Battery Stack Management Makes another Leap Forward

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Any doubts about the viability of electric vehicles have long been put to rest. The primary question now is “how far, how wide and how deep will this new high-power battery technology penetrate?” Perhaps not surprisingly, no one really knows for sure. But it is interesting to consider the evolution of the battery management system (BMS) electronics, and specifically the multicell battery monitor electronics at its heart. Doing so may provide clues to the adoption rate of high voltage battery packs in applications ranging from battery backup systems to exoskeletons. Let’s consider the advances made in one family of products, Linear Technology’s LTC68xx, in terms of safety, accuracy, functionality and development tool support.

In 2008, Linear Technology announced the first high performance multicell battery monitor, the LTC6802. Among its key features, this part included the ability to measure up to 12 Li-Ion cells with 0.25% maximum total measurement error within 13ms. The key capability of these multicell battery monitors is that many can be connected in series, enabling synchronized monitoring of every cell in very long, high voltage battery strings (Figure 1). Since that time, Linear Technology has followed up with the LTC6803, LTC6804 and now, its most advanced multicell battery monitor, the LTC6811. All four of these parts serve the same basic function: they measure the voltage on each battery cell of 12 series-connected cells. The evolution of this family tracks continuous improvements in functional safety, measurement accuracy and integrated functionality.

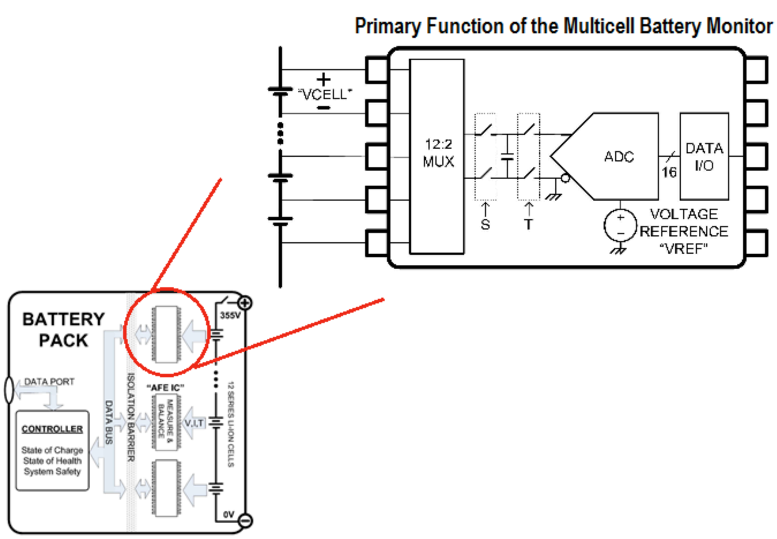

Figure 1. Simplified Description of the Multicell Battery Monitor

The most dramatic progress of the battery monitor electronics is the development of functional safety, as defined by the ISO 26262 standard. In essence, ISO 26262 systematically addresses potential hazards in an automobile that could be caused by the malfunctioning behavior of electronic and electrical systems. Although the ISO 26262 standard involves nearly every phase of product development and use, the system designer must focus on how to continuously confirm the proper operation of every element that could impact safety. The multicell battery monitor plays a central role in this task, since incorrect voltages on the battery cells are the first indicators of a potential problem. This presents a significant design challenge.

Built into the DNA of Linear Technology is the determination to pursue tough analog electronic problems, and automotive electronics are no exception. The multicell battery monitors illustrate the achievement of high reliability, high stability, and high measurement accuracy, with the expectation of years of operation in an environment of high voltages, extreme temperatures, hot plugging and electrical noise. The ISO 26262 standard goes one step further by requiring, among other things, an analysis of potential failures and their remedies. A common method within electronics to recognize and remedy potential failures is to include self-test capability and redundancy. Even before the publication of the ISO 26262, Linear Technology recognized the importance of functional safety and included self-test capability and internal redundancy in the LTC6802. Each new generation of multicell battery monitors added and refined this capability. The latest device, the LTC6811, continues this progression, with improvements to increase its internal diagnostic coverage. These functions include additional redundant measurement paths, improved synchronization between input signals, and improved self-test accuracy. The result is quicker, simpler and more efficient self-tests to help designers achieve their ISO 26262 goals. Even for non-automotive applications, these features give the designer confidence for whatever high reliability applications that they target.

