Application Report
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Turbo Mode 1.0 Setup Steps

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ABSTRACT

This document details the method used to obtain and implement the Turbo Mode 1.0 parameters required to accurately determine peak power deliverables from a power source (battery pack).

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1 Introduction

Turbo Mode 1.0, along with a combination of 8 SBS commands and 10 data flash registers, allows the bq40zxx gas gauge to provide necessary data for the MCU. The MCU must decide what level of peak power consumption can be exercised without causing a system reset, or transient battery voltage level excursion to trigger termination flags.

2 Setup Steps

An example of implementation in the bq40z DF registers is referenced as follows (all values must correspond to the customer configuration of number of cells and measurements made in the following section). These values must be set up for the proper operation of Turbo Mode 1.0.

- **Min Turbo Power**

  Minimum Turbo mode level after all higher levels are disabled (expected at the end of discharge, see Table 1). The negative value is expected. Units: cW.

Table 1. Min Turbo Power

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	Min Turbo Power	I2	–32767	32767	0	cW

  This value is application dependent, and the customer must determine at which power level turbo mode will no longer be applicable in their application. The default is set to 0 only as a demonstration of the Turbo mode down to 0 power, but typically this is a nonzero negative value equal to the base discharge power.

- **10 mSec Max C-Rate**

  Maximum discharge current for 10 ms (see Table 2). Units: 0.1C-Rate Ω

Table 2. Max C-Rate

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	10 mSec Max C-Rate	I1	–12.7	0	–4.0	0.1 C-Rate

  This value is typically set to –4.0C. This value is used to guide the maximum peak power (MPP) of the system (for 10 ms). If required, this value can be adjusted to better reflect the application requirements for the discharge rate that must be sustained for 10 ms.

- **Turbo Adjustment Factor**

  The resistance correction factor, that if used would be a one-time adjustment that the customer would compute from a 10-s pulse test (see Table 3). Units: none

Table 3. Turbo Adjustment Factor

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	Turbo Adjustment Factor	U1	0.5	1.5	1.00	—

  Turbo adjustment factor is a data flash parameter used to enhance the accuracy of the reported peak powers and currents. This parameter is defined as the ratio of the reported sustained peak power (SPP) to the applied power, or the sustained peak power current (SPPC) to the applied current at the instant when the system voltage becomes equal to the minimum system voltage (DF. Term Voltage). This adjustment factor is modified by the user if the reported SPP or SPPC exceeds the applied power or current, which causes the system voltage to hit termination. This factor is primarily used to account for the error associated with the 10-second effective resistance arising from the unaccounted rate dependence.

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Figure 1 shows a scenario where the gauge over estimates the SPPC. The turbo adjustment factor can be computed from a 10-second pulse test. The reported SPPC consists of two parts: the first part which is constrained by the maximum discharge rate (until around the 5-hour mark), and the remaining part where the reported SPPC is the current that causes the system voltage to reach termination. The ends of the pulses, marked in squares and circles, indicate where the system voltage hits termination. In this particular scenario, it can be seen that the system voltage hits termination even while the SPPC is confined by the maximum discharge rate (square) which is an indication of a slightly high error. Because the true SPPC, which causes system shutdown, is not reported during this time, it is important to not choose this SPPC (square), to compute the adjustment factor; instead choose the SPPC that is responsible for voltage termination (circle). The adjustment factor can be computed at the end of each pulse (circle) as the ratio of the reported SPPC (red) to that of the applied current (blue). The user must write the worst (highest) value in the data flash.

