Application Report
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How to Use bq27505 in a Smart Phone System

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ABSTRACT

TI's Impedance Track™ fuel gauge is designed for accurately reporting battery remaining capacity and run time. It is necessary to design and implement the gauge correctly to achieve this. This application report provides an example of how to design the bq27505 into a system motherboard for a smart phone system.

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1 System Requirements on Smart Phone System Design

A smart phone can be designed to use a bq27505 as a single cell Li-ion fuel gauge on the system side. Both the fuel gauge and charge integrated circuits (IC) need to be configured based on the system operation requirements to achieve accurate gauging.

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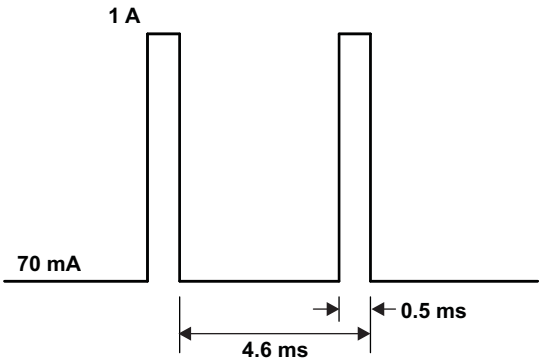

Figure 1. Typical GSM Pulse Load profile

In this design example, a GSM standard is used. GSM uses a TDMA-based frame structure to transmit voice and data. A standard GSM load frame is 4.615 ms (217 Hz) in length, consisting of eight time slots on each channel. When a call is in progress, the peak current can go up to 1 A or 2.3 A with 12% of duty cycle, i.e., for a period of 550 µs. Figure 1 shows the typical current waveform of the GSM phone.

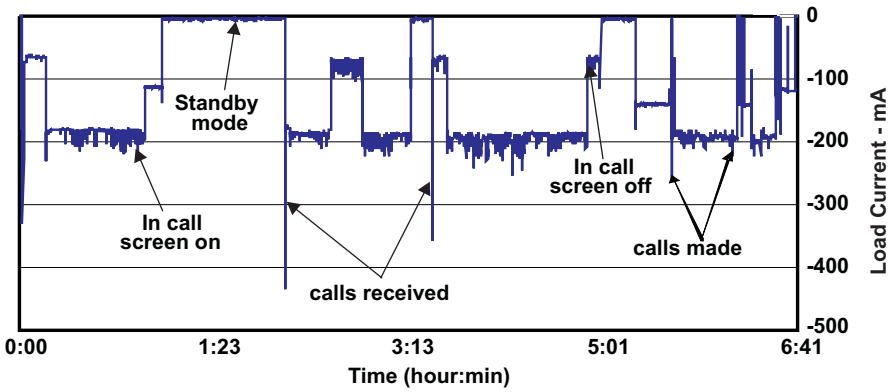

Figure 2. Typical Smart Phone Average Load Profile

The phone usually operates in constant power mode. In normal operation, the maximum current spike is about 1 A for a short period of time and average current is around 300 mA. The minimum average discharge current under normal operation is 100 mA. The system standby current is around 5 mA, and the system shuts down when battery voltage drops below 3.2 V (Figure 2). Figure 2 shows the battery average discharge current waveforms recorded by gauge. The gauge averages the measured current every 1 second and saves the averaged current in the data RAM. Also, the capacitor in parallel with the battery provides high instantaneous current, so, the GSM current spike is not shown in Figure 2. The system has a battery low-interrupt capability that requires an active-low signal.

A charger device on the system board has a SYSOFF feature. The SYSOFF is used to disconnect the battery, which can be controlled by the bq27505. The Impedance Track™ algorithm also requires the charger to be disabled when the battery pack is inserted into the phone. The charger can be disabled through the bq27505 BAT_GD pin with an active- low signal (refer to Figure 5 system schematic for details). The following are the charger requirements based on cell specifications, and system and fuel gauge requirements.

1. The cell voltage must not exceed the maximum allowed charge voltage, typically, 4.2 V.
2. The charge current must be less than 1C charge rate or specified from cell manufacturers.
3. The taper (termination) current is low enough to meet bq27505 termination condition (the charge taper current in the charger must be set lower than the termination current set by the fuel gauge) .
4. The charger must be disabled when temperature is outside the safety range.
5. The charger must be disabled through the BAT_GD signal during the OCV measurement period.

