Texas Instruments

Application Report

SLUA429 – July 2007

Transition From Prior bqJunior Gauges to the bq27x10

Bill Jackson

Algorithm changes in the bq27x10 gas gauge allow it to achieve improved accuracy over its predecessors. The algorithm improvements include improved remaining capacity compensation at cold temperature, age compensation of remaining capacity, and rate and temperature compensation of the EDV1 threshold.

The bq27x10 does not compute the maximum load current, maximum load time-to-empty, available energy, and average power functions that are available in the bq27x00, but all other functions are retained, including the time-to-empty at constant power function that is computed from the energy and power values in the bq27x00. The at-rate time-to-empty function can be utilized by the host in place of maximum load time-to-empty. The host can also compute available energy and average power if needed.

Table 1. Memory Map Comparison

Address	bq2650x	bq27x00	bq27x10
0x00/0x01	CTRL/MODE Limited command set	CTRL/MODE A few added commands	CTRL/MODE Extensive command set
0x02/0x03	AR (3.0uV)	AR (3.57uV)	AR (3.57uV)
0x04/0x05	ARTTE	ARTTE	ARTTE
0x06/0x07	TEMP	TEMP	TEMP
0x08/0x09	VOLT	VOLT	VOLT
0x0A	FLAGS	FLAGS	FLAGS
0x0B	RSOC	RSOC	RSOC
0x0C/0x0D	NAC (3.0uVh) Ref. to learned LMD	NAC (3.57uVh) Ref. to learned LMD	NAC (3.57uVh) Uncompensated
0x0E/0x0F	CACD (3.0uVh) Rate compensated	CACD (3.57uVh) Rate compensated	LMD (3.57uVh) Uncompensated full capacity
0x10/0x11	CACT (3.0uVh) Rate and temperature compensated	CACT (3.57uVh) Rate and temperature compensated	CAC (3.57uVh) Rate and temperature compensated
0x12/0x13	LMD (3.0uVh) Last learned capacity	LMD (3.57uVh) Last learned capacity	FCAC (3.57uVh) Dynamic rate and temperature compensated full capacity
0x14/0x15	RSVD	AI (3.57uV)	AI (3.57uV)
0x16/0x17	RSVD	TTE	TTE
0x18/0x19	RSVD	TTF	TTF
0x1A/0x1B	RSVD	SI (3.57uV)	SI (3.57uV)
0x1C/0x1D	RSVD	STTE	STTE
0x1E/0x1F	RSVD	MLI (3.57uV)	RSVD
0x20/0x21	RSVD	MLTTE	CEDV
0x22/0x23	RSVD	SAE	RSVD
0x24/0x25	RSVD	AP	RSVD
0x26/0x27	RSVD	TTECP	TTECP
0x28/0x29	RSVD	CYCL	CYCL
0x2A/0x2B	RSVD	CYCT	CYCT
0x2C	RSVD	CSOC	CSOC

Table 2. EEPROM Memory Map Comparison

Address	bq2650x	bq27x00	bq27x10
0x76	ILMD (768uVh)	ILMD (914uVh)	ILMD (914uVh)
0x77	SEDVF	SEDVF	SEDVF
0x78	SEDV1 (at typical load)	SEDV1 (at typical load)	SEDV1 (at light load)
0x79	ISLC (6.0uV)	ISLC (7.14uV)	MSN: ISLC (57.1uV) LSN: EDVT
0x7A	MSN: DMF (6.0uV) LSN: SD (2.34/SDR)	MSN: DMF (4.9uV) LSN: SD (1.61/SDR)	MSN: DMF (4.9uV) LSN: SD (1.61/SDR)
0x7B	Bits7:0: TAPER (192uV)	Bits6:0 TAPER (228uV) Bit7 Enab. LMD aging	Bits6:0 TAPER (228uV) Bit7 Enab. LMD aging
0x7C	PKCFG Bits4:2: RSVD	PKCFG Bits4:2 Board offset	PKCFG Bits4:2 Board offset
0x7D	ID#3	IMLC or ID#3	Bits7:6 Gain Age Factor Bits5:0 EDV1 Dsg Cmp
0x7E	Bits7:2 Dsg Cmp Gain Bits1:0 Dsg Cmp Offset	Bits7:2 Dsg Cmp Gain Bits1:0 Dsg Cmp Offset	Bits7:3 Dsg Cmp Gain Bits2:0 Dsg Cmp Offset
0x7F	MSN: Tmp Cmp Gain LSN: Tmp Cmp Offset	MSN: Tmp Cmp Gain LSN: Tmp Cmp Offset	Bits7:3 Tmp Cmp Gain Bits2:0 Tmp Cmp Offset