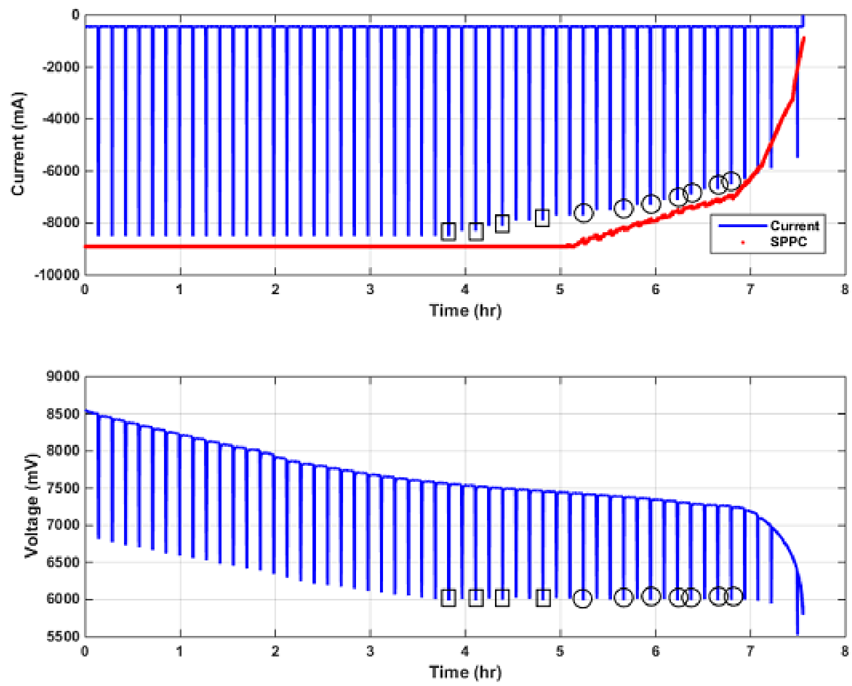

Figure 1. Computing Turbo Adjustment Factor

- **Reserve Energy %**

  Energy that remains at the present average discharge rate (as defined in DF.Load Select) until the maximal peak power reaches the value reported by the MAX_POWER command (see Table 4).

Table 4. Reserve Energy %

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	Reserve Energy %	I1	0	100	2	%

This value is a safety factor to ensure that there is some head room with respect to the predicted SPP and MPP. The default value of 2% works well for most systems.

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- High-Frequency Resistance
  Cell high-frequency resistance (see Table 5), Units: mΩ

Table 5. High-Frequency Resistance

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	High-Frequency Resistance	I2	0	32767	20	mΩ

The procedure to obtain the high-frequency cell resistance R_{HF} parameter follows (see Figure 2).

- If the ID was released for this cell:
  - Obtain R_{HF} from the chemistry selection table. Divide the value by the number of parallel cells used.
- If the chem. ID selection procedure is set up by the customer, the following procedure is required:
  1. Perform the selection test like before using rel-dis-rel, and select chem. ID using the mathcad tool.
  2. Perform a 4C, 10-ms pulse discharge test, and collect 1 ms or higher sampled data with the oscilloscope (see reference waveform).
  3. Use Equation 1 to find high-frequency resistance:

$$Rhf\_cell\_mOhm = \left(1000 * \left(Vbefore\_pulse - V\_end\_of\_pulse\right) / \left(I\,before\_pulse - I\_pulse\right)\right) - Rsys\_mOhm - Rpack\_mOhm) / N\_serial\_cells \quad (1)$$

  4. Pulse must have a 10-ms duration, and measure at the load terminals (so the discharge path includes $R_{(sys)}$ and $R_{(pack)}$).

The setup guidelines:

- Discharge current: C/4 rate
- Pulse duration: 10 ms with 4C discharge
- Pulse frequency: 1 second
- Sampling rate: 1 ms or higher
- Voltage measurement performed at load inputs (same point used earlier to find system resistance)
- If the customer does not have an oscilloscope that can collect data, 10-ms capable load, or has some difficulty with this test, do the following:
  - Send the cell to TI.
  - TI runs the OCV/relaxation test with HF sampling.
  - The results are used to obtain both the chem. ID selection and R_{HF} value.
  - The R_{HF} value and ID selection is sent to customer.

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Figure 2 is a point of reference for voltage and current measurements for the high-frequency resistance R_{HF} measurements.

