TI Designs: TIDM-1021
Liquid Tolerant Capacitive Touch Keypad Design

TEXAS INSTRUMENTS

Description

The Liquid Tolerant Capacitive Touch Keypad Design (TIDM-1021) is a reference design that implements a liquid-tolerant capacitive-touch human-machine interface (HMI). The design integrates the TI MSP430FR2633 microcontroller (MCU) and features high-performance CapTIvate™ touch technology with an optimized sensor layout design and software. This reference design demonstrates how to design capacitive touch hardware and software that can work reliably when exposed to liquids and that can pass challenging tests for conductive noise immunity.

Resources

TIDM-1021	Design Folder
MSP430FR2633	Product Folder

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Features

- MSP430™ CapTIvate MCU for Liquid-Tolerant Capacitive-Touch Sensing
- Advanced Human-Machine Interface Design With 12-Button Keypad
- 12 LEDs Driven by the MSP430 CapTIvate MCU for Backlighting
- Passes IEC 61000-4-6 Conducted Noise Immunity Test at 3-V_{rms} Stress Level
- No False Touch Detection and Accurately Detects Touched Button Under IPX5 Rating Test With AC Power

Applications

- Appliances
- Factory Automation & Control
- Building Automation
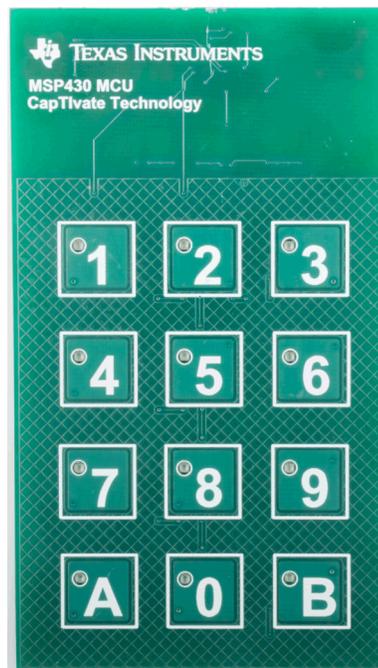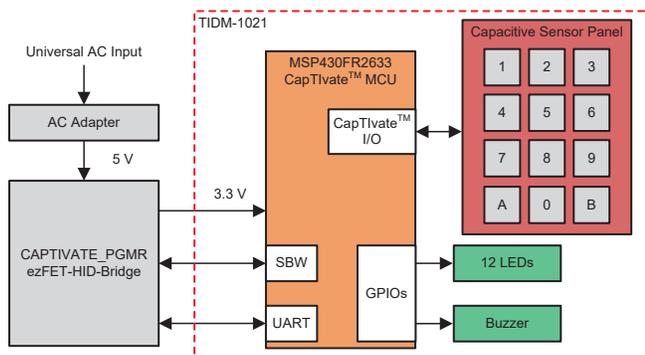
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1   System Description

Capacitive touch technology is becoming more popular in today's homes and workspace. However, one challenge is that the sensing measurement results change if liquid is on the touch surface. This is particularly important for appliance, factory automation, and building automation applications. The TIDM-1021 reference design demonstrates a capacitive touch solution that can reliably operate in an environment with liquid on the touch sensors. This reference design includes an optimized sensor layout and software algorithms to help prevent false triggers and also to ensure accurate touch detection even when liquid is present. The system operates reliably with a well grounded power supply in the IPX5 rating test environment.

1.1   Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Buttons	12 square buttons, 10 mm x 10 mm each
Measurement mode	Mutual capacitance mode
Scan rate	25 Hz
Input voltage	3.3 VDC
Average current consumption[1]	3.63 mW (1.1 mA)
Serial interface	250-kbps UART
MSP430FR2633 FRAM code footprint	8314 bytes (54%)
Printed circuit board (PCB) size (W x L)	63 mm x 109 mm
PCB thickness	1.6-mm 2-layer PCB
Noise immunity test	IEC 61000-4-6 conducted noise immunity (CNI) with 3-V_{rms} noise voltage

[1]   This reference design is optimized for noise immunity and liquid tolerance but is not optimized for low power consumption. For more information on low-power optimization, refer to the CapTIvate Technology Guide.

Although the hardware and firmware design can be different depending on specific design requirements, this reference design is optimized to use mutual capacitance topology for 12 buttons with a well grounded power supply. The design works reliably when exposed to a continuous stream of water and operates under these conditions without false detections and with accurate detection of a touched button.

2   System Overview

2.1   Block Diagram

Figure 1 shows the block diagram of this reference design, which includes:

● 12 mutual capacitance buttons

● 12 LEDs for touch indication feedback

● An audio buzzer for touch indication feedback
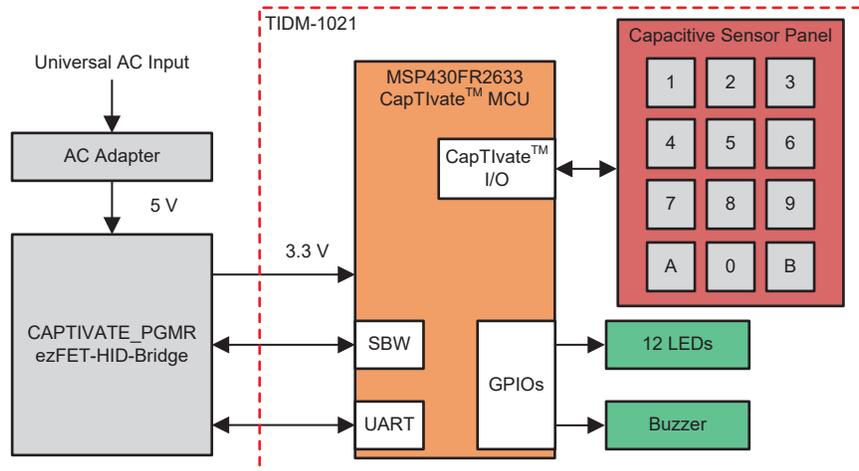
● An MSP430FR2633 MCU

Figure 1. TIDM-1021 Block Diagram

2.2   Design Considerations

2.2.1   Classification of Scenarios With Liquid Present

Scenarios with liquid present are difficult to quantify, because the fluid has no fixed shape and its movement is dynamic. This document describes operation in three scenarios: dry, with water droplets, and with a continuous stream flow (see Figure 2). The amount of liquid applied on the touch surface is different in each scenario.
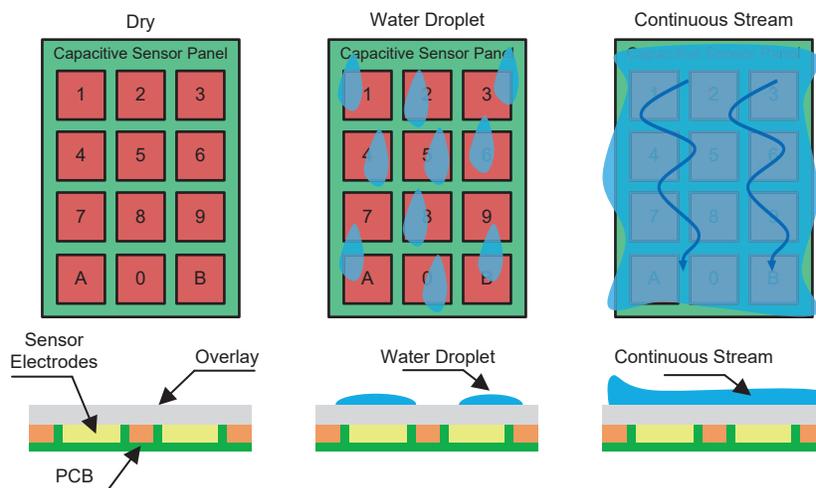

Figure 2. Scenarios With Liquid Present

2.2.2 Liquid Influence on Capacitive Touch Sensing

It is critical to design the user interface to work reliably under all expected environments. Unlike a mechanical button that uses physical movement to trigger a touch event, a capacitive touch button is fundamentally different. It triggers a touch event by detecting the changes in the electric field and capacitance of the sensors over time. Unfortunately, this operating principle makes capacitive touch buttons more vulnerable to influence by liquids. The changes in the electric field and capacitance of the sensors can be due to human interaction, such as a finger or hand, but the human body is not the only thing that can affect the electric field and capacitance. Water and other liquids on the touch surface can also create changes to the electric field and capacitance similar to the changes causes by the human body. The changes caused by the presence of liquids result in the false touch detections or inaccurate touch detections.

Different end equipment can have different requirements for handling detection when liquids are present. For some products, the user interface is designed to reject any touch events if there is liquid covering the touch surface. For other products, the user interface needs to accurately detect a touch event even when liquid covers the touch surface.

2.2.3 Self Capacitance and Mutual Capacitance

Self capacitance and mutual capacitance are the two capacitive sensing methods to detect touch events, and they behave slightly different when exposed to liquids.

2.2.3.1 Self Capacitance

The self capacitance method measures changes in capacitance with respect to earth ground. When a user's finger touches the self capacitance sensor electrode, the finger provides a path that couples the sensor to earth ground (see Figure 3). Because of this, an additional touch capacitance is added to C_{self}, which increases the capacitance. When a liquid covers the touch surface, the liquid also provides a path that couples the sensor to the surrounding ground on the sensor PCB. The additional capacitance C_{liquid} is added to C_{self} and increases the capacitance.

With the self capacitance method, both the finger touch and liquid presence increase the sensed capacitance, which means that the self capacitance method is sensitive to liquid on the touch surface.
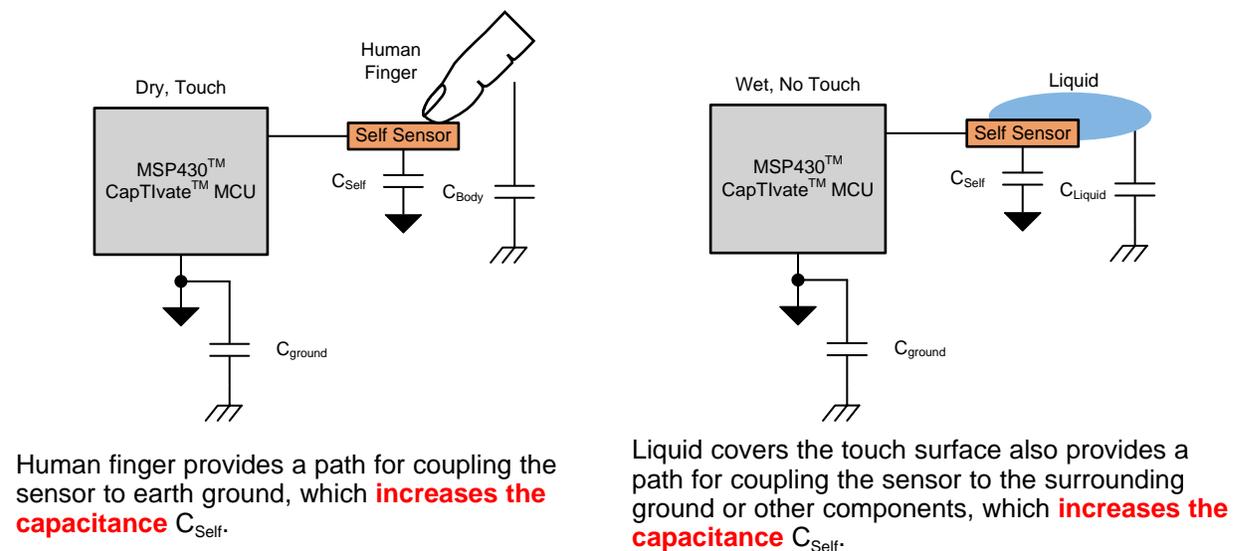

Human finger provides a path for coupling the sensor to earth ground, which **increases the capacitance** C_{Self}.

