TI Designs
Touch Remote Control With CapTIvate™ Technology

TEXAS INSTRUMENTS

Design Overview

The touch remote control demonstrates a capacitive-touch 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, slider, GesturePad, and proximity sensor) for smart TV, set-top box (STB), and sound system remote applications for future application extensions with various communication interfaces available. The design allows operators to extend the battery life through low-power active and standby modes.

Design Resources

TIDM-CAPTIVATE-REMOTECONTROL	Design Folder
MSP430FR2633	Product Folder
CapTIvate Design Center	Tools Folder
TIDC-SPPBLE-SW-RD	Tools Folder
CC2650EM	Tools Folder
DRV2605L	Product Folder

TI E2E™ Community

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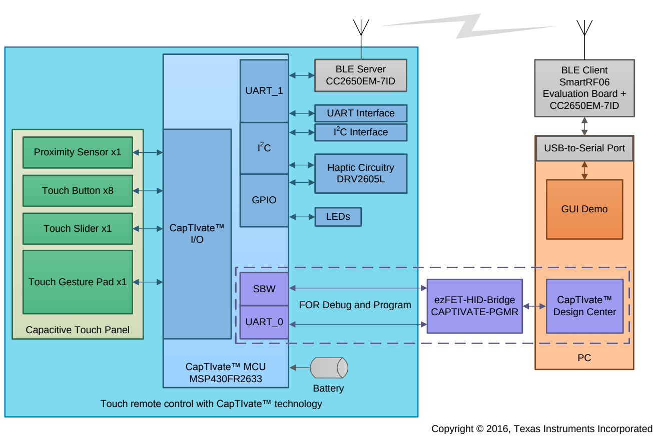
Design Features

- CapTIvate Capacitive Touch Functions
  - Eight Touch Buttons
  - One Touch Slider for Volume Control
  - One GesturePad for Slide and Tap Gestures
  - One Proximity Sensor for Grip Detection
- Two LEDs to Indicate Power Status and Touch Operation
- Wake-On Grip Detection With Ultra-Low-Power Standby Mode
- PC GUI for Demonstration of Remote Control Capabilities
- *Bluetooth*® Low Energy Connectivity to PC Through *Bluetooth* EVM CC2650EM-7ID
- I^2C and UART Communication Interfaces
- Haptic Circuitry Available

Featured Applications

- Smart TV Remotes
- Set-Top Box Remotes
- Sound System Remotes



An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 Key System Specifications

Table 1 lists the key system specifications.

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Touch button size	7 × 7 mm	Section 4.2.1
Touch slider size	35 × 9 mm	Section 4.2.2
Touch GesturePad size	43 × 43 mm	Section 4.2.3
Proximity sensor size	120 × 4 mm	Section 4.4
Touch panel overlay	Acrylic, 2-mm thickness	
Memory footprint of MSP430FR2633	2385 bytes of RAM, 6816 bytes of FRAM	
Power supply	Two AAA batteries	Section 7.1
Power consumption	Active mode: 481 µA	
	Wake-on-proximity mode: 3.05 µA	

2 System Description

2.1 MSP430FR2633

The MSP430FR2633 is an ultra-low-power, FRAM-based MSP430 MCU equipped with CapTIvate technology. The device 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 MSP430 peripheral set and a large memory footprint makes the MSP430FR2633 optimized for low-power user interface (UI) development.

Figure 1 shows the block diagram of the MSP430FR2633 MCU.

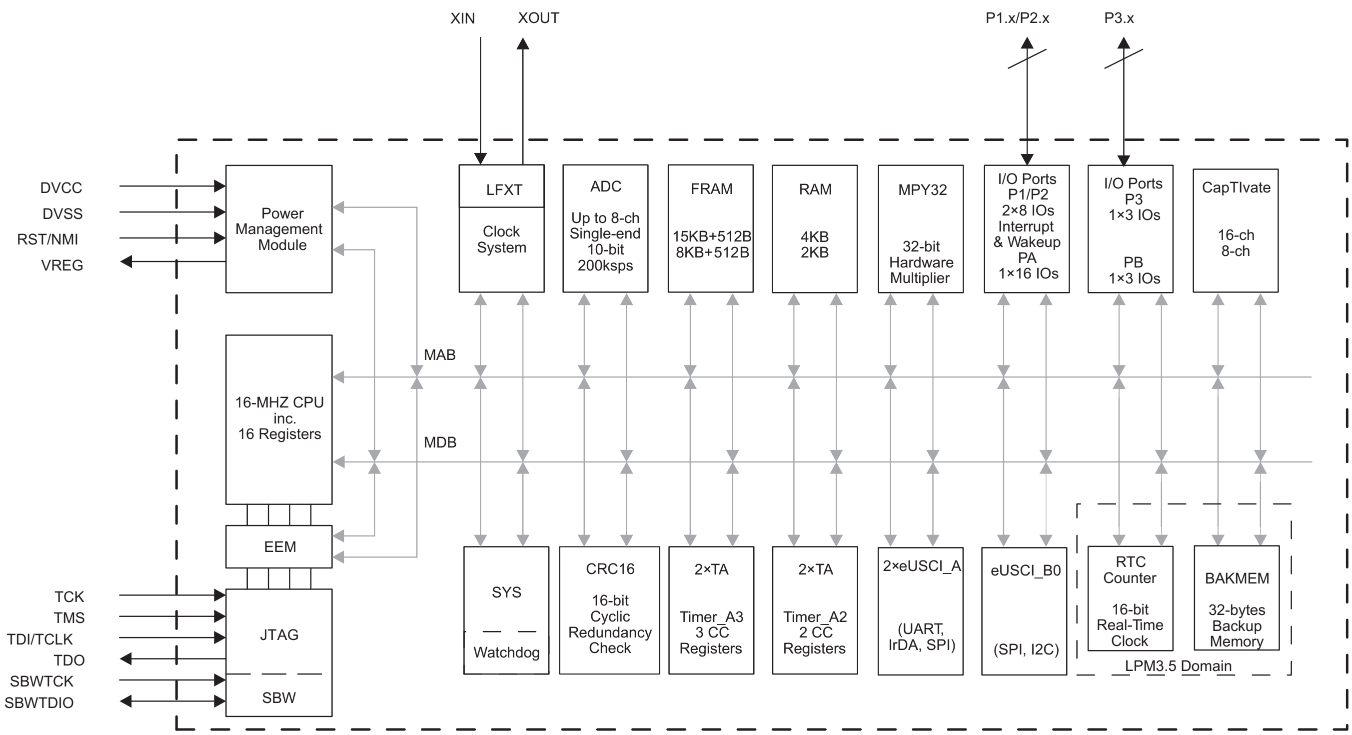


Figure 1. Block Diagram of MSP430FR2633 MCU

3 Block Diagram

Figure 2 shows the block diagram of the remote control with CapTIvate technology.

