TI Designs
CapTIvate™ E-Lock Design Guide

TEXAS INSTRUMENTS

Description

The TIDM-CAPTIVATE-E-LOCK demonstrates an ultra-low-power capacitive touch panel solution based on a single MSP430™ microcontroller (MCU) with CapTIvate™ technology. This design uses self and mutual capacitance technology to enable a multifunctional capacitive touch panel (buttons and proximity sensor) for E-Lock, as well as for future application extension with various human interfaces available. This TI Design demonstrates how to extend battery life by duty-cycling the MSP430 CPU and switching between low-power mode and active mode. In addition, the design tests and demonstrates the moisture immunity feature.

Resources

TIDM-CAPTIVATE-E-LOCK	Design Folder
CapTIvate Design Center	Tools Folder
MSP430FR2633	Product Folder
TPS62745	Product Folder
TPS61020	Product Folder

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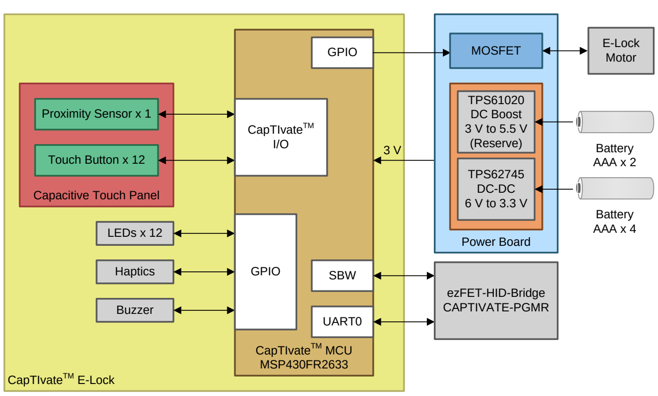
Features

- CapTIvate Capacitive Touch Functions:
  – 12 Touch Buttons
  – One Proximity Sensor for System Wakeup and Guard Key
- 12 LEDs Indicate Touch Operation
- Wake-On Proximity With Ultra-Low-Power Standby Mode
- Haptics Available When Touched
- Buzzer Indicates Touch Feedback and Lock Status
- Motor Drive Circuitry Available
- Two AAA or Four AAA Battery Reference Power Circuitry

Applications

- Smart Entrance
- Control Panel



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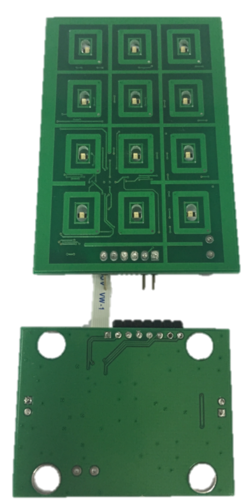

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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Button count	12 mutual capacitance buttons	Section 4.2.1
Touch panel size	75 mm × 50 mm	Section 4.2.2
Proximity sensor size	75 mm × 50 mm, one self-capacitance sensor	Section 4.2.2
LED count	12 LEDs driven by I/Os directly	—
Response time	Active mode: 33 ms (configurable) Wake-on-proximity mode: 100 ms (configurable)	—
Power consumption	Active mode: 264 uA (scan rate = 30 Hz) Wake-on-proximity mode: 3.5 uA (scan rate = 10 Hz)	Section 7.1

2 System Description

TIDM-CAPTIVATE-E-LOCK demonstrates a capacitive touch panel e-Lock solution based on a single MSP430 microcontroller (MCU) with CapTIvate technology. This design uses self- and mutual-capacitance technology to enable multifunctional capacitive touch panel (buttons and proximity sensor) for e-Lock and control panel, as well as for future application extension with various human machine interfaces available. The TI Design lets the operator extend the battery life using the low-power active and standby modes.

2.1 MSP430FR2633

The MSP430FR2633 is an ultra-low-power, FRAM-based MSP430 MCU equipped with CapTIvate technology. The MSP430FR2633 MCU includes 15.5KB of FRAM and 4KB 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 development of a low-power user interface. Figure 1 shows the block diagram of the MSP430FR2633 MCU.

