagnetic fields nearby. The ground flood can be made very close 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 (Cp) 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 Cp 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 Cp 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.

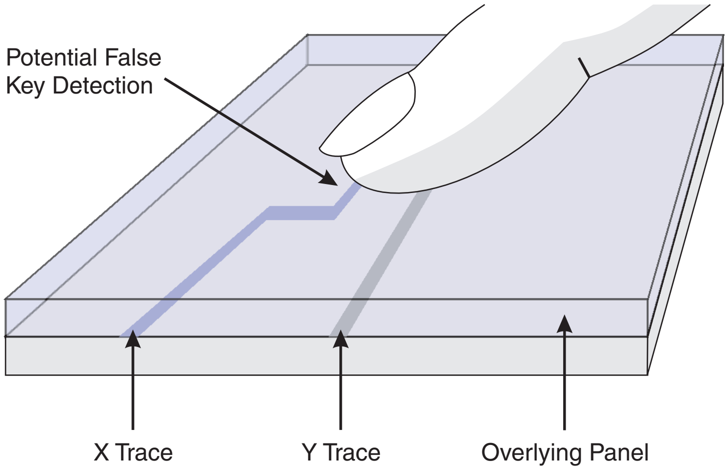
4.2.4.2 Y Routing

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 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 4-8).

Figure 4-8. Potential False Key



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(1) High kHz to hundreds of kHz in particular.

4.2.4.3 Avoiding False Key Detection

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)

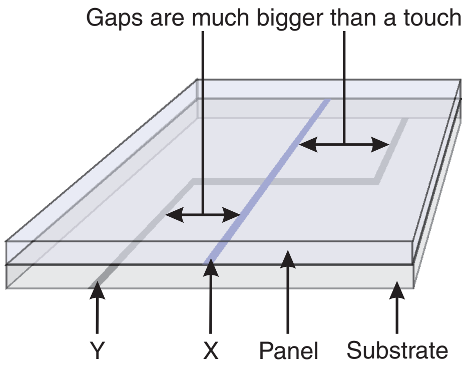


Figure 4-9.b. Separating ground Trace

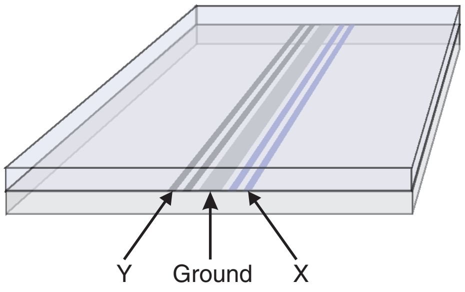


Figure 4-9.c. X Under Ground Trace

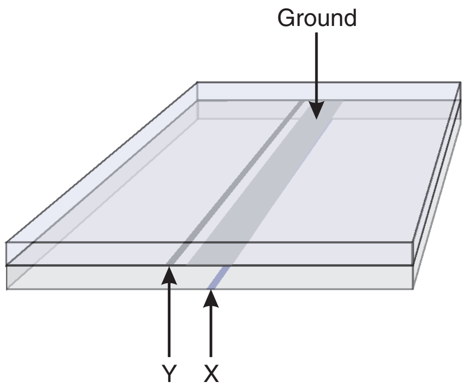
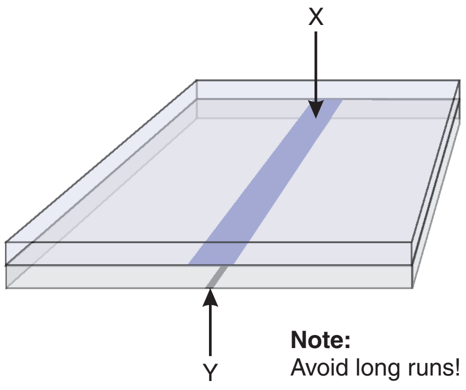


Figure 4-9.d. Y Under X



Note:
Avoid long runs!

---

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 though, much as described in Section 3.2.5 "Illumination Effects" on page 3-5. The rules for LEDs are described in Section 2.4 "Nearby LEDs" on page 2-7.

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 3.2.6 "Floating Conductive Items" on page 3-6.

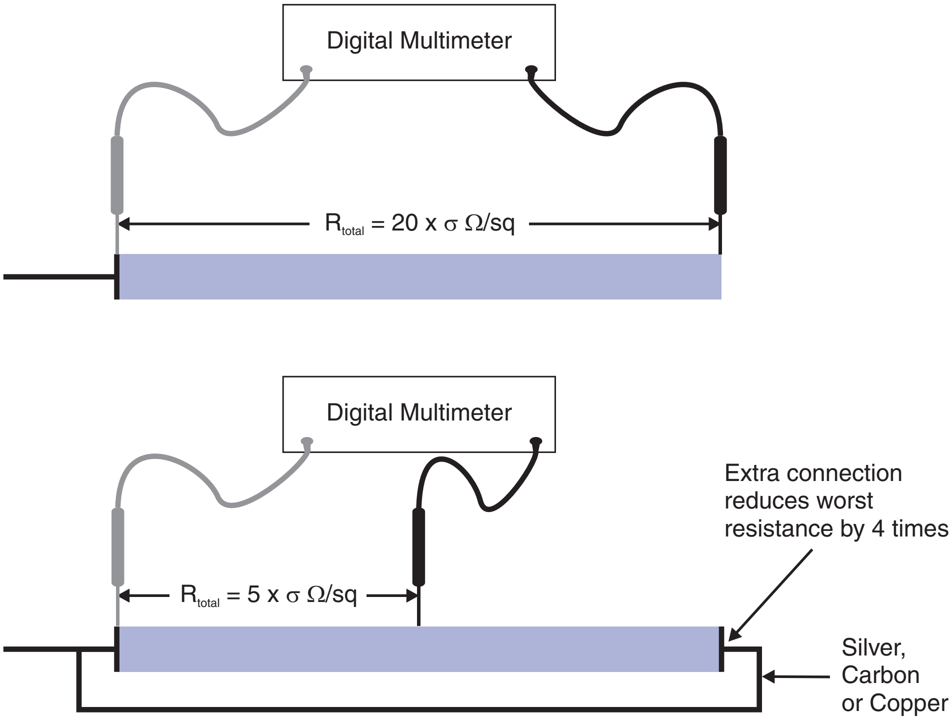
4.2.7 Conductive Paints

The considerations for the use of conductive paints described in Section 3.2.7 "Conductive Paints" on page 3-7 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 4-13). 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

