# *TI Designs*
# *SimpleLink™ CC2650 uTag–Ultra-Compact Bluetooth® Smart Reference Design*

## TI Designs

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## Design Resources

| | |
|---|---|
| TIDC-CC2650-uTAG | Design Folder |
| SimpleLink™CC2650 | Product Folder |
| SimpleLink™CC2640 | Product Folder |
| TMP102 | Product Folder |
| BLE Stack Software | Tool Folder |
| BLE SW Developer's Guide | Documentation |
| BLE Wiki | Wiki Page |
| BLE Forum | *Bluetooth*® Low Energy Forum |

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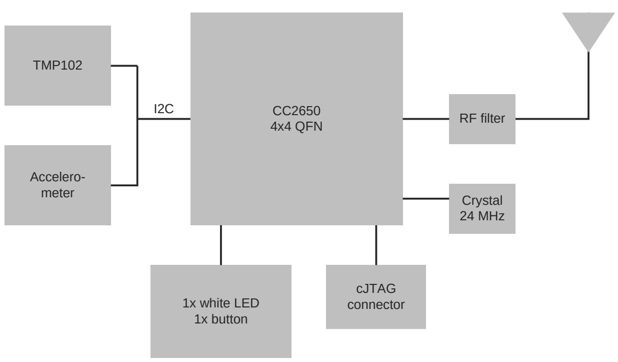
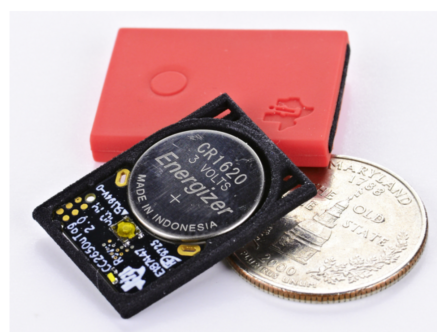
## Design Features

- Ultra-Compact PCB Layout
- Onboard Accelerator and Temperature Sensor
- Small Size Chip Antenna
- Designed for *Bluetooth*® Smart

## Featured Applications

- Medical Applications
- *Bluetooth Low Energy* Beacon
- Home Automation
- Environmental Sensor
- IoT Applications

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# 1 Key System Specifications

- **PCB Size:** 141 $mm^2$, or approximately 16×9 $mm^2$.
- **Antenna:** Johanson 2450AT07A0100 (0402 size with PCB area requirement = 4×3 $mm^2$.
- **Crystal:** NDK NX2016SA 24 MHz EXS00A-CS07553.
- **RF Range:** Same-room indoor coverage.
- **Battery:** CR1620 coin cell.
- **Battery Life Time:** 3 months with continuous 1 s connection.

## 2 Design Features

Figure 1 shows the C2650 µTag Block Diagram.

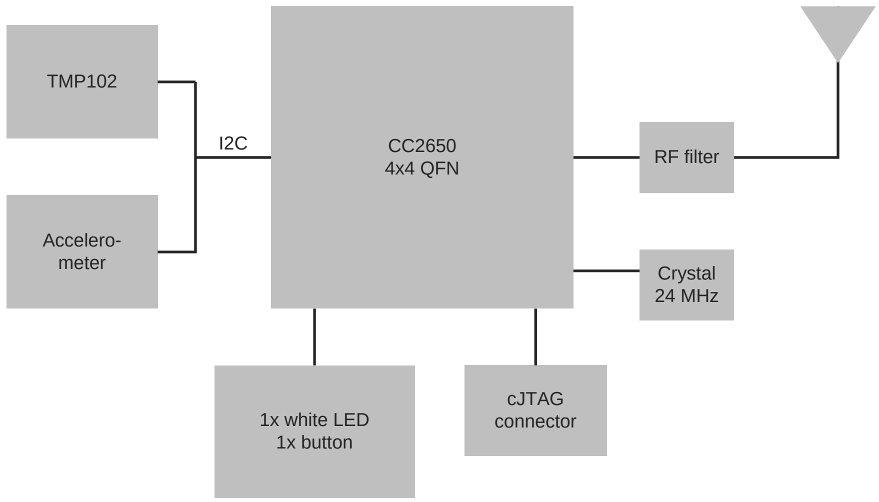


**Figure 1. C2650 µTag Block Diagram**

## 3 System Description

The CC2650 µTag is an ultra-compact reference design for the CC26xx family of devices. The PCB measures 141 $mm^2$, or approximately 16×9 $mm^2$, and contains the CC2650, a TMP102 temperature sensor, an accelerometer, push button, and an LED. The board also contains a single ended, discrete component RF filter and a very compact 0402 chip antenna. The board is powered from a CR1620 coin cell (16 mm diameter) battery. There is also a 6-pin TagConnect interface for cJTAG access on the PCB.

