

Using the bq78350

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ABSTRACT

This application report contains a variety of information to assist the user in configuring the bq78350 Battery Management Controller and bq769x0 Analog Front End (AFE) protection devices.

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1 Introduction

The bq78350 Li-Ion and LiFePO₄ fuel gauge and battery management controller and bq769x0 Analog Front End (AFE) Protection devices are used as a chipset for a wide variety of cell combinations and applications. This chipset can have a wide range of features enabled, although the chipset requires only a few for the device to operate correctly.

The following are four key documents that need to be available to the application note reader:

1. *bq78350 Data Sheet (DS)*, [SLUSB48](#)
2. *bq78350 Technical Reference Manual (TRM)*, [SLUUAN7](#)
3. *bq76920, bq76930 and bq76940 Data Manual (DM)*, [SLUSBK2A](#)
4. *bq769x0 EVM User Guide (UG)*, [SLUV924B](#)

This document uses the bq78350/bq769x0 Evaluation Module (EVM) and associated Texas Instruments Battery Management Studio (bqSTUDIO) evaluation software as the reference, unless noted otherwise. There is an expectation that the reader be familiar with EVM and bqSTUDIO software. The Battery Management Studio (bqSTUDIO) graphical user interface is shown in [Figure 1](#).

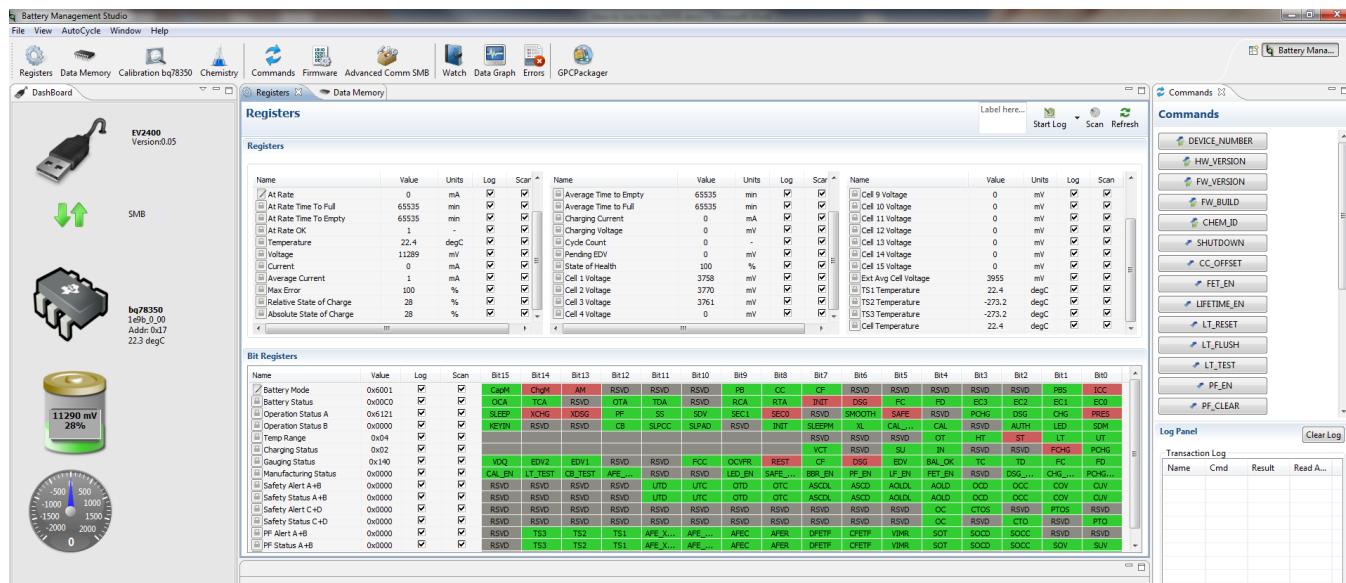


Figure 1. Battery Management Studio (bqSTUDIO) Graphical User Interface

All documentation, including further application notes, specific to the bq769x0 device, software, samples, and EVM hardware is available through www.ti.com.

2 Basic Configuration

The default data flash configuration of the bq78350 includes all required configurations for the bq76920 companion AFE. Upon power up of the bq78350, the bq78350 device will configure the bq76920 device based on the required configuration settings. The default data flash settings are available for reference in the *bq78350 Technical Reference Manual* and are visible on the bqSTUDIO software 'Data Memory' screen. On the 'Data Memory' screen, click 'Read All' for the software to read all data flash values from the device.

The default state of the bq78350 is for the FETs, SAFE pin activation, and nearly all input and output features to be OFF. Enable features and capabilities, if needed, through various data flash and **ManufacturingAccess()** commands, which are detailed in the *bq78350 Technical Reference Manual (SLUUAN7)*.

2.1 Cell Connectivity

The key default configuration is the number of series cells that the bq78350 is configured, which is a 3-series cell. This default value is set in **AFE CELL MAP** (Figure 2).

AFE Cell Map								
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
MSB	RSVD	CELL_15	CELL_14	CELL_13	CELL_12	CELL_11	CELL_10	CELL_9
LSB	CELL_8	CELL_7	CELL_6	CELL_5	CELL_4	CELL_3	CELL_2	CELL_1

Figure 2. AFE Cell Map

The AFE CELL MAP register indicates which VCx inputs to the bq769x0 AFE have cells connected, but is NOT programmed with the number of cells. Each bit refers to a VCx, where bit 0 = VC1, bit 1 = VC2, and so forth. Bit 15 should always be 0. The sum of the '1s' in the register is the number of series cells.

