TI Designs
Industry 4.0 NFC and Bluetooth® low energy User Interface Reference Design for IoT Metering

Description

This TI Design demonstrates *Bluetooth*® low energy (BLE) connectivity between TI’s CC2640 wireless microcontroller (MCU) and an Android™ device by interfacing with the TIDA-01012 wireless digital-multimeter (WDMM) to interactively display measurements. The design also demonstrates automated pairing using the RF430CL330H dynamic near-field communication (NFC) transponder. This software design utilizes the TIDA-01012 WDMM hardware as a platform to show how the human-machine interface (HMI) can easily be enhanced, adding meaningful features and significantly lowering product costs associated with metering using TI's wireless connectivity solutions. This design also describes fundamental development theories to guide users through source code generation and optimization. In summation, this design presents the source code, display presentation, testing, and results.

Resources

TIDC-01012	Design Folder
CC2640	Product Folder
RF430CL330H	Product Folder
TIDA-01012	Product Folder

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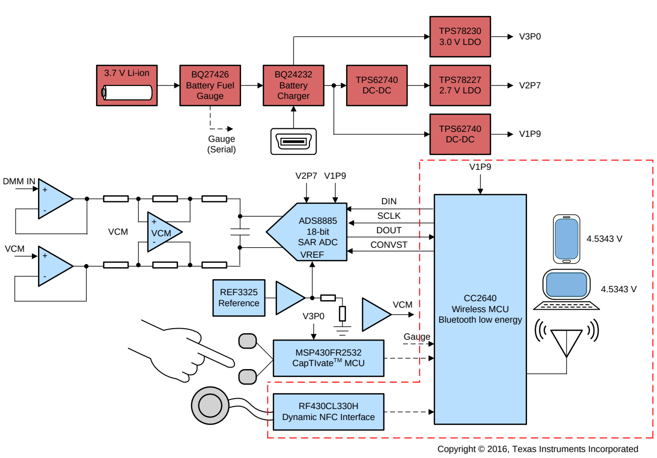
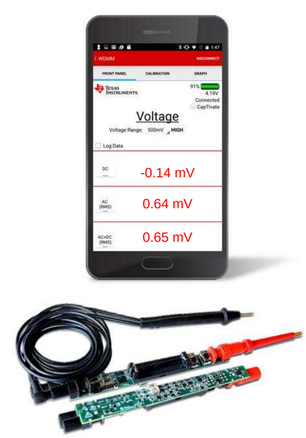
Features

- Replaces Input and Output User Interface Subsystem of WDMM With Android Device, Minimizing Board Size and Cost
- Available Source Code Enables Easy Process for Developers to Create Personalized Applications for Wireless Meters
- Automated BLE Pairing Through NFC
- Displays Basic DMM Measurement Modes:
  - Voltage: 50 V, 5 V, 500 mV, and 50 mV
  - Current: 50 mA and 500 µA
- Calibration Support
- Graphical Display Provides Ability to Graph AC and DC Measurements
- Application Available on Google Play™ Store

Applications

- Digital Multimeter (DMM)
- Internet of Things (IoT)
- Industrial Lab Instrumentation
- Industrial Field Instrumentation
- Wireless Instrumentation





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1 System Overview

1.1 System Description

This TI Design highlights the capabilities of TI's CC2640 wireless MCU and RF430 NFC transponder in enabling the IoT in industrial test equipment. This design demonstrates *Bluetooth* low energy (BLE) connectivity between the CC2640 and an Android device as well as automated pairing using NFC. This design enables Android devices to interface with the TIDA-01012 WDMM reference design to function as the input or output user interface and interactively display readings.

The TIDA-01012 WDMM TI Design demonstrates a wireless 4½ digit, 100-kHz true RMS DMM with BLE connectivity, NFC *Bluetooth* pairing, and an automatic wake-up feature enabled by TI's CapTIvate™ capacitive sense technology. The WDMM comprises numerous subsystems including:

- A wireless MCU for system control, BLE communication, and data processing
- An analog front end (AFE) for signal conditioning of voltage and current measurements
- A dynamic NFC interface
- An ultra-low-power MSP430™ MCU with CapTIvate technology
- System power distribution
- Battery management and monitoring

For more information on the WDMM reference design, please see the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz True RMS Digital Multimeter Reference Design*[1].

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Platform	Android	—
Operating system	Android 4.3 or higher	—
Wireless protocol	BLE	—
	NFC	For automated BLE pairing
Voltage display (DC, AC (RMS)), AC+DC (RMS)	Configurable input ranges	50 mV, 500 mV, 5 V, and 50 V
	Resolution	50000 display counts
		1 uV, 10 uV, 100 uV, and 1 mV
	Update interval	6.5 updates per second
Current display (DC, AC (RMS)), AC+DC (RMS)	Configurable input ranges	500 µA, 50 mA
	Resolution	50000 display counts
		10 nA, 1 µA
	Update interval	6.5 updates per second
Battery gauge display	Battery charge	%
	Battery voltage	V
Measurement logging	Saves to SD card	.txt file
Pseudo real-time interactive graphing	Displays DC and AC (RMS)	—
	Displays sample size, maximum, minimum, and mean	
Calibration support	—	—

