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# Determining the Values to Program the bq26500/bq26501 EEPROM

*Portable Power Management*

## ABSTRACT

Customers can program ten EEPROM registers to optimize the ability of the bq26500/bq26501 to monitor the battery capacity of a given group or type of Li-ion pack cells. This document explains how to obtain the values to be programmed in EEPROM by using information known by the pack/system designers and manufacturers and data collected from packs. HP34401A multimeters and a test setup that includes an environment control unit can collect the data by using a program that logs the time, voltage, and current results. Battery capacity is determined by integrating the current readings.

Use this document along with documents SLUA298, *Configuring the bq26500 for Gas Gauge Applications*, SLUS567 (bq26500 data sheet) and SLUS586 (bq26501 data sheet).

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# 1 TEST PARAMETERS

To obtain sufficient battery characteristic data, submit the packs to full charge and full discharge cycles at different discharge rates and temperatures. The discharge rates at room temperature may be C, C/2, C/4, C/8 and typical load rate of system. These discharge rates may vary depending on the minimum and maximum expected load rates of the system. At the least, test up to a rate higher than the expected maximum load rate. The temperatures at which the packs are exposed while discharging at typical load are 25°C, 20°C, 10°C, 0°, -10°C. The charge cycles used throughout all tests are at C/2 rate or whichever rate is controlled by system charger. It is important to plan according to the parameters that will be used for testing because the process of charging and discharging battery packs at all the determined load rates and different temperatures is time-consuming. The tests should offer enough information to determine capacity at typical load rates, high load rates, different temperature rates, end of discharge voltage thresholds, and charge termination voltage.

# 2 EEPROM REGISTERS

The following sections describe how to determine the values that are programmed into the ten EEPROM registers

## 2.1 Initial Last Measured Discharge (ILMD) Address 0x76

The battery pack tested for this example is a 1000-mAh capacity pack. To determine the actual capacity, the pack is submitted to a full charge and discharge cycle at the typical load rate. The system designer provides the minimum voltage at which the system is designed to operate. The minimum voltage should allow a margin before actually reaching an out-of-limits voltage. Throughout the rest of this document the minimum operating voltage of 3.2 V is used. Using the data, how much capacity is depleted from the pack at the moment the minimum operating voltage is reached when discharging indicates the true operating capacity of the given pack when powering this specific system. The capacity determined was 1048.35 mAh.
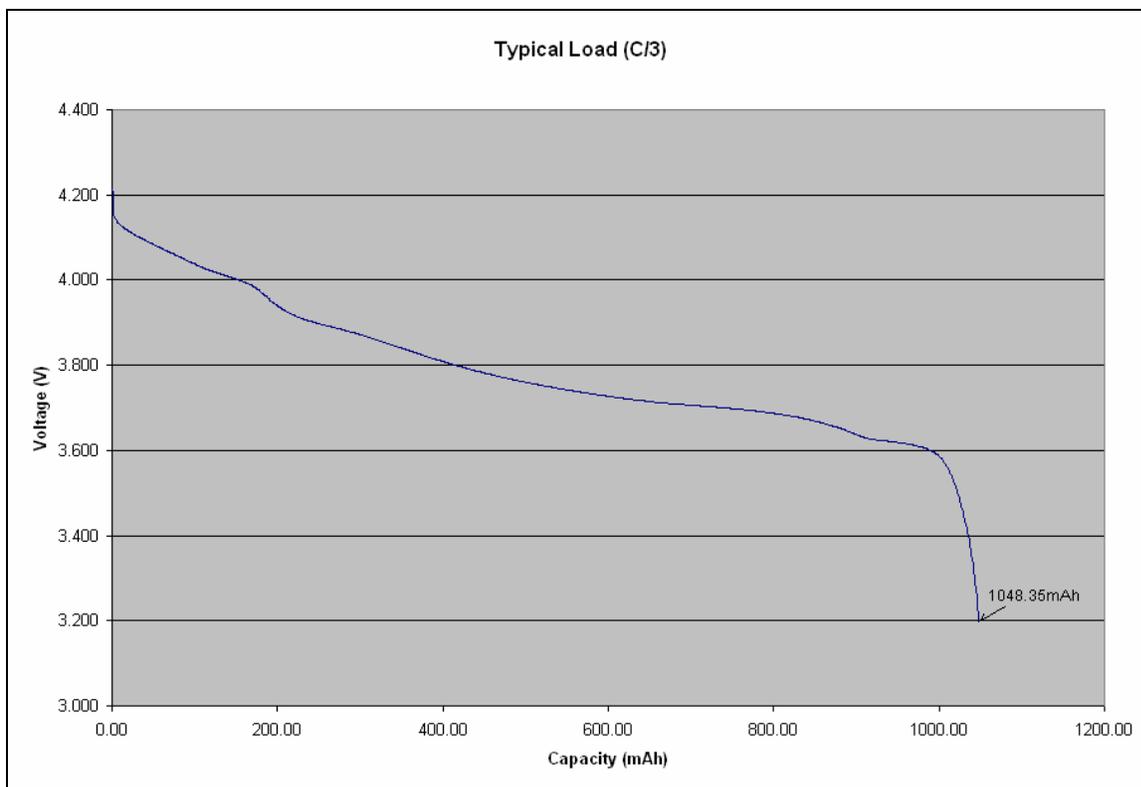
**Figure 1.    Determination of Battery Capacity**

