TI Designs
Enhanced Accuracy Battery Fuel Gauge Reference Design for Low-Power Industrial IoT Field Metering

Description

The TIDA-01014 reference design features an enhanced accuracy battery fuel gauge for low-power applications such as *Bluetooth*® enabled wireless IoT field metering devices. This TI Design uses TI's wireless digital multimeter reference design, TIDA-01012, as a platform to demonstrate the enhanced resolution and accuracy battery fuel gauge and also highlights the state-of-battery reporting capabilities of the bq27426 fuel gauge. Furthermore, the TIDA-01014 also features TI's NFC Bluetooth automatic pairing and CapTIvate™ capacitive touch technologies.

Resources

TIDA-01014	Design Folder
bq27426	Product Folder
CC2640	Product Folder
MSP430FR2532	Product Folder
RF430CL330H	Product Folder
SimpleLink™	Tools Folder
TIDA-01012	Design Folder
TIDC-01012	Design Folder

TI E2E™ Community

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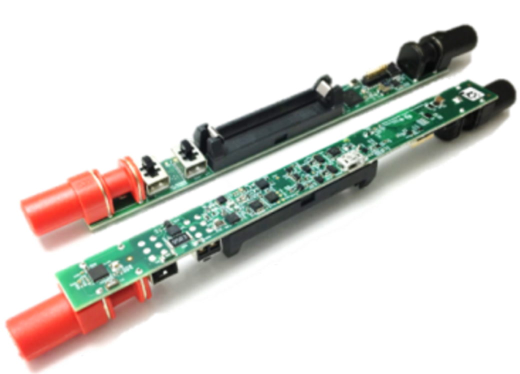
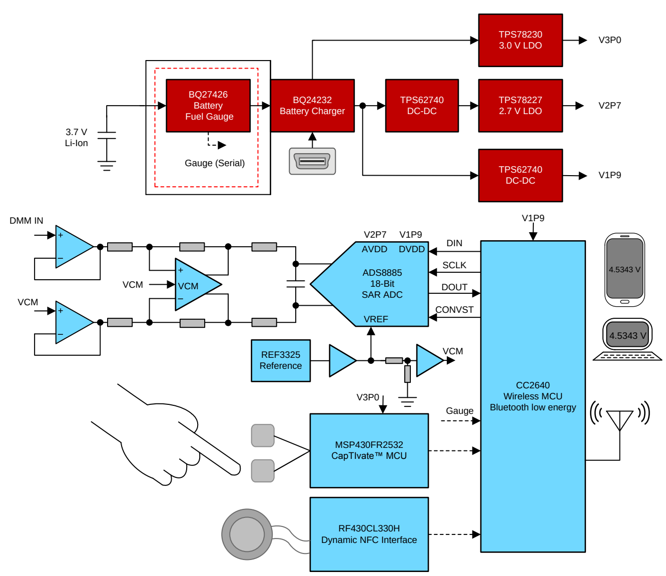


Features

- Monitors Battery Discharge
- Increased Accuracy for Battery Fuel Gauging
- *Bluetooth* low energy (BLE) MCU Enabling Wireless IoT Communication

Applications

- Field Instrumentation
- Battery Management
- Data Acquisition (DAQ)
- Digital Multimeter (DMM)
- Internet of Things (IoT)
- Lab Instrumentation
- Sensors



1 System Overview

1.1 System Description

The Internet of Things (IoT) revolution is efficiently connecting applications and products, enabling battery-powered, wide-scale, very low-power sensor deployment. Industrial field instruments and data acquisition (DAQ) systems deployed throughout and outside factories are remote monitors used to sense and report in any number of environment and operating conditions. New technologies such as TI's advanced sensor and low-power connectivity devices are enabling these instruments to be designed as battery-powered wireless systems, dramatically improving cost, deployment, reliability, performance, and complexity. As a result, battery management design, specifically for low-power systems, becomes a new and important challenge for remote wireless, battery-powered, instrumentation system designers.

To ensure battery-powered, remote field instruments are reliable and perform quality measurements, understanding the battery's state of charge (SoC) is important. TI's battery management portfolio consists of numerous products used to ensure proper monitoring and operation. The TI bq27426 is a great example of a fuel gauge that requires minimal user-configuration and system microcontroller (MCU) firmware development. While originally targeted for higher current and higher battery capacity applications such as smartphones, the bq27426 can also support lower current applications such as sensor nodes for remote field instruments as demonstrated by this reference design.

Enabled by Texas Instruments' SimpleLink ultra-low power wireless MCU platform, the TIDA-01014 reference design uses the TIDA-01012 wireless digital multimeter (DMM) reference design to demonstrate how the bq27426 can be used to enhance the battery management system's fuel gauge performance and ultimately optimize consumption. The TIDA-01014 features a wirelessly connected, 4½ digit, 100-kHz true RMS DMM with Bluetooth low energy connectivity, NFC Bluetooth pairing, and an automatic wake-up feature enabled by TI's CapTIvate technology. Illustrated in Figure 1, the TIDA-01014 focuses on improving gauging accuracy for low-power applications. This TI Design addresses design theory, component selection, and testing and presents measured results that demonstrate an improved gauging system.

See the TIDA-01012 product page for the full description, design, specification, tests, and results of the wireless DMM reference design.

1.2 Key System Level Specifications

Table 1. Key System Level Specifications

PARAMETER	CONDITIONS	TARGET SPECIFICATION
Remaining capacity error	Over full discharge cycle	±1 mAh
Remaining time error	Over full discharge cycle	±10 minutes