1.3 Block Diagram

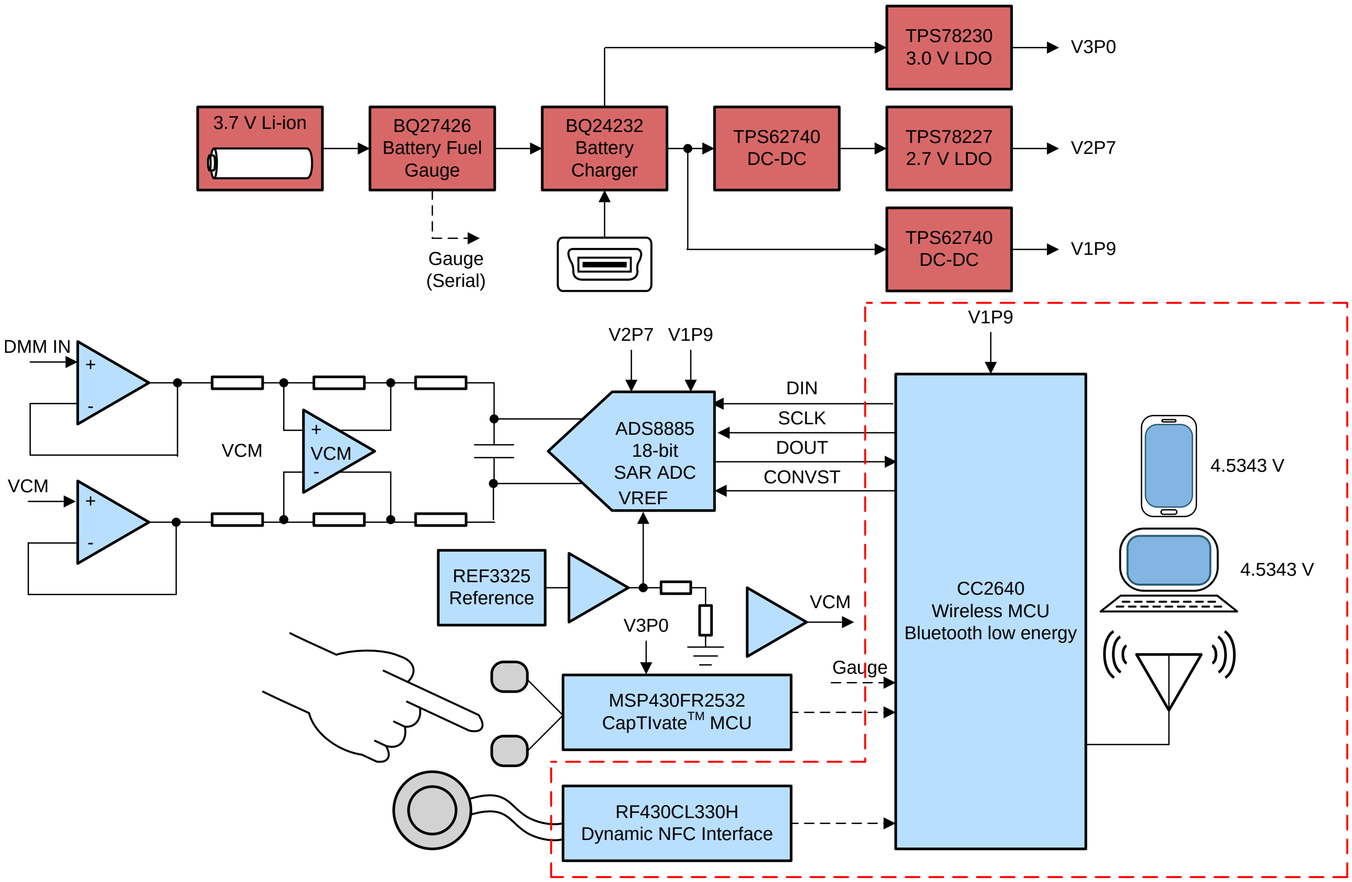

Figure 1. TIDC-01012 Block Diagram

1.4 Highlighted Products

The key devices utilized in this reference design are as follows:

- CC2640: SimpleLink™ platform ultra-low power wireless MCU for BLE
- RF430CL330H: Dynamic dual-interface NFC transponder

1.4.1 CC2640

The CC2640 device is a wireless MCU targeting BLE applications.

The CC2640 device is a member of the CC26xx family of cost-effective, ultra-low-power, 2.4-GHz RF devices. The 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. Figure 2 shows the CC2640 block diagram.

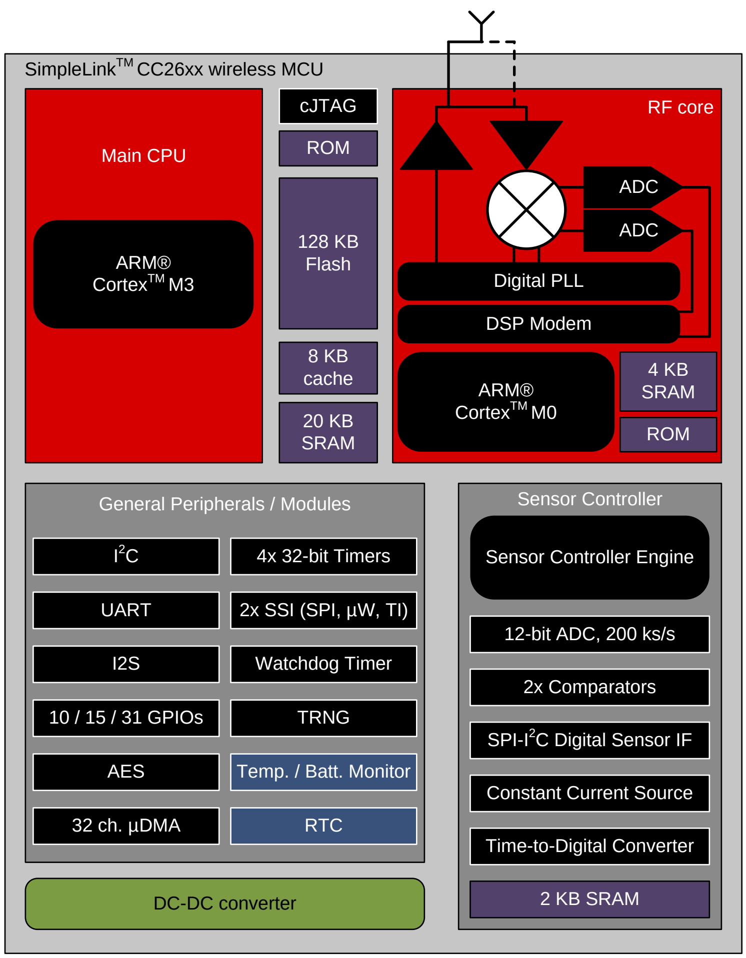

Figure 2. CC2640 Block Diagram

The BLE controller is embedded into read-only memory (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 Bluetooth stack is available free of charge from TI's BLE software stack page.

For more information on this device, see TI's CC2640 product folder.

1.4.2 RF430CL330H

The dynamic NFC interface transponder RF430CL330H from TI is an NFC tag type-4 device that combines a wireless NFC interface and a wired serial peripheral interface (SPI) or I²C interface to connect the device to a host. The NFC data exchange format (NDEF) message in the SRAM can be written and read from the integrated SPI or I²C serial communication interface and can also be accessed and updated wirelessly through the integrated ISO14443B-compliant RF interface that supports up to 848 kbps. Figure 3 shows the RF430CL330H Block Diagram.

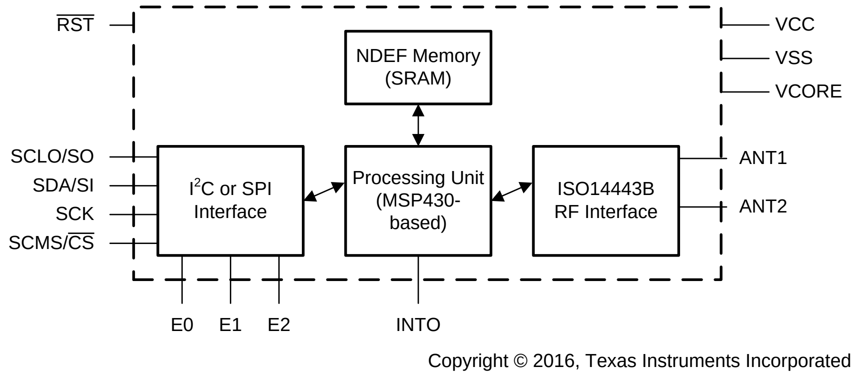

Figure 3. RF430CL330H Block Diagram

This operation allows NFC connection handover for an alternative carrier like BLE 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.

