Application Report

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Sensitivity, SNR, and design margin in capacitive touch applications

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ABSTRACT

This application report describes the fundamental concepts of sensitivity, signal-to-noise ratio (SNR), and design margin. It then describes how to use these concepts as tools to evaluate the reliability and robustness of capacitive touch applications that are built with CapTIvate™ touch sensing MCUs.

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1 Overview

Capacitive touch sensing is the process of periodically monitoring for changes in the capacitance of a sensing electrode over time and determining if those changes are due to a user's touch or some other non-touch phenomena. This process executes periodic capacitance-to-digital conversions to obtain digital values that represent the capacitance of the sensing electrode over time, and post processing algorithms interpret the measurement results and differentiate a true touch or proximity detection from long term drift and background noise.

It is important for the designer of a capacitive touch interface to understand the basic concepts of sensitivity, signal-to-noise ratio (SNR), and design margin and, more importantly, how to leverage these metrics to ensure that a capacitive touch solution is reliable and robust. This document provides an overview of these performance metrics as they relate to capacitive touch sensing, with a focus on providing a methodology to assess the reliability and robustness of a capacitive touch solution built using CapTIvate MCUs.

1.1 Design Objectives

The primary objective of a capacitive touch design engineer is to develop a system that:

- Meets the functional needs of the application
- Integrates well into the overall product or parent system
- Is cost optimized
- Is reliable
- Is robust

Often, the designer focuses on the first three objectives the most during product development and does not focus on the last two objectives (reliability and robustness) until much of the design work is complete and the qualification phase is beginning. This document primarily focuses on the last two objectives but does not consider them as separate activities to be completed after the other objectives are met. Rather, these objectives should be assessed throughout the design and development phases.

1.1.1 Reliability

Reliability refers to the ability of a system to function properly throughout the expected lifetime of the product when the product is within in its expected conditions. For a capacitive touch interface operating within its expected conditions, this typically means:

- Correctly detecting all true touch and proximity events
- Rejecting false touch and proximity events due to noise, an environmental change, or some other factor

1.1.2 Robustness

Robustness refers to the ability of a system to operate as intended even when it is not used within the specified operating conditions. For example, a product is reliable if it operates correctly within its expected temperature range. However, the product may be considered reliable *and* robust if the product operates correctly even when it is outside of the expected temperature range. Likewise, a capacitive touch interface could be considered robust if it operates correctly in a residential environment for which it was designed, but it also operates correctly in a harsher commercial or industrial environment for which it was not designed. This is an important distinction for capacitive touch interfaces for two reasons:

- Due to the small signal levels involved in capacitive sensing, getting the best performance (such as the longest proximity detection range, the fastest response time, or the highest resolution) often requires trading off some amount of robustness.
- It is often not possible to test, or even predict, all of the possible ways and environments in which an end user will attempt to use a product.

1.2 The Designer's Dilemma

Because getting the best performance possible sometimes involves giving up some robustness, and it is very difficult (if not impossible) to predict or test all of the ways an end user will use a product, the capacitive touch designer is often left with critical decisions that need to be made to satisfy all of the competing design objectives (functional, integration, financial, reliability, and robustness). Ultimately, the balance between performance and robustness varies by the type of product and the market into which it is sold.

To aid the designer in effectively balancing these two critical trade offs, this document presents a set of useful terms to make reliability and robustness easier to understand. Furthermore, this document also provides a procedure for assessing the reliability and robustness of a capacitive touch application using CapTIvate technology.

2 Recommended Actions for Developers

TI recommends that all capacitive touch designers using CapTIvate follow this process to assess the robustness and reliability of their capacitive touch implementation during the development and prototyping phase before they transition from prototypes to mass production.

2.1 Run SNR and Design Margin Tests

During the prototyping phase, use the CapTIvate Design Center development tool to measure the SNR and design margins for each touch sensor in the application. This must be done to determine whether or not there is enough design margin to limit the possibility of false touch detection in a large volume production build. When conducting this testing, the test environment must be as close as possible to the expected use environment of the end product. This means that all possible noise aggressors that the capacitive touch sensor may be exposed to during operation of the product should be active during the measurement. For example, if a system has a motor, radio, or other internal or external noise source, measure SNR and check the design margins with those noise sources present and active.

NOTE: Version 1.80.00.00 or later of the CapTIvate Design Center contains the latest SNR and design margin analysis features.

NOTE: This procedure assumes that the user is reasonably familiar with the CapTIvate Design Center tool and CapTIvate Software Library. If that is not the case, review the getting started workshop before attempting to measure SNR.

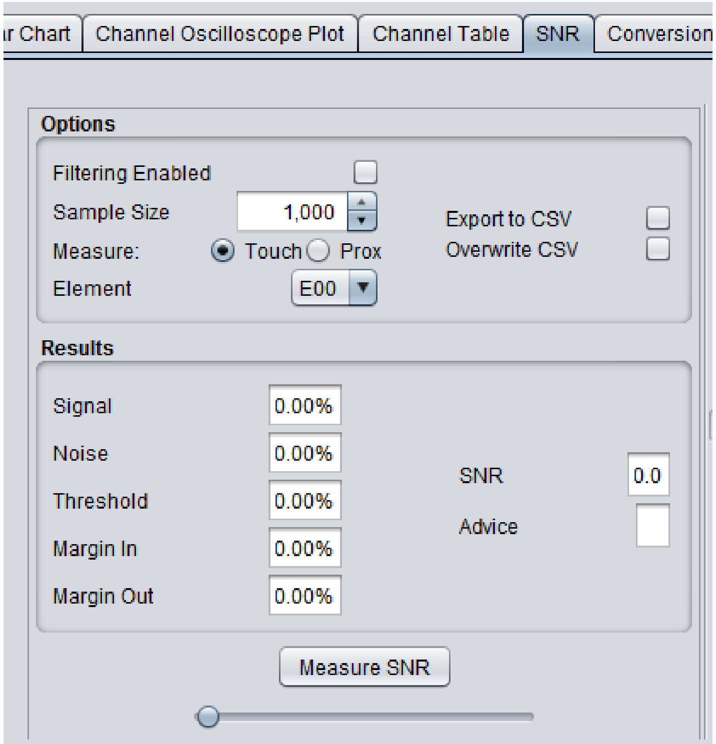

Figure 1. SNR View Before Running Test

1. Use the CAPTIVATE-PGMR debug tool to connect your test hardware to a host computer running CapTIvate Design Center. Configure the target application and CapTIvate Design Center for UART or BULK_I2C communication. Connect the selected serial interface (UART or I2C) of the MCU under test to the CAPTIVATE-PGMR. See the CapTIvate Technology Guide for information on connecting signals to the CAPTIVATE-PGMR. In CapTIvate Design Center, open the Communications menu and select "Connect". If you can see sensor and element data in CapTIvate Design Center views, you have a working connection.
2. With communication established, open the sensor customizer for the sensor that is to be tested by double-clicking the sensor customizer on the CapTIvate Design Center canvas and selecting the 'SNR' tab. A blank SNR screen appears (see Figure 1).
3. Set up the desired filtering, sample size, threshold, element you want to test, and file options before running the test. Unless you want to analyze unfiltered data, enable filtering so that the SNR results are based on post-processed data as they would be in normal use. TI recommends a sample size of 1000 samples to obtain a statistically significant data set. The CSV logging options let you capture all of the tested samples for analysis in another tool if desired.

