

## **Quick-Start Guide for bq27426 Fuel Gauge**

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The bq27426 system-side Impedance Track™ fuel gauge is an easy-to-configure and use battery gauge. The device comes in a tiny die-size ball grid array (DSBGA) package and requires a limited number of parameter configurations to achieve a short time-to-market products goal. The gauge has three selectable pre-programmed battery profiles (chemistry IDs), respectively, for 4.2-, 4.35-, and 4.4-V standard lithium-ion batteries. Once the gauge is assembled on the system, the targeted battery profile correctly selected, and the gauge parameters configurations are done, then the gauge starts battery-gauging directly and accurate gauging results can be read of its registers. This quick-start guide gets you up and running with bq27426 fuel gauge in a very short time.

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## 1 Overview

The gauge powers up with the 4.35-V (3230 chemistry ID) (default) battery profile settings. These settings get uploaded to the RAM of the gauge when the gauge powers up from OFF or SHUTDOWN states. These default settings should be overwritten by the host to match the targeted battery profile if it is different from the default. The gauge requires the following four parameters to start gauging and correctly predicts targeted battery state of charge, the four parameters are: (1) **Design Capacity**, (2) **Design Energy**, (3) **Terminate Voltage**, and (4) **Taper Rate**. Additionally, full and empty battery conditions should also be updated to match the system requirement. The Impedance Track algorithm the bq27426 fuel gauge utilizes continually optimizes gauging accuracy by learning battery capacity and impedance profile to account for any cell-to-cell variation resulting from manufacturing as well as battery aging.

## 2 Choosing Between Different Battery Profiles

As previously mentioned, the bq27426 gauge has three built-in battery profiles; the system designer can select among these three profiles based on the maximum charging voltage of the targeted battery:

- (1202) profile should be used for lithium battery with 4.2-V maximum charging voltage.
- (3230), (default) profile, should be used for lithium battery with 4.35-V maximum charging voltage.
- (3142) profile should be used for lithium battery with 4.4-V maximum charging voltage.

Other types of rechargeable lithium battery chemistries are not currently supported by the bq27426 fuel gauge.

To give further confidence in the suitability of the bq27426 fuel gauge with its built-in battery profiles, order the bq27426EVM and test with the targeted battery. The results of battery gauging can be logged and reviewed using the *Battery Management Studio* (bqStudio) software to verify gauging accuracy.

## 3 Hardware

The bq27426 fuel gauge comes in a tiny 1.62-mm × 1.58-mm, 0.5-mm pin-pitch NanoFree™ (DSBGA) package. A minimum of a 2.2-μF and 0.47-μF ceramic capacitors are required between the  $V_{DD}$  and  $V_{SS}$  pins. The  $V_{DD}$  pin is the output of the 1.8-V internal LDO of the gauge. This LDO is used to power the internal circuitry of the bq27426 and is not intended to provide power to other devices in the system. The fuel gauge has the ability to provide interrupts to the system through the GPOUT pin when the state-of-charge (SOC) changes. The GPOUT pin is an open-drain output and it should be pulled up by typically a 4.7-kΩ or 10-kΩ resistor. The GPOUT pin should not be left floating even if unused and can be configured to simply change polarity when SOC drops below a certain threshold. This polarity transition, high to low or low to high, can also be configured. For more details on configuration options, see the *bq27426 Technical Reference Manual* (SLUUBB0).

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

If **Op Config** bit `[BIE]` = 1 (default), a logic low on the BIN pin is detected as battery insertion. For a removable battery 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 is used. The system board should use a 1.8-MΩ pullup resistor to  $V_{DD}$  to ensure that the BIN pin is high when the battery is removed. If the battery is embedded in the system, TI recommends leaving `[BIN]` = 1 and use a 10-kΩ (or the battery thermistor) as pulldown resistor from BIN to  $V_{SS}$ .

If the host is used to inform the gauge of battery insertion and removal, **the Op Config** bit `[BIE]` must be set to zero and `BAT_INSERT` and `BAT_REMOVE` subcommands must be issued by the host. A 10-kΩ pulldown resistor should be connected to the BIN pin, even if the pin is not used.