The Linear Technology parts have steadily improved and innovated in cell measurement accuracy. Pursuing outstanding accuracy has always been a key design goal because potential measurement error translates to less effective battery management, and ultimately less pack capacity, reliability and/or life. Significant effort was made to optimize the built-in voltage reference, since it is the primary determinant of measurement error. The first Linear Technology multicell battery monitors incorporated a bandgap voltage reference. This was the conventional choice, since bandgap references are small, low power and low dropout. However, a bandgap reference can behave like a strain gauge, converting mechanical stress from PCB assembly, thermal variations, humidity, and long-term drift into measurable error. To avoid this limitation, Linear initiated a unique approach by adding a dedicated sub-surface Zener voltage reference to the design. These references offer outstanding stability, over temperature, time and other operating conditions. The result, available today in the LTC6811, is the ability to measure every battery cell to worst-case accuracy of better than 1.2mV (Figure 2).

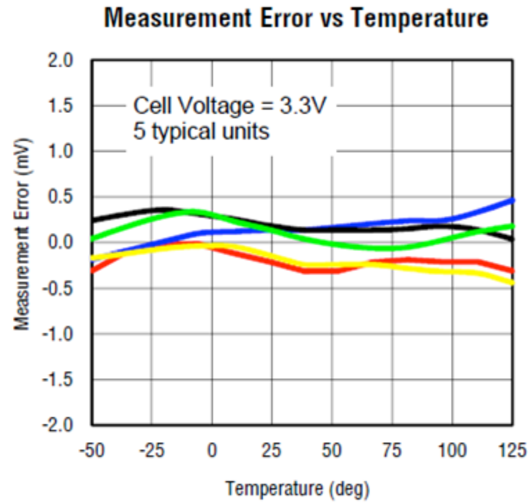

Figure 2. Outstanding Temperature Drift Performance of the Buried Zener Voltage Reference

Furthermore, the Linear Technology parts ensure outstanding measurement accuracy, even in the presence of noise, by filtering the noise on each battery cell voltage. This is accomplished by using delta-sigma analog-to-digital converters rather than the fast SAR converters, commonly used in alternative approaches. Once again, Linear Technology chose to break from the pack, despite the clear speed advantage of SAR converters when measuring hundreds of individual battery cells. This choice was made because the automotive environment is chock-full of noise and transients from motors, solenoids, power inverters, etc. All of this noise affects measurement accuracy. With a delta-sigma converter, the input is sampled many times over the course of a conversion and then averaged. The result is built in low pass filtering to eliminate noise as a source of measurement error, where the cutoff frequency is established by the sample rate. For example, the LTC6802 uses a 2nd order delta-sigma that operates at a fixed 1k sample per second. The result is 36dB of rejection to 10kHz switching noise (Figure 3). The trade-off however, is that measuring 12 cells with the LTC6802 requires 13msec, which is too slow for some applications.[1] Nonetheless, using a delta-sigma converter has remained the most practical method for achieving accurate cell measurement in the noisy real world. For this reason, Linear has continuously improved its delta-sigma approach. Today, the LTC6811 uses a much faster 3rd order delta-sigma ADC with programmable sample rates and 8 selectable cutoff frequencies. The result is outstanding noise reduction and 8 programmable measurement rates (Figure 4), enabling measurement of all 12 battery cells as fast as 290µsec.

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[1] Although the SAR ADC topology allows for faster data conversions, the usefulness of the resulting data is questionable in a noisy system. For the same amount of 10kHz noise rejection as the LTC6802, a 1M sample per sec SAR converter would require a single-pole RC filter on each cell, with a corner frequency of 160Hz (Figure 3). The 12-bit settling time of the RC filter is 8.4msec. Therefore, even though a SAR converter can sequence through 10 channels in 10µsec, scanning more than once every 8.4msec is pointless because of the response of the filter.