1.3 Block Diagram

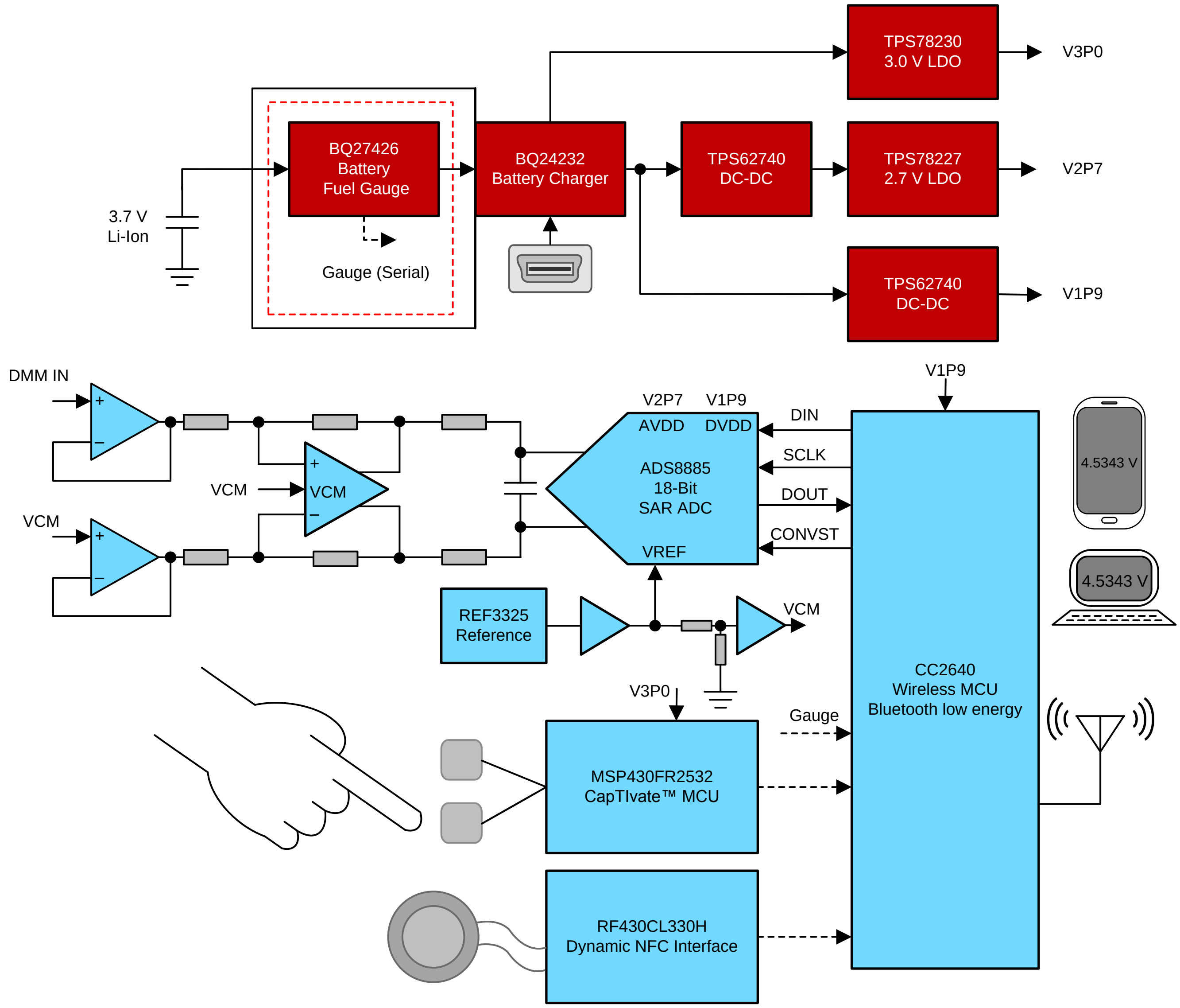


Figure 1. TIDA-01014 Block Diagram

1.4 System Design Theory

To demonstrate how the TIDA-01014 improves fuel gauge reporting accuracy, this TI Design improves coulomb measurement resolution by increasing the fuel gauge's sense resistor and adjusting the relevant bq27426 battery discharge profile parameters accordingly. The bq27426's system-side Impedance Track™ fuel gauge feature is capable of reporting numerous battery conditions such as remaining capacity, average current, battery voltage, average power, SoC, and others. This TI Design further calculates and reports the "time remaining" parameter (as a function of remaining capacity, average power, and average voltage).

An LIR2477 Li-Ion coin cell battery was chosen to demonstrate the TIDA-01014 design capabilities (versus the AAA Li-Ion battery used in the TIDA-01012 design). This 3.7-V, 150-mAh coin cell battery is more representative of the type, form factor, and capacity that might be found in sensor and field metering applications.

The bq27426 uses both impedance tracking and coulomb counting techniques to determine state-of-battery parameters. Both of these techniques are dependent on the current measurement accuracy and resolution of the system current flowing through the sense resistor as shown in Figure 2.

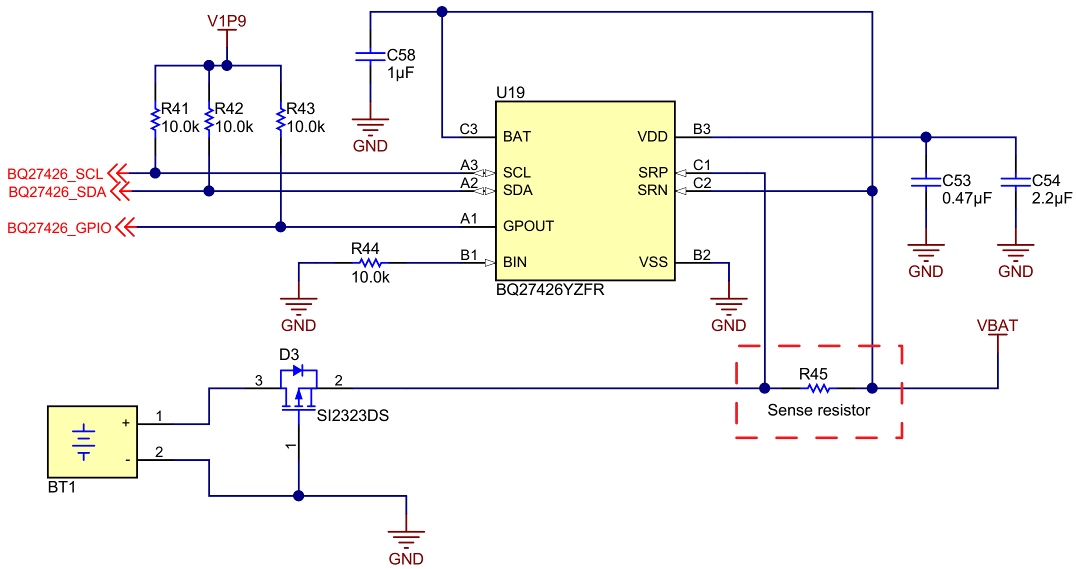


Figure 2. TIDA-01014 Fuel Gauge Circuit Schematic

The bq2746 standard sense resistor value is 10 mΩ, which provides current measurement resolution down to 1 mA. Low-power applications typically possess currents of ≈ 5 mA or less, resulting in a 1-mA resolution. Such a large resolution can lead to significant fuel gauge measurement errors as illustrated in Figure 3.

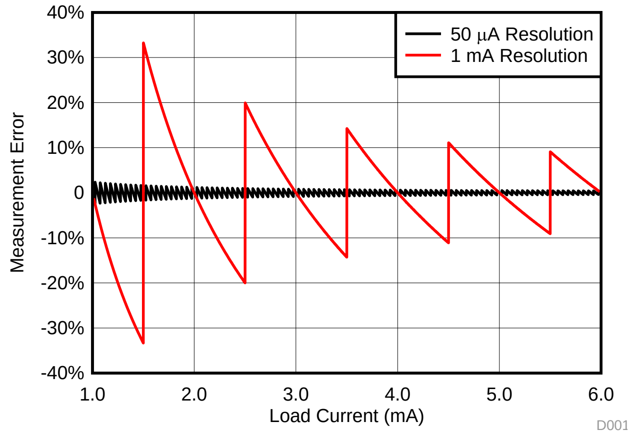


Figure 3. Resolution Measurement Error

Increasing the sense resistor value generates higher voltages for the coulomb counter ADC, which lowers measurement resolution. A 20× scaling factor was chosen for the TIDA-01014 design, resulting in a 50-µA current enhanced measurement resolution using a 200-mΩ sense resistor. Find more details of this scaling technique in the *Enhanced Resolution Gauging for Low Current Application Using Scaling* application note (SLUA792).