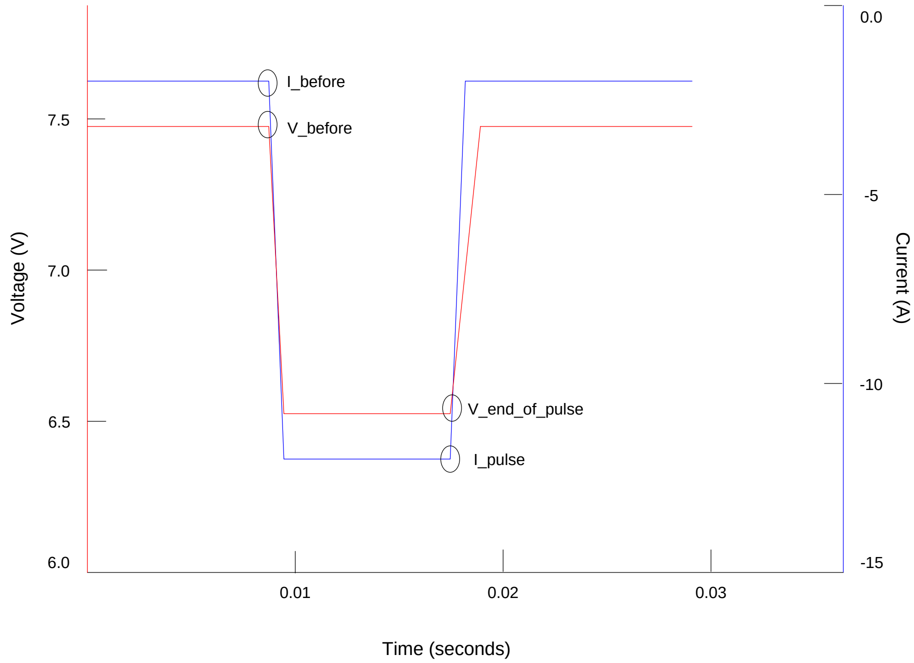

Figure 2. Measuring High-Frequency Resistance

Calculation method for R_{HF} parameter:

$$High\_Frequency\_Resistance = \frac{1000 \times \frac{V\_before - V\_end\_of\_pulse}{I\_before - I\_pulse} - Rsys - Rpack}{N\_serial} \quad (2)$$

– Voltage is measured in volts
– Current is measured in amperes
– $R_{(sys)}$ is measured in mΩ
– $R_{(pack)}$ is measured in mΩ
– N_serial is the number of cells in series
– Resulting high-frequency resistance is in mΩ

- **Pack Resistance**

  Initial value of Pack Resistance (see Table 6). Units: mΩ

Table 6. Pack Resistance

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	Pack Resistance	I2	0	32767	30	mΩ

How to measure $R_{(pack)}$ for the pack side resistance parameter follows (see Figure 3).

– A to B: Measure the impedance from the positive terminal of the cell pack on the PCB (point B) to the Pack+ connector pin on the pack side of the PCB (point A).
– Factors to consider when obtaining this parameter:
  - Total $R_{DS(on)}$ of CHG + DSG FETs for Tj = 125C (from data sheet or measured value)
  - $R_{(cell)}$ resistance is factored in the R_{LF} and R_{HF} DF registers
– C to D: Measure the impedance from the negative terminal of the cell pack (point C) on the PCB to the Pack– connector pin on the pack side of the PCB (point D).