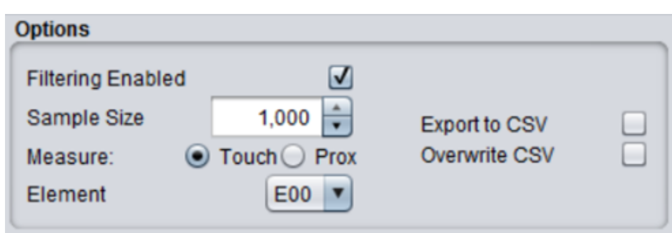

Figure 2. Selecting Options

4. With the desired options selected, select the "Measure SNR" button. A dialog asks you to touch the sensor being tested. At this time, the first Dataset is collected to determine the touch signal levels. After the touched data set is collected, the dialog box asks you to stop touching the button to measure the idle noise of the sensor.

5. After the touched and untouched data sets are collected, the tool computes the signal, noise, threshold, $margin_{in}$, $margin_{out}$, and SNR. It also provides advice about the robustness of the design.

Figure 3 shows an example SNR measurement of Button 1 on the CAPTIVATE-BSWP panel.

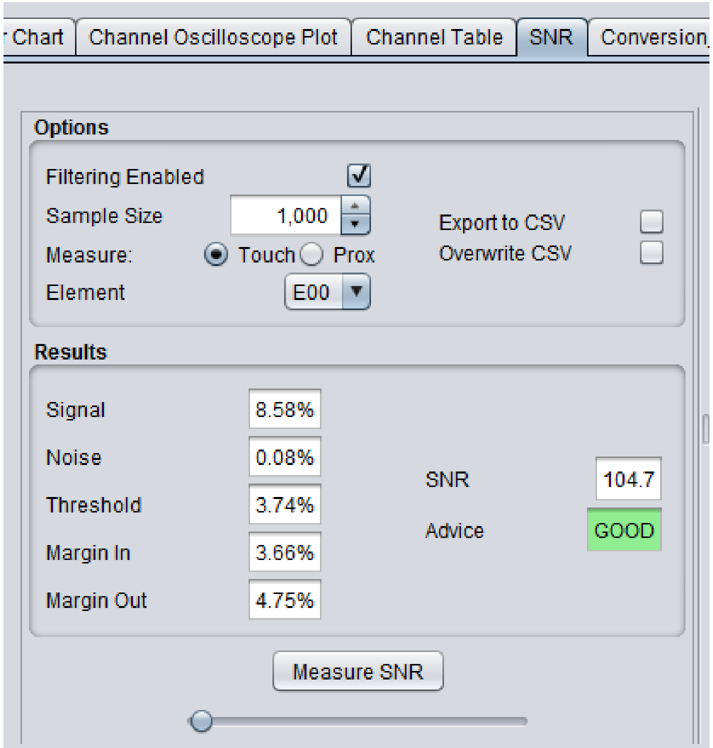

Figure 3. SNR View After Running Test

3 Terminology

This section defines and explains the key terms that are needed to perform a more detailed assessment of reliability and robustness.

Figure 4. Results

- **Signal (S)**
- **Noise (N)**
- **Threshold (Th)**
- **Margin In (Min)**
- **Margin Out (Mout)**
- **SNR (Signal-to-noise ratio)**
- **Advice**

NOTE: **Percent Change in Capacitance:** The unit of choice for analyzing capacitive touch SNR and design margin is percent change in capacitance. Capacitive touch sensing is based on measuring relative changes over time in an existing, but unknown, electrode capacitance. As such, it is most straightforward to work in terms of percent change. Another benefit of this perspective is that it removes any dependencies on the conversion settings. Filtered count and LTA values can vary with conversion settings and other factors, but percent change in capacitance is a function of the electrical hardware (the PCB) and the mechanical hardware (the overlay material). As such, percent change in capacitance is used for all parameters with the exception of ratios (such as SNR). Percent change in capacitance can be easily computed for a given filtered count, LTA, and conversion gain value using the relationship in Equation 1.

$$\Delta C_x = \frac{\text{Conversion\_Gain}}{\text{Count}} - \frac{\text{Conversion\_Gain}}{\text{LTA}} \times 100\% \quad (1)$$

3.1 Signal (S)

To calculate signal-to-noise ratio, it is first necessary to define signal and noise. In a capacitive touch application, the signal is defined as the average change in capacitance of the sensing electrode due to a touch or a proximity event. For example, consider a self-capacitance sensing electrode with a base, untouched parasitic capacitance C_p. If a touch capacitance, C_t, is applied to the sensing net along with C_p, the total electrode capacitance $C_x = C_p + C_t$. In this case, the change in capacitance expressed as a percentage of the untouched capacitance would be the quotient of C_t over C_p. Table 1 shows a simple example.

Table 1. Example of Computing Signal

Parameter	Symbol	Value
Parasitic capacitance	C_p	20 pF
Touch capacitance	C_t	1 pF
Signal	$S = C_t / C_p$	(1 pF / 20 pF) × 100 = **5%**

NOTE: In mutual capacitance sensing, a touch is expected to reduce the electrode capacitance, thus showing up as a negative percent change.

In self capacitance sensing, a touch is expected to increase the electrode capacitance, thus showing up as a positive percent change. For more information about self capacitance and mutual capacitance, see the CapTIvate Technology Guide.

Figure 5 shows the self mode button measurement result in terms of percent change in capacitance for both touched and untouched conditions. The signal is defined as the percent change in capacitance due to a touch event (see the red "Signal" line in the figure).