### 3.1 CC2650

The CC2650 device is a wireless MCU targeting *Bluetooth* Smart, ZigBee™ and 6LoWPAN, and ZigBee RF4CE remote control applications. For more details, refer to the whitepaper, *Bringing Wireless Scalability to Intelligent Sensing Applications* (SWRY014).

The device is a member of the CC26xx family of cost-effective, ultra-low power, 2.4-GHz RF devices. Very low active RF and MCU current and low-power mode current consumption provide excellent battery lifetime and allow for operation on small coin cell batteries and in energy-harvesting applications.

The CC2650 device contains an 32-bit ARM® Cortex®-M3 processor that runs at 48 MHz as the main processor and a rich peripheral feature set that includes a unique ultra-low power sensor controller. The sensor controller is ideal for interfacing external sensors and for collecting analog and digital data autonomously while the rest of the system is in sleep mode. Figure 2 shows the CC2650 block diagram.

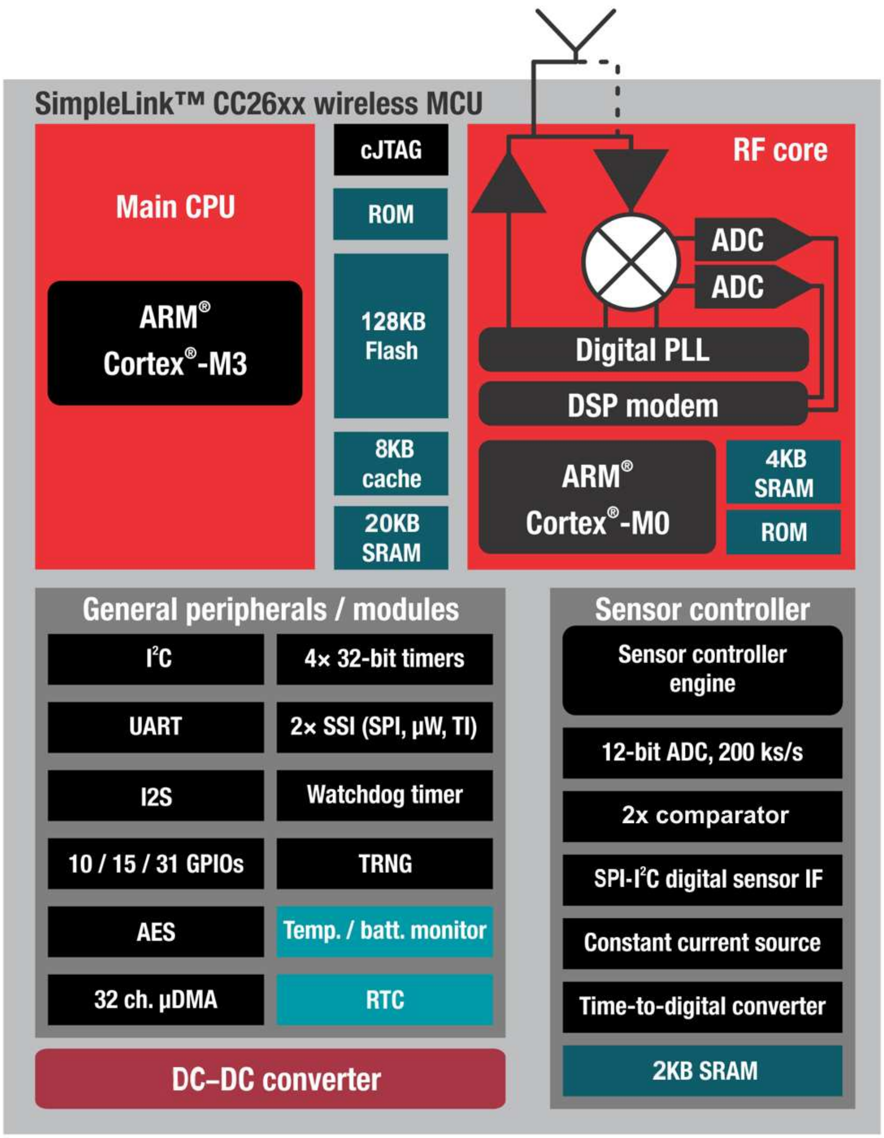


**Figure 2. CC2650 Block Diagram**

### 3.2 TMP102

The TMP102 device is a digital temperature sensor ideal for NTC and PTC thermistor replacement where high accuracy is required. The device offers an accuracy of ±0.5°C without requiring calibration or external component signal conditioning. IC temperature sensors are highly linear and do not require complex calculations or lookup tables to derive the temperature. The on-chip 12-bit ADC offers resolutions down to 0.0625°C.

The 1.6-mm×1.6-mm SOT-563 package has a 68% smaller footprint than an SOT-23 package. The TMP102 device features SMBus™, two-wire and I2C interface compatibility, and allows up to four devices on one bus. The device also features an SMBus alert function. The device is specified to operate over supply voltages from 1.4 to 3.6 V with the maximum quiescent current of 10 µA over the full operating range.

The TMP102 device is ideal for extended temperature measurement in a variety of communication, computer, consumer, environmental, industrial, and instrumentation applications. The device is specified for operation over a temperature range of –40°C to 125°C. Figure 3 shows the TMP102 block diagram.

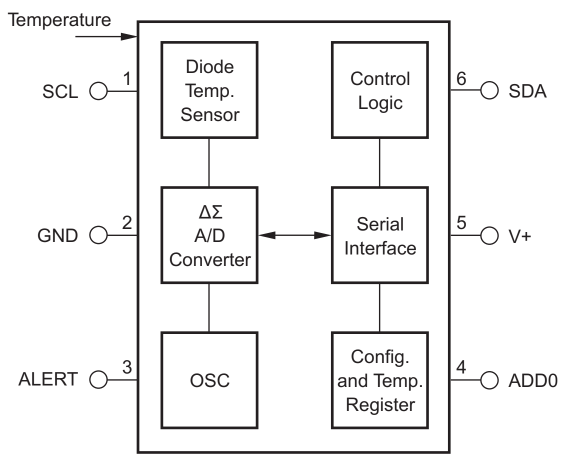


**Figure 3. TMP102 Block Diagram**

# 4 System Design Theory

The CC2650 µTag is designed to be as small as possible, and to run off of a CR1620 coin cell. As such it makes a good starting point for any application where size is the prime focus.