Liquid covers the touch surface also provides a path for coupling the sensor to the surrounding ground or other components, which **increases the capacitance** C_{Self}.

**Figure 3. Influence of Liquid on Self Capacitance Method**

2.2.3.2 Mutual Capacitance

The mutual capacitance method measures changes in capacitance between two electrodes. When a finger touches the area between the TX electrode and RX electrode, the finger reduces the electric field coupling between them, which reduces the mutual capacitance C_{mutual} (see Figure 4). This reduction happens because the finger is coupled to earth ground, so the user interaction disturbs the electric field propagation between the two electrodes.

When liquid covers the touch surface, it affects the sensing capacitance in two ways. The first effect is that the liquid couples to the surrounding ground on the sensor PCB, which reduces the electric field coupling between the RX and TX and reduces the mutual capacitance, C_{mutual}. Because liquid has higher dielectric constant than air, the second effect is that the liquid on the area between the RX and TX electrodes increases the electric field coupling between the electrodes, which increases the mutual capacitance. The increase of C_{mutual} causes the measurement result to go in the opposite direction of a touch, and this opposite result is called a "negative touch". This "negative touch" behavior helps to prevent false touch detection when liquid is present.

For a fixed mutual capacitance sensor design, the overall effect of liquids depends on:

1. The amount of grounding path around the sensors. Liquid couples the sensor to larger grounding path reduces the mutual capacitance and causes the measurement result to go the same direction as a touch.

2. The amount of liquid that is present on the touch surface, which determines how much the mutual capacitance increases and how much the measurement result goes in the opposite direction of a touch.
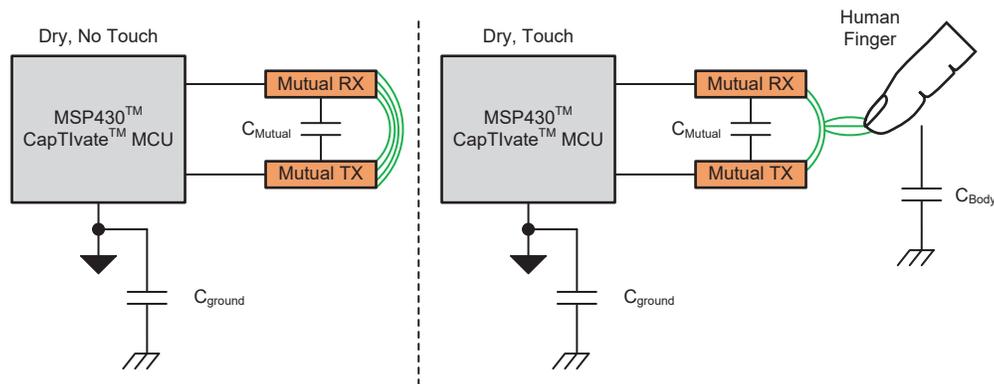
When a finger touches an area where a TX electrode meets RX electrode, it **reduces the capacitance** C_{mutual} between TX and RX electrodes. This is because the human fingers are coupled to earth ground so the user's interaction has the effect of disturbing the electric field propagation between the two electrodes.
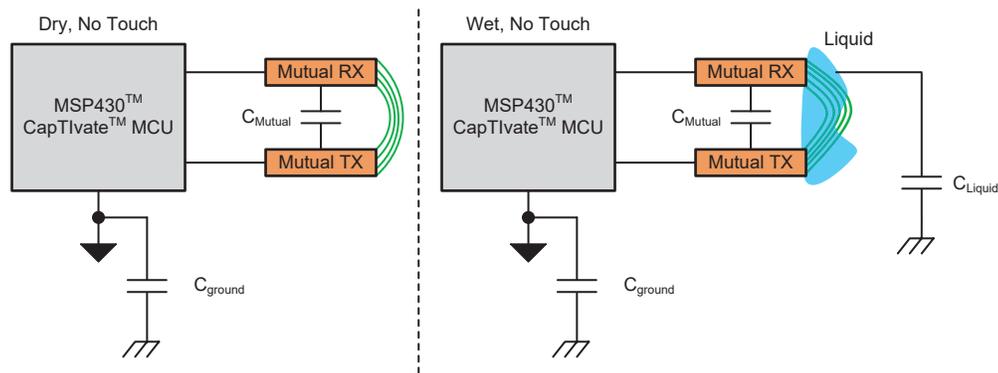
1.   Liquid is also coupled to ground or other components around the sensor. When liquid covers the area where a TX electrode meets RX electrode, it also **reduces the capacitance** C_{mutual} between TX and RX electrodes.
2.   Liquid has higher dielectric constant than air so by having liquid on top of the area between the RX and TX it increases the electric field coupling between RX and TX which **increases the capacitance** C_{mutual}.

Figure 4. Liquid Influence on Mutual Capacitance Method

2.2.4   Other Considerations

In addition to the design considerations that are discussed in this document, other factors must also be taken into account when designing a liquid-tolerant capacitive touch system.

For example, some applications require the capacitive touch system to work properly with liquid present while the user wears gloves to touch the panel. In these cases, the designer must define the expected use conditions and also to consider the tradeoff between responsiveness to gloved fingers and liquid-tolerant performance. The material, structure, and thickness of the glove can significantly affect capacitive touch performance parameters (such as sensitivity). The different capacitive sensing methods (self and mutual) also behave slightly differently when gloves are used while touching the sensors.

Other common design considerations include:

•   Mechanical stackup, which can affect touch sensitivity and reliability
•   Environmental temperature drift, which can cause a drift in the sensing measurement result

- Subsystem interconnection, which can affect the touch sensitivity and introduce additional noise to the measurement result

Overall, it is critical for a product designer to consider typical use cases and system factors (such as the ones listed above) that can affect the capacitive touch performance. This document does not describe all of these factors. This reference design is configured to reliably detect bare-finger touch when exposed to a continuous stream of water and a 3-V_{rms} conductive noise coupling directly to the power supply while eliminating false touch detections.

2.3 Highlighted Products

2.3.1 MSP430FR2633

The MSP430FR2633 is a 16-bit microcontroller with programmable ferroelectric memory (FRAM) and CapTIvate capacitive sensing technology. CapTIvate technology is a flexible and robust capacitive-sensing technology for user interface applications such as buttons, sliders, wheels, and proximity sensors. The CapTIvate technology in the MSP430FR2633 has several key features designed to ensure accurate touch detection in noisy environments. Figure 5 shows the high-level block diagram of the CapTIvate peripheral architecture.
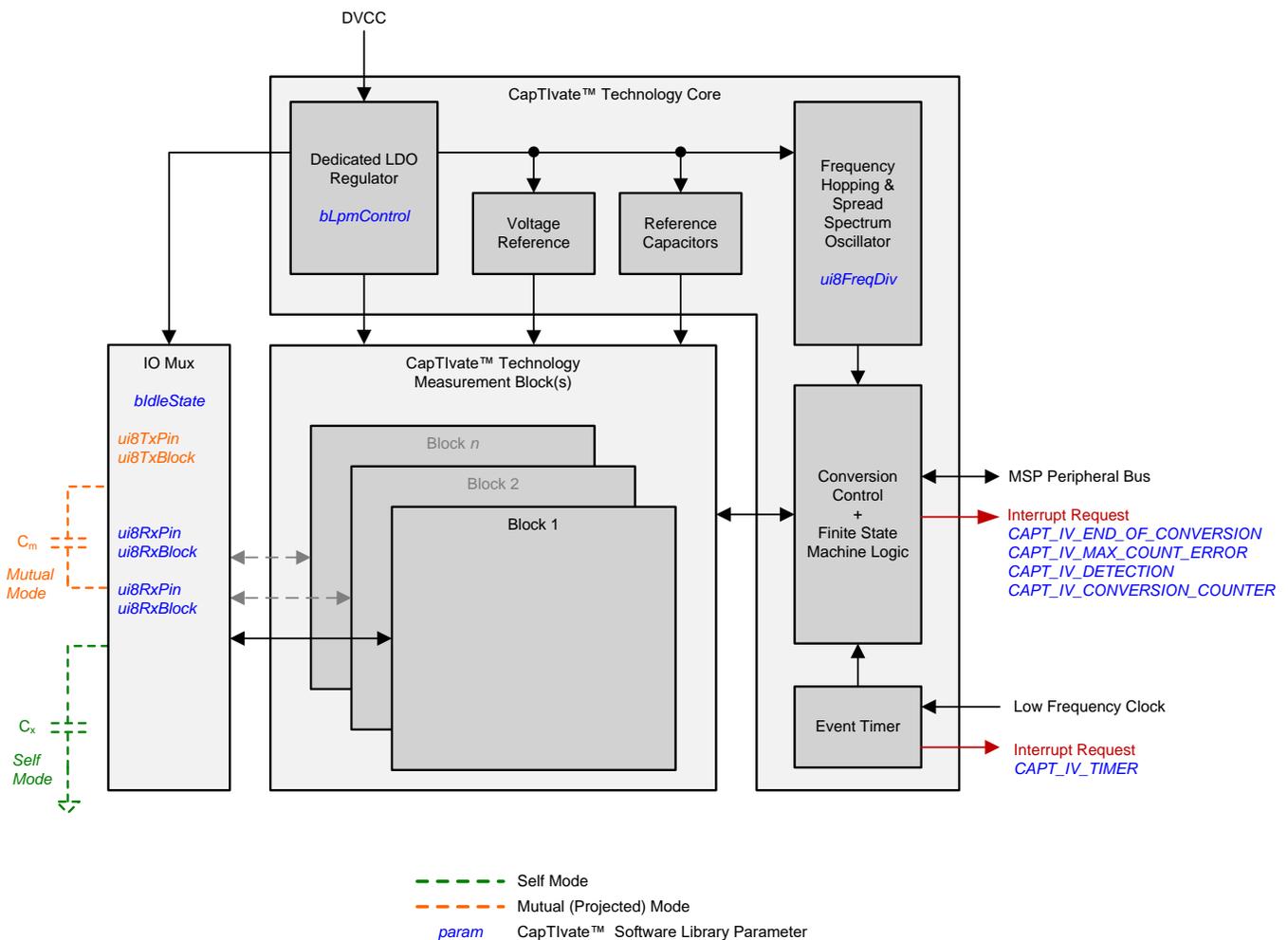

Figure 5. CapTIvate Peripheral Architecture

2.4 System Design Theory

Section 2.2.1 describes different scenarios with liquids present. The requirements for liquid tolerance on HMI subsystem varies for different products. Some applications require that there are no false touch detections and that there is accurate touch detection in the liquid droplet scenario. Some applications must ensure the same performance under the continuous liquid streaming scenario. Some applications require the system to block all of the touch events in the continuous liquid streaming scenario.