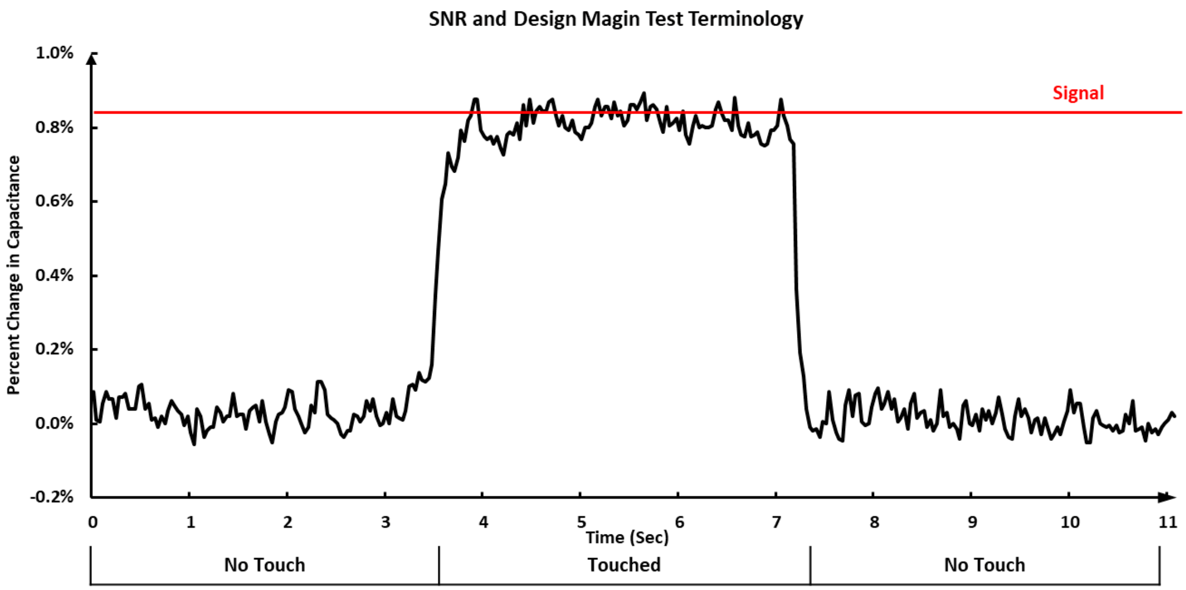

Figure 5. Signal Terminology

A fundamental concept to understand from the definition of signal is that signal is influenced not only by the touch capacitance but also by the parasitic capacitance of the electrode. This makes sense—it is easier to measure a 1-pF change in a 20-pF capacitor (5%) than it is to measure a 1-pF change in a 100-pF capacitor (1%). So, what influences C_p and C_t? C_p is primarily a function of the printed circuit board layout, including the size of the electrode and the proximity of that electrode to nearby conductors such as ground. C_t is a function of the thickness of the overlay, the dielectric constant of the overlay, and the size of the sensing electrode relative to the size of the finger touching the electrode. For details on optimizing these parameters, see the Best Practices section of the *Design* chapter of the CapTIvate Technology Guide.

NOTE: When measuring a physical electrode during development with a CapTIvate MCU, the CapTIvate Design Center SNR tool view can be used to measure the signal 'S' as a percent change in capacitance.

3.2 Noise (N)

Now that signal 'S' is defined, noise 'N' must be defined. It is most efficient to define noise in the same terms as signal, so that the two values can be easily compared (using SNR analysis, for example). This means that noise in a system is defined as the largest observed change in capacitance that is not due to a true touch or proximity event. In this way, noise level 'N' is defined as a measured percent change in capacitance that is unrelated to and thus interferes with the accurate detection of a true touch or proximity event.

There can be several sources of noise to a capacitive touch interface, such as:

- On-chip (IC generated) noise floor
- External conducted or radiated RF noise
- Electrical fast transient or "burst" noise
- 50/60-Hz AC mains noise

The challenge with noise is combining all of the possible noise sources into a single noise value for use in SNR and design margin analysis.

Figure 6 shows the self mode button measurement result in terms of percent change in capacitance for both touched and untouched conditions. The noise is defined as the percent change in capacitance due to the sum of the system noise (see the blue "Noise" line in the figure).

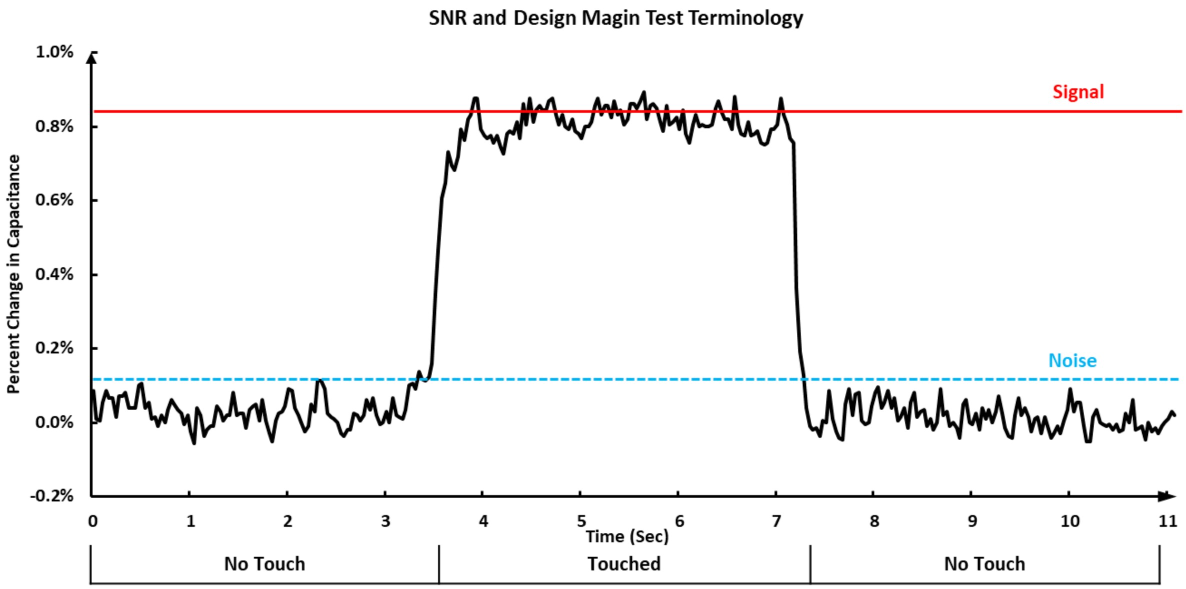

Figure 6. Noise Terminology

NOTE: When measuring a physical electrode during development with a CapTIvate MCU, the CapTIvate Design Center SNR tool view can be used to measure the noise level 'N' as a percent change in capacitance.

3.3 *Threshold (Sensitivity) (Th)*

Sensitivity is a homonym in its use with capacitive sensing. Different individuals each tend to have their own definition of what sensitivity means to them. To bring clarity to this analysis, sensitivity is explicitly used in this document to describe the tuning of the detection threshold in units of percent change in capacitance. Defining sensitivity in the same units as signal and noise (percent change in capacitance) removes any dependence on the configuration of the analog front end and enables values to be compared easily.

As discussed in Section 1, touch and proximity detection reporting is based on a certain change in capacitance. The detection threshold that the user configures in the sensor tuning tab determines the magnitude of change that is required to trigger a touch or proximity detection during post processing of the raw data. As an example, if an application has a sensitivity level set to 5%, a detection is not triggered unless a change in capacitance is greater than 5%.

By defining sensitivity in this way (connecting it to the detection Threshold), it becomes a tuning property that expresses how sensitive the designer of the system has configured the capacitive touch implementation to be. The tuning process ultimately involves finding the best place for the detection threshold (and thus the sensitivity) that allows for good design margins relative to the signal and the noise.

In this SNR analyze tool, the Threshold results are calculated based on the touch/proximity Threshold parameter that user selected in Tunning tab and it is in units of percent change in capacitance.

Figure 7 shows the self mode button measurement result in terms of percent change in capacitance for both touched and untouched conditions. The threshold configured by the user is defined as the percent change in capacitance (see the green "Threshold" line in the figure).

