Capsense Design Guide Learnings

Presented by: Volansys HW (Chintan)

Getting started with Capsense Design Guideline

1. Capsense Technology

2. Design Considerations

Reference Document:-

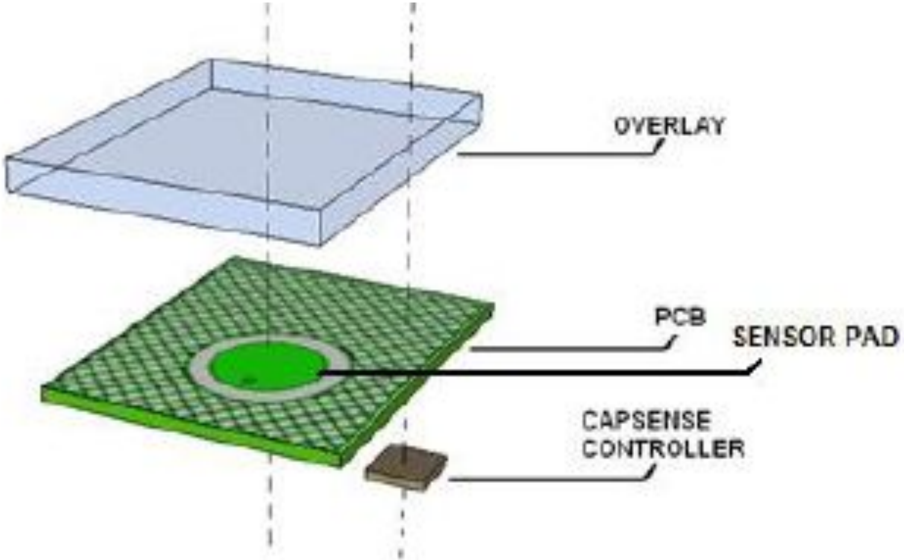
1. **Capsense Design Guideline**
   https://www.infineon.com/dgdl/Infineon-AN64846_Getting_Started_with_CapSense-ApplicationNotes-v26_00-EN.pdf?fileId=8ac78c8c7cdc391c017d071c431e2179&utm_source=cypress&utm_medium=referral&utm_campaign=202110_globe_en_all_integration-application_note

2. **Capsense Design Toolbox**
   https://docs.google.com/spreadsheets/d/1Hg7nS35glb6t3EacXO1DzMQoC67ktqi2/edit#gid=1791189624

1. Capsense Technology

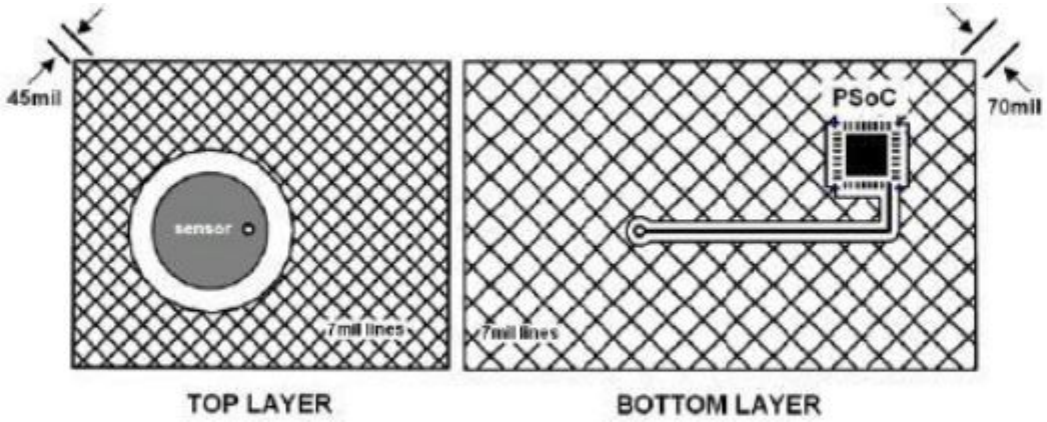
❖ Capsense System Overview:

Hardware Component:



Ground plane:

Typical hatching for the ground fill is 7-mil line, 45 mil spacing on the top layer, and 7-mil line, and 70-mil spacing on the bottom layer.



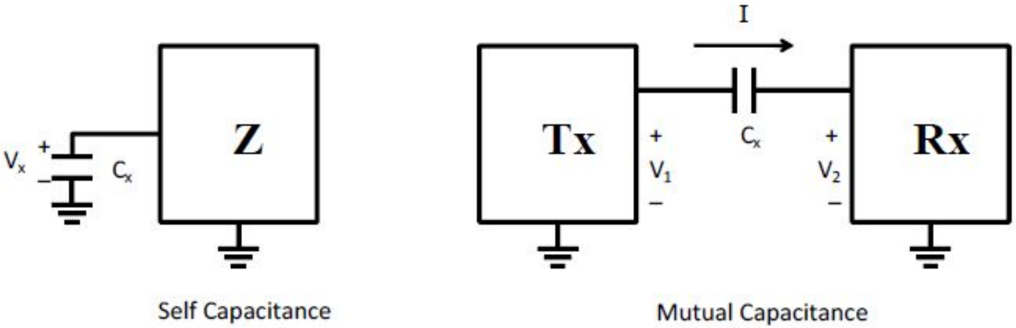
❖ Capsense fundamentals

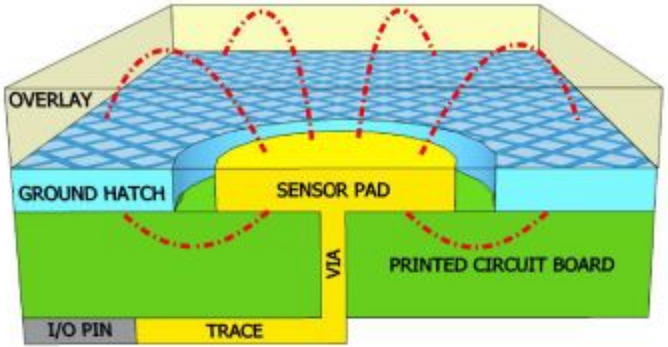
Capacitance can be measured between two points using either self-capacitance or mutual capacitance.

(Finger Capacitance) CF = (ε0*εr*A) / D

With a finger on the sensor surface,

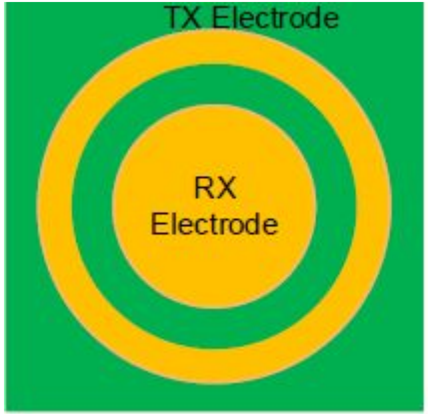
Cs= Cp + Cf

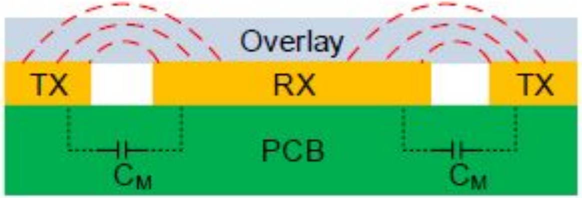




Mutual Capacitance:

- Mutual-capacitance sensing measures the capacitance between two electrodes. One of the electrodes is called the transmit (TX) electrode and the other electrode is called the receive (RX) electrode.
- Digital voltage (signal switching between VDDD and GND) is applied to the TX pin and the amount of charge received on the RX pin is measured
- The mutual-capacitance effect is best suited to multi-touch systems such as touchscreens and trackpads.





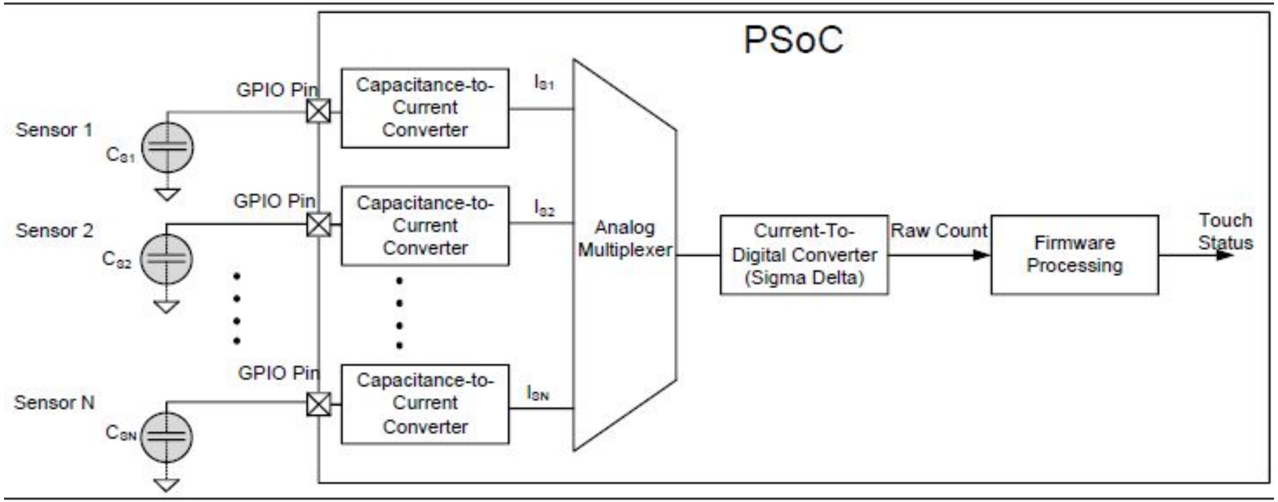
❖ Capacitive touch sensing method

Capsense sigma delta modulator(CSD):

- PIO has a switched-capacitance circuit that converts the sensor capacitance into an equivalent current
- An analog multiplexer then selects one of the currents and feeds it into the current to digital converter
- **The output count of the current to digital converter, known as raw count = Gc*Cs**