The hardware and firmware design of applications will differ depending on the design requirements. This reference design uses a mutual capacitance topology for 12 buttons with a well grounded power supply to work reliably in the continuous liquid streaming scenario without any false detections and with accurate detection of a touched button.

2.4.1 Shield Sensor Electrodes

Section 2.2.2 describes how liquid affects the capacitive touch sensing measurement for both self capacitance and mutual capacitance. One of the effects is due to the conductive nature of the liquid, so the liquid couples the sensor electrodes to surrounding ground or other components, which could cause false triggers. One way to reduce coupling to ground by the liquid is to minimize the ground path around the sensor.

Figure 6 shows a sensor layout that has a hatched filling connected to ground around the sensor electrode. When a liquid droplet covers the sensor area, the liquid couples the sensor to the hatch ground filling.
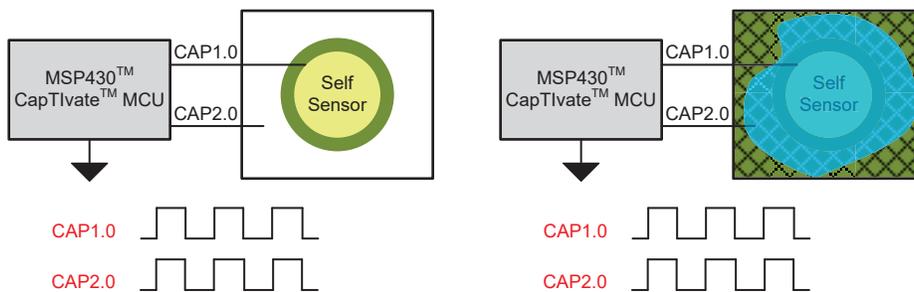

Figure 6. Self Capacitance Sensor With Hatched Filling Connected to Ground

Section 2.2.3.1 describes that for self capacitance topology a finger touching the sensor electrode increases the capacitance and the liquid covering the sensor electrode with surrounding ground also increases the capacitance. For CapTIvate technology, sensor capacitance increasing means the number of charge and transfer cycles to charge the internal sample capacitor decreases, so the raw count measurements decrease when sensor capacitance increases. Figure 7 shows the raw count measurement decrease significantly when liquid droplets cover the sensor. In this scenario, there is only a small raw count difference between a valid touch and the liquid droplet, which might cause false detections.
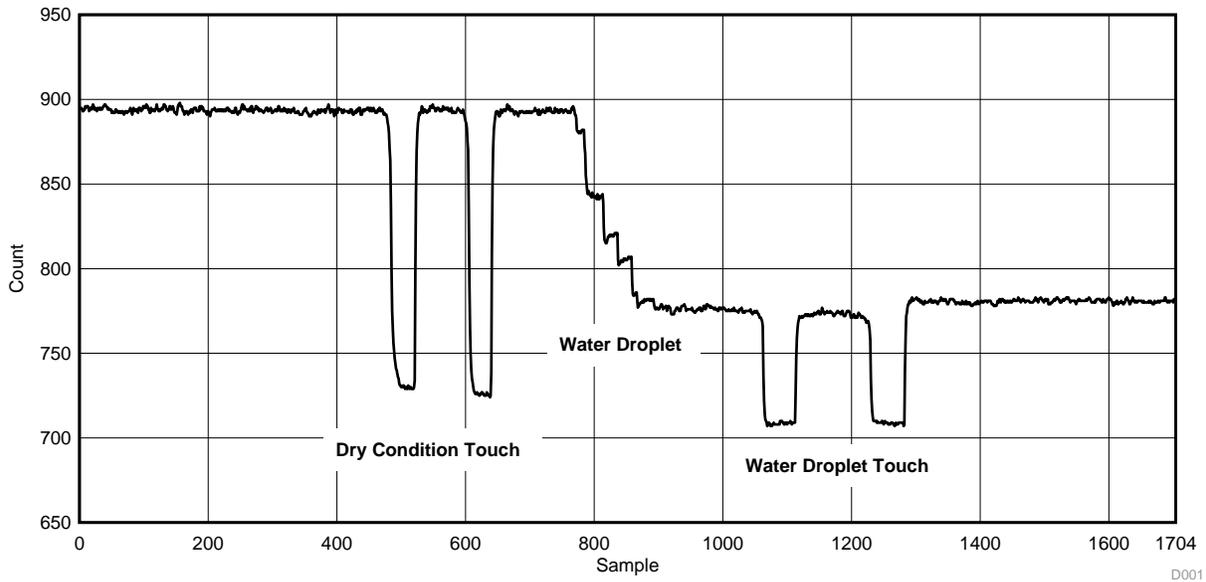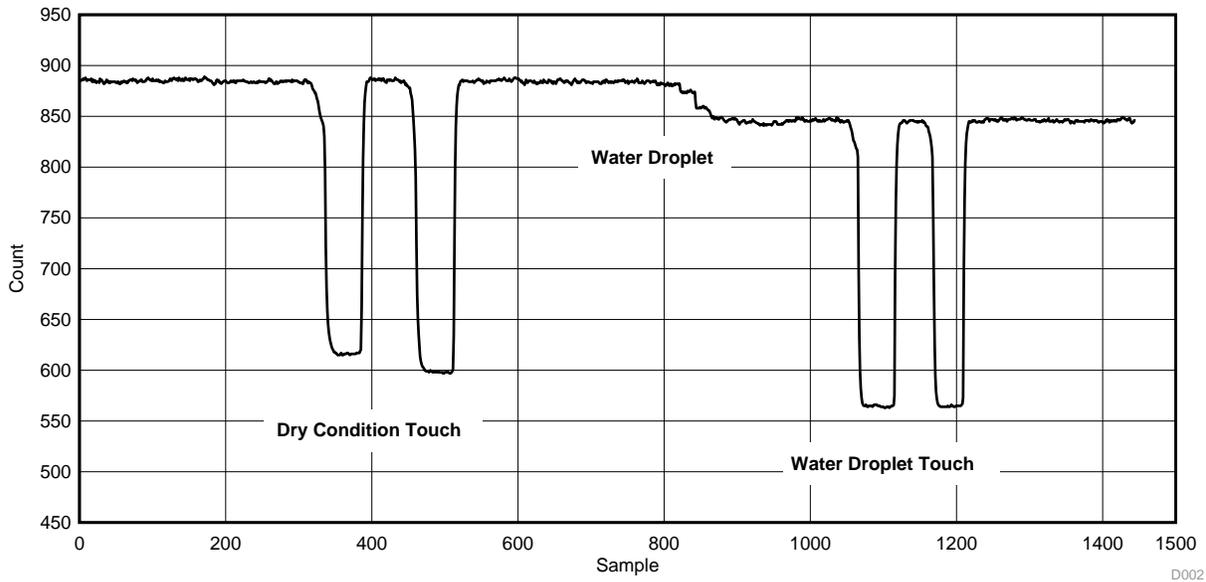
Figure 7. Self Capacitance Sensor Liquid Droplet Measurement Count With Hatched Filling Connected to Ground

To reduce the coupling to ground by the liquid, you must minimize the ground path around the sensor by shielding the sensor electrode. In Figure 8, the hatched filling around the sensor is connected to another CapTIvate I/O pin that acts as a driven shield to protect the sensor electrodes. The signal to drive the sensor electrode and the hatched driven shield have the similar waveform. The waveform makes sure that the driven shield has the same voltage potential as the sensor electrode, so that there is not a large capacitance increase when liquid droplets cover the sensor and the hatched driven shield.

Figure 8. Self Capacitance Sensor With Hatched Filling Connected to CapTIvate I/O

Figure 9 shows that the raw count measurement decreased only a small amount when the liquid droplets cover the sensor. There is still a large raw count difference between a valid touch and liquid droplets, which helps to avoid false triggers and to ensure accurate touch detection.

Figure 9. Self Capacitance Sensor Liquid Droplet Raw Count With Hatched Filling Connected to CapTIvate I/O

2.4.2 Mutual Capacitance Shielding

A mutual capacitance sensor requires a RX electrode and a TX electrode. Typically, mutual capacitive electrodes can be multiplexed with other mutual capacitive electrodes. This means that more than one button can share a common signal. However, to optimize the sensor design for liquid tolerance, the design needs a driven shield to protect the sensors from coupling to surrounding ground or other components. To accurately detect the touched sensor during heavy continuous liquid flow, the design should have an individual RX signal for each sensor instead of multiplexing the RX signal with other sensors.

Unlike in the self capacitance electrode design, in which the hatched filling connects to a CapTIvate I/O for the driven shield, in mutual capacitance mode, the hatched filling connects to the TX signal. This hatched filling is used as a driven shield to protect all of the sensors and the shared TX electrode for all the sensors. For each individual RX electrodes, use a solid pad instead of hollow traces to protect the sensors from coupling to the ground or other components on other layers of the PCB. All of these recommendations about the design of mutual capacitance sensors are optimized for a keypad application that can operate reliably when exposed to heavy continuous liquid flow.

Figure 10 shows the layout of the 12-button keypad. For more details on the layout design, refer to Section 4.3 or download the design files from the TIDM-1021 page.
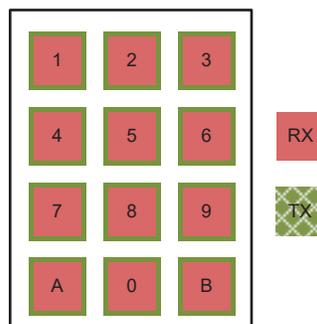
Figure 10. 12-Button Keypad Mutual Capacitance Design Layout

2.4.3   Design for Noise Immunity

This reference design is optimized for a keypad application that operates reliably in a heavy continuous flow of liquid. This design also considers noise immunity requirements. This design passed the IEC 61000-4-6 Conducted Noise test at 3-V_{rms} stress level with Class A pass or fail criteria. Class A requires the following:

- The equipment under test must not exhibit any false touch detections during or after the test.
- The equipment under test must always detect valid touches during and after the test.

Section 3.2 includes the detailed conductive noise test data. For more information on how to design for noise immunity, refer to the Noise-Tolerant Capacitive-Touch Human-Machine Interfaces Design Guide.

2.4.4   Power Supply Grounding Effect

For a capacitive touch system, the measurement result is impacted by all the elements in the whole capacitive loop so how the system is connected to the earth ground can significantly affect the measurement results.

In typical battery-powered scenarios (see Figure 11), the system is not directly connected to earth ground. It is coupled to earth ground with free space coupling. And the further the system is away from the earth ground the weaker the coupling between the system and earth ground which means the smaller $C_{ground\text{-}coupling}$. From the mutual mode capacitive touch sensing perspective, the weak coupling minimize the capability of human finger touch to reduce the mutual capacitance C_{mutual} which result in lower touch sensitivity.

In typical scenarios with a well grounded power supply (see Figure 11), the system is either directly connected to earth ground or strongly coupled to earth ground. From the perspective of mutual capacitance touch sensing, the strong coupling increases the reduction of the mutual capacitance (C_{mutual}) when a human finger touches the surface, which results in higher touch sensitivity.

The sensitivity difference between a battery-powered system and a wall-powered system is more significant in scenarios with liquid present. This is because liquid has higher dielectric constant than air, so liquid on top of the area between the RX and TX increases the electric field coupling between RX and TX, which increase the capacitance, C_{mutual}. With larger C_{mutual}, the reduction of sensitivity in a battery-powered system is more significant.

