Quickstart Guide for bq27421-G1

The bq27421-G1 is the easiest-to-use lithium battery gauge in the industry. For fast time-to-market and virtually no development effort, battery characterization, nor learning cycle is required. Once assembled into the end-system, only a few simple registers need to be configured before accurate gauging results can be read from the IC. This document outlines the minimum procedure required.

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1 Overview

The bq27421-G1 fuel gauge utilizes a standard lithium battery profile that matches typical batteries available in the market. On IC power-up, default settings are loaded into the gauge RAM. These should be over-written by the system to match the actual battery capacity. Additionally, the full and empty battery conditions should be updated to match the system requirements. By configuring only these four parameters, the battery capacity predictions by the gauge can be utilized with confidence. During field operation in the end-equipment, the Impedance Track™ algorithm continually optimizes accuracy by learning the battery capacity and resistance profile to account for cell-to-cell variations and battery aging.

2 Choose Between bq27421-G1A, bq27421-G1B, and bq27421-G1D

Because the bq27421-G1 utilizes standard battery profiles, the system designer can select between three different flavors of the fuel gauge:

- The bq27421-G1A fuel gauge should be used for $LiCoO_2$-based batteries for 4.2-V maximum charge voltage.
- The bq27421-G1B fuel gauge should be used for $LiCoO_2$-based batteries for 4.3-V or 4.35-V maximum charge voltage.
- The bq27421-G1D fuel gauge should be used for $LiCoO_2$-based batteries for 4.35-V or 4.4-V maximum charge voltage.

The other types of rechargeable lithium chemistries are not currently supported by the bq27421.

To give further confidence in the suitability of bq27421-G1A, bq27421-G1B, or bq27421-G1D for a particular battery application, the corresponding EVM can be ordered and tested with the target battery. The results of a battery cycle can be logged with the GaugeStudio companion software and reviewed for accuracy.

The log of a battery cycle can also be analyzed using the *Mathcad™ Chemistry Selection Tool* (SLUC138) to assist in the choice.

3 Hardware

The bq27421-G1 fuel gauge comes in a tiny 9-pin, 1.62 mm × 1.58 mm, CSP package and only requires a single 0.47-µF capacitor to be connected between the V_{DD} and V_{SS} pins. It is also recommended to have a 1.0 uF capacitor connected between the BAT and V_{SS} pins, but this capacitor is optional if the connection between the gauge and the battery is stable.

The fuel gauge has the ability to provide interrupts to the system when state-of-charge (SOC) changes through the GPOUT pin. The GPOUT pin is an open-drain output and should be pulled up, typically with a 4.7-kΩ or 10-kΩ resistor. It should not be left floating, even if unused. The GPOUT pin can also be configured to simply change polarity when SOC drops below a specific threshold. The polarity of the GPOUT pin can also be configured. For more details on configuration options, see SLUUAC5, *bq27421-G1 Technical Reference Manual*.

For accurate gauging the fuel gauge needs to be able to detect that the battery has been inserted into the system. The fuel gauge will not be actively gauging unless the *[BAT_DET]* bit in the *Flags( )* register is set. By default, *[BAT_DET]* is set if the BIN pin is low. Alternatively, the gauge can be configured to rely on the host to inform it when the battery is inserted and removed, thereby setting and clearing the *[BAT_DET]* bit.

If ***Operation Configuration*** bit ***[BIE]*** = 1 (default), a logic low on the pin is detected as battery insertion. For a removable pack, the BIN pin can be connected to V_{SS} through a pulldown resistor on the pack, typically the 10-kΩ thermistor in the battery pack; the system board should use a 1.8-MΩ pullup resistor to V_{DD} to ensure the BIN pin is high when a battery is removed. If the battery is embedded in the system, it is recommended to leave ***[BIE]*** = 1 and use a 10-kΩ (or the battery thermistor) pulldown resistor from BIN to V_{SS}.

If ***[BIE]*** = 0, then the host must inform the gauge of battery insertion and removal with the *BAT_INSERT* and *BAT_REMOVE* subcommands. A 10-kΩ pulldown resistor should be connected to the BIN pin, even if the pin is not used.

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NOTE: The BIN pin should not be shorted directly to V_{CC} or V_{SS}, and any pullup resistor on the BIN pin should only be connected to the bq27421 V_{DD} and not an external voltage rail.

