PSOC™ 4 CAPSENSE™ touchpad design guide

About this document

Scope and purpose

This application note provides guidelines to design the touchpad for various applications with the CAPSENSE™, sensor design guidelines for the diamond pattern, and touchpad-specific hardware design guidelines . Additionally, it provides code examples to implement the firmware and tuning guidelines using the PSOC™ 4 MCU.

Intended audience

This document is primarily intended for engineers who want to become familiar with the CAPSENSE™ design principles for the PSOC™ 4 MCU.

Note: *This document assumes that you are familiar with PSOC™, CAPSENSE™, and ModusToolbox™; see the relevant resources to get started.*

If you are new to	See this
PSOC™ 4 MCU architecture	AN79953 – Getting started with PSOC™ 4 MCU
CAPSENSE™ technology	AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide
Application development for PSOC™ 4 using ModusToolbox™ software	ModusToolbox™ home page

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1 Introduction

Infineon's PSOC™ 4 family combines a high-performance capacitive sensing subsystem, programmable and reconfigurable analog and digital blocks. PSOC™ 4 MCU family with fifth-generation CAPSENSE™ and multi-sense technology (MSC) offers ultra-low power touch HMI solution based on an integrated "Always-On" sensing technology, improved performance to enable modern sleek user interface solutions with superior liquid tolerance and provides robust and reliable touch HMI solution for harsh environments.

Infineon offers a wide range of configurable and programmable CAPSENSE™ controllers. Configurable CAPSENSE™ controllers are hardware or I^2C configurable. CAPSENSE™, i.e., capacitive touch sensing technology measures changes in capacitance between a plate (the sensor) and its environment to detect the presence of a finger on or near the touch surface. CAPSENSE™ supports widgets, broadly classified into buttons (zero-dimensional), sliders (one-dimensional), touchpads (two-dimensional), and proximity sensors (three-dimensional). This document will focus on the implementation of the touchpad.

A touchpad consists of a two-dimensional array of capacitive sensors called "X" and "Y" electrodes, which are placed in the form of a matrix. This pattern helps locating a finger's position in both X and Y dimensions. Figure 1 shows a typical arrangement of a touchpad sensor.

Self- or mutual-capacitive touch sensing methods can be used to design a touchpad:

- **Self-capacitive method**: Measures the change in sensor capacitance (C_S) due to the presence of a finger. Cs is the sum of parasitic capacitance (C_P) and finger capacitance (C_F), where C_P is the capacitance between the electrode and the ground without a finger touch, and C_F is the capacitance between the electrode and the finger
- **Mutual-capacitive**: Measures the capacitance between the transmit (Tx) and receive (Rx) electrodes. When a finger is placed over the touchpad, the effective mutual capacitance (C_M) decreases. This change in parasitic and mutual capacitance is used to detect a valid finger touch and to obtain the accurate position of the finger on the touchpad

For more details, see AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide.

In this application note, touchscreen denotes the panels where the electrodes are constructed using a transparent conducting material, generally indium tin oxide (ITO) on a glass or polyethylene terephthalate (PET) substrate. Whereas, trackpad denotes the panels where electrodes are constructed using copper on FR4-based PCBs. These sensors are connected to the sensing circuitry (CAPSENSE™) in a PSOC™ controller. A finger touch in the vicinity of a sensor electrode changes the capacitance. CAPSENSE™ measures the capacitance of the sensor array and analyzes the change in capacitance to resolve the finger positions.

Note: *This document uses the term "touchpad", where guidelines can be applied for touchscreen as well as trackpad. For application-specific context, the terms touchscreen/trackpad will be used respectively.*

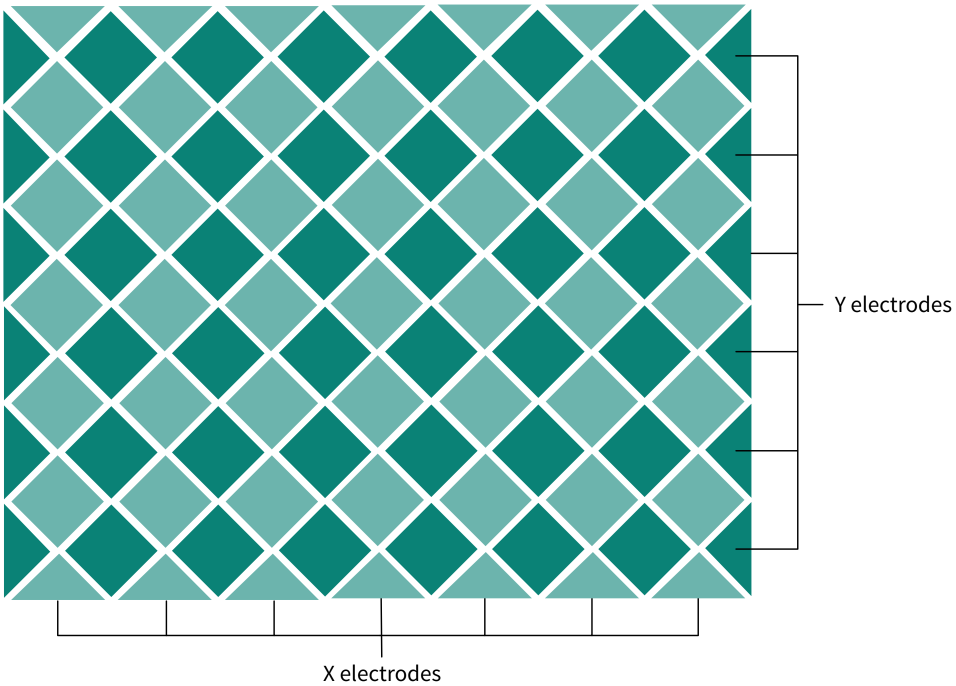


Figure 1 **Touchpad sensor arrangement**

2 Application design considerations

This section describes the significant factors that should be considered while designing the touchpad applications. You need to determine which of these factors are necessary for the application to meet the optimal performance criteria. This application note also attempts to provide alternatives that can be used to achieve these factors. For generic CAPSENSE™ design considerations, see the "Design considerations" section of the AN64846 - Getting started with CAPSENSE™.

2.1 Hardware design considerations

2.1.1 Physical design parameters

Touchpad is one of the classic human machine interface (HMI) technologies that is widely used in a large variety of applications starting from home-appliances to industry-oriented machines. Small-screen touchpads are opted in applications such as smart watches, headphones, and small-sized displays. Generally, touchscreens are implemented in a rectangular-shaped screen, but depending on the application requirements, touchscreens might be of different shapes. Usually, the sensor patterns used for touchpad design are more adapted to rectangular or square shapes. For screen shapes other than rectangle/square, you must keep in mind to follow more advanced configuration and tuning methods to achieve the optimal performance. Irrespective of the screen shape, Infineon recommends using the diamond pattern for designing the touchpad sensor electrodes; see Sensor design guidelines for sensor design guidelines using the diamond pattern.

2.1.2 Selecting the device

You can implement your own algorithms on PSOC™ and customize the CAPSENSE™ sensing to your needs by tuning. It is recommended to select a device that is suitable to your application requirements and evaluate your application on PSOC™ 4 development kits. See the "CAPSENSE™ selector guide" chapter of the AN64846 - Getting started with CAPSENSE™ for guidance to select the appropriate devices depending on the application requirements.

2.2 System design considerations

2.2.1 Selecting the sensing method

The capacitive sigma-delta (CSD) sensing method is recommended for the applications requiring water tolerance, see section Liquid-tolerant sensing for more information on liquid tolerance. CSD-based touchpads suffer from ghost touches; therefore, it supports only single-point touch applications. See the "Buttons" subsection in the AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide for more information on ghost touches. On the other hand, CAPSENSE™ crosspoint (CSX) sensing method can be used in applications requiring multi-touch detection, but requires slightly higher scanning time compared to a CSD touchpad.

Self-capacitive sensing has no inherent liquid tolerance, whereas mutual-capacitive sensing provides some inherent resistance to floating drops. The self-capacitive sensing along with the shield sensor provides water detection, while the mutual-capacitive sensing provides precise multiple touch detection. PSOC™ 4 devices provide the flexibility to use a combination of self- and mutual-capacitive sensing i.e., touchpad sensors can be scanned in both self- and mutual-capacitive sensing method. PSOC™ 4 devices also enable ganging of sensors, which result in reduced total scan time and power consumption.

2.2.2 Low-power

For battery-powered applications, low-power consumption is a key requirement. Simplest way to reduce power consumption is to use an MCU device which consumes least power while operating. Infineon's PSOC™ 4 MCU family with multi-sense low-power technology (MSCLP) offers an ultra-low power touch HMI solution. It has the fifth-generation CAPSENSE™ MSCLP technology that enables scanning low-power sensors while the device is in deep sleep, and processing results to wake the device in the event of a touch. This technology also has an inherent autonomous scanning capability, which does not need CPU intervention for scanning sensors.

See AN234231 - Achieving lowest-power capacitive sensing with PSOC™ 4000T and CE235111 - PSOC™ 4: MSCLP CAPSENSE™ low power for detailed information on low-power implementation.

In case of fourth-generation CAPSENSE™ technology that does not support a deep sleep feature, the following approach can be implemented.

- In case of small-size touchpads, an extra widget can be added and configured as a ganged sensor, where the touchpad peripheral rows and columns are ganged together. This widget can always be scanned and processed
- Modify the application logic such that when the status of this widget is active i.e., in case of finger touch, the touchpad widget will get scanned and processed to report the touch position. This method will save power, as only the extra widget (having lesser total number of scans) will be scanned and processed instead of the touchpad widget (having comparatively more total number of scans) when the touchpad is idle

2.2.3 Liquid-tolerant sensing

Many applications require robust capacitive-sensing operation even in the presence of mist, moisture, water, ice, humidity, or other liquids. In a capacitive-sensing application design, false touch detection can happen because of the presence of liquid droplets on the sensor surface or if the sensor is dipped in liquid. To prevent these sensor false triggers, it is recommended to implement a guard sensor as shown in Figure 2. The driven shield signal and the shield electrode can be used to detect the presence of a streaming liquid or liquid droplets and ignore the status or stop sensing from the rest of the sensors as long as the liquid is present. To achieve robustness to all the liquid presence conditions, both the guard sensor and shield electrode must be implemented.

See the following for more details:

- For more information on implementation of the guard sensor and the shield electrode, see section "Liquid tolerance" of AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide
- PSOC™ 4: MSCLP robust low-power liquid-tolerant CAPSENSE™ for PSOC™ 4000T kit, which implements low-power and liquid-tolerant touch sensing

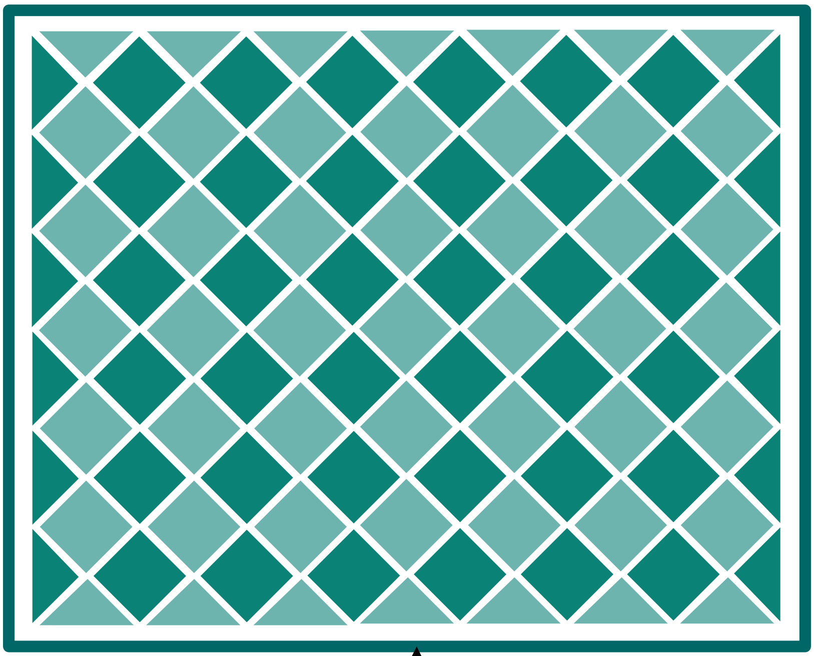


Figure 2 **Guard sensor around touchpad**

2.2.4 Robustness against external noise

External noises such as electrostatic discharge (ESD), electromagnetic interference (EMI), and conducted noise can be injected into the system through the routing trace lines. It is recommended to keep the signal-to-noise ratio (SNR) greater than or equal to 5:1 to achieve reliable touchpad sensing. Including an ESD ring and ground hatch around the sensor helps in improving noise immunity and adds to the overall parasitic capacitance seen by the sensor electrodes. Addition of a ground plane in between the sensor and communication lines isolates the sensor electrodes from high-speed communication interference. See ESD ring for information on implementing an ESD ring to improve immunity against external noises. See section "ESD protection" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide for the detailed guidelines on ESD protection.

In touchscreen applications, noise from the display can couple into the sensor electrodes. To reduce this noise, keep an air gap or a shield layer between the sensors and the display. In addition, use a low-noise display such as an active matrix organic LED (AMOLED).

An advancement to Infineon's 4th generation CAPSENSE™, PSOC™ 4100S MAX, and 4000T devices with 5th generation CAPSENSE™ based on the ratio-metric sensing technology provide better noise immunity resulting in an improved SNR. See section "CAPSENSE™ CSD-RM sensing method (fifth-generation and fifth generation low-power)" and "CAPSENSE™ CSX-RM sensing method (fifth-generation and fifth generation low-power)" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide for a detailed explanation on the ratio-metric sensing technology.

2.2.5 AMUX splitter switch noise

***Note**: This section is specific to the PSOC™ 4100S Max and PSOC™ 4100T Plus devices.*

For the optimal performance of CAPSENSE™, use the pins that are directly connected to the same section of the AMUXBUS as the MSCLP block. This delivers better SNR compared to the pins that are routed through the AMUXSPLITTER switches and the directly connected pins help to avoid parasitic effect of the AMUXSPLITTER switches. See Table 1 for recommended ports.

Table 1 **Recommended port configurations**

Device	Recommended ports
PSOC™ 4100T Plus	0, 1, 3, 4, 5, 6
PSOC™ 4100S Max	Channel 0: 3, 4, 6,10, 11, 12 Channel 1: 0, 5, 7, 8, 9

Figure 3 shows an example of a 4100T Plus device, where the port 2 pins are routed through the AMUX splitter switches.

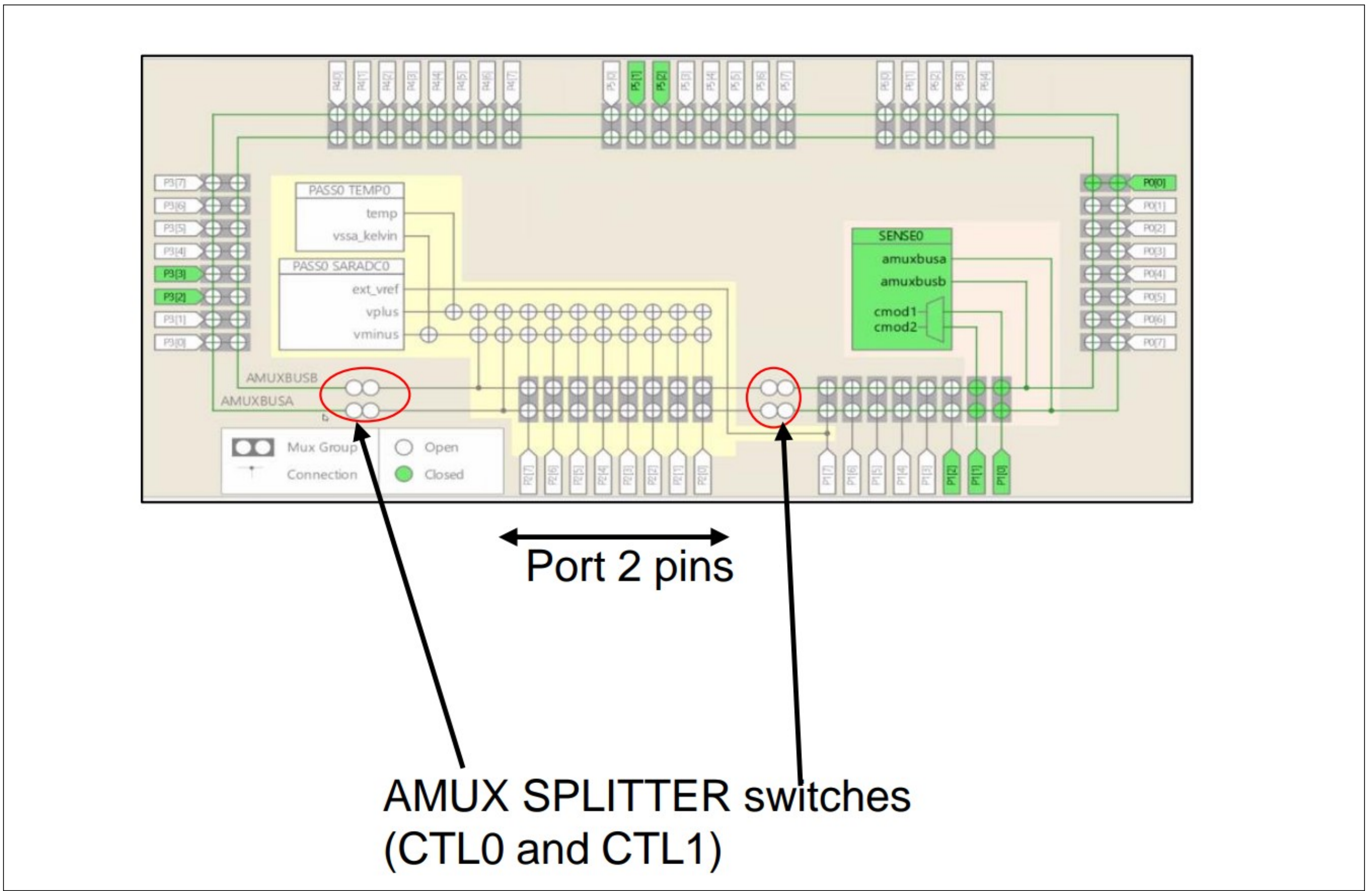


Figure 3 **Splitter switches**

2.3 Firmware design considerations

2.3.1 Sensitivity

Sensitivity is the ability to discern between small signals and small signal changes caused by the touch. For example, in a use case where a horizontal swipe across a slider controls the intensity of the volume. As shown in Figure 4, for a slight change in the finger position, a lower sensitivity will not detect a change in position, but increasing the sensitivity will show a finite difference in touch position. In other words, a lower sensitivity can provide a step-by-step increment/decrement, whereas a higher sensitivity can enable more analogous control over increment/decrement i.e., providing more granular control over the volume change.

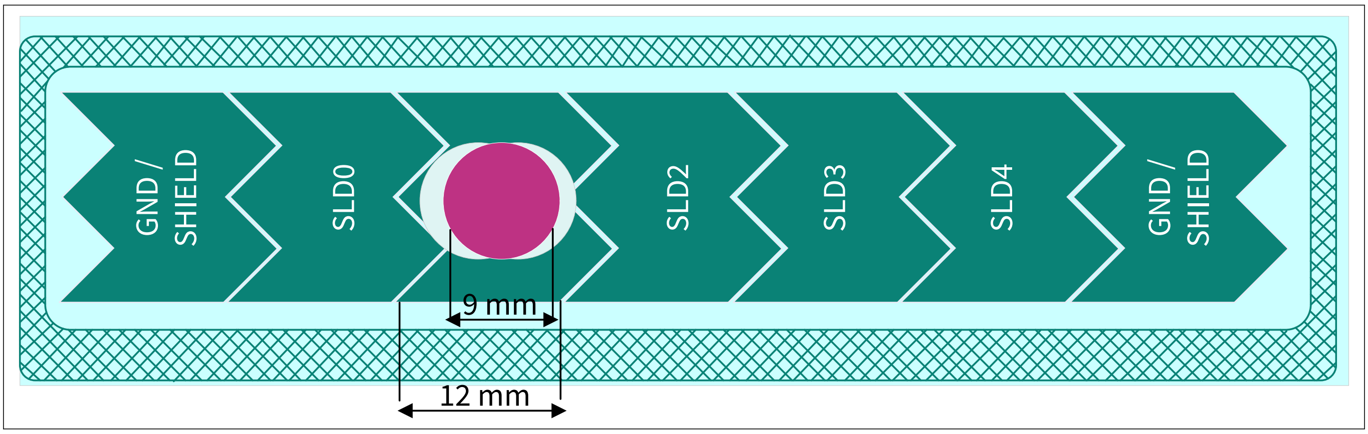


Figure 4 **Sensitivity in case of slider**

Sensitivity is denoted by the report rate, which indicates the percentage of correct detections for N repetitions.

$$R = \frac{D}{p*N}*100\ \% \tag{1}$$

Sensitivity equation

Where, R = report rate, D = total number of detected touches, p = total number of touch points, and N = number of repetitions.

2.3.2 Accuracy

Accuracy of a touch position is measured by the difference in the expected and actual touch position. The system is more accurate if the difference between the expected touch position and the actual touch position is less, and less accurate if the deviation is more.

Accuracy can be optimized by having a balanced sensitivity across rows and columns. Enabling compensation capacitor DAC (CDAC) ensures that the sensitivities of row/column electrodes of a touchpad are similar. Accuracy can be increased by increasing the sensitivity of the touchpad. It can also be increased by the increasing the number of scans for the sensor electrodes.

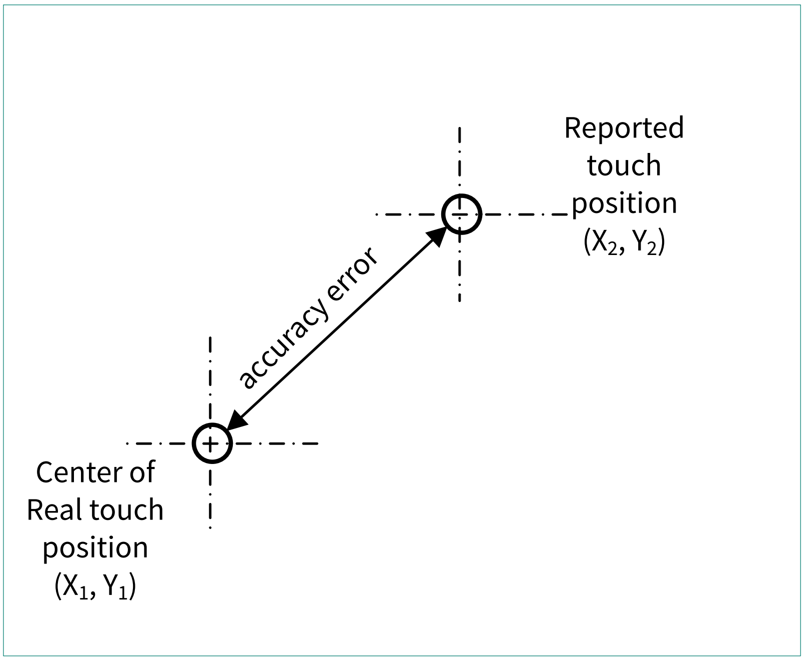


Figure 5 **Accuracy**

2.3.3 Jitter

Jitter is the maximum deviation of the reported position when a stationary touch object is on the touchscreen. When the signal level is low, usually because of the thick overlay on the slider, the estimate of the finger position will appear to vary and jitter even when the finger is held at a fixed position. Jitter noise can be removed using a jitter filter; see section "Jitter filter" of AN64846 - Getting started with CAPSENSE™.

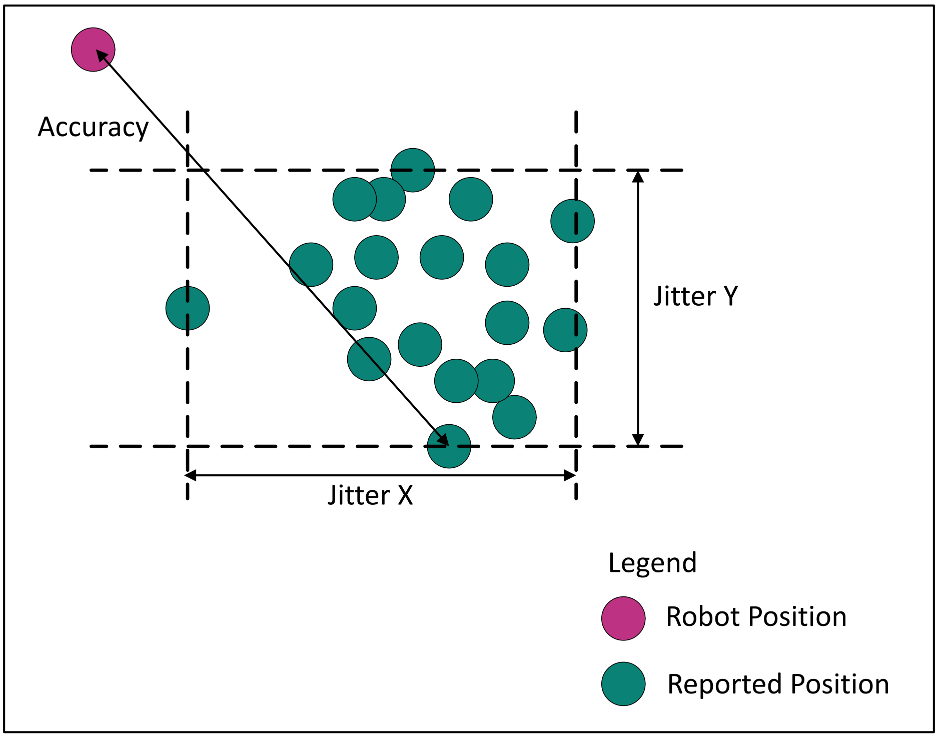


Figure 6 **Jitter**

Use the following equations to estimate jitter; see Figure 6.

JITTx = max (Xr) – min (Xr)

JITTy = max (Yr) – min (Yr)

JITT = max (JITTx, JITTy)

Where,

Xr, Yr = Position reported from the controller

2.3.4 Linearity

Linearity is the shortest distance between the reported position of the touch object and the best-fit line through the reported positions. A sensing electrode area (pitch) greater than the finger diameter reduces the linearity. This reduced linearity or non-linearity hampers the touchpad performance. Therefore, for the touchpad to have optimal linearity, it is recommended to set the sensing electrode pitch such that it is not greater than the finger diameter but also not small enough that the number of sensing electrodes exceed the pin constraint.

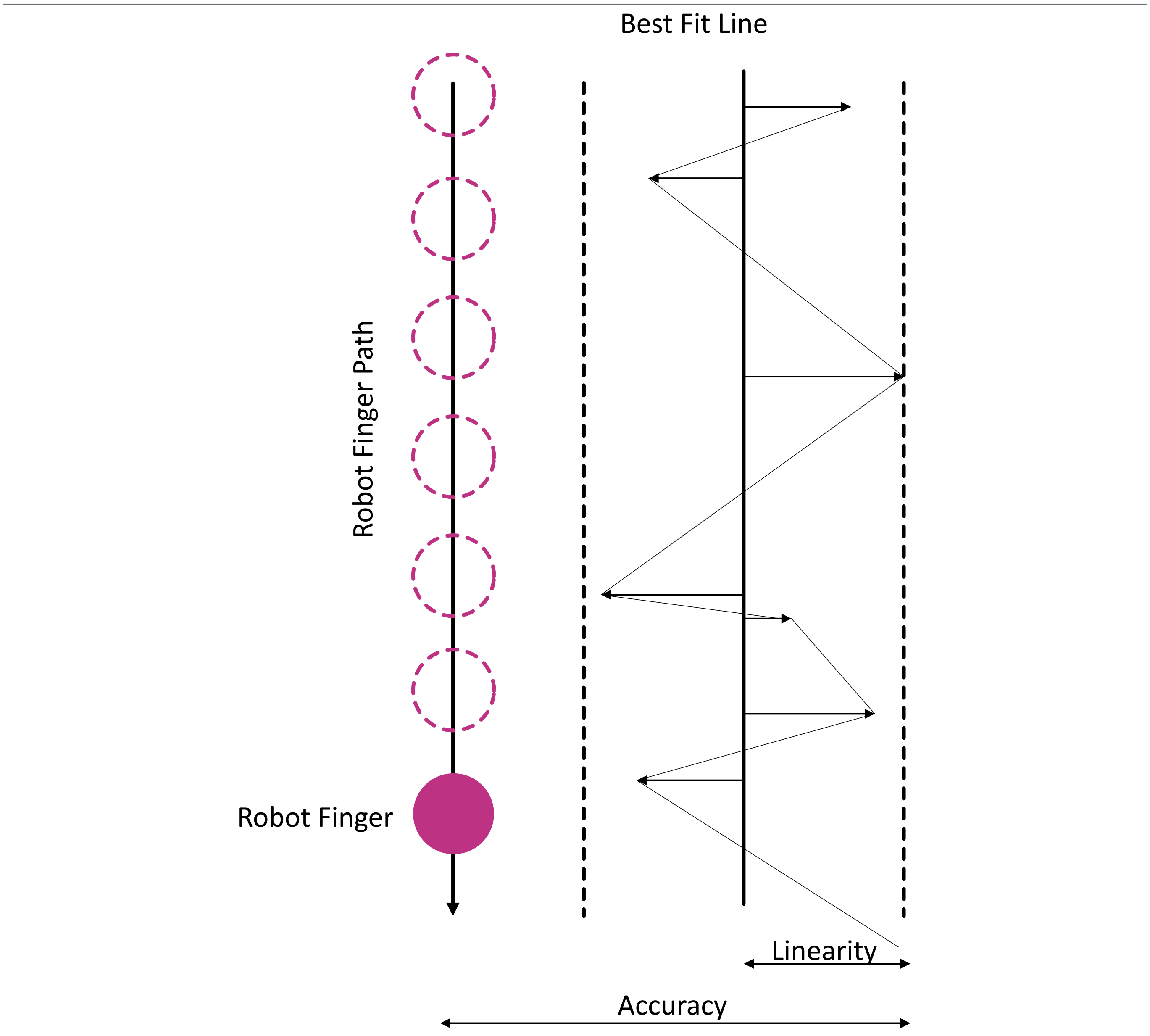


Figure 7 Linearity

2.3.5 Signal disparity when tuning with battery

Signal disparity is the ratio of the grounded (system powered through power supply) touch signal to an ungrounded (system powered through battery) touch signal of a device. This variation in signal should be considered while tuning the touchpad parameters at the time of prototyping.

