EVM User's Guide: BQ27Z855EVM

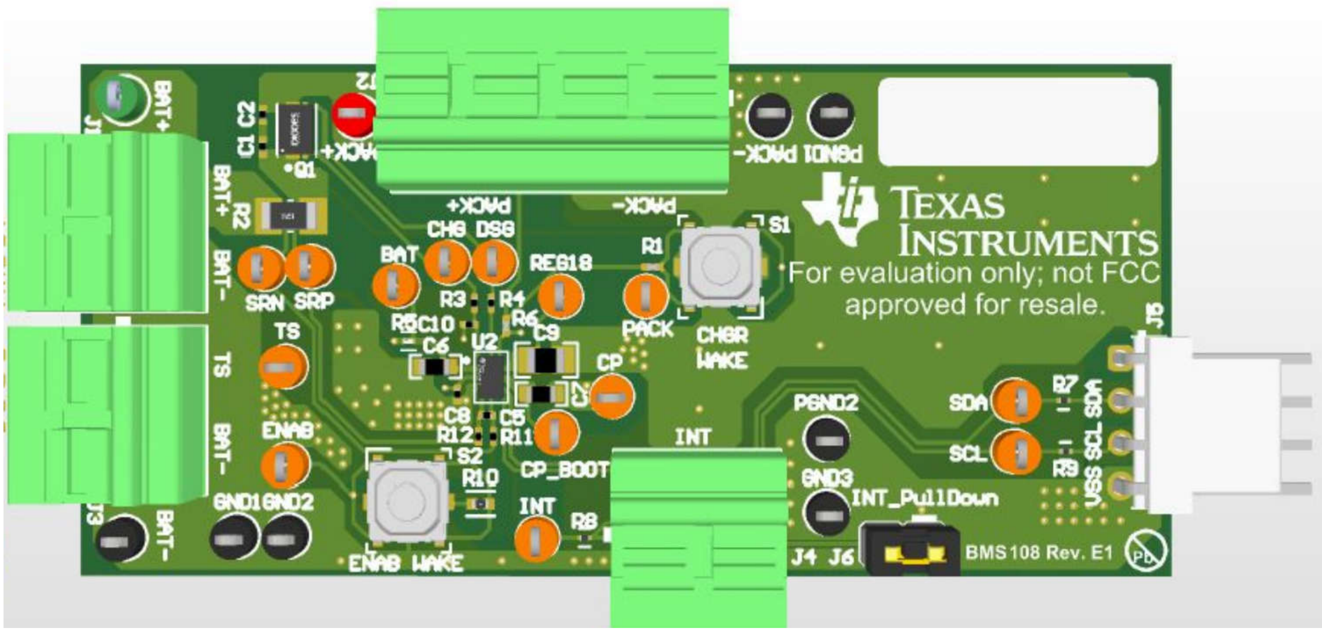
BQ27Z855 Single Cell Battery Fuel Gauge Evaluation Module User's Guide

Description

The BQ27Z855 Evaluation Module (EVM) is a system-level board created to enable users to evaluate the functionalities of the BQ27Z855 fuel gauge within their system. The BQ27Z855 EVM is suitable for applications in which the battery pack is 1-S cell, meaning one series cell. The EVM includes a BQ27Z855 battery fuel gauge, a low-side current sense resistor, integrated high-side protector, an ENAB wake button, a charger wake button, linear battery charger, and other header options to allow for some modifications to meet the intended application.

Features

- Complete evaluation system for the BQ27Z855 Li-Ion Battery Pack Manager Evaluation Module.
- Populated circuit module for quick setup
- Software that allows data logging for system analysis
- Integrated low-side current sense resistor
- Integrated high-side protections
- Integrated linear battery charger
- Dynamic Z-Track™ algorithm



1 Evaluation Module Overview

1.1 Introduction

The BQ27Z855EVM comes with the BQ27Z855 integrated gas gauge and protection IC with external high-side protection N-Channel FETs. This user's guide will walk you through the following tasks:

- Connect the necessary components together to power up the EVM
- Installation of the necessary Texas Instruments software tools
- Setup of the EVM with additional hardware and software
- Configure the integrated linear battery charger
- Calibrate the BQ27Z855 voltage and current readings
- Perform the Chemical ID selection process
- Optimize gauge reporting with a Learning Cycle
- Create and upload a Golden Image
- Use Advanced Communication with the gauge

These tasks will guide users of the BQ27Z855EVM through the process required to prepare for production with the BQ27Z855 by creating a "Golden Pack". A Golden Pack is a single gauge and battery that has had optimization and configuration processes performed on it during the development stage. The resulting values are extracted from the Golden Pack gauge into the “Golden File” or “Golden Image”. The Golden File is a flash image programmed into every gauge used in mass production as there should be minimal pack-to-pack variation during a well-controlled manufacturing process. The Dynamic Z-Track™ algorithm enables the gauge to continue to learn once a pack is deployed to account for manufacturing differences, field conditions, and battery degradation over its lifetime.

1.2 Kit Contents

- BQ27Z855 evaluation module

1.3 Specifications

This section summarizes the performance specifications of the BQ27Z855 circuit module.

Table 1-1. Performance Specification Summary

BQ27Z855 Specification	Min	Typ	Max	Units
Input Voltage Pack+ to Pack-	-0.3		24	V
Input Voltage Bat+ to Bat-	-0.3		6.0	V
Hardware Protection Specification				
Overvoltage protection	3500	4300	5000	mV
Undervoltage protection	2000	2300	4000	mV
Overcurrent in charge protection	4	14	100	mV 1
Overcurrent in discharge protection	-4	-16	-100	mV1

1. Based on 1-mΩ sense resistor.

1.4 Device Information

Table 1-2. Device Information

EVM Part Number	Chemistry	Configuration	Capacity
BQ27Z855EVM	Li-Ion	Single Cell	Any

For information on device firmware and hardware, see the BQ27Z855 Dynamic Z-Track™ Gauge with Integrated Protection, Linear Battery Charger, and Authentication for 1 Cell Battery Packs datasheet and the BQ27Z855 Technical Reference Manual.

2 Hardware

The BQ27Z855 with integrated protection module requires hardware connections for using the evaluation module and creating a Golden File.

2.1 Hardware Requirements

The following hardware is required to complete the steps for creating a Golden File outlined in this guide:

- A PC with Windows® 10 or later
- EV2400 and USB cable
- BQ27Z855 Evaluation Board (EVM)
- Constant-Voltage and Constant-Current Power Supply (preferable 1mV and 1mA accuracy for the power supply)
- Lithium-chemistry 1-cell battery (Golden Pack battery identical to those to be used in production)

2.2 Connecting the BQ27Z855 Circuit Module to a Battery Pack

Figure 2-1 shows how to connect the BQ27Z855 circuit module to the battery, personal computer (PC), and a system load/charger.

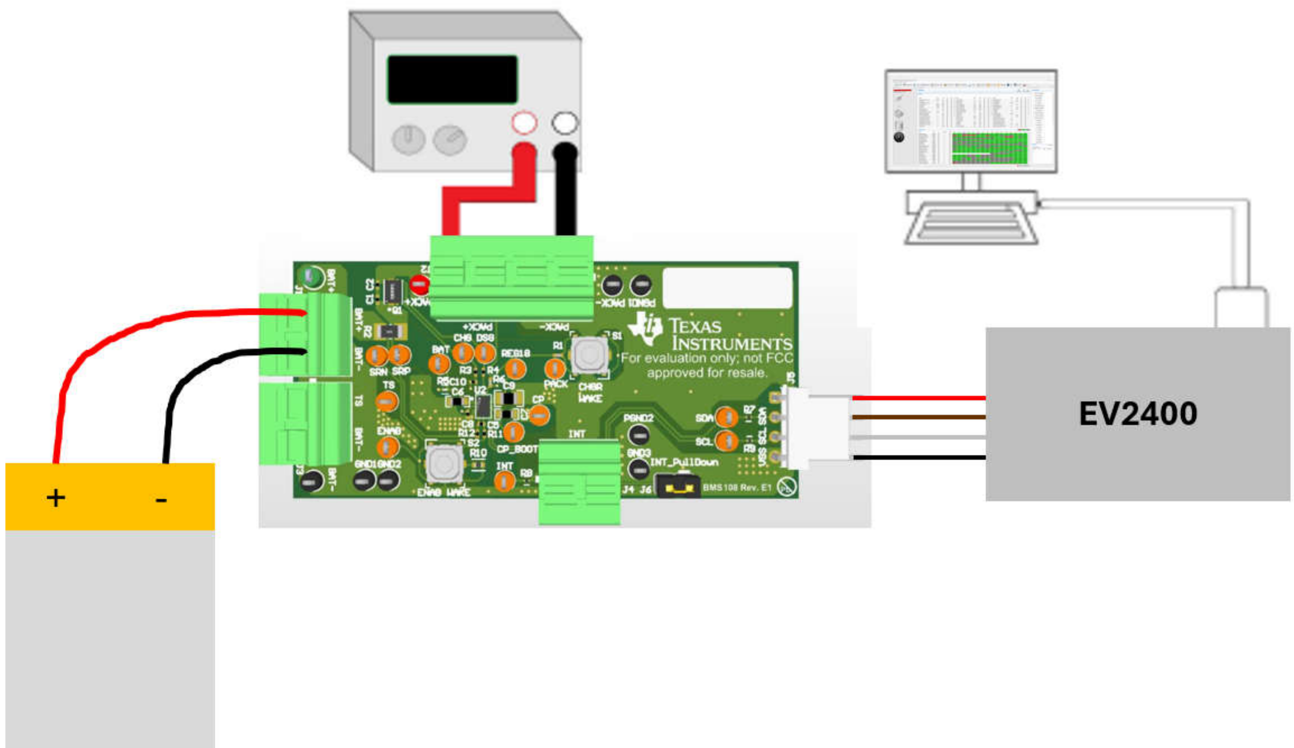


Figure 2-1. Connect the BQ27Z855 Circuit Module to a 1SxP

2.3 EVM Jumpers and Terminal Block Description

The following section describes the critical jumpers and their purpose on this board:

1. J1 – Battery Input: This terminal block is the input for the positive and negative leads of your 1SXP battery pack.
2. J2 – Charger/Load Connection: This terminal block is the input/output for the charger/load. Two of the connections are for PACK- and two of the connections are for PACK+.
3. J3 – External Temperature Sensor Connection: This terminal block connects one lead of an external temperature sensor to the TS pin of the BQ27Z855 and the other lead to BAT- (GND). An external temperature sensor must be present for the gauge to report an accurate temperature if the gauge is

configured for an external temperature measurement. Refer to the BQ27Z855 Technical Reference Manual for directions on how to configure the BQ27Z855 for an external temperature sensor.

4. J4 - Interrupt Pin Output (INT): This terminal block connects to the INT pin of the BQ27Z855. Both connections on this terminal block connect to the INT pin.
5. J5 – I2C Header Connection: This connector is used for I2C communication with the BQ27Z855 and is used to interface with the EV2400.

3 Software

This section describes the installation of the BQ27Z855EVM PC software, and how to connect the different components of the EVM.

3.1 System Requirements

The bqStudio software requires Windows 7 or later. Using earlier versions of Windows operating system may not work with the USB driver support.

3.2 Software Installation

Find the latest software version of bqStudio-test and the EV2400 driver on ti.com. Search for the BQ27Z855 part number to get to the tool folder for the device. Following these steps to install the BQ27Z855 bqStudio software.

1. Run the Firmware updater tool installer. Take note of the location where the Firmware Updater tool is installed on the computer.
2. Connect the EV2400 that is to be updated to the computer.
3. Ensure that no other EV2400 is connected to the computer being used for the firmware update.
4. Go to the location of the Firmware Updater tool installed. Run the Firmware Updater tool.
5. The updater tool should detect the connected EV2400, display the current firmware version, and prompt the user to continue to update the EV2400 firmware.
6. Type Y and press Enter.
7. The Firmware Updater tool should place the EV2400 into FW Update mode, perform a mass erase of the older EV2400 version's firmware, program the EV2400, and then reset the device. The tool will prompt the user to continue when finished.
8. Press Enter to close the Firmware Updater tool.
9. Unplug the EV2400 from the personal computer (PC).
10. Open the archive containing the installation package of bqStudio and copy its contents into a temporary directory.
11. Rename any previous Battery Management Studio folder by adding a version to the end.
12. Open the bqStudio installer file that was downloaded from the TI website.
13. Follow the instructions on-screen until completing the software installation.
14. Before launching the evaluation software, connect the EV2400 USB cable to the computer and I2C port to the EVM board (J5).