To improve the performance for a battery-operated system with heavy continuously flowing liquid, the system must increase the coupling to earth ground. A number of methods can improve the system coupling to earth ground. For example, enlarging the physical size of the hardware system, adding a large ground plane to the system, and placing the system close to physical earth ground surface like a wall or the floor.

The measurement data for both the battery-powered scenario and the wall-powered scenario are included in Section 3.2. The measurement data in this document for a battery-powered scenario demonstrates the sensitivity reduction but each system is designed differently. First, this reference design is only a reference for the human-machine interface subsystem and not for the whole system. Second, as previously described for a battery-powered system, the capacitive touch sensitivity is highly depend on the system coupling to earth ground.
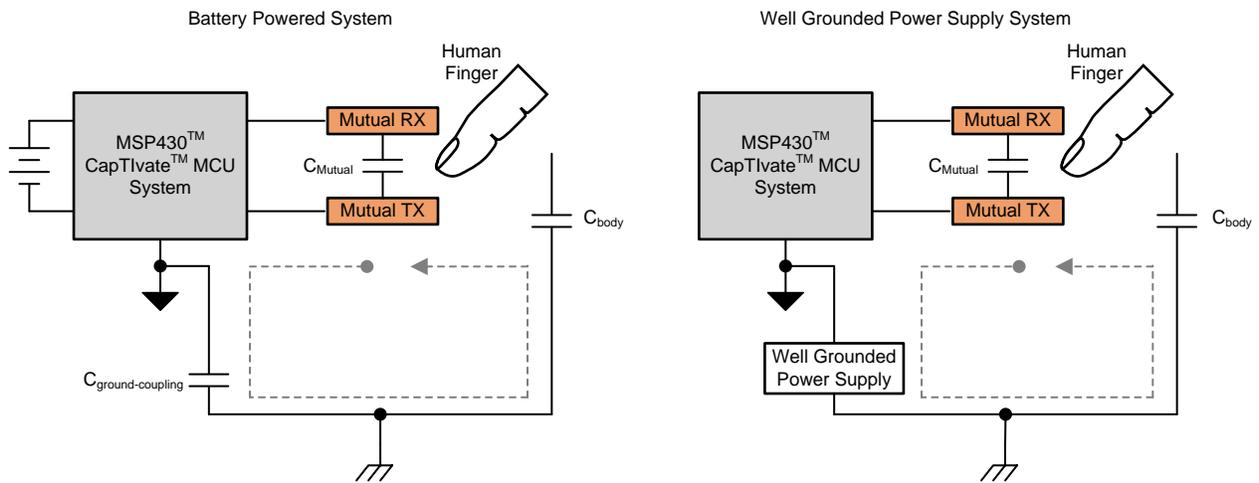
Figure 11. Battery-Powered and Well Grounded Power Supply Capacitive Touch Systems

3 Hardware, Software, Test Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The hardware used in this reference design include the TIDM-1021 PCB (see Figure 12), an MSP430 CapTIvate MCU programmer board (CAPTIVATE-PGMR) (see Figure 13), and a CapTIvate communications isolation board (CAPTIVATE-ISO) (see Figure 14).

The programer board is used to program the MSP430FR2633 MCU on the TIDM-1021 PCB and also to provide the communication to the CapTIvate Design Center GUI for tunning the sensors and collecting the measurement data. The communication isolation board is used to maintain UART communication when TIDM-1021 PCB is powered from an external power source. This is mainly for test data collection purposes and, if the system is powered from the host PC, there is no need for the CAPTIVATE-ISO board.

The TIDM-1021 PCB includes:

- 12 mutual capacitance buttons
- 12 LEDs for touch indication feedback
- An audio buzzer for touch indication feedback
- An MSP430FR2633 MCU
- A 20-pin connector to CapTIvate MCU programmer board

Section 3.2 lists other hardware used to test this reference design in different cases.
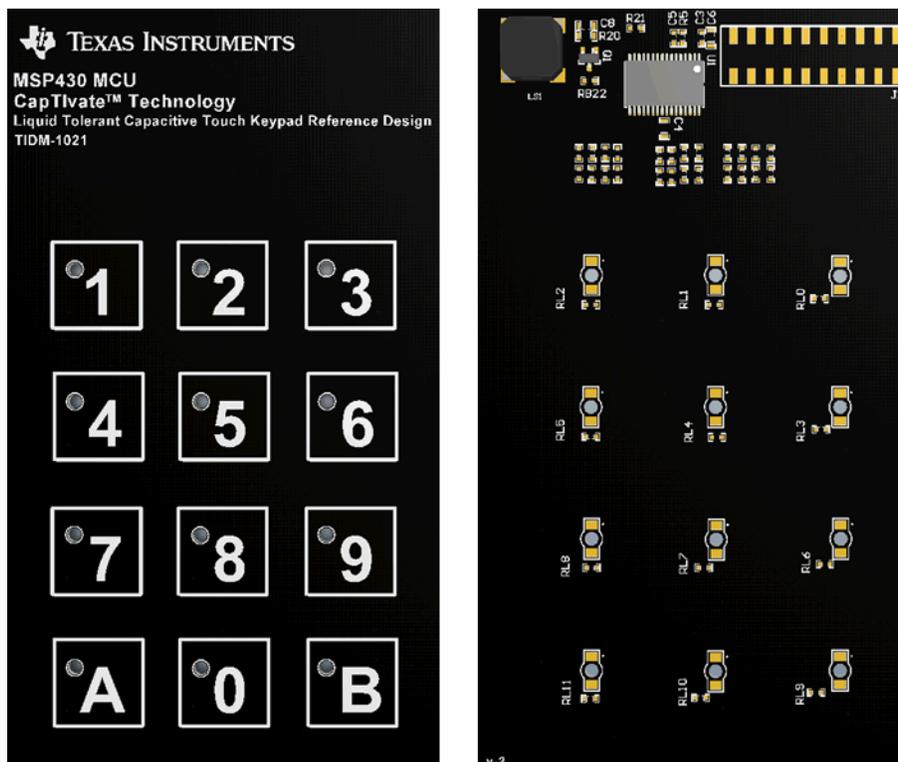
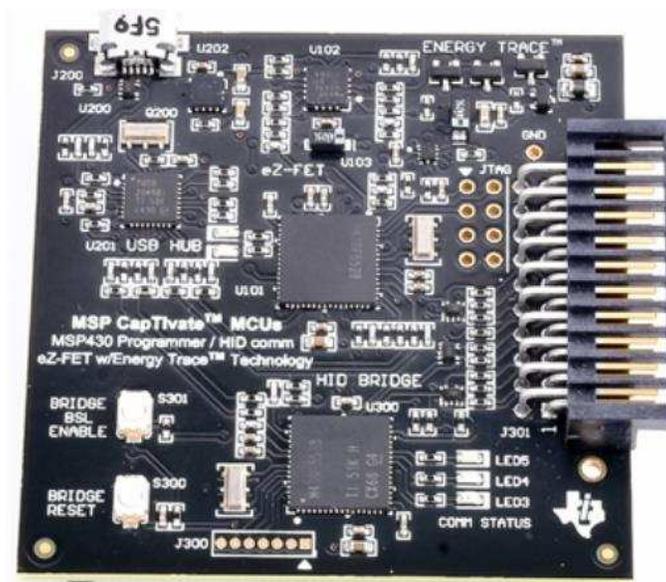**Figure 12. TIDM-1021 Hardware PCB Front (Left) and Back (Right)**

Figure 13. MSP430 CapTIvate MCU Programmer Board (CAPTIVATE-PGMR)
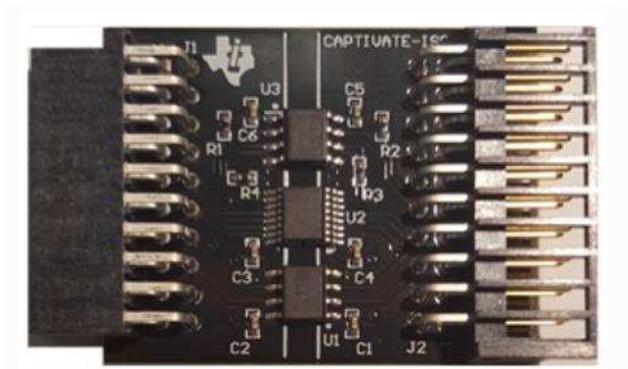

Figure 14. CapTIvate Communications Isolation Board (CAPTIVATE-ISO)

3.1.2 Software

The TIDM-1021 firmware uses the CapTIvate software library to process raw capacitive measurements from the CapTIvate peripheral on the MSP430FR2633 MCU. This software is based on code generated by the CapTIvate Design Center, and the application layer call back function is added to provide the liquid tolerance feature and to control the feedback (the LED and buzzer).

The process of creating this firmware:

1. Use CapTIvate Design Center to generate the code based on the sensor configuration.
2. Disable the negative touch automatic recalibration feature.
   Remove the MAP_CAPT_testForNegativeTouchRecalibration() function in the CAPT_updateUI() function in the CAPT_Manager.c file.
3. Enable the noise immunity feature.
   Change CAPT_CONDUCTED_NOISE_IMMUNITY_ENABLE to true in the CAPT_UserConfig.h file.
4. Implement the call back function. Figure 15 shows the callback function flow chart.

The callback function will first check if there is a "negative touch" to determine whether to halt the LTA. This is to prevent the LTA to track with the "negative touch" count which could trigger false touch detection after the liquid is removed. And then the callback will determine whether to update touched button based on the previous touch status. The callback uses the dominate button algorithm to determine the actual touched button after the sensor touch is detected.