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**NOTE:** Do not short the BIN pin directly to  $V_{CC}$  or  $V_{SS}$ , also only connect any pullup resistor on the BIN pin to the bq27426  $V_{DD}$  pin and not to the external voltage rail.

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**NOTE:** The bq27426 fuel gauge needs accurate measurements of the battery pack voltage, thus BAT and V<sub>SS</sub> 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 the current flowing through voltage measurement traces between the fuel gauge and the battery will affect accuracy. Typically, the fuel gauge should be placed as close as possible to the battery to ensure its onboard temperature sensor is reflecting the battery temperature.

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## 4 Configuring Gauge Parameters

A number of configurable parameters are available in the bq27426 fuel gauge so that it can be tuned to match the targeted battery as well as the system requirement. Most of the defaults can be left alone if desired, but the following four requisite parameters; **Design Capacity**, **Design Energy**, **Terminate Voltage**, and **Taper Rate** must be configured first in order to achieve accurate battery gauging. Additionally, full and empty battery conditions must be set to match the system requirement. If you are using the bq27426EVM, then bqStudio software enables you to configure the gauge to match the targeted battery and the system requirement; otherwise, you need your system microcontroller to write bq27426 requisite parameters along with full and empty battery conditions required by your system.

Set **Design Capacity** in mAh to the nominal battery capacity printed on the battery label or found in the battery data sheet. It gives a starting point for the gauge predictions of actual battery capacity (which varies from battery to battery and changes over time as battery ages) as it will be learned and updated during fuel gauge operation.

Set **Design Energy** in mWh to be **Design Capacity** × battery nominal voltage (Design Voltage). The **Design Energy** value is used when the gauge is operating in the constant power model. The bq27426 gauge can be configured to use either a constant power model (default) or constant current model for the Impedance Track algorithm. When **Load Mode** = 1 (default), the constant power model is used and the **CONTROL\_STATUS [LDMD]** bit in the **Control()** register is set to reflect the status of **Load Mode**.

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**NOTE:** When configuring the bq27426 gauge while using the EVM with bqStudio software, **Design Energy** must be calculated and entered in the *Parameter Q&A* tab of the bqStudio main menu.

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Set **Terminate Voltage** in mV to the minimum operating voltage of your system. This is the target where the gauge typically reports 0% capacity. Usually, it is not necessary to include a guard band when selecting the **Terminate Voltage** value because the gauge also learns the level of load spikes in the system. The gauge automatically uses a higher voltage when necessary to ensure that load spikes, aging, and low temperatures do not allow sudden voltage drop below **Terminate Voltage** before 0% is reported. The actual point at which 0% is reported is 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 parameter ensures that a known amount of energy is available for shutdown activities once 0% SOC is reported, but before **Terminate Voltage** is actually reached.

Calculate the **Taper Rate** in 0.1-Hr Rate, using 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** value can be calculated from the taper current value in mA with the following equation:

$$\text{Taper Rate} = \text{Design Capacity} / (0.1 \times \text{taper current})$$

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 a 1000-mAh battery is used and the charger is set to stop charging when the voltage is 4.2 V, and the current tapers to less than 100 mA ( $\pm 15\%$ ), then the bq27426 **Taper Rate** should be set to 87 (**Taper Rate** =  $1000 / (0.1 \times 115 \text{ mA})$  where taper current = 115 mA) to give a slight guard band. It is important that the gauge detects 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 in the *Flags()* register and then disable the charger when that bit is set.

**NOTE:** When configuring the bq27426 gauge while using the EVM with bqStudio software, **Taper Rate** must be calculated and entered in the *Parameter Q&A* tab of the bqStudio main menu.

Figure 1 shows the flow chart of the procedure and commands required to update the default gauge parameters configuration.