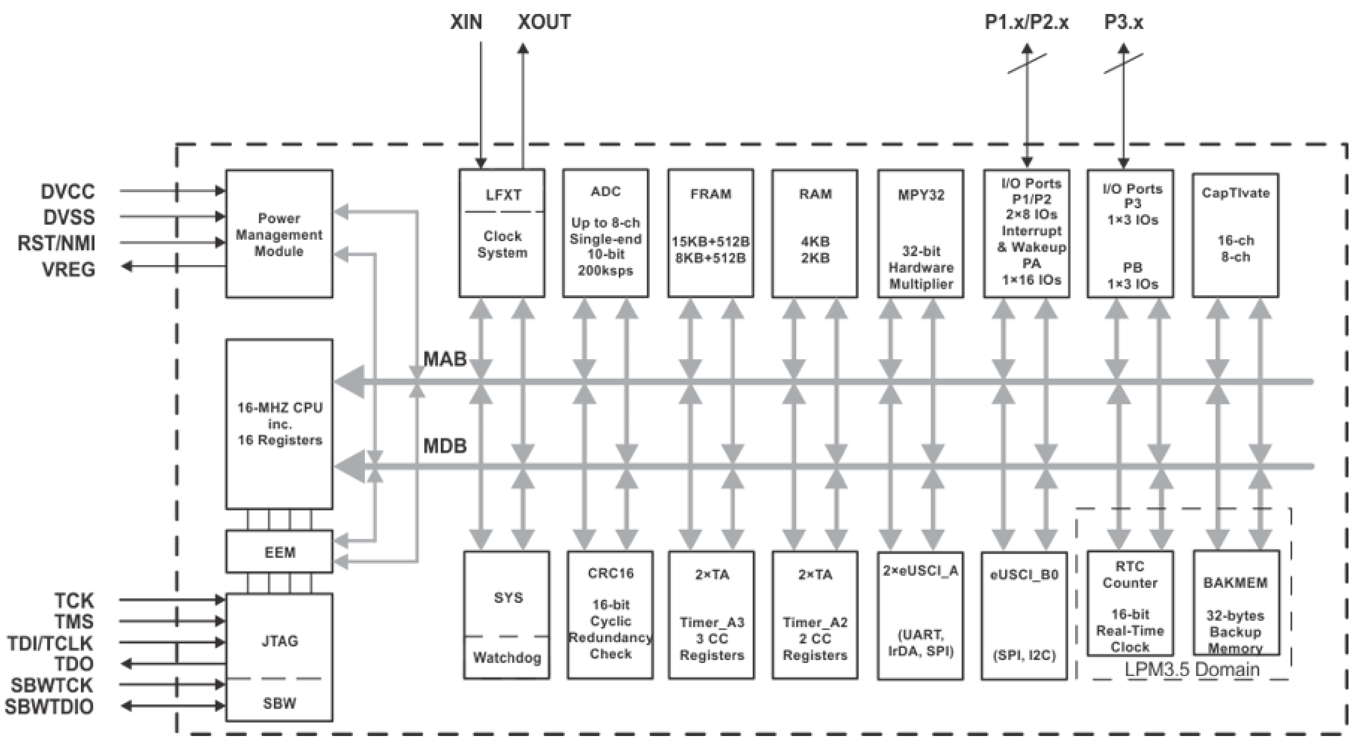

Figure 1. Block Diagram of MSP430FR2633 MCU

3 Block Diagram

This design consists of two boards, a power board and a touch panel board, which are connected by a cable. The power board has two options for power input. One option is the DC Boost (TPS61020,) which supports two AAA battery input and boosts the power to 5.5 V, which can be used by the E-Lock Motor. The other option is the DC-DC (TPS62745), which supports four AAA battery input and provides 3.3-V output for the touch panel board. A MOSFET circuit is reserved for the E-Lock motor control on the power board. The MSP430FR2633 MCU is on the touch panel board with indicator components including: 12 LEDs, one haptic, and one buzzer. The SBW interface is reserved for programing, and the UART for connection with the CapTIvate-PGMR board. Figure 2 shows the block diagram of the CapTIvate E-Lock.

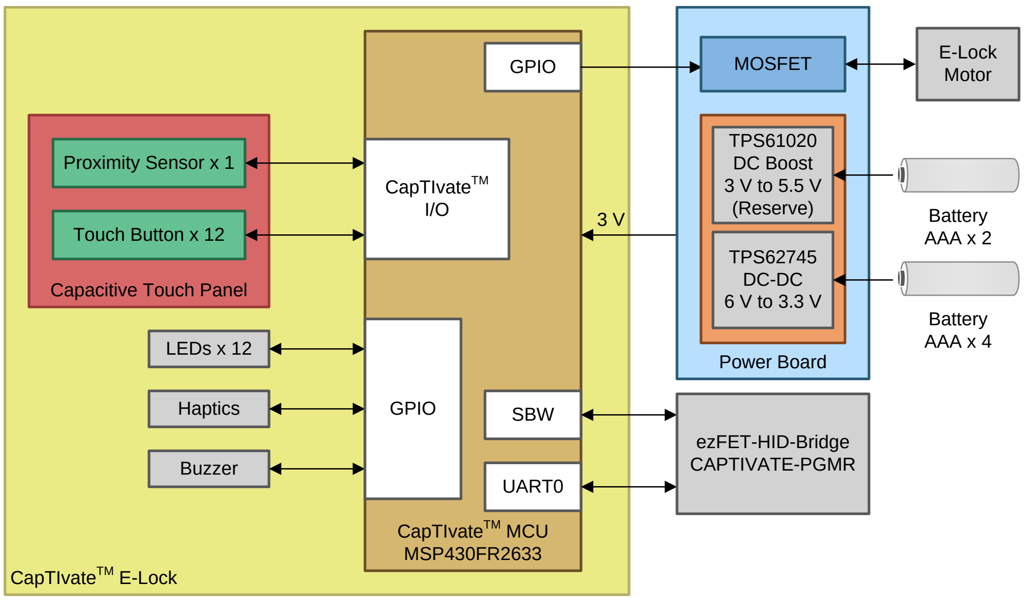

Figure 2. CapTIvate™ E-Lock Block Diagram

3.1 MSP430FR2633

The MSP430FR2633 MCUs are FRAM-based ultra-low-power MSP MCUs featuring CapTIvate touch technology, which make them ideal for use in many capacitive sensing applications.

MSP430FR2633 features:

- 16 CapTIvate technology inputs which 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 of 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^{2}C
- 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

3.1.1 CapTIvate Peripheral

The CapTIvate peripheral enables capacitive buttons and proximity sensing on the TIDM-CAPTIVATE-E-LOCK. CapTIvate peripheral also provides the highest resolution capacitive-touch solution on the market, with high reliability and noise immunity at the lowest power. The CapTIvate peripheral supports concurrent self-capacitance and mutual-capacitance electrodes on the same design for maximum flexibility. Figure 3 shows a block diagram of the CapTIvate peripheral.