For example, if a grounded device provides a touch signal of 200, but provides a touch signal of 100 when ungrounded, then SD = 200 / 100 = 2.

For most designs, an SD ≤ 1.5 is acceptable.

2.3.6 SNR

CAPSENSE™ noise is the peak-to-peak variation in raw counts in the absence of a touch. To achieve good performance, the CAPSENSE™ signal must be significantly larger than the CAPSENSE™ noise. SNR is defined as the ratio of CAPSENSE™ signal to CAPSENSE™ noise, it is the most important performance parameter of a CAPSENSE™ sensor. The minimum SNR recommended for a CAPSENSE™ sensor is 5:1, as shown in Figure 8.

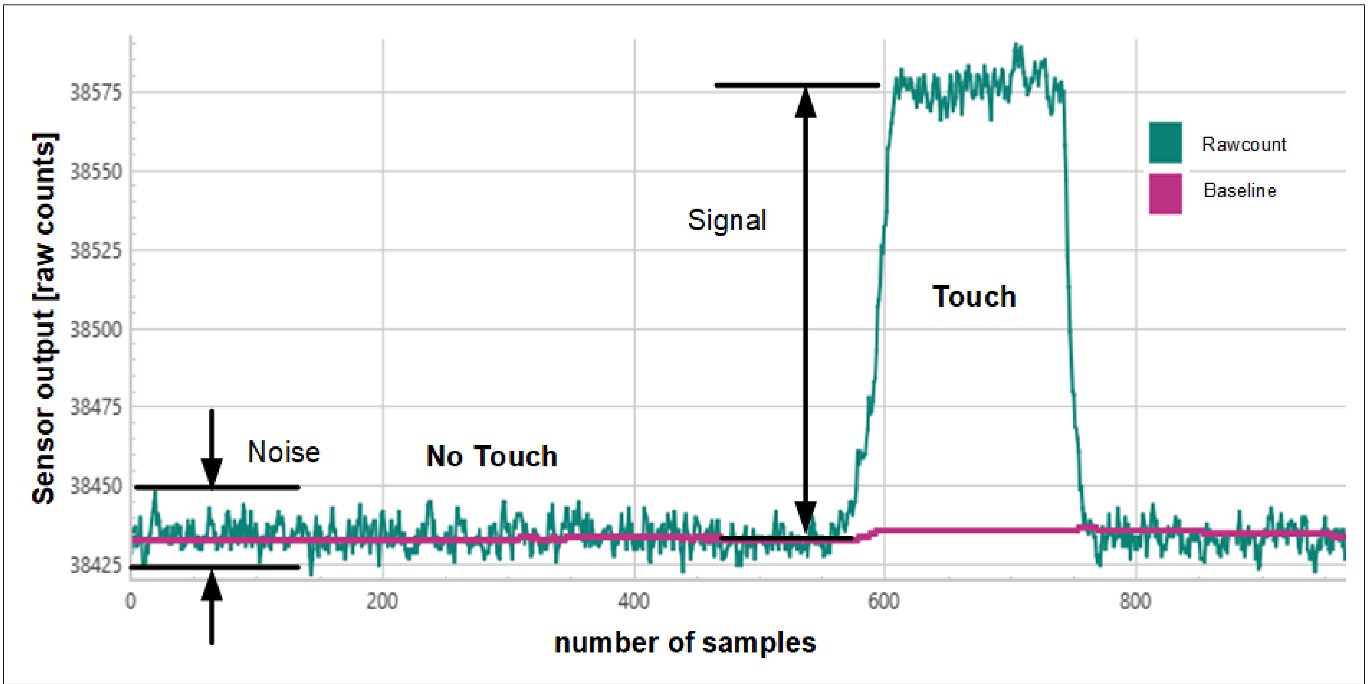


Figure 8 **SNR**

Signal-to-noise ratio (SNR) depends on several factors:

- Noise from external systems and display in case of touchpad applications is one of the major factors affecting SNR, as explained in Robustness against external noise
- SNR varies depending on the overlay material used and the variation in the overlay thickness. Improper grounding cases like battery-operated wearables can also lead to variation in SNR
- Increasing the sensing electrode area provides a higher signal, thereby increasing the SNR but adversely affects linearity

3 Sensor design guidelines

For PSOC™ 4 devices, the diamond pattern is recommended for designing a touchpad because of the following reasons:

- Can be optimized easily to meet the pitch requirements
- Provides flexibility to change or adjust the number of I/O pins
- Can be easily customized for any type or shape of panel
- Enables the implementation of both self- and mutual-capacitive sensing on the same pattern; therefore, can be easily optimized for water detection along with touch
- CAPSENSE™ trackpad component is validated with the diamond pattern. PSOC™-based solution for the diamond pattern performs well in both self- and mutual-capacitive touch sensing

3.1 Diamond pattern sensor design

Touchpad sensors are designed using interleaved and diamond shape pads as shown in Figure 1. All the diamonds in a row are connected together to form one sensor line; similarly, all the diamonds in a column are connected together to form one sensor line. Each row or column connects to one sense electrode of the chip. Therefore, a 5x5 pattern with 25 diamonds will require only 10 pins.

In case of touchscreens, diamond patterns can be implemented in single-layer or double-layer ITO processes. As shown in Diamond pattern sensor design, the touchpad can be designed with the help of a two-dimensional array of sensors. Therefore, ground and Rx for CSD sensing; Tx and Rx for CSX sensing. See section "CAPSENSE™ fundamentals" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide for more information on self-capacitance and mutual-capacitance touch sensing methods.

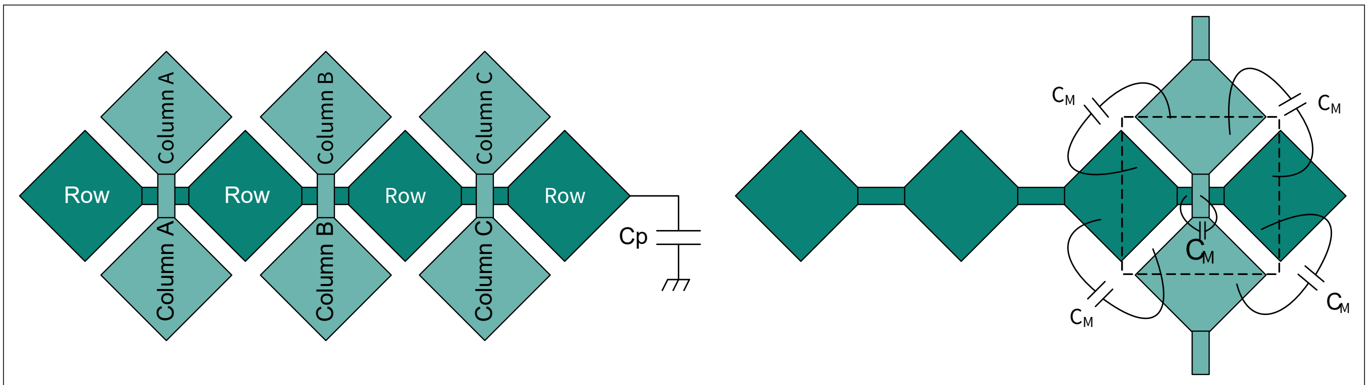


Figure 9 Self- and mutual-capacitance sensor design

3.1.1 Types of diamond patterns

3.1.1.1 Single solid diamond (SSD)

- One row or column of diamond connects to one sensor pin as shown in Figure 10
- Used in self-capacitance-based touchpad designs

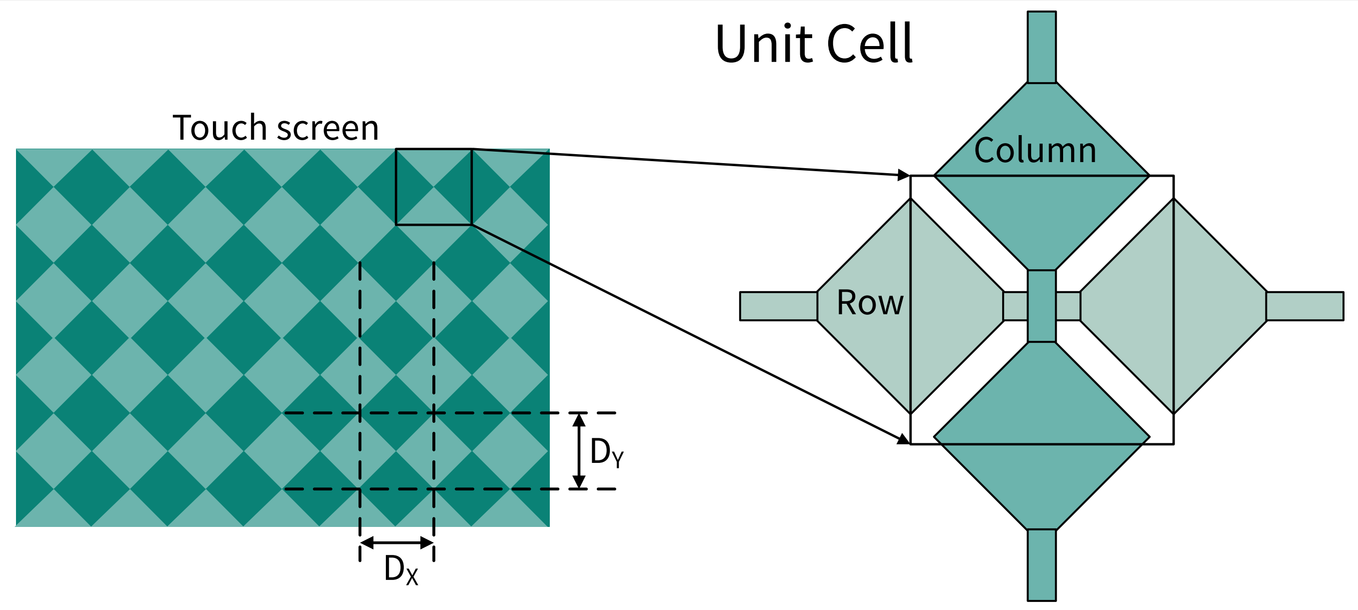


Figure 10 **Single solid diamond pattern**

3.1.1.2 Dual solid diamond (DSD)

- Two rows or two columns connected together to form one sensor line as shown in Figure 11
- Used in mutual-capacitance-based designs because the signal is low if only one row or column is used in mutual-capacitance sensing mode

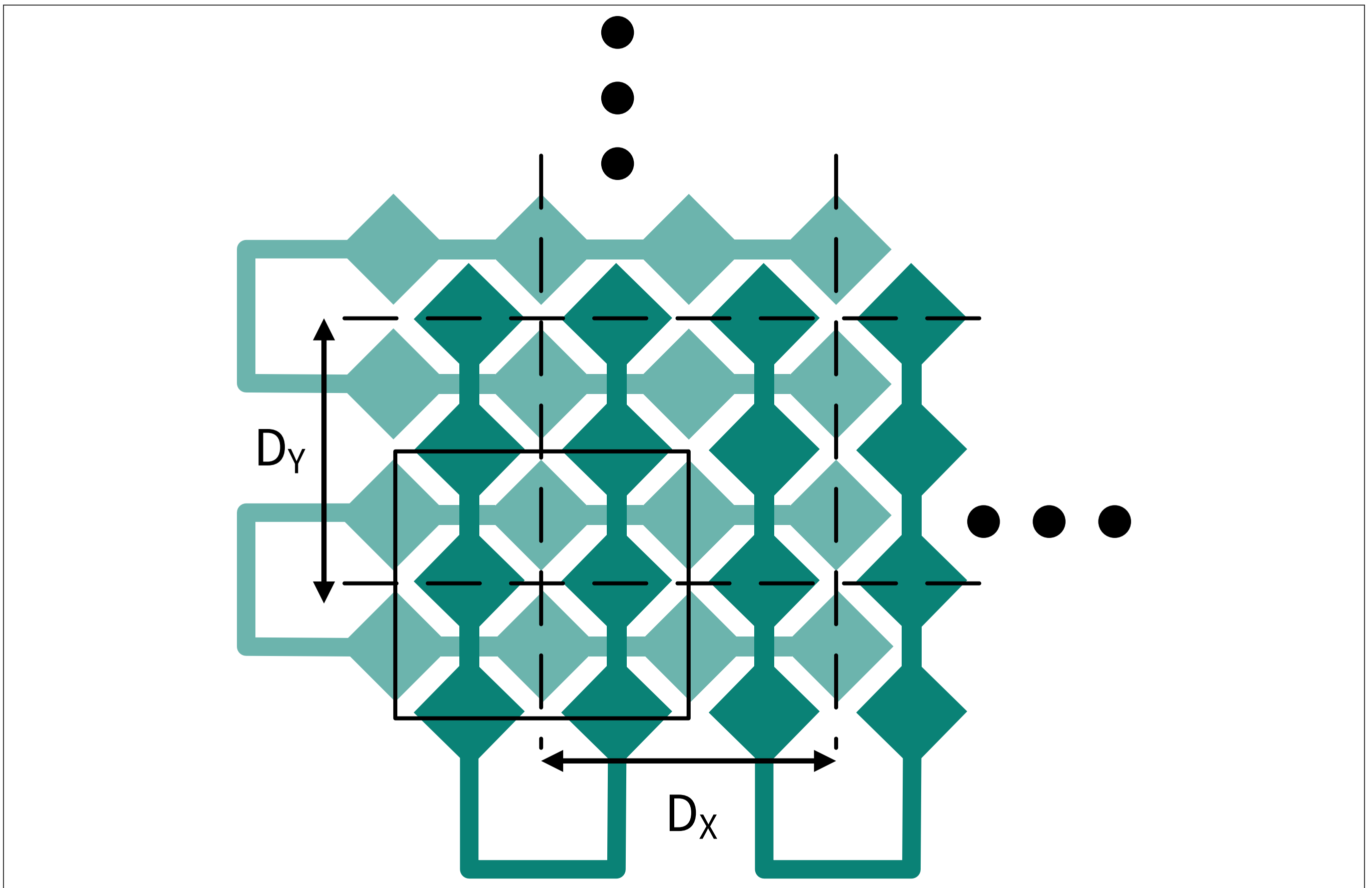


Figure 11 **Dual solid diamond pattern**

3.1.2 Sensor design guidelines

3.1.2.1 Prerequisites

The following parameters are required to determine the dimensions of electrodes:

- **Touchpad area** – Touchpad area (sq.mm or sq.inch) represents the board space available on the top layer. Usually, a thin ESD ring is placed around the sensors; therefore, the effective or active area available for laying diamonds should account for this ESD ring as well. See Bezel for more details
- **Resolution** – Reported number of positions per inch; usually measured in dpi (dots per inch) or pixels. Converting dpi to pixels requires board dimensions

For example, if dpi is 120 and the board dimension is 0.6 inch x 1.6 inch, the resolution is 72 x 192 pixels.

3.1.2.2 Number of diamond segments

The number of diamond segments/electrodes in X/Y direction is equal to the number of sense pins in that direction, see Figure 1. There is no formula for deciding the number of diamonds; the number of electrodes used to construct a touchpad depends on many parameters listed in Table 2 and their associated trade-offs.

Table 2 Parameters affecting number of diamonds

Parameters	Variation with respect to number of electrodes
Accuracy	The centroid algorithm uses an interpolation technique to derive the finger position in terms of pixels. The algorithm resolves better if the finger covers a larger number of diamonds.
Resolution	Reported resolution becomes more granular as the number of diamonds increase.
I/O count	Requirement of sense or I/O pins increases as the number of diamonds increases; therefore, the available number of pins restrict the number of rows/columns.
Scan time	Increase in the number of diamonds increases the overall touchpad scan time, especially in case of a CSX touchpad.
Current consumption	Current consumption is directly proportional to the number of rows/columns, which may prevent you from achieving low power consumption.

3.1.2.3 Diamond dimensions

- **Electrode pitch (Dx-Dy)**: Centerline spacing between the adjacent rows or columns of the electrodes; the spacing can differ in both X and Y directions. Recommended diamond pitch is between 3.8 mm to 5 mm (typical being 5 mm). The electrode pitch affects the accuracy of the reported touches on a touchpad; the smaller the pitch, the higher the accuracy. A design can still use smaller diamonds if required. However, a smaller pitch requires a higher I/O count and a longer RC time constant, which for large panels may lead to a slower maximum scan rate
- **Gap**: Distance between the edges of adjacent diamonds. In case of ITO, for a glass substrate (see Figure 12), the gap typically ranges between 30 µm and 100 µm, and for a PET film technology, the gap typically ranges between 100 µm and 300 µm. The gap between the row and column electrodes helps to determine the optical quality of the touchscreen. Therefore, it is recommended to construct the electrodes with a minimum gap supported by the vendor
- **Bridge width**: Width of the interconnecting bridges for row and column electrodes. This width can be different in the X and Y directions. Depending on the technology, the bridges connecting the rows and

columns can be either ITO or metal. For ITO bridges, the bridge width should be adjusted accordingly to meet the resistance and parasitic capacitance requirements. Metal bridges have lower resistance, including the contact resistances than ITO bridges

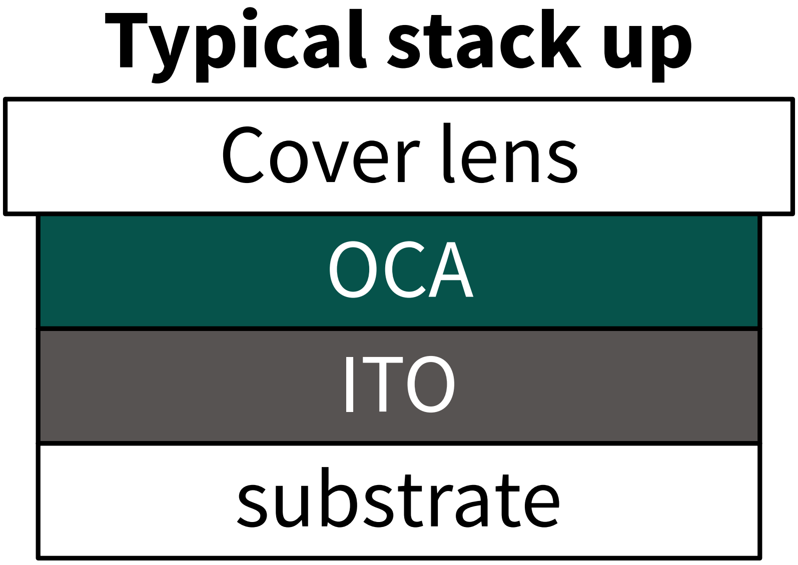


Figure 12 **Typical stack-up**

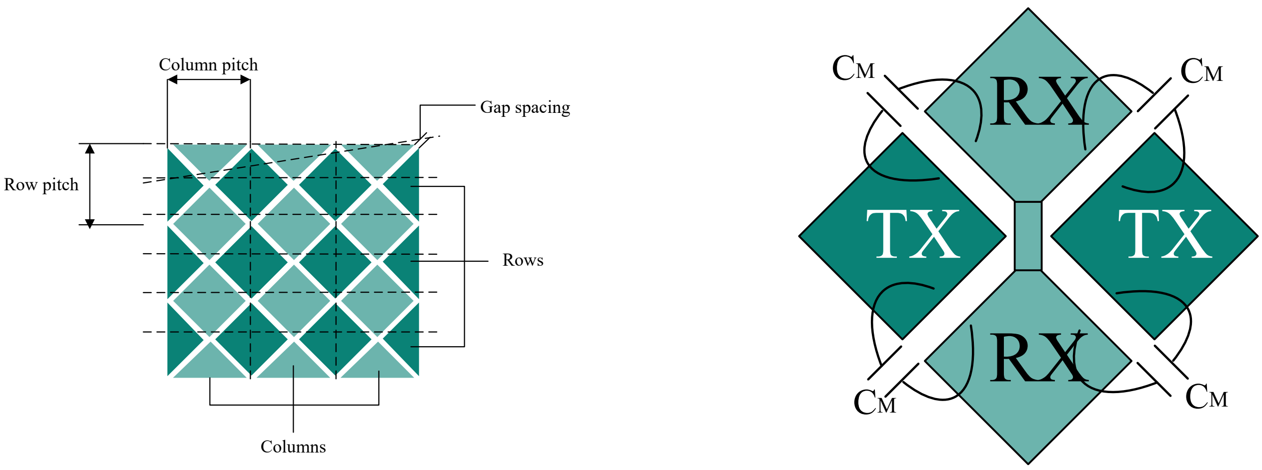


Figure 13 **Diamond pattern design dimensions**

3.1.2.4 ITO characteristics

Applications implementing touchscreen over display use a transparent conducting material, generally indium tin oxide (ITO), to construct sensor electrodes which ensure optical clarity of the underlying display. ITO electrodes are laid out on a glass or plastic film (PET) substrate. ITO used in touchscreens is inherently resistive and when combined with Cp, the resistance creates a low-pass filter. This resistance is measured in Ω/diamond, i.e., the resistance seen at each diamond. For proper operation, the RC time constant of the panel must be sufficiently small to drive Tx electrodes at sufficiently high frequencies. If the panel is slow, scan time is reduced. More importantly, noise from the display may interfere with the scans at lower frequencies, reducing the SNR and making the touchscreen performance poor. Table 3 summarizes the major differences between the copper trackpads and the ITO touchscreens.

Table 3 ITO vs. copper

Parameters	ITO	Copper
Resistance (Ω/sq)	Inherently resistive	Less resistive
Transparency	Transparent and so can be used over displays	Cannot be used over displays
Sense clock frequency	Because of high resistance, RC time constantly increases, limiting the sense clock frequency.	Because of the low RC time constant, the sense clock is driven at sufficiently high frequencies.
SNR	Noise from the display can interfere with the scans at lower frequencies, reducing the SNR.	Provides comparatively high SNR.
Number of layers	Minimum two layers required to implement diamond pattern in ITO; increase in the number of layers increases the cost.	Diamond pattern can be implemented in a single layer by using 0-Ω resistors as bridge to connect electrodes, therefore, reducing the cost. Note that in this case, the PCB thickness is included in overlay thickness as the electrodes will be on the other side of the PCB, as shown in Figure 14.
Bridge width	Bridge width should be sized to meet the resistance and parasitic capacitance requirements.	Bridge width does not have a big impact on copper electrodes.

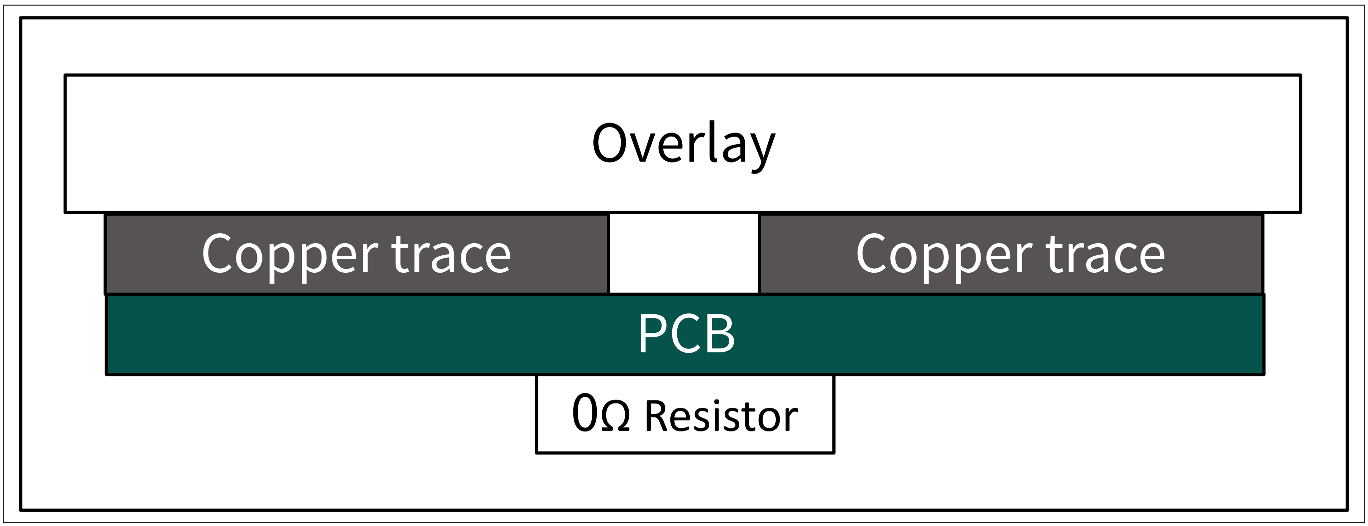


Figure 14 Stack-up for single layer

4 PCB design guidelines

4.1 Pin assignment

Selection of an appropriate pinout optimizes the mapping between the touch controller and the rows/columns of the touchscreen. Touchscreen performance can be negatively affected by poor pinout choice. This section discusses methods and trade-offs for optimizing the touchscreen controller pinout.

4.1.1 Number of pins

The number of electrodes required to achieve a particular pitch (D) with a given panel size is given in the following equation. See Diamond dimensions for information on the trade-offs involved in pitch selection.

$$n_x = \frac{X_{dimension}}{\mathrm{D}} \qquad n_y = \frac{Y_{dimension}}{\mathrm{D}} \tag{2}$$

Number of electrodes calculation equation

4.1.2 Assign Tx or Rx electrodes to X or Y axis

It is recommended to assign the axis such that the number of Rx lines is less than or equal to the number of Tx lines. For example, if $n_x = 10$ and $n_y = 15$, then the touchscreen will have 15 Tx electrodes and 10 Rx electrodes. Following this recommendation ensures that Rx traces follow the shorter axis, resulting in lower parasitic capacitance (Cp). Also, Rx lines are more susceptible to noise, whereas Tx lines are relatively less susceptible.

4.1.3 Pin distribution

Some PSOC™ 4 devices support multiple channels, where the number of channels correspond to the enabled MSC resources. In Multi-channel mode, a scan slot represents a group of sensors scanned together, see section “Multi-channel scanning” of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide. In Single-channel mode, one sensor is scanned per scanning slot.

The touchpad electrodes should be evenly distributed among the channels and across the scan slots. For example, if there are six column electrodes but only two channels, the scan must be divided into three slots, with each slot having two channels connected to two electrodes (evenly distributed).

Electrode	Col0	Col1	Col2	Col3	Col4	Col5
Channel	00	00	00	01	01	01
Ganged	No	No	No	No	No	No
Pin	P3[0]	P3[1]	P3[4]	P3[5]	P0[0]	P0[1]
Slot	Slot 0	Slot 1	Slot 2	Slot 0	Slot 1	Slot 2

	Ch 00	Ch 01
Slot 0	0	0
Slot 1	0	0
Slot 2	0	0

Figure 15 **Pin distribution**

See section "Schematic rule checklist" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide that provides a checklist for CAPSENSE™ schematic guidelines.

4.2 Sensor layout considerations

4.2.1 ESD ring

A touchscreen is inherently susceptible to damage from the electrostatic discharge (ESD). Protection against the ESD requires design elements on the PCB and on the touch panel.

To ensure that the ESD pulse does not jump directly to the sensor routing, place an ESD guard ring around the perimeter of the touch sensor. The guard ring is a grounded trace around the periphery of the touch sensor panel. As shown in Figure 16, when a guard ring is present and there is a discharge near the edge of the display, the ESD discharge path follows the guard ring to the chassis ground, bypassing the touch controller.

