AN2934

Capacitive Touch Sensor Design Guide

Introduction

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This document will guide the Microchip Touch solutions customers towards a robust implementation of their vision for the user interface. This application note will outline common challenges and provide solutions and guidance.

The process for designing products that use touch controls is a complex one 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. The key to this process is the design of the actual sensors (specifically buttons, sliders, wheels, and touch screens) that form the interface with the user.

For further information, how-to videos, step by step guides, touch technology background, visit the following websites:

- www.microchip.com/touch
- www.microchipdeveloper.com section *Functions → Touch Sensing*
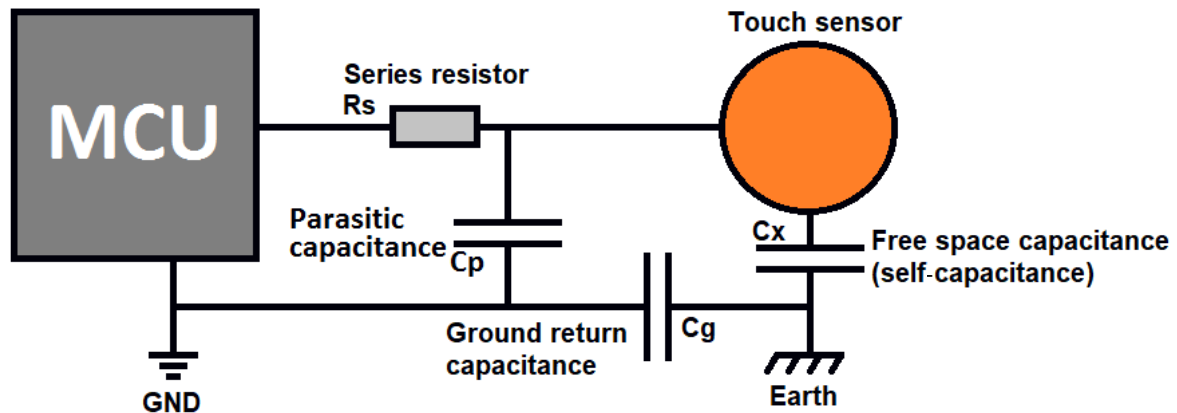
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1. Self-Capacitance Sensors

1.1 Self-Capacitance Measurement

Self-capacitance touch sensors use a single sensor electrode to measure the apparent capacitance between the electrode and the ground of the touch sensor circuit.

Figure 1-1. Self-Capacitance Sensor Model

The base capacitance is formed by the combination of parasitic, sensor, and ground return capacitance. In combination, these form the 'untouched' or default capacitance that is measured during calibration and is used as a reference to detect a capacitance change indicating touch contact.

Figure 1-2. Self-Capacitance Model with Touch Contact
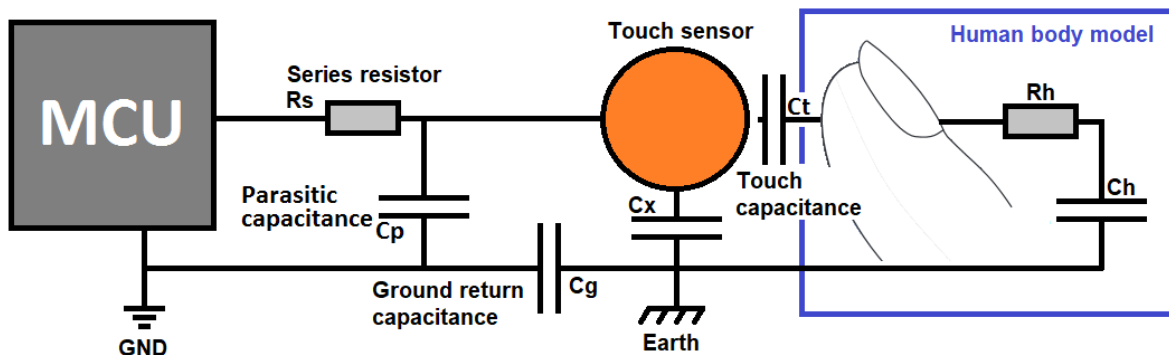
When a touch contact is applied, the apparent sensor capacitance is increased by the introduction of a parallel path to earth through the 'Human Body Model' (HBM). The touch capacitance C_t forms a series combination with the HBM capacitance C_h and ground to earth capacitance C_g. This increase is referred to as the touch 'delta'.

Notice: The HBM resistance R_h does not affect the touch sensitivity.

C_t
- May be approximated as a parallel plate capacitor comprising the touch sensor electrode and the user's fingertip separated by a dielectric in the form of an overlay material

- A user's fingertip placed onto a solid surface may be approximated as a disc with the diameter between 5-10 mm. 8 mm is estimated as a typical user's fingertip diameter and is used in the examples from this document.
- A smaller sensor or thicker cover will reduce the touch capacitance value

C_h

- Human body model capacitance
- Self-capacitance of the human body with respect to earth
- 100 pF to 200 pF for an adult depending on physique

C_g

- Capacitance of the coupling between the application DC ground and earth
- Depends on application type and power system
- Ranging from ~1 pF in a small battery-powered device to infinite capacitance (short circuit) where the DC ground is connected directly to earth

In series capacitors, the dominant effect is that of the smallest capacitor.

Equation 1-1. Series Capacitor Combination

$$Ct = \frac{C_1 C_2}{C_1 + C_2}$$

C_t is much smaller than C_h, and in most applications, C_t is also much smaller than C_g, hence C_t determines the change in the measured capacitance.

Example:

C_t = 1 pF, Ch = 100 pF, C_g = 100 pF

→ C_{Total} = 0.98 pF

However, in an application where C_g is very low, e.g., 2 pF, the sensitivity will be significantly reduced.

Ct = 1 pF, Ch = 100 pF, Cg = 2 pF

→ C_{Total} = 0.662 pF

→ The measured touch delta is reduced by ~33%

1.2 Sensor Design

1.2.1 Touch Capacitance Model

When designing sensors, a simple approximation of C_t may be derived from the parallel plate capacitor formula.

Notice: This approximation loses accuracy where the plate area, *A*, is less than an order of magnitude greater than the dielectric thickness, *d*.

Equation 1-2. Parallel Plate Capacitor

$$C = \frac{\epsilon\, A}{d} = \frac{\epsilon_0\, \epsilon_r\, A}{d}$$

Where '*A*' is the parallel area, '*ϵ*' is the permittivity of the electrolyte defined by the vacuum permittivity ϵ_0 multiplied by the relative permittivity ϵ_r, and *d* is the thickness of the touch cover.

→ The strongest touch delta is achieved with a large sensor electrode, a thin touch cover, and a high permittivity cover material.

Example:

- Touch sensor electrode diameter: 12 mm
- Fingertip area model: 8 mm diameter disc
- Touch cover: 1 mm plastic with relative permittivity ϵ_r = 2
- The vacuum permittivity ϵ_0 is given as 8.85 × 10^{-12} F/m

→ The resulting capacitance is calculated as:

$$C_t = \frac{\left(8.85 \times 10^{-12} F/m\right) \times 2 \times \left(\frac{8 \times 10^{-3}}{2}\right) \times \pi}{1 \times 10^{-3} m} = 0.89 pF$$

Notice: Only the 8 mm diameter plate is used in the equation, as this is the area of overlap between the two plates forming the capacitor.

1.2.2   Button Sensor Design

The simplest implementation of a capacitive sensor is a button. A button is a single sensor and is interpreted as a binary state: In Detect or Out of Detect. When the touch delta – the digitized measurement of touch capacitance C_t – exceeds the Touch Threshold, the sensor is In Detect.

The sensor is touched by a user touch, or a touch emulator such as a conductive bar, which is connected to earth via a human body model circuit. The threshold is set to a proportion – often 50% – of the maximum touch delta.

Figure 1-3. Button Sensor Delta and Threshold
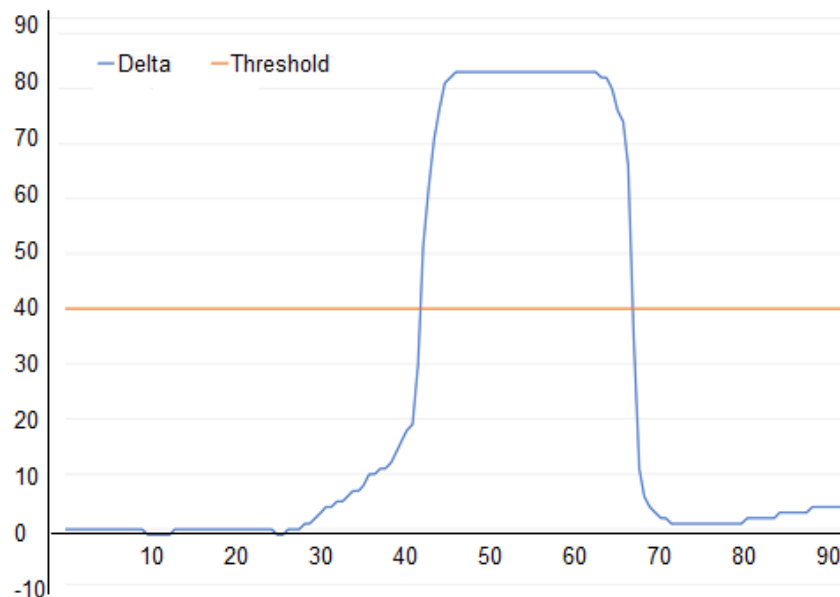
#### Electrode Shapes
A touch electrode is a patch of conductive material, such as copper on a non-conductive substrate. Common shapes are round or rectangular solid areas, however, any shape with sufficient touch contact area may be used. Corners must be rounded to reduce the concentration of electric fields, which may increase the occurrence of Electrostatic Discharge (ESD) to the sensor pad.

Figure 1-4. Standard Button Shapes
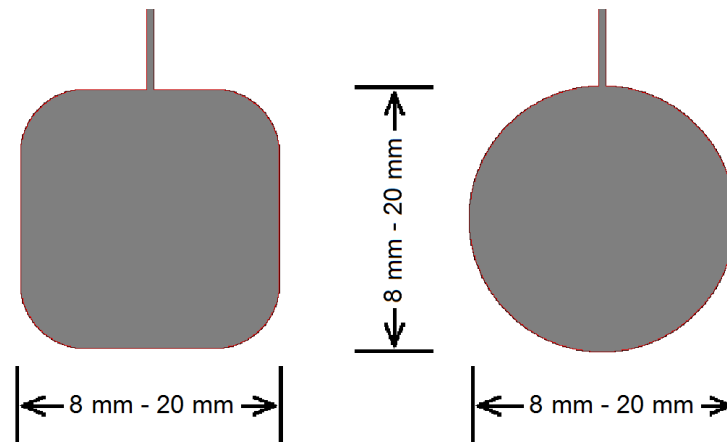
It is also possible to use a hatched pattern (such as a 50% mesh fill) for the electrode if desired. This will not only reduce the load capacitance of the sensor electrode but also reduce the area of one capacitor plate with the touch resulting in a proportional drop in sensitivity.

Figure 1-5. Standard Buttons with Mesh Fill
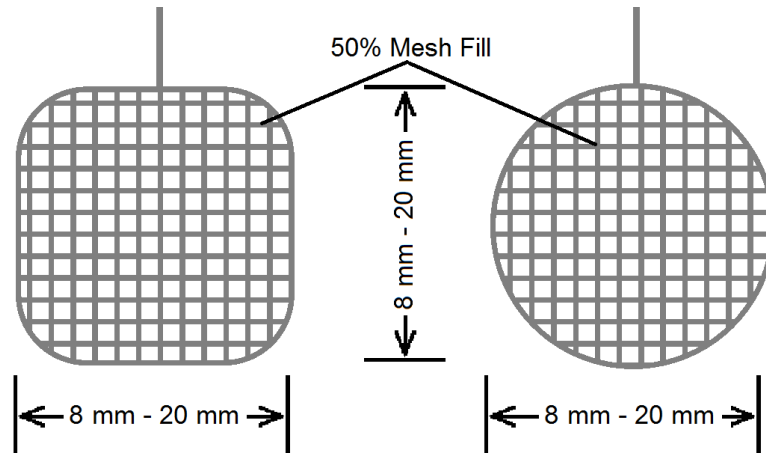
Touch Target Size

The touch sensor electrode must be large enough that a touch contact does not need to be precisely placed to activate the sensor. If the sensor electrode is smaller than the user's fingertip, then sensitivity is reduced by the smaller effective area. For example, an 8 mm diameter touch sensor with an 8 mm diameter touch contact will only show maximum delta when the contact is placed directly at the center of the electrode.

Figure 1-6. 8 mm Touch Sensor
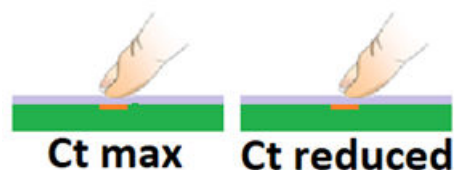
By increasing the size of the sensor, the user may place a contact anywhere over the sensor area with no loss in sensitivity, as long as the entire touch area is kept within the perimeter of the touch sensor. The effective parallel area of the touch contact is limited by the size of the user's fingertip, not the sensor area.
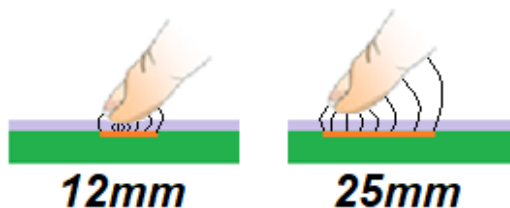
Figure 1-7. 12 mm Touch Sensor

Hand Shadow

An unnecessarily large sensor electrode will show an unintended proximity effect due to coupling to an approaching hand before the fingertip makes contact. The contact capacitance of the fingertip is not easily distinguished from the approach capacitance.

Figure 1-8. 25 mm Sensor with Hand Shadow

Pin Loading

Large sensors have higher default capacitance, and the effect is increased if the sensor is located close to other circuitry including other sensors.

Larger load capacitance causes increased time constant, and the sensor takes longer to charge, discharge, and measure. This can lead to deterioration in touch detect latency and power consumption.

Depending on the measurement technology, high-capacitance sensors may have reduced sensitivity or may exceed the range of the analog front-end compensation circuitry.

> **Notice:** See 3. Appendix A for device-specific information on maximum sensor capacitance.

Electrode Separation

Individual sensor electrodes must be sufficiently separated so that touching one key does not cause an unintentional capacitance change on the neighboring keys, which could be misidentified as another touch contact. The recommended spacing between sensor electrodes is 4 mm + touch cover thickness. In many cases, it is necessary to trade off sensor size and sensor separation to accommodate a dense user interface layout.
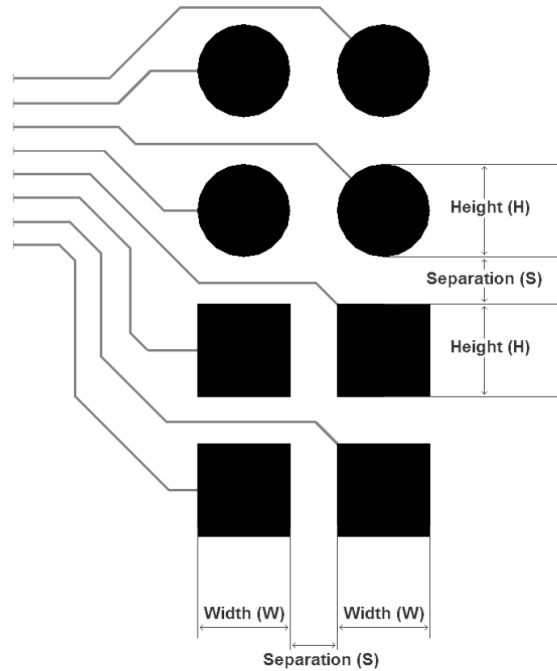
Figure 1-9. Touch Key Dimensions

Table 1-1. Touch Key Dimensions

|	Min.	Typical	Max.
Height (H)	8 mm	12 mm	20 mm
Width (W)	3 mm	6 mm	20 mm
Separation (S)	3 mm	6 mm	-

1.2.3   Slider Sensor Design

A slider is simply a row of two or more touch sensor electrodes, which are measured as individual sensors. The measured touch deltas are combined to determine the position of a touch contact with an increased resolution by interpolation between the sensors.

