Going to Production With the bq2754x

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ABSTRACT

This application report presents a strategy for high speed, economical calibration, and production programming of the bq2754x single-cell gas gauge. Flowchart examples are provided, along with step-by-step instructions for preparing a calibration data set that is required when creating the golden data flash image (DFI) that is programmed into all bq2754x at the pack maker production line.

Introduction

The bq2754x gas gauge is built with new technology and a new architecture for both data flash access and calibration. With this new architecture, unit production cost and capital equipment investment can be minimized, as it is no longer necessary to perform a learning cycle on each pack. A single golden DFI file can be used to program each bq2754x in production. Also, the calibration method is quick and simple because most of the calibration routines are built into the firmware of the target device or can be based on average values.

Determining Data Flash Constants

To configure the bq2754x for a given application, the data flash set must be programmed depending on the cell, application system, and charger. The application report entitled Configuring the bq2754x Data Flash (SLUA410, SLUA503, neither doc released) gives a detailed description of all the data flash constants that the user can modify. All bq2754x ICs for an application must contain the same data flash.

The golden DFI is a file that contains all flash and is used at the pack PCB production line to program the bq2754x. The DFI is programmed using I²C™ communication with the bq2754x using a test platform developed by the customer. Creating the DFI can be summarized with the process depicted in Figure 1.
Calibrate several (20-30 units) bq27541 ICs on designed pack PCB circuit using EVM software

Record calibration values, for CC Gain, CC Delta, Board Offset, Ext Temp Offset and Pack V Offset

Calculate average calibration value for each item

Run bqEASY using bq27541 evaluation module

At calibration step write CC Gain, CC Delta, Board Offset, Ext Temp Offset and Pack V Offset with average values using the Data Flash screen of EVSW

Continue bqEASY to complete Data Flash Image File

Review Data flash values with EVSW Data Flash screen

Write new Data Flash Image with bqEASY

Change individual data flash items through Data Flash screen

Figure 1. DFI Creation Flow at Preproduction

STEP 1: Characterize the Calibration Process

Devices of bq2754x single-cell gas gauges are quick and easy to calibrate. With the Impedance Track™ devices, most calibration routines have been incorporated into firmware algorithms, which can be initiated with I2C commands. The hardware for calibration is also simple. One current source, one voltage source, and one temperature sensor are all that is required. The accuracy of the sources is not important, only their stability. However, accurately calibrated reference measurement equipment must be used for determining the actual arguments to the function.
The user has two strategy choices to follow for calibration. One is to characterize the calibration process and include the characterization results as part of the production DFI; the second is to individually calibrate every printed-circuit board (PCB) with a gauge that goes through the pack manufacturer's production line.

The recommended strategy for bq2754x calibration is to perform the calibration characterization using 20 to 30 final pack PCBs containing the bq2754x IC. All the calibration flash values are to be recorded and averaged among the 20 to 30 samples taken. The average values are the ones to be used when creating the DFI file needed for production. At time of calibration, the I²C pins, both ends of the sense resistor, and battery power must be accessible. The calibration consists of performing coulomb counter offset, current gain, board offset, and temperature offset. The Evaluation Software (EVSW) is used to perform all calibration. Using the EVSW allows the user to verify the affected data flash values due to calibration (see Figure 2).

![Figure 2. bq27541 EVSW Calibration Data Flash Screen](Image)

The voltage calibration is not required for this device given that each IC is calibrated for voltage measurement at the device's final test process by Texas Instruments.

Perform the following calibration tests on each of the system samples:

**CC Offset Calibration** – Select the **CC Offset Calibration** checkbox then click on the **Calibrate Part as indicated below** button and wait for the EVSW to indicate that the calibration is completed. Read back the updated CC Offset data flash value by going to Data Flash screen in EVSW and selecting the Calibration tab. Press Read All button so that all the data is refreshed on screen.

**Temperature Calibration** – Select the **Temperature Calibration** checkbox and have Int. Sensor unchecked and Ext. Sensor 1 checked. Write the actual temperature to which the thermistor is exposed obtained by the reference equipment measurement. Click on the **Calibrate Part as indicated below** button, and wait for the EVSW to indicate that the calibration is completed. Read back and record the Ext Temp Offset value from the Data Flash screen.
Board Offset Calibration – Ensure that no current is flowing through the sense resistor (no charge or no discharge occurring). Confirm that all calibration checkboxes are unchecked. Click on CC Board Offset Calibration button, and wait for the EVSW to indicate that the calibration is completed. Read back and record the updated Board Offset data flash value by going to Data Flash screen in EVSW and selecting the Calibration tab. Press Read All button so that all the data is refreshed on screen.

