CAPACITIVE SENSING MADE EASY, Part 2 – Design Guidelines

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When it comes to capacitive sensing design, layout plays a crucial role. Giving importance to layout not only aids in superior performance (lower noise and higher signal) but also helps in achieving EMI/EMC compliance. It should be kept in mind that a good layout helps in realizing the following two objectives:

1. Higher finger capacitance and lower parasitic capacitance: The signal in a given system is the sum of signals due to parasitic capacitance and those due to finger capacitance. It is important to reduce parasitic capacitance because, in order to increase a particular signal within a fixed range, the other signal must always be reduced to avoid saturating the signal.

2. Lower noise: This helps in making the system more reliable and avoid false detects.

Some of the key guidelines for schematic and layout include:

Sensor shape and size

Capacitive sensing sensors are in demand because of their innovative shape which gives the design a unique and slender look. Understanding what imposes the limitations on selecting a particular shape is important because it affects the performance parameters of the design. Sensors laid on a PCB can be divided into 4 different categories:

1. Independent sensors or buttons

   The most widely used shape is the button, which is either circular or square. However, designers can chose their own shapes, depending upon the board area and other design constraints. This shape is recommended from silicon manufacturers because of the geometry of a finger is also somewhat circular in nature.

An important consideration when choosing a sensor shape is to avoid sharp corners:

- Sharp corners are more sensitive and hence the sensor response w.r.t touch position/direction would be non-linear. This is an unintended behavior

- Corners radiate more EMI, which may cause compliance issues. Corners should be rounded wherever required.

Figure 1 shows some of the recommended patterns.

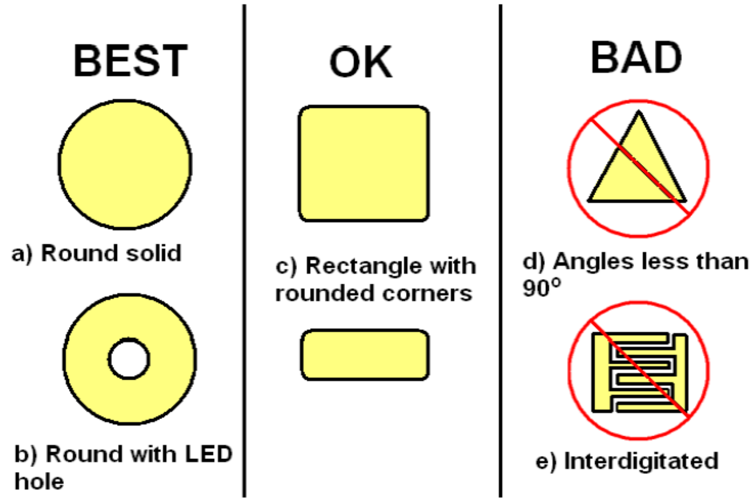


Figure 1. Recommended sensor patterns

The size of the sensor determines the amount of finger capacitance. For a better SNR, finger capacitance should be as high as possible but because of design constraints like overlay thickness, the type of materials used, etc., finger capacitance typically lies in the range of 0.1pF to 1pF.

When a user touches the sensor, the finger acts like the second electrode of a parallel plate capacitor, the sensor pad being the first. Thus, the following formula gives a fair idea of how the sensor size affects the finger capacitance:

$$C = \frac{\epsilon_o \epsilon_r A}{d}$$

Where,

$\boldsymbol{\epsilon_o}$ is absolute permeability = 8.854 x 10e-12

$\boldsymbol{\epsilon_r}$ is relativity permeability and is widely known as the dielectric constant – dielectric constant of overlay.

A is the area of parallel plate capacitor – area of the sensor occupied by finger