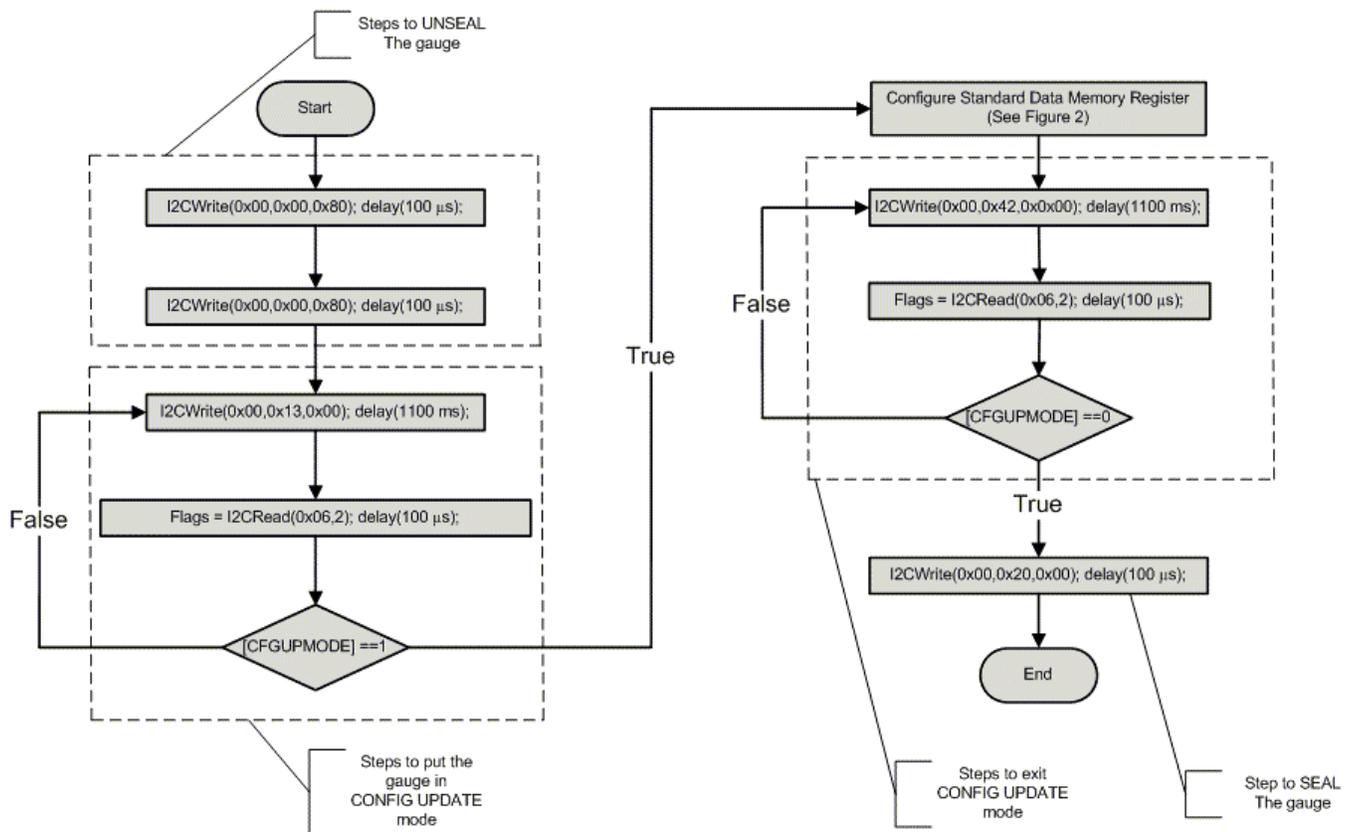