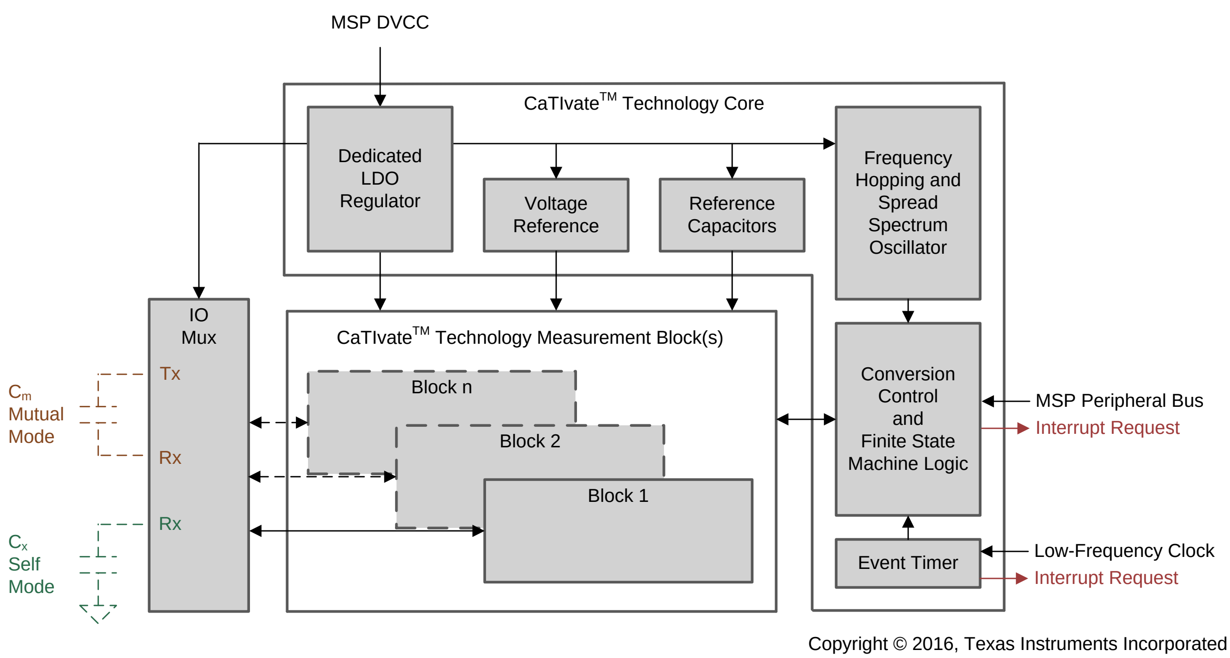

Figure 3. CapTIvate™ Peripheral Block Diagram

4 System Design Theory

4.1 CapTIvate™ Technology

CapTIvate technology is a dedicated MSP430 module that enables robust capacitive sensing. CapTIvate technology uses a unique charge transfer technique to perform capacitance measurements. To accommodate a wide range of external capacitances, CapTIvate technology provides a set of hardware and software tools. For more information on CapTIvate technology, see the *CapTIvate Technology Guide*.

4.1.1 Self-Capacitance Theory

This method of measuring changes in capacitance with respect to earth ground is commonly referred to as self-capacitance measurement. Sometimes it is also referred to as surface capacitance. In a parallel-plate model, the electrode defines one plate of the capacitor, with the other plate being ground or the user's finger. A touch causes the capacitance of the electrode to increase (see Figure 4).

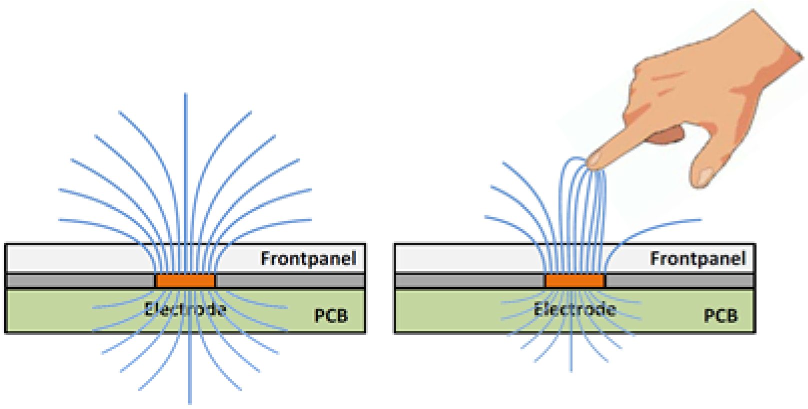

Figure 4. Example for Self-Capacitance Theory

4.1.2 Mutual-Capacitance Theory

Mutual capacitance involves measuring a change in capacitance just like self-capacitance, with one major difference: Mutual capacitance electrodes actually consist of two separate electrode structures, and they require two pins from the MCU (a transmit electrode and a receive electrode). When a user touches an area on the panel where a Tx meets an Rx, the mutual capacitance between those Tx and Rx electrodes is reduced. This reduction occurs because the user's interaction disturbs the electric field propagation between the two electrodes (see Figure 5). Users are coupled to earth ground, and the human body is a conductor. Placing a finger between two mutual capacitance electrodes has approximately the same effect as placing ground between them, and it reduces electric field coupling between them, which reduces the capacitance.

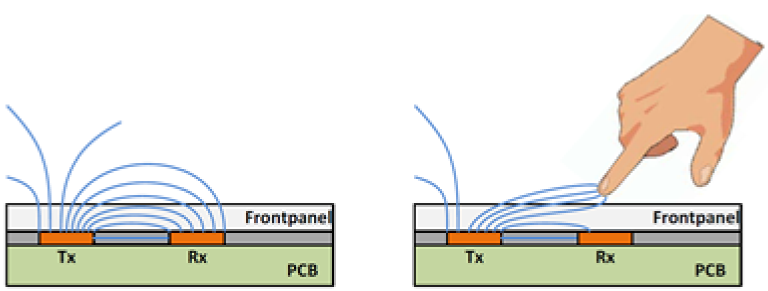

Figure 5. Example for Mutual-Capacitance Theory

4.1.3 Wake-on-Proximity Mode

CapTIvate technology includes a finite state machine (FSM) which enables wake-on-proximity mode, where the sensor has only one cycle and no CPU operation is required to load new cycle related values. The wake-on-touch mode reduces power consumption by keeping the MCU in a low-power mode while measuring a single cycle, until the selected wake-on-proximity sensor detects a proximity event.

4.2 Capacitive Touch Panel Design

The capacitive touch panel includes the following touch sensors:

- 12 touch buttons
- One proximity sensor for system wakeup and guard channel in active mode

Figure 6 shows the capacitive touch panel with touch sensor numbers.