For more information about the firmware and the CapTIvate Design Center project, download them from the TIDM-1021 page, and visit CapTIvate Design Center GUI page CapTIvate Design Center GUI.
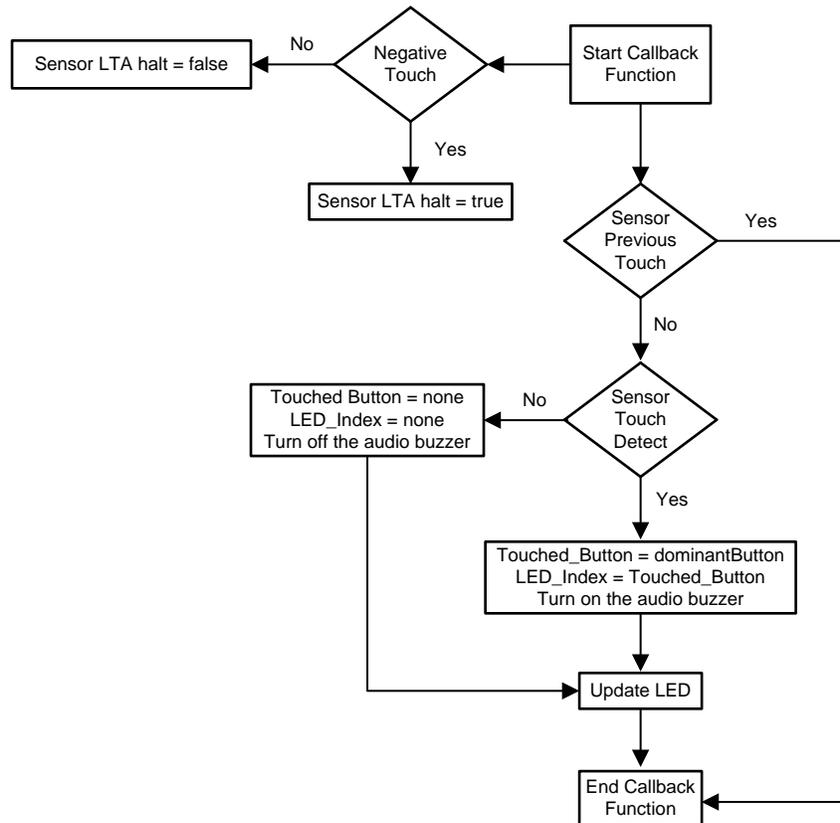
Figure 15. Callback Function Flow Chart

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3.2   Test and Results

3.2.1   Liquid Test With Well Grounded Power Supply

3.2.1.1   Continuous Water Flow Test

Test Setup

Figure 16 shows a tank filled with water and a 12-V pump to provide the continuous water flow for this test. The TIDM-1021 PCB is attached on the back of a 3-mm-thick plastic overlay with 467MP double-sided adhesive. The overlay is mounted on a PCB holder to hold the test unit on a support frame. This setup allows a continuous water flow directly on the touch sensor area. Figure 17 shows a photograph of the test setup. The water used in all the liquid test cases is tap water from the local piped supply.
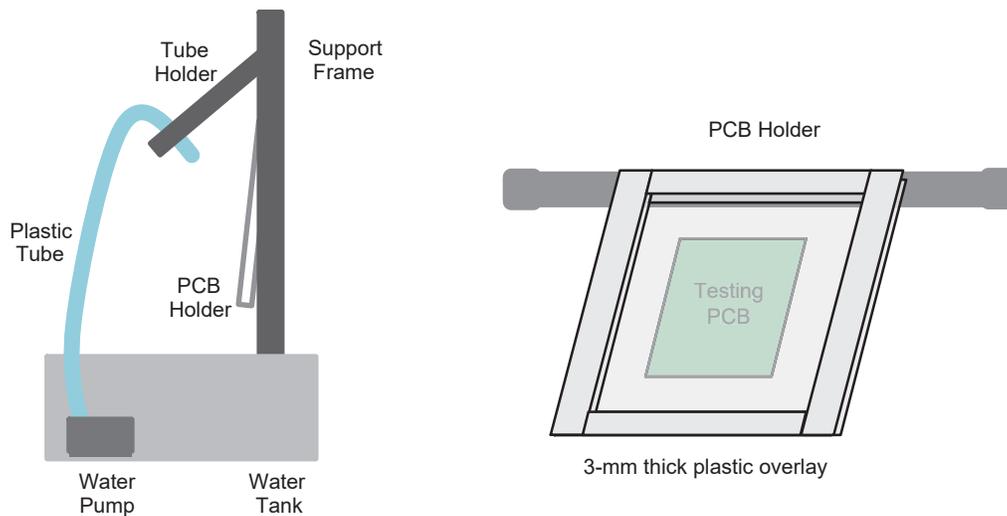
Figure 16. Liquid Test Setup

Figure 17. Continuous Water Flow Test Setup

The TIDM-1021 PCB is connected to the CapTIvate communications isolation board (CAPTIVATE-ISO) and the MSP430 CapTIvate MCU programmer board (CAPTIVATE-PGMR) (see Figure 18). This setup collects the data with a laptop through the USB cable and provides the 3.3-V power to the system using an external DC power supply.
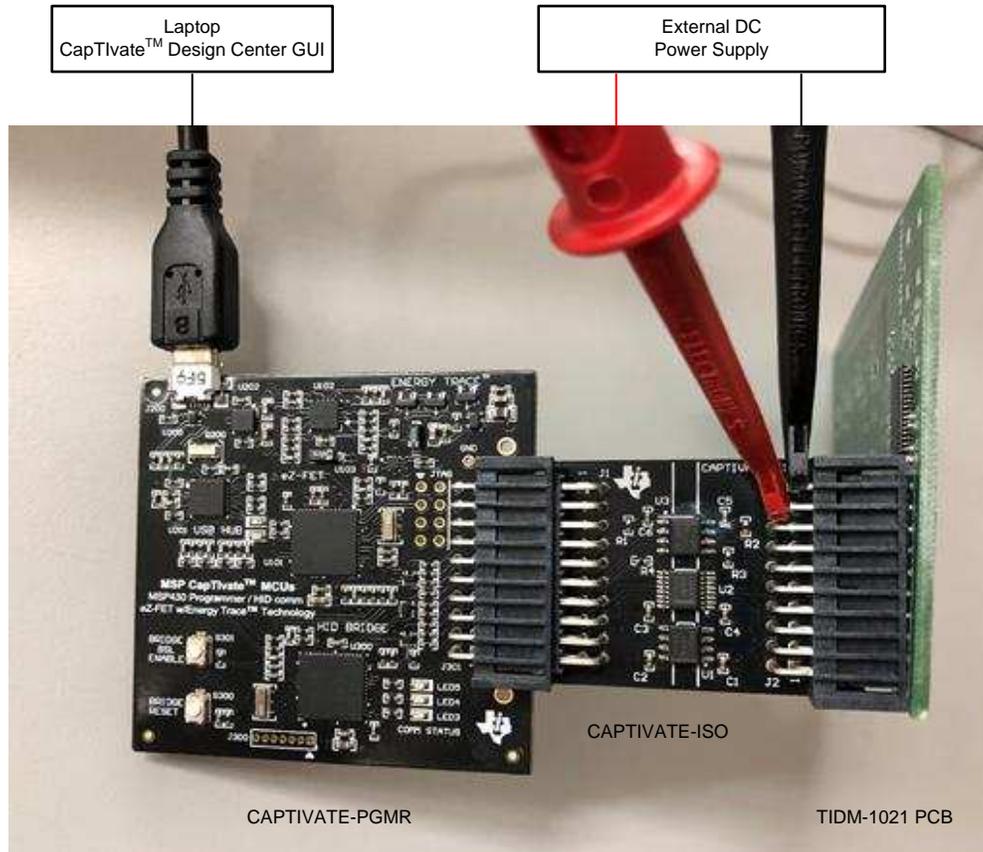
Figure 18. Test Hardware Setup

Test Procedures

1. A user touches each button from Button 1 to Button B.
2. Turn on the water pump with continuous water flow.
3. A user touches each button from Button 1 to Button B.
4. Turn off the water pump.

Test Result

Figure 19 shows the sensor measurement count result for this test. The Y axis represents the sensor measurement count, and the X axis represents the number of samples. Each color represents the data for a specific button. The data shows that the sensor is calibrated at a baseline count of 350, and the touch increases the count to approximately 550 in dry conditions. When the flowing water is applied on the touch sensor area, the data shows the "negative touch" behavior (see Section 2.2.3.2). The flowing water causes the measurement result to go in the opposite direction of a touch event, so no false touch is detected. While the water is continuously flowing on the touch sensor area, each touch event can still cause a distinguishable count increase for the touched button. Based on this test result and by using the software algorithm in Section 3.1.2, the system can reliably operate when exposed to continuous water flow, with no false touch detections and with accurate detection of a button touch.
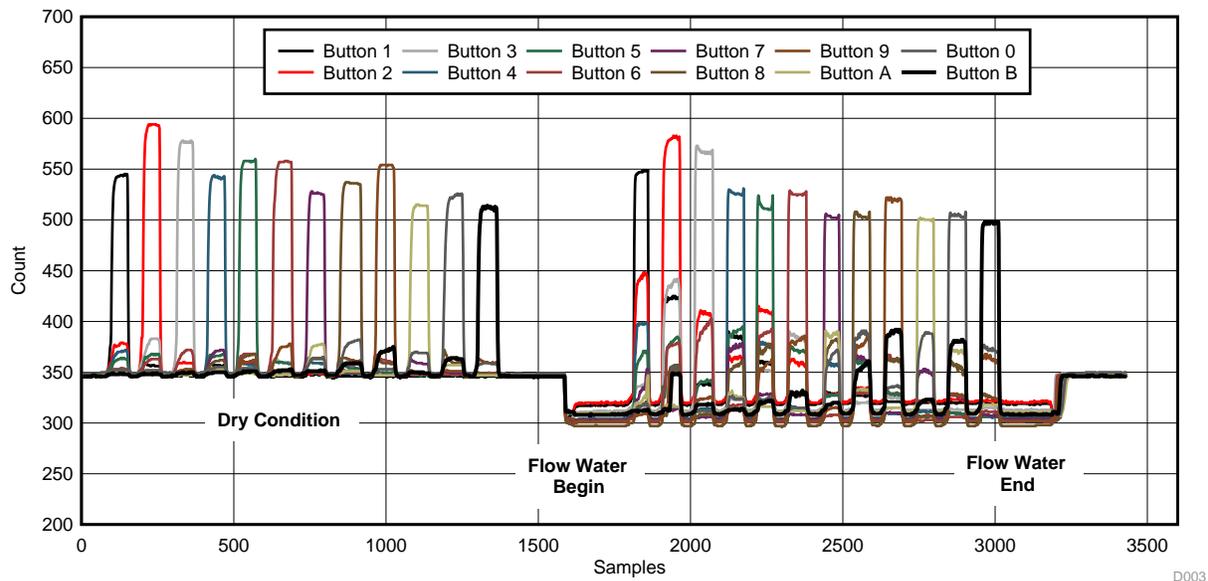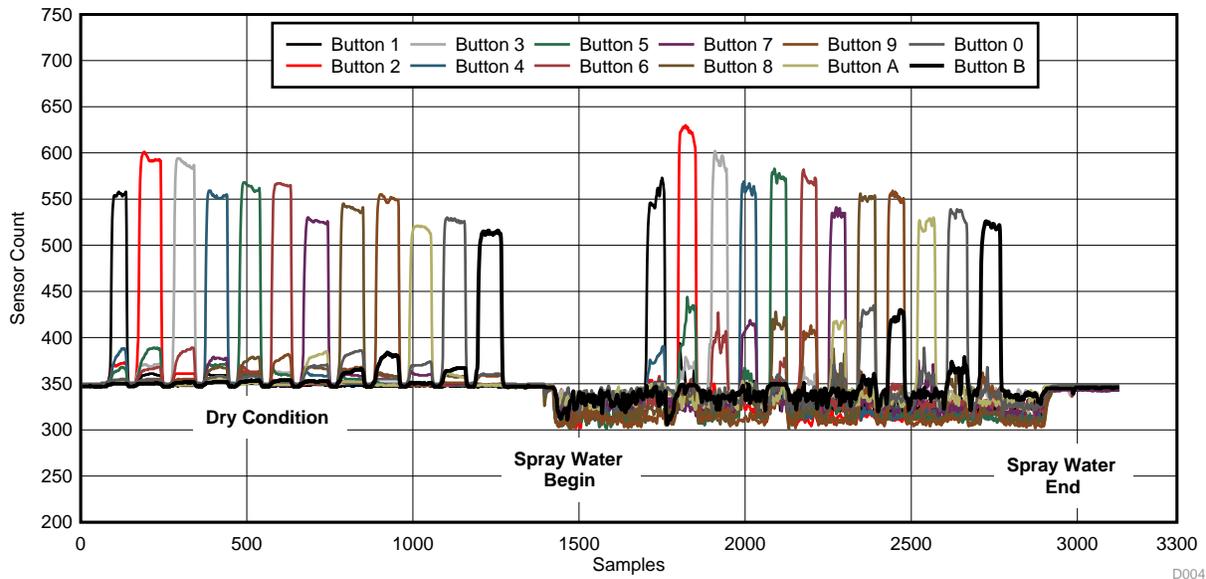
Figure 19. Sensor Count Result With Continuous Water Flow (Well Grounded Power Supply)

3.2.1.2   *Continuous Water Spray Test*

Test Setup

The test setup is similar to the continuous water flow test in Section 3.2.1.1. The difference is a spray nozzle added on the plastic water tube to provide a continuous water spray on the touch sensor area (see Figure 20).