For more information on this device, see TI's RF430CL330H product page.

1.5 System Design Theory

The wireless subsystem on the WDMM consists of the CC2640 wireless MCU and RF430CL330H dynamic NFC transponder and is the focus of this TI Design. By replacing the digital-multimeter traditional input and output user interface with an Android device, this design can achieve considerable enhancements. The Android platform provides a rich, interactive user interface for configuring and viewing measurements on a mobile device such as a smartphone or tablet.

1.5.1 Wireless Digital Multimeter Overview

The TIDA-01012 is the hardware platform used to demonstrate the wireless and connectivity features of the CC2640 and the RF430CL330H. This design showcases the analog front end (AFE), power, and connectivity solutions required to realize a 4.5-digit WDMM. A summary of the design features are given in Table 2. For a full description, please refer to the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz True RMS Digital Multimeter Reference Design*[1].

Table 2 summarizes the features of the WDMM.

Table 2. WDMM Feature Summary

FEATURE	DETAILS
DMM measurement modes	DC and true RMS AC for voltage and current
Voltage ranges	50 V, 5 V, 500 mV, 50 mV
Current ranges	50 mA, 500 µA
Firmware-based true RMS calculations	-
Battery charging and monitoring	Charging though the micro-USB port Reports the state-of-charge and voltage of the lithium ion battery source
Wake-up feature using CapTIvate™ technology	System automatically wakes up from powered down state if touch is detected
NFC enabled BLE pairing	Automated NFC to BLE pairing

1.5.2 BLE Overview

BLE is a low-power wireless standard that is predominantly used in battery-powered applications and where power consumption is a major design consideration. BLE devices use the generic access profile (GAP) and the generic attribute profile (GATT) to advertise, connect, and exchange data.

The *Bluetooth* special interest group (SIG) provides a list of adopted BLE profiles, which are predefined profiles for use in specific applications, such as, heart rate monitoring, and glucose sensing. TI has also developed custom profiles and sample applications for use and included them in the TI BLE stack software development kit (SDK). Some of these applications are based on specifications that have been adopted by the *Bluetooth* SIG, while others are custom implementations developed by TI.

The TI BLE stack does not include a profile for a WDMM application; therefore, a custom BLE profile was implemented in the WDMM reference design.

For more information on TI's custom BLE profiles and creating a custom BLE application, refer to the *CC2640 and CC2650 Bluetooth low energy Software Stack 2.2.1 Developer's Guide*.[2]

1.5.2.1 Terminology

The following subsection provides a summary of key BLE terms:

- **Characteristic** – This contains attributes that include the handle, value, type, UUID, and access permissions.
- **GATT-Based Profile** – This defines a collection of one or more services and how they can be used.
- **GATT Client** – The device that reads from or writes to the GATT server. In this case, the Android device.
- **GATT Server** – The device that contains the characteristics that are read or written. In this case, the WDMM.
- **GATT Service** – This defines a collection of characteristics and how they can be used.
- **Generic Access Profile (GAP)** – This defines how devices advertise and connect to each other.
- **Generic Attribute Profile (GATT)** – This defines how two BLE connected devices transmit and receive data.
- **UUID** – A 16-, 32-, or 128-bit Universal Unique Identifier (UUID) that uniquely identifies every different attribute type.

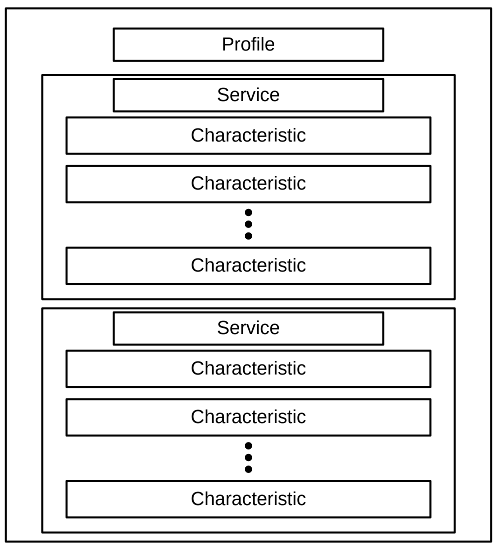

Figure 4. GATT-Based Profile Hierarchy

Understanding the key BLE terms and the hierarchy as shown in Figure 4 is important to developing BLE applications.

1.5.3 WDMM Profile

The custom WDMM profile was implemented in the WDMM reference design by pairing a custom-defined WDMM service with the official SIG device information service. Therefore, the WDMM profile contains two services: the WDMM service and device information service. These services then contain characteristics of their own. The WDMM service contains custom-defined characteristics specific for the DMM application, and the device information service contains the manufacturer information. The characteristics of the WDMM Service are listed in the attribute table in Section 1.5.3.1.

1.5.3.1 BLE Attribute Table

The details of the WDMM service and characteristics are shown in Table 3.

Table 3. TIDA-01012 Attribute Table

ATTRIBUTE HANDLE (DEC)	UUID	DESCRIPTION	READ/ WRITE	LENGTH (BYTES)	VALUE	DATA TYPE
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[(1)]	Voltage range select	W	1	—	UINT8
51	0x2803	GATT characteristic declaration				
52	0x76FF[(1)]	Voltage range mode	R	1	—	UINT8
53	0x2902	Voltage range mode notification	W	2	—	UINT16
54	0x2803	GATT characteristic declaration				
55	0xDB7F[(1)]	Measurement mode	R	1	—	UINT8
56	0x2902	Measurement mode notification	W	2	—	UINT16
57	0x2803	GATT characteristic declaration				
58	0x4323[(1)]	Current range select	W	1	—	UINT8
59	0x2803	GATT characteristic declaration				
60	0xA367[(1)]	Battery capacity level	R	2	—	UINT16
61	0x2902	Battery capacity level notification	W	2	—	UINT16
62	0x2803	GATT characteristic declaration				
63	0x9117[(1)]	Battery voltage level	R	2	—	UINT16
64	0x2902	Battery voltage level notification	W	2	—	UINT16
65	0x2803	GATT characteristic declaration				
66	0xFC10[(1)]	CapTIvate signal	R	1	—	UINT8
67	0x2902	CapTIvate notification	W	2	—	UINT16

(1) The UUID chosen for the WDMM service is based on the following UUID: F000XXXX-0451-4000-B000-0000-0000-0000, where XXXX is the value found in the UUID column of the attribute table.
(2) Gain, DC_Offset, AC_Offset

1.5.4 WDMM BLE Communication

The following subsection describes how to communicate with the WDMM using BLE. As shown in Table 3, characteristics are composed of an attribute handle, UUID, access permission, value, and data type. The relevant WDMM data is stored in the attribute value of the characteristic. To access this data, there are three operations that are used: Read, Write, and Notify.

