User's Guide
SWRU532A–November 2017–Revised March 2018

IMETER-BOOST

This user's guide provides the foundation needed to quickly evaluate and customize the wireless power monitor, including methodology, testing, and design files.

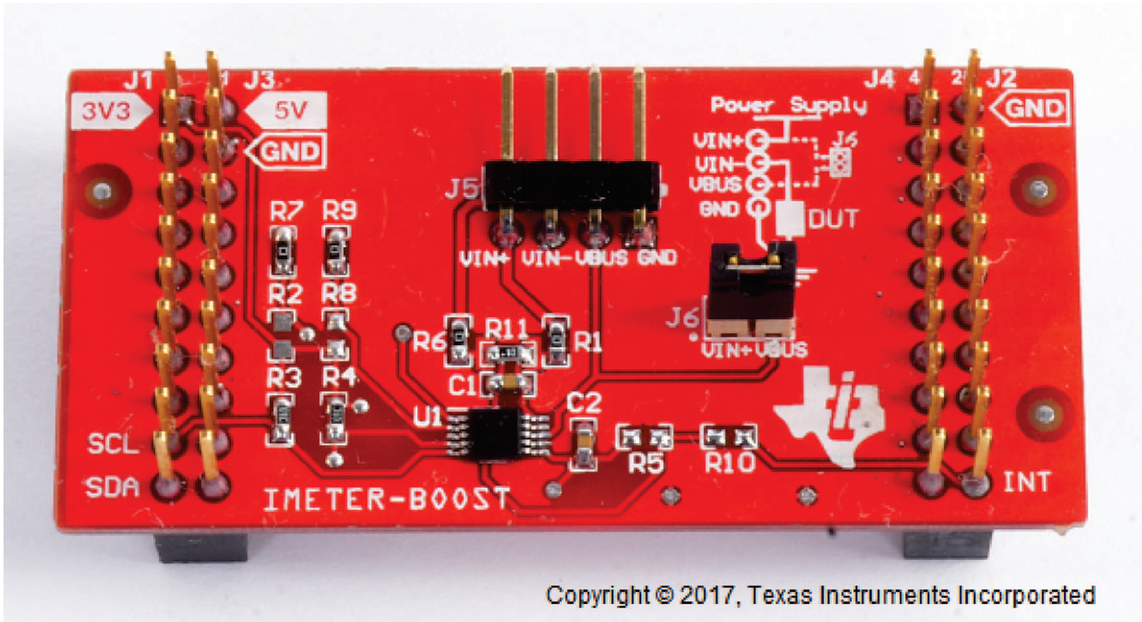

Figure 1. IMETER-BOOST Board

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1 Introduction

The ability to record and analyze the power consumption of a system is important when developing various end-equipment. Measuring power consumption is especially important for battery-powered designs that require low-power operation to achieve extended battery life and provide a positive user experience. One of the fastest growing markets for battery-powered designs is the Internet-of-Things (IoT), where products often need to operate for longer than a year on a battery. However, the proper tools for performing accurate power measurements can be expensive and difficult to master.

The IMETER-BOOST is a low-cost, easy-to-use, power-measurement tool for power sensitive designs. The wireless current monitor features the CC3200 SimpleLink™ Wi-Fi® wireless MCU, with the INA226, an ultra-high-accuracy power monitor, and can be used as a replacement for traditional metering equipment. Together the CC3200 and INA226 devices enable accurately sampled high- or low-side current measurements and voltage data that can be monitored remotely using Wi-Fi.

1.1 Features

- Remote data acquisition
- Cloud connectivity
- Big data collection for use-case analysis
- Power profile generation and comparison
- Use of standard presentation and charting tools (for example, Plot.ly, Excel, and so on)

1.2 Applications

- Data acquisition automation
- Remote measurement
- Low-cost portable test equipment

1.3 Description

The IMETER-BOOST lets customers evaluate their actual power consumption figures, as well as debug and analyze their software. The IMETER-BOOST can also be used as a remote sensor, to wirelessly measure current and voltage of any device. Measurements made with the IMETER-BOOST can easily be saved, to be shared and reviewed at a later time.

The IMETER-BOOST behaves similar to a standard scope, with two analog channels (one for current measurement and one for voltage), and four digital channels, using GPIOs. The user can set triggers for each channel (falling and rising edge, above and below the threshold for a preconfigured interval). Trigger position and stop conditions are also configurable. Samples can be done in one shot or multiple shots. Sampled data can be saved locally (in CSV format) or sent to the cloud (plot.ly).

The IMETER-BOOST is comprised of the following components:

- CC3200 LaunchPad™ (CC3200-LAUNCHXL Rev 4.1)
- INA226 BoosterPack™ (IMETER-BOOST)
- Any PC, laptop, tablet or smartphone (as a client)

The javascript-driven interface includes some useful, easily-accessible measurement aids, such as average current and voltage, as well as energy calculation between configurable cursor boundaries.

1.3.1 Key System Specifications

Table 1 lists the key system specifications.

Table 1. Key System Specifications

Parameter	Specification	Details
Operating voltage	2.7 V to 3.6 V	—
VBAT channel range	0 V to 36 V	—
GPIO channel range	0 V (system supply +0.5 V)	—
Current channel range	–819.71 mA to 819.2 mA (for default 0.1 R shunt)	—
Sample rate	0.12 samples per sec to 7140 samples per second	—
VBAT accuracy	1.25 mV	—
Current accuracy	25 µA (for default 0.1 R shunt)	—
Buffer depth	28K samples (over two seconds on highest sample rate)	—
Working Environment	–40°C to 85°C	—
Average current	Highly dependant on use-case	—
Peak current	Achieved during power-ups	CC3200 Data Sheet

2 Getting Started Hardware and Software

2.1 Hardware

2.1.1 IMETER-BOOST

The IMETER-BOOST (INA226 BoosterPack) is designed to be compatible with the standard 2-row BoosterPack connector format on LaunchPads. Table 2 lists the mapping of the signals between the boards.

Table 2. IMETER-BOOST BoosterPack™ Connector Mapping

	P1	P3	P2	P4
1	VCC	N.C.	GND	N.C.
2	N.C.	GND	N.C.	N.C.
3	N.C.	N.C.	N.C.	N.C.
4	N.C.	N.C.	N.C.	N.C.
5	N.C.	N.C.	N.C.	N.C.
6	N.C.	N.C.	N.C.	N.C.
7	N.C.	N.C.	N.C.	N.C.
8	N.C.	N.C.	N.C.	N.C.
9	I^2C SCL	N.C.	N.C.	N.C.
10	I^2C SDA	N.C.	Alert GPIO	N.C.

2.1.2 Host LaunchPad™ Connection (CC3200-LAUNCHXL)

While the analog signals to the DUT are connected directly to the IMETER-BOOST BoosterPack, the digital GPIOs may be connected directly to J5 of the host LaunchPad. Table 3 lists the mapping of J5.

Table 3. LaunchPad™ J5 Connector Mapping

PIN	IMETER-BOOST GPIO	CC3200 GPIO
1	GPIO1	GPIO7
2	GPIO2	GPIO5
3	GPIO3	GPIO26
4	GPIO4	GPIO27
5	GND	GND

Alternatively to J5, the digital GPIOs can be connected to the stackable headers on the INA226 BoosterPack, according to the CC3200 GPIO map listed in Table 2.

NOTE: The ground signal of J5 on the CC3200 LaunchPad is shared with the ground on the IMETER-BOOST. If a ground is connected to the BoosterPack, there is no need to connect it to J5 as well.

Unless a ground is shared between the DUT and the hosting LaunchPad, (so both the DUT and host LaunchPad are connected to the same PC), at least one of the grounds (J5 or on the BoosterPack) must be connected.

2.1.3 DUT Connection

The connection for the current measurement is done in series to the DUT supply path, to J5. The shunt is located on the IMETER-BOOST. If the measured voltage (VBAT) is the same voltage as Vshunt+, keep J6 mounted. Otherwise, remove J6 and connect the voltage source to be measured directly to J5.

2.2 Software

The software for the IMETER-BOOST runs on four threads under FreeRTOS. The threads follow:

- SimpleLink driver thread
- Scope thread
- Networking thread
- HTTP data server thread

The SimpleLink driver thread runs the SimpleLink host driver. The scope thread is responsible for sampling data from the INA226, based on start and stop conditions and user configurations (such as channel selection), and stores the raw data in the ring buffer.

The networking thread is responsible for all networking activity. The networking thread sends the buffered data to the cloud or to the local client, and handles asynchronous networking events triggered by the SimpleLink host driver.

The HTTP data server thread implements a simple HTTP server on the applications MCU, which runs on port 81. This server is used to transfer raw data to the local client. The HTTP server thread handles the requests even though the actual data is sent by the networking thread.

The main HTTP server resides inside the SimpleLink Wi-Fi Networking Subsystem, running on port 80. The reason for using the main HTTP server for the web interface, and not the data, is that it is more efficient to send a large amount of data on a separate server. Splitting up the interface and data functions allows the internal HTTP server to be available for control commands.

Figure 2, Figure 3, and Figure 4 show flow charts of the software for each thread. These flow charts provide high-level descriptions of the software components. See the source code for details on the actual implementation.