Where Gc = Capacitance to digital conversion gain of CSD, and

Cs = Self-capacitance of the electrode

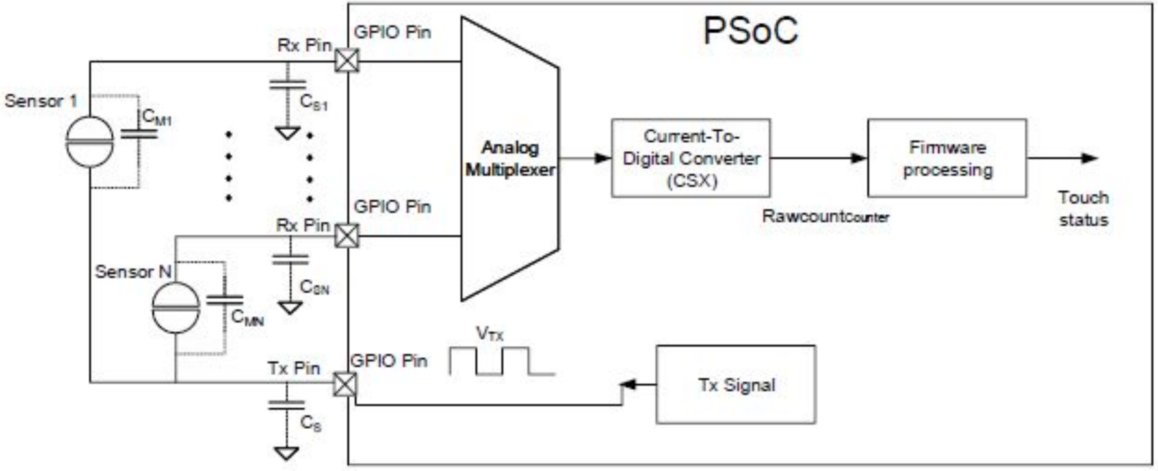


CAPSENSE crosspoint (CSX) sensing method:

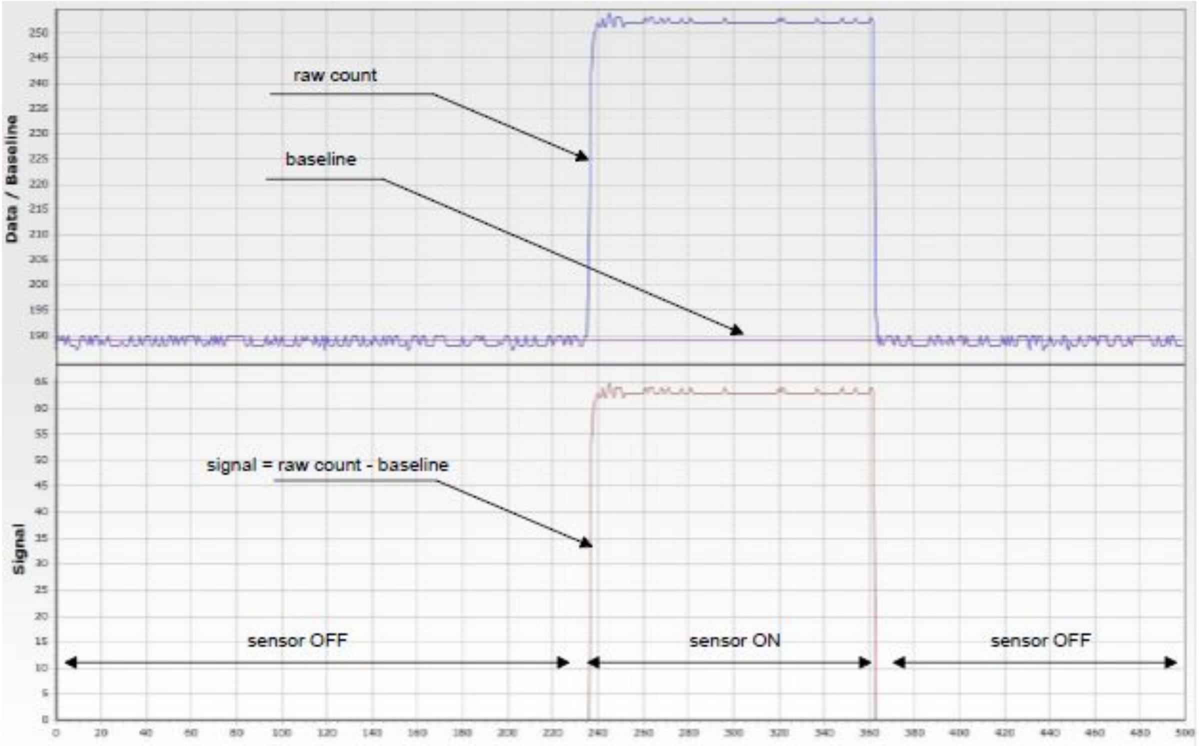
- With CSX, a voltage on the Tx pin (or Tx electrode) couples charge on to the RX pin. This charge is proportional to the mutual capacitance between the Tx and Rx electrodes
- An analog multiplexer then selects one of the Rx channels and feeds it into the current to digital converter.
- **The output count of the current to digital converter, known as Rawcount,** is a digital value that is proportional to the mutual-capacitance between the Rx and Tx electrodes

Rawcount= Gcm * Cm Where, Gcm = Capacitance to digital conversion gain of Mutual Capacitance

CM = Mutual Capacitance between two electrodes



The unprocessed count value is referred to as raw count. Processing of the raw count results in ON/OFF states for the sensor.



Capsense Tuning

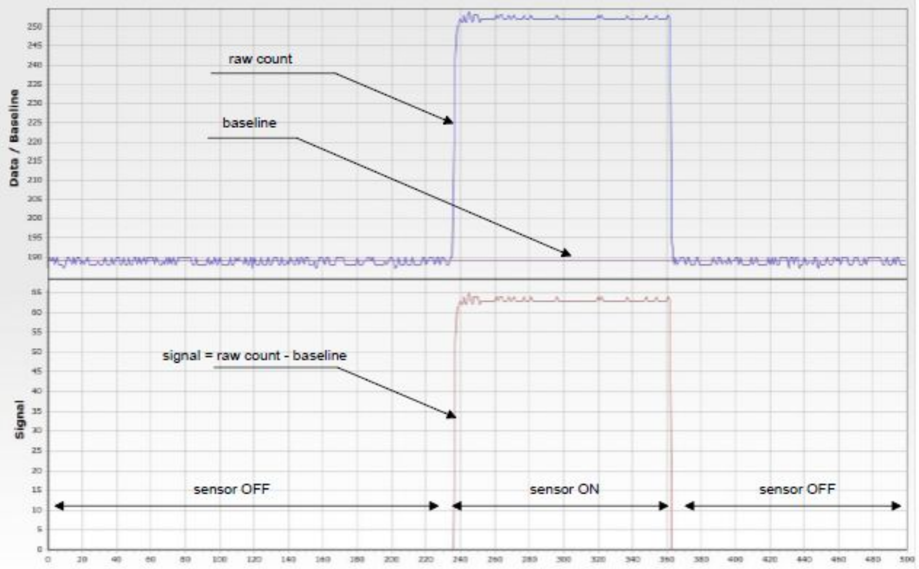
Smartsense Tuning

- **Power-up tuning:** SmartSense tunes the parameters of each sensor based on the individual sensor parasitic capacitance to get the desired sensitivity for the sensor.
- **Runtime tuning:** Noise in the system is measured dynamically. The thresholds are adjusted accordingly for each sensor to overcome false triggering due to dynamic variations in noise in the capsense system

To maintain a minimum SNR of 5:1, you must adjust the dynamic threshold

❖ **Where helpful?**

Manufacturing variations in PCBs, overlays, and noise generators, such as LCD Inverters, AC line noise,and switch-mode power supplies and automatically tunes them out.

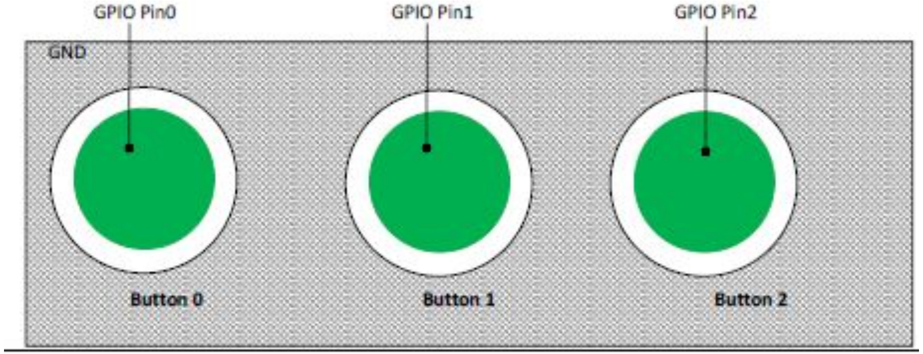


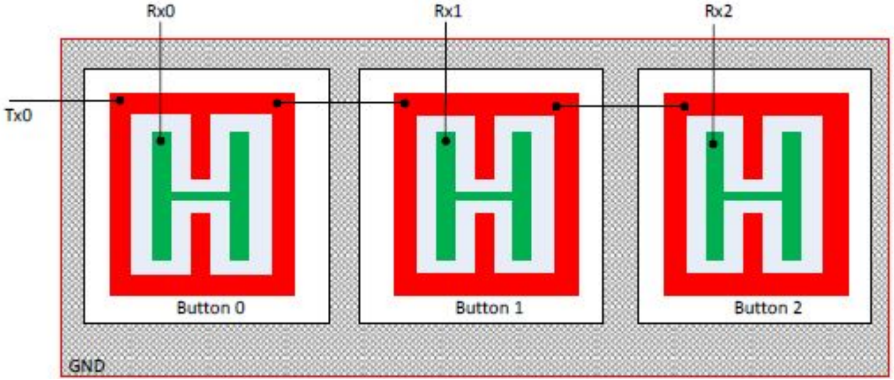
$$\text{Sensor State} = \begin{cases} \text{ON}, & \text{if (Signal} \geq \text{Finger Threshold} + \text{Hysteresis)} \\ \text{OFF}, & \text{if (Signal} \leq \text{Finger Threshold} - \text{Hysteresis)} \end{cases}$$

