EVM User's Guide: BQ41Z50EVM

BQ41Z50 2-S, 3-S, and 4-S Cell Li-Ion Battery Pack Manager Evaluation Module with Dynamic Z-Track™

Description

The BQ41Z50 Evaluation Module (EVM) is a system board created with the intent to evaluate the functionality of the BQ41Z50 Fuel Gauge within applications powered by multi-cell battery systems. The EVM includes a BQ41Z50, a current sense resistor, four thermistors, three LEDs, and header options to allow for proper tailoring to the intended application.

This document serves as a comprehensive guide on how use the BQ41Z50EVM to configure, test, and evaluate the performance of the BQ41Z50 in the user's intended application through sections such as the Quick Start Guide for initial test setup, the IT-DZT Guide for gauging algorithm configuration, along with Hardware and Software sections for further device configuration.

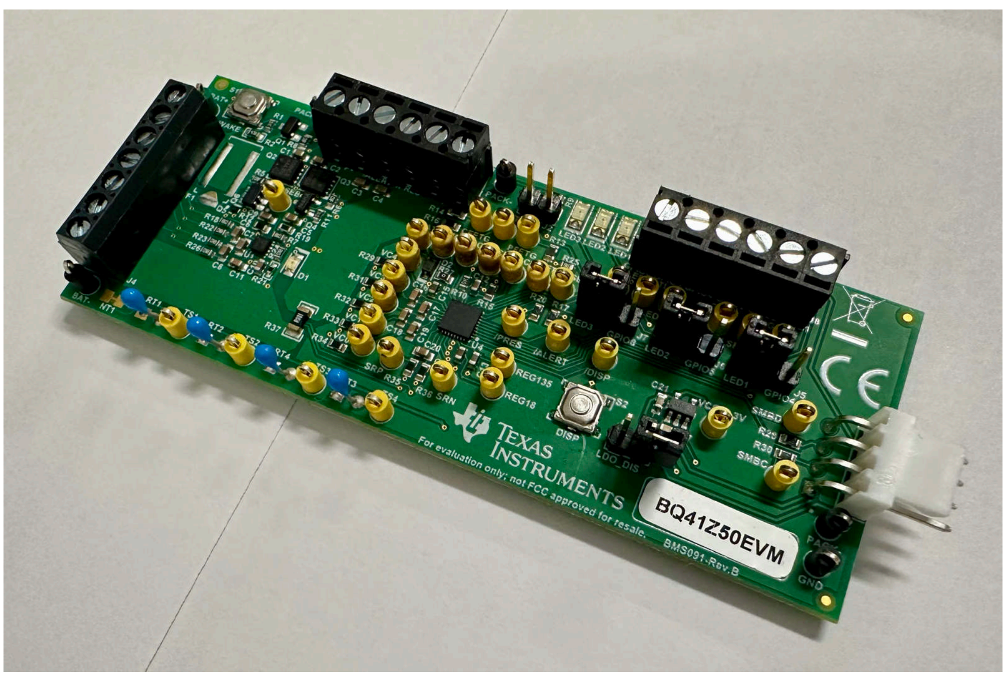
Section IT-DZT Guide To Gauging is an overview and explanation of the Dynamic Z-Track™ (IT-DZT) algorithm. It also goes over how to configure the gauge for a dynamic load profile.

Features

- Complete evaluation system for the BQ41Z50EVM Li-Ion Battery Pack Manager Evaluation Module and BQ296103 independent overvoltage protection IC.
- Populated circuit module for quick setup
- Software that allows data logging for system analysis

Note

The BQ296103 is a 2-4s Overvoltage Protector with LDO Output, which is considered a secondary protector in the BQ41Z50EVM architecture design. Please note that the BQ41Z50 is equipped to operate independently of the BQ296103.



1 Evaluation Module Overview

1.1 Introduction

The BQ41Z50EVM has one BQ41Z50, one BQ296xxx, and all other components necessary to monitor and predict capacity, perform cell balancing, monitor critical parameters, protect the cells from overcharge, over-discharge, short-circuit, and overcurrent in 2-, 3-, or 4-series cell Li-ion or Li-polymer battery packs. The BQ41Z50EVM can be directly connected to the cells in a battery stack. When using the BQ41Z50EVM with the EV2400 or EV2500 interface board and software, the user has the ability to read the device's data registers, program different configurations to the device, log cycling data for further evaluation, and evaluate the overall functionality of the design under different charge and discharge conditions.

1.2 Kit Contents

- BQ41Z50 and BQ296103 circuit module
- Cable to connect the EVM to an EV2400 or EV2500 communications interface adapter

1.3 Specification

This section summarizes the performance specifications of the BQ41Z50EVM and BQ296103EVM.

Table 1-1. BQ41Z50 and BQ296103 Circuit Module Performance Specification Summary

Specification	Min	Type	Max	Unit
Input voltage Pack+ to Pack–	6	15	26	V
Charge and discharge current	0	2	7	A

1.4 Device Information

For complete ordering information, see the product page at www.ti.com.

Table 1-2. Ordering Information

EVM Part Number	Configuration
BQ41Z50EVM	2-, 3-, or 4-cell

For information on device firmware and hardware, see the *BQ41Z50 2-Series, 3-Series, and 4-Series Cell Li-Ion Battery Pack Manager with Dynamic Z-Track™* data sheet and the *BQ41Z50 Technical Reference Manual* on www.ti.com.

2 BQ41Z50EVM Quick Start Guide

This section provides step-by-step instructions how to configure the gauge using the EVM and a battery.

2.1 Items Needed for EVM Setup and Evaluation

- BQ41Z50EVM
- EV2400 or EV2500 communications interface adapter
- Cable to connect the EVM to an EV2400 or EV2500 communications interface adapter
- USB cable to connect the communications interface adapter to the computer
- Computer with Windows 7 (or newer) operating system
- Internet access to download the Battery Management Studio software program.
- Two-to-four battery cells
- A DC power supply that can supply 16.8V and 2A (of constant current and constant voltage capability)

2.2 Software Installation

Find the latest software version in the BQ41Z50 tool folder on https://www.ti.com/tool/download/BQ41Z50-FW. Use the following steps to install the BQ41Z50 Battery Management Studio software:

1. Download and run the Battery Management Studio setup program from the Development Tools section of the BQ41Z50EVM product folder on https://www.ti.com/product/BQ41Z50. See Section 4.1 for detailed information on using the tools in the Battery Management Studio.

The latest version of the Chem Updater software is required for IT-DZT compatible battery chemistries. Download the Chem Updater software: GASGAUGECHEM-SW Design tool | TI.com.

If using EV2400, install the latest version of the EV2400 adapter firmware: EV2400 or EV2500 Interface adapter | TI.com

2.3 EVM Connections

This section covers the hardware connections for the EVM.

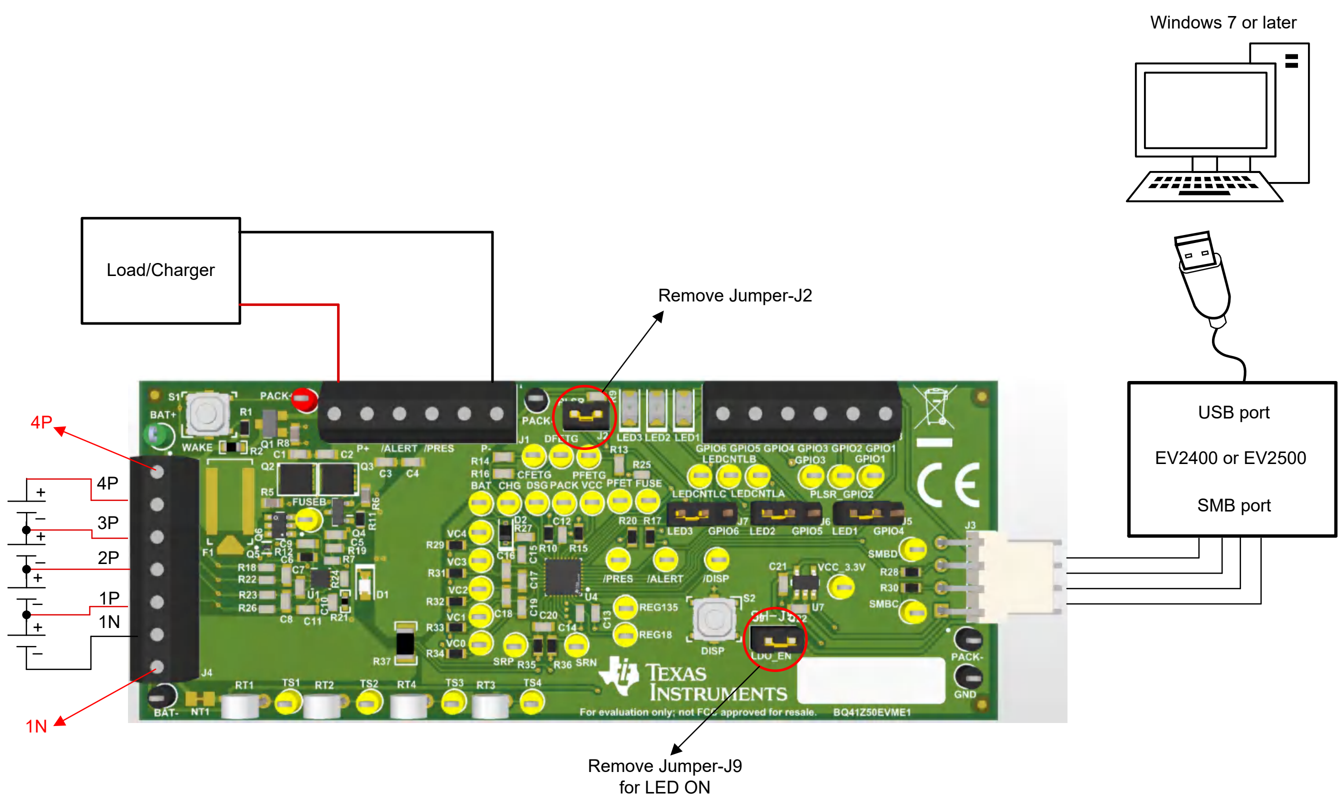


Figure 2-1. BQ41Z50 Circuit Module Connection to Cells and System Load or Charger

Note

To avoid damaging the device and the surrounding passive components, remove J2 before flashing a new firmware.

- Direct connection to the cells: 1N (BAT–), 1P, 2P, 3P, 4P (BAT+)
- Attach the cells as shown in Figure 2-1. It is best practice to start with the lowest cell in the stack (cell 1), then attach cells 2 through 4 in sequence. Other cell connection sequences can potentally damage the U1 and U4 components, which can cause the fuse to blow. If using a 2-cell or 3-cell configuration, confirm a short is placed across the unused voltage inputs. For more details, see Figure 2-2.

Number of Cells	J4 Terminal Block Connection							
	1N		1P		2P		3P	4P
2		-cell1+		-cell2+		short		short
3		-cell1+		-cell2+		-cell3+		short
4		-cell1+		-cell2+		-cell3+		-cell4+

Figure 2-2. Cell Connection Configuration

Note

The BQ41Z50 requires at least 2 attached cells for proper functionality.

- **Serial communications port (SMBC, SMBD)**
  - Attach the communications interface adapter cable to J3 and to the SMB port on the EV2400 or EV2500.
- **System load and charger connections across PACK+ and PACK–**
  - Attach the load or power supply to the J1 terminal block. The positive load or power supply wire must be connected to at least one of the first two terminal block positions labeled PACK+. The ground wire for the load or power supply must be connected to the last terminal block positions labeled PACK–.
- **System-present pin ($\overline{\text{PRES}}$/$\overline{\text{SHUTDN}}$)**
  - To start charge or discharge test, connect the $\overline{\text{PRES}}$/$\overline{\text{SHUTDN}}$ position on the J1 terminal block to PACK–. The $\overline{\text{PRES}}$/$\overline{\text{SHUTDN}}$ pin is sampled by the BQ41Z50 every 250ms, so this connection will need to be kept for the duration of the test. The $\overline{\text{PRES}}$/$\overline{\text{SHUTDN}}$ can be left open if the non-removable (NR) bit is set to 1 in the ***Settings:Configuration:DA Configuration*** register. To test sleep mode, disconnect the $\overline{\text{PRES}}$/$\overline{\text{SHUTDN}}$ pin.
- **Wake-up the device up from shutdown (WAKE)**
  - Press the Wake push-button switch to temporarily connect Bat+ to Pack+. This applies voltage to the PACK pin on the BQ41Z50 to power-up the regulators and start the initialization sequence. If ***Settings:Configuration:DA Configuration*** is correctly configured to reflect the amount of cells in use, then this button only needs to be held for a few seconds. If not, it needs to be held until the setting has been changed.
- **Parameter setup**
  - The default data flash settings configure the device for 3-series Li-Ion cells. The user must change the ***Settings:Configuration:DA Configuration*** register to set up the number of series cells to match the physical pack configuration. This provides basic functionality for the setup. Other data flash parameters must also be updated to fine tune the gauge to the pack. For help with setting the parameters, see *BQ41Z50 Technical Reference Manual*.

2.3.1 Connectors

2.3.1.1 Primary Input and Output Connectors

2.3.1.2 Jumper Placements

Table 2-1 is a description of jumpers functionality.

Table 2-1. Jumper Placements

Pinheader	Contacts	Jumper Connection	Populated by Default
J2	1-2	PLSR	NO
J5	1-3	LED connection to LED1 or GPIO 4	Yes (LED1)
J6	1-3	LED connection to LED2 or GPIO 5	Yes (LED2)
J7	1-3	LED connection to LED3 or GPIO 6	Yes (LED3)
J9	1-2	External LDO to power LEDs (A jumper disables LDO functionality)	NO

2.3.1.3 Battery Connector

Figure 2-3. ED555/7DS (Reference Image Only)

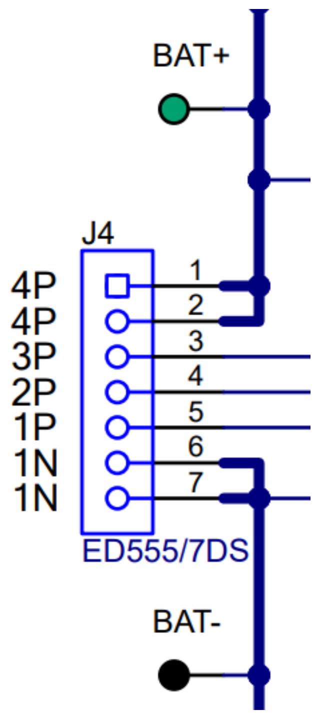


Figure 2-4. Evaluation Board Battery Connector (J4)

Table 2-2. Connector Information

Designator	Manufacturer	Part Number
J4	On-Shore Technology	ED555/7DS

Table 2-3 describes the connections for battery connector.

