TI Designs

64-Button Capacitive Touch Panel With TI Microcontroller With CapTIvate™ Technology Reference Design

TEXAS INSTRUMENTS

Design Overview

TIDM-CAPTIVATE-64-BUTTON is a reference design for an ultralow-power touch panel with 64 buttons that can be controlled by a single MSP MCU with CapTIvate™ Technology. The design uses mutual capacitance technology to enable all 64 buttons to be tightly packed and controlled with only 16 MCU pins. TI designed the touch panel to easily interface with the CAPTIVATE-FR2633 Target MCU Module included in the MSP-CAPT-FR2633 MCU Development Kit.

Design Resources

|	
[TIDM-CAPTIVATE-64-BUTTON](#)	Tool Folder Containing Design Files
[MSP430FR2633](#)	Product Folder
[MSP-CAPT-FR2633 Development Kit](#)	Product Folder
[CapTIvate Design Center](#)	Tools Folder

[ASK Our E2E Experts](#)

Design Features

- Single and Multitouch Detection
- Mutual Capacitance Technology Enables 64 Buttons With Only 16 MCU Pins
- More than 100 Samples-per-Second and 15-ms Typical Response Time with Code Size/Response Time Optimization
- 1.75-µA-per-Button Average Current With Low-Power Optimization and 0.23-µA-per-Button Average Current With Wake-On-Touch Mode
- Easy Plug-and-Play With CAPTIVATE-FR2633 Target MCU Module
- CapTIvate Design Center Supports Real-Time Sensor Tuning With a Host PC

Featured Applications

- Electronic Locks
- Security Systems
- Industrial Panels
- Home Appliances
- Remote Controls
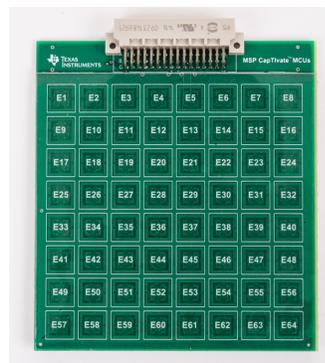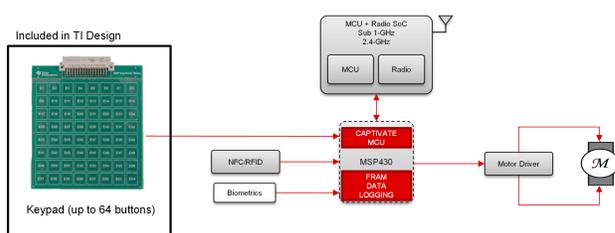
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1 Key System Specifications

Feature	Specification	Additional Details
Touch panel size	4.3 inches × 4.8 inches	Section 2.1
Button count	64-mutual capacitance buttons	Section 4.2.1
Button size	10 mm × 10 mm	
Button pitch	2.7 mm	
Power consumption	Low-power, active mode: 1.75 µA-per-button	Section 7.1
	Wake-on-touch mode: 0.23 µA-per-button	
Measurement time	86-µs/button with response optimization	Section 7.2
Response time	15-ms typical with response optimization	Section 7.2
MCU-MSP430FR2633	The MSP430FR2633 is a low-power, FRAM MCU with integrated CapTIvate Technology for capacitive sensing.	Section 2.2

2 System Description

2.1 Human Machine Interface Introduction

Human machine interfaces (HMIs) are devices dedicated to interpreting user interaction with a system and initiating a response. Common HMIs include buttons, sliders, wheels, and other input devices. Many applications use HMIs including appliances, building automation systems, and personal/consumer electronics.

For HMIs in remote controls, security panels, e-locks, appliances, and building automation systems, it is often important to have a small keypad with a large number of buttons. Using capacitive touch sensing to develop HMIs gives a designer with the flexibility required to meet these kinds of physical constraints for a system. Capacitive touch sensing also enables input devices on HMIs to be tuned for various applications.

TIDM-CAPTIVATE-64-BUTTON is a reference design for a 4.3 inches × 4.8 inches, mutual-capacitance touch panel with 64 buttons. The design demonstrates how to create a large number of buttons in a small form factor, using only 16 inputs on a CapTIvate MCU. TI designed TIDM-CAPTIVATE-64-BUTTON to interface directly with the CapTIvate MCU EVM in the CapTIvate Development Kit for rapid prototyping and easy tuning.

2.2 MSP430FR2633

TI designed TIDM-CAPTIVATE-64-BUTTON to be controlled by an MSP430FR2633 microcontroller. The MSP430FR2633 is an ultralow-power, FRAM-based MSP430™ MCU equipped with CapTIvate Technology. MSP430FR2633 includes 15.5KB of FRAM and 2KB of RAM, making it capable of supporting complex capacitive touch applications. The integration of CapTIvate Technology with the strong MSP430 peripheral set and a large memory footprint makes the MSP430FR2633 an ideal MCU for low-power user interface development.

MSP430FR2633 features:

- 16-CapTIvate Technology inputs that can support up to 64 electrodes in mutual-capacitance mode
- Parallel scanning of up to four electrodes at a time
- CapTIvate Software Library included in a preprogrammed 12KB ROM
- Four 16-bit timers and a 16-bit counter-only real-time clock (RTC)
- Three enhanced serial communications peripherals for UART, IrDA, SPI, and I^2C
- 19 I/Os with 16-interrupt pins for wakeup from low-power modes
- High-performance, 8-channel, 10-bit analog-to-digital converter (ADC)
- Clock system with up to 16-MHz operation

3   Block Diagram

Figure 1 shows how this design might be used in an e-lock application.
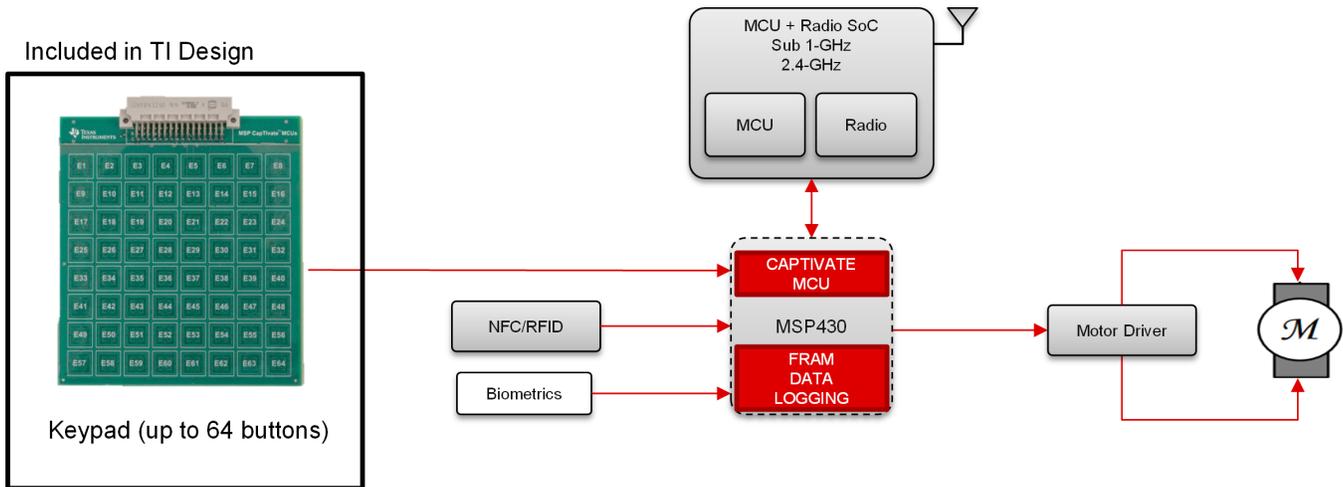

Figure 1. E-Lock Example Block Diagram

3.1   MSP430FR2633 MCU

MSP430FR2633 MCUs feature a diverse peripheral set that make them ideal for use in many capacitive sensing applications. Figure 2 shows the block diagram of the MSP430FR2633 MCU.
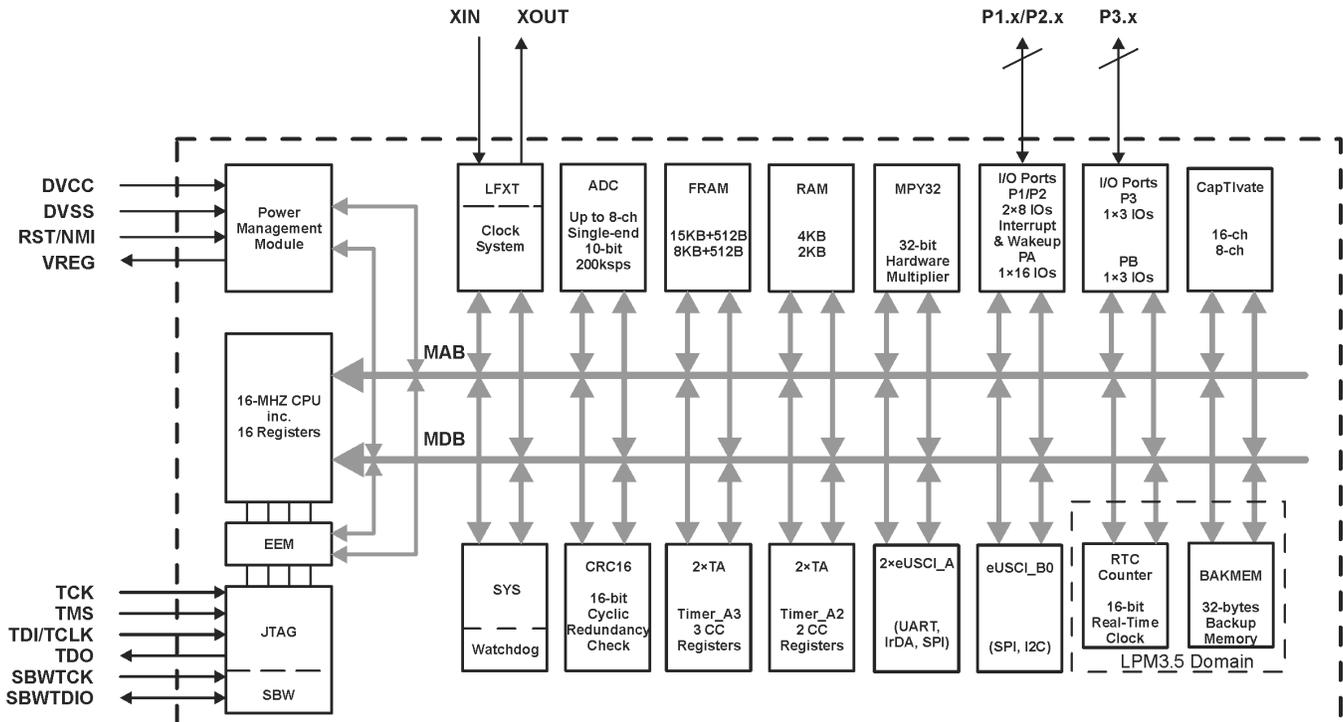