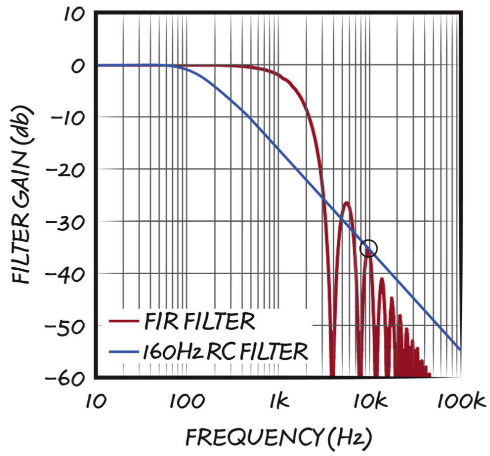

Figure 3. LTC6802 Delta-sigma Converter vs. SAR Converter with RC Circuit.

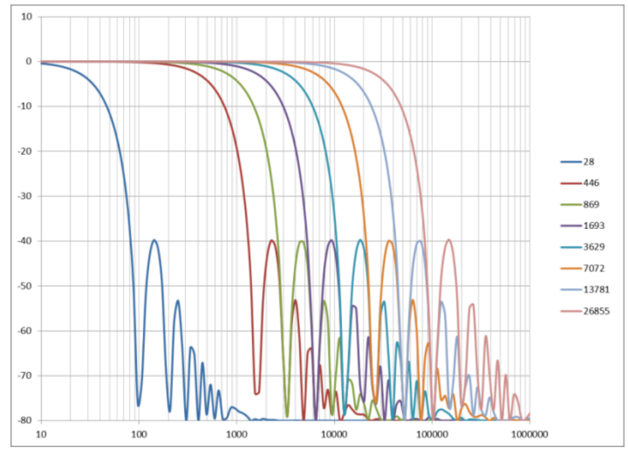

Figure 4. LTC6811 Delta Sigma Converter

Finally, it is interesting to note how the functionality of the multicell battery monitor has expanded. As previously mentioned, the primary task of a multicell battery monitor is to accurately measure cell voltages and communicate this information to a host processor. Furthermore, it is best that the multicell battery monitor not include internal software, as this could present a potential conflict with the system-level battery management; the task of collecting data from all of the cells and determining the state of charge or state of health should be accomplished by the main BMS processor. However, the multicell battery monitor resides at the most critical location in the battery system, directly connected to the cells. Here, it is in an ideal position to monitor other battery sensors, such as current or temperature, and closely correlate these values to cell measurements. For this reason, the multicell battery monitor can act as a central hub between the BMS microprocessor and peripheral devices.

For example, the LTC6811 offers very flexible general purpose I/O that can operate as digital inputs, digital outputs, or as analog inputs. When operated as analog inputs, the LTC6811 can measure any voltage from V- to 5V with the same measurement accuracy as the cell measurements. The LTC6811 can then synchronize these external signals, or the full 12-cell stack voltage, to the cell voltage measurements. Alternatively, the general purpose I/O can be used in a digital mode to control I^2C or SPI slave devices. This enables the LTC6811 to control more complex functions, such as multiplexers for expanded analog inputs or EEPROM to store calibration information.

The LTC6811 has advanced cell balancing capability. Using the SPI master feature, the LTC6811 can control Linear Technology's SPI-based active balancing IC, the LTC3300. The LTC6811 includes internal passive balancing FETS that can discharge individual cells, or directly control larger high-power external FETs. The LTC6811 has the ability to configure each cell discharge pin to operate with an independent period. This enables balancing each cell uniquely over long periods, while the multicell battery monitor is not active. Finally, each passive balancing pin can be used as a serial interface. This is particularly useful for interfacing to Linear Technology's LT8584 monolithic active cell balancers, where active balancing can be controlled and current and temperature can be monitored for each individual battery cell.