d is the overlay thickness

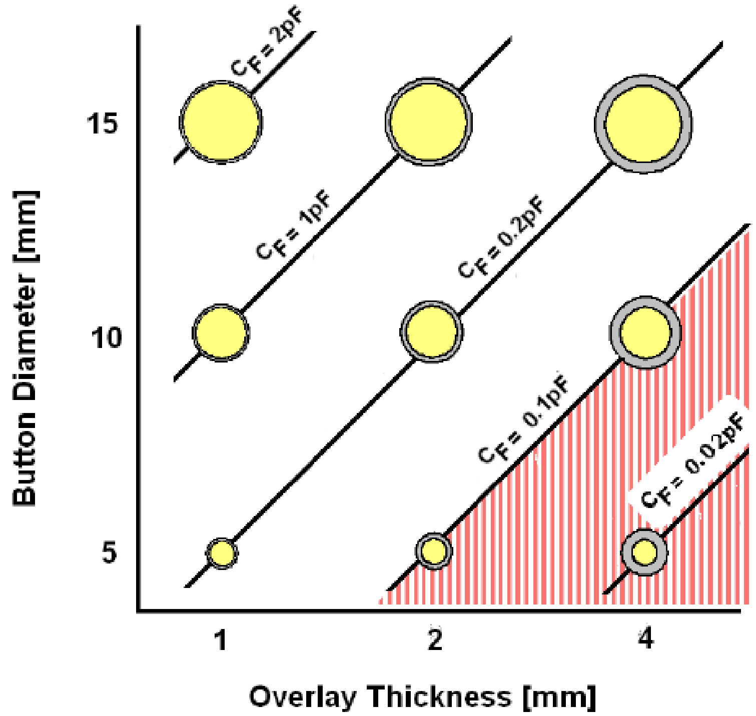


Figure 2. Finger capacitance for different button size and overlay thickness

Fig. 2 shows the finger capacitance with the change in size of the button. One can safely assume that by increasing the sensor area, finger capacitance can be increased but increasing it more than the finger size will not have any effect because the maximum area will always be limited by the area of the second plate; i.e., the finger.

1. Proximity sensors

Proximity sensors are generally used for lowering the power consumption in any application. The sensing device can be put to sleep and a proximity sensor can be implemented to sense the approach of hand towards the keypad, thus activating the required functions like backlighting and keypad scanning.

Shape and size:

Proximity sensing requires that the electric field be projected to much larger distances than buttons or sliders. This demands the sensor area be large; however, there is still a constraint on sensor size imposed by the parasitic capacitance of the sensor which should be as low as possible. This necessitates the implementation of the sensor in such a way that we get a high electric field strength at larger distances while keeping the sensor area as small as possible. Loops with trace thickness of 2-3 mm have proved to be the most successful implementation by far. The rule of thumb for such loops is to have the loop diagonal/diameter equal to the proximity distance required.

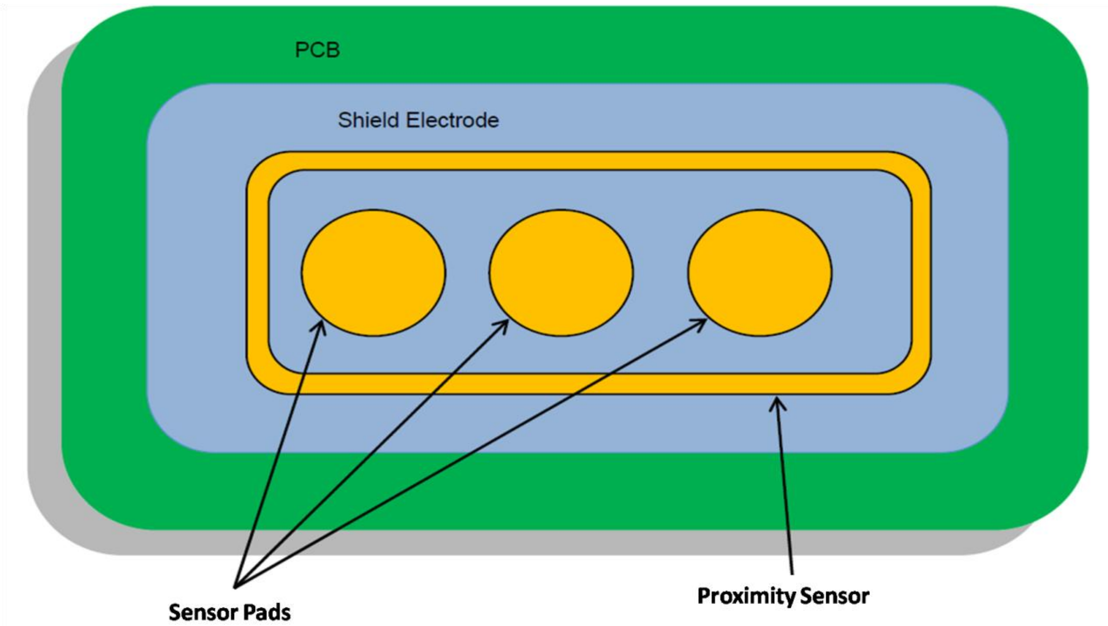


Figure 3: Proximity sensor with shield electrode

Use of shield:

Another way of increasing the electric field projection is through the use of a shield. In Figure 3, there is a ground pattern surrounding the sensor (blue area – representation of hatch pattern). This hatch is generally connected to ground. In the case of proximity sensors, this leads to a lower electric field strength at greater distances, as shown below. Capacitive sensing controllers generally come with a shield electrode pin which is driven with the same voltage as that of the sensor. For proximity sensors, the hatch should be connected to this shield electrode.

2. Linear / Radial slider

Sliders are gaining popularity for volume or intensity control. These can be laid out in different shapes, including linear and circular. A slider is actually a group of multiple independent sensors placed physically adjacent to each other. Actuation of one sensor results in the partial actuation of adjacent sensors. The actual position of the slider is found by computing the centroid location of the set of activated sensors (see Figure 4).

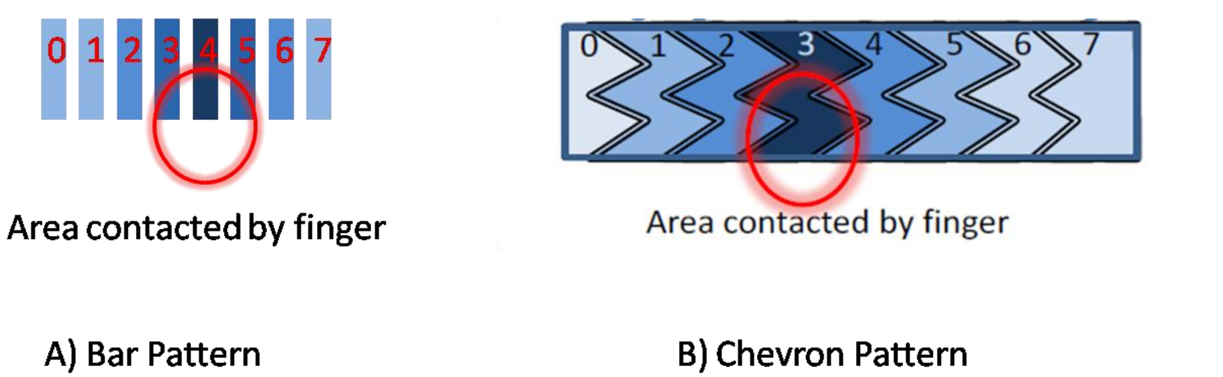


Figure 4. Linear slider layout pattern

For the centroid calculation, a minimum of 2 sensors must be activated when they are touched. To meet this requirement, the size of the segments (i.e., independent sensors) in the slider have to be reduced. This increases the number of segments required to achieve a particular length. Figure 4B shows another arrangement in which sensors are laid in a chevron or W pattern. This pattern has the advantage of having comparatively bigger segments while still being enabling a finger to touch multiple segments when placed or swiped on the slider.

Similar to a linear slider, a radial slider can also be designed. The only difference between the two is the arrangement of the segments and the software algorithm because a circular slider does not have a starting or ending point. Care must be taken in the case of a circular slider that the sensors are not connected at the center.

3. Track pad

As noted in the previous section, a linear slider can only locate a finger in one dimension, thus by arranging two linear sliders in X and Y pattern, we can locate a finger's position in both X and Y dimensions. A typical arrangement of such a sensor pattern is shown in Figure 5.

