ABSTRACT

This application note details manufacture testing, cell voltage calibration, BAT voltage calibration, PACK voltage calibration, current calibration (CC), and temperature calibration for the bq40zxx devices.

Contents

1 Manufacture Testing ........................................................................................................................................... 1
2 Calibration ...................................................................................................................................................... 2
  2.1 Cell Voltage Calibration ............................................................................................................................ 3
  2.2 BAT Voltage Calibration ............................................................................................................................ 4
  2.3 PACK Voltage Calibration ........................................................................................................................ 5
  2.4 Current Calibration .................................................................................................................................... 6
  2.5 Temperature Calibration ........................................................................................................................... 9

1 Manufacture Testing

To improve the manufacture testing flow, the gas gauge device allows certain features to be toggled on or off through ManufacturerAccess() commands. For example, the PRE-CHG FET(), CHG FET(), DS FET(), Lifetime Data Collection(), Calibration() features. Enabling only the feature under test can simplify the test flow in production by avoiding any feature interference. These toggling commands will only set the RAM data, meaning the conditions set by the these commands will be cleared if a reset or seal is issued to the gauge. The ManufacturingStatus() keeps track of the status (enabled or disabled) of each feature.

The data flash ManufacturingStatus provides the option to enable or disable individual features for normal operation. Upon a reset or a seal command, the ManufacturingStatus() will be re-loaded from data flash ManufacturingStatus(). This also means if an update is made to ManufacturingStatus() to enable or disable a feature, the gauge will only take the new setting if a reset or seal command is sent.
2 Calibration

The device has integrated routines that support calibration of current, voltage, and temperature readings, accessible after writing 0xF081 or 0xF082 to ManufacturerAccess() when the ManufacturingStatus([CAL] bit is ON. While the calibration is active, the raw ADC data is available on ManufacturerData(). The device stops reporting calibration data on ManufacturerData() if any other MAC commands are sent or the device is reset or sealed.

**NOTE:** The ManufacturingStatus([CAL] bit must be turned OFF after calibration is completed. This bit is cleared at reset or after sealing.

<table>
<thead>
<tr>
<th>ManufacturerAccess()</th>
<th>Description</th>
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<tbody>
<tr>
<td>0x002D</td>
<td>Enables/Disables ManufacturingStatus([CAL]</td>
</tr>
<tr>
<td>0xF080</td>
<td>Disables raw ADC data output on ManufacturerData()</td>
</tr>
<tr>
<td>0xF081</td>
<td>Outputs raw ADC data of voltage, current, and temperature on ManufacturerData()</td>
</tr>
<tr>
<td>0xF082</td>
<td>Outputs raw ADC data of voltage, current, and temperature on ManufacturerData(). This mode enables an internal short on the coulomb counter inputs (SRP, SRN).</td>
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The ManufacturerData() output format is: ZZYYaaAbbbCcCcDdDeeEeffFFggHHhhIIiiJJjjKkKk, where:

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<tr>
<th>Value</th>
<th>Format</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ZZ</td>
<td>byte</td>
<td>8-bit counter, increments when raw ADC values are refreshed (every 250 ms)</td>
</tr>
<tr>
<td>YY</td>
<td>byte</td>
<td>Output status</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ManufacturerAccess() = 0xF081: 1 ManufacturerAccess() = 0xF082: 2</td>
</tr>
<tr>
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<td>2's comp</td>
<td>Current (coulomb counter)</td>
</tr>
<tr>
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<td>2's comp</td>
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</tr>
<tr>
<td>CCcc</td>
<td>2's comp</td>
<td>Cell voltage 2</td>
</tr>
<tr>
<td>DDDD</td>
<td>2's comp</td>
<td>Cell voltage 3</td>
</tr>
<tr>
<td>EEEE</td>
<td>2's comp</td>
<td>Cell voltage 4</td>
</tr>
<tr>
<td>FFff</td>
<td>2's comp</td>
<td>PACK voltage</td>
</tr>
<tr>
<td>GGgg</td>
<td>2's comp</td>
<td>BAT Voltage</td>
</tr>
<tr>
<td>HHhh</td>
<td>2's comp</td>
<td>Cell current 1</td>
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<tr>
<td>IIii</td>
<td>2's comp</td>
<td>Cell current 2</td>
</tr>
<tr>
<td>JJjj</td>
<td>2's comp</td>
<td>Cell current 3</td>
</tr>
<tr>
<td>KKKk</td>
<td>2's comp</td>
<td>Cell current 4</td>
</tr>
</tbody>
</table>
2.1 Cell Voltage Calibration

Figure 1 illustrates cell voltage calibration.