To integrate all of this functionality and shorten development time, the LTC6811 is fully supported by Linear Technology's Linduino™ One (Figure 5). The Linduino One is an Arduino Uno compatible microcontroller board that is fully USB isolated and connects directly to an LTC6811 demonstration board. With an onboard bootloader for quick in-circuit firmware updates, this platform provides a simple, stable hardware development platform. Since Arduino is an open source platform, BMS designers have easy access to the simple and powerful Arduino integrated development environment (IDE). A library of code, called the bmsSketchbook, provides LTC6811 sample code designed to compile in any standard C compiler. For example, the bmsSketchbook includes routines to read and write configuration, read and write cell voltages, run self-tests, redundancy tests and control the passive balancing.

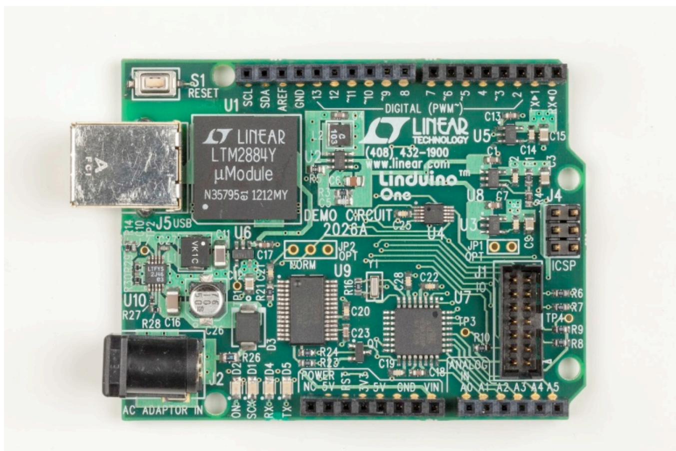

Figure 5. Linduino Development System

Conclusion

Since 2008, Linear Technology has released four generations of multicell battery monitors. The safety features, accuracy and functionality of these devices have evolved significantly over this period, illustrating the growing importance of these ICs in high performance battery management. In addition, new tools simplify and standardize their integration into battery management systems, irrespective of the end application. Linear Technology's most advanced multicell battery monitor, the LTC6811, as shown in Figure 6, provides an impressive set of features for practically any high voltage, high powered battery system.

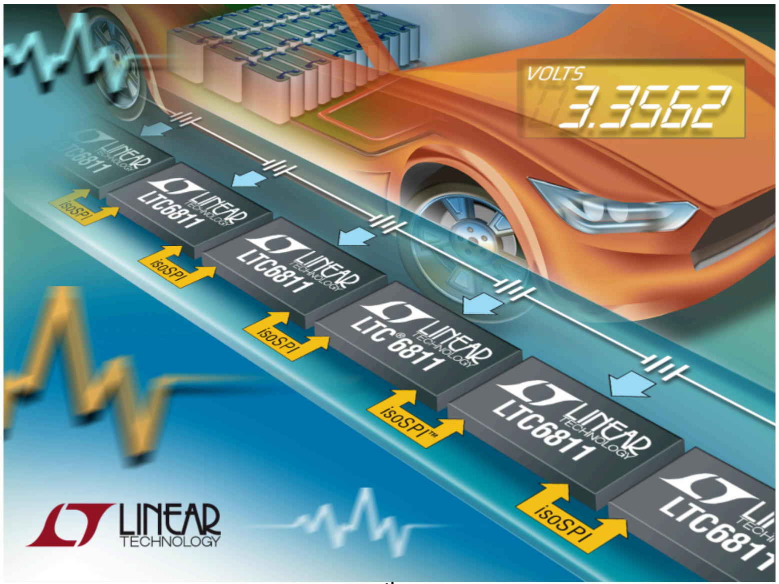

Figure 6. Linear Technology's LTC6811: A 4th Generation Multicell Battery Monitor