# TI Designs
# Bluetooth® Smart Keyboard Module

## TI Designs

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

## Design Resources

| | |
|---|---|
| TIDC-Bluetooth-Smart-Keyboard-Module | Tool Folder Containing Design Files |
| CC2650 | Product Folder |

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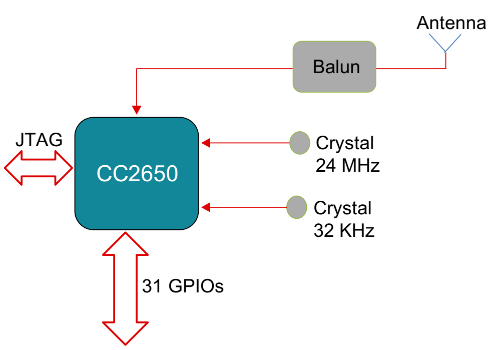
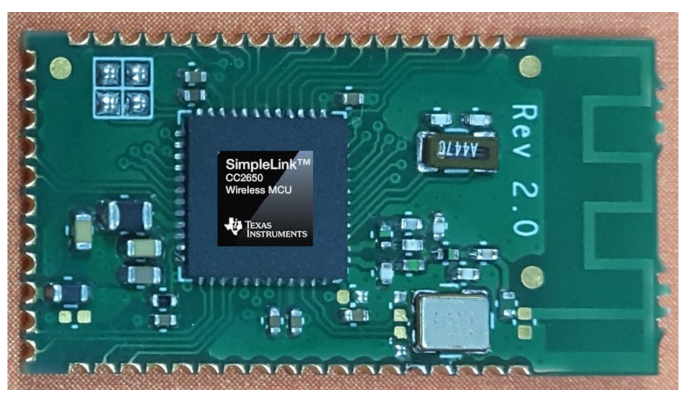
## Design Features

- Low-Power Consumption and Industry-Best Product Battery Life
- Easily Adaptable to any Keyboard Matrix
- Small Form-factor Castellation Design
- Interoperable With Android™, iOS™, and Windows®
- HID Over GATT Profile (HOGP) Compliant, Which Includes Support for Keyboard and Consumer Control Inputs
- Smart Master Switch Feature for Switching Between Pre-paired Masters With the Push of a Button
- Integrated On-board 2.4-GHz Small PCB Antenna
- On-board JTAG Provision for Application Programming and Debugging
- On-board Slow Clock to Wake Up From Standby Keyboard-Module Modes

## Featured Applications

- Bluetooth® Smart HID Keyboard

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# 1 Key System Specifications

**Table 1. System Specifications**

| PARAMETER | SPECIFICATION | DETAILS |
|---|---|---|
| *Bluetooth* Smart chip | The CC2650 is a wireless MCU targeting *Bluetooth* Smart, ZigBee™ and 6LoWPAN, and ZigBee RF4CE remote-control applications | Refer to the following link: http://www.ti.com/product/CC2650 |
| Main Crystal | 24-Mhz crystal | Refer to the following link: http://www.epsondevice.com/docs/qd/en/DownloadServlet?id=ID000658 |
| Slow clock | 32.768-Khz crystal resonator | Refer to the following link: http://www.eea.epson.com/portal/pls/portal/docs/1/1699449.PDF |
| Antenna | Integrated 2.4-Ghz PCB antenna | Refer to Small 2.4-GHz PCB Antenna Application Note (SWRA117) |
| Vin | Input voltage 3.3 V, DC powered | |
| Vout | Output voltage 3.3 V, powers the *Bluetooth* Smart module | |

# 2 System Description

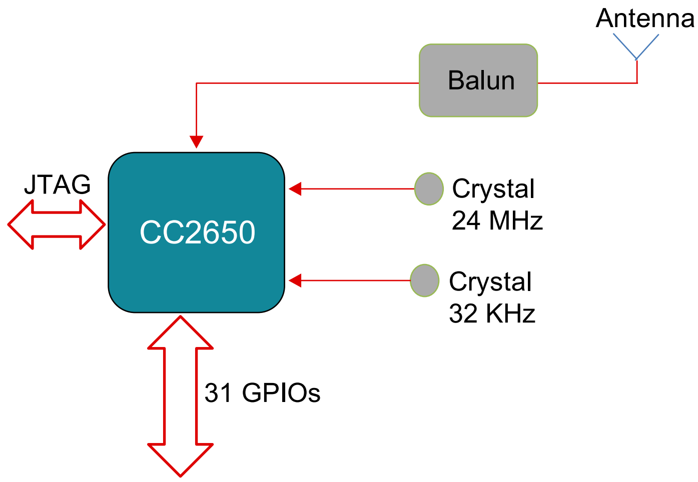


**Figure 1. Keyboard Module Block Diagram**

The TI Keyboard module contains the CC2650 *Bluetooth* Smart Wireless MCU. This module can be integrated with a keyboard motherboard to achieve a very-low power keyboard solution.

The main features of the module are as follows:

- Fully integrated module with CC2650 *Bluetooth* Smart Wireless MCU, crystal filters, matching circuit, and on-board 2.4-GHz PCB antenna
- Small factor, castellation design
- The keyboard module is tested by integrating it with a third-party keyboard matrix (105 keys)
- The functionality of the keyboard is tested by connecting to host devices with these operating systems:
  – Android 4.3 and above
  – iOS 6.0 and above
  – Microsoft® Windows 8
- JTAG availability for debugging
- Easy access to ADC pins to check and monitor low battery conditions