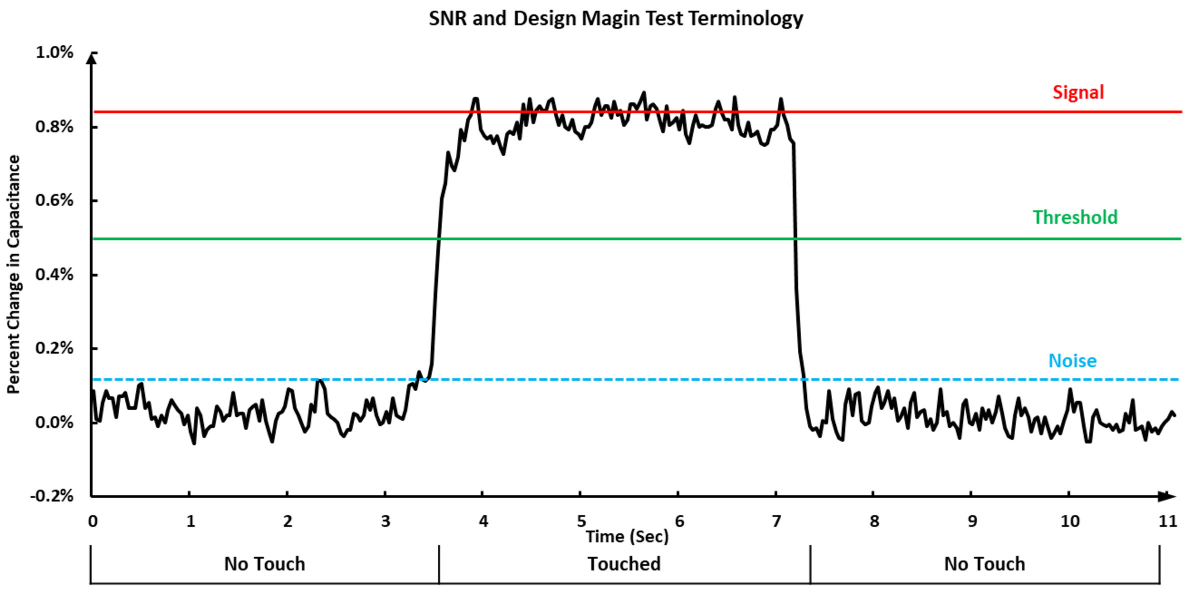

Figure 7. Threshold Terminology

NOTE: As the touch/proximity threshold is decreased (a lower percentage change in capacitance) the sensitivity of the application to touch or proximity is increased. A proximity application is considered high sensitivity, because it is attempting to detect a very small signal (a very small change in capacitance) using a very low detection Threshold (Th). As the sensitivity of an application goes up, the achievable SNR and design margins generally go down.

3.4 Design Margin

While SNR is a good indicator of the signal level with respect to the noise level, it is not the only metric to consider when designing for reliability and robustness. This is where design margin analysis comes in. Design margin, borrowed from threshold-based digital logic noise margin analysis, is very useful for threshold based systems, as it addresses the main limitations of SNR. Design margin analysis takes the detection threshold into account and analyzes the margin of the OFF state and the ON state. The following sections describe both parameters and their importance. Unlike SNR, the design margin parameters are very repeatable across multiple measurements.

3.4.1 False Detection Margin (M_{in})

False detection margin, or M_{in}, is the margin between the detection threshold and the highest noise level (see Equation 2 and Equation 3 andFigure 8).

Self Mode

$$M_{In} = Th - N \qquad (2)$$

Mutual Mode

$$M_{In} = N - Th \qquad (3)$$

This parameter is of particular interest, because it expresses how much margin exists to protect against a false touch detection. For example, if Th = 1% and N = 0.5%, then the false detection margin is a 0.5% change. Because the margin is 50% of the threshold, that implies that the noise level would have to double for a false touch detection to occur.

3.4.2 Detection Margin (M_{out})

Detection margin is the opposite of false detection margin. Detection margin assumes a touched condition and is the difference between the lowest signal value S_{low} as showing in Figure 8 (perhaps due to noise that is present when a touch or proximity is applied) and the detection threshold (see Equation 4 and Equation 5 and Figure 8). This margin shows how stable the system is configured from getting out from the detection, in other words the system should have enough margin from the signal and the threshold so when a user touch is detected the noise will not push the signal out of detect.

Self Mode

$$M_{out} = S_{low} - Th \tag{4}$$

Mutual Mode

$$M_{out} = Th - S_{low} \tag{5}$$

For example, consider the case in which noise is present during a touch, the touch signal 'S' is not constant but has a minimum value of 1.3%, and the detection threshold is set to 1% just like the previous example. The Min in this case would be 1.3% – 1.0% = 0.3%. This parameter gives an idea of how stable the touch or proximity detection state is. If the detection threshold is set too high for a given signal, then the Min is reduced. If the detection threshold is reduced too much, it will be difficult to reliably detect touches without transitioning in and out of detection during a touch when additional noise is present on the signal.

Figure 8 shows the self mode button measurement result in terms of percent change in capacitance for both touched and untouched condition and the Margin In and the Margin Out are also defined as the percent change in capacitance as the blue area are showing in the figure.

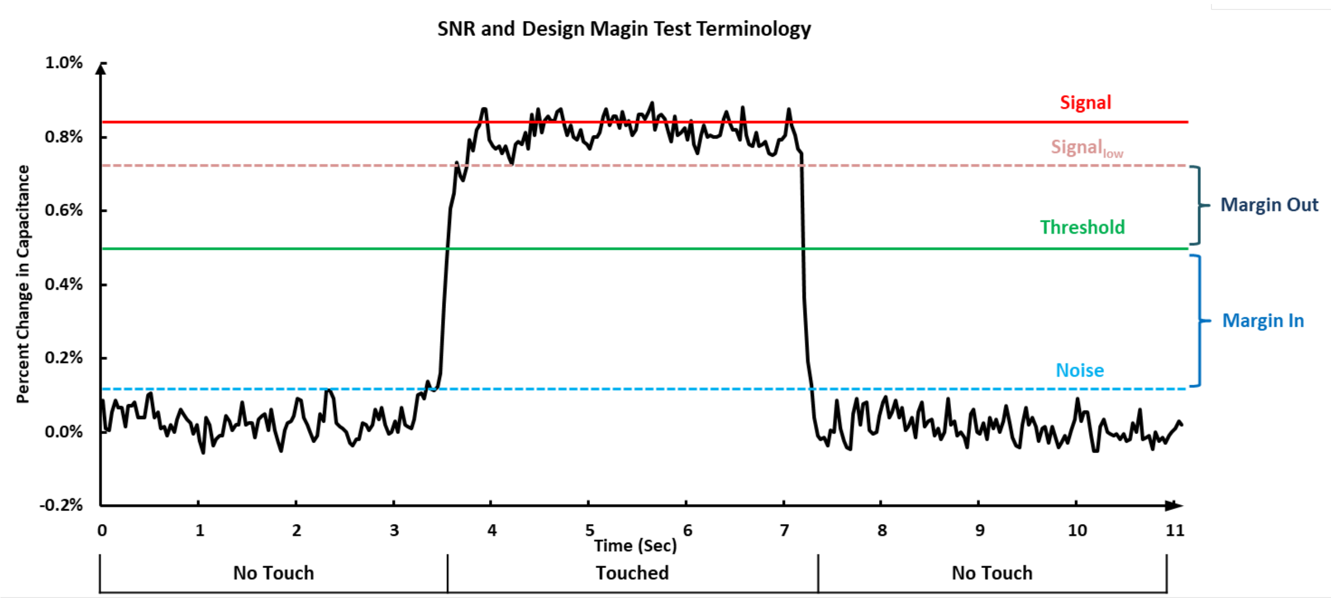

Figure 8. Design Margin Terminology

3.5 Signal-to-Noise Ratio (SNR)

Signal-to-noise ratio, or SNR, is defined as the ratio of signal 'S' with respect to noise 'N'. SNR values greater than 1 imply that the signal magnitude is larger than the noise magnitude. SNR values less than 1 imply that the noise magnitude is larger than the signal magnitude. This parameter is useful for comparing the magnitude of the signal (measured percent change in capacitance due to a touch) to the noise floor (measured percent change in capacitance due to factors other than a touch). Equation 6 shows the SNR equation.

$$\mathrm{SNR} = \frac{S}{N} \tag{6}$$

There are a few differences between this use of SNR and traditional use of SNR.