To calculate the value that is programmed into ILMD, use Equation 1.

$$ILMD = DesignCapacity(mAh) \times \frac{Rs(\Omega)}{256 \times 0.003mVh}$$  (1)

$$ILMD = 1048.35(mAh) \times \frac{0.020(\Omega)}{256 \times 0.003mVh}$$

$$ILMD = 27.3$$

The next smaller value is 27 decimal or 0x1B hexadecimal. Setting ILMD to 0x1B corresponds to 1036.8 mAh. Setting ILMD to 28 or 0x1CD would be 1075.2 mAh which is too high. The capacity of a battery pack decreases with age. After a power-on reset (POR) in bq26500/bq26501, the high byte of LMD is initialized with the value in ILMD register. To avoid overestimating an aged battery pack after a POR event, ILMD is set lower than actual design capacity.

## 2.2   Scaled End-of-Discharge Voltage Final (SEDVF), Address 0x77

This voltage should be set to the threshold where the battery is expected to have zero capacity. As previously mentioned, the minimum operating voltage for this system is 3.2 V. To determine the value to be programmed in EEPROM, use Equation 2.

$$SEDVF = \frac{DesignEDVF(mV)}{8} - 256 \qquad (2)$$

$$SEDVF = \frac{3200(mV)}{8} - 256$$

$$SEDVF = 144$$

A value of 144 decimal or 0x90 hexadecimal is to be programmed into SEDVF.

## 2.3 Scaled End-of-Discharge Voltage First (SEDV1), Address 0x78

This voltage is at which the capacity is learned during a valid discharge cycle. Determine what voltage threshold is passed after reaching 6.25% of capacity. Note that total capacity depends on SEDVF. Take data of time, voltage, and current for discharging battery pack from a full capacity at the typical load rate.

Integrate the current over time to determine charge capacity. Calculate percentage of capacity remaining based on total capacity when discharging at typical load rate. In this case, total capacity is 1048.35 mAh. Locate at what voltage the battery pack has approximately 6.25% of capacity remaining. In this case, battery reaches 6.26% of capacity when voltage is 3.605 V.
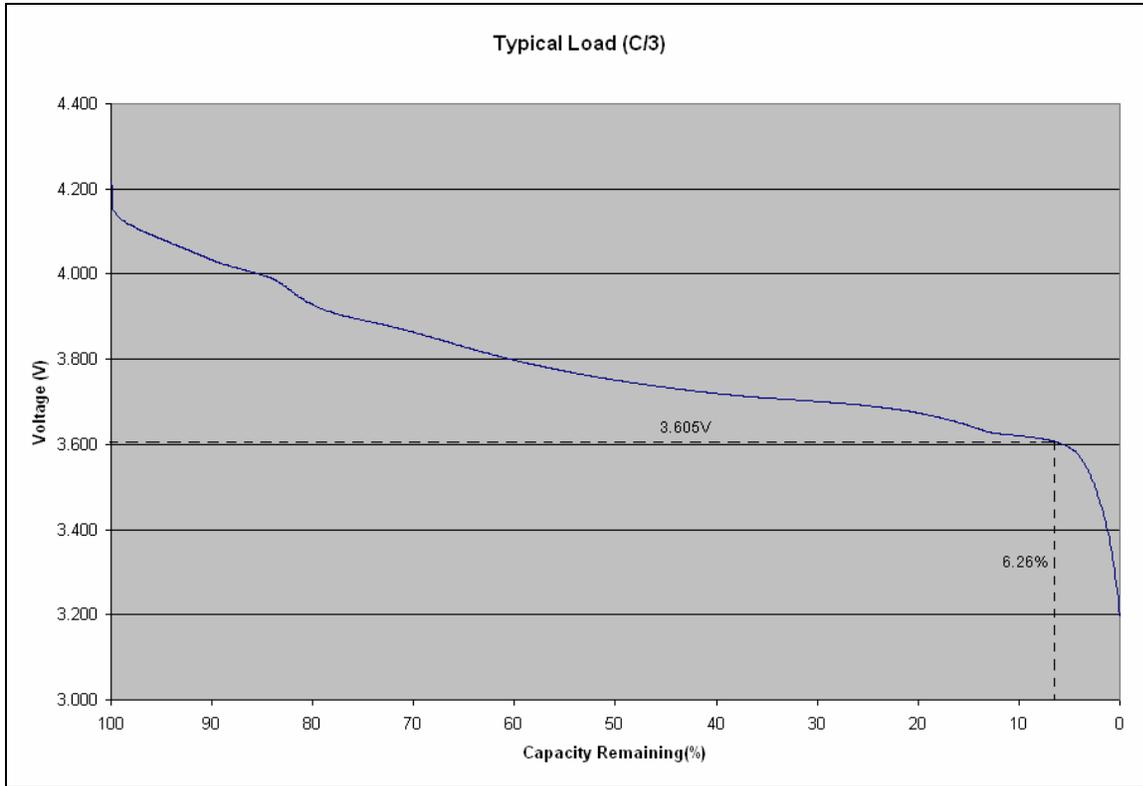
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**Figure 2. Determining SEDV1**