Figure 2. Block Diagram of MSP430FR2633 MCU

3.2 CapTIvate Technology

CapTIvate Technology enables capacitive sensing on the TIDM-CAPTIVATE-THERMOSTAT-UI. CapTIvate Technology is an MSP430FR2(5/6)3x peripheral dedicated to providing robust capacitive sensing measurements. Figure 3 shows a block diagram of the CapTIvate Technology module.
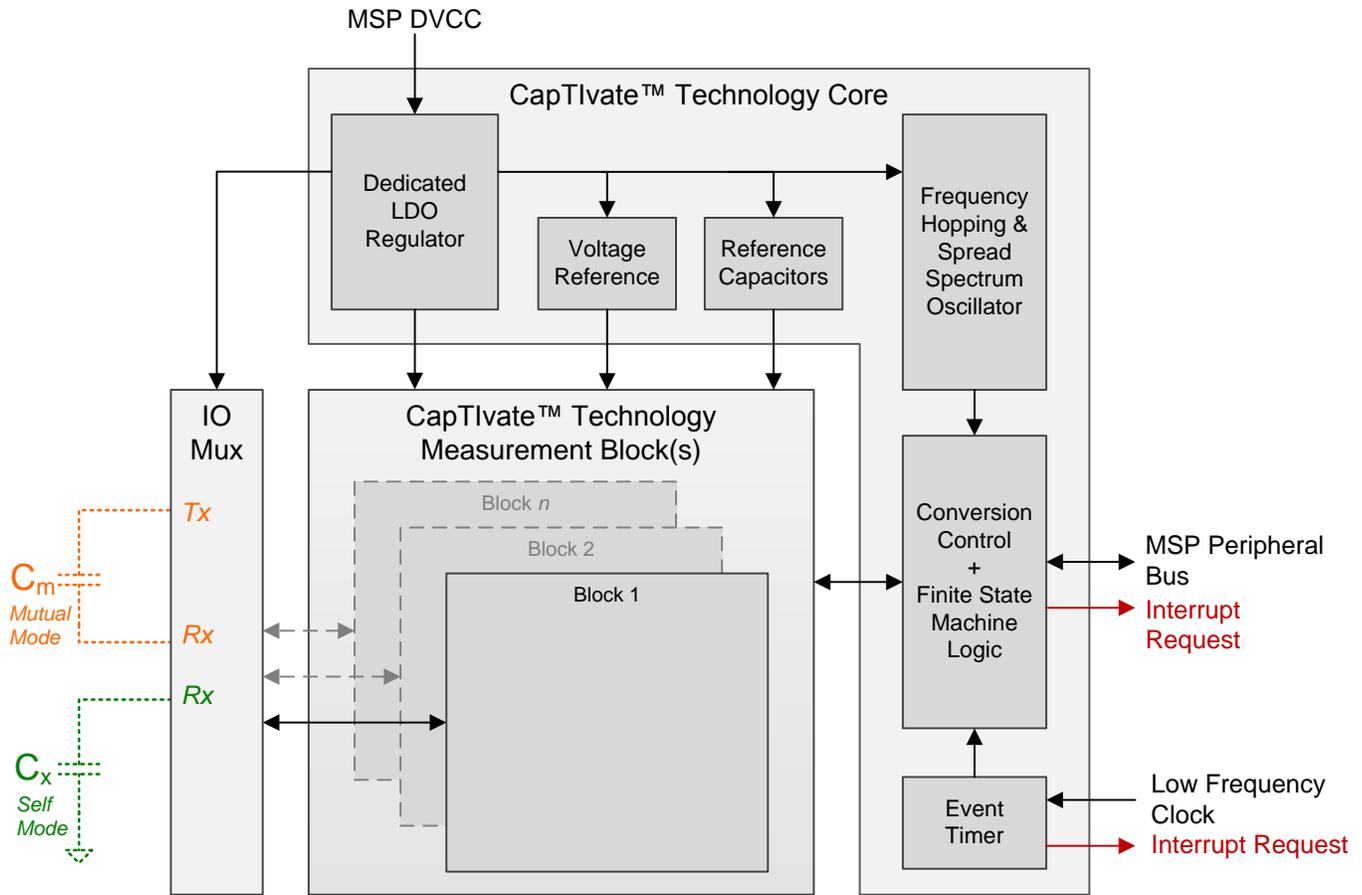

Figure 3. CapTIvate Technology Block Diagram

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4 System Design Theory

4.1 Capacitive Touch Sensing

TIDM-CAPTIVATE-64-BUTTON uses capacitive sensing to implement a 64-button keypad. Capacitive sensing is the ability to measure and detect a change in the capacitance of a sensor. When this change is due to human interaction, the technique is called *capacitive touch sensing*. The use of capacitive sensors provides a designer with flexibility when designing buttons because capacitive sensor elements can be made out of any conductive material, shaped according to touch type, and tuned based on the intended application. This design uses mutual capacitance sensors formed by copper PCB planes to create a 64-button keypad. Figure 4 shows an assembled TIDM-CAPTIVATE-64-BUTTON.
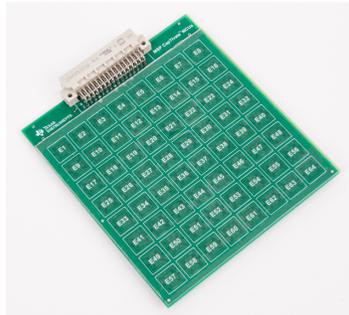
Figure 4. TIDM-CAPTIVATE-64-BUTTON Assembled With 2.5-mm Overlay

4.2 Mutual Capacitance Theory

Mutual capacitance sensors are composed of two separate electrode structures. Each structure acts as a separate plate of a capacitor. One electrode is called the transmit electrode (Tx) and the other is the receive electrode (Rx). User interaction with a mutual capacitance sensor is identified by detecting a change in the capacitance between a Tx and Rx electrode pair. Figure 5 shows a diagram of a mutual capacitance sensor.
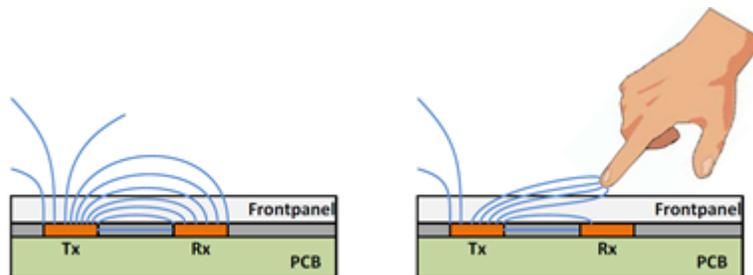

Figure 5. Mutual Capacitance Sensor Diagram and E-Field

Because a person is coupled to earth ground and the human body is a conductor, a touch between the electrodes has roughly the same effect as placing a ground between them. A touch reduces the electric field coupling between the electrodes and reduces the overall capacitance. Some mutual capacitance must exist between a Tx and Rx electrode pair for the pair to act as a sensor because a touch reduces capacitance. Changes in mutual capacitance due to a touch are small (usually less than 1 pF).

When designing mutual capacitance systems, consider the following:

* The two types of parasitic capacitance that exist
* Tightly coupled e-fields between electrodes
* The overlay material requirement
* Mutual capacitance sensitivity

4.2.1   Parasitic Capacitance

There are two types of parasitic capacitance in mutual capacitance systems: mutual and ground.

Parasitic mutual capacitance forms when a Tx trace comes close to an Rx trace. This mutual capacitance, unlike the mutual capacitance between the electrodes, is undesirable because a user will not change the parasitic mutual capacitance when they interact with the sensor.

TI routed Tx and Rx traces on TIDM-CAPTIVATE-64-BUTTON so that parasitic mutual capacitance is reduced. By routing Tx and Rx traces as far from each other as possible and only crossing them when required, parasitic mutual capacitance is reduced. When a Tx and an Rx trace cross, keep the crossing at a 90-degree angle to minimize the area of overlap and the contribution to parasitic capacitance. Route Tx traces next to other Tx traces and Rx traces next to other Rx traces in mutual capacitance designs.

Parasitic capacitance to ground forms between trace lines and ground pours. Keep the surface area of ground pours small when not designing for noise immunity. Keep trace routing between an MCU and an electrode as short as possible to reduce both parasitic mutual capacitance and parasitic capacitance to ground.

4.2.2   Tightly Coupled E-Fields

The electric field created by a mutual capacitance sensor is tightly defined between its two electrodes. Tightly coupled electric fields allow for all 64 buttons in this design to be packed closely together without cross-coupling when a touch on a sensor is not centered. Reducing the chances of cross-coupling in closely packed sensors prevents a touch from unintentionally activating multiple buttons.

4.2.3   Overlay Material Requirement

Overlay material is required for mutual capacitance touch panels. The overlay material provides an area for the electric field to propagate between an Rx and Tx electrode. Without overlay material, a touch on a mutual capacitance sensor can short the Rx and Tx electrodes together.

Because overlay projects a mutual e-field outward with which a user interacts, shape mutual capacitance electrodes according to the thickness of the overlay so that sensitivity is optimized. If Tx and Rx electrodes are placed too closely together in a design with a thick overlay, only a small part of the electric field is exposed above the overlay and sensitivity is low. TI recommends using a polycarbonate overlay with a thickness from 1.5 mm to 2.5 mm with this design.

4.2.4   Mutual Capacitance Sensitivity

The change in capacitance due to a touch on a mutual capacitance electrode is smaller than that of a self-capacitance electrode. A smaller change means that measurements of mutual capacitance electrodes are noisier than self-capacitance electrodes. For this reason, constructing large sliders and wheels from mutual capacitance electrodes can be difficult unless you use many electrodes. Mutual capacitance electrodes work best as button matrices with sensors that have a small node size and high electrode density.

4.2.5 Mutual Capacitance Matrices

A mutual capacitance sensor requires two MCU pins because two separate electrodes are used to form the sensor. Though needing two MCU pins to form mutual capacitance sensors seems like a disadvantage, using two pins provides a unique advantage when sensors are created with an electrode matrix. An electrode matrix is realized by organizing Tx and Rx electrodes such that each Tx pairs with each Rx at a single location. A unique sensor is formed by every Tx and Rx pair in the matrix. Figure 6 shows a capacitive touch matrix consisting of four row electrodes and three column electrodes.
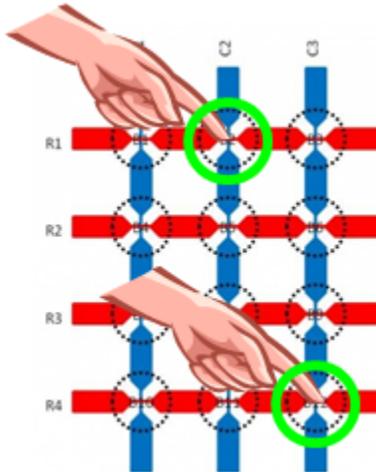
Figure 6. Electrode Matrix in Mutual Capacitance Mode

TIDM-CAPTIVATE-64-BUTTON uses a mutual capacitance matrix formed with eight Tx electrodes and eight Rx electrodes. This matrix forms a 64-button touch panel that is controlled by only 16 MCU pins and supports multi-touch detection. An electrode matrix can be created with self-capacitance electrodes, but a self-capacitance matrix is unable to support multitouch detection due to ghosting effects.

4.3 CapTIvate Technology

CapTIvate Technology is a dedicated MSP430 module that enables robust capacitive sensing. Capacitance measurements are performed by CapTIvate Technology using a unique charge transfer technique. CapTIvate Technology operates on the principle that a capacitor is a charge storage device. As a charge storage device, a capacitive touch electrode holds a certain amount of charge when a specific voltage is applied to it.

CapTIvate Technology measures the amount of charge stored on an external capacitor (electrode or sensor) by charging the capacitor at a DC voltage, then transferring the stored charge into a charge bucket much larger than the external capacitor. The charge bucket is implemented as a large, internal sampling capacitor. By repeating the charge and transfer process until the sampling capacitor is full, CapTIvate Technology provides a relative measurement of the size of the external capacitor.

CapTIvate Technology provides a set of hardware and software tools for accommodating a wide range of external capacitances. Additionally, four instances of the CapTIvate Technology measurement block are included in each CapTIvate MCU to enable sensors to be scanned in parallel. For more information on CapTIvate Technology, see the *CapTIvate Technology Guide* (http://www.ti.com/CapTIvateTechGuide).