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2 Choose the Battery Cell

Many different single-cell, Li-ion battery packs are on the market. The space in the system as well as the system operating requirements limit the type of battery pack a designer can use. With the increase of applications running on a smart phone system, the battery capacity and the system current consumption are the major factors to determine which battery pack to use. In this example, a PL_553562D battery cell is selected. The system is designed to have 5-hr run time for an average 100-mA to 200-mA load. This cell has a design capacity of 1050 mAh with charge voltage of 4.2 V and discharge cutoff voltage of 2.75 V, which is sufficient for this design. The maximum charge current is 1050 mA. Charge temperature range is from 0°C to 45°C and discharge temperature range is from –20°C to 60°C. The cell size is roughly 5.5 mm × 35 mm × 62 mm.

3 Charger IC Selection and Configuration

The charger IC is selected based on the cell specification. A smart phone can be designed to use the bq27505 as fuel gauge. A single-cell, Li-ion battery pack is used. Both the gas gauge IC and charge IC need to be configured based on the system operation requirements to achieve accurate gauging. The PL_553562D cell requires the charge voltage to be 4.2 V. The bq24075 charger can provide up to 1.5-A charge current and 4.2-V charge voltage. It has an SYSOFF pin that can be controlled by the bq27505 BAT_GD signal to disable the charging when bq27505 is measuring OCV. Once the charge is selected, it requires proper configuration

3.1 Configure the Charge Current I_{CHG}

R_{ISET} is the resistor connected from the ISET pin to the VSS pin of the bq24075. The AC charge current can be configured based on the following formula:

$$I_{CHG} = \frac{K_{ISET}}{R_{ISET}}$$

From the data sheet, K_{ISET} is set to be 890. In order to get a 0.5-A charge current, R_{ISET} is 1.780 kΩ. Select the closest standard value, which in this case is 1.787 kΩ.

3.2 Configure the Taper Current I_{TERM}

Charge termination is critical during the gauge learning cycle and the normal operation. So, the Full Charge (FC) bit in the gauge status register can be set, and the Relative State of Charge (RSOC) can be set to 100%. The bq24075 has an internally fixed I_{TERM}, which is set to 10% of the I_{CHG}. In this example, it is set to 50 mA.

The bq27505 also has a data flash setting called terminate current. The charger taper current has to be smaller than the gauge charge terminating current setting.

It is better to first consider the system load profile under different operation modes. Based on these requirements, then the data flash parameters can be correctly configured.

4 Configure Gas Gauge Data Flash

The TI Impedance Track™-based gas gauge requires proper configuration of the data flash to deliver the expected high accuracy on reporting the battery Remaining Capacity and other key parameters. Once the cell is selected and the charger is configured, the gauge can be configured based on the cell, charger, and system requirements. To configure the gauge, an easy-to-use tool has been developed. This tool is integrated with TI Evaluation Software (EVSW) that allows the user to configure the data flash by answering a set of questions. In order for users to better understand the questions and to set these data flash values properly, the following section focuses on these areas.

4.1 Configure Cell Characteristics

Once the cell is selected, the cell characteristic is determined. The cell data sheet has all the information needed. The key parameter is the design capacity and the minimum-rated cell voltage.

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4.2 Configure Charging Parameters

The bq24075 charger has been configured to provide maximum charge current at 0.5 A and charge voltage at 4.2 V. The charger taper current has been configured to 50 mA. The gauge taper current is normally set to 1/10 of the design capacity. In order to have a Full Charge condition during the gauge learning cycle, the gauge taper current has to be set higher than the charger taper current. If the gauge taper current is selected lower than charger taper current, the gauge will never reach the Full Charge condition. The end user may experience a reported battery State of Charge (SOC) always less than 100%. Table 1 shows the gauge-charging parameter setting based on the charger and the cell specification.