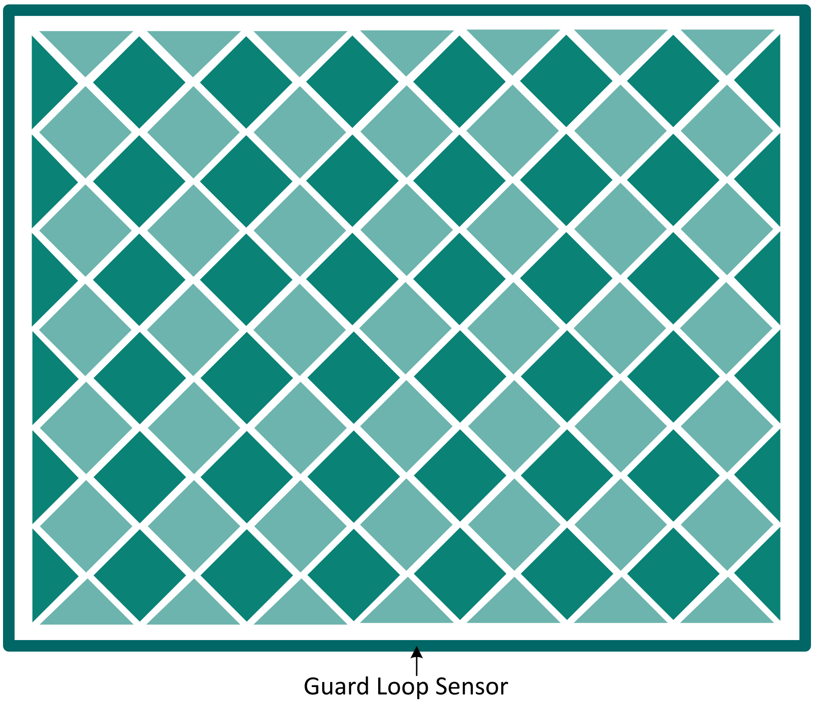


Figure 16 **ESD ring**

The guard ring must be optimized for the specific sensor. Multi-layer sensors have different requirements from single-layer sensors; however, the following guidelines apply to both:

- Configure each guard ring with a gap of approximately 0.1 mm to avoid creating a loop antenna, as shown at the top of the panel in Figure 17
- The guard ring should be as wide as possible and extend as close to the outer edge of the cover lens as allowed by the selected manufacturing process
- The guard ring must be connected to the system ground through a low-resistance/low-inductance path. The resistance of the guard ring should be minimized using metallic plating, silver-loaded ink, or other low-resistance materials. ITO material is not recommended for the guard ring because of its high resistance
- The guard ring must not be tied to the PSOC™ controller ground (VSS pin of the package); instead, it must be tied to the system ground. This directs the energy from any ESD discharge away from the controller
- The guard ring should not be routed close to the row and column routing traces to limit a parasitic capacitance that can negatively impact sensing
- Increase the size of the touch sensor substrate to cover the unused surface area of the cover lens wherever possible to provide greater surface area for guard ring capacitance
- When a passive flexible printed circuit (FPC) is used to route the Tx and Rx signals from the touch sensor to another circuit board, the outer edges of the FPC must have the guard ring lines further connecting to system ground, and keep it spaced from the Tx/Rx traces to prevent ESD arcing into the Tx/Rx traces. This should especially be followed where a flex circuit is routed through an opening in the chassis

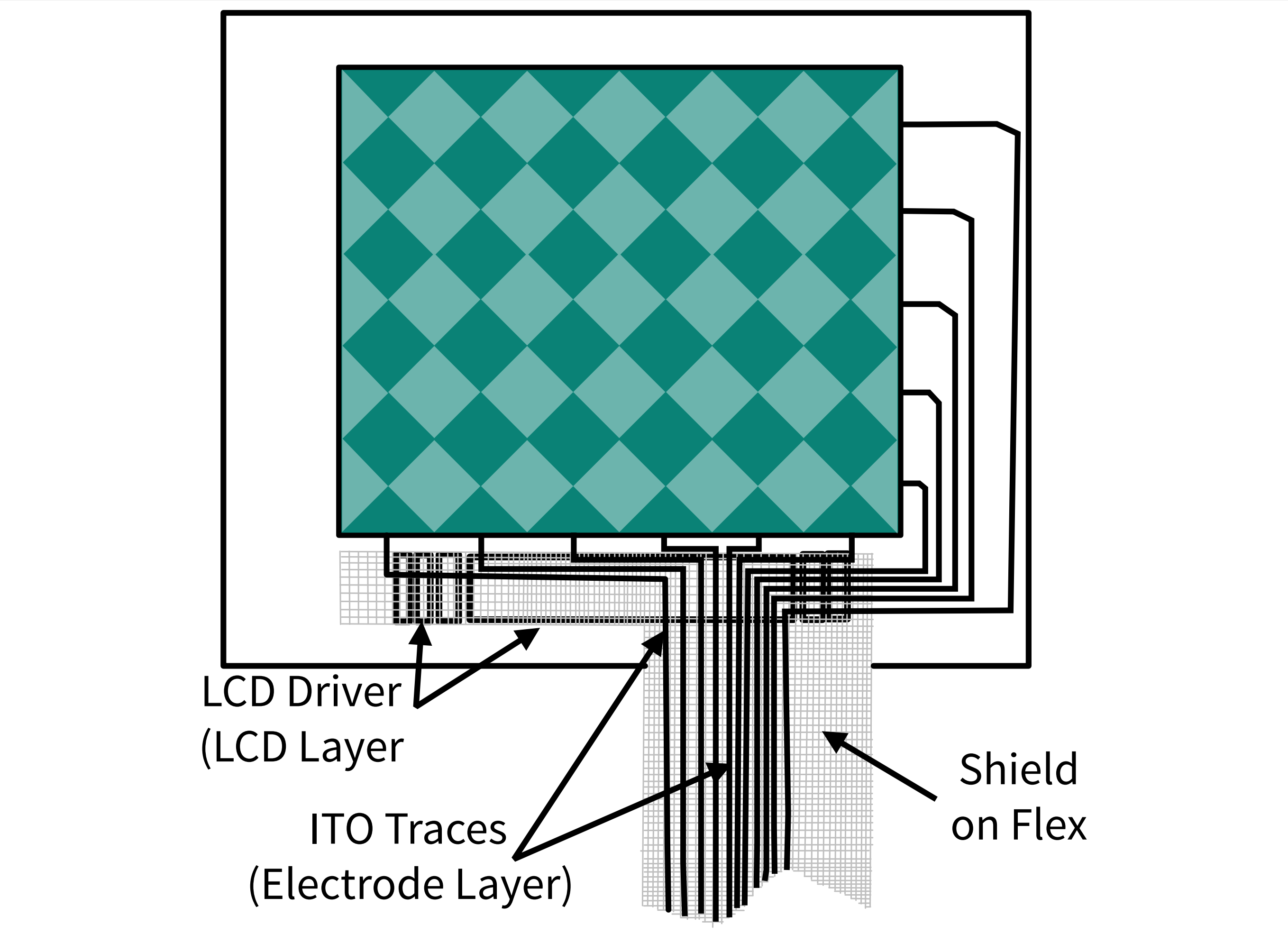


Figure 17 ITO traces shielded from display driver

- In cases where the guard ring must be done in ITO, the resistance of the trace should be less than 5% of the lowest resistance row or column electrode in the panel

4.2.1.1 Guard ring for single-layer sensors

For touch sensors where row or column traces are on the same layer as the guard ring, ensure that the parasitic capacitance between the outer trace and the guard ring does not add excessive parasitic capacitance (Cp) to the overall design.

4.2.1.2 Guard ring for multi-layer sensors

In multi-layer touch sensors, a guard ring is required on all layers.

- The guard ring on each layer should extend as close to the panel edge as allowed by the manufacturing process
- The guard ring on the conductive layer closest to the cover lens should be maximized
- The second guard ring (for example, Tx layer) should fill in any gaps not covered by the guard ring on the upper (Rx) layer. This maximizes the capacitance that provides an alternate discharge path
- The guard ring should be as wide as possible without interfering with the active display area
- Routing a wide guard ring on the conductive layer closest to the cover lens may extend over the row and column routing traces on a different layer. This overlap increases their parasitic capacitance. This leads to a trade-off between guard ring width for ESD immunity and parasitic capacitance limitations. Note

that the increase in the parasitic capacitance because of the wide guard ring has no impact in case of mutual-capacitance sensing

- If the electrodes connected by these traces are also sensed for self-capacitance, the impact of the additional parasitic capacitance must be evaluated. The capacitance can be reduced by changing from a solid to a hatched fill in areas over these signal traces
- If the additional parasitic capacitance is still very high with a hatched fill, remove the additional fill over the traces

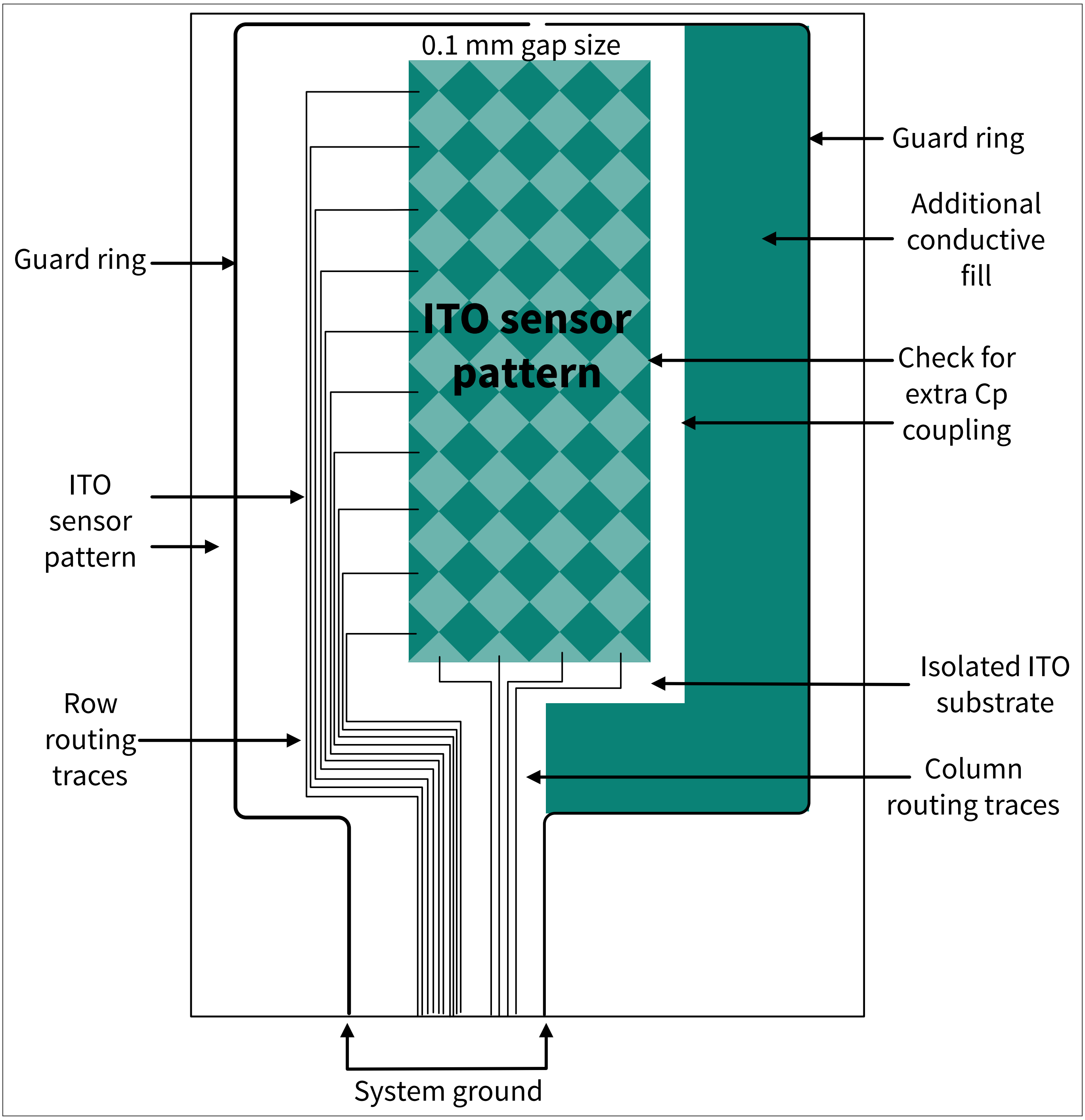


Figure 18 **Touchpad with ESD guard ring traces**

4.2.2 Stack-up/overlay selection

The stack-up is a critical design element for the system. The arrangement, thickness, and material selection of the stack-up determines the amount of change in capacitance (dCm, change in mutual capacitance sensing) as a result of the touch. The stack-up design determines how small a finger can be detected, whether a glove touch can be detected, how much noise the system can tolerate, etc.

4.2.2.1 PCB material

Sensors for touchpads are usually constructed on PCBs like FR4. For applications requiring flexibility, flexible printed circuits (FPC) are generally preferred, whereas for applications requiring transparency, ITO is preferred.

4.2.2.2 Cover lens/overlay

The cover lens or overlay is the top-side layer of the stack-up that provides most of the mechanical strength. The cover lens can be characterized in terms of material and thickness. There are two prevailing material types: glass and plastic. The thickness of the cover lens (plus any coatings and bonding layers) critically affects the touchscreen performance. Overlay material selection is important for optimized system performance in terms of current consumption and ESD protection. See section "Overlay selection" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide for guidelines on overlay selection.

Two parameters associated with the overlay to be decided are as follows:

Types of overlay materials

The selection of the material type depends on the following factors:

- Dielectric constant – Higher is better
- Dielectric strength – Higher is better
- Cost – Cost generally determines the type of cover lens

Thickness of the overlay

The thickness of the overlay material depends on the following:

- Sensitivity of the system – Signal decreases as the thickness of the overlay increases
- ESD requirement – ESD performance increases with increase in thickness
- Mechanical strength – Higher strength requires a thicker overlay

4.2.2.3 Substrate

Touchpad electrodes are laid out on a base material called “substrate”. Commonly used substrates are FR4, PET, and glass. On FR4, traces can be routed on both sides; it is also a low-cost choice. FPCs are commonly made from flexible plastic substrates like polyamide or PEEK (polyether ether ketone) film. PET films or glass can be used as substrates in case of ITO electrodes.

4.2.2.4 Bezel

The bezel of a touch panel is the opaque area around the display perimeter. This bezel area is used to mask the traces between the touchscreen controller and the row/column electrodes. A non-transparent color is typically printed on the second surface (bottom side) of the cover lens to hide the traces. However, the materials used to make different colors can create different electrical performance. For example, carbon black and chrome are conductive and interact with the electric field of capacitance sensing. Therefore, if a product with a touchscreen is offered with multiple bezel colors, all supported colors must be tested across the temperature range supported by the product.

For ESD protection, it is preferred to use a conductive bezel and connect it to the system ground, provided it is not close enough to the routing traces to interfere with performance.

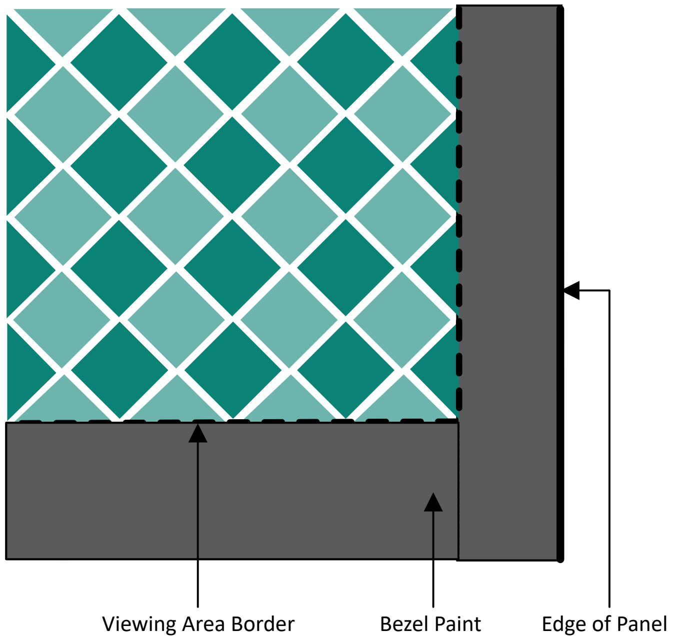


Figure 19 **Bezel**

4.2.2.5 Stack-ups

The following are the common industry stack-ups that are used in the capacitive touchscreen market. They are not drawn to scale. Unless there are additional surface coatings present (such as hard coat, anti-reflection, anti-smudge, and hydrophobic), the top side of the cover lens is what your finger physically touches to operate the touchscreen. OCA is an optically clear adhesive layer that attaches one layer to another.

Glass over glass stack-up is generally used in industrial applications. In addition, it is recommended for applications requiring resilience to temperature variations as the glass substrate is heat-resistant in nature and has good dielectric constant.

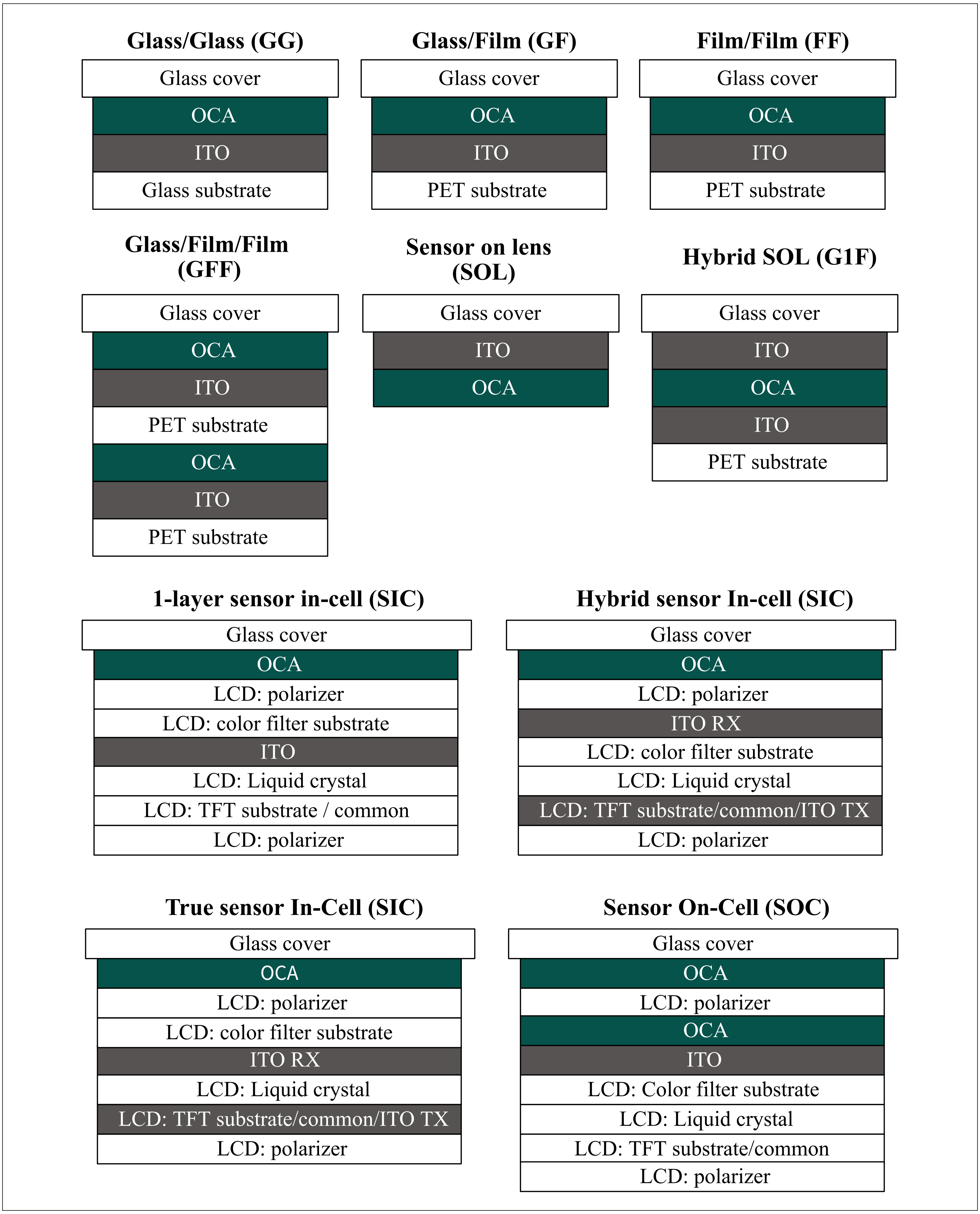


Figure 20 **Stack-ups**

4.2.2.6 Air gap

Some designs have a small air gap, typically less than 1 mm, between the panel stack-up and the display. Make sure to have a constant air gap because changes in the air gap will lead to unstable performance. Although not generally required, an air gap generally gives better performance because of less display noise being coupled into the system.

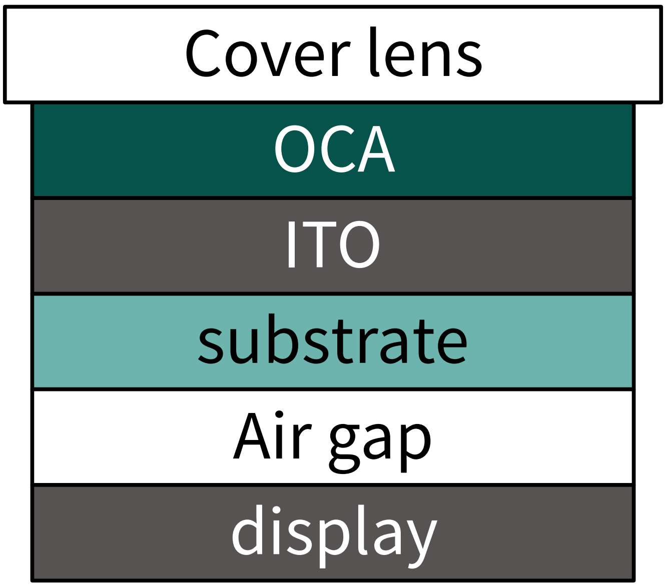


Figure 21 Stack up with air gap

4.2.2.7 Additional layers

Some touchscreen designs include anti-reflective or anti-glare films. These films can be conductive or partially conductive. If any ungrounded conductive film is applied to the panel, it should be designed such that the film does not extend to the panel edge, see Figure 18. Otherwise, ESD events near the panel edge will be coupled to the film and to sensor electrodes, degrading the ESD performance. The film design should leave the largest possible gap not to degrade the visual appearance of the display.

4.3 Routing guidelines

All touchscreen systems require conductive traces to connect the touch panel electrodes to the FPC and to the PSOC™ controller. At least one trace is required for each electrode; the traces are usually routed along the edges of a panel to the location where the FPC or PCB is attached.

The most common routing configurations are single, double, and split. In addition, this section provides guidance on ITO-metal contacts and where to overlap the active and viewing areas with respect to them.

4.3.1 Sensor trace parameters

The following are two critical parameters related to sensor routing traces that affect the touchscreen design and performance:

4.3.1.1 Trace pitch

Trace pitch is the sum of the trace width and space between traces, or the centerline-to-centerline distance of the traces as shown in Figure 22. The trace pitch determines whether it is possible to place all the required traces in the panel border area. Traces must fit under the bezel of the product to remain invisible because they are often made of opaque materials. The allowed trace pitch varies from one manufacturing process to another, in the range of 10 µm to 300 µm.

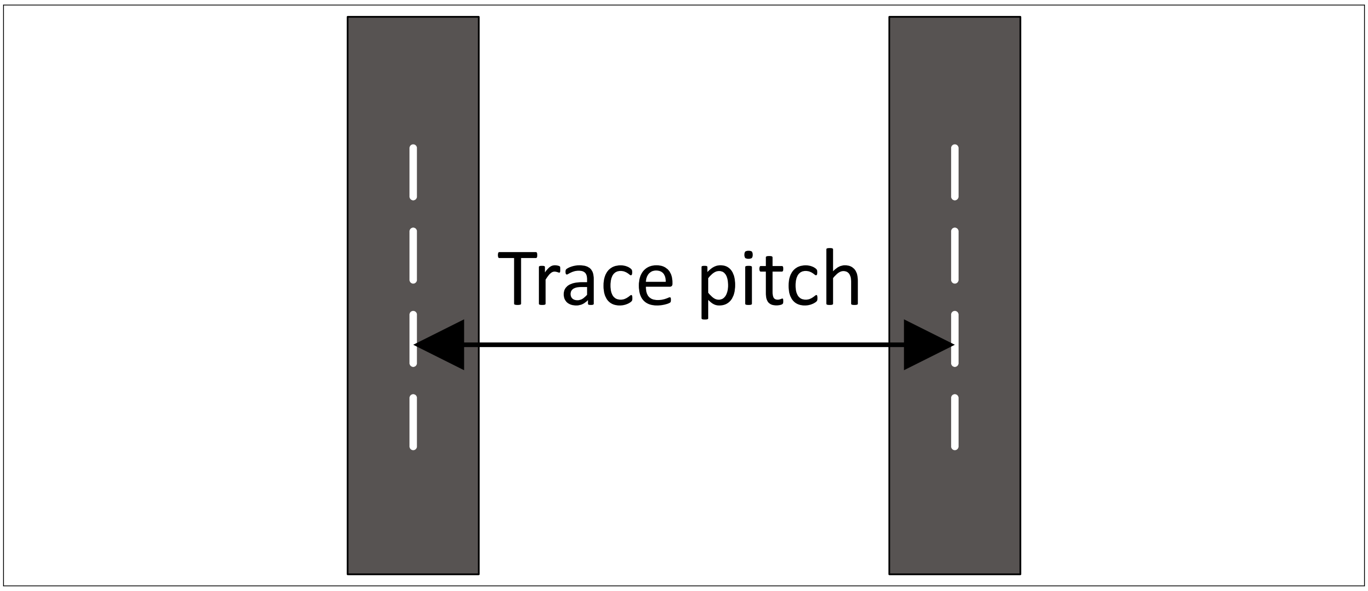


Figure 22 **Trace pitch**

4.3.1.2 Trace resistance and capacitance

The formula for trace resistance is as follows:

Resistance = Trace sheet resistance × Trace length / Trace width

Trace resistance is evaluated relative to the sensor resistance. A high trace resistance compared to the sensor resistance degrades the touchscreen performance. It is recommended to have a trace resistance as 5% of the sensor resistance. Sheet resistivity and width of the traces should be adjusted to meet the recommended value.

4.3.2 Routing configurations

Table 4 gives a summary table indicating which routings to be used when.

Table 4 **Routing configurations**

Routing configuration	Comments
Single routing	If touchpad design has sufficient border area, single routing is preferred.
Split routing	Using this configuration reduces the touchpad border area. But electrodes having this routing side switch see different signal levels, which may lead to finger location error.
Interlaced routing	This configuration is similar to split routing but with overall noise benefit.
Double routing	Double routing is the preferred routing method for large screens. It reduces the RC delay of a row/column by a factor of four, which increases the maximum switching frequency by a factor of four, and improves the maximum refresh rate, noise rejection, and SNR.

4.3.2.1 Single routing

In single routing, shown in Figure 23, traces from each row connect along only one edge of the panel. If there is sufficient border (bezel) area for single routing, do not use split routing.

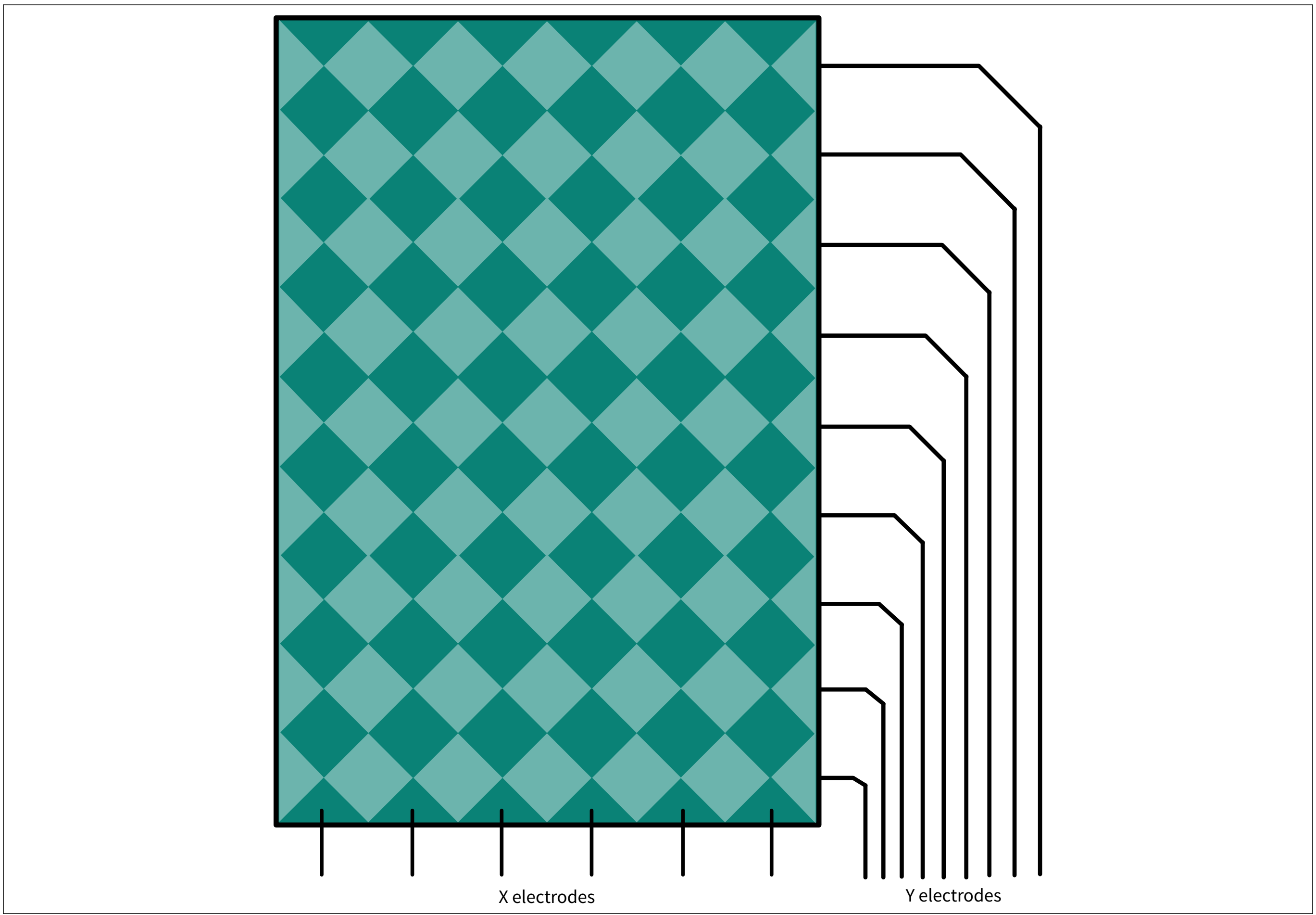


Figure 23 Single routing

4.3.2.2 Split routing

Split routing as shown in Figure 24 is an implementation of single routing in which half of the routes are on each side of the panel. This keeps the bezel width to a minimum. The disadvantage is that there is at least one point in the panel where connections to the row electrodes switch from one side to the other, i.e., one row is connected along the right edge and the adjacent row is connected on the left. Touches occurring along these electrodes are attenuated to a different degree due to the different resistive paths. This can result in an additional finger location error.