5   Getting Started Hardware

The TIDM-CAPTIVATE-64-BUTTON is not sold on the TI store. TI provides the hardware design files as part of the TI Design so you can replicate it. Alternatively, you can purchase an MSP-CAPT-FR2633 MCU Development Kit to evaluate the CapTIvate Technology in a wide range of capacitive touch configurations. For more information, see Figure 7.

Figure 7. MSP-CAPT-FR2633 MCU Development Kit

Included with the kit are a CAPTIVATE-FR2633 Target MCU Module, a self-capacitance touch panel, a mutual capacitance touch panel, and a proximity sensing panel. These touch panels interface directly into the CAPTIVATE-FR2633 module and include premade demonstration projects for easy plug-and-play use.

6   Getting Started Firmware

TI developed the example firmware included with TIDM-CAPTIVATE-64-BUTTON using Code Composer Studio™ (CCS) v6.1.1.0022 and TI Compiler version 4.4.6. Each firmware example is organized into a collection of source files. Table 1 lists a description of the general structure of the firmware examples.

Table 1. Components of Example Firmware

CCS Project File and Folder Name	Description
main.c	Main function used to configure device and run application
captivate	CapTIvate Technology software library
captivate_app	Application layer code
captivate_config	CapTIvate Technology and sensor configuration
driverlib	Driver library that enables the use of high level APIs in application
demo (Illegal Touch Detection Demonstration Only)	Additional demonstration application code

To evaluate the example firmware, do as follow:

1. Download the latest version of CCS and CapTIvate Design Center.
2. Import the projects into a CCS workspace from [TI Design Software Install Root]/Software/*.

> **NOTE:** Each example project for the TIDM-CAPTIVATE-64-BUTTON includes associated CapTIvate Design Center project files.

3. Copy the CapTIvate Design Center configuration files into a new Design Center project from the same Software directory.
4. Program a CAPTIVATE-FR2633 MCU Module using CCS.
5. Run the example firmware.
6. Connect to the MCU Module in the Design Center.
7. Configure and tune sensor performance (optional).
8. Perform SNR measurements for the design in real time (optional).

The following sections provide a description of each example project. For additional information, see [TI Design Software Install Root]/Software/Doxygen/*.

6.1 Basic Demo-Single Sensor Structure

The simplest and most memory efficient way to configure the TIDM-CAPTIVATE-64-BUTTON touch panel in firmware is to define the 16-pin (8-Tx and 8-Rx) electrode matrix as a single sensor structure containing 64-independent buttons. In this case, the sensor structure is divided into 16-measurement cycles, each containing four separate buttons that are attached to different Rx electrodes. The four buttons on each cycle are measured in parallel using the four measurement blocks in the CapTIvate Technology. This method keeps the measurement time low for the entire sensor structure.

In the single-sensor example application, LED1 and LED2 light up to indicate if a single touch or a multitouch event is detected by the controller. LED1 lights up when a single touch is detected and both LEDs light up when multiple touches are detected.

6.2 Ultralow-Power Demonstration

The ultralow-power demonstration is based on the same application code as the basic demonstration, but it optimizes the sensor configuration and tuning for low-power operation. By reducing the scan rate of the keypad and the bias current used to drive the Rx electrodes, TI achieved lower power consumption. An ultralow-power configuration is best suited for an application in which the touch panel must be battery powered.

The scan rate of the touch panel is reduced to 8 Hz in the ultralow-power demonstration. Reducing the frequency with which the keypad is measured increases the amount of time that the application is in its low-power mode and decreases overall power consumption. Reducing the frequency also slows response time because buttons are measured less frequently.

> **NOTE:** Do not reduce the scan rate arbitrarily because it slows the response time of the keypad.

The bias current applies only to mutual capacitance sensors. The bias current reduces the effect of parasitic capacitance to ground. An amplifier that drives Rx electrodes during a sample and hold period of a measurement cycle supplies the bias current. This ensures that the only charge associated with the mutual capacitance between the Tx and Rx electrode accumulates on the CapTIvate Technology sample capacitor during the measurement.

In the ultralow-power demonstration, the bias current is reduced to 10 µA, which is half of the default value. Reducing the bias current saves power during measurement periods. When power is not a concern, keep the bias current at its default highest value because reducing it can affect sensitivity and increase noise.

6.3 Wake-On-Touch Demonstration

CapTIvate Technology includes a finite state machine (FSM) that enables wake-on-touch operation. The wake-on-touch operation is a special use case of the FSM where the context of one sensor cycle is loaded into the CapTIvate Technology and continuously measured. In this mode, CPU interaction is unneeded to load new cycle related values or update long-term average and filter count values. When a device is in wake-on-touch mode, a detection interrupt, maximum counter error interrupt, or conversion counter interrupt wakes the CPU. Wake-on-touch mode reduces power consumption by keeping the MCU in a low-power mode while measuring a single cycle until the CapTIvate technology detects a touch.

In the traditional way of using wake-on-touch mode with a 64-button panel, the number of CapTIvate Technology measurement blocks on the MCU limits the number of mutual capacitance buttons measured in wake-on-touch mode. Because the MSP430FR2633 contains four measurement blocks, a single measurement cycle is limited to four mutual capacitance buttons. To enable all 64 buttons to wake the application from wake-on-touch mode, an additional sensor configuration must be added to the firmware. The additional sensor configuration is required for the 64-button panel to operate like a 4-element, self-capacitance sensor during wake-on-touch mode. When all the CapTIvate IOs used by the sensor serve as receive lines and are enabled, the TIDM-CAPTIVATE-64-BUTTON operates like a 4-element, self-capacitance sensor.

Setting up and enabling the IOs this way makes all the sensor elements connected to the same CapTIvate measurement block appear as a single, self-capacitance button. When using this configuration, measuring any IO on the block produces a measurement for the entire button. Group the four buttons formed by the measurement blocks on the MSP430FR2633 in a single measurement cycle that can be used in wake-on-touch mode. Using the cycle for wake-on-touch mode enables all 64 buttons to wake the CPU.

This demonstration project shows the steps required in firmware to create the additional, self-capacitance sensor configuration for the 64-button panel. The project also shows how to switch between the standard configuration for the panel and the self-capacitance configuration in the application. In the demonstration, the CapTIvate Technology is set up to measure the panel using the standard configuration during active mode and using the self-capacitance configuration during wake-on-touch mode.

> **NOTE:** The CapTIvate Design Center cannot be used to view sensor data for both configurations at the same time. A separate application must be created that uses only the self-capacitance configuration to tune the performance of the panel for wake-on-touch mode.

When the CapTIvate Technology is configured to measure the panel as a 4-element, self-capacitance sensor; the exact location and type of detection made by the sensor can not be identified. The device can detect a general proximity or touch event on the sensor. The application is put into wake-on-touch mode until one of these events is identified. After an event, the CPU wakes up, the CapTIvate Technology is set up again for the active mode configuration, and active mode resumes. The power consumption achieved with this example is even lower than the ultralow-power demonstration.

6.4 Code Size and Response Time Optimized Demonstration

The code size optimized demonstration shows how to modify the basic demonstration to use a minimal amount of memory for application code. Functions from the CapTIvate Technology Software library are called directly from the main function instead of from a separate application layer. Most of the board support package (BSP) code is eliminated to reduce code size.

In the code size optimized example, the system is put into low-power mode 3 in main until a conversion timer flag is set. When the conversion flag is set, CAPT_updateUI is directly called to update the measurements of the buttons and the flag is reset. When the update of the keypad sensor measurements is complete, a callback function is called to light the LEDs as in the basic demonstration. The controller returns to low-power mode 3 after the sensor measurements are updated and the callback function completes.

The system setup in this demonstration changes so that the master clock speed is set to 16 MHz instead of 8 MHz as in the other example projects. The tuning for the keypad sensor is also changed to have an increased scan rate. Increasing master clock speed and scan rate decreases the response time of the touch panel.

6.5 Illegal Touch Detection Demonstration

The illegal touch detection demonstration is an example of a complex capacitive sensing application based on the 64-button keypad. This demonstration project shows how to build off of the basic demonstration by using a callback function to handle keypad touch events and a simple algorithm to restrict the types of touches accepted by the system.

The application determines a touch to be valid or invalid based on the number of buttons in a touch state and the number of additional buttons in a detect state. A button is set to a touch state when its capacitance changes by more than a set threshold and is maintained for the number of measurements set by the debounce parameter on the button. A button is in a detect state when it has a capacitance change greater than a proximity threshold.

A valid touch is any touch that causes three or less buttons to be in a touch state while causing at most one additional button to be in a detect state. LED1 lights when the application detects a valid touch. If the application detects an invalid touch, LED2 lights and rejects any valid touches for at least 1 second.

Restricting the type of touches accepted by the system in firmware is beneficial in that it adds a layer of safety to an application. A specific multitouch event could be required by an application that controls an appliance before the appliance turns on, such as an oven or washing machine. Requiring a specific multitouch event can help to prevent the appliance from running due to an improper touch or accidental interaction. Using software to restrict input in this manner is similar to the use of a guard channel; a hardware design technique that enables the rejection of invalid touches such as palm presses on buttons.

6.6 Two-Sensor Demo

TIDM-CAPTIVATE-64-BUTTON can be flexibly configured to behave as if different regions of the touch panel are independent sensor structures. The two-sensor example project shows how the design can be split into two 32-button sensor structures in software. In this example, one of the 32-button groups represents the top-half of the touch panel and the other represents the bottom half. One benefit of using two sensor structures is that they can be tuned independently, which allows for additional design flexibility.

In the example, the total number of measurement cycles is the same as in the single sensor example. The key to maintaining the same number of measurement cycles is to split the sensors so that one includes four of the Tx electrodes and the other contains the remaining four. You could use this configuration method to further divide the touch panel into four separate quadrants, while maintaining the same number of measurement cycles. The disadvantage of configuring the 64-button touch panel by region is that it uses more memory. Additional memory stores the configuration parameters for two sensor structures rather than one.

6.7 Memory Allocation

Each of the firmware examples uses a different amount of available memory on the MSP430FR2633. The memory used in different CapTIvate Technology applications varies based on the following:

- The number of elements, cycles, and sensor structures used in the application
- The use of additional CapTIvate software library features such as serial communication and noise immunity
- The size of the application code

Table 2 shows the memory allocation for each example.

Table 2. Example Firmware Memory Allocation

Example	RAM	FRAM
Basic demonstration – single sensor structure	3.0KB	7.2KB
Ultralow-power demonstration	2.5KB	4.7KB
Wake-on-touch demonstration	2.7KB	5.3KB
Code size and response time optimized demonstration	2.5KB	4.1KB
Illegal touch detection demonstration	3.0KB	7.6KB
Two-sensor demonstration	3.0KB	6.8KB

To view the amount of memory used by a custom CapTIvate Technology application using CCS, navigate to View→Memory Allocation.

6.8 Modifying Examples with CapTIvate Design Center

The CapTIvate Design Center offers the ability to generate complete source code for the CCS and IAR integrated development environments. This feature can be used to quickly modify how sensor elements are grouped into sensor structures and how the sensors are tuned in the example source code. The CapTIvate Design Center installation includes complete documentation for the CapTIvate Software Library API. To view this documentation, do as follows:

1. Click Help→Topics to navigate to the CapTIvate Technology Guide in the Design Center.
2. Navigate to Software Library→Software Library API.
3. Click the link.

For more information on the CapTIvate Design Center, visit www.ti.com/capTIvate.