Units: The bq27xx0 reports capacity with a resolution of 3.57uAh per lsb compared to the 3.0uAh per lsb reported from the bq2650x. This scale factor change applies to the raw values read or written to the gauge. The TI evaluation software for the bq27xx0 will make the correct conversion from native units to engineering units if the engineering unit display is enabled and the correct sense resistor value is entered.

CTRL/MODE: The bq27x10 is backward compatible with the bq27x00 and bq2650x and executes all the same MODE commands. The bq27x10 includes additional commands to change LMD and CYCT and to change the values in RAM from their EEPROM-initialized values. The bq27x10 uses MODE[2] as an INIT flag to indicate to the host that any changes made in RAM to the EEPROM-initialized values have been lost and that the new values need to be rewritten. The bq27x00 executes all the MODE commands available in the bq2650x, and also includes offset calibration commands useful in determining whether a non-zero board offset needs to be programmed in PKCFG.

NAC/LMD: NAC is the uncompensated available capacity in the bq27x10 and indicates the available capacity at a light load, where impedance drops are negligible. NAC is never allowed to increase above LMD when charging. LMD is the full capacity at light load in the bq27x10. In the earlier bq27x00 and bq2650x gauges, LMD is the learned capacity determined by the load conditions present when EDV1 is detected during the learning cycle. NAC is likewise capped at LMD in these earlier gauges and reports available capacity based on that previous load condition when LMD was last learned.

CACT/CAC: CACT and CAC are both available capacity compensated for discharge rate and temperature. The cold temperature compensation is improved in the bq27x10. CAC also is compensated with age (cycle count).

FCAC: FCAC is the full capacity of the battery at the present discharge rate, temperature, and cycle count. When a learning cycle occurs, LMD is adjusted so that the FCAC value computed using the programmed compensation values equals the measured capacity at the load and temperature conditions present when EDV1 is detected. FCAC is a dynamic value and fluctuates as the load and temperature conditions vary.

MLI/MLTTE/SAE/AP: These functions are available only in the bq27x00. The bq27x10 is functionally compatible with the bq27x00 if these functions are not needed by the host. The host can write the equivalent MLI value to AR. ARTTE then reads the expected time-to-empty at the max load current value written by the host. The bq27x10 does not provide the available energy and average power functions, but doe provide the TTECP function that is mathematically equivalent to the same function in the bq27x00.

CEDV: The CEDV function available in the bq27x10 may aid the validation of proper EDV1 rate and temperature compensation coefficients during initial evaluation of the bq27x10.

CSOC: The compensated state-of-charge available in the bq27xx0 parts is more useful than RSOC, because it comprehends the expected reduction in the available capacity set by the various compensation coefficients.

Programming the EEPROM

ILMD: The Initial last measured discharge (ILMD) value is the design capacity (DC) of the battery. The bq27x00 and bq2650x should be programmed to a conservative value for the capacity expected at nominal load. This is usually less than the manufacturer's published DC for the battery unless typical load currents are C/5 or less. There is an 84% scale factor difference between the native units of these two parts. The bq27x10 ILMD value should be the DC at light load. The manufacturer's data sheet DC value, usually measured at C/5, is probably a good value to use.

SEDVF: The zero capacity voltage threshold is usually set by the minimum system operating voltage, and may include some safety factor.

SEDV1: EDV1 is the voltage threshold where the remaining battery capacity is 6.25% of DC. The EDV1 threshold for the bq2650x and bq27x00 should be set using nominal or maximum load conditions. The EDV1 threshold for the bq27x10 should be set using a light load condition. The compensated EDV1 coefficients should be chosen to reduce the EDV1 threshold under load and at cold temperatures to the value that corresponds to a remaining capacity equal to 6.25% of DC.