![Diagram of cell voltage connections and circuit components](image)

**Figure 1. Cell Voltage Calibration**

1. Apply known voltages in mV to the cell voltage inputs:
   - $V_{\text{CELL1}}$ between VC1 pin and VSS pin
   - $V_{\text{CELL2}}$ between VC2 pin and VC1 pin
   - $V_{\text{CELL3}}$ between VC3 pin and VC2 pin
   - $V_{\text{CELL4}}$ between VC4 pin and VC3 pin

2. If $\text{ManufacturerStatus}()[\text{CAL}] = 0$, send 0x002D to $\text{ManufacturerAccess()}$ to enable the $[\text{CAL}]$ flag.

3. Send 0xF081 or 0xF082 to $\text{ManufacturerAccess()}$ to enable raw cell voltage output on $\text{ManufacturerData()}$.

4. Poll $\text{ManufacturerData()}$ until the 8-bit counter value increments by 2 before reading data.

5. Read the ADC conversion readings of cell voltages from $\text{ManufacturerData()}$:
   \[
   \text{ADC}_{\text{CELL1}} = \text{BBbb of } \text{ManufacturerData}()
   \]
   Is $\text{ADC}_{\text{CELL1}} < \text{0x8000}$? If yes, use $\text{ADC}_{\text{CELL1}}$; otherwise, $\text{ADC}_{\text{CELL1}} = -(\text{0xFFFF} - \text{BBbb} + \text{0x0001})$.

6. Average several readings for higher accuracy. Poll $\text{ManufacturerData}()$ until ZZ increments, to indicate that updated values are available:
   \[
   \text{ADC}_{\text{CELL1}} = \frac{[\text{ADC}_{\text{CELL1}}(\text{reading } n) + \ldots + \text{ADC}_{\text{CELL1}}(\text{reading } 1)]}{n}
   \]

7. Calculate gain value:
   \[
   \text{Cell Gain} = \frac{V_{\text{CELL1}}}{\text{ADC}_{\text{CELL1}}} \times 2^{16}
   \]

8. Write the new **Cell Gain** value to data flash.

9. Re-check voltage readings and if they are not accurate, repeat steps 4 – 6.

10. Send 0x002D to $\text{ManufacturerAccess()}$ to clear the $[\text{CAL}]$ flag if all calibration is complete.
2.2 BAT Voltage Calibration

BAT Voltage Calibration is shown in Figure 2.

Figure 2. BAT Voltage Calibration

1. Apply known voltages in mV to the voltage input:
   • VBAT between VC4 pin and VSS pin
2. If ManufacturerStatus(CAL) = 0, send 0x002D to ManufacturerAccess() to enable the [CAL] flag.
3. Send 0xF081 or 0xF082 to ManufacturerAccess() to enable raw cell voltage output on ManufacturerData().
4. Poll ManufacturerData() until the 8-bit counter value increments by 2 before reading data.
5. Read ADC conversion readings of cell stack voltage from ManufacturerData():
   • ADCBAT = GGgg of ManufacturerData(),
6. Average several readings for higher accuracy. Poll ManufacturerData() until ZZ increments to indicate that updated values are available:
   • ADCBAT = [ADCBAT(reading n) + ... + ADCBAT(reading 1)]/n
7. Calculate gain value:
   \[
   \text{BAT Gain} = \frac{V_{\text{BAT}}}{\text{ADCBAT}} \times 2^{16}
   \]  
   (2)
8. Write the new BAT Gain value to data flash.
9. Re-check voltage readings and if they are not accurate, repeat steps 4 – 6.
10. Send 0x002D to ManufacturerAccess() to clear the [CAL] flag if all calibration is complete.
2.3 **PACK Voltage Calibration**

PACK voltage calibration is illustrated in Figure 3.

![Figure 3. PACK Voltage Calibration](image)