Equation 3 determines the value to be programmed in EEPROM.

$$SEDV1 = \frac{DesignEDV1(mV)}{8} - 256 \qquad (3)$$

$$SEDV1 = \frac{3605(mV)}{8} - 256$$

$$SEDV1 = 194.63$$

The closest value to be programmed is 195 decimal or 0xC3 hexadecimal. This value gives an actual SEDV1 level of 3608 mV.

## 2.4 Initial Standby Load Current (ISLC), Address 0x79

The bq26500 disables learning a new LMD if a learning discharge cycle terminates at SEDV1 when the average discharge current is less than or equal to two times the programmed standby load current value. Standby load current is the expected current drawn by a system when in a minimum power load. To determine this value, the system designer must know the load requirements of individual components in the system when the system seems to be in an off mode from the end customer's point of view, or when the system is in a standby mode. The best way to actually determine standby load current would be to measure the current provided by the battery to the system when turning off the system or if in standby mode (if there is a standby mode available). A standby load current of 4.5 mA is used for this example. To determine the EEPROM value for ISLC, use Equation 4.

$$ISLC = \frac{DesignStdbyCurrent(mA) \times R_S(m\Omega)}{6\mu V} \tag{4}$$

$$ISLC = \frac{4.5(mA) \times 20(m\Omega)}{6\mu V}$$

$$ISLC = 15$$

The value to be programmed in ISLC is 15 decimal or 0x0F hexadecimal.

## 2.5 Digital Magnitude Filter and Self-Discharge Rate (DMFSD), Address 0x7A

### 2.5.1 DMF

If the signal level measured between the SR pins is less than the digital magnitude filter threshold, the signal is ignored and assumed to be zero. Because of such low expected standby load currents, a digital magnitude filter threshold is selected so that it is lower than the standby load current but still high enough to ignore small signals due to offset caused by PCB layout. In this case, a value to correspond with a signal caused by a 2-mA current through a 20-mΩ load is selected. To determine the value for DMF, use Equation 5

$$DMF[3:0] = \frac{DesignThreshold(\mu V)}{6\mu V} \tag{5}$$

$$DMF[3:0] = \frac{40(\mu V)}{6\mu V}$$

$$DMF[3:0] = 6.66$$

The next smaller value is 6 decimal or 0x6 hexadecimal.

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### 2.5.2 SD

The self-discharge rate estimate sets the rate at 25°C that is used to estimate the self-discharge capacity loss in 1 day when the battery is not being charged. This rate is automatically compensated for temperature by doubling the programmed rate for every 10°C increase or halving the programmed rate for every 10°C decrease. Figure 3 shows an example of a self-discharge chart. Charts like this may be found in battery cell data sheets of cell manufacturers.
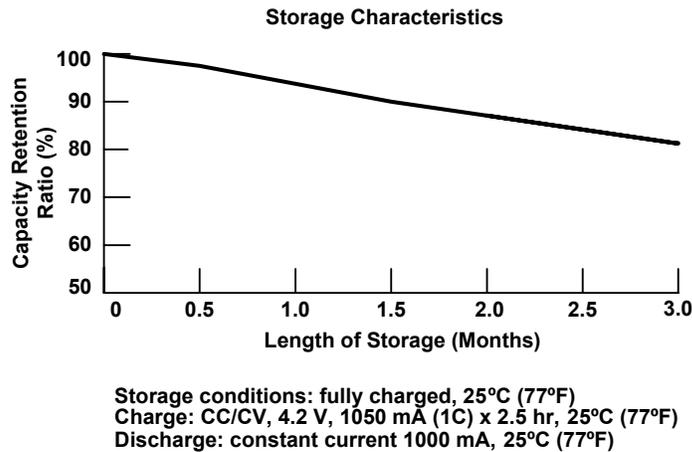
**Storage Characteristics**



Storage conditions: fully charged, 25ºC (77ºF)
Charge: CC/CV, 4.2 V, 1050 mA (1C) x 2.5 hr, 25ºC (77ºF)
Discharge: constant current 1000 mA, 25ºC (77ºF)

**Figure 3.    Self-Discharge Chart**

As Figure 3 shows, the self-discharge capacity loss in one day can be estimated. In this example, the curve seems almost linear. Notice that the capacity of cell has depleted 10% after a month and a half in storage at room temperature. With this information, the following computations are made to determine self-discharge percentage per day:

Self-Discharge % per day = 10% / 45 days

Self-Discharge % per day = 0.222% / day

Use Equation 6 for determining the EEPROM value for SD.

$$SD[3:0] = \frac{2.34}{DesignSD}$$
(6)

$$SD[3:0] = \frac{2.34}{0.222}$$

$$SD[3:0] = 10.54$$

The closest value is 11 decimal or 0xB hexadecimal.