Note

The EV2400 should remain plugged into the computer during the entire firmware updating process.

3.3 Updating Firmware

Find the latest firmware version in the appropriate BQ27Z855 folder on www.ti.com. Use the following steps to install the BQ27Z855 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, restart Battery Management Studio, then the EVM is ready to use with the latest firmware.

3.4 Troubleshooting Unexpected Dialog Boxes

The user that is downloading the files must be logged in as the administrator. The driver is not signed, so the administrator must allow installation of unsigned drivers in the operating system. If using Windows 7, install the software with administrator privileges.

4 Using bqStudio

This section details the operation of the BQ27Z855 gauge with the bqStudio software.

4.1 Starting the Program

Run bqStudio from the desktop. The window consists of a tools panel at the top, and other child windows that can be hidden, docked in various positions or allowed to float as separate windows. When bqStudio first starts up the Gauge Dashboard window, the Registers window, and Data Memory window should be seen in the main window. Registers, Data Memory, Commands, and other windows can be added to the main window by clicking on the corresponding icon in the tools panel at the top of the main window. Data should appear initially in the Gauge Dashboard, Registers and Data Memory sections. The Refresh (single time scan) or the Scan (continuous scan) buttons can be clicked to update the data in the Registers and Data Memory windows. Continuous scan is enabled when the Scan checkbox is highlighted green and disabled when the Scan checkbox is not highlighted. The continuous scanning interval can be set with the stopwatch icon next to the Scan button. When the stopwatch icon is clicked, a drop-down menu appears, and the desired scanning interval can be selected. The scan interval value shows up next to the stopwatch icon. The Registers page can also be used to collect a log file. To start a log file the “Start Log” button can be pressed, then the desired file name and file location can be chosen. The log file will periodically log everything present in the Registers page.

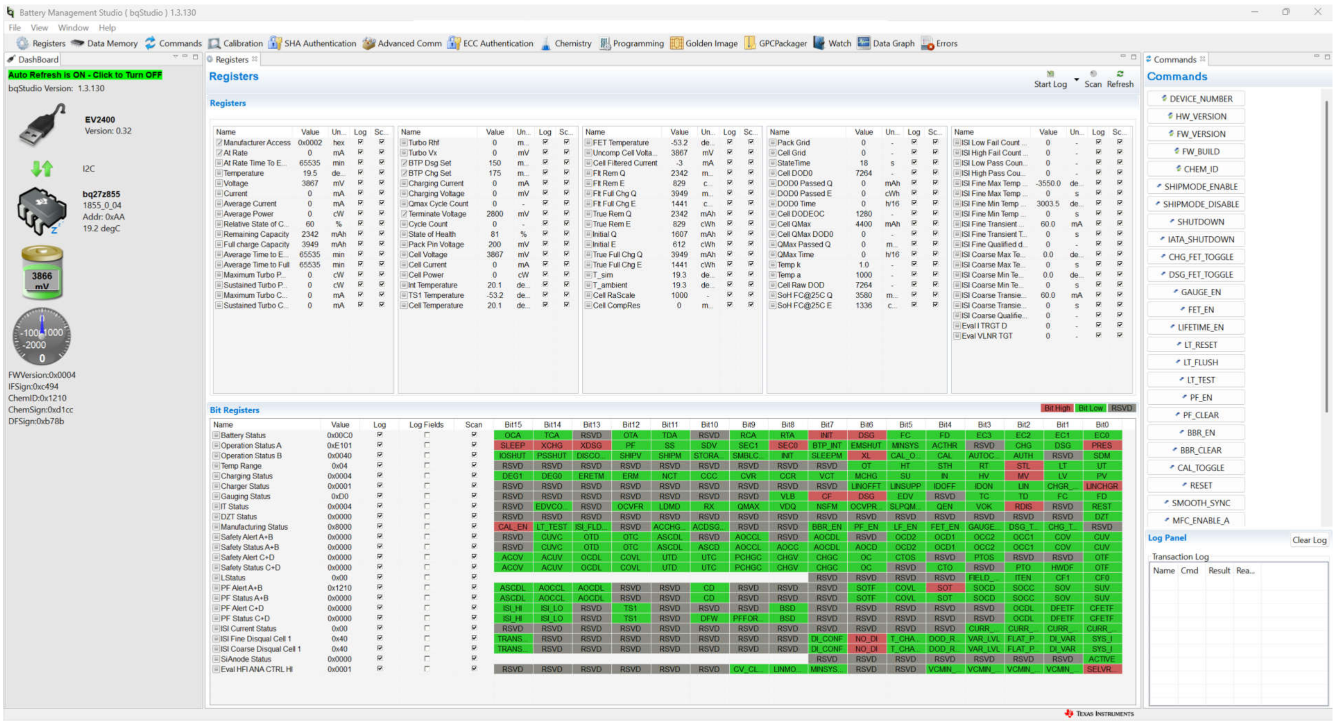


Figure 4-1. Registers Screen

Figure 4-1 shows the main bqStudio window. Additional Flag and Control Status data can be viewed at the bottom of the registers window.

4.2 Setting Programmable BQ27Z855 Options

The BQ27Z855 comes configured in accordance with the default settings detailed in the BQ27Z855 Technical Reference Manual. Ensure that the settings are correctly changed to match the pack and application for the BQ27Z855 solution being evaluated.

Note

The correct setting of these options is essential for best performance. Configure these settings using the *Data Memory* window seen in the main bqStudio window (Figure 4-2).

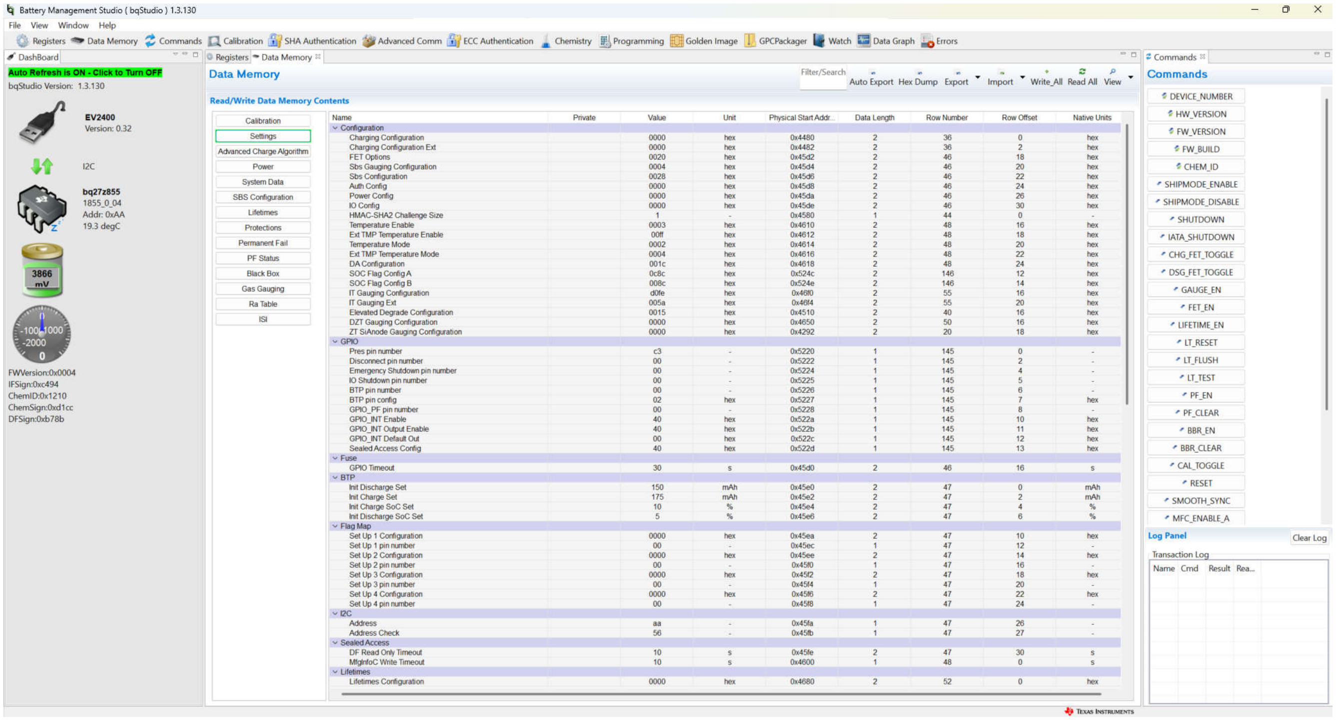


Figure 4-2. Data Memory Screen

To read all of the data from the BQ27Z855, click the Read All button in the Data Memory window. For ease of configuration, a text file with a .gg.csv extension can be extracted, modified, and imported back onto the device. Use the export and import buttons as seen in Figure 4-2 to export and import .gg.csv files. The auto export button enables gg files to be exported periodically at intervals. This feature is useful when debugging issues with the gauge. A write command is necessary if a .gg.csv file is imported to ensure that all changes made on the .gg.csv file are affected on the gauge. Use the read command to read back all the data written to the gauge to verify the changes were made. The filter/search field enables the user to search for a particular parameter in the data memory content.

Note

Do not make modifications to the .gg.csv file using Microsoft Excel® as it makes changes to the file, which bqStudio rejects. Make sure to use a text editor like notepad or similar to edit a .gg.csv file.

4.3 Configuring the Integrated Linear Battery Charger

The BQ27Z855 has an integrated linear battery charger feature to control the CHG FET in a linear operating mode to function as a linear battery charger. This linear battery charger function allows the BQ27Z855 device to directly and autonomously control battery charging with a large suite of firmware programmable settings and controls.

The minimum parameters to configure for the linear battery charger functionality are as follows:

- LINCHGR: The Charging Configuration Ext[LINCHGR] bit must be set to enable the linear charging function for the BQ27Z855, and the advance charging algorithm will control the charging current and voltage of the integrated linear battery charger.
- Current Gain: The Current Gain parameter in data flash must be configured based on the external sense resistor value (RSENSE) connected between SRP and SRN pins. The formula is:

  Current Gain = 5294 × (RSENSE / 20 mΩ)

  The default value of 2646 is configured for a 10 mΩ sense resistor. Incorrect configuration will result in charging current errors.
- Precharge Current: Set in Advanced Charging Algorithm PCHG Current. The actual current depends on correct Current Gain configuration.

- Fast Charge Current: Set in Advanced Charging Algorithm CHGC Current. The actual current depends on correct Current Gain configuration.
- The CHGR_DET functionality: The CHGR_DET bit is a status indicator reflecting whether a valid upstream charger is attached. The device firmware monitors the voltage difference between PACK+ (VPACK) and the battery (VBAT) using configurable thresholds with hysteresis to prevent noise-induced toggling. Please refer to the BQ27Z855 Technical Reference Manual for guidance on how to configure the CHGR_DET On Voltage and the CHGR_DET Off Voltage.
- Minimum System Voltage: Charger Minimum System Voltage (default 3000mV) to enter MINSYS operation.
- Advanced Charge Algorithm: The remainder of the Advanced Charge Algorithm parameters must be configured in accordance with the specification outlined in the BQ27Z855 Technical Reference Manual to achieve the desired system requirements.
- Zero Volt Charging (ZVCHG): The ZVCHG parameters must be configured to meet the system requirements in accordance with the cell specifications.

Please refer to the *BQ27Z855 Datasheet* and the *BQ27Z855 Technical Reference Manual* for more on the battery charging features, controls, and the complete list of parameters needed to be configured to achieve the system requirements.