ISLC: The initial standby load current (ISLC) value is only used by the bq2650x to disqualify learning if average current is less than 2*ISLC. The bq27xx0 retains this function, and also computes an adaptive SI value that is the long-term average of AI, whenever 0 < AI < 2*ISLC. The value for ISLC is not critical, as long as 2*ISLC is less than the minimum current in a non-standby operating mode. The bq27x10 only uses bits 4, 5, and 6 of EEPROM address 0x79 (bit 7 must be zero) and has more granularity in setting the initial standby current value than in the bq27x00 or bq2650x.

EDVT: EDVT is the temperature coefficient adjustment for the EDV1 threshold in the bq27x10. If EDVT=0, there is no adjustment of EDV1 with temperature. The temperature compensation adjustment is made by increasing the programmed EDV1 discharge rate compensation, so that the temperature adjustment of EDV1 is proportional to AI.

The EDVT compensation increases the EDV1 rate compensation gain (DEDV) programmed in 0x7D in increments of 0.78% (EDVT/128) per degree for each degree below the TOFF threshold programmed in TCOMP. For example: If EDVT=8 (6.25%/°C), DEDV=23 (184mV/1C-rate), TOFF=12°C, and TEMP=0°C, EDV1 will be reduced by 184mV*[1+(12°C – 0°C)*(8/128)] = 184mV*1.75 = 322mV at a 1C load, compared with only a 184mV reduction at 12°C and warmer temperatures.

DMF/SD: The digital magnitude filter (DMF) and self-discharge (SD) EEPROM values are programmed the same way for all bqJunior parts except for a scale factor difference in the bq2650x.

TAPER: The taper current threshold is programmed the same way for all bqJunior parts except for a scale factor difference in the bq2650x. Bit 7 is used in the bq27xx0 parts to enable an LMD age reduction algorithm. If there is no learning cycle to learn a new LMD, the age reduction algorithm decreases LMD slightly with cycle count and also with self-discharge to keep LMD more conservative. Setting bit 7 in the bq27xx0 parts is recommended for most applications.

PKCFG: The pack configuration (PKCFG) program word is similar for all the bqJunior parts. Bits 2, 3, and 4 are unused in the bq2650x. These bits are used to program a board offset value in the bq27xx0 parts. The typical value for this board offset is 0. The TI evaluation software can be used to evaluate whether a non-zero board offset value in PKCFG will improve the accuracy of low value current measurements.

Bits 5, 6, and 7 perform the same function in all bqJunior parts. Bits 0 and 1 also perform the same function in all bqJunior parts, but the default rate and temperature compensation values enabled in the bq27x10 has been set to compensate at a lower rate to reflect some of the newer cells available on the market. If the default compensation values are used on a prior design using the bq2650x or bq27x00 and achieve good results, the equivalent compensation can be achieved using the bq27x10 by setting bits 0 and/or 1 to zero and then programming DCOMP and TCOMP to achieve the desired compensation.

The default DCOMP value in the bq2650x and bq27x00 is 6.25% discharge compensation gain at load currents above C/4 and is equivalent to setting DCOMP=0x42. The default DCOMP value in the bq27x10 is 5.08% discharge compensation gain at load currents above C/2 and is equivalent to setting DCOMP=0x6C. If the 6.25% gain and C/4 offset values are desired in the bq27x10, DCOMP can be programmed to 0x82. The programmed value is different to achieve the same compensation, as the coefficient scaling is different than in the earlier gauges.

The default TCOMP value in the bq2650x and bq27x00 is 0.68% of DC per degree below 12°C and is equivalent to setting TCOMP=0x7C. The default TCOMP value in the bq27x10 is a 25% increase in the discharge compensation gain (DCGN) per degree below 12°C and is equivalent to setting TCOMP=0x46. Since the temperature compensation in the bq27x10 is proportional to current, it is not possible to achieve an equivalent compensation to the bq2650x or bq27x00 temperature compensation except at a specific load condition. If the bq27x10 is programmed with DCOMP=0x82 to match the default compensation in the bq27x00 or bq2650x, the default TCOMP value of 0x46 will provide a very similar temperature compensation at a load current of C/3.