7 Testing

7.1 Power Consumption

TI recorded a measure of the power consumption of TIDM-CAPTIVATE-64-BUTTON for the ultralow-power configuration and the wake-on-touch configuration. TI captured the measurements using a high-resolution source-meter with UART/I2C communications disabled. Figure 8 shows a screenshot of the ultralow-power configuration measurements.
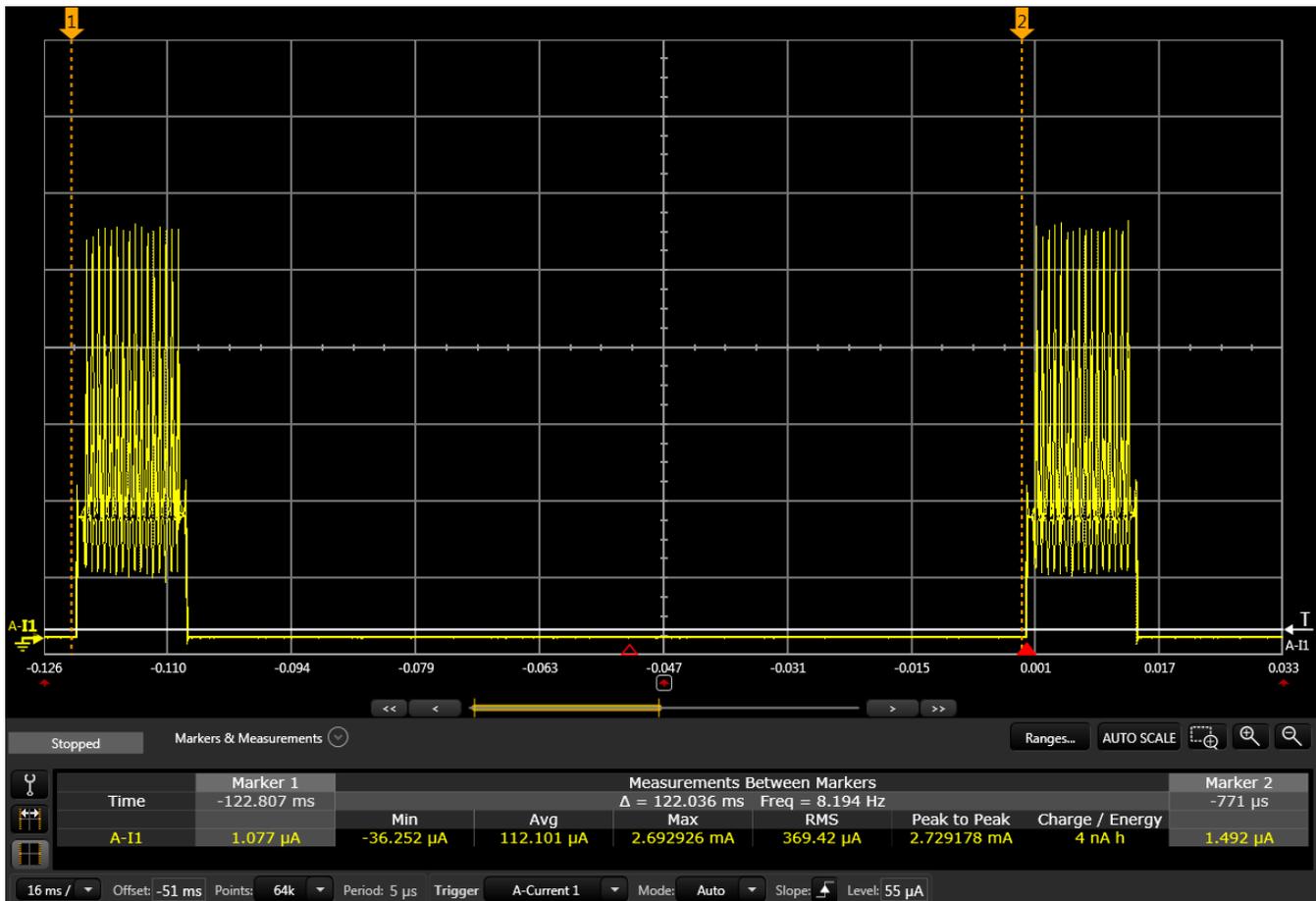
Figure 8. Average Power Consumption of TIDM-CAPTIVATE-64-BUTTON for a Single Measurement Period, Ultralow-Power Configuration

TI obtained the measurement using TIDM-CAPTIVATE-64-BUTTON connected to a CAPTIVATE-FR2633 Target MCU Module, and a 3-V power supply from the source meter. Figure 8 shows the average current recorded with this setup was 112.1 µA, which corresponds to only 1.75 µA per button. The power consumption shown in Figure 8 is identical to the power consumption of the wake-on-touch example when the application is in active mode.

Figure 9 shows a measurement of the power consumption of TIDM-CAPTIVATE-64-BUTTON in wake-on-touch mode.

Figure 9. Average Power Consumption of TIDM-CAPTIVATE-64-BUTTON for a Single Measurement Period, Wake-On-Touch Configuration

Figure 9 shows the average current recorded when the device was in wake-on-touch mode was 15 µA. Switching to a wake-on-touch mode lets the panel conserve power while not in use. With an average current of 15 µA, this design could be powered for approximately 5.5 years on AAA batteries.

7.2   *Measurement and Response Time*

Keep measurement and response time low in capacitive touch interface designs to provide the best experience. Keeping measurement and response time low can be challenging in interface designs with a large number of inputs. The code size optimized demonstration project included in the firmware examples shows how to keep measurement and response time for TIDM-CAPTIVATE-64-BUTTON low.

TI observed the measurement time of TIDM-CAPTIVATE-64-BUTTON by recording its current consumption using a high-resolution source meter. Indicated by a set of 16 peaks in the current consumption, the duration of a single period of CPU activity represents the measurement time of the touch panel. During this measurement period, the CPU wakes from LPM3 16 times to read measurement data from a completed measurement cycle out of the CapTIvate Technology and then load the context for the next cycle. Figure 10 shows that this time is approximately 5.5 ms or approximately 86 µs per button.
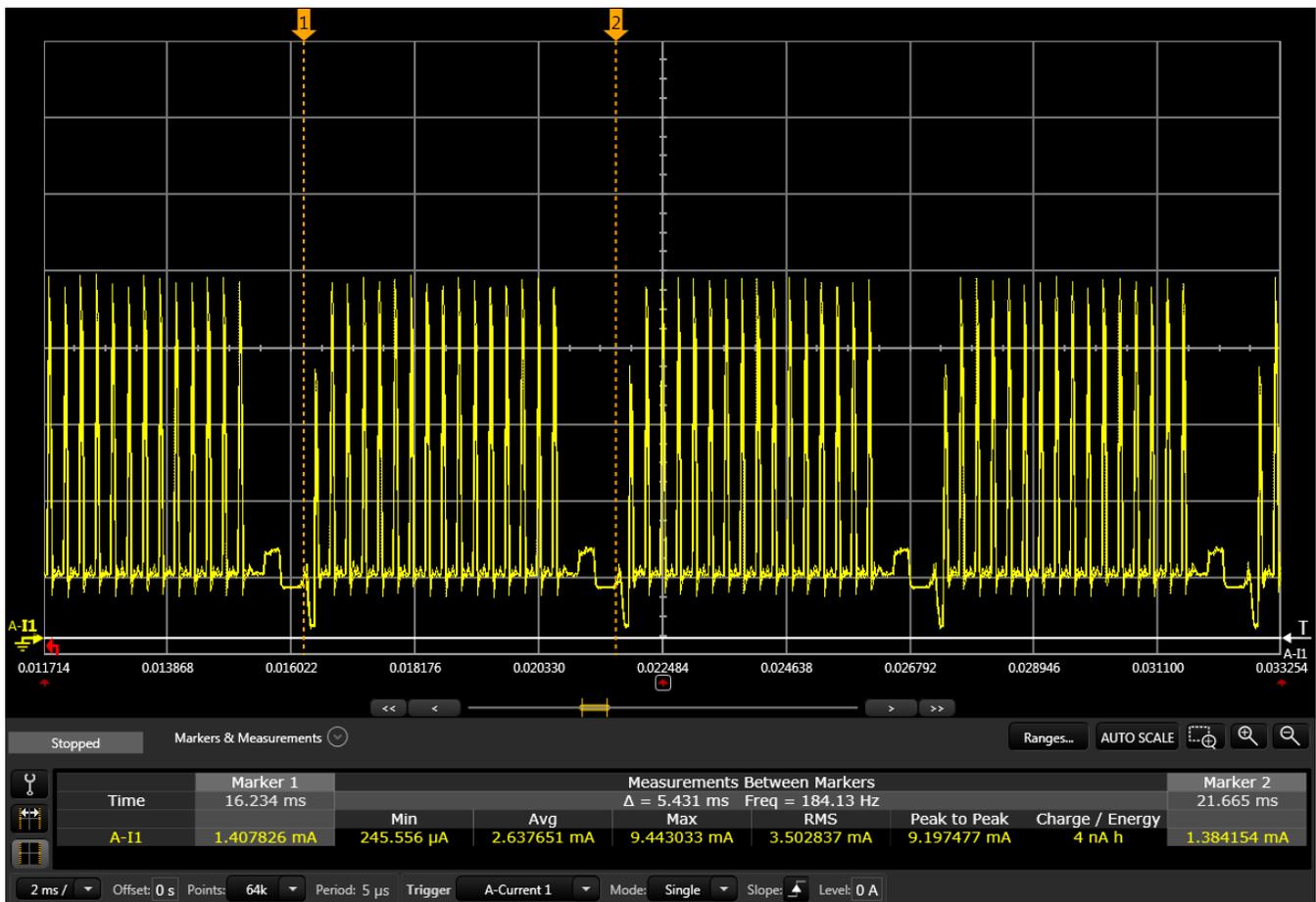
Figure 10. Measurement Period Length With Code Size and Response Time Optimization

Using this measurement time, you can estimate for the worst-case response time of TIDM-CAPTIVATE-64-BUTTON. The worst-case response time occurs if a button is touched immediately after completing its previous measurement. In this case, the press is not identified for at least one additional measurement period. Test the worst case response time by doing as follows:

1. Press a button on TIDM-CAPTIVATE-64-BUTTON.

2. Measure the delay between the setting of its detect flag and touch flag.

3. Add the delay and the measurement period time.

The estimate is a worst-case measurement because the measurement assumes that the touch occurs at least one cycle before it is observed and the detect flag must be set on the first measurement in which the press affects the sensor. The sum of the delays is at least the response time of the touch. Table 3 shows a summary of 10 measurements of this worst-case response time for the touch panel.