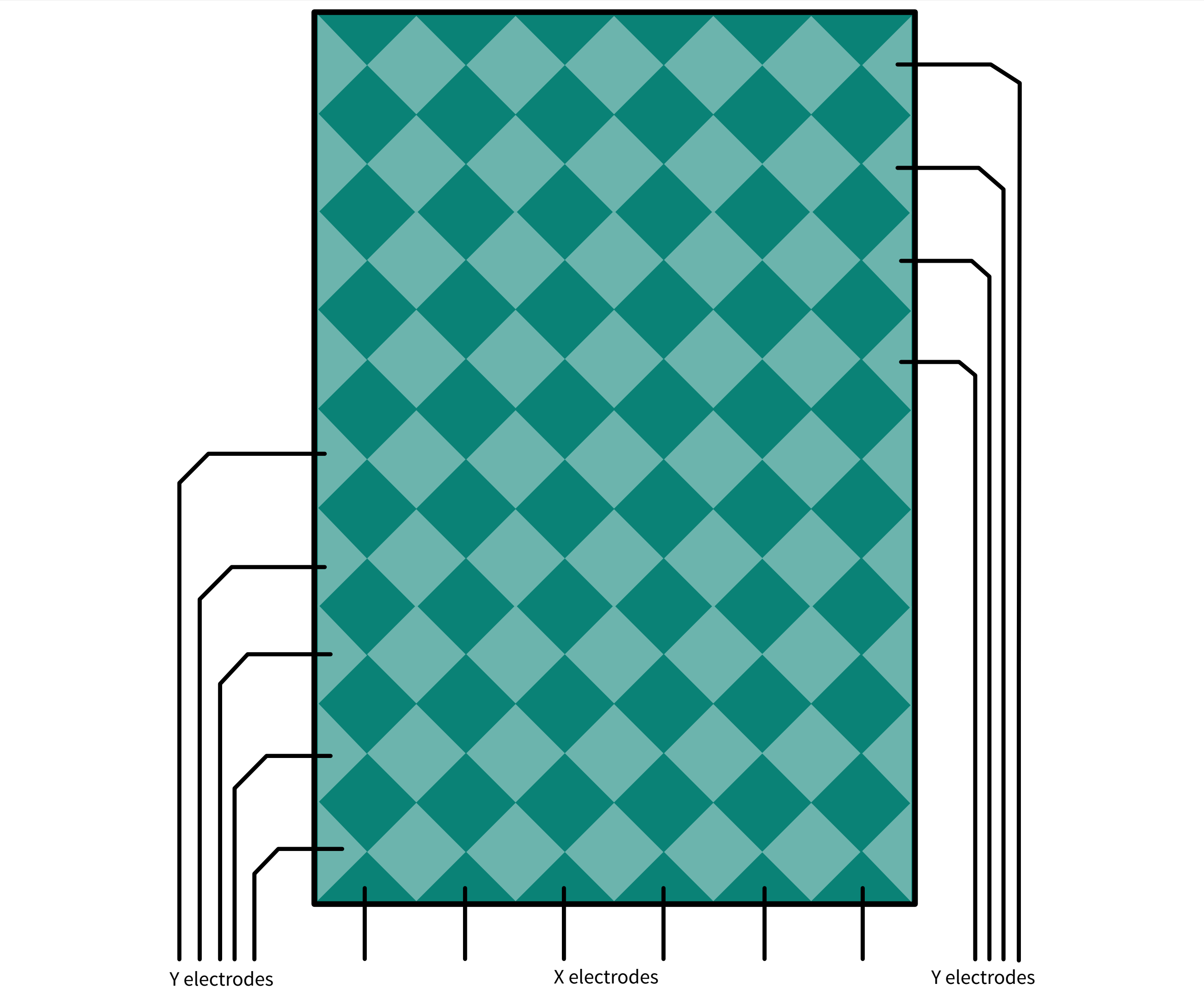


Figure 24 **Split routing**

4.3.2.3 Interlaced routing

Interlaced routing (a variation of split routing) can be useful in circumstances where other routing options do not work from a layout standpoint, or where there is an overall noise benefit.

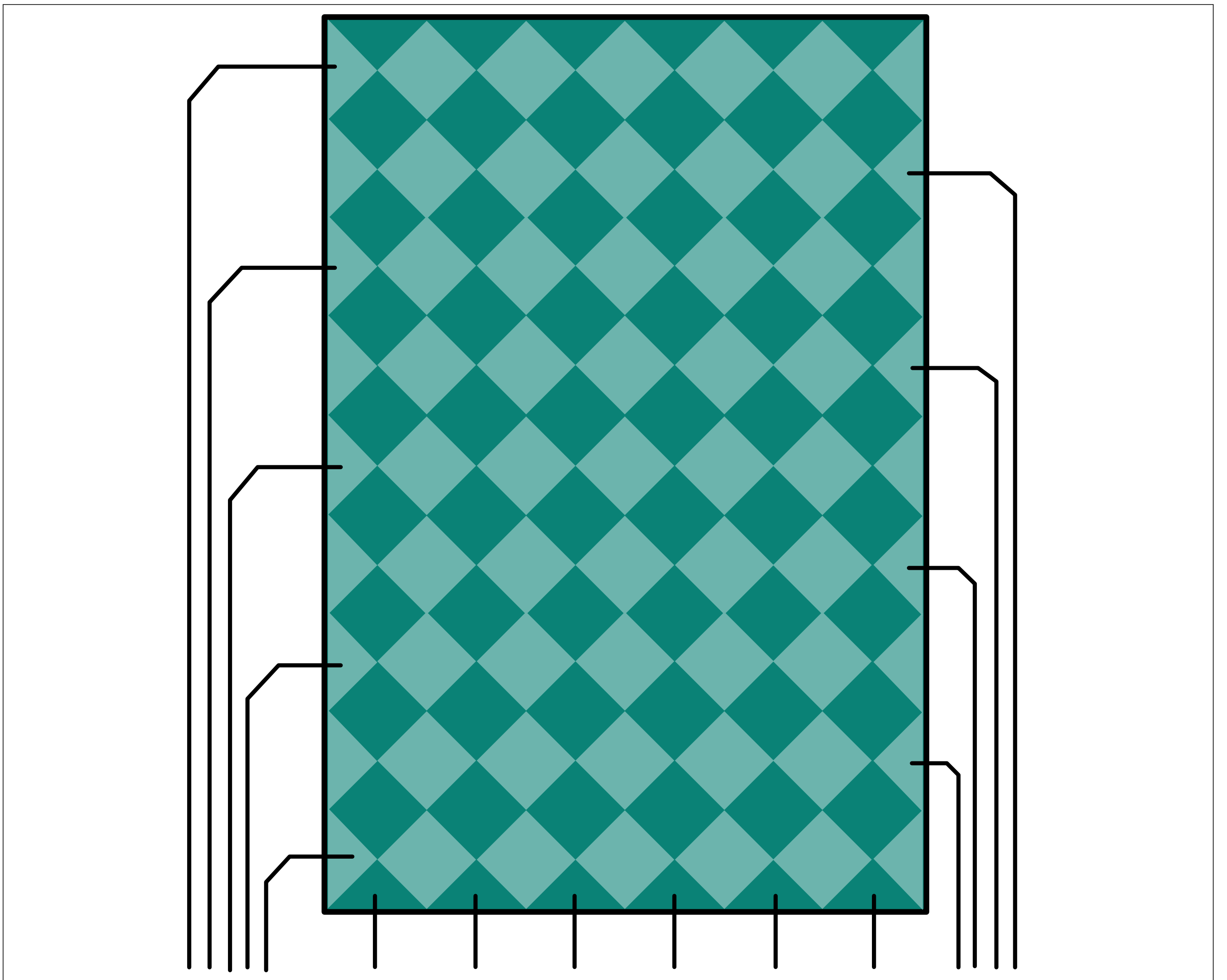


Figure 25 **Interlaced routing**

4.3.2.4 Double routing

Double routing is the preferred routing method for large screens. In double routing, a routing trace is connected to both ends of each row or column. Figure 26 shows (from left to right) X-double routing, Y-double routing, and XY-double routing. The pairs of traces corresponding to a particular row or column are typically shorted together on the FPC and routed to a single sensor pin of the touchscreen controller. Double routing reduces the RC delay of a row or column by a factor of four. This means that the maximum switching frequency can be increased by up to a factor of four, which significantly improves the maximum refresh rate, noise rejection, and SNR.

In practice, Y-double routing often makes more sense for SSD/DSD sensors because the columns tend to have a longer RC delay. X-double routing is more appropriate for a landscape panel (consider this option each time the screen's aspect ratio exceeds 1.5). Double-route all panels along the highest-resistance axis in cases where the border area allows.

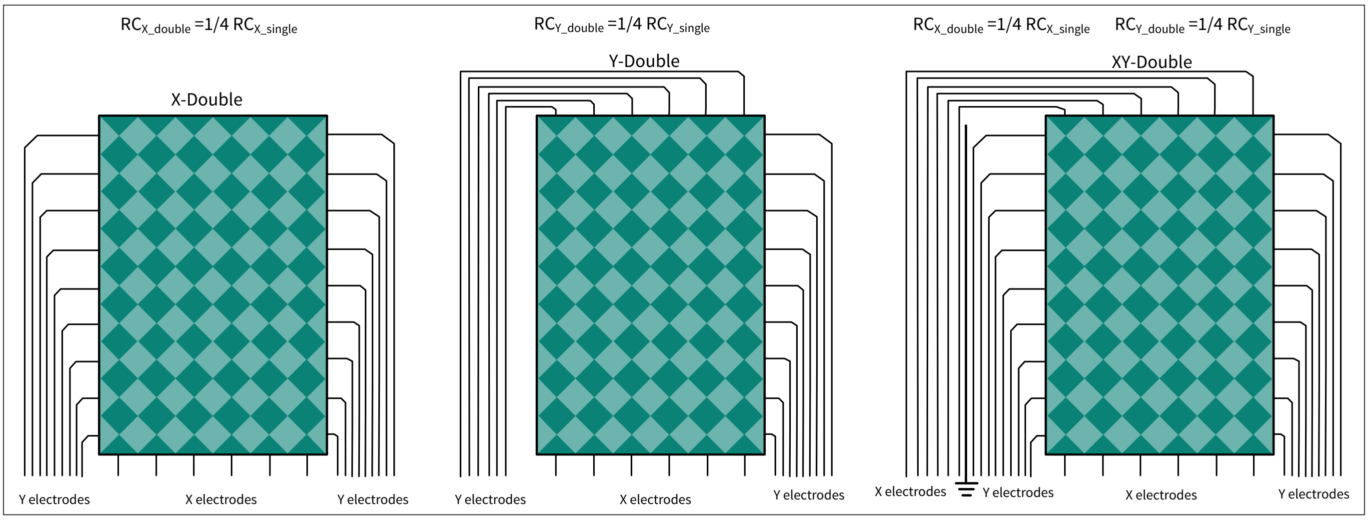


Figure 26 **Double routing**

4.3.3 Sensor routing guidelines

Do not let the Tx and Rx traces overlap for more than 1 mm. If they must overlap, insert a shield-layer between the Tx and Rx traces. Figure 27 shows an example of overlapping Tx and Rx traces.

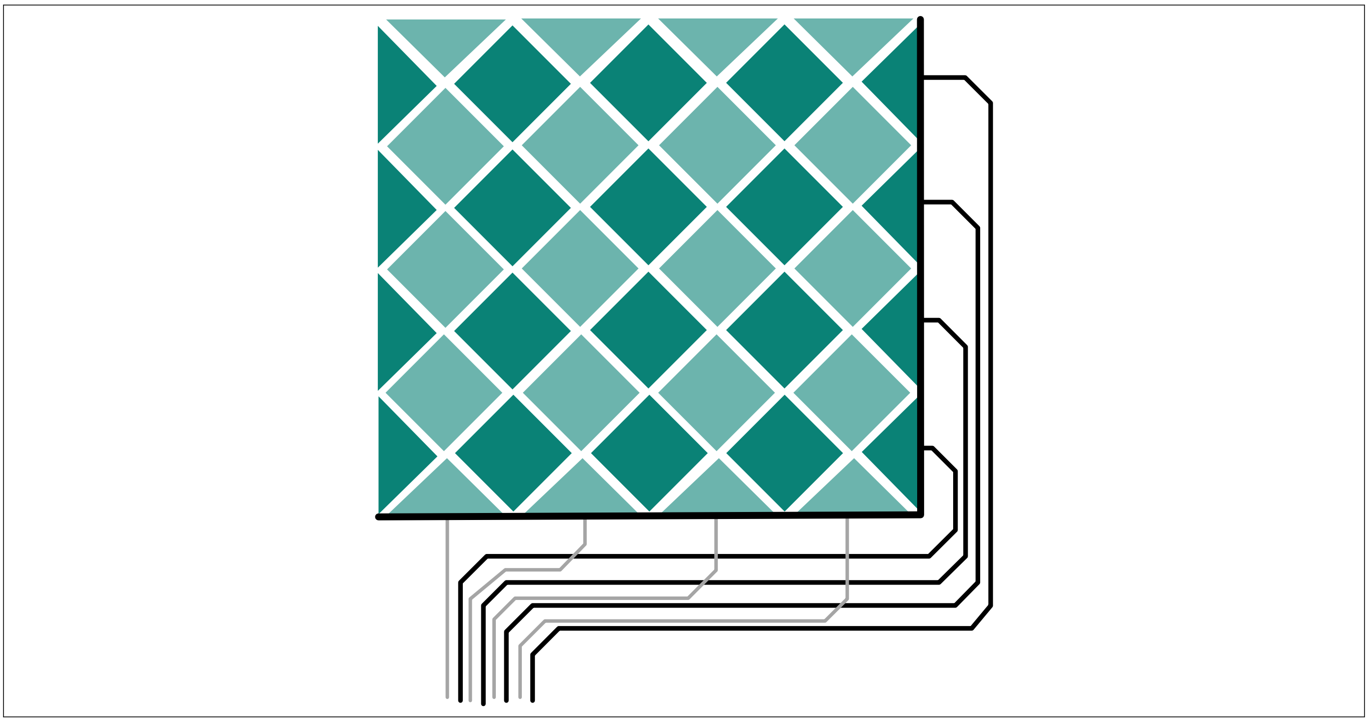


Figure 27 **Overlapped routing traces**

- If the mechanical design cuts into the corners of the active area, cut at angles, not in unit cells. Although cutting at angles will lead to variation in the active electrode area, i.e., the effective sensor capacitance, it will provide touch response over the full display

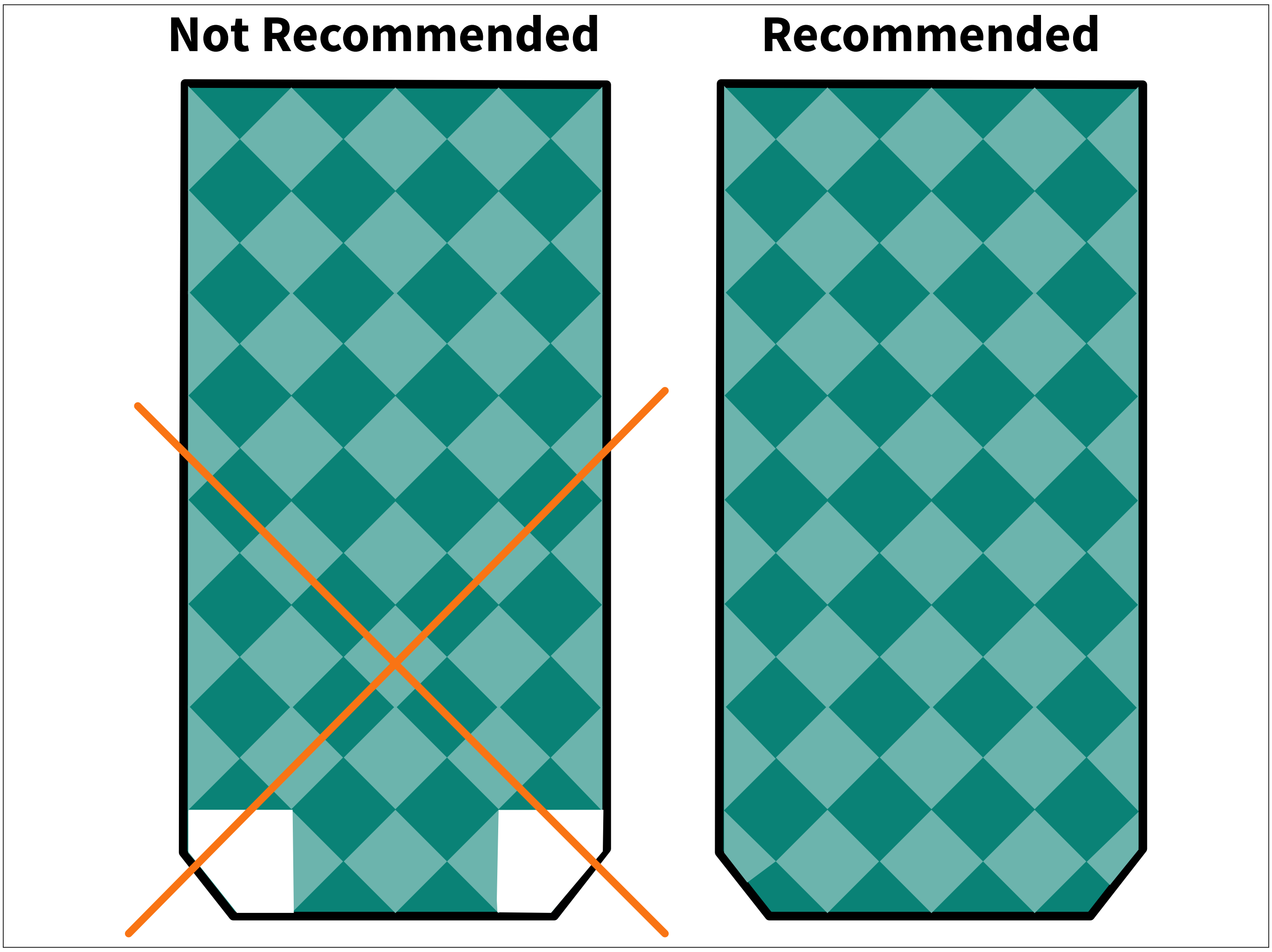


Figure 28 **Pattern corner cutting**

- Use a thicker trace (about 10 mils wherever possible) for VDD, GND, and CMOD traces
- The diamond should be as uniform as possible at every location of the board. Therefore, every side needs to be terminated with a half diamond as shown in Figure 28

4.3.4 Metal-to-ITO contacts

To achieve a good yield and electrical performance, a solid contact between the end of each electrode and the metal routing trace is necessary. The position of the contact area relative to the active and viewing areas can also affect accuracy along the edge of the screen.

The active and viewing areas are:

- **Active area**: The area that capacitance is sensed, i.e., the area that is covered by ITO, excluding the ITO to metal contact area
- **Viewing area**: The area that is transparent to the user to be able to view the display

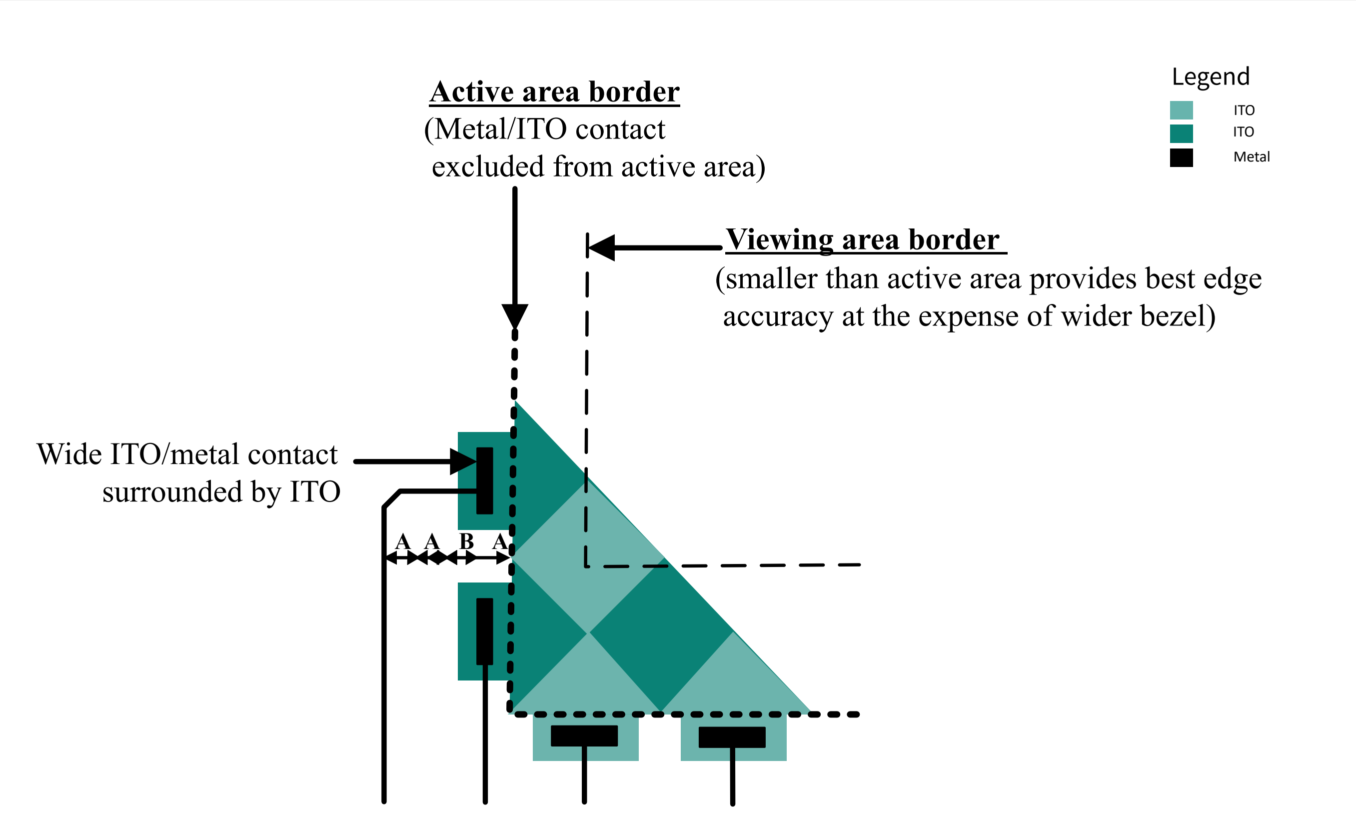


Figure 29 **ITO or metal contacts**

The metal-to-ITO contact area can produce extra signals when touches are present over the contact area. This causes a different performance from the touches over an edge with no metal to ITO contact area. To balance this extra signal, extend the ITO active area at the far end of the sensor (non-contact edge). This produces a consistent touch behavior for all edges (see Figure 30). The metal-to-ITO contact area adds more ITO area to the half-diamonds on one axis. Adding the same area to the half-diamonds on the other axis helps to match the areas of the two electrodes. If the sensor pattern already extends beyond the viewing area by 0.3–0.5 mm, this may not be required.

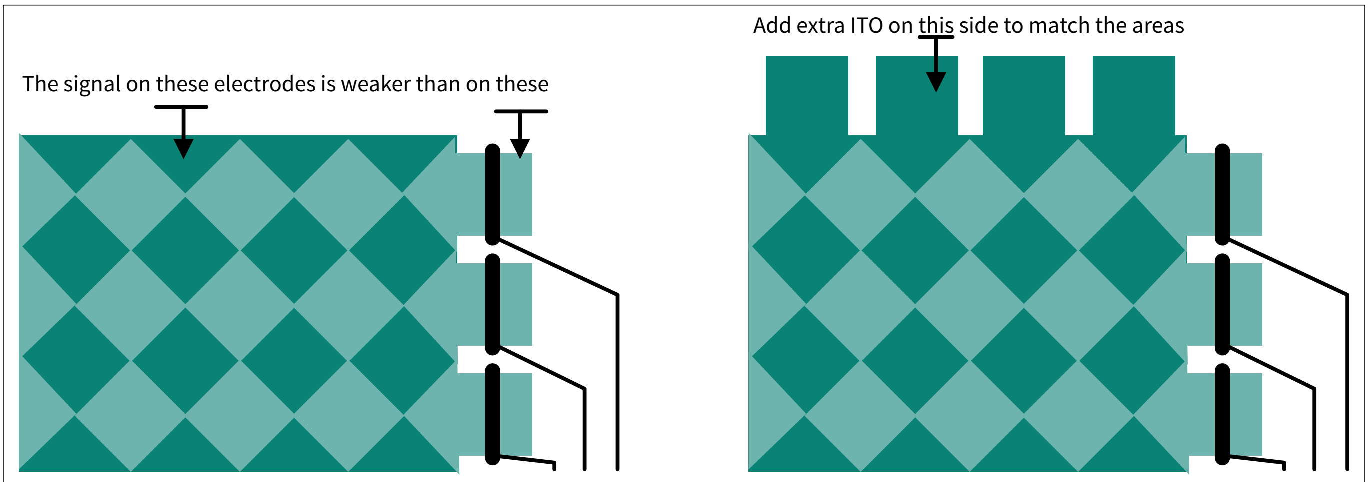


Figure 30 **Extending ITO sensors to match the ITO metal contact area**

4.3.4.1 Guidelines for metal-to-ITO contacts

- Make the metal traces over the ITO landing pads large enough to guarantee a low contact resistance. This requires a certain minimal width of the trace over a landing pad, i.e., B. The value of B for a given manufacturing process is established by the ITO partner. See Figure 29
- In manufacturing, the metal and the ITO layers do not always align perfectly and therefore, requires a certain minimal width of the landing pad, i.e., A. For a given amount of misalignment (specified by the ITO partner), allow extra space in the following places:
  - Between the metal trace and the visible (sensor) area; otherwise, there is a risk of metal being visible
  - Between the metal trace and the edge of the ITO landing pad; otherwise, the contact area might fall below B
  - Between a landing pad and an unrelated metal trace; otherwise, shorts may occur

This combination of rules dictates that the minimum width of the ITO landing pad must be 2A + B, as illustrated in Figure 29, where the values of A and B are established by the ITO partner.

- For PET substrates with silver ink routing traces, a minimum of 0.3 mm contact width is recommended
- For glass substrate with metal routing traces, a minimum of 0.1 mm contact width is recommended
- A minimum contact height of 90% of the electrode pitch is recommended, independent of substrate materials

4.3.5 Grounding

There is approximately 10% increase in Cp when solid ground fill is used on the bottom layer compared to grid fill. This 10% increase may not be significant enough to cause a 1-bit resolution increase causing increased current consumption. Solid ground is important for improving the board's mechanical strength particularly when the board thickness is less than 1 mm. Solid fill prevents the board from expanding and twisting when temperature or stress is applied. However, solid fill is not recommended for FPC-based designs.

4.3.6 Shielding

Capacitive touchscreens operate by detecting changes in the electric field coupling caused by a finger or other conductive object. This makes them inherently sensitive to electromagnetic interference (EMI). Touchscreen devices typically contain multiple EMI sources, with the display often being the worst offender because of its close proximity to the touchscreen. An effective mitigating technique for designs challenged by EMI from the display is to add an ITO shield layer between the touchscreen and the display.

The advantages of a shield layer include:

- Suppresses display noise, offering better SNR
- Reduces raw count changes due to panel flexing (for assemblies with an air gap between the touch sensor and display)
- Reduces the parasitic capacitance (when driven as an active shield)

In touchscreens with an air gap between the sensor and the display, if the cover material of a panel is not sufficiently rigid (for example, poly-methyl methacrylate (PMMA)) and the sensor substrate is made of PET film, a shield layer is mandatory to prevent raw count changes due to panel flexing.

4.3.6.1 Shield design

The ITO shield layer is applied to the bottom side of a stack-up (see Substrate), and must cover all the ITO row and column electrodes. The shield prevents electronic noise coupling from the display into the touchscreen. If not shielded by the FPC, all the traces routed near the display controller, display tail, or display driver must also be covered. For the shield to be effective, its sheet resistance must be less than or equal to that of the electrodes it is shielding.

For applications that require only the EMI shield function of this layer, the ITO shield is connected to system ground on the FPC. Routing traces should be made with either metal (preferable) or silver ink, and the termination at the ITO shield should be routed around the entire perimeter of the ITO shield layer (under the bezel) to minimize shield resistance (see Figure 31). The diamond shapes in Figure 31 are the touchscreen electrodes, and the light green area is the shield. Routing traces are on the same layer as the touchscreen electrodes, while the metal ground ring (wide black line) is on the same layer as the shield.

Because the shield layer is grounded and closer to the row and column sensing electrodes than the display's ground reference, the use of a shield increases the parasitic capacitance (Cp) in self-capacitance sensing, and the load on the Tx driver for mutual-capacitance sensing. This reduces the overall dynamic range of the measurement system for those touch controllers that do not have hardware baseline compensation. The magnitude of the parasitic capacitance is determined by the thickness and dielectric constant of the substrate and attachment layers of the shield.

For applications that require sensing of objects at significant distance from the top side of the touch sensor, or objects that generate very small signal changes, it is possible to actively drive the shield to reduce or remove most of the parasitic capacitance (Cp) of the X and Y sensor electrodes. When measuring self-capacitance, a significant amount of the dynamic range of the Rx channel is used in measuring the parasitic capacitance of these X and Y electrodes. By driving the shield layer in matched phase and amplitude with the electrodes being measured, this parasitic capacitance is removed.