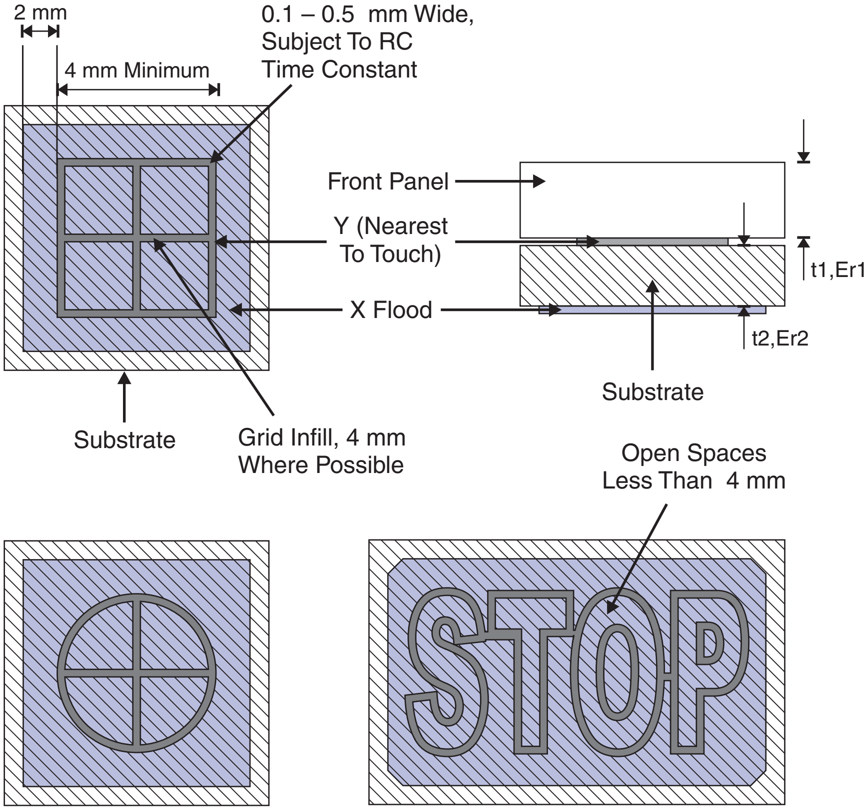
The flooded-X two-layer method distributes the X and Y electrodes across two layers of a substrate. This style has some great advantages in terms of sensitivity for small keys, and has some good intrinsic noise rejecting capabilities. Another useful property is that because the X electrode completely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

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.

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



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].

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[1] QMatrix measurements have the useful property that placing an isolated water drop so that it couples between and 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 proptionately 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.

For example, with the stack shown in Figure 4-10 on page 4-11:

$$S_{YToXStack} = \varepsilon_{r_2}/t_2$$

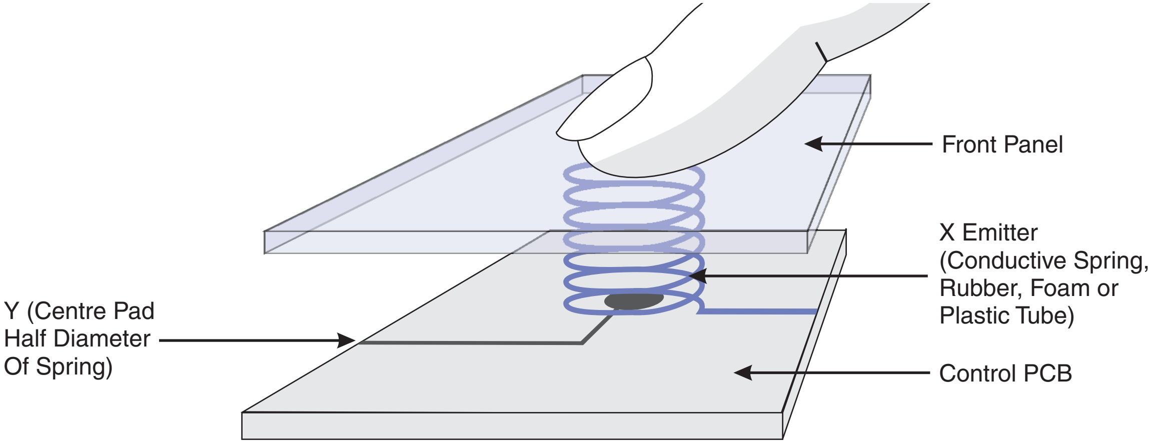
$$S_{TouchToXStack} = \frac{1}{\left(\frac{t_1}{\varepsilon_{r_1}} + \frac{t_2}{\varepsilon_{r_2}}\right)}$$

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 (1). 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.

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).

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



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.

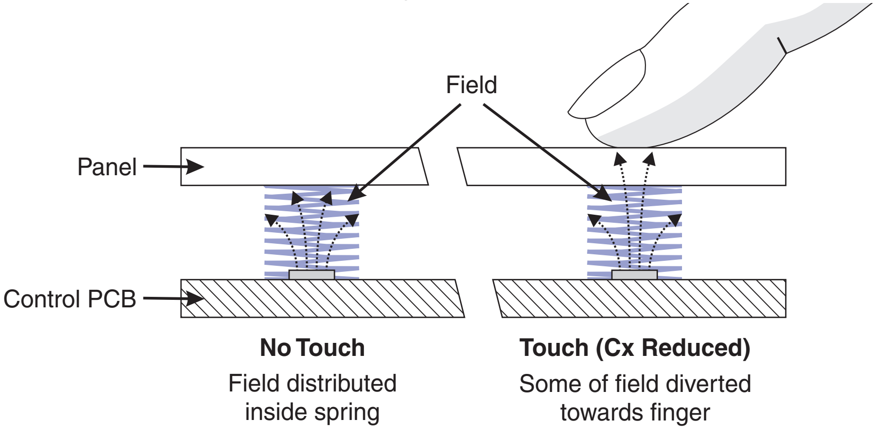
The compressed length of the spring, and hence the distance from the inside of the panel to the front of the PCB, should be less than 1 spring inner diameter. The pitch of the coils of the spring is not vitally important, but generally try to have the gaps approximately the same size as the diameter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

Neighboring coils can be arranged next to each other, ideally with a minimum center-to-center distance of 1.5 x spring outer diameter (2).

---

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

Figure 4-12. Effect of a Touch With a Spring



Note that the spring is not intended to compress when touched; it is always maintained in a compressed state. The spring forms a static electrode that bridges the gap between the touch panel and the component PCB. The change happens because the field inside the spring is redistributed during a touch (see Figure 4-12 on page 4-13).

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

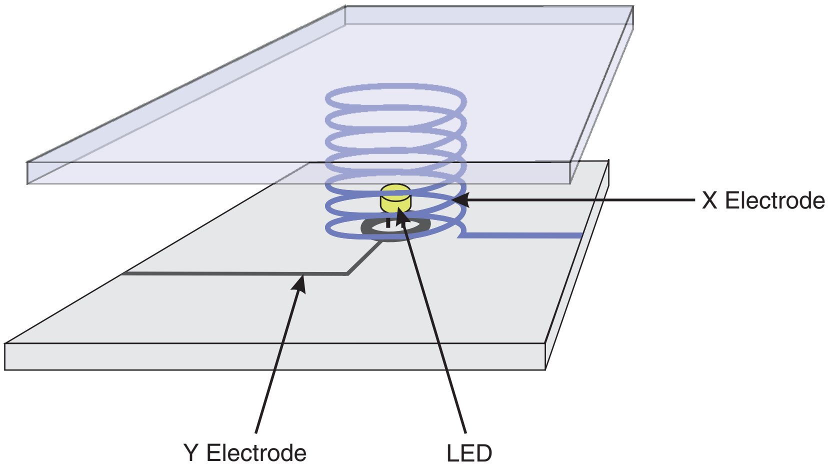
A non-planar construction method tends to have less potential for signal loss from nearby ground loads, and so is generally far less sensitive than a planar design. Flooded-X style sensors are particularly good in this regard because the X drive has a low impedance. This means that it can be loaded with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

4.3.6 Illumination Effects

The issues for illumination are very similar to those presented in Section 3.3.5 “Illumination Effects” on page 3-10. 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 4-13 on page 4-14). 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 4-13. 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 3.2.7 "Conductive Paints" on page 3-7 apply.

