Simple Calibration Circuit Maximizes Accuracy in Li-Ion Battery Management Systems

Design Note 471
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Introduction
In Li-Ion battery systems it is important to match the charge condition of each cell to maximize pack performance and longevity. Cell life improves by avoiding both deep discharge and overcharge, so typical systems strive for operation between 20% and 80% states of charge (SOC). Detection and correction of charge imbalances assures that all cells track within the desired SOC window, preventing premature aging of some cells that could compromise the entire pack capacity. Highly accurate measurements are required to determine SOC with Li-Ion cells due to their exceptionally flat discharge characteristics, particularly with the lower voltage chemistries (see example in Figure 1).

Accounting for the Error Sources
Fundamentally, there are several key characteristics that comprise an overall accuracy specification:
- Quantization error of the ADC
- Initial accuracy of the ADC (or calibration reference)
- Variation from channel to channel
- Variation with temperature
- Hysteresis effects, primarily that of the soldering process
- Variation with operating time (long-term drift)

The maximum specified error in the data sheet for the LTC6802IG-2 includes the first four items and is ±0.22%; about ±7mV when measuring 3.3V, the most demanding region of the discharge curve. The spec budgets ±3.3mV (±0.1%) as the maximum variation over the −40°C to 85°C operating temperature. Since the differential non-linearity (DNL) of the ADC is about ±0.3 LSB, the quantization error contribution is about ±0.8 LSB, or ±1.2mV.
Typical channel-to-channel variation is minimal, under ±1mV, leaving about ±1.5mV for trim resolution and accuracy in the IC manufacturing process. Thermal hysteresis is specified as 100ppm, and an additional approximately ±0.1% error may develop from the shift of the printed-circuit soldering process.

Projected typical long-term drift is under 60ppm/√khr. If the practical vehicle battery system active life cycle is targeted at 5khr (about 15 years or 150,000 miles), an uncertainty of around ±0.5mV could develop. This is a relatively small contribution to total error.

The LT1461AIS8-3.3 voltage reference IC has an output tolerance of ±0.04% and less than ±1.2mV of change over temperature with its exemplary 3ppm/°C worst-case stability. The LT1461 exhibits a long-term drift of under 60ppm/√kHr and thermal hysteresis of 75ppm. Solder reflow shift is expected to be under 250ppm (±0.8mV).

Since a significant portion of the LTC6802 ADC error accumulates after the initial delivery of the IC, an external calibration technique improves accuracy in a finished product.

**Examining Calibration Strategies**

There are a number of options to improve system accuracy, at the expense of additional complexity. With the simple circuit of Figure 2, several options are available that take advantage of the external calibration reference. Accuracy projections of several methods are tabulated in Table 1 and described below.

The simplest scheme (method 1) involves no local memory or measurements at production. This method takes readings of the nominal 3.300V calibration voltage periodically and normalizes all ADC readings with the same computed correction factor. The tolerance and drift of the reference and channel-to-channel variations are left uncorrected but the net uncertainty would be improved by almost a factor of 2, to ±6.2mV.

A slightly more complex technique (method 2) involves storage of a single correction factor that accounts for the true reference voltage as measured with high accuracy test-fixure instrumentation. This then eliminates the initial error of the LT1461, improving the overall accuracy to ±4.1mV, nearly a 3× total improvement.

While small, there is still some channel-to-channel variation that can be calibrated out with a method that uses more initial test-fixure measurements (method 3). This is similar to method 2, but with high accuracy measurements of every channel taken (including the reference) and the saving of individual correction factors for each. This further reduces the error to ±3.1mV (almost a 4× total improvement).

**Conclusion**

A precision voltage reference, such as the LT1461, can improve the accuracy of an LTC6802-based battery management system to about ±3mV worst-case. The reference is a simple addition to the highly integrated LTC6802 Li-Ion monitoring solution, thanks to the spare general-purpose ADC channels available. The low operating current of the LT1461 voltage reference also makes it ideal for this and other battery-powered applications.

**References**


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**Table 1. Accuracy of Calibration Methods Described for 3.3V Measurements**

<table>
<thead>
<tr>
<th>EXTERNAL CALIBRATION METHOD (ALL TOLERANCES SHOWN IN ±mV)</th>
<th>QUANTIZATION FACTORY TRIM</th>
<th>SOLDERING SHIFT</th>
<th>CHANNEL MATCH</th>
<th>THERMAL VARIATION</th>
<th>THERMAL HYSTERESIS</th>
<th>LONG-TERM DRIFT</th>
<th>TOTAL ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC6802 Without External Calibration</td>
<td>1.2</td>
<td>1.5</td>
<td>3.3</td>
<td>1.0</td>
<td>3.3</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>1: Calibration with LT1461, No Stored Information</td>
<td>1.2</td>
<td>1.3</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>2: Calibration with LT1461, Store Calibration Values for Reference Voltage</td>
<td>1.2</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>1.2</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>3: Calibration with LT1461, Store Calibration Values for Reference Voltage and Each Input</td>
<td>1.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

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