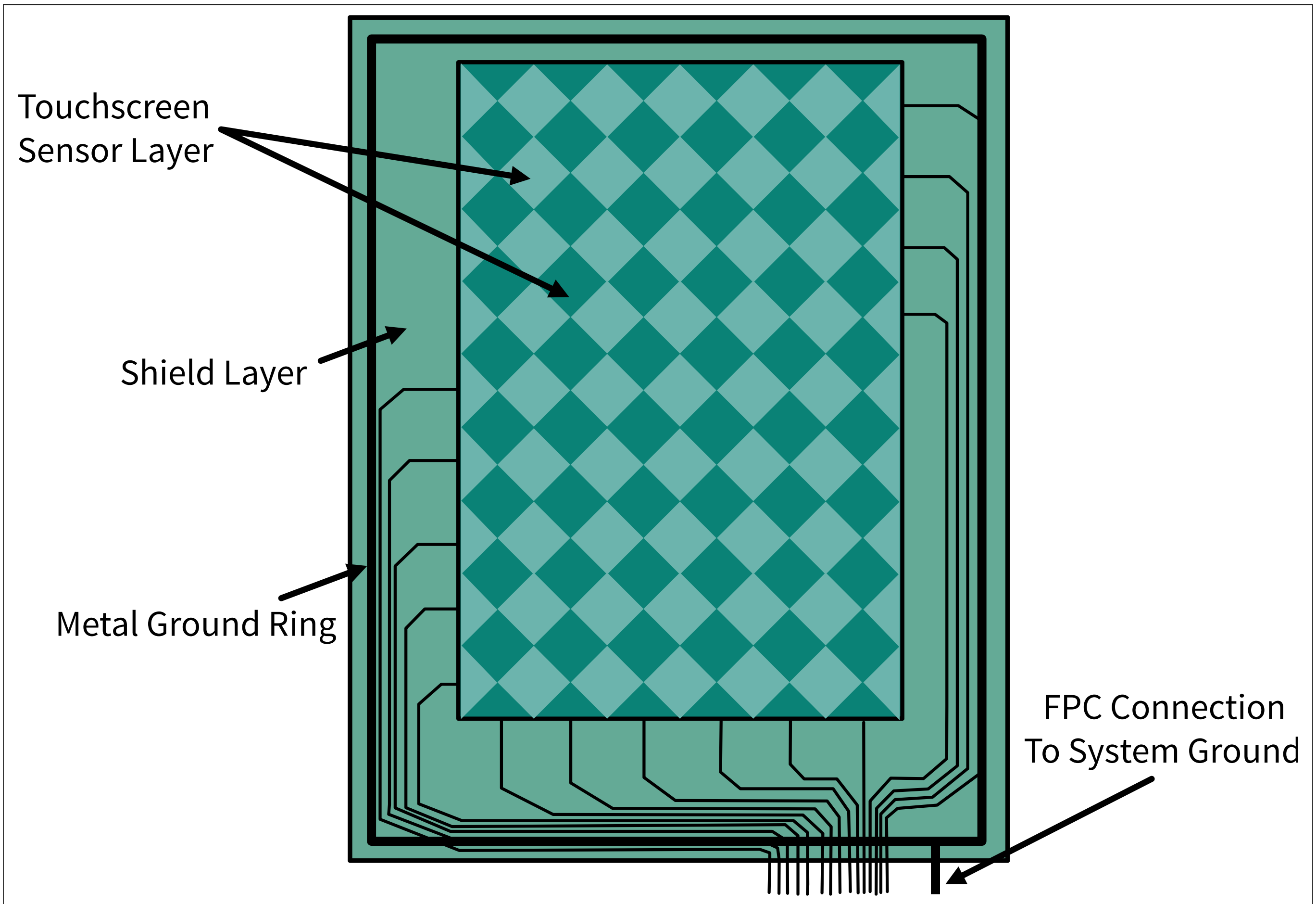


Figure 31 **ITO shield and metal ground ring**

4.4 FPC guidelines

This section focuses on guidelines for the flexible printed circuit (FPC) that is typically used to connect the PCB to the touch panel.

4.4.1 Stack-ups

There are two prevailing types of FPC stack-ups (Figure 32): two-layer and four-layer.

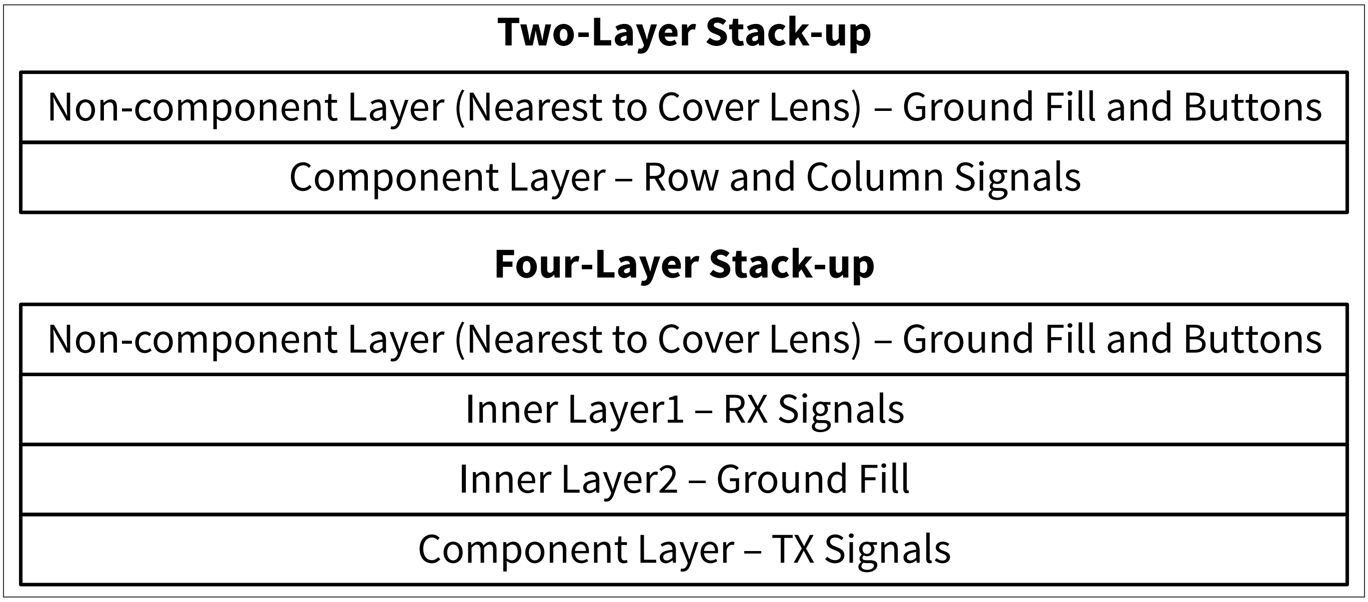
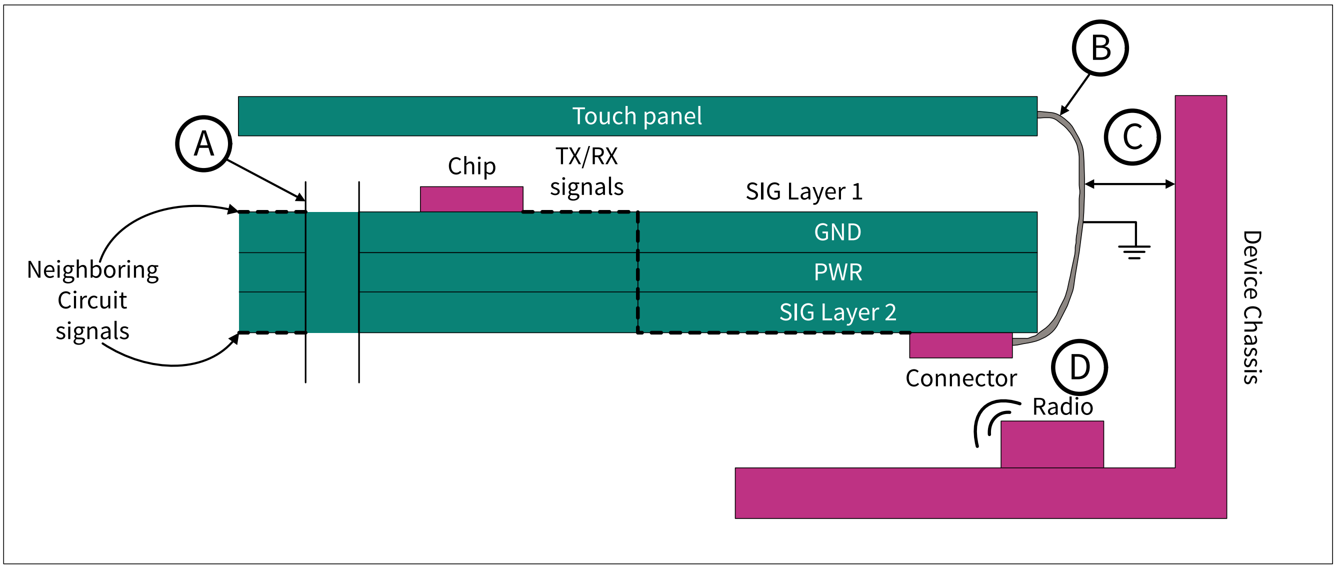


Figure 32 Stack-ups

4.4.2 Passive FPC location guidelines

This section describes passive tail designs where the chip is on a main PCB and Tx/Rx signals are routed on a passive FPC to the touch panel, and describes production designs and manufacturing test boards. Figure 33 provides guidelines on multi-layer routing, FPC tail length, and FPC tail shielding.



A	All Layer partition gap > 0.1 mm keeps neighbor power/ground noise away from chip power/ground
B	Flex tail length < 50 mm to keep parasitic capacitance of flex < 10 pF
C	Flex tail distance from chassis > 1 mm to protect against noise interference and ESD
D	Flex tail ground layer is 50% mesh and facing potential noise interference

Figure 33 FPC guidelines

4.4.3 Layout guidelines

4.4.3.1 Shield layer with ground fill

The FPC should always have a shield layer with ground fill and any unused space on the FPC should be filled by ground plane. The ground fill should be tied to the system ground and not the VSS ground of the PSOC™ device. This helps to isolate noise and redirect ESD energy away from the controller. Another benefit of adding ground fill wherever possible is that it reduces the impedance of the ground net, improving its high frequency response. The disadvantage of doing so is the increase of self-capacitance between sensor traces and the ground plane. To reduce this side effect, use 30% to 60% copper hatch fill for ground areas that are directly above or below row/column signals.

For designs that use only mutual-capacitance scanning, use solid fill.

For designs that use self-capacitance scanning, if the traces are less than 5 cm (assuming 0.1-mm trace width, with the flex layer thickness greater than 0.05 mm) use solid fill; otherwise, use 10% copper hatch fill ground.

Make the shield layer (ground fill) large enough to cover the FPC tail and display-driver pads. Connect the ground to system ground, not the controller's VSS pin. The design of the FPC "tail", where the sensor traces are routed off the panel to connect with the PSOC™ controller, is critical. Figure 34 is an example of a poor layout.

The display driver is located near the bottom of the display, and the row/column pixel drivers are routed to pads at the bottom of the display, outside the viewing area. These pads are driven with high-speed digital signals whose logic-level transitions can couple noise to sensor traces routed in close proximity.

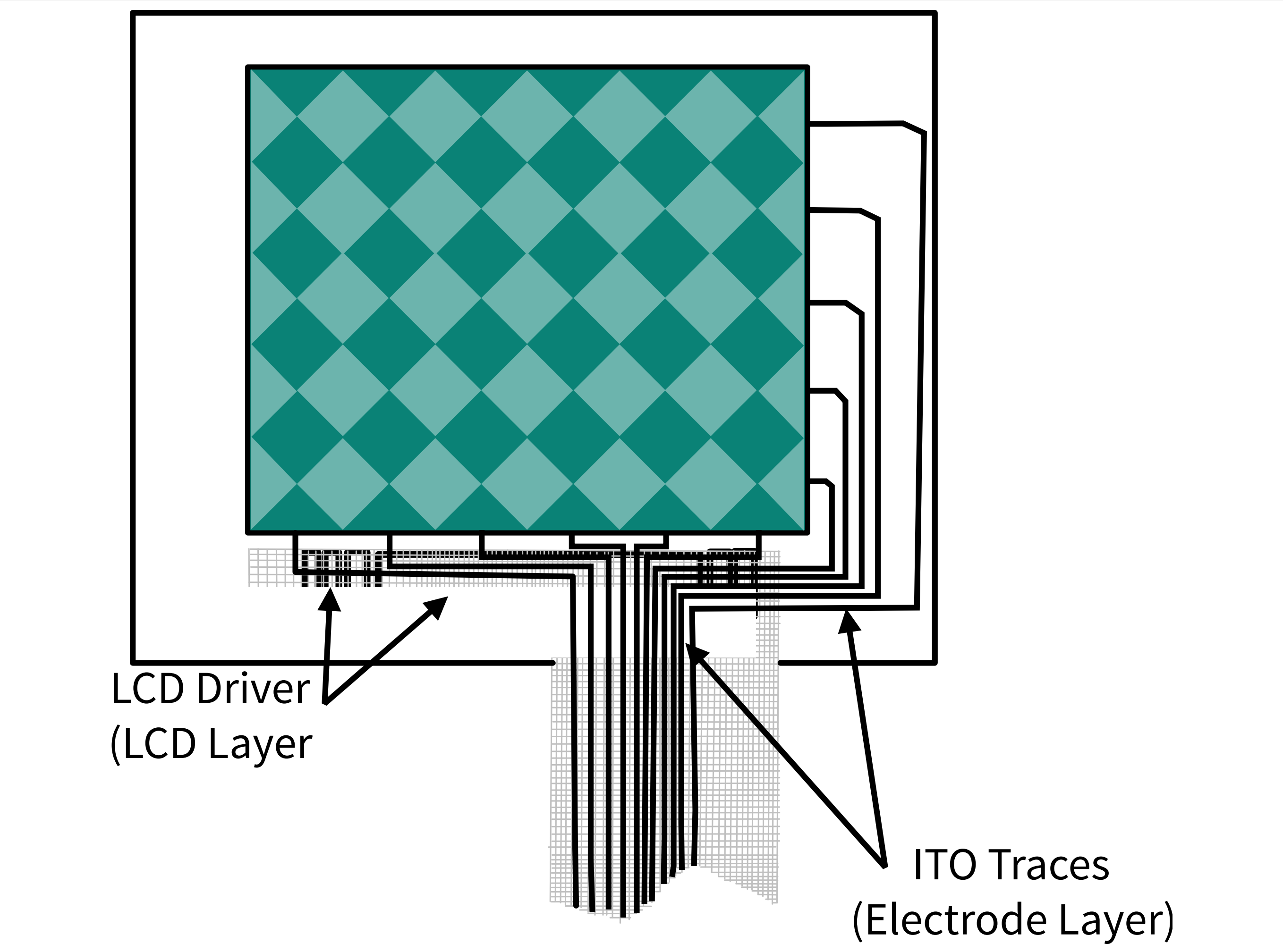


Figure 34 ITO traces not shielded from display driver

To solve this problem, increase the size of the FPC and corresponding shield, as shown in Figure 35, so that it covers the display driver pads. This design consideration applies to both two-layer and four-layer stacks.

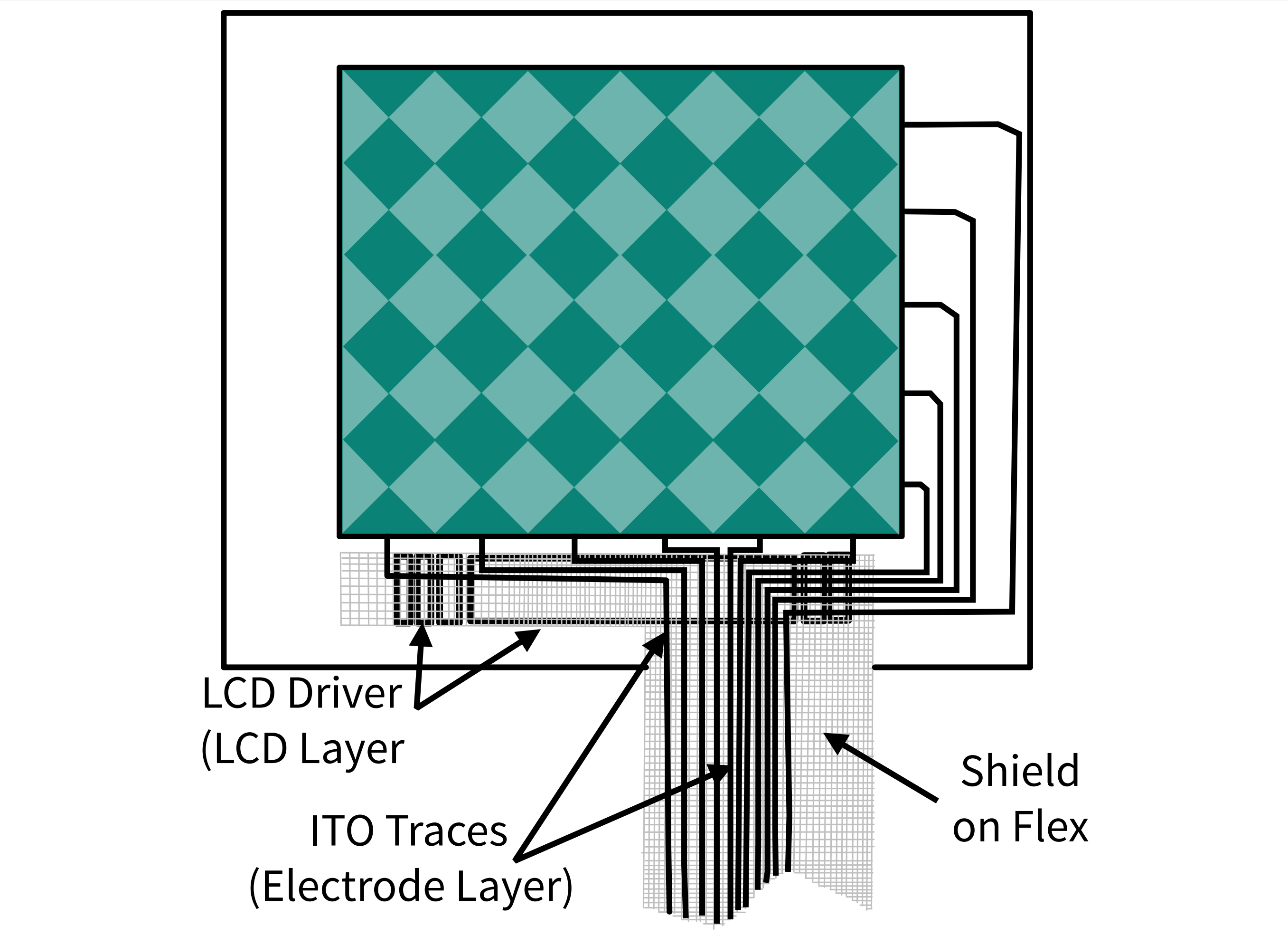


Figure 35 ITO traces shielded from display driver

Be careful of display driver Chip-on-Board (COB) interfering with ITO panel FPC routing.

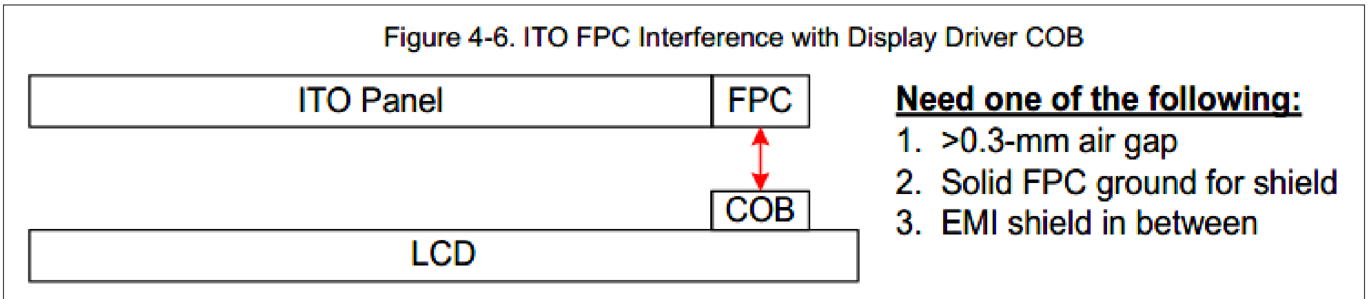


Figure 36 ITO FPC interference with display driver COB

The traces between the PSOC™ controller and electrodes should be kept as short as possible.

Rx sensor traces should be shielded for the entire length of their run on the FPC. The area in blue in Figure 37 is the bottom layer of the FPC and is the suggested shield area because it is closest to the display driver signals. It is important to shield the sensor traces in this case because the display driver is directly underneath the touchscreen column traces. Another technique for reducing the coupling between the sensor traces and the display driver is to connect the FPC tail on the opposite end of the module from the display driver.

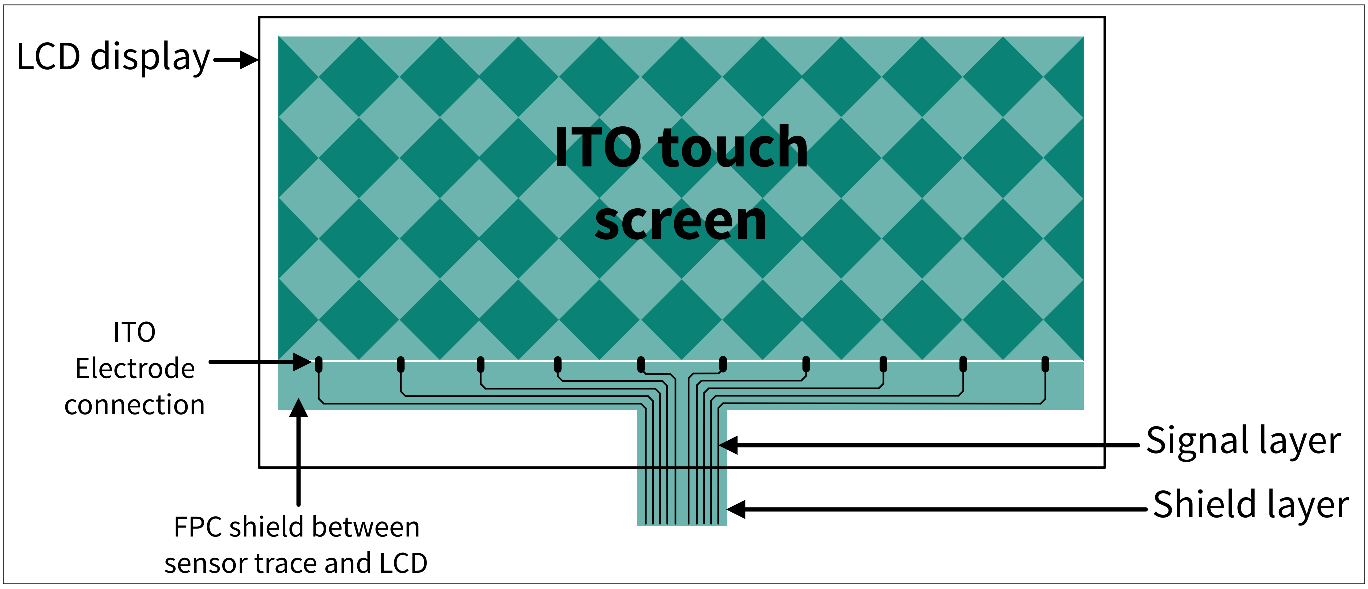


Figure 37 **FPC layout with copper shield coverage**

The Rx electrodes and corresponding traces are most susceptible to noise. The rules to avoid coupling noise into the signals are as follows:

- Shield the Rx traces from other traces if routed in parallel
- Route the Rx traces 90 degrees to other noisy traces
- Route the Rx traces farthest from the display

Tx traces are relatively low-impedance and do not need to be shielded. Tx traces may be routed in parallel with other Tx traces; if Tx traces must cross Rx traces, the intersection angle should be as close to 90 degrees as possible.

4.4.4 FPC/panel bonding

Touchscreen sensors are generally bonded to the FPC with anisotropic conductive film (ACF). To have a reliable contact, it is recommended to have the contact density between 1:5 and 1:10 for the ACF material, i.e., the ratio of the sphere size to the gap between the conductive spheres; see Figure 38. Furthermore, the contact pads interfacing the FPC and touch panel should be drawn based on the geometries (width, spacing, and height) recommended by the panel and ACF manufacturers, whichever offers the highest contact or yield rate. For instance, the typical width and space of the contact pads on PET Film is 0.5 mm and 0.5 mm, respectively.

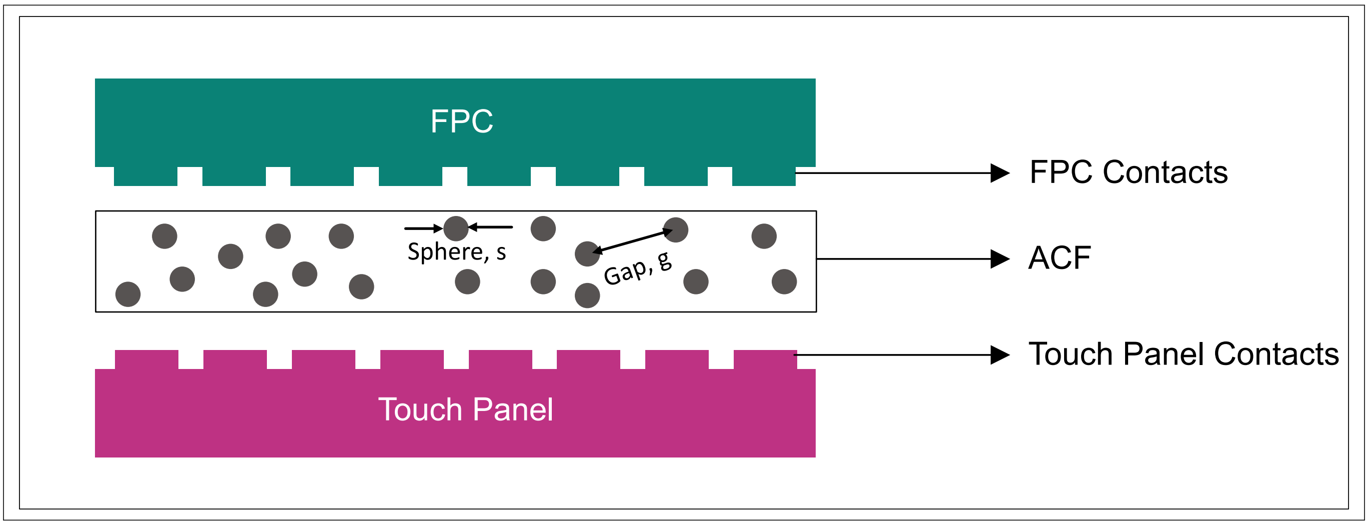


Figure 38 **ACF bonding**

5 Firmware and tuning guidelines for touchpad

See section "CAPSENSE™ performance tuning" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide for a detailed explanation on tuning of CAPSENSE™ for better performance. For details on the Component and all related parameters, see the component datasheet.

5.1 CSD touchpad widget

A slider consists of a one-dimensional array of capacitive sensors called segments, which are placed adjacent to one another. Touching one segment also results in partial activation of adjacent segments. The firmware processes the raw counts from the touched segment and the nearby segments to calculate the position of the geometric center of the finger touch, which is known as the centroid position. The actual resolution of the calculated centroid position is much higher than the number of segments in a slider. For example, a slider with five segments can resolve at least 100 physical finger positions. This high resolution gives smooth transitions of the centroid position as the finger glides across a slider.

A touchpad based on self-capacitance is essentially two sliders implemented in the horizontal and vertical directions. Therefore, it is also tuned in a similar way as that of a slider to obtain an even response across the touchpad. To gain true multi-touch performance, it is recommended to use a touchpad based on mutual-capacitance.

5.1.1 Finger touch detection algorithm

The touchpad centroid algorithm obtains the signals (diff-counts) from all the segments and calculates the X and Y position co-ordinates. The CSD touchpad reuses the slider's centroid algorithm that is applied individually to row and column sensors treated as simple sliders. Therefore, the centroid position calculation formula for a CSD touchpad is the same as that of the slider; see section "Slider widget tuning" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide.

Ensure that C_P values between sensors are similar, this will help minimize the tuning effort, avoid nonlinearity in the centroid and ensure that the signal from all segments is equal giving an even response across the entire touchpad. When a finger is placed between two segments, exactly two sensors report a valid signal (valid signal means that the difference count of the segment is greater than or equal to the noise threshold value). If a finger is placed at the exact middle of any segment, the adjacent sensors should report a difference count <= noise threshold. These conditions are required since the centroid position calculation is based on the closest segment to the finger and two neighboring segments as shown in (3).

$$centroid\ position = \left(\frac{S_{x+1} - S_{x-1}}{S_{x+1} + S_{x-1}} + x\right) \times \frac{Maxcount}{(n-1)} \tag{3}$$

CSD touchpad centroid position calculation equation

Where,

Maxcount = Maximum raw count which is displayed in the "Widget/Sensor Parameters" window in CAPSENSE™ Tuner.

n = Number of sensor elements (segments) in X or Y axis

x = Index of segment which gives maximum signal

S_i = Difference counts (with subtracted noise threshold value) of the segment

5.1.2 CSD touchpad widget tuning

CAPSENSE™ supports two types of tuning methods that can be used for all widgets:

- SmartSense
- Manual tuning

Each method has its own benefits and limitations which are explained in "Selecting between SmartSense and manual tuning" section of AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide.

***Note**: Configurator snapshots shown in this section are for MSCLP IP, if you are using any other IP few features cannot be applicable for the same.*

Figure 39 shows an overview of the manual tuning procedure for CSD touchpad, for a detailed step-by-step procedure, see the PSOC™ 4: MSCLP self-capacitance touchpad tuning code example.