An additional requirement of the bq769x0 family of AFEs is to have at least three cells of each five cells connected to ensure the device operates correctly. A few example AFE CELL MAP Register configurations are in Table 1.

Table 1. AFE Cell Map Register

SERIES CELLS	AFE CELL MAP REGISTER																
	Hex Value	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3	0x0013	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
5	0x001f	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
7	0x0277	0	0	0	0	0	0	1	0	0	1	1	1	0	1	1	1
12	0x5ef7	0	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1

NOTE: When setting the **AFE CELL MAP**, this must correspond to the connectivity of the cells. Otherwise, the device may detect a **Safety Over Voltage [SOV]** or **Safety Under Voltage [SUV]** fault and enter Permanent Failure Mode (and blow a fuse, if enabled) on a cell that does not have a **Cell Over Voltage [COV]** or **Cell Under Voltage [CUV]** 1st-level detection enabled. This is because HW detects SOV or SUV and FW controls the COV or CUV and uses the AFE Cell Map to determine which cell data to monitor.

2.2 Measurement System

2.2.1 CellVoltage() and Battery Voltage() Data

Once the bq78350 configures the bq769x0 AFE for the correct cell connections, the bq78350 reads cell-voltage measurement data at 1-s intervals from the bq769x0 AFE using the *CellVoltage1()..CellVoltage15()* commands. The stack series connection is the basis for the reported *CellVoltage1()..CellVoltage15()* data and not the AFE CELL MAP register bit locations. For example: In the 12 s example above, *CellVoltage11()* is the top cell in the stack, even though its connection is to VC14. The bqSTUDIO software tool always shows *CellVoltage1()* through *CellVoltage15()*. Unused cells report '0' data and also log the data in the same way, if logging is used.

The update period is configurable in SLEEP Mode. Extending the update period can help reduce overall power consumption in this mode. Take care to understand that extending **Sleep: Voltage Time** means that *CellVoltage1()..CellVoltage15()* data-based decisions occur at the same rate. The default rate is 5 s.

The *Voltage()* command is a simple sum of the *CellVoltage1()..CellVoltage15()* data of those cells with connections indicated in AFE CELL MAP.

Each *CellVoltage1()..CellVoltage15()* can be calibrated with an additional offset value, if needed. The bqSTUDIO 'Calibration bq78350' tab can perform this calibration. Details of the procedure are in the *bq78350 Technical Reference Manual (SLUUAN7)*.

2.2.2 Current() and AverageCurrent() Data

The bq78350 device reads coulomb count data from the bq769x0 AFE every 250 ms. The *Current()* data updates with the average of the previous four 250-ms internal readings during normal operating mode using a 1-s interval. *AverageCurrent()* is an IIR filter of the *Current()* data with a maximum 14.5-s time period.

The update period is configurable in Sleep Mode. Extending this update period can help reduce overall power consumption in this mode. Care should be taken to understand that extending **Sleep: Current Time** means that decisions based on *Current()* data occur at the same rate, default rate is 20 s.

Current() uses coulomb count data and gas-gauging uses it for coulomb counting. Accuracy in *Current()* data is important for gas gauging accuracy. The sense resistor selection has a very strong influence over this accuracy. Take care to ensure the component selection and PCB layout allow for the accuracy required. See *Sense Resistor Selection* in [Section 2.3.1](#) for more details.

Each bq769x0 AFE comes factory calibrated. Additionally, the *Current()* data calibration can be for both Offset and Gain, if needed. Use the bqSTUDIO 'Calibration bq78350' tab to perform this calibration. See the *bq78350 Technical Reference Manual (SLUUAN7)* for calibration procedure details.

2.2.3 Temperature() Data

The bq78350 reads the temperature-sensor (TS) voltage data from the bq769x0 AFE at the same rate as the cell voltage data. The default configuration uses the external TS input(s) for the temperature data. This data is converted to a temperature reading with the default thermistor, which is currently the Semitec 103AT (10k@25°C).

Depending on the AFE in use, there are a number of different sensors available. For the bq76920, there is one; the bq76930, there are two; and the bq76940, there are three. However, it is not necessary to use all available sensors. For example: it is possible to use only one sensor with the bq76940, if desired.

Configuration for the source of the temperature data and the specific temperature sensors to use is set in **Settings: Configuration: Temperature Enable**. When selecting whether to use Internal or External temperature sensors, it is for all available sensors. A mix of internal and external sensors is not possible.

When more than one temperature sensor is available, there is an option of using the maximum or average value of the enabled sensors. This option is set in **DA Configuration [CTEMP]**.

When the sensor takes each new reading, it filters simply with respect to the previous reading. The filter algorithm is as follows:

$$\text{Temperature}() = \text{Old Value} \times (145 / 256) + \text{New Value} \times (256 - 145) / 256$$