- On-board 32.768 KHz to enable wake-up from deep modes

## 2.1 CC2650—*Bluetooth* Smart Wireless MCU

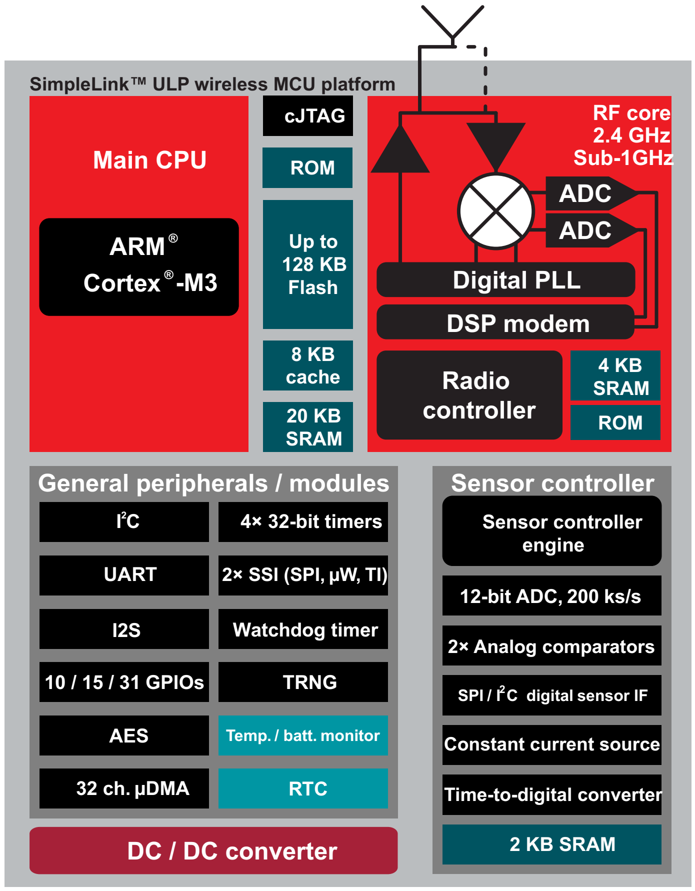


**Figure 2. CC2650 Block Diagram**

The CC2650 is a wireless MCU targeting *Bluetooth* Smart application. The device is a member of the CC26xx family of cost-effective, ultralow-power, 2.4-GHz RF devices. Very-low active RF and MCU currents and low-power mode current consumption provide excellent battery life and allow operation on small coin-cell batteries and in energy-harvesting applications.

The CC2650 contains a 32-bit ARM® Cortex®-M3 running at 48-MHz as the main processor and a rich peripheral feature set, including a unique ultralow-power sensor controller, which is ideal for interfacing external sensors or collecting analog and digital data autonomously while the rest of the system is in standby mode.

Click here for more information on the CC2650.

# 3 System Design Theory

The *Bluetooth* Smart module is designed to cater to the HID keyboard and other markets where the similar-dimension modules are used. The module is a four-layer printed circuit board with integrated 2.4-GHz PCB antenna. This section covers the technologies and procedures used.

The keyboard module is connected to the keypad matrix through a set of GPIOs. A key press / release is detected by the keyboard application by using a key-scan algorithm, which refers to the GPIO state. The key detections are communicated to the connected host device using the *Bluetooth* Smart communication mechanism. The HID over GATT Protocol (HOGP) is used between the keyboard and host device for interpreting the key strokes. The working of the keyboard module is visualized in Figure 3.

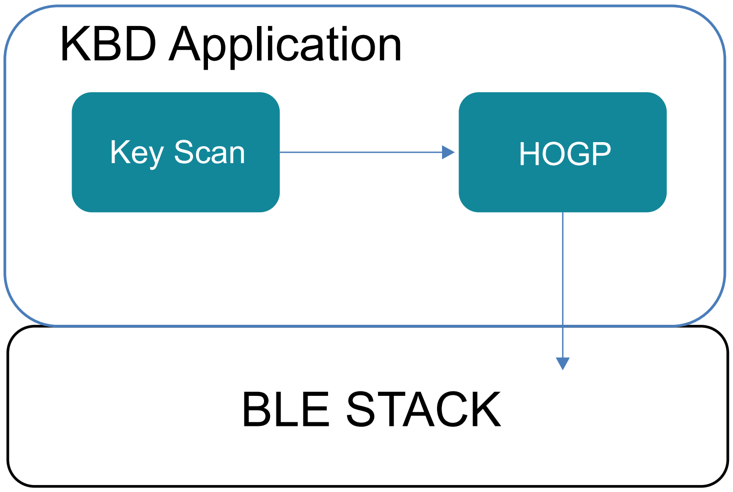


**Figure 3. HID Keyboard Blocks**

## 3.1 *Bluetooth* Smart

For the keyboard to work, it must establish a *Bluetooth* Smart connection with the host device. Also, the host device operating system must support a *Bluetooth* Smart-enabled keyboard. Windows 8.1, Android 4.3, and iOS 6.0 onwards devices can be used as the host because these devices support *Bluetooth* Smart keyboards through a HID over GATT profile (HOGP).

During the *Bluetooth* Smart connection, the keyboard will be the slave / peripheral device, and the Windows / Android / iOS devices will be the master / host device. When first connecting, the host device “pairs” with the keyboard and uses the “pairing” information to connect with the keyboard subsequently. Figure 4 describes the various states of the keyboard.