1. Apply known voltages in mV to the voltage input:
   - \( V_{PACK} \) between PACK pin and VSS pin
2. If \( \text{ManufacturerStatus()}[\text{CAL}] \) = 0, send 0x002D to \( \text{ManufacturerAccess()} \) to enable the [CAL] flag.
3. Send 0xF081 or 0xF082 to \( \text{ManufacturerAccess()} \) to enable raw cell voltage output on \( \text{ManufacturerData()} \).
4. Poll \( \text{ManufacturerData()} \) until the 8-bit counter value increments by 2 before reading data.
5. Read ADC conversion readings of pack voltage from \( \text{ManufacturerData()} \):
   - \( \text{ADC}_{PACK} = \text{FFff of } \text{ManufacturerData()} \)
6. Average several readings for higher accuracy. Poll \( \text{ManufacturerData()} \) until ZZ increments to indicate that updated values are available:
   - \( \text{ADC}_{PACK} = [\text{ADC}_{PACK}(\text{reading n}) + \ldots + \text{ADC}_{PACK}(\text{reading 1})]/n \)
7. Calculate gain value:
   \[
   \text{PACK Gain} = \frac{V_{PACK}}{\text{ADC}_{PACK}} \times 2^{16}
   \]  
8. Write the new **PACK Gain** value to data flash.
9. Re-check voltage readings and if they are not accurate, repeat steps 4 – 6.
10. Send 0x002D to \( \text{ManufacturerAccess()} \) to clear the [CAL] flag if all calibration is complete.
2.4 Current Calibration

A diagram of current calibration is shown in Figure 4.

![Figure 4. Current Calibration](image)

2.4.1 CC Offset Calibration

**NOTE:** Due to hardware improvements in this device, CC Offset calibration is not necessary. Only run the CC Offset Calibration procedure if current is observed when no current should be present.

1. Apply a known current of 0 mA, and ensure no current is flowing through the sense resistor connected between the SRP and SRN pins.
2. If ManufacturerStatus()[CAL] = 0, send 0x002D to ManufacturerAccess() to enable the [CAL] flag.
3. Send 0xF082 to ManufacturerAccess() to enable raw cell voltage output on ManufacturerData().
4. Poll ManufacturerData() until ZZ increments by 2 before reading data.
5. Obtain the ADC conversion readings of current from ManufacturerData():
   - ADC\textsubscript{CC} = AAaa of ManufacturerData()
   - Is ADC\textsubscript{CC} < 0x8000? If yes, use ADC\textsubscript{CC}; otherwise, ADC\textsubscript{CC} = -(0xFFFF – AAaa + 0x0001).
6. Average several readings for higher accuracy. Poll ManufacturerData() until ZZ increments to indicate that updated values are available:
   - ADC\textsubscript{CC} = [ADC\textsubscript{CC}(reading n) + … + ADC\textsubscript{CC}(reading 1)]/n
7. Read Coulomb Counter Offset Samples from data flash.
8. Calculate offset value:
   - CC offset = ADC\textsubscript{CC} \times (Coulomb Counter Offset Samples)
9. Write the new CC Offset value to data flash.
10. Re-check the current reading and if it is not accurate, repeat steps 1 – 10.
11. Send 0x002D to ManufacturerAccess() to clear the [CAL] flag if all calibration is complete.
2.4.2 Board Offset Calibration

**NOTE:** Due to hardware improvements in this device, Board Offset calibration is not necessary. Only run the Board Offset Calibration procedure if board offset current is observed.

1. Ensure that Offset Calibration was performed first.
2. Apply a known current of 0 mA, and ensure no current is flowing through the sense resistor connected between the SRP and SRN pins.
3. If `ManufacturerStatus()[CAL] = 0`, send 0x002D to `ManufacturerAccess()` to enable the `[CAL]` flag.
4. Send 0xF081 to `ManufacturerAccess()` to enable raw cell voltage output on `ManufacturerData()`.
5. Poll `ManufacturerData()` until ZZ increments by 2 before reading data.
6. Obtain the ADC conversion readings of current from `ManufacturerData()`:
   - `ADC_{CC} = AAaa` of `ManufacturerData()`
     - If `ADC_{CC} < 0x8000`? If yes, use `ADC_{CC}`; otherwise, `ADC_{CC} = -(0xFFFF - AAaa + 0x0001)`.
7. Average several readings for higher accuracy. Poll `ManufacturerData()` until ZZ increments to indicate that updated values are available:
   - `ADC_{CC} = \left(ADC_{CC}(reading \ n) + \ldots + ADCCC(reading \ 1)\right)/n`
8. Read **Coulomb Counter Offset Samples** from data flash.
9. Calculate offset value:
   - Board offset = `(ADC_{CC} - CC Offset) \times` Coulomb Counter Offset Samples
10. Write the new **Board Offset** value to data flash.
11. Re-check the current reading. If the reading is not accurate, repeat steps 1 – 10.
12. Send 0x002D to `ManufacturerAccess()` to clear the `[CAL]` flag if all calibration is complete.
2.4.3 CC Gain/Capacity Gain Calibration

1. Apply a known current (typically 1 A to 2 A), and ensure ICC is flowing through the sense resistor connected between the SRP and SRN pins.