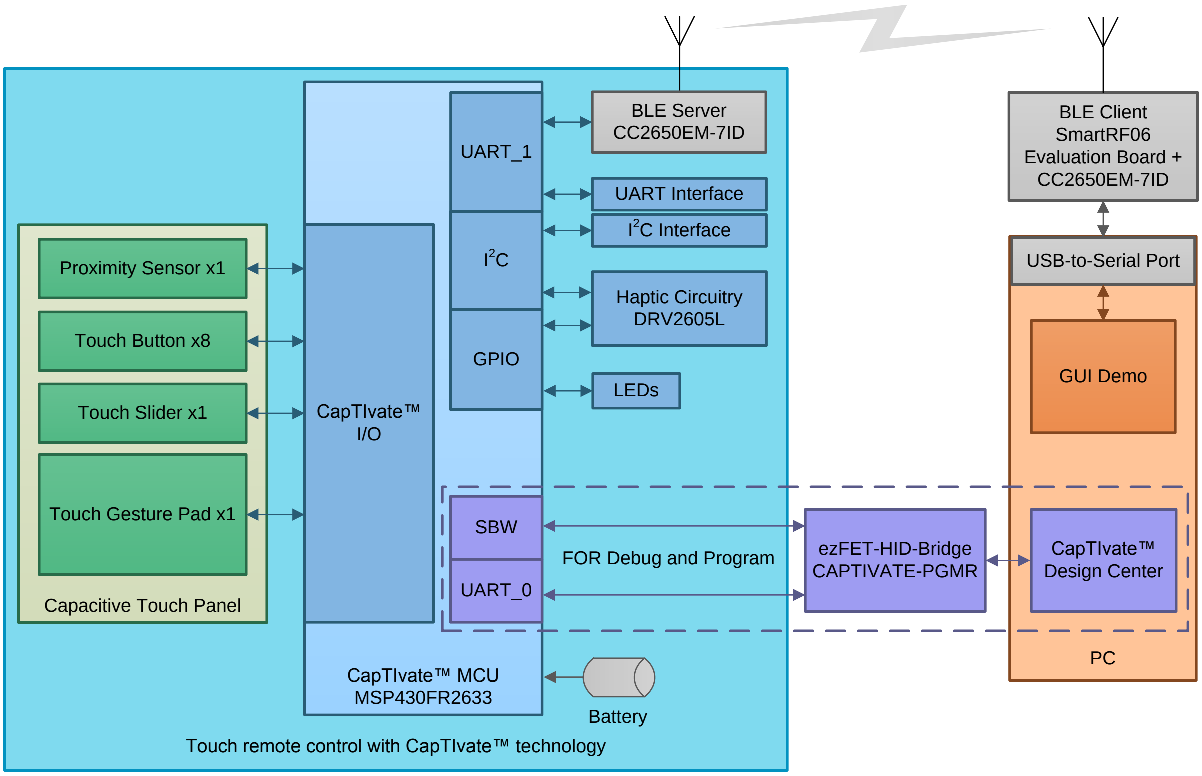


Figure 2. Block Diagram

3.1 MSP430FR2633

The MSP430FR2633 features:

- 16 CapTIvate technology inputs that support up to 64 electrodes in mutual-capacitance mode
- Parallel scanning of up to 4 electrodes at a time
- CapTIvate software library includes a preprogrammed 12KB of ROM
- 4 16-bit timers and a 16-bit counter-only real-time clock (RTC)
- 3 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)

3.1.1 CapTIvate™ Technology Peripheral

CapTIvate technology peripheral enables capacitive buttons, slider, GesturePad and proximity sensing on the TIDM-CAPTIVATE-REMOTECONTROL.

CapTIvate technology peripheral provides the highest resolution capacitive-touch solution on the market with high reliability and noise immunity at the lowest power. CapTIvate technology 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 technology peripheral.

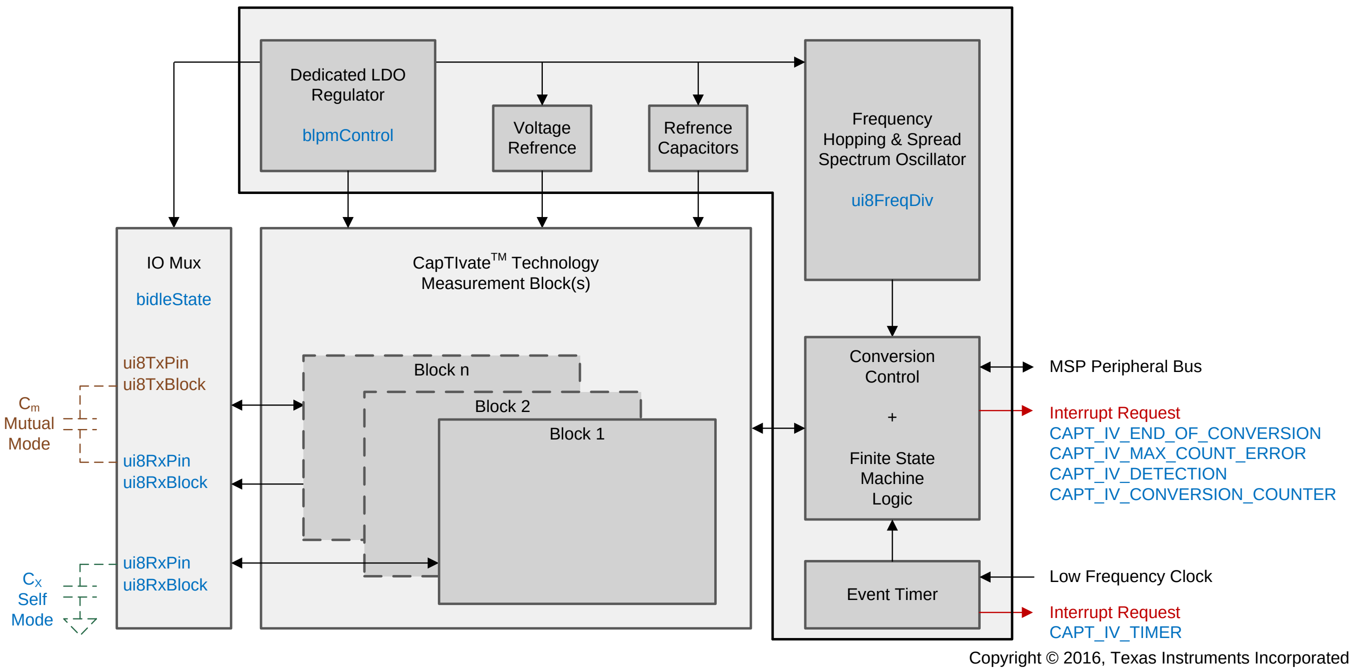


Figure 3. CapTIvate™ Technology Peripheral Block Diagram

4 System Design Theory

4.1 CapTIvate™ Technology

CapTIvate technology is a dedicated MSP430 module that enables powerful capacitive sensing. CapTIvate technology performs capacitance measurements by using a unique charge transfer technique. CapTIvate technology provides a set of hardware and software tools for accommodating a wide range of external capacitances. For more information on CapTIvate technology, refer to the CapTIvate™ Technology Guide.

4.1.1 Self-Capacitance Theory

The self-capacitance measurement is a way to measure change in capacitance with respect to earth ground; this method is also referred to as surface capacitance. In a parallel-plate model, the electrode defines one plate of the capacitor and the other plate is either ground or the user. A touch causes the capacitance of the electrode to increase.

Figure 4 shows an example of self-capacitance theory.

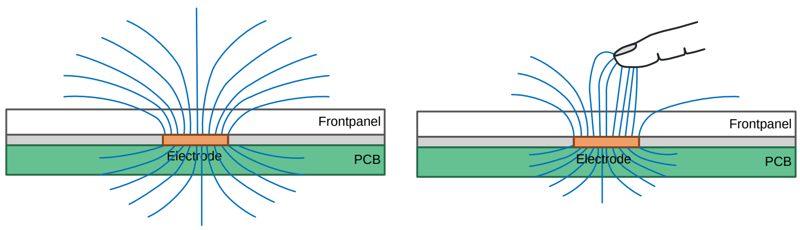


Figure 4. Example for Self-Capacitance Theory

4.1.2 Mutual-Capacitance Theory

Like self-capacitance theory, mutual-capacitance theory involves measuring a change in capacitance. However, mutual-capacitance electrodes have two separate electrode structures and 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 the Tx and Rx electrodes reduces. This interaction disturbs the electric field propagation between the two electrodes that causes the reduction in mutual capacitance. The human body is a conductor, and users couple to earth ground. Placing a finger between two mutual-capacitance electrodes places ground between them. The ground reduces the electric-field coupling between them, reducing the capacitance.

Figure 5 shows the example for mutual-capacitance theory.

