An Integrated Solution to Li-ion Battery Management

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Lithium-ion batteries are now ubiquitous in portable equipment owing to their attractive performance and cost metrics. However, they must have accurate charge and discharge control to be safe, requiring the implementation of a battery management system

This article discusses the issue and describes cost-effective integrated solutions that can also add extra user benefits, including state-of-charge and state-of-health monitoring.

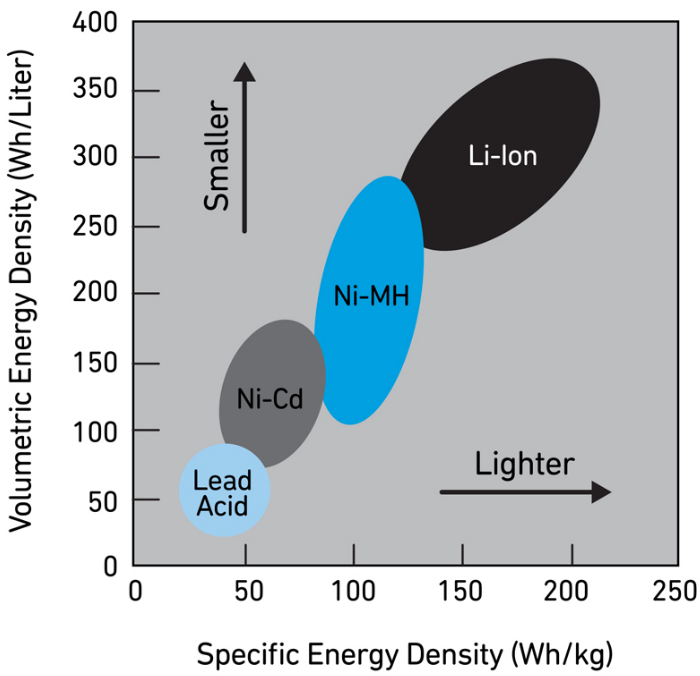

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Figure 1: Some battery chemistries compared

Going back in history, perhaps hundreds of chemistries have been proposed for batteries. These have ranged from the original copper, zinc and cardboard primary cell 'piles' invented by Italian Alessandro Volta around 1800, through the familiar rechargeable lead acid types, to exotic (and still theoretical) 'quantum' batteries that could recharge an EV in 90 seconds [1]. For the moment though, lithium-ion batteries are the preferred type in applications at a wide range of power and energy levels, from 10 Wh in a typical cellphone to hundreds of kWh in an EV. Sometimes concerns are voiced about the rarity of lithium, with only 14 million tons estimated as a global reserve by Volkswagen [2]. However, the company calculates that this still represents more than 150 years of consumption at 2018 rates.

Li-ion batteries – their benefits

So, Li-ion batteries are going to be around for a while, and the science and engineering community is working to steadily improve their performance, both in capacity but also in their safety, which remains a major consideration. Li-ion's appeal is mainly down to its combination of gravimetric energy density (Wh/kg), volumetric energy density (Wh/liter) and cost. (**Figure 1**). These are commercially important measures, but there are additional benefits as well compared with other battery types, including longer life cycle, low self-discharge rate, low toxicity and a conveniently high cell voltage, around 3.8 V.

Addressing the downsides

The downsides of Li-ion are now perhaps well-known through some high-profile failures. Charging voltage must be carefully controlled, charge and discharge currents must be monitored and limited (along with cell temperature), and charge must be terminated at or before 100% capacity. Ignoring these strictures risks explosion or fire. At the same time, the charge profile should be tailored to achieve the best combination of time-to-capacity and low stress, to maintain high cell reliability and adequate lifetime.

Illustrated in **Figure 2,** the usual regime is a constant current at about 1 C, for example 1 A for a 1-Ah battery (period 1 in the graph) until the cell reaches about 70% capacity, (point 2). This is followed by constant applied voltage (period 3). Under this condition, the cell current gradually falls, and charge is terminated when the value drops below 3-5% of the 1 C figure (point 4). This is for a traditional cobalt-blended Li-ion cell. As mentioned, self-discharge of Li-ion batteries is low, but some schemes will detect an eventual voltage drop and 'top-up' the battery with a short charge cycle.