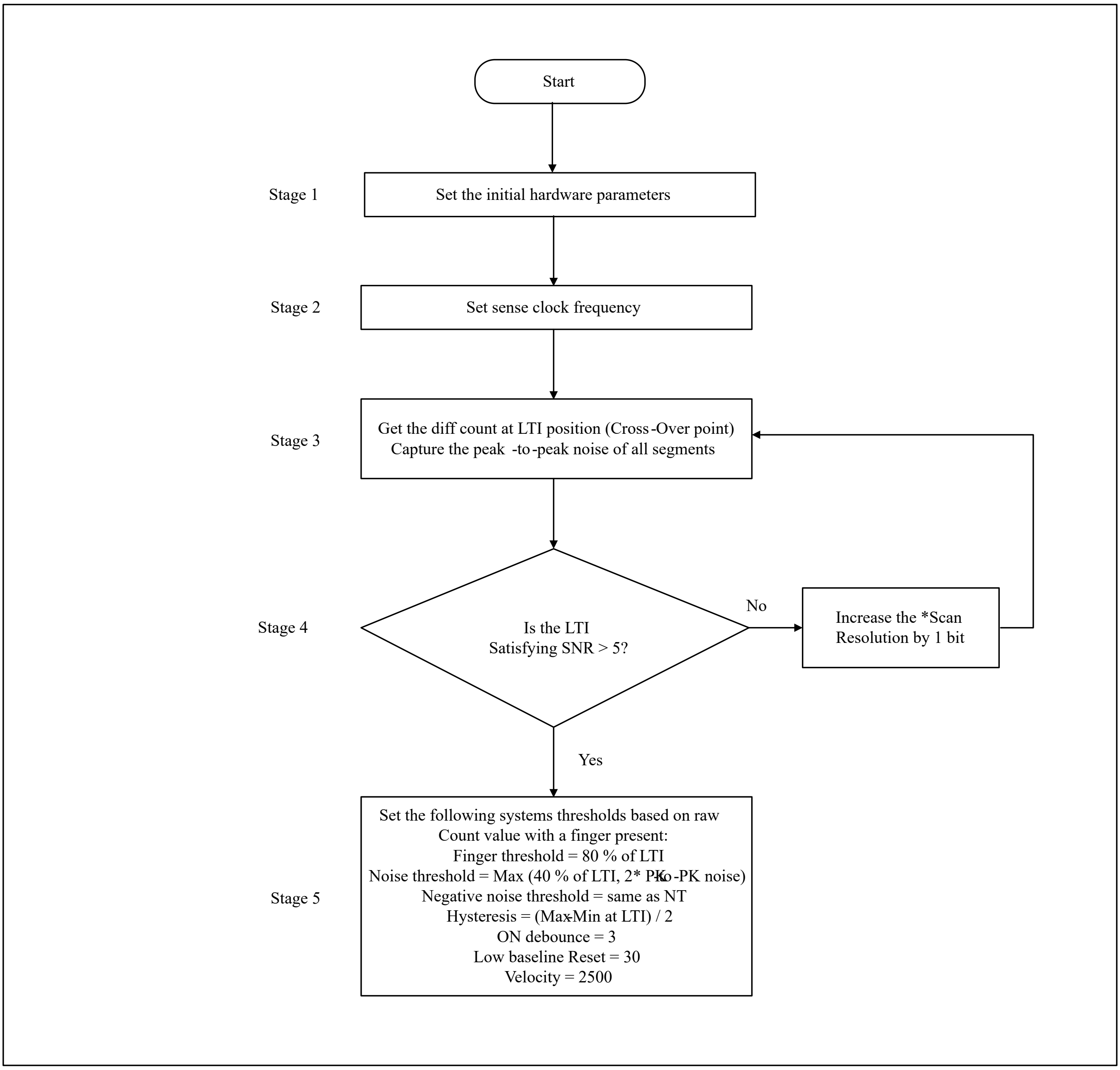


Figure 39 CSD manual tuning flow chart

Here, The LTI signal is measured at the farthest point of the touchpad from the device, where the sensors have the worst case RC-time constant.This gives the least valid touch signal.

This section will provide a brief description of tuning parameters for touchpad. For more information on general tuning parameters, see the AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide to understand all parameters and advanced configurations.

Do the following to tune the touchpad widget:

1. Create a touchpad widget

a. Connect the PSOC™ 4 board to your PC

b. Launch the Device Configurator tool

You can launch the Device Configurator in Eclipse IDE for ModusToolbox™ from the Tools section in the IDE **Quick Panel** or in standalone mode from {ModusToolbox™ install directory}/ ModusToolbox/tools_{version}/device-configurator/device-configurator. In this case, after opening the application, select File > Open and open the design.modus file of the respective application, which is present in the {Application root directory}/bsps/TARGET_APP_<BSP-NAME>/ config/ folder

c. Enable CAPSENSE™ in the Device Configurator as shown in Figure 40

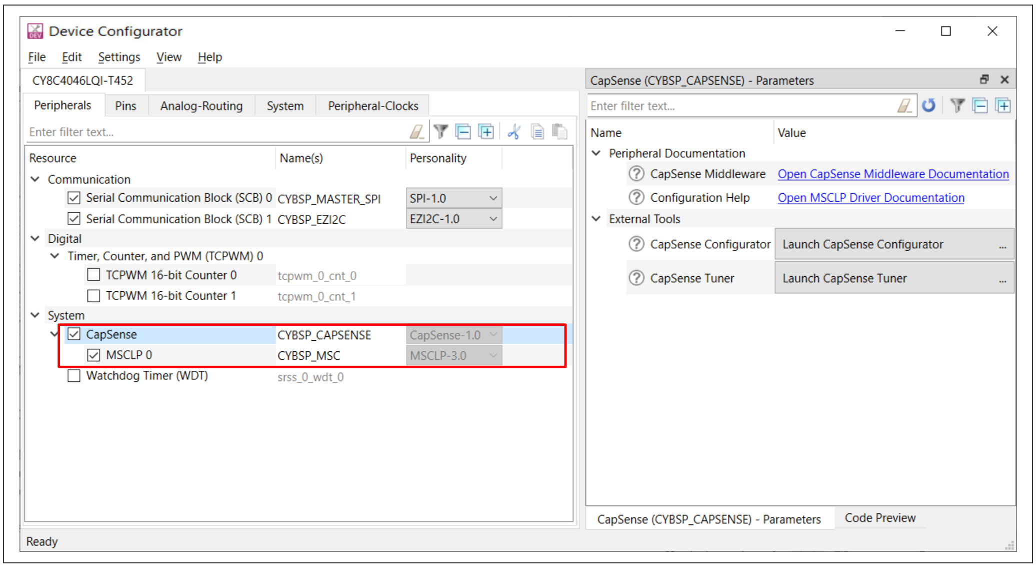


Figure 40 Enabling CAPSENSE™ in device configurator

d. Launch the CAPSENSE™ Configurator tool

You can launch the CAPSENSE™ Configurator tool in Eclipse IDE for ModusToolbox™ from the CAPSENSE™ peripheral setting in the Device Configurator or directly from the Tools section in the IDE **Quick Panel**. You can also launch it in standalone mode from {ModusToolbox™ install directory}/ModusToolbox/tools_{version}/capsense-configurator/capsense-configurator. In this case, after opening the application, select **File** > **Open** and open the design.cycapsense file of the respective application, which is present in the {Application root directory}/bsps/ TARGET_APP_<BSP-NAME>/config/ folder

e. In the Basic tab, add a 'Touchpad_SELF_CAP' widget and configure it in CSD RM (self-cap) Sensing Mode

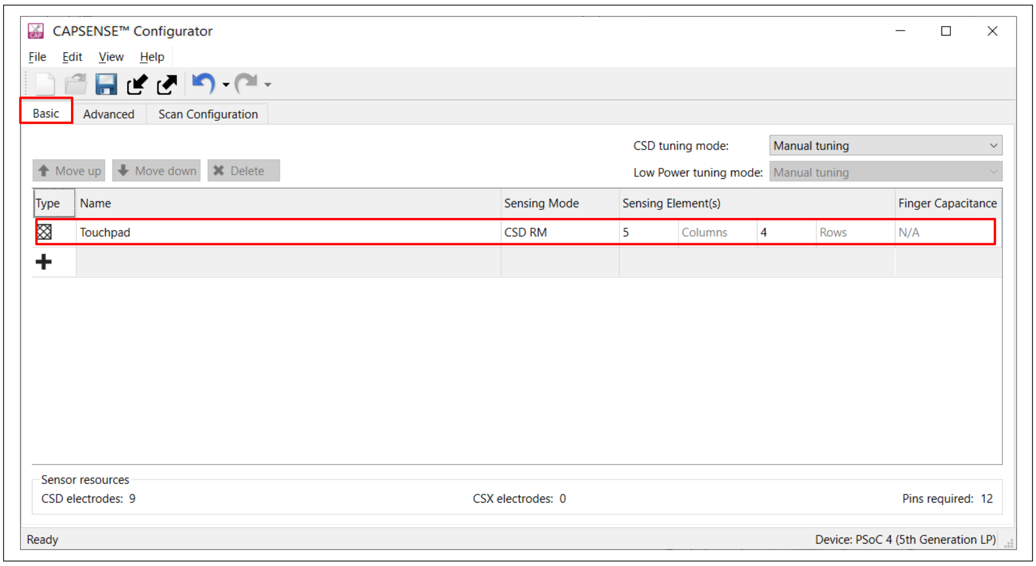


Figure 41 CAPSENSE™ configurator – Basic tab

2. Set general parameters for the touchpad in the General tab. For PSOC™ 4 fifth-generation low-power devices, it is recommended to Enable CIC2 hardware filter

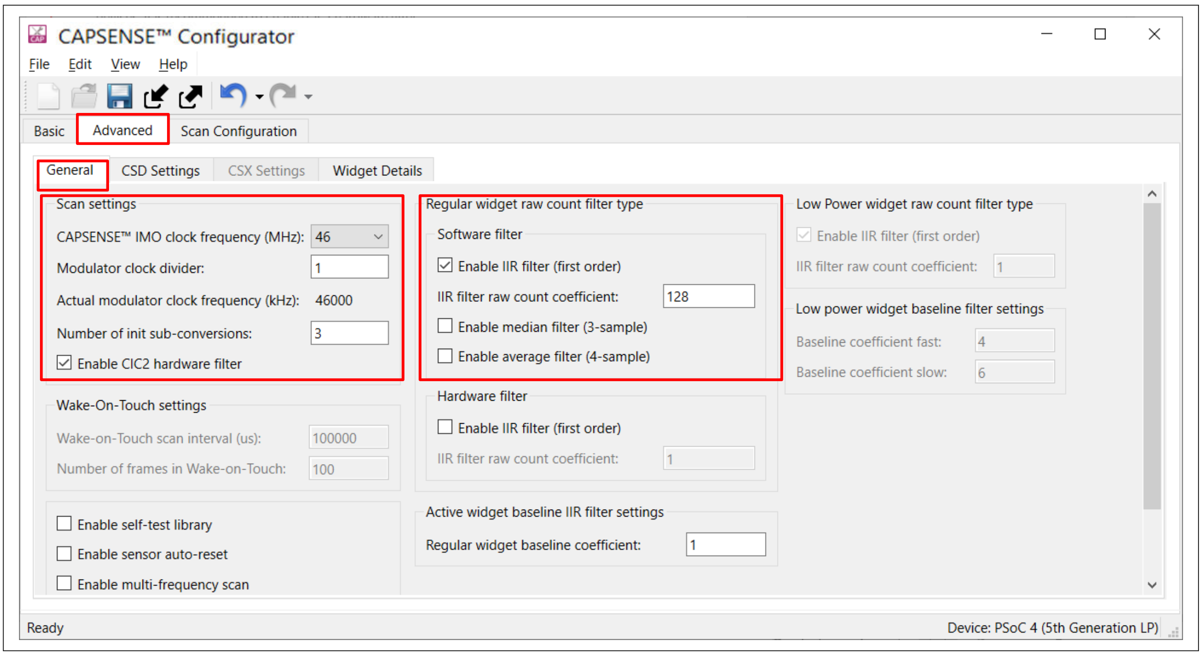


Figure 42 CAPSENSE™ configurator – General tab

See the following table that lists the parameters for General tab along with their recommended values.

Table 5 General tab tuning parameters

Parameter	Description	Recommended values
IMO clock frequency	Frequency of clock used as source for the CAPSENSE™ peripheral.	48 MHz (Maximum IMO clock frequency)[1)]
Modulator clock divider	Divider value used to divide system clock; the resulting clock then used as clock for sigma-delta modulation.	1

(table continues...)

Table 5 (continued) General tab tuning parameters

Parameter	Description	Recommended values
IIR filter raw count coefficient	It is recommended to Enable IIR filter (first order) when the CIC2 filter is enabled.	128

1) Maximum IMO clock frequency is 46 MHz for the PSOC™ 4000T kit.

3. Set touchpad parameters in the CSD Settings tab

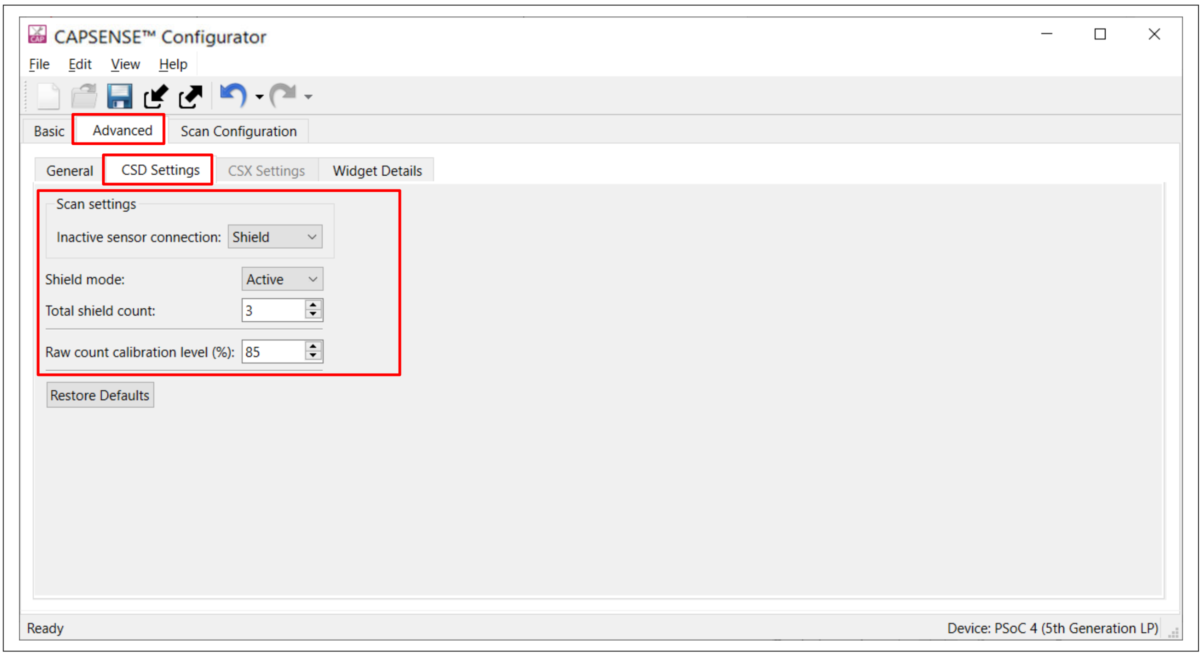


Figure 43 CAPSENSE™ configurator – Advanced CSD settings

See the following table that lists the parameters for the CSD settings tab along with their recommended values.

Table 6 CSD Settings tab tuning parameters

Parameter	Description	Recommended values
Inactive sensor connection	Inactive sensors connected to shield provide better performance in terms of SNR and refresh rate (as the use of shield results in reduction of sensor Cp) and can also be used if your design requires liquid tolerance.	Shield
Shield mode	5^{th} generation and 5^{th} generation low-power CAPSENSE™ provide active and passive shielding. Active shielding is preferred for high-performance applications. Before enabling this option, ensure that your design has shield electrodes.	Active
Raw count calibration level (%)	Helps in achieving the required CDAC calibration levels (85% of maximum count by default) for all sensors in the widget, while maintaining the same sensitivity across the sensor elements. This can be reduced if the application reaches the saturation level on a touch event.	85%

4. Set touchpad-specific widget parameters in the Widget Details tab

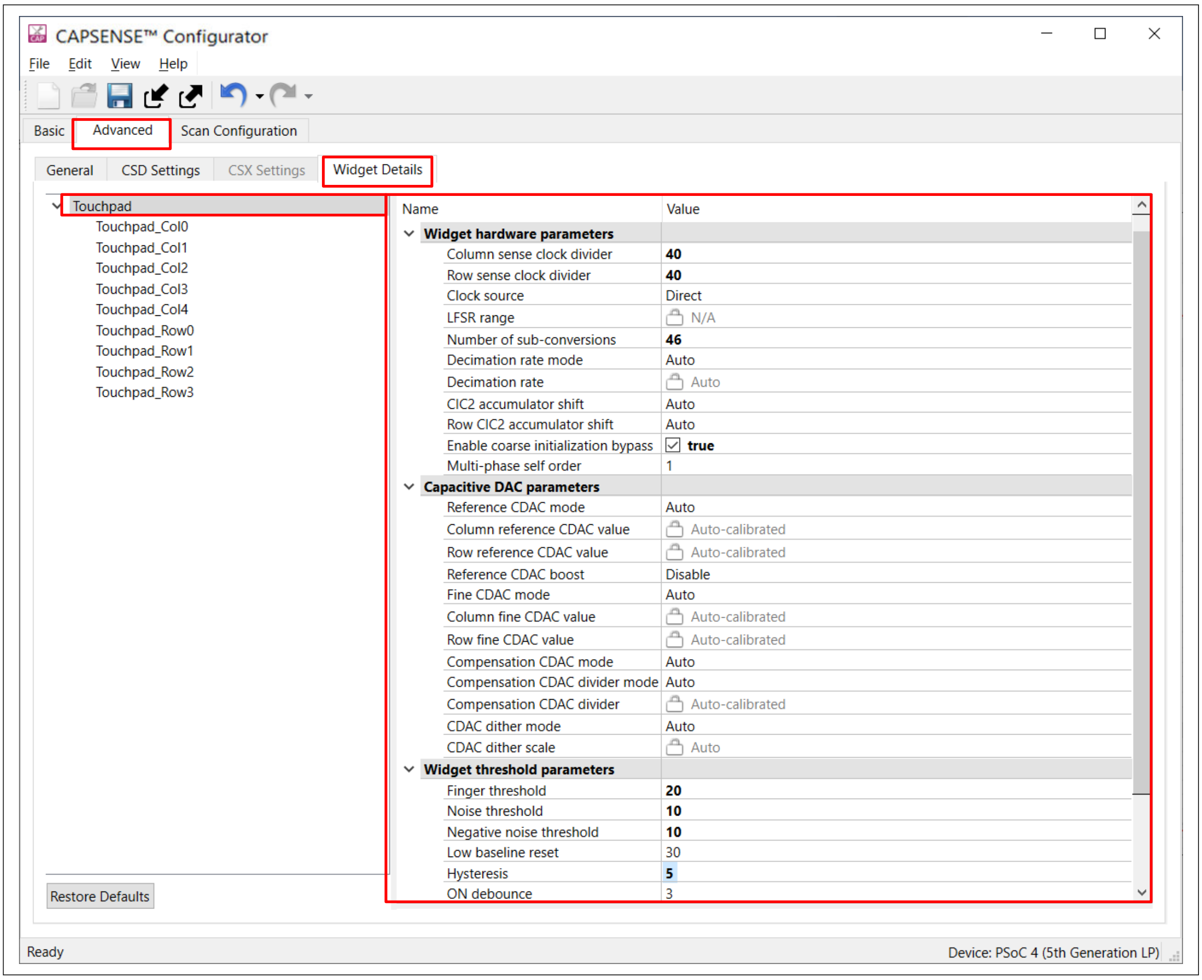


Figure 44 CAPSENSE™ configurator – Advanced widget details

See the following table that lists the parameters for the widget details tab along with their recommended values.

Table 7 Widget Details tab tuning parameters

Parameter	Description	Recommended values
Sense clock divider	Divider to the system clock (IMO clock frequency); the resulting clock is used to drive the sensor.	Set the divider such that the resulting sense clock frequency ensures proper charging and discharging of the sensor/shield electrodes.
Clock Source	Source of the clock to be used for CAPSENSE™. There are three sources available:	Recommended using direct clock

(table continues...)

Table 7 (continued) Widget Details tab tuning parameters

Parameter	Description	Recommended values
Number of sub conversions (N_{SUB})	The number of sub-conversions decides the sensitivity of the sensor and sensor scan time. For a fixed modulator clock and Sense clock, increasing the number of sub-conversions (N_{SUB}) increases the signal and SNR. However, increasing the number of sub-conversions also increases the scan time of the sensor by the following equation: $Scan\ time = \frac{N_{SUB}}{\text{Sense clock frequency}}$	Maximize this parameter till the point where SNR is >= 5:1, diff count is at least 50 and response time does not feel delayed. Minimize N_{SUB} to reduce power consumption.
Decimation rate (CIC2) (5th Gen CAPSENSE™)	Decimation rate or down sampling rate of CIC logic is calculated by the following equation: $Decimation\ rate = FLOOR\left\lfloor \frac{Sns\_Clk\_Div\ {*}Nsub}{3} \right\rfloor$	Auto
CIC2 accumulator shift (5th Gen CAPSENSE™)	Represents CIC2 hardware divider used to divide output raw count. Refer “CIC2 filter” section of AN234231 - Achieving lowest-power capacitive sensing with PSOC™ 4000T	Auto
Reference CDAC mode	This feature enables the firmware to automatically calibrate the CDAC (at initialization) to achieve the required calibration target of 85%.	Auto
Reference CDAC boost	This feature will help increasing the sensitivity.	Disable unless you want to increase the sensitivity based on use case.
Fine CDAC mode	It is a programmable CDAC, which is used to achieve finer resolution for the reference CDAC.	Auto
Enabling Compensation CDAC	The compensation capacitor is used to compensate excess capacitance from the sensor to increase the sensitivity. Enabling this results in increased signal. Enabling compensation CDAC ensures that the sensitivities of row/column electrodes of a touchpad are similar.	Compensation CDAC is recommended to be Auto for most cases unless the Cp is too low.
Enable CDAC Dither	As the input capacitance is swept, the raw count should increase linearly with capacitance. There are regions where the raw count does not change linearly with input capacitance these are called flat-spots, see sub-section “Flat-spots” of “CSD-RM sensing method (fifth-generation)”section of AN85951 – PSOC™ 4 and PSOC™ 6 CAPSENSE™ design guide for more details. Dithering helps to reduce flat-spots using a dither CDAC. The dither CDAC adds white noise that moves the conversion point around the flat region.	Auto

(table continues...)

Table 7 (continued) Widget Details tab tuning parameters

Parameter	Description	Recommended values
Finger threshold	Raw count above which CAPSENSE™ Tuner shows a positive result for a touch detected over touchpad.	80 percent of the signal. Signal that gives 5:1 SNR and satisfies conditions mentioned in Touch detection criteria section.
Noise threshold	Raw count limit above which the baseline is not updated. In other words, the baseline remains constant as long as the raw count is above the baseline + noise threshold.	40 percent of the signal
Negative noise threshold	Raw count limit below which the baseline is not updated for the number of samples specified by the low baseline reset parameter.	40 percent of the signal
Low baseline reset	Maximum number of samples above which baseline is reset to current raw count, if the raw count of all these samples is abnormally below the negative noise threshold.	30
Hysteresis	Raw count value is used in conjunction with the finger threshold to prevent the sensor status output from toggling due to system noise. Sensor state is reported: • ON: If the Difference Count > Finger Threshold + Hysteresis • OFF: If the Difference Count < Finger Threshold – Hysteresis	10 percent of the signal
ON debounce	This parameter indicates the number of consecutive CAPSENSE™ scans during which a sensor must be active to generate an ON state from the component. Debounce ensures that high-frequency, high-amplitude noise does not cause false detection.	3
Multi-frequency scan	Enabling multi-frequency scan, the CAPSENSE™ component performs a sensor scan with three different sense clock frequencies and obtains corresponding difference count. The median of the sensor difference-count is selected for further processing.	Use this feature for robust operation in the presence of external noise at a certain sensor scan frequency. See the code example - CE227719 CAPSENSE™ with multi-frequency scan.
Reference CDAC value	Multiplier to internal capacitor (Cref) which is used to measure sensor capacitance. Sensor capacitance is measured by multiple charge transfer cycles using the C_{ref}, more the C_{ref} lesser the number of cycles required and lower the total raw count. Auto calibrated when ‘CDAC auto calibration’ is enabled.	Recommended to set to “Auto-calibrated”.

(table continues...)

Table 7 (continued) Widget Details tab tuning parameters

Parameter	Description	Recommended values
Compensation CDAC divider	Divider to 'Sense clock divider', which decides the number of times the compensation capacitor is switched in a single sense clock. Auto calibrated when 'CDAC auto calibration' is enabled.	Recommended to set to "Auto-calibrated".
Scan resolution (4th Gen CAPSENSE™)	Scan resolution is resolution of the sigma delta converter of CAPSENSE™. Scan resolution defines scan time and sensitivity. Increase in sensitivity increases effective touchpad resolution. It is configurable from 6-bit to 16-bit in 4th Gen CAPSENSE™. For 5th Gen CAPSENSE™, scan resolution is auto calculated based on multiple factors such as Modulator clock, N_{SUB}, sense clock and use of CIC2 filter.	Maximum available (16).

5. Configure pins for the touchpad electrodes in Scan configuration tab. The basic rules for the Scan Order tab for using the CSD-RM Touchpad Widget on multi-channels are as following:

- Scanning in fifth-generation CAPSENSE™ is ordered using slot numbers. In Multi-channel mode, a scan slot represents a group of sensors scanned together. In Single-channel mode, one sensor is scanned per scanning slot
- For CSD-RM touchpad, assign the same slot only to the row or to the column, which avoids the scanning of a row and column element together which will cause cross-talk
- Assign the slot numbers in such a way that there is maximum distance between the sensors with the same slot number
- Do not mix CSD and CSX sensors in a single slot
- Divide touchpad sensors equally between channels to optimize the scan duration
- Ensure that all channels have an equal number of sensors (scans) for "consensus" method to work. If the number of sensors in each channel is not equal, "empty slots" are added to the respective channels
- Ensure that all sensors within a slot have the same sense clock and the same number of sub-conversions

Figure 45 shows an example of slot configuration for an 8x6 CSD-RM touchpad.

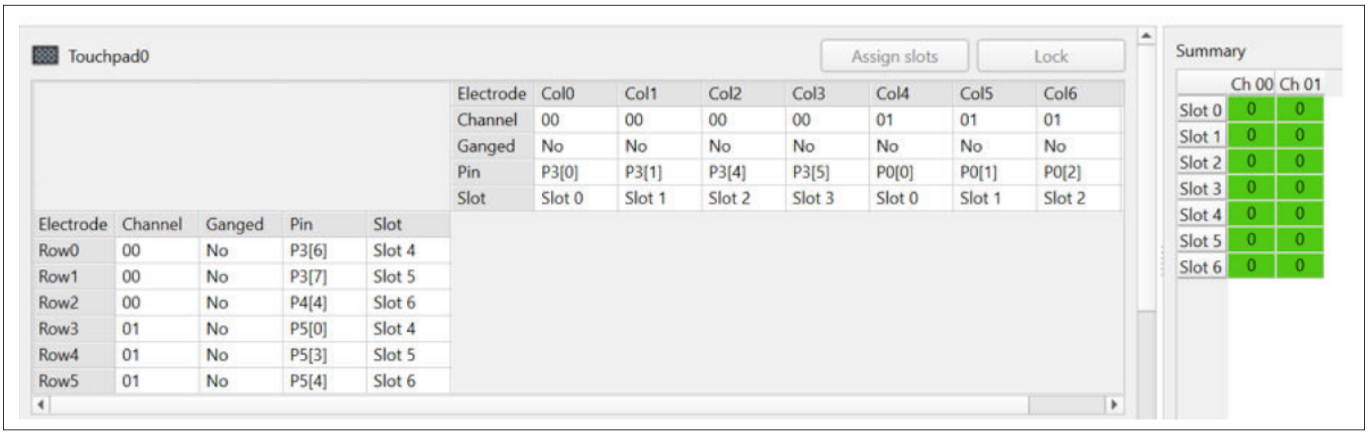


Figure 45 Slot configuration for an 8x6 CSD-RM touchpad

5.1.3 Touch detection criteria

The touch in a CSD touchpad is reported to the host when all the following finger detection criteria are satisfied:

1. Z_peak > FingerThreshold ± Hysteresis
2. Z_peak > (FingerThreshold ± Hysteresis) × Z3_Filt_Scale/2 -> (At panel edge)
3. Z_Peak > (Finger Threshold ± Hysteresis) × Z3_Filt_Scale/4 -> (At panel corner)

Where,

Z_Peak = Maximum signal when the finger is present at the center of the sensor

Z3_sum = Sum of signals of the segment with the maximum signal and two neighboring segments

Z3_Filt_Scale = (0.8 * Z3_Sum)/Finger Threshold

The Z3_Filt_Scale value ensures that the detected object is of the correct proportions.

Z3_sum (of both row and column) condition is checked to see if the absolute mass of the finger is large enough to be recognized as a finger. The Z3_sum condition may prevent noise-induced false touches.