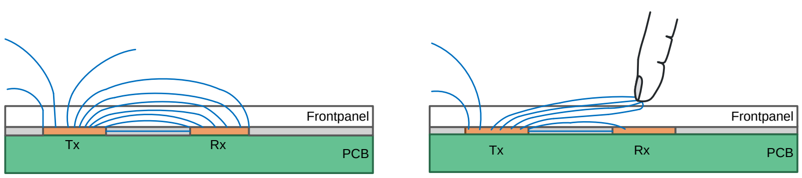


Figure 5. Example for Mutual-Capacitance Theory

4.1.3 Wake-on-Proximity Mode

CapTIvate technology includes a finite state machine (FSM) that enables wake-on-proximity mode. In this mode, the sensor has one cycle and no CPU operation is required to load new cycle-related values. The wake-on-proximity 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:

- Eight touch buttons
- One touch slider for volume control
- One proximity sensor for grip protection

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

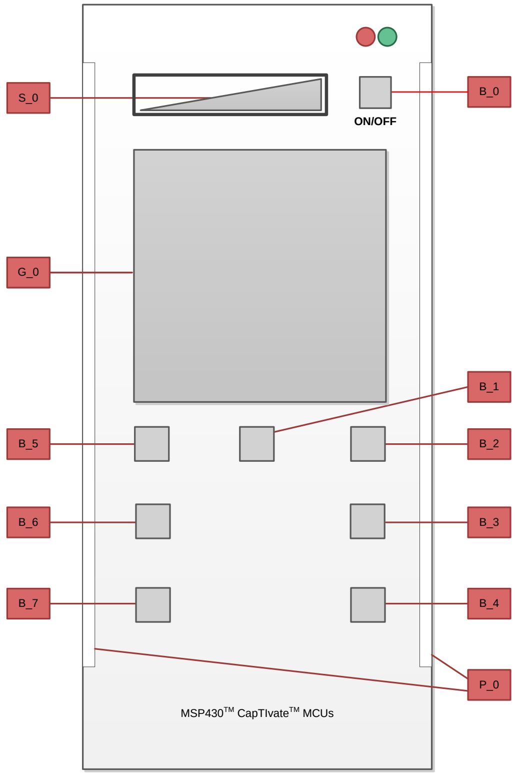


Figure 6. Capacitive Touch Panel

The capacitive touch panel is connected with the MSP430FR2633 through the pin assignment shown in Table 2.

Table 2. Capacitive Touch Panel Pin Assignment

Controller			Sensors			
Port	Use Mode	Parallel Block	Buttons	CentralPad	ProxPad	Slider
CAP0.0	Unrestricted	B0				
CAP0.1	Unrestricted	B1	RX00	RX00		RX00
CAP0.2	Unrestricted	B2	TX00			
CAP0.3	Unrestricted	B3		TX00		
CAP1.0	Unrestricted	B0		TX01		
CAP1.1	Unrestricted	B1	RX01	RX01		RX01
CAP1.2	Unrestricted	B2				
CAP1.3	Unrestricted	B3				
CAP2.0	Unrestricted	B0		TX02		
CAP2.1	Unrestricted	B1	RX02	RX02		RX02
CAP2.2	Unrestricted	B2		TX03		
CAP2.3	Unrestricted	B3		TX04		
CAP3.0	Unrestricted	B0				TX00
CAP3.1	Unrestricted	B1	RX03	RX03		
CAP3.2	Unrestricted	B2	TX01			
CAP3.3	Unrestricted	B3			RX00	

Table 3 lists the touch sensor names and descriptions.

Table 3. Touch Sensor Descriptions

TOUCH SENSOR DESCRIPTION	NUMBER	NAME
Touch button	B_0	BUTTON_POWER
	B_1	BUTTON_B
	B_2	BUTTON_C
	B_3	BUTTON_INPUT
	B_4	BUTTON_MUTE
	B_5	BUTTON_A
	B_6	BUTTON_CHUP
	B_7	BUTTON_CHDOWN
Touch slider	S_0	SLIDER_VOL
Touch GesturePad	G_0	CENTRALPAD
Proximity sensor	P_0	PROXPAD

4.2.1 Touch Buttons

The touch panel has eight mutual-capacitance buttons with four Rx pins and two Tx pins. BUTTON_POWER is specified for the power-ON or power-OFF host functions, such as on a smart TV. Other host functions use different buttons. The area of the rectangular electrode is 7 × 7 mm.

Figure 7 shows an example of the mutual-capacitance button pattern.

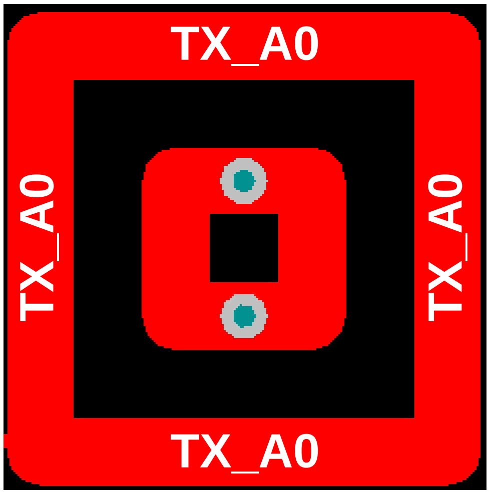


Figure 7. Example of Mutual-Capacitance Button Pattern

4.2.2 Touch Slider

The touch panel contains one mutual-capacitance slider with three Rx pins and one Tx pin. The slider is used for host volume control. The area of the rectangular electrode is 35 mm × 9 mm.

Figure 8 shows an example of a mutual-capacitance slider.

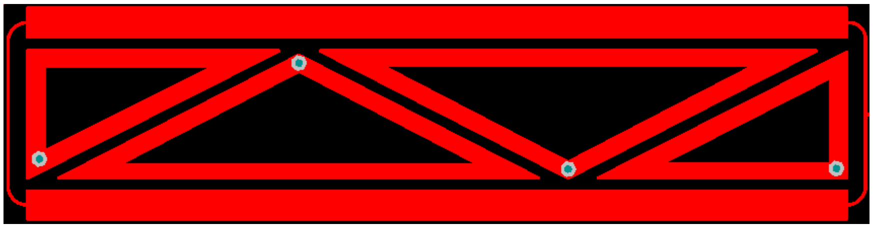


Figure 8. Example of Mutual-Capacitance Slider Pattern

4.2.3 Touch GesturePad

The touch panel contains one mutual-capacitance GesturePad with five Rx pins and five Tx pins. The GesturePad acts as a 25-button matrix to detect the gestures of the user, such as a directional slide starting from anywhere on the GesturePad moving up or down and right or left. Users can also tap on the GesturePad to switch the focus and select. The area of the rectangular electrode is 43 mm × 43 mm.

Figure 9 shows an example of a touch GesturePad.

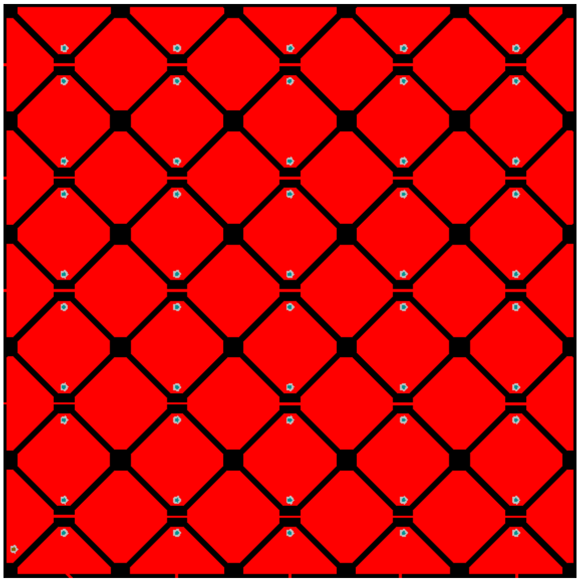


Figure 9. Example of Mutual-Capacitance GesturePad Pattern

4.2.4 Proximity Sensor

The touch panel has one self-capacitance proximity sensor that includes one Rx pin. The proximity sensor acts as the grip detection sensors on the two edges of the remote control. These sensors are selected as the wake-on-proximity sensor that can wake up the CPU when the remote control is gripped in wake-on-proximity mode. The touch sensor contains two rectangular electrodes that have each an area of 120 mm × 4 mm.

Figure 10 shows an example of a self-capacitance proximity sensor.