As with any RF design, reducing the physical size of the board, and thus the available area for antenna and ground plane, will affect the RF performance. This design utilizes a very compact chip antenna from Johanson Technology™ that offers great performance within the physical limits of the board, but has the same range as larger boards.

CR1620 coin cell batteries offers limited capacity, and the life time of the battery is also greatly affected by peak current consumption. Make sure to keep the current draw in mind when designing the system SW.

## 4.1 Physical Board Size and Components

The PCB is designed to be compact, thus, the design uses as physically small components as possible. For passives, this means that 0201 components are used wherever possible. Some components, such as the DCDC output inductor and capacitor, are in 0603 and 0402 sizes due to the large inductance and capacitance, but these are still smaller than for the regular CC2650 reference design.

The RF output configuration used on the board is a single-ended output with an internal bias. This configuration only requires 4 components on the RF output, one pi-filter, and a DC blocking capacitor. Additionally, there is an added one shunt component close to the antenna for antenna tuning.

Although the PCB is physically small, the board only has 2 copper layers. Minimum copper width and clearance is 0.1 mm and 0.1 mm.

The CC2650 is used in the 4x4 mm QFN package. At the time of writing, a WCSP variant of CC2640 is planned for release in the 3rd quarter of 2016. This package is also an alternative for ultra-compact designs.

## 4.2 24 MHz Crystal

The crystal used is a 2016 size variant from NDK. The crystal is 60% smaller than the 3225 size crystal used in the regular CC2650 reference designs. When selecting physically small crystals, keep in mind that parameters such as $ESR_{max}$ (maximum Equivalent Series Resistance) and $L_m$ (Motional Inductance). These typically increase compared to larger crystals which will lead to higher start-up time, and thus higher current consumption. Selecting a crystal with a low $C_L$ (Load Capacitance) value reduces the srart-up time. Thus, TI recommends to use as low a $C_L$ value as possible, especially when using physically small crystals.