Table 2-3. Pin Description

Pin	Name	Comment
7 (1N)	CELL0/GND	Negative terminal of CELL1, Connected directly to GND of device
6 (1N)	CELL0/GND	Negative terminal of CELL1, Connected directly to GND of device
5 (1P)	CELL1	Positive terminal of CELL1, negative terminal of CELL2
4 (2P)	CELL2	Positive terminal of CELL2, negative terminal of CELL3 / Shorted to pins 3, (2 or 1) for 2-series
3 (3P)	CELL3	Positive terminal of CELL3, negative terminal of CELL4 / Shorted to pins 2 or 1 for 3-series
2 (4P)	CELL4	Positive terminal of CELL4, Direct connection to BAT
1 (4P)	CELL4	Positive terminal of CELL4, Direct connection to BAT

2.3.1.4 Load/Charger Connector

Figure 2-5. ED555/6DS (Reference Image Only)

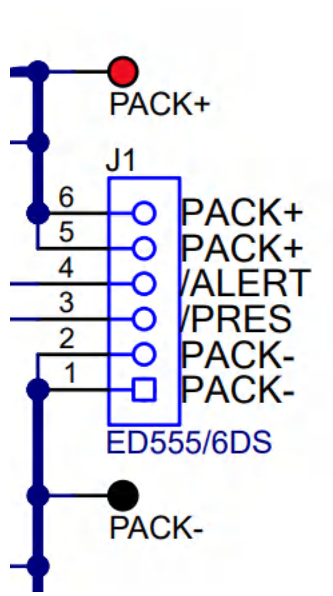


Figure 2-6. Evaluation Board Load/Charger Connector (J1)

Table 2-4. Connector Information

Designator	Manufacturer	Part Number
J1	On-Shore Technology	ED555/6DS

Table 2-5 describes the connections for pins that are typically exposed in system applications.

Table 2-5. Pin Description

Pin	Name	Comment
6	LOAD+/PACK +	Positive terminal of charger or load
5	LOAD+/PACK+	Positive terminal of charger or load
4	/ALERT	Alert digital signal output to signal interrupt detection
3	/PRES	Input for removable battery pack or emergency system shutdown input
2	LOAD-/PACK-	Negative terminal of charger or load
1	LOAD-/PACK-	Negative terminal of charger or load

2.3.1.5 GPIO Connector

Figure 2-7. ED555/6DS (Reference Image Only)

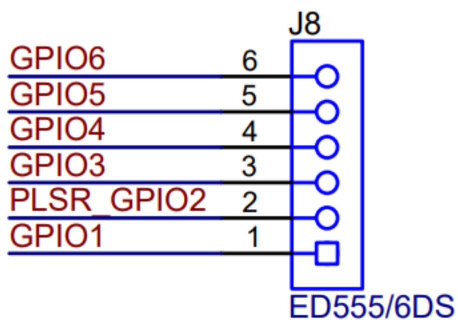


Figure 2-8. Evaluation Board GPIO Connector (J8)

Table 2-6. Connector Information

Designator	Manufacturer	Part Number
J8	On-Shore Technology	ED555/6DS

Table 2-7 describes the pinouts for the six available GPIOs.

Table 2-7. Pin Description

Pin	Name	Comment
1	GPIO1	Multifunction push-pull pin, general-purpose digital input or general-purpose digital output.
2	PLSR_GPIO2	Multifunction push-pull pin, general-purpose digital input or general-purpose digital output.
3	GPIO3	Multifunction open drain pin, general-purpose digital input or general-purpose digital output.
4	GPIO4	LED display segment that drives the external LEDs via an internal current sink depending on the firmware configuration. Alternatively, this pin is push-pull and can be configured as a general-purpose digital input or general-purpose digital output pin.
5	GPIO5	LED display segment that drives the external LEDs via an internal current sink depending on the firmware configuration. Alternatively, this pin is push-pull and can be configured as a general-purpose digital input or general-purpose digital output pin.
6	GPIO6	LED display segment that drives the external LEDs via an internal current sink depending on the firmware configuration. Alternatively, this pin is push-pull and can be configured as a general-purpose digital input or general-purpose digital output pin.

2.4 Update Firmware

Find the latest firmware version in the appropriate BQ41Z50 folder on www.ti.com. Use the following steps to install the BQ41Z50 *Battery Management Studio* software:

1. Run *Battery Management Studio* from the **Start | Programs | Texas Instruments | Battery Management Studio** menu sequence, or the *Battery Management Studio* shortcut.
2. Follow the directions in Programming Screen, select the firmware .bq.fs file downloaded from www.ti.com, and click the **Program** button.
3. Once programming is finished, the EVM is ready to use with the latest firmware.

3 Hardware

3.1 BQ41Z50 Production Calibration Guide

Please refer to the BQ41xxx Production Calibration Guide.

Note

Please note that this calibration method is for mass production. This is different from a generic calibration using the EVM referenced at Calibration Screen.

4 Software

4.1 Battery Management Studio

4.1.1 Registers Screen

The Registers section allows the user to view the reported parameters from the gauge. The Bit Registers section provides bit level picture of status and fault registers. A green background color indicates that the bit is 0 (low state) and a red background color indicates that the bit is 1 (high state). Data begins to update once the *Refresh* (single-time scan) button is selected, or scans continuously if the *Scan* button is selected.

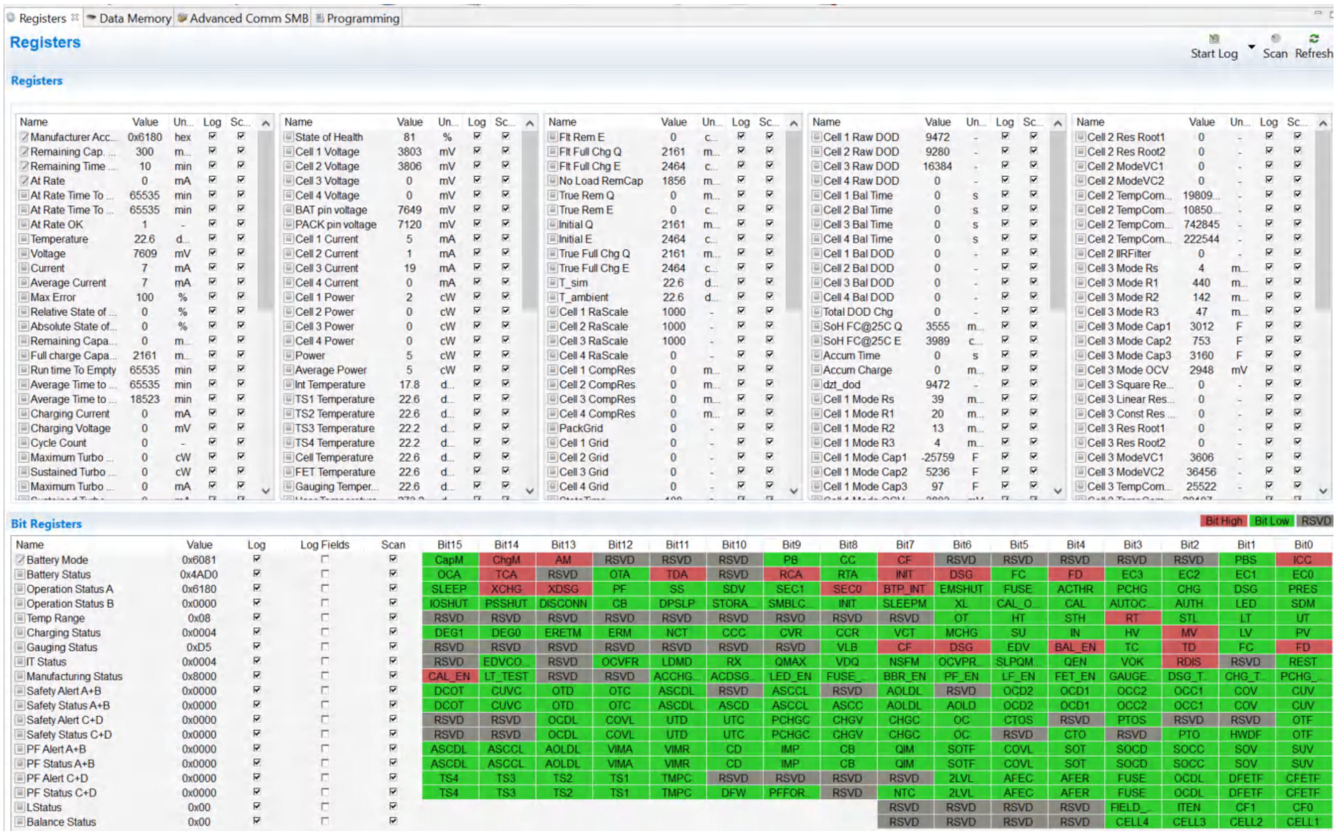


Figure 4-1. Registers Screen

The continuous scanning period can be set via the | Window | Preferences | SBS | Scan Interval | menu selections.

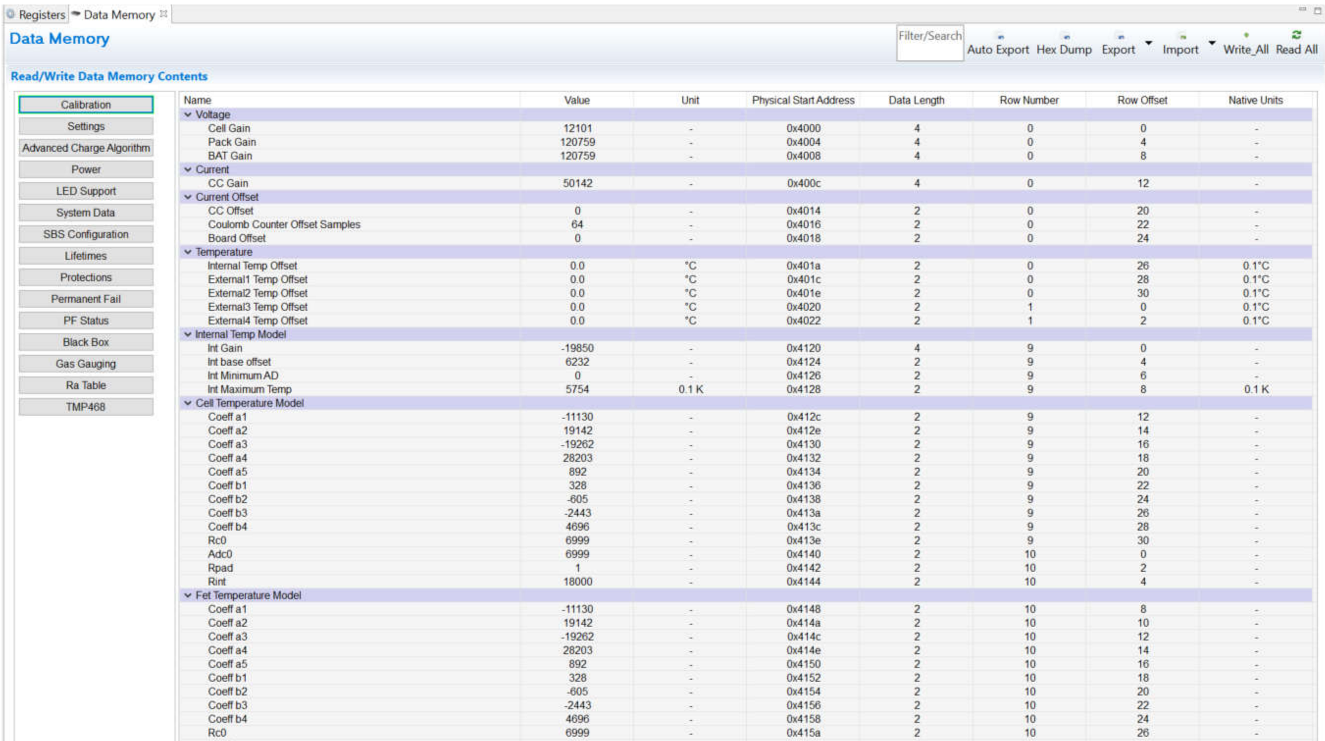
Battery Management Studio has the ability to record specific parameters over a period of time, which can be initiated by clicking the "Start Log" button. To specify which values to be recorded within the .log file, parameters can be selected using the Log check boxes located beside each parameter in the Register section. Logging can be stopped by pressing the "Stop Log" button.

4.1.2 Setting Programmable BQ41Z50 Options

The BQ41Z50 data flash comes configured per the default settings detailed in the BQ41Z50 TRM. Make sure that the settings are compatible with the pack and application for the design being evaluated.

Note

The correct setting of these options is essential to get the best performance. The settings can be configured using the Data Memory screen (see Figure 4-2).