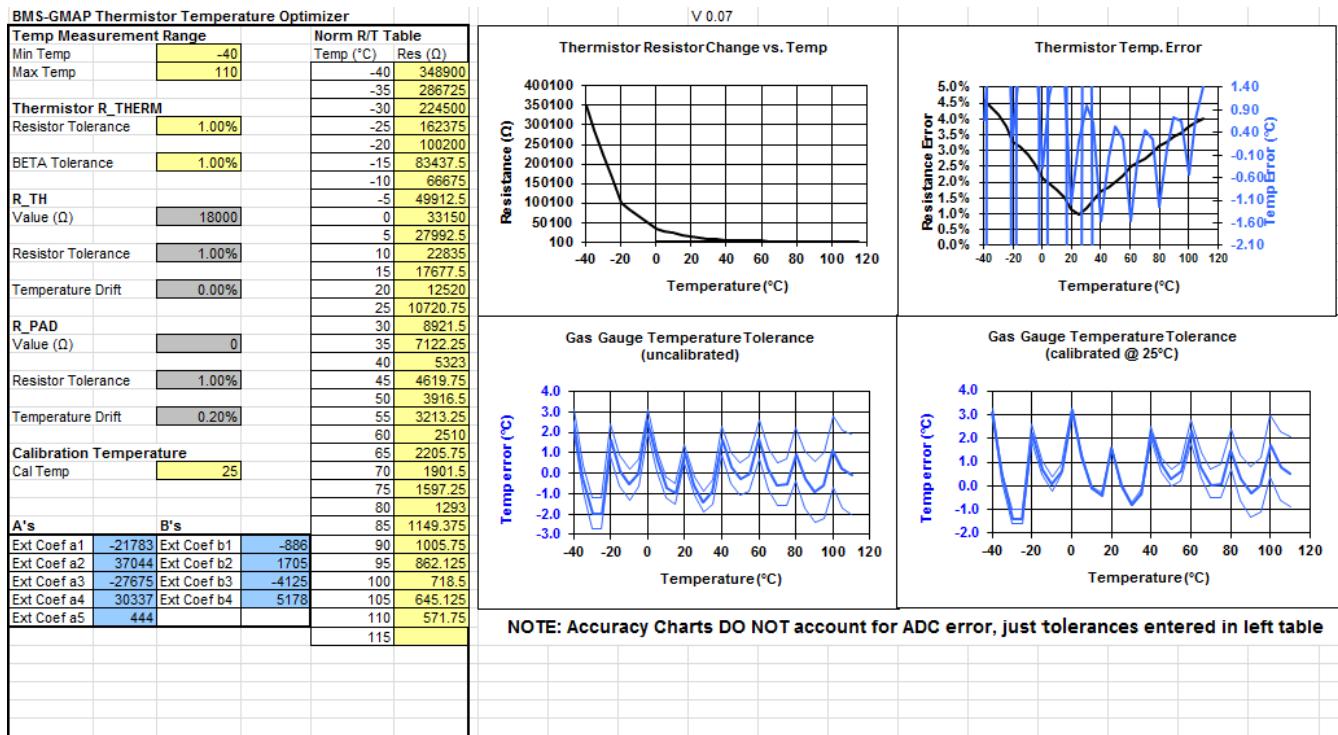
Each temperature sensor used in creating *Temperature()* can be calibrated with an additional offset value, if needed. Use the bqSTUDIO 'Calibration bq78350' tab to perform this calibration. The detailed procedure is in the *bq78350 Technical Reference Manual* ([SLUUAN7](#)).

If a different negative temperature coefficient (NTC) is used, then update the **Calibration: Cell Temperature Model**.

Cell Temperature Model	
Coeff a1	-11130
Coeff a2	19142
Coeff a3	-19262
Coeff a4	28203
Coeff a5	892
Coeff b1	328
Coeff b2	-605
Coeff b3	-2443
Coeff b4	4696
Rc0	11703
Adc0	11703

Figure 3. Cell Temperature Model

Use the 'bq78350 family Thermistor Coef Calculator.xlsx' ([SLUC568](#)) to determine the new correct coefficients. Do not change **Rc0** and **Adc0** from the default values.


Figure 4. bq78350 Family Thermistor Coefficient Calculator

2.2.4 Changing Data Format to Support Large Format Batteries

The normal range of *Voltage()* is 0 to 65535 mV, but for battery voltages greater than this value the *VSCALE* option in *SpecificationInfo()* needs to be set to 0x1. This essentially changes the units of the reported value to 10 mV. For example: for a battery voltage of 67500 mV (4500 mV x 15 series cells) and *VSCALE* = 0x1 then *Voltage()* data will be 6750 (decimal).

The normal range of *Current()* is -32767 to 32768 mA but for charge, or most likely, discharge currents greater than this value the *IPSCALE* option in *SpecificationInfo()* needs to be set to 0x1 or 0x2. This essentially changes the units of the reported value to 10 mA or 100 mA, respectively. For example: for a load current of 100 A (100000 mA) and *IPSCALE* = 0x01 then *Current()* and *AverageCurrent()* data will be 1000 (decimal).

Take care to ensure that power-related (*BatteryMode()* [*CapM*] = 1) data is scaled within bounds. Reported power values are a sum of *Voltage()* x *Current()*, so can extend beyond the reportable value easily.

Some examples, of the settings that affect the scaling in large format batteries, are in [Table 2](#).

Table 2. Scaling Example Values

IPSCALE	VSCALE	CAPM	DESIGNCAPACITY() UNITS (ENTER VALUE)	REMAININGCAPACITY() UNITS (SYSTEM PRESENTS)
0	0	0	mAh	mAh
0	0	1	10mWh	10mWh
0	1	0	mAh	mAh
0	1	1	100mWh	100mWh
1	0	0	10mAh	10mAh
1	0	1	100mWh	100mWh
1	1	0	10mAh	10mAh
1	1	1	1Wh	1Wh

2.3 Gas Gauging

The bq78350 default configuration supports a 4400-mAh LiCoO₂ battery with a chemical ID of 1210. This is a generic setting that allows for some evaluation. For accurate gas gauging, the Chemical ID needs to be updated. Other secondary lithium-Ion based Chem IDs can be obtained from [MathCAD Chemistry Selection Tool \(SLUC138\)](#).