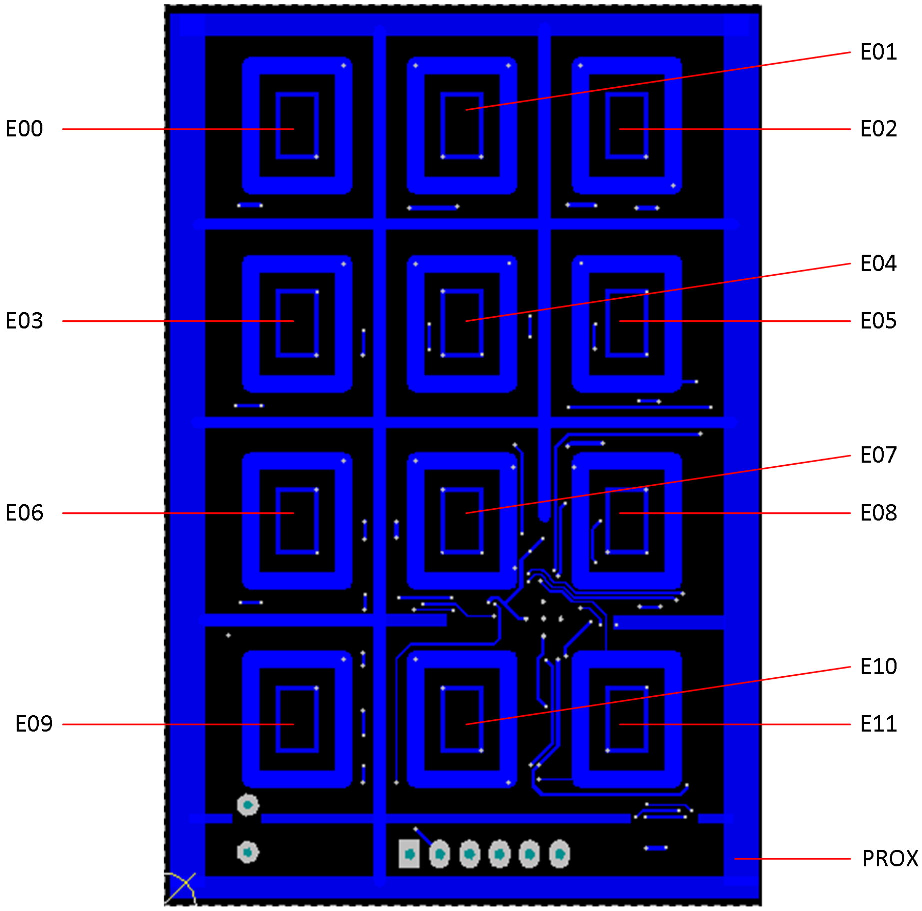

Figure 6. Capacitive Touch Panel Diagram

Table 2 lists the touch sensor name and description.

Table 2. Sensor Name

TOUCH SENSOR DESCRIPTION	NUMBER	NAME
Touch button	E00	BTN0000_E00
	E01	BTN0000_E01
	E02	BTN0000_E02
	E03	BTN0000_E03
	E04	BTN0000_E04
	E05	BTN0000_E05
	E06	BTN0000_E06
	E07	BTN0000_E07
	E08	BTN0000_E08
	E09	BTN0000_E09
	E10	BTN0000_E10
	E11	BTN0000_E11
Proximity sensor	PROX	PRX0000

Figure 7 shows the configuration for 12 touch buttons. In this configuration, the author has set the *Capacitive Mode* to *MUTUAL* and set the *Electrode config* to *4 Tx* by *3 Rx*.

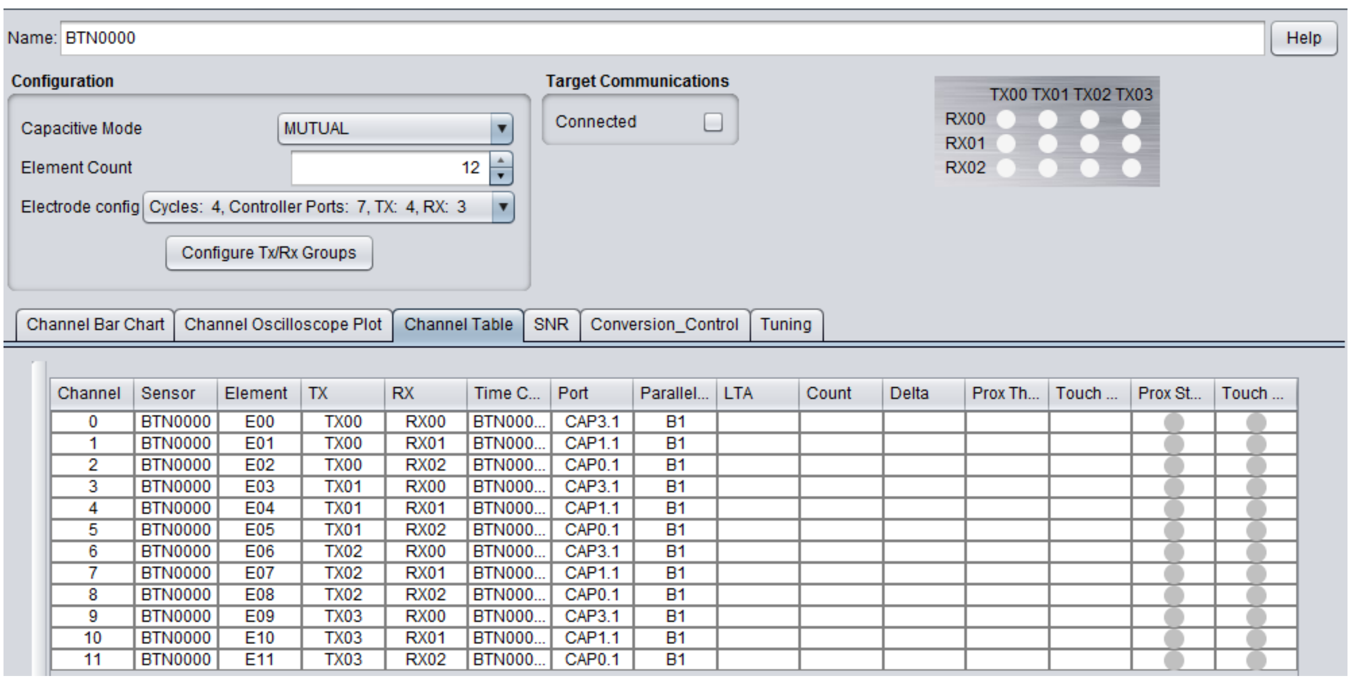

Figure 7. Capacitive Touch Panel (1 of 2)

[Figure 8](#) shows the connection for each Tx and Rx. Setting Tx in the same block and Rx in a different block gets the shortest scan time. In [Figure 8](#), the authors set all four Tx in block 2 and the three Rx in block 0, block 1, and block 3. The proximity sensor is connected to CAP0.3.