Name	Value	Unit	Physical Start Address	Data Length	Row Number	Row Offset	Native Units
Voltage							
Cell Gain	12101	-	0x4000	4	0	0	-
Pack Gain	120759	-	0x4004	4	0	4	-
BAT Gain	120759	-	0x4008	4	0	8	-
Current							
CC Gain	50142	-	0x400c	4	0	12	-
Current Offset							
CC Offset	0	-	0x4014	2	0	20	-
Coulomb Counter Offset Samples	64	-	0x4016	2	0	22	-
Board Offset	0	-	0x4018	2	0	24	-
Temperature							
Internal Temp Offset	0.0	°C	0x401a	2	0	26	0.1°C
External1 Temp Offset	0.0	°C	0x401c	2	0	28	0.1°C
External2 Temp Offset	0.0	°C	0x401e	2	0	30	0.1°C
External3 Temp Offset	0.0	°C	0x4020	2	1	0	0.1°C
External4 Temp Offset	0.0	°C	0x4022	2	1	2	0.1°C
Internal Temp Model							
Int Gain	-19850	-	0x4120	4	9	0	-
Int base offset	6232	-	0x4124	2	9	4	-
Int Minimum AD	0	-	0x4126	2	9	6	-
Int Maximum Temp	5754	0.1 K	0x4128	2	9	8	0.1 K
Cell Temperature Model							
Coeff a1	-11130	-	0x412c	2	9	12	-
Coeff a2	19142	-	0x412e	2	9	14	-
Coeff a3	-19262	-	0x4130	2	9	16	-
Coeff a4	28203	-	0x4132	2	9	18	-
Coeff a5	892	-	0x4134	2	9	20	-
Coeff b1	328	-	0x4136	2	9	22	-
Coeff b2	-605	-	0x4138	2	9	24	-
Coeff b3	-2443	-	0x413a	2	9	26	-
Coeff b4	4696	-	0x413c	2	9	28	-
Rc0	6999	-	0x413e	2	9	30	-
Adc0	6999	-	0x4140	2	10	0	-
Rpad	1	-	0x4142	2	10	2	-
Rint	18000	-	0x4144	2	10	4	-
Fet Temperature Model							
Coeff a1	-11130	-	0x4148	2	10	8	-
Coeff a2	19142	-	0x414a	2	10	10	-
Coeff a3	-19262	-	0x414c	2	10	12	-
Coeff a4	28203	-	0x414e	2	10	14	-
Coeff a5	892	-	0x4150	2	10	16	-
Coeff b1	328	-	0x4152	2	10	18	-
Coeff b2	-605	-	0x4154	2	10	20	-
Coeff b3	-2443	-	0x4156	2	10	22	-
Coeff b4	4696	-	0x4158	2	10	24	-
Rc0	6999	-	0x415a	2	10	26	-

Figure 4-2. Data Memory Screen

4.1.3 Calibration Screen

Current, voltage and temperature measurements can be calibrated for optimal performance.

Press the *Calibration* button to select the Advanced Calibration window. See Figure 4-3.

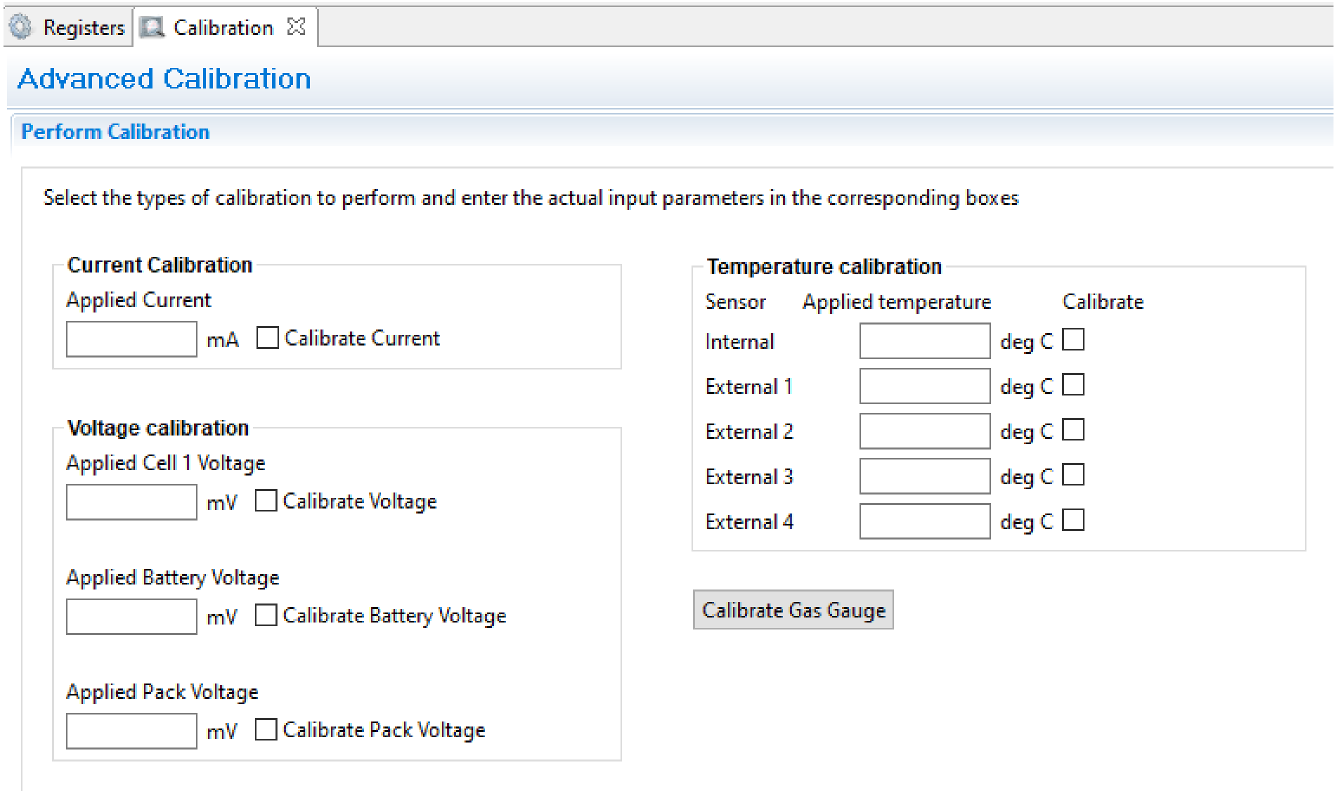


Figure 4-3. Calibration Screen

4.1.3.1 Voltage Calibration

- Measure the voltage from Cell 1 to 1N and enter this value in the Applied Cell 1 Voltage field and select the Calibrate Voltage box.
- Measure the voltage from Bat+ to Bat– and enter this value in the Applied Battery Voltage field and select the Calibrate Battery Voltage box.
- Measure the voltage from Pack+ to Pack– and enter this value in the Applied Pack Voltage field and select the Calibrate Pack Voltage box. If the voltage is not present, then turn the charge and discharge FETs on by sending the ManufacturerAccess() FET Control Command (0x0022). For instructions to accomplish this, please refer to Section 4.1.6 *Advanced Comm SMB Screen.*
- Press the *Calibrate Gas Gauge* button to calibrate the voltage measurement system.
- Deselect the Calibrate Voltage boxes after voltage calibration has completed.

4.1.3.2 Temperature Calibration

- Enter the room temperature in each of the Applied Temperature fields and select the Calibrate box for each thermistor to be calibrated. The temperature values must be entered in degrees Celsius.
- Press the *Calibrate Gas Gauge* button to calibrate the temperature measurement system.
- Deselect the Calibrate boxes after temperature calibration has completed.

4.1.3.3 Current Calibration

The Board Offset calibration option is not offered in Battery Management Studio, because the Board Offset calibration is not required when using the BQ41Z50EVM.

- Connect and measure a -2A current source from 1N (–) and Pack– (+) to calibrate without using the FETs. (TI does not recommend calibration using the FETs).
- Enter –2000 in the Applied Current field and select the Calibrate Current box.
- Press the *Calibrate Gas Gauge* button to calibrate.
- Deselect the Calibrate Current box after current calibration has completed.

4.1.4 Chemistry Screen

The chemistry file contains parameters that the simulations use to model the cell and the operating profile. A critical issue is to program a Chemistry ID that matches the cell into the device. Some of these parameters can be viewed in the Data Memory section of the Battery Management Studio.

1. Press the *Chemistry* button to select the Chemistry window.

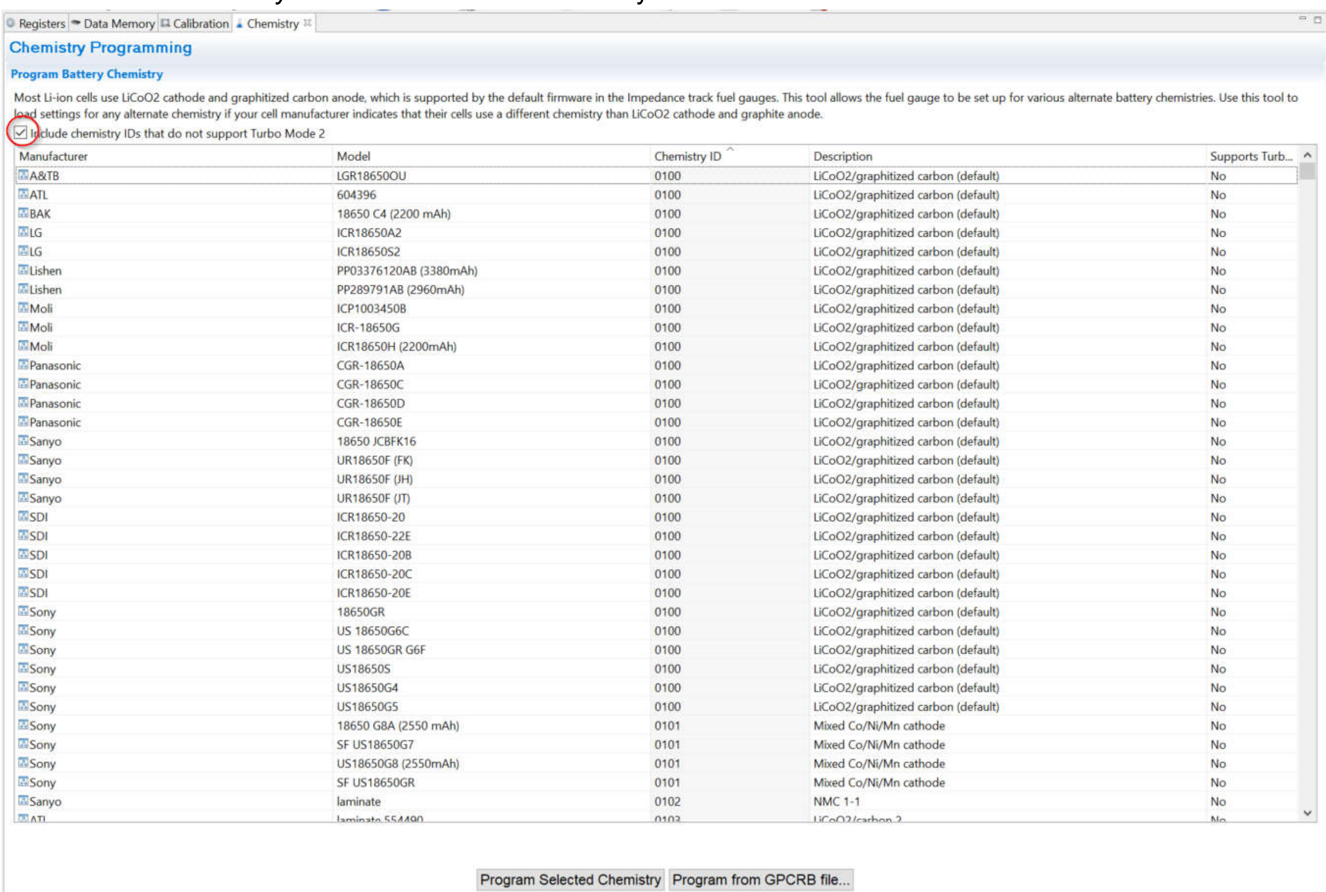


Figure 4-4. Chemistry Screen

2. The table can be sorted by clicking the desired column. for example: Click the Chemistry ID column header. Please ensure that the box in the top left corner is selected to ensure that only IT-DZT ChemIDs are available.
3. Select the ChemID that matches your cell from the table (see Figure 4-4).
4. Press the *Program Selected Chemistry* button to update the chemistry in the device.
5. If the GPCRB tool has been used for low temperature optimization tool Press *Program from GPCRB file* button to program the Chemdat file. This step is not required.

4.1.5 Programming Screen

Press the *Programming* button to select the Firmware Programming window. This window allows the user to export and import the device firmware.

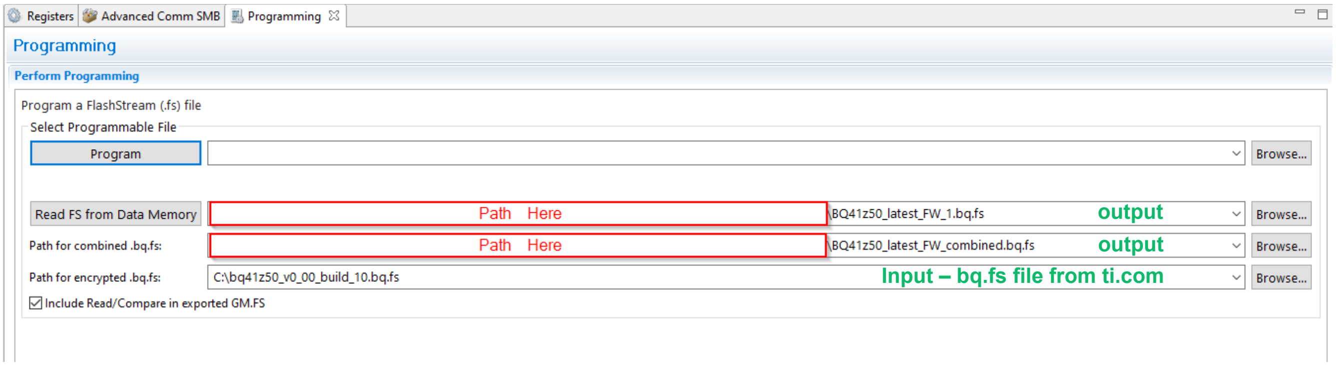


Figure 4-5. Programming Screen

4.1.5.1 Programming the Flash Memory

The upper section of the Programming screen is used to program firmware (.bq.fs) or configuration (.df.fs) to the BQ41Z50 (see Figure 4-5).

- Search for the .bq.fs file using the *Browse* button.
- Press the *Program* button and wait for the download to complete.

4.1.5.2 Exporting the Flash Memory

The lower section of the Programming screen is used to export all of the flash memory from the device (see Figure 4-5).

1. In the first lower box, press the *Browse* button and enter a .df.fs filename. This contains the encrypted gauge configuration.
2. In the *Path for combined .bq.fs*, press the *Browse* button and enter a .bq.fs filename that defers from the name above (for example, filename_combined), see example Figure 4-5. The combined .fs file contains the encrypted FW and user specific settings to be uploaded in production.
3. In the *Path for encrypted .bq.fs*, press the *Browse* button and upload the encrypted bq.fs file available on from ti.com. This encrypted file is the default .bq.fs that the user can download from ti.com.
4. Press the *Read FS from Data Memory* to save the Flash memory contents to the file. Wait for the *Operation executed successfully* message at the left bottom corner of the BQStudio screen.