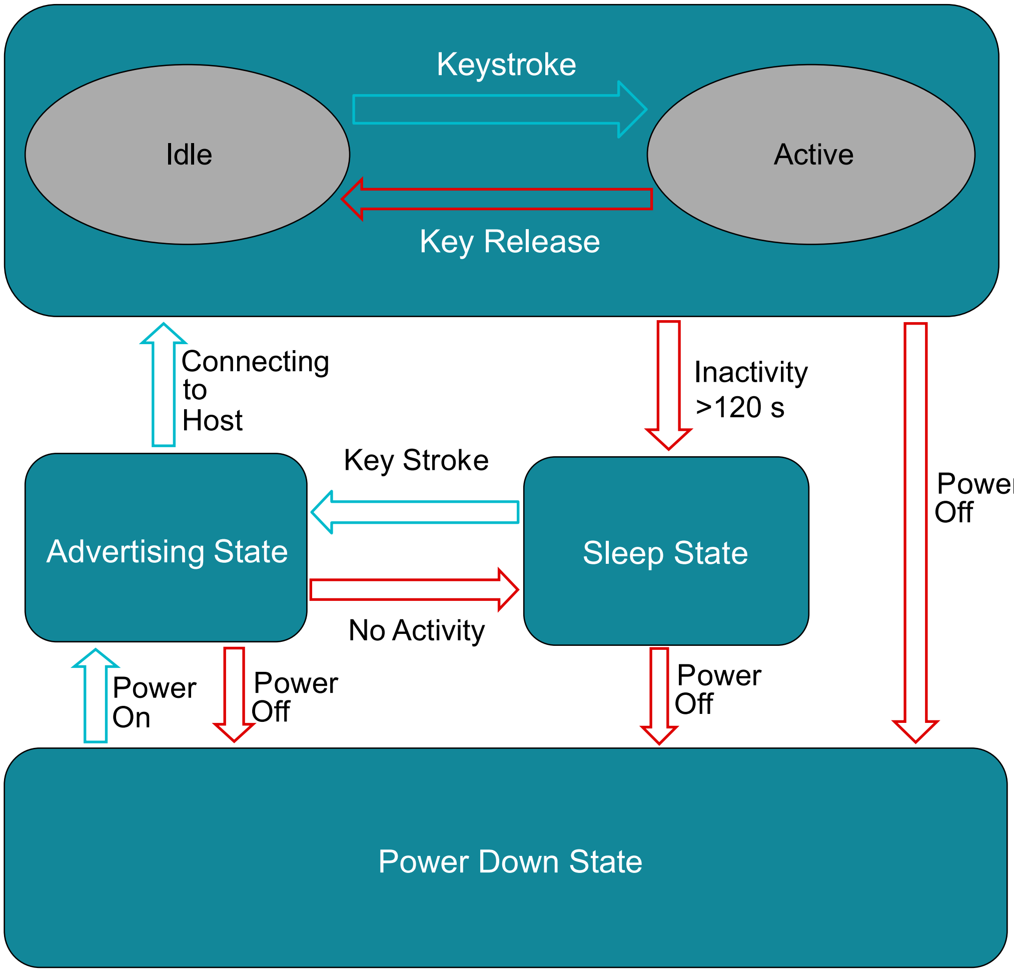


**Figure 4. Keyboard State Diagram**

1. **Connected State**
   The keyboard enters a connected state when the *Bluetooth* Smart connection with a host device (after pairing with host) is successful. The keyboard connected state can be divided into two sub states:
   (a) **Idle**
   In Idle mode, the *Bluetooth* Smart connection is established and maintained with the host device. The keyboard sends periodic *Bluetooth* Smart activity data to maintain connection, but no keyboard-related data is sent to host by the Bluetooth Smart radio. The keyboard remains in 'Idle' state until a key-stroke detection or until the inactivity timer times out.
   (b) **Active**
   The keyboard moves into 'Active' state when a key stroke is detected. The key stroke triggers an interrupt, and the key-scan algorithm is used to detect the key pressed. The detected keys are sent to the host as HID reports. The keyboard remains in 'Active' state until the key press is released. Upon release of all active keys, the device goes back to 'Idle' state.
2. **Standby State**
   During prolonged periods of inactivity (>120 seconds), the keyboard terminates the *Bluetooth* Smart connection to conserve power and enters 'Standby state. No *Bluetooth* Smart or key-press activity occurs in this state. The keyboard can be woken up from this state by a key press.

3. **Advertising State**
   When a key press occurs in 'Standby' state, the keyboard wakes up and enters 'Advertising' state. In this state, the keyboard sends a *Bluetooth* Smart advertisement, which can be detected by host devices. If a pre-paired host detects these advertisement packets, the host device will enter into a connection with the keyboard, and the keyboard moves to 'Connected-Idle' state. If no host device initiates a connection to the keyboard, the keyboard will move back to 'Standby' state after advertising for a fixed duration in 'Advertising' state.
4. **Power Down State**
   The keyboard goes into 'Power Down State' when the power switch is turned OFF. The device can enter 'Power Down' state from any state, but it can come out of 'Power Down' state only when power switch is turned ON, and it always goes into 'advertising' state.

### *3.2 HOGP*

The keyboard uses a HID slave implementation of HID over GATT protocol (HOGP). The host device uses the HID host implementation of HOGP. The HOGP HID slave implementation uses various services, such as one or more instances of HID service, one instance of device-info service, one or more instance of battery service, and others along with the HID slave role as shown in Figure 5.

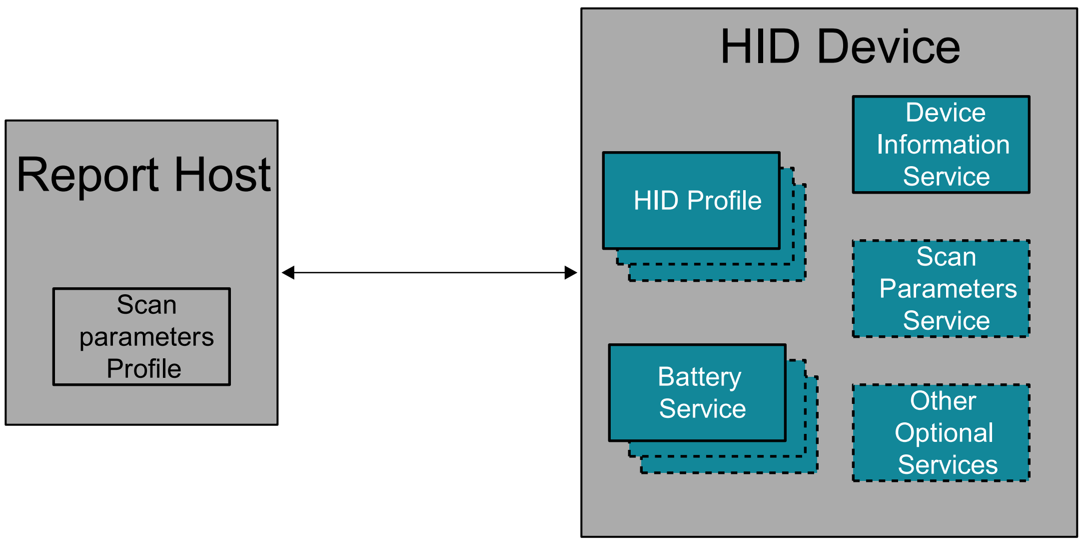


**Figure 5. HID Host and HID Device (Keyboard) Roles / Service Relationships**

When a *Bluetooth* Smart connection is formed between the host device and keyboard, the HID host reads the services supported by the keyboard. The keystrokes and their releases are sent as HID reports that are interpreted by the HID host with the help of the HID report map, which the HID host read earlier when the connection was formed. This process is shown in Figure 6.