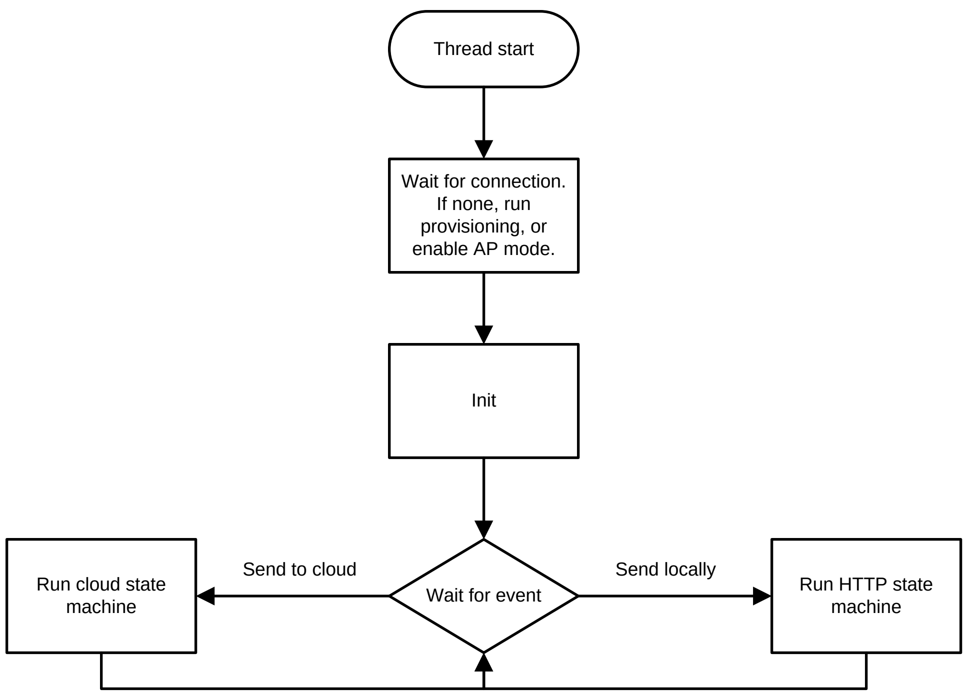


Figure 2. Networking Thread Flow

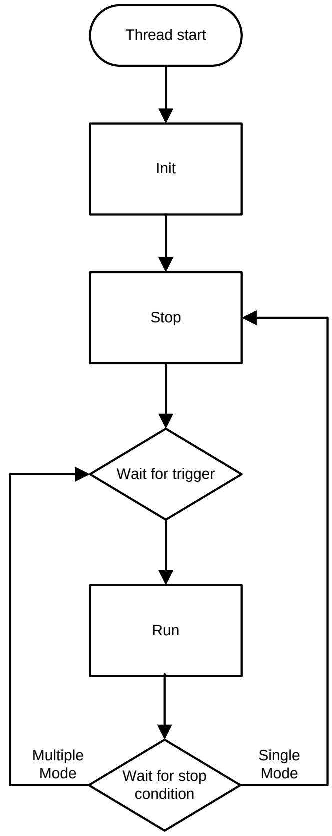


Figure 3. Scope Thread Flow

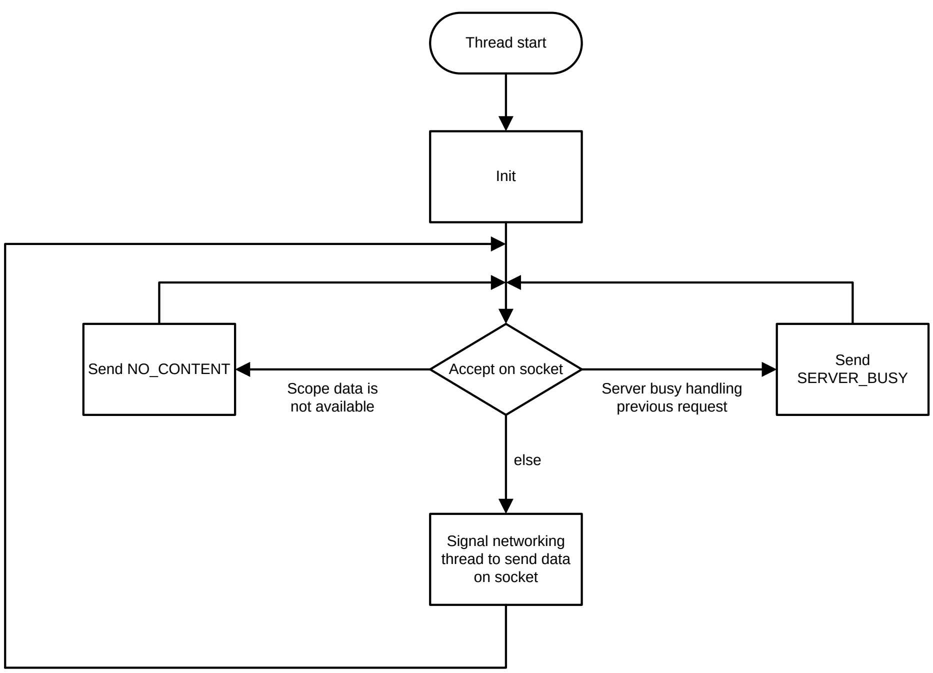


Figure 4. Data HTTP Server Flow

2.2.1 Provisioning

When the system boots-up, it attempts to connect to a known AP. If the system fails to find one in a predefined amount of time, the provisioning procedure is activated. An indication that the provisioning procedure is running is given by the LEDs on the CC3200 LaunchPad. When provisioning has started, the red LED turns on and the other two LEDs turn off.

The purpose of the provisioning procedure is to connect the IMETER-BOOST to a new AP. Connecting to an AP can be done in one of two ways:

- Run TI's provisioning procedure for seamless transfer of the credentials using a mobile phone app. To use TI's provisioning procedure:
  1. Download the SimpleLink Starter Pro smartphone app. When the red LED on the LaunchPad is lit, press SW2. The yellow LED turns on.
  2. Run the SimpleLink Starter Pro app, and follow the instructions on the screen. At the end of the procedure, the devices tab may be pressed to retrieve the IP address of the IMETER-BOOST on the target network.
  3. Once the procedure is done, the IMETER-BOOST is fully operational. Consecutive power-ups cause the IMETER-BOOST attempt to reconnect to the updated AP.
- Activate the IMETER-BOOST in AP mode, and either work in AP mode (without cloud connectivity) or add new AP credentials, to be used during the next power-up. To add a new AP manually or work in AP mode:
  1. Press SW3 on the LaunchPad when the red LED is on. The yellow and green LEDs turn on to signal that the IMETER-BOOST is ready in AP mode. Connect to the IMETER-BOOST using any Wi-Fi enabled device (its name will be "mysimplelink-XXXXXX", where XXXXXX is a part of its MAC address).
  2. On your client device (laptop, smartphone, tablet) open a browser and go to http://192.168.1.1/profiles_config.html. Follow the instructions on that web page to add a new profile, and restart the device.

NOTE: Spaces in the name of the target AP are not supported.

2.2.2 HTTP User Interface

The web user interface provides a convenient way to control the tool. Table 4 list the controls available to the user.

Table 4. Web Graphical User Interface Icons

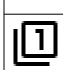
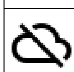
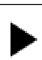
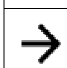
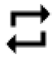
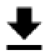
ICON	DESCRIPTION
	Graph mode: Use this mode for capturing dynamic profiles, or long-term trends.
	Numeric mode: Use this mode for average voltage and current measurements. Available only for local mode.
	Local mode: Select this mode to keep captured samples locally with the option to download them to the disk.
	Cloud mode: Select this mode to upload the sampled profile to the cloud, and optionally share it with others.
	Start button: This button changes the state of the IMETER-BOOST to *waiting for trigger.* If no trigger is defined (auto-trigger), the sampling starts immediately.
	Stop button: This button stops any ongoing activity, whether the IMETER-BOOST is waiting for trigger, or sampling or transferring data. Pressing this button returns it to idle mode.
	Sample once: After the sample is complete, the IMETER-BOOST returns to idle mode.

Table 4. Web Graphical User Interface Icons (continued)

ICON	DESCRIPTION
	Sample multiple: After the sample is complete, the scope returns to *waiting for trigger* mode. Data from the previous sample may be downloaded until data from the new sample starts to be transferred.
	Continuous sampling and display of measured data: Use this mode for real-time analysis or long-term measurements. In local mode, sampled data can be saved. **NOTE:** Displayed data is truncated after a certain amount of samples have been taken, but all data can be reviewed by navigating the graph or when saving the data.
	Help button: Pressing this button opens help menus with answers to all frequently asked questions.
	Download sampled data: Use this button to download the last sampled data to the local disk in CSV format.
	Load saved data: Use this button to load saved data for offline analysis.
	Trigger settings menu: This menu contains all the trigger and stop condition configurations.
	Plot.ly configuration menu: This menu contains all plot.ly related parameters.
	General settings menu: Contains GPIO labels, autosave option, and sliding window length for continuous sampling.
	Resets data in numeric mode.

Apart from the icons, there are two other controls at the bottom of the screen – a slider that determines the sample rate of the IMETER-BOOST, and channel selection.

2.2.3 Triggers Menu

The triggers menu lets the user select start and stop triggers for any enabled channel.

Possible start triggers:

- Auto trigger
- Rising and falling edge
- Above and below threshold for given time

Possible stop triggers:

- Buffer full
- Rising and falling edge
- Above and below threshold for given time
- Time from start trigger

In addition, the start trigger position is configurable. Time logged for the samples is relative to the start trigger. Any value captured before the start trigger have a negative time value.