4.1.6 Advanced Comm SMB Screen

Press the *Advanced Comm SMB* button to select the Advanced SMB Comm window. This tool provides access to parameters using SMB and Manufacturing Access commands. See Figure 4-6.

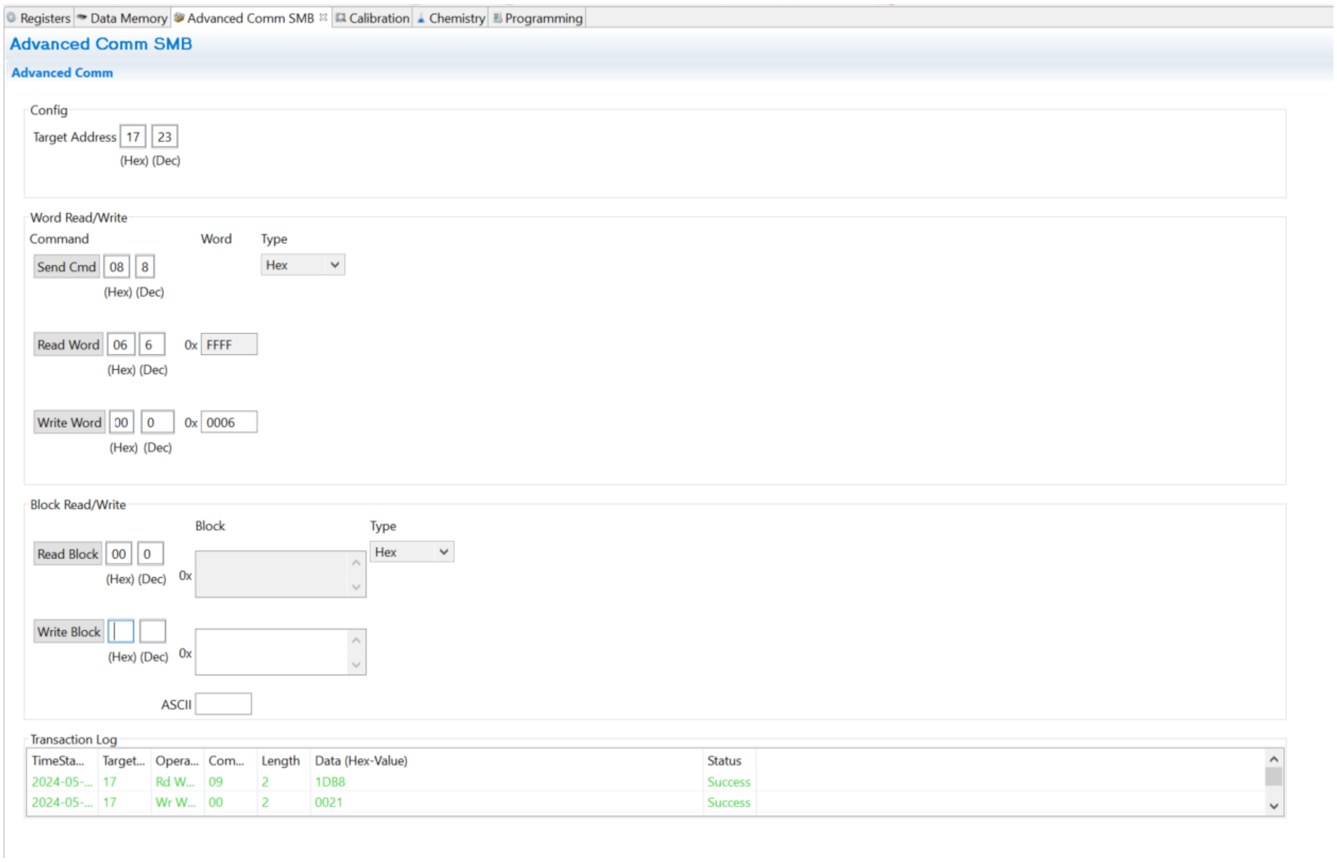


Figure 4-6. Advanced Comm SMB Screen

Examples:

Reading an SMB Command.

- Read SBData Voltage (0x09)
  - SMBus Read Word. Command = 0x09
  - Word = 0x3A7B, which is hexadecimal for 14971mV

Sending a MAC Gauging() to enable IT via ManufacturerAccess().

- With Impedance Track™ disabled, send Gauging() (0x0021) to ManufacturerAccess().
  - SMBus Write Word. Command = 0x00. Data = 00 21

Reading Chemical ID() (0x0006) via ManufacturerAccess()

- Send Chemical ID() to ManufacturerAccess()
  - SMBus Write Block. Command = 0x44. Data sent = 00 06
- Read the result from ManufacturerData()
  - SMBus Read Block. Command = 0x44. Data read = 06 00 10 12
  - That is 0x1210, chem ID 1210

5 IT-DZT Guide To Gauging

5.1 What is Dynamic Z-Track™ (IT-DZT)?

Dynamic Z-Track™ (IT-DZT) is an extension to Impedance Track™ (IT) used to accurately gauge battery conditions under variable load conditions. IT-DZT provides reliable performance and improved battery longevity for applications with fluctuating load currents such as but not limited to power tools, drones, and Intel® Turbo Boost Technology. This section serves as an overview of the IT-DZT algorithm as an extension of IT.

5.2 Overview of IT-DZT

The IT-DZT algorithm builds on the basics of the IT algorithm. As such, it is crucial to have a basic understanding of the factors that go into IT-DZT gauging. Both IT and IT-DZT gauging algorithms use factors such as Depth of Discharge (DoD), total chemical capacity (Qmax) and internal cell resistance R_{BAT} (DoD, Temperature) to calculate the remaining capacity and the full charge capacity.

DOD and Qmax update timing shows the timing of updates during a cycle. After a 30 minute relaxation period, OCV readings are taken every 100 seconds. The OCV readings are correlated with a predefined OCV table using linear interpolation, resulting in a DoD. The first DoD measurement is DOD_0. The OCV table remains the same for a particular battery chemistry. Subsequent DOD measurements are found using DOD Formula.

$$DOD = DOD_0 + \frac{Passed\ Charge}{Qmax}$$

Figure 5-1. DOD Formula

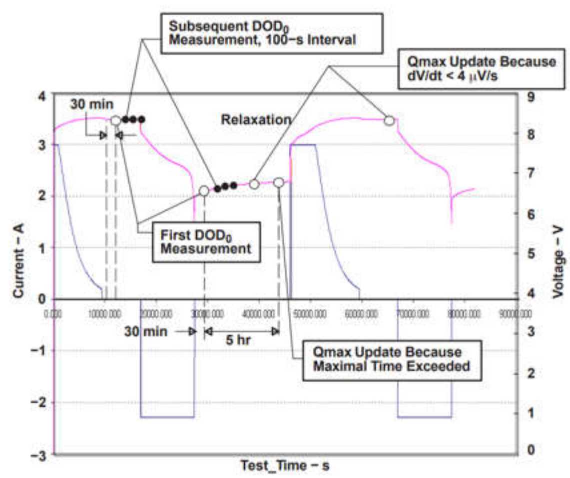


Figure 5-2. DOD and Qmax Update Timing

Qmax is updated based on two DOD readings, DOD1 and DOD2, made before and after a charge or discharge cycle, which is then calculated using Figure 5-3.

$$Qmax = \frac{\Delta Q(t_1, t_2)}{DoD(t_2) - DoD(t_1)}$$

Figure 5-3. Qmax Formula

Qmax updates larger than 30% from the last updated Qmax value are filtered to avoid jumps. Note that Qmax updates only occur when the change in DoD between t2 and t1 is larger than 37% in passed charge. Accurate

Qmax measurements are critical for accurate gauging. The gauge has additional TI proprietary safe-guards preventing Qmax updates if the conditions are unfavorable.

During a discharge cycle, the voltage drop between the OCV curve and the measured IR drop voltage (V) is used to calculate the resistance using the formula based on Ohm's law as seen in equations below Loaded voltage equation.

$$dV = V - OCV(DoD, T)$$

$$R(DoD, T) = dV/I$$

Figure 5-4. Loaded Voltage Equation

Resistance values as a function of DoD and temperature are calculated using resistance factors Ra and Rb. Normalized resistance values are calculated using Resistance equation. The values are updated in the data flash through Ra tables. Ra tables are updated after each 11.1% of DoD charge is exceeded. Once DoD reaches 77.7%, further updates to the Ra tables occur after every 3.3% DoD charge exceeded, totaling 15 Ra updates. The updates are then stored in a grid where each grid point represents a DoD as seen in Ra Grid Table.

$$R(DoD, Tmp) = R_a(DoD, T)e^{R_b(DoD)(T-25)}$$

Figure 5-5. Resistance Equation

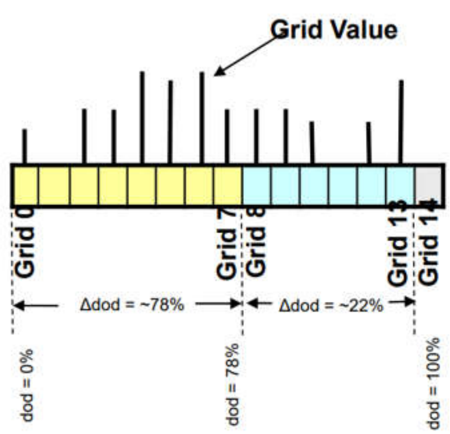


Figure 5-6. Ra Grid Table

Resistance estimates in the grid are further refined through regression based on nearby grid estimates. The refined values are then used to scale the rest of the values for subsequent resistance updates.

The IT algorithm uses grid arrays for the average current (Iav) and average temperature (Tav) measured via current sensing and thermistors, respectively. These measurements are mainly used to compute Ra updates. If some entries have zero values, linear interpolation is applied and nearby estimates are averaged for the new value.

TI Impedance Tracking works off of a steady state model to determine full charge capacity consisting of a resistor to model internal cell resistance. Battery resistance changes due to factors such as age and temperature, while chemical capacity of the battery changes due to aging.

While Impedance Tracking gauges provide accurate gauging for current loads that are fairly consistent, their accuracy diminishes with variable loads. This is because IT gauges require at least a 500 second (default value) settling time during discharge routines to accurately gauge and update the Ra table. In applications with fluctuating load currents, such as power tools and drones, IT gauges may not update the Ra table due to delaying the update until finding a point to settle for the 500 second period, leading to overestimated cell resistance and underestimated battery State of Charge (SoC).

Dynamic Z-Track™ (IT-DZT) extends IT by using model that is a more accurate representation of the battery under load, done through the usage of specific battery parameters that allow it to model the transient response of the battery more accurately without needing constant current loads or long relaxation periods. This model incorporates advanced algorithms to process variable current loads using regressions techniques to update the Ra table by selecting input data that reflects real-time changes in current. This ensures that the resistance values remain accurate even with significant load fluctuations. Under a constant current load, the IT-DZT model performs similarly to the IT model.

Figure 5-7 below shows a comparison between the IT and the IT-DZT enhanced battery model. For the same load, the enhanced battery model performs much more accurately when compared to the OCV + IR drop model. As can be seen, the IT model requires a longer settle time to accurately start gauging after a discharge cycle.

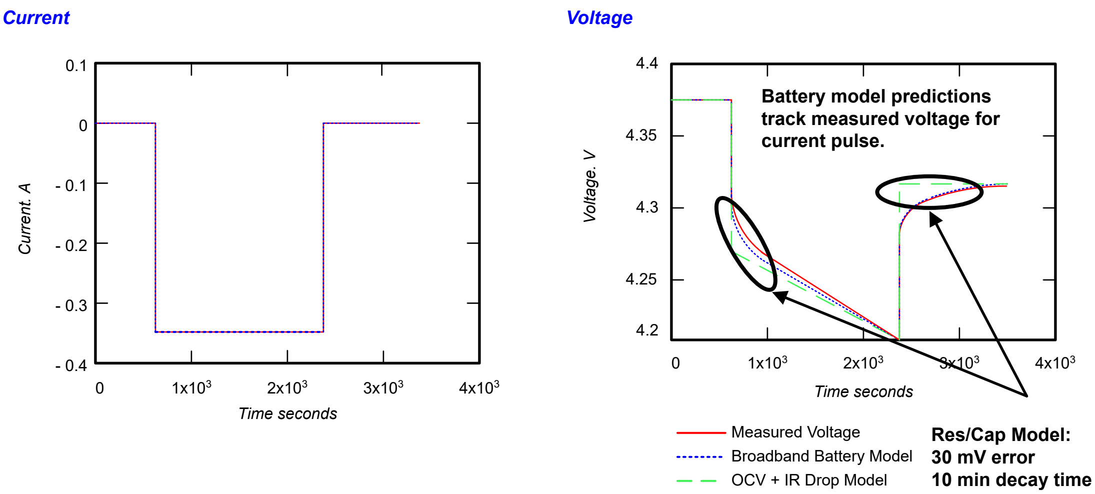


Figure 5-7. IT-DZT vs IT Simulation Model

5.3 Critical IT-DZT Parameters

The BQ41Z50 comes configured per the default settings detailed in the Technical Reference Manual.

This section outlines the minimal settings which must be set for a specific application. A short description is included which can be used as a recommendation how to set the parameter value. Additional updates are needed for a production setting.

An example configuration is provided in Implementation of Dynamic Load.

[Gas Gauging][Design][Design Capacity mAh] : Set this value based on the cell manufacturer datasheet. This represents the full unloaded nominal capacity of the cell. Design Capacity should be set to the # of cells in parallel * Design Capacity of individual cell.

[Gas Gauging][Design][Design Voltage] : Design voltage must be set to the nominal voltage of your battery pack. For a multi-cell application, note that Design Voltage = (number of series cells) * nominal cell voltage. The nominal voltage of a cell is specified in its datasheet.

[Gas Gauging][Design][Design Capacity cWh] : This value must be set to the product of **[Design Voltage]** and **[Design Capacity mAh]**.