Controller			Sensors		Time Cycles				
Port	Use Mode	Parallel Block	BTN0000	PRX0000	BTN0000_...	BTN0000_...	BTN0000_...	BTN0000_...	PRX0000_...
CAP0.0	Unrestricted	B0							
CAP0.1	Unrestricted	B1	RX02		E02	E05	E08	E11	
CAP0.2	Unrestricted	B2							
CAP0.3	Unrestricted	B3		RX00					E00
CAP1.0	Unrestricted	B0							
CAP1.1	Unrestricted	B1	RX01		E01	E04	E07	E10	
CAP1.2	Unrestricted	B2							
CAP1.3	Unrestricted	B3							
CAP2.0	Unrestricted	B0	TX03					TX	
CAP2.1	Unrestricted	B1	TX02				TX		
CAP2.2	Unrestricted	B2	TX01			TX			
CAP2.3	Unrestricted	B3	TX00		TX				
CAP3.0	Unrestricted	B0							
CAP3.1	Unrestricted	B1	RX00		E00	E03	E06	E09	
CAP3.2	Unrestricted	B2							
CAP3.3	Unrestricted	B3							

Figure 8. Capacitive Touch Panel (2 of 2)

4.2.1 Touch Button

The touch panel has 12 mutual-capacitance buttons with three Rx pins and four Tx pins. The electrode shape is rectangular sizes of 11.5 mm × 9.5 mm. [Figure 9](#) shows an example of the mutual-capacitance button. For details on the mutual capacitance electrode design, see the *CapTIvate Technology Guide*.

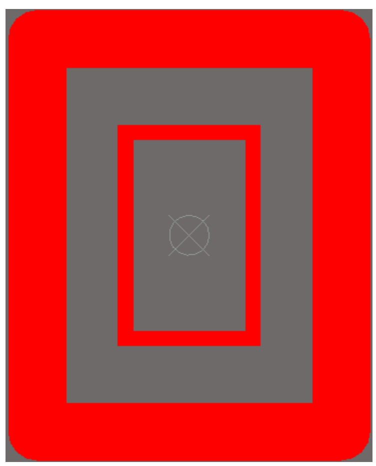

Figure 9. Example of Mutual-Capacitance Button Pattern

4.2.2 Proximity Sensor and Guard Key

The touch panel has one self-capacitance proximity sensor with one Rx pin. The proximity sensor acts as a wake-on-touch sensor which can wake up the system when a finger is close to the panel in wake-on-touch mode. The electrode is all around the panel with sizes of 75 mm × 50 mm, and some small bars between the buttons. Figure 10 shows an example of the self-capacitance proximity sensor.

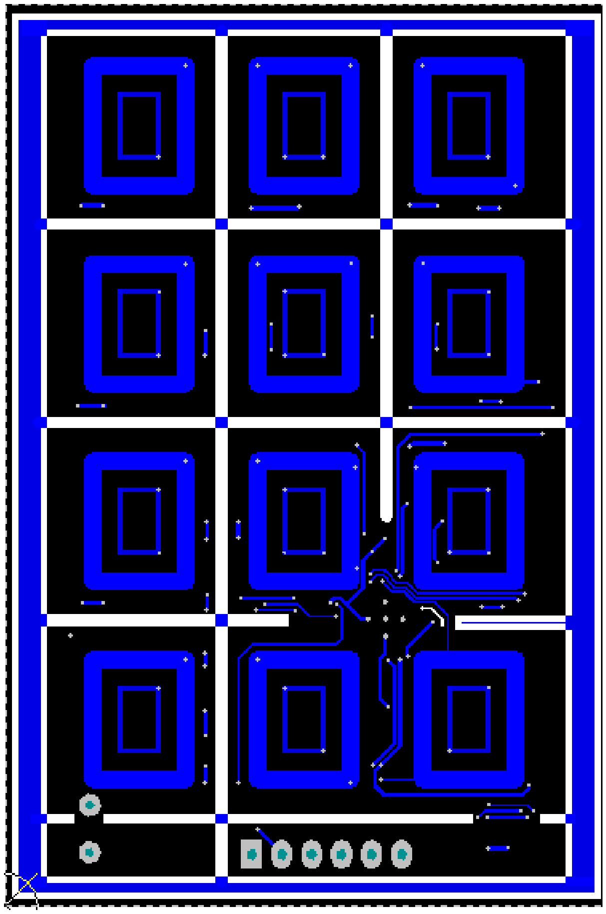

Figure 10. Example of Self-Capacitance Proximity Sensor Pattern

4.3 Communication Interface

The CapTIvate E-Lock TI Design supports various communication interfaces for future application extension. Table 3 lists the hardware communication interfaces.

Table 3. Communication Interface

COMMUNICATION INTERFACE	HARDWARE CONNECTOR
UART_1	CONN Header, Unshrouded
I^2C	CONN Header, Unshrouded

Using UART or I^2C, the E-Lock board can be connected to the CapTIvate Design Center through the Capacitive Touch MCU Development Board. See the *CapTIvate Technology Guide* for a detailed introduction.

4.4 Indicator

The *CapTIvate™ E-Lock TI Design* has many ways to indicate the touch operation and lock status. Designers can select the best method for customer specifications. Table 4 lists the specification of the indicators.

Table 4. Indicator for Feedback

INDICATOR	SPECIFICATION
LED	Indicate the touch operation
Buzzer	Indicate the touch operation and lock status
Haptics	Indicate the touch operation

Figure 11 shows the circuit for 12 LEDs; 7 GPIOs are used as the matrix connection to realize 12 LEDs control.