The TIDA-01014 fuel gauge circuit topology is slightly different than the TIDA-01012 reference design. As shown in Figure 2, the BAT pin of the bq27426 and its associated bypass capacitor on the TIDA-01014 reference design have been moved to the load side of the sense resistor. This configuration allows the ≈50-µA operating current of the bq27426 to be included in the fuel gauge current measurements, which increases fuel gauging accuracy in this higher resolution, lower power application.

Based on the procedure outlined in the application note and targeted to the TIDA-01014 battery and system charge and discharge currents, the system design parameters are shown in Table 2:

Table 2. System Design Parameters

DESIGN PARAMETER	VALUE
Battery capacity	150 mAh
Nominal battery voltage	3.7 V
Current measurement resolution	50 µA
Average system discharge current range	4 to 6 mA
Charging current	150 mA (max)
Charging voltage	4.2 V
Termination voltage	3.2 V

The bq27426 parameter values shown in Table 3 were chosen to support the system design parameters in Table 2.

Table 3. TIDA-01014 bq27426 Design Parameters

DESIGN PARAMETER	CLASS	SUBCLASS	STANDARD VALUE	SCALED VALUE
Design capacity (mAh)	Gas gauging	State	150	3000(1)
Design energy (mWh)	Gas gauging	State	555	11100(1)
Taper rate (0.1-hr rate)	Gas gauging	State	120	120
Chg current threshold ((0.1-hr rate)	Gas gauging	Current threshold	100	100
Dsg current threshold (0.1-hr rate)	Gas gauging	Current threshold	400	400
Quit current threshold (0.1-hr rate)	Gas gauging	Current threshold	600	600
V at chg term (mV)	Chemistry info	Chem data	4192	4192
Taper voltage (mV)	Chemistry info	Chem data	4100	4100

(1) 20× scaling factor applied as described in Section 6.3 of the application note *Enhanced Resolution Gauging for Low Current Applications Using Scaling* (SLUA792)

1.5 Highlighted Products

The TIDA-01014 reference design features the bq27426, CC2640, RF430CL330H, and MSP430FR2532 devices.

For a full list of devices, see Section 3.1 of the TIDA-01012 design guide (TIDUBV5). For more information on each of these devices, see their respective product folders at www.TI.com.

1.5.1 bq27426

The bq27426 is a single-cell battery gauge with a pre-programmed chemistry profile. The bq27426 fuel gauge accurately predicts the battery capacity and other operational characteristics of a single Li-based rechargeable cell using patented Impedance Track technology. The device can be interrogated by a system processor to provide cell information such as SoC.

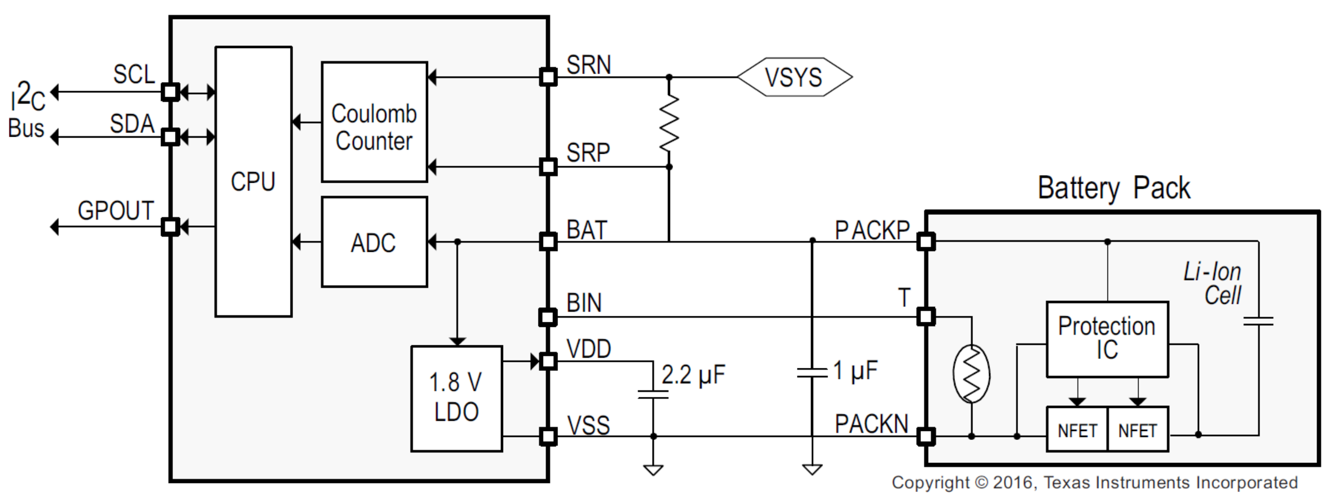


Figure 4. bq27426 Functional Block Diagram

The bq27426 battery gauge features the option of three selectable pre-programmed profiles for 4.20-V, 4.35-V, and 4.40-V cells. The device also reports the remaining capacity and SoC with a smoothing filter. It adjusts automatically for battery aging, self-discharge, temperature, and rate changes while estimating battery state-of-health (aging). The part supports the 400-kHz I^2C serial interface.

Find the full device features and specifications at the bq27426 product folder.

1.5.2 CC2640

The CC2640 device is a wireless MCU targeting Bluetooth low energy applications. The device is a member of the CC26xx family of cost-effective, ultra-low-power, 2.4-GHz RF devices. A 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 CC2640 device contains a 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. This 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. Thus, the CC2640 device is ideal for a wide range of applications where long battery lifetime, small form factor, and ease of use is important. The Bluetooth low energy controller is embedded into ROM and runs partly on an ARM Cortex-M0 processor. This architecture improves overall system performance and power consumption and frees up flash memory for the application.

The CC2640 wireless MCU with a 12-Bit, 200-ksps ADC is an ultra-low-power controller with 100 nA of shutdown current and supports up to a 48-MHz clock speed. The CC2640 has a 2.4-GHz RF transceiver compatible with the Bluetooth low energy 4.2 Specification. This device also features four 32-bit general-purpose timer modules and a 12-bit ADC at 200-ksps with an 8-channel analog mux. The CC2640 also has UART, 2xSSI (SPI, Microwire, TI), I^2C, and I^2S communication peripherals.

Find the full device features and specifications at the CC2640 product folder.

1.5.3 RF430CL330H

The Dynamic NFC Interface Transponder RF430CL330H is an NFC Tag Type 4 device that combines a wireless NFC interface and a wired SPI or I^2C interface to connect the device to a host.

The NDEF message in the SRAM can be written and read from the integrated SPI or I^2C serial communication interface and can also be accessed and updated wirelessly through the integrated ISO14443B-compliant RF interface that supports up to 848 kbps.

