

Differentiating Noise from Real Touch – The Key to Robust Capacitive Sensing

By Kannan Srinivasagam, Product Marketing Manager Senior & Vibheesh B., Applications Engineer Senior Cypress Semiconductor Corp.

Capacitive sensing is emerging as a popular interfacing alternative to switches and knobs in consumer electronics, front panel display applications, and many industrial and automotive sensors. This article describes different kinds of noise impacting any capacitive sensing technology and the methods that can be implemented to overcome different kinds of noise under varied environmental conditions.

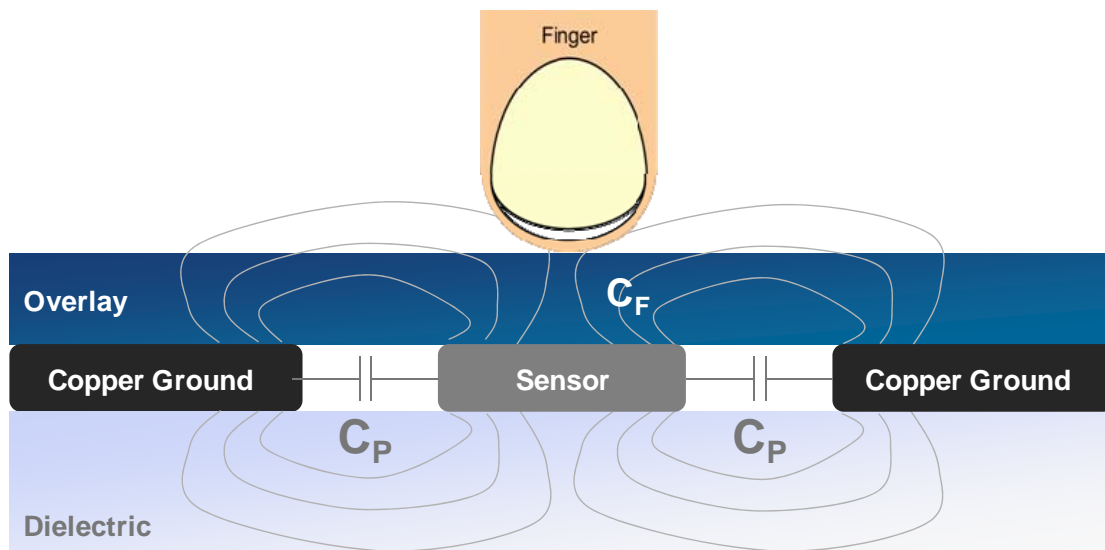
Capacitive sensing enables lower cost, robustness, flexibility, and an intuitive user interface without breaking compatibility with existing form factors and feature sets. Capacitive sensing also enables other innovative user interface (UI) features such as proximity effects and LED (Light Emitting Diode) dimming and fading effects. All of this is dependent on having robust capacitive sensing performance. The key aspect of a robust capacitive sensing performance is to differentiate between noise and a real signal (i.e., coming from a finger touch). The robustness of capacitive sensing technology depends on how well this is done to avoid false button presses in harsh, noisy environments.

Capacitive Sensing Basics

At the heart of any capacitive-sensing system is a set of conductors on a PCB which interact with electric fields. Placing a finger near fringing electric fields adds capacitance to the system. As shown in figure 1 below, the additional charge storage capacity added by the finger is known as C_F (finger capacitance). The capacitance of the sensor without a finger present is denoted as C_P (parasitic capacitance). The measurement system determines the variation in C_X (total capacitance) due to the addition of C_F for the detection of the finger. This variation in capacitance due to a finger is in the range of less than 1pF. External noise affecting the sensors either has roots in charge or voltage, and this produces noise at the digital output that looks like capacitance change on the input. This induces a challenge in terms of avoiding any noise which can also cause the same amount of capacitance change.