[Gas Gauging][IT Cfg][Term Voltage] : This is the empty pack voltage where the gauge will report 0% state of charge. This value should be set to the minimum voltage required by the system. For an n-cell series application, the term voltage should be set to [Term Voltage] * n cells.

Note

Note that the BQ41Z50 also has the ability to report 0% for SOC based on individual cell voltage. This helps for applications where the internal resistance of the cells varies and there is a bit of cell imbalance during discharge. See **IT Gauging Configuration** register description for **CELL_TERM** bit in TRM.

[Advanced Charge Algorithm][Termination Config][Charge Term Taper Current] : It is important to set the taper current programmed in the data flash of the gauge slightly higher than the taper current threshold of the charger so the gauge detects the battery is fully charged before the charger cuts off charge. This value can be set using the given formula.

[Gas Gauging][Current Thresholds][Dsg Current Threshold] : Absolute current value greater than this threshold indicates the gauge is discharging. This value must be greater than the Quit Current (absolute value).

[Gas Gauging][Current Threshold][Chg Current Threshold] : Current values greater than this threshold indicates the battery is charging. This value must be less than the Taper Current.

[Gas Gauging][Current Threshold][Quit Current Threshold] : Absolute current value less than this threshold indicates the battery is in RELAX mode.

Note

Taper Current > Chg Current Threshold > Quit Current

Dsg Current Threshold > Quit Current

[Settings][Manufacturing][Mfg Status Init] : Ensure the Gauge_EN bit is set to allow gauging. It is recommended that set FET_EN to allow firmware control the protection FETs (CHG and DSG), however this is optional.

Note

FET_EN and GAUGE_EN commands can be sent to enable very easily.

[Settings][Configuration][Temperature Enable] : This value determines which thermistor is being used. Set the appropriate bits to enable the thermistor. Temperature measurement is a crucial parameter used in the IT-DZT algorithm. It is critical to ensure that this value is set accordingly. A thermistor must be secured firmly against a cell allowing the thermistor to take accurate cell temperature measurements.

Note

Make sure thermistor is seating on one of the cells.

[Settings][Configuration][Temperature Mode] : This value determines the mode of the thermistor being used. Set the appropriate thermistor bit to Cell Temperature mode. Set the rest of the unused thermistor bits to FET temperature mode. Setting it to zero, enables thermistor and these will be reported to **Temperature()0x08**. Setting it to 1, enables FET temperature mode which disables the thermistor to be reported to **Temperature()0x08.**

[Gas Gauging][State][Update Status] : Once the GAUGE_EN command is sent, updates status will equal to 0x04 which means gauging is enabled. Since IT-DZT ID is an exact match, TI will provide to customer the Qmax value. User can set update status to 0x05. 0x05 indicates the Qmax has already been learned.

[Gas Gauging][State][Qmax Cellx] : These values should auto-populate upon programming the desired chemID. If not, please request these values from TI's gauge experts by reaching out to your local TI representative.

5.4 IT-DZT Chemistry Details

Dynamic load (IT-DZT) applications require a specific Chemistry ID different from the standard IT Chemistry ID. If TI has already created a Chemistry ID and it has High Frequency data (Turbo Mode), TI can use the high frequency data to create the IT-DZT ID.

If this has not been done, the user must contact their local Field Applications Engineer (FAE) to ship cells in to be characterized and formatted into a Chemistry ID.

All IT-DZT profiles will be added to the chemistry settings once user programs the IT-DZT-ChemID. User still needs to ensure that DZT Critical Parameters are configured properly.

Note

For the BQ41Z50 gauge, it is crucial that users use a custom IT-DZT ChemID. If a ChemID is not shown under the list of available battery chemistries, check for latest chemistry update on https://www.ti.com/tool/GASGAUGECHEM-SW.

5.5 Implementation of Dynamic Load (IT-DZT)

This section highlights the benefits of IT-DZT under a dynamic load using the BQ41Z50 Evaluation module. The characteristics of the battery are shown in the table below. These parameters are crucial to configure the gauge as given in the previous sections.

Table 5-1.

Cell Type	Li-Ion
Design Capacity	4680mAh
Charging Volatge	4430mV
Termination Voltage	3000mV
Design Voltage	3860mV

The Data Memory configuration for this implementation is shown in the table below. These parameters ensure accurate gauging and IT-DZT functionality.

Note

Notice how Term Voltage and Design Voltage are multiplied by 3. The application used for this test was 3S1P.

Table 5-2.

[Gas Gauging][Current Thresholds][Dsg Current Threshold]	100mA
[Gas Gauging][Current Thresholds][Chg Current Threshold]	50mA
[Gas Gauging][IT Cfg][Term Voltage]	8100mV
[Settings][Manufacturing][Mfg Status Init]	18
[Advanced Charge Algorithm][Termination Config][Charge Term Taper Current]	269mA
[Gas Gauging][Design][Design Capacity mAh]	4680mAh
[Gas Gauging][Design][Design Voltage]	11580mV
[Gas Gauging][Design][Design Capacity cWh]	5419cWh
[Gas Gauging][Current Thresholds][Quit Current Threshold]	10mA

- **Discharge and charge current thresholds:** Set to 100 mA and 50 mA respectively to accurately determine discharge or charge modes during operation. These parameters can be set according to the application. Ensure that both DSG and CHG current thresholds are greater than the quit current threshold. Quit current was kept as default 10mA.
- **Term voltage**: Set to 2700 mV * 3 cells in series : 8100 mV. This value must be set to the lowest voltage or terminal voltage in the cell manufacturer datasheet.
- **Mfg Status Init**: Set to 0x18. Send GAUGE_EN and FET_EN commands.
- **Taper Current:** Set to 269 mA based on a C/20 rate with a 10% overhead. It is recommended to use a C/20 taper current. However, the gauge's taper current must be 10-15% higher than the charger's taper current to ensure the gauge has a smooth charge termination before the charger cuts off the charging current.
- **Design Capacity:** Set to 4680mAh based on cell datasheet.
- **Design Voltage:** Set to 3860mV × 3 cells in series = 11580mV.

- **Design Capacity cWh:** Set to **[Design Capacity]*[Design Voltage]** = 4680mAh × 11580mV ~= 5419cWh.
- **Update Status:** Set to 0x05. Qmax is already known.

Note

Based on the descriptions of the Update Status values below, the Update Status could also be set to 0x06 since the internal resistance of the cell is known from the chemID creation. However, the purpose of this exercise is to represent how the gauge accurately tracks the internal impedance of the cell under a dynamic load.

Note

- Update Status = 0x04 -> Gauge is enabled, but Qmax and Ra are not learned
- Update Status = 0x05 -> Gauge is enabled and Qmax is learned
- Update Status = 0x06 -> Gauge is enabled, Qmax is learned, Resistance is learned
- Update Status = 0x0E -> Same as 0x06, but an additional Qmax (field Qmax) has been learned.

Under **[Settings][Configuration]**, set **[Temperature Enable]** to the right thermistor pin. In this example, the TS1 pin was used, so **[Temperature Enable]** was set to 2. The BQ41Z50EVM has 4 thermistors, which must be set based on the thermistor pin being used for the implementation. All unused TS pins must be disabled. Figure 5-8 shows the temperature enable register with the appropriate TS pins enabled.

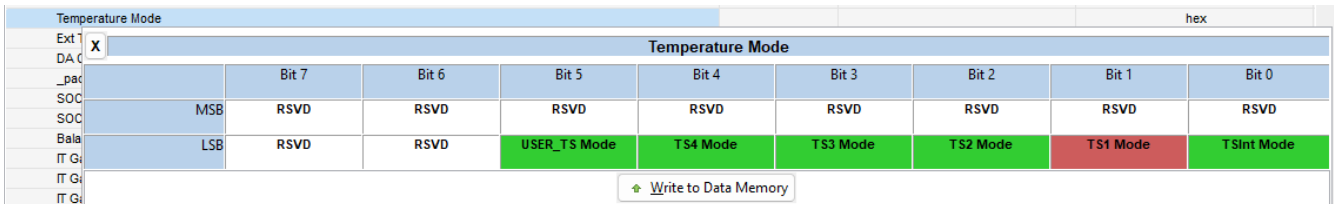


Figure 5-8. Temperature Enable Register

TS1 is the only thermistor seated on the battery and measuring cell temperature. Disable all other thermistor pins to prevent interference from other temperature readings. Under **[Settings][Configuration][Temperature Mode],** clear the TS1 mode bit to **Cell Temperature** mode and set all other TSn modes to **FET Temperature mode**.

Using the commands tab, reset the gauge to clear VOK and set **RDIS** temporarily. Ensure the cells are balanced before starting a cycle to avoid inaccurate Depth of Discharge (DoD), State of Charge (SoC) readings, or may even fail to get Qmax updates. It is recommended that **RDIS** is set during the first cycle to prevent the gauge from getting a resistance update before it gets a Qmax update.

Note

Alternatively, if Qmax is known and battery has already been charged to full, user can leave **RDIS** bit clear (by not sending RESET command) and allow resistance learning in the first discharge cycle.

This implementation utilized an Arbin battery tester to execute charge-discharge cycles according to predefined schedules. The custom schedule for this IT-DZT test encompasses charging, resting, discharging as well as a pulse load to simulate rapid charge and discharge sequences. Figure 5-9 below illustrates the charge-relax-discharge cycle. During the discharge routine, the Ra value updates, and the fluctuating load helps determine if the gauge accurately captures resistance changes. By monitoring these rapid transitions, it is possible to assess whether the gauge receives and processes resistance updates effectively, ensuring accurate performance under arbitrary load conditions.

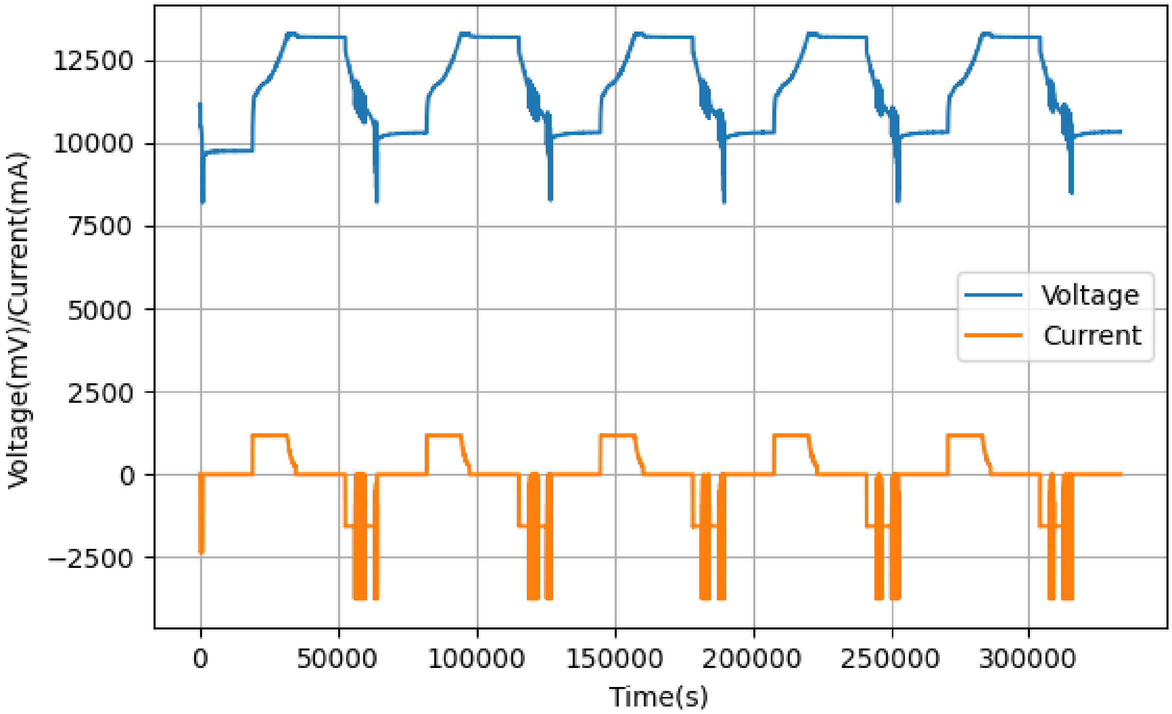


Figure 5-9. Current and Voltage vs Elapsed Time

5.6 Results

The graphs below show various metrics obtained during the sample IT-DZT implementation described in the previous section.

The Figure 5-11 below shows the capacity accuracy prediction under a dynamic discharge load. Notice how the SOC error percent is within 2%.