This operation allows NFC connection handover for an alternative carrier like Bluetooth, Bluetooth low energy, and Wi-Fi® as an easy and intuitive pairing process or authentication process with only a tap. As a general NFC interface, the RF430CL330H enables end equipment to communicate with the fast-growing infrastructure of NFC-enabled smart phones, tablets, and notebooks.

Find the full device features and specifications at the RF430CL330H product folder.

1.5.4 MSP430FR2532

The MSP430FR263x and MSP430FR253x are FRAM-based ultra-low-power MSP MCUs that feature CapTIvate touch technology for buttons, sliders, wheels (BSW), and proximity applications. CapTIvate technology provides the highest resolution capacitive-touch solution in the market with high reliability and noise immunity at the lowest power. CapTIvate technology supports concurrent self-capacitance and mutual-capacitance electrodes on the same design for maximum flexibility. Using the CapTIvate Design Center, engineers can quickly develop BSW applications with an easy-to-use GUI.

The TI MSP family of low-power MCUs consists of several devices that feature different sets of peripherals targeted for various applications. Combined with extensive low-power modes, the architecture is optimized to extend battery life in portable measurement applications. The MCU 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 the MCU to wake up from low-power modes to active mode typically in less than 10 µs.

This part enables the use of CapTIvate, TI's innovative capacitive-touch technology, enabling the power-down and wake-up feature for this TI Design while maintaining the typical low-power consumption of the MSP430™ family.

Find full device features and specifications at the MSP430FR2532 product folder.

2 Getting Started Hardware and Firmware

2.1 Hardware

Figure 5 highlights the various features of the TIDA-01014 hardware.

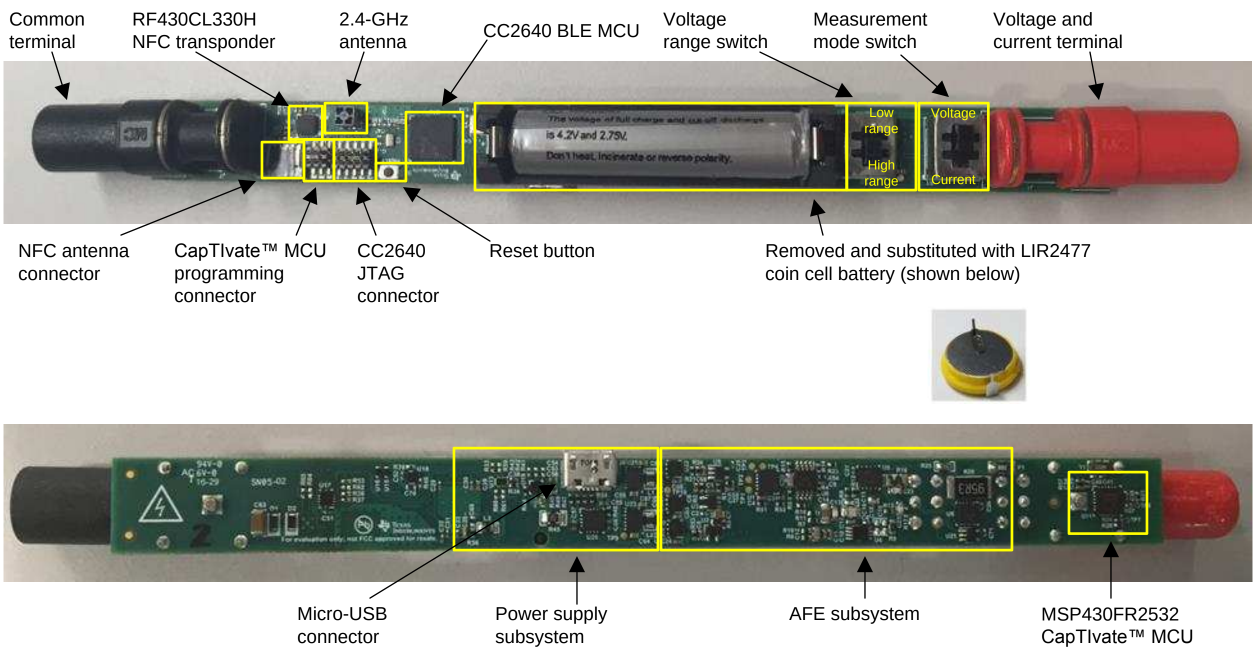


Figure 5. TIDA-01014 Hardware Features

2.1.1 Hardware Operation Overview

After the CC2640 firmware has loaded through the procedure outlined in Section 6.2 in the TIDA-01012 design guide, the board hardware and firmware can be initialized by momentarily pressing the reset button. The system will enter its active state and begin sending advertisement beacons for Bluetooth low energy, waiting for a host environment to recognize the system and begin the Bluetooth low energy connection process.

The TIDA-01014 will continue Bluetooth low energy advertisements for approximately 15 minutes. If a host has not initiated a connection within that time, the TIDA-01014 will automatically power down to conserve battery life. When in this power-down mode, the TIDA-01014 no longer sends Bluetooth low energy advertisement packets and, therefore, cannot connect to a host until the system returns to active mode through a CapTIvate event or the reset button is pressed. If a Bluetooth low energy connection is established, the auto-power down counter is reset and will remain in a reset state until a Bluetooth low energy disconnect event occurs.

When Bluetooth low energy connects with a host, the TIDA-01014 will begin streaming both DC and AC measurement data to the host at approximately 6.5 samples per second. The TIDA-01014 will also send state-of-battery information to the host at approximately 2 samples per minute. Battery status information includes average current, voltage, power, nominal available capacity, remaining capacity, full available capacity, full charge capacity, state of charge, state of health, temperature, and status flag register values.

The TIDA-01014 firmware also monitors the voltage range and measurement mode switches and sends the new state of these switches to the host when a change has been detected. The host will respond back to the TIDA-01014 with appropriate voltage or current range settings.

Initiating battery charges is accomplished by simply plugging in a powered Micro-USB cable to the TIDA-01014 USB port. The TIDA-01014 becomes completely operational when powered through the USB port, regardless of the state of the battery. Battery charge state is constantly monitored by the bq27426 battery gauge device.

NOTE: Because the TIDA-01014 reference design is focused primarily on measurement performance metrics, limited overvoltage and overcurrent protection mechanisms have been implemented in this TI Design. The AFE includes a resettable fuse in the current measurement portion of the AFE to prevent against excessive current into the board. However, input overvoltage protection is not included on the voltage input section.

Also, because the TIDA-01014 reference design uses the same terminals for both current and voltage measurements, take care when setting or changing the measurement mode switch when a device under test is connected to ensure overvoltage and overcurrent limits are not exceeded.

See the TIDA-01012 design guide for more information.

2.2 Host Environment (Android™ App)

The TIDC-01012 Android application (Industry 4.0 NFC and Bluetooth low energy User Interface Reference Design for IoT Metering) was selected as the host application for the TIDA-01014 design. Versions 2.0 or higher support the TIDA-01014 features. See this device's design guide for installation and feature details.

