*TI Designs*
# *Bluetooth Low Energy Keyboard Reference Design*

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## Design Resources

| | |
|---|---|
| TIDM-BLE-KEYBOARD | Tool Folder Containing Design Files |
| MSP430G2444 | Product Folder |
| CC2541 | Product Folder |

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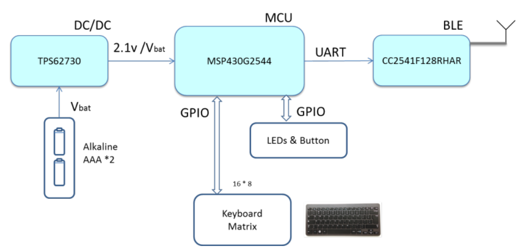
## Design Features

- Low power, 3 mW average when typing at 300 characters per minute speed
- Designed with TI Bluetooth Low Energy (BLE) protocol stack, including HOGP implementation
- Full feature keyboard support of up to 128 keys (16 x 8 matrix) without PCB modification
- Turnkey solution for BLE keyboard applications

## Featured Applications

- Keyboard for tablet PC and Smart Phone





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# 1 System Description

This solution uses the MSP430G2444 and CC2541 to implement a Bluetooth Low Energy keyboard.

## 1.1 MSP430G2444

The Texas Instruments MSP430 family of ultra-low power microcontrollers consists of several devices, featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally-controlled oscillator (DCO) allows a wake-up from low-power mode to active mode in less than 1 µs.

The MSP430G2x44 series are ultra-low power mixed signal microcontrollers with built-in 16-bit timers, up to 32 GPIO, and a built-in communication capability using the universal serial communication interface. In addition, the MSP430G2x44 family members have a 10-bit A/D converter. Typical applications include low-cost sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system.