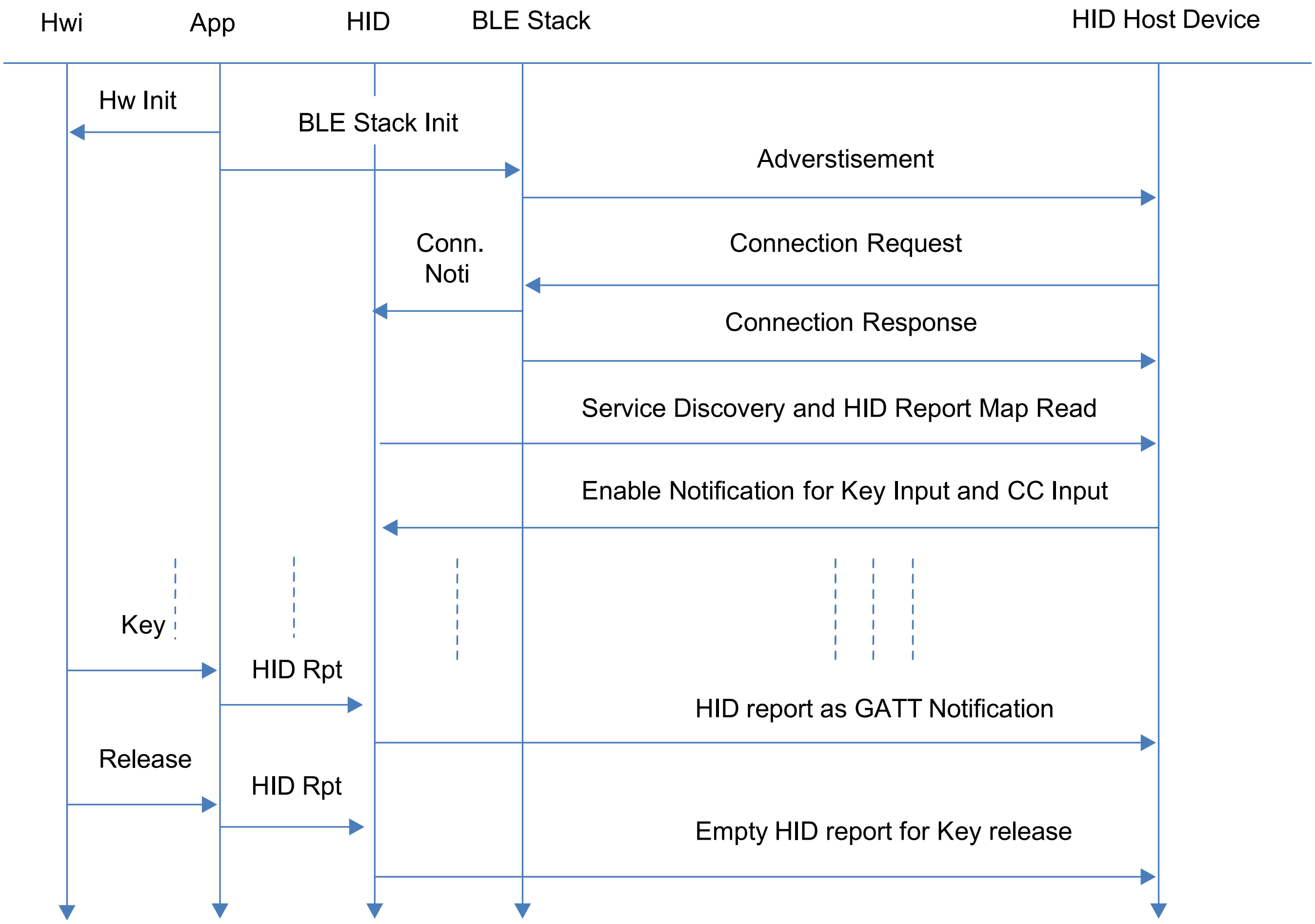


**Figure 6. HID Service Discovery**

## 3.3 Key Scan Application

### 3.3.1 Key Matrix

The keyboard controller presented in this document implements a key matrix of rows and columns. The implementation shown uses a 16 row × 8 column matrix, which allows up to 128 keys but only uses 80 keys in total. An example key matrix is shown in Figure 7.

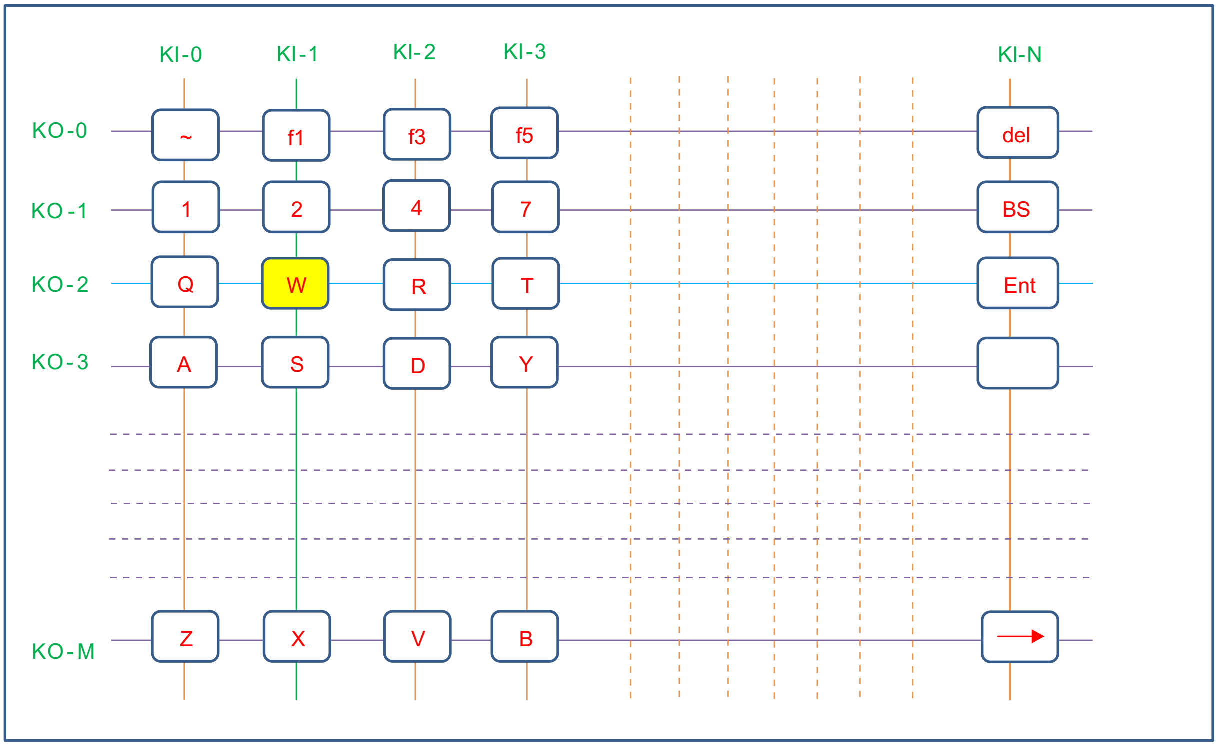


**Figure 7. Key Matrix Configuration**

The pins labeled KI-0 to KI-N are configured as input pins with a weak internal pull-up (input pins with high value that can be overridden by external signals). Interrupts are enabled on these input pins for a falling-edge scenario. The pins labeled KO-0 to KO-M are configured as output pins with a low value driven to them.

When a key gets pressed, the input line and output line gets shorted, which drives a low value on the input pin and triggers the interrupt for that input pin. For example, when a user presses the letter 'W', the input line KI-1 gets shorted to output line KO-2, triggering an interrupt on KI-1. The interrupts are handled using a Hwi task by RTOS (Real-Time Operating System—For more details, refer to *SimpleLink Bluetooth Low Energy CC2640 Wireless MCU Software Developers Guide* [SWRU393]). The Hwi task saves the pin that triggered the interrupt and posts an event to the application task, which handles the key-scan logic to determine the actual key being pressed. The key press is detected by toggling the input-line and output-line configuration and then by reading the input-pin values. The following detailed steps show the process for key detection.

**Initial Configuration**

1. Configure the 24 GPIOs of CC26XX as 16 input pins and 8 output pins (refer to the pin-mapping Excel sheet in the download section).
   - The 8 output pins are pulled low, and the 16 inputs pins are configured for falling-edge interrupt.