Sensor Pitch

With large sensors and no spatial interpolation, the consistency of the reported touch position vs. actual position is very poor. As a contact moves across the slider, most of the time, there is a touch contact only on one of the four electrodes. Position interpolation can only occur while the contact is crossing from one sensor to the next.

Figure 1-10. Slider Position without Interpolation
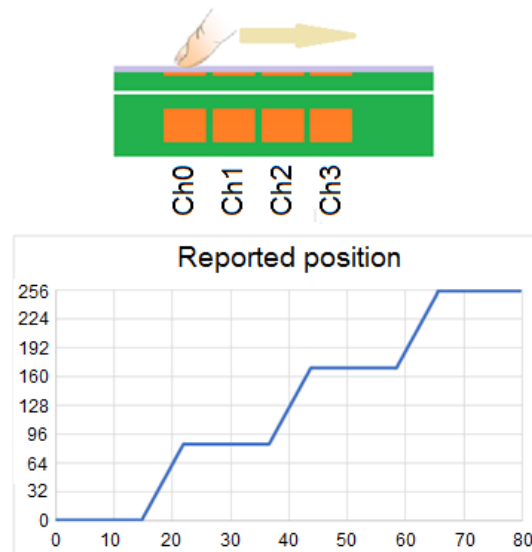
This may be improved by reducing the sensor size and increasing the number of sensors. If the sensor pitch is reduced to ~ ½, the width of a touch contact (i.e., sensor pitch ~4 to 5 mm), then there will always be two to three sensor electrodes under the touch contact area, and several touch deltas are available for interpolation wherever the contact is placed.
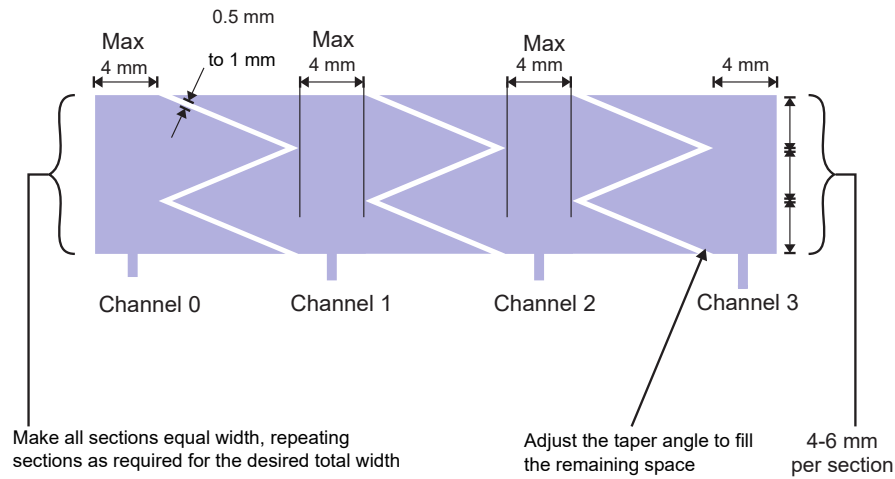
Figure 1-11. Slider Position with Interpolation
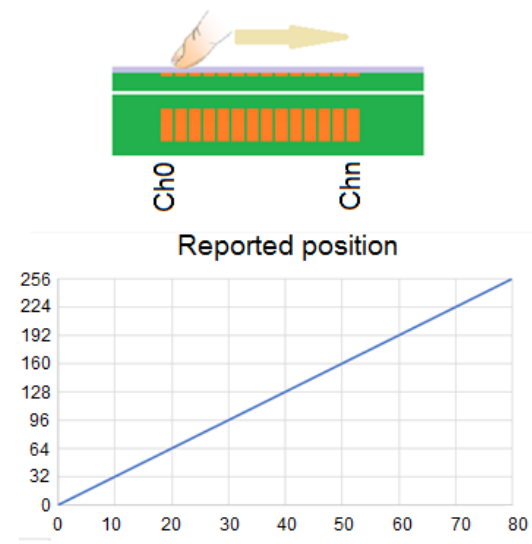
However, this is not always the optimal solution as it requires more sensor electrodes than necessary. This will reduce the availability of general-purpose I/O pins, complicate the PCB routing, or require more touch channels than are available on the microcontrollers. Also, the touch acquisition time is proportional to the number of electrodes, meaning that, for a long slider, the required number of sensor electrodes can lead to an unacceptable touch latency.

An alternative is to use spatial interpolation to 'stretch' the crossover position from one slider electrode to the next. One example is the electrode shape illustrated below. This design has tapered overlapping edges to ensure that a touch contact anywhere along the length of the slider will always have contact area with at least two sensor electrodes.

Figure 1-12. Slider with Extended Interpolation

Make all sections equal width, repeating sections as required for the desired total width

Adjust the taper angle to fill the remaining space

4-6 mm per section

Spacing Between Slider Electrodes

Each element of the slider is loaded by its default capacitance and by the capacitance between it and its neighboring electrodes as other electrodes are usually driven to a static DC level while a particular sensor is being measured.

Notice: The exception to this is the implementation of 'Driven Shield+'. See 1.4 Shielding for further details.

The recommended separation between the sensor electrodes depends on the size of the electrodes and their overlap lengths.

A slider consisting of small keys with no extended interpolation must have a separation of 0.5 mm, or smaller, between electrodes. This improves touch delta consistency as the contact moves from one element to the next, without the occurrence of reduced touch delta in between. See Table 1-2 for recommended separation distances.

Figure 1-13. Button Slider Dimensions

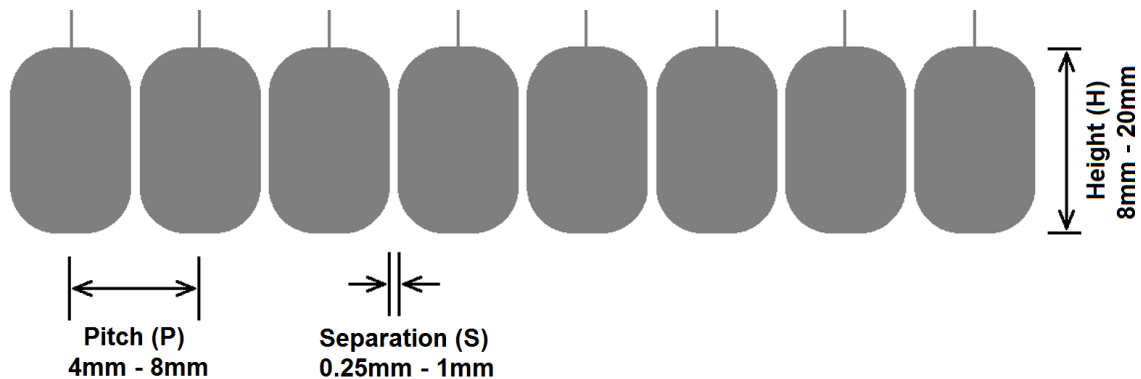Pitch (P)
4mm - 8mm

Separation (S)
0.25mm - 1mm

Height (H)
8mm - 20mm

Table 1-2. Button Slider Dimensions

	Min.	Typical	Max.
Slider Height (H)	8 mm	12 mm	20 mm
Electrode pitch (P)	4 mm	6 mm	8 mm

..........continued	Min.	Typical	Max.
Electrode separation (S)	0.25 mm	0.5 mm	1 mm

A slider consisting of large electrodes with long overlap lengths must have increased separation between the sensor electrodes to avoid excess sensor load capacitance. In such a design, the separation can be increased to 1 mm or more.

The electrodes must be close together for continuous sensitivity, but too little separation can cause increased loading capacitance, as each sensor electrode has a parasitic load against its neighboring electrodes. The spacing must be increased to a maximum of 1.5 mm in the cases when there are long parallel edges between the electrodes due to extensive interpolation. See Table 1-3 for recommended separation distances.

As with the button sensor design, sharp corners in the slider electrodes must be rounded to minimize susceptibility to ESD. The points of the triangles forming the interpolated slider must be truncated to a rounded end with a ~2 mm diameter.
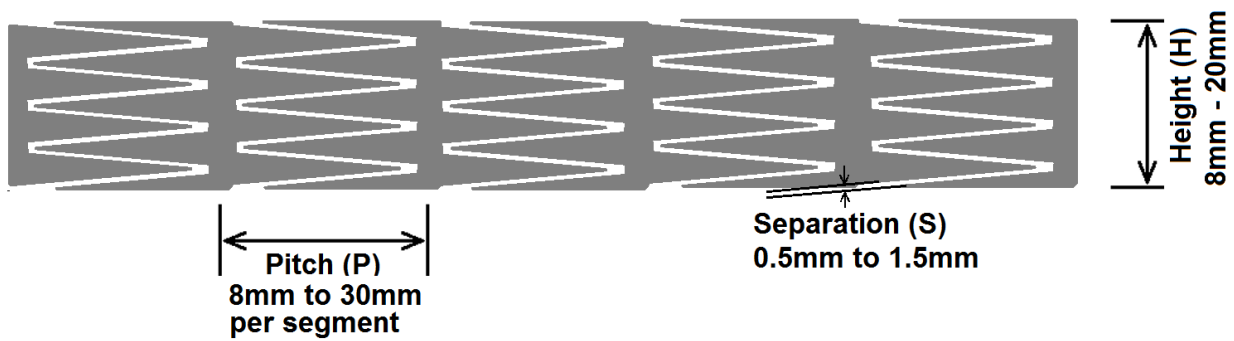
Figure 1-14. Interpolated Slider Dimensions

Table 1-3. Interpolated Slider Dimensions

	Min.	Typical	Max.
Slider height (H)	8 mm	12 mm	20 mm
Electrode pitch (P)	8 mm	16 mm	30 mm
Electrode separation (S)	0.5 mm	1 mm	1.5 mm

1.2.4 Wheel Sensor Design

A wheel sensor consists of a row of three or more sensor electrodes, which are arranged in a circle.

> **Notice:** A minimum of three electrodes is needed as position calculation requires unique crossover regions.

A wheel sensor operates in the same way as a slider sensor, with the single exception being that it is wrapped around from Channel n to Channel 0, so there are no end electrodes in the design.

As with a slider, a wheel can be made with discrete non-overlapping sensors.

Figure 1-15. Three-Channel Button Wheel
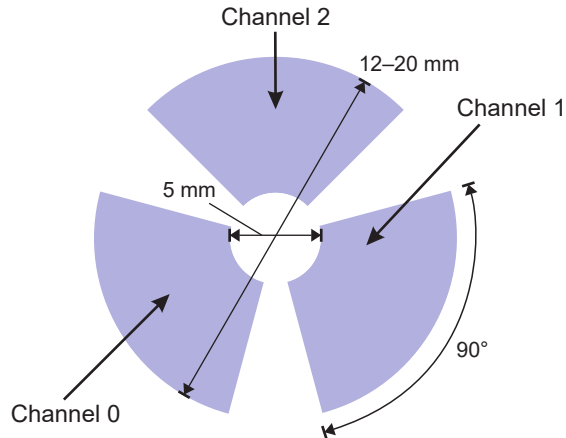
A larger wheel may be implemented by increasing the number of sensor keys used or by increasing the segment interpolation, as in the case of the slider.

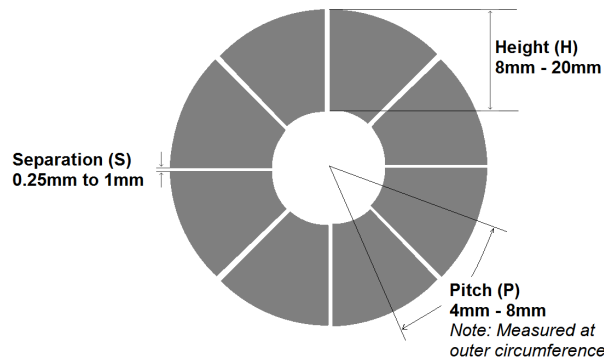**Figure 1-16. Button Wheel Dimensions**

Table 1-4. Button Wheel Dimensions

	Min.	Typical	Max.
Wheel Height (H)	8 mm	12 mm	20 mm
Electrode pitch (P)	4 mm	6 mm	8 mm
Electrode Separation (S)	0.25 mm	0.5 mm	1 mm

As with other sensors, sharp corners in the electrodes need to be rounded to minimize susceptibility to ESD. The points of the triangles forming the interpolation must be truncated to a rounded end of ~2 mm diameter.

Wheel electrodes must be close together for continuous sensitivity, but too little separation can cause increased loading capacitance, as each sensor electrode has a parasitic load against its neighboring electrodes. The spacing should be increased up to a maximum of 1.5 mm in the cases when there are long parallel edges between electrodes due to extensive interpolation.
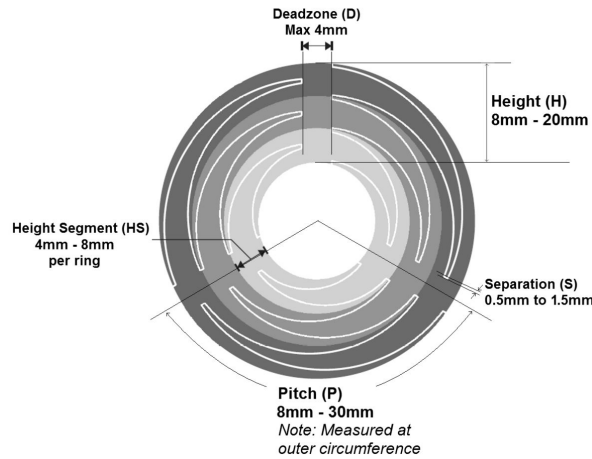
Figure 1-17. Interpolated Wheel Dimensions

Table 1-5. Interpolated Wheel Dimensions

	Min.	Typical	Max.
Slider Height (H)	8 mm	12 mm	20 mm
Height Segment (HS)	4 mm	6 mm	8 mm
Electrode Pitch (P)	8 mm	16 mm	30 mm
Electrode Separation (S)	0.5 mm	1 mm	1.5 mm
Deadzone (D)	—	—	4 mm

1.2.5 Surface Sensor Design

A self-capacitance touch surface consists of 'row' and 'column' electrodes whose measurements are used to implement slider functionality in both the horizontal and vertical directions. The results can be combined to accurately resolve touch coordinates and detect 2D gestures, including dual-touch gestures like pinch-and-zoom.