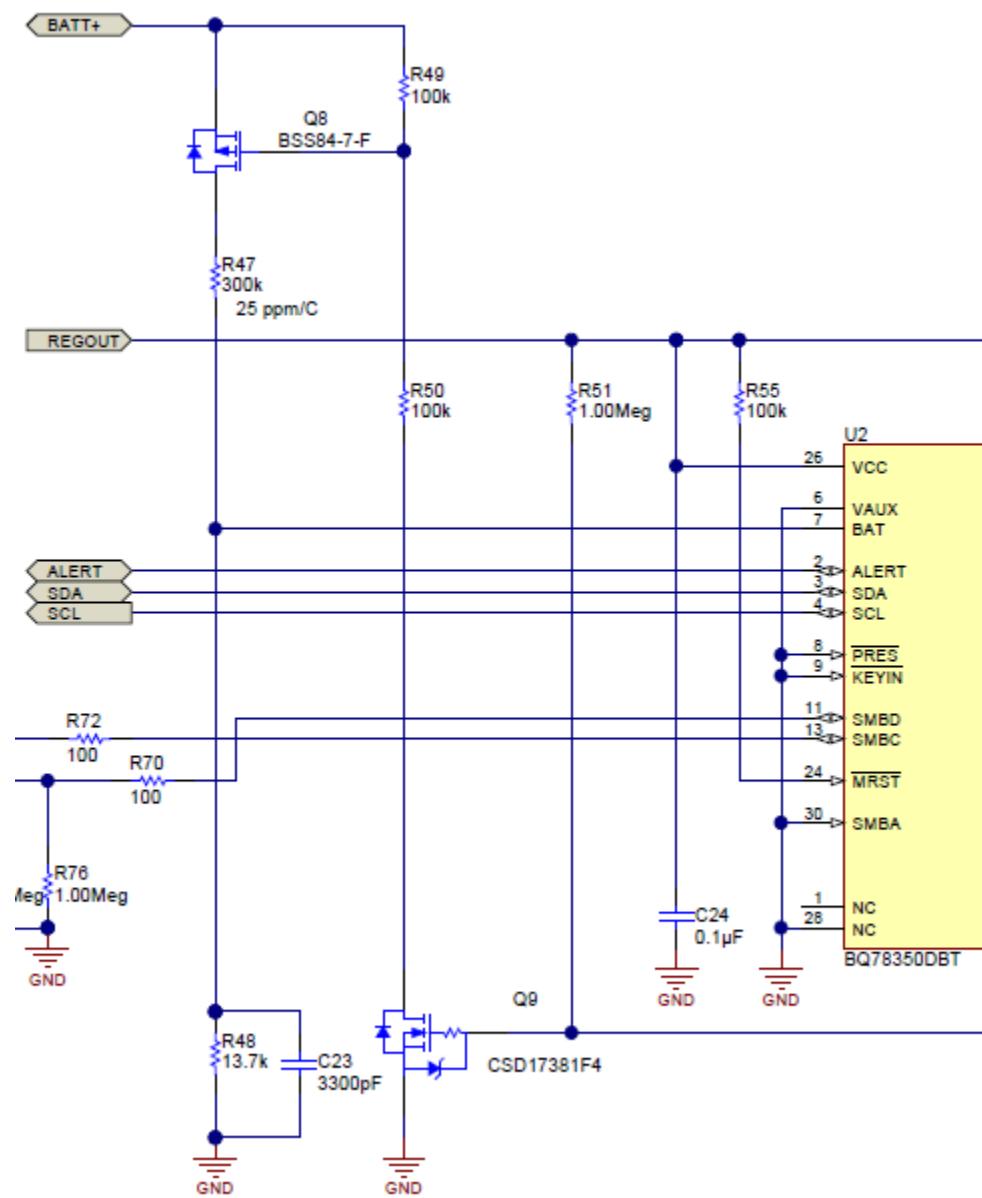
The default maximum chemical capacity (QMAX) of the battery is 4400mAh. Change QMAX based on the chosen cell and battery configuration.

QMAX = Design Capacity of the Cell × # of parallel cells

Where: Design Capacity of the Cell can be taken from the manufacturer data sheet

The Compensated End-of-Discharge Voltage (CEDV) gas-gauging algorithm requires seven coefficients to enable accurate gas gauging. The default values are generic for Li-CoO₂ chemistry, but for accurate gas gauging recalculate these coefficients can be updated. The procedure to gather the required data and generate the coefficients is in <http://www.ti.com/tool/GAUGEPCRAL>.

The voltage used for CEDV is a single-cell based reference, which can either use the *CellVoltage1()*...*CellVoltage15()* data or the *ExtAveCellVoltage()* data. To provide the best accuracy across a wide operating temperature range, use the default *ExtAveCellVoltage()*. Take care to reduce the errors in this external circuit by using low tolerance and low-temperature drift components. The key components in this circuit Q8, R47, and R48 are shown in [Figure 5](#).


Figure 5. Key Components

2.3.1 Sense Resistor Selection

The aim of the sense resistor selection is to use the widest input-voltage range for the analog-to-digital converter (ADC) as possible with the lowest error across the application operating temperature.

To maximize accuracy, calculate the sense resistor value using the following formula:

$$RSNS_{(min)} = V_{SRP} - V_{SRN} / I_{(max)}$$

Where: $|V_{SRP} - V_{SRN}| = 270$ mV

$I_{(max)}$ = Maximum magnitude of charge of discharge current (transient or DC)

NOTE: RSNS_(min) should include tolerance, temperature drift over the application temperature, and PCB layout tolerances when selecting the actual nominal resistor value. A temperature drift of 75 ppm, or greater, is recommended for applications that vary in operating temperature.

When selecting the RSNS value, be aware that when selecting a small value, such as 1 mΩ, the resolution of the current measurement will be > 1mA. In the example of RSNS = 1 mΩ, the current LSB will be 8.44 mA.