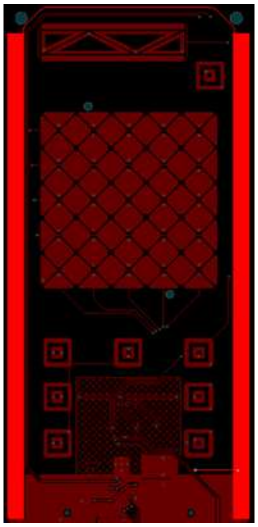


Figure 10. Example of Self-Capacitance Proximity Sensor Pattern

4.3 Communication Interface

The remote control with CapTIvate technology supports various communication interfaces for future application extensions. By default, a CC2650EM-7ID board can be connected with the remote control with CapTIvate technology board for *Bluetooth* low energy communication to the host. Users can connect other communication boards to the CONN Header with UART_1 or I^2C.

Table 3 lists the hardware communication interfaces.

Table 4. Hardware Communication Interfaces

COMMUNICATION INTERFACE	HARDWARE CONNECTOR
UART_1	Connector with CC2650EM-7ID
	CONN header, unshrouded
I^2C	CONN header, unshrouded

4.3.1 Touch Command on UART Interface

The touch command can be reported by the UART_1 communication interface. A CC2650EM-7ID board must be connected when using the UART to *Bluetooth* low energy bridge design (TIDC-SPPBLE-SW-RD) as the wireless communication part with the host.

Table 4 lists the default UART settings used in this TI Design.

Table 5. Default UART Settings

UART PARAMETERS	DEFAULT VALUE
Baud rate	115200
Data length	8
Parity	None
Stop bits	1
Flow control	None

The UART_1 touch command packets have a fixed length of 16 bits.

Table 5 lists the format of command packets.

Table 6. Command Packet Formats

BIT [15:12] COMMAND DIRECTION	BIT [11:8] TOUCH SENSOR	BIT [7:0] COMMAND DATA
0h: Remote control to the host 1h: Host to the remote control	1h: Touch GesturePad	11h: GESTUREPAD_SLIDE_UP 12h: GESTUREPAD_SLIDE_DOWN 13h: GESTUREPAD_SLIDE_LEFT 14h: GESTUREPAD_SLIDE_RIGHT 21h: GESTUREPAD_TAP
	3h: Touch button	00h: BUTTON_POWER 01h: BUTTON_CHUP 02h: BUTTON_CHDOWN 03h: BUTTON_A 04h: BUTTON_B 05h: BUTTON_C 06h: BUTTON_INPUT 07h: BUTTON_MUTE
	5h: Touch slider	xxh: SLIDER_POSITION
	Fh: Error	FFh: Error
	0h: Null	00h: Null

4.4 Indicator

The remote control with CapTIvate technology uses two LED indicators to indicate the power status and touch operation. Table 6 lists the specifications of the LED indicators.

Table 7. LED Indicator Specifications

LED INDICATOR	SPECIFICATION
Green LED	Indicate the Wake-On-Touch with grip detection
Red LED	Indicate the command transmitting

A haptic circuitry is also available on the TI Design board.

4.5 Software

Figure 11 shows the experience software flowchart.

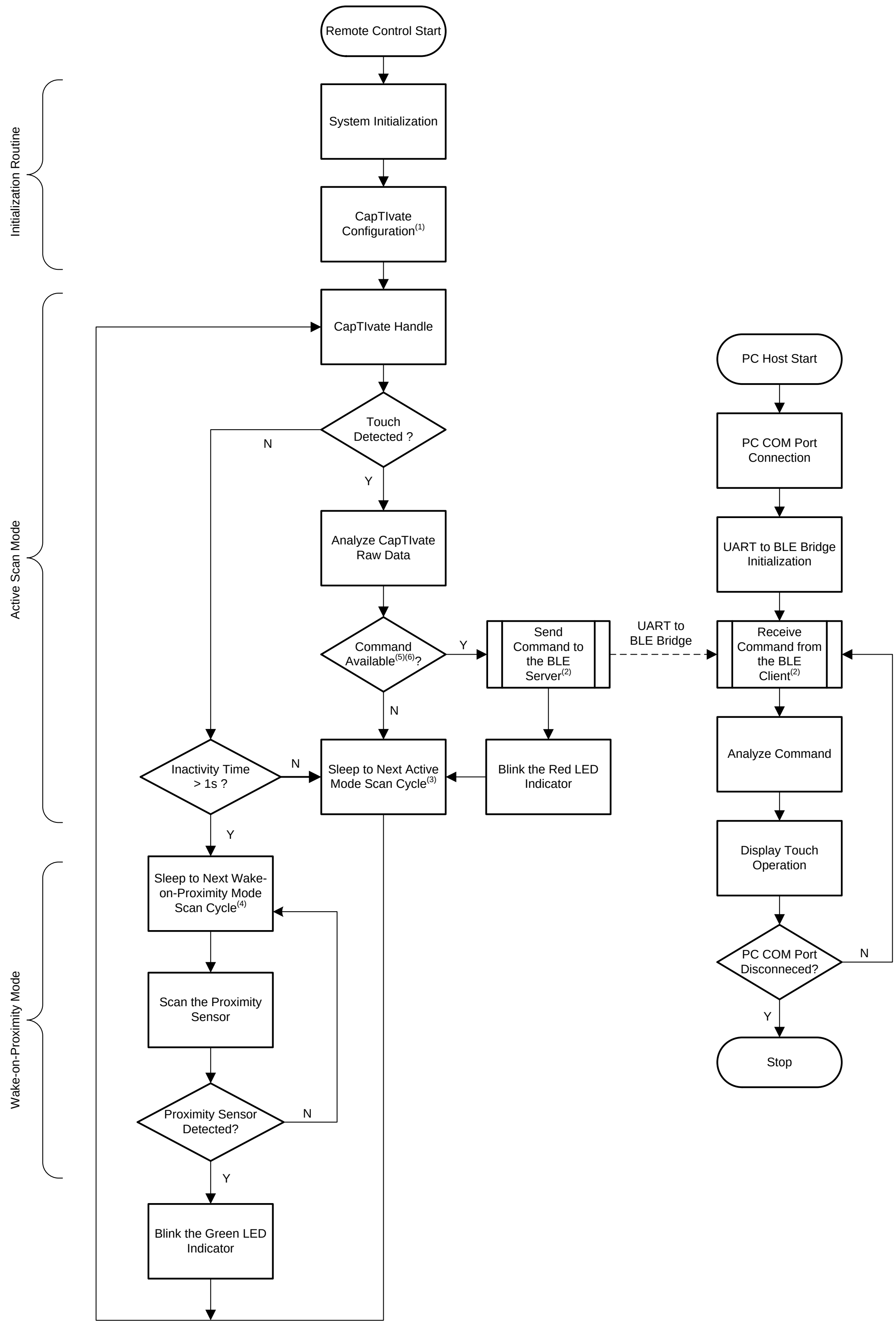


Figure 11. Experience Software Flow Chart

NOTE:

1. See Section 4.2 for CapTIvate configuration.
2. The BLE server is connected with the remote control. The BLE client is connected with the PC host.
3. The active mode scan rate is 33 ms.
4. The wake-on-proximity mode scan rate is 200 ms.
5. See Section 4.3.1 for available touch command specification.
6. For the buttons' touch operation, the consecutive touch, which is detected within 1.5 s for BUTTON_POWER button or 0.5 s for the other buttons, does not make sense for a real remote control operation and will be ignored.

4.5.1 Remote Control Software Flow

In the initialization routine, DCO is configured to 8 MHz and stabilized by the FLL. The SMCLK is configured to 2 MHz. The external crystal XT1 with 32768-Hz typical frequency is selected as a clock reference into FLL. The MSP430 pins are configured, and unused pins are configured to output low for the lowest power consumption. The CapTIvate touch panel is configured by CapTIvate library based on the settings described in Section 4.2.

In the main loop, the remote control will run as two different modes, active scan mode and wake-on-proximity mode. The remote control will firstly run into active scan mode and scan for any of touch operation every 33 ms. If a touch operation is detected, the raw data of conversion result can be analyzed and a command, if available, will be sent to the connected BLE server board via the UART_1 interface. The red LED indicator will be blinked. If BLE server board receives the touch command, it will transmit the command to BLE client board through BLE wireless.