Table 1. Gauge-Charging Parameter Setting

Data Flash Items	Data Flash Name	Setting
Maximum charge voltage	Charging Voltage	4200 mV
Maximum taper current	Taper Current	100 mA
Maximum temperature allowed (charging)	Suspend High Temp, OT Chg	45°C
Minimum temperature allowed (charging)	Suspend Low Temp	0°C

4.3 Configure Discharging Parameters

Discharge temperature range usually is wider than the charging temperature range. The most critical setting during the discharge is the system current consumption. The system has minimum discharge current under active mode and also has maximum discharge current during normal mode. At standby, the system also draws a small amount of current. For a smart phone system, the standby current is around 10 mA. In this design example, the standby current is 5 mA. For GSM pulse, the maximum current can go up to 1 A to 2 A for a short period (approximately 0.5 ms) (see Figure 1). In this example, the system has a 1-A pulse for a short time and maximum average current of 300 mA at normal operation. The minimum average discharge current under normal operation is 100 mA. In standby mode, the system wakes up periodically to maintain synchronization.

Based on the actual system design, these average currents at normal operation can be determined. Table 2 has shown the gauge discharging parameter setting based on system operation and cell specification.

The bq27505 also has the ability to trigger the SYSDOWN flag based on the cell voltage. As the cell voltage drops below the system shutdown voltage, the SYSDOWN bit in the flag register is asserted. In this design example, the system shuts down once the cell voltage is below 3.2 V.

System shutdown voltage setting is based on the load profile as well as battery capacity. With a pulse load having a high current peak, the cell voltage can drop significantly towards the end of discharge. In order to have sufficient cell capacity and voltage for the system to operate properly, the system shutdown voltage sometimes sets as high as 3.4 V; at this time, the usable cell capacity is less. The SOC1 flag is used by the system to indicate that the cell capacity is low and the system needs to prepare for shutdown. By selecting a higher SOC1 threshold, the system shutdown voltage can be set lower. System shutdown has a SYSDOWN flag that can be set once the battery voltage is below the *SysDown Set Voltage Threshold*. Normally, it is set to 100 mV above the system shutdown voltage. In this example, the SOC1 is set to 30 mAh, and the system shutdown voltage is set to 3.2 V.

Table 2. Gauge-Discharging Parameter Setting

Data Flash Items	Data Flash Name	Setting
Maximum temperature allowed (discharging)	Suspend High Temp, OT Dsg	60°C
Capacity threshold to set SOC1	SOC1 Set Threshold	30 mAh
Voltage threshold to set SYSDOWN bit	SysDown Set Voltage Threshold	3300 mV
System shutdown voltage	Final Voltage	3200 mV

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4.4 Reserve Capacity and Load Characteristics

It is necessary that the cell has enough capacity to allow the system to properly shut down when the end-of-discharge voltage is reached. In this system design, because the system shutdown voltage is set to 3.2 V, the reserved capacity can be set to 0 mAh.

Normally, the smart phone system is running in constant power mode. In this mode, the normal operation current increases slightly when cell voltage is dropped.

4.5 Configure Impedance Track™ Algorithm Operation Mode Current Threshold

The Impedance Track™ algorithm fuel gauge has different algorithm operation modes according to the battery discharge current. The current thresholds have to be set properly so that the cell can be determined to be in charge mode, discharge mode, or relaxation mode. In this design example, the smart phone average discharge current during normal operation is between 70 mA and 300 mA. The discharge current threshold must set to 60 mA. As long as the battery discharge current is above 60 mA, the fuel gauge is defined as operating in the discharge mode. The configuring charger provides a maximum 500-mA charge current, and the taper current threshold is set to 100 mA. (Usually, the taper current is set to 10% of the fast charge current if the termination pin is unavailable like the bq24075.) The charge current threshold is then set to 75 mA. If the charge current is above 75 mA, the Impedance Track™ algorithm ???considers??? the cell operating in charge mode. To determine if the cell is in relaxation mode, a quit current threshold is defined and it must be set smaller than either the discharge current threshold or charger current threshold. For the Impedance Track™ algorithm to work properly, the gauge has to be in normal operation mode so that Impedance Track™ algorithm can determine the proper Impedance Track™ operation mode. The quit current must be set above the gauge sleep current. In this design example, it is set to 30 mA (see Table 3). Figure 3 shows the definitions of discharge, charge, and relaxation modes.