The TIDC-01012 application monitors and reports the following fuel gauge measurements:

- Nominal Available Capacity (mAh): Uncompensated (less than C/20 load) remaining battery capacity
- Full Available Capacity (mAh): Uncompensated (less than C/20 load) capacity of the battery when fully charged
- Remaining Capacity (mAh): Filtered remaining battery capacity compensated for load and temperature
- Full Charge Capacity (mAh): Filtered, load and temperature compensated capacity of the battery when fully charged
- Voltage (mV): Measured battery voltage
- Average Current (mA): Average current flow through the sense resistor
- Average Power (mW): Average power during the charging or discharging of the battery
- State of Charge (%): Predicted remaining battery capacity expressed as a percentage of Full Charge Capacity with a range of 0 to 100%
- Temperature (°K): Internal temperature sensor reading in units of 0.1°K
- State of Health (%): Battery state of health expressed as a percentage from 0% to 100%

See the bq27426 technical reference manual for more details about these measurements, as well as other bq27426 features and measurement types.

In addition to these bq27426 measurement readings, the TIDA-01014 reference design also calculates and reports a "Remaining Time" measurement:

- Remaining Time (hours): Estimated remaining charge time assuming the present system operating mode and system current load

Because the TIDA-01012 hardware design uses DC-DC converters to maximize system power efficiency, the system load presented to the battery is essentially a constant power load. Therefore, Remaining Time can be approximated using Equation 1:

$$\text{Remaining\_Time} = \frac{\text{Remaining\_Capacity} \times \text{Remaining\_Average\_Voltage}}{\text{Average\_Power}} \quad (1)$$

where:

- Remaining_Capacity is the value read from bq27426
- Average_Power is the value read from bq27426
- Remaining_Average_Voltage is the estimated battery voltage from present state to end of discharge (to 3.2 V)

For the TIDA-01014 design, Remaining_Average_Voltage is determined by estimating the average voltage along the remaining battery discharge path as shown in Figure 6.

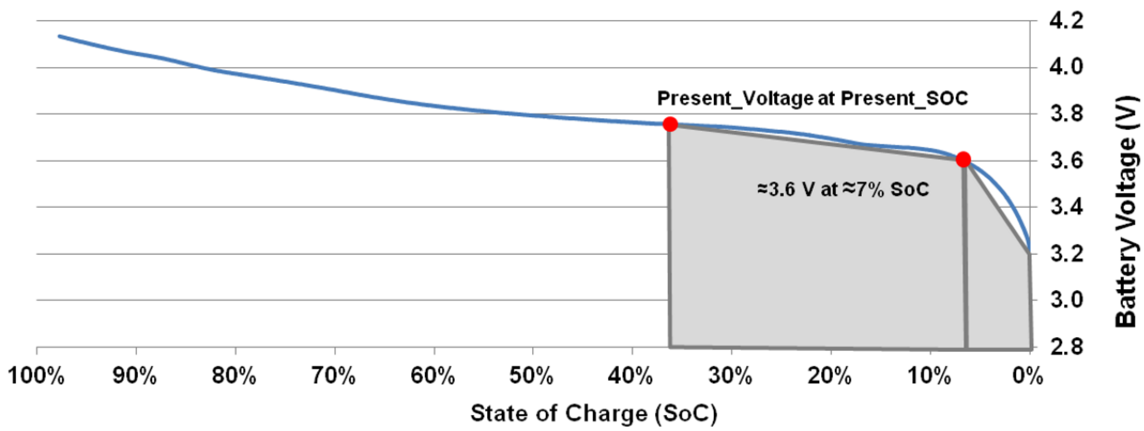


Figure 6. Remaining Average Voltage Estimation

As shown in Figure 6, characterization of the LIR2477 battery shows that the knee of the discharge curve occurs at approximately 7% SOC. The battery voltage at this point is ≈ 3.6 V. The Remaining_Average_Voltage for the example in Figure 6 can be estimated using Equation 2:

$$\text{Remaining\_Average\_Voltage} = \frac{\frac{(\text{Present\_Voltage} + 3.6)}{2} \times (\text{Present\_SOC} - 7\%) + \frac{(3.6 + 3.2)}{2} \times 7\%}{\text{Present\_SOC}} \quad (2)$$

If the present SoC is less than 7%, the equation reduces to:

$$\text{Remaining\_Average\_Voltage} = \frac{(\text{Present\_Voltage} + 3.2)}{2} \quad (3)$$

Achieve a more precise estimation by defining more piece-wise linear points along the curve.

Figure 7 illustrates examples of the TIDC-01012 Android application GUI highlighting the measurement readings and logging functions. See the TIDC-01012 design guide for more detailed information.

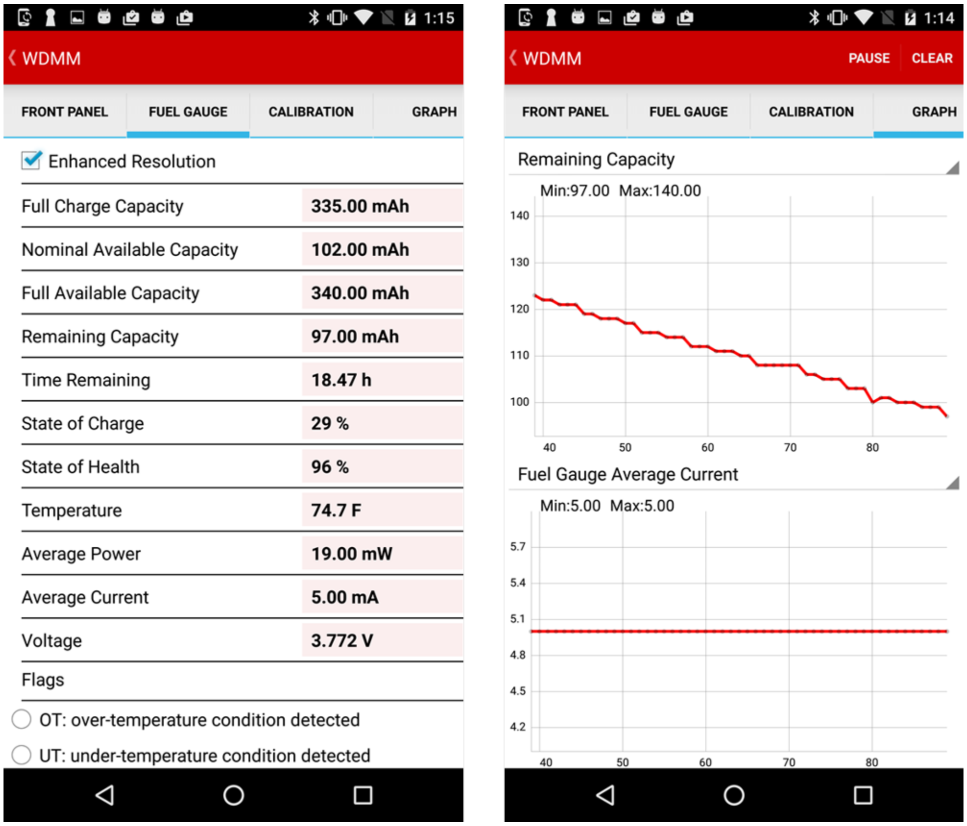


Figure 7. TIDC-01012 Fuel Gauge Snapshots

2.3 *Firmware*

The TIDA-01014 firmware is a revision of the TIDA-01012 firmware, which supports the bq27426 features demonstrated in the TIDA-01014 reference design. See Sections 6.1 to 6.2 of the TIDA-01012 design guide for instructions on compiling and loading the TIDA-01014 firmware.