The simplest pattern is the 'diamond' pattern shown below. In this example, sensors H0 to H5 provide the horizontal location of a touch contact, while V0 to V4 provide the vertical location.
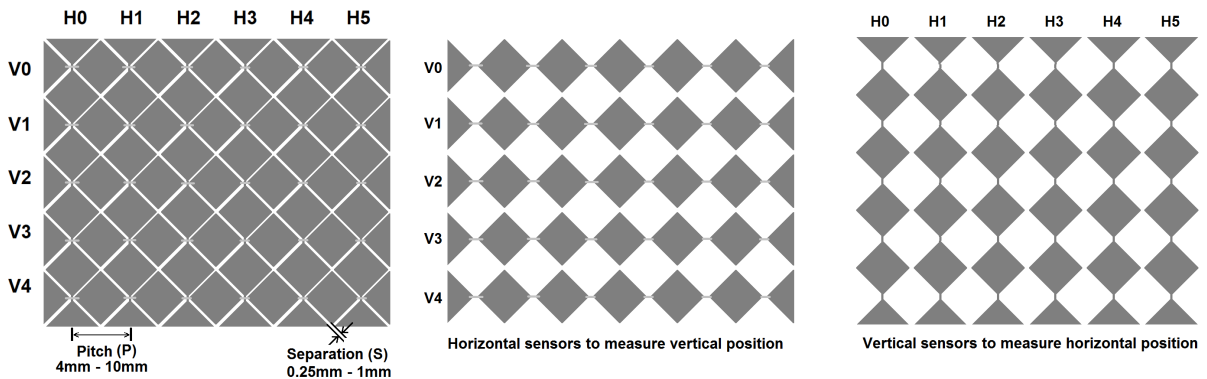
Figure 1-18. Touch Surface Diamond Pattern

Table 1-6. Diamond Patten Dimensions

Type	Min.	Typical	Max.
Electrode Pitch (P)	4 mm	6 mm	10 mm
Electrode Separation (S)	0.25 mm	0.5 mm	1 mm

The sensor is characterized by its pitch and separation:

- Horizontal and vertical sensor pitch is the distance between column and electrode centers, respectively
- Sensor separation is the perpendicular distance between the parallel edges of adjacent diamonds

Each sensor electrode forms a chain of squares (symmetrical node pitch) or diamonds (asymmetrical pitch), which are turned 45° to improve interpolation in the horizontal and vertical directions.

Electrode Pitch

The ideal electrode pitch is approximately 5 mm for a user touch area of 8 mm. This ensures that a contact placed anywhere on the surface will include an overlap area with at least two sensor electrodes in each dimension and thus enables the best interpolation of the touch position.

For larger touch surface designs, this means a high number of sensor electrodes is required to maintain optimum linearity. However, more sensors mean longer acquisition time, which may lead to reduced response time. In many cases, the designer must compromise between sensor linearity and the number of sensors.

Extended Interpolation

As with sliders and wheels, it is possible to design electrodes for a surface sensor with increased interpolation between adjacent sensors. This allows the designer to increase the electrode pitch while maintaining linearity.

One example is the 'flower' pattern, where each element of the sensor array has increased spatial interpolation with its neighbors.
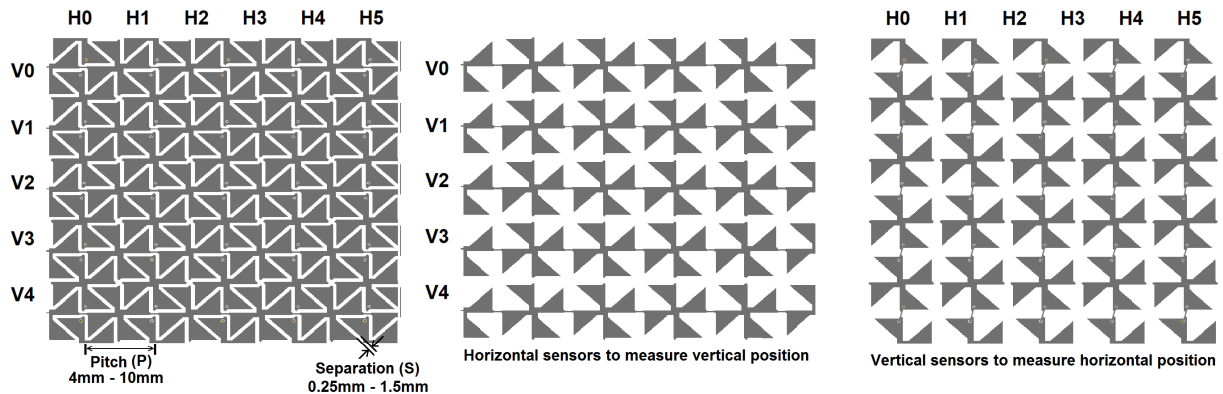
Figure 1-19. Touch Surface Flower Pattern

Horizontal sensors to measure vertical position

Vertical sensors to measure horizontal position

Table 1-7. Flower Patten Dimensions

Type	Min.	Typical	Max.
Electrode pitch (P)	4 mm	6 mm	10 mm
Electrode separation (S)	0.5 mm	1 mm	1.5 mm

As with other sensors, sharp corners in the electrodes have to be rounded to minimize susceptibility to ESD. The points of the triangles forming the interpolation must be truncated to a rounded end of ~2 mm diameter.

Notice: Simultaneous detection of two touch contacts requires that the contact centers are separated by a distance of at least twice the sensor pitch.

1.3 Touch Cover Effect

A thicker touch cover increases the distance between the user's fingertip and the sensor electrode. This causes reduced capacitance between the user and the sensor electrode and a proportional decrease in touch sensitivity.

This can be compensated by increasing the size of the electrode. A thicker cover also has the effect of diffusing the electric field formed between the fingertip and electrode and thus a larger electrode can effectively increase the contact area.

For maximum sensitivity, each sensor electrode must be designed to extend beyond the touch contact by at least the thickness of the touch cover.

All sensor types must be wide enough to extend beyond the dimensions of a touch contact by at least the thickness of the touch cover on both inside and outside. See the examples below:

- 1 mm touch cover/8 mm contact: recommended width = 10 mm
- 3 mm touch cover/8 mm contact: recommended width = 14 mm
- 6 mm touch cover/8 mm contact: recommended width = 20 mm

For an interpolation sensor (slider, wheel, surface with flower pattern), the diffusion of the electric fields results in an extended crossover area between adjacent electrodes and improved accuracy in the reported contact position.

1.4 Shielding

In many applications, it is necessary to shield the touch sensors to prevent incorrect activation by the Electromagnetic Interference (EMI), or by touch contact at a location that is not intended to be touch-sensitive such as the PCB tracks leading to the sensor.

A variety of shield types may be used with self-capacitance sensors depending on the measurement technology.

These may be generally classed into 'passive' shield, where a shielding electrode is driven to a DC level, and 'active' shield, where the shield is driven with the same signal as the electrode being acquired.

> **Notice:** See 3. Appendix A for more information on the shield support by the device.

1.4.1 Passive Shield

- Usually connected to DC ground
- May also use V_{DD} or any ground-referenced DC level
- Rear copper flood (on a layer behind the electrodes) prevents touch or EMI from behind
- Coplanar flood (around the electrodes on the same layer) provides better isolation of touch sensors
- May be hatched to reduce the capacitive load
- Detrimental to moisture tolerance

Effect of Ground Loading

DC or ground loading adds directly to the sensor base capacitance, which increases the RC time constant and thus the acquisition time.

> **Notice:** The ground in this context includes any conductor close to the sensor or its trace that is referenced to the DC ground. This encompasses any circuit element or signal track that is nearby.

Passive sensors are usually driven to a DC level, and the traces to these idle channels behave as though connected to the ground. If a trace leading to Key 1 is routed close to Key 2, then Key 2 is loaded as though to a ground trace.

Ground referenced electrodes or traces close to the touch sensor will cause a reduction in touch sensitivity as the electric field emitted by the sensor electrode is attracted to the ground plane. This reduces the strength of the electric field available to interact with the user's touch contact.

Rear Ground Shield

Sometimes it is desirable to shield an electrode on its rear side to prevent false detection from moving parts behind, or to prevent interference from switching signals, for example, from backlighting or driver circuitry.

If a driven shield cannot be implemented, then a ground plane may be used. This must be connected directly to the circuit ground at a single point.

A rear ground plane will most likely significantly reduce the sensitivity of the touch sensors, as the DC ground attracts the electric field emitted by the touch sensor electrode. This must be taken into consideration, particularly where the touch cover may be thicker than the separation between electrode and ground layers.

To alleviate this problem, the electrode and ground plane must be separated by the maximum distance possible. For example, on a multilayer printed circuit board PCB, the touch sensors must be on the top layer and the ground on the bottom.

Additionally, the ground shield may be reduced to 50% or 25% hatched fill, which reduces the sensor loading while still providing some shielding effect.

If the application does not risk accidental touch contact from the rear of the sensor board, the rear ground plane may be cut out behind the sensor keys. This reduces the capacitive loading of the sensors while providing sensor isolation from other circuit components or EMI.

Coplanar Ground Shield

A coplanar ground shield may be implemented to improve the isolation between the touch sensors, to reduce EMI to the touch sensors, and to reduce the interference caused by common-mode noise when a touch contact is present.

Use a solid fill as a coplanar shield since the shield does not overlap the touch area.

To minimize the loss in sensitivity, the ground shield must be kept at a distance from any touch sensor of approximately 2 mm.
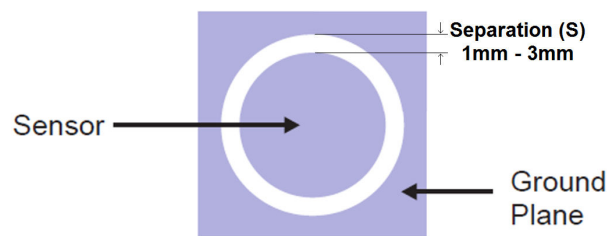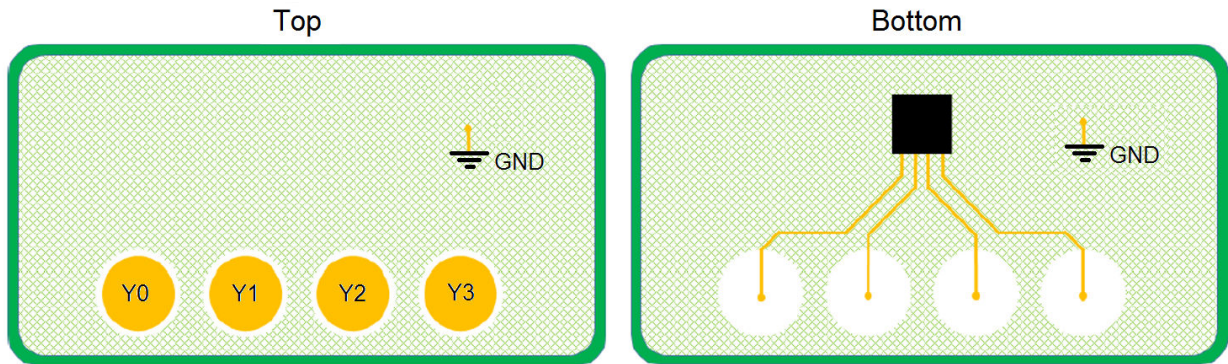
Figure 1-20. Coplanar Ground Plane Separation

Table 1-8. Sensor to Ground Separation

Type	Min.	Typical	Max.
Sensor – Gnd Separation (S)	1 mm	2 mm	3 mm

Example Layout

Figure 1-21. Sensor Layout with Front and Rear Hatched Ground Plane

Increasing or decreasing the gap between the sensor and the ground affects the sensor operation in several ways.

Sensor capacitance is increased when the gap is reduced. This proportionally increases the sensor time constant and thus the total measurement time. Large sensor electrodes or electrodes with complex perimeter shapes must have an increased gap to avoid excessive sensor capacitance.

Noise tolerance is reduced by increasing the gap. The ground shield improves noise tolerance by providing a lower impedance path to ground for noise injected via the touch cover.

Moisture tolerance is improved by increasing the gap. To trigger due to water on the touch cover, the water must bridge between the sensor electrode and another path to the ground. Placing a ground shield very close to the sensor electrode makes it possible for a very small amount of water to bridge the gap.

1.4.2   Active Shield

1.4.2.1   Driven Shield

- Drives a 'shield' electrode with the same signal as the sensor being required on
- Requires a dedicated shield electrode
- Reduces or eliminates loading of sensors due to capacitance with neighbors since there is no potential difference, so there is no electric field between electrodes
- Rear shield prevents touch from behind
- Provides improved water tolerance

Any ground-referenced trace near a sensor will load that sensor, reduce its sensitivity, and may even produce false touches in certain environmental conditions, such as specifically wet or very humid conditions.

Figure 1-22. Driven Shield Circuit
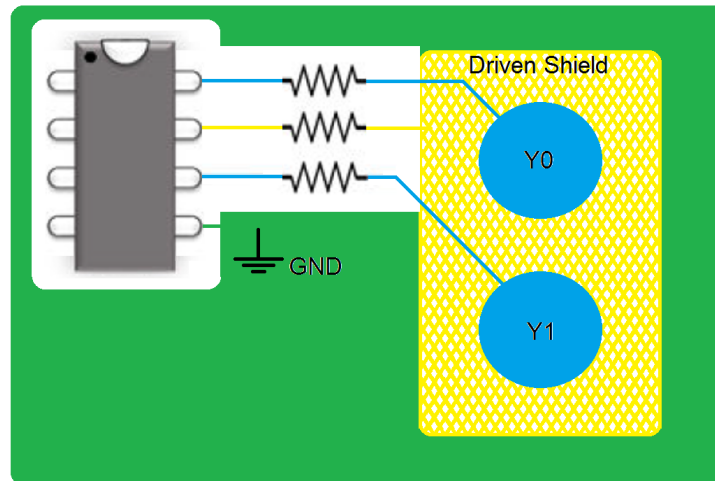
Two classes of driven shield are available on Microchip touch sensor devices: three-level shield and two-level shield.

Three-Level Shield

A three-level shield is driven through a sequence of voltages matching the electrode potential at each stage in measurement. This effectively decouples the touch sensor from the ground, reducing the capacitive loading and provides an electrical shield to the EMI, improving the Signal-to-Noise Ratio (SNR) of the sensor. By placing the shield between the sensor and other circuit components, the operation in the presence of moisture is greatly improved.

A rear flooded shield may be placed over the full board area. A coplanar shield placed with a separation of 0.5 mm will be effective and allow an easy layout of the sensor.

Figure 1-23. Level Shield Signals
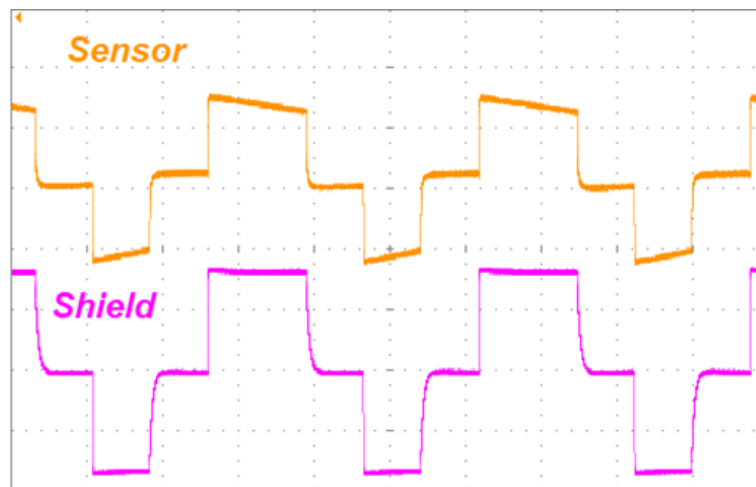
Two-Level Shield

A two-level shield drives a charge pulse during the sensor measurement, which shields the sensor from outside influence while additionally boosting the sensitivity of the sensor.