5 Calibrating Gauge Measurements

This section describes the process of using bqStudio and the hardware setup required to calibrate a gauge's voltage and current readings. It is important for rest of the processes inside of this guide to have a calibrated gauge.

5.1 Voltage Calibration

Set up the EVM and other hardware as pictured in Figure 4-1. The BAT pins can be connected to a battery or a power supply, but the voltage of this source must be known to millivolt precision for accurate calibration.

Inside of bqStudio, navigate to the Calibration window. Then, as shown in Figure 5-1, enter the precise value of the voltage source used, check **Calibrate Voltage**, and then press the **Calibrate Gas Gauge** button.

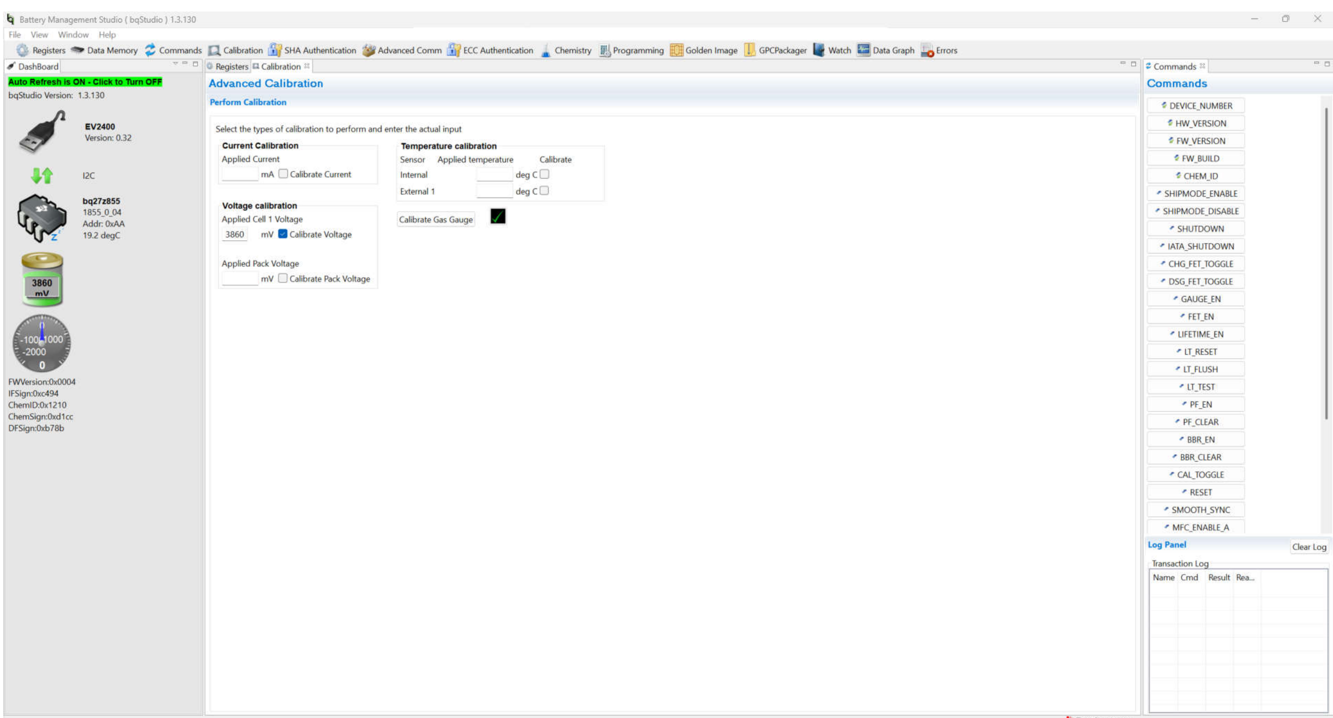


Figure 5-1. Voltage Calibration in bqStudio

5.2 Current Calibration

Set up the EVM, a voltage power supply (either a battery or a bench power supply can be used), and a power supply capable of supplying a constant current with milliamp precision. The constant-current supply should be connected to the BAT- and PACK- headers. The exact circuit layout is shown in Figure 5-2. The constant-current supply is shown as being attached to the test point of BAT-, but can also be attached to the BAT- header, as well.

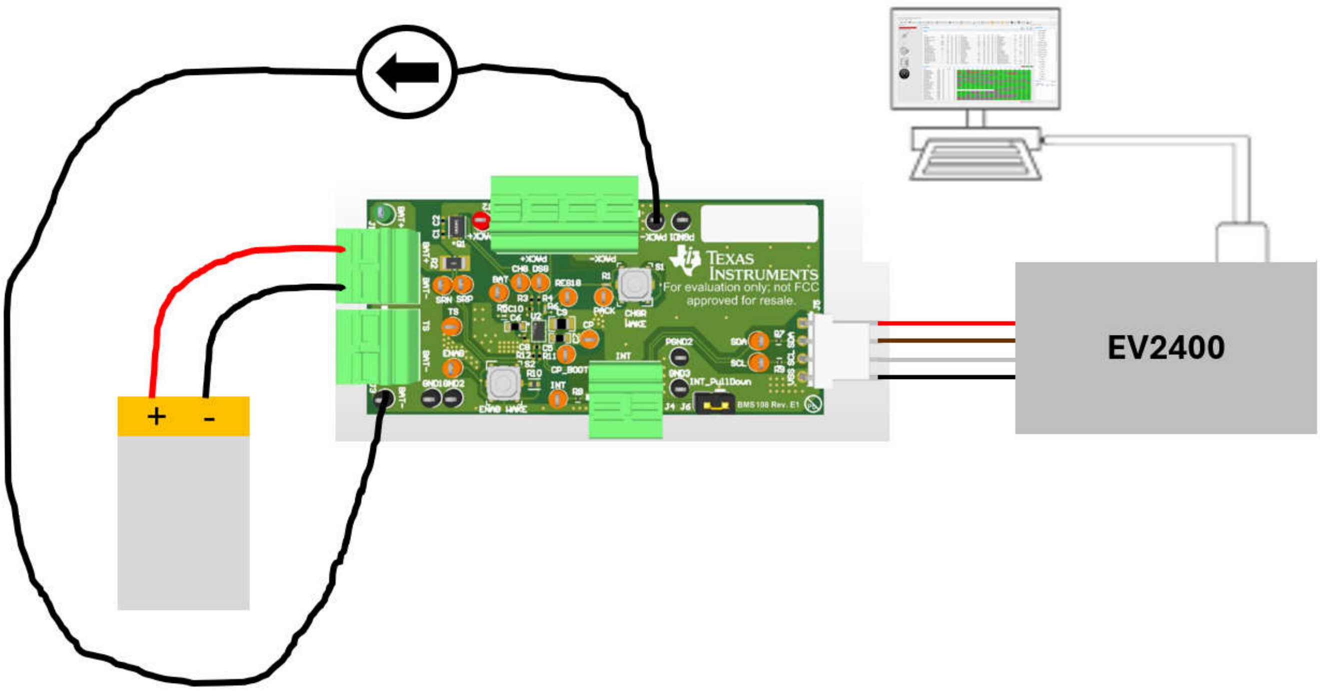


Figure 5-2. Current Calibration Hardware Setup

As shown in Figure 5-3, from the *Calibration* window in bqStudio, enter the precise value of current being supplied, click to check the **Calibrate Current** box, and then press the **Calibrate Gas Gauge** button.

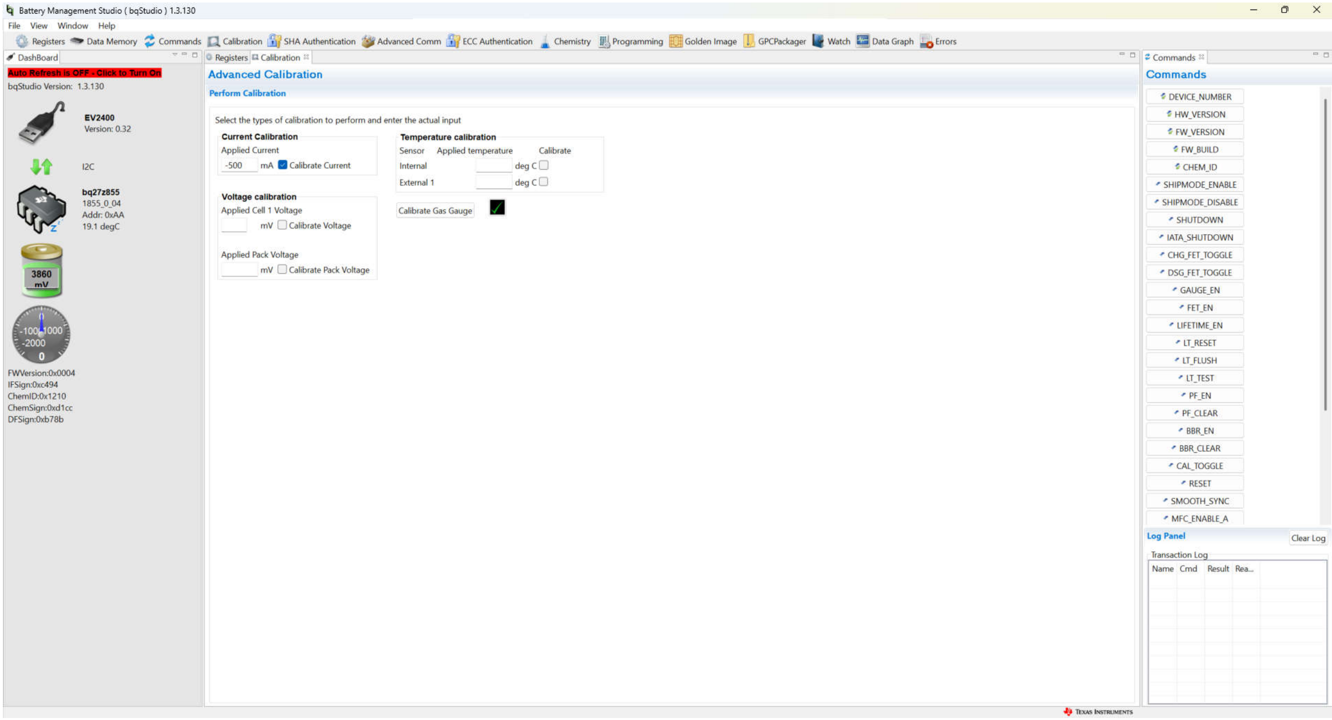


Figure 5-3. Current Calibration in bqStudio

6 Chemical ID

This section describes the process of finding the chemistry identifier, sometimes referred to as "Chemical ID" or "ChemID", of a battery that will be used. The ChemID is a necessary element of the Dynamic Z-Track™ algorithm that needs to be identified before performing a learning cycle. For the Golden File creation process, it is necessary that this battery is the exact same type that will be used in production. Use this battery for the proceeding sections, as well.

Texas Instruments has a database of thousands of battery profiles, and the ChemID selection process will identify either the exact battery profile or the most similar. This ChemID is then programmed into the gauge, updating dataflash with the battery profile. This profile is used in the IT algorithm for capacity and resistance learning as well as for capacity prediction and other features.

The Chemical ID selection process consists of recording the current, voltage, and temperature (IVT) of a battery during a charge and discharge. This data is then submitted to the online Gauging Parameter Calculator (GPC) Tool, which then gives the customer a report with a best-fit Chemistry ID to program into their gauge. The process performed with this hardware is a charge-relaxation-discharge-relaxation test. A programmable power supply is recommended for this process.

6.1 Chemical ID Selection Process

The test consists of the following steps:

1. Test is performed at room temperature. If the cell was at a different temperature, let the cell relax for two hours at room temperature prior to the test.
2. Charge using CC or CV charging to full using taper current (for example, C/100). Use nominal CC charge rate and CV voltage. If another charging method is specified by the cell maker, use that method.
3. Let the battery relax for two hours to reach full equilibrium open circuit voltage (OCV).
4. Discharge the battery at C/10 rate until the minimal voltage (as specified by the cell manufacturer) is reached.
5. Let the battery relax for five hours to reach full equilibrium OCV.