2.2.4 Cloud Settings Menu

The cloud settings menu includes all cloud-related configurations. Currently all configurations are for Plot.ly cloud service. On the left side of the Cloud Settings menu, the user account details may be entered (username, password, e-mail). On the right side Cloud Settings menu, an optional filename may be entered. This filename is displayed as both the graph title and filename on the cloud servers. An additional and optional parameter is the stream token. This token can be used for live streaming of samples to the plot.ly servers (continuous sampling).

NOTE: The plot.ly API offers many functions that are not exposed in the GUI and implemented in the firmware. For example, whether or not to overwrite the plot, graph styling, axes placement, and so on.

CAUTION

Accessed Services; Third Party Materials. TI provided software and materials may enable you to access third party services and web sites, including but not limited to the Plot.ly service available at https://plot.ly/ (collectively and individually, “Accessed Services”). Use of the Accessed Services may require internet access and may require that you accept additional terms of service for the Accessed Services; for example, if you access Plot.ly, you will be subject to Plot.ly’s terms of service available at https://plot.ly/terms-of-service/. Your use of such Accessed Services may also be subject to other privacy practices and policies. It is your responsibility to read, understand, and accept any applicable terms if you elect in your discretion to use Accessed Services.

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2.2.5 General Settings Menu

This menu includes some miscellaneous configurations as follows:

- GPIO labels – Enables naming each GPIO with a label. The label can be saved and loaded afterwards to maintain measurement context.
- Saving mode – Enables choosing automatic saving for each sample. This mode is useful when used in conjunction with multiple triggered sampling events. Saving mode enables a user to save a large amount of similar triggered events for comparison.
- Continuous window length – Sets the width (in samples) of the displayed data for continuous mode. When more data than the defined window length is captured, older samples are not displayed anymore. The samples are not discarded, the user can view them by zooming out or saving them when the capture is done. Any value below the minimum is not allowed, and the minimum is used instead. Although there is no maximum amount of samples, this setting must be used with caution, as a large amount of displayed data is strenuous on the client.

2.2.6 API

If the supplied Javascript code is not applicable, directly interfacing with the IMETER-BOOST is also possible. The scope responds to three addresses, as follows:

- [IP Address]/ → Homepage
- [IP Address]/status → Returns the current status, formatted as [status code, buffer level, buffer size]
- [IP Address]/data:81 → Returns data from the buffer in entries formatted as follows:

```
[Base time, current, voltage, GPIOs]\r\n
[Delta time, current, voltage, GPIOs]\r\n
[Delta time, current, voltage, GPIOs]\r\n
[Delta time, current, voltage, GPIOs]\r\n
//And so on...//
```

Table 5 lists the other parameters that can be obtained from the IMETER-BOOST by embedding HTTP tokens in an HTML page (see SimpleLink documentation for more details).

Table 5. HTTP GET Tokens

PARAMETER	TOKEN NAME	DESCRIPTION
Device mode	__SL_G_D.M	Current device mode according to predefined enum
Average VBAT	__SL_G_A.V	Applicable in average mode only
Average Current	__SL_G_A.S	Applicable in average mode only
Stream Token	__SL_G_S.S	Plot.ly stream token
Buffer Level	__SL_G_B.L	String of [current, total]
Cloud username	__SL_G_C.U	—
Cloud password	__SL_G_C.P	—
Cloud E-mail	__SL_G_C.E	—
URL	__SL_G_C.L	Available only after the first run

Configuring the IMETER-BOOST is done by sending POST tokens to the internal HTTP server. Table 6 lists the supported tokens.

Table 6. HTTP POST Tokens

PARAMETER	TOKEN NAME	DESCRIPTION
Mode	__SL_P_W.D	Select the working mode according to the given enum
Trigger mode - VBAT	__SL_P_V.T	Select the trigger mode according to the given enum
Trigger mode - Current	__SL_P_S.T	Select the trigger mode according to the given enum
Trigger mode - GPIOs	__SL_P_G.T	Select the trigger mode according to the given enum
Trigger time - VBAT	__SL_P_T.V	Value in hex, 0.1 ms, when user selects above or below threshold time
Trigger time - Current	__SL_P_T.S	Value in hex, 0.1 ms, when user selects above or below threshold time
Trigger time - GPIO	__SL_P_T.G	Value in hex, 0.1 ms, when user selects above or below threshold time
Channels selection	__SL_P_C.T	Select required channels. Any combination is permitted. Current = 0x1 VBAT = 0x2 GPIOs = 0x4
Trigger value – VBAT	__SL_P_V.H	Raw hex value, only when applicable
Trigger value – Current	__SL_P_C.H	Raw hex value, only when applicable
Trigger value – GPIOs	__SL_P_G.H	Raw hex value, only when applicable
Averaging	__SL_P_A.V	Value according to enum. presented to the user as a single value (sample rate) in conjuncture with conversion time
Conversion time	__SL_P_C.V	Value according to enum. presented to the user as a single value (sample rate) in conjuncture with averaging
Cloud filename	__SL_P_C.F	File name without extension. Limited to maximum length and protected against illegal characters
Cloud username	__SL_P_C.U	—
Cloud password	__SL_P_C.P	—
Cloud e-mail	__SL_P_C.E	—
Trigger position	__SL_P_T.P	Defined according to enum
Stream Token	__SL_P_S.S	Plot.ly stream token

The ENUM values for the relevant tokens are as follows:

Device mode (POST):

```
enum workingModes_t
{
  MODE_STOP,
  MODE_SINGLE_LOCAL,
  MODE_SINGLE_CLOUD,
  MODE_MULTIPLE_LOCAL,
  MODE_MULTIPLE_CLOUD,
  MODE_CONTINUOUS_LOCAL,
  MODE_CONTINUOUS_CLOUD,
  MODE_AVERAGING_LOCAL
};
```

Trigger Mode (POST), any channel:

```
enum channelTriggerConditions_t
{
  TRIGGER_AUTO,
  TRIGGER_THRESHOLD_RISING_EDGE,
  TRIGGER_THRESHOLD_FALLING_EDGE,
  TRIGGER_ABOVE_THRESHOLD_TIME,
  TRIGGER_BELOW_THRESHOLD_TIME
};
```

Sampling rate parameters (SET):

```
enum conversionTime_t
{
  CT_140uS, //0
  CT_204uS, //1
  CT_332uS,
  CT_588uS,
  CT_1100uS,
  CT_2116uS,
  CT_4156uS,
  CT_8244uS //7
};
```

```
enum numofAveraging_t
{
  AVG_1, //0
  AVG_4, //1
  AVG_16,
  AVG_64,
  AVG_128,
  AVG_256,
  AVG_512,
  AVG_1024 //7
};
```

Trigger Position – given in percentage of total buffer size (SET):

```
enum triggerPosition_t
{
  TRIGGER_POSITION_0,
  TRIGGER_POSITION_10,
  TRIGGER_POSITION_25,
  TRIGGER_POSITION_50,
  TRIGGER_POSITION_75,
  TRIGGER_POSITION_90,
  TRIGGER_POSITION_100,
  TRIGGER_POSITION_NUMBER_OF_ENTRIES
};
```

Device mode (GET):

```
enum scopeStates_t
{
  STATE_SCOPE_START,
  STATE_SCOPE_INIT,
  STATE_SCOPE_STOP,
  STATE_SCOPE_CONFIG,
  STATE_SCOPE_WAIT_TRIGGER,
  STATE_SCOPE_RUN,
  STATE_SCOPE_EMPTY_BUFFER,
  STATE_SCOPE_DRAW_GRAPH,
  STATE_SCOPE_STOP_ONGOING
};
```

The sample rate is a derivative of two INA226 parameters, conversion time and averaging. In this design, conversion time has precedence. Table 7 shows the various configurations of conversion times and averaging values vs the resulting sample rate. Although the INA226 on the IMETER-BOOST supports different conversion time figures for current and for data, the same value is always applied to both in this design.

Table 7. Conversion Time and Averaging Values VS Sample Rate

AVERAGING	CONVERSION TIME [µSec]	USER SAMPLING RATE [µSec]	USER SAMPLING RATE
1	140	140	7.14 KSps
1	204	204	4.9 KSps
1	332	332	3 KSps
1	558	558	1.8 KSps
1	1100	1100	900 Sps
4	332	1328	750 Sps
1	2116	2116	472 Sps
1	4156	4156	240 Sps
1	8244	8244	121 Sps
4	4156	16624	60 Sps
4	8244	32976	30 Sps
16	4156	66496	15 Sps
16	8244	131904	7.5 Sps
64	8244	527616	1.9 Sps
128	8244	1055232	0.95 Sps
256	8244	2110464	0.47 Sps
512	8244	4220928	0.23 Sps
1024	8244	8441856	0.12 Sps

2.3 Getting Started Hardware

To start using the IMETER-BOOST perform the following steps:

1. Format the CC3200 device.
2. Flash the UniFlash session (see Section 2.4.1 for details) and the latest service pack for the CC3200.
3. Mount the IMETER-BOOST on the LaunchPad
4. Power the LaunchPad using a USB connector or a direct battery connection to J20. For initial connections, the green and amber LEDs turn off. After a few moments the red LED turns on.
5. To work in AP mode, press SW3. For provisioning mode, press SW2 (see Section 2.2.1 for completing the provisioning process).

2.4 Getting Started Firmware

2.4.1 UniFlash

Use the UniFlash bundle to program all files into the host CC3200-LAUNCHXL. These files include the HTML pages, javascript files, and MCU image.

NOTE: The application does not work without programming the UniFlash bundle.