If there is no touch operation been detected more than 1 second, the remote control will go to wake-on-proximity mode and just scan the proximity sensor. In wake-on-proximity mode, the scan rate will be slow down to 200ms and the other touch panel will not be scanned. The remote control will blink the green LED indicator after the proximity sensor being detected and wake up to active scan mode.

4.5.2 PC Host Software Flow

The PC host can connect to the BLE client board via the COM port. After the UART to BLE Bridge Initialization (refer to section 6.2 for the details), the BLE client board will wait for a command from BLE server and transmit to PC host. The GUI on PC host can analyze the command received from BLE client and display the touch operation.

5 Getting Started Hardware

5.1 UART_1 to *Bluetooth*® Low Energy Bridge

The remote control with CapTIvate technology uses the UART to BLE bridge (TIDC-SPPBLE-SW-RD) as the wireless communication part with the host. The user can follow the instructions in Section 2.1.3 of [2] to set up the UART to *Bluetooth* low energy bridge.

A CC2650EM-7ID board, which has been downloaded the SPPBLEServer project, can act as the BLE server part and connect to the remote control board via the RF1/RF2 connector.Figure 12 shows the connector for the CC2650EM-7ID board.

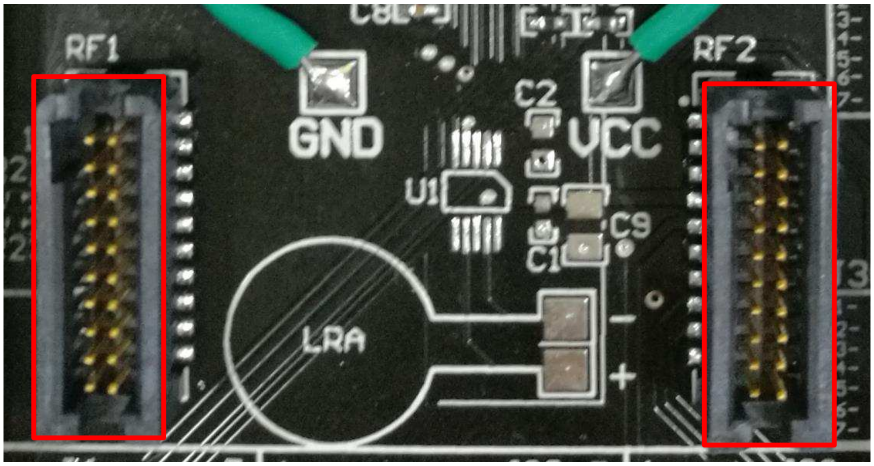


Figure 12. Connector of CC2650EM-7ID Board

Figure 13 shows the UART_1 to BLE Bridge hardware.

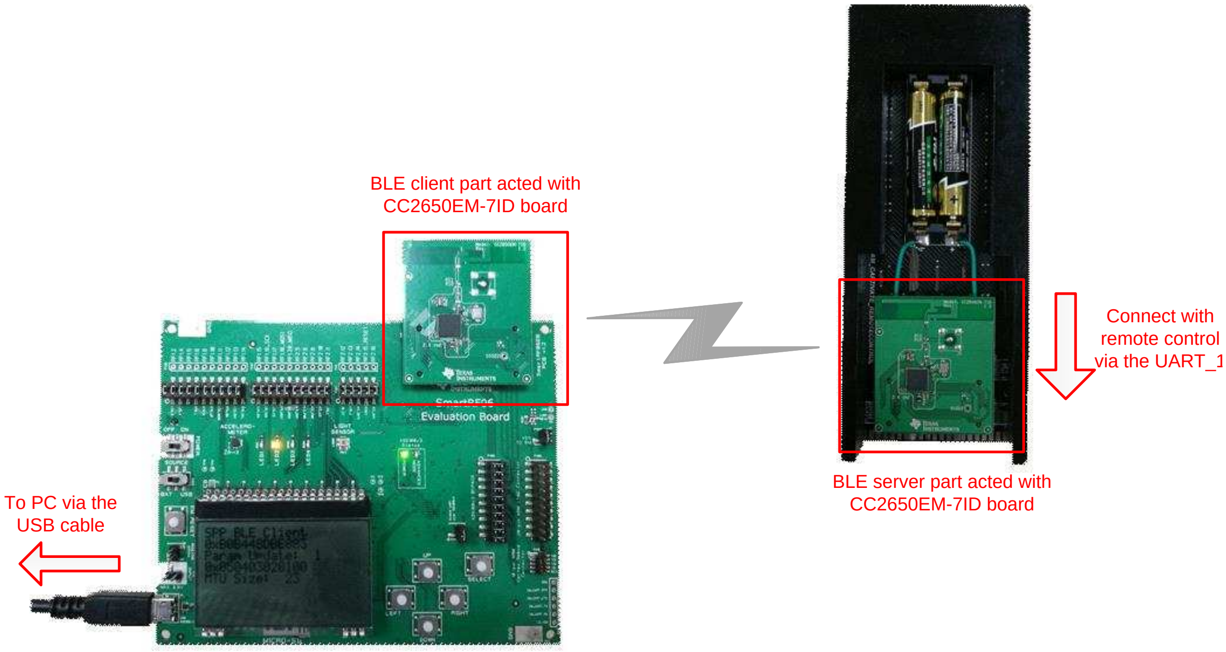


Figure 13. UART_1 to BLE Bridge Hardware

The remote control connected with BLE server part, which is a CC2650EM-7ID board running the SPPBLEServer project.

Another CC2650EM-7ID board which been downloaded the SPPBLEClient project can act as the BLE client part and connect to the SmartRF06 board. The SmartRF06 board with BLE client part can be connected with PC via the USB cable.

Figure 14 shows the whole hardware system setup for remote control.

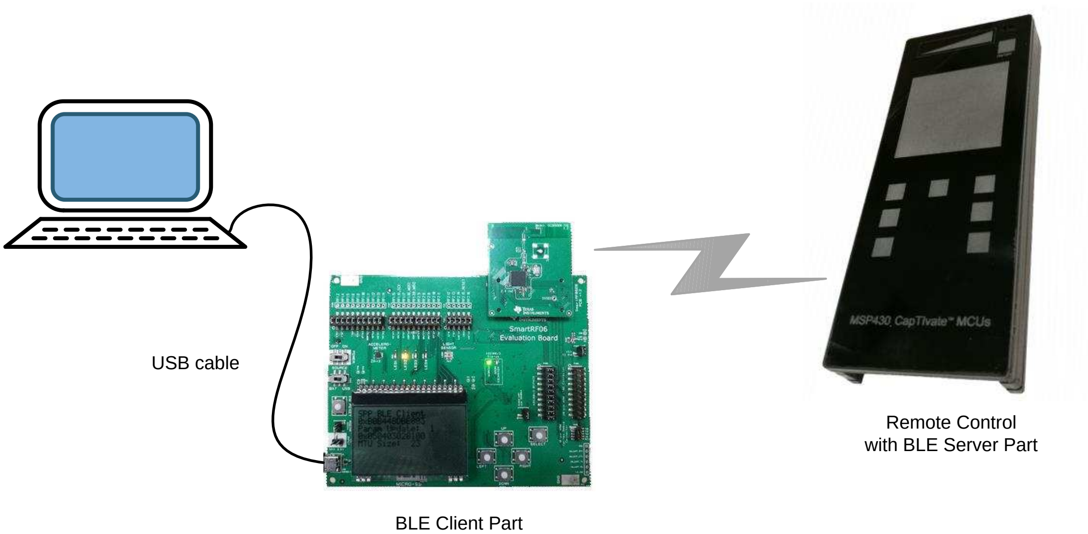


Figure 14. Hardware System Setup for Remote Control

5.2 *Communication Interface Extension*

This TI Design supports communication interface extension with UART or I²C. Users can connect a communication module to J6 on the remote control board.