**Interrupt Detection**

2. Press a key to cause the output line (for example, KO-2) to come in contact with the input line and cause an interrupt on the input line (for example, KI-1).
   - This input line (KI-1) is reported to the application by the ISR.
3. Disable interrupts and clear the interrupt flag.
   - After the de-bounce timeout, the application checks for the output line responsible for triggering the interrupt on the input line (KI-1).

**Polling State**

4. For this check, make all output lines as inputs ("KI") with weak pull up.
5. Toggle only one line from "KI" to the output line with low value.
6. Read the status of the input lines.
   - All other input lines should read high except the input lines, which share the pressed keys with the output line used in step 5.
7. Use the schematics of the keypad matrix to find the key press corresponding to a particular combination of input and output lines.
8. Toggle another line as output similar to step 5.
9. Redo steps 5 to 8 until all lines from "KI" are checked.
10. Continue polling operations until no key press is detected on the keyboard.

**Re-Enabling Initial Configuration**

11. Revert the pin configuration to the original configuration.
12. Enable interrupt on the input lines.

**NOTE:** This detected key is checked for potential 'ghost' keys. If the detected key passes the ghost-key test, it will be sent to the host device in the form of an HID report. The key release is handled in the software; when a key is released, an empty HID report is sent to signal the release to the HID host device.

A HID report is constructed for each new key press. This HID report also consists of the status of the modifier keys (Left / Right Shift / Alt / Ctl / GUI). These reports are then sent to the HID task, which sends them out to the host device, while only the last reported Key release is sent to the HID host.

The key release and detection of new keys on the same input line are carried out by setting software timers and checking the input line status regularly when these timers finish. A key release is notified by sending a blank HID report. Only the recently sent key release is notified. The flow chart of the key detection and release process is given in Figure 8.

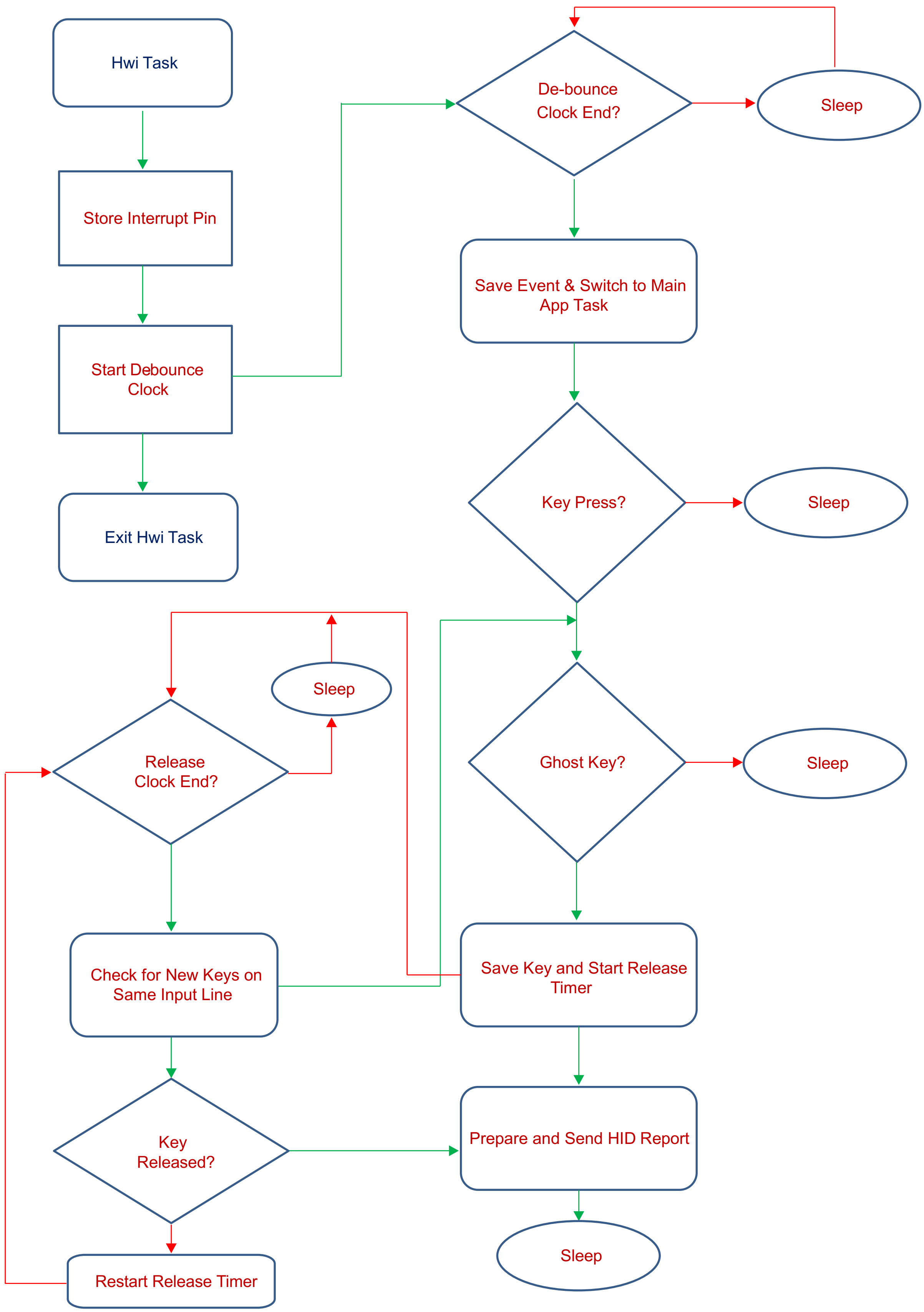


**Figure 8. Key Detection and Release Procedure**

### 3.3.2 Ghost Key

When three or more keys sharing rows and columns are pressed at the same time, unwanted "keys" can be falsely detected as shown in Figure 9. For example, when keys 'W', '2', and '4' are pressed together, the key scan algorithm will also detect key 'R', which is a false detection. The software present in the key-scan algorithm tries to eliminate these wrongly detected keys known as ghost keys.

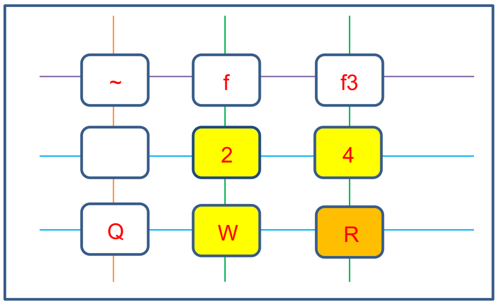


**Figure 9. Ghost Key**

## 4 Getting Started Hardware

The *Bluetooth* Smart keyboard module is brought out as a castellation form factor with dimensions of 15 mm × 28.2 mm.