The shield electrode is driven with pulses synchronized to the measurements. These pulses have the effect of boosting the self-capacitance measurement by an injection of additional charge to the sensor capacitance. Touch sensitivity is increased through the interaction between the touch contact and the sensor-shield electric field.

The sensor load capacitance is reduced as the shield isolates the sensor from nearby ground-referenced circuit components.

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Table 1-9. Sensor to Shield Separation for Two-Level Shield

Type	Min.	Typical	Max.
Sensor – Shield Separation (S)	1 mm	2 mm	3 mm

If the shield electrode is too close to the sensor electrode, then the shield-sensor capacitance may exceed the sensor-ground capacitance. This results in reduced SNR, nonlinear operation or in some cases calibration failure.

This is of particular concern when using the two-level driven shield+ (see 1.4.2.2 Driven Shield+) as the sensor traces and electrodes all contribute to the shield-sensor capacitance.

Figure 1-24. Level Shield Signals
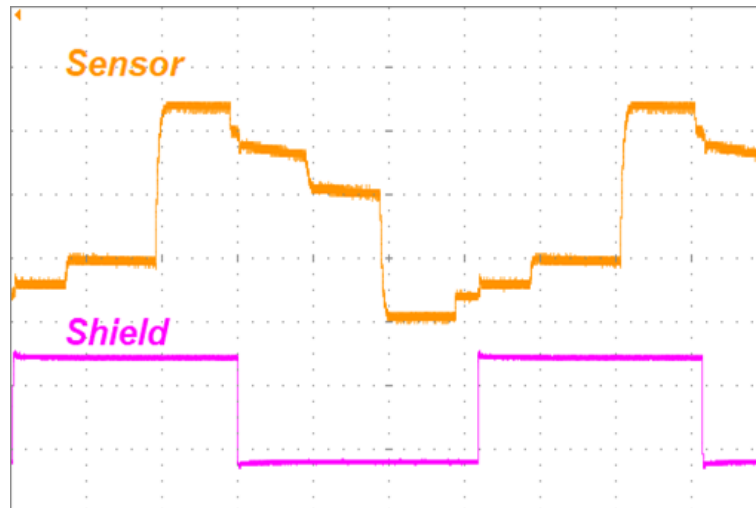
Driven Shield Examples
A coplanar driven shield is implemented on the same layer as the touch sensors electrodes, with appropriate separation between the electrodes.

A rear shield is placed on the layer behind the electrodes. To reduce shield loading (two-level shield), the rear shield may be cut out or hatched with 10% to 50% fill behind the sensor electrodes.

Figure 1-22 shows a sensor implementation with a coplanar shield around the sensor area and a flooded rear shield with cutouts behind each sensor electrode.

Figure 1-25. Driven Shield Layout
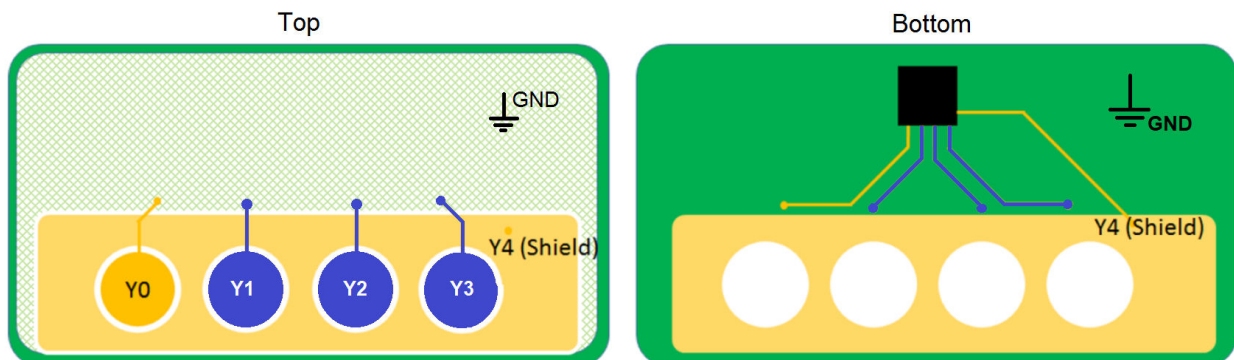
Alternatively, a 'ring shield' (see Figure 1-23) may be used to isolate each of the sensor electrodes from each other and the ground plane. The ring shield consists of a coplanar shield electrode surrounding each touch sensor.

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Notice: The shield must not form a complete ring around the sensor electrode, as this may lead to problems with the RF noise. Breaking the ring also allows simplified routing and enables a single layer sensor design.

Figure 1-26. Ring Shield Layout
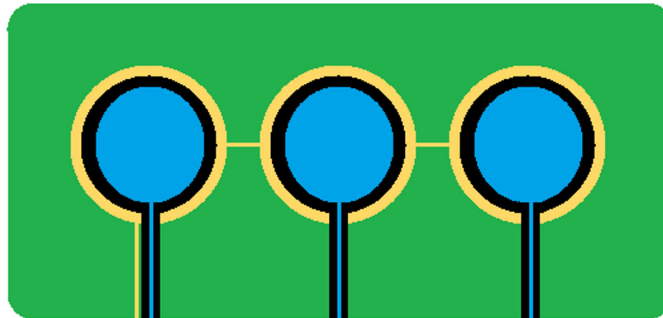
1.4.2.2 Driven Shield+

Some devices are capable of driving the 'shield' signal – two or three-level – not only to a dedicated shield electrode but also to other touch sensor electrodes on the user interface.

Even in the case where all pins are used as touch sensors, and there are no pins available for a separate shield electrode, the Driven Shield+ can be used to drive the other sensors as a shield. In the application examples shown in Figure 1-27, Y0 is the active sensor, and all other electrodes are driven as a shield.

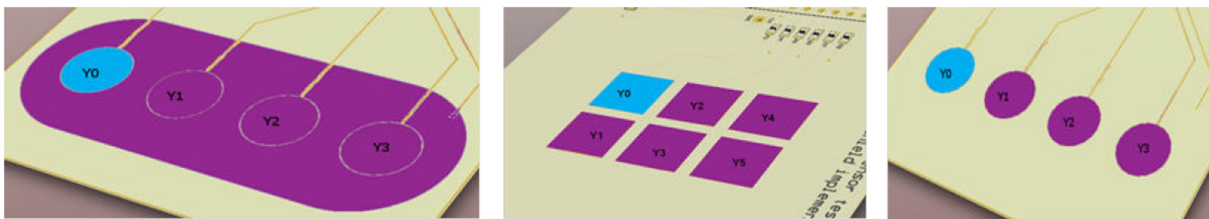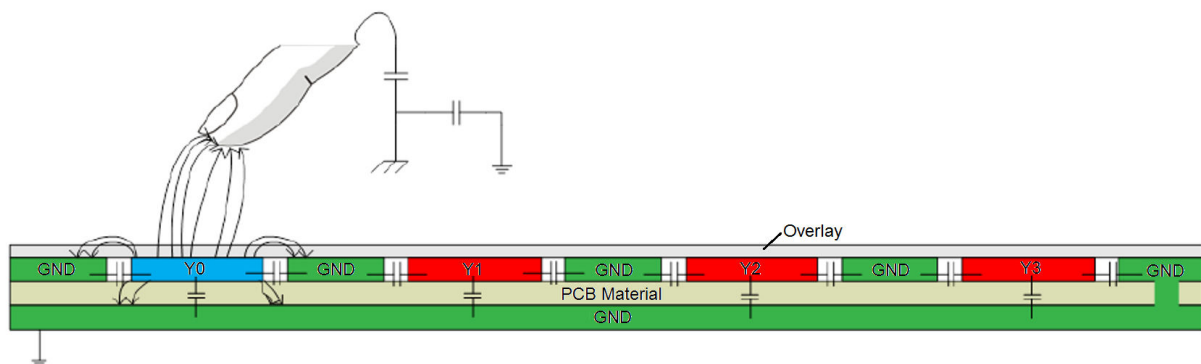**Figure 1-27. Driven Shield+ Examples**

Figure 1-28. Sensors with Ground in Close Proximity

In Figure 1-28, sensor Y0 is measured while all other sensors are held static at V_{DD}. There is also a ground flood or signal near the sensors. In this scenario, additional capacitance exists between Y0 and the ground. Charge driven into Y0 will be shared with the ground, reducing the electric field at the touch surface, thus reducing touch sensitivity. As discussed in section 1.4.1 Passive Shield, this may be mitigated by increasing the space between the sensor and the ground shield, but this is not always possible in user interface designs with a high sensor density.

Figure 1-29. Sensors with Driven Shield+
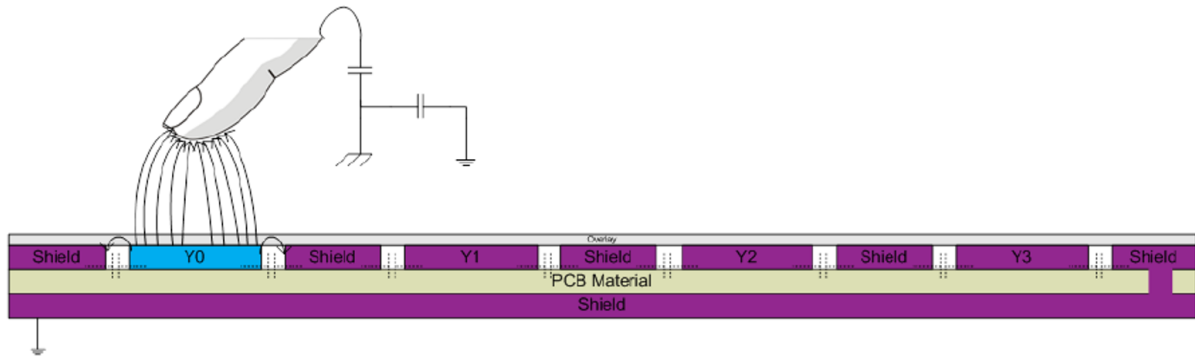
With Driven Shield+, there is little capacitive loading between Y0 and the other electrodes as they are driven to the same potential. There is a stronger electric field between the sensor and the user, which increases sensitivity and Signal-to-Noise Ratio.

This effect of using Driven Shield+ allows greater field projection and improved performance in both conventional touch designs as well as in proximity sensor applications.

Moisture Tolerance

With Driven Shield+, water coupling between a sensor and the shield does not create a touch delta because the shield and sensor are driven to the same potential. Where a driven shield is used, but the adjacent keys are not shielded, water can potentially cause a false touch detection due to coupling to neighboring keys. Microchip's Driven Shield+ technology ensures that all electrodes are driven with the same signal, thus also preventing false touches if water bridges between two keys – even if there is no guard between them.

Care must always be exercised when designing systems where the touch sensor may be exposed to water. If the water bridges across the shield signal and to a ground reference, then some field from the touch sensor will couple to the ground through water, which may cause false touch detection.

Figure 1-30. Effect of Water on Touch Sensors

Adjacent key driven   Adjacent key NOT driven
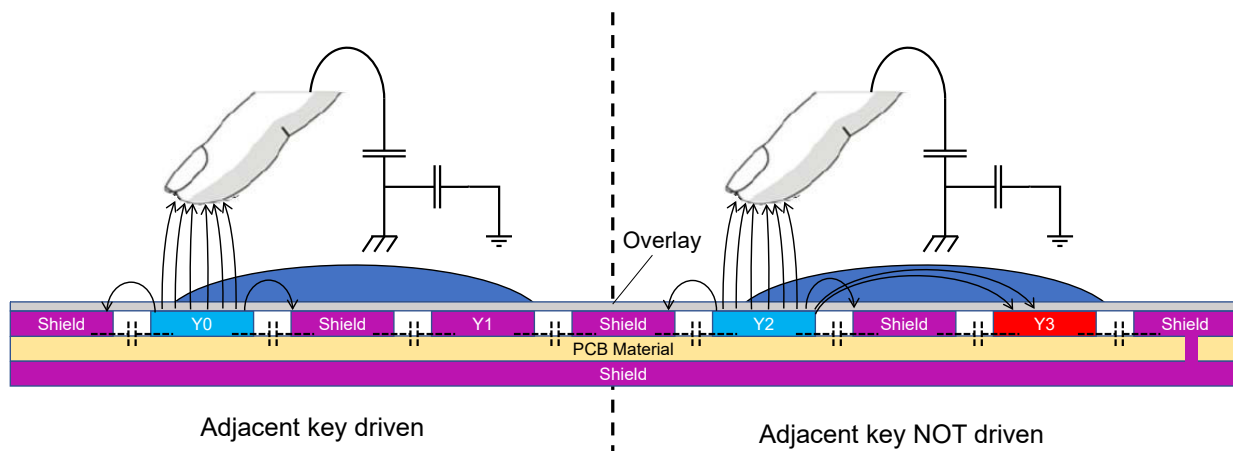
A **three-level shield** shows little or no change in measured signal when water is dropped on the sensor. As the shield is driven to the same potential as the sensor, there is no charge transfer.

A **two-level** shield is a hybrid self/mutual capacitance measurement.

- Water causes an increase in capacitance on a self-capacitance sensor, resulting in towards touch delta
- Water on a mutual capacitance sensor also causes an increase in measured capacitance. However, as a touch contact usually causes a reduction in mutual capacitance, the resulting measurements show an anti-touch delta
- The combined effect may be either:
  - Towards touch delta – false detection is possible

– Anti-touch delta – anti-touch recalibration may cause false detection when the water is removed
• Operation of a sensor with a two-level shield depends on the amount and location of water. Issues may be partially mitigated by sensor design and cover stack but may be dependent on application processing.

Figure 1-31 illustrates the operation of Driven Shield+ on a sensor layout with coplanar and rear-driven shields. As all the sensor electrodes are driven as Shield, water will not cause a false detection unless a larger spill bridges across the ground area.

Figure 1-31. Driven Shield+ Layout Example
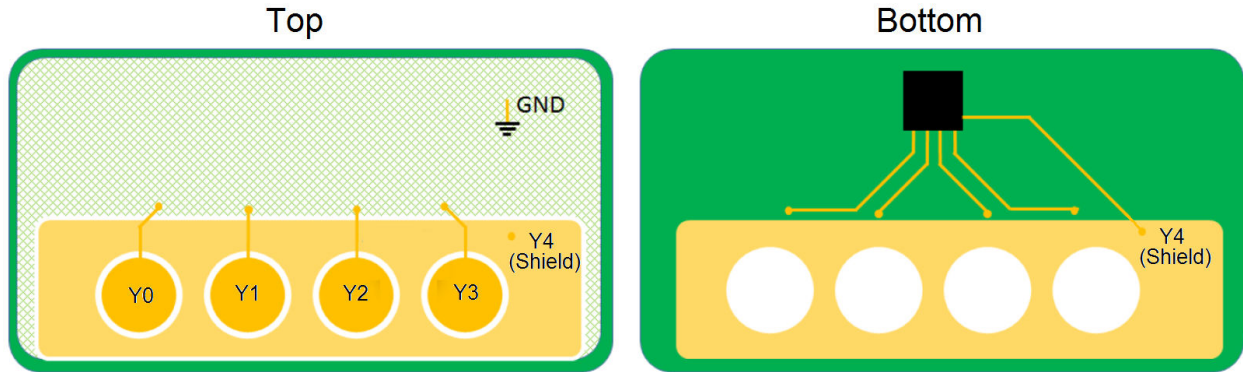
1.4.3   Radiated Emissions

Depending on the application and its environment, the use of a driven shield may cause excessive radio frequency emissions. This is caused by high-speed switching of large-area electrodes and can lead to products failing to meet the required RFI standards.