NOTE: The fuel gauge needs accurate measurements of the battery pack voltage. The BAT and V_{SS} pins should be Kelvin-connected directly to the battery terminals for maximum gauging accuracy, with system current flowing through separate traces. Any I×R drop caused by current flowing through voltage measurement traces between the fuel gauge and the battery will reduce accuracy. Typically, the fuel gauge should be placed as close to the battery as possible to ensure its on-board temperature sensor is reflecting the battery temperature. However, since no sense resistor is required, more flexibility in layout is allowed as long as a Kelvin connection is ensured.

4 Programming the Configuration

A number of configuration parameters are available in the bq27421-G1 so that it can be tuned to match the target battery as well as the system requirements. Most of the defaults can be left alone if desired, but there are four important parameters that should be configured in order to achieve accurate gauging of the target battery. These parameters are ***Design Capacity***, ***Design Energy***, ***Terminate Voltage***, and ***Taper Rate***. If you are using the bq27421-G1 EVM, then GaugeStudio can be used to configure the gauge to fit the target battery. You can download GaugeStudio at www.ti.com/product/bq27421-g1.

Design Capacity should be set to the nominal battery capacity printed on the battery label or found in the battery datasheet. It gives a starting point for the gauge predictions, and actual battery capacity (which varies from battery to battery and changes over time) is learned during operation.

Design Energy should be set to be ***Design Capacity*** × 3.7 if using the bq27421-G1A or ***Design Capacity*** × 3.8 if using the bq27421-G1B or bq27421-G1D. ***Design Energy*** is used when the gauge is operating in constant-power model. The bq27421-G1 defaults to constant-power model and this is reflected by the *[LDMD]* bit in the *Control()* register being set.

NOTE: When updating the fuel gauge with an EVM using GaugeStudio, ***Design Energy*** is automatically calculated based on the type of gauge connected and the ***Design Capacity***.

Terminate Voltage should be set to the minimum operating voltage of your system. This is the target where the gauge typically reports 0% capacity. It is not usually necessary to include a guard band when selecting this value, because the gauge also learns the level of load spikes in the system and automatically uses a higher voltage when necessary to ensure that load spikes, aging, and low temperatures do not allow sudden voltage drops below ***Terminate Voltage*** before 0% is reported. The actual point at which 0% is reported is therefore dynamic, so ***Terminate Voltage*** should be set to the minimum operating voltage supported by the system. If additional reserve capacity is desired between the 0% point and the actual ***Terminate Voltage***, then the optional ***Reserve Capacity*** memory parameter can also be configured. This ensures that a known amount of energy is available for shutdown activities once 0% SOC is reported, but before ***Terminate Voltage*** is actually reached.

Taper Rate should be set to the current threshold in mA below which your charger IC is set to stop charging once it considers the battery to be full. The ***Taper Rate*** is stored in units of 0.1-hr rate and can be derived from the taper current value in mA by the following equation:

Taper Rate = Design Capacity / (0.1 * ***Taper Current***)

This is simply a way to store the taper current value with respect to ***Design Capacity***. The ***Taper Rate*** value allows the gauge to synchronize its full charge detection point with that of the charger. The gauge ***Taper Rate*** should be set to a value slightly higher than the taper current detection threshold of the charger (including charger tolerances).

For example, if using a 1000-mA battery and the charger is set to stop charging when the voltage is 4.2 V and the current tapers to less than 100 mA (±15%), then the bq27421-G1 ***Taper Rate*** should be set to 87 (***Taper Rate*** = 1000 / (0.1 × 115 mA) where Taper Current = 115 mA) to give a slight guard band. It is important that the gauge detect full charge (*StateOfCharge()* = 100%) before the charger shuts off. An alternative system design to improve synchronization is to have the system read the *[FC]* (full charge) bit from the *Flags()* register and then disable the charger when it is set.

NOTE: When updating the fuel gauge with an EVM using GaugeStudio, ***Taper Rate*** is calculated automatically based on the Taper Current value.

The procedure and commands required to update the configuration parameters are shown in the flowchart of Figure 1.