Table 3. Worst-Case Response Time Measurements

Measurement Number	Detect to Touch Delay (ms)	Measurement Period (ms)	Worst-case Response Time (ms)
1	5.6	5.5	11.1
2	5.6		11.1
3	11.1		16.6
4	5.6		11.1
5	5.6		11.1
6	27.4		32.9
7	5.6		11.1
8	16.5		22.0
9	5.6		11.1
10	5.6		11.1
Average	**9.4**		**14.9**

7.3 Cross coupling

TI performed a simple cross-coupling test on TIDM-CAPTIVATE-64-BUTTON by ensuring that a touch between buttons would activate only one button at a time. TI performed the test by continuously recording the raw count value and touch state of each button in the first row of the keypad while performing a sweeping touch from left to right. During the test, the basic demonstration firmware project ran while CapTIvate Design Center recorded data from the buttons. Figure 11 shows the results from the test.
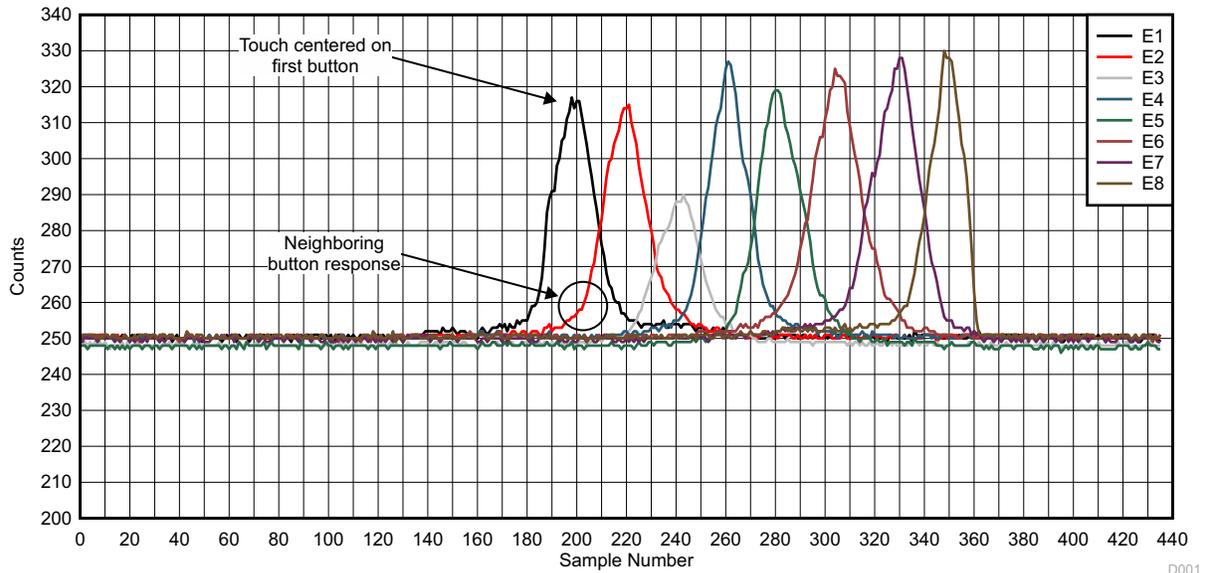
Figure 11. Row1 Raw Counts vs Time

NOTE: The raw response and peak raw count value for each button is slightly different because the buttons do not have identical sensitivity.

Figure 11 shows the point in the sweep when the touch was centered on the first button. At this point, the number of counts for the second button is slightly increased from 250 to 257. This change of 7 counts is less than 18% of what is required to put the second button into a touch state because the touch threshold for the second button is an increase of approximately 40 counts. A response of less than 18% of the touch threshold is acceptable and does not affect the behavior of the button. Every button in the row exhibited an acceptable response to a touch on a neighboring button. The results show that cross coupling occurs at a minimal level. Figure 12 shows the touch state of each button during the test.
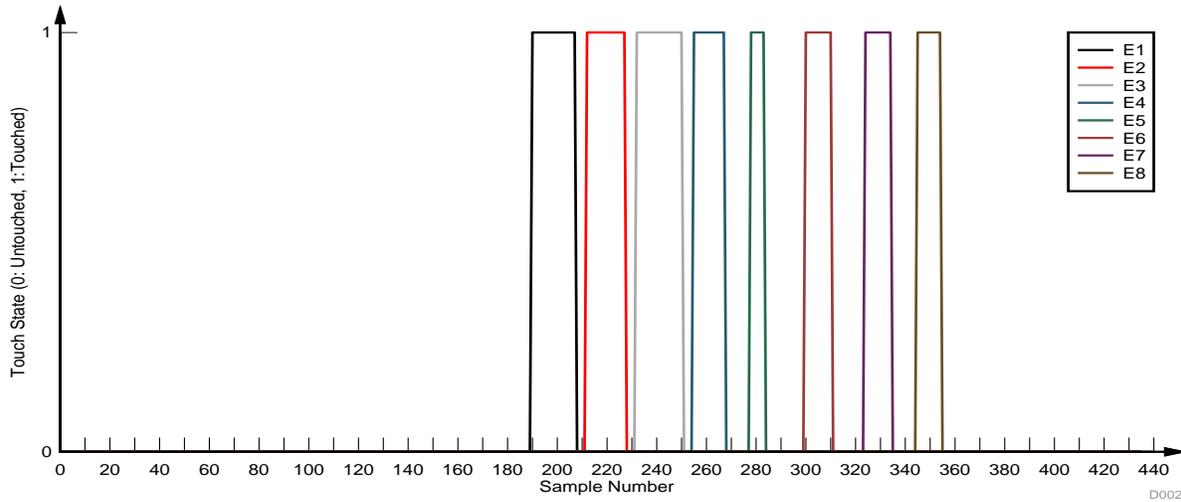
Figure 12. Row1 Touch State vs Time

Figure 12 shows that as the touch swept across the row, no two buttons entered a touched state at the same time. This result demonstrates how the physical design and tuning of TIDM-CAPTIVATE-64-BUTTON work together to provide an appropriate response to touch.

NOTE: The results of this test vary with touch size, sensor tuning, and speed with which touch is swept across the button row. TI collected the results by manually sweeping a finger across the first button row at an approximately constant speed.

7.4 Overlay Comparison

Using overlays of different thickness with a mutual capacitance touch panel can affect the sensitivity of the sensors on the panel. This test used the example code of the basic demonstration to compare the sensitivity on a single button on TIDM-CAPTIVATE-64-BUTTON when using two different overlay thicknesses. TI used a 1.5-mm and a 2.5-mm thick polycarbonate overlay during the test. TI compared the sensitivity of the E1 button with each overlay by recording the raw count value on the button with and without a touch. Figure 13 shows the results.
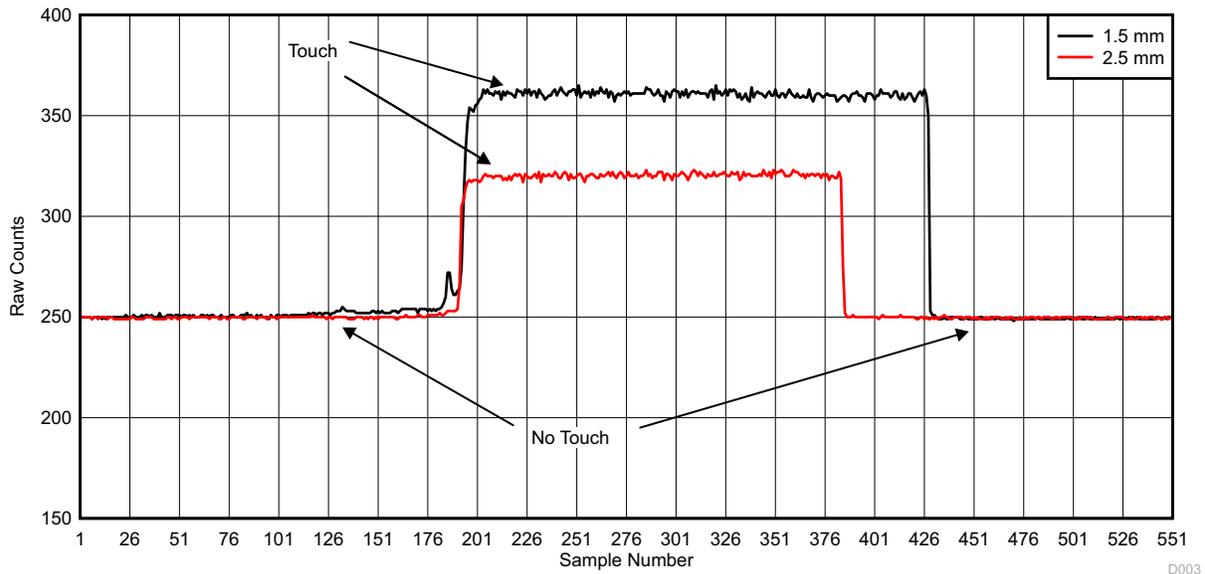
Figure 13. Overlay Thickness Comparison

With an overlay thickness of 2.5 mm, the maximum count value on E1 was roughly 320. With a 1.5-mm overlay, the maximum count value was approximately 360. The additional 40 counts achieved with a 1.5-mm overlay shows that the change in capacitance caused by a touch was greater when using a 1.5-mm overlay. The change in capacitance was greater with a 1.5-mm overlay because more of the e-field between the Tx and Rx electrodes was exposed and affected by the touch.

8 Design Files

The design files for the TIDM-CAPTIVATE-64-BUTTON were created using Altium Designer version 14.3.18.

8.1 *Schematics*

See Figure 14 for the schematics. To download the schematics for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.
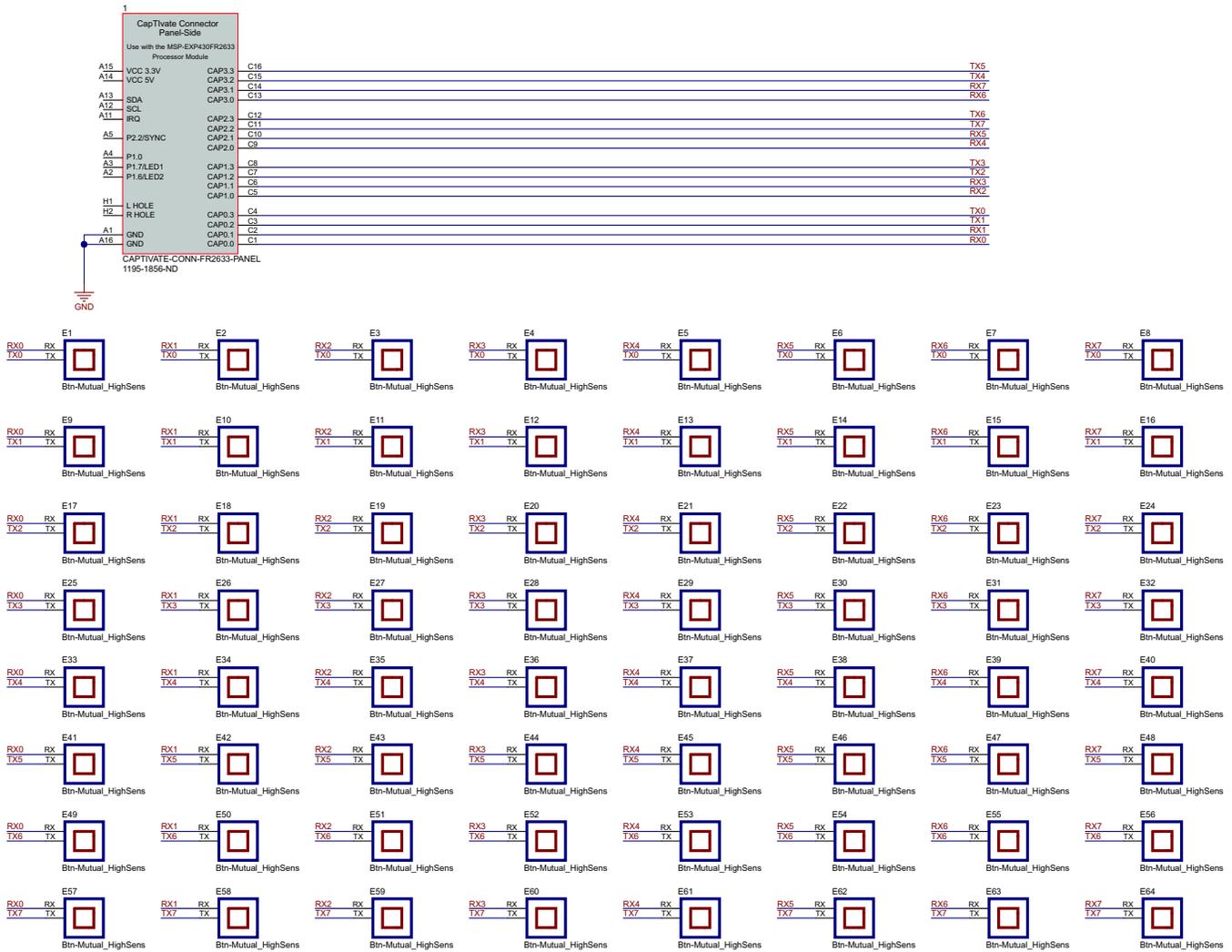
**Figure 14. TIDM-CAPTIVATE-64-BUTTON Schematic**

8.2 Bill of Materials

See for the bill of materials, Table 4. To download the bill of materials (BOM) for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.