Figure 13 shows the connector for the Communication Interface Extension.

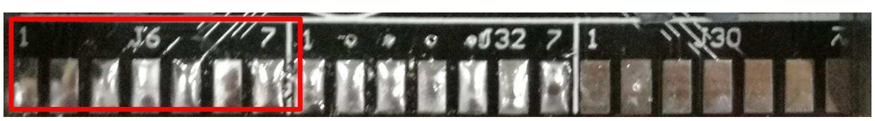


Figure 15. Connector for Communication Interface Extension

Table 7 lists the pin assignment of J6.

Table 8. Pin Assignments

PIN NO.	ASSIGNMENT
J6-1	TXD_MSP
J6-2	RXD_MSP
J6-3	P1.1_MSP
J6-4	P1.0_MSP
J6-5	SDA_MSP
J6-6	SCL_MSP
J6-7	GND

6 Getting Started Firmware

6.1 *Download Project Using CCS v6*

The software project of this TI Design can be downloaded here.

To download the project using CCS v6, follow these instructions:

1. Insert the software project (*Menu → Project → Import CCS Projects*).
2. Click  to build the project (CTRL + B, Menu → Project → Build All).
3. Connect the SBW interface (pins J32-2 and J32-3) from the reference design board to the MSP-FET tool.
4. Connect the MSP-FET tool to the PC with the USB cable.
5. Click  to download the project to the device (FLL, *Menu → Run → Debug*).
6. Click  to execute the program (or close the debugger and reset the device).

Table 8 lists the pin assignment of J32.

Table 9. Pin Assignments

PIN NUMBER	ASSIGNMENT
J32-1	GND
J32-2	RST/SBWTDIO
J32-3	TEST/SBWTCK
J32-4	BRIDGE_TXD
J32-5	BRIDGE_RXD
J32-6	GND
J32-7	VCC_BAT

6.2 Setup the UART to BLE Bridge

After power on, the SmartRF06 board (BLE client part), the remote control (BLE server part), and the buttons (UP/LEFT/SELECT) on the SmartRF06 board can be used to setup the UART to BLE bridge. Figure 16 shows the flow of setup the communication.

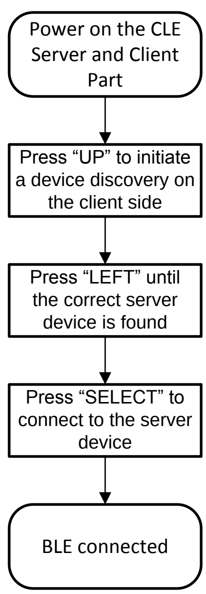


Figure 16. BLE Communication Setup Flow

6.3 Demonstration With PC GUI

6.3.1 Remote Control Touch Operation

The remote control touch panel supports below operations:

1. Touch Button_Power: Touch to switch the ON/OFF power switch of a TV set. The consecutive touch within 1.5 s will be ignored.
2. General Touch Buttons: General purpose buttons of a TV set. The consecutive touch within 0.5 s will be ignored.
3. Touch Slider: Slider to control the volume of a TV set. The touched position will be the volume value.
4. Touch GesturePad: GesturePad that supports gestures of sliding right, left, up, and down as well as a single tap on the pad.

6.3.2 Setup the Demonstration With Online GUI Tool

The GUI demonstration tool was developed by GUI Composer v2.0 and can be launched on TI Cloud Tools website and run online. Users can go to the Gallery of TI Cloud Tools, and search with *GUI_for_TIDM-CAPTIVATE-REMOTECONTROL*. The tool will be shown on the dashboard of the gallery.

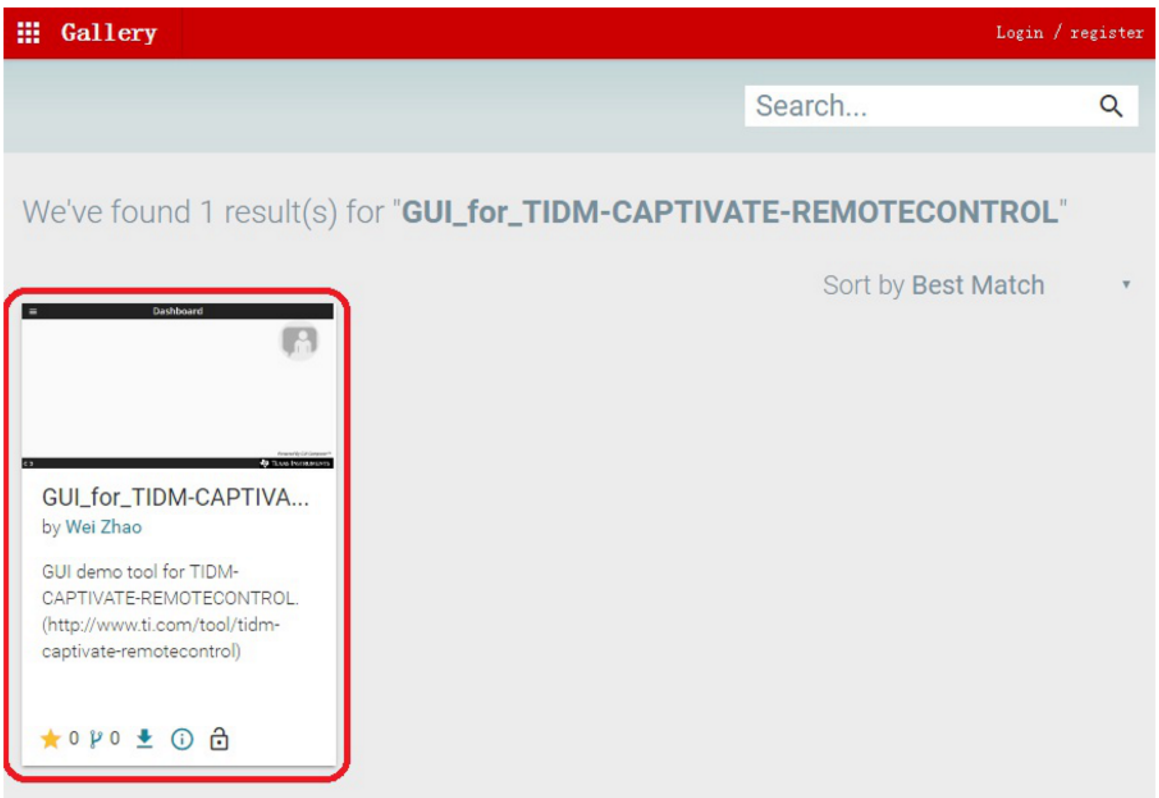


Figure 17. GUI_for_TIDM-CAPTIVATE-REMOTECONTROL on Dashboard of Gallery

Users can click the tool and run it online. Figure 18 shows the GUI tool view running online.