Table 3. Impedance Track™ Algorithm Operation Mode Current Threshold

Data Flash Items	Data Flash Name	Setting
Discharge current threshold for DSG mode	Dsg Current Threshold	60 mA
Charge current threshold for CHG mode	Chg Current Threshold	75 mA
Quit current for entering relaxation mode	Quit Current	30 mA

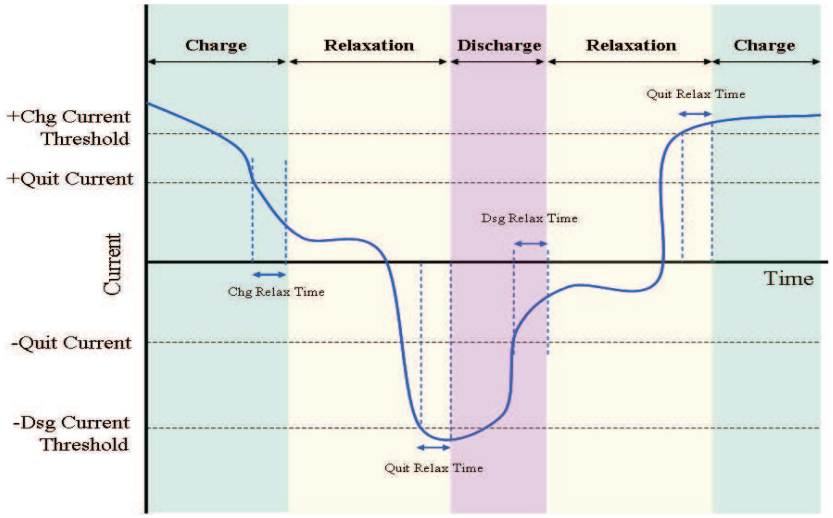

Figure 3. Discharge Mode, Charged Mode, and Relaxation Mode

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4.6 Configure Fuel Gauge Operation Mode Current Threshold

The bq27505 has four operation modes. They are different than the Impedance Track™ algorithm operation modes or system operation modes. These gauge operation modes are *normal mode*, *sleep plus mode*, *sleep mode*, and *hibernate mode*. In *normal mode* the gauge is in fully operational mode. The *sleep plus* mode and *sleep mode* are entered when the average current is less than the preset Sleep Current threshold in data flash. Because the system standby current is 5 mA, the sleep current threshold for the gauge is set to 10 mA. Once the system is in standby mode, the gauge is in sleep mode. The gauge wakes up every 20 seconds to measure the current and the cell voltage, but without an SOC update. The *hibernate mode* is entered when the HIBERNATE bit is set and the cell is relaxed and average current is less than the Hibernate Current threshold in data flash, or the cell is relaxed and the cell voltage is less than Hibernate Voltage threshold. Hibernate mode is mainly used during the pack transportation for pack-side applications. Once the gauge is in hibernate mode, it does not take any measurement, including coulomb counting. If the system consumes small current from the battery, and the gauge is in hibernate mode, the gauge will have a large error in terms of remaining capacity calculation. This design has no hibernate requirement. Figure 4 shows the relation among the fuel gauge operation modes, system operation mode, and the size of the sense resistor.

