

# Quickstart Guide for bq27441-G1

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The bq27441-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 bq27441-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 gauge's battery capacity predictions 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 bq27441-G1A and bq27441-G1B

Because the bq27441-G1 utilizes standard battery profiles, the system designer can select between two different flavors of the fuel gauge. The bq27441-G1A should be used if the cathode is a traditional LiCoO<sub>2</sub> chemistry and/or the battery data sheet recommends a maximum charging voltage of 4.2 V. The bq27441-G1B should be selected if the cathode is a lithium-manganese type and/or the maximum recommended charging voltage is 4.3 V or 4.35 V. These two types of rechargeable lithium chemistries are the most popular in the industry and other types are not currently supported by the bq27441.

To give further confidence in the suitability of bq27441-G1A or bq27441-G1B 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 bq27441-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<sub>DD</sub> and V<sub>SS</sub> pins. Optionally, a 1.0-μF capacitor can be also connected between the BAT and V<sub>SS</sub> pins. The fuel gauge has the ability to provide interrupts to the system through the GPOUT pin. The GPOUT pin is an open-drain output that can be configured to use the internal pullup resistor of the gauge to 1.8 V or an external 4.7-kΩ pullup resistor can be used.

For accurate gauging the fuel gauge needs to be able to detect that the battery has been inserted into the system. The fuel gauge has the ability to detect battery insertion through the use of the BIN pin (**[BIE]** bit in **Op Config** register is set) or with the host sending the **BAT\_INSERT** subcommand (**[BIE]** bit in **Op Config** register is cleared). If using the BIN pin for battery detection, then one of the following options can be used:

- Host can drive the BIN pin to a logic low to indicate the battery is inserted, or
- A weak 1.8-MΩ pullup resistor can be connected between the BIN and V<sub>CC</sub> pins to pull the BIN pin high. When a battery pack with a pulldown resistor (typically the battery pack thermistor) is connected to the system, a logic low is generated, or
- If the battery will remain in the system permanently, then the BIN pin can be tied to V<sub>SS</sub> through a weak 4.7-MΩ pulldown resistor.

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**NOTE:** The BIN pin must not be connected directly to V<sub>SS</sub>.

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**NOTE:** The GPOUT internal pullup voltage is 1.8 V. If an external pullup resistor is used, then the internal pullup resistor must be disabled (default), and the GPOUT pin can be connected to a voltage between 1.8 V and 3.6 V through a 4.7-kΩ resistor.

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## 4 Programming the Configuration

A number of configuration parameters are available in the bq27441-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 bq27441-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/bq27441-G1](http://www.ti.com/product/bq27441-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's 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 bq27441-G1A or **Design Capacity** × 3.8 if using the bq27441-G1B. **Design Energy** is used when the gauge is operating in constant-power model. The bq27441-G1 defaults to constant-power model and this is reflected by the [LDMD] bit in the *Control()* register being set.

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**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**.

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**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:

$$\text{Taper Rate} = \text{Design Capacity} / (0.1 * \text{Taper Current})$$

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).