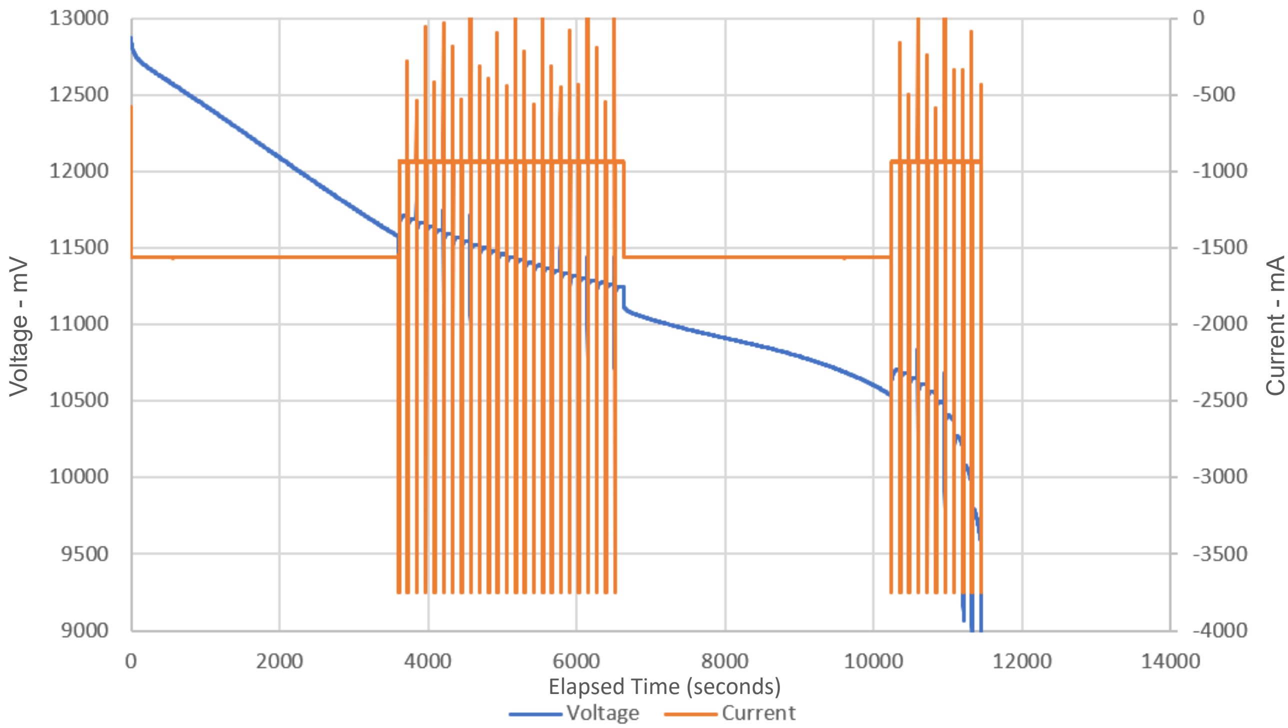


Figure 5-10. Application Load

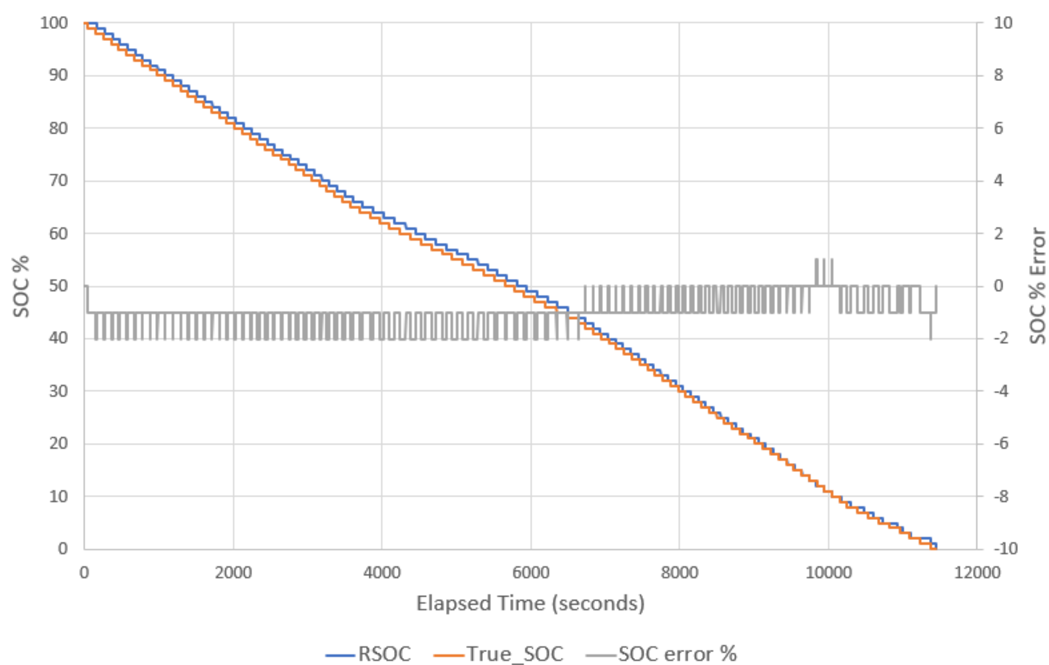


Figure 5-11. SOC Accuracy

See Figure 5-12 for a plot of the remaining capacity and the full charge capacity throughout the cycle. Note that the FCC can not be accurate until the end of the first cycle. Notice that the FCC remains approximately the same during all discharge cycles.

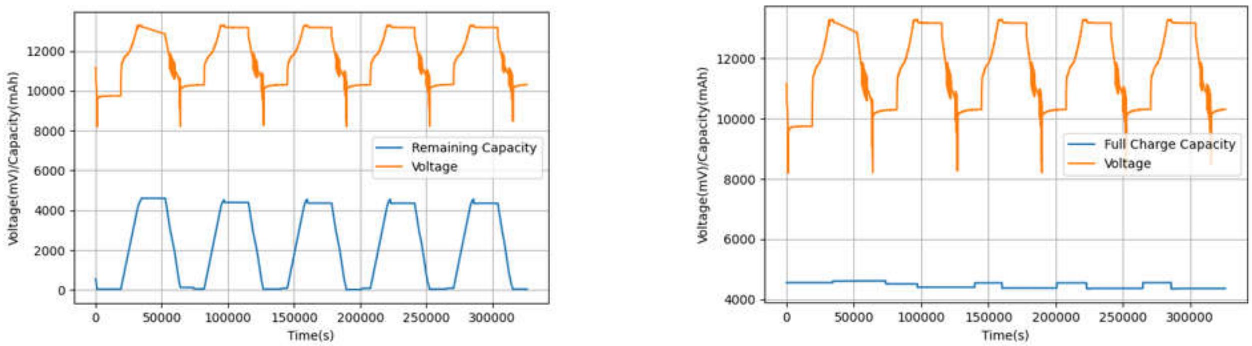


Figure 5-12. Remaining Capacity and FCC Estimations

The table to the left in Figure 5-13 below shows the Ra table during the start of the cycle, these are the default values programmed to the gauge after programming the chemID using bqStudio. The table to the right, includes the updates made to the Ra tables. The individual cell R_a flags update to 0x0055 which implies that both cell impedance and Qmax were updated and the table is being used. The left table indicates before the test. The right table indicates after the test.

Ra Table	R_a0	Cell0 R_a flag	ff55	-
Ra Table	R_a0	Cell0 R_a 0	186	mOhm
Ra Table	R_a0	Cell0 R_a 1	92	mOhm
Ra Table	R_a0	Cell0 R_a 2	95	mOhm
Ra Table	R_a0	Cell0 R_a 3	111	mOhm
Ra Table	R_a0	Cell0 R_a 4	130	mOhm
Ra Table	R_a0	Cell0 R_a 5	91	mOhm
Ra Table	R_a0	Cell0 R_a 6	102	mOhm
Ra Table	R_a0	Cell0 R_a 7	94	mOhm
Ra Table	R_a0	Cell0 R_a 8	95	mOhm
Ra Table	R_a0	Cell0 R_a 9	97	mOhm
Ra Table	R_a0	Cell0 R_a 10	99	mOhm
Ra Table	R_a0	Cell0 R_a 11	94	mOhm
Ra Table	R_a0	Cell0 R_a 12	124	mOhm
Ra Table	R_a0	Cell0 R_a 13	195	mOhm
Ra Table	R_a0	Cell0 R_a 14	224	mOhm
Ra Table	R_a1	Cell1 R_a flag	ff55	-
Ra Table	R_a1	Cell1 R_a 0	186	mOhm
Ra Table	R_a1	Cell1 R_a 1	92	mOhm
Ra Table	R_a1	Cell1 R_a 2	95	mOhm
Ra Table	R_a1	Cell1 R_a 3	111	mOhm
Ra Table	R_a1	Cell1 R_a 4	130	mOhm
Ra Table	R_a1	Cell1 R_a 5	91	mOhm
Ra Table	R_a1	Cell1 R_a 6	102	mOhm
Ra Table	R_a1	Cell1 R_a 8	95	mOhm
Ra Table	R_a1	Cell1 R_a 9	97	mOhm
Ra Table	R_a1	Cell1 R_a 10	99	mOhm
Ra Table	R_a1	Cell1 R_a 11	94	mOhm
Ra Table	R_a1	Cell1 R_a 12	124	mOhm
Ra Table	R_a1	Cell1 R_a 13	195	mOhm
Ra Table	R_a1	Cell1 R_a 14	224	mOhm
Ra Table	R_a2	Cell2 R_a flag	ff55	-
Ra Table	R_a2	Cell2 R_a 0	186	mOhm
Ra Table	R_a2	Cell2 R_a 1	92	mOhm
Ra Table	R_a2	Cell2 R_a 2	95	mOhm
Ra Table	R_a2	Cell2 R_a 3	111	mOhm
Ra Table	R_a2	Cell2 R_a 4	130	mOhm
Ra Table	R_a2	Cell2 R_a 5	91	mOhm
Ra Table	R_a2	Cell2 R_a 6	102	mOhm
Ra Table	R_a2	Cell2 R_a 7	94	mOhm
Ra Table	R_a2	Cell2 R_a 8	95	mOhm
Ra Table	R_a2	Cell2 R_a 10	99	mOhm
Ra Table	R_a2	Cell2 R_a 11	94	mOhm
Ra Table	R_a2	Cell2 R_a 12	124	mOhm
Ra Table	R_a2	Cell2 R_a 13	195	mOhm
Ra Table	R_a2	Cell2 R_a 14	224	mOhm

Ra Table	R_a0	Cell0 R_a flag	55	-
Ra Table	R_a0	Cell0 R_a 0	184	mOhm
Ra Table	R_a0	Cell0 R_a 1	91	mOhm
Ra Table	R_a0	Cell0 R_a 2	90	mOhm
Ra Table	R_a0	Cell0 R_a 3	100	mOhm
Ra Table	R_a0	Cell0 R_a 4	115	mOhm
Ra Table	R_a0	Cell0 R_a 5	79	mOhm
Ra Table	R_a0	Cell0 R_a 6	96	mOhm
Ra Table	R_a0	Cell0 R_a 7	97	mOhm
Ra Table	R_a0	Cell0 R_a 8	104	mOhm
Ra Table	R_a0	Cell0 R_a 9	109	mOhm
Ra Table	R_a0	Cell0 R_a 10	113	mOhm
Ra Table	R_a0	Cell0 R_a 11	118	mOhm
Ra Table	R_a0	Cell0 R_a 12	164	mOhm
Ra Table	R_a0	Cell0 R_a 13	307	mOhm
Ra Table	R_a0	Cell0 R_a 14	350	mOhm
Ra Table	R_a1	Cell1 R_a flag	55	-
Ra Table	R_a1	Cell1 R_a 0	180	mOhm
Ra Table	R_a1	Cell1 R_a 1	89	mOhm
Ra Table	R_a1	Cell1 R_a 2	87	mOhm
Ra Table	R_a1	Cell1 R_a 3	96	mOhm
Ra Table	R_a1	Cell1 R_a 4	111	mOhm
Ra Table	R_a1	Cell1 R_a 5	76	mOhm
Ra Table	R_a1	Cell1 R_a 6	93	mOhm
Ra Table	R_a1	Cell1 R_a 8	101	mOhm
Ra Table	R_a1	Cell1 R_a 9	105	mOhm
Ra Table	R_a1	Cell1 R_a 10	110	mOhm
Ra Table	R_a1	Cell1 R_a 11	115	mOhm
Ra Table	R_a1	Cell1 R_a 12	158	mOhm
Ra Table	R_a1	Cell1 R_a 13	298	mOhm
Ra Table	R_a1	Cell1 R_a 14	338	mOhm
Ra Table	R_a2	Cell2 R_a flag	55	-
Ra Table	R_a2	Cell2 R_a 0	167	mOhm
Ra Table	R_a2	Cell2 R_a 1	83	mOhm
Ra Table	R_a2	Cell2 R_a 2	81	mOhm
Ra Table	R_a2	Cell2 R_a 3	89	mOhm
Ra Table	R_a2	Cell2 R_a 4	104	mOhm
Ra Table	R_a2	Cell2 R_a 5	71	mOhm
Ra Table	R_a2	Cell2 R_a 6	88	mOhm
Ra Table	R_a2	Cell2 R_a 7	88	mOhm
Ra Table	R_a2	Cell2 R_a 8	93	mOhm
Ra Table	R_a2	Cell2 R_a 10	101	mOhm
Ra Table	R_a2	Cell2 R_a 11	105	mOhm
Ra Table	R_a2	Cell2 R_a 12	146	mOhm
Ra Table	R_a2	Cell2 R_a 13	268	mOhm
Ra Table	R_a2	Cell2 R_a 14	310	mOhm

Figure 5-13. Ra Update

Figure 5-14 below shows a comparison of IT and IT-DZT algorithms. The blue and orange plots are based on a BQ40Z50 IT gauge and the BQ41Z50 IT-DZT gauge, both under dynamic load as shown in Dynamic Load. These are compared against the golden Ra obtained after ID characterization which is called "Expected Ra".