First, SNR is traditionally a ratio of average powers (average signal power with respect to average noise power). This is not useful for capacitive sensing, because capacitive sensing involves looking at long-term step response signals rather than continuous time changing signals. Noise may indeed be thought of as a time changing signal with a frequency component, but it is more difficult to think of a sustained touch signal this way.

Second, SNR is traditionally presented in decibel (dB) format on a logarithmic scale to allow for comparison of values across a very wide dynamic range. Because capacitive touch signal values are typically within an order of magnitude or two of noise levels, there is little to no advantage to working on a logarithmic scale, and it can often make SNR values more difficult to compare than if a standard scale were used. Therefore, this document use simple ratios for SNR and not decibel values. However, if decibel equivalents are desired, the correct computation is 20 times the base 10 logarithm of 'S' over 'N' (see Equation 7). A multiple of 20 is used, because 'S' and 'N' represent magnitudes and not powers.

$$\mathrm{SNR} = 20\log_{10}\left(\frac{S}{N}\right) \tag{7}$$

When measuring SNR with CapTIvate Design Center, you may find that it can be difficult to obtain consistent values when running the test multiple times. This is usually because, in many CapTIvate setups, the noise value may only be one or two counts as it is quantized in low-resolution measurements. Thus, if one SNR measurement has 1 count of noise and the next measurement has 2 counts of noise, the SNR would reduce by 50%, even though the reliability and robustness of the sensor may not have drastically changed. This is one limitation of SNR as an analysis tool in low-resolution capacitive sensing applications. Due to variance that can be seen in SNR, other metrics like design margin should also be considered.

3.6 Advice

The CapTIvate Design Center SNR and Design Margin Test Tool provides advice as to whether the design margins are good or poor based on all the above measured parameters comparing to the minimum recommendation according to devices.

Table 2 shows the logic on how the tool determines the Advice result. For the minimum recommendation value, see Section 4.

NOTE: The CapTIvate Design Center SNR tool assumes the product is designed to operate down to 0°C and the characterization process is performed under normal room temperature at 25°C. To analyze the system under different operating or characterization temperature, you can either refer to Table 4 or use the CapTIvate SNR and Design Margin Advice Tool.

Table 2. Advice Logic

| Threshold | < Minimum recommended threshold or Margin in < Minimum recommended margin in	Advice = **POOR**
Else	Advice = **GOOD**

4 CapTIvate Device Performance

4.1 *Minimum Recommended Values*

Table 4 shows the **Minimum Recommended Threshold** and **Minimum Recommended Margin In** for both First-generation and Second-generation CapTIvate technology devices under different operating temperatures and we assume the user tune the system at room temperature.

Table 3 shows the formulas on how to calculate these parameters for different operating temperature and characterization process temperature. Minimum Recommended Threshold is calculated by adding the expected maximum device noise floor with a predefined safety factor. Minimum Recommended Margin In value is calculated by looking at the difference between the minimum recommended threshold and the typical noise floor values.

Table 3. Minimum Recommendation Parameters Formulas

Minimum recommended threshold	=	Expected maximum device noise floor at operating temperature	+	Safety factor		
Minimum recommended margin in	=	Expected maximum device noise floor at operating temperature	–	Typical device noise floor at characterization temperature	+	Safety factor

Example: A product uses MSP430FR2633 (first generation) and it is designed to operate down to 0°C and the characterization process is performed under normal room temperature at 25°C.

Minimum recommended threshold = 0.8% + 0.1% = 0.9%

Minimum recommended margin in = 0.8% – 0.07% + 0.1% = 0.83%

Table 4. CapTIvate Minimum Recommended Design Margins

CapTIvate Technology	Ambient Temperature	Typical Device Noise Floor	Expected Maximum Device Noise Floor	Safety Factor	Minimum Recommended Threshold	Minimum Recommended Margin In
First generation	25°C	0.07%	0.5%	0.1%	0.6%	0.53%
	0°C	0.09%	0.8%		0.9%	0.83%
	-40°C	0.13%	1.3%		1.4%	1.33%
Second generation	25°C	0.06%	0.2%	0.1%	0.3%	0.24%
	-40°C	0.09%	0.2%		0.3%	0.24%

The device noise floor can vary from unit to unit, as indicated by the typical and minimum SNR range and the typical and maximum noise floor. TI recommends considering the worst-case performance (minimum SNR and maximum noise floor) when analyzing an application. The SNR tool incorporates device variation analysis when it provides advice. The device noise floor also has a temperature dependency. Applications that must operate in cold environments should be designed with higher Margin In values to accommodate higher noise levels at colder temperatures.

4.2 *CapTIvate Device SNR*

Table 5 lists typical and minimum SNR values for CapTIvate devices for an example use case with a 0.5-pF touch capacitance and a 20-pF electrode parasitic capacitance. The equivalent signal 'S' is 0.5 pF divided by 20 pF, which equals 2.5% change in capacitance.

Table 5. CapTIvate Device SNR

CapTIvate Technology	Touch Capacitance	Electrode (Parasitic) Capacitance	Signal	Ambient Temperature	Typical SNR	Expected Minimum SNR
First generation	0.5 pF	20 pF	2.5%	25°C	36:1	5:1
	0.5 pF	20 pF	2.5%	0°C	28:1	3.1:1
	0.5 pF	20 pF	2.5%	-40°C	19:1	1.9:1

Table 5. CapTIvate Device SNR (continued)

CapTIvate Technology	Touch Capacitance	Electrode (Parasitic) Capacitance	Signal	Ambient Temperature	Typical SNR	Expected Minimum SNR
Second generation	0.5 pF	20 pF	2.5%	25°C	42:1	13:1
	0.5 pF	20 pF	2.5%	-40°C	28:1	13:1

NOTE: SNR values, particularly expected minimum SNR values, are provided for informational purposes to assist in application development. Refer to the device-specific data sheet for specified SNR values.

The SNR values for CapTIvate devices in Table 5 are characterized and tested using a count filter beta of 3, an LTA filter beta of 7, and a scan rate of 167 sps.

It is possible to derive the equivalent typical and maximum device noise floor (a useful parameter for margin analysis) from the SNR parameters by backing out the test case (2.5% signal). Divide the signal by the SNR value to obtain the noise floor. These values are obtained by solving the SNR equation for noise (see Equation 8).

$$N = \frac{S}{SNR} \tag{8}$$

5 Interpreting the Results

With the SNR test complete, the SNR test results can be used to analyze the reliability and robustness of the sensor which was measured.