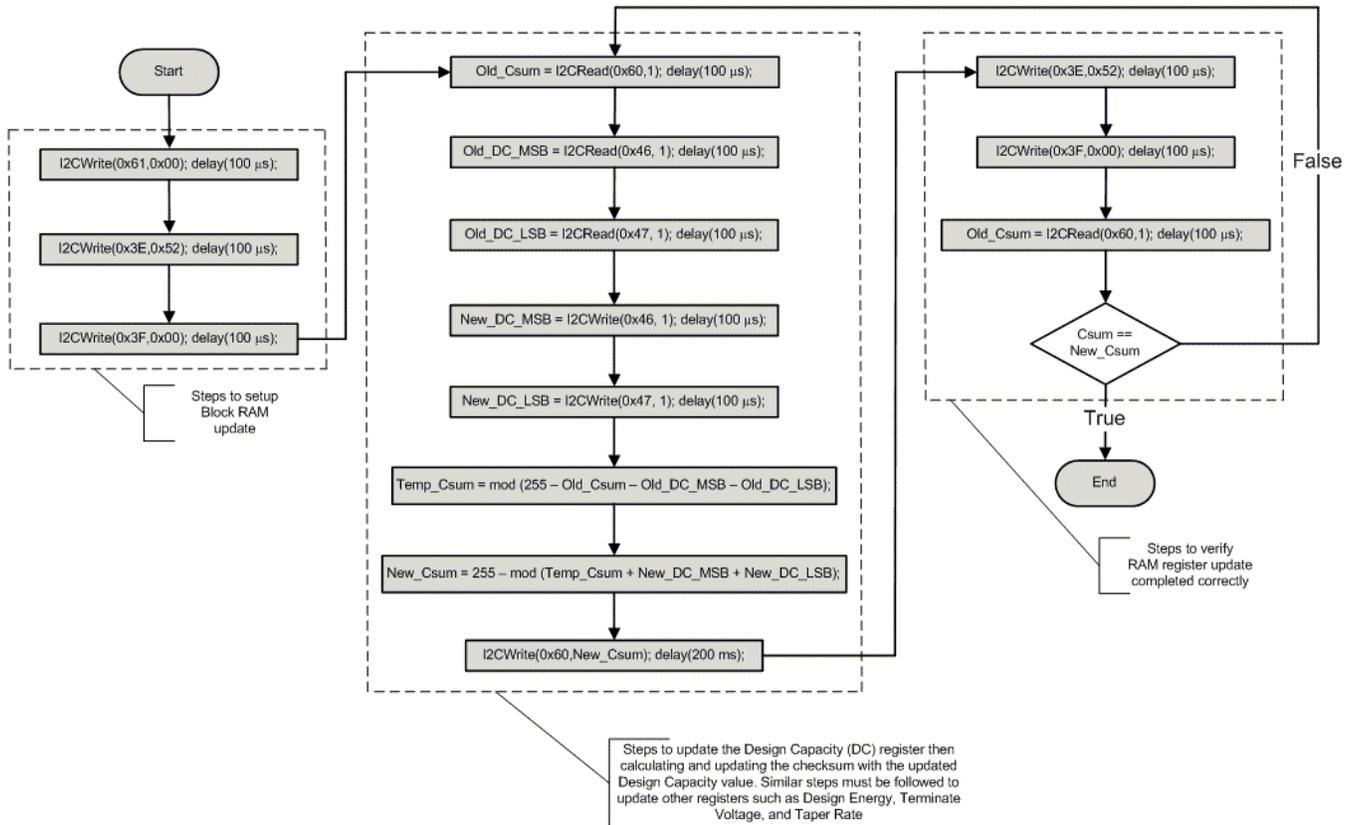