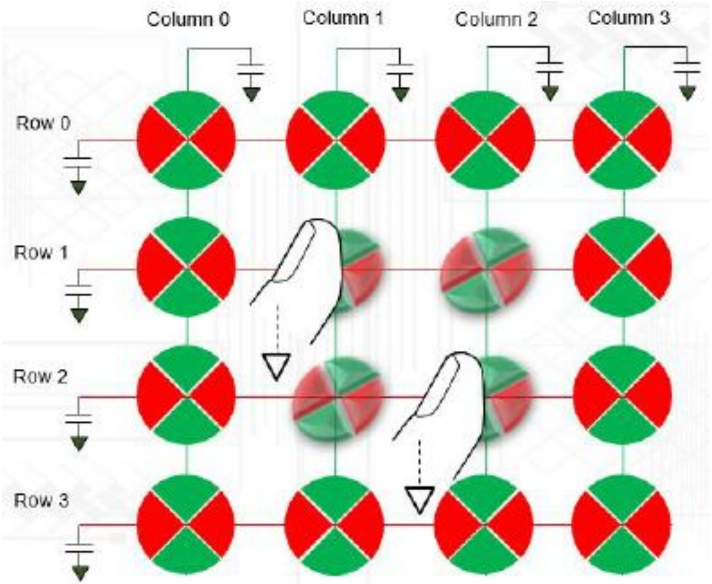
Capsense Widgets

- **3 Types of Widgets**

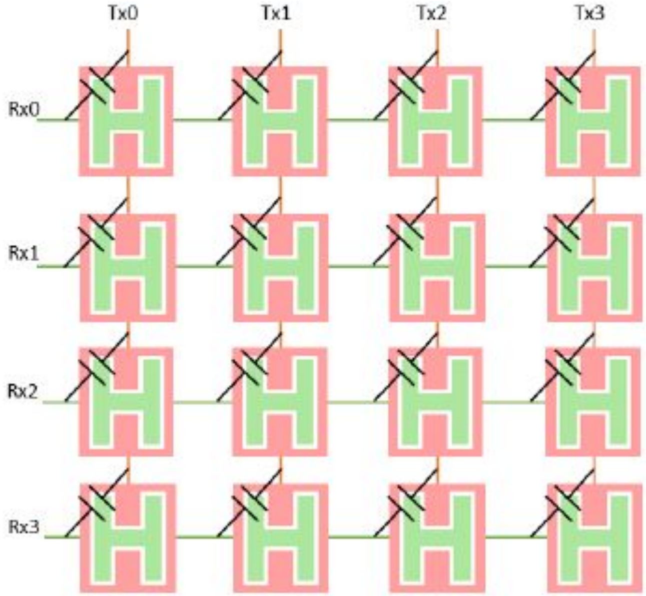
- **Buttons (zero-dimensional)**





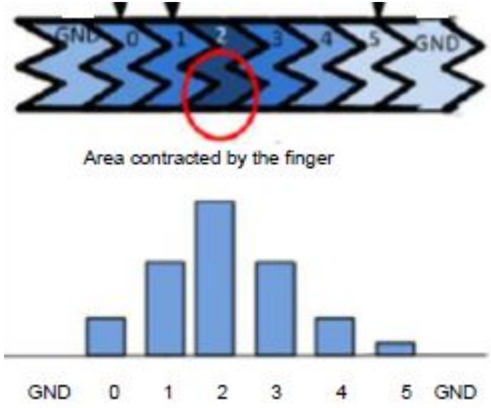


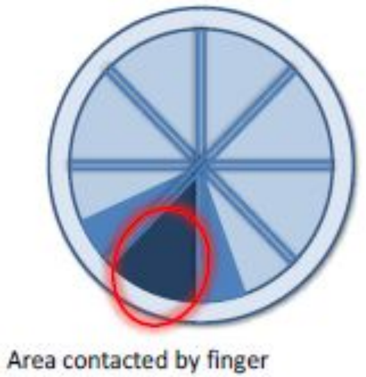
Ghost effect in matrix button based on CSD



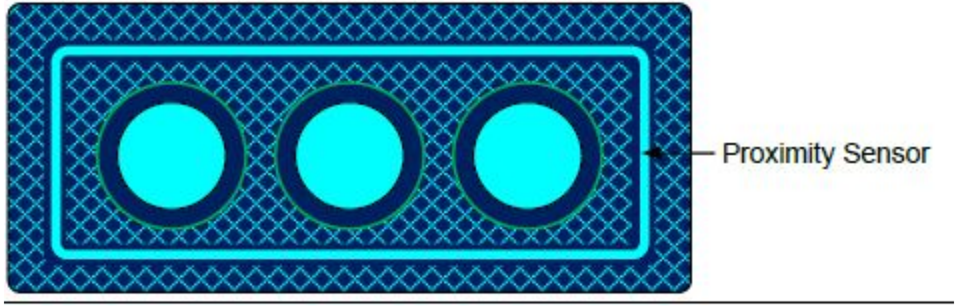
Matrix button based on CSX

- **Slider (One dimensional):**



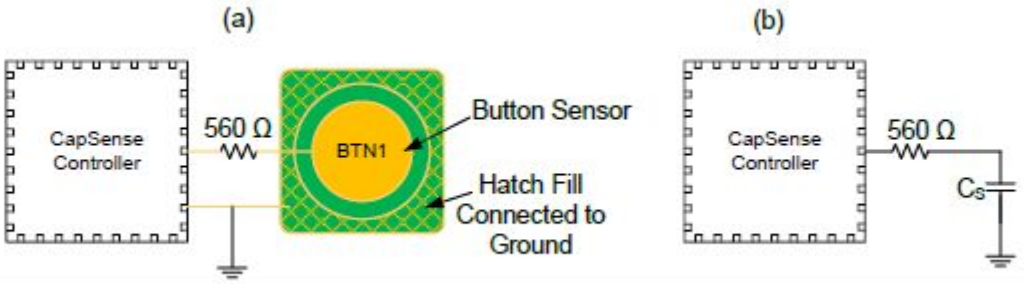


- **Proximity (three-dimensional sensors)**

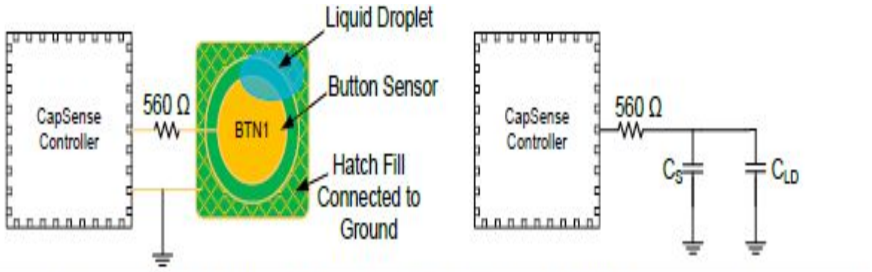


Liquid Tolerance

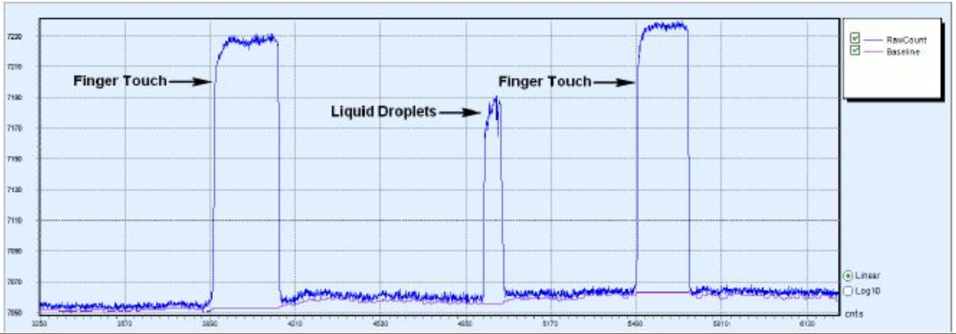
- **Effect of liquid droplets and liquid stream on Capsense**



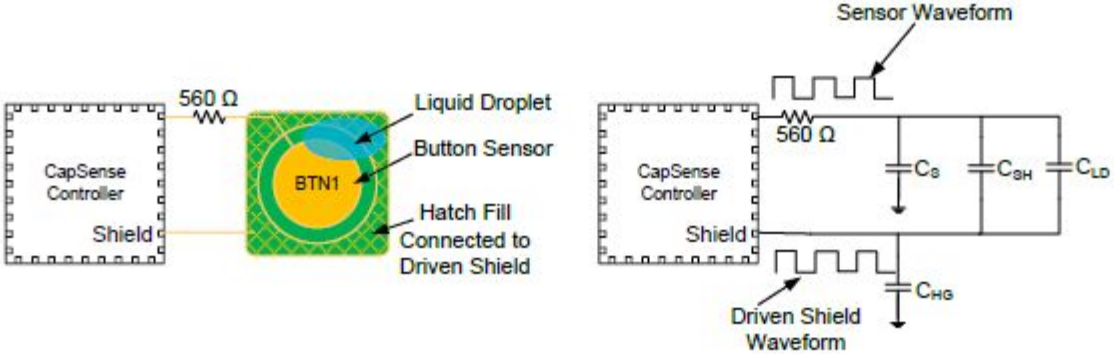
Typical CAPSENSE™ system layout



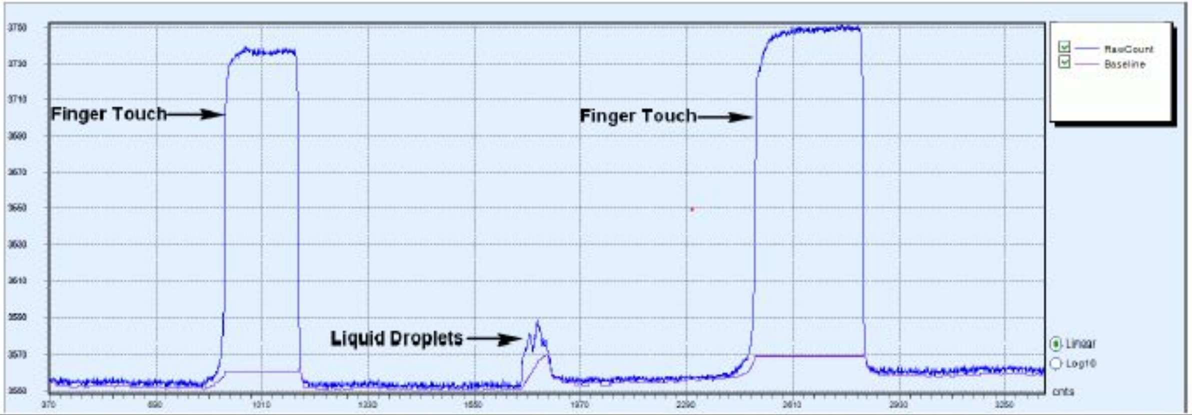
Capacitance added by liquid droplet when the hatch fill is connected to ground



36 **Effect of liquid droplet when the hatch fill around the sensor is connected to ground**



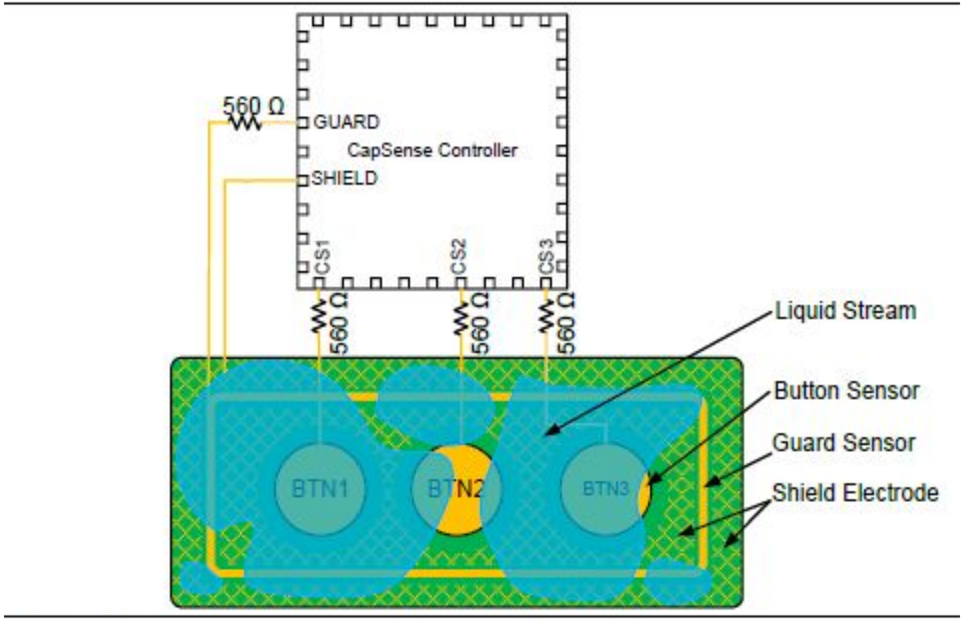
Capacitance added by liquid droplet when the hatch fill around the sensor is connected to shield



e 38 Effect of liquid droplet when the hatch fill around the sensor is connected to the driven shield

Guard Sensor

- A guard sensor is similar to a button sensor and is used to detect the presence of liquid stream. When a guard sensor is triggered, the firmware can disable the scanning of all other sensors in the system to prevent a false touch sensing.
- Because the sensors are not scanned when the guard sensor is triggered, the touch cannot be detected when there is a liquid stream.