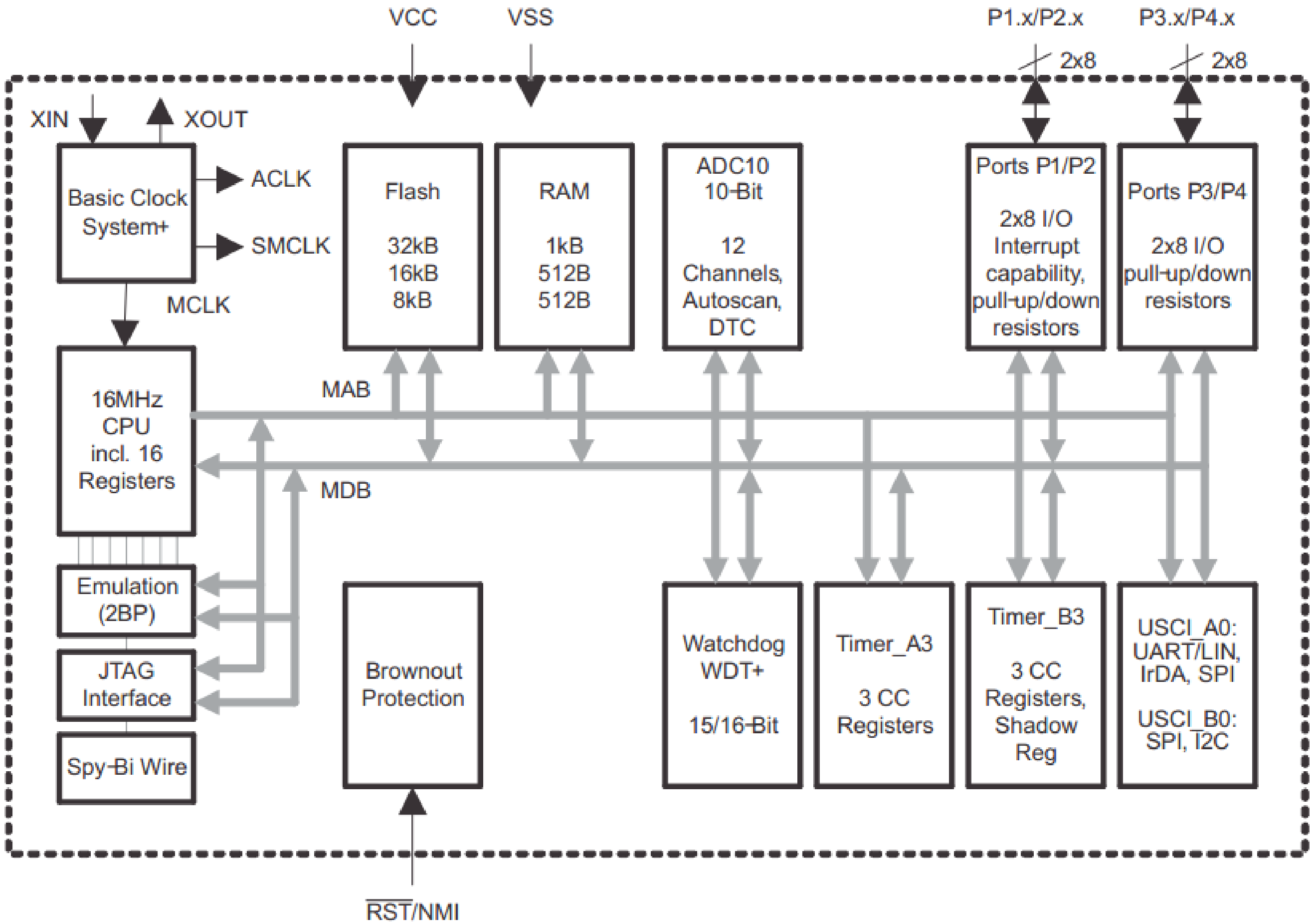


**Figure 1. Functional Block Diagram, MSP430G2x44**

## 1.2 CC2541

The CC2541 is a power-optimized, true system-on-chip (SoC) solution for both Bluetooth Low Energy and proprietary 2.4 GHz applications. The CC2541 enables network nodes to be built with low total bill-of-material costs. The CC2541 combines the performance of a leading RF transceiver with an industry standard-enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and other powerful supporting features and peripherals. The CC2541 is highly suited for systems requiring ultralow power consumption. This is specified by various operating modes. Short transition times between operating modes enable low power consumption.