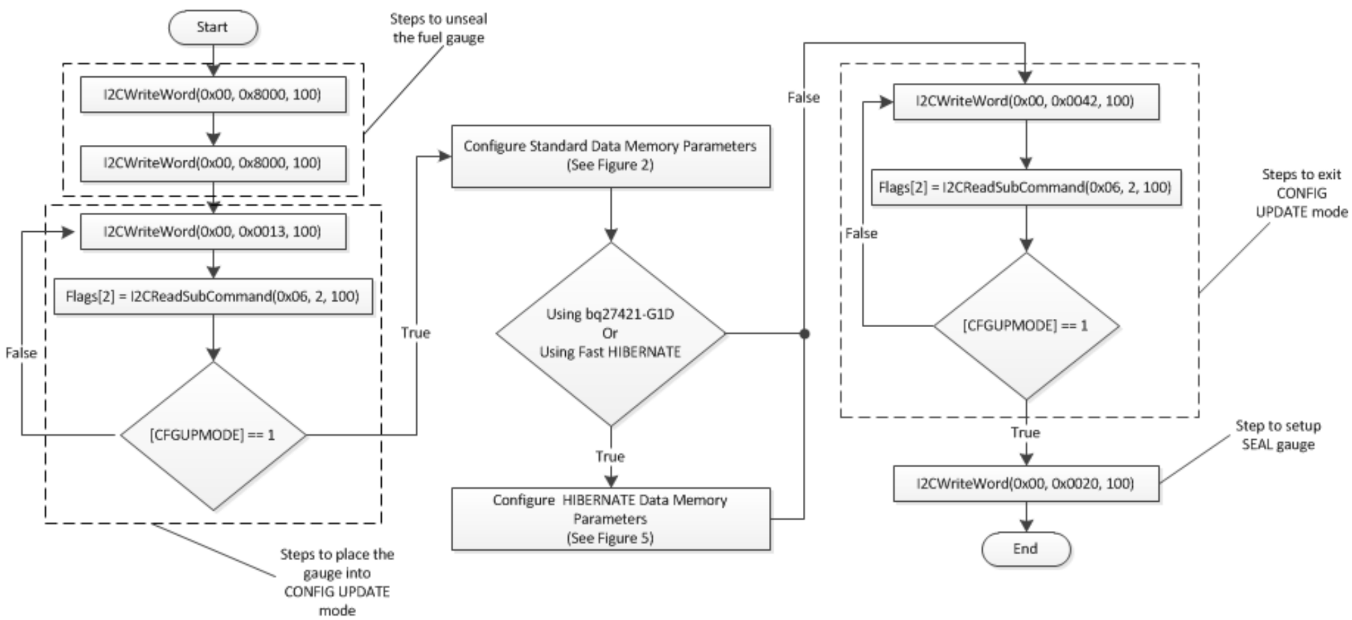

Figure 1. Flowchart for Updating the Gauge Configuration Parameters

NOTE: The process for updating the RAM can also be handled through parsing the data contents in a *.dffs file generated by GaugeStudio. A *.dffs is a series of I^2C commands that can be processed by the host. Using the *.dffs file will allow the host an alternative route to updating the RAM instead of following the flow outlined in Figure 1.