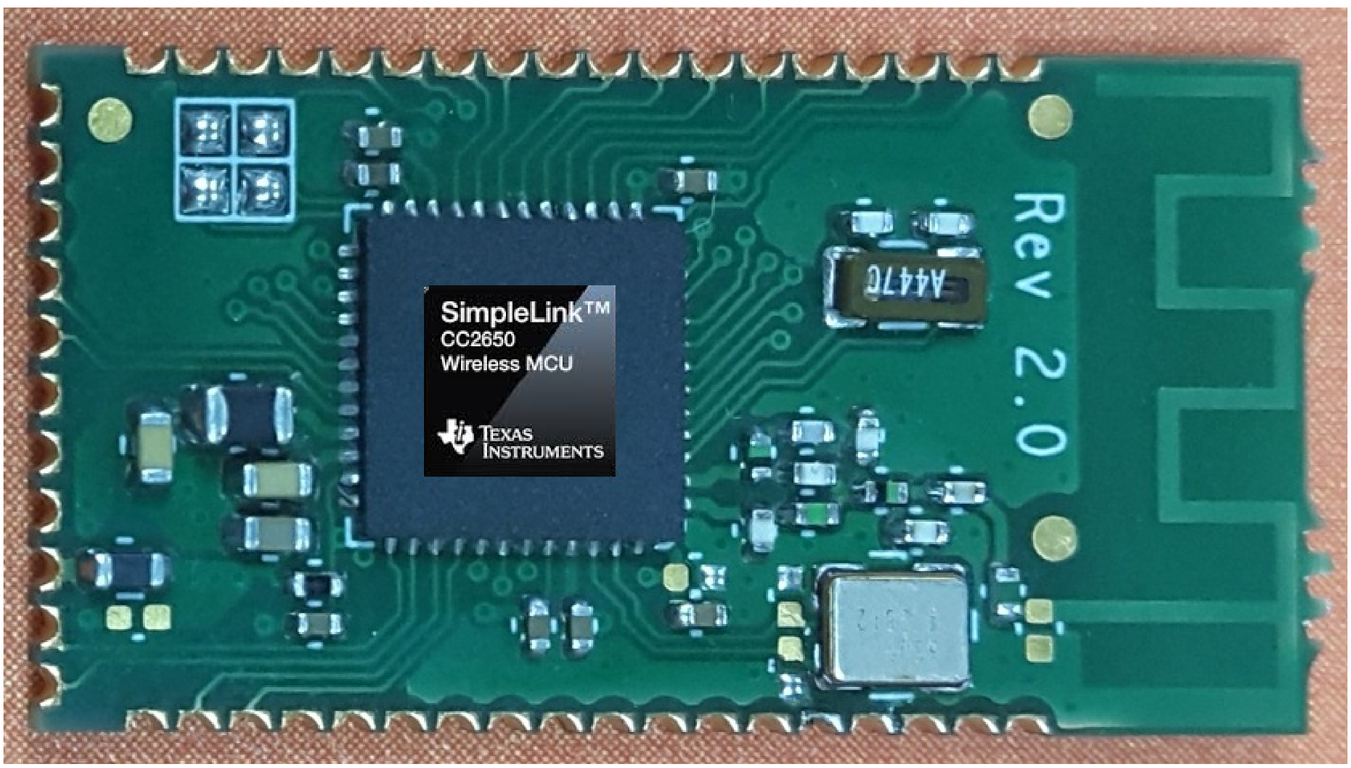


**Figure 10.** ***Bluetooth*** **Smart Keyboard Module**

### 4.1 Integration with a Motherboard

The keyboard module fits any similar-dimension keyboard motherboard, and it provides access to all the GPIOs and peripherals present in the CC2650 wireless MCU, as shown in Figure 11.

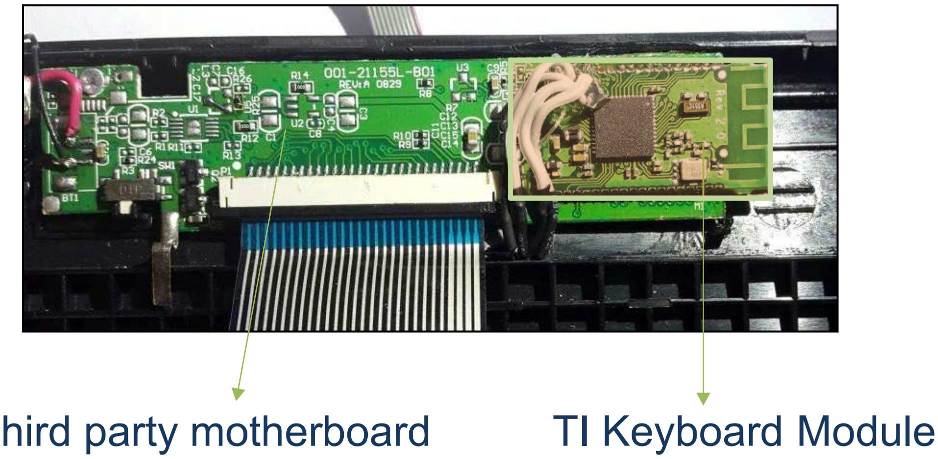


**Figure 11. Keyboard Module Integrated with Third-Party Mother Board**

The motherboard would have provisions for a pinout area, which matches the keyboard-module-pad dimensions and comprises an LDO, key matrix connector (depending on the number of keys), and an ON / OFF switch.

To ensure optimum performance, users must take care in the design to place the antenna part away from the motherboard (as depicted in Figure 11), with no battery or metal above or beneath it.

### 4.2 Download and Debugging

There are provisions for programming and debugging the CC2650 Wireless MCU chip using the on-board JTAG pins. To start this process, connect the four JTAG pins available on the keyboard module, to a 10-pin ARM debug connector (P410) on a SmartRF™06 board.

Details are provided on page 26 of the SmartRF06 user guide.

## 5 Getting Started Firmware

In this section, we discuss how to build and flash the keyboard software for the keyboard layout. Use the following software and tools to build the keyboard binary:

1. The *Bluetooth* Low-Energy Stack (BLE-STACK-v2.1) available for download here
2. The keyboard patch file provided along with this reference design
3. IAR 7.30.4 or later for building and flashing the keyboard binary through JTAG
4. SmartRF Flash Programmer v2 (optional) available for download here.

### 5.1 Installation Instructions

1. Download the *Bluetooth* Low-Energy SDK v2.1 and follow the instructions to install the *Bluetooth* Low-Energy SDK along with associated tools (SimpleLink™ and XDC tools). Install the SDK in the default location.
2. Unzip the keyboard patch file to the SDK installation directory (C:/ti/simplelink/ble_cc26xx_2_01_00_xx if the default location is used).
3. The HID keyboard project is under <PROJ_LOC>/Projects/ble location.
4. The default board files will be created under <PROJ_LOC>/Projects/ble/common/cc26xx/boards/keyboard_cc26xx.
5. Several other files will be updated in the SDK.