Sensor Capacitance = C_X

$$C_X = C_P + C_F$$



* Diagram not to scale

Figure 1 – Basics of Capacitive Sensing – Capacitance to be measured

Noise

Noise is a random fluctuation in an electrical signal. Noise generated by electronic devices varies greatly, as it can be produced by several different effects and sources. Noise can also be described as a summation of unwanted or disturbing energy from natural and man-made sources. Some examples of noise include power supply noise, Wi-Fi transmitters, mobile phone transmitter, and environmental conditions like humidity and temperature changes.

As explained above, noise may be interpreted as C_F which can cause a false detection of a finger presence. The problem is to reduce the impact of noise on C_X as much as possible. The parameter which needs to be taken into account for this is the SNR (Signal to Noise Ratio). The SNR should be as high as possible with a minimum of at least 5:1; i.e., capacitance change from a finger touch should be 5 times more than a capacitance change from noise sources.

Capacitive Sensing Algorithms

One important aspect for overcoming noise in capacitive systems is to have a robust sensing method which has low input impedance. There are various capacitive sensing controllers on the market today using various sensing algorithms such as the Relaxation oscillator method, methods based on switched capacitor front-ends, Mutual capacitance sensing, phase delay and amplitude measurement, and others.

The two most prevalent methods are:

1. Switched capacitance front-end (SC method) – The SC method converts the capacitance to count by charging or discharging a reference capacitor with sensor capacitance at a high frequency
2. Relaxation oscillator method (RO method) and its variants – The RO method contracts the oscillator using the capacitance of sensor and the variation in the frequency is converted into counts

Explaining Noise with relation to Capacitive Sensing thresholds

Figure 2 below shows the different noise amplitude levels and the impact on robustness. With relation to capacitive sensing thresholds, noise levels can be divided into three groups:

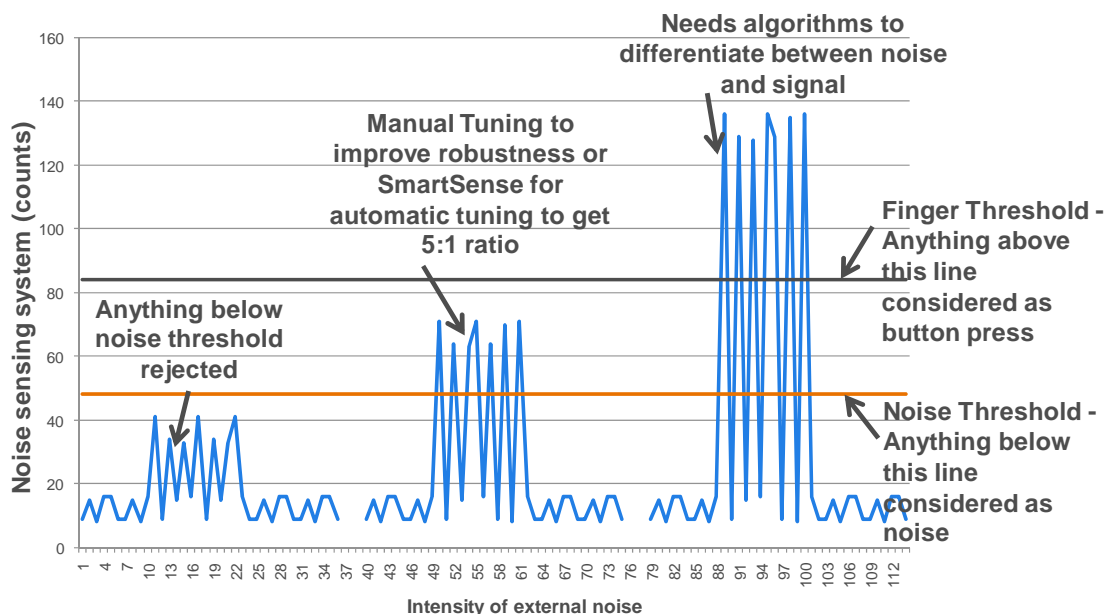


Figure 2 – Different noise levels with relation to capacitive sensing thresholds

1. Signal below noise threshold – Always considered to be noise and avoided. In order to record a signal, amplitude of the signal should be more than this noise threshold.
2. Signals with amplitude below finger threshold and more than noise threshold - Considered as spurious signals and not as finger touches.
3. Signals whose amplitude is more than finger threshold – Detected as finger touch.