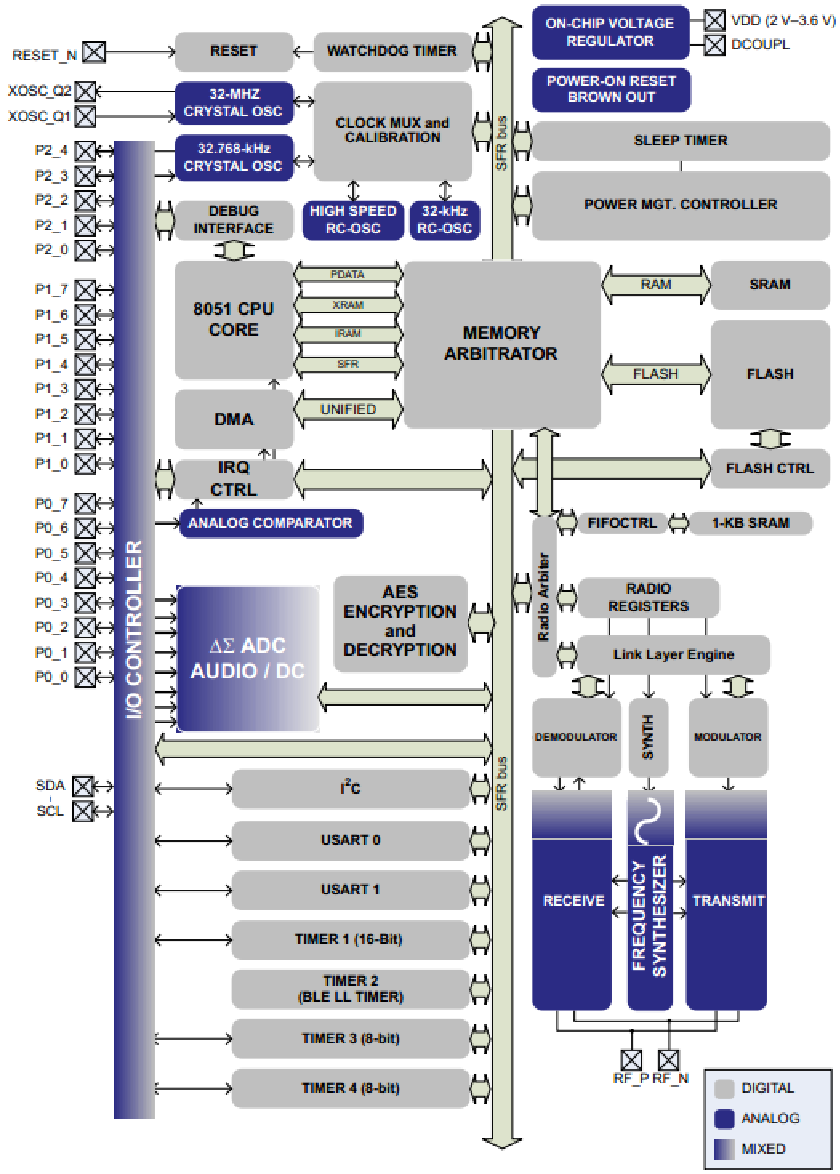


**Figure 2. CC2541 Simplified Block Diagram**

## 2 Block Diagram

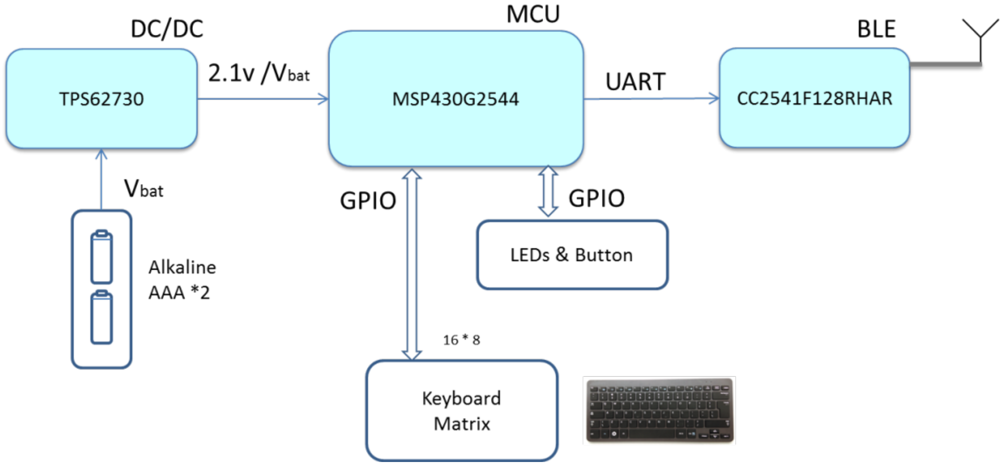


**Figure 3. Hardware Block Diagram**

## 3 System Design Theory

For this keyboard to work properly, the host operating system must support a BLE-enabled keyboard. Windows 8.1 can be used as the host, as it already supports BLE keyboards through a HID over GATT profile. The HID over GATT profile defines the procedures and features used by Bluetooth Low Energy HID Devices using GATT, and Bluetooth HID hosts using GATT. As shown in Figure 4, the keyboard is the device and Windows 8.1 is the host in this solution.

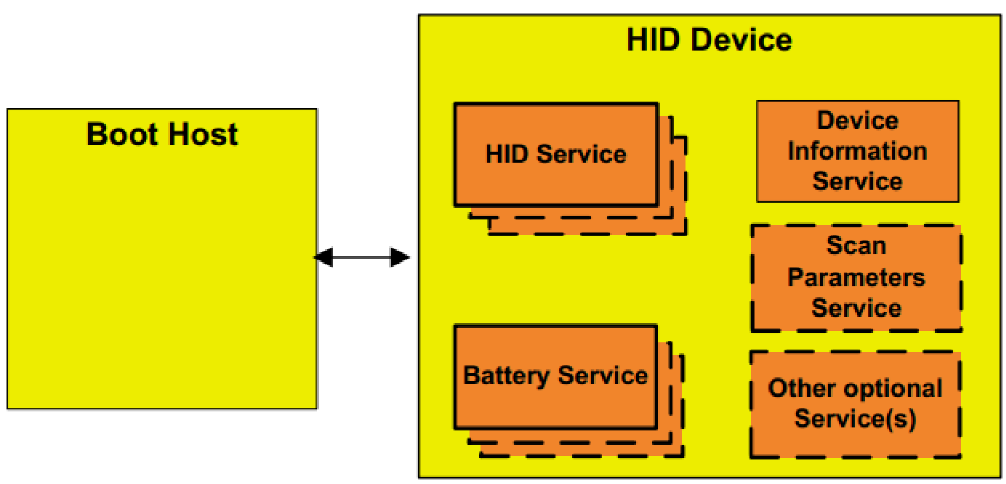


**Figure 4. Host and HID device Roles in HOGP**

# 4 Getting Started Hardware

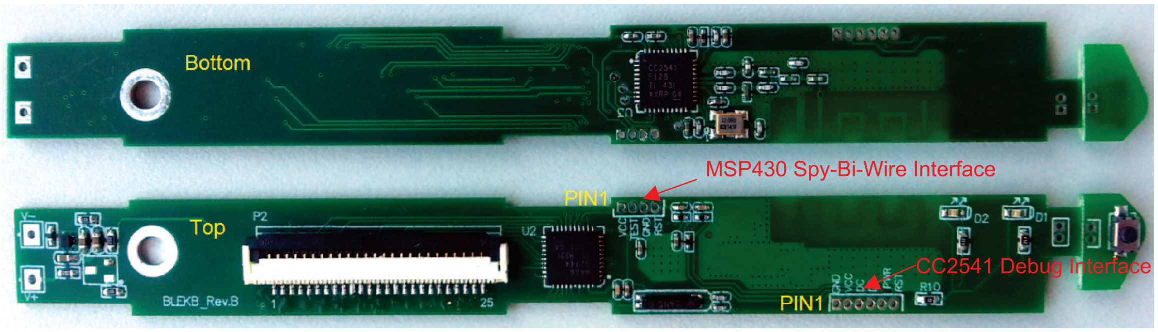


**Figure 5. Debug and Programming Interface**

## *4.1 MSP430G2444 JTAG (SPY-BI-WIRE) Connection*

To download the program into flash for the MSP430, use the connections between the PCBA and the JTAG tool shown in Table 1:

**Table 1. PCBA and JTAG Connections**

| PCBA PIN | JTAG |
|---|---|
| 1 | VCC |
| 2 | TEST |
| 3 | GND |
| 4 | RESET |

## *4.2 CC2541 Debug Interface Connection*

To download the program into flash for the CC2541, use the connections between the PCBA and the debug or programming tool shown in Table 2:

**Table 2. PCBA and Debug Tool Connections**

| PCBA PIN | Debug I/F |
|---|---|
| 1 | GND |
| 2 | VCC |
| 3 | DC |
| 4 | DD |
| 5 | PWR |
| 6 | RESET |

# 5 Getting Started with Firmware

## 5.1 *Keyboard Work Mode State Machine*

Figure 6 depicts the working mode of the keyboard: this assumes that the keyboard is already paired and bounded with the host.

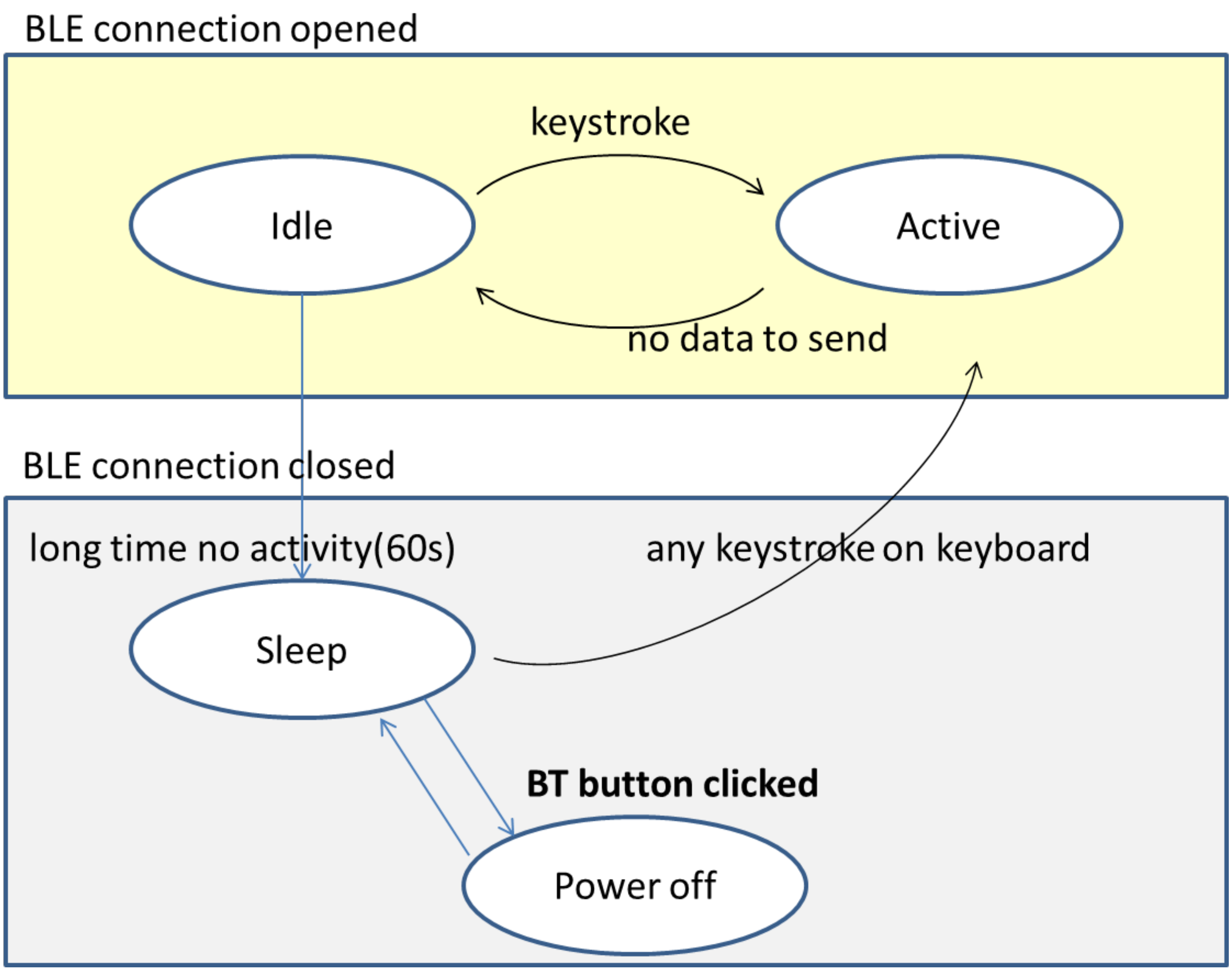


**Figure 6. Working Mode State Machine**

### 5.1.1 Idle Mode

After a successful pairing progress, the keyboard enters idle mode. In idle mode, the BLE connection is established with the host. No data is sent by the BLE radio, but the keyboard waits for any keystroke and the BLE radio works periodically to keep the BLE connection.