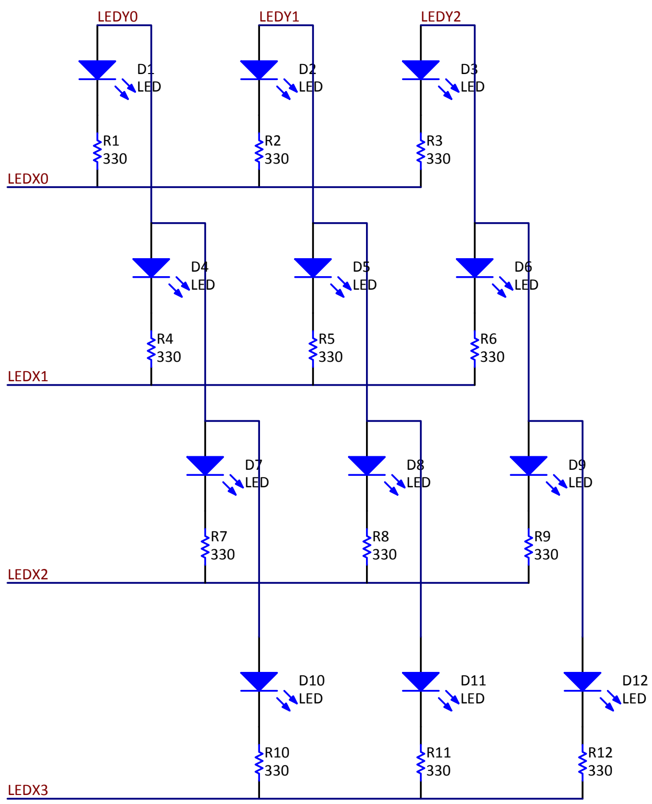

Figure 11. LED Control Circuit

Figure 12 shows the buzzer circuit; one GPIO and NPN transistor are used to control the buzzer.

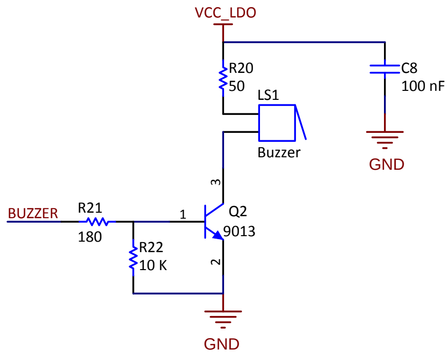

Figure 12. Buzzer Control Circuit

Figure 13 shows the haptics control circuit, which uses one GPIO and PMOSFET.

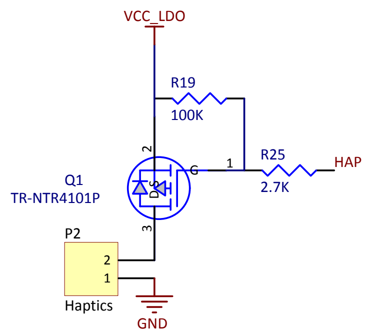

Figure 13. Haptics Control Circuit

5 Getting Started Hardware

5.1 Communication Interface Extension

This TI Design supports communication interface extension with UART or I^2C. Users can connect a communication module to P3 on the E-Lock board or P4 on the E-Lock power board.

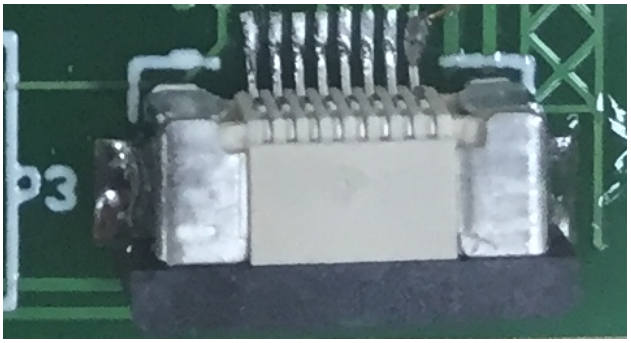

Figure 14. Connector for Communication Interface Extension on E-Lock Board (1 of 2)

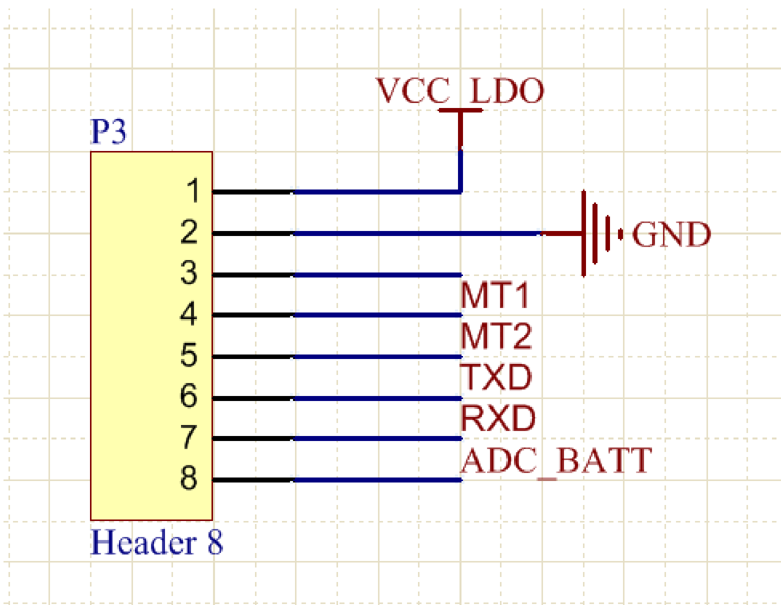

Figure 15. Connector for Communication Interface Extension on E-Lock Board (2 of 2)

Table 5 shows the pin assignment of P3.

Table 5. P3 Pin Assignment

PIN No.	ASSIGNMENT
P3-1	VCC
P3-2	GND
P3-3	Reserve
P3-4	MT1/SDA
P3-5	MT2/SCL
P3-6	MSP_TXD
P3-7	MSP_RXD
P3-8	ADC_BAT

Figure 16 shows the connector on the E-Lock power board.

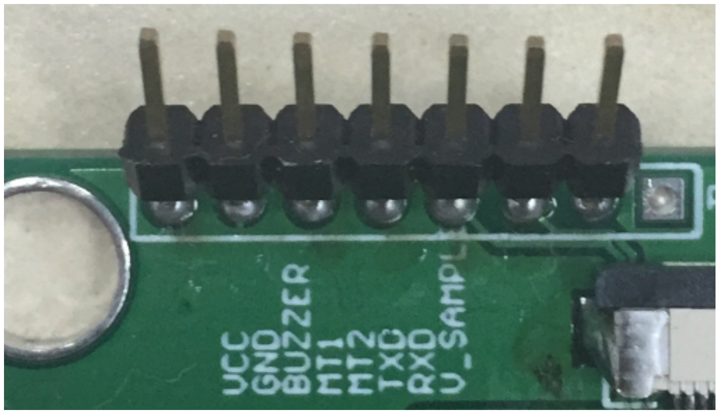

Figure 16. Connector for Communication Interface Extension on E-Lock Power Board

Table 6 lists the pin assignment of P4.