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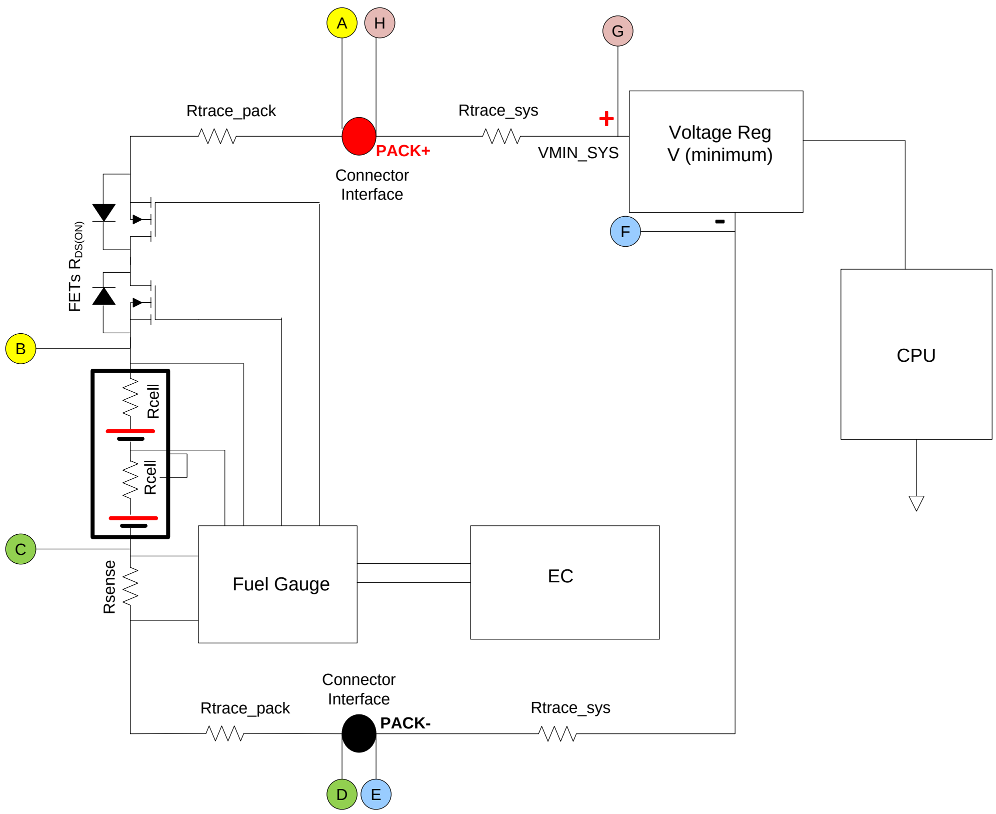

$R_{(pack)}$ Resistance = A to B + C to D
$R_{(sys)}$ Resistance = E to F + G to H

Figure 3. Measuring Pack and System Resistance

- **System Resistance**

  Initial value of system resistance (see Table 7). Units: mΩ

Table 7. System Resistance

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	System Resistance	I2	0	32767	0	mΩ

How to measure $R_{(sys)}$ for the system-side resistance parameter follows (see Figure 4).

– G to H: Measure the impedance from the Pack+ connector pin on the system side of the PCB (point H) to voltage regulator positive input of Vcore supply (point G).

– E to F: Measure the impedance from the voltage regulator negative pin of Vcore supply (point F) to Pack– of connector (point E).

- **Cell 1 to 4 Interconnect Resistance**

  Interconnects between cells must be measured from the point where the measurement line branches out to the top of the lower cell and separately to the bottom of the next cell (see Table 8). Units: mΩ

Table 8. Cell 1 to 4 Interconnect Resistance

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	Turbo Cfg	System Resistance	I2	0	32767	0	mΩ

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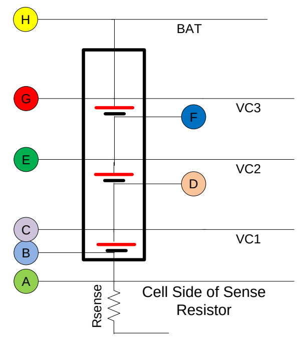
To determine the cell interconnect resistance, the following resistance must be measured in the configuration of the circuit.



Cell 1 Interconnect Resistance = A to B + (C to D) /2
Cell 2 Interconnect Resistance = (C to D) /2 + (E to F) /2
Cell 3 Interconnect Resistance = (E to F) /2 + G to H

Figure 4. Measuring Cell Interconnect Resistance

NOTE: C, E, and G are the points where the Cell +ve is going to the gauge voltage measurement, and not the Cell +ve tabs.

How to measure the cell 1 to 4 interconnect resistance parameter follows:

– A to B: Measure the impedance from the Rsens connector on the cell side of the PCB (point A) to Cell1 –ve tab (point B).
– C to D: Measure the impedance from the Cell1 +ve tab that goes to the bq40zxx device pin VC1 (point C) to Cell2 –ve tab (point D).
– E to F: Measure the impedance from the Cell2 +ve tab that goes to the bq40zxx device pin VC2 (point E) to Cell3 –ve tab (point F).
– G to H: Measure the impedance from the Cell3 +ve tab that goes to the bq40zxx device pin VC3 (point G) to BAT (point H).