Section 5

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 3-8 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 guidlines should be followed when designing the traces for slider and wheel sensors:

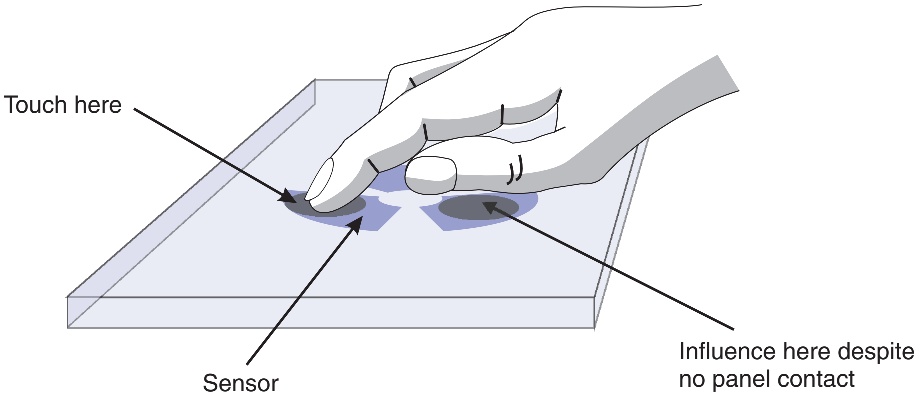
- Always run all three channel connections together as a group and keep them well away from noisy sources and ground loads.
- Keep the traces as short and thin as possible and space the traces with a gap equal to the track width.
- When routing traces from the electrodes, use a via, if possible, for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

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 3.2.6 "Floating Conductive Items" on page 3-6 apply.

5.2.5 Conductive Paints

The considerations for the use of conductive paints described in Section 3.2.7 "Conductive Paints" on page 3-7 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.

The designs shown in this section use the method of “two plus two half” electrodes, with the highest channel (channel 2) split in half. This means 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, so the same sensor chip can drive either electrode style.

Note: There is no preferred order for the channels; the order simply determines the direction in which the sensor increases or decreases (left/right or up/down for a slider, and clockwise/counter-clockwise for a wheel). Refer to a specific chip’s datasheet for additional information.

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)

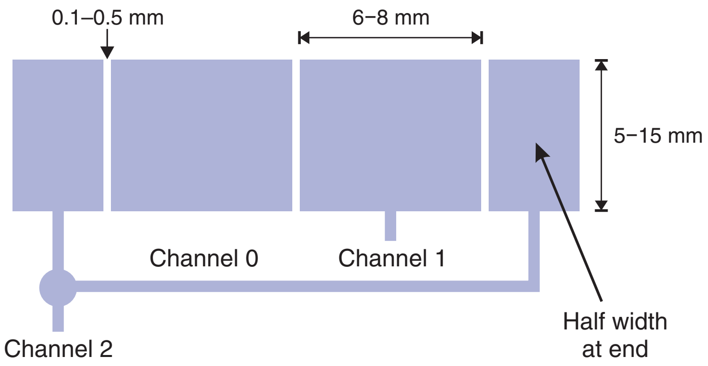
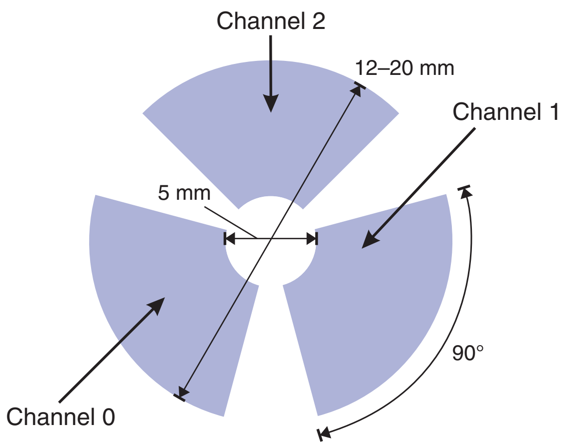


Figure 5-3. Small Wheel (Spatially Interpolated)



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)

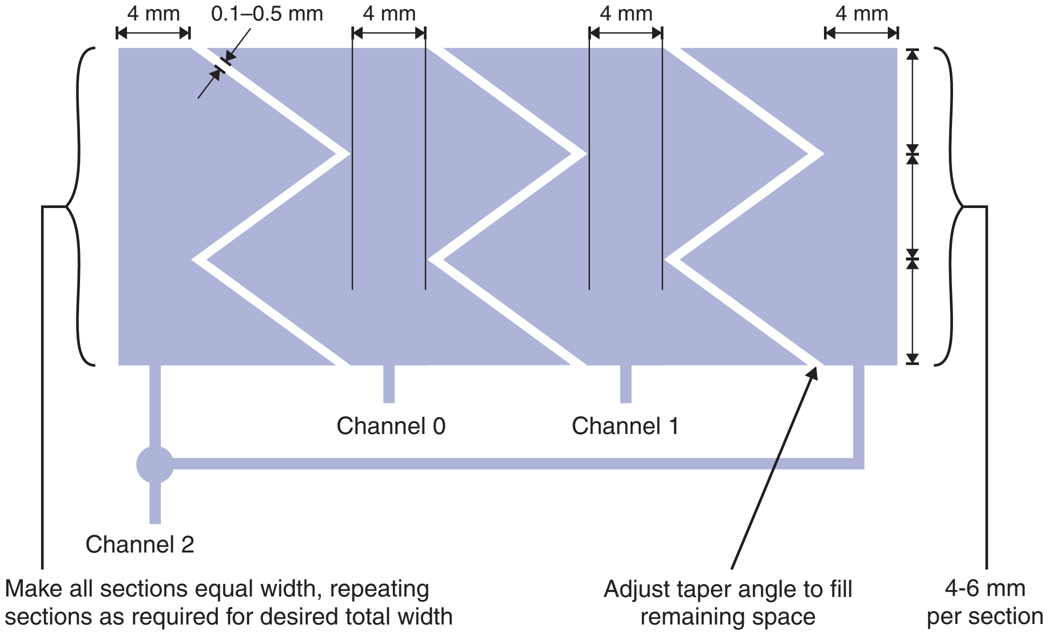
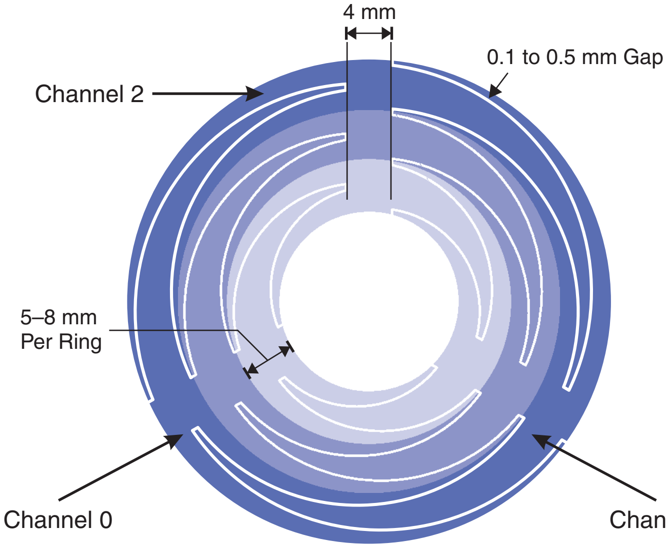


Figure 5-5. Medium/Large Wheel (Spatially Interpolated)



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 Introduction

A resistively interpolated wheel or slider sensor uses more than three electrodes in total, but only three of them are directly connected to the sensor chip. In the case of a slider, the highest channel (channel 2) is split across the end electrodes (see Figure 5-6).