Pack Current Calibration – Select the Pack Current Calibration checkbox. Write the actual current measured by the meter (negative sign indicates current in discharge direction). Click on the Calibrate Part as indicated below button, and wait for the EVSW to indicate that the calibration is completed. Read back and record the updated CC Gain and CC Delta data flash values by going to the Data Flash screen in EVSW and selecting the Calibration tab. Press Read All button so that all the data is refreshed on screen.

The average CC Gain, CC Delta, Ext Temp Offset, and Board Offset values are entered into the DFI file in Step 2.

STEP 2: Using bqEASY™ Software for Production Preparation

The bqEASY™ software (see Figure 4) is a tool embedded within the EVSW that provides detailed instructions and automates processes that, on completion, creates the DFI and ROM (not implemented yet) files that will be used at production to program all bq2754x for a given application.
The data flash of the bq2754x is configured based on a Q and A session within the Configure section of the bqEASY™ software. The questions involve topics specific to the battery pack, the charger, and the system application.

At the Calibrate session of the bqEASY™ software, it is expected of the user to navigate to the Data Flash section of the EVSW and enter the average calibrations obtained from the process described in the Characterize the Calibration Process section of this document.

The Chemistry session in the bqEASY™ software is a valuable tool that allows the user to select the chemistry of their battery pack from a database. If the user does not know the chemistry of its battery pack, then the bqEASY™ software gives instructions on testing the battery for determining the chemistry. The discharge during the test is automated. For automated discharge, a setup as described in Figure 5 is required. The load must be selected so that it has a C/5 rate when turned on. During automated discharge, the EV2300 board controls when to enable and disable the discharge, allowing the necessary relaxation periods for OCV measurements. Once the chemistry is determined, the data flash of bq27541 is updated so that it contains the proper OCV data that is characteristic of the selected chemistry. Having proper chemistry data is integral for the Impedance Track™ algorithm to perform accurately.

![Figure 4. bqEASY™ Screen](image)

The Chemistry session in the bqEASY™ software is a valuable tool that allows the user to select the chemistry of their battery pack from a database. If the user does not know the chemistry of its battery pack, then the bqEASY™ software gives instructions on testing the battery for determining the chemistry. The discharge during the test is automated. For automated discharge, a setup as described in Figure 5 is required. The load must be selected so that it has a C/5 rate when turned on. During automated discharge, the EV2300 board controls when to enable and disable the discharge, allowing the necessary relaxation periods for OCV measurements. Once the chemistry is determined, the data flash of bq27541 is updated so that it contains the proper OCV data that is characteristic of the selected chemistry. Having proper chemistry data is integral for the Impedance Track™ algorithm to perform accurately.

![Figure 5. Load Connection for Automated Discharge](image)
The final session of the bqEASY™ software is for running a learning cycle so that Qmax and the impedance tables are updated. The bqEASY™ software provides step-by-step instructions on how to perform the learning cycle. By having learned Qmax and impedance values, the DFI can be created so that when used to program bq2754x ICs in production, a learning cycle is unnecessary before a device can perform accurate battery fuel gauging as of first cycle in system.

**Figure 6. bqEASY™ Process Flowchart**

**STEP 3: Data Flash Review**

When following the actual steps of the bqEASY™ algorithm, the tool prompts the user to review the data flash constants for advanced configurations that may not have been addressed by the bqEASY™ software. The application report *Configuring the bq2754x Data Flash (UNPUBLISHED)* defines all the bq2754x data flash constants. Use this document for reference when reviewing the data flash configuration against the application needs.

To modify the data flash constants, proceed to the Data Flash screen of the evaluation software, and search for the desired data flash value to be modified and change accordingly.
STEP 4: Writing the DFI at Production

Pack PCB designers must ensure that the I\textsuperscript{2}C lines of bq2754x are accessible at time of writing DFI in production, if the device is intended to be used as a single-wire, communication-enabled device. It is expected that the pack manufacturers add the Write DFI step within their final complete system test that verifies the product to be functional for release to market. The flowcharts in Figure 8, Figure 9, and Figure 10 show the steps that must be followed to write the DFI created with the bqEASY™ software using their own test setup. Test developers can use the flowchart to call I\textsuperscript{2}C commands with their test setup and program all the flash of the bq2754x.

If customers develop their own tools to program the DFI and need to set the device to HDQ mode, the following steps are required.