3 Testing and Results

The following sections describe the test setups, procedures, and performance results for the various tests that were performed on the TIDA-01014 reference design board.

3.1 *LIR2477 Battery Characterization Test Setup and Procedure*

The first step involves characterizing the LIR2477 battery to establish the unique battery cell parameters associated with this battery type.

The following test equipment was used for LIR2477 battery characterization with configuration shown in Figure 8:

- bq27426 EVM
- LIR2477 battery

See the bq27426EVM-738 user's guide for details on its setup and use.

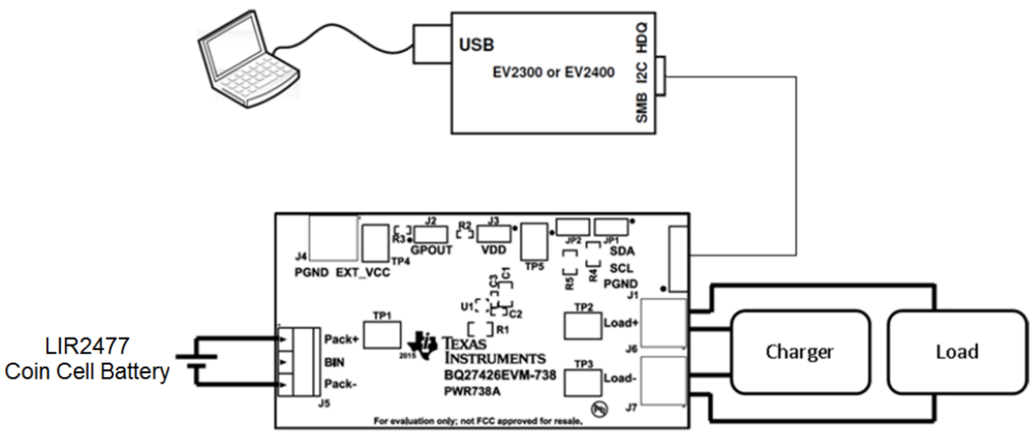


Figure 8. LIR2477 Characterization Setup

After setting up and launching the bq27246 EVM application, the user defined parameters shown in Table 3 were input in the appropriate locations in the application. The LIR2477 was then cycled through a full charge and discharge cycle to allow the bq27246 to "learn" the LIR2477 battery cell parameters. The resulting parameters were then exported to a gm.fs file for a subsequent import to the TIDA-01012 CC2640 firmware to support the test measurements described in this design guide.

Because the purpose of the TIDA-01014 reference design is to compare the relative performance of the bq27426 fuel gauging with standard and enhanced resolution configurations, *the LIR2477 characterization process must be performed with both 10-mΩ and 200-mΩ sense resistor configurations.*

3.2 TIDA-01014 Fuel Gauge Test Setup and Measurements

The following test equipment was used for capturing, reporting, and evaluating the performance of the TIDA-01014 reference design:

- Agilent™ 34401A multimeters
- GPIB-to-USB interface
- USB dongle
- USB cable
- PC
- LIR2477 battery (used in Section 3.1)

LabVIEW™ was chosen as the measurement environment (instead of the TIDC-01012 application) in order to leverage LabVIEW instrumentation capabilities for the Agilent multimeters. The test setup is shown in Figure 9.

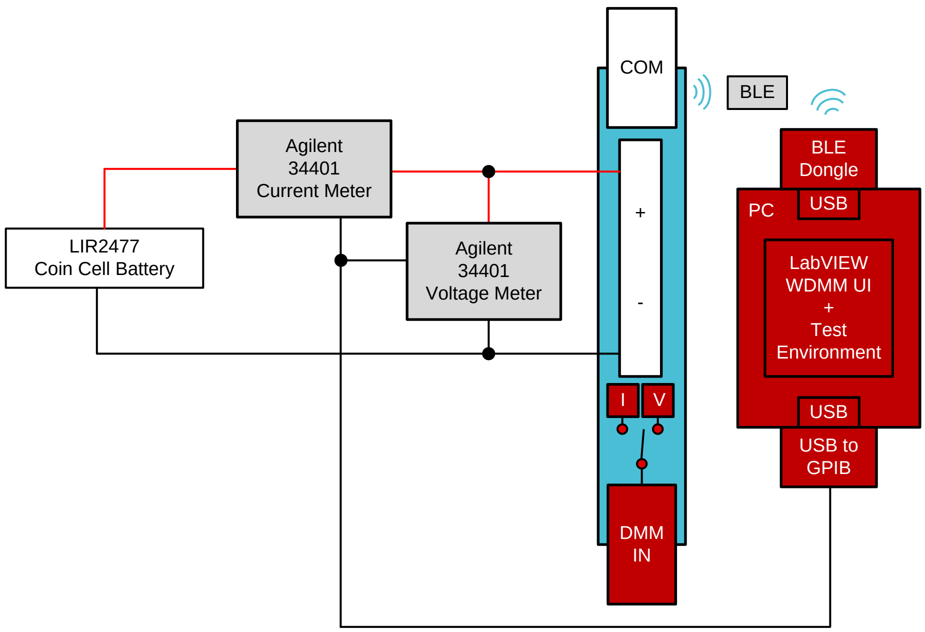


Figure 9. Fuel Gauge Test Setup

The basic measurement capture process is as follows:

1. Set up the system according to Figure 9.
2. Fully charge the LIR2477 using the micro-USB cable.
3. Launch the LabVIEW environment and establish a Bluetooth low energy connection with the TIDA-01014 hardware under test.
4. Using a 30-second read interval, begin logging the bq27426 Remaining_Capacity, Average_Current, Voltage, and Average Power readings, along with the Agilent 34401 current and voltage readings.
5. After a full discharge (to a 3.2-V battery voltage), export the log data to Excel® to calculate and compare the bq27426 fuel gauge readings to actual results based on the Agilent 34401 log data.
6. Complete Steps 1 to 5 for 10-mΩ and 200-mΩ configurations and create the Remaining Capacity Error and Remaining Time Error graphs accordingly.

3.2.1 Test Results and Conclusions

The following graphs show the measurement error associated with the standard resolution (10 mΩ) and enhanced resolution (200 mΩ) configurations. In each case, the battery starts fully charged and is through its full discharge cycle. The error values in all of these plots are represented in terms of estimated performance values (based on bq27426 readings) minus actual performance values (based on the Agilent multimeter log data).