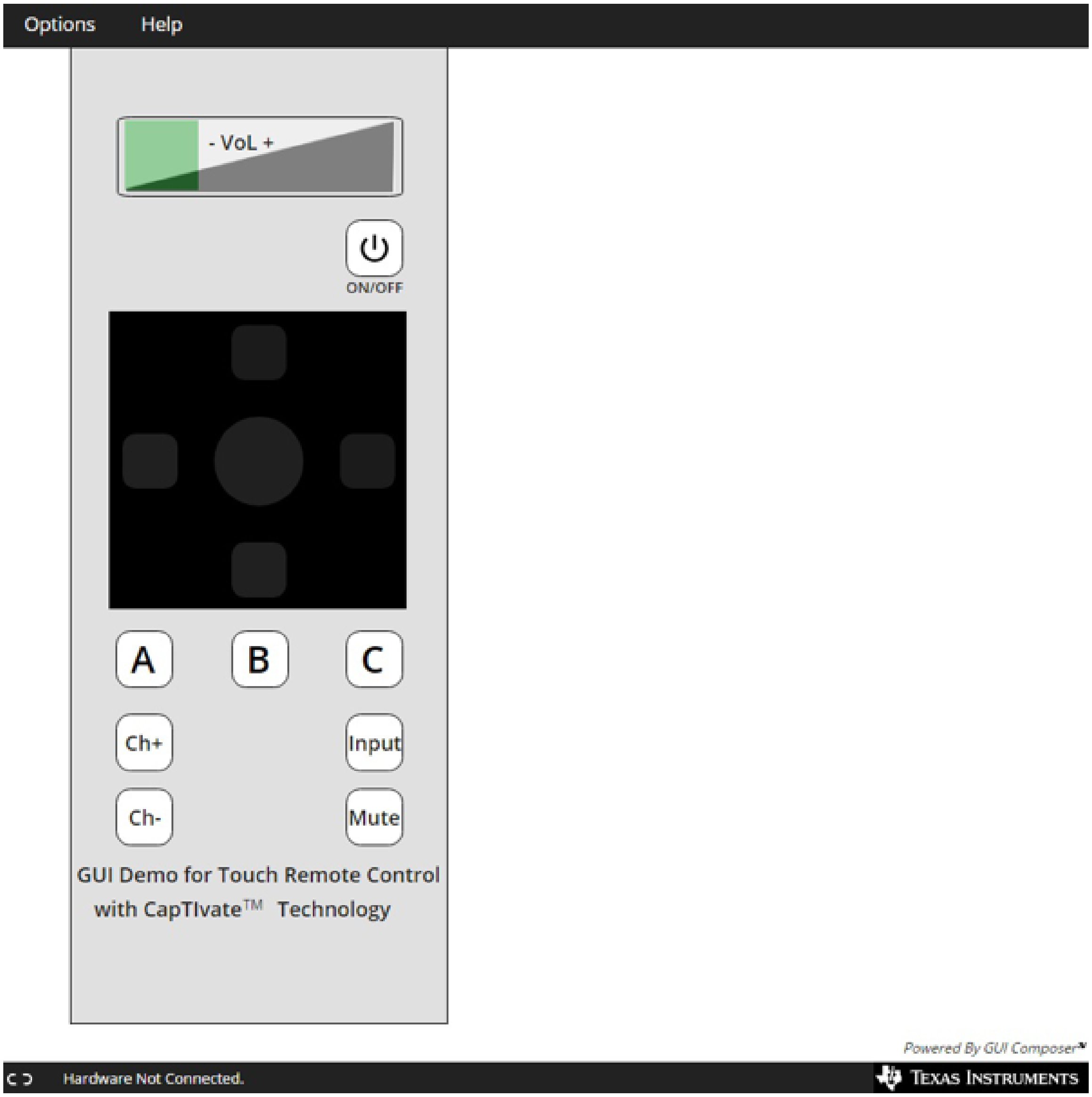


Figure 18. GUI Tool View Running Online

Users can follow the below steps to setup the GUI demonstration:

1. Plug in your SmartRF06 board (BLE client part) the PC.
2. Confirm the COM port number of the USB Serial Port, which can be found in the list of *Computer Management → Device Manager → Ports (COM & LPT)*.
3. Choose your COM port by clicking on *Options → Serial Port* (the main window upper left corner shown in Figure 18) and choosing COM port. Keep the BaudRates to be 115200 by the default setting. Then click *CONFIGURE* to connect the COM port. The COM port configuration window is shown in Figure 19.

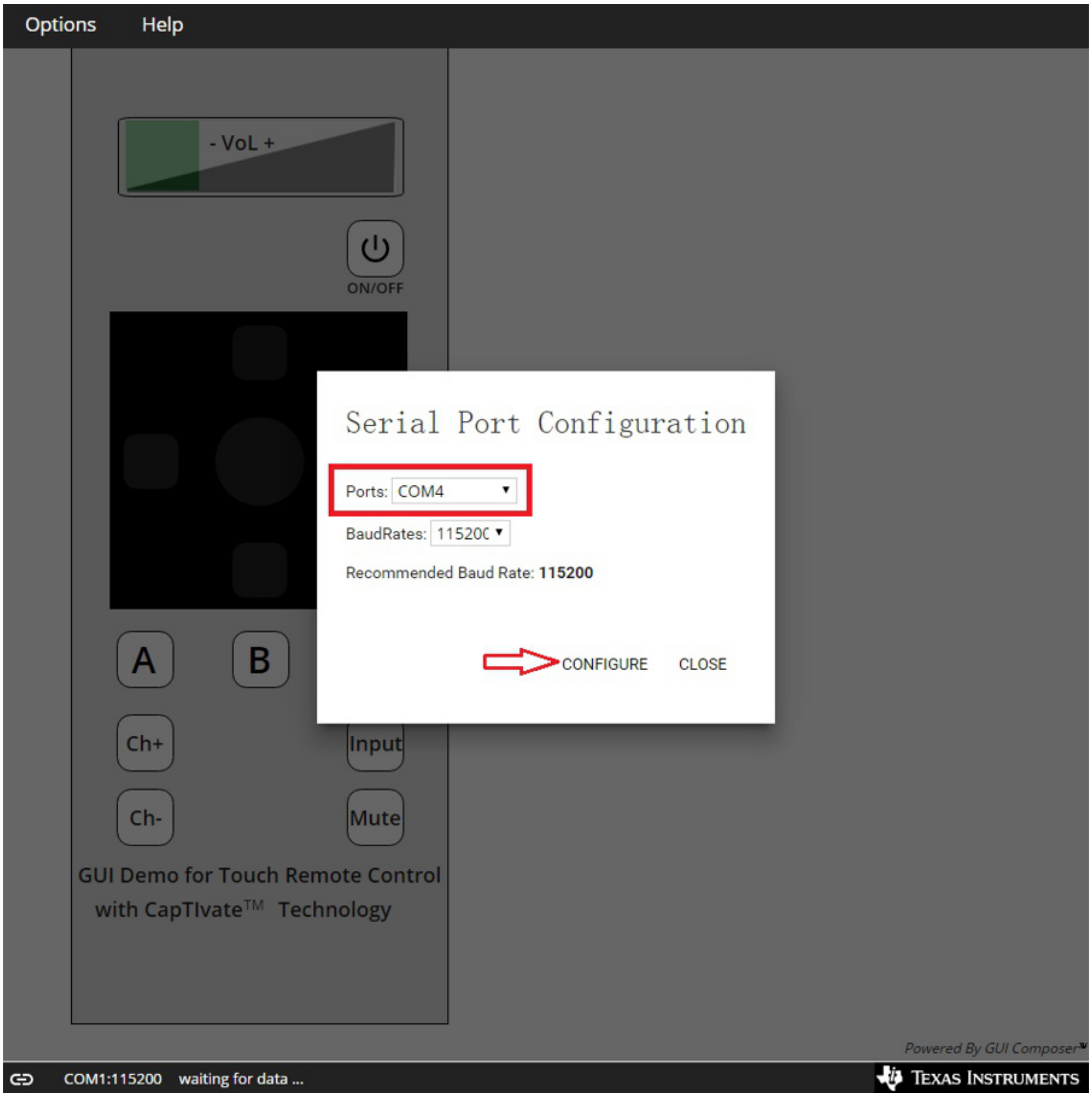


Figure 19. COM Port Configuration

4. Wait until *COMxx : 115200 waiting for data ...* appears in the lower left corner of the main window.
5. Press on the remote control touch panel to see events being reflected in the GUI.

NOTE: The above instructions for the GUI demonstration can be shown by clicking on *Help* → *View README.md*.

6.3.3 Offline Demonstration With Downloaded GUI Tool

The GUI tool can be downloaded for a standalone installation package and run offline. Users can click the download button to download the tool on the dashboard of the Gallery of TI Cloud Tools for specific OS platforms. Figure 20 shows the standalone GUI tool package downloading process.