Input Impedance – The Key to Robust Capacitive Sensing

One of the common methods to reduce impact of noise on the input of a system is to reduce the input impedance of the circuit by providing a pull up or pull down resistance at the input. This attenuates the amplitude of noise picked up at the input.

As an example, the RO (Relaxation Oscillator) method has a higher input impedance than the SC (Switched Capacitor) method. This makes the RO method less immune to external noise. Many of the RO methods in the market usually have noise immunity dependent on the power supply voltage.

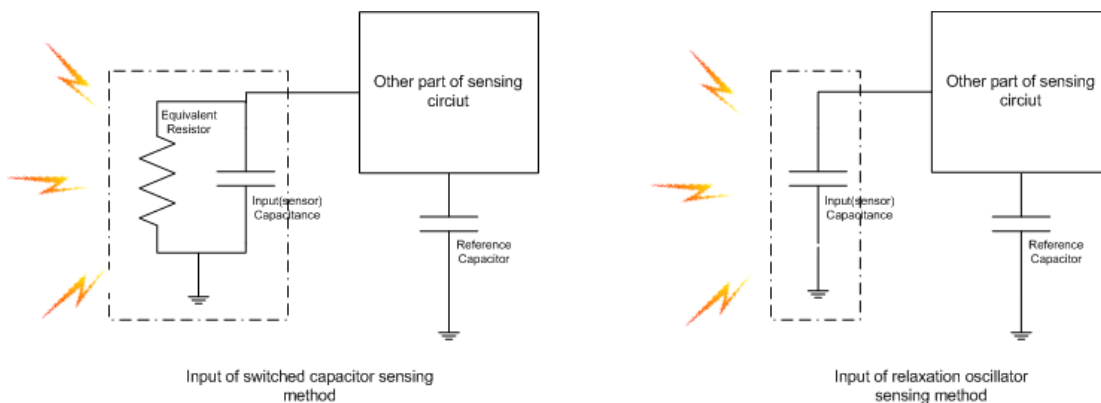


Figure 3 – Input of Switched Capacitor and Relaxation Oscillator method

As seen in figure 3 above, switched capacitor-based capacitive sensing inherently has equivalent resistance (determined by the frequency of operation and parasitic capacitance of the sensor) in parallel to input, providing lower input impedance by default. An RO method does not have this special equivalent resistance, leading to higher input impedance. Most of the time, It is not possible to add an external parallel resistance to RO method to improve immunity without also affecting the performance of the sensing method or circuit.

Figure 4 below shows how the risk of getting false button press increases when a circuit is operated in noisy environments (especially with circuits which have higher input impedance) when layout best practices are completely followed.

Case A - low noise environment

Case B - high noise environment.