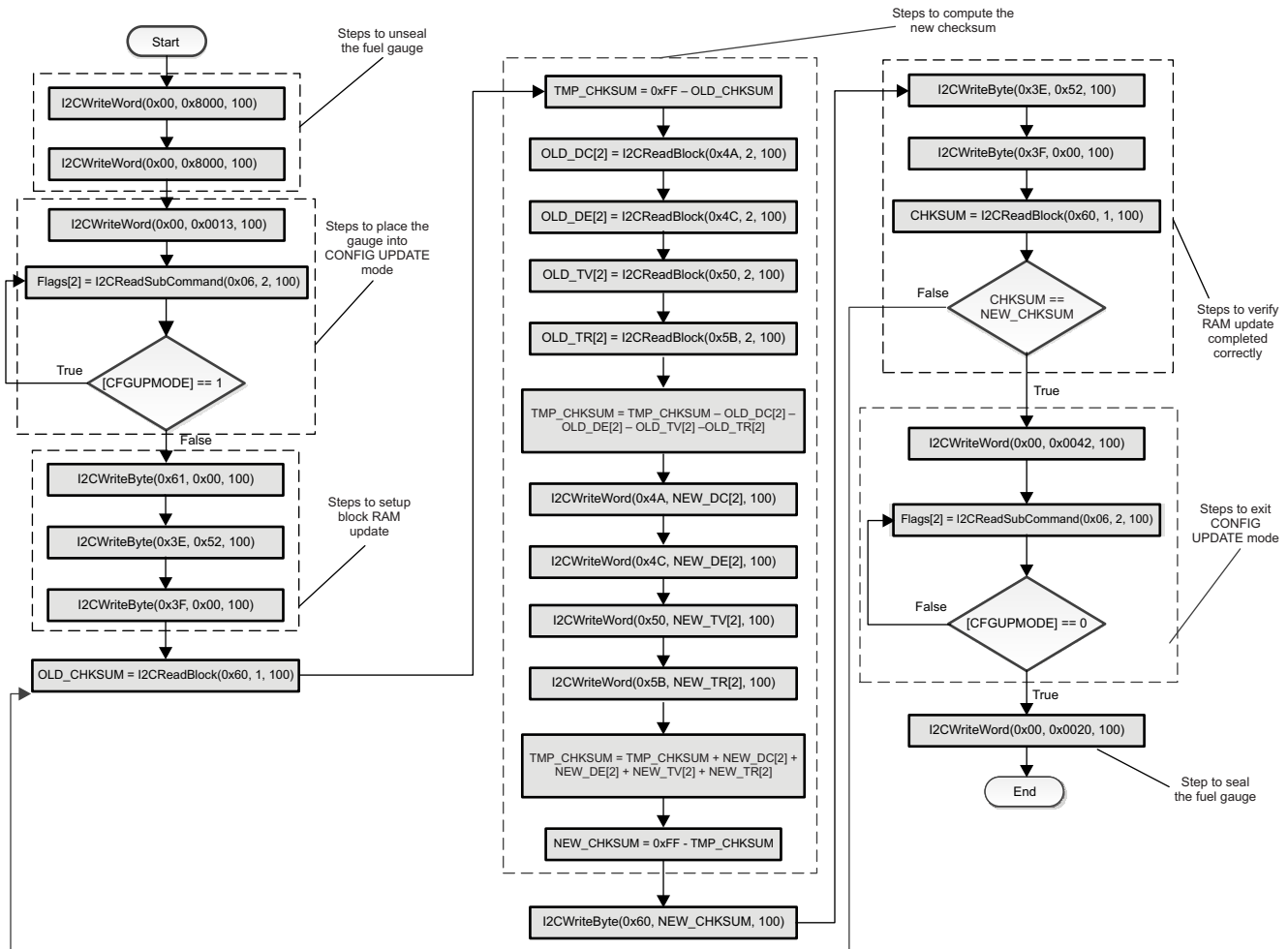
For example, if using a 1000-mA battery and the charger is set to stop charging when the voltage is 4.2 V and the current tapers to less than 100 mA (±15%), then the bq27441-G1 **Taper Rate** should be set to 87 (**Taper Rate** = 1000 / (0.1 × 115 mA) where Taper Current = 115 mA) to give a slight guard 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.

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

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The procedure and commands required to update the configuration parameters are shown in the flowchart of [Figure 1](#).