Capacitance measurement with a liquid stream

2. Design Considerations

Overlay Selection:

Overlay material is placed over the sensor pad to protect it from the environment and prevent direct finger contact.

(i) Overlay Material

In Self-capacitance,finger capacitance.

$C\text{F} = \varepsilon 0 * \varepsilon r * A/D$

Where:

$\varepsilon 0$ = Free space permittivity

εr = Dielectric constant of overlay

A = Area of finger and sensor pad overlap

D = Overlay thickness

Cf = Finger capacitance

Conductive material cannot be used as an overlay. Do not use paints that contain metal particles in the overlay.

Table 3 Dielectric constants of common materials

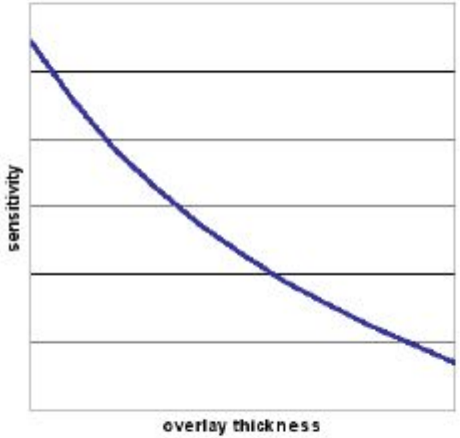
Material	ε_r
Air	1.0
Formica®	4.6–4.9
Glass (Standard)	7.6–8.0
Glass (Ceramic)	6.0
PET Film (Mylar®)	3.2
Polycarbonate (Lexan®)	2.9–3.0
Acrylic (Plexiglass®)	2.8
ABS	2.4–4.1
Wood Table and Desktop	1.2–2.5
Gypsum (Drywall)	2.5–6.0

(ii) Overlay Thickness

Sensitivity is inversely proportional to overlay thickness. Both signal and noise are affected by the overlay properties.

Recommended overlay thickness

Design element	Maximum overlay thickness (mm)
Button	5
Slider	5
Touchpad	0.5



(iii) Overlay Adhesives

3M™ makes a high-performance acrylic adhesive called 200MP that is widely used in CAPSENSE™ applications in the form of adhesive transfer tape (product numbers 467MP and 468MP).

❖ ESD Protection

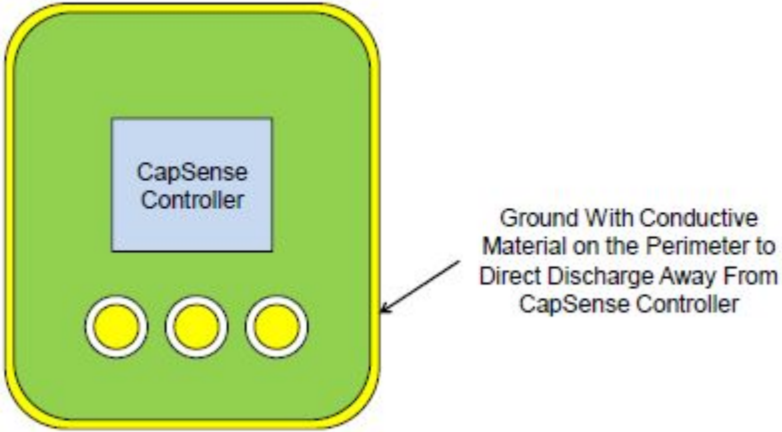
it is possible to withstand an 18-kV discharge event without any damage to the CAPSENSE controller. Refer the table 5 of design guideline document for material thickness and Breakdown voltage for various overlay material.

(i) Preventing ESD discharge

Design your system to maintain an appropriate distance between the CAPSENSE™ controller and possible sources of ESD. If it is not possible to maintain adequate distance, place a protective layer of a high-breakdown voltage material between the ESD source and CAPSENSE™ controller

(ii) Redirect

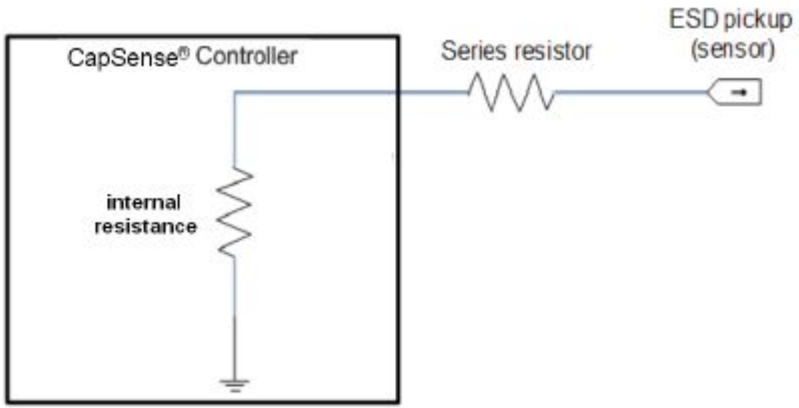
If your product is densely packed, it may not be possible to prevent the discharge event. In this case, you can protect the capsense controller by controlling where the discharge occurs. A standard practice is to place a guard ring on the perimeter of the circuit board. The guard ring should connect to chassis ground.



(iii) Clamp

Because CAPSENSE™ sensors are placed in close proximity to the touch surface, it may not be practical to redirect the discharge path. Including series resistors or special purpose ESD protection devices may be appropriate.

The recommended series resistance added to the CAPSENSE™ inputs is 560 ohms. We can also used ESD protection devices for capsense need to be low capacitance.



❖ Electromagnetic compatibility (EMC)

CMOS analog and digital circuits have very high-input impedance. As a result, they are sensitive to external electric fields.

(i) Radiated interference and emissions

The interference enters the CAPSENSE™ chip at the PCB level through the sensor traces and other digital and analog inputs. it can also contribute to electromagnetic compatibility (EMC) issues in the form of radiated emissions(RE).

Following techniques to minimize radiated interference and emissions.

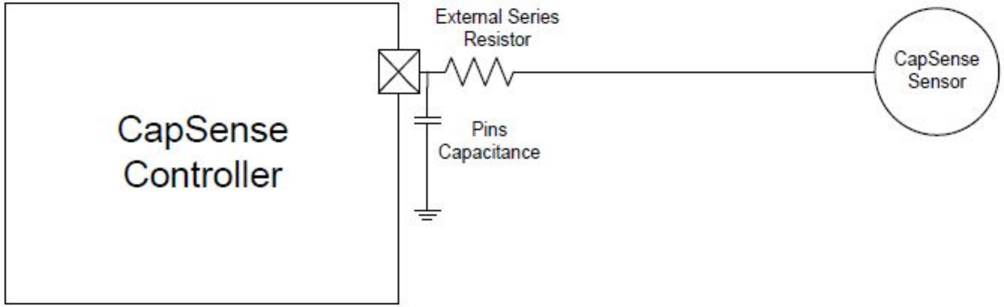
(i) General EMI/EMC guidelines

Ground Plane:-

Solid ground increase the Cp value. It is thus recommended to use **hatched ground planes surrounding the sensor.** A solid ground may be used below the device and other circuitry on the PCB, which is far from CAPSENSE sensors and traces. **A solid ground flood is not recommended within 10 mm of CAPSENSE sensors or traces.** If board with four layers or more, then provide a complete layer for ground that will further help to reduce emissions as it reduces the ground bounce significantly.

Series Resistor:-

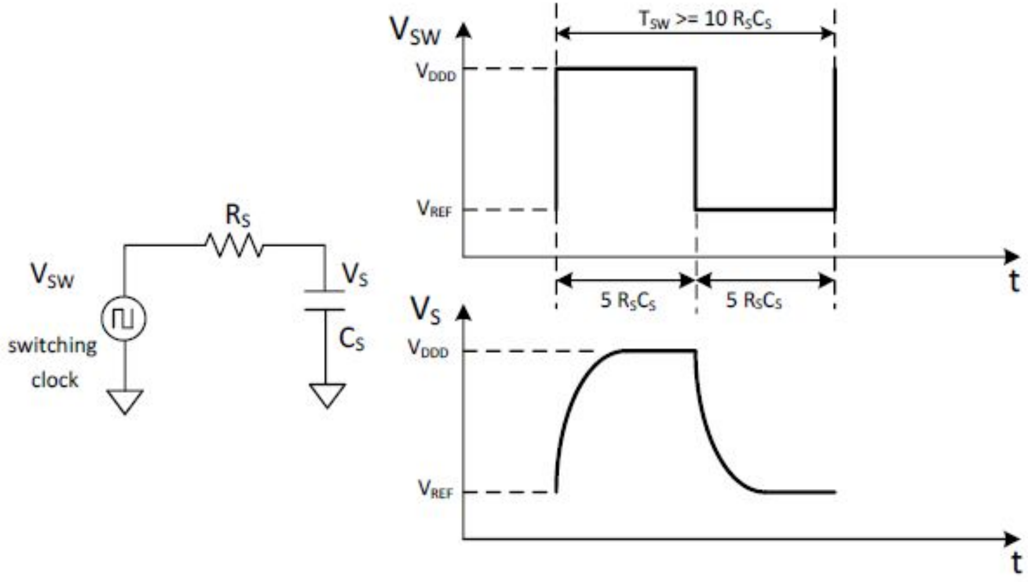
Every CAPSENSE™ controller pin has some parasitic capacitance (CP) associated with it. Adding an external resistor forms a low-pass RC filter with the parasitic capacitance of the trace connected to the pin that can significantly reduce RF emissions. series resistors help in eliminating higher-order harmonics and attenuating the RF interference and emission. It is recommended that you place series resistors within 10 mm of the PSoC pins.