High emissions are particularly prevalent not at the switching frequency of the touch sensors but higher frequencies dependent on the MCU core speed and the I/O pin slew rate.

Radiation Mitigation

The following describes design techniques that will reduce radiation from the shield.

• Add or increase the series resistor to the shield electrode:
    – By increasing the series resistance, the time constant of the RC shield is increased, and the amount of energy available at high frequencies is reduced

    Note: The resistor package has a parasitic capacitance which at RF frequencies may be lower impedance than the resistor itself.

• Reduce the area of the driven shield.
    – Instead of using a full flood, consider utilizing patches of shield electrodes behind each touch sensor, extending beyond the edge of each sensor. This layout is shown in Figure 1-32.
    – Connect the patches at a single physical point and connected to the resistor in a 'star' formation. This layout is shown in Figure 1-32.

**Figure 1-32. Minimum Driven Shield Area**
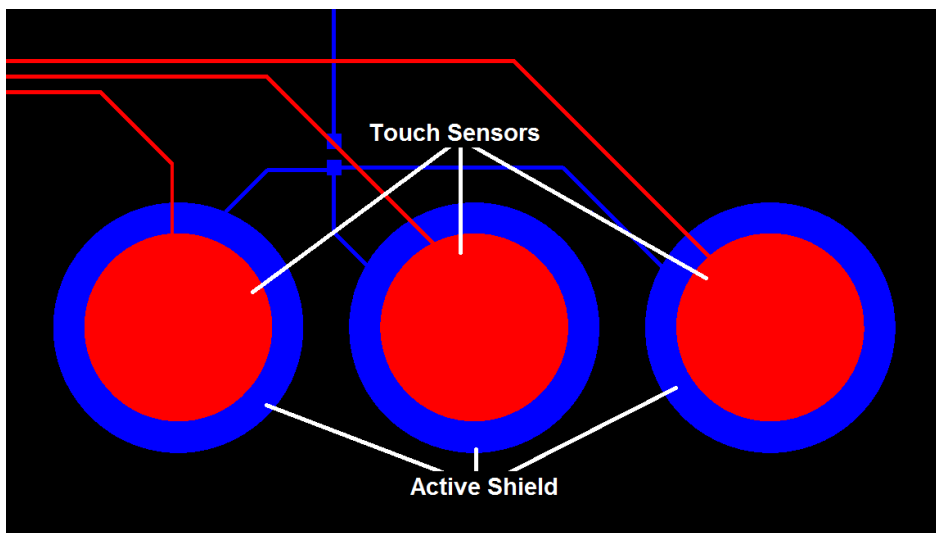
2. Mutual Capacitance Sensors

2.1 Mutual Capacitance Measurement

Mutual capacitance touch sensors use a pair of electrodes for each sensor node and measure the capacitance between them. The sensor is formed where the electrodes are placed close together, usually with interleaved segments to optimize the length of the parallel conductors forming the base capacitance of the sensor node.

Figure 2-1. Mutual Capacitance Sensor
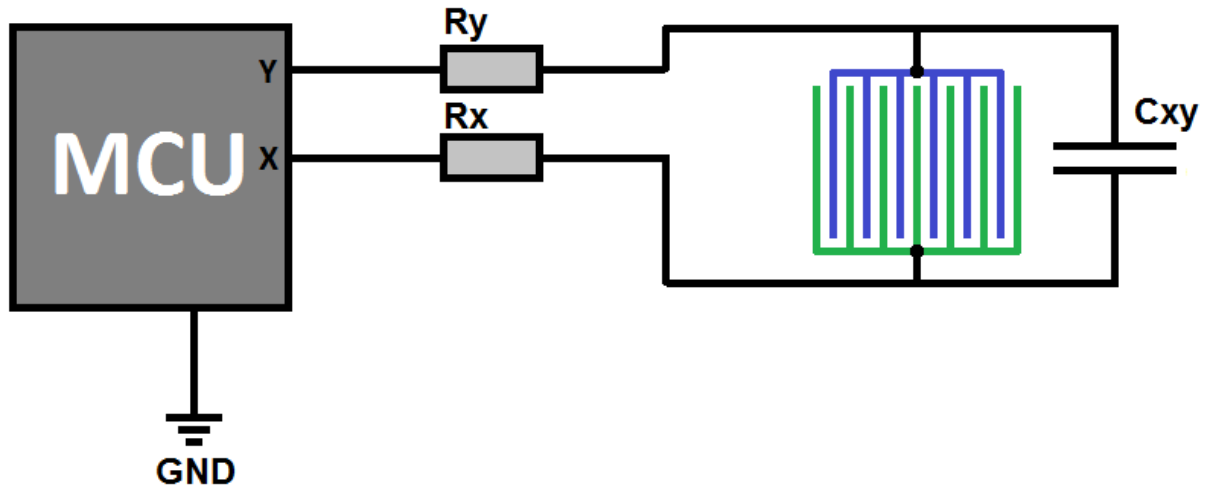
When a touch contact is placed over the sensor, the user's fingertip interacts with the electric field between the X (transmit) and Y (receive) electrodes. To model touch effects in the circuit, the sensor capacitance C_{xy} is replaced with an equivalent overall capacitance formed by two capacitors in series each of value $2C_{xy}$.

Figure 2-2. Mutual Capacitance Sensor with Touch Contact
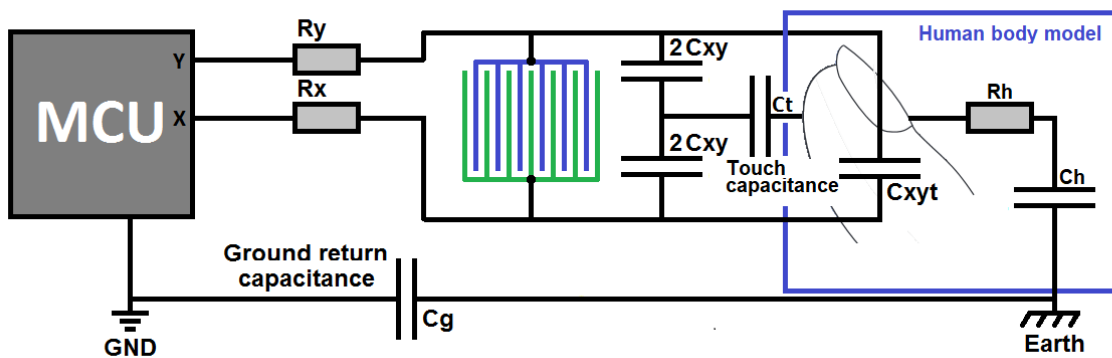
The touch contact is a complex interaction of two competing effects:

1. The finger forms a third electrode in the X-Y capacitor and increases the coupling between X and Y. This is modeled by the capacitor labeled C_{xyt}.
2. The touch capacitance C_t forms a ground return path via C_h - human body model (HBM) capacitance - and C_g (ground-to-earth capacitance), which reduces the amount of charge transferred from X to Y, causing an apparent decrease in the X–Y capacitance.

👉 **Notice:** The HBM resistance R_h does not affect touch sensitivity because each capacitance must be fully charged or discharged during the measurement.

C_t

- The series capacitance between the sensor and fingertip

C_{xyt}

- Parallel capacitance between X and Y due to the fingertip

Ch

- Human body model
- 100 pF to 200 pF

C_g

- Coupling between the application DC ground and earth
- Depends on application type and power system
- As little as ~1 pF in a small battery-powered device and infinite capacitance/short circuit where the DC ground is connected directly to earth

As in self-capacitance sensors, C_t is much smaller than C_h or C_g for most applications; the measured touch delta is dominated by C_t, which is controlled by the sensor design.

The equivalent XY capacitance is:

Equation 2-1. Equivalent XY capacitance

$$C_{eq} = \frac{4C_{xy}{}^2}{4C_{xy} + C_f} + C_{xyt}$$

where C_f is the series combination of C_t, C_h and C_g.

2.2   Sensor Design

2.2.1   Touch Capacitance Model

Unlike for self-capacitance measurements, there is no simple way to approximate the expected touch capacitance for a given mutual sensor layout. The parallel plate approximation is not applicable as the 'plates' in this case are segments of the X and Y electrodes, which are much smaller than the touch cover. The user's touch contact is dominated by edge and point fields between the electrode pair and the fingertip.

Figure 2-3. Electric Fields in Mutual Capacitance Sensors

Touch cover

Sensor PCB

X / Transmit   **Y / Receive**
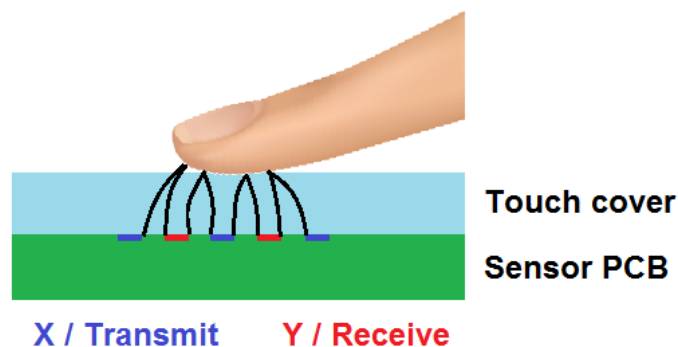
When designing mutual capacitance sensors, the node layout may be optimized to suit application requirements such as:

- Maximum sensitivity
- Best noise tolerance
- Best water rejection
- Minimum default sensor capacitance (some acquisition technologies have a limit on the sensor capacitance)
- Minimum power consumption
- Minimum touch latency

All applications will require a trade-off between these properties, as achieving one will mean compromising others.

As an example, the strongest sensitivity is achieved using high interleaving of electrodes. However, achieving minimum sensor capacitance requires a larger spacing between X and Y.

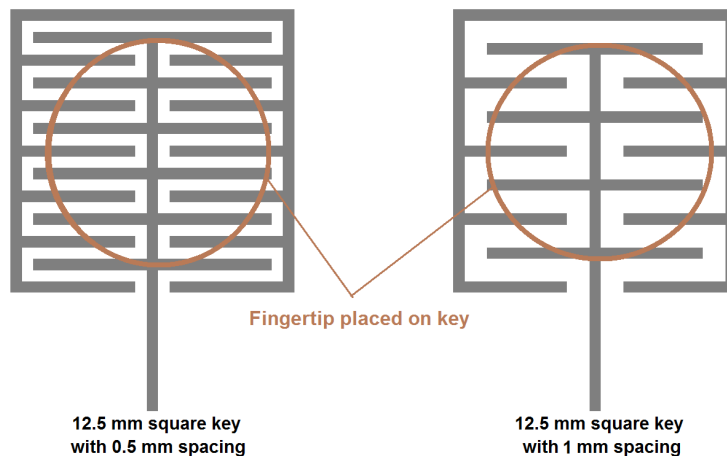Excess sensor capacitance increases acquisition time and power consumption.

Increasing X-Y separation reduces default X-Y capacitance, but it also reduces the lengths of parallel segments between the electrodes.

Figure 2-4. 0.5 mm vs. 1 mm XY Spacing

12.5 mm square key
with 0.5 mm spacing

12.5 mm square key
with 1 mm spacing
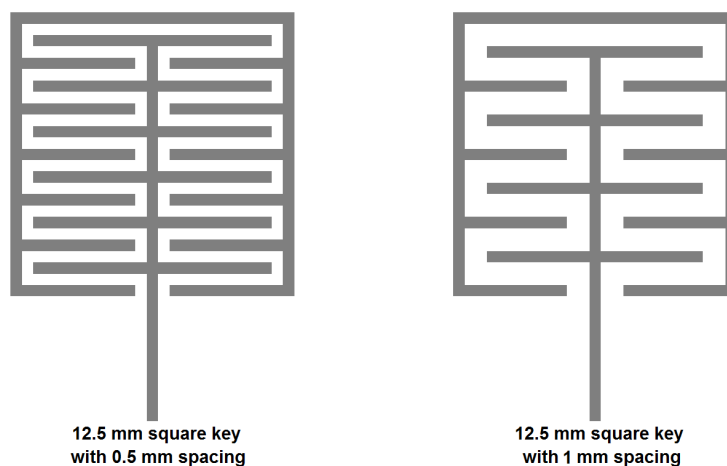
When a user touches the sensor with larger spacing, a smaller total length of parallel segments is covered by the touch. This translates to a reduced X-Y field interaction and hence a proportional reduction in sensor sensitivity.

Figure 2-5. Touch Contact 12 mm Key

Fingertip placed on key

12.5 mm square key
with 0.5 mm spacing

12.5 mm square key
with 1 mm spacing

2.2.2   Button Sensor Design

The simplest implementation of a capacitive sensor is a button, where the sensor consists of a single X-Y node and is interpreted as a binary state: In Detect or Out of Detect. When the touch delta – the digitized measurement of touch capacitance C_t – exceeds the touch threshold, the senor is In Detect.

Figure 2-6. Button Sensor Delta and Threshold
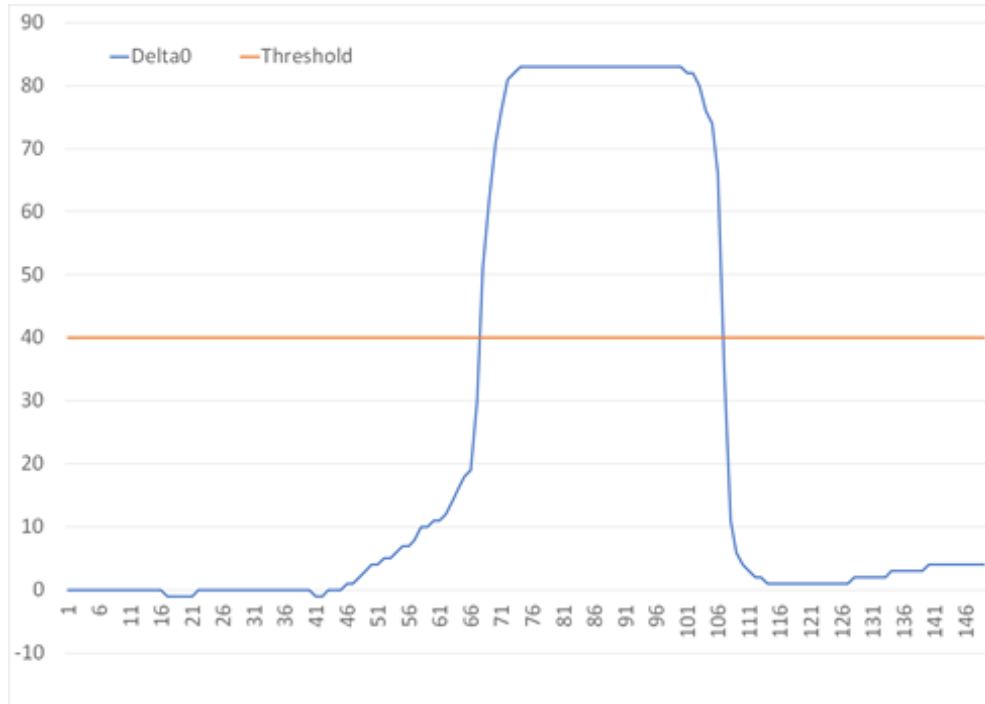
Electrode Shapes

A sensor node is formed everywhere a pair of X and Y electrodes form an area of coupling. Common button shapes are round or rectangular, although any shape with parallel segment coupling of X and Y electrodes may be used.