3 Basic Features

This section describes the key settings that should be considered when changing the basic features default data flash configurations.

3.1 Configuring the Protection

Configure the various protection features using the bqSTUDIO tool 'Protections' and 'Permanent Fail' section of the 'Data Memory' tab. Enable or disable each feature using the 'Settings' section of the 'Data Memory' tab, as needed.

To enable features, take care to ensure that the correct values are programmed based on the cell maximum ratings, system design parameters, and any applicable industry standards.

3.1.1 Using VAUX for Discharge Current Fault Recovery

If the battery circuit uses high-side protection FETs (requires external-circuitry support for the bq769x0 AFE), then enable the VAUXVoltage() for use as part of the protection recovery for selected current faults. The default setup of the bq78350 and bq769x0 AFE EVM is for low-side FETs so the default for VAUXVoltage() is disabled.

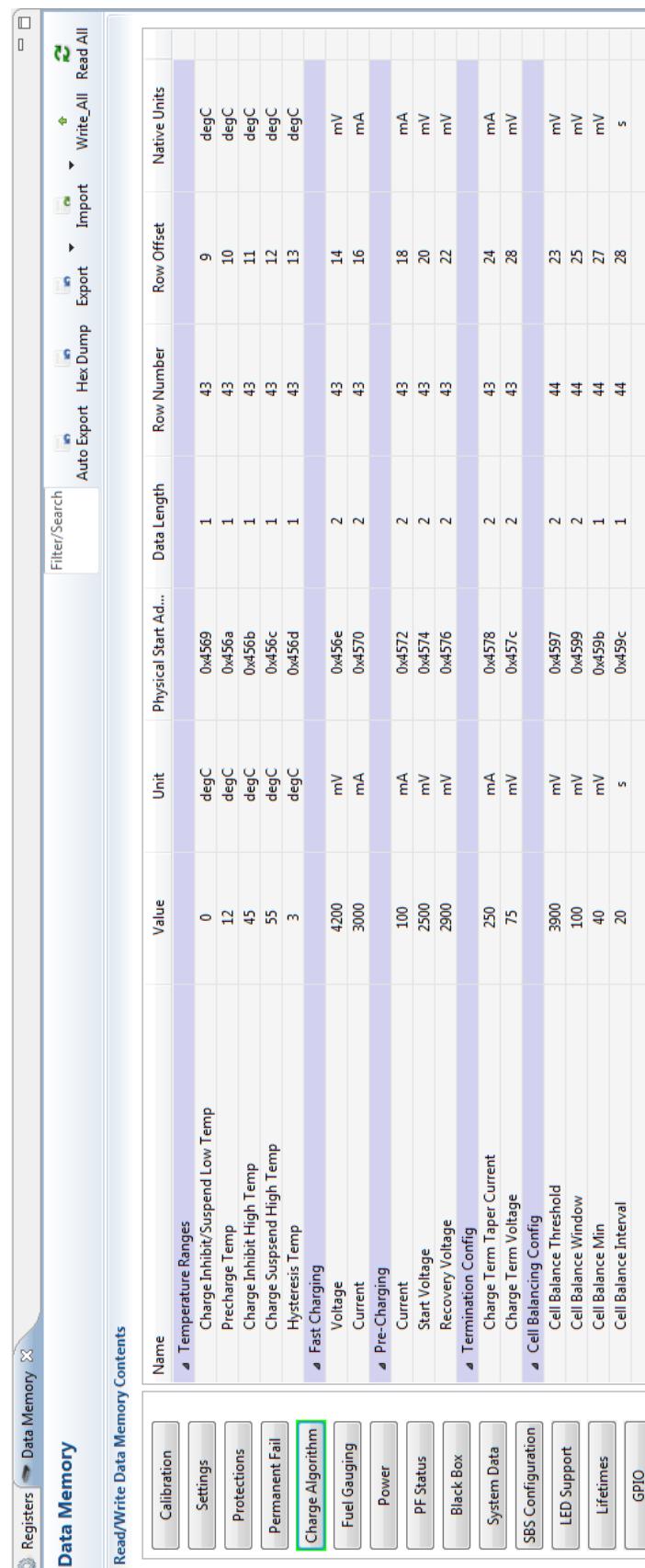
When enabled, the intent is for the VAUX input to be a scaled-voltage measurement of the battery PACK node using a copy of the circuit used for the BAT input, except the top of the divider is connected to PACK (opposite side of the FETs from the BAT divider). If this voltage is higher than the battery voltage, then this voltage indicates a charger is present and is used for recovery.

3.2 Configuring the Charge Algorithm

The bq78350 can be used in conjunction with smart or dumb chargers, which means chargers that read or receive charge control data from the bq78350, or not.

3.2.1 Basic Configuration

The charge algorithm configuration (Figure 6) changes ChargingVoltage() and ChargingCurrent() based on voltage, current, and temperature data and can halt charging, if faults are detected. The charge algorithm can also trigger the LED display (see **LED Configuration [LEDCHG]**) to be enabled during charging and FET actions (see **FET Options [CHGFET]**) upon termination detection, if these features are enabled.