IMLC: The initial maximum load current is only used on the bq27x00 and sets the max load current (MLI) used to compute maximum load time-to-empty (MLTTE). The MLI value will be increased from the initial EEPROM value to any larger AI value measured by the gauge. This function is not present on the bq2650x or bq27x10. If the host knows the expected maximum load current, it can write that value to AR and read the ARTTE value. The host can determine the maximum load current if required, by simply reading AI from time to time and recording the maximum value it reads.

DEDV: The EDV1 discharge compensation coefficient is programmed in the lower six bits of EEPROM address 0x7D of the bq27x10. This value is the desired EDV1 reduction with current, programmed in units of 8mV reduction per 1C-rate current. For example, if an EDV1 reduction of 92mV is desired at a load current of C/2 (without compensation for cold temperature), then DEDV should be programmed for 184mV/8 = 23 (0x17). EDV1 cannot be compensated in the bq2650x or bq27x00.

GAF: The gain age factor (GAF) is programmed in the upper two bits of EEPROM address 0x7D of the bq27x10. This function does not exist in the bq27x00 or bq2650x. If GAF=0, there is no adjustment of compensated capacity with age (cycle count). If GAF=1, the discharge compensation gain factor (DCGN) programmed in DCOMP is linearly increased by a factor equivalent to the programmed temperature compensation at 12°C below the TOFF value programmed in TCOMP as cycle count (CYCT) increases by 192 cycles. The age compensation occurs two or three times faster (with proportionally fewer cycle counts) if GAF equals 2 or 3, respectively. Programming GAF=1 should give reasonably conservative results for most applications.

DCOMP: The discharge compensation (DCOMP) method and scaling is identical in the bq2650x and bq27x00. DCOMP in the bq27x10 uses the same general compensation method, but uses three bits instead of two to allow increased range for the discharge compensation offset (DCOFF). DCOFF can be set in increments of C/8 from 0 to 7C/8 in the bq27x10. The discharge compensation gain (DCGN) scaling remains the same (0.39% per step), but the maximum compensation value is reduced to 12.1% (DCGN=31).

TCOMP: The temperature compensation (TCOMP) method and scaling is identical in the bq2650x and bq27x00. TCOMP in the bq27x10 uses a completely different method and is now used to scale the DCGN compensation value. This makes the temperature compensation proportional to current, so it is essentially an impedance-based compensation and more closely matches the actual performance of the battery at cold temperature.

There is no compensation for cold temperature applied if the temperature is greater than the temperature offset (TOFF) threshold programmed in TCOMP. TOFF is programmed in the 3 lsbs of TCOMP. The actual offset temperature in °C is equal to twice the value programmed in the 3 lsbs, so 12°C would be programmed as a 6 in these three bits (xxxxx110). The temperature compensation gain (TCGN) factor programmed in the upper five bits of EEPROM address 0x7F adjusts the rate compensation gain (DCGN) factor by 3.125% per degree below TOFF for each count in TCGN. For example, if TCGN=8 and TOFF=6, DCGN will increase by 25% for each degree that temperature falls below 12°C.

TOFF also is used to disqualify a learning cycle if temperature is below this threshold in the bq2650x and bq27x00. The cold temperature learning disqualification is fixed at 0°C in the bq27x10.

Example EEPROM comparison: Table 3 shows approximately equivalent EEPROM content for the same battery back for each of the bqJunior products. The additional coefficients and improved algorithms allow improved overall accuracy under wide dynamic operating conditions as the user transitions from a bq2650x product to a bq27xx0 or from a bq27x00 to a bq27x10.