Table 4. BOM

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
PCB1	1		Printed Circuit Board		TIDM-CAPTIVATE-64-BUTTON	Any
1	1		CapTIvate Panel-Side Connector	3 × 16 Connector, 100-mil pitch	9231486921	Harting
FID1, FID2, FID3, FID4	4		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
H1, H2	2		Black Bumpon	Bumpon, Cylindrical, 0.312 × 0.200, Black	SJ61A1	3M

8.3 PCB Layout Recommendations

The goal when creating a layout for a capacitive touch PCB is to maximize the signal strength and minimize noise to increase sensitivity. Even though sensitivity can be controlled by firmware, provide good sensitivity with hardware because it can help reduce the power consumption of a solution. Two components of a capacitive touch layout that have a large impact on sensitivity are the routing of traces and electrode design.

You can increase the overall sensitivity provided by a signal in a capacitive touch system by decreasing the parasitic capacitance in a layout. Traces can be a major source of parasitic capacitance. Parasitic capacitance forms between pairs of traces as well as traces and ground. These two types of parasitic capacitance, mutual and ground, must be kept in mind when routing traces.

The electrode design in a capacitive touch panel must provide sufficient signal, while also having a minimal parasitic capacitance. Size the electrodes according to the required touch area to provide the correct amount of signal. The electrodes in mutual capacitance sensors are often rectangular and are sized around 10 mm × 10 mm or smaller. The sensor design in TIDM-CAPTIVATE-64-BUTTON uses a rectangular Tx electrode and an Rx electrode formed by four corners of a rectangle. Figure 15 shows this type of geometry.
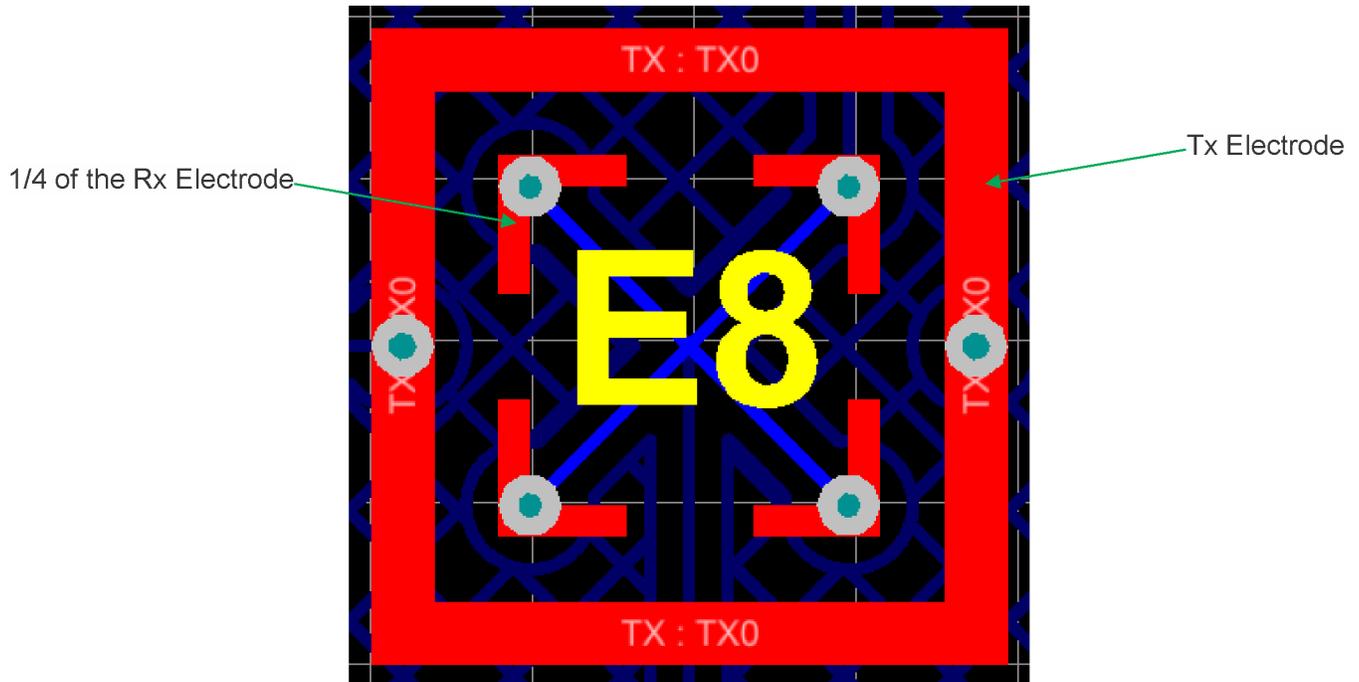
Figure 15. Mutual Capacitance Sensor Design

Eliminating part of the edges of the Rx electrode forces the e-field lines to be concentrated near the corners of the sensor, which reduces parasitic capacitance and improves sensitivity. For exact dimensions on a 10-mm × 10-mm example button and additional tips for PCB layout, see the design section of the CapTIvate Technology Guide (http://www.ti.com/CapTIvateTechGuide).

8.3.1   Layout Prints

To download the layout prints for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.
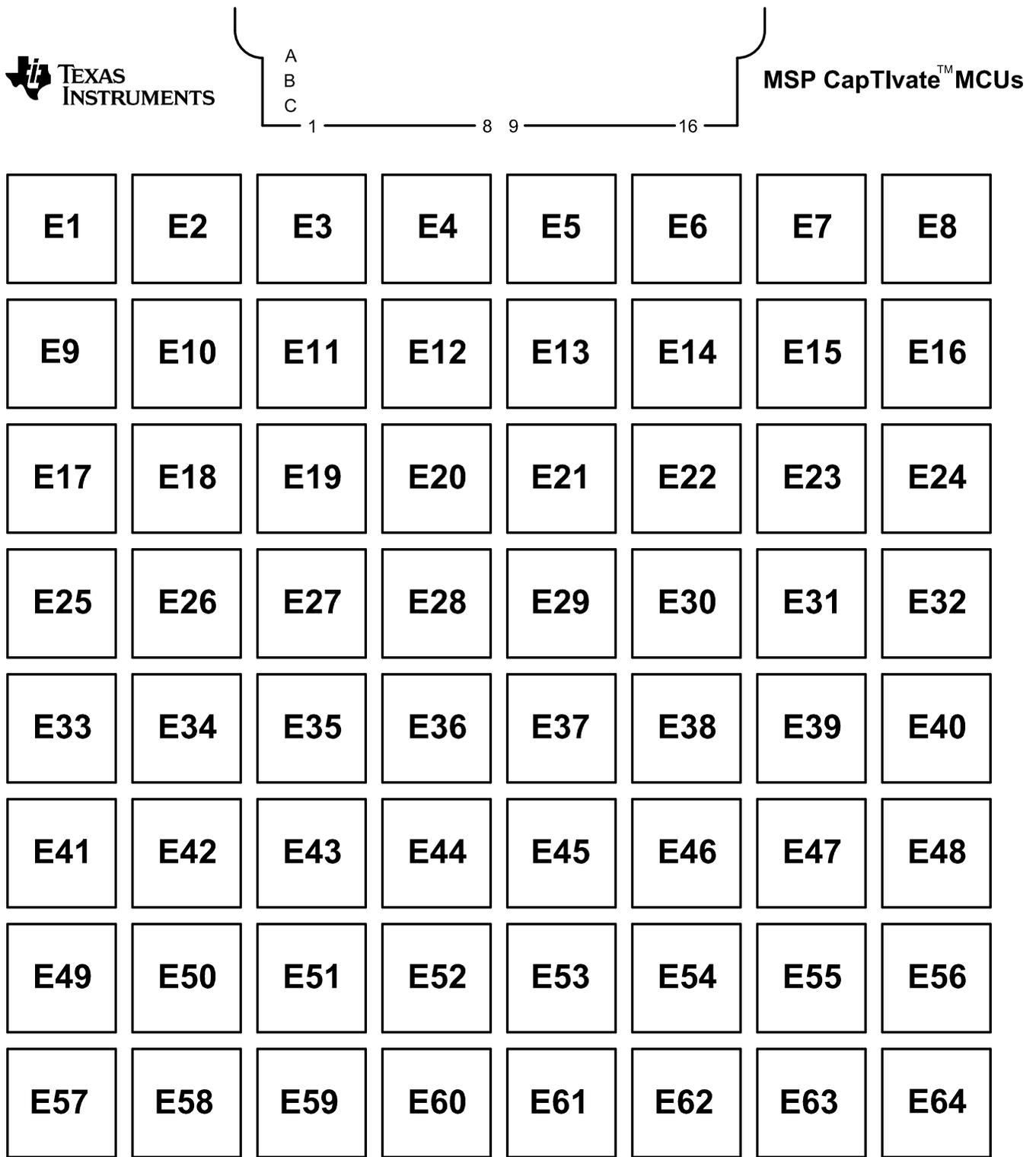
Figure 16. TIDM-CAPTIVATE-64-BUTTON Top Silkscreen Print