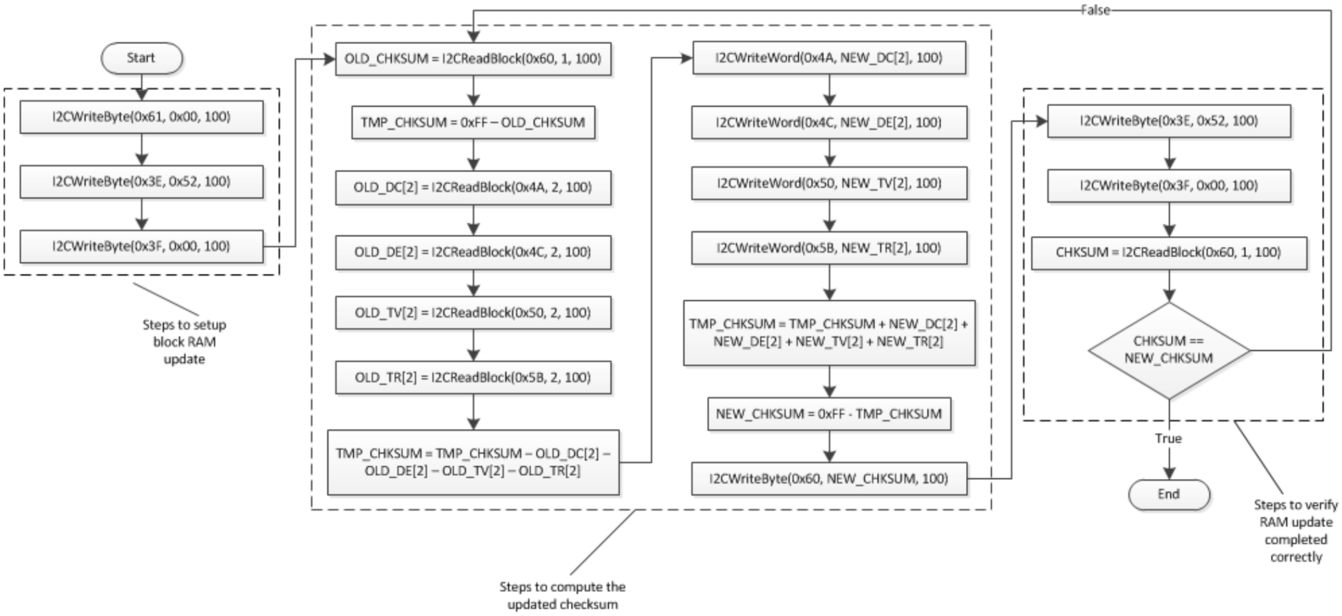

Figure 2. Configure Standard Data Memory Parameters

5 Reading the Gauge Registers

There are a total of 15 registers available for the system to read from the bq27421. The registers most commonly used are *Voltage( )*, *Temperature( )*, *AverageCurrent( )*, and *StateOfCharge( )*. The commands to read these registers are shown in Figure 3. Other useful registers include *Control()*, *Flags()*, *RemainingCapacity()*, *FullChargeCapacity()*, and *StateOfHealth()*.