Using the bundle requires the latest version of the UniFlash Standalone Flash Tool.

1. Install UniFlash on your PC and run it.
2. Load the .ucf file located at the root of the UniFlash files folder, Figure 5 shows an example.

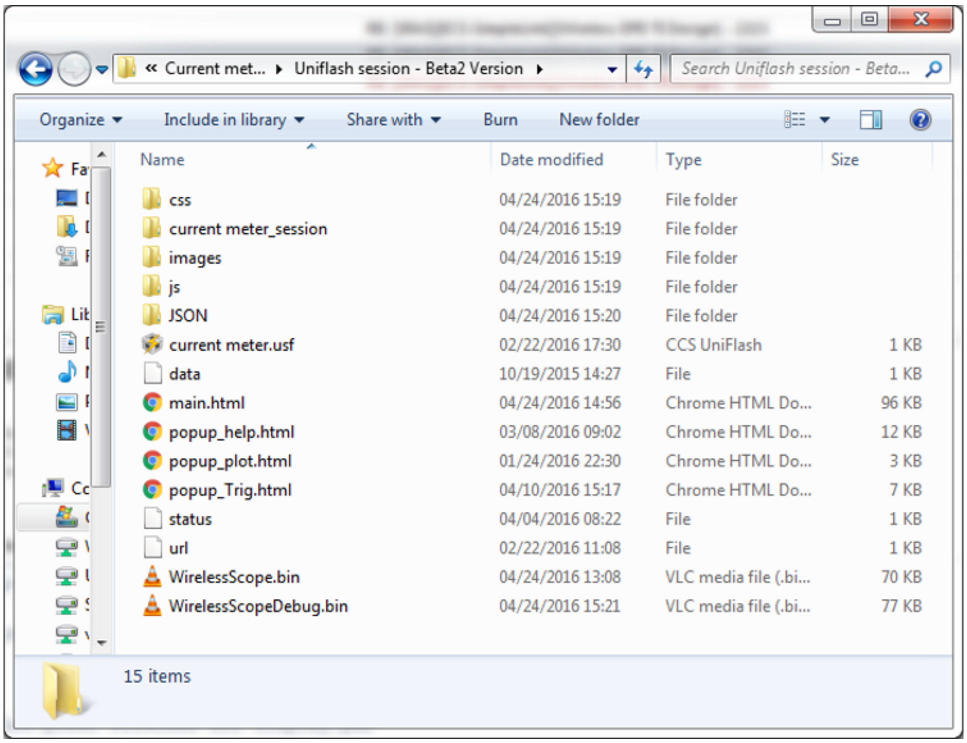

Figure 5. UniFlash Folder Example

3. Once UniFlash has loaded, determine the COM port number assigned to the LaunchPad by your PC. Refer to Section 2.4.2.1 for details (user logs are output on the same COM port).
4. Ensure the SOP2 jumper on your LaunchPad is assembled to enable programming.
5. Update the COM port field with the correct COM port number.
6. If required (or if this is the first use of the LaunchPad), format the Serial Flash by pressing the Format button and selecting the 1MB serial flash value.
7. Press the reset button on the LaunchPad when prompted.
8. Update to the latest service pack by pressing the Service Pack Programming button.
9. Press the reset button on the LaunchPad when prompted.
10. Check and make sure the mcuimg.bin is pointing to the mcuimg.bin inside the directory.
11. Finally, program all user files by pressing the Program button.
12. Press the reset button on the LaunchPad when prompted.
13. Once all programming is done, remove the SOP2 jumper from the LaunchPad, and press the reset button once again.

The software starts running, and the splash screen graphics appear if you programmed one.

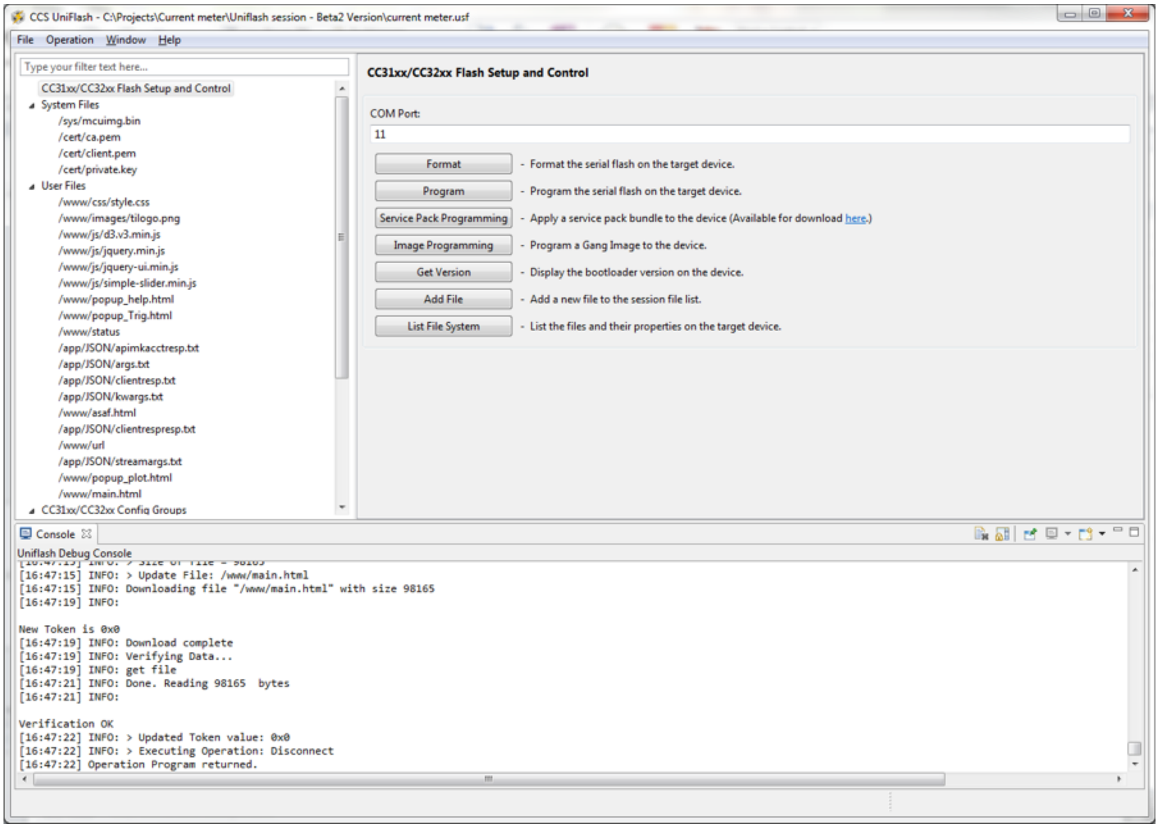

Figure 6. UniFlash Interface

2.4.2 Software

Asssuming all required information is present in the SimpleLink filesystem, upon power-up the green and amber LEDs are turned off, and after a short time the red LED turns on. This signal indicates that the IMETER-BOOST is in provisioning mode. Follow the instructions in Section 2.2.1.

Use provisioning to connect the SimpleLink Wi-Fi device to a local AP (see Section 2.2.1 for details). If the green and amber LEDs have turned off and then on again, it indicates that the IMETER-BOOST is connected to the AP. The scope advertises its HTTP server using mDNS. Use any mDNS browser to detect its IP address and connect to it, or use the device scanner in the SimpleLink Starter Pro (Devices tab) to locate it on your local network.

Once running, the state of the IMETER-BOOST is displayed by the LEDs on the LaunchPad. Table 8 lists the states of the LEDs.

Table 8. IMETER-BOOST LED State Indication

GREEN LED	AMBER LED	RED LED	STATE
On	On	Off	Idle
On	On	Blinking slowly	Waiting for trigger
On	On	Blinking rapidly	Sampling in progress
On	On	On	Transferring data
Blinking slowly	Blinking slowly	Blinking slowly	Error communicating with the INA226 BP
Blinking rapidly	Blinking rapidly	Blinking rapidly	Network fatal error
Off	Off	Off	Waiting for WLAN connection (at power-up)
Off	Off	On	Provisioning mode (at power-up)

NOTE: Running the scope in debug mode impacts its performance. UART to the terminal currently does not use DMA, so when a message is sent over UART, data is not sampled over I²C.

2.4.2.1 TeraTerm

The use of a terminal software is optional. Terminal software can be used to give some insight into the internal process of the TIDC-01000.

NOTE: By default the terminal function is disabled because it impacts the performance of the scope during sampling, and reduces the buffer sample to accommodate the strings.

To enable the terminal, compile the software without the global NOTERM symbol defined, then flash the resulting binary to the CC3200 device. The rest of this section assumes the debug variant is loaded to the CC3200.

1. When the USB cable is connected to the LaunchPad, check Windows Device Manager, whose COM port was opened for the LaunchPad (see Figure 7).

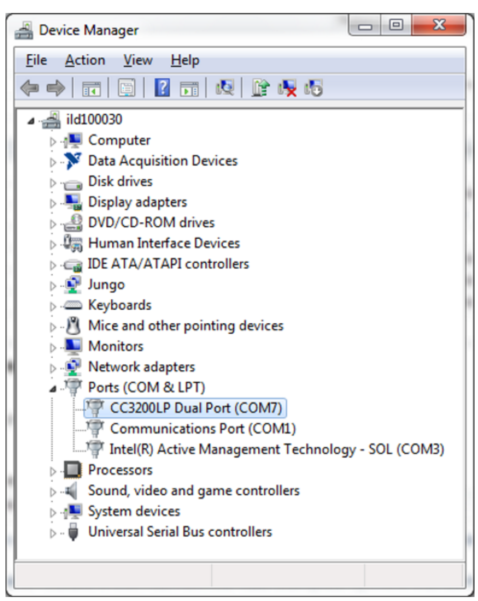

Figure 7. Detecting COM Port of LaunchPad™

2. Once the COM port number has been determined (COM7 in this case), open your favorite terminal and set it to this port number with a baud rate of 115200. This communication channel is unidirectional and only displays plots from the software (see Figure 8).