Interleaved Key

The simplest sensor layout is a coplanar interleaved key. See Figure 2-7.

An interleaved key is typically between 8-20 mm wide. To avoid excess X-Y capacitance – and associated increase acquisition time – the electrode spacing must be increased for larger keys.

The electrode segment width must usually be the minimum track width available but may be increased up to 1 mm where the sensors are formed on a high-sheet resistance material such as ITO.
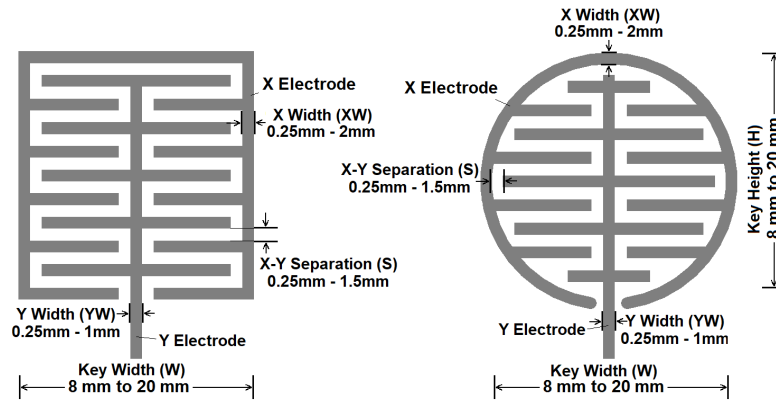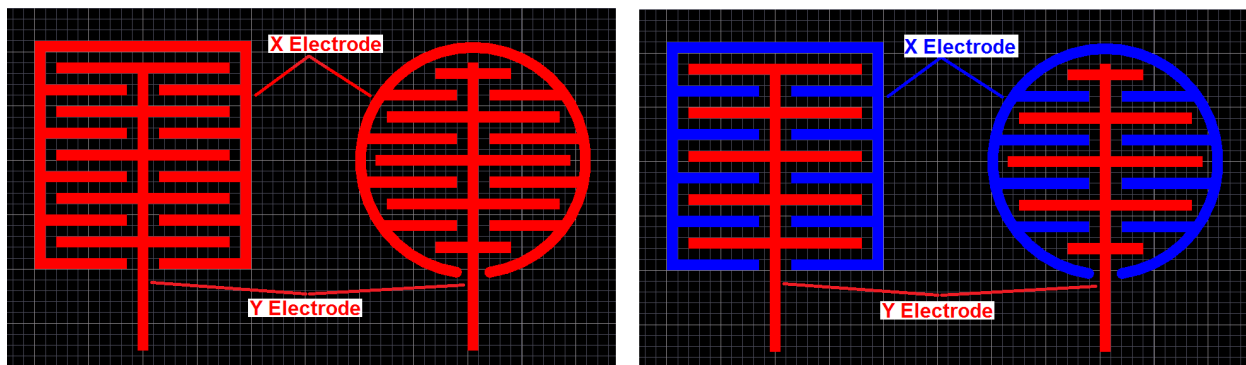
Figure 2-7. Interleaved Key Dimensions

Table 2-1. Interleaved Key Dimensions

	Min.	Typical	Max.
Key Height (H)	8 mm	12 mm	20 mm
Key Width (W)	8 mm	12 mm	20 mm
X Width (XW)	0.25 mm	0.5 mm	2 mm
Y Width (YW)	0.25 mm	0.5 mm	1 mm
X-Y Separation (S)	0.25 mm	0.5 mm	1.5 mm

The interleaved key is typically implemented on a single PCB layer but may be split between two layers with the X electrodes on the layer furthest from the touch surface. A two-layer design combines high sensitivity with low default sensor capacitance. It provides a maximum length of the parallel segments under the touch contact for increased sensitivity while increasing X-Y separation and thus reducing the default sensor capacitance.

A two-layer interleaved sensor is highly suitable for implementation on a flex-PCB as it simplifies the routing for X and Y electrodes. However, with a thicker substrate, e.g, 1.6 mm FR4, a reduction in sensitivity may be expected.

Figure 2-8. Split Level Layout

Standard key - X and Y electrodes both on the top layer

Split level key - X electrodes on bottom layer, Y on top

Flooded X Sensor

An alternative layout is 'flooded X', where the X electrode is implemented as a solid area behind a segmented Y electrode. The X area must extend beyond the Y electrode by at least 2 mm on each side.
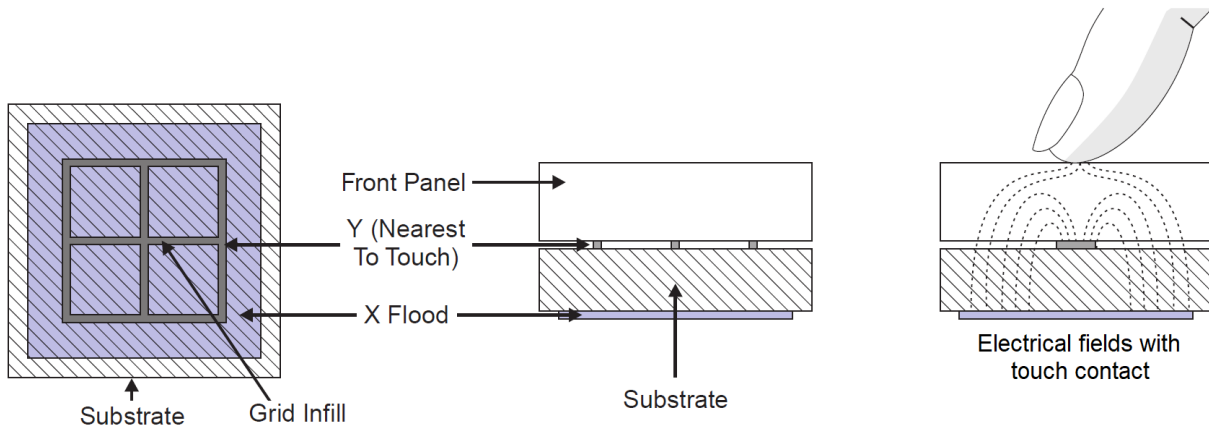
Figure 2-9. Flooded X Layout
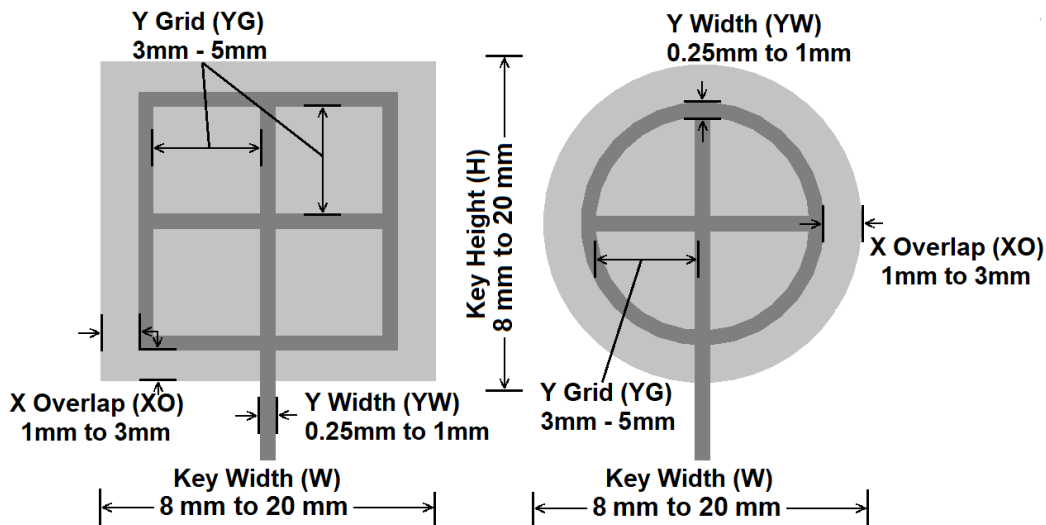

Figure 2-10. Flooded X Key Dimensions

Table 2-2. Flooded X Key Dimensions

	Min.	Typical	Max.
Key Height (H)	8 mm	12 mm	20 mm
Key Width (W)	8 mm	12 mm	20 mm
X Overlap (XO)	1 mm	2 mm	3 mm
Y Width (YW)	0.25 mm	0.5 mm	1 mm
Y Grid (YG)	3 mm	4 mm	5 mm

This layout also has the advantage that the X area shields the Y sensor from circuit noise from behind the X electrode. However, in an application requiring a thicker touch cover, flooded X sensors suffer from poor sensitivity.

Generally, flooded X sensors must only be used where the touch cover is thinner than the substrate separating the two electrodes. With standard 1.6 mm FR4 circuit boards, no touch cover thicker than 1.6 mm must be considered.

Notice: Flooded X sensors are generally not suitable for implementation on flex PCB, as the thin substrate requires an equally thin touch cover.

Notice: Flooded X sensors are not suitable for use with some devices. See 5. Appendix C for device-specific information.

2.2.3   Slider Sensor Design

A slider may be implemented as a row of two or more sensors placed together. The measurements of the sensor group are combined to determine the position of a touch contact with an increased resolution by interpolation between the sensors.

The slider must be between 8-20 mm wide. To avoid excess XY capacitance – and an associated increase in acquisition time – the electrode dimensions and spacing should be increased for larger keys.

As noted in the previous section, large sensors without interpolation lead to poor linearity.

Figure 2-11. Slider Position without Interpolation
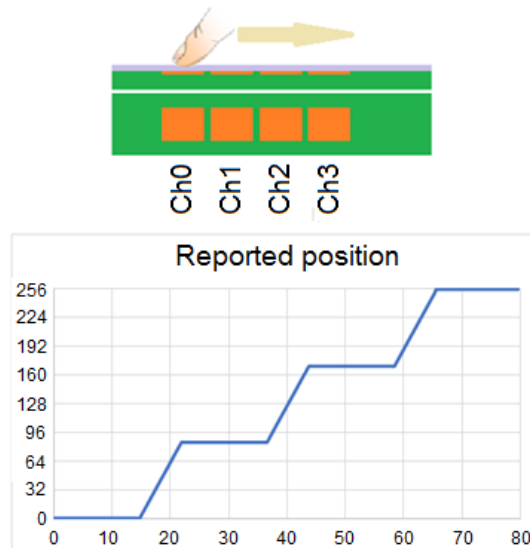
This may be mitigated by increasing the sensor count and decreasing sensor width, but at the cost of total measurement time and touch channel usage. Capacitive or resistive interpolation may be implemented to improve slider linearity.

Figure 2-12. Slider Position with Interpolation
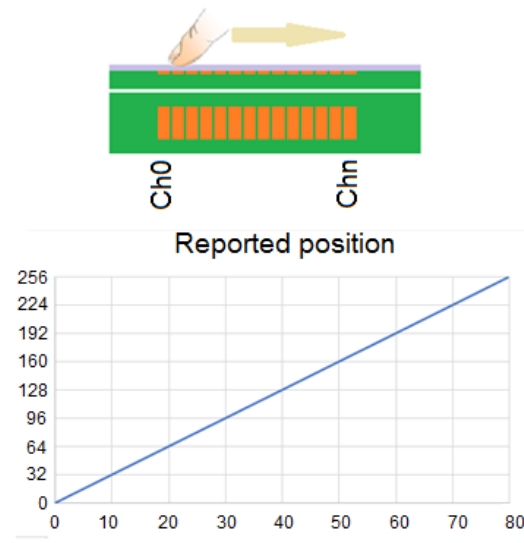
Interleaved Slider

Spatial interpolation ensures good linearity with fewer sensors and can be implemented using an interleaved layout, where the sensor nodes are formed by alternating X and Y electrodes.

Typically, a single Y line is used with multiple X lines as this allows for the easiest sensor routing, as the Y line sensor trace must be routed with more care to avoid capacitive loading and increased time constant.
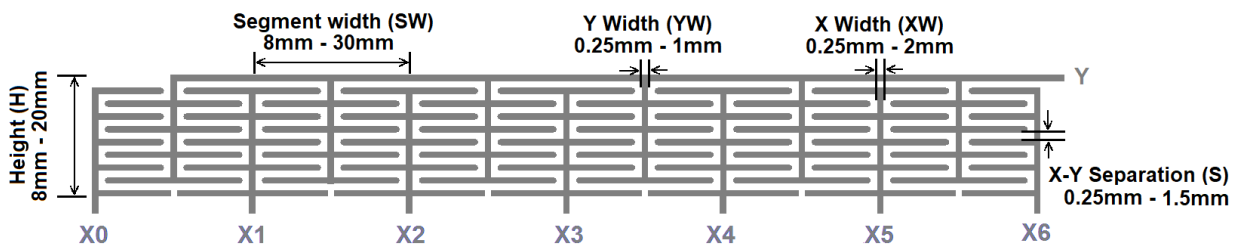
Figure 2-13. Interleaved Slider Layout

Table 2-3. Interleaved Slider Dimensions

	Min.	Typical	Max.
Slider Height (H)	8 mm	12 mm	20 mm
Segment Width (SW)	8 mm	12 mm	30 mm
X Electrode Width (XW)	0.25 mm	0.5 mm	2 mm
Y Electrode Width (YW)	0.25 mm	0.5 mm	1 mm
X-Y Separation (S)	0.25 mm	0.5 mm	1.5 mm

The interleaved slider may be formed as a coplanar sensor, with X and Y electrodes on the same layer or split to different layers with X on the layer further from the touch surface.

Flooded X Slider

A flooded X slider provides improved linearity as the X electrodes are on a separate PCB layer. Spatial interpolation may be extended without complex routing around the Y electrodes. The X-layer pattern for a flooded X slider is identical to the interpolated self-capacitance slider presented in the previous section.
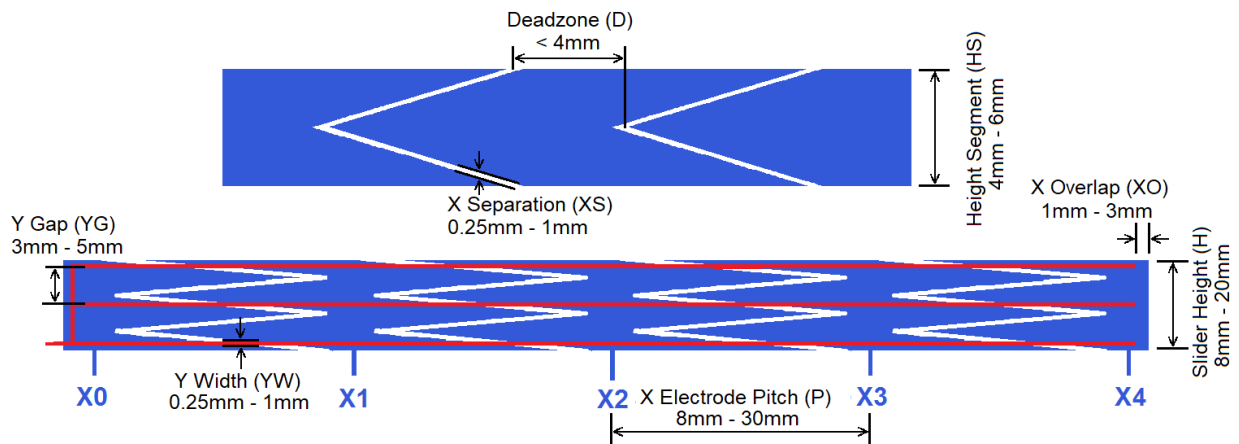
Figure 2-14. Flooded X Slider Layout

Table 2-4. Flooded X Slider Dimensions

|	Min.	Typical	Max.
Slider Height (H)	8 mm	12 mm	20 mm
Height Segment (HS)	4 mm	5 mm	6mm
X Electrode Pitch (P)	8 mm	12 mm	30mm
X Segment Separation (XS)	0.25 mm	0.5 mm	1 mm
X Electrode Overlap (XO)	1 mm	2 mm	3 mm
Deadzone (D)	-	2 mm	4 mm
Y Electrode Width (YW)	0.25 mm	0.5 mm	1 mm
Y Gap (YG)	3 mm	4 mm	5 mm

Resistive Interpolation

In both interdigitated and flooded X slider designs, it is possible to reduce the number of sensor node measurements while maintaining linearity by resistive interpolation of some sensor nodes.

