

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).

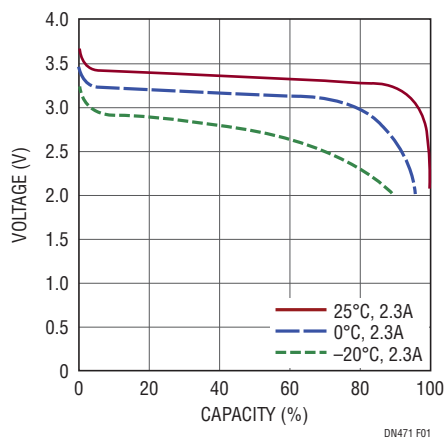


Figure 1. Discharge Characteristics of 3.3V Li-Ion Cell

Although the popular LTC®6802 Battery Stack Monitor offers high accuracy analog-to-digital conversion, some applications demand accuracy that is only attainable with a dedicated voltage reference IC. The LT®1461 is especially suited as a high performance calibration source, available in the small SO-8 package. Figure 2 illustrates this configuration. The calibration reference is measured with an ADC channel normally intended for temperature measurement. A programmable I/O bit controls power to the reference.

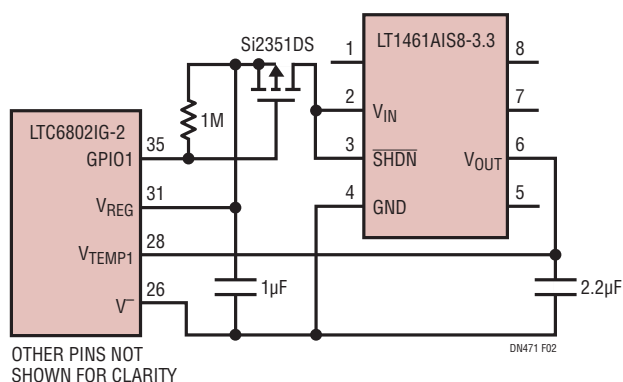


Figure 2. LT1461 as an External Calibration Source for an LTC6802 Li-Ion Battery Monitor

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 $\pm 0.22\%$; about $\pm 7\text{mV}$ when measuring 3.3V, the most demanding region of the discharge curve. The spec budgets $\pm 3.3\text{mV}$ ($\pm 0.1\%$) 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 $\pm 1.2\text{mV}$.

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Typical channel-to-channel variation is minimal, under $\pm 1\text{mV}$, leaving about $\pm 1.5\text{mV}$ for trim resolution and accuracy in the IC manufacturing process. Thermal hysteresis is specified as 100ppm, and an additional approximately $\pm 0.1\%$ error may develop from the shift of the printed-circuit soldering process.

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

The LT1461AIS8-3.3 voltage reference IC has an output tolerance of $\pm 0.04\%$ and less than $\pm 1.2\text{mV}$ of change over temperature with its exemplary $3\text{ppm}/^\circ\text{C}$ worst-case stability. The LT1461 exhibits a long-term drift of under $60\text{ppm}/\sqrt{\text{kHz}}$ and thermal hysteresis of 75ppm. Solder reflow shift is expected to be under 250ppm ($\pm 0.8\text{mV}$).

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 $\pm 6.2\text{mV}$.

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-fixture instrumentation. This then eliminates the initial error of the LT1461, improving the overall accuracy to $\pm 4.1\text{mV}$, nearly a $3\times$ 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-fixture 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 $\pm 3.1\text{mV}$ (almost a $4\times$ total improvement).

Conclusion

A precision voltage reference, such as the LT1461, can improve the accuracy of an LTC6802-based battery management system to about $\pm 3\text{mV}$ 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

"Battery Stack Monitor Extends Life of Li-Ion Batteries in Hybrid Electric Vehicles," *Linear Technology Magazine*, Volume 19, Number 1, March 2009, page 1.

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

EXTERNAL CALIBRATION METHOD (ALL TOLERANCES SHOWN IN $\pm\text{mV}$)	QUANTIZATION	FACTORY TRIM	SOLDERING SHIFT	CHANNEL MATCH	THERMAL VARIATION	THERMAL HYSTERESIS	LONG-TERM DRIFT	TOTAL ERROR
LTC6802 Without External Calibration	1.2	1.5	3.3	1.0	3.3	0.3	0.5	11.1
1: Calibration with LT1461, No Stored Information	1.2	1.3	0.8	1.0	1.2	0.2	0.5	6.2
2: Calibration with LT1461, Store Calibration Values for Reference Voltage	1.2	-	-	1.0	1.2	0.2	0.5	4.1
3: Calibration with LT1461, Store Calibration Values for Reference Voltage and Each Input	1.2	-	-	-	1.2	0.2	0.5	3.1

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dn471f LT/TP 1009 116K • PRINTED IN THE USA



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