Figure 1. Flow Chart for Updating Default Gauge Parameters Configurations

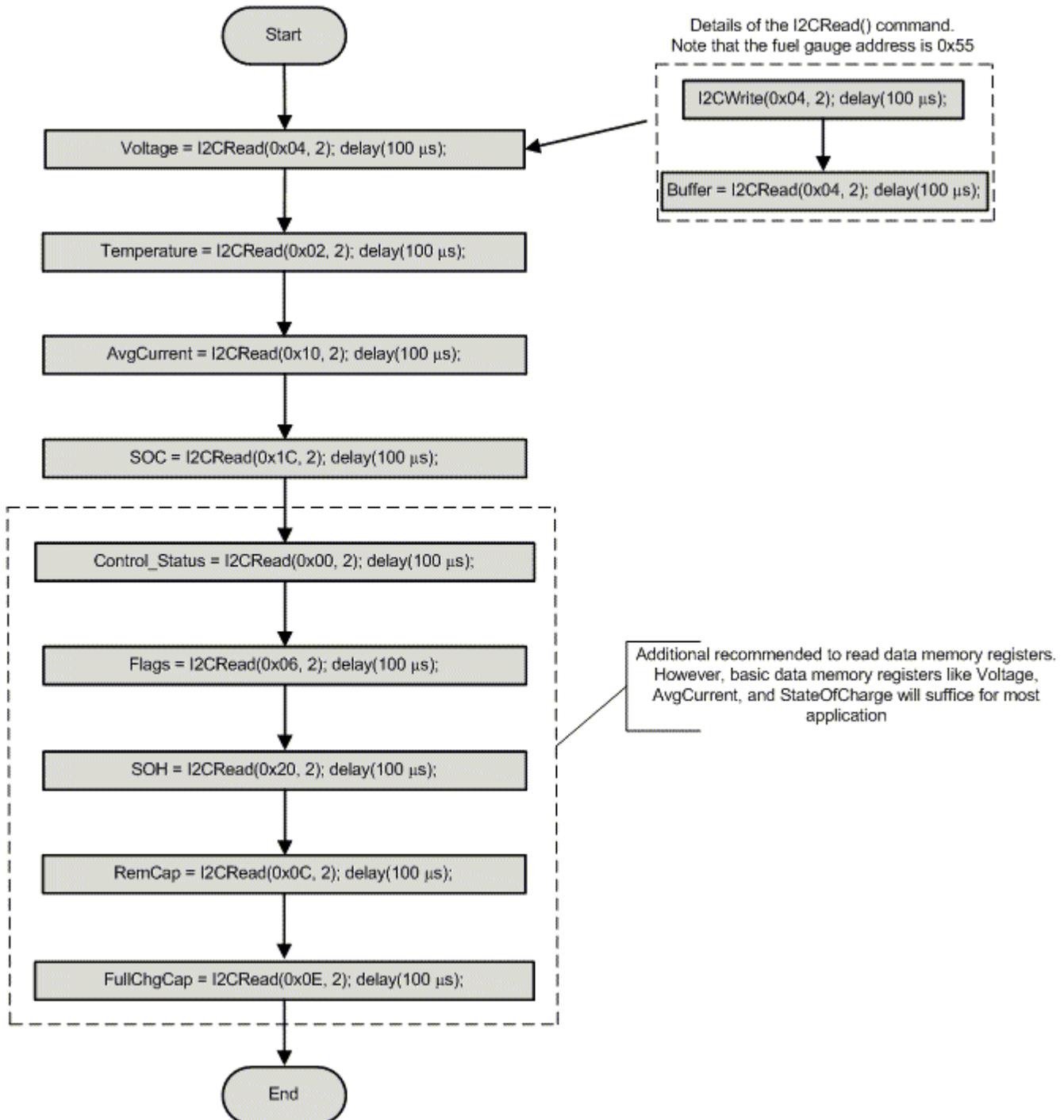
**NOTE:** The process for updating the default gauge parameters can also be handled through parsing the data contents of a \*.gm.fs file generated by bqStudio software. The \*.gm.fs file consists of series of I2C commands that can be processed by the host. Using the \*.gm.fs file allows the host to use an alternative route to update parameters instead of following the flow chart outlined in Figure 1.



**Figure 2. Configuring Gauge Standard Data Memory Parameters**

## 5 Reading the Gauge Registers

There are a total of 18 registers available in the bq27426 fuel gauge memory for the system to read from. The registers most commonly read and logged are *Voltage()*, *Temperature()*, *AverageCurrent()*, and *StateOfCharge()*. Figure 3 shows the commands to read these registers are shown in . Other useful registers include *Control()*, *Flags()*, *RemainingCapacity()*, *FullChargeCapacity()*, and *StateOfHealth()*.



**Figure 3. Gauge Register Reading Commands**

## 6 Gauge Learning Cycle to Improve Gaging Accuracy

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. The gauge stores the learned maximum battery chemical capacity in Qmax and the learned battery resistance profile in the Ra table. As long as the gauge has power, Qmax and the Ra table both will be updated once the proper update conditions for each 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 is set, a battery resistance (Ra table) update is allowed. The `[RES_UP]` bit in the `Control()` register is set once there has been an update to the Ra table, the battery resistance update happens only during discharge. Both `[QMAX_UP]` and `[RES_UP]` bits remain set until the gauge is reset or a battery insertion event occurs.