The DMFSD register is written to for both the digital magnitude filter and self-discharge. To write the value for this register, combine the two values obtained. In this case, the value to be programmed in register 0x7A of EEPROM is 0x6B.

## 2.6 Taper Current (TAPER), Address 0x7B

The taper current threshold is typically C/20. Based on 1000-mAh battery pack, C/20=50 mA. It is preferable to program a value in EEPROM that is higher than expected threshold to ensure that the capacity is adjusted to LMD when the charger terminates. Note that value determined here is based on typical charging operation and depends on the charger. Ensure that charger has a taper current threshold lower than the value that corresponds to EEPROM. Take in consideration the tolerance for current measurement between the charger and the bq2650x. Make the necessary changes to determine appropriate TAPER register value.

In Equation 7, use 60 mA to ensure that the taper current threshold is met by the charger.

$$TAPER = \frac{DesignTaperCurrent(mA) \times R_S(m\Omega)}{192\mu V} \tag{7}$$

$$TAPER = \frac{60(mA) \times 20(m\Omega)}{192\mu V}$$

$$TAPER = 6.25$$

When selecting the closest number to the value calculated, select the one higher to ensure that the taper current is reached. In this case, the value is 7 decimal or 0x07 hexadecimal.

## 2.7 Pack Configuration (PKCFG), Address 0x7C

The pack configuration register contains parameters for different bq26500 features.

PKCFG[7]: This bit sets the state of GPIO pin when a POR occurs. If the GPIO pin is unused, the preferred setup is to set the GPIO pin as an open-drain output. This is accomplished by writing bit 7 = 0.

  PKCFG[7] = 0

PKCFG[6:5]: These bits correspond to QV1 and QV0. Four combinations are available for setting the qualification voltage. The setting chosen must be the highest threshold that can be selected but still ensures that voltage will be higher than it is at charge termination.

There will be a difference between the voltage forced by the charger and the voltage measured by bq2650x. The bq2650x bases its measurement on the actual cell, while the charger applies its regulated voltage across the battery pack (the pack voltage is distributed between the battery cell and the small voltage drop across the charge FET which is part of the pack's protection circuit). The qualification voltage threshold will be set to 4064 mV to account for any differences mentioned. Assuming the charger is set for 4200 mV with a +/-2% tolerance, the voltage could be as low as 4116 mV. The voltage measurement accuracy of bq26500 is +/-20 mV. A 4116-mV level can be measured as low as 4096 mV. The highest QV setting available lower than 4096 mV is 4064 mV.

  PKCFG[6:5] = 1 0

PKCFG[4-2]: These bits are unused by the bq26500.

PKCFG[1]: This bit (DCFIX) can be used to select a fixed discharge rate compensation value and allow the DCOMP location in EEPROM to be used for a customer identification or serial number. By testing capacity with different load rates, it was determined that the fixed discharge rate compensation could actually be an appropriate setting for the battery pack tested. See the DCOMP EEPROM register section in this document for details on how this was determined.

PKCFG[1] = 0  (With this setting, the DCOMP value must be programmed accordingly.)

PFCFG[0]: This bit (TCFIX) can be used to select a fixed temperature compensation value and allow the TCOMP location in EEPROM to be used for a customer identification or serial number. A TCOMP value will be programmed so that TCFIX will not be enabled.

PKCFG[0] = 0

By using the information in this section, the value determined to program in PKCFG is 64 decimal or 0x40 hexadecimal.

## 2.8  Identification Byte #3 (ID3), Address 0x7D

This register may be programmed to any desired value. The contents do not affect the operation of the bq26500.