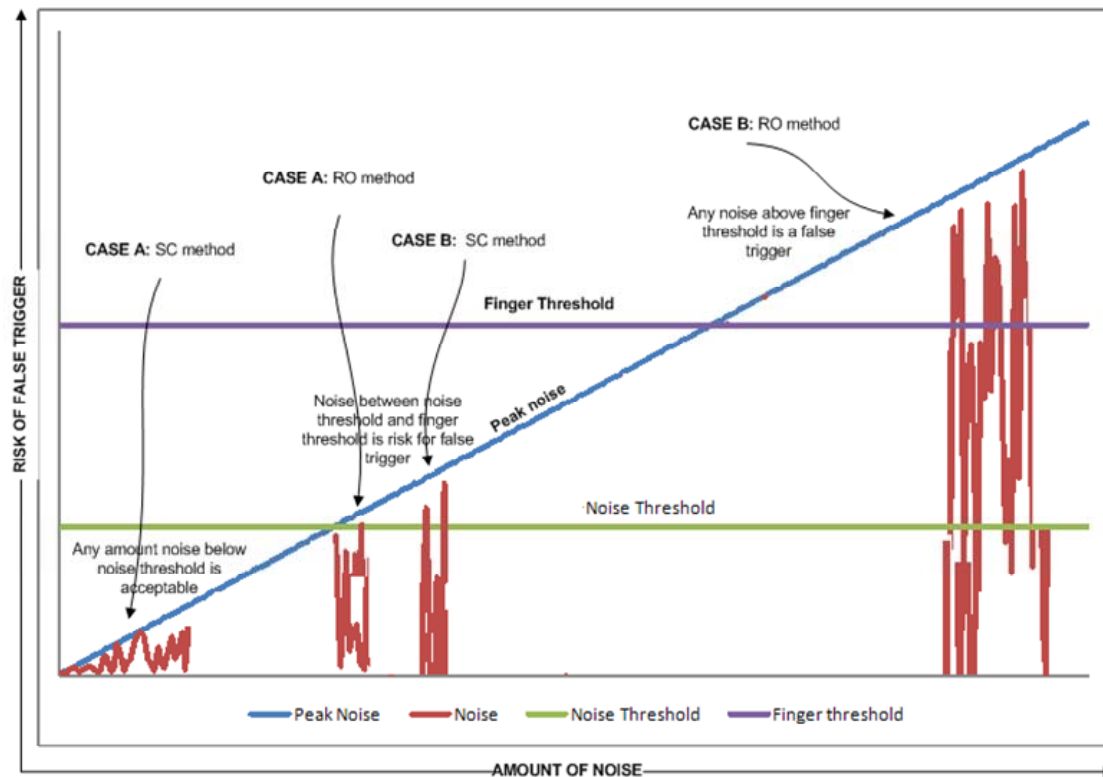


Figure 4 – Graph showing the impact of specific noise conditions on SC and RO methods

Any signal that has amplitude less than the noise threshold is rejected automatically. Thus, any amount of noise below noise threshold is not a concern for any sensing method. But when both methods (SC and RO) are operated in same environment (say case A), the amount of noise that can enter into system is different based on the sensing method.

If we take the example of Case B, the RO method will produce false trigger while the SC method will have noise levels in between noise and finger threshold which can be further fine-tuned to improve the SNR.

Different Kinds of Noise

A capacitive interface circuit is prone to mainly three types of noise:

1. Radiated noise - Radiated noise may be generated from a device like a mobile phone transmitter, LCD (Liquid Crystal Display) backlight power supply, SMPS (Switch Mode Power Supply), Wi-Fi transmitters, or wireless walky-talky. When a capacitive user interface circuit is within the vicinity of any of the noise sources mentioned above, the user interface module may generate false button detection (button triggering without a finger touch).
2. Conducted noise - Conducted noise usually enters into a system through the power supply line, such as a mobile phone or digital photo frame with capacitive user interface getting charged from an adaptor connected to AC mains, and resulting in a false button detection. The 50/60Hz low frequency AC signal can also couple to the system through the body of the user and produce unintentional operation of the system in some cases.
3. Environmental changes - The output of the capacitive sensing system is dependent on environmental parameters like temperature and humidity. Sometimes changes in temperature or humidity change the system response and affect the SNR. This type of noise has a slow trend over time.

All three noise source can be as high as 100% of C_F . This will induce a false button detection. These noise sources should be limited to at most 20% of C_F to maintain an SNR of 5:1.

Any system designed for white good, consumer, industrial markets needs to be certified as per the specification of International Electro technical commission (IEC) by UL, FCC, or the respective regulatory body of the country in which the

product will be sold. During this certification testing, heavy amounts of radiated and conducted noise are purposefully injected into the system to make sure there is stable and harmless operation of the product in the field. For many systems and circuits, passing the certifications tests for the respective regulatory body of each country is a real challenge. It is thus important to choose a robust sensing algorithm for capacitive user interface design. This is to make sure the quality of the product in the field and the regulatory body certification requirements are met.