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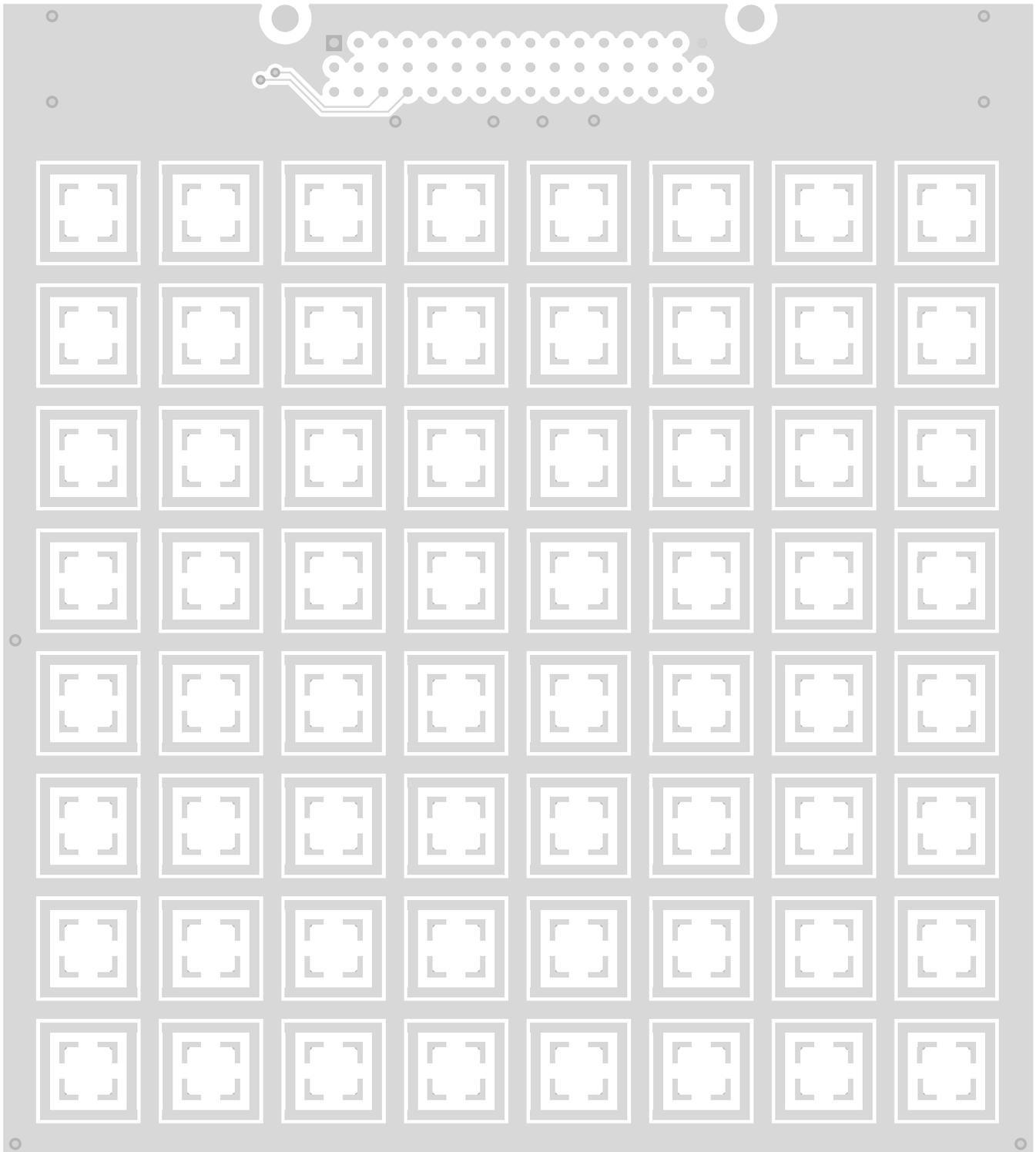
Figure 17. TIDM-CAPTIVATE-64-BUTTON Top Layer Print
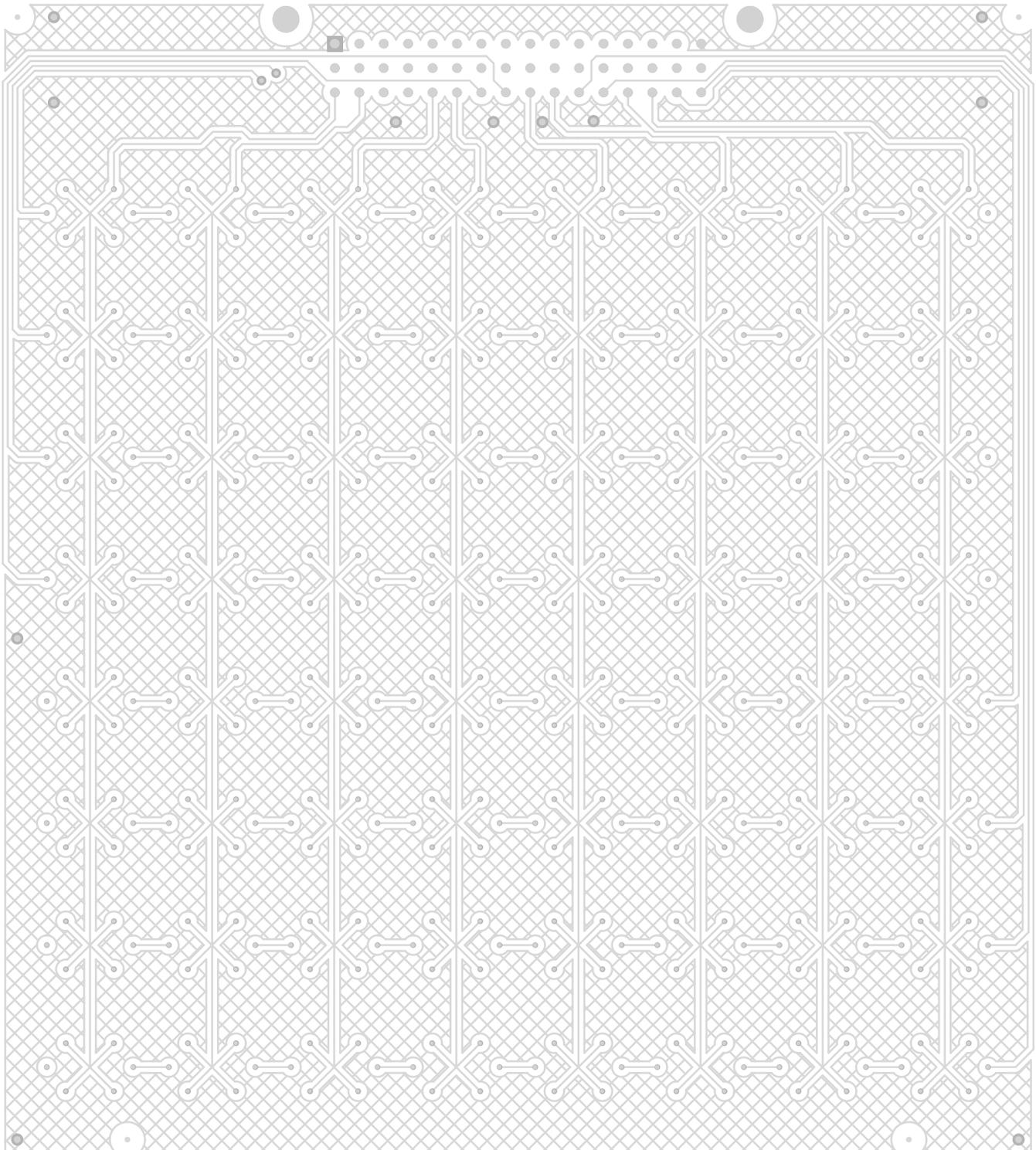
Figure 18. TIDM-CAPTIVATE-64-BUTTON Bottom Layer Print

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Figure 19. TIDM-CAPTIVATE-64-BUTTON Bottom Silkscreen Print
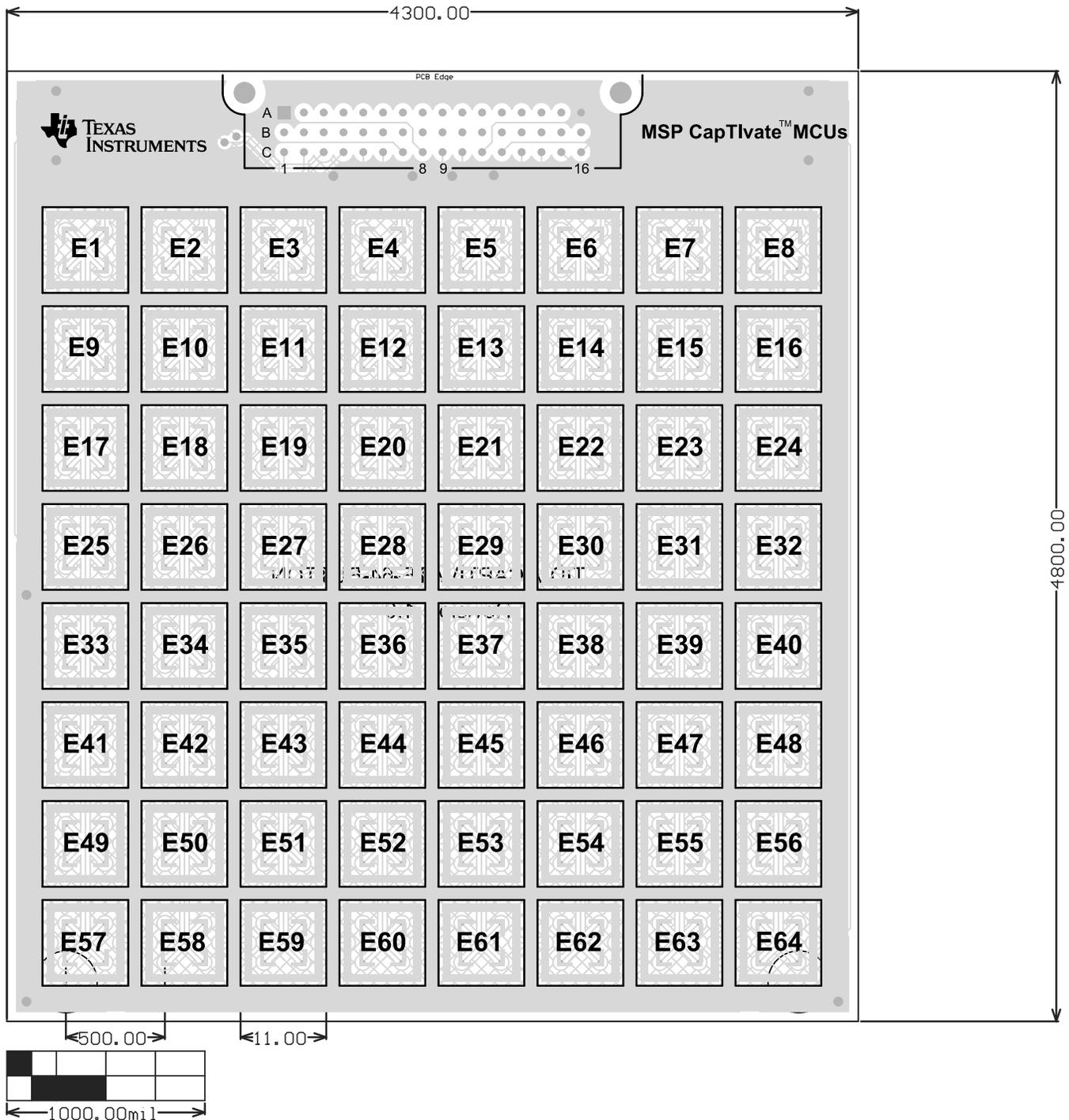
Figure 20. TIDM-CAPTIVATE-64-BUTTON Complete Layout Print With Mechanical Dimensions