Capsense Input line:-

Series resistors are generally used in the range of 560 Ω–4.7 kΩ for EMC purpose. The actual maximum value of the series resistor that can be used varies from device to device.

Rs=GPIO resistance+series resistance



The rule of thumb is to allow a period of 5RsCs for charging and discharging cycles. Equations for the minimum time period and maximum frequency are:

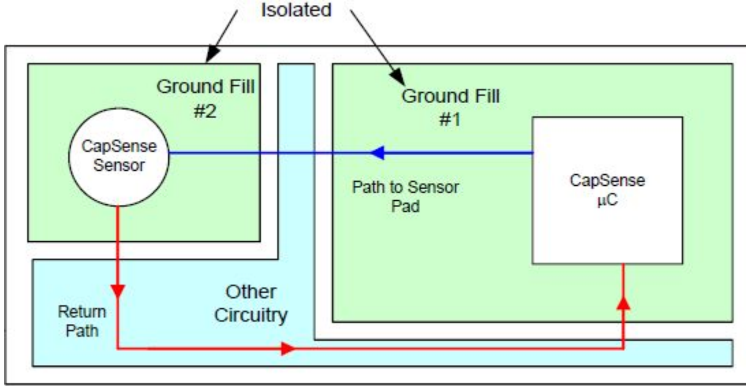
$$Tsw(minimum) = 10RsCs, \quad Fsw(maximum) = 1/10RsCs$$

Trace length:-

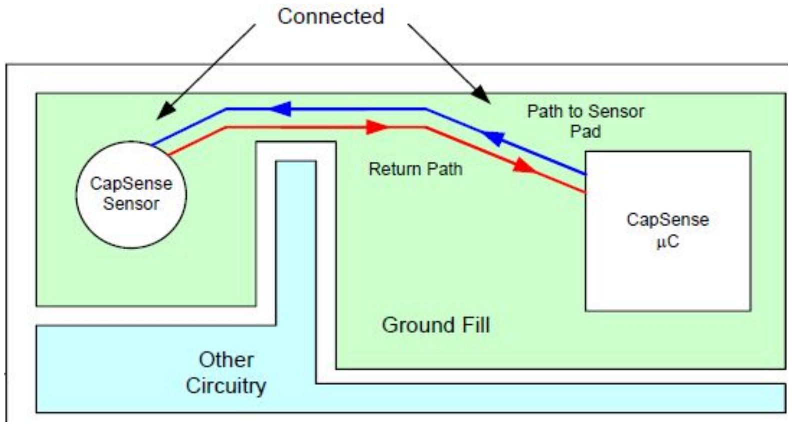
Long trace also add to Cp value. Minimize trace length whenever possible.

Current loop area:-

Improper current loop layout



Proper Current loop layout



NOTE: Refer the document for Radiated Emission(RE) and Conducted Emission(CE)

❖ Proximity sensing design

Selecting proximity sensor implementation method

Proximity sensor type	When to use
Button sensor	Use this method when the required proximity-sensing distance or the area available for the sensor is very small.
Ganged sensor	Use this method when there is no sensor pin or area available on the PCB for implementing a proximity sensor. Ganging sensors can achieve a larger proximity-sensing distance compared to using button sensors.
PCB trace	Use this method when the required proximity-sensing distance is very large. This method is preferred in most cases.
Wire loop	Use this method when the required proximity-sensing distance is very large. This method has the disadvantage of higher manufacturing cost compared to the implementation with PCB trace.

Note: Refer below Link to design "Proximity sensing with Capsense"

https://www.infineon.com/dgdl/Infineon-AN92239_Proximity_Sensing_with_CapSense-ApplicationNotes-v03_00-EN.pdf?fileId=8ac78c8c7cdc391c017d07249aac4906&utm_source=cypress&utm_medium=referral&utm_campaign=202110_globe_en_all_integration-an_vanitylink&redirId=AN_VL1169

Factors Affecting Proximity Distance (Refer the documents for detail analysis)

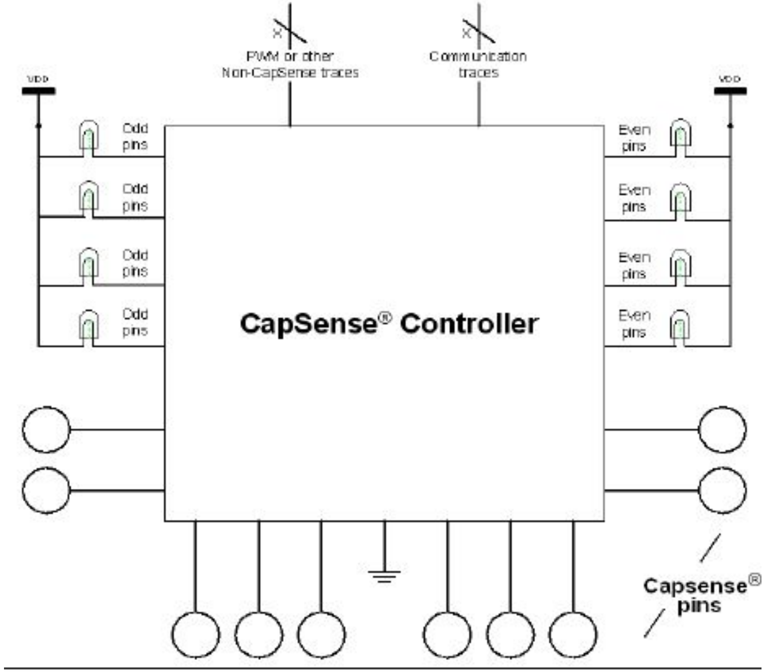
- Hardware parameters
  - Type of the sensor
  - Size of the sensor
  - Parasitic capacitance (CP) of the sensor
  - Overlay material and thickness
  - Nearby floating or grounded conductive objects

- Software parameters
  - Resolution of the sensor
  - Firmware filters

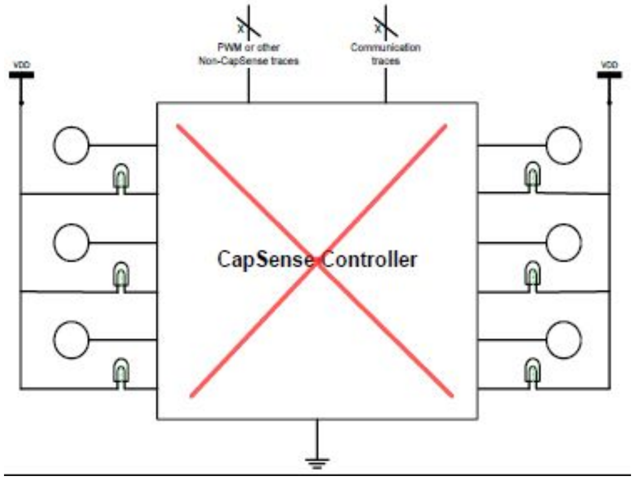
- System parameters
  - Power consumption
  - Response time
  - EMI/EMC/ESD performance

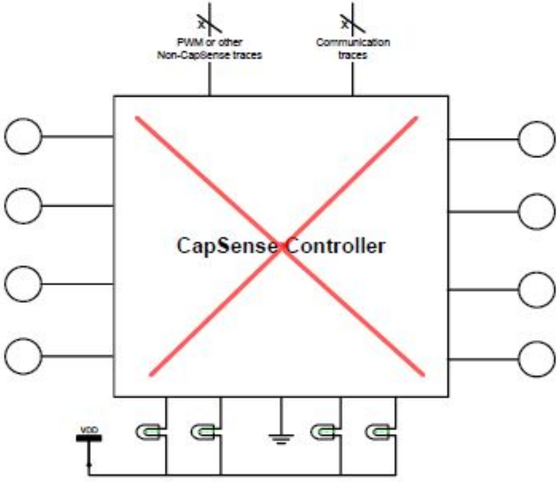
Pin Assignments

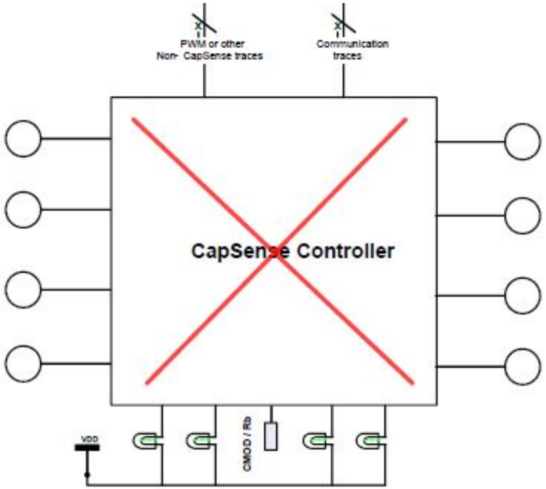
An effective method to reduce interaction between CAPSENSE™ sensor traces and communication and non-capsense traces is to isolate each by port assignment



Recommended: Port isolation for communication, CAPSENSE, and LEDs







Not recommended – Capsense and non-Capsense pins in proximity

Not recommended – LEDs and ground pins in proximity

Not recommended: Cmod/Rb and LED pins in proximity

PCB Layout Guideline

Parasitic Capacitance, Cp:-

An increase in sensor size, an increase in trace length and width, and a decrease in the annular gap all cause an increase in CP.

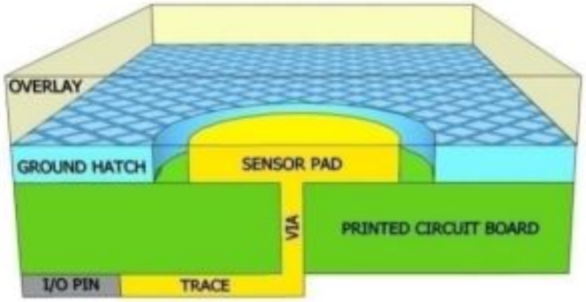
One way to reduce CP is to increase the air gap between the sensor and ground. Unfortunately, widening the gap between sensor and ground will decrease noise immunity.

Board Layers:-

Most applications use a two-layer board with sensor pads and a hatched ground plane on the top side and all other components on the bottom side. See below Two-layer stack-up for CAPSENSE boards.