### 5.1.2 Active Mode

When the user types any key on the keyboard when in idle mode, it enters active mode. In active mode, the keystroke data is sent out to the host. The keyboard returns to idle state when no data remains. The BLE radio in this mode is on full duty.

#### 5.1.3 Sleep Mode

When there is no user input for 60 seconds, the keyboard enters sleep mode. In sleep mode, the BLE connection closes to save power. If the user strikes any key on the keyboard, the keyboard tries to build a BLE connection and rolls into active mode if successful. In sleep mode, the BLE radio is shut off.

#### 5.1.4 Power Off Mode

The power off mode is similar to sleep mode, other than that when in this mode, a keystroke cannot wake up the entire system. The BT button on the bottom-right side of the keyboard is the only key able to power on the keyboard. This mode avoids accidentally triggering the keyboard, to save power consumption.

### *5.2 Keyboard User's Guide*

To make the keyboard work, see Figure 7 and follow the steps:


**Figure 7. BT Button and LED**

1. Insert 2 AAA alkaline batteries by unlocking the battery case, as illustrated in Figure 7. The BT LED will blink two times and enter sleep mode.
2. Prepare the BLE host, which in this example is a Windows 8.1 tablet PC. Go to the Device Manager – Bluetooth and enable the BT device. The keyboard should appear in the list in the next step.

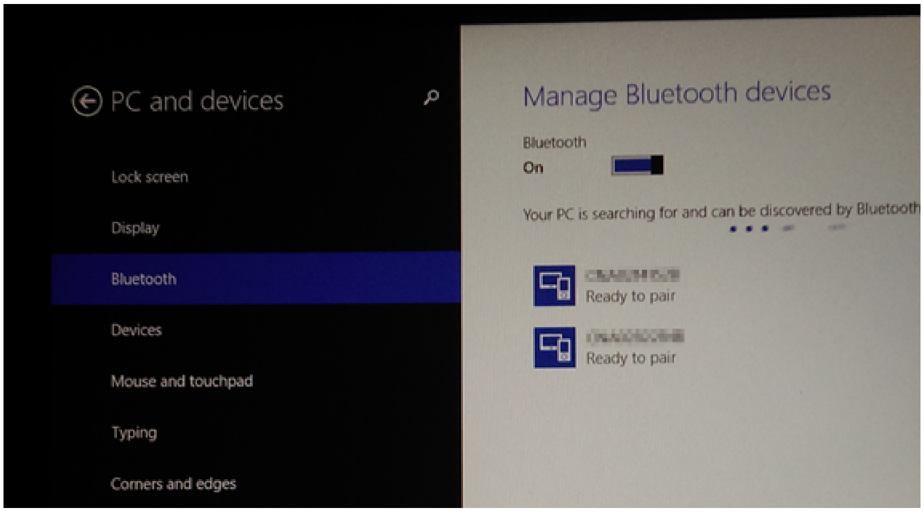


**Figure 8. Enable Bluetooth Device in Windows 8.1**

3. Hold the BT button until the BT LED starts blinking quickly. The keyboard should now be listed as BLE Keyboard; click on it and select Pair to pair and bind the keyboard with the tablet. The user will be prompted to input a 6 digit number. Wait until the operation is successful. The keyboard only needs to be bound one time with the tablet; to bound the keyboard to another tablet, remove the binding from this tablet first.
4. After the keyboard is paired and bound to the host, any keystroke on the keyboard will cause the keyboard to try and connect with the host (except in power off mode). If the host is ready, the BLE connection is established automatically.
5. The keyboard automatically goes into sleep mode if there is no user input for around 60 seconds, to save power. Press the BT button to toggle Power On/ Power Off mode for the keyboard. See Figure 6 for more details.

# 6 Test

This section describes how to measure the power consumption of the keyboard.