Figure 20. Continuous Water Spray Test Setup

Test Procedures

The test procedures are the same as the continuous water flow testing (see Section 3.2.1.1).

Test Result

Figure 21 shows the sensor measurement count result. The result is similar to the continuous water flow test result (see Section 3.2.1.1). The difference is that when the continuous water spray is applied on the touch sensor area, the measurement count is not as consistent as the continuous water flow test case. This is because the spray water does not contact the touch sensor area consistently. The "negative touch" behavior is still present, which means that the spray water causes the measurement result to go in the opposite direction of a touch event. Therefore, there is no false touch detection. While the continuous water spray is applied on the touch sensor area, each touch event still causes a distinguishable count increase for the touched button. Based on this test result and by using the dominant button lock algorithm (see Section 3.1.2), the system can reliably operate when exposed to continuous water spray, with no false touch detections and with accurate detection of a button touch.

Figure 21. Sensor Count Result With Continuous Water Spray (Well Grounded Power Supply)

3.2.2 Conductive Noise Immunity Test

Test Setup

The test setup follows the IEC 61000-4-6 standard and complies with the guidelines provided in the standard. Three separate tests must be performed for conducted immunity:

*   Class B verification with the standard frequency sweep as specified to ensure that no false detects occur for any sensor due to the noise
*   Class A verification for a single button must remain in detect for the test to ensure that valid touches can be detected in the presence of noise throughout the frequency range.
*   Class A verification of the functionality of the entire panel while at specific frequencies that are most susceptible to conducted noise.

This reference design is tested under the IEC 61000-4-6 test level 2 with 3-V_{rms} test voltage. The noise is coupled directly onto the 3.3-V system power supply.

Test Procedures

Two types of test data are shown: frequency sweeps and frequency dwells. Frequency sweeps are tests in which the response of an electrode is measured while the noise frequency is swept. The response is tested with and without a simulated touch present. Frequency dwells are tests in which the response of an electrode is measured while the noise frequency is held constant. The response to several sequential touches is tested to compare the touched and untouched states.

Test Result

There are four data sets for this test: a sweep with no touch, a sweep with a touch, and two dwell tests, one for dry condition and another for flowing water condition.

Figure 22 shows the result of the frequency sweep with no touch. The filtered count remains below the touch threshold throughout the test with no false button detection. The raw data (4 MHz, 3.675 MHz, 3.275 MHz, 2.800 MHz) identifies the fundamental conversion frequencies and the harmonics. When the noise frequency overlaps with a conversion frequency or one of its harmonics, the measurements at that conversion frequency exhibit corrupted and unusable data. The other frequencies remain undisturbed. The sweep with no touch passes the test with no false detections.
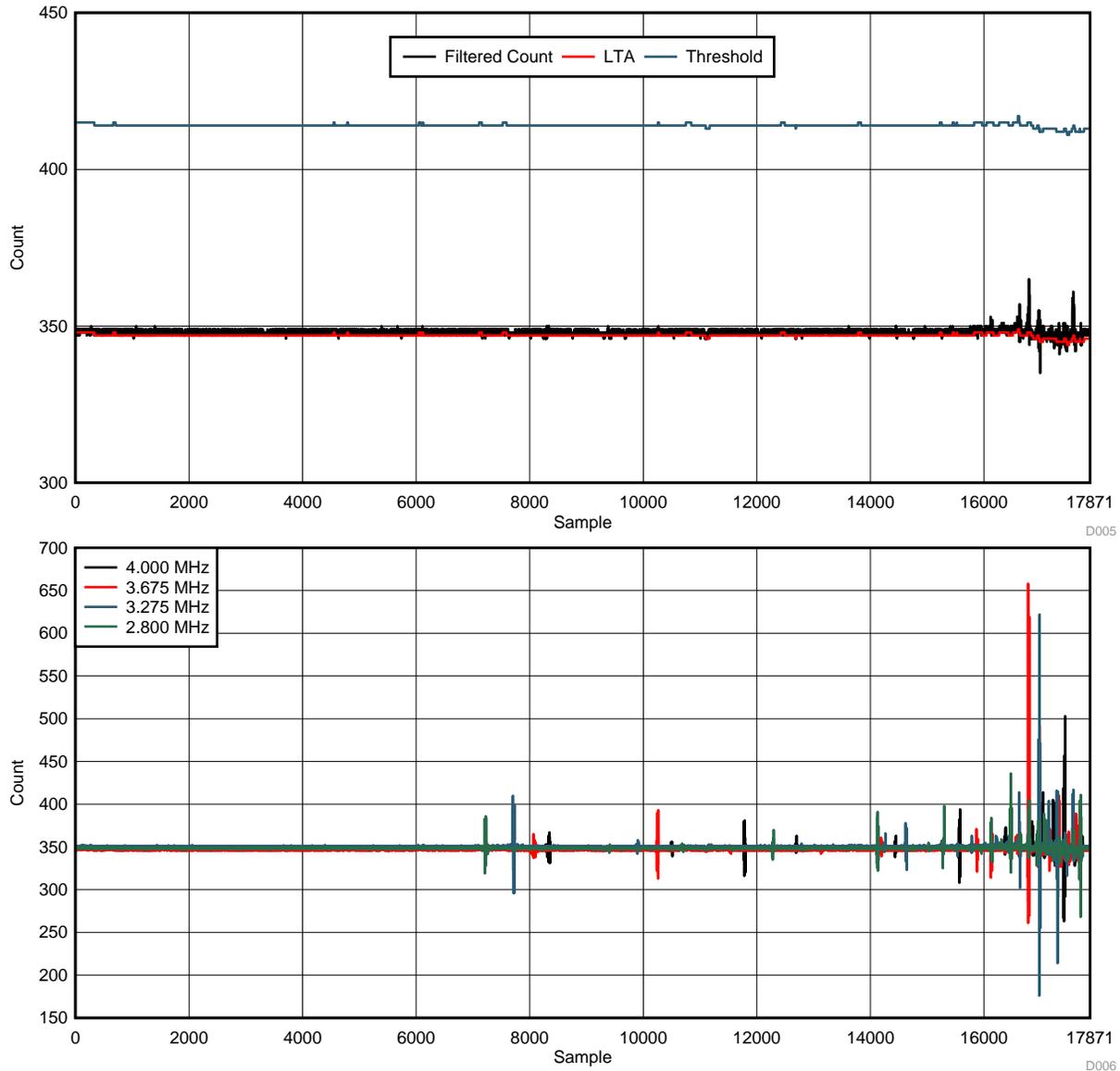
Figure 22. Sensor Data for 3 V$_{rms}$ Conductive Noise Test; No Touch Sweep; Dry Condition

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[Figure 23](#) shows the result of the frequency sweep with touch. The noise level increases when a button is touched. The filtered count has more fluctuations, especially near the primary base-conversion frequency at 4 MHz. In the raw data (4 MHz, 3.675 MHz, 3.275 MHz, 2.800 MHz), the noise amplitude increases and the noise bandwidth expands. Overall, the filtered count remains above the touch threshold throughout the test, which means that the button did not exit the detection throughout the test. The sweep with touch passes the test.
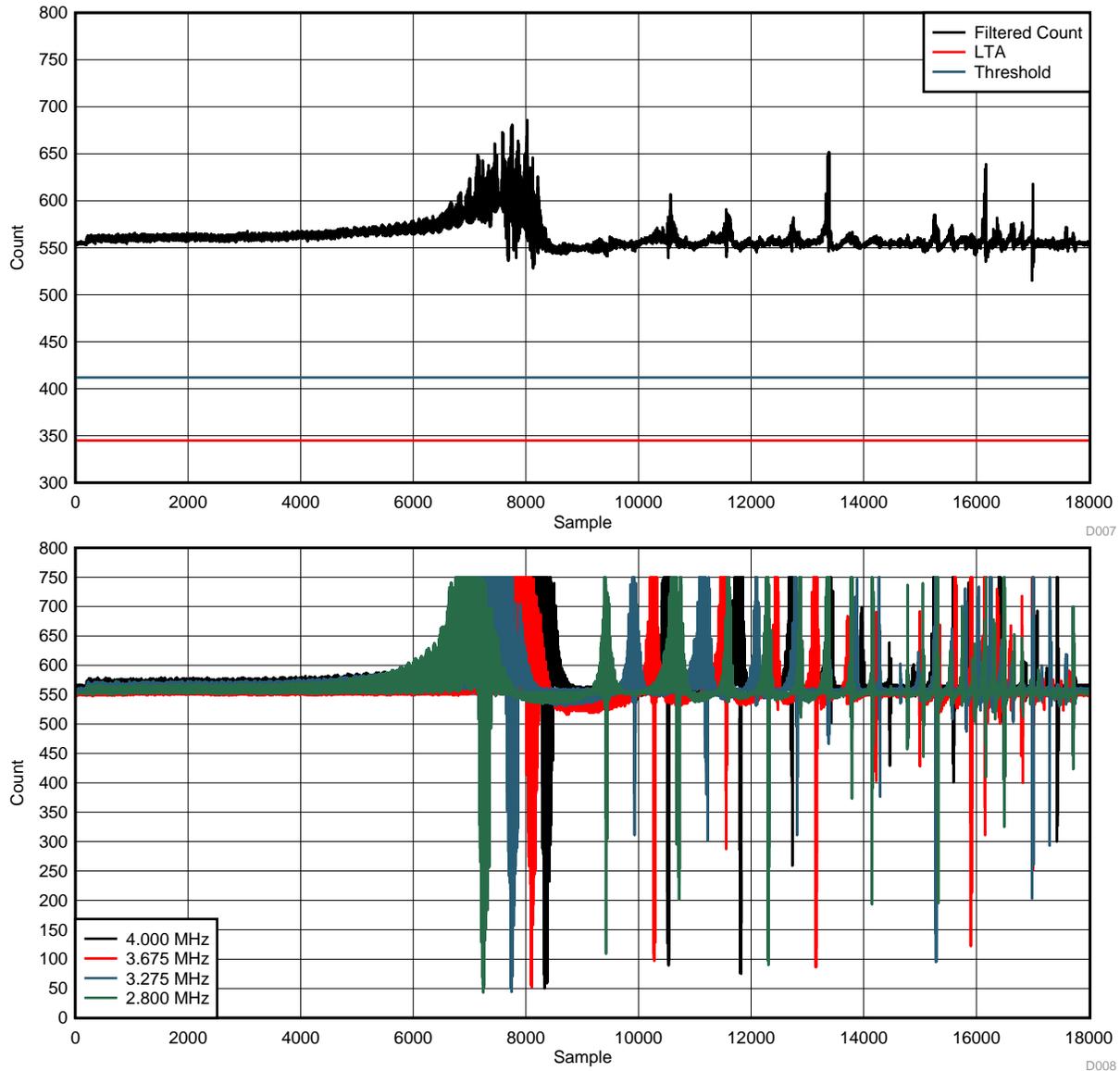
Figure 23. Sensor Data for 3 V$_{rms}$ Conductive Noise Test; Touched Sweep; Dry Condition