- Read - The client device requests to retrieve a characteristic stored on the server device. In this application, the Read operation is used when the Android device requires reading a value from the WDMM only once.
- Write - The client device requests to transmit data for a specific characteristic to the server device.
- Notify - The server device transmits data to the client device each time new data is available.

Client device: Android

Server device: WDMM

1.5.4.1 Read

According to the attribute table, the following characteristics have read permissions: *DC Reading*, *AC Reading*, *Voltage Range Mode*, *Measurement Mode*, *Battery Capacity*, *Battery Voltage*, *CapTIvate*, and *Cal Constants*. In the Android application, the Read operation is only utilized during device initialization to retrieve the initial state of the WDMM. The Notify operation is used for all subsequent readings.

1.5.4.2 Write

The *Voltage Range Select*, *Current Range Select*, and *Cal Constants* characteristics have Write permissions. These characteristics enable the Android device to configure the voltage and current range by writing to the respective characteristic. Table 4 and Table 5 show the values that need to be written to the WDMM to select a certain range.

Table 4. Voltage Ranges

VALUE	RANGE
0x01	50 mV
0x02	500 mV
0x03	5 V
0x04	50 V

Table 5. Current Ranges

VALUE	RANGE
0x01	500 µA
0x02	50 mA

1.5.4.3 Notify

The Notify operation enables the WDMM to automatically transmit data each time there is new data available. This operation is utilized for reading the following characteristics: *DC Reading*, *AC Reading*, *Voltage Range Mode*, *Measurement Mode*, *Battery Capacity*, *Battery Voltage*, and *CapTIvate*. Subscribing to notifications requires writing *01 00* to the notification control characteristic. Alternatively, writing *00 00* will disable notifications.

Due to the asynchronous nature of BLE communication, it is recommended that the host device incorporates a queue to catch all transmissions.

1.5.4.4 Characteristic Properties

The characteristic properties provide detail to the client on which operations are permitted for the characteristic. It consists of an 8-bit field as shown in Table 6.

Table 6. Characteristic Properties

Bit	Property
0	Broadcast
1	Read
2	Write Without Response
3	Write
4	Notify
5	Indicate
6	Authenticated Signed Writes
7	Extended Properties

Prior to performing any of the operations listed above, the client device should read the properties to see if the desired operation is supported. If an operation's corresponding bit is set then that operation is supported.

1.5.5 NFC Enabled BLE Pairing

The WDMM reference design features BLE pairing through NFC, enabled by TI's RF430CL330H NFC transponder. This method of pairing requires an Android device with NFC. The pairing sequence is initiated when the Android device's NFC antenna (usually found at the back of the device) is placed in close proximity to the NFC antenna on the WDMM. The RF430 stores the BLE generic access profile (GAP) information as a handover select NDEF message that the Android device then reads. Once the pairing information has been read, the Android device will attempt to pair with the WDMM. BLE pairing with NFC is native to the Android OS; therefore, no action is required by the application to initiate the pairing. Once paired, the Android application needs to take charge of establishing an active communication channel with the WDMM. The flowchart in Figure 5 shows how the RF430 fetches and stores the BLE pairing information from the CC2640.

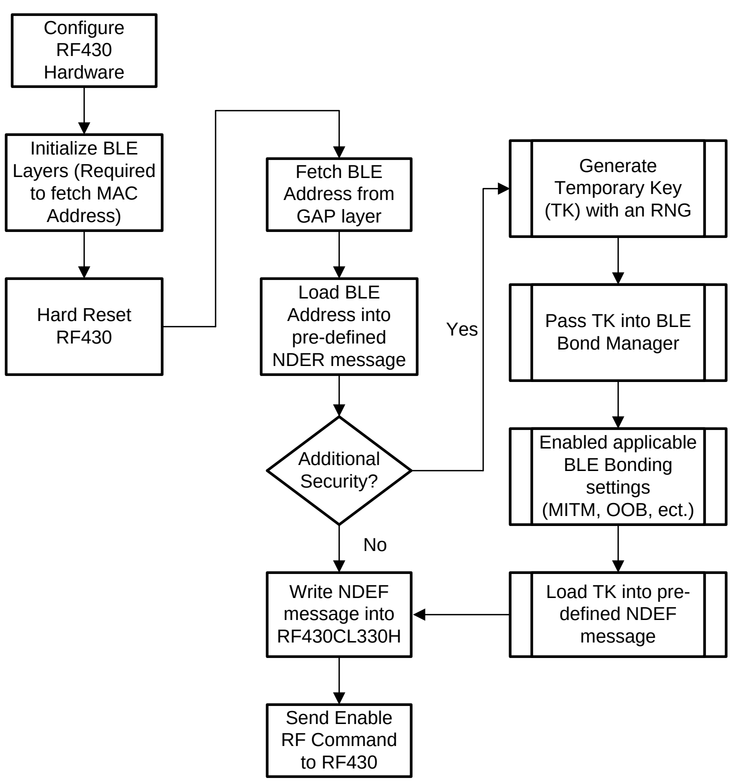

Figure 5. BLE Pairing Sequence Flow Diagram

The NDEF message for initiating BLE pairing is formatted as listed in Table 7.

Table 7. BLE Pairing NDEF Message

DATA	TYPE
0xD2, 0x76, 0x00, 0x00, 0x85, 0x01, 0x01	NDEF Tag Application
CAPABILITY CONTAINER	
0xE1, 0x03	Capability Container (CC) ID
0x00, 0x0F,	CC Length
0x20	Mapping version 2.0
0x00, 0xF9	MLe (49 bytes); Maximum R-APDU data size
0x00, 0XF6,	MLc (52 bytes); Maximum C-APDU data size
0x04,	Tag, File Control TLV (4 = NDEF file)
0x06	Length, File Control TLV (6 = 6 bytes of data for this tag)
0xE1, 0x04	Type 4 Tag File ID
0x0B, 0xDF	Max NDEF Size
0x00	Read Privileges
0x00	Write Privileges
0xE1, 0x04	NDEF File ID
0x00, 0x70	Length of File
NDEF FOR HANDOVER SELECT	
0x91	NDEF Record Holder
0x02	Record Type Length
0x0A	Record Type Length
0x48, 0x73,	Record Type: "hs"
0x12	Version number 1.2
0xD1,0x02,0x04,0x61,0x63,0x01,0x01,0x30,0x00,	
RECORD TYPE NAME = application/vnd.bluetooth.le.oob	
0x5A	NDEF Record Header (TNF = 010b)
0x20	Record Type Name Length = 32 bytes
0x3C	Payload Length (Starts after Payload ID)
0x01	Payload ID Length = 1
0x61, 0x70, 0x70, 0x6C, 0x69, 0x63, 0x61, 0x74, 0x69, 0x6F, 0x6E, 0x2F, 0x76, 0x6E, 0x64, 0x2E, 0x62, 0x6C, 0x75, 0x65, 0x74, 0x6F, 0x6F, 0x74, 0x68, 0x2E, 0x6C, 0x65, 0x2E, 0x6F, 0x6F, 0x62,	Record Type Name
0x30	Payload ID = 0
BLE PAIRING INFORMATION	
DEVICE ADDRESS INFORMATION	
0x07	BLE Device Address length = 6
0x1B	Data Type[1] = BLE Device Address
0xAA, 0xBB, 0xCC, 0xDD, 0xEE, 0xFF	BLE MAC Address – changes dynamically
0x02	LE Role Length
0x1C	Data Type[1] = LE Role
0x00	LE role = Peripheral only
SECURITY	
0x11	Security Key Length
0x10	Data Type[1] = Security Manager TK Value
0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF	Security TK value
DEVICE APPEARANCE	
0x03	Appearance length