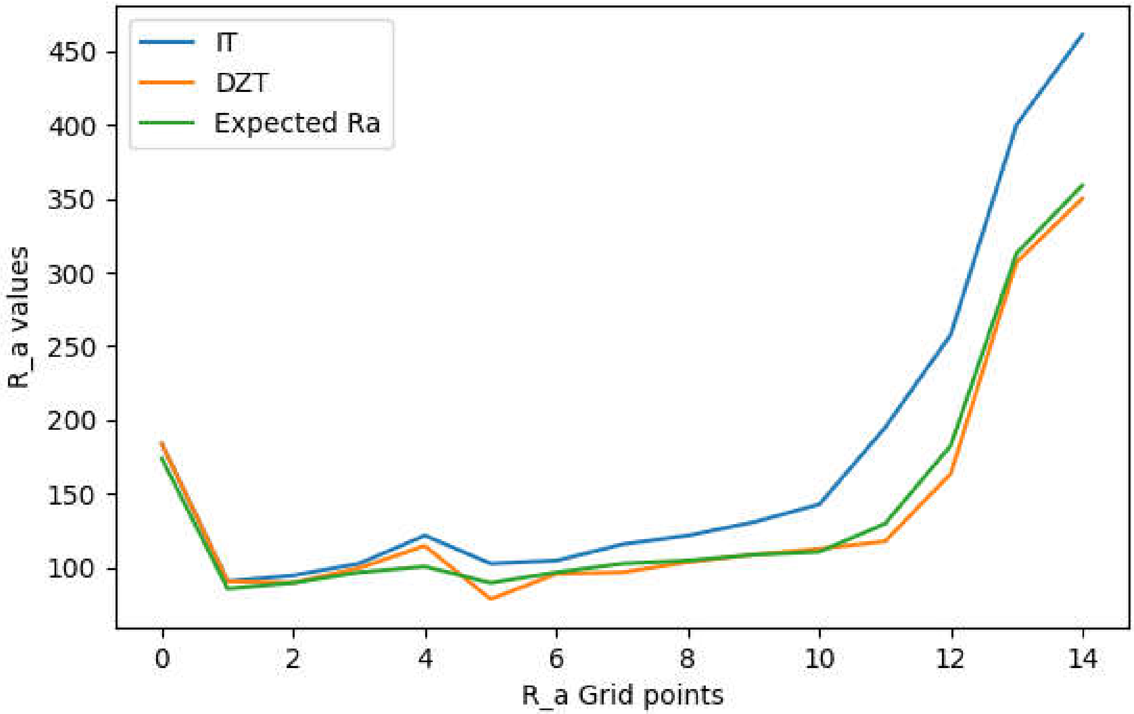
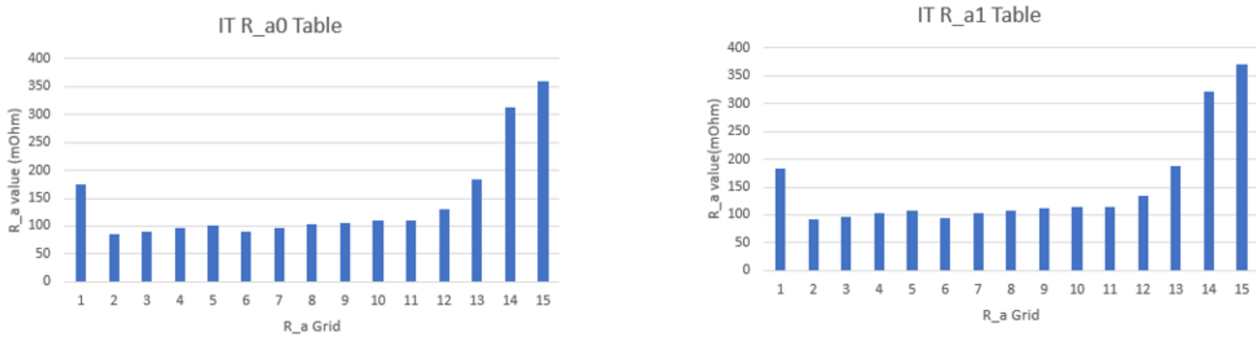


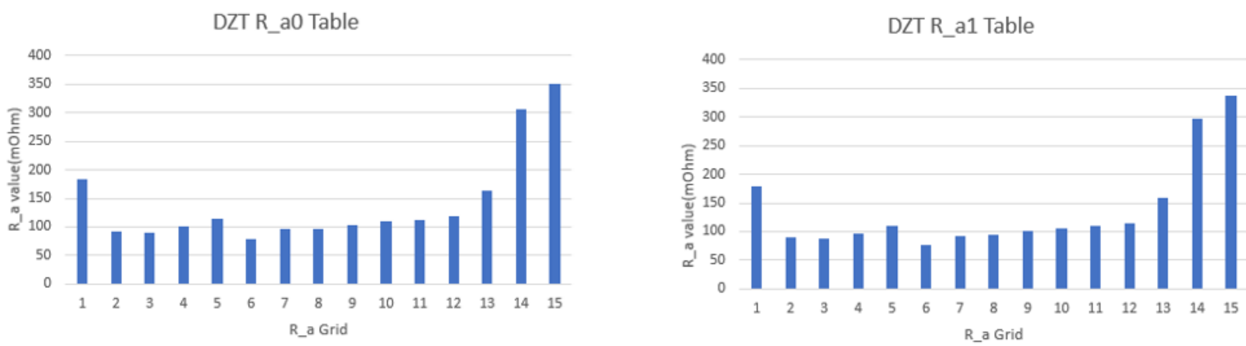
Figure 5-14. IT vs IT-DZT vs Expected Ra

As can be seen in the results above, the IT-DZT algorithm measures resistance more accurately during dynamic load scenarios compared to the standard IT algorithm due to its need of long settling times during discharge cycles to update the Ra table. The tests run on the gauge indicate short periodic fluctuating loads, which is an ideal use case for Dynamic Z-Track™ gauges.

Impedance Track™ is highly accurate with constant current loads. A comparison between an IT gauge (BQ40Z50) under constant load and BQ41Z50 under dynamic load is shown in the Figure 5-15 below. Note that the difference in R_a values between IT-DZT and IT Gauging is under 15%.



R_a0/1 tables for an Impedance Tracking gauge (40z50) on constant load.



R_a0/1 tables for Dynamic Impedance Tracking gauge (41z50) on dynamic load.

Figure 5-15.

6 Hardware Design Files

6.1 BQ41Z50EVM Circuit Module Schematic

This section contains information on modifying the EVM and using various features on the reference design.

6.1.1 LED Control

The EVM is configured to support three LEDs to provide state-of-charge information for the cells. Press the *LED DISPLAY* button to illuminate the LEDs for approximately 5 seconds.

Note

Notice how LEDs are powered from the external LDO device. Make sure the LDO_EN jumper-J9 is removed. LEDs are no longer charlieplexed together as LEDs used to be in the BQ40z50 family devices. The EVM requires an external LDO to power LEDs.

6.2 Circuit Module Physical Layouts

This section contains the printed-circuit board (PCB) layout, assembly drawings, and schematic for the BQ41Z50 and BQ296103 circuit modules.

6.2.1 Board Layout

This section shows the dimensions, PCB layers, and assembly drawing for the BQ41Z50 modules.