## 6.1 Test Enviroment

Test instrument: FLUKE 287C, mA/uA

Voltage for 2 AAA alkaline batteries: 3.2 V no load

## 6.2 Test Mode

1. Active mode
2. Idle mode
3. Sleep mode and power off mode

## 6.3 Test Data

| Keyboard Work Mode | Average Current | Comments |
|---|---|---|
| Active | 1.0 mA | Typing rate is around 300 characters per minute |
| Idle | 165 uA | |
| Sleep and power off | <1 uA | |

# 7 Design Files

## 7.1 Schematics

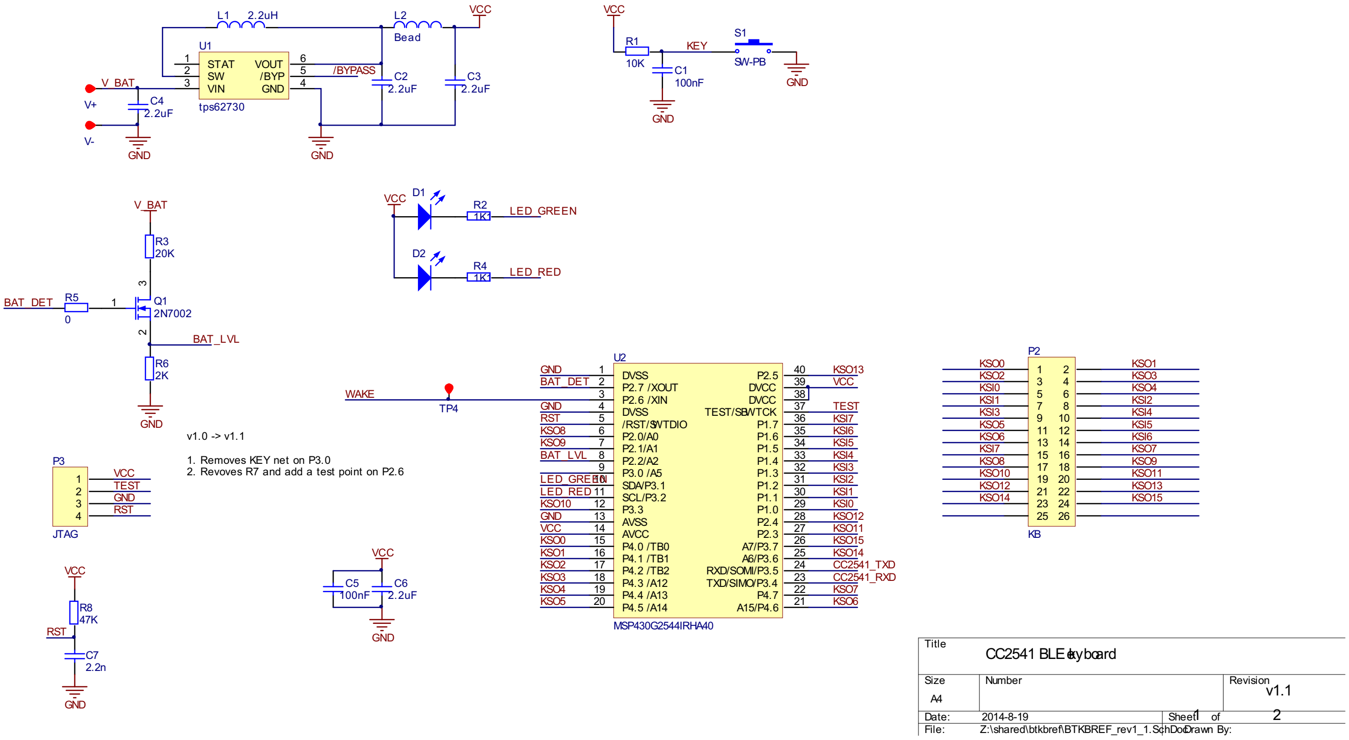


**Figure 9. Schematic 1**

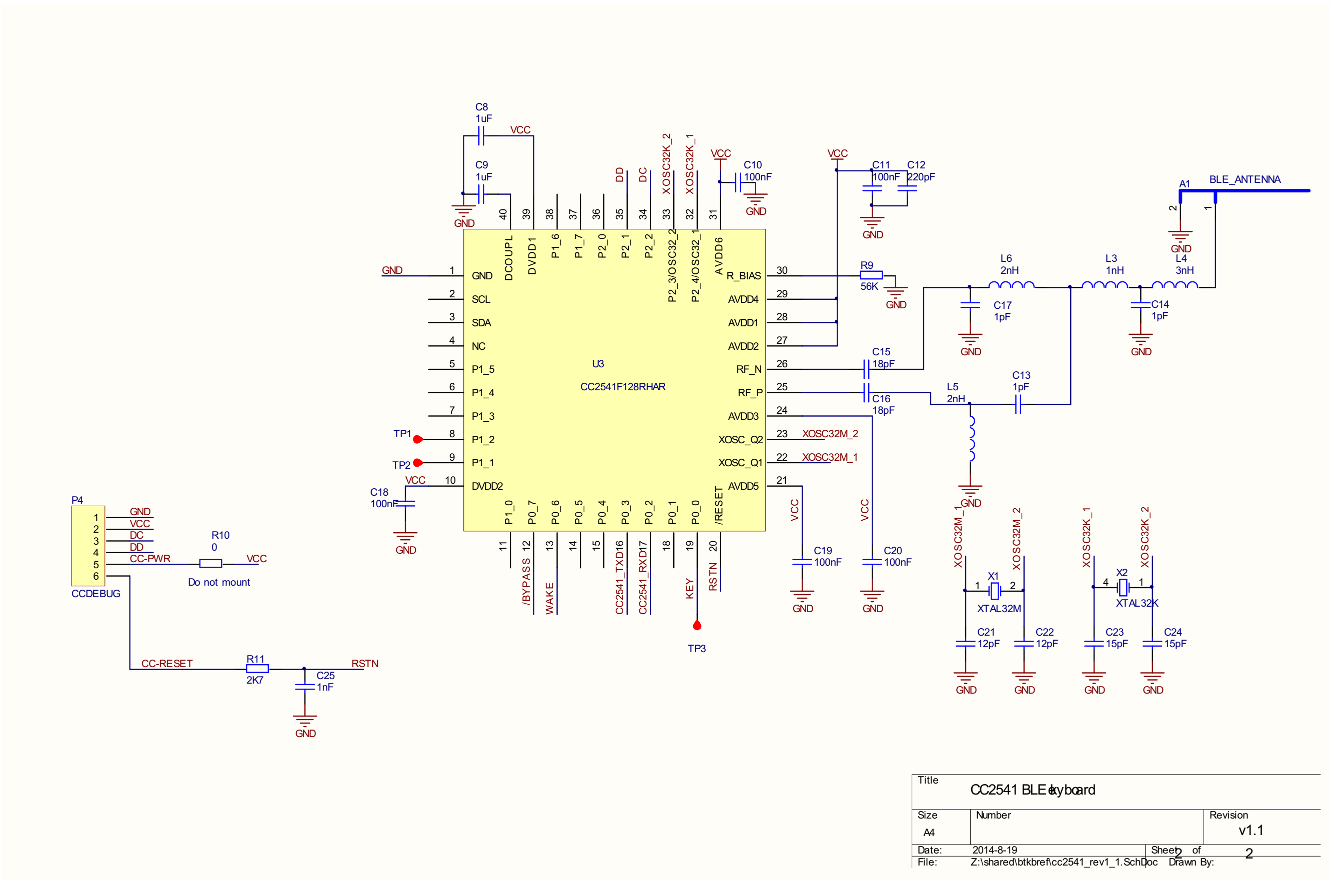


**Figure 10. Schematic 2**

## 7.2 Bill of Materials

**Table 3. BOM**

| Item | Qty | Reference | Value | Part Description | Manufacturer | Manufacturer Part Number | PCB Footprint |
|---|---|---|---|---|---|---|---|
| 1 | 3 | C1, C5, C18 | 100 nF | CAP CER 100 nF 6 V 10% 0402 | | | 0402 |
| 2 | 1 | C6 | 2.2 uF | CAP CER 2.2 uF 6 V 10% 0402 | | | 0402 |
| 3 | 1 | C7 | 2.2 nF | CAP CER 2.2 uF 6 V 10% 0402 | | | 0402 |
| 4 | 2 | C8, C9 | 1 uF | CAP CER 1 uF 6 V 10% 0402 | | | 0402 |
| 5 | 1 | C25 | 1 nF | CAP CER 0.1 UF 6 V 10% 0603 | | | 0402 |
| 6 | 2 | C21, C22 | 12 pF | Capacitor, 12p, 0402, NP0, 5%, 50 V | Murata | GRM1555C1H120JA01D | 0402 |
| 7 | 2 | C23, C24 | 15 pF | Capacitor, 15p, 0402, NP0, 5%, 50 V | Murata | GRM1555C1H150JA01D | 0402 |
| 8 | 2 | C15, C16 | 18 pF | Capacitor, 18p, 0402, NP0, 5% 25 V | Murata | GRM1555C1H180JZ01D | 0402 |
| 9 | 3 | C13, C14, C17 | 1 pF | Capacitor, 1p, 0402, NP0, +/-0.25 pF 50 V | Murata | GRM1555C1H1R0CZ01D | 0402 |