The rest of the electrodes are connected using resistors to provide an electrical interpolating effect. 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.

Note: There is no preferred order for the channels; the order simply determines the direction in which the sensor increases or decreases (left/right or up/down for a slider, and clockwise/counter-clockwise for a wheel). Refer to a specific chip's datasheet for additional information.

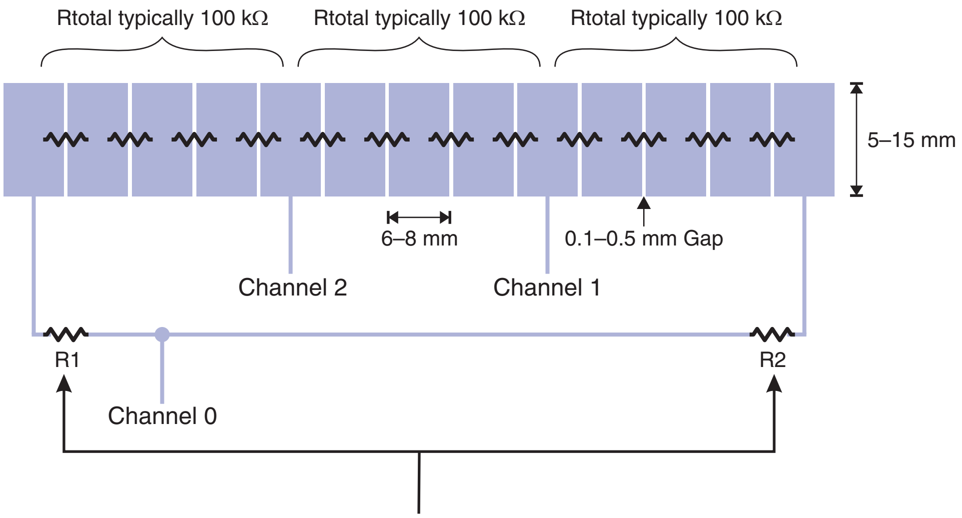
5.4.2 Medium/Large Slider Or Wheel

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.

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).

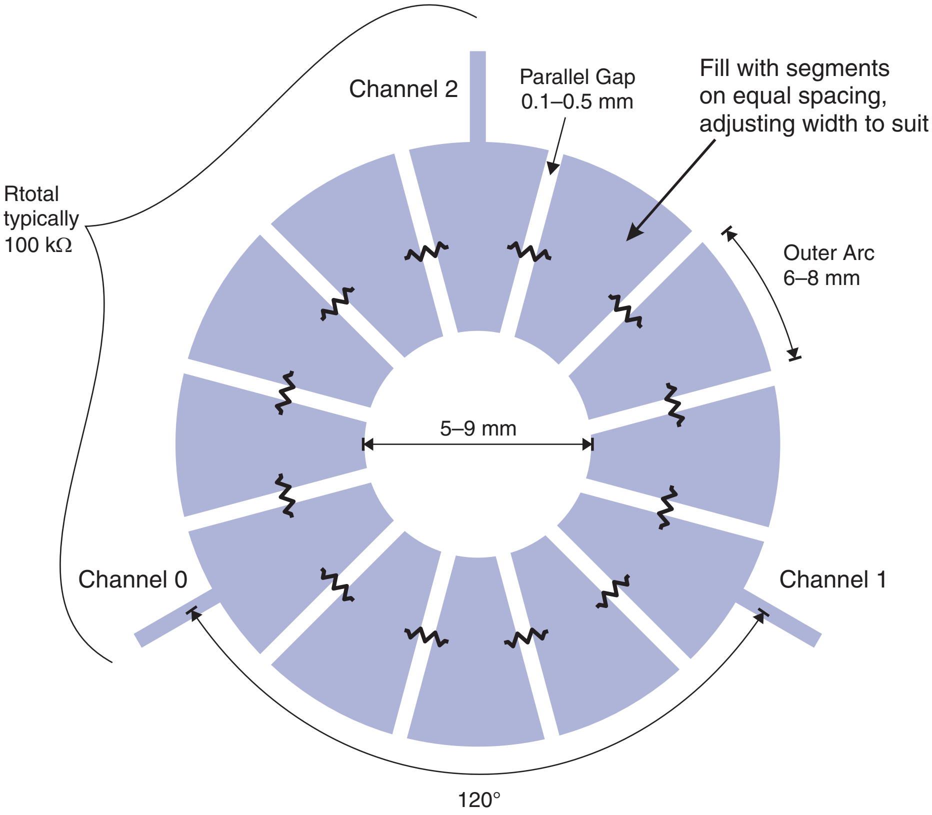
Figure 5-6. Medium/Large Slider (Resistively Interpolated)



Resistors R1 and R2 form a "dead band" at the each end to stop end wrap-around.
Make them approximately 5 percent of Rtotal 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)



Section 6

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 3.2.7 “Conductive Paints” on page 3-7 apply.

6.3 Typical Spatially Interpolated Method

6.3.1 Introduction

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

Note: There is no preferred order for the channels; the order simply determines the direction in which the sensor increases or decreases (left/right or up/down for a slider, and clockwise/counter-clockwise for a wheel). Refer to a specific chip's datasheet for additional information.

6.3.2 One-Layer Small Slider Or Wheel

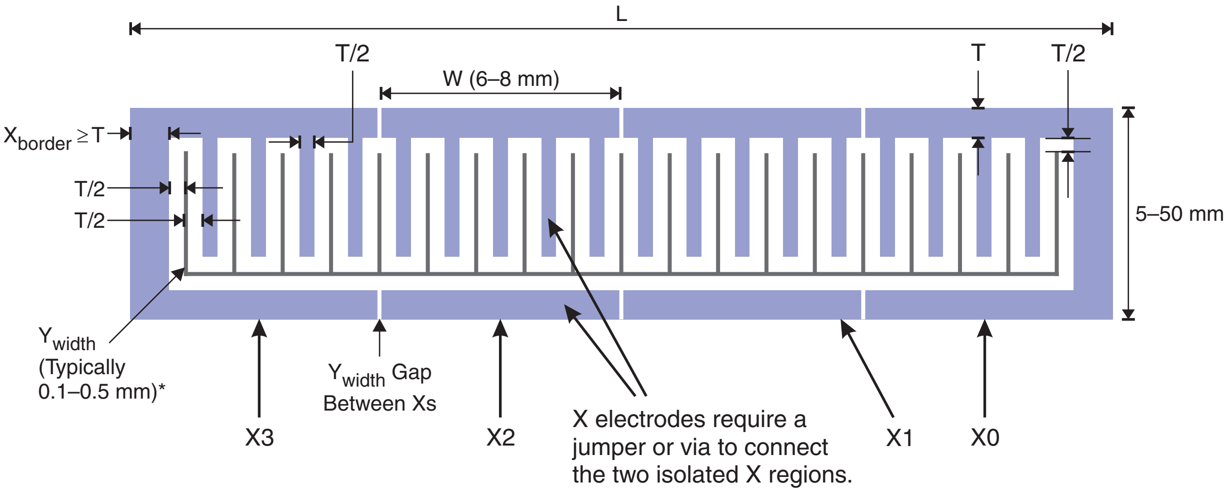
6.3.2.1 Slider

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* x 6 mm to *n* x 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

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

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

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

Where:

- $\lfloor ... \rfloor$ 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:

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

   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 $(X_{fingers} + 2) / keys$. 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.