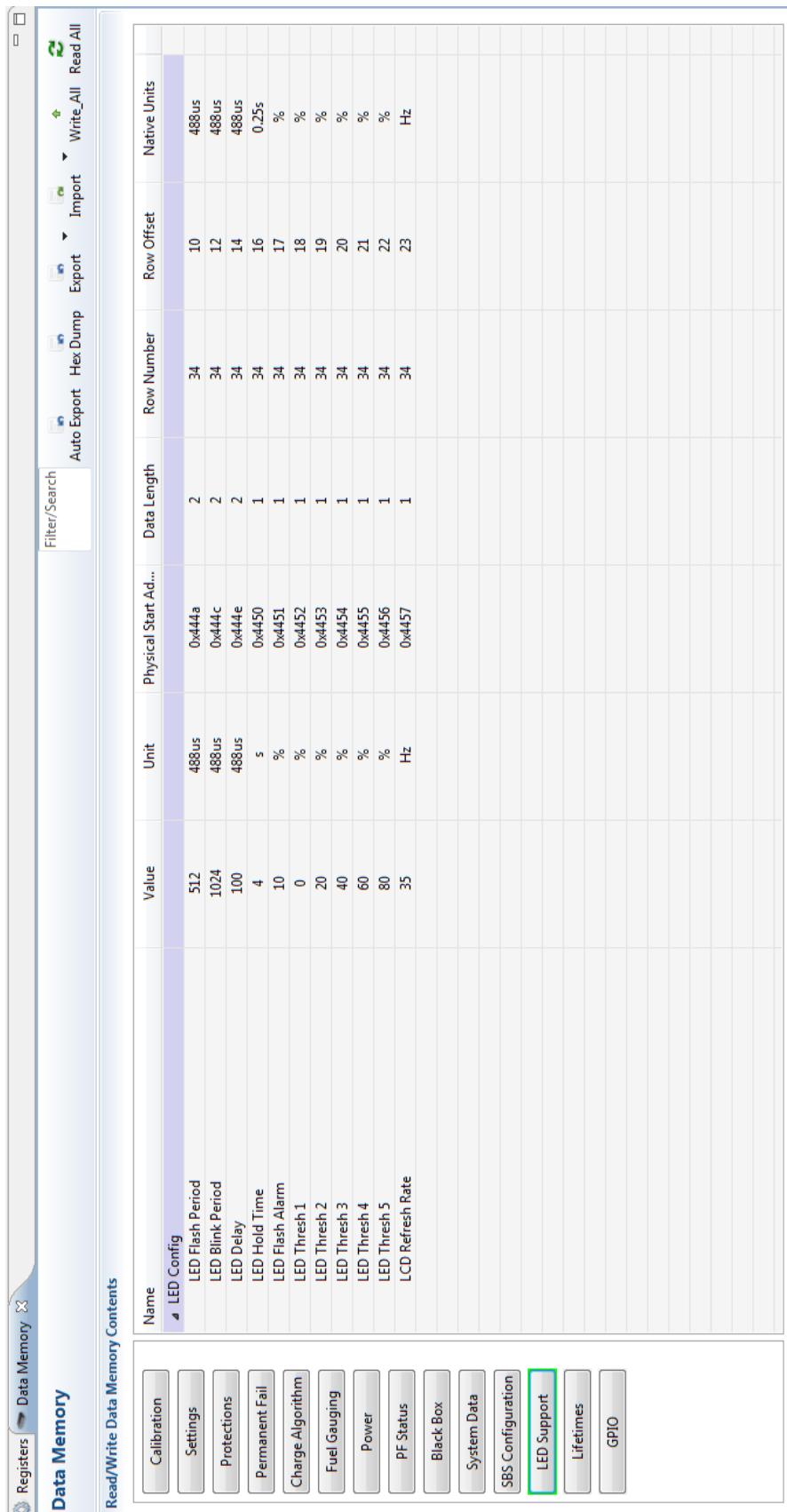

Figure 6. Charge Algorithm Configuration

3.3 Configuring Display

The bq78350 is configured with a 5-Bar LED display by default with a variety of configurable options in 'LED Support' and 'Settings' in the 'Data Memory' tab ([Figure 7](#)).

The main settings to consider are the **LED Thresh 1..5 %** values, which determine at what value of *RemainingStateofCharge()* (RSOC) the specific LED illuminates. When wanting to use less than five LEDs and where the extra LED pins are not used as configurable I/O (GPIO), program the **LED Thresh** value to 100% and tie the pin to VSS. When configuring less than five LEDs, the LEDs used MUST go from LED 1 up to the number required. For example: when a 3-LED display is needed, use LED1, LED2, and LED3. The display function will not operate correctly if LED1, LED2, and LED4 are used for a 3-LED display.

The **LED Delay Time** is the time between when the LEDs will turn ON, providing the effect of the 'ramp up' of the bar-graph. Once all the appropriate LEDs are ON, they will turn OFF all at once after the **LED Hold Time** completes.



Name	Value	Unit	Physical Start Adr...	Data Length	Row Number	Row Offset	Native Units
LED Config	512	488us	0x444a	2	34	10	488us
LED Flash Period	1024	488us	0x444c	2	34	12	488us
LED Blink Period	100	488us	0x444e	2	34	14	488us
LED Delay			0x4450	1	34	16	0.25s
LED Hold Time	4	5					
LED Flash Alarm	10	%	0x4451	1	34	17	%
LED Thresh 1	0	%	0x4452	1	34	18	%
LED Thresh 2	20	%	0x4453	1	34	19	%
LED Thresh 3	40	%	0x4454	1	34	20	%
LED Thresh 4	60	%	0x4455	1	34	21	%
LED Thresh 5	80	%	0x4456	1	34	22	%
LCD Refresh Rate	35	Hz	0x4457	1	34	23	Hz
Black Box							
System Data							
SBS Configuration							
LED Support							
Lifetimes							
GPIO							

Figure 7. Display Configuration

The setting of **LED Flash Alarm** causes the display to flash when RSOC < than the programmed % and **DISP** activates the display. This is very similar to the **[LEDRCA]** feature, which causes the display to flash when **BatteryStatus()** **[RCA]** is set and the **DISP** activates the display (Figure 8).