Board thickness:-

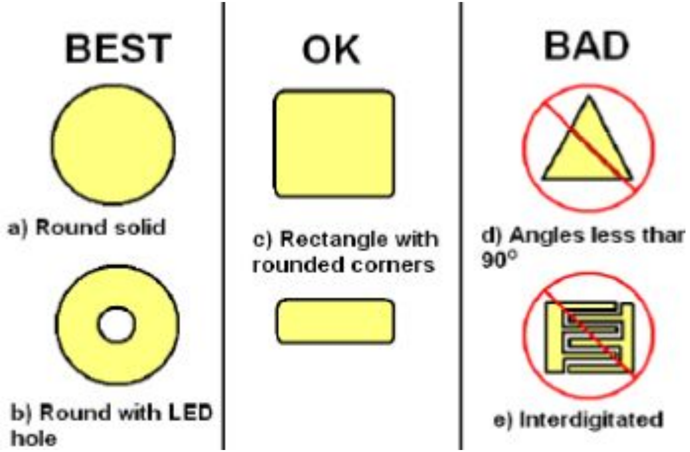
FR4-based PCB designs perform well with board thicknesses ranging from 0.020 inches (0.5 mm) to 0.063 inches (1.6 mm).



(I) Button Design:-

Button diameter can range from 5mm to 15mm. A larger diameter helps with thicker overlays. Annular gap size should be equal to the overlay thickness, but no smaller than 0.5 mm,and no larger than 2mm.

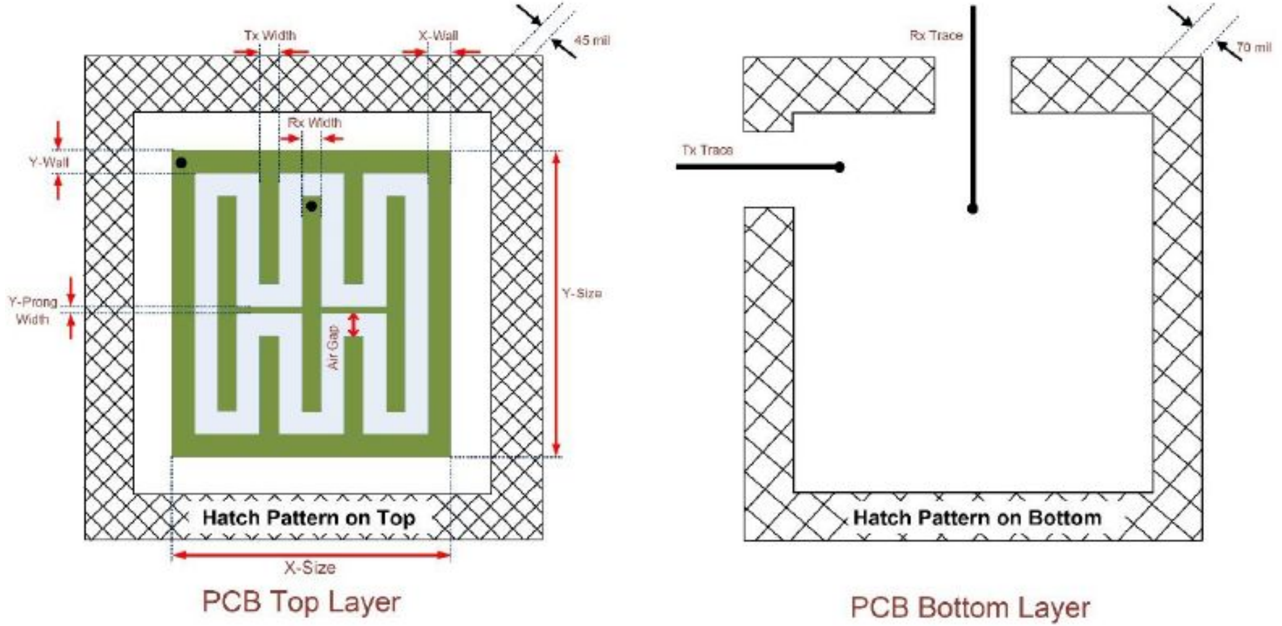
The spacing between the two adjacent buttons should be large enough that if one button is pressed, a finger should not reach the annular gap of the other button.



Self-cap button structure

The sensor pattern should be designed in such a way that the finger disturbs the electric field between the electrodes to a maximum extent. Prongs or fishbone are standard shapes for mutual-capacitance buttons.

The gap between the outer wall of the Tx electrode and the coplanar hatch ground should be greater than the air-gap of Tx and Rx electrodes. The reference plane (PCB bottom layer) of the fishbone structure should have void region as shown in figure



Mutual cap buttons of fishbone structure

Below table shows lists some of the common fishbone structure dimensions.

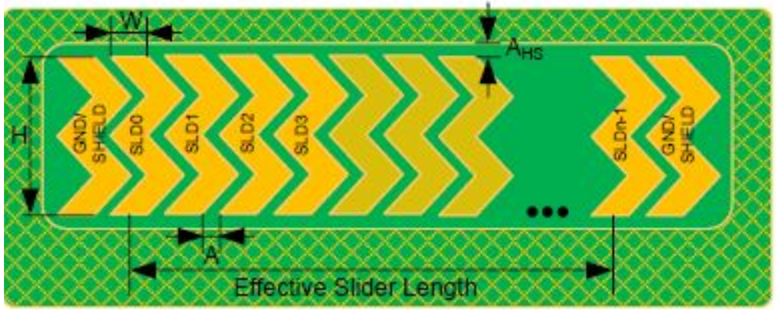
Table 11 Dimension of fishbone buttons (all units in mm)

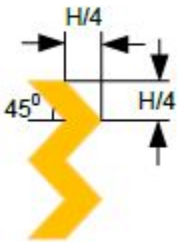
Key size (X-size, Y-size)	PCB thickness	Number of Rx-prongs	Gap between Tx and Rx	Tx width	Rx width	X-wall width	Y-wall width
13, 10	1.5	2	1.4	1.8	1.8	1	1
13, 10	0.1	3	1.2	0.7	1.2	0.4	0.3
20, 13	0.1	2	1.2	2.7	2.7	3	3.55
10, 13	1.5	2	1.2	0.6	0.6	1.7	1.5
10, 10	1.5	2	1.4	1	1	0.7	0.7

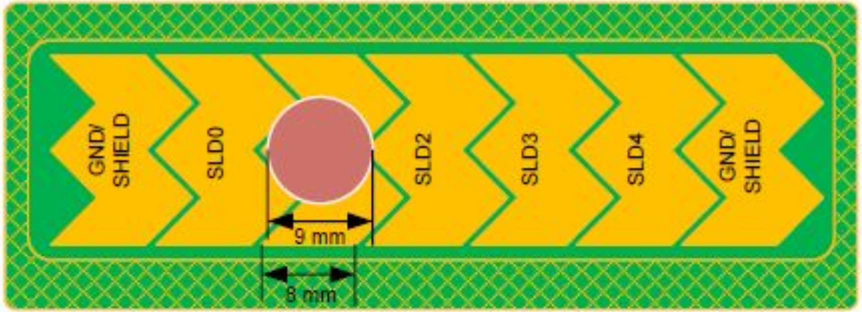
(II) Slider Design:-

Segment width and air-gap relation with finger diameter **“$W + 2A$ = finger diameter”**

If the **slider-segment-width + 2 * air-gap** is lesser than finger diameter then centroid response will be non-linear.







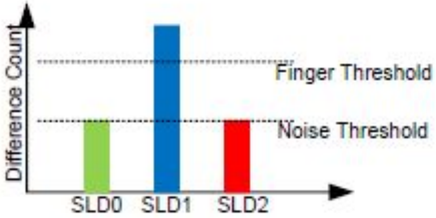


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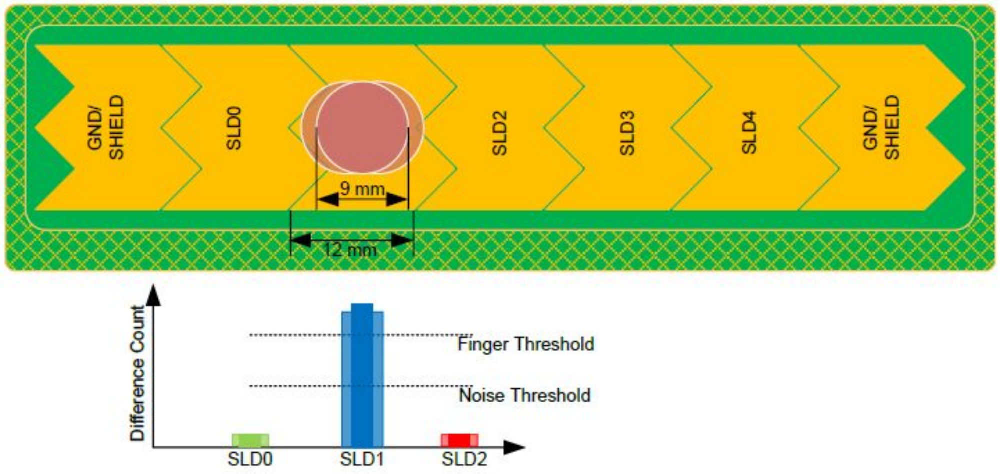
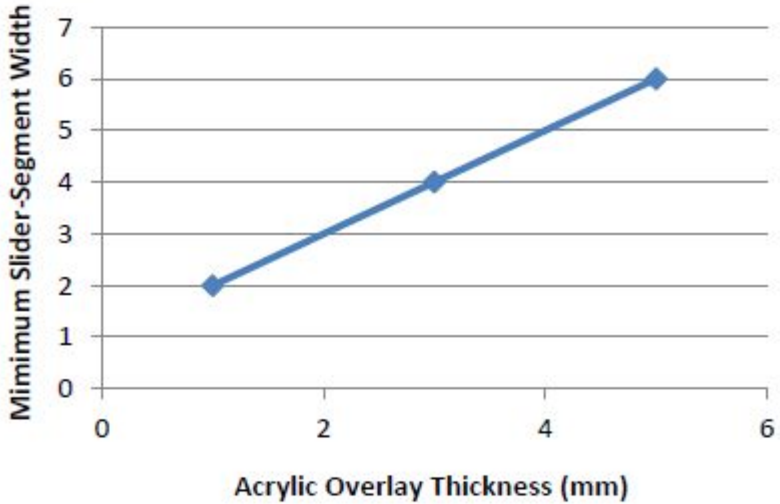
Table 12 Linear slider dimensions

Parameter	Acrylic overlay thickness	Minimum	Maximum	Recommended
Width of the segment (*W*)	1 mm	2 mm	-	8 mm[6]
	3 mm	4 mm	-	
	4 mm	6 mm	-	
Height of the segment (*H*)	-	7 mm[7]	15 mm	12 mm
Air-gap between segments (*A*)	-	0.5 mm	2 mm	0.5 mm
Air-gap between hatch and slider (A_{HS})	-	0.5 mm	2 mm	Equal to overlay thickness





Signal on slider segments when slider segment width is higher than recommended

Minimum slider-segment-width with respect to overlay thickness for an acrylic overlay

Dummy segments at the ends of slider:-

To maintain a uniform signal level from all the slider segments, it is recommended to physically connect the two segments at the both ends of a slider to either ground or driven shield signal.