| 10 | 1 | C12 | 220 pF | Capacitor, 220p, 0402,N P0, 5%, 50 V | Murata | GRM1555C1H221JA01D | 0402 |
| 11 | 4 | C10, C11, C19, C20 | 100 nF | Capacitor, 100n, 0402, X5R, 10%, 10 V | Murata | GRM1555R71A104KA01D | 0402 |
| 12 | 3 | C2, C3, C4 | 2.2 uF | CAP CER 2.2 uF 6 V 10% 0402 | Murata | GRM155R60J225ME15D | 0603 |
| 13 | 2 | D1, D2 | | RED LED 0603 | | | 0603 |
| 14 | 1 | R1 | 10K | Resistor, 10K, 0402, 5% | | | 0402 |
| 15 | 1 | R8 | 47K | Resistor, 47K, 0402, 5% | | | 0402 |
| 16 | 1 | R9 | 56K | Resistor, 56K, 0402, 1% | | | 0402 |
| 17 | 1 | R11 | 2.7K | Resistor, 2.7K, 0402, 5% | | | 0402 |
| 18 | 1 | R5 | 0 | Resistor, 0, 0402, 5% | | | 0603 |
| 19 | 2 | R2, R4 | 1.1K | Resistor, 1.1K, 0402, 5% | | | 0603 |
| 20 | 1 | R6 | 2K | Resistor, 2K, 0402, 5% | | | 0603 |
| 21 | 1 | R3 | 20K | Resistor, 20K, 0402, 5% | | | 0603 |
| 22 | 1 | R10 | 0 | Resistor, 0, 0402, 5% | | | 0603 |
| 23 | 1 | Q1 | 2N7002 | N-Channel MOSFET | | | SOT23-3P |
| 24 | 1 | L2 | Bead | EMI filter bead, 0402 1k ohms tape GHz Band | Murata | BLM15HG102SN1D | 0603 |
| 25 | 1 | L3 | 1 nH | Inductor, 1n0, 0402, Monolithic +/-0.3 nH | Murata | LQG15HS1N0S02D | 0402 |
| 26 | 2 | L5, L6 | 2 nH | Inductor, 3n0, 0402, Monolithic +/-0.3 nH | Murata | LQG15HS2N0S02D | 0402 |
| 27 | 1 | L4 | 3 nH | Inductor, 2n0, 0402, +/-0.3 nH | Murata | LQG15HS3N0S02D | 0402 |
| 28 | 1 | L1 | 2.2 uH | Inductor, 2.2 uH, 0603,500 mA 30% | Murata | LQM21PN2R2NGC | 0603 |