## 2.9  Discharge Rate Compensation Constants (DCOMP), Address 0x7E

High discharge rates may decrease the capacity of a battery as shown in Figure 4. Notice how with the C-rate load, the cell capacity is less than with the C/2 or C/4 rate.
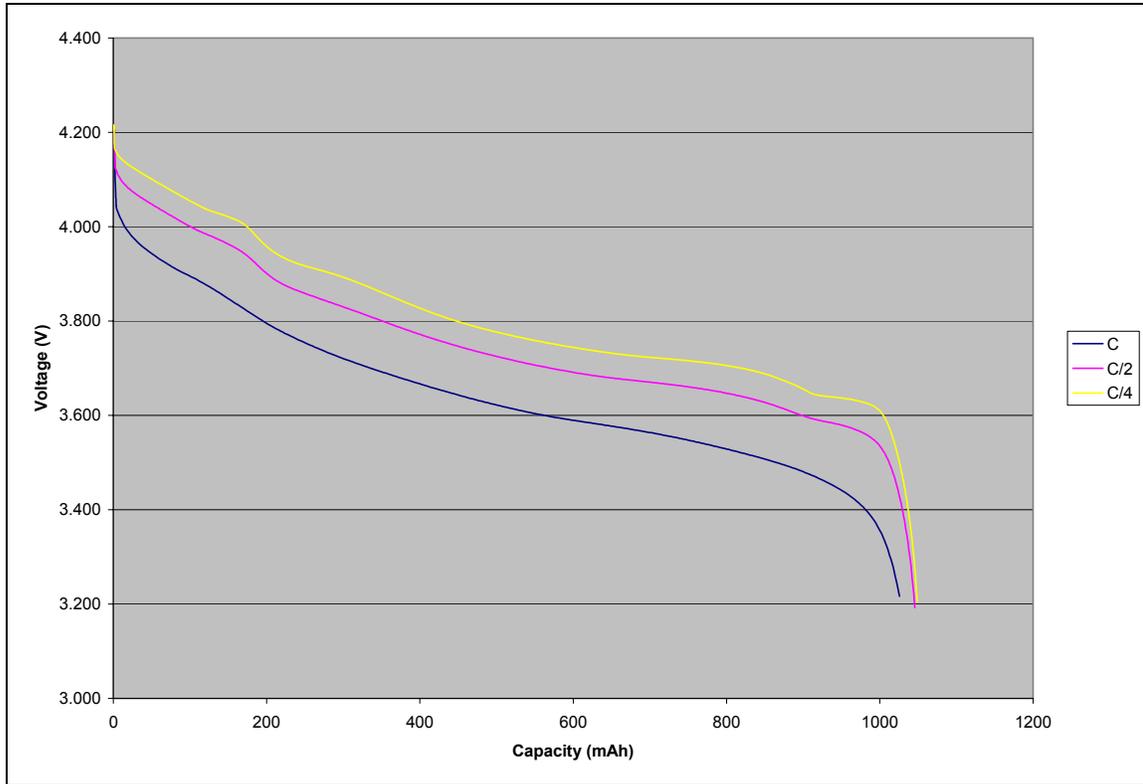
**Figure 4.  Discharge Profiles for Different Load Rates**

The DCOMP value in EEPROM sets the factors used to calculate the reduction in NAC due to load current. The resulting CACD value is the available capacity, compensated for discharge rate. If DCFIX in the PKCFG register is set to 1, a default compensation of 6.25% of the discharge current that exceeds C/4 is used for the discharge rate compensation factor, and the value in the DCOMP location is ignored. The default discharge rate compensation is equivalent to programming DCOMP with 0x42.

As part of the battery testing plan, data must be taken to at least determine battery capacity when discharging at C, C/2, C/4, and typical load rates. Use data to plot capacity as a function of discharge rate.

Set a horizontal line at the level that is programmed at ILMD. For this example, that would be 1036.8 mAh. Using the capacity as a function of discharge rate curve, go along the discharge rates that are used as thresholds to set DCOFF (0, C/2, C/4, and C/8). Determine the decrease in capacity at each of the thresholds. The data used for this application note presents only a 0.291% decrease in capacity when discharging at C/2 rate. Use C/2 as the threshold to be programmed for DCOFF. In any other case, use as the threshold the first rate from which the capacity decreases at least 2% from maximum capacity.

Evaluate the capacity as a function of discharge rate curve, up to just above the highest rate that is expected to be used by the battery-powered system. Determine the percentage decrease per C rate from the discharge threshold to just above the highest rate expected. In this case, the discharge curve was 1045.63 mAh at C/2 and 1025.60 mAh at C. That is a 1.92% decrease in a 0.5C interval, for which the percentage decrease per C rate is 3.83%/C. See Figure 5.
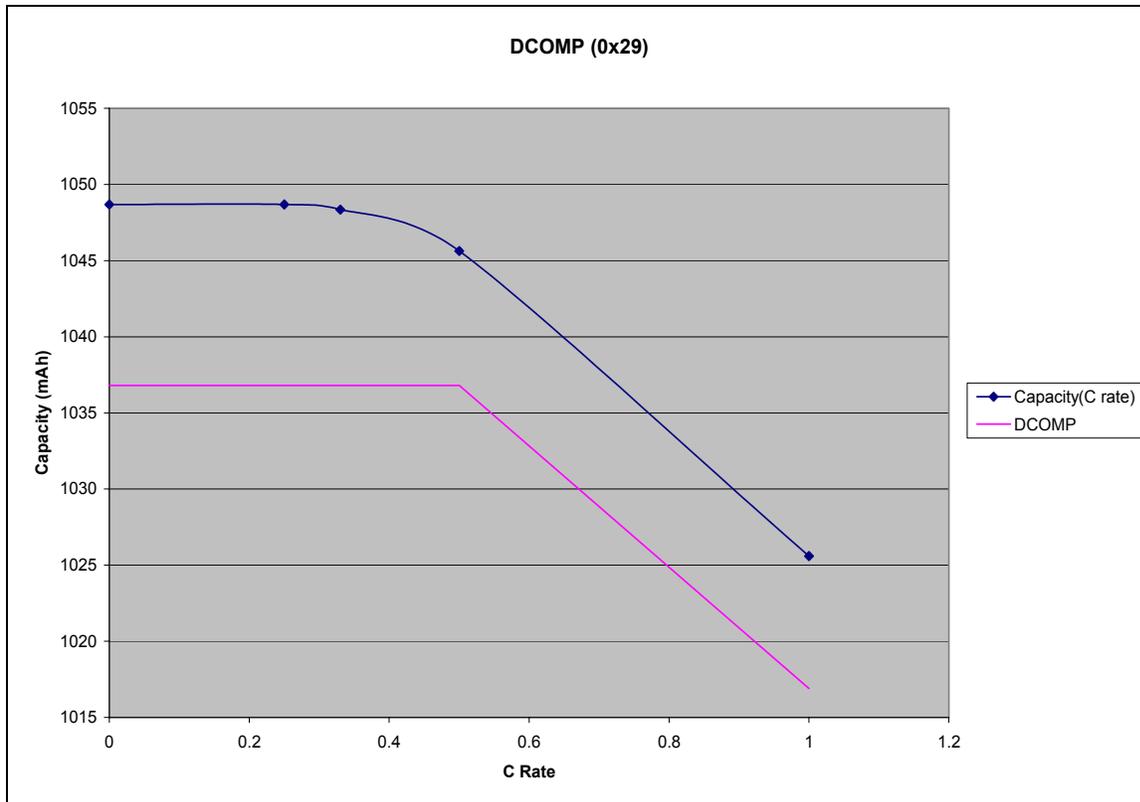
**Figure 5.  Curves Used to Determine DCOMP**