5.1 Interpreting the Advice

The CapTIvate Design Center provides advice as to whether the measured design margins are good, poor.

Advice: GOOD

If the advice is GOOD, the application that was tested has a safe threshold setting and sufficient false detection margin (Min).

Advice: POOR

If the advice is 'poor', than the application has a very low design margin in or a very low threshold setting.

1. Check the "Noise" result. If it is higher than typical (0.02% to 0.12%), analyze the system to determine if a noise aggressor is present.
2. Increase the "Touch/Proximity Threshold" setting in the "Tuning" tab while still being able to detect a touch event. Perform the SNR measurement test again or on multiple units.
3. Repeat Step 2. If the advice is still POOR and the "Touch/Proximity Threshold" is too high for the system to detect a touch or proximity event, then the hardware and or mechanical design must be modified to increase the signal.

5.2 Check Other Results

Section 3 introduces the result parameters (signal, noise, threshold, margin in, margin out, and SNR). The most important parameter to inspect are the **Threshold** and **Margin In**, which is the amount of additional noise that can be tolerated before a false detection occurs. This margin is needed to prevent increased external noise or an increased device noise from triggering a false detection. TI recommends having an Margin In value that is larger than the minimum recommended Margin In as showing in Table 4.

NOTE: The CapTIvate Design Center SNR tool assumes the product is designed to operate down to 0°C and the characterization process is performed under normal room temperature at 25°C. To analyze the system under different operating or characterization temperature, you can either refer to Table 4 or use the CapTIvate SNR and Design Margin Advice Tool.

Example: The product uses the MSP430FR2633 device, and the designer wants to see the design margin analysis for operating temperatures of 25°C, 0°C, and -40°C with the characterization process performed at 25°C. The Threshold value (%) from the SNR tool is 1.13% and the Margin In value from the SNR tool is 1.07%. Figure 9 shows the CapTIvate SNR and Design Margin Advice Tool results for three different operating temperature. The tool outputs the Minimum Recommended Threshold, Minimum Recommended Margin In, and Advice based on the system conditions.

Msp430 CapTIvate SNR and Design Margin Advice Tool		
Step 1	Please select what MSP430 device you use.	
	MSP430 Device:	MSP430FR2633
Step 2	Please select the temperature the product is designd to operate down to.	
	Product Operating Temperature:	25C
Step 3	Please select the temperature the product is characterized at. (Normally 25C)	
	Characterization Temperature:	25C
Step 4	Please enter the Threshold result from CapTIvate Design Center SNR tool.	
	SNR Tool Threshold Value (%):	1.13
Step 5	Please enter the Margin In result from CapTIvate Design Center SNR tool.	
	SNR Tool Margin In Value (%):	1.07
Minimum Recommended	Minimum Recommended Threshold (%)	0.6
	Minimum Recommended Margin In (%)	0.53
Advice	Good	

Msp430 CapTIvate SNR and Design Margin Advice Tool		
Step 1	Please select what MSP430 device you use.	
	MSP430 Device:	MSP430FR2633
Step 2	Please select the temperature the product is designd to operate down to.	
	Product Operating Temperature:	0C
Step 3	Please select the temperature the product is characterized at. (Normally 25C)	
	Characterization Temperature:	25C
Step 4	Please enter the Threshold result from CapTIvate Design Center SNR tool.	
	SNR Tool Threshold Value (%):	1.13
Step 5	Please enter the Margin In result from CapTIvate Design Center SNR tool.	
	SNR Tool Margin In Value (%):	1.07
Minimum Recommended	Minimum Recommended Threshold (%)	0.9
	Minimum Recommended Margin In (%)	0.83
Advice	Good	

Msp430 CapTIvate SNR and Design Margin Advice Tool		
Step 1	Please select what MSP430 device you use.	
	MSP430 Device:	MSP430FR2633
Step 2	Please select the temperature the product is designd to operate down to.	
	Product Operating Temperature:	-40C
Step 3	Please select the temperature the product is characterized at. (Normally 25C)	
	Characterization Temperature:	25C
Step 4	Please enter the Threshold result from CapTIvate Design Center SNR tool.	
	SNR Tool Threshold Value (%):	1.13
Step 5	Please enter the Margin In result from CapTIvate Design Center SNR tool.	
	SNR Tool Margin In Value (%):	1.07
Minimum Recommended	Minimum Recommended Threshold (%)	1.4
	Minimum Recommended Margin In (%)	1.33
Advice	Poor	

Figure 9. CapTIvate SNR and Design Margin Advice Tool

6 Application of Terms

This section applies the parameters discussed above to an application use case. In this example, the test hardware is the CAPTIVATE-FR2633 MCU PCB with the CAPTIVATE-BSWP sensor PCB. This sensor board is designed for a 1.5-mm overlay. To show both the GOOD and POOR advice examples, an additional 6 mm of overlay material was applied on top of the existing 1.5-mm overlay material to create an overall overlay thickness of 7.5 mm. Using a 7.5-mm overlay instead of a 1.5-mm overlay reduces the touch capacitance (C_t), which reduces the signal and design margins, so the SNR analyze tool gives a POOR advice.

6.1 Count and Percent Change Analysis With 7.5-mm Overlay, Advice = POOR

Because the capacitive touch sensing process involves a change in capacitance over time, the capacitive touch software must maintain a reference value that represents the untouched capacitance. This reference value is a slow moving average referred to as the long-term average, or LTA. Each new sample is compared against this moving average to determine if a touch is present or not. Figure 10 shows the count and the long-term average of the test hardware with a 7.5-mm overlay when a touch is applied and then removed. Note that the count value (the conversion result) decreases from the long-term average value of approximately 1410 to approximately 1264 (a change of approximately 146 counts). Some noise is also present in this particular measurement.