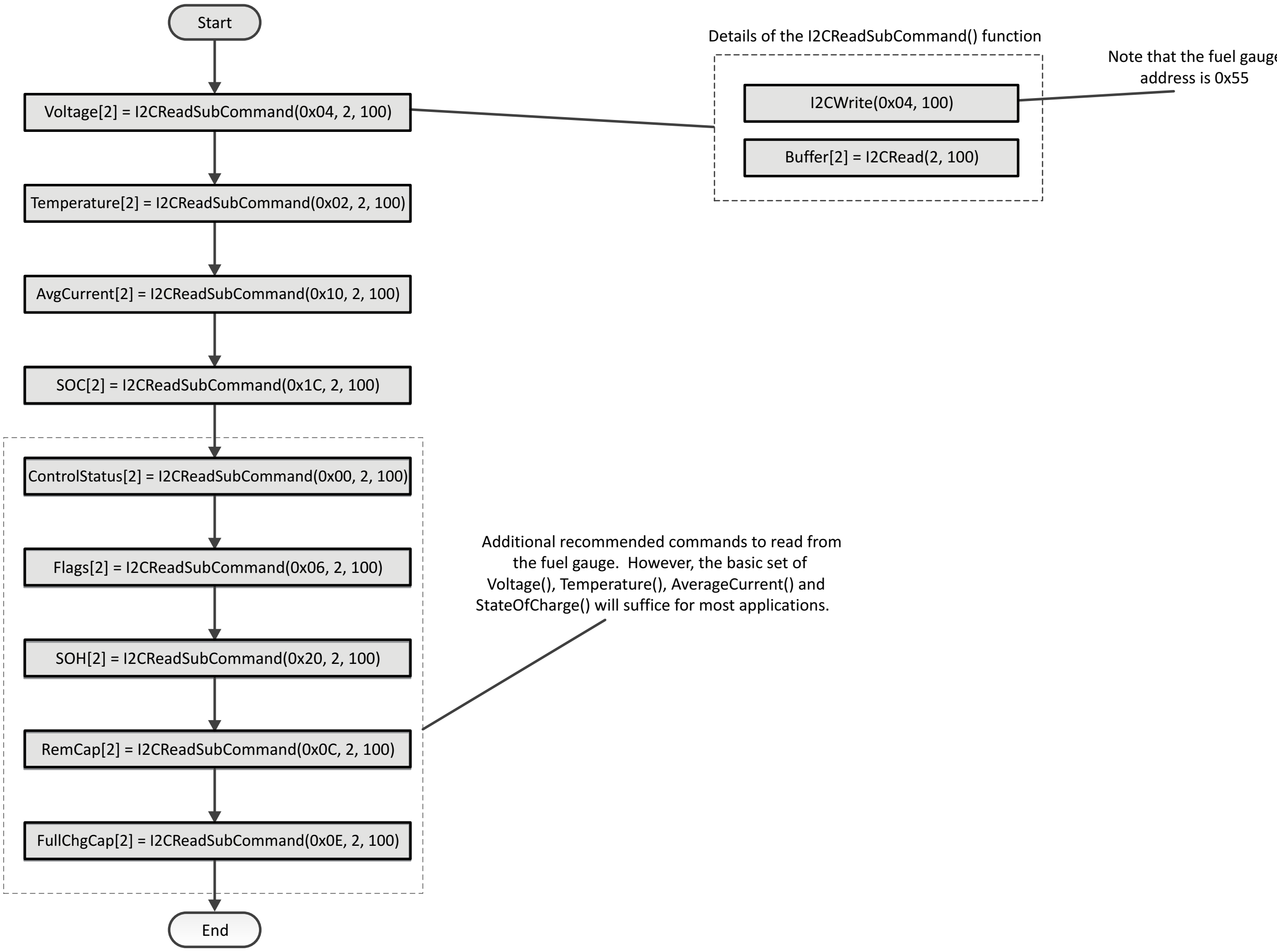

Figure 3. Gauge Register Commands

6 Gauge Learning

The gauge makes initial capacity predictions using the value entered in ***Design Capacity***. However, as the battery is charged and discharged, the gauge is learning the true battery capacity which is usually slightly different from the nominal capacity. It stores the learned maximum battery chemical capacity in Qmax, as well as the learned resistance profile in the Ra table. As long as the gauge has power, Qmax and the Ra profile will update once the proper conditions for an update have been met.

The *[QMAX_UP]* bit in the *Control()* register can be checked by the host to see if there has been a Qmax update. The *[QMAX_UP]* bit is set on the first Qmax update after a reset or battery insertion event. Once the *[QMAX_UP]* bit has set, resistance updates are allowed. The *[RES_UP]* bit in the *Control()* register is set once there has been an update to the Ra profile during discharge. Both the *[QMAX_UP]* and *[RES_UP]* bits remain set until the gauge is reset or a battery insertion event occurs.

It is recommended that the host save the Qmax and Ra profile in the system NVM once the *[QMAX_UP]* and *[RES_UP]* bits have set. After the initial Qmax update, updates to Qmax most likely occur upon:

- Entering discharge mode
- Exiting discharge mode
- Being in relaxation mode for a while after a certain amount of charge has been removed or added to the battery.

Subsequent resistance profile updates occur only during discharge as long as a Qmax update has previously occurred which can be verified by the *[QMAX_UP]* bit in the *Control()* register being set.

Ideally, the system should be designed so that the bq27421-G1 is always powered by the battery, even during system shutdown. The gauge maintains the learned values in RAM as long as it is powered and operates in NORMAL, SLEEP, or HIBERNATE mode. The gauge automatically transitions to SLEEP mode when the system current is low to minimize power consumption.

If the battery is removed or the gauge is put into SHUTDOWN mode, the learned values stored in RAM are lost. Once powered up again, the *[ITPOR]* bit in the *Flags()* register is set indicating that all values are initialized to the defaults, including ***Design Capacity***, ***Design Energy***, ***Terminate Voltage***, and ***Taper Current***. The *[ITPOR]* bit indicates one of the following:

- The fuel gauge has been reset due to loss in power.
- A full *RESET* (0x0041) *Control()* subcommand has been sent to the gauge.
- The gauge has exited the SHUTDOWN mode.

Sending a *SOFT_RESET* (0x0042) *Control()* subcommand to the gauge clears the *[ITPOR]* bit. The host can use the *[ITPOR]* bit to determine if the gauge memory parameters need to be reloaded. If the *[ITPOR]* bit is set, at a minimum the ***Design Capacity***, ***Design Energy***, ***Terminate Voltage***, and ***Taper Current*** values should be reloaded to the gauge. Additionally, the host has the option of saving the learned Qmax and Ra values into the system NVM periodically.