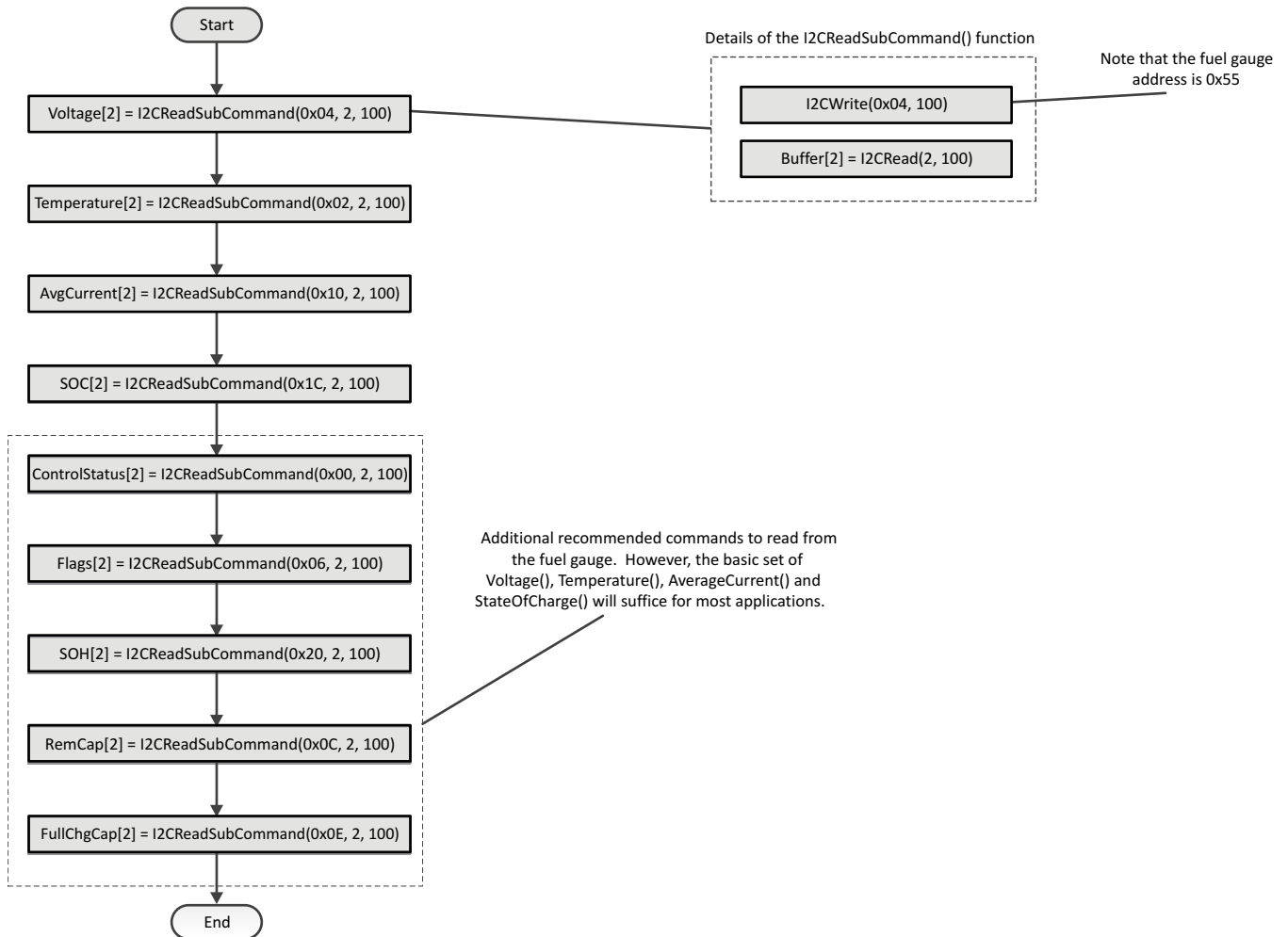


**Figure 1. Flowchart for Updating the Gauge Configuration Parameters**

**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<sup>2</sup>C 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](#).

## 5 Reading the Gauge Registers

There are a total of 15 registers available for the system to read from the bq27441. The registers most commonly used are *Voltage()*, *Temperature()*, *AverageCurrent()*, and *StateOfCharge()*. The commands to read these registers are shown in [Figure 2](#). Other useful registers include *Control()*, *Flags()*, *RemainingCapacity()*, *FullChargeCapacity()*, and *StateOfHealth()*.



**Figure 2. 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 bq27441-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.

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

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See [Figure 1](#) for more details on the RAM update process.

## 7 Recommended Flowchart

Figure 3 incorporates all of the best practices described above and describes the recommendation for system software implementation in programming and interacting with the bq27441-G1 fuel gauge. As seen in Figure 3, the host system can decide to check the bq27441-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 bq27441-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 bq27441-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.