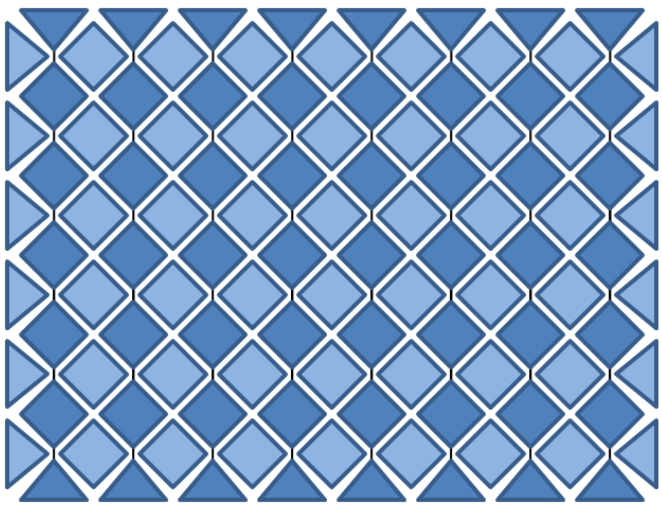


Figure 5. Trackpad sensor arrangement

In this arrangement, sensors are laid in the form of a diamond pattern. All the diamonds in a single row are connected together to act as a single segment of the Y slider. Similarly, diamonds in a single column are connected to act as a single segment of the X slider. The resolution and linearity required determine the size of the diamond. A typical diamond size is 4 mm. While increasing the size further would certainly reduce the number of pins required, the resulting response would not be linear.

Routing considerations

While placing the sensors on a PCB, care must be taken that no communication or switching signals are routed in parallel to sensor traces as this will introduce crosstalk or switching noise on the sensor traces. This problem can be dealt in a number of ways:

1. **Routing on a different layer:** On a multilayer board, one layer can be used only for routing sensor traces while another layer is used for switching signals. Care must be taken that the two layers are isolated with a Vdd or Gnd layer between them.

2. **Proper allocation of pinouts:** Group sensors on one side of the IC and LED/communication signals on the other. This will ease the routing of traces by providing considerable space between the sensor and other switching signals.

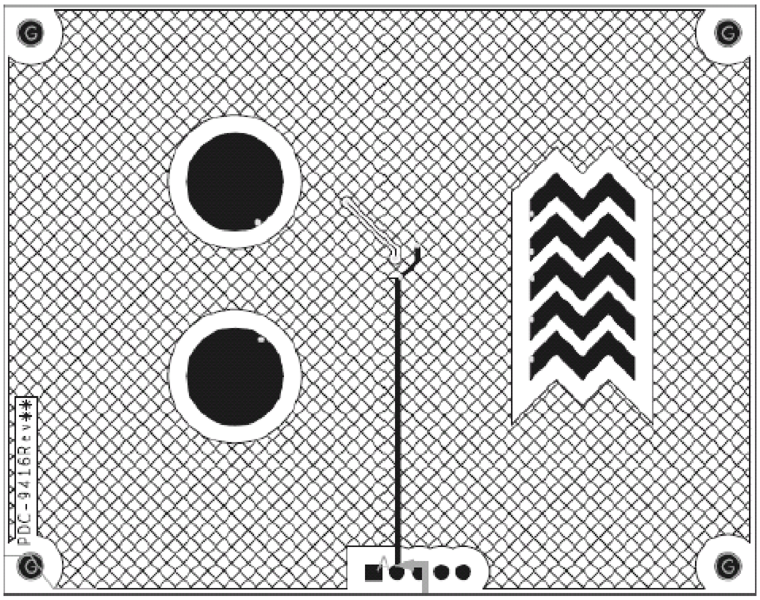
3. **Shielding:** Sometimes it is not feasible to have more than a 2-layer PCB because of cost constraints. It may also not be possible to group sensor and LED/communication signals separately because of hard-wired pinouts. In such cases, one must shield the sensor traces with ground traces to reduce the effect of crosstalk.

4. **Orthogonal routing:** If nothing else can be done, traces should cross orthogonally instead of running parallel to limit the effect of crosstalk to a minimum.

Ground considerations

In order to make the design immune to environmental noise, all sensors should be surrounded by ground. Placing ground in close proximity provides a distinct advantage by reducing the noise significantly; however, it also increases the parasitic capacitance of the sensor. This goes against our objective.

This problem can be resolved by compromising between the two. Use of hatched/meshed ground patterns help in reducing the noise. They reduce noise less than a solid ground pattern but keep parasitic capacitance in control (see Figure 6).