TI recommends that the host save Qmax and Ra table in the system NVM once the `[QMAX_UP]` and `[RES_UP]` bits have been set. After the initial Qmax update, subsequent Qmax updates most likely occur upon:

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

Subsequent Ra table updates also occur only during discharge and a previous Qmax update had occurred, this can be verified by the `[QMAX_UP]` bit in the `Control()` register being set.

Ideally, the system should be designed so that the bq27426 is always powered by the battery even during system shutdown. The gauge retains the learned values in its RAM as long as it has power and operates in NORMAL or SLEEP Modes. The gauge automatically enters SLEEP Mode when the system current goes below the SLEEP Mode current setting (default = 10 mA) to minimize power consumption.

If the battery is removed or the gauge is forced into SHUTDOWN Mode, the learned values stored in the gauge RAM along with the configured gauge parameters are lost. Once the gauge powers up again, the `[ITPOR]` bit in the `Flags()` register is set indicating that all gauge parameters and learned values are initialized to the defaults. The defaults in **Design Capacity**, **Design Energy**, **Terminate Voltage**, and **Taper Rate** are also initialized. When the `[ITPOR]` bit is set, that indicates one of the following:

- The fuel gauge has been reset due to power loss.
- 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 without affecting the gauge configured nor learned parameters. 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 the minimum, the **Design Capacity**, **Design Energy**, **Terminate Voltage**, and **Taper Rate** values should be reloaded. Additionally, the host has the option to save the learned Qmax and Ra table values into the system NVM periodically.

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**NOTE:** The `SOFT_RESET` subcommand is used to exit the RAM update process as well, 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 Flow Chart

Figure 4 incorporates all of the best practices previously presented and describes the recommendation for system software implementation in programming and interacting with the bq27426 fuel gauge. By default, the bq27426 issues an interrupt on the GPOUT pin when it enters a discharge mode. The host can then check to see if the *[DSG]* bit in the *Flag()* register is set in order to verify that the gauge is in discharge mode. Using interrupts from the gauge allows the host to reduce the system power consumption. The host can use an alternative approach by checking the gauge after a certain period of time (12 hours as an example, another period can be selected upon the system needs) to decide after this time period what action must be done.