- **Term Voltage**

  The minimum voltage in which the system still operates at the system power converter input (see Table 9). A capacity gauging algorithm uses this value to converge to 0 remaining capacity at this voltage. This value is also used to compute MAX_POWER. Term Voltage can be overwritten with command MIN_SYS_V. Units: mV.

Table 9. Term Voltage

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Gas Gauging	IT Cfg	Term Voltage	I2	0	32767	9000	mV

- **Gauging Configuration: TDELTAV**

  1: Enable calculating Delta Voltage, which corresponds to the power spike defined in DF.Min Turbo Power (see Table 10).

  0: Enable use of DF.Delta Voltage learned as maximal difference between the instantaneous and average voltages.

  Location: Settings, Configuration, IT Gauging Configuration, 2 bytes, bit 13 (lowest bit counted as zero)

Table 10. Gauging Configuration

Class	Subclass	Name	Type	Minimum	Maximum	Default	Unit
Settings	Configuration	IT Gauging Config	H2	0x0	0xFFFF	0x5FE	Hex

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3 Turbo Mode 1.0 SBS Commands

3.1 AC Peak Power Mode (Turbo Mode 1.0)

The bq40zxx supports Turbo mode 1.0 operation by providing the host MCU with information about the ability of the battery pack to deliver peak power. This method of operation is based on the host MCU reading register 0x59 (MAX_POWER) to determine if the selected power level for Turbo mode is below the maximum power reported by the gas gauge. Several data flash registers are associated with the Turbo mode operation. A listing of the registers for system configuration follows. The following additions to the extended SBS commands are required to implement this feature.

- **MaxPeakPower()**

  Block read: command 0x59

  Reads the maximum peak power value (cW) for the 10-ms pulse occurring on top of a pulse of magnitude DF.Ten Second Max C Rate. The gauge computes a new RAM value, MaxPeakPower, every second. The value is expected to be negative. MaxPeakPower is initialized to present the value of MaxPeakPower on reset or power up. The intended use of this command is for the system to read the value for maximum peak power and to decide on switching to a system operation mode with power requirements below the value for reported maximum peak power.

- **MPPCurrent()**

  Block read: command 0x5e

  Reads the maximum peak current value, MPPCurrent (mA), that can occur on top of a pulse of magnitude DF. Ten Second Max C Rate. The gauge computes a new RAM value, MPPCurrent, every second. The value is expected to be negative. MPPCurrent is initialized to present the value of MPPCurrent on reset or power up. The intended use of this command is for the system to read the maximum peak current and to make a decision about switching to a current mode below the reported maximum peak current value.

- **PackResistance()**

  Block read/write: command 0x5b

  Read/write in Unsealed mode, Read in Sealed mode

  Sets the RAM value of the battery pack serial resistance that includes FETs, traces, sense resistor, and so on, inside the battery pack $R_{(pack)}$, in mΩ. PackResistance() is initialized to data flash value: DF.Pack Resistance. Writing to this command overwrites the DF value.

- **SysResistance()**

  Block read/write: command 0x5c

  Read/write in Unsealed mode, Read in Sealed mode

  Sets the RAM value of the system serial resistance along the path from the battery to the system power converter input that includes FETs, traces, and so on, $R_{(sys)}$, in mΩ. SysResistance() is initialized to data flash value: DF.System Resistance. Writing to this command overwrites the DF value.

- **MinSysVoltage7()**

  Block write: command 0x5d

  Read/write

  Sets the minimum voltage at the system power converter input in which the system still operates, in mV. MIN_SYS_V is initialized to data flash the value: DF.Terminate Voltage. Writing to this command overwrites the DF value. The intended use of this command is to write it once on the first use to adjust for possible changes in the system design from the time the battery pack was designed.

- **TURBO_FINAL()**

  Block write: command 0x60

  Read/write

  Sets the DF.Min Turbo Power, which represents the minimum turbo-mode power level during active operation (nonsleep), after all higher turbo-mode levels are disabled (expected at the end of discharge), Unit: cW. A negative value is expected. Writing to this command overwrites the DF value.

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