Table 3. Example EEPROM Comparison

<table>
<tr><th>Address</th><th>bq2650x</th><th>bq27x00</th><th>bq27x10</th></tr>
<tr><td rowspan="2">0x76</td><td colspan="3">DC = 2000mAh @ C/5, DC = 1900mAh @ expected C/2 load, Rsr = 20mohms</td></tr>
<tr><td>DC = 1900mAh
ILMD = 0x34</td><td>DC = 1900mAh
ILMD = 0x2A</td><td>DC = 2000mAh
ILMD = 0x2C</td></tr>
<tr><td>0x77</td><td>EDVF = 3000mV
SEDVF = 0x77</td><td>EDVF = 3000mV
SEDVF = 0x77</td><td>EDVF = 3000mV
SEDVF = 0x77</td></tr>
<tr><td rowspan="2">0x78</td><td colspan="3">Set EDV1 = 3248mV at typical C/2 load (DEDV = 304mV/C-rate)
Set EDV1 = 3248mV + 304mV/2 = 3400mV at no load, bq27x10 only</td></tr>
<tr><td>EDV1 = 3248mV @ C/2
SEDV1 = 0x96</td><td>EDV1 = 3248mV @ C/2
SEDV1 = 0x96</td><td>EDV1 = 3400mV (AI=0)
SEDV1 = 0xA9</td></tr>
<tr><td rowspan="2">0x79</td><td colspan="3">Standby Current = 10mA, Rsr = 20mohms
Reduce EDV1 by 114mV at 0°C @ C/2 (DEDV = 304mV/C-rate, TOFF = 12°C)</td></tr>
<tr><td>ISLC = 0x21
EDVT = N/A</td><td>ISLC = 0x1C
EDVT = N/A</td><td>ISLC = 0x4
EDVT = 0x8
SI/EDVT = 0x48</td></tr>
<tr><td rowspan="2">0x7A</td><td colspan="3">Digital Magnitude Filter = 24uV, Self-discharge = 0.2%/day @ 25°C</td></tr>
<tr><td>DMF = 0x4
SD = 0xC
DMF/SD = 0x4C</td><td>DMF = 0x5
SD = 0x8
DMF/SD = 0x58</td><td>DMF = 0x5
SD = 0x8
DMF/SD = 0x58</td></tr>
<tr><td rowspan="2">0x7B</td><td colspan="3">Taper current threshold = C/20 (100mA), Rsr = 20mohms</td></tr>
<tr><td>AGEN = N/A
TAPER = 0x0B</td><td>AGEN = 1
TAPER = 0x09
AGEN/TAPER = 0x89</td><td>AGEN = 1
TAPER = 0x09
AGEN/TAPER = 0x89</td></tr>
<tr><td>0x7C</td><td>GPIEN = 0
QV = 3
BOFF = N/A (0)
DCFIX = 0
TCFIX = 0
PKCFG = 0x60</td><td>GPIEN = 0
QV = 3
BOFF = 0
DCFIX = 0
TCFIX = 0
PKCFG = 0x60</td><td>GPIEN = 0
QV = 3
BOFF = 0
DCFIX = 0
TCFIX = 0
PKCFG = 0x60</td></tr>
<tr><td rowspan="2">0x7D</td><td colspan="3">Max Load Current = 1500mA, Rsr = 20mohms, Recommended GAF value = 1,
Set EDV1 compensation for 304mV/C-rate (must determine from battery data)</td></tr>
<tr><td>ID#3 = Customer ID
IMLC = N/A
GAF = N/A
DEDV = N/A</td><td>ID#3/IMLC = 0x42
GAF = N/A
DEDV = N/A</td><td>ID#3/IMLC = N/A
GAF = 1
DEDV = 0x26
GAF/DEDV = 0x66</td></tr>
<tr><td rowspan="2">0x7E</td><td colspan="3">No discharge rate compensation below C/4
Discharge rate compensation of 6.25% above C/4
Must determine compensation values from battery data</td></tr>
<tr><td>DCGN = 0x10
DCOFF = 2
DCOMP = 0x42</td><td>DCGN = 0x10
DCOFF = 2
DCOMP = 0x42</td><td>DCGN = 0x10
DCOFF = 2
DCOMP = 0x82</td></tr>
<tr><td rowspan="2">0x7F</td><td colspan="3">No temperature compensation above 12°C, DCGN = 6.25%
Temperature compensation of 0.68% of DC per °C below 12°C at C/2 typ load
Must determine compensation values from battery data</td></tr>
<tr><td>TCGN = 0x7
TOFF = 0xC
TCOMP = 0x7C</td><td>TCGN = 0x7
TOFF = 0xC
TCOMP = 0x7C</td><td>TCGN = 0x05
TOFF = 6
TCOMP = 0x2E</td></tr>
</table>