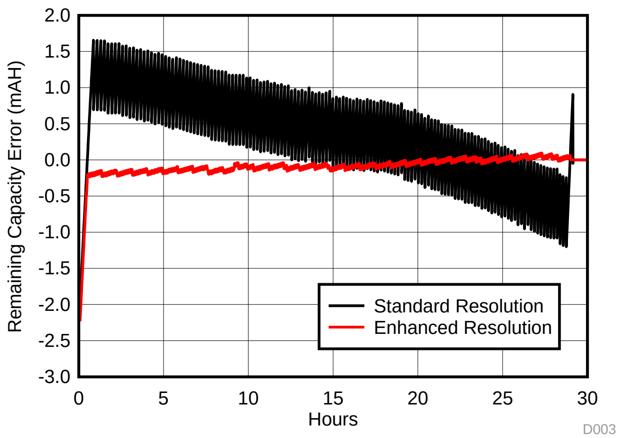


Figure 10. Remaining Capacity Error

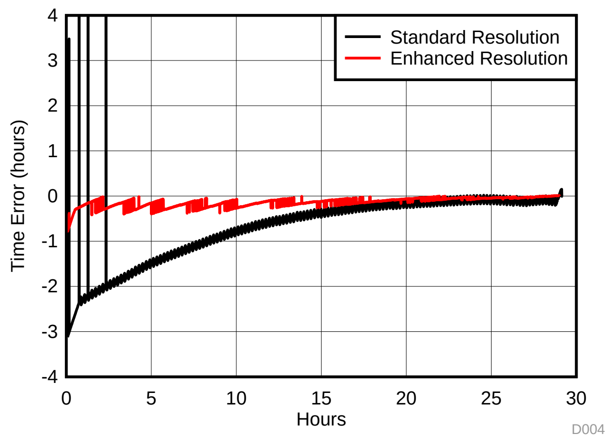


Figure 11. Remaining Time Error

As the graphs illustrate, the remaining capacity and remaining time error associated with the enhanced resolution configuration is significantly lower and more consistent across the full discharge cycle.

The improved performance is especially highlighted in the early hours of Figure 11, where the large measurement error spikes of the standard resolution results correspond to the fuel gauge current measurements at a 1-mA resolution boundaries as shown in Figure 12.

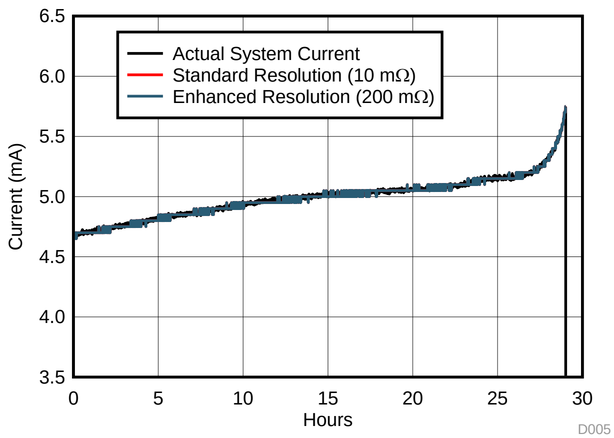


Figure 12. Average Current Measurements

Note that after the initial ≈1-hour stabilization period, the remaining capacity error is a positive value while the remaining time error is negative. This seems counterintuitive because the positive remaining capacity should result in a positive remaining time. However, as shown in Figure 12, the reported bq27426 current measurement during this time is higher than the actual average current. Therefore, this higher bq27426 measurement value overcompensates for the remaining capacity error by significantly lowering the estimated time remaining calculation, causing the remaining time error (or delta) to become negative.

Note that this performance delta will become even more significant in systems and applications that consume even lower power as shown by the increased measurement error in Figure 3.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01014.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01014.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01014.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01014.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01014.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01014.

5 Software Files

To download the software files, see the design files at TIDA-01014.

6 References

1. Texas Instruments, *bq27426EVM-738 User's Guide* (SLUUBE1)
2. Texas Instruments, *bq27426 Technical Reference Guide* (SLUUBB0)
3. Texas Instruments, *Enhanced Resolution Gauging for Low Current Application Using Scaling*, bq27426 Application Report (SLUA792)
4. Texas Instruments, *Wireless IoT, Bluetooth® low energy, 4½ Digit, 100-kHz True RMS Digital Multimeter Reference Design*, TIDA-01012 Design Guide (TIDUBV5)
5. Texas Instruments,*Industry 4.0 NFC and Bluetooth low energy User Interface Reference Design for IoT Metering*, TIDC-01012 Design Guide (TIDUCM2)

6.1 Trademarks

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7 Terminology

IoT— Internet of Things

BLE— Bluetooth low energy

NFC— Near field communication

8 About the Authors

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9 Appendix: BLE Profile Characteristics and Attributes

Table 4. TIDA-01014 BLE Profile Attribute Table

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
1	0x2800	GATT Primary Service Declaration				
2	0x2803	GATT Characteristic Declaration				
3	0x2A00	Device Name			—	
4	0x2803	GATT Characteristic Declaration				
5	0x2A01	Appearance			—	
6	0x2803	GATT Characteristic Declaration				
7	0x2A04	Preferred Connection Parameters			—	
8	0x2800	GATT Primary Service Declaration				
9	0x2800	GATT Primary Service Declaration				
10	0x2803	GATT Characteristic Declaration				
11	0x2A23	System ID			—	
12	0x2803	GATT Characteristic Declaration				
13	0x2A24	Model Number String			TIDA-01012 TIDesign	
14	0x2803	GATT Characteristic Declaration				
15	0x2A25	Serial Number String			Serial Number	
16	0x2803	GATT Characteristic Declaration				
17	0x2A26	Firmware Revision String			Firmware Rev: 1.0	
18	0x2803	GATT Characteristic Declaration				
19	0x2A27	Hardware Revision String			Hardware Rev: 1.0	
20	0x2803	GATT Characteristic Declaration				
21	0x2A28	Software Revision String			Software Rev: 1.0	
22	0x2803	GATT Characteristic Declaration				
23	0x2A29	Manufacturer Name String			Texas Instruments	
24	0x2803	GATT Characteristic Declaration				
25	0x2A2A	IEEE 11073-20601 Regulatory Certification Data List			Experimental	
26	0x2803	GATT Characteristic Declaration				

Table 4. TIDA-01014 BLE Profile Attribute Table (continued)