## 4.3 RTC (Real Time Clock) Source

To reduce the component footprint as much as possible, the CC2650 µTag does not have a 32 kHz crystal on the board. Instead, the CC2650 uTag uses the internal RC oscillator (RCOSCLF) as a clock source for the RTC. For this solution to be BLE compliant, run a calibration of the RCOSCLF at least once a second for the oscillator to be within the ±500 ppm accuracy.

The increase in RTC tolerance will affect the current consumption of the connected BLE peripheral devices as the active RX time at each connection interval must be increased.

More details about deriving the RTC from the internal RCOSCLF and the calibration routine may be found in an application note available on the CC2640 product page.

## 4.4 Battery

The CC2650 µTag is powered by a CR1620 coin cell battery. Based on the Energizer datasheet these batteries have a typical capacity of 79 mAh, and approximately 800 hours lifetime with a 30 kohm load (approximately 100 uA current consumption). Although the user may think that a BLE device with an average current consumption of 10 uA would get close to 1 year of battery life time, the peak currents in the mA range reduces this, depending on use case.

Further studies of the Energizer datasheet show that adding a pulse current of 6.5 mA for 2 seconds every 2 hours will reduce the capacity by approximately 19%. The pulse current itself is conveniently close to the peak current of the CC2650 when operating the radio; however, the 2 second every 2 hours does not fit any BLE application scenario. A typical use case is advertising on three channels (approximately 4 ms duration of *high* current) every few seconds, or connected as a slave device with connection intervals lasting approximately 2.5 ms at certain intervals.

A practical test was designed to investigate how much life time a CR1620 actually provides for a BLE application. A CC2650EM was connected to a CR1620 battery, and the CC2650 was programmed with a SimpleBLEPeripheral modified to measure the battery voltage at every connection interval. The CC2650EM was connected to a CC2540 USB Dongle with a 1 second effective connection interval (0 slave latency). The CC2540 was controlled by BTool and the battery voltage of the CC2650EM was read out on every connection interval. With this setup, the CR1620 lasted for approximately 3 months.

The experiment above shows that CR1620 coin cell batteries are limited to certain applications with high focus on low power consumption. For example, by very rare RF and active mode activity, or applications where a shorter battery life is acceptable.

**NOTE:** The battery life experiment was performed on a CC2650 running with an RTC derived from the internal RC oscillator. This reduces the RTC accuracy to ±500 ppm, which increases the active RX time on each connection event. For a 1 s effective connection interval, this raises the average current consumption of the CC2650 from approximately 10 uA to approximately 14 uA. Battery life time may potentially be significantly better with 32 kHz crystal as the RTC source.

## 5 Software Design Theory

The CC2650 µTag is intended both for BLE broadcasting and used as a BLE Peripheral. Thus, the SimpleBLEBroadcaster and SimpleBLEPeripheral are both good starting points for developing the software for the board. If the application requires maintaining BLE connections, the 32 kHz RC oscillator calibration must be enabled since the RTC is derived from this clock source. This process is described in an app note available on the CC2640 product page.

## 6 Design Files

All the design files for the CC2650 µTag reference design are available for download from the TI Design page. The CAD tool used for this design is Cadence Allegro.

## 7 References

1. CC2640 SimpleLink *Bluetooth* Smart Wireless MCU (SWRS176A)
2. TMP102 Low-Power Digital Temperature Sensor with SMBus and Two-Write Serial Interface in SOT-563 (SBOS397E)
3. High Frequency Ceramic Solutions, http://johansontechnology.com/datasheets/antennas/2450at07a0100.pdf
4. *NX2016SA (for OA / AV and Short-range Wireless)*http://www.ndk.com/en/products/search/crystal/1189458_1494.html
5. Energizer Datasheet, http://data.energizer.com/PDFs/cr1620.pdf.

## 8 About the Author

**FREDRIK KERVEL** is a manager for the *Bluetooth* Smart Applications team at TI. Fredrik has more than 4 years' experience with developing and testing low power RF designs for 2.4 GHz systems (BLE, RF4CE, Zigbee, and more). Fredrik earned his Master of Science in Electrical Engineering (MSEE) from the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

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