## 5.2 Update of Board Files

1. In the keyboard patch file, there will be a KeyScanGenerator Tool in the Accessories folder.
2. Follow the instructions in the Key_Matrix_Generator.doc to update the key_matrix.xlsx as per the board layout.
3. Run the Key_Scan.exe as described in the Key_Matrix_Generator.doc to create new board files.
4. As instructed in the Key_Matrix_Generator.doc, copy the board files to <ProJ_LOC>/Projects/ble/common/cc26xx/boards/keyboard_cc26xx.
5. Ensure that Board_HIDUsagekey.h is replaced in <ProJ_LOC>/Projects/ble/HIDKeyBoard/CC26xx/Source/Application.

## 5.3 Building and Flashing of Keyboard Binary

1. Open the HID keyboard project in IAR 7.30.4 and import the CC26xx-RTOS variables using Tools → Configure Custom Argument variables if not already imported.
2. Connect the JTAG on the keyboard to the SmartRF06 evaluation board JTAG connector, which will be connected to the PC running IAR.
3. Build the app-and-stack sub-projects.
4. Download the app-and-stack projects either through IAR → Project → Download → Download Active Application option or through flash programmer.

## 5.4 Pairing and Connecting to Host

1. Prepare the *Bluetooth* Smart host by turning on *Bluetooth*, and start scanning for *Bluetooth* devices.
2. Turn on the keyboard. The keyboard appears in the list of available devices.
3. The keyboard should be listed as ‘TI BLE HIDKeyboard’; click on it and select Pair to pair and bind the keyboard with the tablet or phone.
4. Wait until the operation is successful. The keyboard only needs to be bound one time with the tablet or phone; to bind the keyboard to another device, remove the binding from this device first or turn off *Bluetooth* on this device.
5. After the keyboard is paired and bound to the host, the keyboard will connect to the host.
6. Now any key stroke on keyboard will be sent to the host. Open any application like Notes or Email to start typing using the connected *Bluetooth* Smart keyboard.
7. To save power, the keyboard automatically goes into standby mode if there is no user input for around 120 seconds.
8. Any keystroke on the keyboard will wake up the keyboard and it will try to connect with the host (except in power off mode). If the host is ready, the *Bluetooth* Smart connection is established automatically.

# 6 Test Setup

## 6.1 Current Measurement Setup

This section describes how to measure the power consumption of the keyboard. The keyboard is powered by a 3.0-V DC power supply. While describing power measurement, assume the keyboard to be powered by a 3.0-V DC supply and hence will mention only the current consumed by the keyboard. The power consumed by the keyboard can be calculated in the following manner:

Power (in Watts) = Voltage (in Volts) × Current (In Amperes) (1)

The measurement setup is described in Figure 12.

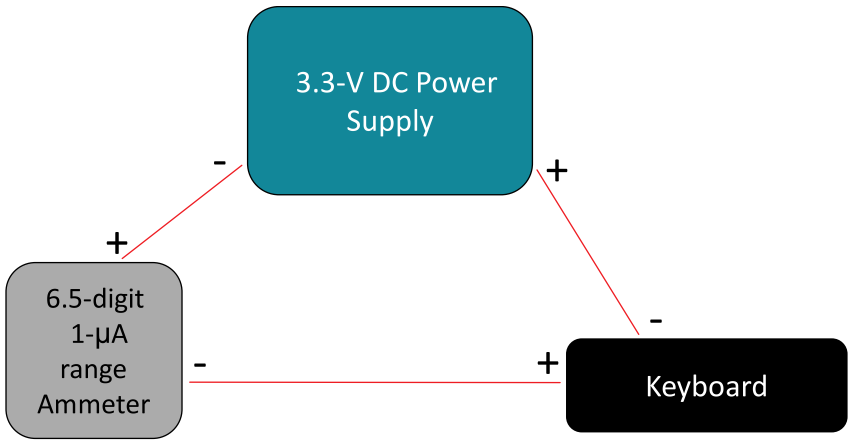


**Figure 12. Current Measurement Setup**

The ammeter is connected in a series with the power supply and keyboard. The ammeter used should be high precision; preferably one with a 6.5-digit accuracy to accurately measure standby current and small transient current.

# 7 Test Data

The current consumption test results for the various scenarios are listed in Table 2. For testing, the keyboard was connected to an iPad Mini® running iOS 8.2 on *Bluetooth* Smart.

**Table 2. Current Profile**

| SCENARIO | CURRENT CONSUMPTION |
|---|---|
| Advertising | Approximately 182 µA |
| Connected Idle | Approximately 117 µA |
| Disconnected (Standby) | Approximately1.8 µA |
| Key-press at 300 keys / minute | Approximately 400 µA |
| Continuous key press without release | Approximately 900 µA |

The connection parameters used are listed in Table 3:

**Table 3. Connection Parameters**

| PARAMETER | VALUE |
|---|---|
| Connection Interval | 15 ms |
| Slave Latency | 4 |
| Advertising Interval | 100 ms |
| Key Scan Polling Interval | 4 ms |

## *7.1 Current Consumption Graphs*

The following sections show current consumption graphs for Advertising, Connected-Idle, and Continuous-Typing states.