Table 7. BLE Pairing NDEF Message (continued)

DATA	TYPE
Appearance length	Data Type[1] = Appearance
0x01, 0x80	0x01, 0x80
DEVICE NAME	
0x1A	Complete Local Name length
0x09	Data Type[1] = Complete Local Name
0x4e, 0x46, 0x43, 0x20, 0x50, 0x61, 0x69, 0x72, 0x65, 0x64, 0x20, 0x42, 0x4c, 0x45, 0x20, 0x50, 0x65, 0x72, 0x69, 0x70, 0x68, 0x65, 0x72, 0x61, 0x6c	Name = NFC Paired BLE Peripheral

When the Android device reads this message, the device will automatically begin the pairing process.

For more information on creating NDEF pairing messages, please see the Bluetooth Generic Access Profile standards and the *Automating Bluetooth Pairing With Near-Field Communications (NFC) Application Report.*[3]

1.5.6 Calculations

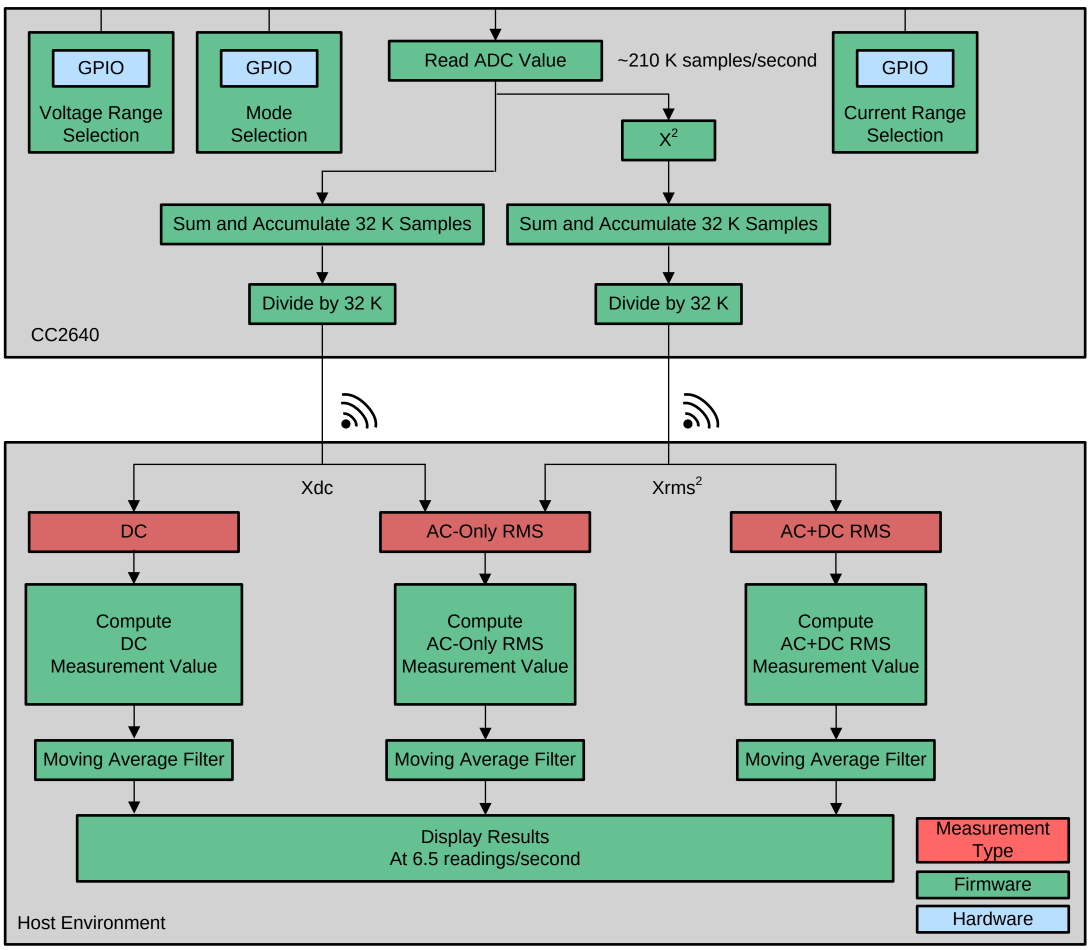

Figure 6. WDMM Measurement Flow Diagram

As shown in the flow diagram in Figure 6, the WDMM offloads some calculations to the host environment. This is to leverage the performance of the host device and maximize the battery life of the WDMM. The calculations performed are listed in the following subsection and can be found in full detail in the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz Tue RMS Digital Multimeter Reference Design*[1].

1.5.6.1 DC Measurement

$$\text{DC Value} = \text{Gain} \times (\text{Xdc} - \text{Xdc\_offset}) \quad (1)$$

where:

- Gain = gain factor determined from calibration
- Xdc = value read from the *DC Reading* characteristic
- Xdc_offset = AFE DC offset component of the sampled ADC value determined from calibration

1.5.6.2 AC (RMS) Measurement

$$\text{AC}_{\text{Only}}\text{RMS} = \text{Gain} \times \text{Xac}_{\text{rms}} = \text{Gain} \times \sqrt{\left|\text{Xrms}^2 - \text{Xdc}^2 - \text{Xnoise}^2\right|} \quad (2)$$

where:

- Gain = gain factor determined from calibration
- Xrms = value read from the *AC Reading* characteristic
- Xnoise = system intrinsic RMS noise component determined from calibration
- Xdc = DC value of the ADC input signal as described above

1.5.6.3 AC+DC (RMS) Measurement

$$\text{AC} + \text{DC RMS} = \sqrt{\text{DC\_Value}^2 + \text{AC}_{\text{Only}}\text{RMS}^2} \quad (3)$$

1.5.6.4 Exponential Moving Average Filter

The Android application implements an exponential moving average filter for smoothing the output values. The equation is shown below:

$$\text{OUTPUT}_t = a \times X_t + (1 - a) \times \text{OUTPUT}_{(t-1)} \quad (4)$$

2 Getting Started Hardware and Software

2.1 Hardware

For the most comprehensive guide on configuring the WDMM hardware, please refer to section 5 of the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz Tue RMS Digital Multimeter Reference Design Guide*.[1]

After the CC2640 firmware has been loaded through the procedure outlined in section 6.2 of the Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz Tue RMS Digital Multimeter Reference Design Guide[1], the board hardware and firmware can be initialized by momentarily pressing the reset button. The system will enter its active state and begin sending BLE advertisement beacons waiting for a host environment to recognize the system and begin the BLE connection process.