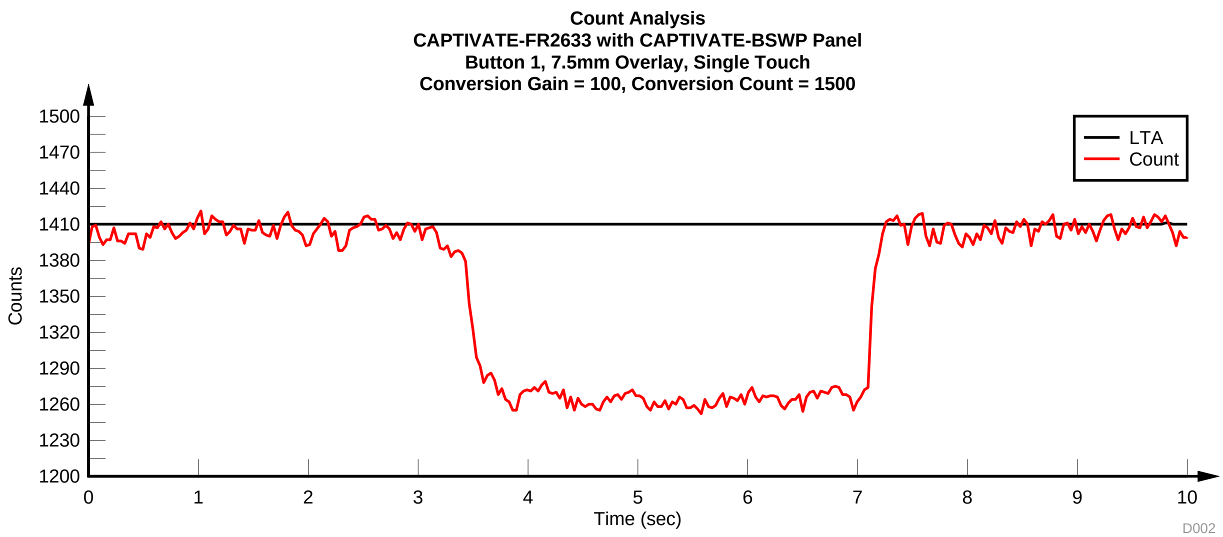

Figure 10. Count Analysis With 7.5-mm Overlay

To determine the signal 'S' and noise 'N' parameters for this data set, the count and LTA values must be converted into a percent change in capacitance format. This is necessary, because the CapTIvate analog front end has a programmable offset feature to amplify small changes in capacitance. The 1410 to 1264 count change due to a touch is a –10% change in counts. However, this is not the change in capacitance. The change in counts appears larger than the change in capacitance, because offset is applied in the conversion to remove the effect of some of the electrode's parasitic capacitance (C_p). Equation 9 shows the relationship between counts and percent change.

$$\Delta C_x = \left(\frac{\text{Conversion\_Gain}}{\text{Count}} - \frac{\text{Conversion\_Gain}}{\text{LTA}}\right) \times 100\% \tag{9}$$

In this equation, the Conversion_Gain parameter is taken from CapTIvate Design Center, and the LTA and count are taken from the data set. Applying this equation to the LTA an count values in the previous example gives the result in Figure 11.

Example: Signal Percent Change in Capacitance = [(100/1264) – (100/1410)] × 100% = 0.82%. Note that a decrease in counts represents an increase in capacitance, which is why the direction of change due to a touch appears to flip.

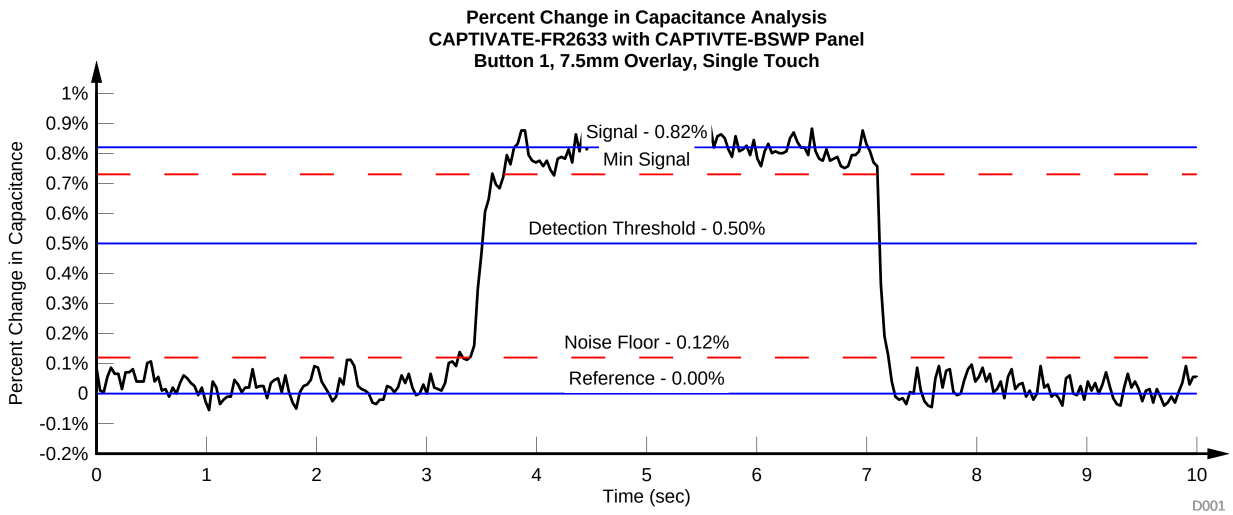

Figure 11. Percent Change Analysis With 7.5-mm Overlay

The application of Equation 9 in Figure 11 provides a clear picture of how the electrode's capacitance changed as a result of the touch. As can be seen in the figure, the touch created an average change in capacitance of 0.82%. Also note that the noise level in the direction of a touch was as high as 0.12% in this example. These values provide the signal 'S' and noise 'N' respectively. It is now possible to compute an SNR for this example.

$$SNR = \frac{S}{N} = \frac{0.82\%}{0.12\%} = 6.8:1 \quad (10)$$

With 'S', 'N', and SNR now available, a detection threshold can be placed and the design margin can be analyzed. Design margin provides more information than SNR for capacitive touch applications, because it indicates the margin between the highest noise levels and the detection threshold. This provides insight into false detection risk. The reason this needs to be considered along with SNR is that if the detection threshold is set to a smaller than normal value for some reason, the SNR does not change but the false detection risk does (because the distance between the noise floor and the detection threshold is smaller).

Figure 11 shows that the Threshold (Th) = 0.5%. Based on Table 4, the minimum recommended threshold for 0°C operating temperature is 0.9%. This means that if this example is designed to operate down to 0°C then the SNR analyze tool will give an advice as POOR.

Equation 11 calculates the Min in this example. In this example, the Min of 0.38% is also lower than the minimum recommended margin in 0.83% as showing in Table 4. This means that if this example is designed to operate down to 0°C then the SNR analyze tool will give an advice as POOR.

$$M_{in} = Th - N = 0.5\% - 0.12\% = 0.38\% \quad (11)$$

Equation 12 calculates the Mout. This is the difference between the lowest percent change during a touch and the detection threshold.

$$M_{out} = S_{low} - Th = 0.73\% - 0.50\% = 0.23\% \quad (12)$$

6.2 *Count and Percent Change Analysis With 1.5-mm Overlay, Advice = GOOD*

The example in Section 6.1 used the CAPTIVATE-BSWP sensing panel, which is designed for 1.5mm overlay, with a 7.5-mm overlay. This example demonstrates a poor design margin and SNR case. This SNR can be improved in two ways:

- Reducing the parasitic electrode capacitance C_p
- Increasing the touch capacitance C_t

Reducing the overlay thickness has the effect of increasing the touch capacitance C_t, leading to a larger percent change in capacitance due to a touch. With the standard 1.5-mm overlay, the change in counts is now 1490 – 690 = 800 counts, and the signal 'S' improves from 0.82% to a very ideal 7.8% change in capacitance (see Figure 12 and Figure 13).