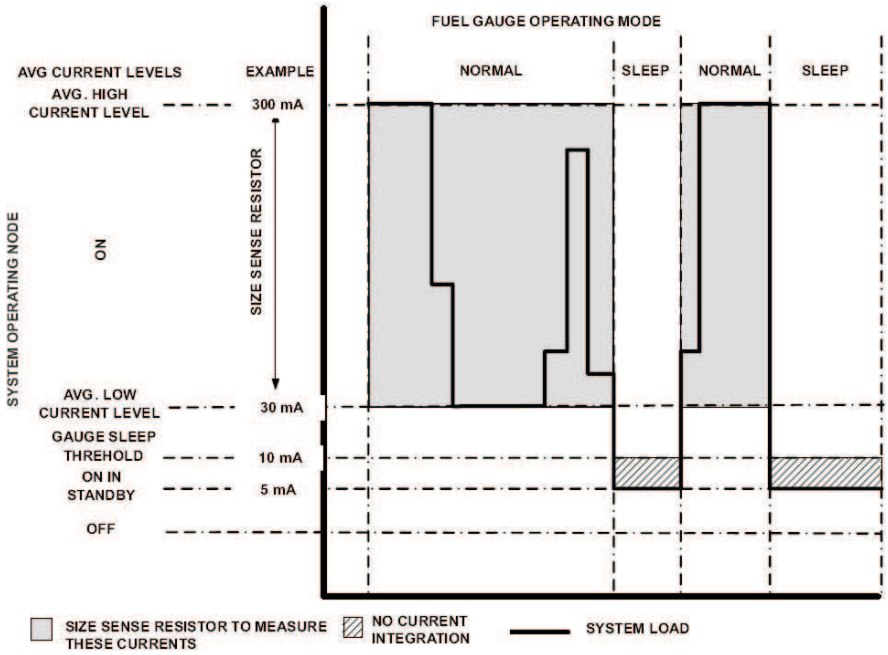

Figure 4. Fuel Gauge Operation Modes and Size of the Sense Resistor

4.7 Configure the BAT_LOW and BAT_GD Pin

BAT_LOW is one of the bq27505 general-purpose input/output (GPIO) pins that can be configured to indicate that the battery capacity is below the threshold set by SOC1. BAT_GD pin is mainly used to control the charger so that it can disable the charging and discharging through bq24075 SYSOFF pin when the battery is first inserted into the system, in order to allow the gauge to read the battery cell Open Circuit Voltage (OCV) correctly (see Figure 5) . Both the polarity of BAT_LOW and BAT_GD can be configured in Data Flash Operation Configuration A register (SLUA525).

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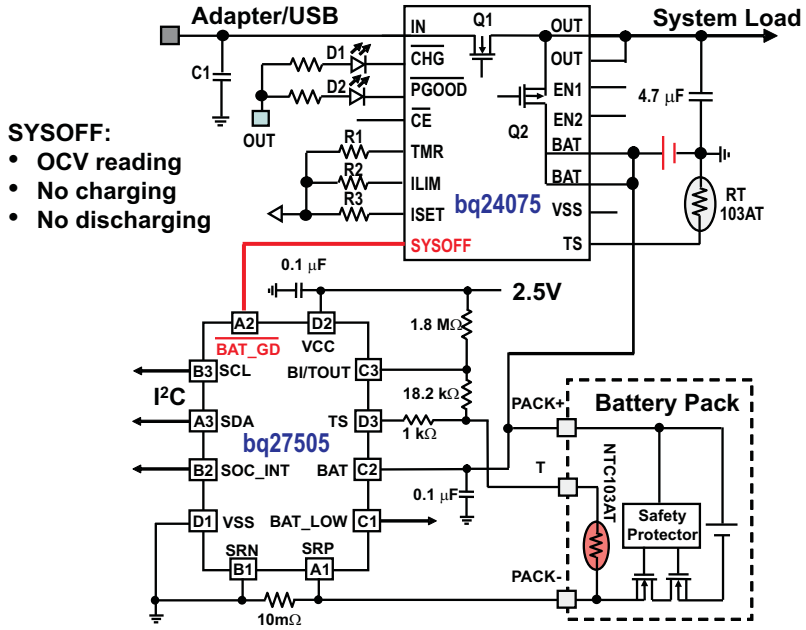

Figure 5. Overall bq27505 and bq24075 System Schematic

5 Sense-Resistor Selection

Sense-resistor selection is based on the power dissipation and current measurement accuracy. In order to get an accurate current reading, the sense-resistor temperature coefficient must be no greater than 100 PPM/C with 1% tolerance.

The hardware platform for the bq27505 requires that the coulomb counter ADC input range is within ±125 mV. For a maximum operation current of 1 A in this design example, the resistance value cannot be greater than 125 mΩ. The standby current of the system is 5 mA. The sleep current threshold of the gauge is set to 10 mA. The minimum sensed current must be smaller than the sleep current. Due to the fact that the ADC offset error is 10 µV, the sleep current is set to 10 mA, and the lowest sense resistor that can be used is 1 mΩ. Normally, it is selected to be 10 mΩ (see Figure 4). The maximum power dissipation at maximum average discharge load is listed in Table 4. The sense-resistor size needs to be as small as possible in the smart phone design. In this design example, a 10-mΩ sense resistor with 0603 package is selected which has 1% tolerance and temperature coefficient of 100 ppm/°C.

There are tradeoffs by selecting different size of sense resistor. The higher the resistance value, the smaller the current error but higher power dissipation (see Table 4).