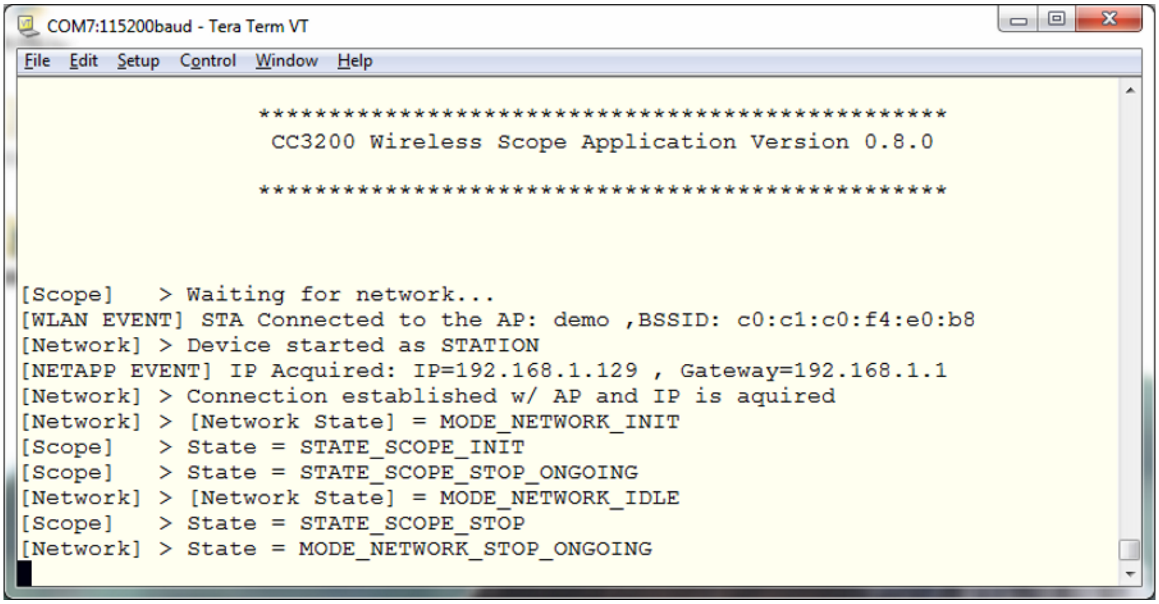

Figure 8. Software Logger Terminal Output

3 Testing and Results

3.1 Test Setup

Dynamic validation of the wireless scope's current profile accuracy was done by connecting it in series with an NI-DAQ USB-6210, and comparing measured profile averages of the same scenario. Dynamic validation of the wireless scope's voltage profile accuracy was done by connecting it in parallel to a Tektronix MSO 3034 oscilloscope. Static voltage measurement was performed in parallel to an Agilent voltmeter, and the difference was 0.5 mV.

3.2 Test Data

3.2.1 Current Measurements

Current measurement tests were conducted by connecting an Ni-DAQ USB-6210 (16-bits, 250 KSps) in series with the IMETER-BOOST, and measuring the same profile in both. Since the software that uses the Ni-DAQ has no triggering capabilities, the measurements were conducted in close proximity, but were not sampled concurrently.

The first measurement made was of a CC3100 in transceiver mode, waking from hibernate, and transmitting three packets (see Figure 9 and Figure 10).

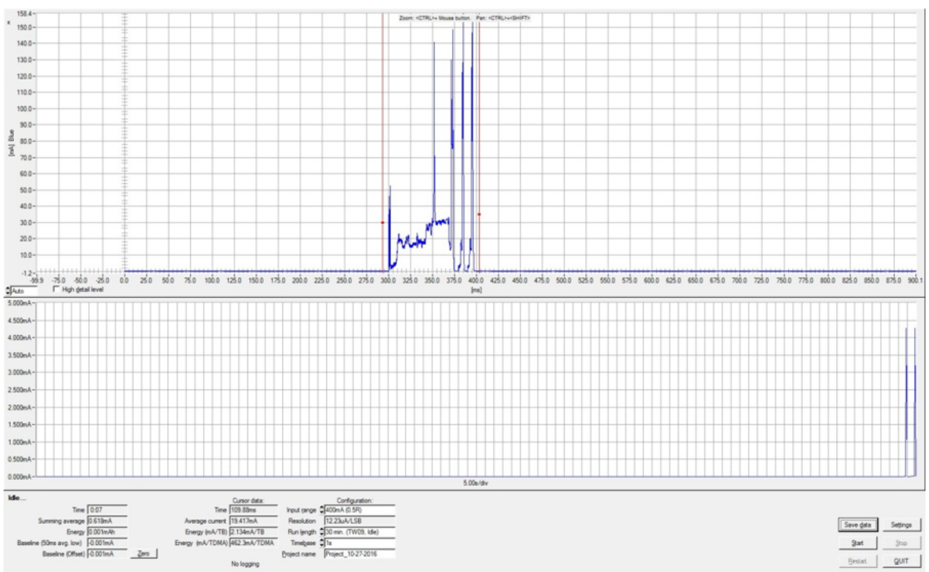

Figure 9. NiDAQ Measurement of Transceiver Mode

Figure 10. Wireless Scope Measurement of Transceiver Mode

Figure 9 and Figure 10 show that the profile measured with both tools is comparable. The average current consumption was measured to be 19.417 mA with the NiDAQ, and 19.862 mA with the IMETER-BOOST.

The second measurement was of a typical initialization sequence of the CC3100, captured by running an example program from the CC3100 SDK (see Figure 11 and Figure 12).

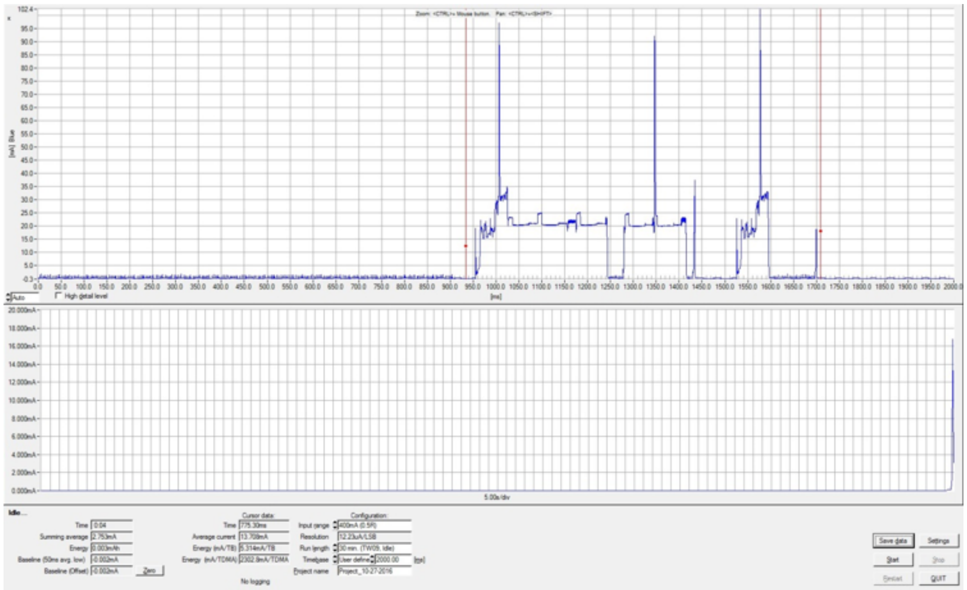

Figure 11. NiDAQ Measurement of Sample CC3100 Program Initialization

Figure 12. Wireless Scope Measurement of Sample CC3100 Program Initialization

The current profiles can again be seen as comparable. The average current measured was 13.708 mA with the NiDAQ, and 14.073 mA with the IMETER-BOOST.

The third measurement performed was of the CC3100 wake-up from complete shutdown (see Figure 13 and Figure 14).