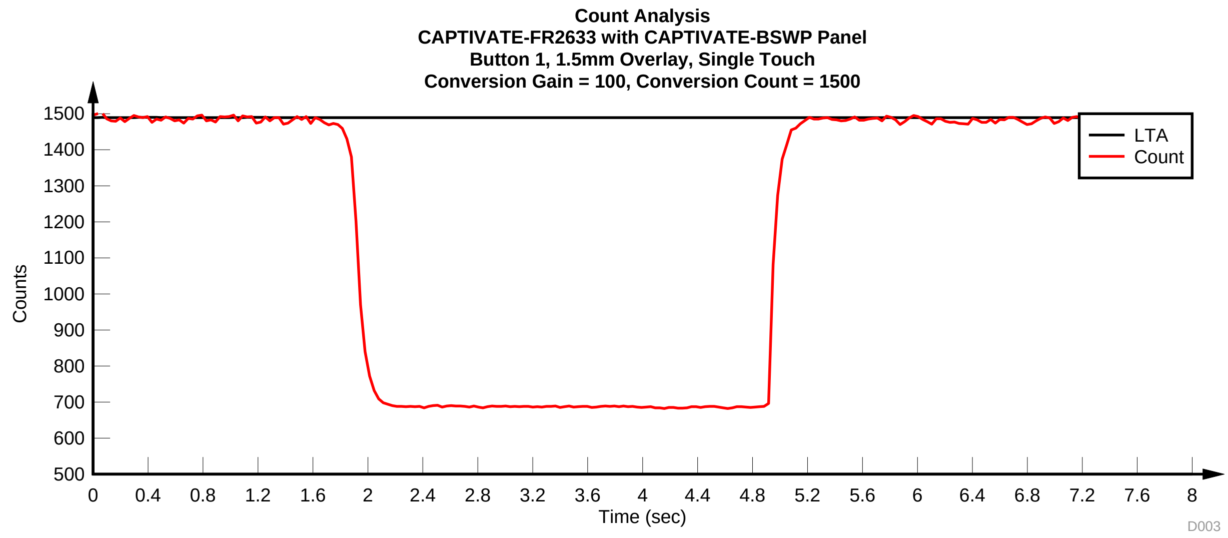

Figure 12. Count Analysis With 1.5-mm Overlay

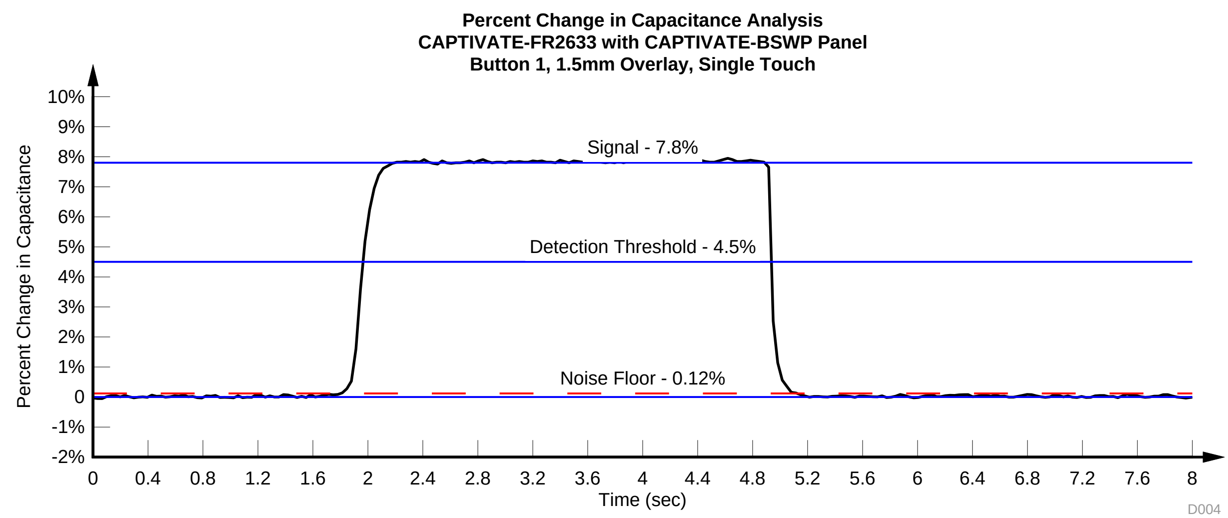

Figure 13. Percent Change Analysis With 1.5-mm Overlay

The SNR for this configuration can be calculated by Equation 13.

$$\mathrm{SNR} = \frac{S}{N} = \frac{7.8\%}{0.12\%} = 65:1 \quad (13)$$

Figure 13 shows that the Threshold (Th) = 4.5%. Based on Table 4, the minimum recommended threshold for 0°C operating temperature is 0.9% and the Threshold (Th) for this design is 5 times higher than the minimum recommendation. This means that if this example is designed to operate down to 0°C then the SNR analyze tool will give an advice as GOOD.

Equation 14 calculates the Min in this example. In this example, the Min of 4.38% is also 5 times higher than the minimum recommended margin in (Min) 0.83% as showing in Table 4. This means that if this example is designed to operate down to 0°C then the SNR analyze tool will give an advice as GOOD.

$$M_{in} = Th - N = 4.5\% - 0.12\% = 4.38\% \quad (14)$$

Equation 15 calculates the Mout. This is the difference between the lowest percent change during a touch and the detection threshold.

$$M_{out} = S_{low} - Th = 7.7\% - 4.5\% = 3.2\% \quad (15)$$

This shows that reducing the overlay thickness by a factor of 5 improved the SNR by a factor of almost 10.

6.3 Count and Percent Change Analysis (1.5-mm Overlay vs 7.5-mm Overlay)

Table 6 shows a count and percent change analysis comparison between the two different thickness overlay with the same sensor panel board.

Table 6. 1.5-mm Overlay vs 7.5-mm Overlay

Parameter	CAPTIVATE-BSWP Panel Board With 1.5-mm Overlay Results (%)	CAPTIVATE-BSWP Panel Board With 7.5-mm Overlay Results (%)	Minimum Recommended Value (%)
Signal (S)	7.8	0.82	
Minimum signal (S_{low})	7.7	0.73	
Noise (N)	0.12	0.12	
Threshold (Th)	4.5	0.5	0.9
Margin in (M_{In})	4.38	0.38	0.83
Margin out (M_{out})	3.2	0.23	
Advice	GOOD	POOR	

6.4 Effect of Post-Processing and Sampling Rate

It is important to note that measured noise 'N' is affected by filtering of the count value, the tracking rate of the LTA, and the overall sampling rate. In the previous examples, a count filter beta of 1, LTA filter beta of 7, and scan rate of 30 samples per second (sps) was used. In general, a low noise level (and thus better SNR) is achieved by increasing the count filter beta. Increasing the count filter beta can add some phase lag to the count signal. Thus, when increasing the count filter beta it is best to increase the sampling rate along with the count filter beta to maintain the desired response time to a touch.

7 Summary

When designing a capacitive touch system for reliability, check each sensor's design margins to ensure that the design is tolerant of higher noise levels that can occur when the system is operated across the required temperature range or if a unit has a higher than typical noise floor. To go one step further and build in additional robustness, consider the ways in which an end customer may use a product that go above and beyond the system's specification, and take that information into account as well when checking the design margins.

Be sure to leverage the SNR tool in the CapTIvate Design Center to easily measure your system.

For more information on capacitive touch design best practices, see the CapTIvate Technology Guide Design Guide chapter.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from August 18, 2018 to March 25, 2019 **Page**