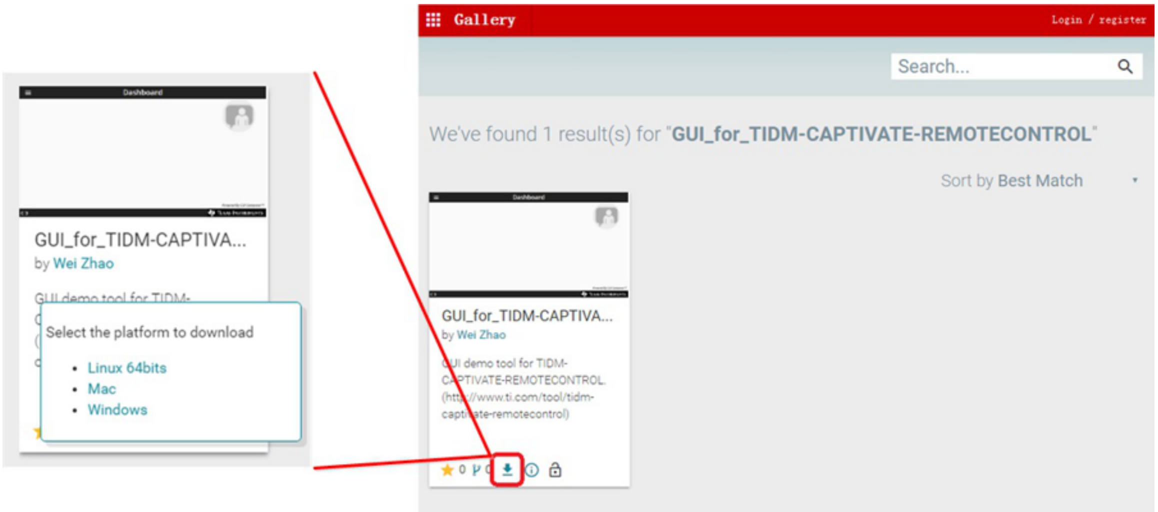


Figure 20. Standalone GUI Tool Package Downloading Process

Please follow below instruction during the GUI tool standalone package installation:

- Keep the default installation folders for both application directory and runtime directory.
- GUI Composer Runtime is required to be installed as a standalone component that can be leveraged to deploy the GUI tool. Users can select to download it from web or from a standalone installer, which can found at GUI Composer Wiki .

Figure 21 shows the installation step of the standalone GUI tool.

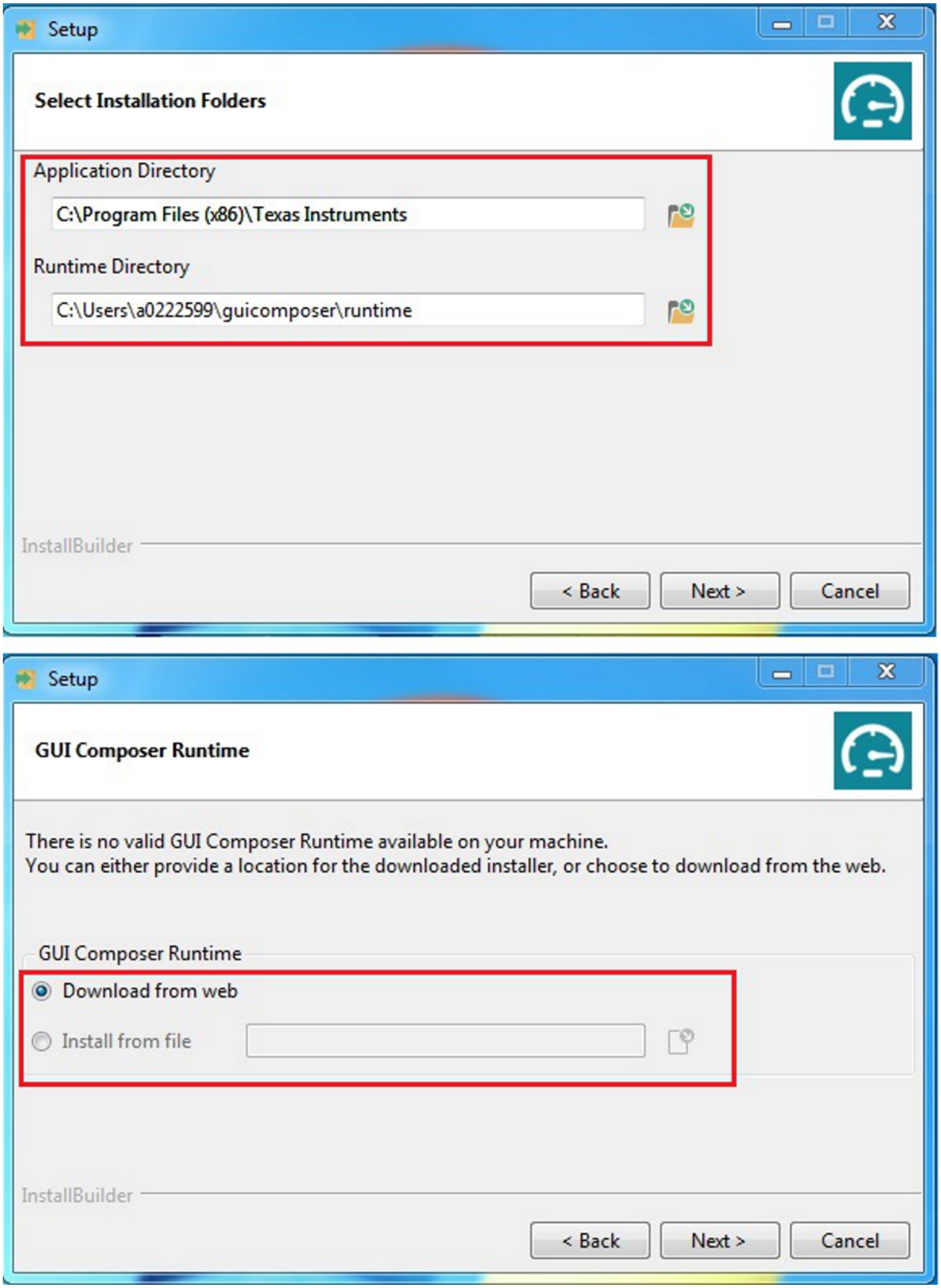


Figure 21. Installation Step of the Standalone GUI Tool

After installing the GUI tool, users can run the application and follow steps 1 through 5 in Section 6.3.2 to setup the GUI demonstration.

7 Test Data

7.1 Power Consumption

TI recorded a measure of the power consumption of TIDM-CAPTIVATE-REMOTECONTROL for the active and wake-on-proximity modes. TI obtained the measurement using TIDM-CAPTIVATE-REMOTECONTROL disconnected with the CC2650EM-7ID board as well as the haptic circuitry. Table 10shows the average current for 5 seconds for full-functional configuration as well as reduced functional configuration, which only the Touch GesturePad sensor is enabled and other sensors are disabled.

Table 10. Average Power Consumption

SENSOR CONFIGURATION	OPERATION MODE	DURATION	AVERAGE CURRENT
Full-functional configuration	Active mode	5 s	481 µA
	Wake-on-proximity mode	5 s	3.05 µA
Reduced functional configuration	Active mode	5 s	264 µA

8 Design Files

8.1 Schematics

To download the schematics for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

8.2 Bill of Materials

To download the bill of materials (BOM) for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

8.3 PCB Layout Recommendations

8.3.1 Layout Prints

To download the layout prints for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

8.4 Altium Project

To download the Altium project files for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

8.5 Gerber Files

To download the Gerber files for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

8.6 Assembly Drawings

To download the assembly drawings for each board, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

9 Software Files

To download the software files, refer to the design files at TIDM-CAPTIVATE-REMOTECONTROL.

10 Related Documentation

1. Texas Instruments, *MSP430FR4xx and MSP430FR2xx Family*, User's Guide (SLAU445)
2. Texas Instruments, *UART to Bluetooth® low energy (BLE) Bridge Design Guide*, TIDU997 Reference Design (TIDU997)

10.1 Trademarks

All trademarks are the property of their respective owners.

11 Terminology

- **Self-Capacitance:** The method of measuring changes in capacitance with respect to earth ground.
- **Mutual-Capacitance:** The method of measuring changes in capacitance on a sensor structure in which both plates of the capacitor are defined by electrode structures.

12 About the Author

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Revision A History

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

Changes from Original (July 2016) to A Revision **Page**

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