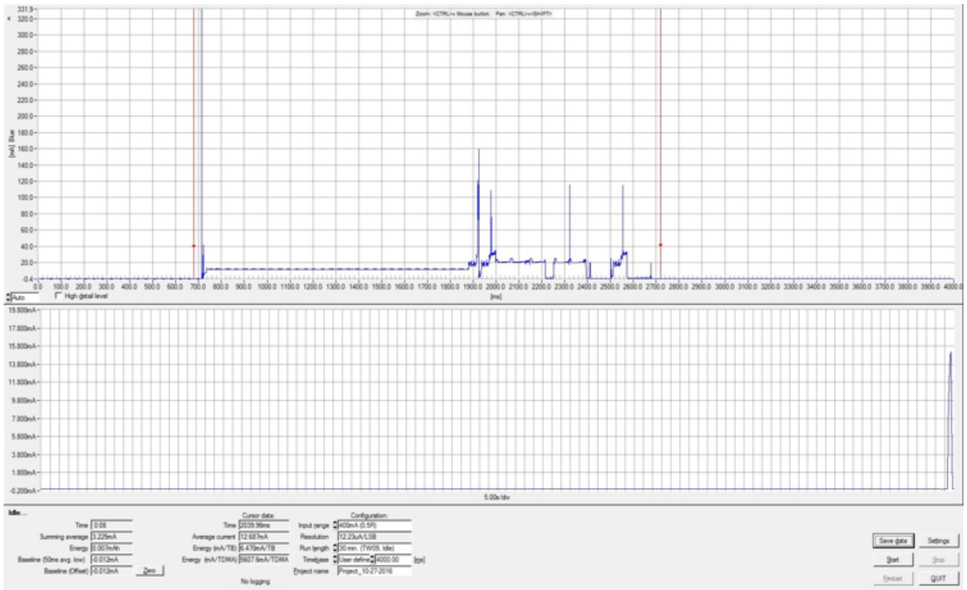

Figure 13. NiDAQ Measurement of CC3100 Wake-Up From Shutdown

Figure 14. Wireless Scope Measurement of CC3100 Wake-Up From Shutdown

The NiDAQ measured an average current of 12.687 mA during wake-up from complete shutdown, while the IMETER-BOOST measured an average current of 12.964 mA.

The last measurement shows the overall accuracy of the IMETER-BOOST, by measuring a static hibernate scenario (see Figure 15 and Figure 16). Note the subtle difference between the two measurements, which is less than the LSB of the INA226.

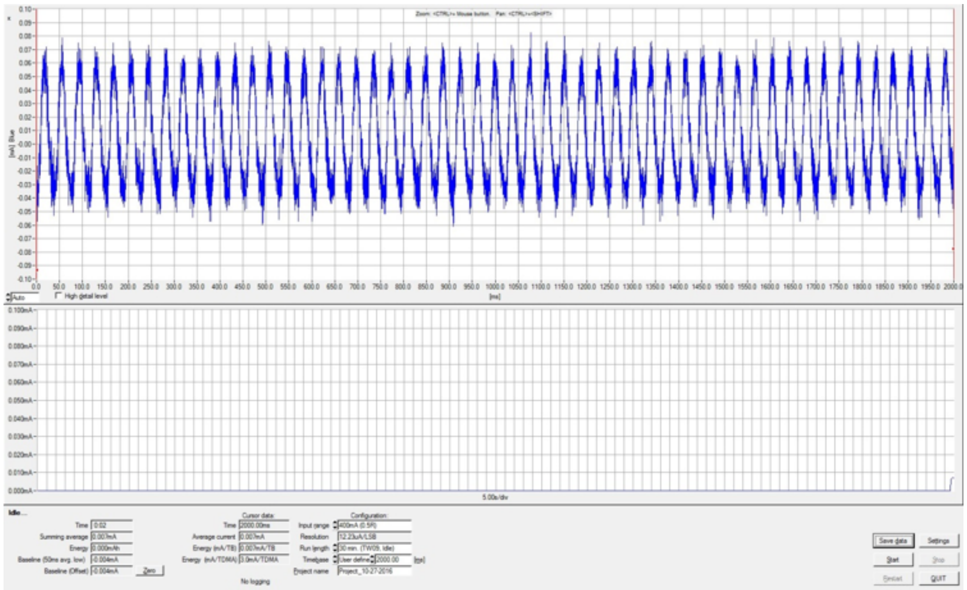

Figure 15. NiDAQ Measurement of CC3100 Hibernate

Figure 16. Wireless Scope Measurement of CC3100 Hibernate

The NiDAQ measured an average current of 0.007 mA during hibernate, while the IMETER-BOOST measured an average current of 0.005 mA.

3.2.2 Voltage Measurements

Voltage measurements were done by connecting the IMETER-BOOST to a signal generator, in parallel with a Tektronix 2.5 gsps oscilloscope.

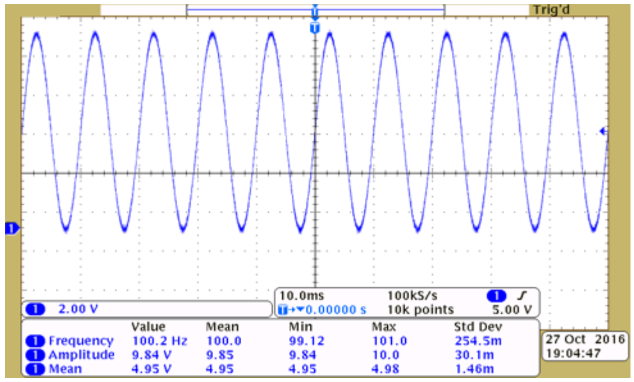

Figure 17. Oscilloscope Measurement of 100-Hz Sine Wave

Figure 18. Wireless Scope Measurement of 100-Hz Sine Wave

The Tektronix oscilloscope shows a an average voltage of 4.95 V (see Figure 17). The IMETER-BOOST shows a comparable average of 5.022 V (see Figure 18).

The following measurements (see Figure 19 and Figure 20) show 1-ms pulses at 100 Hz, with an amplitude of 10 V.

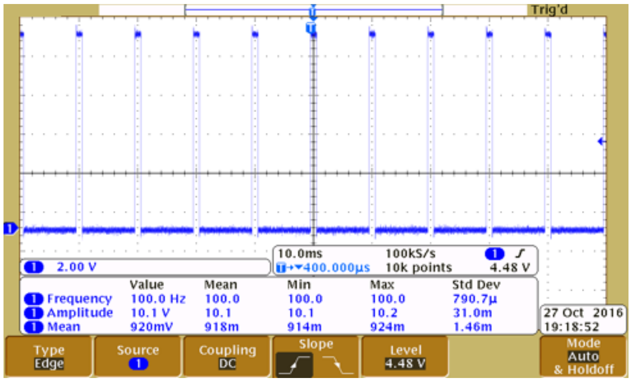

Figure 19. Oscilloscope Measurement of 100 Hz 1-ms pulses

Figure 20. Wireless Scope Measurement of 100 Hz 1-ms pulses

The Tektronix oscilloscope (Figure 19) and IMETER-BOOST (Figure 20) both show an amplitude of 10 V. The expected average voltage for this measurement is 1 V. The Tektronix oscilloscope and IMETER-BOOST show an average measurement of 920 mA and 1004 mA, respectively.

The third waveform is a ramp wave with a frequency of 100 Hz and amplitude of 10 V.

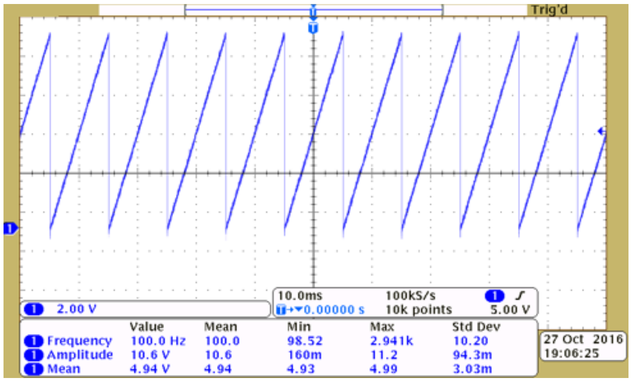

Figure 21. Oscilloscope Measurement of 100-Hz Ramp Wave

Figure 22. Wireless Scope Measurement of 100-Hz Ramp Wave

Both the Tektronix oscilloscope (see Figure 21) and the IMETER-BOOST (see Figure 22) can accurately represent the ramp waveform.

4 Board Layout

4.1 Block Diagram

Figure 23 shows a high-level block diagram of the system. The hardware is comprised of the standard CC3200 LaunchPad (Rev 4.1), and the IMETER-BOOST, which features the INA226 (see Figure 24).

An internet connection is not mandatory. If the plot.ly server is not found, the system works only in local mode. A local network access point (AP) is not mandatory either. The system can operate in AP mode, allowing the front-end device (laptop or smartphone) to connect to it directly. Cloud connectivity is unavailable when the system is operating in AP mode.