LED Configuration									
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
MSB	RSVD	RSVD	RSVD	LCDEN	LEDMODE	LEDCHG	LEDRCA	LEDR	

Figure 8. LED Configuration

Setting **[LEDR]** simulates the **DISP** pin function as soon as the device exits power-on-reset (POR). This is not commonly used, but can be useful for diagnostic purposes.

3.3.1 Configuring LCD Display

The same **LED Threshold** configuration information is used for the LCD display (**LED Configuration** **[LCDEN]** = 1), but all the other LED configuration settings are not used as the LCD is on permanently in Normal mode.

There is one extra configuration necessary for the LCD, the **LCD Refresh** rate. This data is something the LCD manufacturer can provide. This value has no affect if **[LCDEN]** = 0.

The electrical connections for the LCD are shown in the following schematic (Figure 9). Pay particular attention to LED1...LED5 and COM.

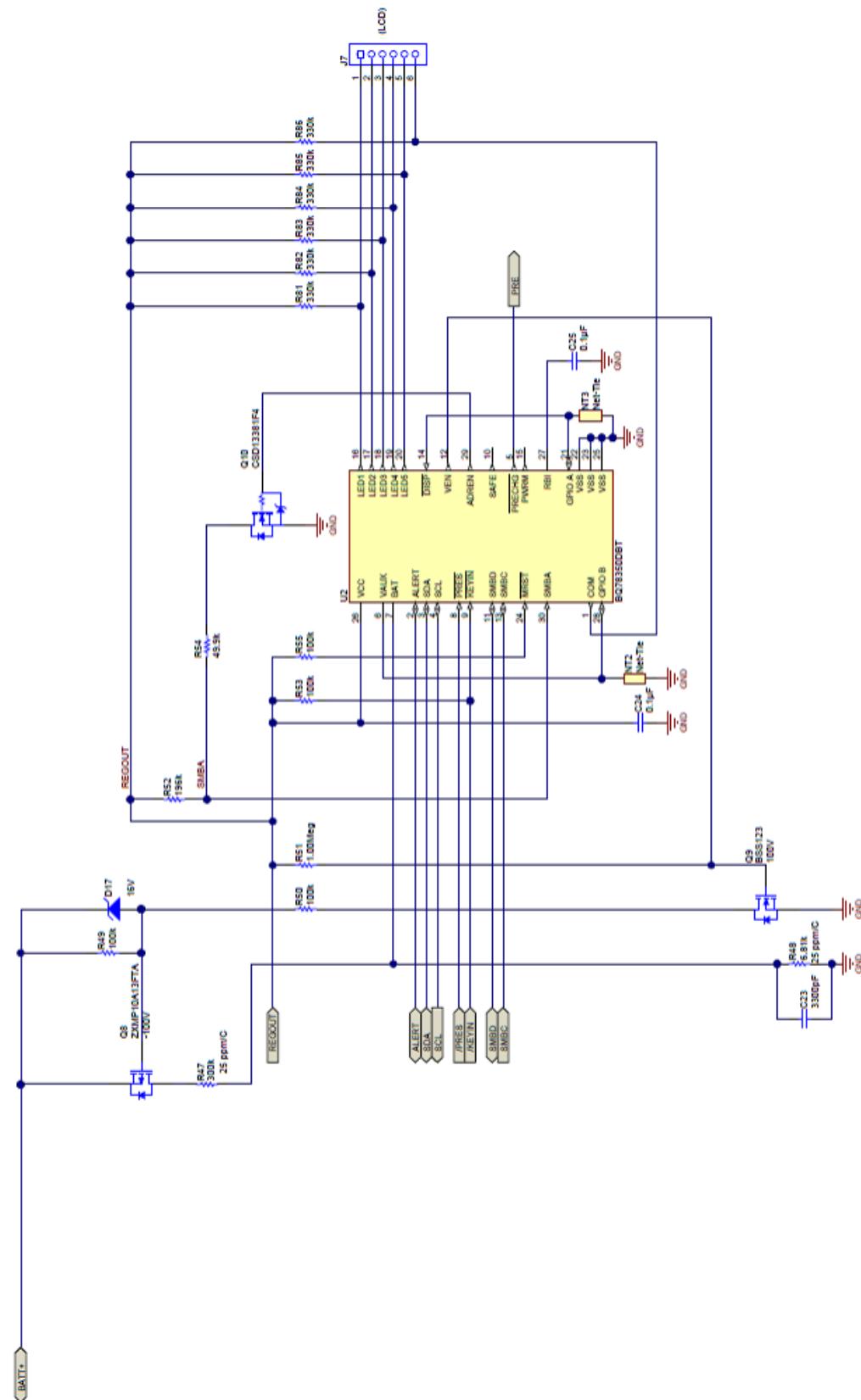


Figure 9. LCD Display Support

4 Advanced Features

The bq78350 offers a variety of advanced features not required for basic operation, but which can enhance overall system capabilities.

4.1 How to Use Host GPIO Functions

There are seven pins that GPIO can use that can be controlled through the SMBus interface. Two of these pins are available always as GPIO and the LED Display feature shares five.

The configuration settings in data flash and the SMBus commands have each bit corresponding to a physical pin.

BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0
GPIO B	GPIO A	LED5	LED4	LED3	LED2	LED1	RSVD

Set **GPIO Config** for the pins intended for use as GPIO. Remember, that pins used as LEDs must be continuous from LED1, LED2, LED3... and so forth, and cannot be LED1, LED3, LED4 while using LED2 as GPIO.