The Android application requires an Android device with *Bluetooth* and Android 4.3 or higher. NFC is required for the automated pairing feature only. If NFC is not available, the BLE Scanning method must be used to connect to the WDMM as described in Section 2.2.1.

2.2 Software

For configuring the firmware on the WDMM, please refer to section 6 of the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz Tue RMS Digital Multimeter Reference Design Guide*.[1]

Once the WDMM has been configured, the next step is to download the WDMM Android application. This application can be downloaded directly from the Google Play store for quick evaluation. The source code is also available for download at the TIDC-01012 design folder. The source code is provided as an example to help users develop mobile applications for connecting to TI's wireless connectivity solutions. For comprehensive guides on developing in Android, TI recommends visiting the Android developer website: https://developer.android.com/training.

2.2.1 Connecting to the WDMM

The Android application can connect to a WDMM through either BLE scanning or NFC pairing. The procedures for both methods are described below.

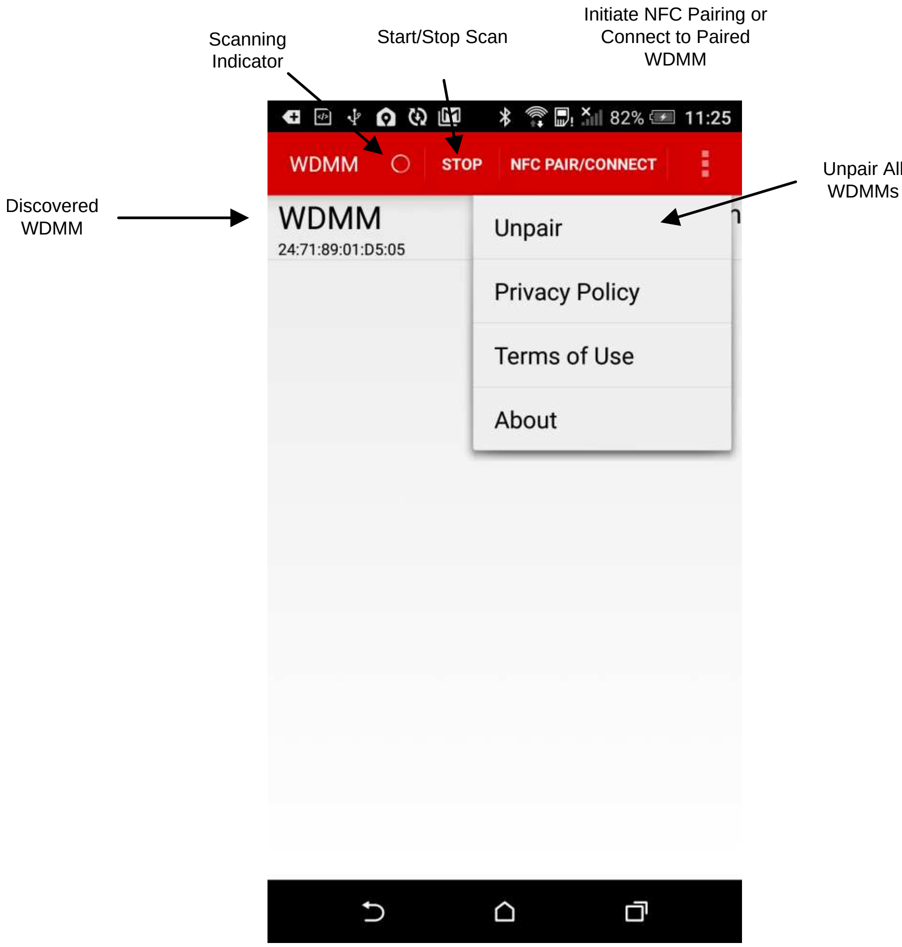

Figure 7. Opening Screen

BLE Scanning

The following describes the procedure for connecting to a WDMM using BLE scanning.

1. Press the *Start Scan* button shown in Figure 7 to begin scanning for WDMMs.
2. If *Bluetooth* is disabled on the device, the device will ask to enable it. Press *yes* to continue.
3. BLE scanning in Android requires location services to be enabled. If this is the first time running the application, and the device is running Android 6.0+, the device will ask to enable location services. Press *yes* to continue scanning
4. WDMMs will populate the list upon discovery. A device filter has been implemented to show only devices labeled *WDMM*.
5. Select the desired device. Once selected, the main screen will be launched.

NFC Pairing

The following describes the procedure for connecting to a WDMM using NFC pairing. This method is useful for when there are multiple WDMMs in-range.

1. Press the *NFC Pair/Connect* button shown in Figure 7 to initiate the pairing process.
2. If NFC is disabled on the device, the device will prompt to turn it on. If NFC is not supported on the device, this feature will be disabled.
3. After pressing the *NFC Pair/Connect* button, place the back of the Android device where the NFC

antenna is located near the NFC antenna on the WDMM.

4. Once in range, the Android device will ask to pair. Press *yes* to begin pairing.
5. Return to the application. If the main screen does not launch automatically, press the "NFC Pair/Connect" button again to connect.
6. The *NFC Pair/Connect* button can now be used to directly connect the paired WDMM.
7. If more than one WDMM is paired with the device, the application will attempt to connect to the first one on the list. The *Unpair* button can be pressed to unpair all paired WDMMs.

   The WDMM can be also be paired manually through the Android device's *Bluetooth* settings. To manually pair, select the desired WDMM from the list of available devices and enter *000000* as the passcode.

2.2.2 Front Panel

The following subsection describes the features of the front panel as labeled in Figure 8.