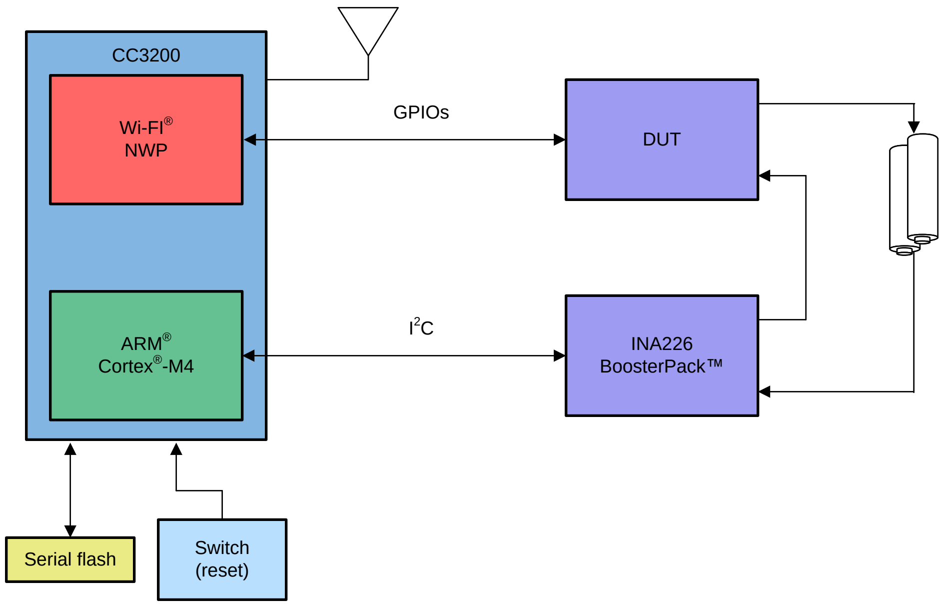

Figure 23. High Level System Block Diagram

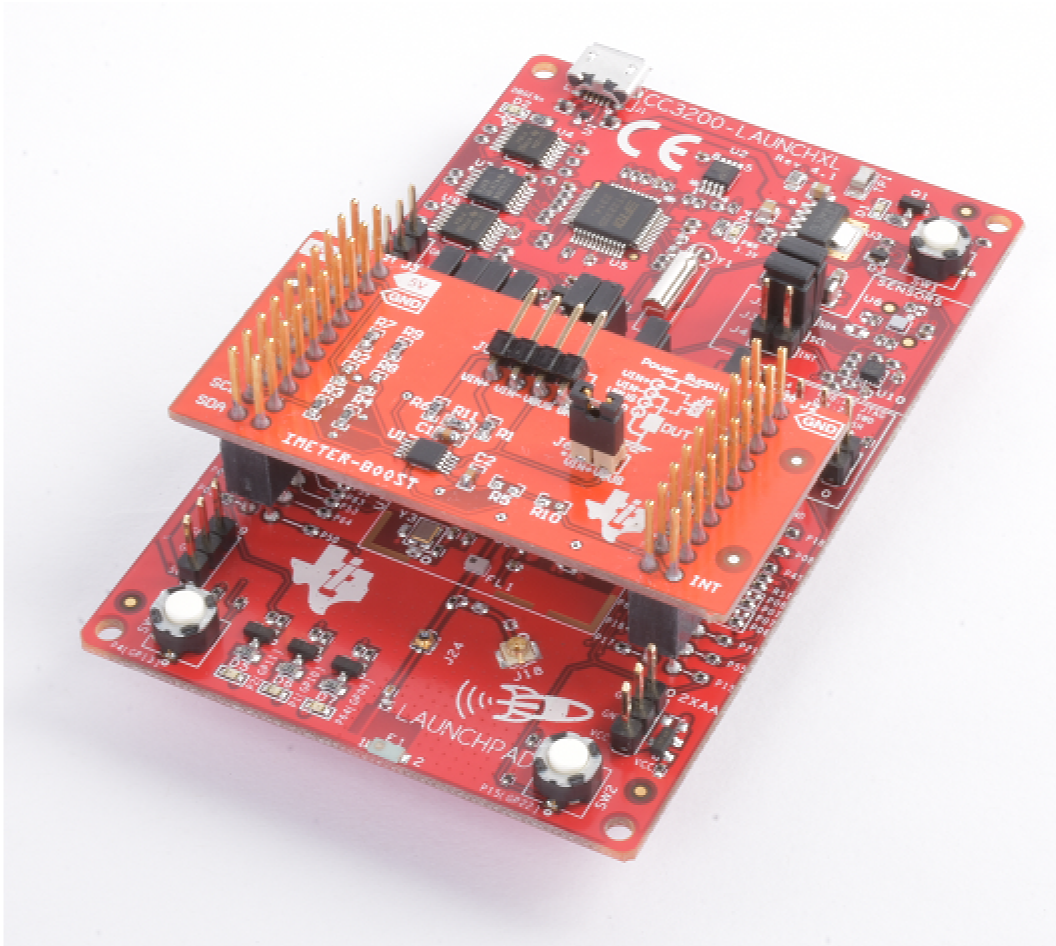

Figure 24. CC3200-LAUNCHXL EVM

4.2 Highlighted Products

This design uses the CC3200 SimpleLink Wi-Fi wireless MCU and INA226 current shunt and power monitor.

4.2.1 CC3200 SimpleLink™ Wi-Fi® and IoT Solution

Created for the IoT, the SimpleLink CC3200 device is a wireless MCU that integrates a high-performance ARM® Cortex®-M4 MCU, which lets customers develop an entire application with a single IC. With on-chip Wi-Fi, Internet, and robust security protocols, no prior Wi-Fi experience is required for faster development. The CC3200 device is a complete platform solution including software, sample applications, tools, user and programming guides, reference designs, and the TI E2E support community. The device is available in a QFN package that is easy-to-layout.

The applications MCU subsystem contains an industry-standard ARM Cortex-M4 core running at 80 MHz. The device includes a wide variety of peripherals, including a fast parallel camera interface, I2S, SD/MMC, UART, SPI, I^2C, and four-channel ADC. The CC3200 family includes flexible embedded RAM for code and data, as well as ROM with external serial flash bootloader and peripheral drivers.

The Wi-Fi network processor subsystem features a Wi-Fi Internet-on-a-Chip and contains an additional dedicated ARM MCU that completely offloads the applications MCU. This subsystem includes an 802.11 b, 802.11 g, 802.11 n radio, baseband, MAC with a powerful crypto engine for fast, secure Internet connections with 256-bit encryption. The CC3200 device supports station, AP, and Wi-Fi Direct® modes. The device also supports WPA2 personal and enterprise security, and WPS 2.0. The Wi-Fi Internet-on-a-chip includes embedded TCP/IP and TLS/SSL stacks, HTTP server, and multiple Internet protocols.

The power-management subsystem includes integrated DC-DC converters supporting a wide range of supply voltages. This subsystem enables low-power consumption modes, such as the hibernate with RTC mode requiring less than 4 µA of current.

4.2.2 INA226

The INA226 is a current shunt and power monitor with an I^2C- or SMBUS-compatible interface. The device monitors both a shunt voltage drop and bus supply voltage. Programmable calibration value, conversion times, and averaging, combined with an internal multiplier, enable direct readouts of current in amperes and power in W.

The INA226 senses current on common-mode bus voltages that can vary from 0 V to 36 V, independent of the supply voltage. The device operates from a single 2.7-V to 5.5-V supply, drawing a typical of 330 µA of supply current. The device is specified over the operating temperature range between –40°C to 125°C, featuring up to 16 programmable addresses on the I^2C-compatible interface.

4.3 System Design Theory

The IMETER-BOOST is designed to be used as a low-cost power measurement and debugging tool, both on a local network and over the Internet.

On the local network the scope can capture any combination of current, VBAT, and GPIO channels at any supported sample rate either once, multiple times, or continuously. Refer to Table 7 in Section 2.2.6 for the list of supported sample rates.

Averaging mode is another working mode when working locally. In this mode the system acts as a digital multimeter, accurately showing the average voltage and current, and the global average since the measurement began.