The 4-MHz dwell point was chosen because it directly overlaps with the primary base-conversion frequency of 4 MHz. Figure 24 shows two sequential touches under dry condition. The dominant noise is present only in the raw data at 4 MHz. The filtered count remains below the threshold when there is no touch and remains above the threshold with no fluctuations when there is a touch. This is a passing dwell test.
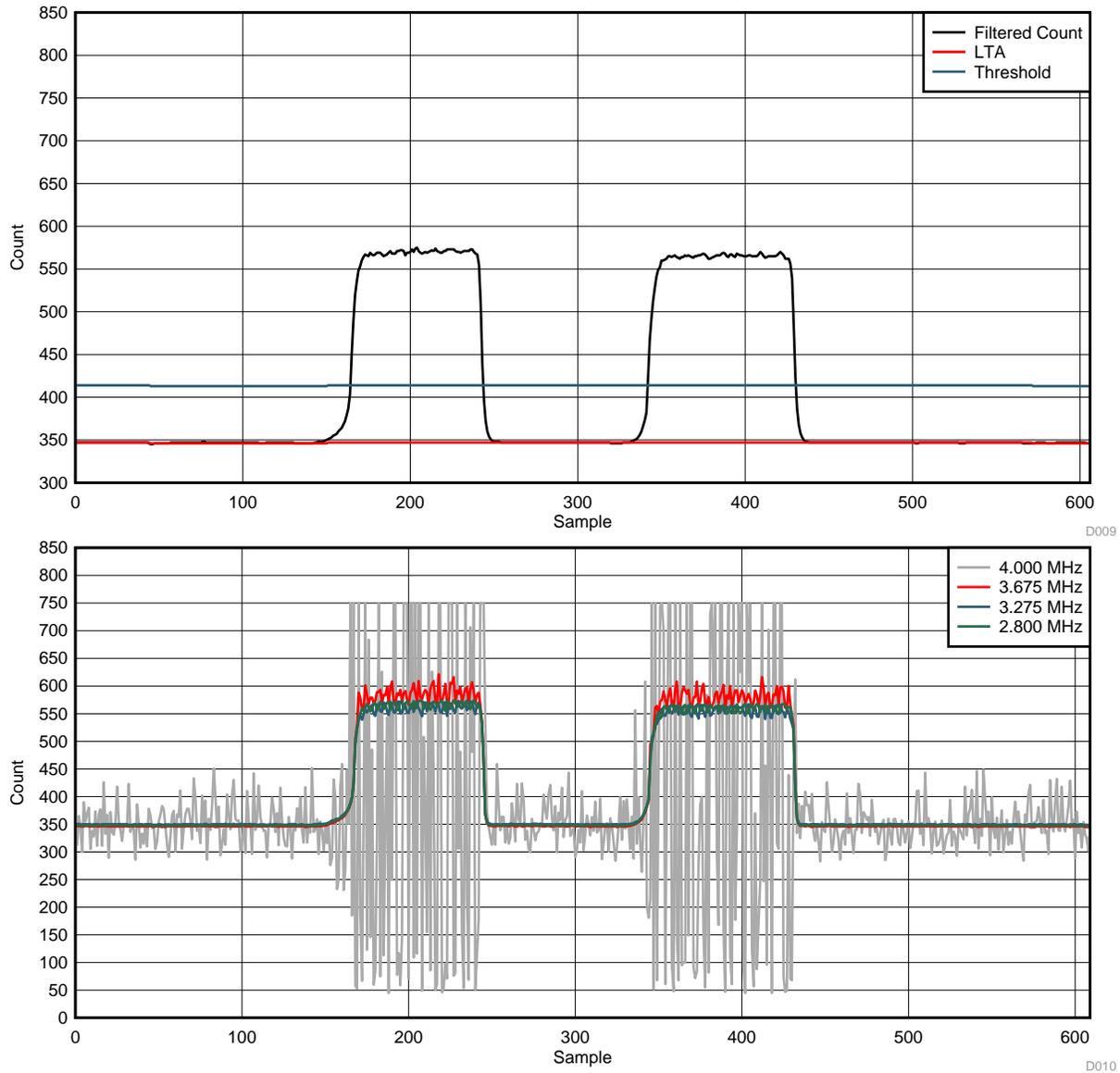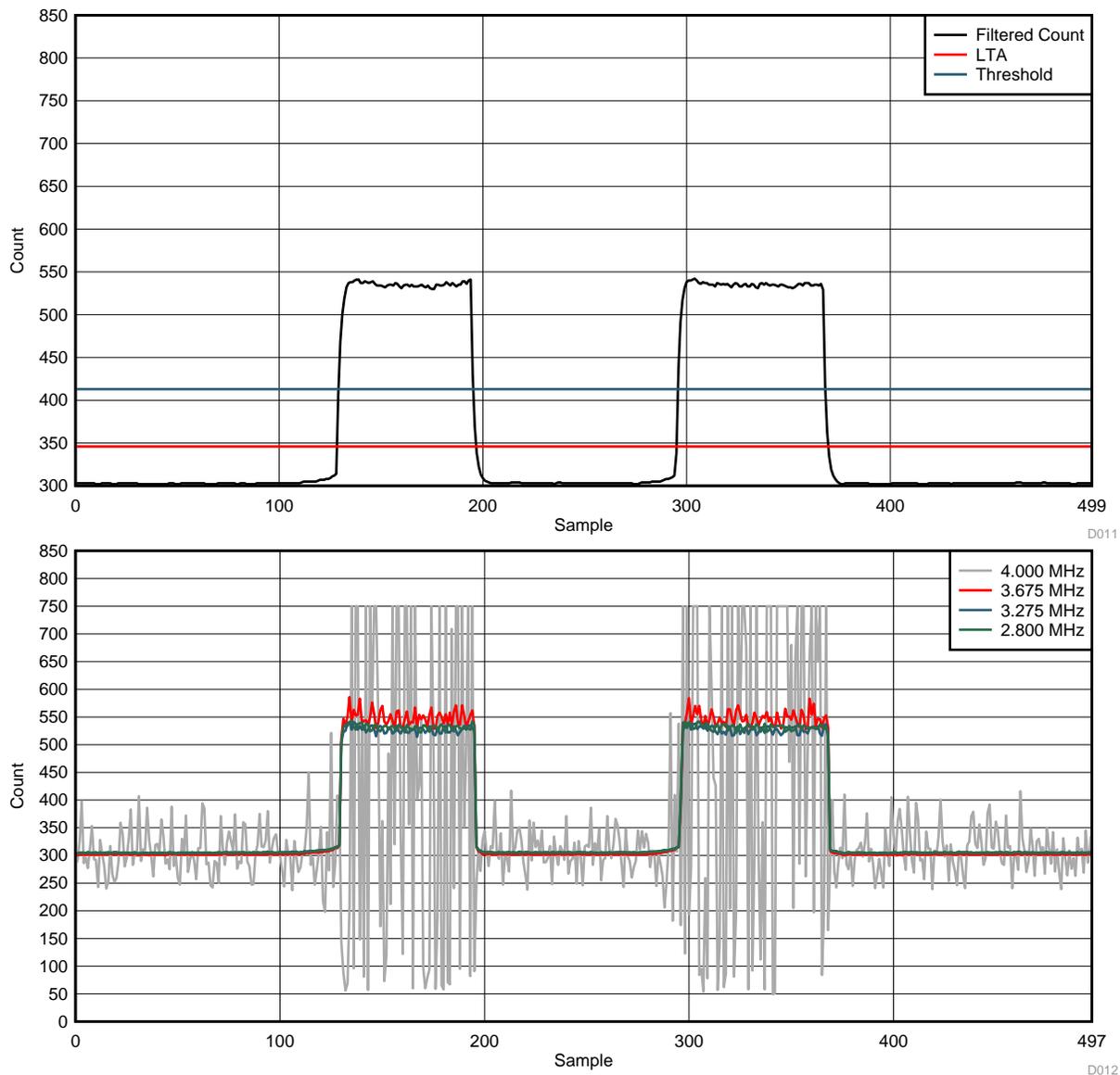

Figure 24. Sensor Data for 3 V$_{rms}$ Conductive Noise Test; Dwell at 4 MHz, Dry Condition

Figure 25 shows the dwell test result at 4 MHz with two sequential touches under the flowing water condition. Similar to the dwell test in dry conditions, the dominant noise is present only in the raw data at 4 MHz. The filtered count remains below the threshold when there is no touch and remains above the threshold with no fluctuations when there is a touch. This is a passing dwell test.

Figure 25. Sensor Data for 3 V$_{rms}$ Conductive Noise Test; Dwell at 4 MHz, Flowing Water

3.2.3   Liquid Test With Battery-Powered Supply

The liquid test with a battery-powered supply is performed the same as the well grounded power supply liquid test in Section 3.2.1. The differences are that the system is powered by a battery, and the data is collected wirelessly with *Bluetooth*® low energy (BLE) communication. This setup makes sure that the system is powered by a battery without any physical connection to the earth ground.

The measurement data in this section is for a battery-powered application and demonstrates the sensitivity reduction but each system is designed differently. This reference design is only a design for the human-machine interface subsystem and not for the whole system, the capacitive touch performance can be affected by other elements in a battery-powered system.

3.2.3.1 *Continuous Water Flow Test*

Figure 26 shows the sensor measurement count results for this test. The Y axis represents the sensor measurement count and the X axis represents number of samples. Each color represents the data for a specific button. The data shows that the sensors are calibrated at baseline count of 350, and the touch increases the count to approximately 450 in dry conditions. The increased delta is smaller than the well grounded power supply scenario.

When the flowing water is applied on the touch sensor area, the data shows the "negative touch" behavior (see Section 2.2.3.2). The flowing water causes the measurement result to go in the opposite direction of a touch event, so no false touch is detected. While the water is continuously flowing on the touch sensor area, each touch event still causes a count increase, and the touched button is still distinguishable. However, the amplitude of the count increase is significantly lower compare to well grounded power supply scenario. As the data shows, it is challenge to set the touch threshold for the system to work reliably under both dry conditions and flowing water conditions. If the threshold tracks with the "negative touch" behavior, there could be a false detection after the flowing water is removed, because the data shows that the count returns to the baseline when the flowing water stops.

This data is only intended to demonstrate the sensitivity reduction, and Section 2.4.4 describes methods to design a system with stronger coupling to earth ground, which improves the sensitivity in flowing water conditions.