Figure 2-15. Sliders with Resistive Interpolation
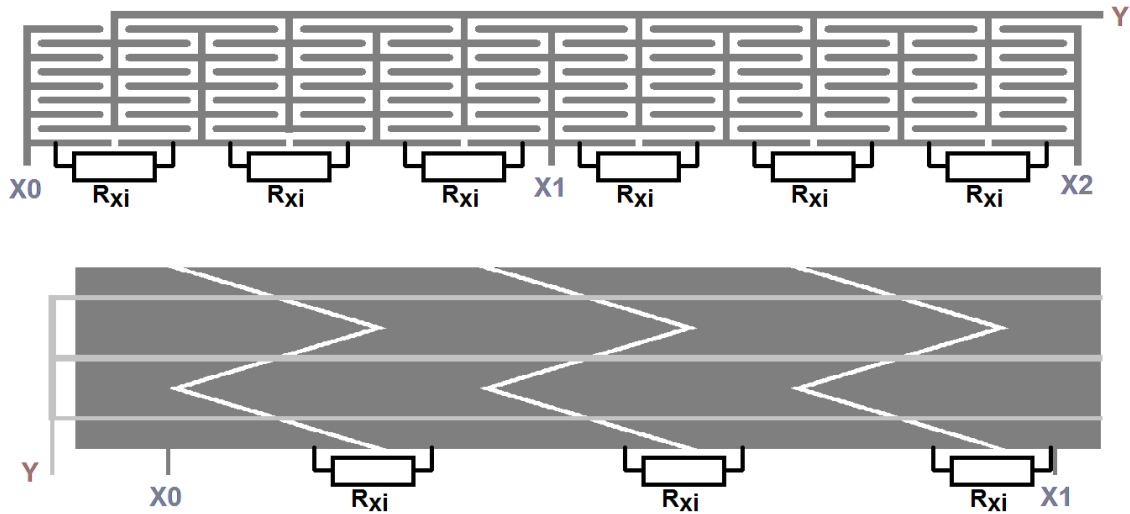
A minimum of at least two directly routed X electrodes is required, placed at either end of the slider. Intermediate nodes are joined with a series of resistors, forming a resistive divider driving each intermediate node at a fraction of the X drive voltage.

Figure 2-16. Contact Location by Resistive Interpolation
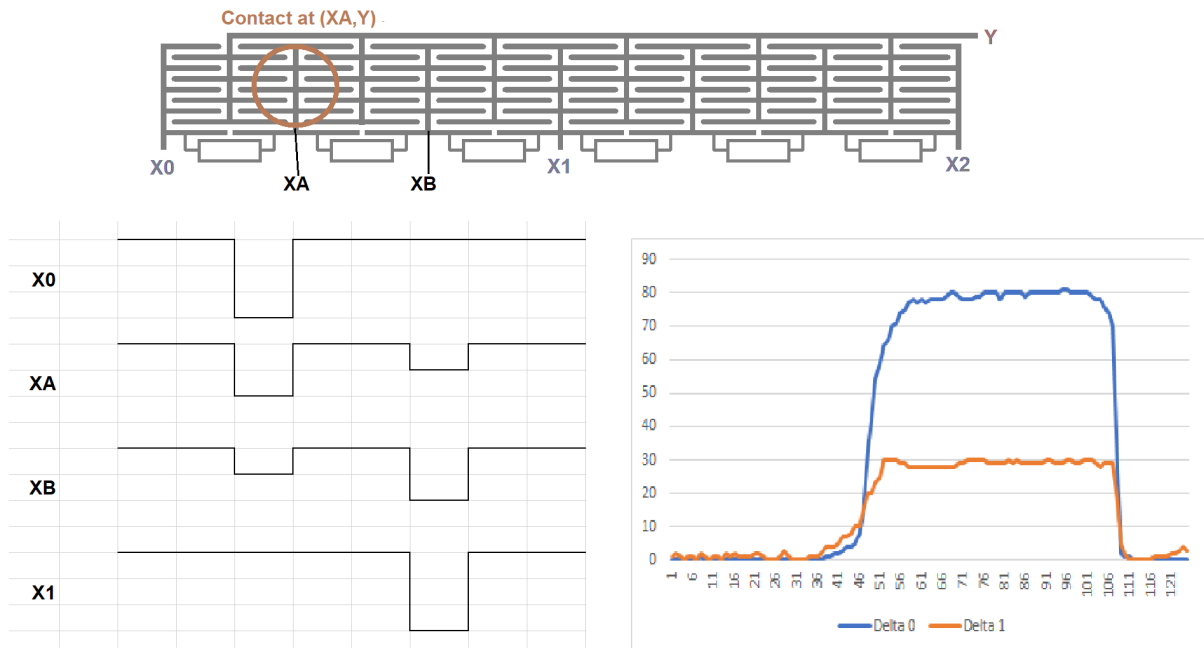
A touch contact on an intermediate node XA causes a proportional touch delta on each of the direct nodes X0 and X1. Reduced pulse amplitude at XA and XB causes proportionally less touch delta at these locations, allowing interpolation between nodes (X0,Y) and (X1,Y).

In this example, with two intermediate nodes, the delta measured at (X0,Y) is 2/3 while that at (X1,Y) is 1/3.

Segment interpolation resistors R_{xi} must be selected so that the total series combination between each pair of directly connected X lines is in the range of 10-20 kOhm.

2.2.4 Wheel Sensor Design

A wheel sensor consists of a row of three or more sensor nodes arranged in a circle.

Notice: At least three electrodes are required, as position calculation needs unique crossover regions.

A wheel sensor operates in the same way as a slider sensor, with the single exception that it is wrapped around from Channel n to Channel 0 so there are no end electrodes in the design.

The sensor width must be between 8-20 mm wide. To avoid excess XY capacitance – and an associated increase in acquisition time – the electrode spacing must be increased for larger sensors.

The electrode segment width must usually be the minimum track width available but may be increased up to 1 mm where the sensors are formed on a high sheet resistance material such as ITO.

Interleaved Wheel

Like the interleaved slider, the simplest implementation is a coplanar interleaved wheel. X and Y electrodes are formed on the same PCB layer. The design may also be split across two PCB layers to reduce default capacitance, with the X electrodes on the layer further from the touch cover.
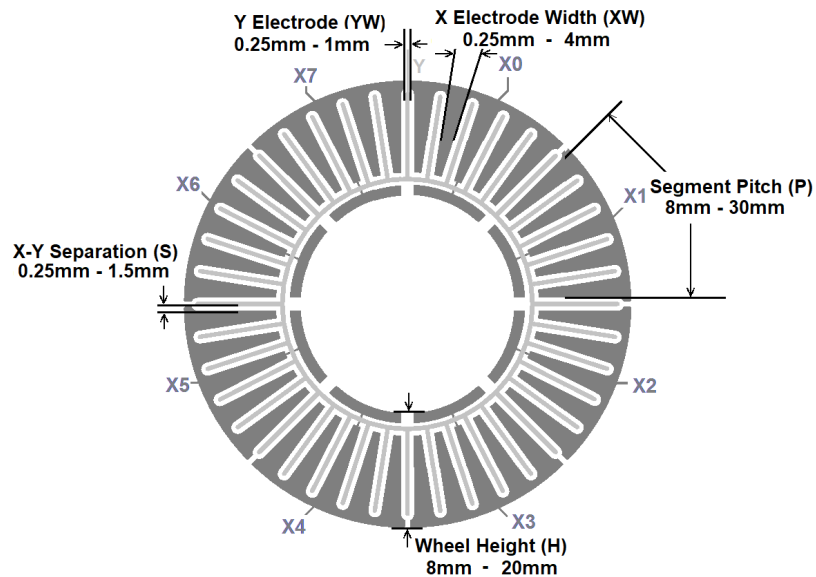
Figure 2-17. Interleaved Wheel Layout

Table 2-5. Interleaved Wheel Dimensions

	Min.	Typical	Max.
Wheel Height (H)	8 mm	12 mm	20 mm
Segment width	8 mm	12 mm	30 mm
X electrode width	0.25 mm	0.5 mm	4 mm*
Y electrode width	0.25 mm	0.5 mm	1 mm
XY spacing	0.25 mm	0.5 mm	1.5 mm

Notice: * Taper needs to be within this range at both ends.

Flooded X Wheel

As the X electrodes in a flooded X design sit on a separate PCB layer, spatial interpolation may be extended without complex routing around the Y electrodes. This allows the flooded X design to provide improved linearity over the interleaved layout. The X layer pattern for a flooded X slider is identical to the interpolated self-capacitance wheel presented in the previous section.

The wheel is made up of concentric segments of 4-6 mm, each containing the interleaved electrode pattern. The sensor must include enough segments to make up the desired width.
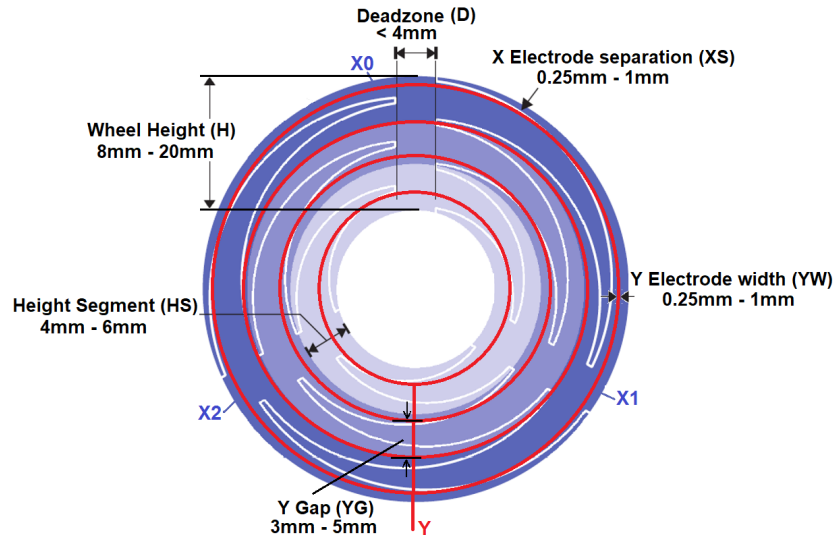
Figure 2-18. Flooded X Wheel Layout


Table 2-6. Flooded X Wheel Dimensions

	Min.	Typical	Max.
Wheel Height (H)	8 mm	12 mm	20 mm
Height Segment (HS)	4 mm	5 mm	6 mm
X Electrode Pitch (P)	8 mm	16mm	30 mm
X Electrode Separation (XS)	0.25 mm	0.5mm	1 mm
X Electrode Overlap (XO)	1 mm	2 mm	3 mm
Deadzone (D)	-	2 mm	4mm
Y Electrode Width (YW)	0.25 mm	0.5 mm	1 mm
Y Gaps (YG)	3 mm	4 mm	5 mm

Resistive Interpolation

In both coplanar and flooded X designs, it is possible to reduce the number of sensor node measurements while maintaining linearity by resistive interpolation of some sensor nodes.

A minimum of three directly routed X-electrodes is required, placed symmetrically around the wheel. Intermediate nodes are joined with a series of resistors that form a resistive divider driving each intermediate node at a fraction of the X-drive voltage.

Figure 2-19. Wheel with Resistive Interpolation
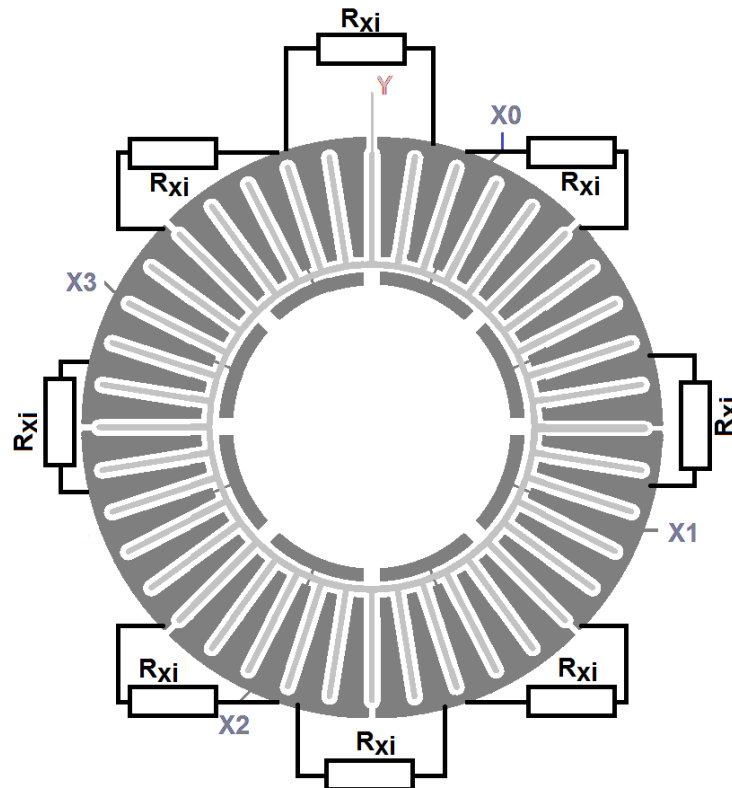
A touch contact on an intermediate node causes a proportional touch delta on each of the neighboring direct nodes. Reduced pulse amplitude causes proportionally less touch delta at these locations, allowing interpolation between measured nodes.

Segment interpolation resistors Rxi must be selected so that the total series combination between each pair of directly connected X lines is in the range of 10-20 Ohm.

2.2.5 Surface Sensor Design

A mutual capacitance touch surface consists of 'row' and 'column' electrodes, which are implemented as X and Y, respectively. Each row or column is measured, and the data are combined to implement slider functionality in both the horizontal and vertical directions.

> **Notice:** Dual touch detection requires a center-to-center touch point separation of at least twice the sensor pitch for two unique touchpoints to be registered.

Interleaved Surface

The interleaved slider pattern may be extended to two dimensions to form an interleaved surface sensor. The surface pattern requires two routing layers to allow crossovers as each row must be joined from left to right and each column from top to bottom.