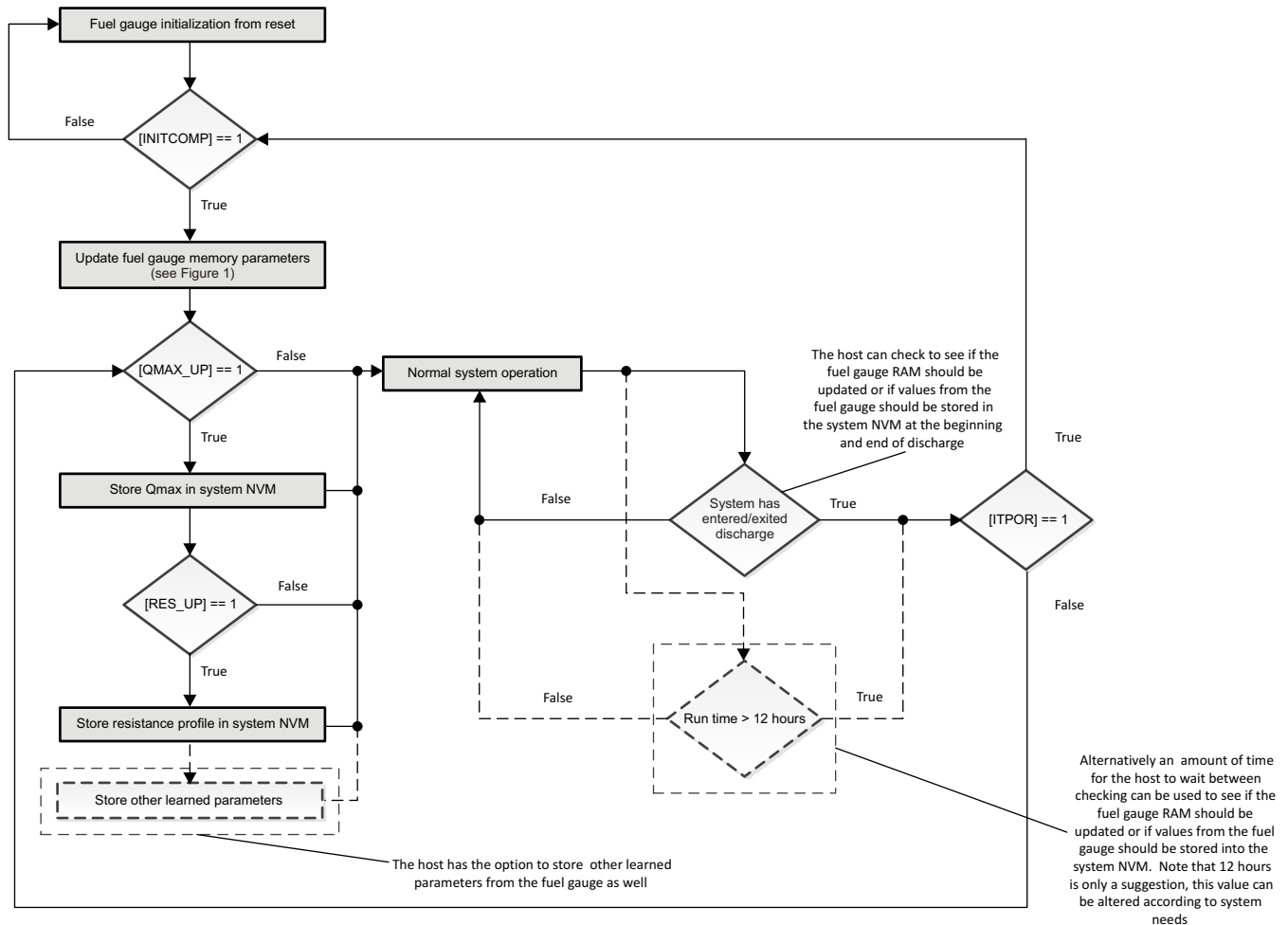


Figure 3. Recommended Flowchart

## 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 bq27441EVM, 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 Summary

By requiring no battery characterization and only needing a minimum of four registers to be updated on power-on reset (POR), the bq27441-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.

## 10 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](http://www.ti.com).

1. *bq27441-G1, System-Side Impedance Track™ Fuel Gauge Data Sheet* ([SLUSBH1](#))
2. *bq27441-G1, Technical Reference Manual* ([SLUUAC9](#))
3. *bq27441-G1, EVM: Single-Cell Impedance Track™ Technology User's Guide* ([SLUUAP4](#))

## 11 Revision History

Version	Change Date	Description
—	December 2013	Initial Release



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