Figure 8-1 shows an example of what this process looks like graphically.

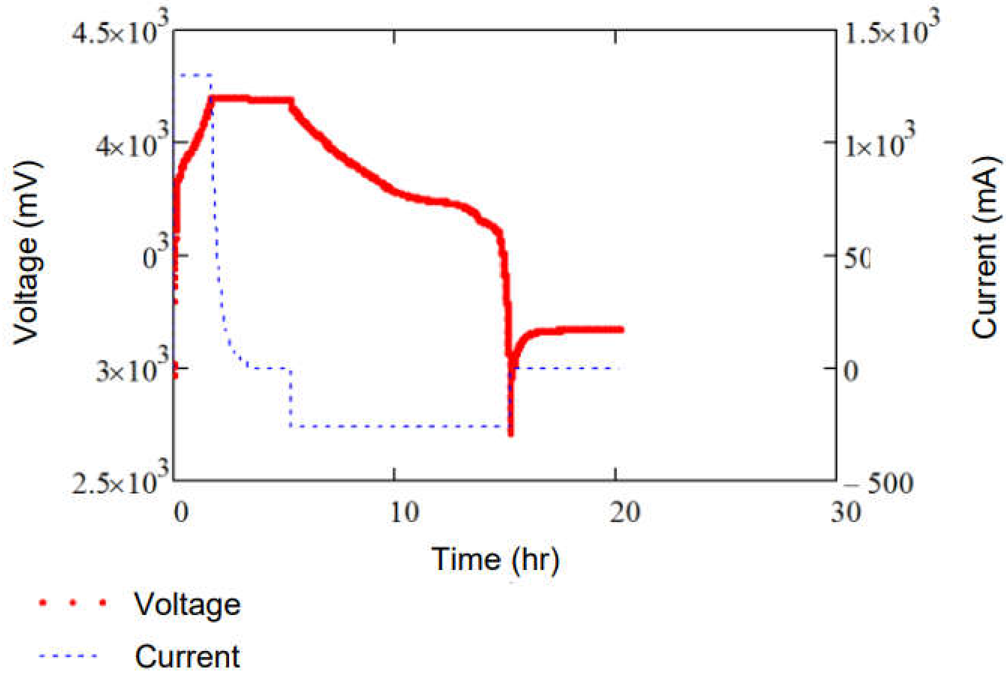


Figure 6-1. Graph of IV Data in Charge-Relax-Discharge-Relax

6.2 Hardware Requirements and Setup

Performing the charge and discharge cycle and recording the IVT characteristics of a battery can be done using a battery, a constant-voltage and constant-current power supply, bqStudio, and a BQ27Z855EVM.

Start by setting this hardware up as shown in Figure 6-2. This setup is identical to Figure 4-1.

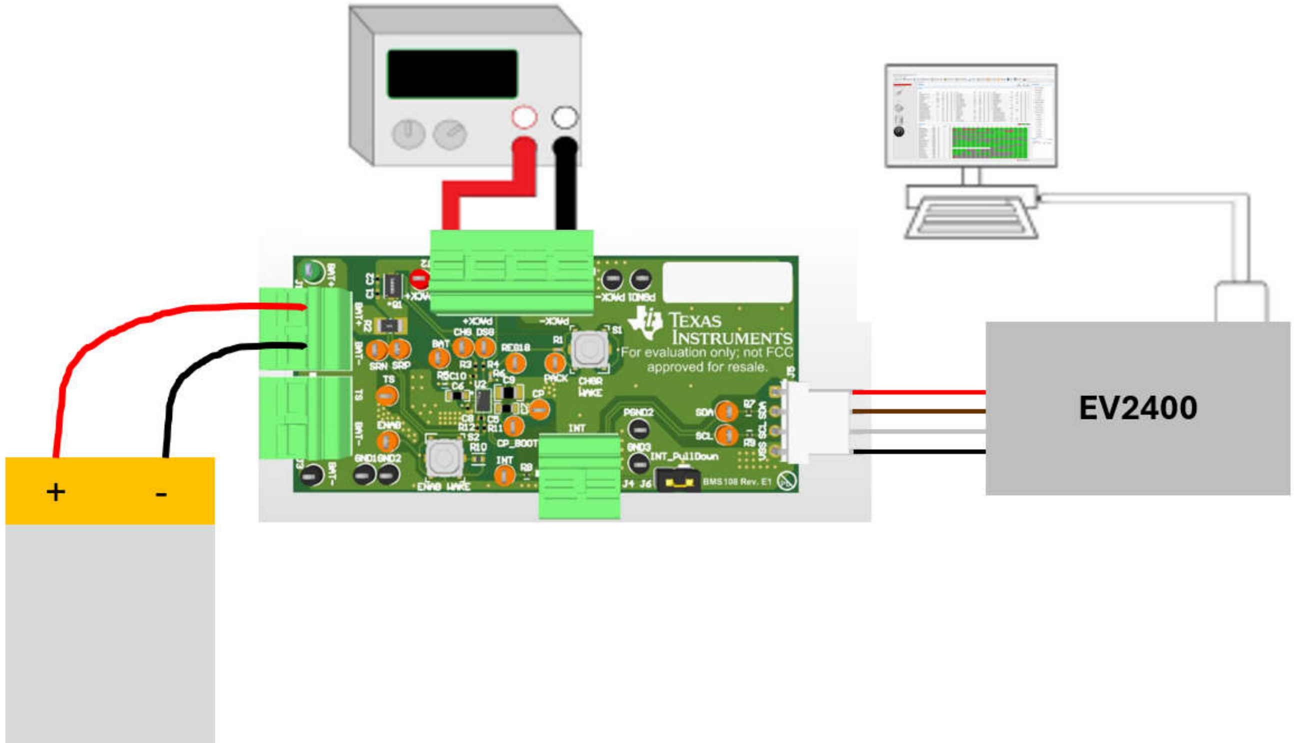


Figure 6-2. ChemID Hardware Setup

6.3 Logging Data in bqStudio

The recording of voltage, current, and temperature can be done with bqStudio. The logging functionality in bqStudio allows a constant capture and recording of the registers of a connected gauge. The default elapsed interval is 4000 milliseconds. To change this interval, go to Window, select Preferences, choose Registers, and change Scan/Log Interval from 4000 to a minimum of 1000 milliseconds. There is no need to log faster than 1 second as the gas gauge updates the registers once every second.

To begin recording the battery's IVT properties during charge and discharge, use the **Start Log** button on the *Registers* window in bqStudio as shown in Figure 6-3.

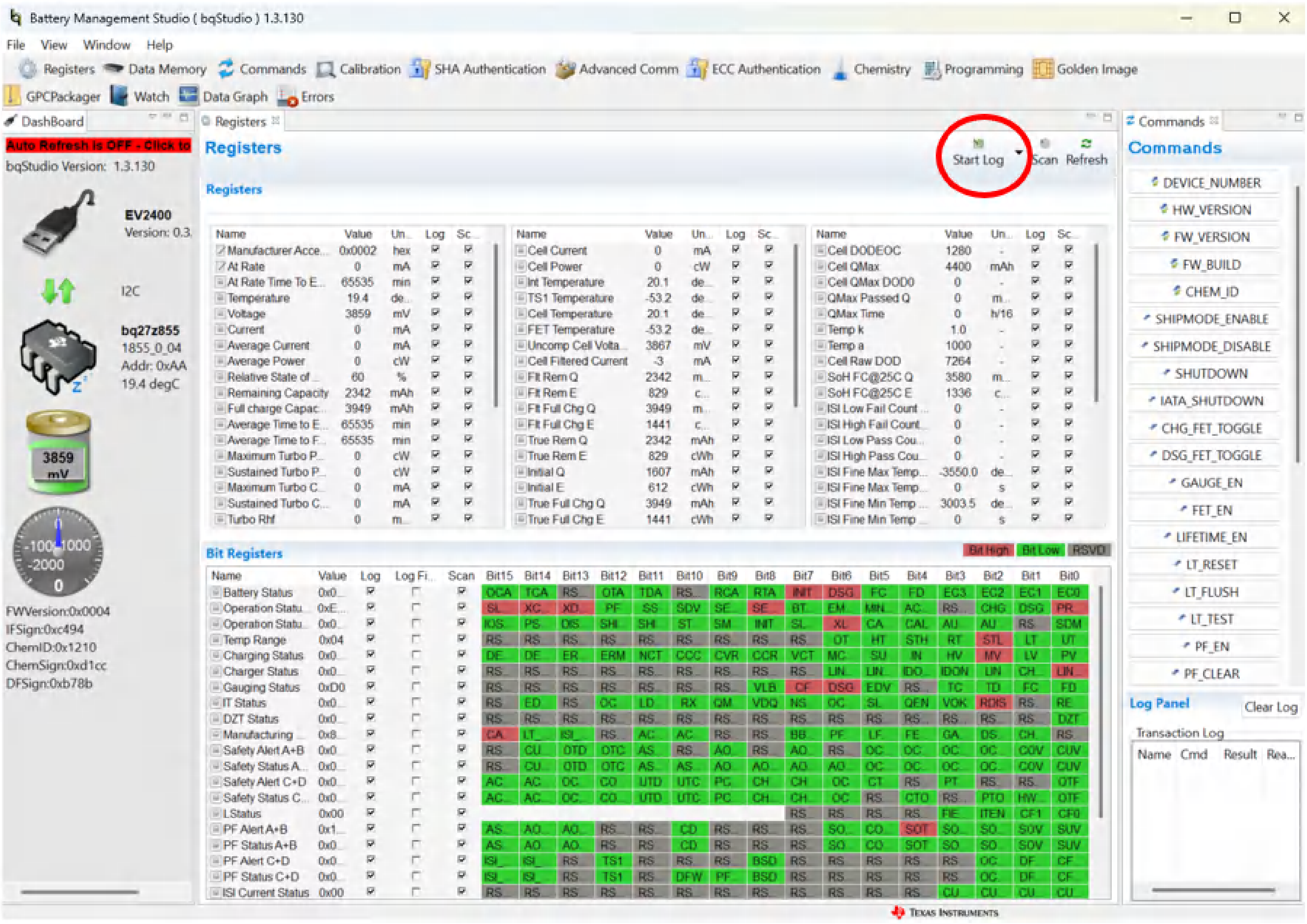


Figure 6-3. Start Log Button in bqStudio

Upon pressing the **Start Log** button, a prompt to select a location for the .log file to save will be shown. Select a location to save this file. The .log file type can be changed to the .csv format and viewed inside of Microsoft Excel™ or a similar application to facilitate debugging of the register states through the course of the logging period. At the end of the relaxation period after the gauge has been allowed to discharge, use the **Stop Log** button in bqStudio to end logging.

6.4 GPCChem Tool

Convert the .log file to a .csv file by renaming the file format. Create a blank .csv file and copy into the first, second, third, and fourth columns the time, voltage, current, and temperature, respectively. Ensure that your units for each of these are seconds, millivolts, milliamps, and Celsius. The first row can be names for each of the columns, which the tool will skip assuming there is only one row of names before the data begins. Figure 6-4 is an example of the required .csv file formatting as well as the first few rows of data.

	A	B	C	D
1	ElapsedTime (sec)	Voltage (mV)	Current (mA)	Temperature (°C)
2	1.01	3950	0	19.6
3	2.401	3950	0	19.6
4	3.766	3950	0	19.6
5	5.156	3950	0	19.7
6	6.485	3950	0	19.7
7	7.949	3950	0	19.7
8	9.21	3950	0	19.7
9	10.405	3950	0	19.7
10	11.838	3950	0	19.7
11	13.138	3950	0	19.7
12	14.374	3950	0	19.7
13	15.738	3950	0	19.7
14	16.994	3950	0	19.7
15	18.263	3950	0	19.7
16	19.573	3950	0	19.7
17	20.704	3950	0	19.7
18	22.06	3950	0	19.7
19	23.326	3950	0	19.7
20	24.649	3950	0	19.7
21	25.878	3950	0	19.7
22	27.091	3950	0	19.7
23	28.389	3950	0	19.7

Figure 6-4. Cell Formatting for .csv

1. Save this created file with the name “roomtemp_rel_dis_rel.csv”.
2. Create a second file "config.txt" and write the following in it:
   a. ProcessingType = 2
   b. NumCellSeries = 1
   c. ElapsedTimeColumn = 0
   d. VoltageColumn = 1
   e. CurrentColumn = 2
   f. TemperatureColumn = 3
3. Create a folder with any name. Put both the roomtemp_rel_dis_rel.csv and config.txt files in this folder, and convert the folder to a .zip file. Submit this .zip file to the GPC Tool through the web interface found on ti.com.