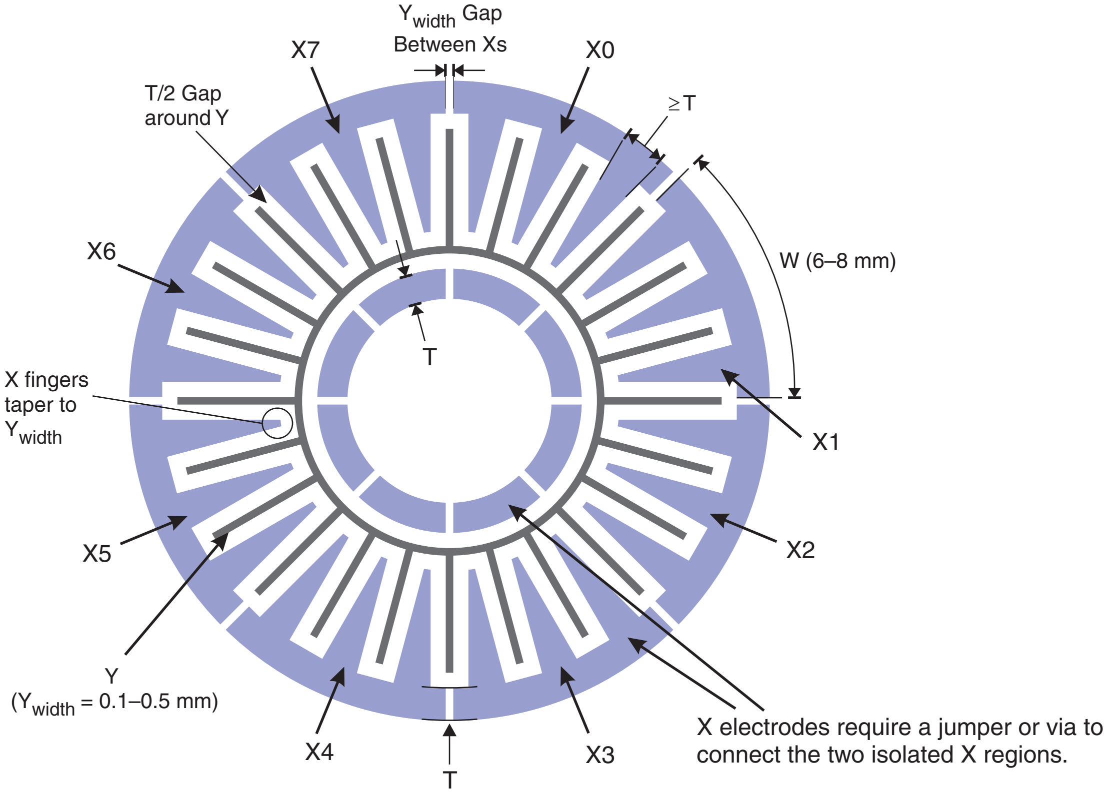
   Note that the outer two keys, of course, have slightly more X to Y coupling because they do not have a shared Y finger at the ends; this is normal.

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:

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

   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)

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

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

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

Where:

- $\lfloor ... \rfloor$ 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 ($X_{fingers}$ / 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)

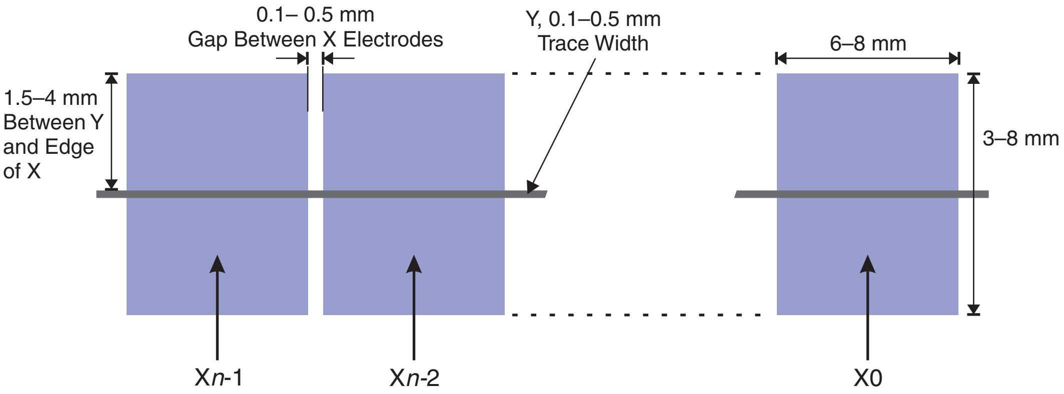
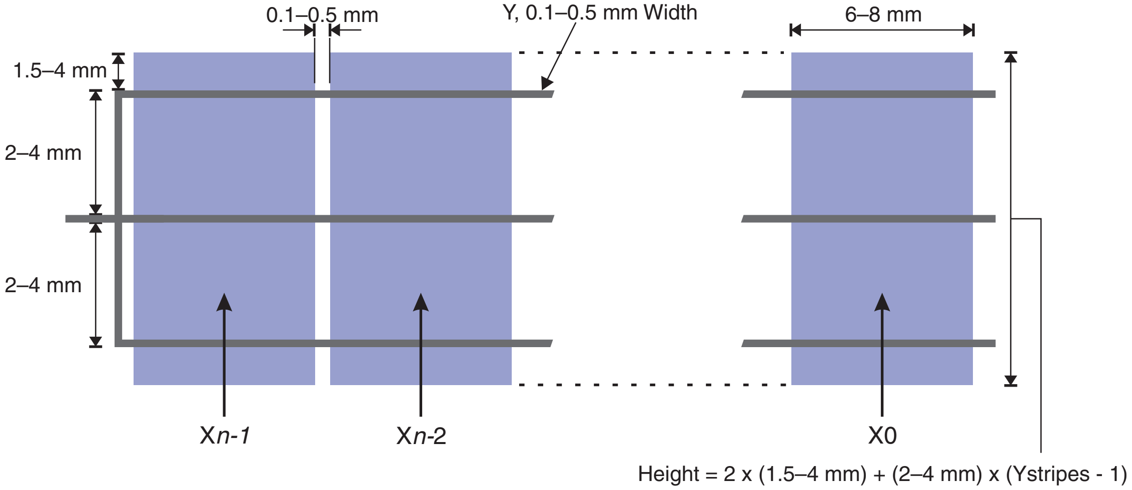