All the information needed to determine the value to be programmed into DCOMP EEPROM register has been obtained. The DCOMP register is composed of DCGN[5:0] and DCOFF[1:0]. Using Table 4 of bq26500 or bq26501 data sheet for a threshold of C/2 the DCOFF = [0 1]. Equation 8 is used to determine DCGN[5:0].

$$DCGN[5:0] = 2.56 \times DesignCompensationGain\% \qquad (8)$$

$$DCGN[5:0] = 2.56 \times 3.83\%$$

$$DCGN[5:0] = 9.8$$

The closest integer value is 10. DCGN[5:0] = [0 0 1 0 1 0].

By combining DCGN and DCOFF, it is determined that DCOMP = [0 0 1 0 1 0 0 1] = 0x29.

## 2.10  Temperature Compensation Constants (TCOMP), Address 0x7F

In the DCOMP section of this document, it is noted that high discharge rates have an effect on the capacity of a battery. Exposing a battery to cold temperatures has the same effect on batteries. Figure 6 shows that as temperatures decreases, the capacity of the cell diminishes considerably.
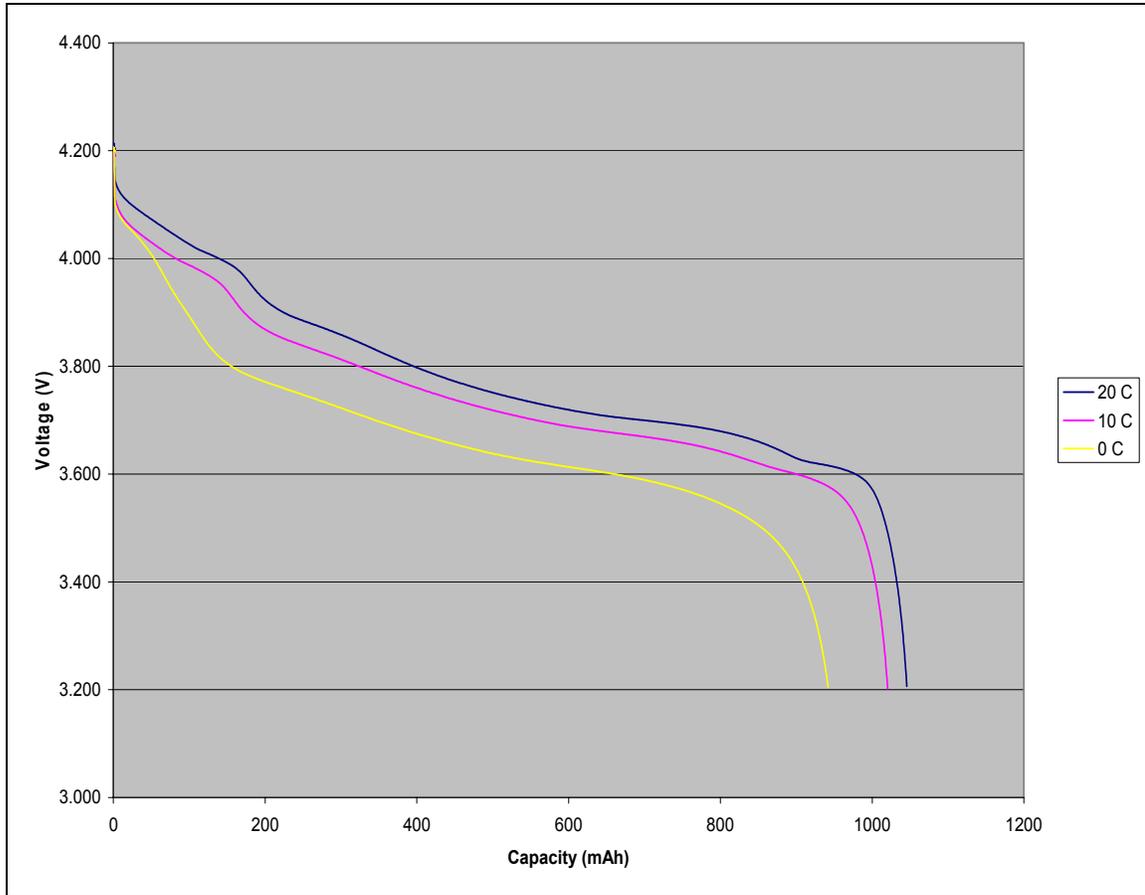
**Figure 6.  Discharge Profiles for Different Temperature Rates**