After processing, an e-mail with a report that indicates the results of the tool’s process is sent to the e-mail address you provided when logging into ti.com to use the GPC Tool. The report contains the selected ChemID and a list of additional ChemIDs that satisfy the “less than 3%” error criteria. For example, this can be useful to verify that a ChemID used previously is still suitable. If any formatting mistakes or other errors are present, they are reflected in the report.

6.5 Programming a Chemical ID

The ChemID is programmed into the gauge using bqStudio. Navigate to the “Chemistry” window in bqStudio. A view of this window is shown in Figure 6-5.

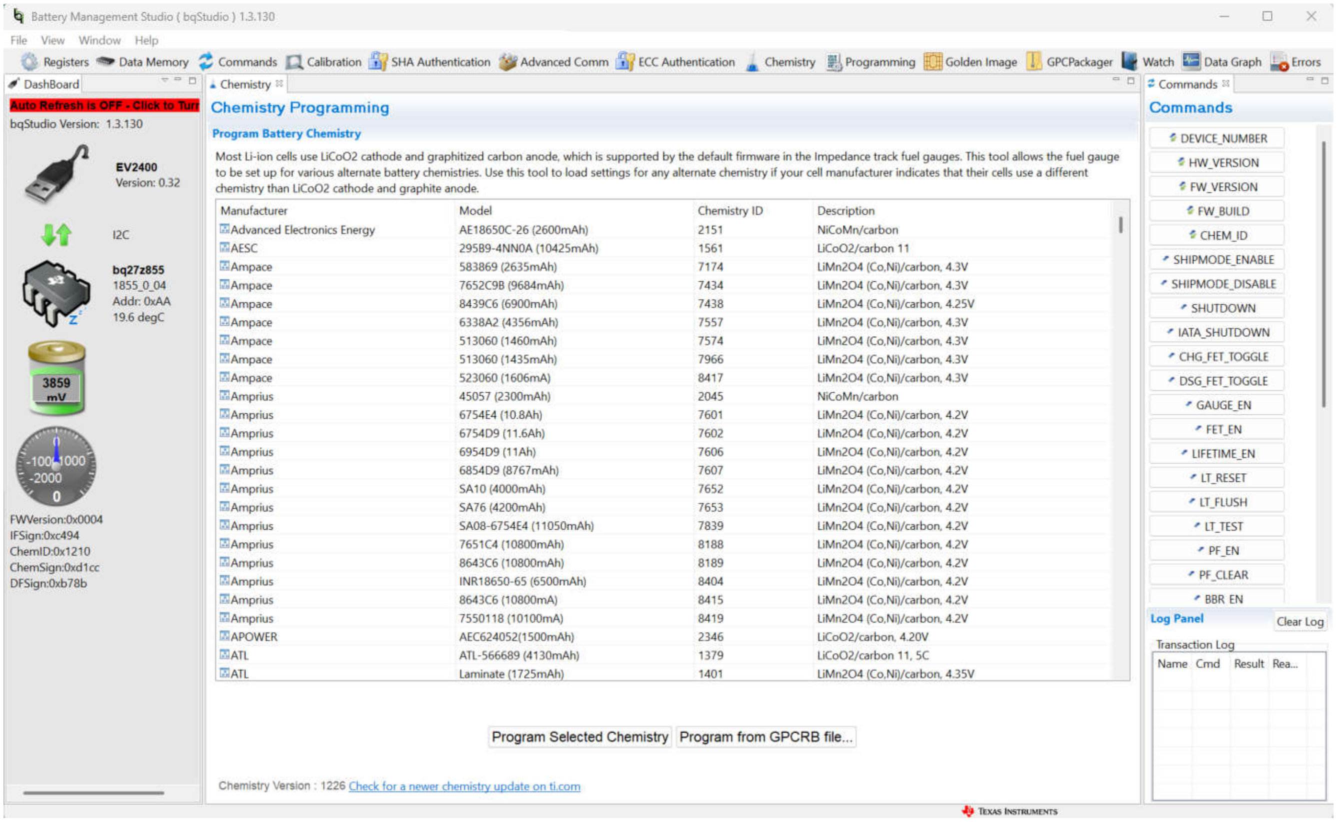


Figure 6-5. Chemistry Window View in bqStudio

Sort by a given parameter by clicking the top of that column once. It is recommended that you sort the table by Chemistry ID so that the ChemIDs are ordered numerically. Scroll down to the Chemistry ID that was reported as the best fit in the GPC Tool report, select this Chemistry ID, and then press the **Program Selected Chemistry** button.

If you do not see your Chemistry ID in this list, update the Chemistry version in bqStudio. To do so, see to the gas gauge chemistry resources found on ti.com.

Once the gauge is programmed with this chemistry, the ChemID can be confirmed by pressing the **CHEM_ID** button in the Commands window, shown on the right side of Figure 6-5. Check the *Log Panel* window, shown in the bottom-right corner of Figure 6-5, and confirm that the correct Chemistry ID was returned.

6.6 Further Resources for Chemical ID Process

For further details and more instruction on finding a Chemistry ID with the GPC Tool, refer to the "Simple Guide to Chemical ID Selection Tool (GPC) (Rev. A)" document found on ti.com.

7 Learning Cycle and Golden Image

The learning cycle process is the initial optimization that Impedance Track gauges perform in order to ensure accuracy of the gauge in reporting state of charge. The learning cycle allows the gauge to learn a specific battery’s resistance and maximum chemical capacity, ensuring accuracy as the cell ages. It is necessary that a correct ChemID, with less than 3% of error, has been identified and programmed into the gauge before attempting a learning cycle.

7.1 Learning Cycle Process Description

The learning cycle process consists of charge – relaxation – discharge – relaxation – charge while certain data memory parameters are set in the gauge, enabling the gauge to begin the cycle and accurately recognize when state changes have occurred over the charge/discharge process. Through the course of the learning cycle, the **[LStatus]** register updates as different states are achieved, marking three points in the progression of the learning cycle.

The first **[LStatus]** update goes from 0x00 to 0x04 when the gauge has had the Impedance Track bit enabled, allowing the learning cycle to begin. **[LStatus]** goes from 0x04 to 0x05 when the post-charge relaxation has allowed the battery to relax enough so that the change in voltage is very low (dV/dt < 1 μV/s). The *[REST]* flag will be set indicating that the battery has adequately relaxed. The final **[LStatus]** update to 0x06 happens after the second discharge when the change in voltage is very low.

For more details on the register updates and flags set at each point in the learning cycle, see the *Learning Cycle Procedure* section of the *Achieving the Successful Learning Cycle*.

For more details on the learning cycle registers, refer to the *BQ27Z855 Technical Reference Manual*.

7.2 Data Memory Configuration

The gauge's Data Memory is configured in bqStudio from the Data Memory window. This window is shown below in Figure 7-1.

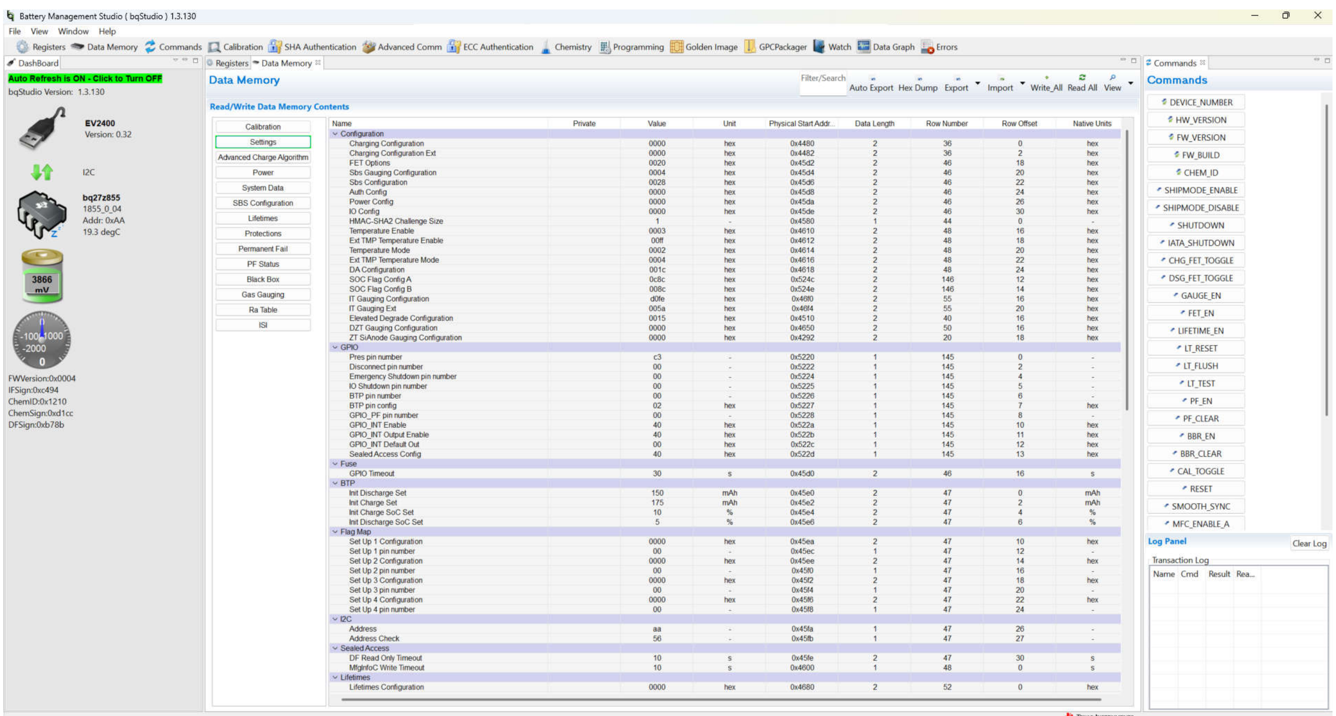


Figure 7-1. Data Memory View in bqStudio

The necessary data memory configurations will be made in this screen, using only the **[Advanced Charging Algorithm]** and **[Gas Gauging]** sections of the data memory window. Use the *Filter/Search* box to find specific parameters. Use the **Write All** button to write data memory parameters that have been changed on this screen to the gauge. Use the **Read All** button to read the current data memory configurations from the gauge and verify a successful write. Ensure that each value is programmed in the correct unit, indicated in the third column for each data memory parameter.

The following are the data memory values that should be programmed:

- **[Advanced Charging Algorithm][Termination Config][Charge Term Taper Current]:** This value should be set slightly higher than the actual taper current between C/10 and C/100. This value should also be higher than the **[Chg Current Threshold]** value.
- **[Gas Gauging][Design][Design Voltage]:** This value can be found in the battery data sheet as the nominal or average voltage.
- **[Gas Gauging][Design][Design Capacity mAh]:** This value can be found in the battery data sheet as battery capacity and is often referred to as C.
- **[Gas Gauging][Design][Design Capacity cWh]:** This value is the battery capacity in centiwatt hours. This value might be in the battery datasheet, or can be found by multiplying the capacity in mAh by the terminal voltage in Volts, then dividing by 10.
- **[Gas Gauging][IT Cfg][Term Voltage]:** This value can be found in the battery data sheet as the terminal voltage. This is the lowest voltage that the gauge should charge to.
- **[Gas Gauging][Current Thresholds][Dsg Current Threshold]:** This current value is where the gauge recognizes that the battery is being discharged. Set this value below C/10, as a positive number. The gauge will interpret it as a negative.
- **[Gas Gauging][Current Thresholds][Chg Current Threshold]:** This current value is where the gauge recognizes that the battery is being charged. Set this value below C/10 and also lower than the Charge Term Taper Current.
- **[Gas Gauging][Current Thresholds][Quit Current Threshold]:** This value is where the gauge enters relax mode. It should be less than C/20 and lower than the **[Dsg Current Threshold]** and **[Chg Current Threshold]**.