Section 2.4.4 explains the sensitivity reduction in battery powered system for both dry conditions and flowing water conditions. More water on the touch sensor area causes more significant sensitivity reduction. Section 3.2.3.2 describes the spray water test, which has less water applied to the touch surface, compared to the flowing water test.
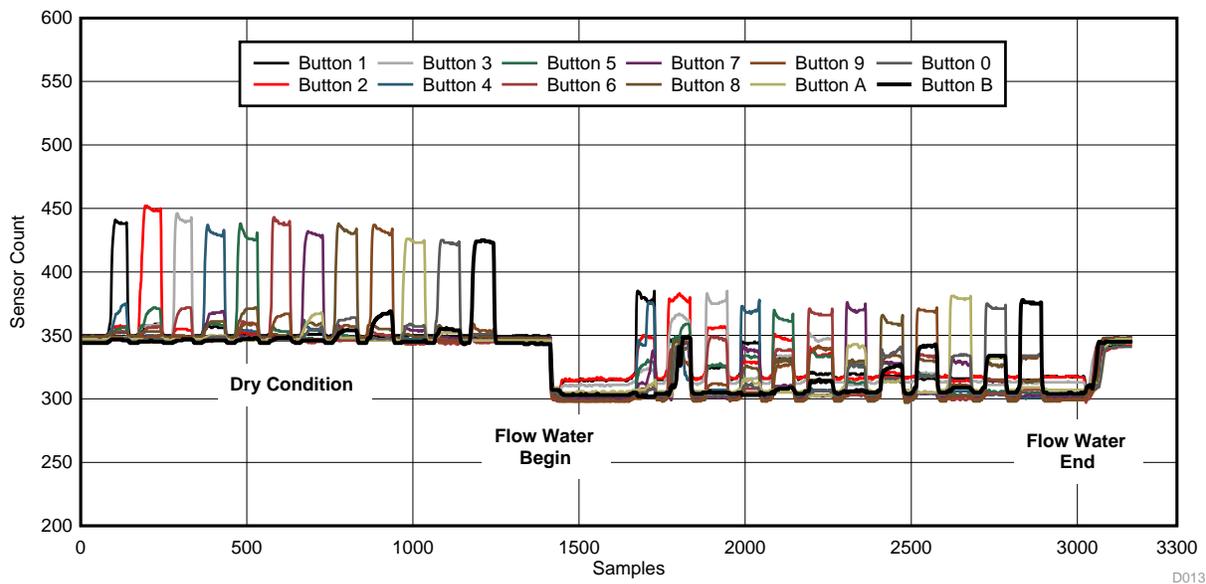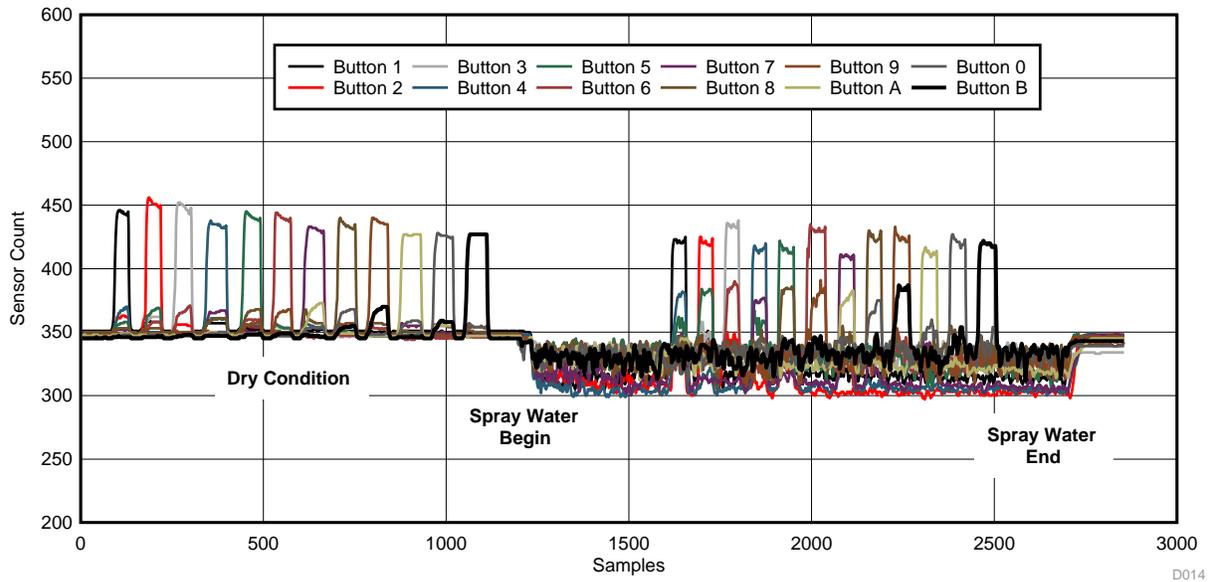

Figure 26. Sensor Count Result With Continuous Water Flow (Battery Power)

3.2.3.2 *Continuous Water Spray Test*

Figure 27 shows that the sensors are calibrated at a baseline count of 350, and a touch increases the count to approximately 450 in dry conditions. The increased delta is smaller compare than in the well grounded power supply scenario. When the spray water is applied on the touch sensor area, the data shows the "negative touch" behavior (see Section 2.2.3.2). The water spray causes the measurement result to go in the opposite direction of a touch event, so no false touch is detected. While the water is continuously spraying on the touch sensor area, each touch event still causes a count increase, and the touched button is still distinguishable. The sensitivity under the water spray condition is comparable with the sensitivity under the dry condition, which means that the touch threshold can be set to reliably work for both dry and spray water conditions.

Figure 27. Sensor Count Result With Continuous Water Spray (Battery Power)

3.2.4   Third Party Test Report

Intertek Testing Services in Plano, TX tested this TI Design PCB in accordance with the standard "Degrees of Protection Provided By Enclosures (IP Code) IEC 60529". The objective of the test was to demonstrate that the unit was able to work properly under IPX5 conditions, the pass criteria consisted of:

- No false triggers during the test or after test
- Accurately detect the button being touched during the test

The test unit includes a TIDM-1021 PCB mounted in a sealed enclosures and powered by a well grounded AC power supply.

A detailed test report is available from http://www.ti.com/lit/pdf/tidl001.

4   Design Files

4.1   Schematics

To download the schematics, see the design files on the TIDM-1021 page.

4.2   Bill of Materials

To download the bill of materials (BOM), see the design files on the TIDM-1021 page.

4.3   PCB Layout Recommendations

4.3.1   Layout Prints

Section 2.4.2 describes the mutual capacitance shielding and how to optimize the layout to work with continuous water flow. As Figure 28 shows, each individual mutual capacitance button is constructed with a individual solid RX electrode and a shared TX electrode that covers the touch area. The sensor structure is still the same as other mutual capacitance sensor, but the solid RX electrode shields the sensor from ground coupling on other layers. The shared TX electrode that covers the touch area also shields the sensor from ground coupling. For more information on the layout, download the design files. To download the layer plots, see the design files on the TIDM-1021 page.

LED holes
Individual RX electrode
Shared TX electrode
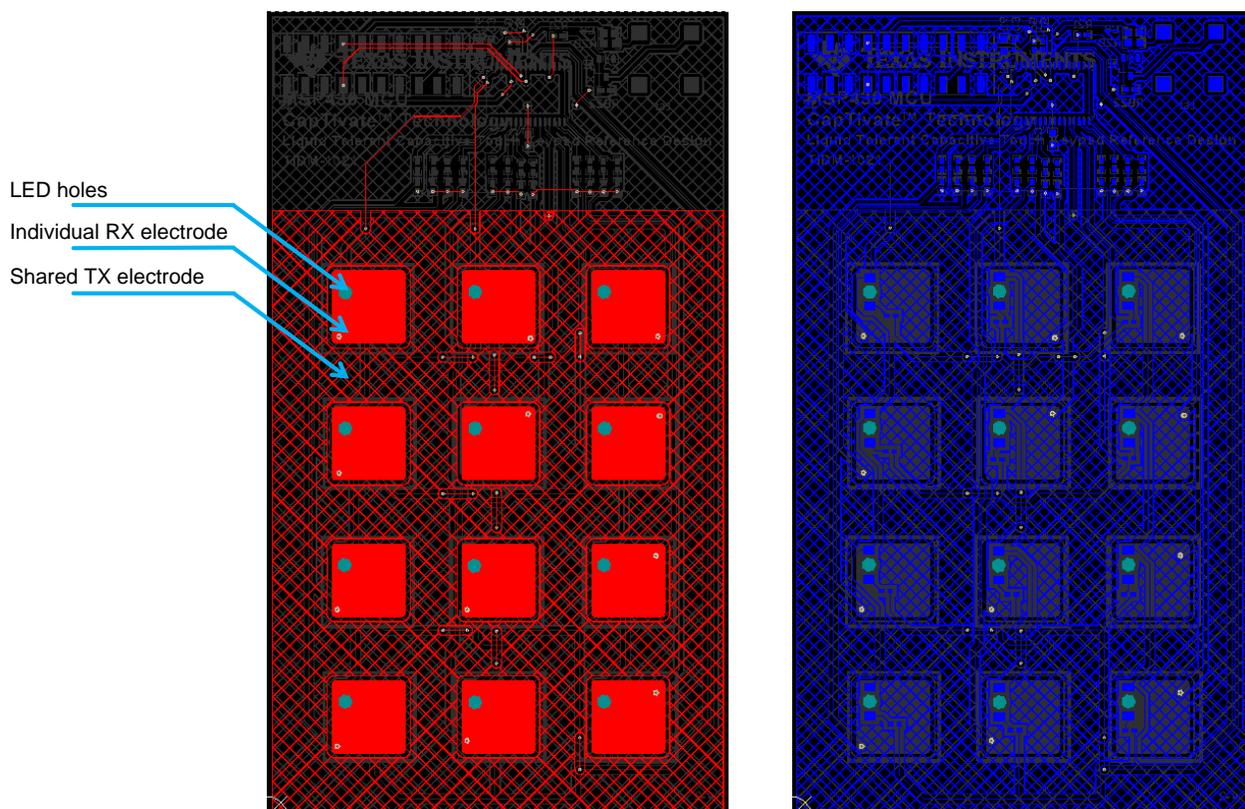
Figure 28. TIDM-1021 Layout Top Layer (Left), Bottom Layer (Right)

4.4   Altium Project

To download the Altium Designer® project files, see the design files on the TIDM-1021 page.

4.5   Gerber Files

To download the Gerber files, see the design files on the TIDM-1021 page.

4.6 Assembly Drawings

To download the assembly drawings, see the design files on the TIDM-1021 page.

5 Software Files

To download the software files, see the design files on the TIDM-1021 page.

6 Related Documentation

1. CapTIvate™ Technology Guide
2. Enabling Noise Tolerant Capacitive Touch HMIs With MSP CapTIvate™ Technology

6.1 Trademarks

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All other trademarks are the property of their respective owners.

7 About the Author

Yiding Luo is a Systems Application Engineer at Texas Instruments. He focuses on capacitive-touch sensing solution design includes hardware development, software development, and ecosystem development. He has been working at TI since 2015. Yiding received his Bachelor of Science in Electrical Engineering (BSEE) from the University of Texas at Dallas in 2015.

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