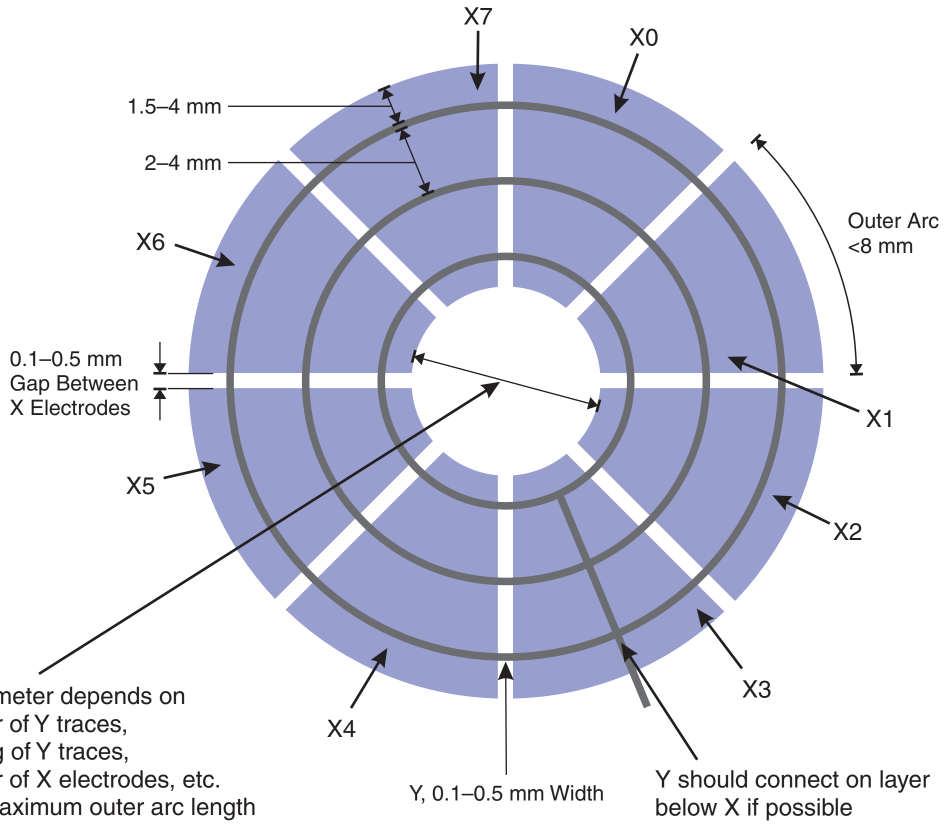
Figure 6-4. Two-layer Small Slider: Multiple Y Traces (Spatially Interpolated)



6.3.4.3 Wheel

To form a wheel, the design is simply is 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 Traces (Spatially Interpolated)



6.3.5 Two-layer Medium/Large Slider Or Wheel

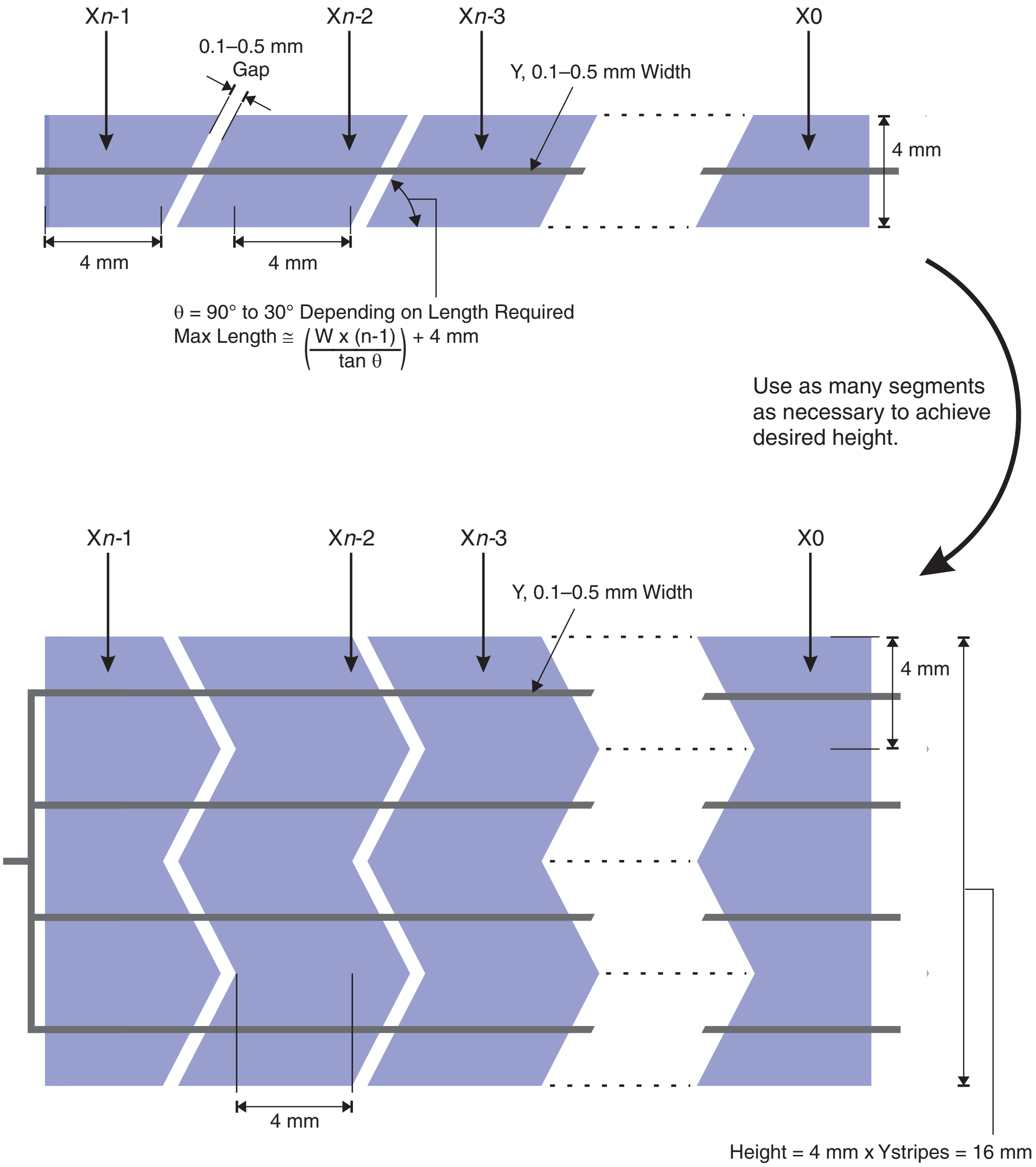
6.3.5.1 Introduction

When construcing 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.