The sensor may be implemented on a single layer with connections only on the second layer, or as a split-level design with X electrodes on the layer further from the touch cover and Y electrodes on the closer layer.
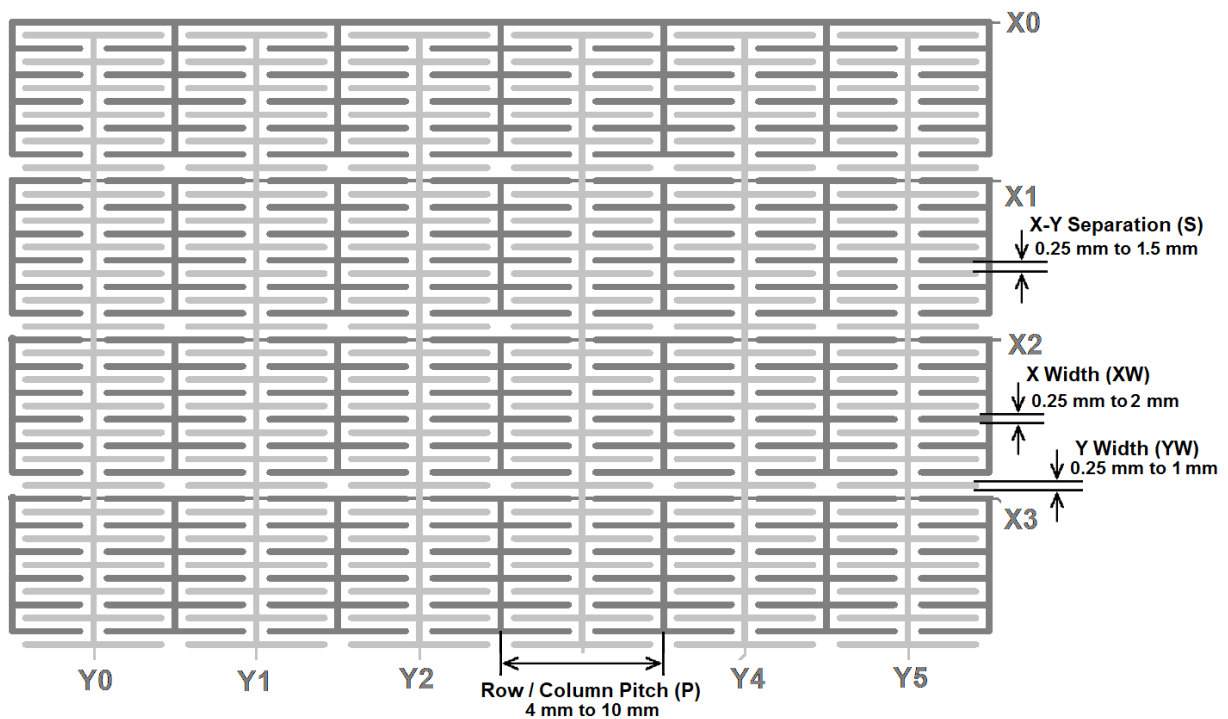
Figure 2-20. Interleaved Surface Layout

Table 2-7. Interleaved Surface Parameters

	Min.	Typical	Max.
Row/Column Pitch (P)	4 mm	6 mm	10 mm
X Electrode Width (XW)	0.25 mm	0.5 mm	2 mm
Y Electrode Width (YW)	0.25 mm	0.5 mm	1 mm
XY Separation (S)	0.25 mm	0.5 mm	1.5 mm

Diamond Pattern

The diamond pattern presented in 2.2.5 Surface Sensor Design for the self-capacitance surface may also be implemented as a mutual capacitance sensor.

Horizontal sensor nodes may be driven as X lines, while vertical nodes are measured as Y or vice versa. The X- and Y- electrodes may be arranged as a coplanar design or as a split-level configuration with X-electrodes at the rear, as described above for buttons, sliders, and wheels.

Notice: Implementations using reversible X-Y electrodes (i.e., the pin may be driven as X or measured as Y) must be located on a single layer to have consistent sensitivity.

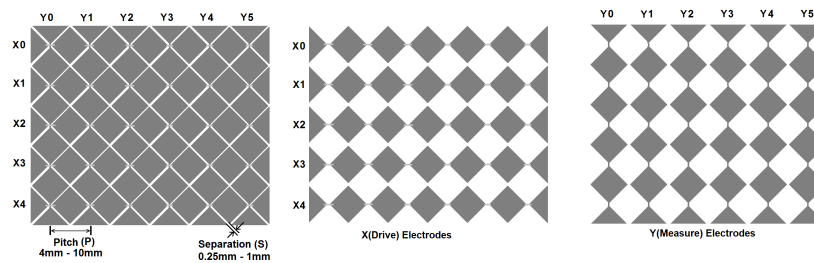**Figure 2-21. Mutual Surface Diamond Pattern**

Table 2-8. Diamond Pattern Parameters

	Min.	Typical	Max.
Row/Column Pitch (P)	4 mm	6 mm	10 mm
XY Separation (S)	0.25 mm	0.5 mm	1 mm

Similarly, the flower pattern surface described in 1.2.5 Surface Sensor Design may be used for the mutual capacitance surface.

Flooded X Surface

The sensor is formed with X electrodes as vertical bars to the rear, and Y electrodes as narrow traces horizontally spaced on the top layer. Interpolation along Y nodes provides the vertical position, interpolation along X nodes the horizontal.

Figure 2-22. Flooded X Pattern
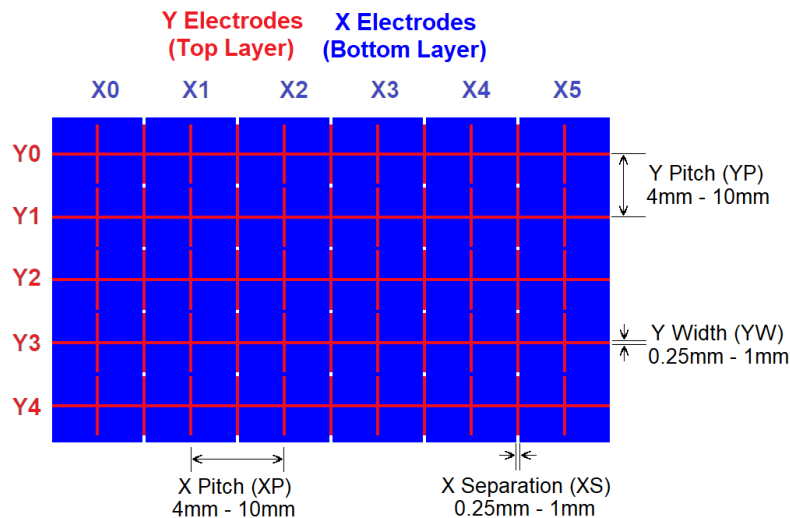
Table 2-9. Flooded X Pattern Parameters

	Min.	Typical	Max.
Y Pitch (YP)	4 mm	6 mm	10 mm
Y Width (YW)	0.25 mm	0.5 mm	1 mm
X Pitch (XP)	4 mm	6 mm	10 mm
X Separation	0.25 mm	0.5 mm	1 mm

2.3　Touch Cover Effects

A thicker touch cover increases the distance between the user's fingertip and the sensor electrodes and has the effect of diffusing the electric field formed between them. There is a reduction in touch contact capacitance, but this can be compensated by increasing the size of the electrode and the amount of interdigitation.

For maximum sensitivity, each sensor must be designed to extend beyond the touch contact by at least the thickness of the touch cover.

In the case of a 1 mm touch cover thickness, the smallest touch button or the narrowest slider/wheel must be $(8 \ mm + (2 \times 1 \ mm) = 10 \ mm$.

For a 3 mm cover, this is increased to $(mm + (2 \times 3 \ mm) = 14 \ mm$.

In an interpolated sensor (slider, wheel or surface), a thicker cover benefits from an extended crossover area between adjacent electrodes and thus improved accuracy in the reported contact position.

For flooded X sensors, a thicker cover leads to a more pronounced reduction in sensitivity. It is recommended not to use a touch cover thicker than the X-Y layer separation.

2.4　Shielding

In many applications, it is necessary to shield the touch sensors to prevent incorrect activation. This may be caused by EMI or by touch contact at a location that is not intended to be touch-sensitive.

Mutual capacitance sensors may be isolated with a passive shield.

2.4.1　Passive Shield

- Usually connected to DC ground
- May also use V_{DD} or any ground-referenced DC level
- Rear flood prevents touch or EMI from behind
- Coplanar flood provides better isolation of touch sensors
- May be hatched to reduce the capacitive load
- Detrimental to moisture tolerance

Rear Ground Shield

Sometimes it is desirable to shield an electrode on its rear side to prevent false detection from the rear, or to prevent interference from switching signals from, e.g., backlighting or other power driver circuitry.

A ground plane may be used. This must be connected directly to the circuit ground at a single point.

For mutual capacitance sensors, the effect of a ground area behind the sensor node reduces the overall capacitance of the sensor node. This can be beneficial in some applications as it allows more keys to be lumped together. However, the sensor's time constant may be increased by loading the Y-line electrode.

A rear ground plane may significantly reduce the sensitivity of the touch sensors, as the DC ground attracts the electric field emitted by the X electrode. This must be taken into consideration, particularly where the touch cover may be thicker than the separation between sensor and ground layers.

The electrode and ground plane must be separated by the maximum distance possible. For example, on a multi-layer PCB, the touch sensors must be on the top layer and the ground on the bottom.

The ground shield may be reduced to 50% or 25% hatched fill, which alleviates the reduction in sensitivity while still providing the shielding effect.

If the application does not risk accidental touch contact from the rear of the sensor board, the rear ground plane may be cut out behind the sensors. This eliminates the desensitization of the sensors while providing isolation from other circuit components or EMI.

Coplanar Ground Shield

A coplanar ground shield may be implemented to improve isolation between touch sensors and reduce EMI and common mode noise effects.

As a coplanar shield does not overlap the area of the touch sensors, a solid fill may be used.

To minimize the loss in sensitivity, the ground shield must be kept at a distance from any touch sensor of approximately 2 mm, which may be increased for better moisture tolerance. However, if it is increased beyond 5 mm, the effectiveness of the shielding is reduced.

Figure 2-23. Coplanar Ground Plane Separation
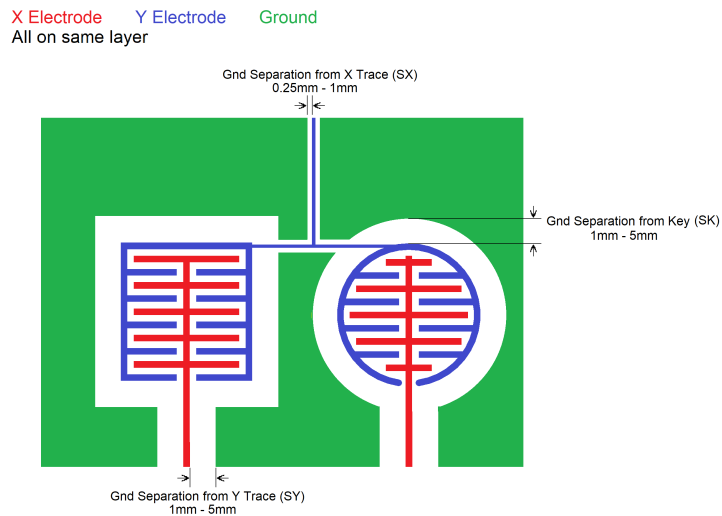
Table 2-10. Sensor to Ground Separation

	Min.	Typical	Max.
Ground Separation from Key (SK)	1 mm	2 mm	5 mm
Ground Separation from Y Trace (SY)	1 mm	2 mm	5 mm
Ground Separation from X Trace (SX)	0.25 mm	0.25 mm	1 mm

2.4.2   Moisture Tolerance

With mutual capacitance sensors, moisture droplets on an isolated sensor node will not cause accidental touch detection. The sensor will show a negative touch delta, often denoted an 'anti touch', as the droplets increase the X-Y coupling – via the capacitance formed between the water and the X line, C_{wx}, and the one between the water and the Y line, C_{wy}, – but do not provide a significant ground return path.

Figure 2-24. Droplet on Isolated Sensor
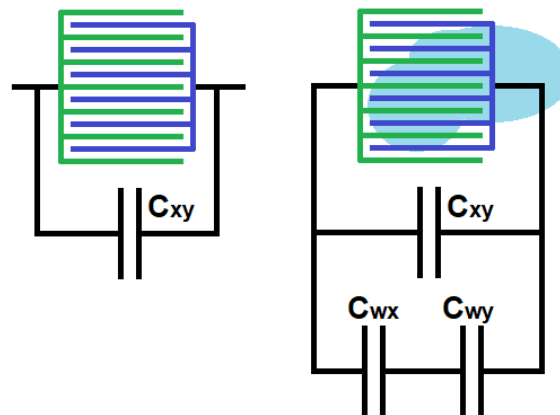
In many designs, the sensor is one of a group of sensors near each other and shares the PCB with many components and signals. In this case, a water droplet that crosses from the sensor node over to any other circuit component and forming a capacitive coupling to both will cause an increase in ground return coupling. In this case, the net result may be towards touch delta and false touch detection.

Figure 2-25. Droplet Crossing to Ground Flood
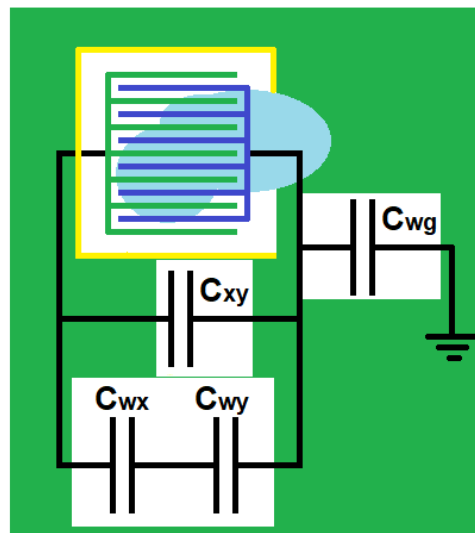
3. Appendix A

Device Family	Maximum Self-Capacitance Sensor Capacitance [pF]	Maximum Mutual Capacitance Sensor Capacitance [pF]
ATtiny81X/161X/321X	53	32
ATmega324PB/ATmega328PB	32	32
ATSAML10/L11	63	32
ATSAML22	32	32
ATSAMC20/C21	32	32
ATSAMD10/D11	32	32
ATSAMD20/D21/DA1/ATSAMHA1	32	32
ATSAML21	32	32
ATSAMD51/ATSAME51/ATSAME53/ATSAME54	63	32

4. Appendix B

Device Family	Active Shield Support
ATtiny81X/161X/321X	Driven Shield+ (Three Level)
ATSAML1X	
ATSAMD2X/ATSAMDA1/ATSAMHA1	Driven Shield (Two Level)
ATSAMC2X/ATSAML2X	
ATSAME5X/ATSAMD5X	
PIC® MCU without HCVD	
ATmega328PB/ATmega324PB	Active Shield not supported
PIC® MCU with dual ADC	Driven Shield+ (Two Level)
PIC® MCU with ADCC	Driven Shield+ (Two Level)

5. Appendix C

Device Family	Suitable for Flooded X Design[1]
ATtiny81X/161X/321X	Yes
ATmega324PB/ATmega328PB	No
ATSAML10/L11	Yes
ATSAML22	No
ATSAMC20/C21	No
ATSAMD10/D11	No
ATSAMD20/D21/DA1/ATSAMHA1	No
ATSAML21	No
ATSAMD51/ATSAME51/E53/E54	Yes

Note: 1. Yes = devices support I/O drive for X lines.

6. Revision History

Doc. Rev.	Date	Comments
B	07/2020	Restructured document sections and updated figures
A	02/2019	Initial document release

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