Technologies and Techniques to Overcome Noise Issues

There are number of technologies and techniques available for improving robustness:

1. Auto-tuning - Another innovative method evolved recently in the industry are real-time compensation algorithms that automatically determine the changing noise level in the system to differentiate a real finger touch from noise. The tradeoff to this approach is the need for additional processing capacity to implement the algorithm.
2. Manual tuning - Tuning is required during the design phase to make sure that the signal is at a level which is 5 times more than the noise seen in end applications. This technique of tuning takes some amount of time to learn to make sure the device is perfectly tuned for the end application.
3. Filters – Filters are the most commonly used method to suppress noise in a system. Capacitive sensing controllers incorporate a hardware filter, a firmware filter, or both, depending upon the application's requirements and capabilities.
4. Compensation algorithms –Baseline compensation can be used to overcome changes in noise affecting CF. i.e. when noise occurs in a system, the device compensates to adjust the baseline (reference level). The noise threshold is thus automatically adjusted so as to keep most of the noise below noise threshold. This method is very effective for low frequency noise due to environmental changes.
5. Overcoming Qualification Testing Requirements – In this case, noise can be above the finger threshold in some case if best practices are not completely followed, making it hard to distinguish noise from an actual signal. This is because during qualification testing, high amount of noise is injected to test the system for robustness. Algorithms are available which can identify a specific signature in the noise pattern. The signature of this specific noise pattern is then rejected, leaving behind only the signal from finger touch and thus avoiding false presses.

Limitations Induced by Different Kinds of Noise

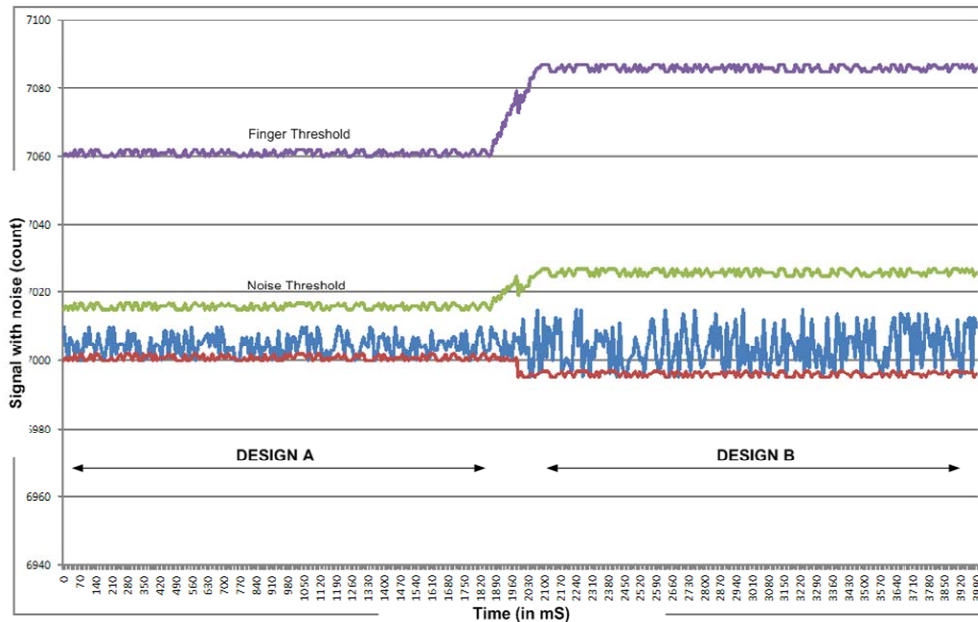
Although robustness can be improved by a number of techniques listed above, there are still some limitations based on end system requirements which are induced by these different kinds of noise. Some of these are listed below:

1. Multiple tuning efforts are needed especially if noise levels are in between noise and finger thresholds. If there is a need to support multiple models across a platform – for example, having 25 different TV models - multiple tuning efforts are needed.
2. Noise which was not accounted for in the design stage but occurs in the production stage can cause field failures.