NOTE: The *SOFT_RESET* subcommand is used to exit the RAM update process. Therefore, the *[ITPOR]* bit clears after the RAM has been updated.

See Figure 1 for more details on the RAM update process.

7 Recommended Flowchart

Figure 4 incorporates all of the best practices described above and describes the recommendation for system software implementation in programming and interacting with the bq27421-G1 fuel gauge. As seen in Figure 4, the host system can decide to check the bq27421-G1 for updating the RAM or storing some of the memory parameters into system NVM based on when the gauge has entered or exited discharge mode. By default, the bq27421-G1 issues an interrupt on the GPOUT pin when the device enters into discharge mode, the host can then check to see if the *[DSG]* bit in the *Flags()* register is set to verify that the gauge is in discharge mode. Using interrupts from the gauge allow the system to reduce power. The alternative approach to when the host system can decide to check the bq27421-G1 is after a certain amount of time between checks has passed. The time limit of 12 hours is only a suggested amount of time between checks and this value can be reduced or increase based upon the needs of the system.

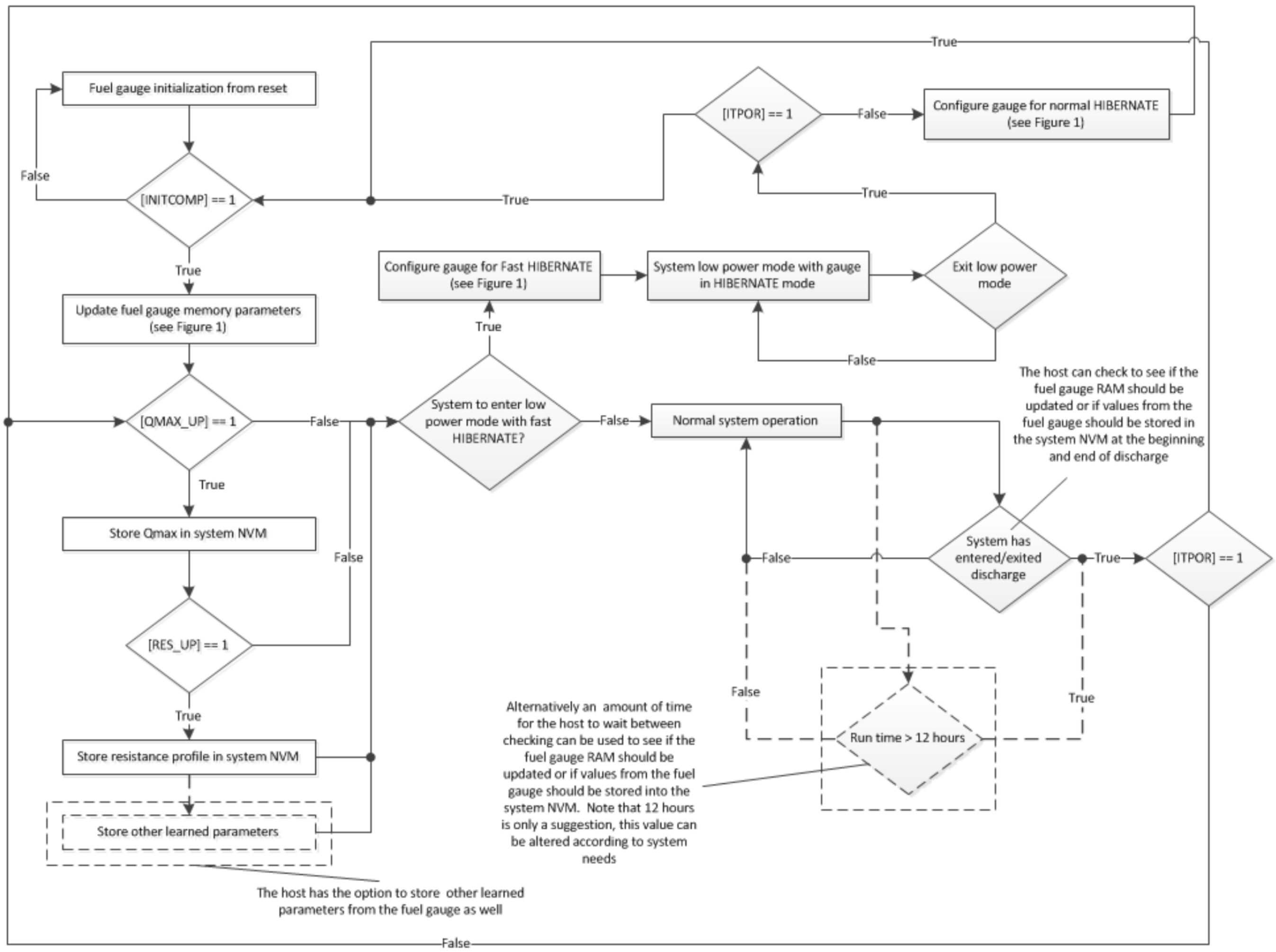

Figure 4. Recommended System Operation Flowchart

8 Other Configuration Options

The previous instructions outlined the minimum registers to update for accurate fuel gauging. Other registers are available for configuration to enable different options (such as interrupt conditions) as well as to pre-optimize the battery profile.