Figure 7-2 shows a visual representation of the current during the course of a learning cycle relative to the data memory current parameters set.

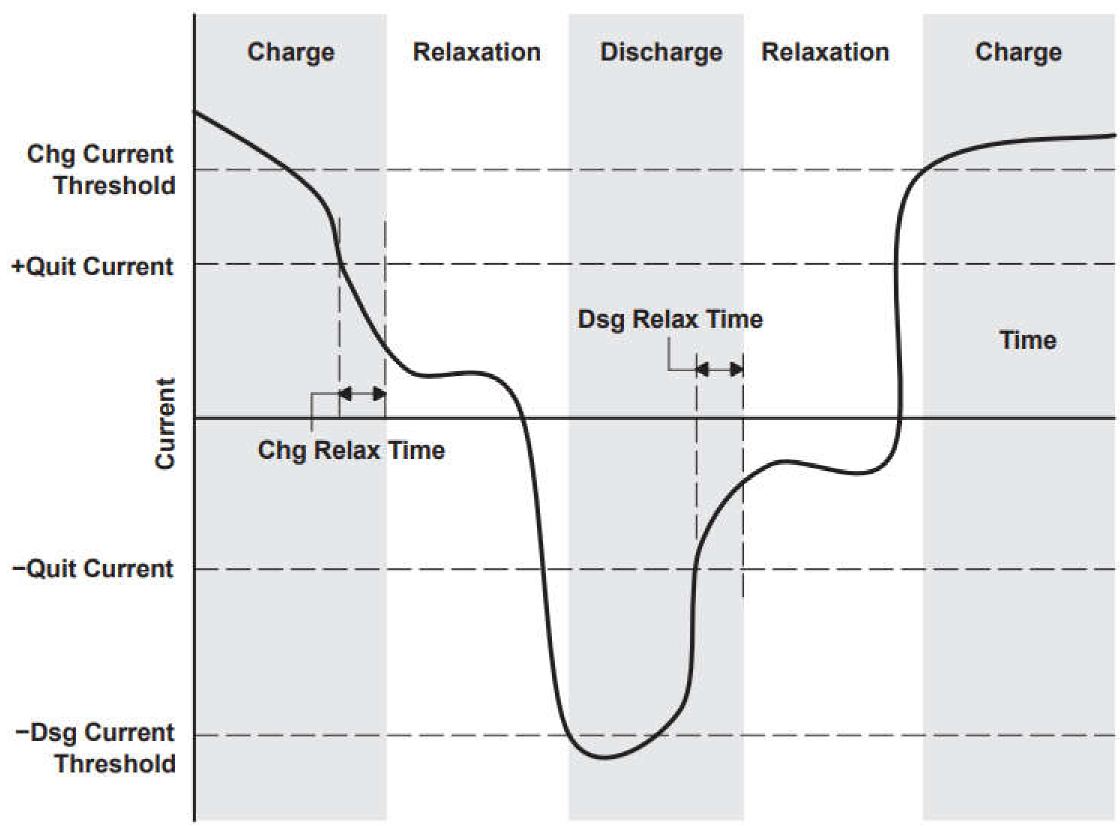


Figure 7-2. Graph of Learning Cycle Current

7.3 Learning Cycle Steps

The hardware setup for performing a learning cycle consists of the same setup as used in the Chemical ID process. This setup is described in Section 6.2 and shown in Figure 6-2. The charging and discharging process is very similar to a ChemID, except the first step is an initial discharge of the battery to its terminal voltage.

Before beginning the learning cycle process, starting a log in bqStudio is recommended to allow for debugging of any issues that might occur during the learning cycle.

Conducting a learning cycle consists of the following steps:

1. Test is performed at room temperature. If the cell was at a different temperature, let the cell relax for two hours at room temperature prior to the test.
2. Use the **GAUGE_EN** command in the Command window. Use the **RESET** command in the Command window. Confirm that the **[LStatus]** register has updated to 0x04.
3. Discharge the battery at C/5 until it reaches Term Voltage.
4. Relax the battery for 5 hours.
5. Charge using CC until the battery reaches the Full Charge Voltage.
6. Charge using CV at the Full Charge Voltage. Cut off CV charging at a point in between **[CHG Current Threshold]** and **[Quit Current Threshold]**.
7. Let the battery relax for two hours to reach full equilibrium open circuit voltage (OCV). The **[LStatus]** register should update to 0x05.
8. Discharge the battery at C/10 rate until the **[Term Voltage]** is reached.
9. Let the battery relax for five hours to reach full equilibrium OCV. The **[LStatus]** register should have updated to 0x06.

7.4 Low Temperature Optimization

Gauge State of Charge (SOC) reporting often loses accuracy in low temperatures due to higher cell impedances. Impedance Track gauges allow SOC reporting to be improved significantly for gauges that will experience low temperatures by using the GPCRB Tool. This simple test requires a similar process to the Chemical ID process, but adds a much greater degree of accuracy for low temperature gauging.

The test setup required to use the GPCRB Tool is very similar to the setup shown in Figure 6-2. The only difference is that the EVM thermistor must be connected to the surface of the battery and a temperature-controlled chamber, such as Arbin or Maccor, is required to create a low-temperature environment where the gauge can monitor the battery's IVT characteristics.

For more information about this process, see the GPCRB page on ti.com.

7.5 Creating the Golden Image File

The current EVM has completed all optimization steps at this point. The Golden Gauge can be used to program all other gauges in production using a Golden Image. This will ensure gauges begin with an accurate starting point to begin reporting on and further learning about a battery's chemistry.

To get the necessary file for programming gauges, navigate to the Programming window in bqStudio. Choose the output directory and file name for the Golden Image under the "Path for combined .bq.fs:" row, this will be the .bq.fs file that contains the encrypted firmware and the custom configuration in data flash. Choose the input directory and .bq.fs file for the encrypted firmware downloaded from ti.com under the "Path for encrypted .bq.fs:" row. Then click "Read FS from DM", this will create the combined .bq.fs Golden Image file that can be programmed onto other battery packs in production.

7.6 Programming the Golden Image File

An exported Golden Image file can be uploaded to another gauge in bqStudio or through custom production processes. To upload a Golden Image file to a new gauge in bqStudio, connect the new gauge to bqStudio and open the Programming window. Click Browse and navigate to and select the Golden Image file, or enter the Golden Image's file address. Click Program to upload Golden Image files to the gauge.

To use Golden Image files in production, the .bq.fs file format is recommended. For further guidance on using the .bq.fs file format, refer to Section 5 of the "Gauge Communication" document found on ti.com.

8 Gauge Communication

This section introduces host-processor communication with the BQ27Z855. The BQ27Z855 gauge uses an I2C communication interface with communication speeds up to 1MHz. Further hardware and software specifications for the I2C interface for this gauge can be found in the *BQ27Z855 Data Sheet* and the *BQ27Z855 Technical Reference Manual*.

8.1 Advanced Communication in bqStudio

To communicate with the gauge in bqStudio, navigate to the *Advanced Communication* window. This window allows the user to send read and write commands to the gauge for easy communication with the gauge over I2C. The I2C Address of the gauge, visible in the *DashBoard* window in bqStudio, and the Start Register are needed for each Read and Write command, and can be written in the text field. Read commands require the Number of Bytes to Read and Write commands require the Bytes to Write to be specified.

8.2 Standard Data Commands

Standard commands are common commands from the Smart Battery Specification (SBS) industry-standard which defines smart battery interfacing. Standard commands use a command code pair to associate the registers associated with each command. Read and write commands should be addressed to the LSB of the command code.

Example: Read the *RelativeStateOfCharge*.

1. Perform a Read Operation:
   a. I2C Address (Hex) = AA
   b. Start Register (Hex) = 2C
   c. Number of Bytes to Read (Decimal) = 2
2. View the results in *Transaction Log*:
   a. The Data window will show the hex value of the battery's SOC in little endian format.

Figure 8-1 shows 0x3B 00 in the Data column of the *Transaction Log* sub-window. This value is 59 in decimal, corresponding to the RSOC%.

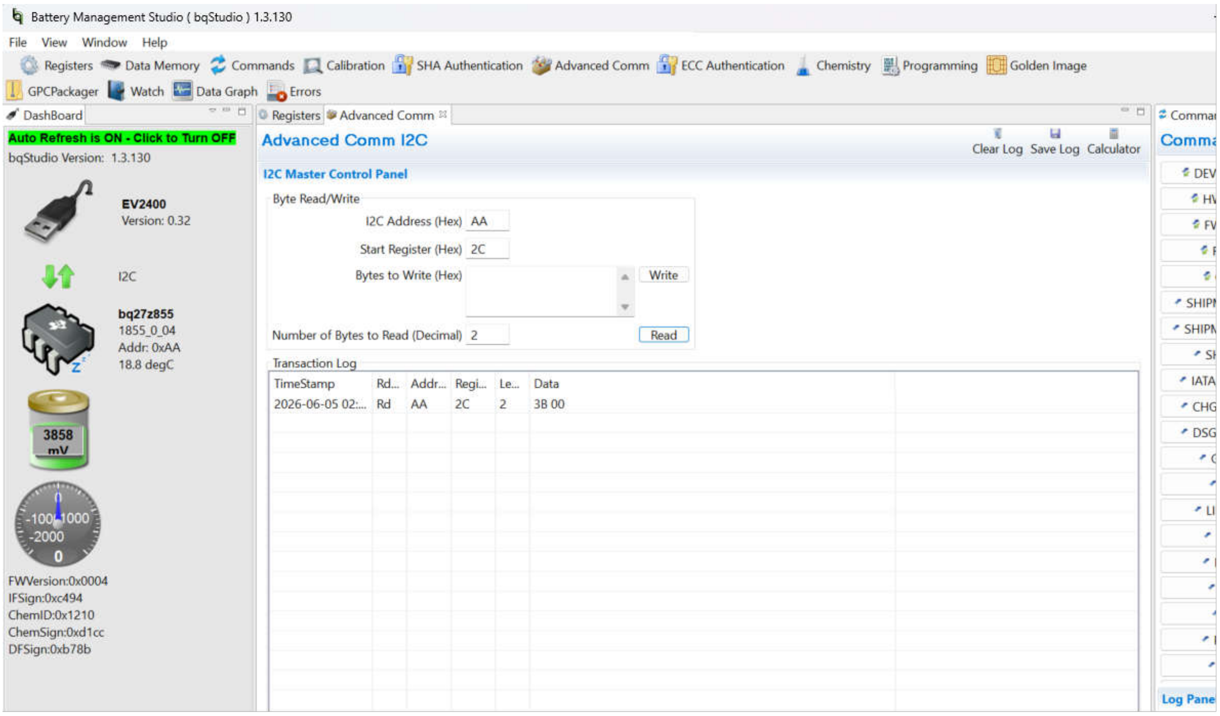


Figure 8-1. Standard Data Command Example

8.3 Manufacturer Access Commands

Manufacturer Access (MAC) commands are defined by Texas Instruments. MAC commands require a write to the *AltManufacturerAccess()* registers at 0x3E and 0x3F, and then an additional write to the *AltManufacturerAccess()* sub-command being used. The complete list of all MAC commands in the BQ27Z855 and an example of a Command Write operation with MAC commands can be found in the *0x00, 0x01 ManufacturerAccess() and 0x3E, 0x3F AltManufacturerAccess()* chapter of the *BQ27Z855 Technical Reference Manual*.