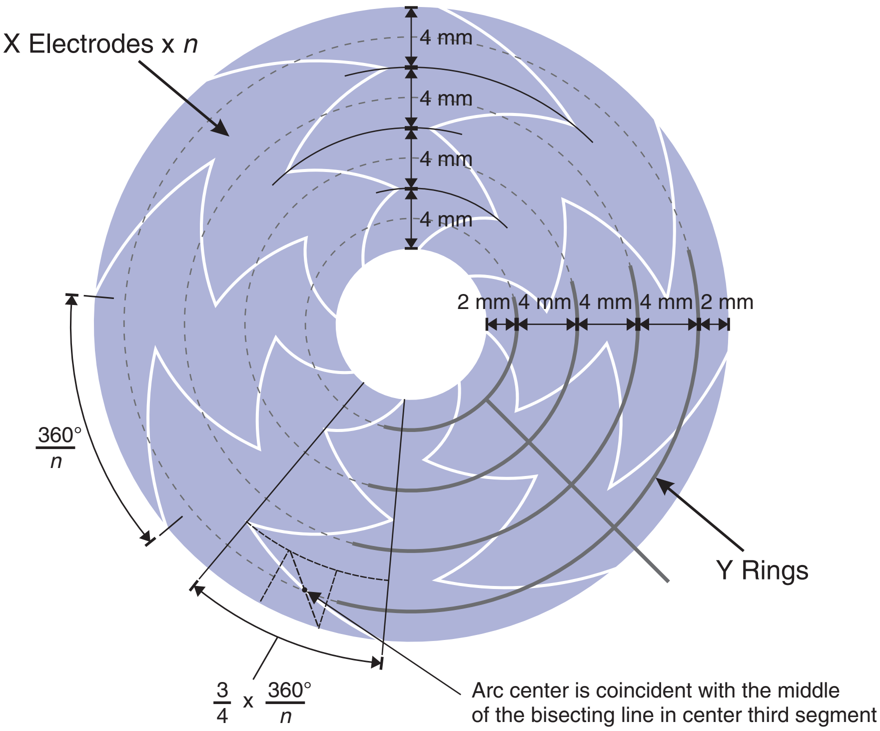
Figure 6-6. Two-layer Medium/Large Slider (Spatially Interpolated)



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

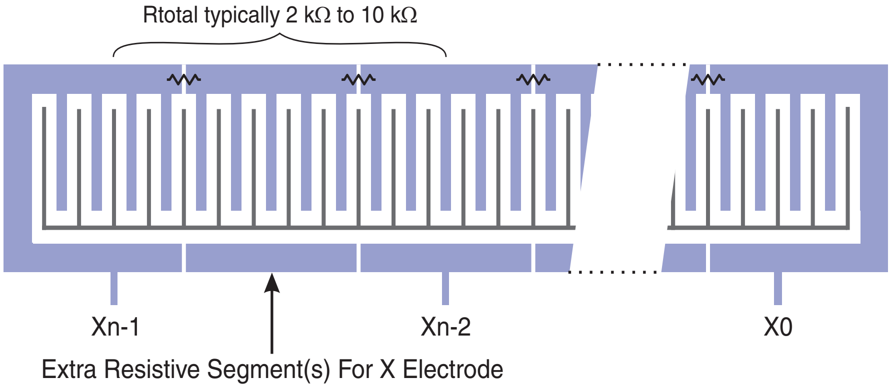
This method uses an array of key segments connected by resistors. The advantage of this method is that each key (or channel) in the sensor is formed by one or more segments. This makes it possible to construct larger sliders and wheels than would be possible with the spatially interpolated method described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

Note: There is no preferred order for the channels; the order simply determines the direction in which the sensor increases or decreases (left/right or up/down for a slider, and clockwise/counter-clockwise for a wheel). Refer to a specific chip's datasheet for additional information.

6.4.2 One-Layer Medium/Large Slider Or Wheel

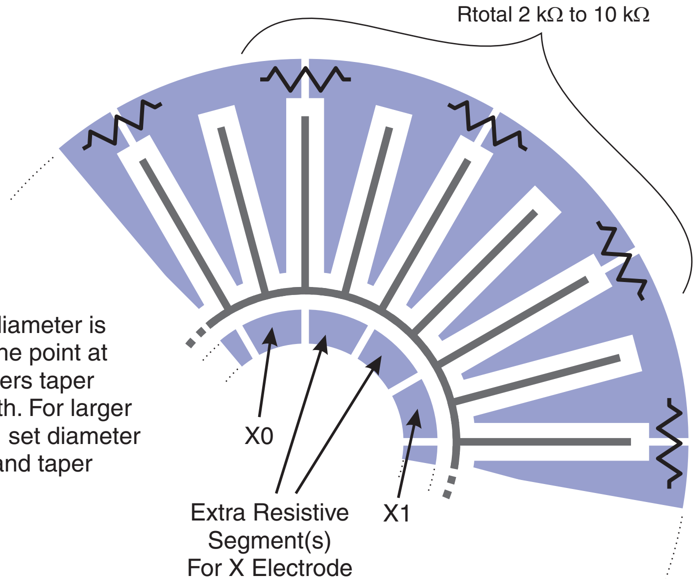
The basic design is the same as that shown in Section 6.3.2 on page 6-2. However, to increase the length or diameter of the sensor, extra segments are created using resistive dividers on the X lines.

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)



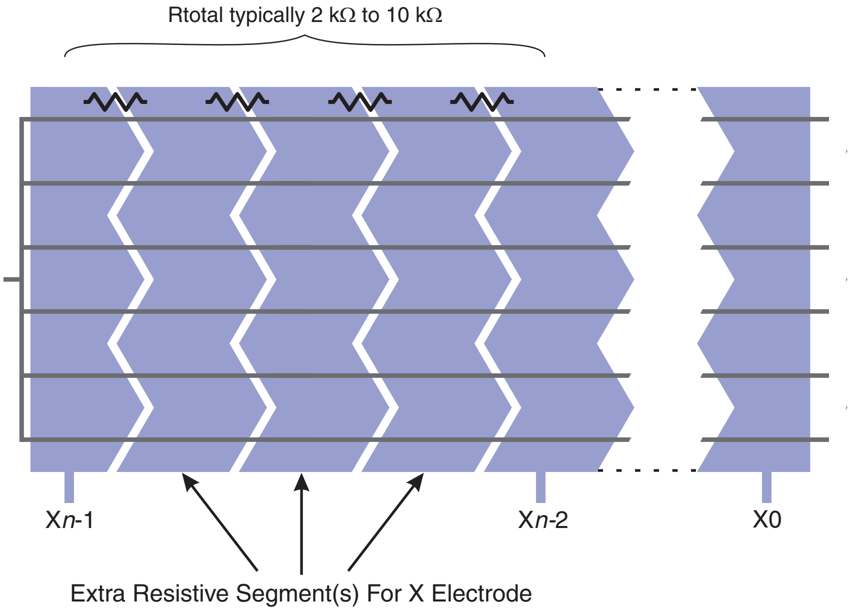
Smallest inner diameter is determined by the point at which the X fingers taper to minimum width. For larger inner diameters, set diameter to desired size and taper X fingers to suit.