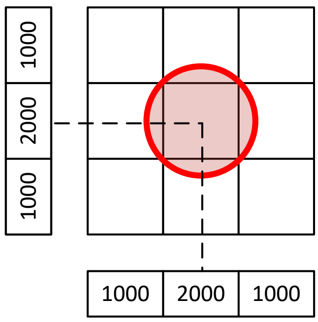


Figure 46 Defining peak

5.2 CSX touchpad widget tuning

A mutual-capacitance-based touchpad widget supports up to three simultaneous finger touches. A slightly different centroid algorithm compared to the CSD touchpad is applied in a CSX touchpad widget.

5.2.1 Finger touch detection algorithm

A 3x3 algorithm is used for calculating the X and Y position using the centroid algorithm as shown in the (4).

$$positionX = \left(\frac{S_{x+1} - S_{x-1}}{S_{3x3}} + x\right) \times \frac{ResolutionX}{(n_x - 1)} \quad (4)$$

CSX touchpad centroid positionX calculation equation

Calculating X-position using centroid algorithm in CSX touchpad.

Where,

ResolutionX = Maximum X-axis position

nx = Number of sensor elements in the X-direction

x = Index of element which gives maximum signal

S_{x+1} = Sum of three neighboring elements at the left from maximum (x)

S_{x-1} = Sum of three neighboring elements at the right from maximum (x)

S_{3x3} = Total sum of 3x3 difference array

$$positionY = \left(\frac{S_{y+1} - S_{y-1}}{S_{3x3}} + y \right) \times \frac{ResolutionY}{(n_y - 1)} \quad (5)$$

CSX touchpad centroid positionY calculation equation

Calculating Y-position using centroid algorithm in CSX touchpad.

Where,

ResolutionY = Maximum Y-axis position

ny = Number of sensor elements in the Y-direction

y = Index of element which gives maximum signal

S_{y+1} = Sum of three neighboring elements at the top from maximum (y)

S_{y-1} = Sum of three neighboring elements at the bottom from maximum (y)

5.2.2 CSX touchpad widget tuning

Figure 47 shows an overview of the manual tuning procedure for CSX touchpad, for a detailed step-by-step procedure see the PSOC™ 4: MSCLP multitouch mutual-capacitance touchpad tuning code example.

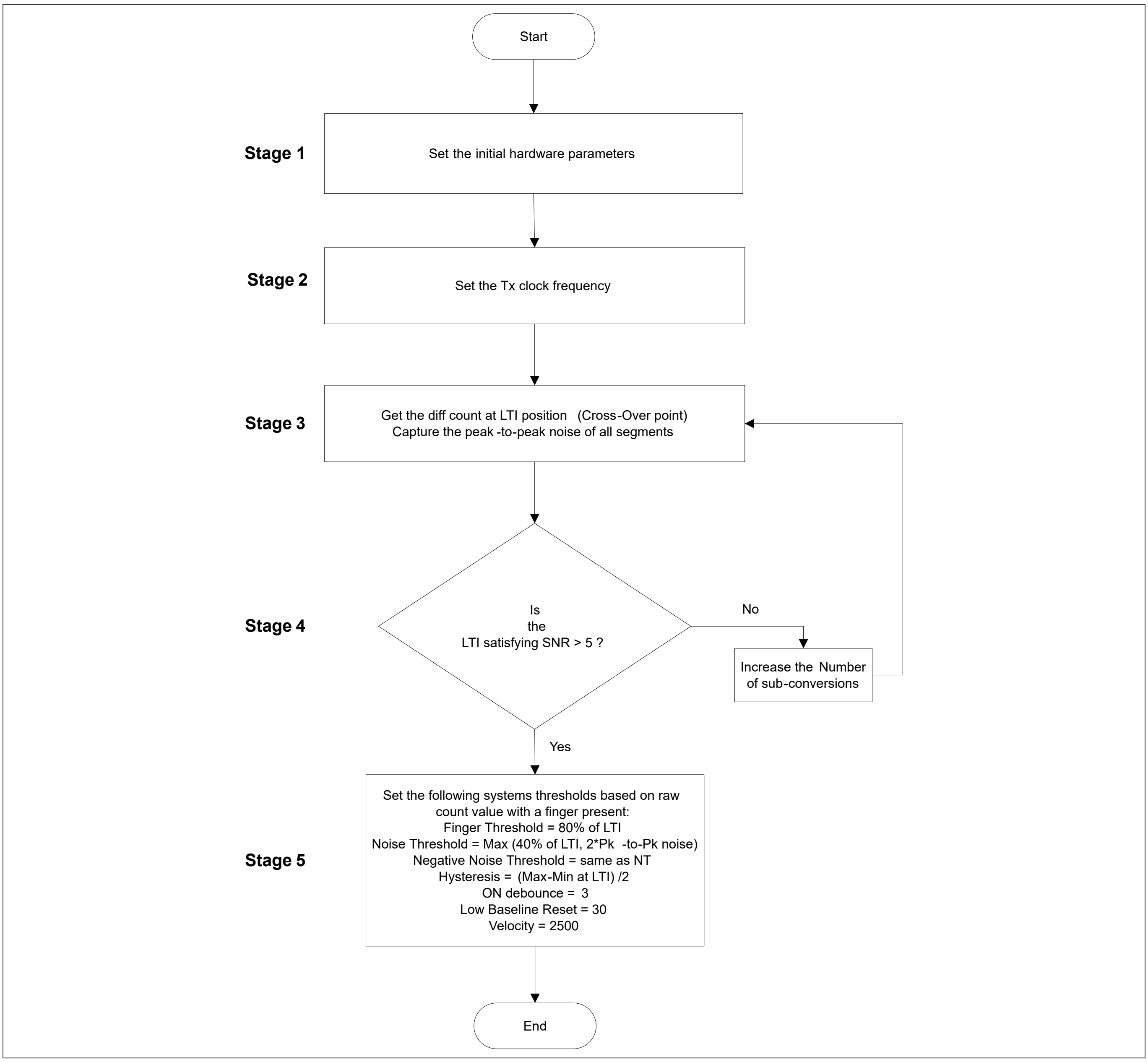


Figure 47 CSX manual tuning flowchart

Most of the steps to tune the CSX touchpad widget are same as CSD touchpad tuning steps as mentioned in CSD touchpad widget tuning section. The following steps differ from CSD touchpad widget tuning:

1. In the Basic tab, add a 'Touchpad' widget and configure it in CSX RM (mutual-cap) sensing mode

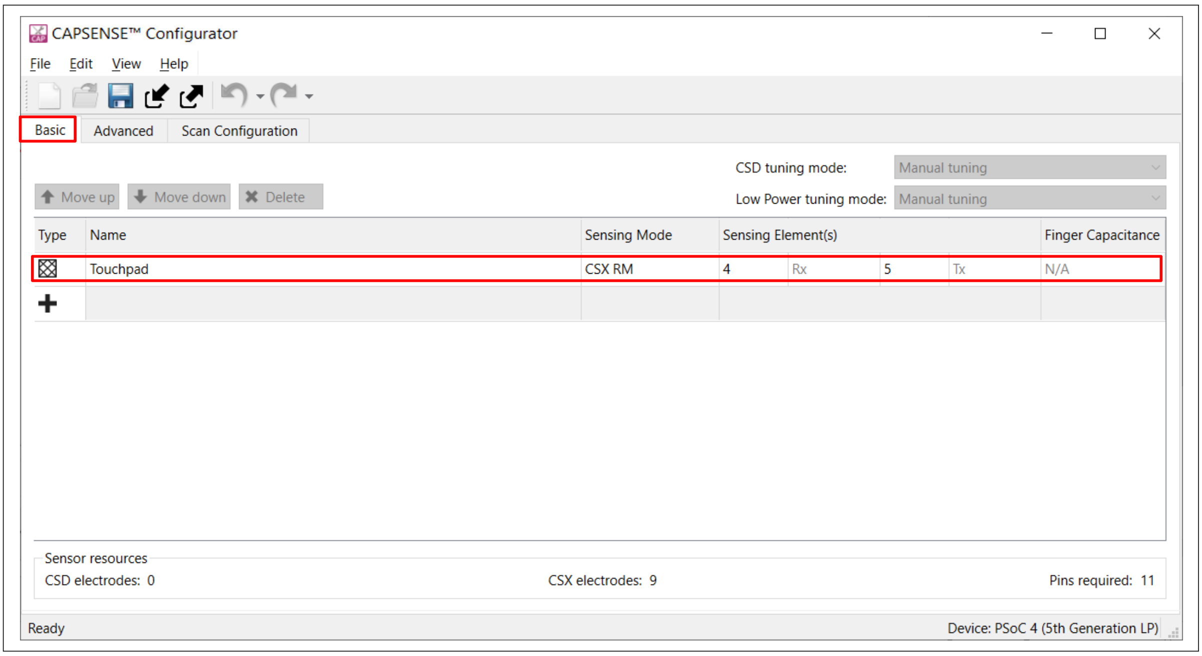


Figure 48 **CAPSENSE™ configurator – Basic tab**

2. Set touchpad parameters in the CSX Settings tab

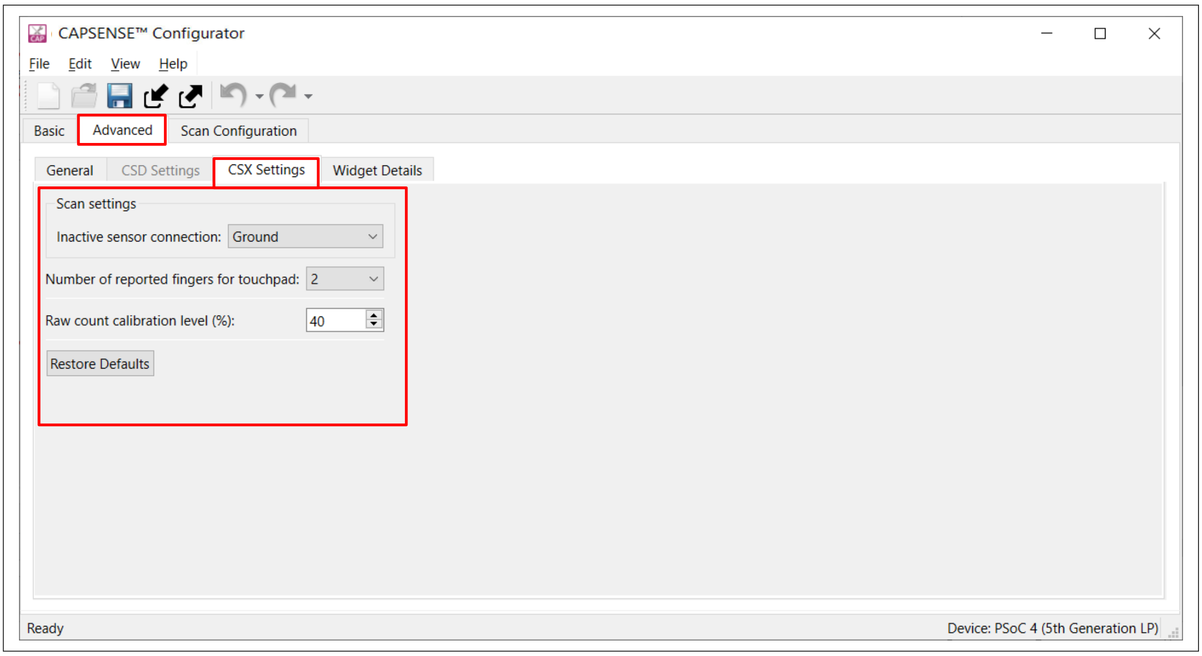


Figure 49 **CAPSENSE™ configurator – Advanced CSX settings**

See the following table that lists the parameters for CSX settings tab along with their recommended values.

Table 8 CSX settings tab tuning parameters

Parameter	Description	Recommended values
Inactive sensor connection	Inactive sensors connected to Shield provide better performance in terms of SNR and refresh rate (as the use of shield results in reduction of sensor Cp) and can also be used if your design requires liquid tolerance. However, there is a risk of higher radiated emission due to inactive sensors getting connected to Shield.	Ground
Number of reported fingers for touchpad	Number of fingers that can be detected using the CSX touchpad.	2

3. Configure pins for the touchpad electrodes in Scan configuration tab. Rules for the Scan Order tab for CSX widget when multi-channels are enabled are as follows:

- Scanning in fifth-generation CAPSENSE™ is ordered using slot numbers. A single slot number can be assigned to one sensor in all the channels; scanning that particular slot scans all the sensors in that slot in sync
- Assign the slot numbers in such a way that there is a maximum distance between the Rx electrode with the same slot number; therefore, avoiding any potential cross-talk
- Assign the Tx and Rx electrodes of a sensor to two different channels or the same channel. The sensor belongs to the channel where the sensor Rx electrode is connected
- Divide the Rx electrodes equally between channels to optimize the scan duration
- Note that any channel can generate the Tx signal for all channels
- Assign the Tx electrodes in any order between channels.
- Ensure that all channels have an equal number of sensors (scans) for “consensus” method to work. If the number of scans in each channel is not equal, “empty slots” are added to the respective channels
- Do not mix CSD and CSX sensors in a single slot
- Ensure that all sensors within a slot have the same sense clock and the same number of sub-conversions

Figure 50 shows an example of slot configuration for an 8x6 CSX-RM touchpad.

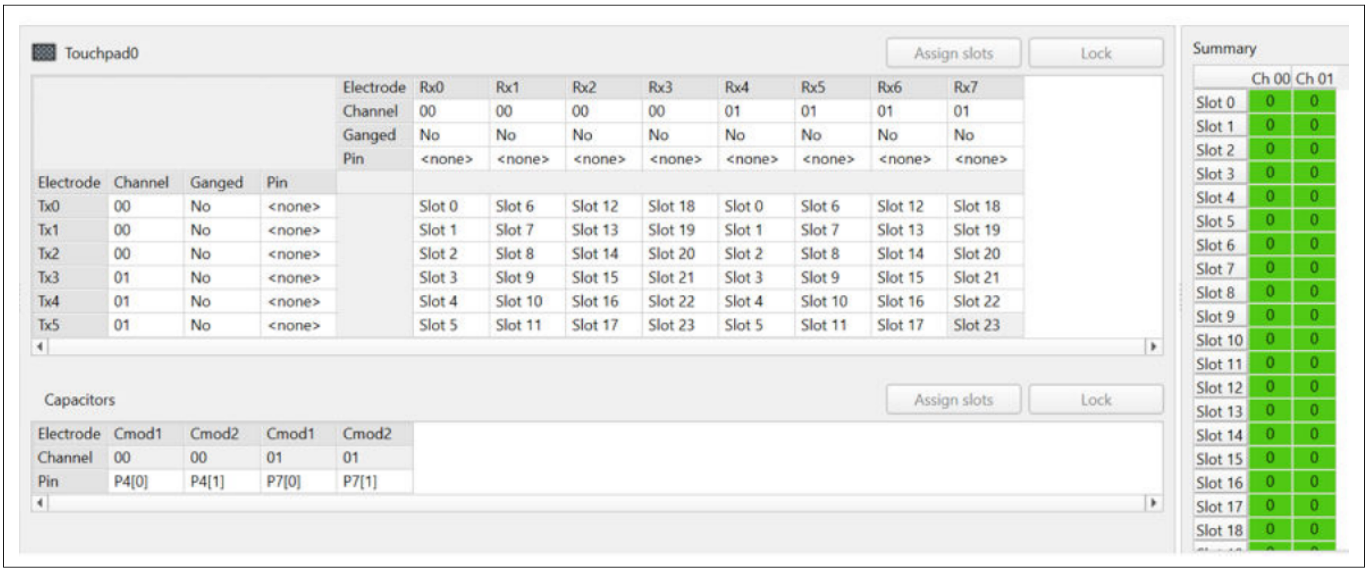


Figure 50 **Slot configuration for an 8x6 CSX-RM touchpad**

5.2.3 CSX finger detection criteria

The touch in a CSX touchpad is reported to the host when all the following finger detection criteria are satisfied:

- Z_Peak > Finger threshold ± Hysteresis
- Z9_Sum condition
  - Z9_Sum > ((Finger threshold + Hysteresis) * Z9_Filt_Scale) (At panel core)
  - Z9_Sum > ((Finger threshold + Hysteresis) * Z9_Filt_Scale/2) (At panel edge)
  - Z9_Sum > ((Finger threshold + Hysteresis) * Z9_Filt_Scale/4) (At panel corner)
- Z8_sum condition
  - Z8_sum > Z_peak * Z8_Filt_Scale (At panel core)
  - Z8_sum > Z_peak * Z8_Filt_Scale/2 (At panel edge)
  - Z8_sum > Z_peak * Z8_Filt_Scale/4 (At panel corner)

Where,

Z_peak = Maximum signal obtained; 2000 and 250 in the example.

Z9_sum = Total sum of 3x3 difference array, i.e., the sum of the peak and the eight surrounding sensors; 3600 and 1000 in the example

Z8_sum = Z9_Sum – Z_peak, i.e. sum of the peak's eight surrounding sensors, but not including the peak; 1600 and 750 in the example

Z9_Filt_Scale = (0.8 * Z9_Sum)/Finger threshold

Z8_Filt_Scale = (0.8 * Z8_Sum)/Finger threshold

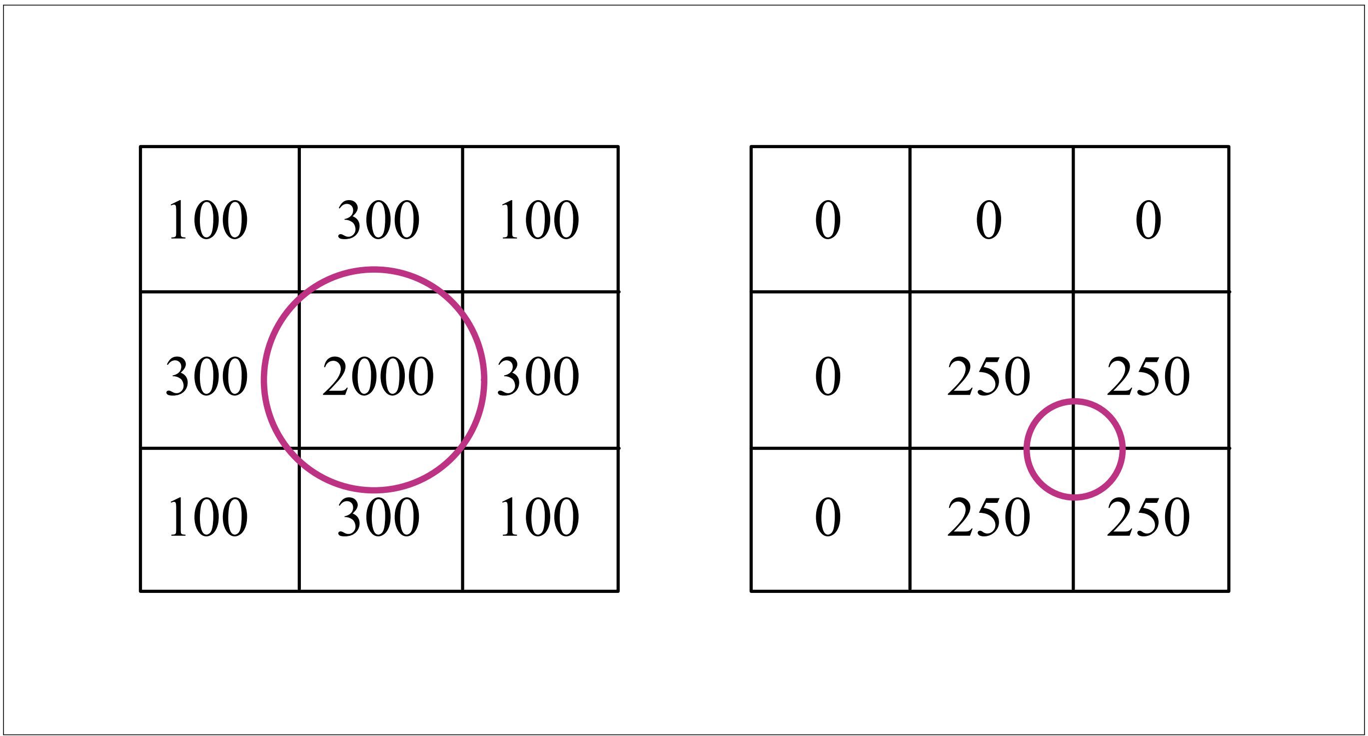


Figure 51 **Defining peak**

These values ensure that the detected object is of the correct proportions.

- Z8_sum condition is checked to see if the relative mass of the finger is large enough to be recognized as a finger. This is done to discard very high noise in a segment when the neighboring sensors have no signal detected
- Z9_sum condition is checked to see if the absolute mass of the finger is large enough to be recognized as a finger. Similar to the Z8 condition, the Z9 condition may prevent noise-induced false touches

5.3 PSOC™ 4100T PLUS device

The general guidelines discussed in the document are being used for a bigger touchpad (17x10). Figure 52 and Figure 53 shows high-level layout diagrams of the top and bottom layers of a board using PSOC™ 4100T PLUS chips.

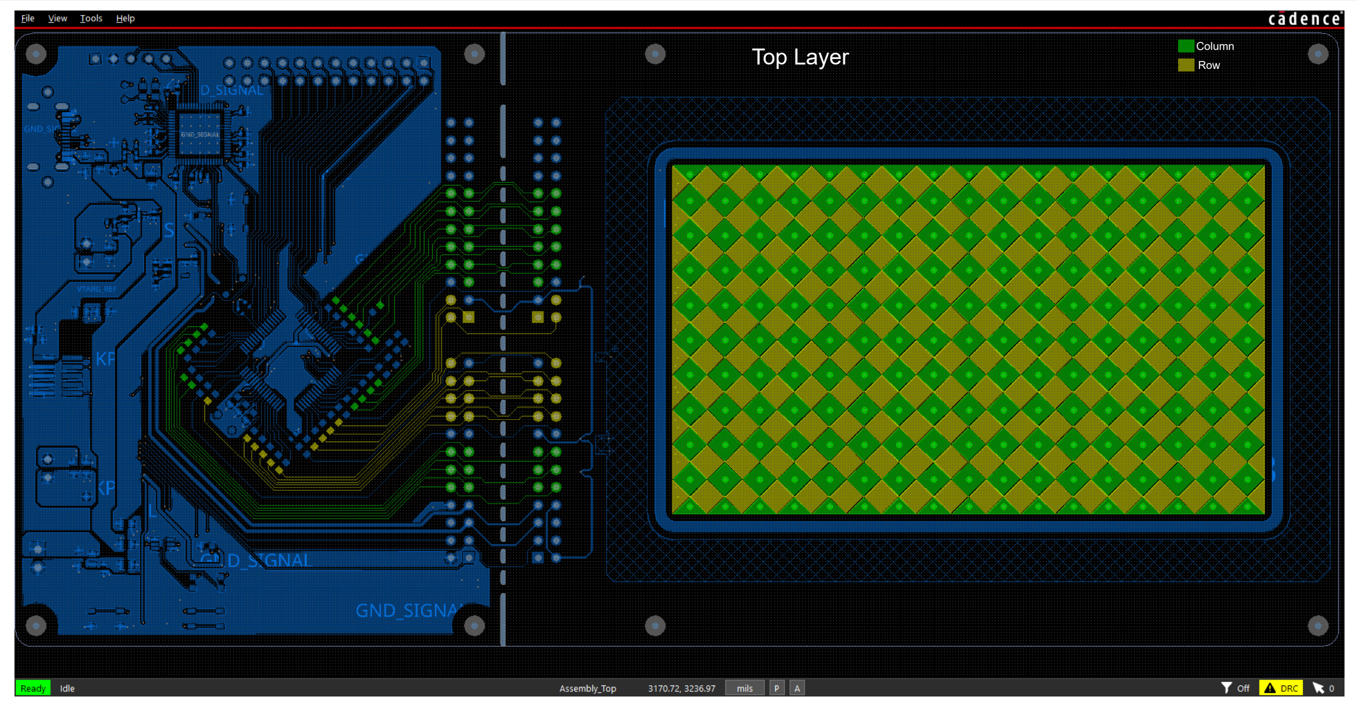


Figure 52 **PCB top layer layout**

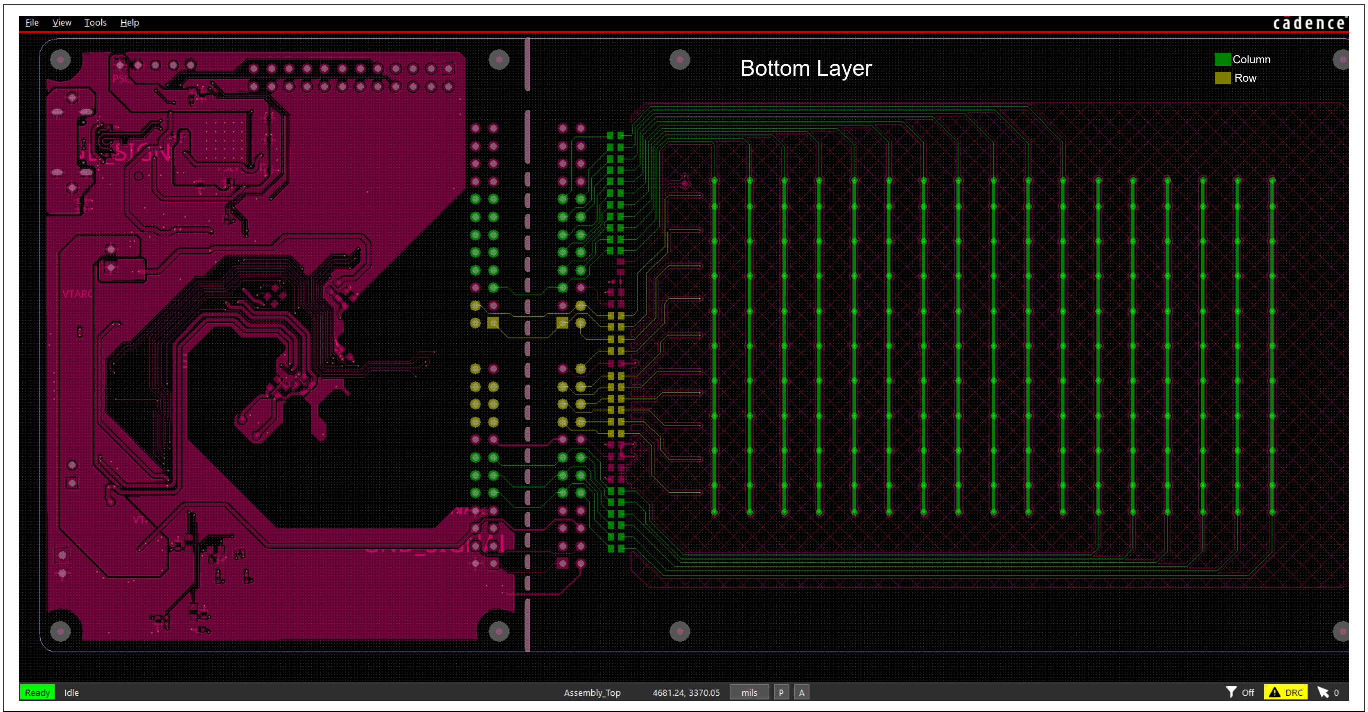


Figure 53 **PCB bottom layer layout**

To minimize crosstalk between adjacent traces, maintain a minimum spacing of two times the trace width, as mentioned in the section "Trace length and width" of AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide. The Figure 54 shows the incorporation of a ground trace between rows and columns, which helps to reduce cross-coupling between them. Deviation from this guideline can result in an increased variation between parasitic and mutual capacitance, which can cause calibration errors. Analyze and mitigate capacitance variations in the design using tools like CapExt before production.

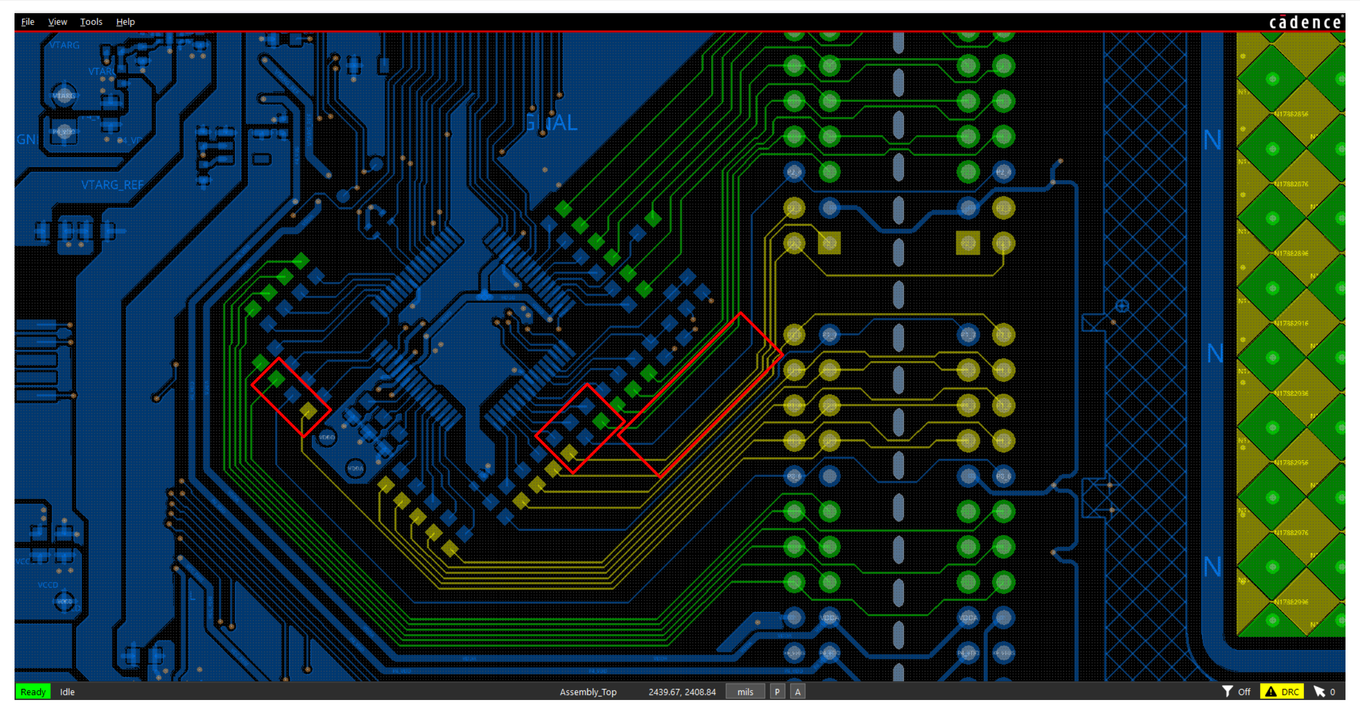


Figure 54 **Spacing between rows and columns**

6 CSX multi-phase TX (MPTX)

Capacitive sensing refers to sensing technology where changes in capacitance are measured to detect an event. CAPSENSE™ controllers from Infineon are designed to measure changes in capacitance to detect the presence of a finger on or near a sensor. This is accomplished with measuring the sensor capacitance by exciting it using a signal. The characteristics of this signal and how the sensors in the system are scanned can have a significant effect on the SNR.