The TCOMP value in the EEPROM sets the factors used to calculate the reduction in CACD due to temperature. The resulting CACT value is the available capacity, compensated for by both discharge rate and temperature. The EEPROM value may alternatively be used for a customer identification number or serial number, if TCFIX (bit 0 in PKCFG) is set to 1. When this option is used, a default compensation of 0.6836% of design capacity per degree C below 12°C is used for the temperature compensation factor, and the value in the TCOMP location is ignored. The 12°C threshold also is used to disqualify any learning cycles where the temperature is less than or equal to 12°C. The default temperature compensation is equivalent to programming TCOMP with 0x7C.

Plot a capacity as a function of temperature curve. The temperature rates used can be chosen depending on the resolution desired of the capacity curve. As an example for this document the rates used were 20, 10, 0, and -10°C while discharging at a proposed typical load rate of 330 mA. A procedure similar to determining DCOMP is used to determine the TCOMP constants.

See Figure 7 for the following explanation. The TOFF for this example was chosen to be 10°C because the capacity decreases at least 2.65% from the capacity when discharging at typical load rate and at room temperature. By choosing TOFF to be 10°, this temperature also is being used as the cold temperature disqualification for learning cycle.
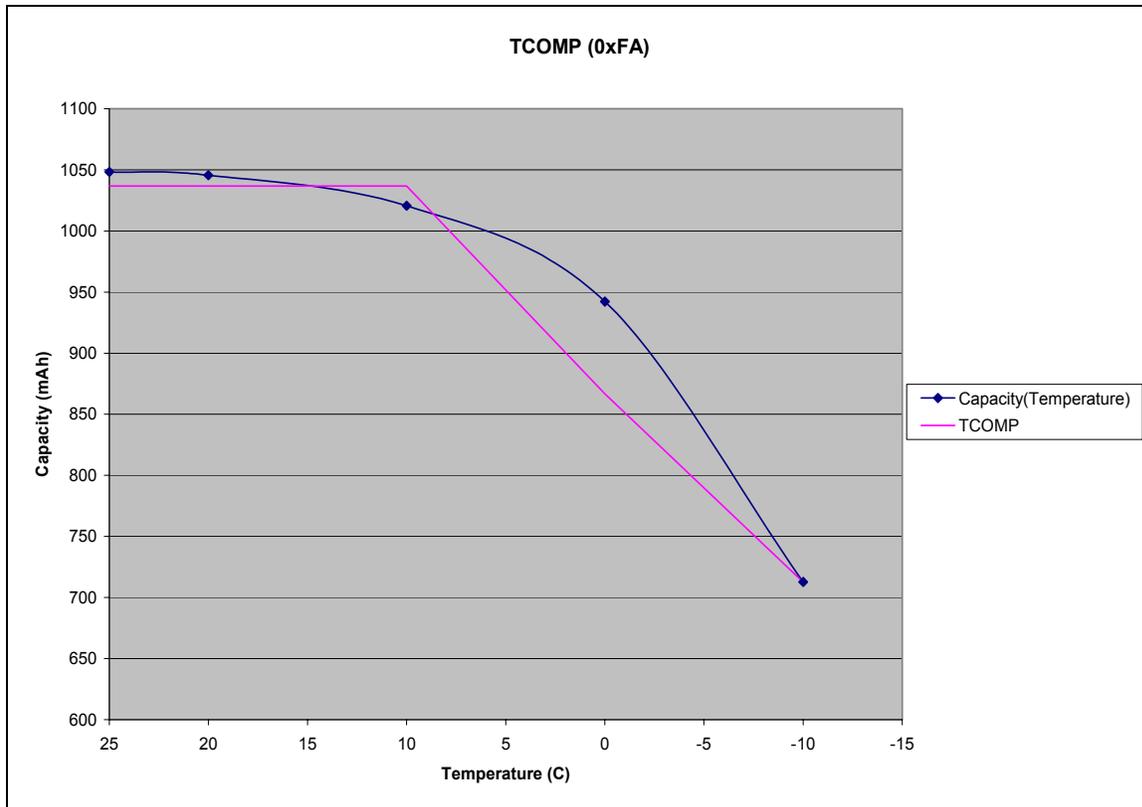
**Figure 7.    Curves Used to Determine TCOMP**