2. If `ManufacturerStatus()/CAL` = 0, send 0x002D to `ManufacturerAccess()` to enable the [CAL] flag.

3. Send 0xF081 to `ManufacturerAccess()` to enable raw CC output on `ManufacturerData()`.

4. Poll `ManufacturerData()` until ZZ increments by 2 before reading data.

5. Read the ADC conversion readings of current from `ManufacturerData()`:
   - `ADC_{CC} = AAaa` of `ManufacturerData()`
     - Is `ADC_{CC} < 0x8000`? If yes, use `ADC_{CC}`; otherwise, `ADC_{CC} = -(0xFFFF - AAaa + 0x0001)`.

6. Average several readings for higher accuracy. Poll `ManufacturerData()` until ZZ increments to indicate that updated values are available:
   - `ADC_{CC} = [ADC_{CC}(reading n) + ... + ADC_{CC}(reading 1)]/n`

7. Read **Coulomb Counter Offset Samples** from data flash.

8. Calculate gain values:

   \[
   CC\ Gain = \frac{I_{CC}}{ADC_{CC} - \frac{Board\ Offset + CC\ Offset}{Coulomb\ Counter\ Offset\ Samples}}
   \]

   \[
   Capacity\ Gain = CC\ Gain \times 298261.6178 \tag{4}
   \]

9. Write the new **CC Gain** and **Capacity Gain** values to data flash.

10. Re-check the current reading. If the reading is not accurate, repeat steps 1 – 9.

11. Send 0x002D to `ManufacturerAccess()` to clear the [CAL] flag if all calibration is complete.

**NOTE:** There is a conversion factor for CC Gain and Capacity Gain parameters entered in bqStudio.

<table>
<thead>
<tr>
<th>Name</th>
<th>Data Type</th>
<th>Data Flash Default</th>
<th>bqStudio Default</th>
<th>DF-to-Studio Conversion</th>
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</thead>
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<td>F4</td>
<td>3.58422</td>
<td>1.036</td>
<td>3.714528/DF</td>
</tr>
<tr>
<td>Capacity Gain</td>
<td>F4</td>
<td>1069035.256</td>
<td>1.036</td>
<td>1107901.13/DF</td>
</tr>
</tbody>
</table>
2.5 Temperature Calibration

Figure 5 illustrates temperature calibration.

![Figure 5. Temperature Calibration](tsx-vss-vtsx.png)

2.5.1 Internal Temperature Sensor Calibration

1. Apply a known temperature in 0.1°C, and ensure that temperature \( T_{INT} \) is applied to the device.
2. Read the \( T_{INT} \) offset from **Internal Temp Offset**.
3. Read the reported temperature from \( DAStatus2() \):
   - \( T_{INT} = AAaa \) of \( DAStatus2() \)
   - Is \( T_{INT} > 0 \)? If yes, \( T_{INT} = AAaa - 2732 \).
4. Calculate temperature offset:
   \[
   T_{INT} \text{ offset} = TEMP_{TINT} - T_{INT} + T_{INT} \text{ offset}_{\text{old}}
(5)
   \]
5. Write the new **Internal Temp Offset** value to data flash.
6. Re-check the \( DAStatus2() \) reading. If the reading is not accurate, repeat steps 1 – 5.

2.5.2 TS1–TS2–TS3–TS4 Calibration

1. Apply a known temperature in 0.1°C, and ensure that temperature \( TEMP_{TSx} \) is applied to the thermistor connected to the TSx pin. "TSx" refers to TS1, TS2, TS3, or TS4, whichever is applicable.
2. Read the TSx offset from **External x Temp Offset**, where \( x \) is 1, 2, 3, or 4.
3. Read the appropriate temperature from the \( DAStatus2() \) block as TSx.
4. Calculate the temperature offset:
   \[
   TSx \text{ offset} = TEMP_{TSx} - TSx + TSx \text{ offset}_{\text{old}}
(6)
   \]
   Where \( x \) is 1, 2, 3, or 4.
5. Write the new **External x Temp Offset** (where \( x \) is 1, 2, 3, or 4) value to data flash.
6. Re-check the \( DAStatus2() \) reading. If the reading is not accurate, repeat steps 1 – 5.

Revision History

Changes from Original (March 2015) to A Revision | Page
--- | ---
• Added ‘+’ sign to value of \( ADC_{CELL1} \) in number 5 in the **Cell Voltage Calibration** section. | 3
• Deleted factor \( "V_{CELL1}" \) from Equation 1. | 3
• Added ‘+ J +’ to ‘...’ in step 6 of **BAT Voltage Calibration** section. | 4
• Changed ‘+ J +’ to ‘...’ in number 6 in the **PACK Voltage Calibration** section. | 5

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.
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