When configured with the nominal battery capacity, the fuel gauge automatically begins learning the true battery capacity and resistance profile during operation in the end-equipment. This means accuracy automatically optimizes itself as the user charges and discharges the battery. If desired, the system designer can perform a simple one-day optimization cycle before production to determine the best settings for the fuel gauge. This refinement is easiest to perform using the bq27421EVM, but the actual system can also be used. Once determined, these optimized parameters can be included in the configuration update outlined above and require no additional overhead. This pre-optimized golden file allows the end user to experience higher initial accuracy out of the box without having to wait for the gauge to learn during operation.

Whether the optimization is performed during R&D or in the field operation of the end-equipment, the patented Impedance Track™ algorithm continually learns and updates the battery capacity and resistance profile as the battery ages. This enables it to be the only gauging algorithm available in the market that can maintain the same accuracy for aged batteries as for new ones. Even if the user swaps between batteries of different ages, the fuel gauge quickly learns and regains optimum accuracy.

9 Fast HIBERNATE

The bq27421-G1D by default is configured to enter HIBERNATE mode in approximately 3 seconds. Other devices in the bq27421-G1 family are configured by default to enter HIBERNATE mode on the order of minutes.

The fast HIBERNATE configuration, though only the default configuration for the bq27421-G1D, can be used in all devices in the bq27421-G1 family. However, for all devices, when in normal operation the gauge configuration should be set to normal HIBERNATE mode settings. See Figure 4 for a general system flow and Figure 5 for a detailed flow on updating HIBERNATE mode settings.

See SLUUAC5, *bq27421-G1 Technical Reference Manual*, for more details on Fast HIBERNATE mode configuration.