For design rules, see Figure 6-2 on page 6-4

6.4.3 Two-Layer Medium/Large Slider Or Wheel

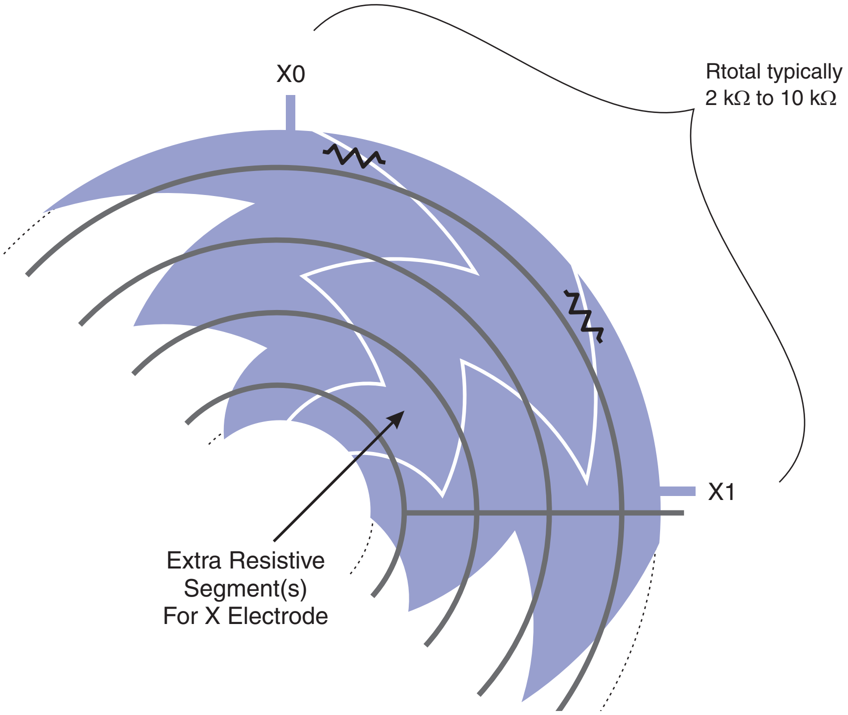
Creating larger sliders and wheels when using a flooded X design follows the same principles as in Section 6.3.5 “Two-layer Medium/Large Slider Or Wheel” on page 6-8, except that extra segments are introduced using resistive dividers on the X lines.

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

Appendix A

Glossary of Terms

Channel

One of the capacitive measurement point at which the sensor controller can detect capacitive change.

See also *node*.

Electrode

The patch of conductive material on the substrate that forms the sensor. An electrode is usually (but not always) made from copper, carbon, silver ink, Orgacon™ or Indium Tin Oxide (ITO).

False Touch

An unexpected key detection caused by an interaction of the Y traces with the X traces. False touches can occur anywhere that X and Y are too close and the field between them is allowed to be influenced by touch. See Section on page 4-7.

Hand Shadow

The situation in which a false touch is detected from the user's hand as it is held over a sensor, rather than from the user's finger. This effect occurs when a sensor is particularly large in proportion to a hand. It is a particular problem for large self-capacitance sliders and wheels. See Section 5.2.3 on page 5-2.

Jitter

The peak-to-peak variance in the reported location for an axis when a fixed touch is applied. Typically jitter is random in nature and has a Gaussian (1) distribution, therefore measurement of peak-to-peak jitter must be conducted over some period of time, typically a few seconds. Jitter is typically measured as a percentage of the axis in question.

For example a 100 x 100 mm touchscreen that shows ±0.5 percent jitter in X and ±1 percent jitter in Y would show a peak deviation from the average reported coordinate of ±0.5 mm in X and ±1 mm in Y. Note that by defining the jitter relative to the average reported coordinate, effects of linearity are ignored.

Key

A simple zero-dimensional electrode arrangement whose capacitance changes when touched, allowing touched or not-touched status (on or off) detection.

Line

The logical X or Y line used for the detection of touches, as opposed to a physical trace.

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1. Sometimes called Bell-shaped or Normal distribution.

Linearity

The measurement of the peak-to-peak deviation of the reported touch coordinate in one axis relative to the absolute position of touch on that axis. This is often referred to as the nonlinearity. Nonlinearities in either X or Y axes manifest themselves as regions where the perceived touch motion along that axis (alone) is not reflected correctly in the reported coordinate giving the sense of moving too fast or too slow. Linearity is measured as a percentage of the axis in question.

For each axis, a plot of the true coordinate versus the reported coordinate should be a perfect straight line at 45°. A non linearity makes this plot deviate from this ideal line. It is possible to correct modest nonlinearities using on-chip linearization tables, but this correction trades linearity for resolution in regions where stronger corrections are needed (because there is a stretching or compressing effect to correct the nonlinearity, so altering the resolution in these regions). Linearity is typically measured using data that has been sufficiently filtered to remove the effects of jitter. For example, a 100 mm slider with a nonlinearity of ±1 percent reports a position that is, at most, 1 mm away in either direction from the true position.

Multi-touch

The ability of a touchscreen to report multiple concurrent touches.

See also *Two Touch*.

Mutual-capacitance Sensor

A sensor with 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. This type of sensor is suitable for implementating sensors for use with QMatrix™ sensor controllers.

See also *self-capacitance sensor*.

Node

One of the capacitive measurement point at which the sensor controller can detect capacitive change. A node and a channel are really the same thing, but the term node is used in the context of a touchscreen or slider as it conveys the sense of spatial distribution better.

See also *channel.*

Non-planar Construction

A method of construction in which the electrodes are fabricated 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 form of construction has several advantages over a planar form of construction. See Section 3.3 on page 3-7.

See also *planar construction*.

One-dimensional Sensor

A sensor 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.

Panel

The front, or uppermost, layer of a touchscreen or touchpad that is touched by the user. Common front panel materials include glass, plexiglas, polycarbonate and PMMA.

Planar Construction

A method of construction in which 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). See Section 3.2 on page 3-1.

See also *non-planar construction*.

Resolution

The measure of the smallest movement on a slider or touchscreen in an axis that causes a change in the reported coordinate for that axis. Resolution is normally expressed in bits and tends to refer to resolution across the whole axis in question. For example, a slider of length 100 mm and a resolution of 10 bits could resolve a movement of 0.0977 mm. Jitter in the reported position degrades usable resolution.

Self-capacitance Sensor

A sensor with only one direct connection to the sensor controller. A self-capacitance sensor tends to emit electric fields in all directions. This type of sensor is suitable for implementating sensors for use with QTouch™ sensor controllers.

See also *mutual-capacitance sensor*.

Sensor

The component that detects a touch. That is, a zero-dimensional key, a one-dimensional slider or wheel, or a two-dimensional touchscreen or touchpad. Sensors consist of one or more electrodes.

Slider

A one-dimensional arrangement of electrodes whose capacitance changes when touched, allowing the location of touch to be computed in one axis.

Substrate

The base material carrying the electrodes. The substrate is usually a low-loss material, such as PCB materials, acrylic, polycarbonate or glass, but it can be almost any insulating material.

Touchscreen

A two-dimensional arrangement of electrodes whose capacitance changes when touched, allowing the location of touch to be computed in both X and Y axes. The output from the XY computation is a pair of numbers, typically 10-bits each, ranging from 0 to 1023, representing the extents of the touchscreen active region.

Two-dimensional Sensor

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

Two Touch

The ability of a touchscreen to report two concurrent touches. The touches are reported as two separate sets of XY coordinates.

Zero-dimensional Sensor

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

Revision History

Revision No.	History
Revision A – December 2008	• Initial version
Revision B – January 2009	• Updates to advice on interdigitated electrodes • Additional advice added on PCB components, ESD protection, floating conductive items and conductive paint
Revision C – February 2009	• Updated Section 2 • Updated advice on zero-dimensional sensors • Added Appendix A
Revision D – April 2009	• Other minor updates
Revision E – September 2009	• Added Quick Start section • Numbering of channels altered on sliders in Section 5 • Other minor updates

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