After writing the DFI but before sending the commands to exit ROM mode, send the following commands:

(a) I2C Command 0x00: Byte 0x16
(b) I2C Command 0x04: Byte 0x05
(c) I2C Command 0x64: Byte 0x1B
(d) I2C Command 0x65: Byte 0x00

Finish the programming process by exiting ROM mode and sending the following commands:

(a) I2C Command 0x00: Byte 0x0F
(b) I2C Command 0x64: Byte 0x0F
(c) I2C Command 0x65: Byte 0x00

Once the DFI writing is complete the pack manufacturer can build the packs and do all necessary pack testing (protection circuit functionality). If customers develops their own tools to program the DFI and need to set the device to HDQ mode, the following steps are required.

On completing all tests, proceed to last step before shipping packs.

The last step of the bq27541 configuration at production is to give the IT ENABLE (0x0021) and SEALED (0x0020) commands. These commands are given by writing the corresponding two-byte data value into the CONTROL register (command 0x00/0x01), using whichever communication protocol the bq27541 has been set to at production.
0.1 bq2754x Production Flow

Pack Maker

Make PCBs

Program DFI
I2C mode at the PCB Level
- PCB Test with I2C access
- Program Golden DFI using I2C
- Calibrate (optional)
- Convert I2C to HDQ if required

Build Packs

Test Packs
- Pack Test SW
  (Customer Developed)
- Enable IT
- Check Voltage accuracy
- Check Current accuracy
- Seal Pack

Ship Packs

Texas Instruments

Ship Parts
- Default Program (DFI)
- I2C Interface
- FW version 1.1x
- HW version B5

Figure 7. High Level Production Flow
Start Read and Erase First Two Rows of Instruction Flash (IF)

Read the Flash Image into a byte array such as yDataFlashImage[0 to 0x3FF]

Write Command 0x00 and Data 0xF00

Create a 96 bytes array from each row
yIFRowData_0[0 to 95]
yIFRowData_1[0 to 95]

iRow = 0

Write command 0x00 and Data 0x00

Write command 0x01 and Data 0x00+iRow
Write command 0x02 and Data 0x00

Write command 0x04 and Data 0x00+iRow
Write command 0x05 and Data 0x00

Read 96 bytes from data register address 0x04 to 0x63 into yIFRowData_iRow

20 msec delay

iRow = iRow+1

NO
iRow >1?
YES

Write command 0x00 and Data 0x03

Write command 0x64 and Data 0x03

Write command 0x64 and Data 0x03

Write command 0x65 and Data 0x00

20 msec delay

NO
Read register 0x66, Data = 0x00?
YES

Erase the first two rows (one page erase)

Checksum consists of 0x03.

Checksum required to complete erase command.

Abort after so many attempts

See figure 9 for DFI programming flow

Figure 8. DFI Write Flow
I2C device address 0x16 is used for all remaining communication. Send data flash Mass Erase command.

Setup for Mass Erase command.

Checksum consists of 0x0C+0x83+0xDE.

Checksum required to complete Mass Erase command.

This is Write Row command

Checksum consists of adding 0x0A, the corresponding row and the bytes of data to be programmed in row. The checksum is only two bytes

Command 0x64 and 0x65 are for LSB and MSB of Checksum respectively

Checksum is required to complete Write Row command

If register 0x66 does not return 0x00 then there is no data integrity.

The total number of rows is determined by total data flash size (0x0400) divided by 32 bytes per row.

Setup for Data Flash Checksum command.

DFI checksum verification

See figure10 for programming the first two row of IF back

Figure 9. Continuation of DFI Write Flow
This is the Program Row command

Copy corresponding 96 bytes of iRow IF data from system memory into yIFRowData_iRow[0 to 95]

Write command 0x00 and Data 0x02

Write command 0x01 and Data 0x00+iRow
Write command 0x02 and Data 0x00

Write command 0x04 and yIFRowData_iRow array

Checksum=[0x02+iRow+sum(yIFRowData_iRow)] mod 0x10000

Write command 0x64 and Data 0x0F
Write command 0x65 and Data 0x0F

This command indicates the row to operate in

Command 0x64 and 0x65 are for LSB and MSB of Checksum respectively
Checksum is required to complete Write Row command

20 msec delay

If register 0x66 does not return 0x00 then there is no data integrity.

This is the Program IF Row command

End Program IF Row

Program second row then program first row

This command exits from ROM Mode.
Command 0x64 and 0x65 are for LSB and MSB of Checksum respectively
Checksum required to complete Exit ROM Mode command

End Writing Image

iRow = 1

Read register 0x66, Data = 0x00?
NO
YES

iRow = iRow-1

iRow <0?
YES
NO

Figure 10. Continuation of DFI Write Flow
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