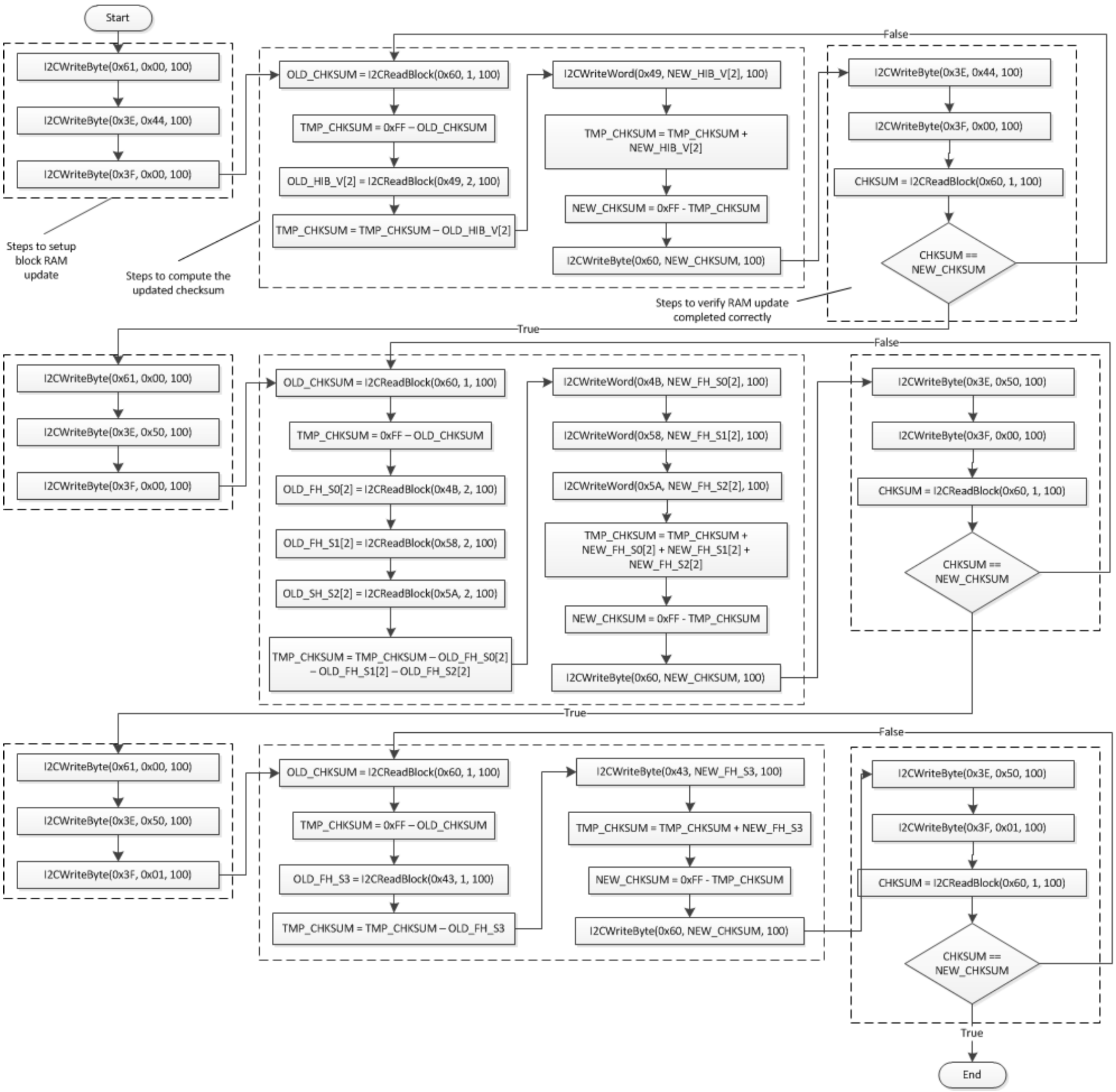

Figure 5. Configure HIBERNATE Mode Data Memory Parameters

10 Summary

By requiring no battery characterization and only needing a minimum of four registers to be updated on power-on reset (POR), the bq27421-G1 fuel gauge allows system designers to quickly incorporate fuel gauging functionality into their design with minimal effort. Using the patented features of the Impedance Track™ algorithm allows the gauge to continually optimize its predictions during end-equipment operation to account for battery variations and aging.

11 Related Documentation from Texas Instruments

To obtain a copy of any of the following TI documents, call the Texas Instruments Literature Response Center at (800) 477-8924 or the Product Information Center (PIC) at (972) 644-5580. When ordering, identify this document by its title and literature number. Updated documents also can be obtained through the TI Web site at www.ti.com.

1. *bq27421-G1, System-Side Impedance Track™ Fuel Gauge with Integrated Sense Resistor* Data Sheet (SLUSB85)
2. *bq27421-G1, Technical Reference Manual* (SLUUAC5)
3. *bq27421-G1, EVM: Single-Cell Impedance Track Technology* User's Guide (SLUUA63)

Revision History

Changes from A Revision (September 2013) to B Revision **Page**

- Added bq27421-G1D and Fast HIBERNATE to the Quickstart Guide 2
- Updated Section 2, *Choose Between bq27421-G1A, bq27421-G1B, and bq27421-G1D* 2
- Updated Section 3, *Hardware* 2
- Added Section 9, *Fast HIBERNATE* 9

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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.

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EVMs entering Japan are NOT certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If user uses EVMs in Japan, user is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

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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1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
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なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします

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日本テキサス・ インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

http://www.tij.co.jp

Texas Instruments Japan Limited

(address) 24-1, Nishi-Shinjuku 6 chome, Shinjuku-ku, Tokyo, Japan

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