Table 6. P4 Pin Assignment

PIN No.	ASSIGNMENT
P4-1	ADC_BAT
P4-2	MSP_RXD
P4-3	MSP_TXD
P4-4	MT2/SCL
P4-5	MT1/SDA
P4-6	Reserve
P4-7	GND
P4-8	VCC

6 Getting Started Firmware

6.1 Download Project Using TI Code Composer Studio™ (CCS) Software v6

The software project of this TI Design can be downloaded at TIDM-CAPTIVATE-E-LOCK. To download the project using CCS v6, do as follows:

1. Insert the software project (*Menu → Project → Import CCS Projects…*).
2. Click  to build the project (*Ctrl + B*, then *Menu → Project → Build All*).
3. Connect the SBW interface (P1-3 and P1-4) of the reference design board to the MSP-FET tool. Table 7 lists the pin assignment of P1.

Table 7. P1 Pin Assignment

PIN No.	ASSIGNMENT
P1-1	VCC
P1-2	GND
P1-3	RST/SBWTDIO
P1-4	TEST/SBWTCK
P1-5	TXD
P1-6	RXD

4. Connect the MSP-FET tool to the PC with the USB cable.
5. Click  to download the project to the device (F11, *Menu → Run → Debug*).
6. Click  to execute the program (or close the debugger and reset the device).

6.2 Demo Operation

When running the demo, install two AAA batteries for power, as shown in Figure 17.

Figure 17. Two AAA Batteries

Connect the power line to the E-Lock board, as shown in Figure 18.

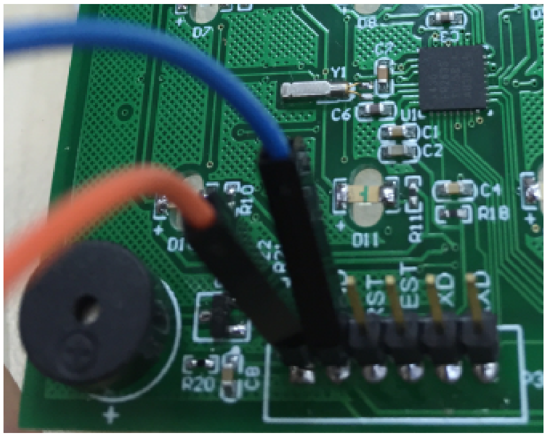

Figure 18. Power to E-Lock Board

When users touch the touch panel, the corresponding LED illuminates, while the buzzer and haptics motor turn on at the same time, as shown in Figure 19.

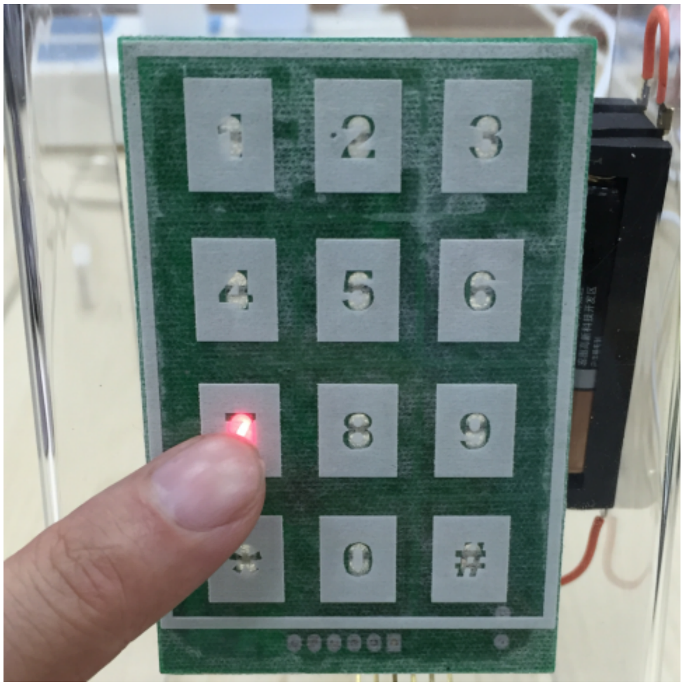

Figure 19. Touch With Finger

7 Test

7.1 Power Consumption

TI recorded a measure of the power consumption of the TIDM-CAPTIVATE-E-LOCK for the active and wake-on-proximity modes. TI obtained the measurement using the TIDM-CAPTIVATE-E-LOCK. Table 8 lists the average current for 5 seconds.

Table 8. Power Consumption

OPERATION MODE	DURATION	AVERAGE CURRENT
Wake-on-proximity mode	5 s	3.5 uA
Active Mode (scan 12 buttons)	5 s	264 uA
Per LED	5 s	1.9 mA
12 LEDs	5 s	23.3 mA
Haptic module	5 s	56.5 mA
Buzzer	5 s	31.4 mA

7.2 Moisture Test

E-Lock is a moisture tolerant application which is able to operate with touch detection in the presence of steam, mist, and spray (see Figure 20). Whether or not moisture tolerance is feasible for an application depends on the mechanical design and environment. This design shows how to enhance the moisture tolerance from the PCB layout as follows:

1. Provide big spacing between the buttons.
2. Provide significant spacing between the buttons and nearby ground planes.
3. Route all Rx connection traces on the PCB layer furthest from the surface.
4. Set sensor idle states to high-z (floating) so that nearby sensors do not provide coupling points that can cause false detections.

For more details on the moisture immunity application used in this design guide, refer to the *CapTIvate Technology Guide*. In moisture tests, this design worked with moisture on the panel without false detection.