The technique described in this section offers a way to increase SNR over the traditional CSX method and can also be employed to suppress common mode noise, white noise, e.g., LCD noise, to a certain extent.

6.1 What is multi-phase capacitive sensing?

It refers to differential measurement of the target sensor capacitance with respect to the rest of the sensors present in the system, therefore, it requires more than one sensor to work at a time. Typical applications are keypad matrix and touchscreens.

Note: *For self-capacitance, another technique called multi-phase self-cap differential (MPSC-D) is used. See section "CAPSENSE™ multi-phase scanning method" of* AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide *for more details.*

6.1.1 Working of mutual-capacitance (CSX)

In regular (CSX) scanning, each node (cross section of Tx and Rx) is scanned independently. The scanned result is a raw count that corresponds to the mutual-capacitance of the scanned node. To scan all nodes that belong to one Rx electrode, several scans are performed which are equal to the number of Tx electrodes.

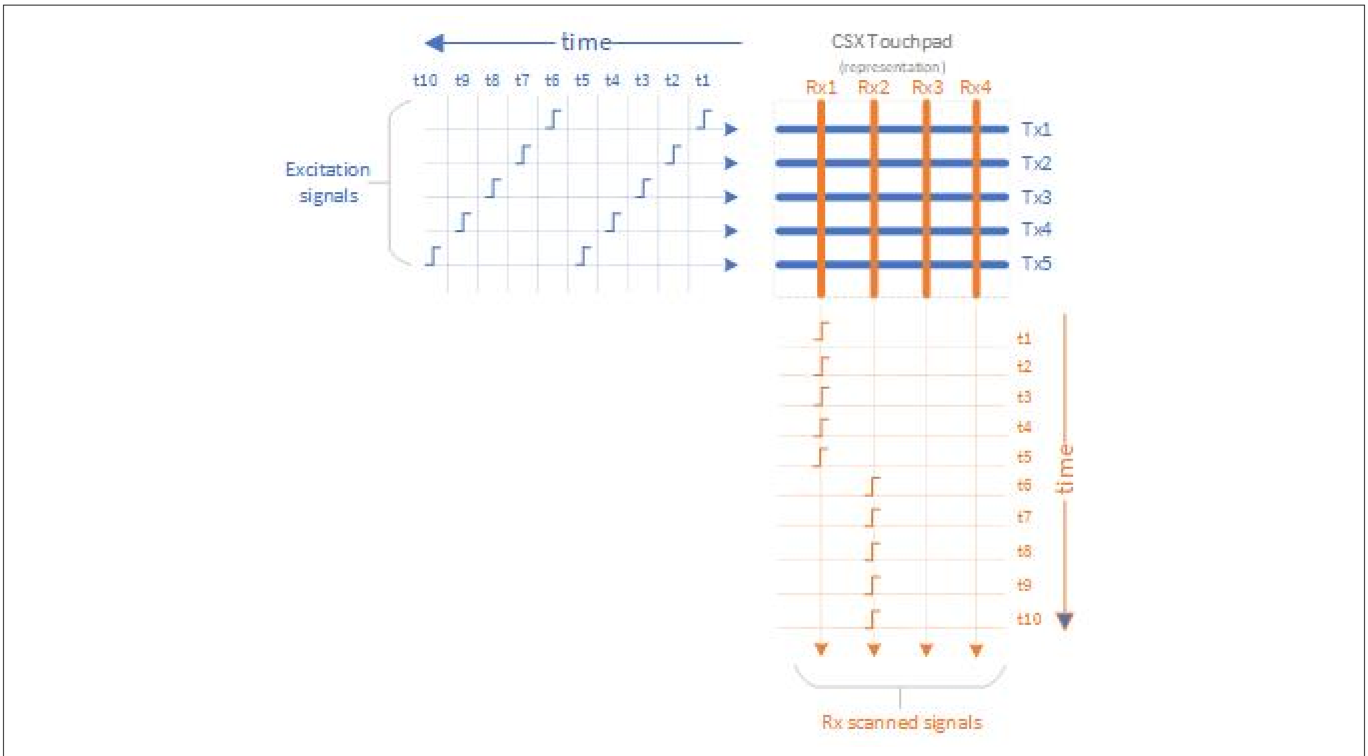


Figure 55 **Conventional CSX scanning technique**

6.1.2 Working of MPTX

Multi-phase TX is a technique used for mutual-capacitance sensing where multiple Tx electrodes are driven simultaneously with modulated patterns by the firmware and the result then deconvoluted. The advantage is higher SNR as MPTX performs spatial filtering of the result with $\sqrt{(N_{Tx})}$ improvement in noise, where N_{Tx} are the number of Tx electrodes driven and the scan is performed for N_{Tx} times longer than a single sensor scan.

In multi-phase Tx mode, multiple Tx electrodes are driven simultaneously for each Rx, meaning multiple nodes on a Rx electrode are scanned at once. The number of Tx electrodes scanned simultaneously is defined by MPTX order. The scan is repeated several times on each Rx electrode. The multi-phase order defines the number of scans repeated. Therefore, the total scan duration is the same as for the normal scanning. However, each node is scanned longer (depending on the multi-phase order) resulting in increased integration time and in turn reduction in white noise by $\sqrt{(N_{MPTX})}$ times, where 'N_{MPTX}' is a multi-phase order. Alternatively, the scan time can be reduced, keeping the SNR unchanged.

Tx electrode in MPTX mode could be driven directly (positive) or with an inverted (negative) phase signal. A predefined sequence decides the phase of the Tx electrode for each excitation. A higher multi-phase order increases the benefit of using the MPTX method.

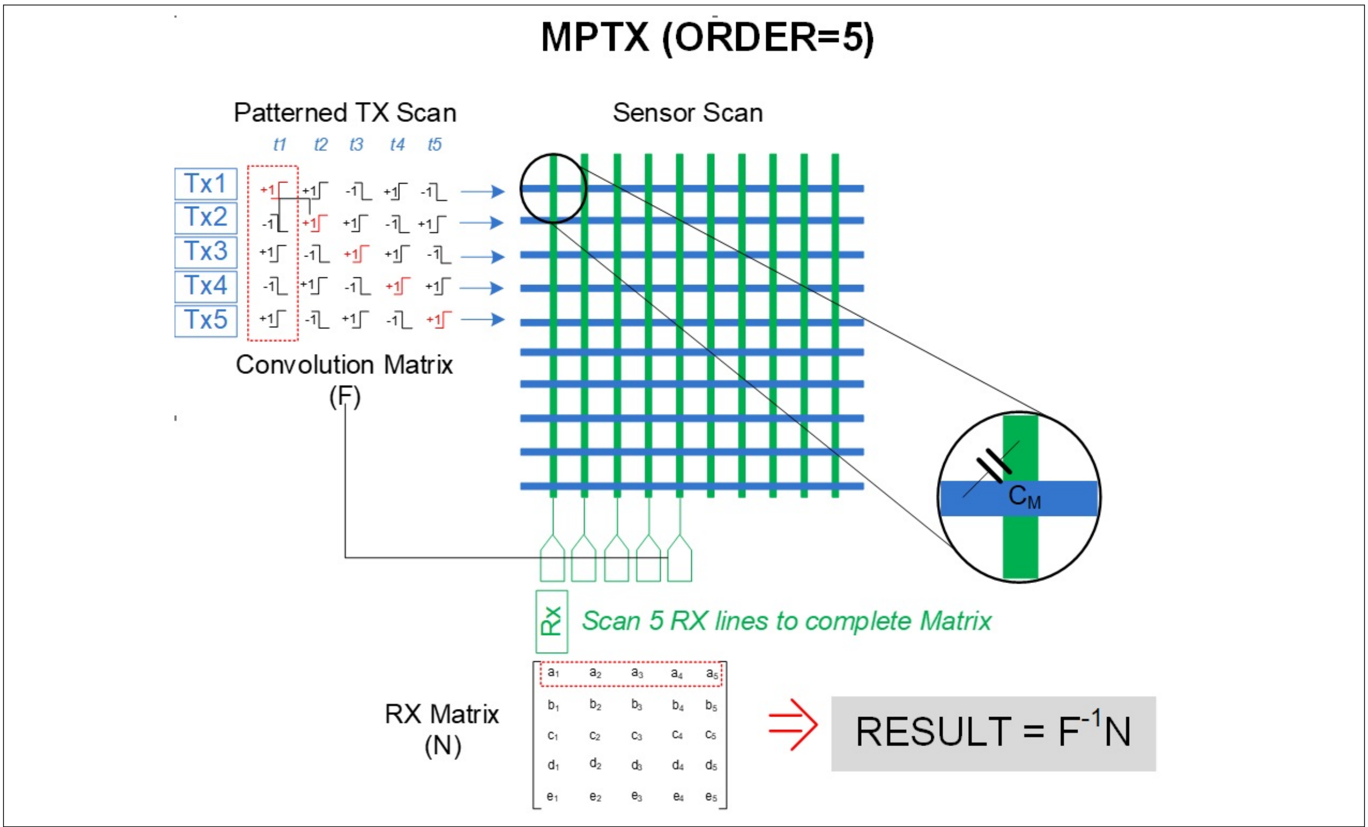


Figure 56 MPTX scanning technique

Raw counts achieved are convoluted with the excitation matrix used for Tx electrodes. As the Tx excitation convolution sequence is known, the signal for each sensor is calculated using deconvolution.

6.2 Advantages

The MPTX technique offers a number of advantages over the regular single-phase CSX techniques as follows:

Improved SNR

The MPTX technique provides a theoretical improvement in SNR by the multiple of $\sqrt{(N_{MPTX})}$ for white noise, where N_{MPTX} is the multi-phase order.

Figure 57 (SNR = 6.69 without MPTX) and Figure 58 (SNR = 9.96 with MPTX5) show the SNR improvement obtained in practice with the CYC8KIT-040T kit and a CSX touchpad configured with an MPTX order of 5 (MPTX5). This comparison shows the SNR improvement of approximately 50%.

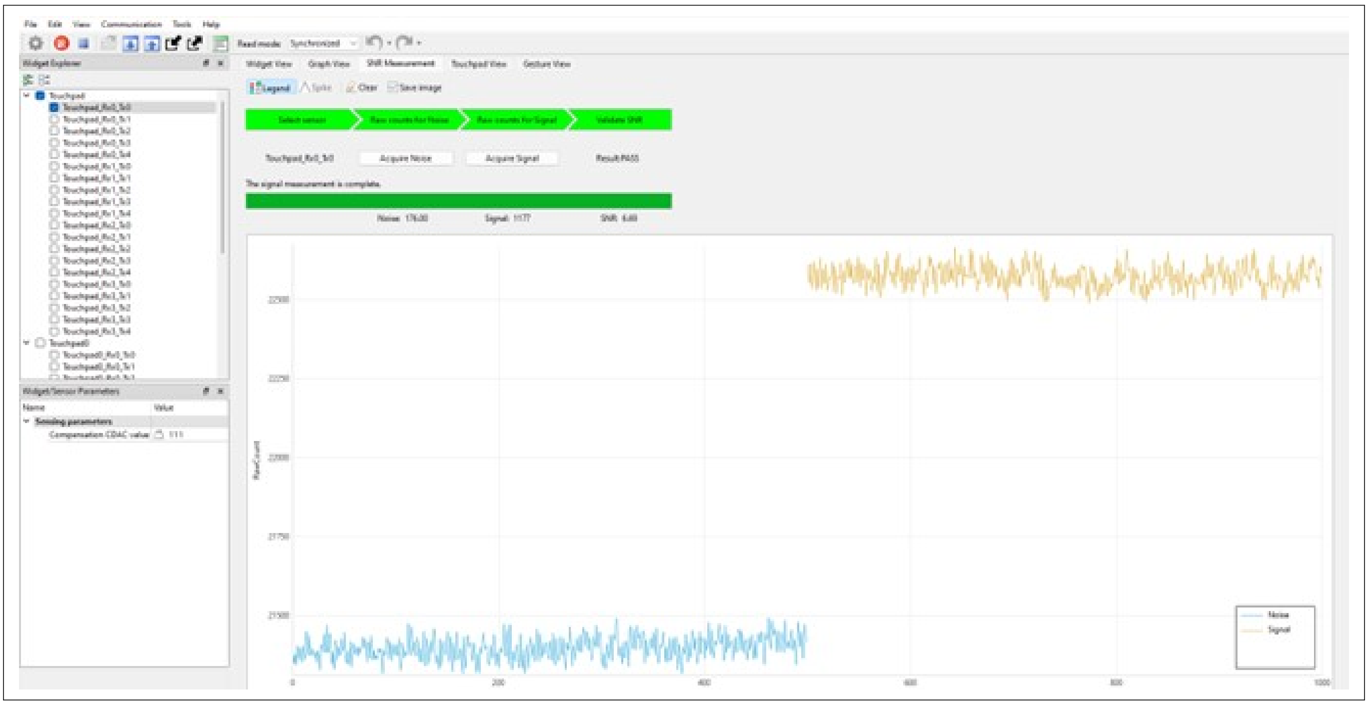


Figure 57 CY8CKIT-040T kit SNR without MPTX

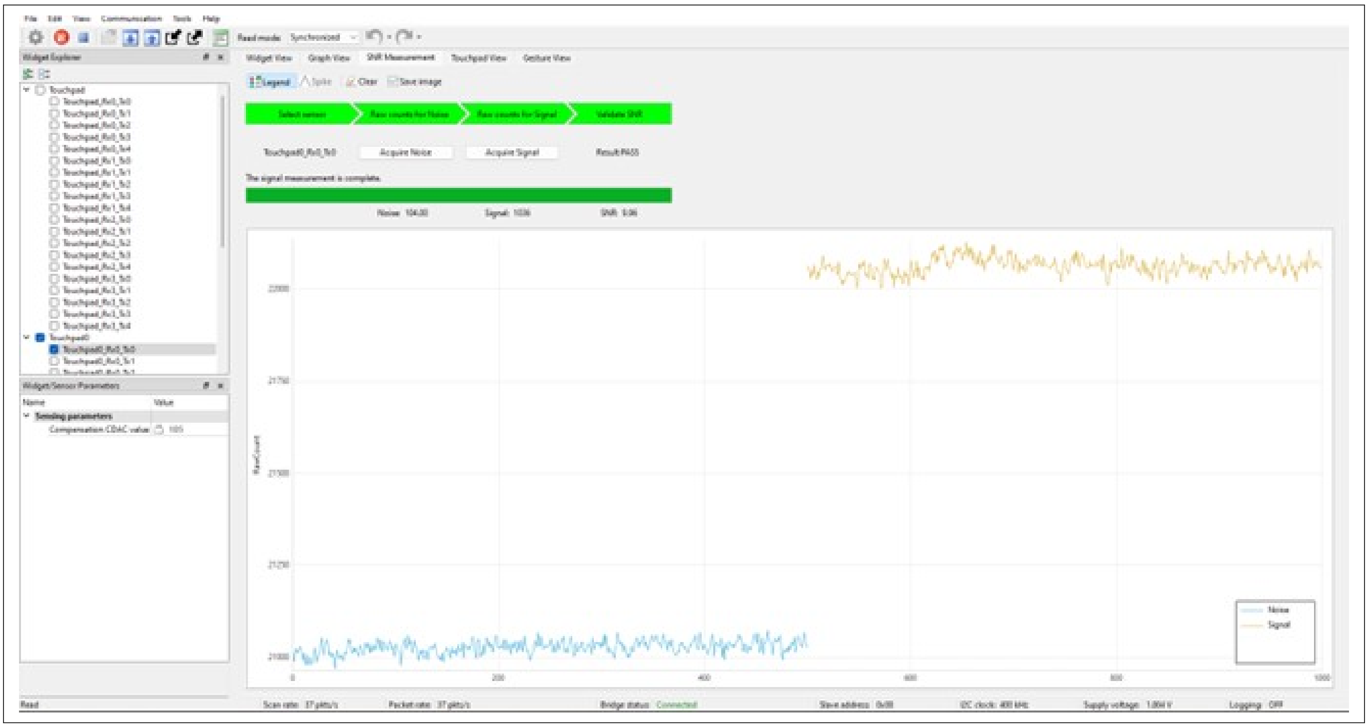


Figure 58 CY8CKIT-040T kit SNR with MPTX

Noise reduction

The MPTX technique described above helps in suppressing common mode noise, e.g., white noise, LCD noise.

6.3 Limitations of MPTX

Increased power consumption

Enabling MPTX results in increased power consumption due to driving multiple Tx electrodes at the same time. The Tx and Rx currents can be calculated as follows:

- **Tx current** = Approx. $N_{TX} \times I_{TX}$, (N_{Tx} = number of Tx, I_{TX} = Tx current with regular CSX technique)
- **Rx current** >= $2 \times I_{RX}$, (I_{RX} = Rx current with regular CSX technique)

For a touchpad with Tx = 5 and Rx = 4 on the CYC8KIT-040T device, a comparison of the overall current consumption is:

- 8.51 mA without MPTX
- 8.77 mA with MPTX5

Additional computing

As described earlier, MPTX employs convolution and deconvolution methods that require additional computing consisting of multiply accumulate type deconvolution operations ($N_{Tx}*N_{Rx}^2$).

The process time measured in practice for the touchpad widget on the CYC8KIT-040T kit with Tx = 5 and Rx = 4 shows:

- 127 µs without MPTX
- 224 µs with MPTX5

Where the configuration for the measurement is as follows:

- Source clock = IMO 46 MHz
- F_{MOD} = 46 MHz
- Tx Clock divider = 20
- N_{SUB} = 255

Tail effect

As the scan duration is very long, a slow moving finger across the panel can lead to a tail effect that is the finger will be detected/observed on several previously scanned Rx lines.

6.4 Implementing MPTX

The MPTX technique can be used with any CSX widget with more than three Tx electrodes. As MPTX is not beneficial for CSX widgets with less than four electrodes, the MPTX is not supported for those configurations.

To use MPTX, a touchpad widget can be added as shown in the following figure with the number of Tx electrodes greater than three.

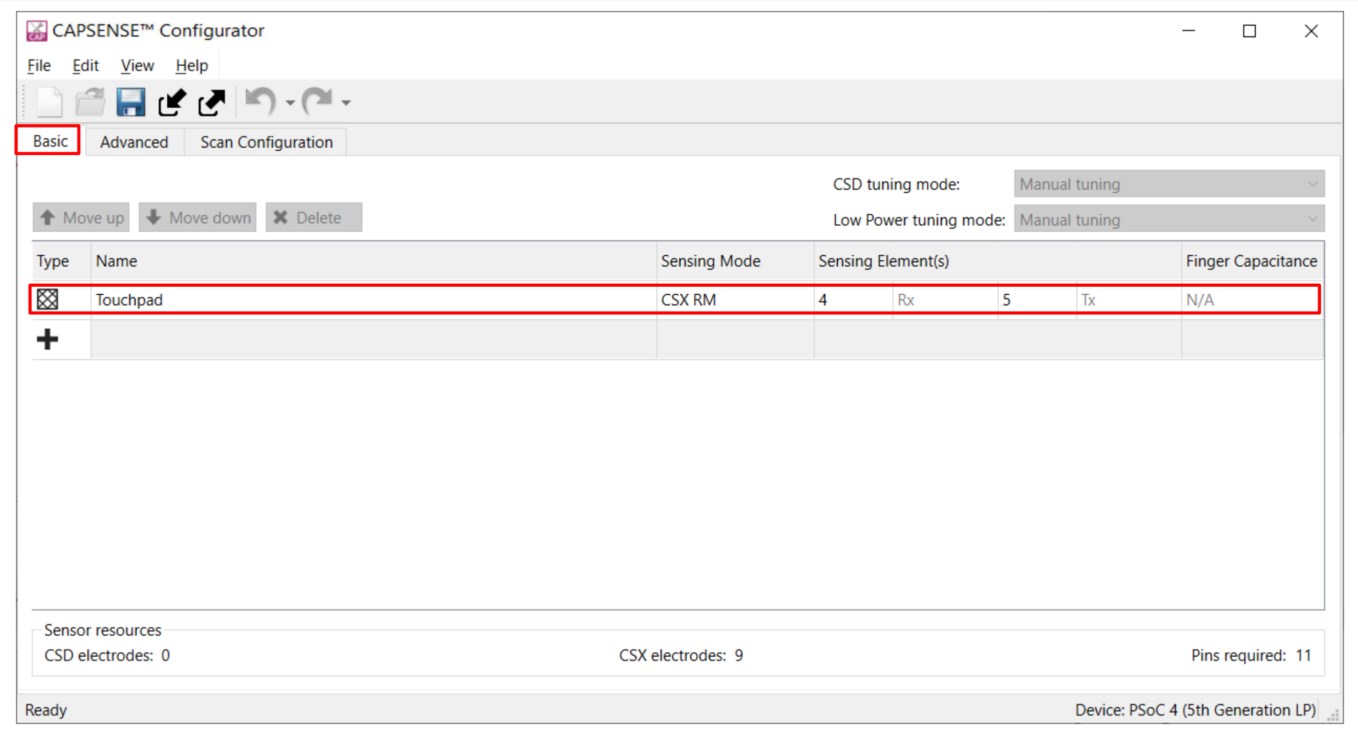


Figure 59 **Adding CSX touchpad in CAPSENSE™ Configurator**

Each CSX widget with more than three Tx electrodes has a parameter called "MPTX Order" that is set to '1' by default, meaning multi-phase Tx is disabled. The number of Tx electrodes involved in the scanning defines the MPTX order. For a given CSX widget, the **Multi-phase Tx order** can be set to equal the number of Tx electrodes or to a factor of that number, e.g., if the number of Tx electrodes N_{Tx} = 12, the MPTX order can be set to 4, 6, or 12.

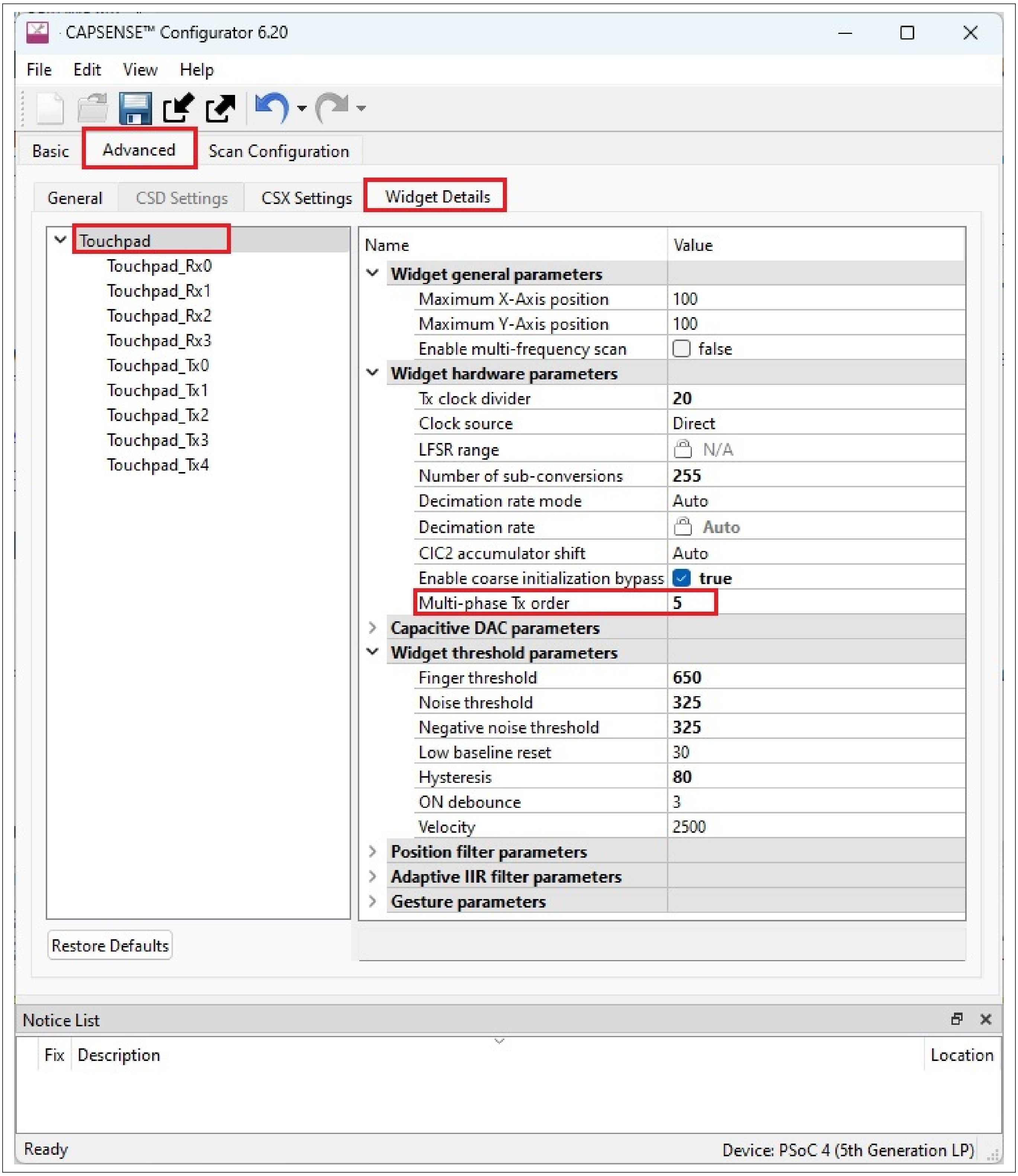


Figure 60 **Enabling the MPTX in the configuration**

With the **Multi-phase Tx order** set to the number of Tx electrodes or factor of number of Tx electrodes, the MPTX will be enabled in the system.

There are no specific hardware design guidelines other than those applicable to CAPSENSE™ CSX techniques, which need to be followed for the MPTX implementation.

***Note**: The average raw count without touch (baseline raw count) value for even MPTX order will be 50% of the equivalent regular CSX widget baseline raw count value (without MPTX enabled).*

References

[1] AN85951 - PSOC™ 4 and PSOC™ 6 MCU CAPSENSE™ design guide

[2] AN 79953 – Getting started with PSOC™ 4 MCU

[3] AN72845 – Design guidelines for Infineon quad flat no-lead (QFN) packaged devices

[4] AN86233 – PSOC™ 4 low-power modes and power reduction techniques

[5] AN80994 – Design considerations for electrical fast transient (EFT) immunity

[6] AN57821 – PSOC™ 3, PSOC™ 4, and PSOC™ 5LP mixed-signal circuit board layout considerations

[7] AN88619 - PSOC™ 4 MCU hardware design considerations

[8] PSOC™ 4 application notes

[9] PSOC™ 4 device datasheets

[10] PSOC™ 4 reference manuals

The PSOC™ 4 kit schematics are good examples of how to incorporate PSOC™ into board schematics. It may be helpful to review the following kit schematics:

[1] CY8CKIT-040 – PSOC™ 4000 Pioneer Kit

[2] CY8CKIT-041-41XX – PSOC™ 4100S CAPSENSE™ Pioneer Kit

[3] CY8CKIT-0 42 – PSOC™ 4200 Pioneer Kit

[4] CY8CKIT-042-BLE – PSOC™ 4200 Bluetooth® LE Pioneer Kit

[5] CY8CKIT-044 – PSOC™ 4200M Pioneer Kit

[6] CY8CKIT-043 – PSOC™ 4200M Prototyping Kit

[7] CY8CKIT-045S - PSOC™ 4500S Pioneer Kit

[8] CY8CKIT-046 – PSOC™ 4200L Pioneer Kit

[9] CY8CKIT-147 – PSOC™ 4100PS Prototyping Kit

[10] CY8CKIT-149 – PSOC™ 4100S Plus Prototyping Kit

[11] CY8CKIT-041S-MAX - PSOC™ 4100S Max Pioneer Kit

[12] CY8CKIT-148 – PSOC™ 4700S Inductive Sensing Evaluation Kit

[13] CY8CKIT-148-COIL Inductive Sensing Coil Breakout Board

Revision history

Document revision	Date	Description of changes
**	2023-07-26	Initial release
*A	2024-04-10	Updated template Updated for middleware 5.0 and ModusToolbox™ 3.2 Added section CSX multi-phase TX (MPTX)
*B	2025-04-04	Added section AMUX splitter switch noise Added section PSOC™ 4100T PLUS device Updated Figure 8 Added a note in What is multi-phase capacitive sensing?
*C	2025-09-24	Updated section Assign Tx or Rx electrodes to X or Y axis
*D	2025-10-31	Updated hyperlink reference

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