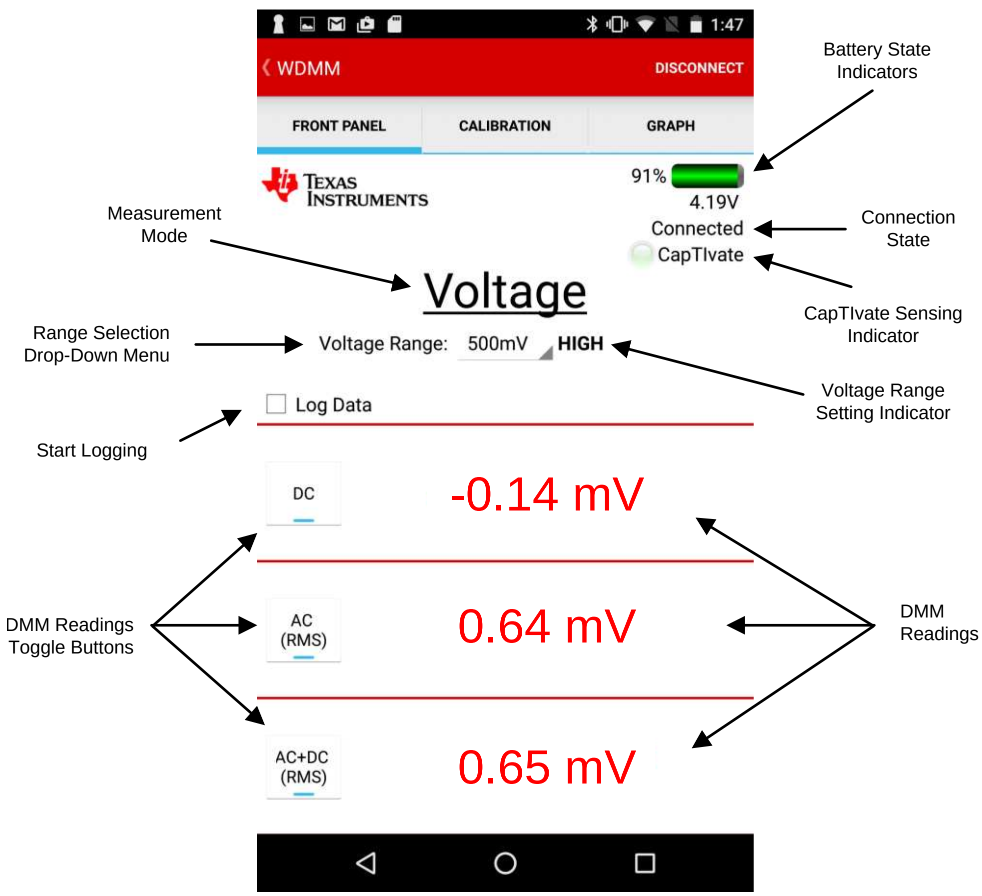

Figure 8. Front Panel Screen

Measurement Mode: Indicates whether the DMM is measuring voltage or current.

Range Selection Drop-Down Menu: Allows the user to set the voltage or current range.

Start Logging: Records readings and stores them on external storage such as an SD card. The application will ask for storage permissions on initial use, press *yes* to begin logging. The readings will be stored in a text file with a date and time stamp for each reading in the following format: 11-01-2016 03:24:55: -0.142mV DC.

DMM Readings Toggle Buttons: These buttons can be used to toggle the DC, AC, and AC+DC readings.

Battery State Indicators: Displays the charge and voltage of the battery.

CapTIvate Sensing Indicator: Indicates when the CapTIvate sensor has been activated.

Voltage Range Setting Indicator: Indicates whether the voltage range setting of the DMM is set to high or low. In high voltage mode, 50 V, 5V, or 500 mV are available to select. In low voltage mode, only 50 mV is available to select.

DMM Readings: Displays the DC, AC, and AC+DC readings.

2.2.3 Calibration

Calibration can be done using the Android application. To start calibration, press the *Calibration* tab and select the default offset and gain factor values as seen on Table 8.

Table 8. Calibration Setting Defaults

RANGE	GAIN	DC OFFSET	SYSTEM INTRINSIC RMS NOISE
Voltage, 50 mV	0.001	0	0
Voltage, 500 mV	0.001	0	0
Voltage, 5 V	1	0	0
Voltage, 50 V	1	0	0
Current, 50 mA	0.001	0	0
Current, 500 µA	0.000001	0	0

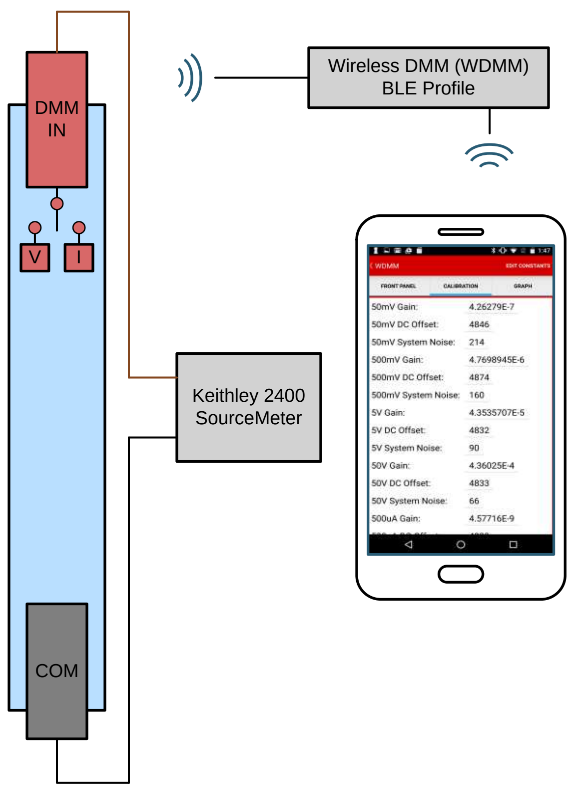

Figure 9. Calibration Setup

1. Configure the system as shown on Figure 9.
2. Set the measurement mode switch to voltage or current.
3. Capture the TIDA-01012 voltage and current readings versus the Keithley 2400 voltage and current input at full range negative, zero (0), and full range positive settings.
4. Perform linear regression using these three data points to determine the gain (1/slope) and the DC and AC-Only (system intrinsic noise) offsets (y-intercept) values.

5. Repeat steps 2 through 4 for all voltage and current ranges.
6. Press the *Edit Constants* button and enter the measured calibration constants.
7. Send and update the device calibration constants by pressing the *Save Constants* button.

2.2.4 Graphing

The *Graph* tab enables the pseudo real-time graphing of the DC and AC readings. This tab allows for highlighting plot points and showing the maximum, minimum, and average, as seen in Figure 10. The tab also allows for zooming and panning for better usability.