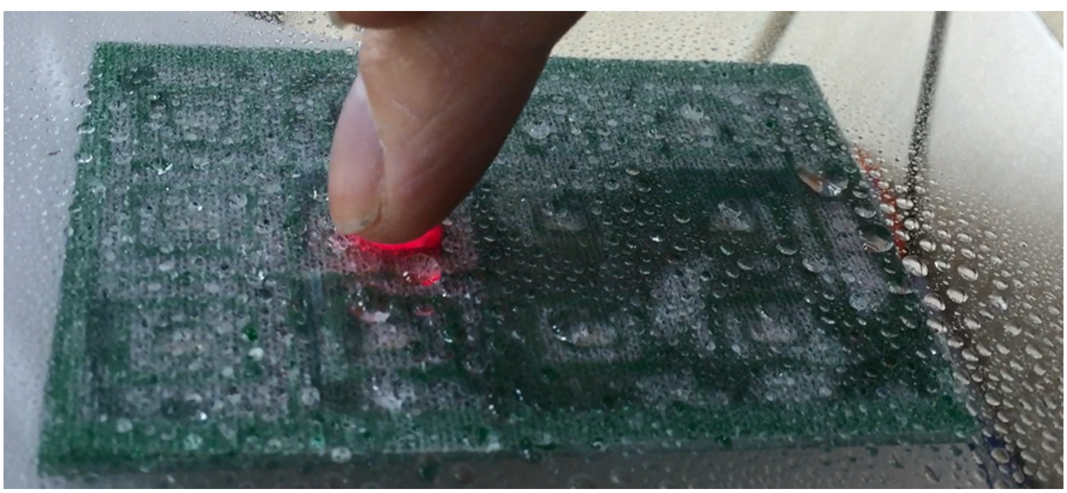

Figure 20. Moisture Test on E-Lock Panel Board (1 of 2)

7.3 Spill Rejection Test

The spill rejection function is needed in outdoor E-Lock design. The goal of spill rejection is to not enable full touch detection (which is extremely difficult when moisture or fluids cover multiple keys and/or the ground), but simply to detect the presence of a spill, and lock out the keypad until the spill is cleared by the user. This detection is most commonly achieved with the use of a guard channel, whose purpose is to detect large objects as well as spills. In this design the proximity sensor can be used as a guard channel in active mode. Figure 21 show cases the spill rejection test, it locks the keypad until all water flows away.

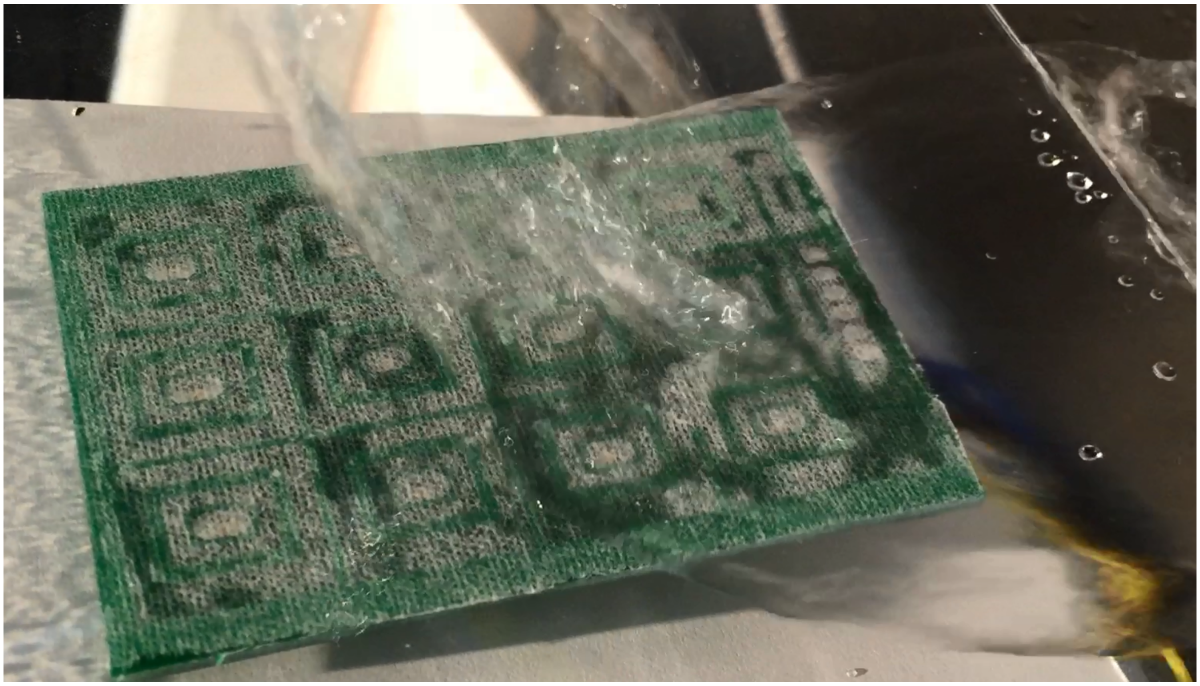

Figure 21. Moisture Test on E-Lock Panel Board (2 of 2)

7.4 Sensor Tuning To Work With Moisture

When using different PCB layout and mechanical designs, users must fine tune the parameters of the sensors to work with moisture. The Touch_Threshold setting for the buttons and guard key are the primary parameters. The Touch_Threshold setting for the guard key is difficult, because high sensitivity causes the panel to be easily locked by moisture, but with low sensitivity the spill rejection test fails. Similarly, when users set Touch_Threshold for the buttons, the setting must consider appropriate finger touch sensitivity and not respond to moisture.

For other parameters which impact sensitivity of the sensors, refer to the CapTIvate Technology Guide.

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDM-CAPTIVATE-E-LOCK.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.3 PCB Layout Recommendations

8.3.1 Layout Prints

To download the layer plots, see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.4 Altium Project

To download the Altium project files, see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.5 Gerber Files

To download the Gerber files, see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.6 Assembly Drawings

To download the assembly drawings, see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.7 Software Files

To download the software files, see the design files at: TIDM-CAPTIVATE-E-LOCK.

8.8 References

1. Texas Instruments. *MSP430FR4xx and MSP430FR2xx Family User's Guide*
2. Texas Instruments. *CapTIvate Technology Guide*, CapTIvate Technology Guide

9 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

For detailed information about self and mutual capacitance, refer to the CapTIvate Technology Guide.

10 About the Author

KC XU is an applications engineer on the MSP430 applications team. KC has worked as a system applications engineer for TI since 2012, after more than ten years of working for other electronic IC companies. KC earned his master's of Electronic Engineering at Shanghai Jiao Tong University in China.

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