Solving Limitations Due to Noise

Advanced auto-tuning algorithms address both of the limitations mentioned above arising from different kinds of noise by dynamically adjusting compensation to match changing model and environmental conditions. Automatically adjusting baseline and thresholds also speeds system design and achieves a constant SNR of 5:1 to optimize sensor performance.

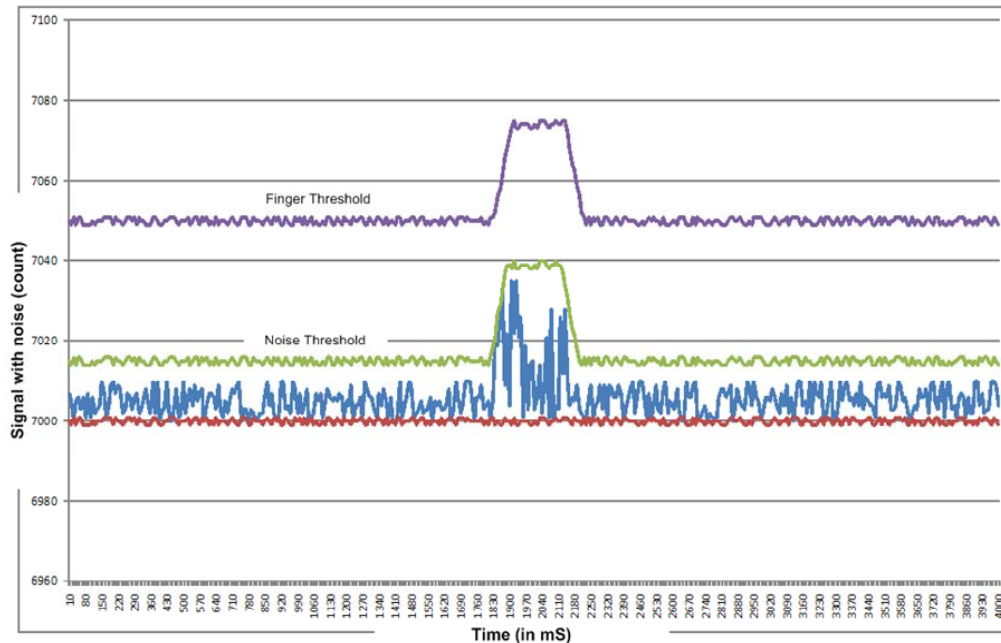
1. Multiple tuning efforts needed: Auto-tuning adjusts thresholds dynamically for different noise environments. In figure 5, Design A and Design B have different noise levels. Based on the dynamic threshold adjustment, a minimum SNR of 5:1 is maintained. This allows seamless transition from one model to another with minimal or no tuning required.



Noise and Finger Thresholds – are automatically adjusted when going from one design to another, thus maintaining a robust 5:1 Signal to Noise ratio

Figure 5 – Different noise levels in Design A & B being compensated automatically

2. Noise spike post production – Auto-tuning also compensates for noise spikes that occur during production which may not have been seen during design stage (see figure 6). This powerful feature avoids false button presses rather than having to go through a failure analysis for a mass production design.



For the same design any noise spike will be mapped. Noise and Finger thresholds will be automatically adjusted to maintain a robust Signal to Noise Ratio

Figure 6 – Noise spikes automatically taken care of avoiding false presses

User interface and industrial design are the central driving forces behind creating and improving most of today's consumer electronic products. With this in mind, manufacturers are focusing on innovative techniques such as capacitive sensing for replacing space-consuming buttons and switches. Recent advances in capacitive sensing technology have not only brought down the expense of touch sensors to the point where they are cost-effective to implement in a wide range of consumer products, but also enable robust performance. Using the technologies and techniques presented here, it is possible implement a robust capacitive sensing method in harsh noisy environments, making capacitive touch sensors a practical alternative to mechanical components.



Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
<http://www.cypress.com>

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