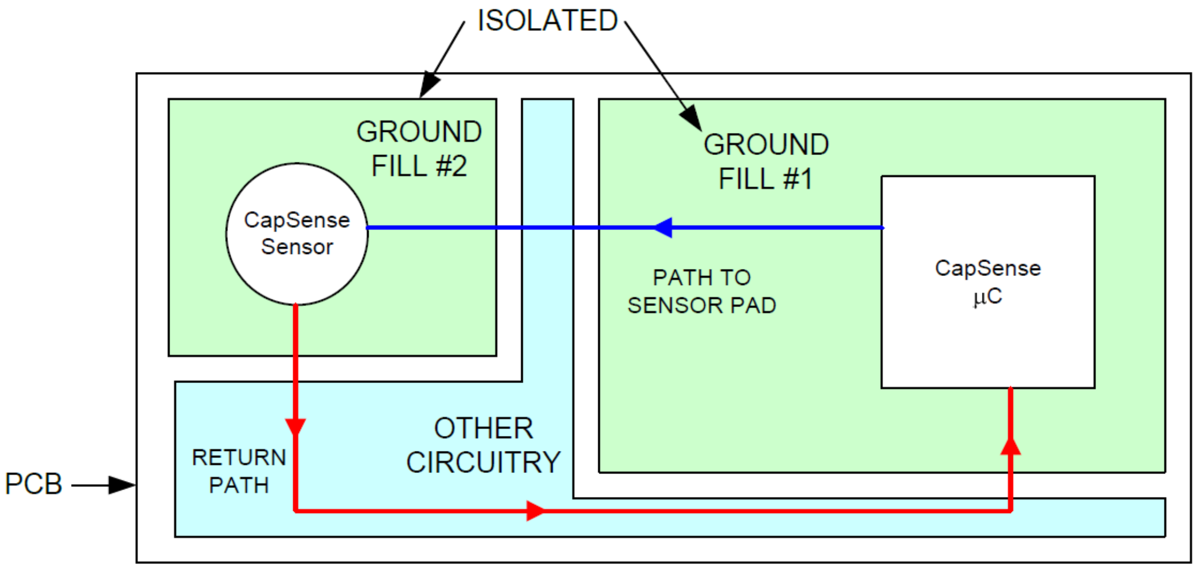


Another important consideration is the button-to-ground or segment-to-segment clearance. The following golden rule can be used when deciding upon the button-to-ground clearance:

Clearance (min: 0.5mm; max: 2mm) = Overlay thickness (acrylic)

This means that the clearance between the sensor and ground or segment and segment should be equal to the overlay thickness (in case of acrylic) with the minimum clearance being 0.5 mm and the maximum being 2 mm.

Ensure that the ground surrounding the sensor is connected to the IC ground to keep the current loop area as small as possible. Figure 7 shows an example where ground is not connected properly.



Violating this not only nullifies the effect of grounding but can also cause both immunity and emission problems.

Radiated Emissions

Any trace laid on the PCB can act as an antenna which is capable of both radiating and receiving. Using a Pseudo Random Sequence (PRS) generator for switching the sensor traces helps in reducing emissions. Additional circuitry is required to make the system immune to RF noise from the surroundings.

Having filters in software does help in improving the noise response but the first attempt should always be to not to let the noise enter into the device in the first place. This can be achieved by placing a simple series resistor of 560 Ω next to the sensor pin. The pin capacitance of the sensor and the resistor together form a simple low pass filter which filters out RF noise in the range of several 100 MHz and does not let it to enter into the device. Noise which is less than 100 MHz is not a concern to us because such signals need an antenna with a trace length of several meters (l = lambda/4).

Placing the series resistor not only helps in increasing the immunity but also reduces the surges of current required to charge the sensor, thus reducing the switching noise on Vdd which in turn reduces the emission.

Conducted Immunity and Emissions

Proper usage of the decoupling capacitor and small current loop helps in keeping conducted immunity and emissions under control. For noisy systems, a passive filter or a ferrite bead on the power supply line helps in keeping the noise level under control.

By following the guidelines mentioned above, one can safely improve the SNR and have a reliable working board.

Tuning for Production

So far, we have discussed various aspects of a capacitive touch sensor design, various types of capacitive sensing technologies, which to use for which purpose, and which sensor patterns are appropriate. We also discussed the performance and reliability related parameters. To address board-to-board and device-to-device variations due to production, tuning and calibration of these parameters is required for optimum performance in the field.

Tuning is one of the largest concerns for capacitive keypad designers. Engineers have always been wary of the apparent hard and time-consuming nature of this process. While it is true that there are many considerations to be made when calibrating a capacitive keypad, the process becomes much easier once we understand the variations to be considered and there implications. In the next part of this series, we'll discuss how to accommodate and account for variation to create a reliable application.

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