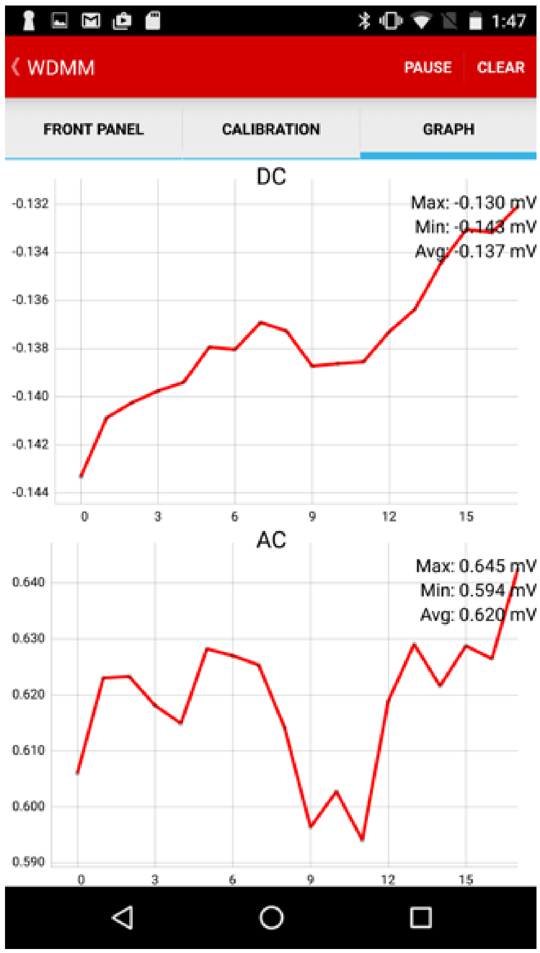

Figure 10. Graphing Screen

3 Testing and Results

To see testing and results for the WDMM reference design, please see section 8 of the *Wireless IoT, Bluetooth low energy, 4½ Digit, 100kHz Tue RMS Digital Multimeter Reference Design Guide*[1].

The Android application has been tested to meet the key system specifications found in Table 1. The DC, AC RMS, and AC+DC RMS readings were compared against the LabView™ application and found to be within acceptable ranges. The application was successfully tested on the following devices: LG® Escape2™, Motorola® Moto™ X Pure, Samsung® Galaxy® Tab Active, and HTC™ One A9.

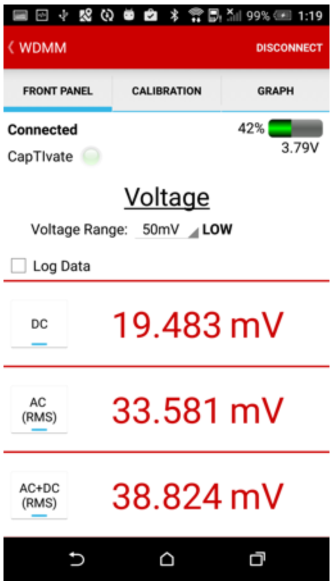

Figure 11. 50-mV Range

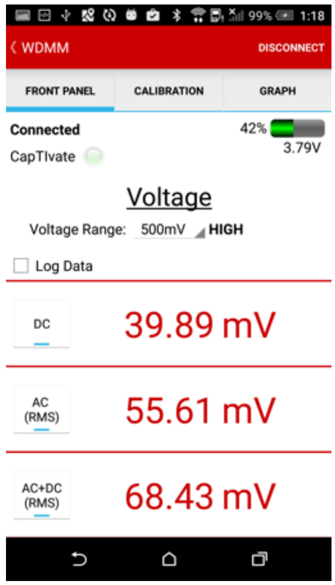

Figure 12. 500-mV Range

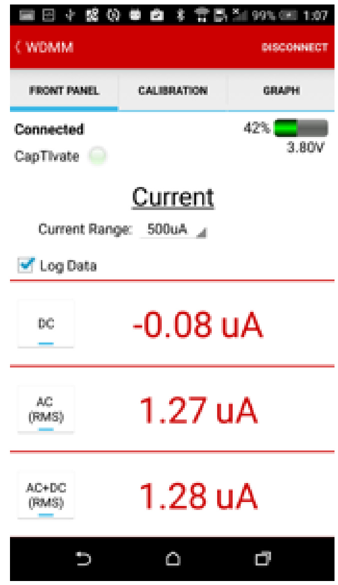

Figure 13. 500-µA Range

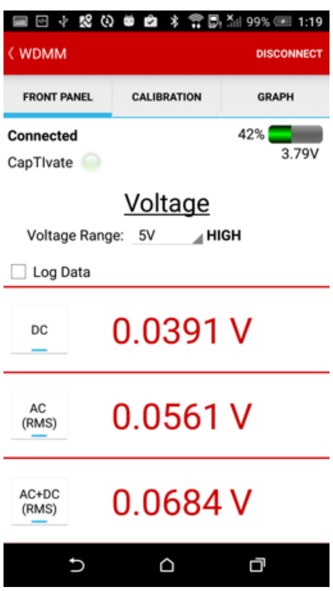

Figure 14. 5-V Range

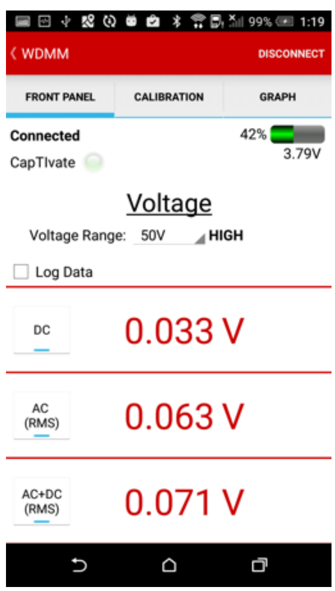

Figure 15. 50-V Range

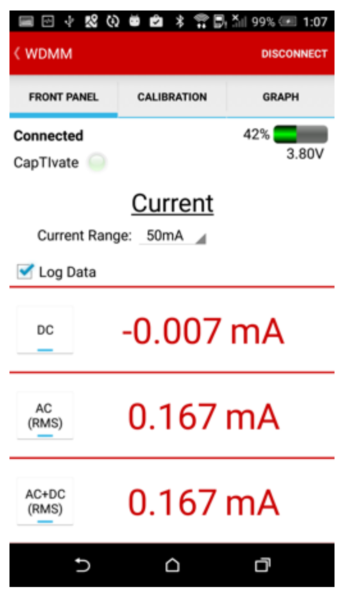

Figure 16. 50-mA Range

4 Software Files

To download the software files, see the design files at TIDC-01012.

5 Related Documentation

1. Texas Instruments, *Wireless IoT, Bluetooth® low energy, 4½ Digit, 100kHz True RMS Digital Multimeter Reference Design Guide*, TIDA-01012 Design Guide (TIDUBV5)
2. Texas Instruments, *CC2640 and CC2650 SimpleLink Bluetooth low energy Software Stack 2.2.1*, Developer's Guide (SWRU393)
3. Texas Instruments, *Automating Bluetooth Pairing With Near-Field Communications (NFC)*, Application Report (SLOA187)
4. Texas Instruments, *SimpleLink Academy v1.11*
5. *Bluetooth* SIG, *Bluetooth Specifications*

5.1 Trademarks

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6 About the Author

SAHIN OKUR is an Applications Engineer at Texas Instruments where he is responsible for developing reference design solutions for the Industrial Test and Measurement Sector. Sahin earned his Bachelor of Science in Electrical Engineering (BSEE) from University of Central Florida.

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