The connection to ground or to the driven shield signal depends on the value that will be specified in the "Inactive sensor connection" parameter. Therefore, if your application requires an 'n' segment slider, it is recommended to create n + 2 physical segments.

If it is not possible to have two segments at the both ends of a slider due to space constraints, you can implement these segments in the top hatch fill.

For a given slider length, L, calculate the number of segments required using the following formula:

Number of segments = {slider length / (slider segment width+air gap) + 1}

Note: that a minimum of two slider segments are required to implement a slider.

Linear slider pattern when first and last segments are connected to top hatch fill due to space constraint

- Relationship between minimum PCB length and slider length

  PCB length = slider length + 3 x slider segment width + 2 x air gap

  (If the available PCB area is lesser than that required per above equation, you can remove the dummy segments.)

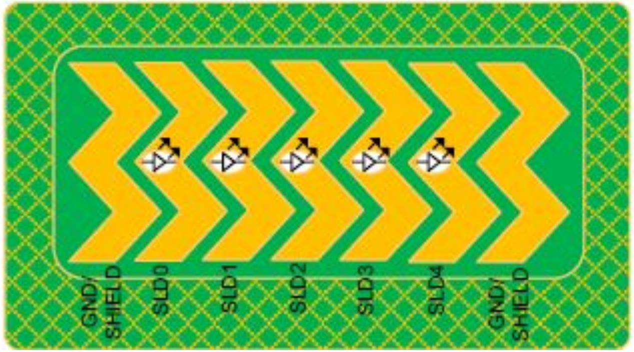
- In this case, the minimum PCB length required will be as follows:

  PCB length = slider length + slider segment width

(III) Slider Design with LEDs

When a hole is drilled for placing an LED, the effective area of the slider segment reduces. To achieve an **SNR > 5:1**, you need to have a slider segment with a width larger than the LED hole size.

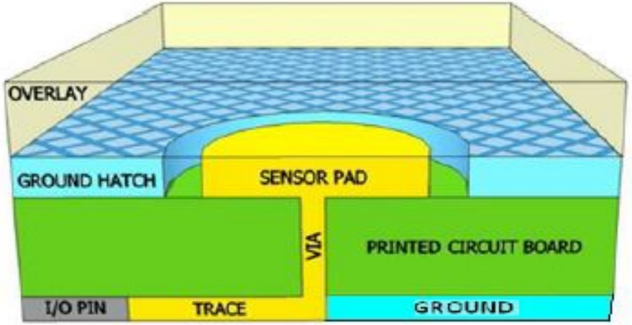
Reference: Slide no. 20 and Crosstal section



Slider design with LED backlighting

Sensor and device placement:

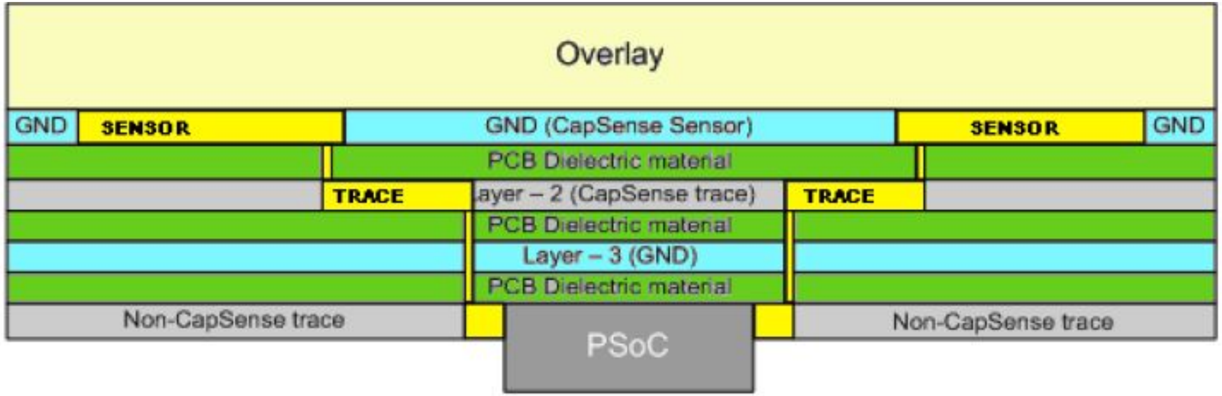
(I) 2 Layer PCB



(II) 4 Layer PCB

Place the sensors on the top layer of the PCB.

- Route the sensor traces in the layer-2.
- Place a hatch fill of 7-mil trace and 70-mil spacing and connect it to ground in layer-3.
- Place components in the bottom layer. The unoccupied areas can be filled with a hatch copper fill of 7-mil trace and 70-mil spacing and should be connected to ground.



In addition to these guidelines, follow the best practices to ensure a robust and reliable CAPSENSE™ design.

- Minimize the trace length from the CAPSENSE™ controller pins to the sensor pad to optimize signal strength.
- **Mount series resistors within 10 mm of the controller pins** to reduce RF interference and provide ESD protection.
- Mount the controller and all other components on the bottom layer of the PCB.
- **Isolate switching signals,** such as PWM, I2C communication lines, and LEDs, from the sensor and the sensor PCB traces. Do this by placing them at least 4 mm apart and fill a hatched ground between CAPSENSE traces and non-CAPSENSE™ traces to avoid crosstalk.
- **Avoid connectors between the sensor and the controller pins** because **connectors increase Cp** and decrease noise immunity.

- Four (or more)-layer PCB:
  - Top layer: Hatch fill with 7 mil trace and 45 mil grid (25 percent fill). Hatch fill should be connected to the driven-shield signal
  - Layer-2: Hatch fill with 7 mil trace and 70 mil grid (17 percent fill). Hatch fill should be connected to the driven-shield signal
  - Layer-3: V_{DD} Plane
  - Bottom layer: Hatch fill with 7 mil trace and 70 mil grid (17 percent fill). Hatch fill should be connected to ground

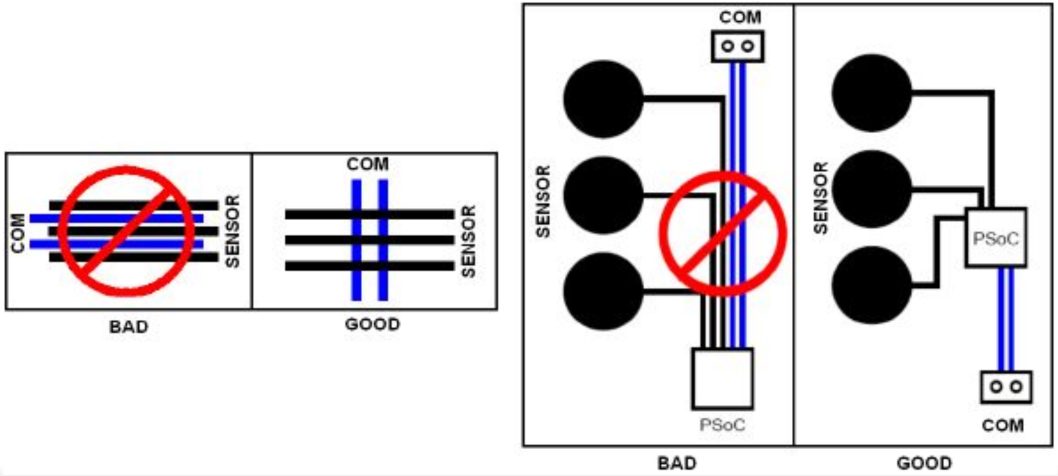
- Capsense sensor/button to the ground hatch separation shall be 20 mils
- Capsense shield trace to the sensor pad separation shall be 10 mils and the shield trace to GND hatch separation shall be 15 mils
- GND hatch directly below the capsense buttons shall be there

Trace length and width:

- The maximum recommended trace length is 12 inches (300 mm) for a standard PCB and 2 inches (50 mm) for flex circuits.
- Trace width should not be greater than 7 mil (0.18 mm). Capsense traces should be surrounded by hatched ground with trace-to-ground air gap of 10 mil to 20 mil (0.25 mm to 0.51 mm).

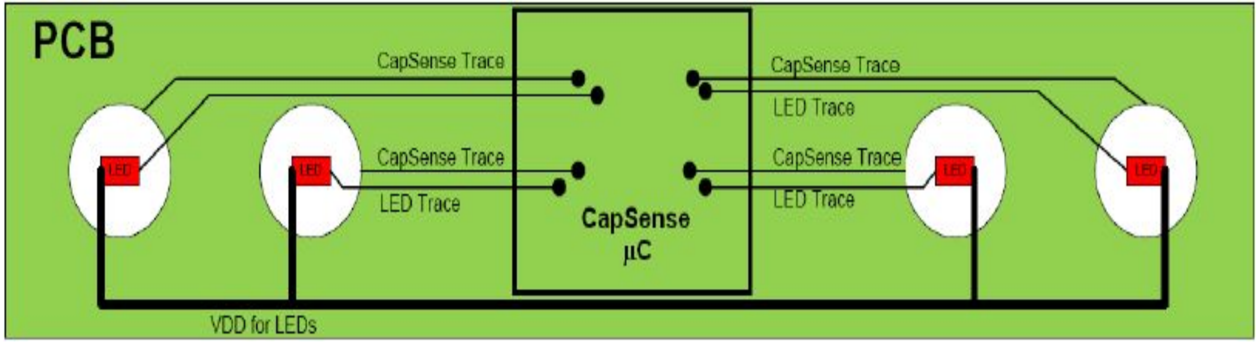
Trace routing:

- Do not route traces directly under any sensor pad unless the trace is connected to that sensor.
- Do not run capacitive sensing traces in close proximity to communication lines, such as I2C or SPI masters. If it is necessary to cross communication lines with sensor pins, make sure the intersection is at right angles