Example: Read *Chemical ID()* to *AltManufacturerAccess().*

1. Send Chemical ID() to AltManufacturerAccess().
   a. I2C Address (Hex) = AA
   b. Start Register (Hex) = 3E
   c. Bytes to Write (Decimal) = 06 00 (this write data must be written in little endian)
2. Read the result from AltManufacturerAccess() and MACData().
   a. I2C Address (Hex) = AA
   b. Start Register (Hex) = 3E
   c. Number of Bytes to Read (Decimal) = 36
3. View the results in Transaction Log.
   a. The first two bytes "06 00" is the MAC command (for verification)
   b. The second two bytes "10 12" are the ChemID in little-endian (the ChemID can be seen if the **CHEM_ID** button is checked in the *Command* window)

c. The final two bytes is the checksum and length. The length here is 6. The checksum is 0xFF - (sum of the first length - 2 bytes). The length and checksum are used to validate the block response.

Figure 8-2 shows this in bqStudio. To perform this process, fill out all of the fields as shown, then click **Write** and **Read**.

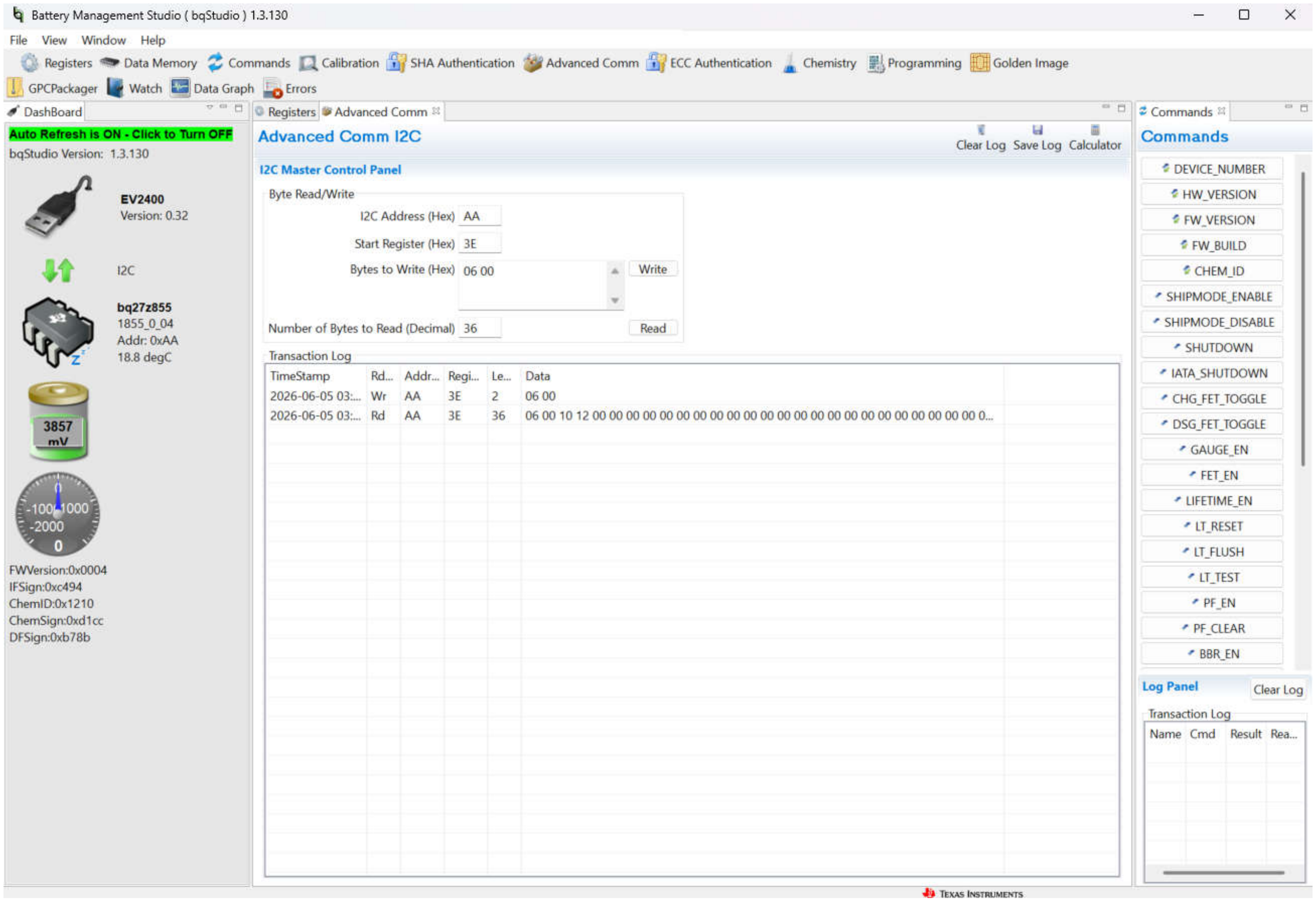


Figure 8-2. MAC Command Example

8.4 Further Resources on Gauge Communication

Further resources for communicating with gauges, including host controller driver development, can be found in the "Gauge Communication" document found on ti.com.

9 BQ27Z855-Based Circuit Module

The BQ27Z855 based circuit module is an example solution of a BQ27Z855 circuit for battery management. The circuit module incorporates a BQ27Z855 battery gas gauge and protection integrated circuit (IC) with external sense resistor to accurately predict the capacity of a 1-series Li-ion cell. In addition, it includes external N-channel FETs for high-side battery protection.

9.1 Circuit Module Connections

Contacts on the circuit module provide the following connections:

- Direct cell connection to the battery pack (J1): BAT+, BAT–
- Direct system connection for charging and discharging (J2): PACK+, PACK–
- External temperature sensor connection (J3): TS
- Interrupt pin connection (J4): INT
- I2C™ communications via external EV2400 to Windows-based PC USB port (J5): SDA, SCL, VSS

9.2 Pin Descriptions

Table 9-1. Pin Descriptions

Pin Name	Description
PACK+	Pack positive terminal
PACK-	Pack negative terminal
BAT+	Battery positive terminal
BAT-	Battery negative terminal
SDA	External I2C communication data line
SCL	External I2C communication clock line
VSS	Device ground
INT	Programmable output interrupt to host
TS	External temperature sensor connection

10 Hardware Design Files

This section contains the board layout, bill of materials, and schematic for the BQ27Z855 circuit module.

10.1 Schematic

This section contains the schematic of the different (PCB) components.

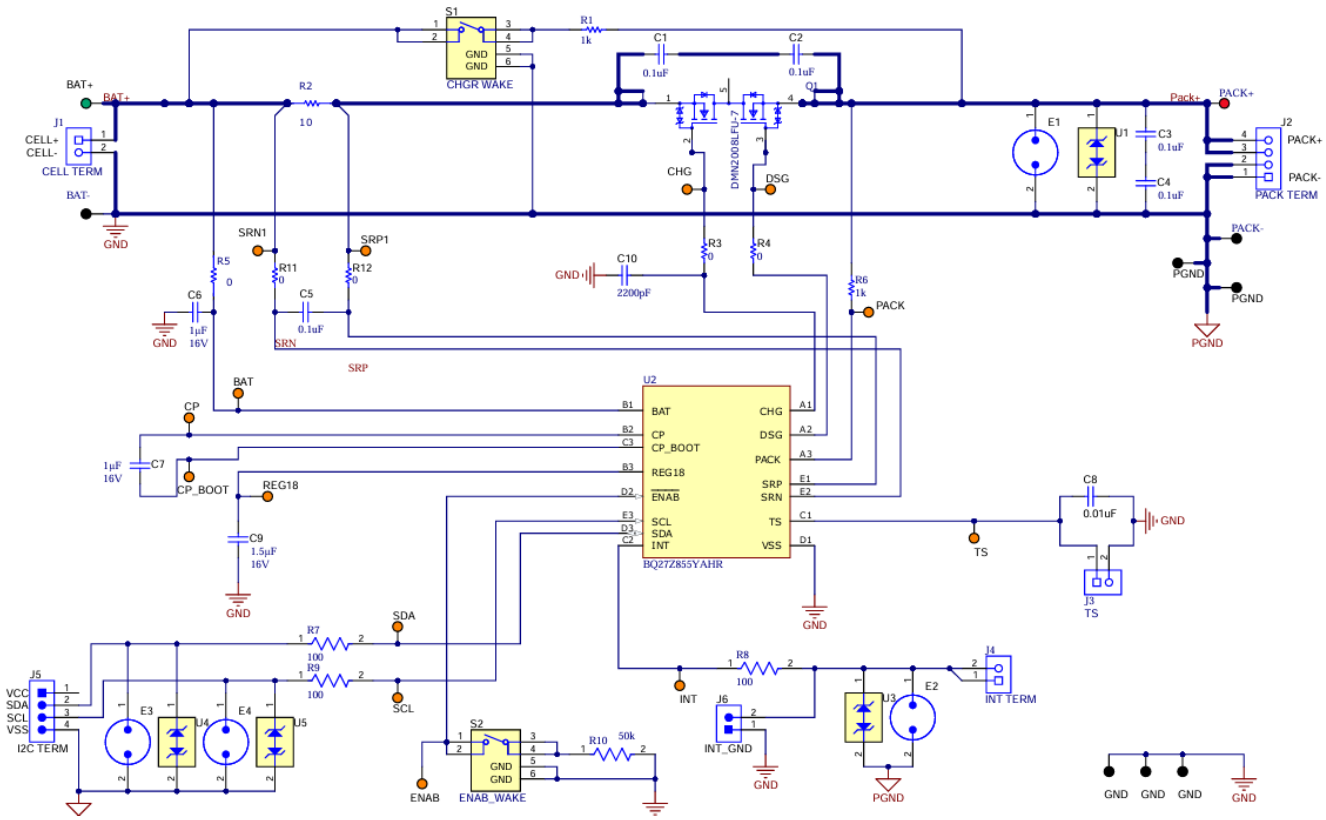


Figure 10-1. BQ27Z855EVM Reference Schematic

10.2 Bill of Materials (BOM)

Table 10-1. Bill of Materials

Fitted	Description	Designator	PartNumber	Quantity	Manufacturer	PackageReference	Value	Alternate Manufacturer	Alternate PartNumber
Fitted	Printed Circuit Board	!PCB1	BMS108	1	Any				
Fitted	Test Point, Orange, 1-Pin THD, RoHS	BAT, CHG, CP, CP_BOOT, DSG, ENAB, INT, PACK, REG18, SCL, SDA, SRN1, SRP1, TS	5003	14		5003			
Fitted	Test Point, Miniature, Black, TH	BAT-, GND1, GND2, GND3, PACK-, PGND1, PGND2	5001	7	Keystone	Black Miniature Testpoint			
Fitted	Test Point, Miniature, Green, TH	BAT+	5116	1	Keystone	Green Miniature Testpoint			
Fitted	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X5R, 0201	C1, C2, C3, C4	GRM033R61E104KE14J	4	MuRata	0201	0.1uF		
Fitted	CAP, CERM, 0.1 uF, 16 V,+/- 10%, X7R, 0201	C5	GRM033Z71C104KE14D	1	MuRata	0201	0.1uF		
Fitted	CAP, CERM, 1 uF, 16 V, +/- 10%, X7R, 0603	C6, C7	EMK107B7105KA-T	2	Taiyo Yuden	0603	1uF		
Fitted	CAP, CERM, 0.01 uF, 10 V, +/- 10%, X5R, 0201	C8	GRM033R61A103KA01D	1	MuRata	0201	0.01uF		
Fitted	CAP, CERM, 1.5 uF, 16 V, +/- 10%, X7R, 0805	C9	C0805C155K4RACTU	1	Kemet	0805	1.5uF		
Fitted	CAP, CERM, 2200 pF, 16 V, +/- 10%, X7R, 0201	C10	GRM033R71C222KA88D	1	MuRata	0201	2200pF		
Fitted	Fiducial mark. There is nothing to buy or mount.	FID1, FID2, FID3	N/A	3	N/A	N/A			
Fitted	Terminal Block, 5mm, 2x1, R/A, TH	J1, J3, J4	1792863	3	Phoenix Contact	Terminal Block, 5mm, 2x1, R/A, TH			

Table 10-1. Bill of Materials (continued)