To determine TCGN, find an average slope that describes the percentage decrease of capacity per °C. Due to that this curve does not have a constant slope from the point where TCOFF was set to capacity at minimum temperature tested, the slope was chosen by using the ILMD capacity at TCOFF and the minimum capacity of the curve as the end points of the slope. If there were an interest in just the temperatures above 0°C, a less steep slope could have been used to accommodate that portion of the curve where it is more linear (see Figure 8). It is up to the battery pack designer to decide temperature range of interest. Using the curve shown in Figure 7 as an example, the slope is determined to be 1.56% per °C.
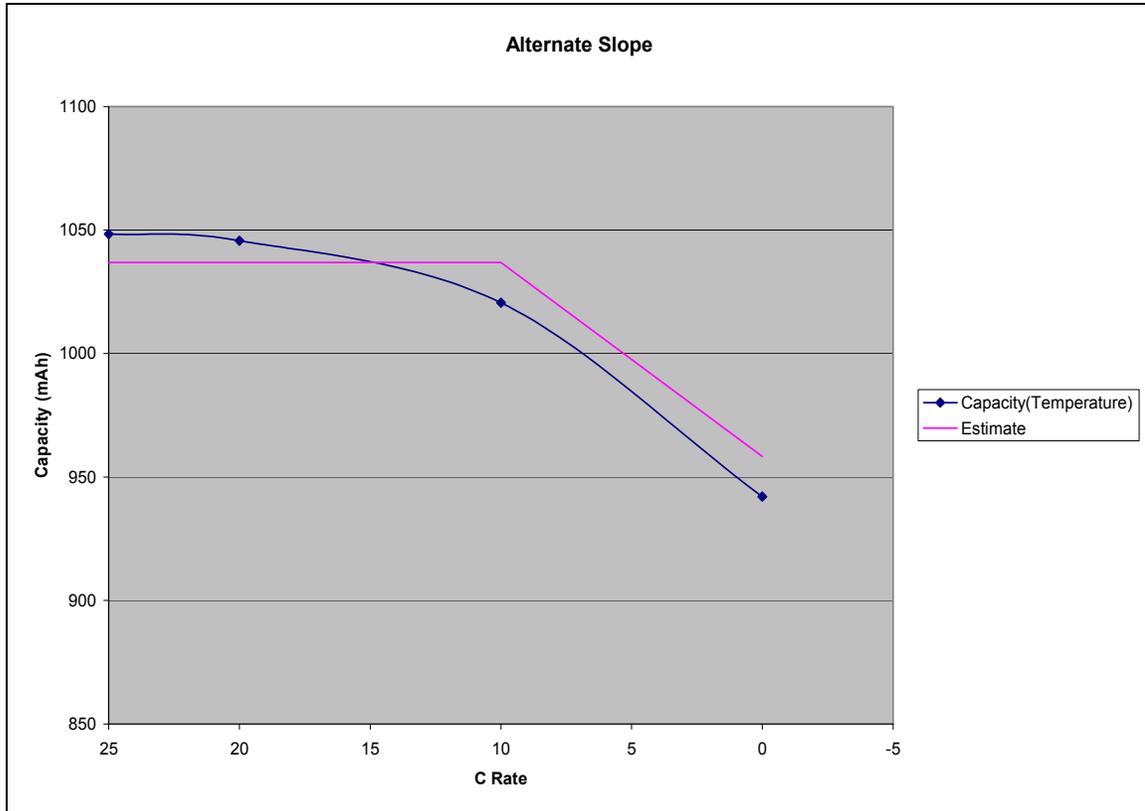
**Figure 8. Using 0°C as Minimum Temperature**

All the information needed to determine the value to be programmed into TCOMP EEPROM register has been obtained. The TCOMP register is composed of TCGN[3:0] and TCOFF[3:0]. Equation 9 is used to determine TCGN[3:0].

$$TCOFF[3:0] = DesignTemperatureCompensationOffset(^o K) - 273 \qquad (9)$$

$$TCOFF[3:0] = 283(^o K) - 273$$

$$TCOFF[3:0] = 10$$

$$TCOFF[3:0] = [1010]$$

Equation 10 is used to determine TCGN[3:0].

$$TCGN[3:0] = 10.24 \times DesignTempCompensationGain\%DC/^o C \qquad (10)$$

$$TCGN[3:0] = 10.24 \times 1.56\%DC/^o C$$

$$TCGN[3:0] = 15.96$$

The maximum value possible is 15.

By combining TCGN and TCOFF, it is determined that TCOMP = [1 1 1 1 1 0 1 0] = 0xFA.

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