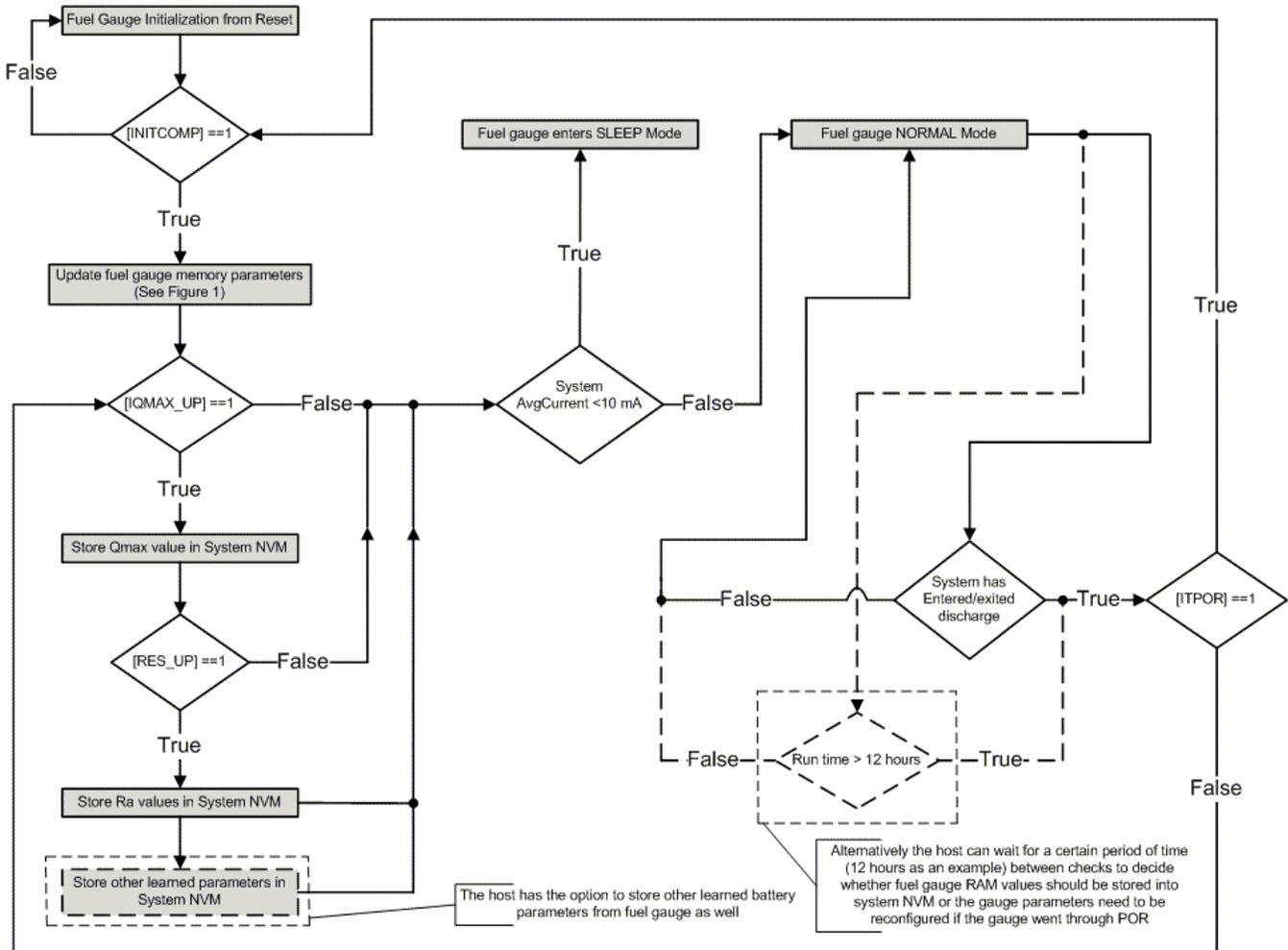


Figure 4. Recommended System Operation Flow Chart

## 8 Other Gauge Parameter Configuration Options

The previous sections outlined the minimum gauge parameters, and registers that need to be updated from defaults for accurate fuel gauging. There are other gauge parameters readily available to be configured in order to enable different options such as interrupt conditions well as to pre-optimize the battery profile.

When the gauge is configured with the nominal battery capacity (design capacity), it automatically begins to learn the true battery capacity and resistance profile while operating in the end-equipment. This means that gauging 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 approach is easily done using the bq27426EVM, but the actual system can also be used. Once determined, these optimized parameters can be included in the previously-mentioned gauge configuration process. This pre-optimized gauge parameters (golden file) allows the end-user to experience higher initial accuracy right out of the box without having to wait for the gauge to learn during system operation.

Whether this optimization is performed during research and development or in the field operation of the end-equipment, the patented Impedance Track algorithm continually learns and updates the battery capacity and resistance profile. Impedance Track does this as the battery ages, enabling it to be the only gauging algorithm available in the market that can maintain the same gauging accuracy for aged batteries as for new ones. This gauging algorithm that the bq27426 gauge uses will quickly learn and regain optimum accuracy even if the user swaps between batteries with different ages.

## 9 Entering SLEEP Mode

The bq27426 gauge enters SLEEP Mode, by default, if system current is below the gauge SLEEP Mode current setting (default = 10 mA). During SLEEP Mode, the gauge wakes-up briefly every 20 seconds to take data measurements and if the measured *AverageCurrent()* is above sleep current setting, the gauge exits SLEEP Mode. Alternatively, an early wake-up before the 20 second interval is possible if the instantaneous current detected by the internal hardware comparator connected to SRP and SRN pins is above an approximate threshold of  $\pm 30$  mA.

See the *bq27426 Technical Reference Manual (SLUUBB0)*, for more details on SLEEP Mode.

## 10 Summary

By requiring no battery characterization and only needing a minimum of four parameters, registers, to be configured upon power-on reset (POR), the bq27426 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](http://www.ti.com).

1. Texas Instruments, [bq27426 System-Side Impedance Track™ Fuel Gauge Data Sheet](#) )
2. Texas Instruments, [bq27426 Technical Reference Manual](#)
3. Texas Instruments, [bq27426EVM-738 EVM: Single-Cell Impedance Track™ Technology User's Guide](#)

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