Fitted	Description	Designator	PartNumber	Quantity	Manufacturer	PackageReference	Value	Alternate Manufacturer	Alternate PartNumber
Fitted	Terminal Block, 5mm, 4x1, R/A, TH	J2	1792889	1	Phoenix Contact	Terminal Block, 5mm, 4x1, R/A, TH			
Fitted	Header, 2.54mm, 4x1, R/A, Tin, TH	J5	640455-4	1	TE Connectivity	Header, 2.54mm, 4x1, R/A, TH			
Fitted	Header, 2.54 mm, 2x1, Gold, TH	J6	GBC02SAAN	1	Sullins Connector Solutions	Header, 2.54 mm, 2x1, TH			
Fitted	Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	LBL1	THT-14-423-10	1	Brady	PCB Label 0.650 x 0.200 inch			
Fitted	Test Point, Miniature, Red, TH	PACK+	5000	1	Keystone	Red Miniature Testpoint			
Fitted	Transistor MOSFET Array Dual N-CH 20V 14.5A 6-Pin uDFN2030 T/R	Q1	DMN2008LFU-7	1	Diodes Inc.	U-DFN2030-6			
Fitted	Res Thick Film 0201 1K Ohm 1% 1/20W ±200ppm/°C Molded SMD SMD Paper T/R	R1, R6	CRCW02011K00FNED	2	Vishay Dale	0201			
Fitted	10 mOhms ±1% 1W Chip Resistor 1206 (3216 Metric) Current Sense, Moisture Resistant Metal Element	R2	CSNL1206FT10L0	1	Stackpole Electronics	1206	10m		
Fitted	RES, 0, 5%, 0.05 W, 0201	R3, R4, R11, R12	CRCW02010000Z0ED	4	Vishay-Dale	0201	0		
Fitted	0 Ohms Jumper 0.1W, 1/10W, 5.8A Chip Resistor 0201 (0603 Metric) Automotive AEC-Q200 Metal Foil	R5	HCJ0201ZT0R00	1	Stackpole Electronics	0201	0		

Table 10-1. Bill of Materials (continued)

Fitted	Description	Designator	PartNumber	Quantity	Manufacturer	PackageReference	Value	Alternate Manufacturer	Alternate PartNumber
Fitted	RES SMD 100 OHM 1% 1/20W 0201, ERJ-1GNF1000C	R7, R8, R9	ERJ1GNF1000C	3	Panasonic Electronic Components	0201	100Ω		
Fitted	RES Thick Film, 50kΩ, 1%, 0.063W, 100ppm/°C, 0402	R10	CRCW040250K0FKED	1	Vishay	0402			
Fitted	Switch, SPST-NO, Off-Mom, 0.02 A, 15 VDC, SMD	S1, S2	EVQ-PLHA15	2	Panasonic	4.9x4.9mm			
Fitted	Shunt, 100mil, Gold plated, Black	SH-J1	SNT-100-BK-G	1	Samtec	Shunt	1x2	3M	969102-0000-DA
Fitted	Single-Channel ESD in 0402 Package With 10pF Capacitance and 6V Breakdown, DPY0002A (X1SON-2)	U1, U3, U4, U5	TPD1E10B06DPYR	4	Texas Instruments	DPY0002A		Texas Instruments	TPD1E10B06DPYT
Fitted	BQ27Z855YAHR	U2	BQ27Z855YAHR	1	Texas Instruments	DSBGA15			
Fitted	Thermistor NTC, 10.0k ohm, 1%, Disc, 5x8.4 mm, Fitted in T6 header	RT1	103AT-2	1	SEMITEC Corporation	Disc, 5x8.4 mm	10k		

10.3 PCB Layouts

This section shows the printed-circuit board (PCB) layers (Figure 10-3 through Figure 10-4), and assembly drawing for the BQ27Z855 module.

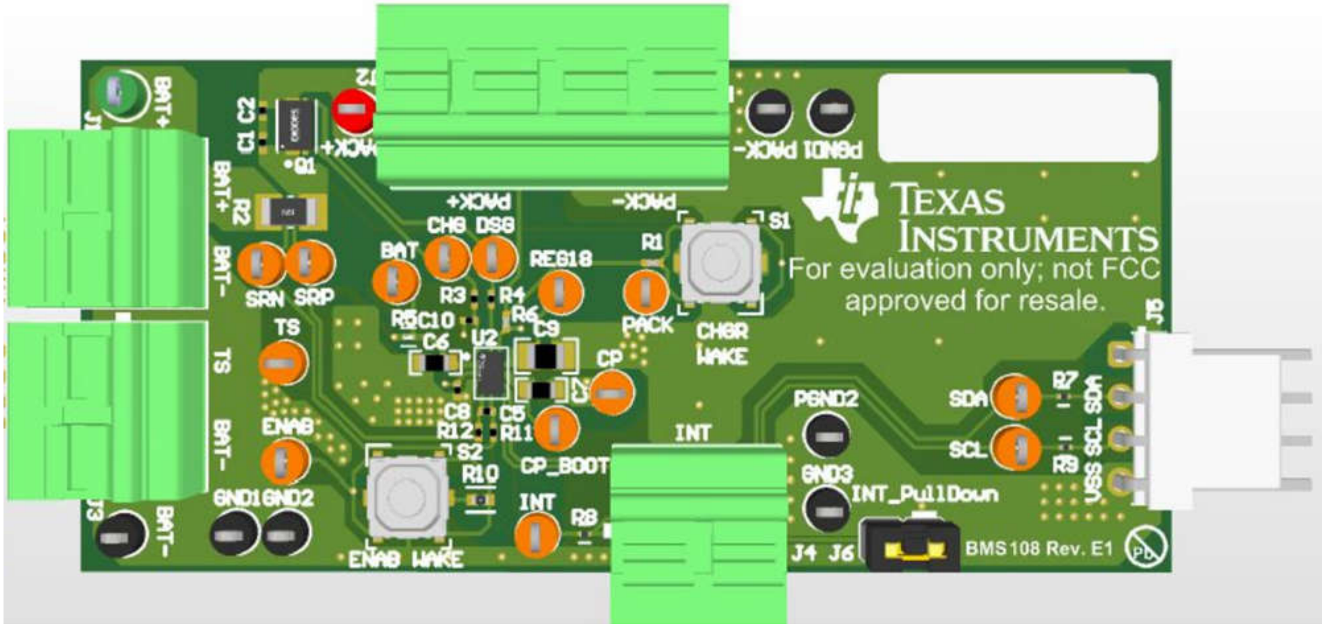


Figure 10-2. EVM Image

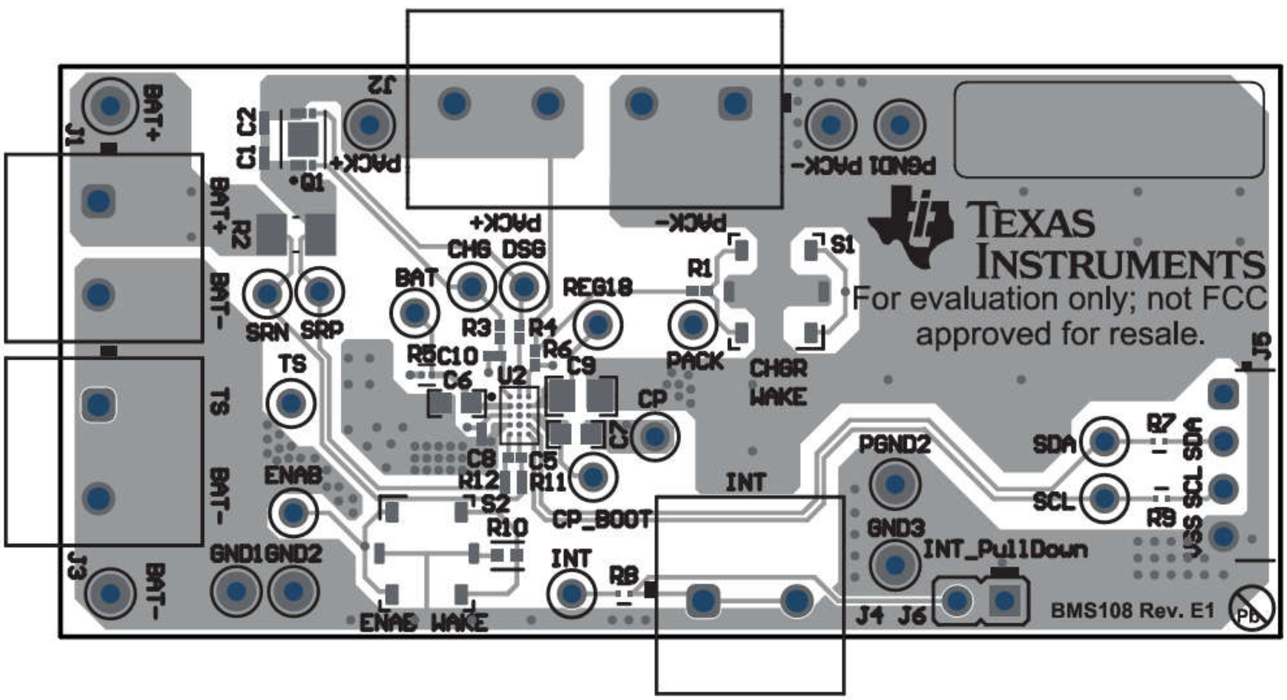


Figure 10-3. Top Layer Composite

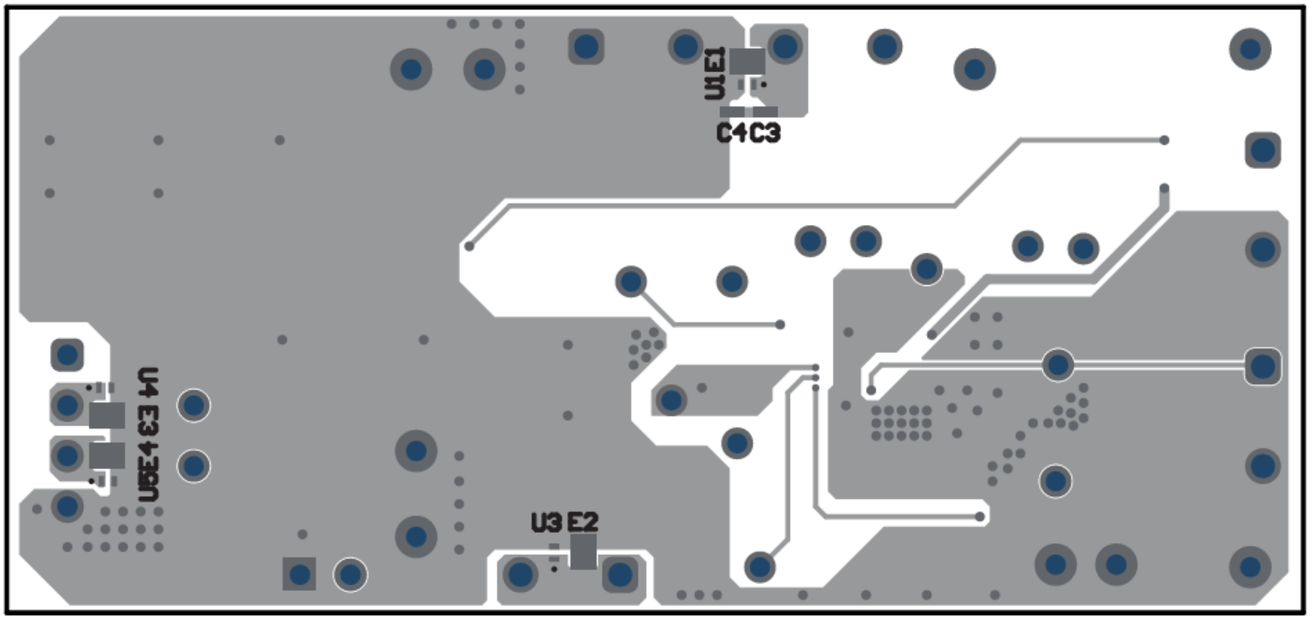


Figure 10-4. Bottom Layer

11 Additional Information

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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

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- *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.

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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

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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.

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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