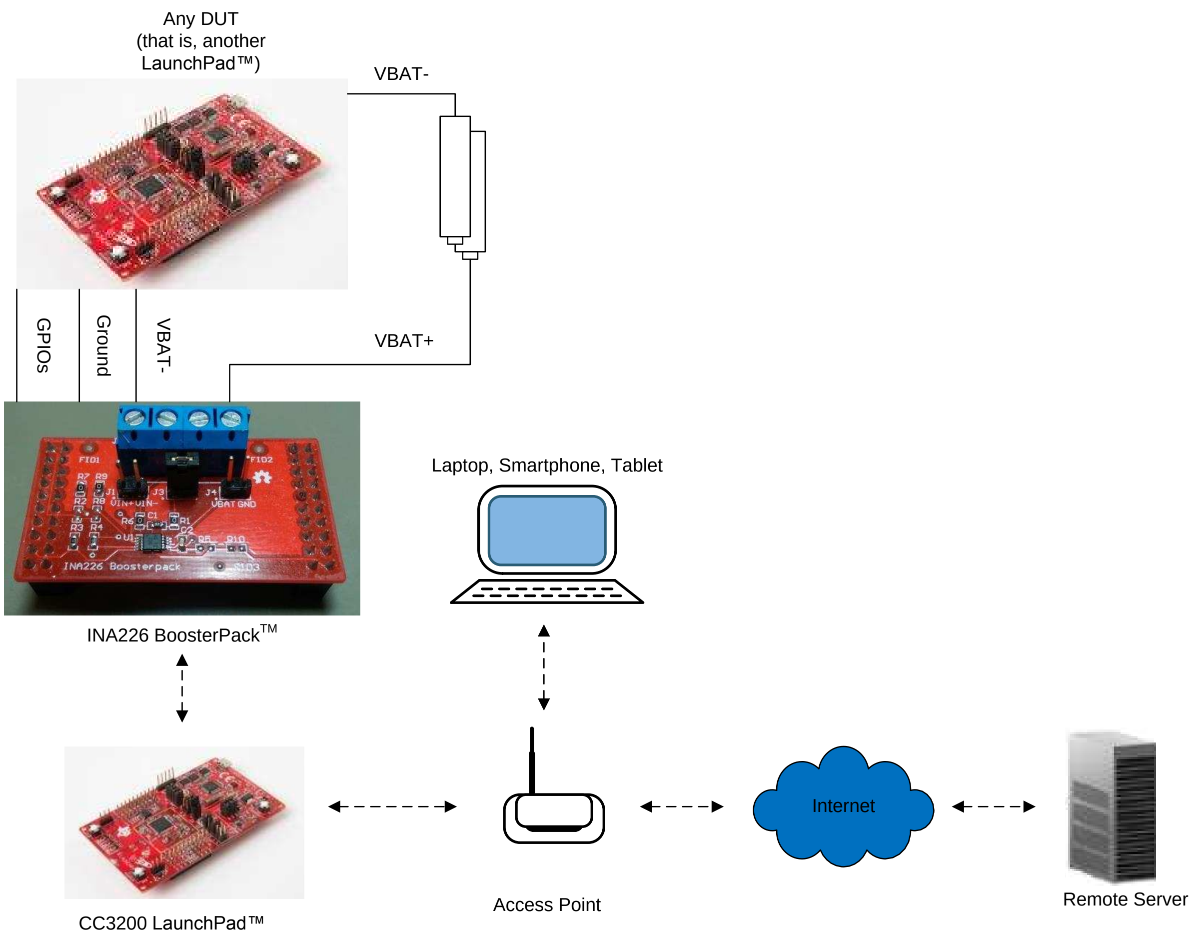

Figure 25. System Design Theory

5 Design Files

5.1 Schematics

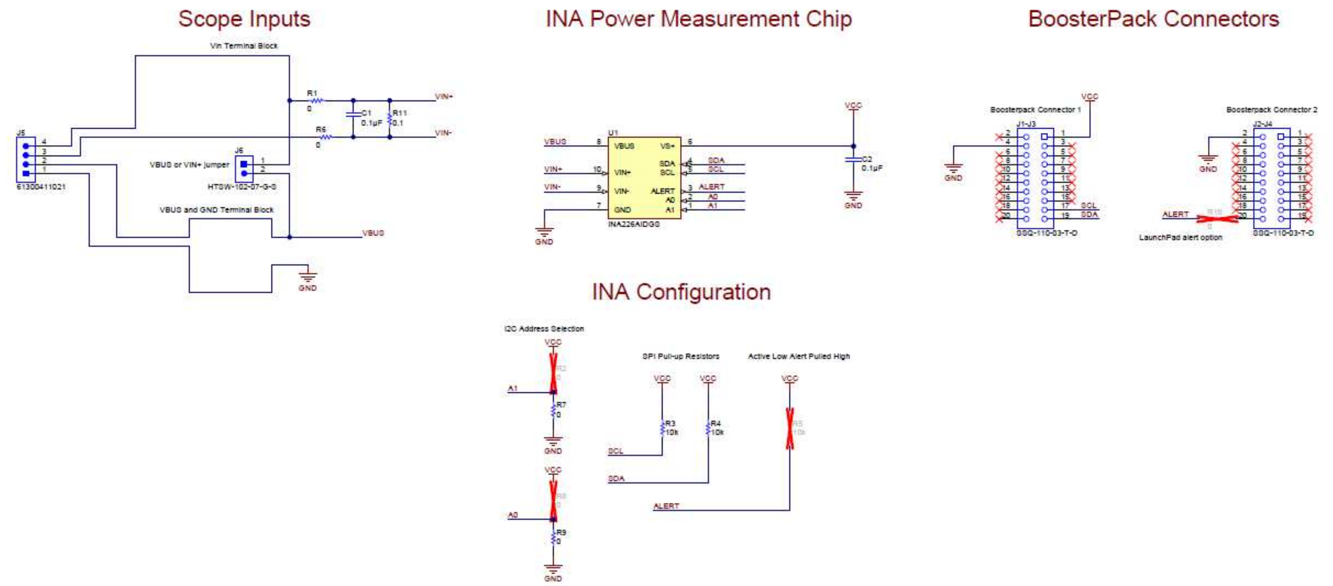

Figure 26. IMETER-BOOST Schematic

5.2 Bill of Materials

Item No.	Designator	Quantity	Value	Part Number	Manufacturer	Description
1	C1, C2	2	0.1 µF	0603YC104JAT2A	AVX	Capacitor, Ceramic, 0.1 µF, 16 V, ±5%, X7R, 0603
2	J1 to J3, J2 to J4	2		SSQ-110-03-T-D	Samtec	Receptacle, 2.54 mm, 10 × 2, Tin, TH
3	J5	1		61300411021	Wurth Elektronik	Header, 2.54 mm, 4 × 1, Gold, R/A, TH
4	J6	1		HTSW-102-07-G-S	Samtec	Header, 100mil, 2 × 1, Gold, TH
5	R1, R6, R7, R9	4	0 Ω	CRCW06030000Z0EA	Vishay-Dale	Resistor, 0, 5%, 0.1 W, 0603
6	R3, R4	2	10 kΩ	RC1608J103CS	Samsung Electro-Mechanics	Resistor, 10 k, 5%, 0.1 W, 0603
7	R11	1	0.1 Ω	ERJ-3RSFR10V	Panasonic	Resistor, 0.1, 1%, 0.1 W, 0603
8	U1	1		INA226AIDGS	Texas Instruments	High-or low-side measurement, bidirectional current/power monitor with I^2C Interface, DGS0010A
9	R2, R8, R10	0	0 Ω	CRCW06030000Z0EA	VIshay-Dale	Resistor, 0, 5%, 0.1 W, 0603
10	R5	0	10 kΩ	RC1608J103CS	Samsung Electro-Mechanics	Resistor, 10 k, 5%, 0.1 W, 0603

5.3 PCB Layout Recommendations

There is no special requirement in terms of layout or routing. A Kelvin connection was done on the shunt resistor, according to the layout recommendations of the INA226 device.

5.3.1 Layout Plots

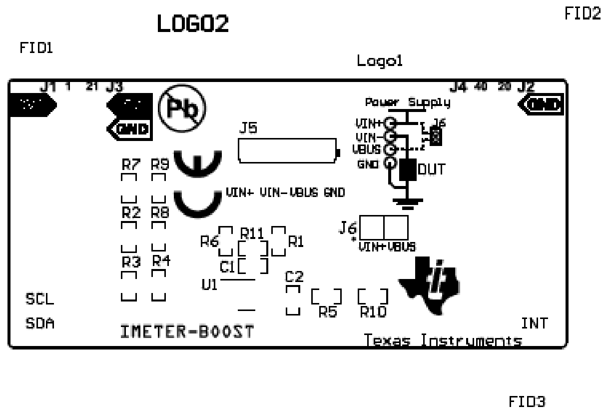

Figure 27. Top Overlay

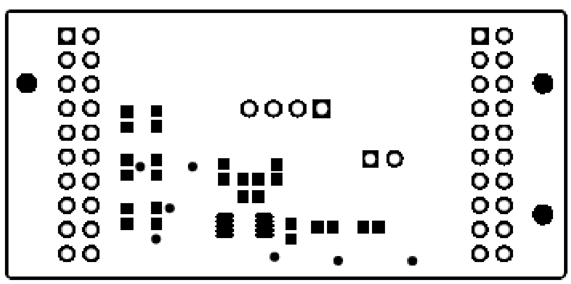

Figure 28. Top Solder

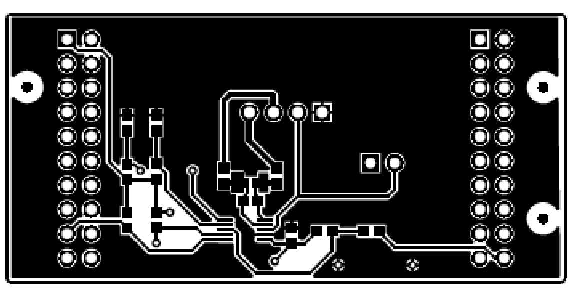

Figure 29. Top Layer

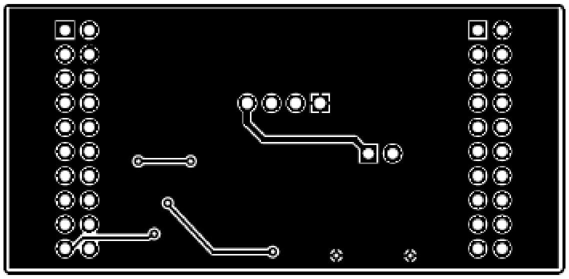

Figure 30. Bottom Layer

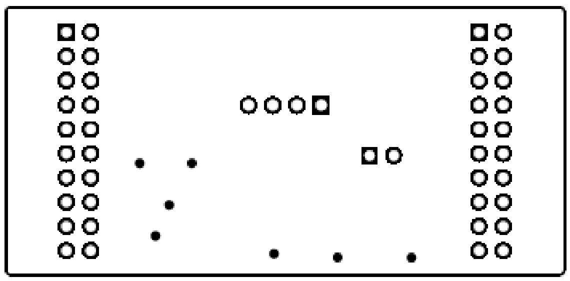

Figure 31. Bottom Solder

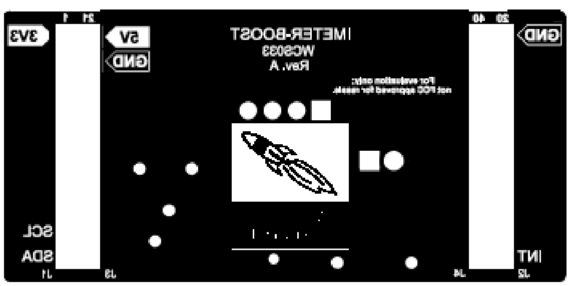

Figure 32. Bottom Overlay

5.4 Software Files

See the software files at IMETER-BOOST.

5.5 Terminology

WLAN— Wireless Local Area Network

AP— Access Point

6 About the Author

ASAF CARMELI is a Systems Engineer at Texas Instruments, where he defines hardware modules and software flows for the SimpleLink devices. Asaf has 10 years of experience in System Engineering.

Revision History

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

Changes from Original (November 2017) to A Revision	**Page**
• Updated links, images, and content in the *Design Files* section	31

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