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
27	0x2A50	PnP ID			—	
28	0x2800	GATT Primary Service Declaration				
29	0x2803	GATT Characteristic Declaration				
30	0x1F2B[(1)]	DC Reading	R	4	—	INT32
31	0x2902	DC_Reading Notification Control	W	2	—	UINT16
32	0x2803	GATT Characteristic Declaration				
33	0xDE2F[(1)]	AC Reading	R	8	—	INT64
34	0x2902	AC Reading Notification Control	W	2	—	UINT16
35	0x2803	GATT Characteristic Declaration				
36	0x5D3D[(1)]	Voltage Range 1 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
37	0x2803	GATT Characteristic Declaration				
38	0x44B6[(1)]	Voltage Range 2 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
39	0x2803	GATT Characteristic Declaration				
40	0xDB69[(1)]	Voltage Range 3 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
41	0x2803	GATT Characteristic Declaration				
42	0x0602[(1)]	Voltage Range 4 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
43	0x2803	GATT Characteristic Declaration				
44	0x4084[(1)]	Current Range 1 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
45	0x2803	GATT Characteristic Declaration				
46	0xD358[(1)]	Current Range 2 Cal Constants	R/W	12	—	FLOAT, INT32, INT32[(2)]
47	0x2803	GATT Characteristic Declaration				
48	0xACE3[(1)]	Initiate Power Down	W	1	—	UINT8
49	0x2803	GATT Characteristic Declaration				
50	0xE636[(3)]	Voltage Range Select	W	1	—	UINT8
51	0x2803	GATT Characteristic Declaration				
52	0x76FF[(3)]	Voltage Range Mode	R	1	—	UINT8
53	0x2902	Voltage Range Mode Notification	W	2	—	UINT16
54	0x2803	GATT Characteristic Declaration				
55	0xDB7F[(3)]	Measurement Mode	R	1	—	UINT8
56	0x2902	Measurement Mode Notification	W	2	—	UINT16
57	0x2803	GATT Characteristic Declaration				

(1) "XXXX" subset of the 128-bit F000-XXXX-0451-4000-B000-0000-0000-0000 UUID
(2) Gain, DC_Offset, AC_Offset
(3) "XXXX" subset of the 128-bit F000-XXXX-0451-4000-B000-0000-0000-0000 UUID

Table 4. TIDA-01014 BLE Profile Attribute Table (continued)

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
58	0x4323(3)	Current Range Select	W	1	—	UINT8
59	0x2803	GATT Characteristic Declaration				
60	0xA367(3)	Battery Capacity Level	R	2	—	UINT16
61	0x2902	Battery Capacity Level Notification	W	2	—	UINT16
62	0x2803	GATT Characteristic Declaration				
63	0x9117(3)	Battery Voltage Level	R	2	—	UINT16
64	0x2902	Battery Voltage Level Notification	W	2	—	UINT16
65	0x2803	GATT Characteristic Declaration				
66	0xFC10(3)	CapTIvate Signal	R	1	—	UINT8
67	0x2902	CapTIvate Notification	W	2	—	UINT16
68	0x2803	GATT Characteristic Declaration				
69	8FF2(3)	Sampling Rate Select				
70	0x2803	GATT Characteristic Declaration				
71	6406(3)	Reporting Rate Select				
72	0x2803	GATT Characteristic Declaration				
73	7C0F(3)	Temperature Compensation V1				
74	0x2803	GATT Characteristic Declaration				
75	23A4(3)	Temperature Compensation V2				
76	0x2803	GATT Characteristic Declaration				
77	3E68(3)	Temperature Compensation V3				
78	0x2803	GATT Characteristic Declaration				
79	7251(3)	Temperature Compensation V4				
80	0x2803	GATT Characteristic Declaration				
81	8A85(3)	Temperature Compensation I1				
82	0x2803	GATT Characteristic Declaration				
83	FB1D(3)	Temperature Compensation I2				
84	0x2803	GATT Characteristic Declaration				
85	A980(4)	Reserved 1				
86	0x2902	Reserved 1 Notification	W	2	—	UINT16
87	0x2803	GATT Characteristic Declaration				
88	EC6D(4)	Reserved 2				
89	0x2902	Reserved 2 Notification	W	2	—	UINT16

(4) "XXXX" subset of the 128-bit F000-XXXX-0451-4000-B000-0000-0000-0000 UUID

Table 4. TIDA-01014 BLE Profile Attribute Table (continued)

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
90	2800	GATT Primary Service Declaration				
91	0x2803	GATT Characteristic Declaration				
92	6B54[4]	Remaining Capacity Unfiltered	R	2		INT16
93	0x2902	Remaining Capacity Unfiltered Notification	W	2	—	UINT16
94	0x2803	GATT Characteristic Declaration				
95	2CEC[4]	Average Power	R	2		INT16
96	0x2902	Average Power Notification	W	2	—	UINT16
97	0x2803	GATT Characteristic Declaration				
98	CE36[4]	Full Charge Capacity	R	2		INT16
99	0x2902	Full Charge Capacity Notification	W	2	—	UINT16
100	0x2803	GATT Characteristic Declaration				
101	DD2A[4]	State of Health	R	2		UINT16
102	0x2902	State of Health Notification	W	2	—	UINT16
103	0x2803	GATT Characteristic Declaration				
104	219D[4]	Internal Temperature	R	2		UINT16
105	0x2902	Internal Temperature Notification	W	2	—	UINT16
106	0x2803	GATT Characteristic Declaration				
107	316D[4]	State of Charge	R	2		UINT16
108	0x2902	State of Charge Notification	W	2	—	UINT16
109	0x2803	GATT Characteristic Declaration				
110	A3FB[4]	Full Charge Capacity Filtered	R	2		INT16
111	0x2902	Full Charge Capacity Filtered Notification	W	2	—	UINT16
112	0x2803	GATT Characteristic Declaration				
113	68D5[4]	Remaining Capacity Filtered	R	2		INT16
114	0x2902	Remaining Capacity Filtered Notification	W	2	—	UINT16
115	0x2803	GATT Characteristic Declaration				
116	B77B[5]	Average Current	R	2		INT16
117	0x2902	Average Current Notification	W	2	—	UINT16
118	0x2803	GATT Characteristic Declaration				
119	927A[5]	Remaining Capacity	R	2		INT16
120	0x2902	Remaining Capacity Notification	W	2	—	UINT16
121	0x2803	GATT Characteristic Declaration				

(5) "XXXX" subset of the 128-bit F000-XXXX-0451-4000-B000-0000-0000-0000 UUID

Table 4. TIDA-01014 BLE Profile Attribute Table (continued)

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
122	F2C0[5]	Full Available Capacity	R	2		INT16
123	0x2902	Full Available Capacity Notification	W	2	—	UINT16
124	0x2803	GATT Characteristic Declaration				
125	0B44[5]	Voltage	R	2		UINT16
126	0x2902	Voltage Notification	W	2	—	UINT16
127	0x2803	GATT Characteristic Declaration				
128	F0F3[5]	Temperature	R	2		UINT16
129	0x2902	Temperature Notification	W	2	—	UINT16
130	0x2803	GATT Characteristic Declaration				
131	26A5[5]	Nominal Available Capacity	R	2		INT16
132	0x2902	Nominal Available Capacity Notification	W	2	—	UINT16
133	0x2803	GATT Characteristic Declaration				
134	8C88[5]	Full Charge Capacity Unfiltered	R	2		INT16
135	0x2902	Full Charge Capacity Unfiltered Notification	W	2	—	UINT16
136	0x2803	GATT Characteristic Declaration				
137	91F2[5]	State of Charge Unfiltered	R	2		UINT16
138	0x2902	State of Charge Unfiltered Notification	W	2	—	UINT16
139	0x2803	GATT Characteristic Declaration				
140	6FED[5]	Flags	R	2		UINT16
141	0x2902	Flags Notification	W	2	—	UINT16