### 7.1.1 Advertising

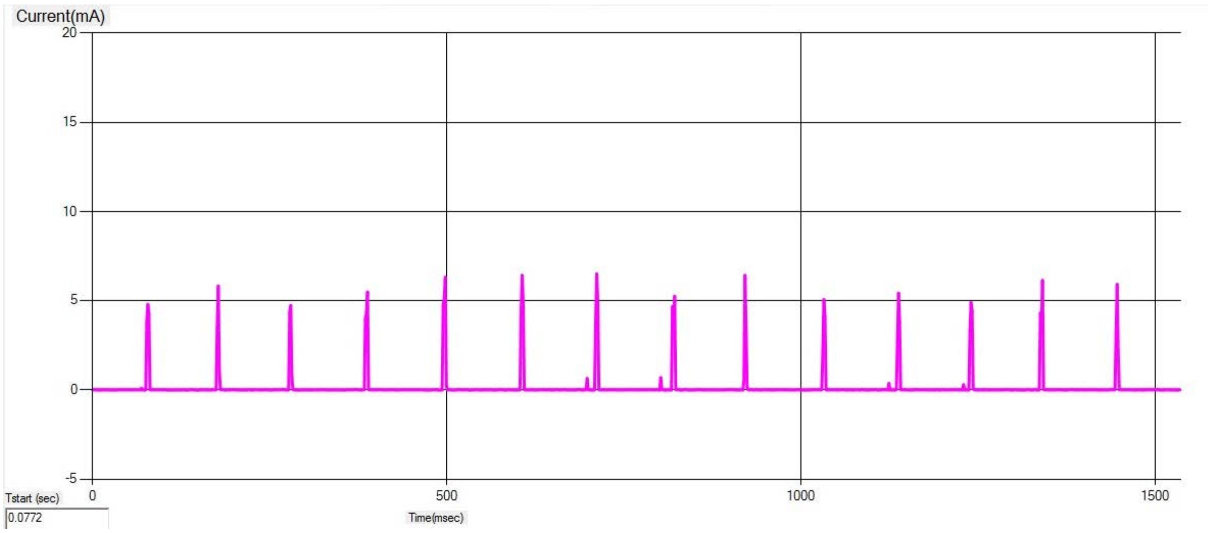


**Figure 13. Advertising State Current Consumption**

### 7.1.2 Connected Idle

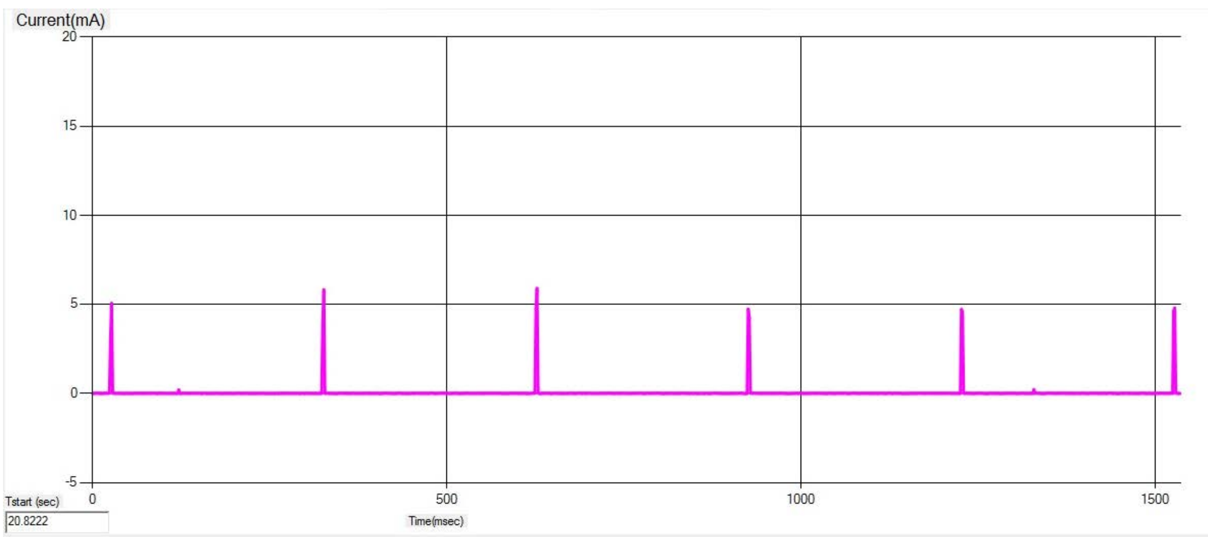


**Figure 14. Connected Idle State Current Consumption**

### 7.1.3 Continuous Typing

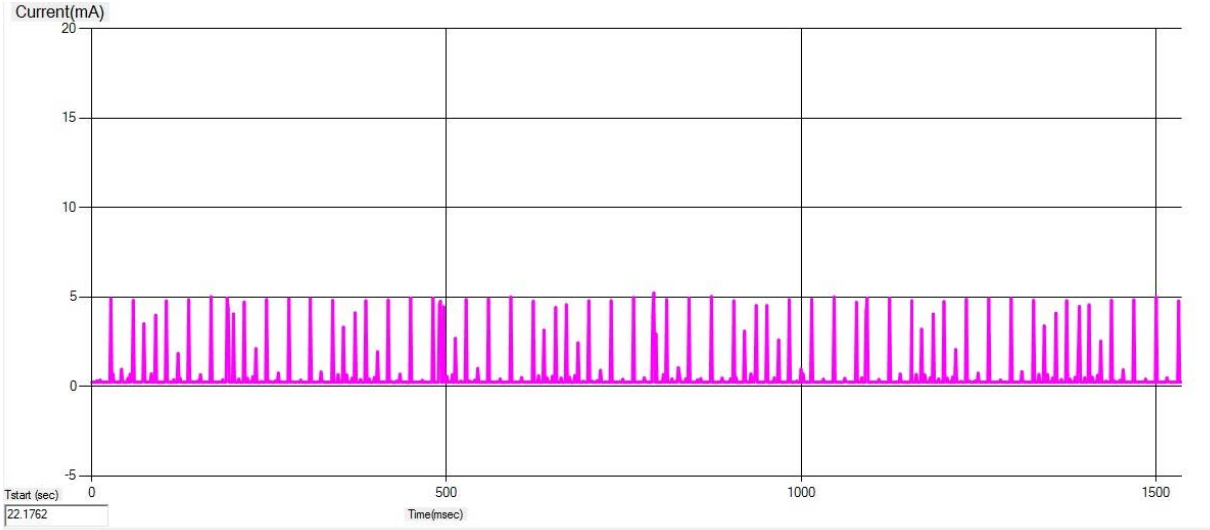


**Figure 15. Continuous Typing State Current Consumption**

## 8 Design Files

### 8.1 Schematics

To download the schematics, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.3 Layer Plots

To download the layer plots, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.4 Altium Project

To download the Altium project files, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.5 Layout Guidelines

To download the layout guidelines, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.6 Gerber Files

To download the Gerber files, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.7 Assembly Drawings

To download the assembly drawings, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

### 8.8 Software Files

To download the software files, see the design files at TIDC-Bluetooth-Smart-Keyboard-Module.

# 9 Terminology

**ATT—** Attribute Protocol

**BLE—** *Bluetooth* Low Energy

**BT—** *Bluetooth*

**GAP—** Generic Access Profile

**GATT—** Generic Attribute Profile

**IDE—** Integrated Development Environment

**HID—** Human Interface Device

**HOGP—** HID over GATT

**L2CAP—** Logical Link Control and Adaptation Protocol

**LE—** Low Energy

**LL—** Link Layer

**NV—** Non-Volatile

# 10 References


1. *CC26xx SimpleLink Wireless MCU* (SWCU117)
2. *SimpleLink Bluetooth Low Energy CC2640 Software Developer's Guide* (SWRU393)
3. HID over GATT Profile (HOGP)

## 11 About the Author

**ARUN MENON** is a systems application engineer at TI, where he develops *Bluetooth* Smart reference design solutions for the HID market. Arun has experience in application support for *Bluetooth* Smart wireless products. Arun earned his Master of Engineering in Electrical Engineering (ME-EE) from the Indian Institute of Science in Bangalore, India.

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# Revision History

| Changes from July 24, 2015 to August 24, 2015 | Page |
| --- | --- |
| • Updated from CC2640 to CC2650 throughout document | 1 |

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

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