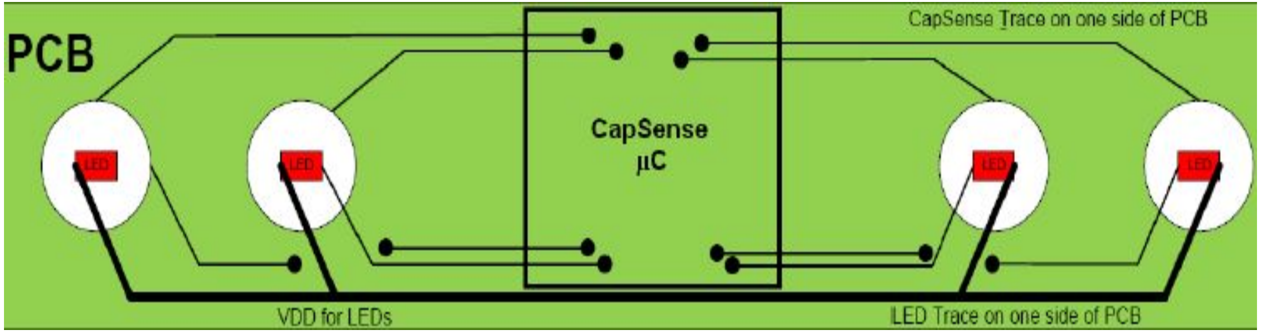


Crosstalk solutions:

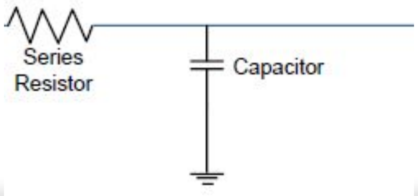
- Not recommended – LED and CAPSENSE™ in close proximity



- Recommended – LED and CAPSENSE™ with wide separation



- Another approach to reducing crosstalk is to slow down the rising and falling edges of the LED drive voltage using a filter capacitor. The value of 0.1 µF is typical

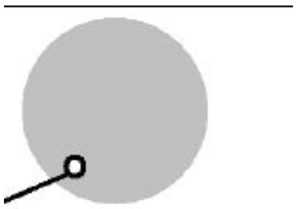


LEDs close to CAPSENSE™ sensors:

- To avoid the effect of LEDs that are placed close to the sensors, the LEDs must be bypassed with a capacitor with a typical value of 1 nF.
- To avoid the effect of LEDs that are placed close to the sensors, the LEDs must be bypassed with a capacitor with a typical value of 1 nF.

Vias:

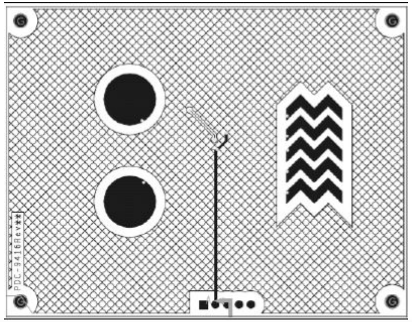
- Use the minimum number of vias to route Capsense and usually on the edge of the sensor pad



Via at edge, same function, minimizes trace length

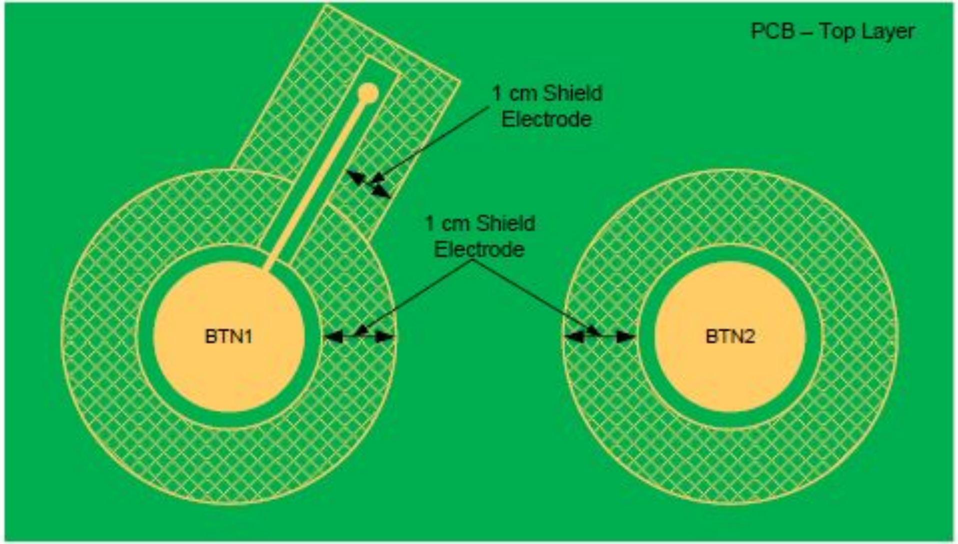
Ground Plane:

- Typical hatching for the ground fill is 25 percent on the top layer (7 mil line, 45 mil spacing) and 17 percent on the bottom layer (7-mil line, 70-mil spacing).



Shield electrode construction for liquid tolerance:

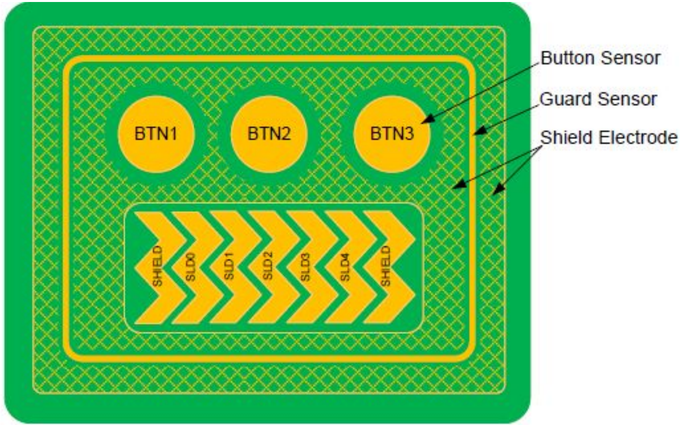
- Spreading the shield electrode beyond 1 cm has negligible effect on system performance.
- having a large shield electrode might increase the radiated emissions.
- If the board area is very large, the area outside the 1-cm shield electrode should be left empty as shown in the below image.



Shield electrode placement when sensor trace is routed in top and bottom layer

Guard sensor:

- To ensure the guard sensor is not accidentally triggered, place the guard sensor at a distance greater than 1 cm from the sensors
- Otherwise, the button sensors and slider sensor scanning will be disabled and the Capsense system become non-operational until the guard sensor is turned OFF.
    - **guidelines for implementing the guard sensor:**
        - The guard sensor should be in the shape of a rectangle with curved edges and should surround all the sensors.
        - Recommended thickness for a guard sensor is 2 mm.
        - Recommended air gap between the guard sensor and the shield electrode is 1 mm.



CAPSENSE™ system design with ITO:

- Trace length for the sensors should be kept at minimum to reduce the overall sensor resistance.
- The formula for trace resistance is:-

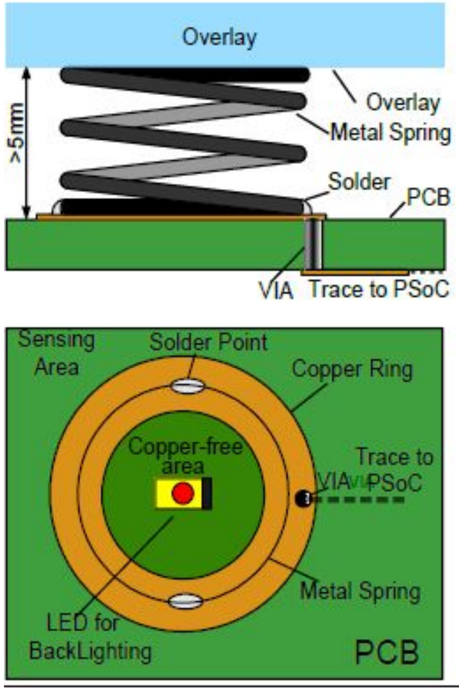
$$\text{Resistance} = (\text{Trace sheet resistance} \times \text{Trace length}) / \text{Trace width}$$

- Below are layout guidelines for ITO sensors

Category	Parameter	Min	Typ	Max	Units	Remarks
ITO	Sheet resistance (glass substrate)	-	-	120	Ω/sq	-
	Sheet resistance (film substrate)	-	-	270	Ω/sq	-
	Sensor maximum resistance	-	1	30	kΩ	End-to-end
	Spacing between traces	30	50	100	µm	-
	Routing channel trace width	10	30	50	µm	-

Mounting springs to the PCB:

- When using thick overlay then spring diameter must be larger than the overlay thickness by at least 2 or 3 times.
- Distance between the PCB and the overlay must be 5 mm or more.



Series resistor on CAPSENS lines:

- If the series resistance value is set larger than 560 ohms, the slower time constant of the switching circuit limits the amount of charge that can transfer, which in turn lowers SNR.
- Smaller values are better, but are less effective at blocking RF.

3W Rule:

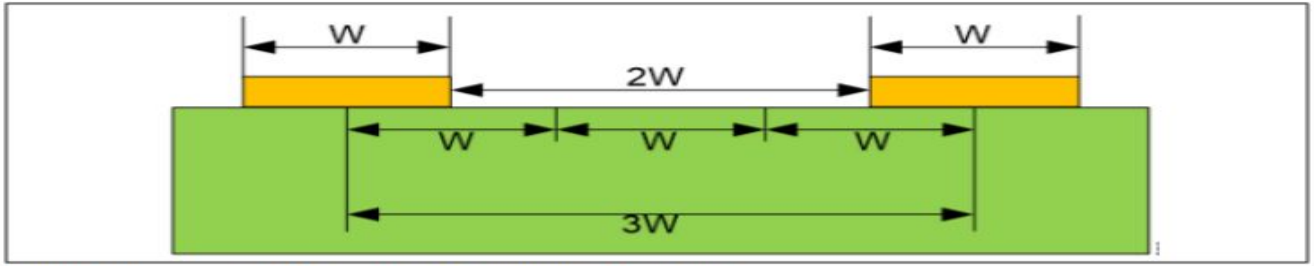


Figure 140 **3W trace spacing to minimize cross talk**

- Do not run Tx and Rx lines parallel to each other. The trace routing should be separated as much as possible
- If the layout constraints require Tx and Rx run parallel for short distances, the space between Tx and Rx should be greater than the distance between Tx and Rx inside the key (2 times the Tx-Rx key spacing is preferred) or add ground between them
- Keep as much clearance around Rx as possible to prevent noise on the touch keys. It is critical to follow this guideline for spacing to power traces and LED lines (high speed switching, power). Ground should also follow this rule, but it is less critical. Ground will provide noise protection but will reduce key sensitivity
- For a given set of sensors, the number of Rx lines must be less than or equal to Tx lines. Rx lines are susceptible to noise, whereas Tx lines are relatively less susceptible

Note: Refer the appendix B (Schematic and layout checklist) (Page no. 130)

Schematic and layout checklist:

I. Buttons
II. Slider
III. Overlay
IV. Sensor traces
V. Vias on sensors
VI. Ground plane/mesh
VII. Series resistor
VIII. Shield electrode
IX. Guard sensor

Thank you

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