Table 4. Sense-Resistor Tradeoffs (ADC Offset Error = 10 µV)

Sense-Resistor Nominal Value	Maximum Sense Voltage at 1 A	Average Sense Range (10 mA to 300 mA)	Maximum Power Dissipation at Maximum Average Discharge Load (300 mA)	Worst-Case, Low-Discharge Current Error (10 mA) With 10-µV ADC Offset	Sleep Wake-Up Range (10 mA)
5 mΩ	5 mV	50 µV to 1.5 mV	0.45 mW	20%	8 mA to 12 mA
10 mΩ	10 mV	100 µV to 3.0 mV	0.90 mW	10%	9 mA to 11 mA
25 mΩ	25 mV	250 µV to 7.5 mV	2.25 mW	4%	9.6 mA to 10.4 mA
50 mΩ	50 mV	500 µV to 15 mV	4.5 mW	2%	9.8 mA to 10.2 mA

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6 Gas Gauge Thermistor Selection

Both the bq24075 and the bq27505 use a thermistor for monitoring battery cell temperature. The charger uses it to determine the allowed charging temperature range. The bq27505 uses it to determine cell temperature for the Impedance Track™ algorithm and also to determine if a battery pack is inserted or not through the BI/TOUT pin. The thermistor network is composed of a voltage divider between the thermistor and an 18.2-kΩ resistor. The voltage divider is sourced by the BI/TOUT pin and is measured by the TS pin (see Figure 6). A 1.8-MΩ resistor connected between VCC and BI/OUT provides logic transition when connecting or removing a pack from the system for battery pack insertion detection.

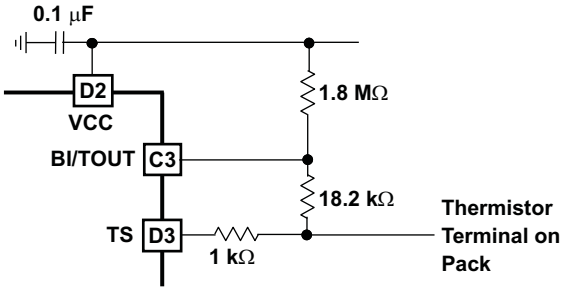

Figure 6. bq27505 Thermistor Network

The bq27505 has a set of external temperature coefficients that is based on the NTC103AT thermistor. This type of thermistor is necessary for accurate temperature measurement by the gauge. In some cases, if the pack does not have a built-in NTC103AT thermistor, the bq27505 can be configured to use the internal temperature sensor or to receive the temperature from the host by enabling the WRTEMP bit in the Operation Configuration B register (SLUA525). If the internal temperature sensor is used, the gauge has to be located closer to the battery pack to sense the cell temperature. The gauge accuracy will be degraded in this case.

To enable the battery pack insertion detection feature, the 1.8-MΩ resistor must be resized so that the highest resistance of the thermistor that is used on the pack still produces a low logical level (< 0.4 V) at the BI/TOUT pin. The TS pin must be left floating or tied to the ground.

Because the temperature sensing scheme in the battery charger is different from the fuel gauge, the same temperature sensing circuit cannot be shared, i.e., it requires two thermistors to monitor the battery temperature.

7 System Power Up and Battery Pack Insertion/Removal Consideration

During the system power up, the host has to check several gauge parameters to make sure that the battery pack has enough capacity left for proper operation. Usually, the host checks the SOC1 bit status and if the SOC1 bit is set, the host goes into the shutdown process. Ideally, the host checks the cell voltage as well prevents the power-up issue if the SOC1 bit is erroneously set, even with a fully charged pack.

When no adapter or other power source is present, once the battery pack is inserted and detected by the gauge, a series initialization begins. The initialization process includes setting the BAT_GD pin, taking the OCV measurement, taking the temperature measurement, selecting the appropriate battery profiles, and starting the Impedance Track™ algorithm simulation. The first OCV reading is used to calculate the initial State of Charge (SOC). During the OCV measurement, it is required that the charge or discharge current is less than C/20 (C is the capacity rating of the cell) for an accurate OCV reading. If the charger is present, the BAT_GD is used to disable the charger so that an accurate OCV measurement can be taken.

The low-dropout regulator (LDO) plays an important role in battery removal and insertion. In some cases, the battery is removed and then re-inserted in a short time. With the capacitance on the power rail, the gauge relies on the LDO output capacitor to provide the power for this short time even though the battery pack is removed. In this case, the gauge can report an erroneous SOC or temperature reading which can cause a system power-up issue. LDO output must be pulled to ground when the LDO input is below a certain threshold. In this example, a Texas Instruments TPS71525 has been selected to power the bq27505.

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