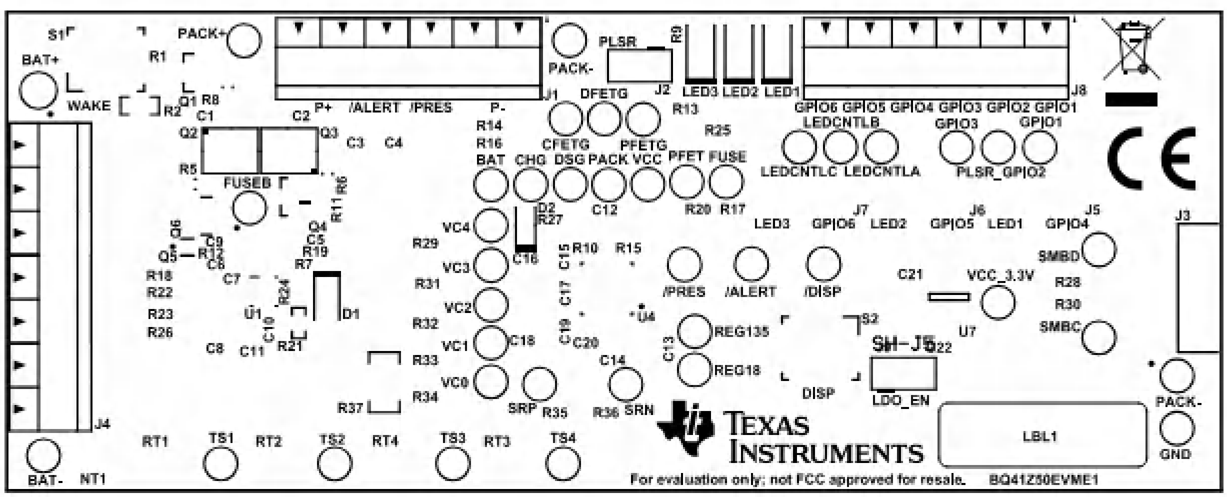


Figure 6-1. Top Silk Screen

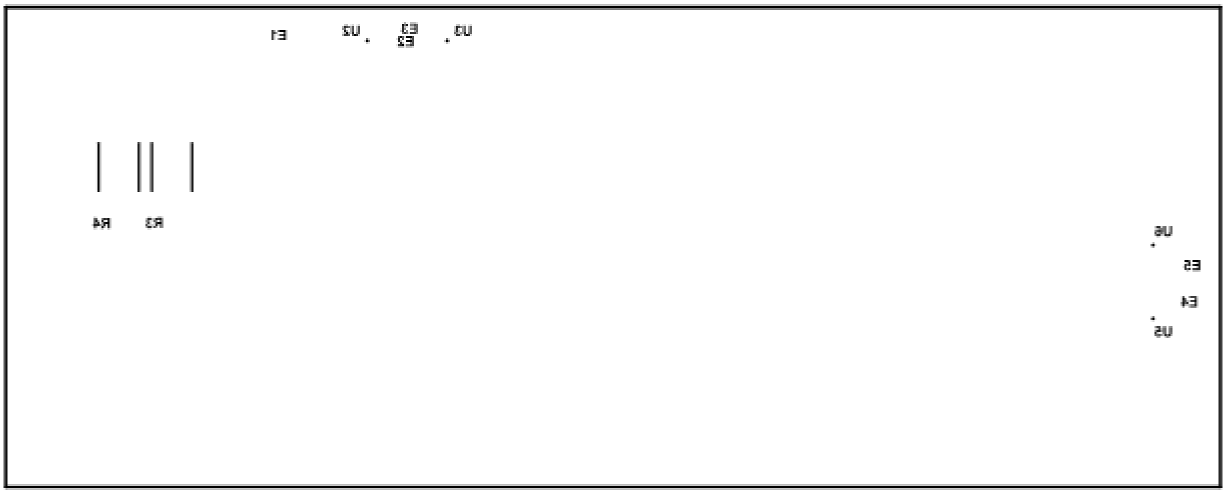


Figure 6-2. Bottom Silk Screen

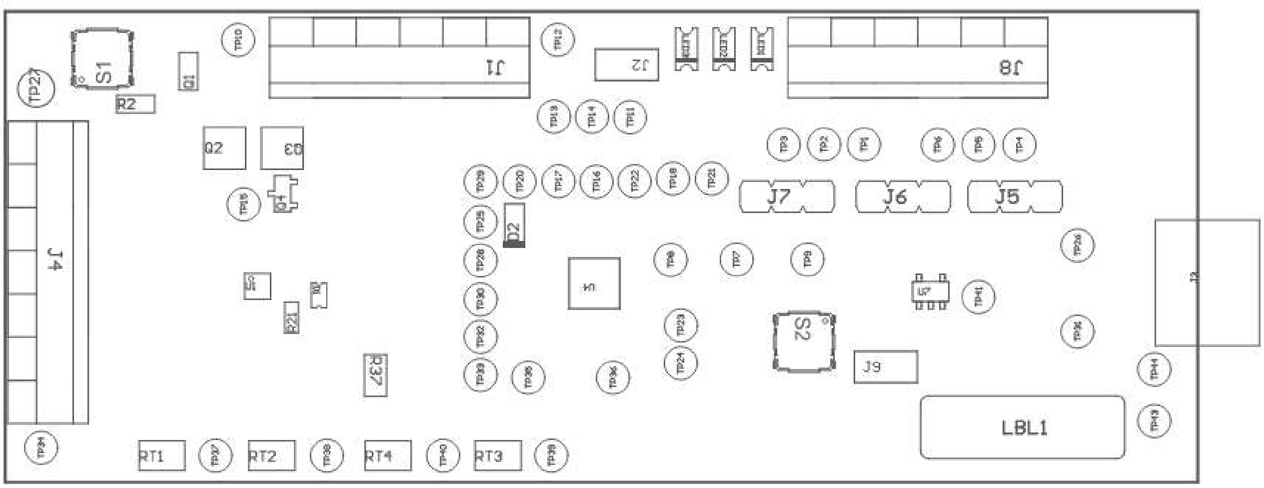


Figure 6-3. Top Assembly

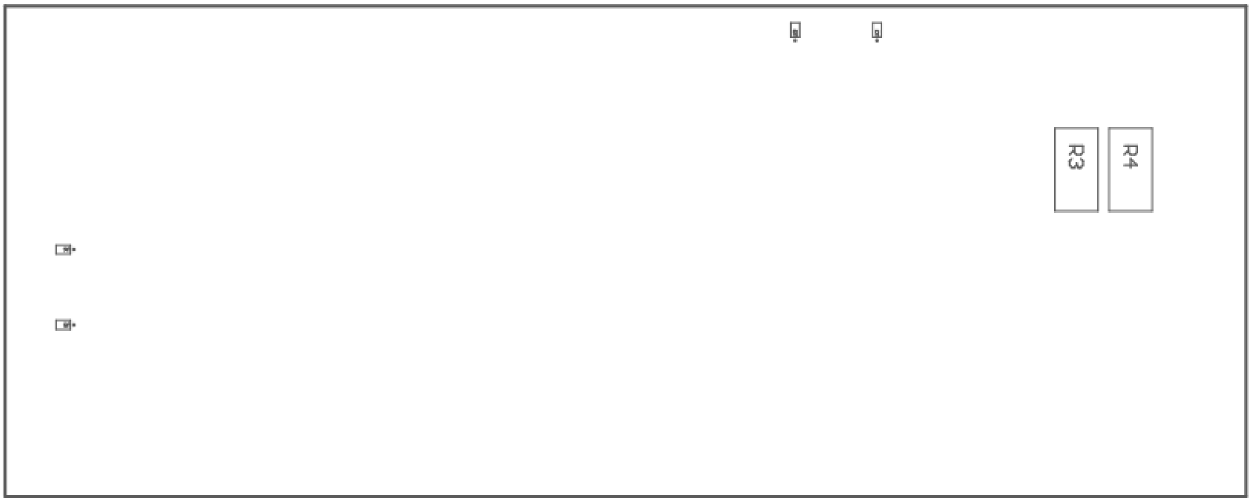


Figure 6-4. Bottom Assembly

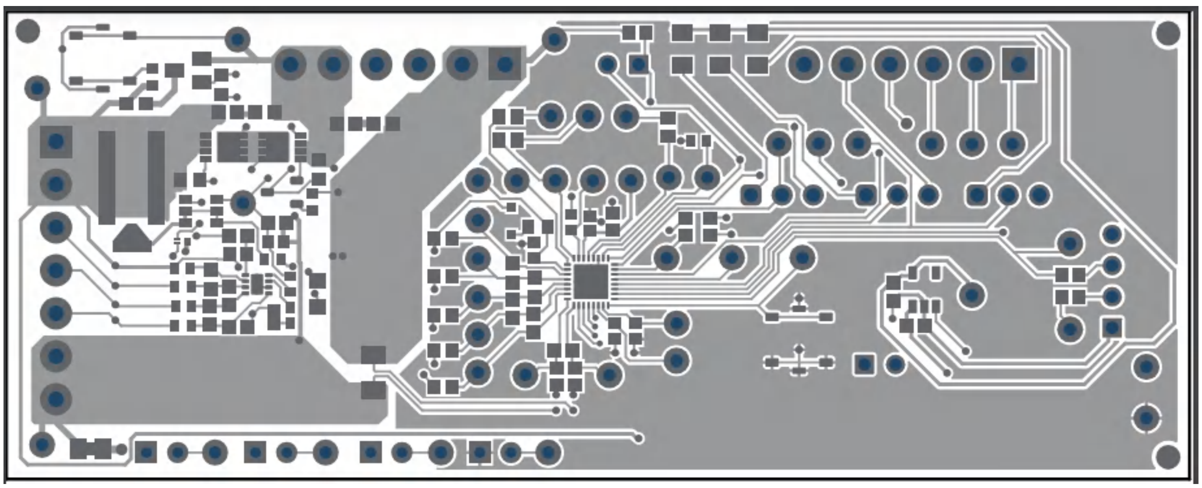


Figure 6-5. Top Layer

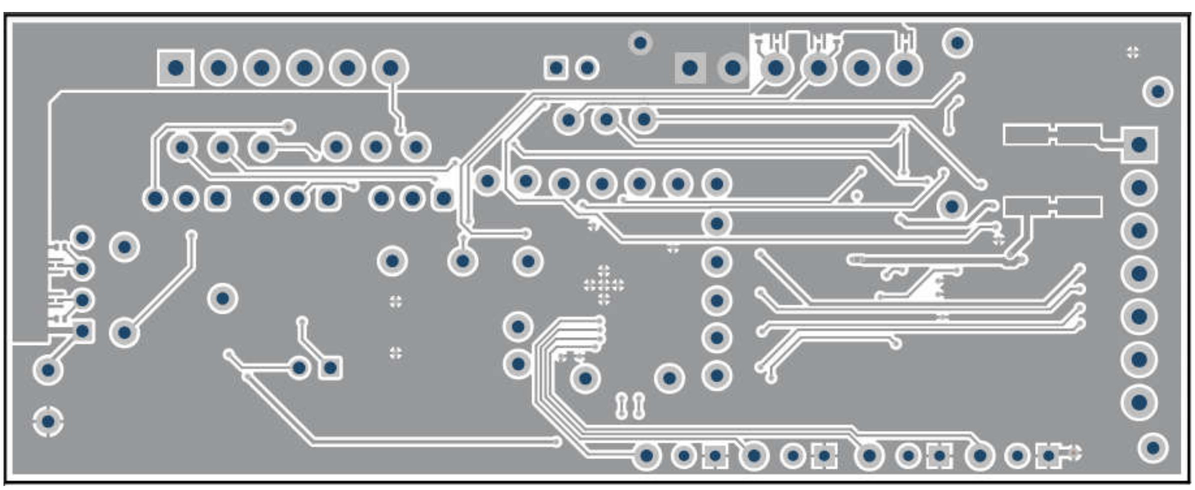


Figure 6-6. Bottom Layer

6.2.2 Schematic

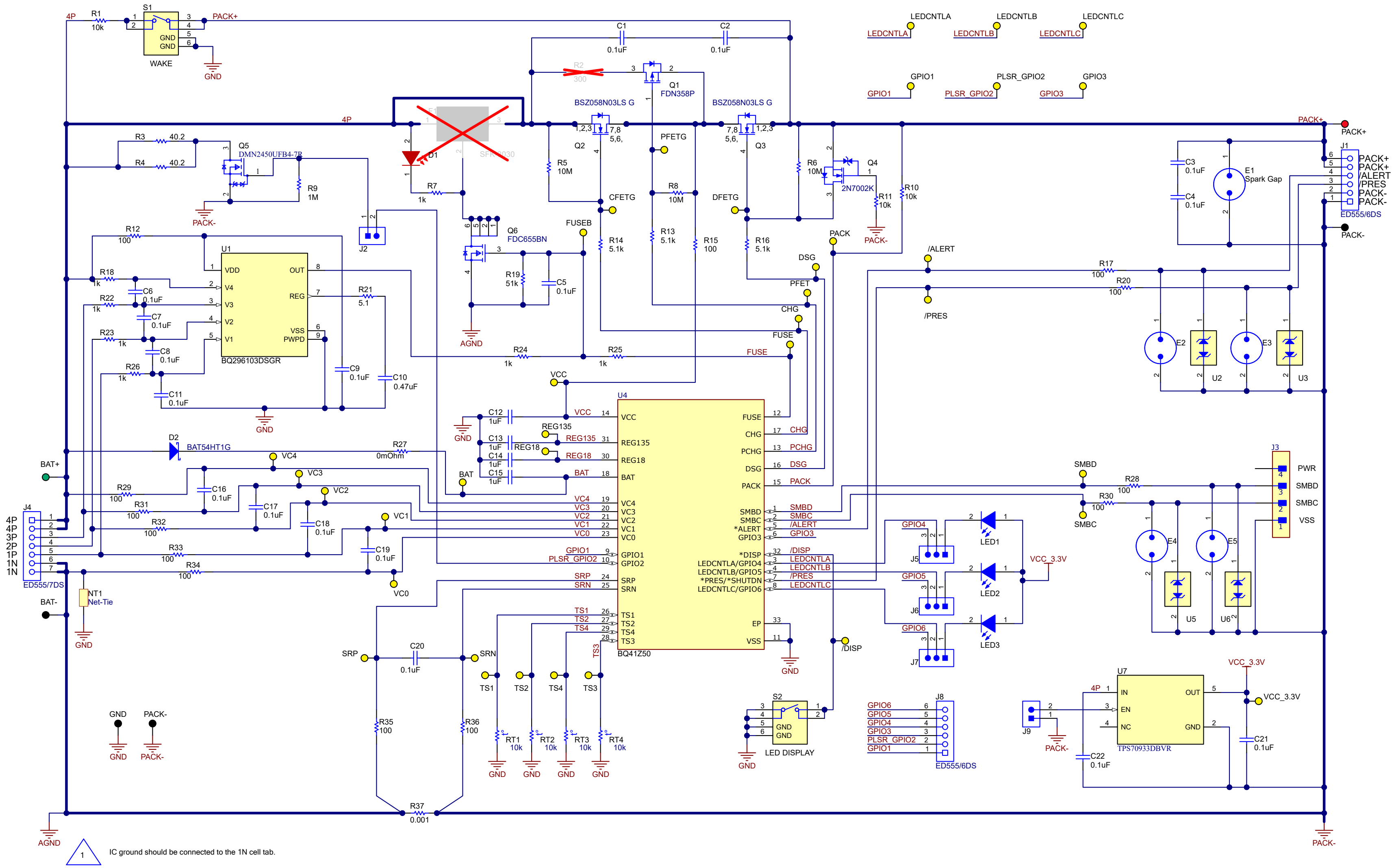


Figure 6-7. BQ41Z50 Schematic

Note

The precharge function is currently unavailable on the initial EVM revision. R2 was unpopulated for this reason.

6.3 Bill of Materials

Table 6-1. Bill of Materials

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
!PCB	1		Printed Circuit Board		BQ41Z50EVM	Any		
C1, C2, C3, C4, C5, C6, C7, C8, C9, C11, C16, C17, C18, C19, C20, C21, C22	17	0.1uF				AVX Interconnect / Elco		
C10	1	0.47uF	Multilayer Ceramic Capacitors MLCC - SMD/SMT 16V 0.47uF X7R 0603 10% Flex Soft			Kemet		
C12, C13, C14, C15	4	1uF	Multilayer Ceramic Capacitors MLCC - SMD/SMT 25V 1uF X7R 0603 10%			Kemet		
D1	1	Red	LED, Red, SMD	LED_0805	150080RS75000	Wurth Elektronik		
D2	1	30V	Diode, Schottky, 30V, 0.2A, SOD-323	SOD-323	BAT54HT1G	ON Semiconductor		
J1, J8	2		Terminal Block, 3.5mm Pitch, 6x1, TH	20.5x8.2x6.5mm	ED555/6DS	On-Shore Technology		
J2, J9	2		Header, 100mil, 2x1, Tin, TH	Header, 2 PIN, 100mil, Tin	PEC02SAAN	Sullins Connector Solutions		
J3	1			HDR4	22-05-3041	Molex		
J4	1		Terminal Block, 3.5mm Pitch, 7x1, TH	24x.5x8.2x6.5mm	ED555/7DS	On-Shore Technology		
J5, J6, J7	3		Header, 2.54mm, 3x1, Gold, TH	Header, 2.54mm, 3x1, TH	61300311121	Wurth Elektronik		
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650 x 0.200 inch	THT-14-423-10	Brady		
LED1, LED2, LED3	3		LED, Green, SMD	1206	SML-LX1206GC-TR	Lumex		
Q1	1	-30V	MOSFET, P-CH, -30V, -1.5A, SSOT-3	SSOT-3	FDN358P	Fairchild Semiconductor		None
Q2, Q3	2	30V	MOSFET, N-CH, 30V, 40A, PG-TSDSON-8	PG-TSDSON-8	BSZ058N03LS G	Infineon Technologies		None
Q4	1	60V	MOSFET, N-CH, 60V, 0.3A, SOT-23	SOT-23	2N7002K-T1-E3	Vishay-Siliconix		None
Q5	1		DMN2450UFB4-7R Trans Mosfet N-ch 20V 1A 3-PIN Dfn SMD T/r					
Q6	1		MOSFET N-CH 30V 6.3A SSOT-6			ON Semiconductor		

Table 6-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
R1, R10, R11	3	10k	Chip Resistor, 10 KOhm, ±1%, 0.1 W, -55 to 155 deg°C, 0603 (1608 Metric), RoHS, Tape and Reel			Panasonic		
R2	1	300	RES, 300, 5%, 0.1W, 0603	0603	RC0603JR-07300RL	Yageo		
R3, R4	2	40.2	RES, 40.2, 1%, 1W, AEC-Q200 Grade 0, 2512	2512	CRCW251240R2FKEG	Vishay-Dale		
R5, R6, R8	3	10M	10M 0.1W 1% 0603 (1608 Metric) SMD					
R7, R18, R22, R23, R24, R25, R26	7	1k	SMD Chip Resistor, 1 kOhm, ± 1%, 100mW, 0603 [1608 Metric], Thick Film, General Purpose			Yageo		
R9	1	1M	SMD Chip Resistor, 1 MOhm, ± 1%, 100mW, 0603 [1608 Metric], Thick Film, General Purpose			Vishay Dale		
R12, R15, R17, R20, R28, R29, R30, R31, R32, R33, R34, R35, R36	13	100	Chip Resistor, 100 Ohm, ± 1%, 100mW,-55 to 155 deg°C, 0603 (1608 Metric), RoHS, Tape and Ree	0603		Vishay Semiconductor		
R13, R14, R16	3	5.1k	Res 5.1K Ohm 1% 1/3W 0603			KOA Speer		
R19	1	51k	Res Thick Film 0603 51K Ohm 1% 0.1W ±100ppm/°C Molded SMD Punched Carrier T/R			Panasonic		
R21	1	5.1	RES, 5.1, 5%, 0.063 W, 0402	0402	CRCW04025R10JNED	Vishay-Dale		
R27	1		Chip Resistor, 0 Ohm,± 5%, 0.1W, -55 to 155 deg°C, 0603 (1608 Metric), RoHS, Tape and Reel			Yageo		
R37	1	0.001	RES, 0.001, 1%, 1W, AEC-Q200 Grade 0, 1206	1206	CSNL1206FT1L00	Stackpole Electronics Inc		
RT1, RT2, RT3, RT4	4	10k	Thermistor NTC, 10.0k ohm, 1%, Disc, 5x8.4mm	Disc, 5x8.4 mm	103AT-2	SEMITEC Corporation		
S1, S2	2		Switch, SPST-NO, Off-Mom, 0.02A, 15 VDC, SMD	4.9x4.9mm	EVQ-PLHA15	Panasonic		
SH-J1, SH-J2, SH-J3, SH-J4, SH-J5	5	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec	969102-0000-DA	3M

Table 6-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP11, TP13, TP14, TP15, TP16, TP17, TP18, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP28, TP29, TP30, TP31, TP32, TP33, TP35, TP36, TP37, TP38, TP39, TP40, TP41	36		Test Point, Miniature, Yellow, TH	Yellow Miniature Test point	5004	Keystone		
TP10	1		Test Point, Miniature, Red, TH	Red Miniature Test point	5000	Keystone		
TP12, TP34, TP43, TP44	4		Test Point, Miniature, Black, TH	Black Miniature Test point	5001	Keystone		
TP27	1		Test Point, Miniature, Green, TH	Green Miniature Test point	5116	Keystone		
U1	1		2-4S Overvoltage Protector with LDO Output, DSG0008A (WSON-8)	DSG0008A	BQ296103DSGR	Texas Instruments	BQ296103DSGT	Texas Instruments
U2, U3, U5, U6	4		Single-Channel ESD in 0402 Package With 10pF Capacitance and 6V Breakdown, DPY0002A (X1SON-2)	DPY0002A		Texas Instruments	TPD1E10B06DPYT	Texas Instruments
U4	1		Battery Management Platform, WQFN32	WQFN32	BQ41Z50	Texas Instruments		
U7	1		150mA, 30V, Ultra-Low IQ, Wide Input Low-Dropout Regulator with Reverse Current Protection, DBV0005A (SOT-23-5)	DBV0005A	TPS70933DBVR	Texas Instruments	TPS70933DBVT	Texas Instruments
F1	0		Fuse, 30A, 62VDC, SMD	9.5x2x5mm	SFK-3030	Dexerials Corporation		
FID1, FID2, FID3	0		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A		

7 Additional Information

7.1 Trademarks

Impedance Track™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

8 Related Documentation

- Texas Instruments, *BQ41Z50 2-Series, 3-Series, and 4-Series Cell Li-Ion Battery Pack Manager with Dynamic Z-Track™* data sheet
- Texas Instruments, *BQ41Z50 Technical Reference Manual*
- Texas Instruments, *BQ296xxx Overvoltage Protection for 2-Series, 3-Series, and 4-Series Cell Li-Ion Batteries with Regulated Output Supply* data sheet
- Texas Instruments, *BQ41xxx Production Calibration Guide*

9 Revision History

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

Changes from Revision * (June 2024) to Revision A (April 2025) **Page**

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265