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8.4   *Altium Project*

To download the Altium project files for the touch panel, see the design files at
http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.
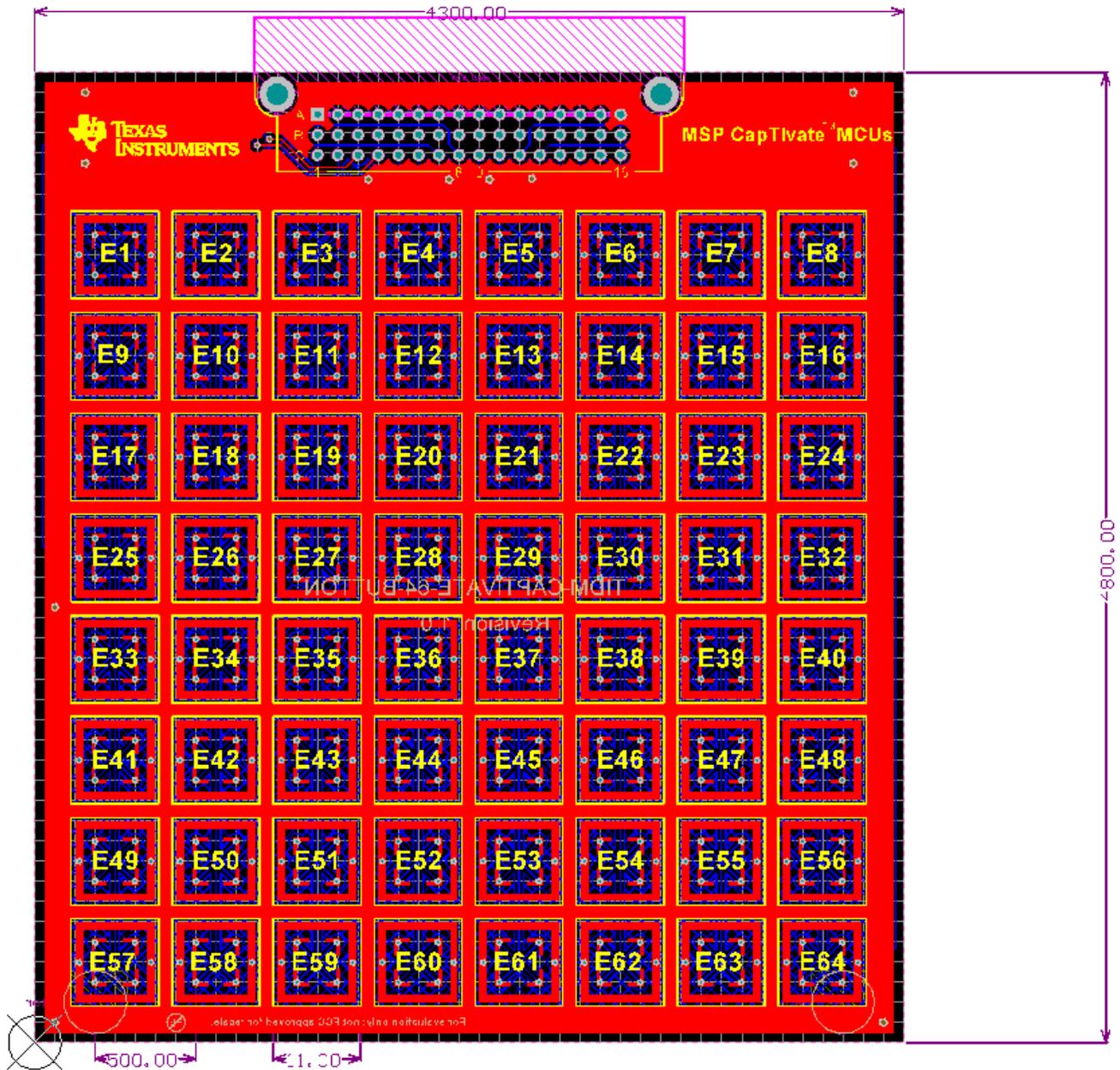
Figure 21. TIDM-CAPTIVATE-64-BUTTON Layout – Top Layer

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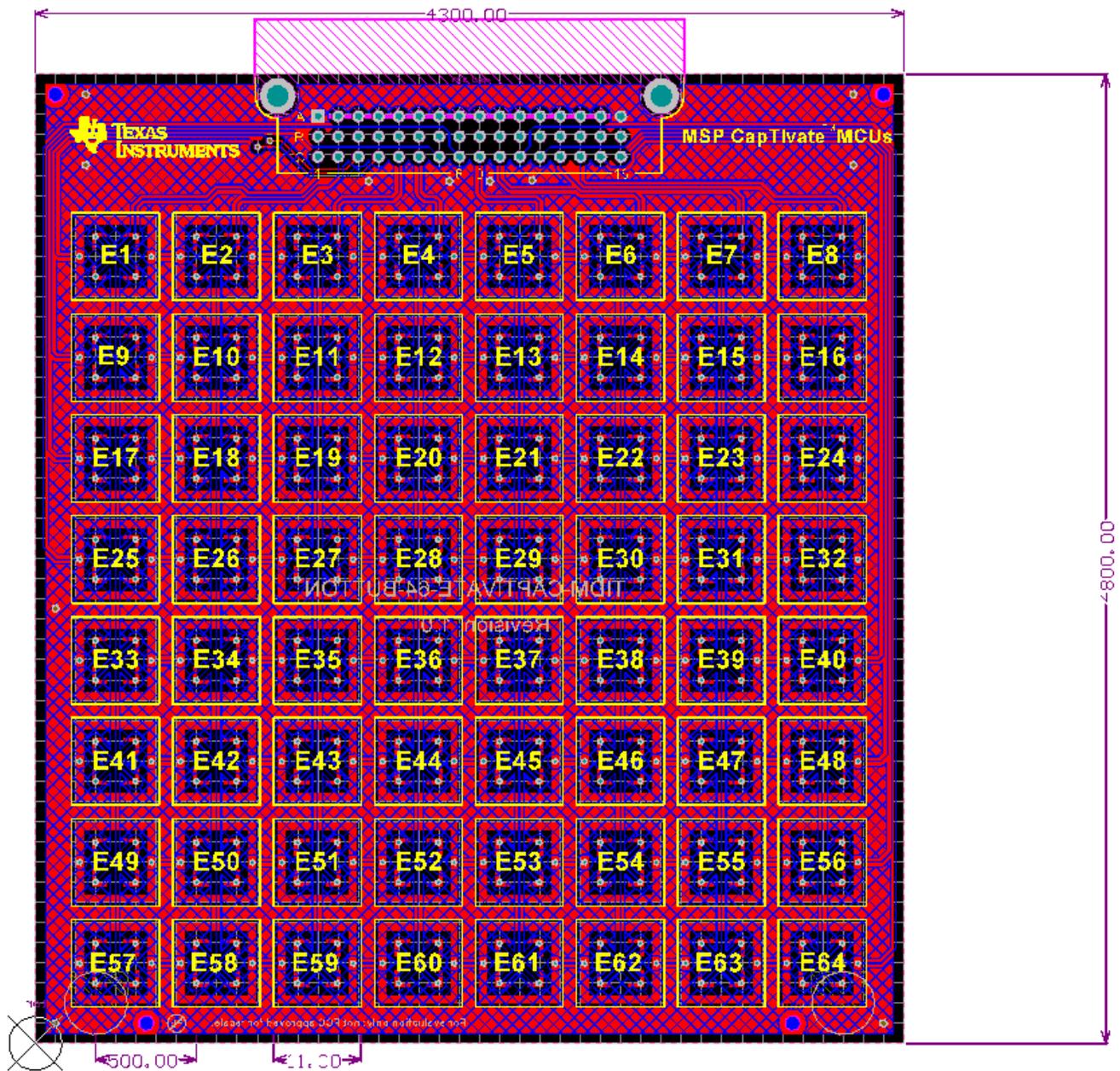
Figure 22. TIDM-CAPTIVATE-64-BUTTON Layout – Bottom Layer

8.5   *Layout Guidelines*

To download the layout guidelines for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.

Using a hatched ground pour when possible to reduce parasitic capacitance to traces and electrodes

Route Tx and Rx traces away from each other and avoid crossing, except at buttons
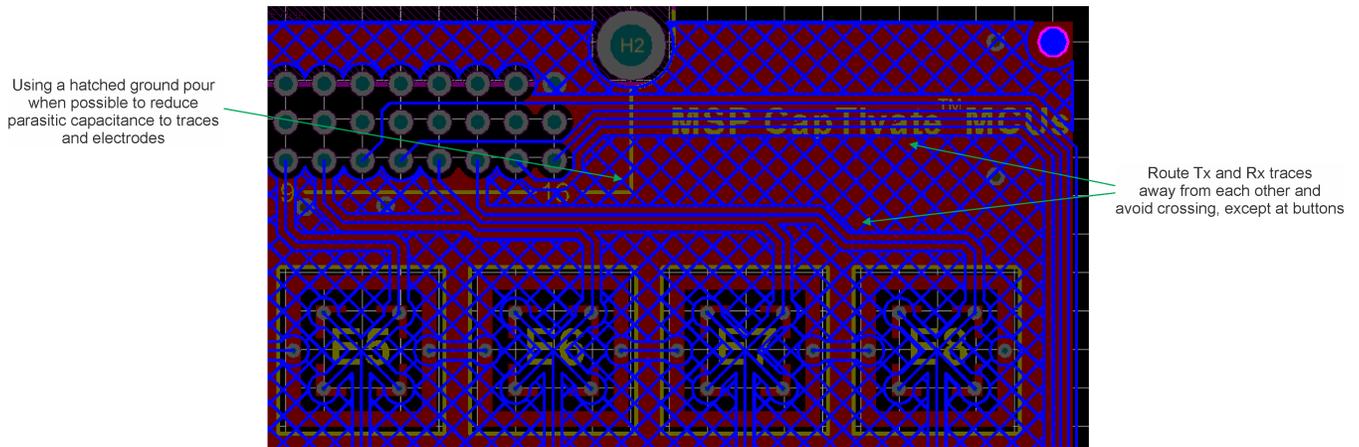
Figure 23. Bottom Layer Layout Guidelines

Keep the ground pour away from electrodes to minimize parasitic capacitance

Use a ground pour around keys to reduce noise and cross-talk
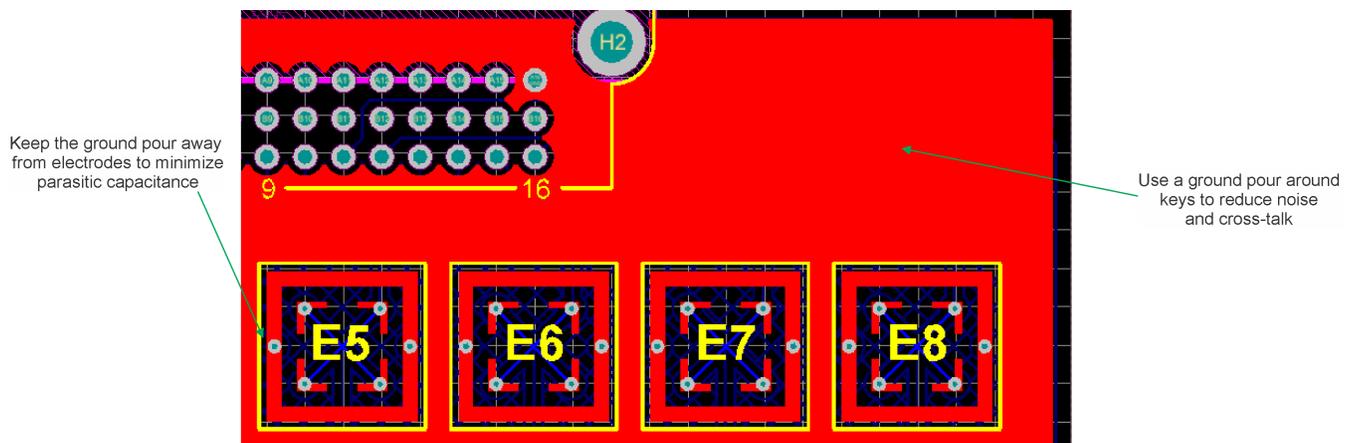
Figure 24. Top Layer Layout Guidelines

8.6   Gerber Files

To download the Gerber files for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.

8.7   Assembly Drawings

To download the assembly drawings for the touch panel, see the design files at http://www.ti.com/tool/TIDM-CAPTIVATE-64-BUTTON.

9   References

1. *TI CapTIvate Technology Guide*, http://www.ti.com/CapTIvateTechGuide
2. *TI CapTIvate Design Center*, http://www.ti.com/CapTIvate
3. *TI E2E Community*, http://e2e.ti.com/

10   Terminology

Self-Capacitance —The method of measuring changes in capacitance with respect to earth ground

Mutual Capacitance —Measuring the change in capacitance on a sensor structure in which both plates of the capacitor are defined by electrode structures

11   About the Author

BENJAMIN MOORE is an applications engineer at TI on the MSP Microcontroller System Applications Team. Benjamin has worked as an applications engineer with TI since 2013 in the C2000 and MSP business units and earned his Bachelor of Science in Electrical and Computer Engineering (BSECE) from The Ohio State University in Columbus, OH.

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