| 29 | 1 | U2 | MSP430G2444 | MCU | Texas Instruments | MSP430G2444IRHA40R | IC-QFN40-RHA-RTB |
| 30 | 1 | U1 | tps62730 | DC-DC | Texas Instruments | TPS62730DRYR | DRY0006A |
| 31 | 1 | U3 | CC2541F128 | BLE SOC | Texas Instruments | CC2541F128RHAR | IC-QFN40-RHA-RTB |
| 32 | 1 | X2 | XTAL32K | CRYSTAL, OSCILATOR, 32.768 kHz, -20PPM/ + 20PPM, -40DEGC/ +85DEGC, 12.5 pF, SMD | Epson Toyocom | 12-00422 | SSP-T-32768 |
| 33 | 1 | X1 | XTAL32M | CRYSTAL, OSCILATOR, 32 MHz, 10 pF, -10PPM/+10PPM, -40DEGC/+85DEGC, SMD | Epson Toyocom | 12-00430 | XIAL4P-SMT3*2X5 |
| 34 | 1 | SW1 | Button switch | Button switch | | | SW-PB-SMT3*4*2 |
| 35 | 1 | P3 | JTAG connector | JTAG connector for MSP430 | | | MHDR1X4 |
| 36 | 1 | P2 | Keyboard connector | 25-pin connector | | | FFC-25-P1.0 |
| 37 | 2 | S1, S2 | Connector | 2-pin connector | | | MHDR1X2 |
| 38 | 1 | P4 | CCDEBUG | debug connector for CC2541 | | | MHDR1X6 |

### 7.3 PCB Layouts

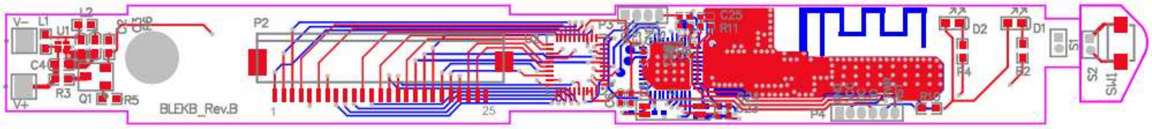

**Figure 11. PCB Layouts**

## 8 Software Files

## 9 References

1. MSP430G2x44 - Mixed Signal Microcontroller (SLAS892B)
2. CC2541 -2.4-GHz Bluetooth low energy and Proietary System-On-Chip (SWRS110D)
3. HID OVER GATT PROFILE SPECIFICATION v10r00

## 10 About the Author

**NAN JIANG** is an MCU Systems Application Engineer at Texas Instruments, responsible for developing system solutions for IoT (Internet of Things) and industrial applications.

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