Set **GPIO Output Enable** for those pins declared as GPIO in **GPIO Config** as Inputs (0) or Outputs (1). Settings for pins not set in **GPIO Config** are ignored.

Set **GPIO Output Default** for those pins declared as outputs in **GPIO Output Enable**, which need to be set high upon a reset of the device. Settings for pins not set in **GPIO Config** are ignored.

Set **GPIO Type** to enable either a 3 mA current sink (0) or open drain (1) configuration for the pins enabled as outputs in **GPIO Output Enable**. Settings for pins not set in **GPIO Config** are ignored.

Once these configurations are set, then all pins declared as GPIO in **GPIO Config** can be read via **GPIOStatus()** [0x2c] and all pins enabled as outputs in **GPIO Output Enable** can be controlled via **GPIOControl()** [0x2d].

5 Preparing for Production

The bq78350 defaults have many features turned OFF to allow for a controlled evaluation and a controlled battery assembly process. However, many of these features can be set prior 'Golden File' creation.

The key items to ensure are correctly configured are:

- Chemical ID
- CEDV Coefficients
- QMAX Pack
- Temperature Model Coefficients
- Protection settings
- Charge algorithm settings
- Enable/disable advanced features

During battery production, several features may accumulate data that should be cleared so that the data that the device gathers is from the battery being in service and not influenced by the battery assembly and test process. These include:

- Cycle Count
- Lifetime data Reset
- Black Box Recorder Reset
- Permanent Fail Data Reset
- Mfg Status Init

During production the **FullChargeCapacity()** value will be established based on the Chemical ID.

6 Troubleshooting Tips

6.1 Minimizing Leakage Current When Protection FETs are Off

During normal operation, the protection FETs are ON and the host system is powered by the battery. In this configuration, when the protection FETs turn OFF then the host system powers down. However, in systems where there is an alternative power supply for the host, when the battery protection FETs are turned OFF there is a leakage path between PACK+ (TBD) and BAT- through the I/O connection between the pack and the system. This is commonly seen when the battery electronics are in development.

If this current is of concern, the following changes (Figure 10) can be made to the circuit so each I/O is floated when the FETs are OFF, regardless of the pull up state on the host-system side of the I/O.

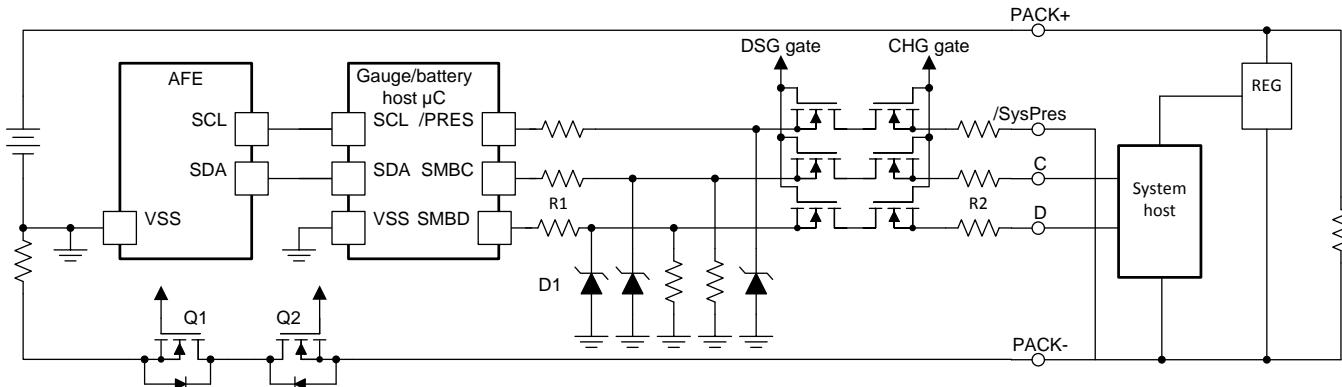


Figure 10. Circuit Changes

6.2 Gauging Error Tips

The gas gauging Compensated End of Discharge Voltage (CEDV) algorithm has many different sources of error, some are obvious and some are not. Listed are some of those sources and details on how to improve the performance.

6.2.1 Gauging Error at Extreme Temperatures

This could be related to several factors:

1. CEDV Coefficients are temperature related. If the normal operating temperature is low or high, it is best to calculate the CEDV coefficients with data in the expected use range. If the expected use range of temperature is wide, then there will be variation in gas gauging accuracy.
2. Sense resistor choice can affect coulomb counting at extreme temperatures. The parts per million (ppm) / °C rating of the sense resistor should be accounted for in the gas gauging error budget, a 75 ppm or better sense resistor is recommended for optimal accuracy.

6.2.2 Accuracy After Reset is Poor Until a Learn Cycle

This source of error can be corrected easily by setting the **QMAX Pack** value to one close to the real QMAX of the battery pack. If this value is over or under estimated, it can cause the initial values loaded into *RemainingCapacity()* to be inaccurate.

6.2.3 Avoiding System Shutdown When Gauging Error is Unavoidable

The reserve capacity feature is intended to allow for some capacity to remain in the battery, even after *RemainingStateOfCharge() = 0%*. This capacity can be used for a controlled shutdown after 0% has been reached or to offset any expected error in the RSOC() value.

6.3 Data Flash Changes are not Affecting Device Operation

After a data flash update has occurred, there are many settings that require the device to be reset (*ManufacturerAccess()* [0x0041]) before the device will use the new setting.

Revision History

DATE	REVISION	NOTES
July 2014	*	Initial Release

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