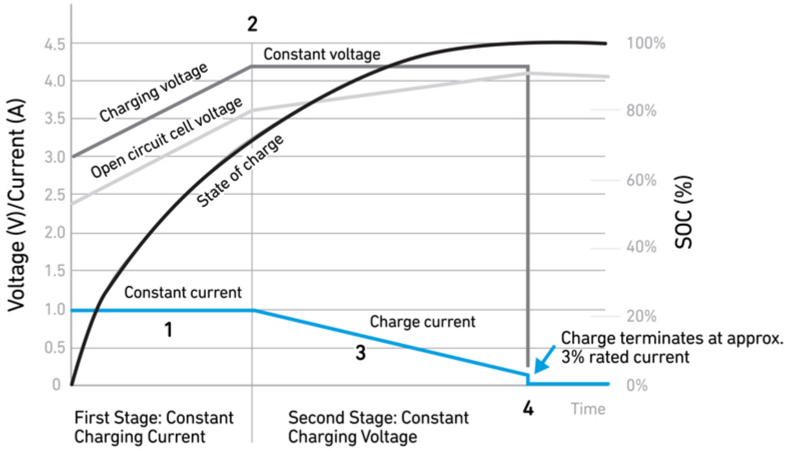

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Figure 2: A typical lithium-ion battery charging regime

Determining state of charge is not easy

Detecting the 70% state of charge (SOC) point to trigger a change to constant voltage operation is problematic. However, it can be approximated by momentarily disconnecting the charger and measuring the open-circuit cell voltage and comparing this with an expected value for 70% charge. This can be done with a removeable battery module inserted in its charger, but if the battery is built-in and charged in a product, it can be difficult to ensure that no load is present, and the 'open circuit' voltage measured is a real reflection of SOC. On discharge, again, cell voltage is not a great measure of SOC, as a Li-ion cell has the desirable property of a fairly flat discharge voltage characteristic up to exhaustion.

Alternatively, the characteristics of a battery can be learned and SOC estimated by coulomb counting or gas gauging. If current over time is measured, then cumulative charge introduced and taken can be calculated, and SOC derived. This depends on awareness or memory of the initial state of charge, which might be unknown. For a degree of accuracy, the calculation should be periodically re-calibrated by a near-complete discharge. Cell phone users will be familiar with this effect. Loss of capacity with variation of temperature and with age also needs to be factored in.

Knowing state of health is important

SOH – state of heath, or loss of capacity, is important to know, as 100% indicated SOC means less actual run-time as a battery age, or at low temperatures. A battery with poor health and degraded run-time is perhaps just an annoyance in a hand tool or portable appliance, but, as Li-ion cells are incorporated into a wider range of mobility and utility applications, SOH awareness can become a safety issue. An exhausted mobility scooter on the sidewalk is a critical problem to the user and a way to achieve 'predictive maintenance', triggering changeout a battery before end-of-life, is highly desirable.

As with SOC, cell voltage is not a good measure of SOH, but internal resistance can be an indicator, calculated from cell terminal voltage drop with a given current step. Better SOH calculations rapidly get more complex and require the assembly of a model of the particular battery plus its predicted age and environment-related degradation. The data set to generate the model over time can be unfeasibly large and processing via machine learning and neural networks might be needed to achieve accurate results [3].

Battery management systems are needed

To optimize for safety and efficiency, a battery management system (BMS) is needed to control charge and discharge while also calculating SOC and SOH to an acceptable accuracy. Theoperating environment though can be tough and unpredictable. A large part of the Li-ion battery market is for hand tools and garden machinery, now including ride-on mowers, chain saws and leaf/snow blowers. Then there are e-bikes, scooters and similar applications with strings of batteries up to 90 V or more. All of these are in typically uncontrolled environments, subject to shock/vibration, pollution, humidity and temperature extremes, and often with dubious maintenance schedules.

The higher voltages also pose the challenges of potential electric shock and high energy discharge. At the same time, commercial pressure is to make the batteries and their associated management system as small, lightweight and low cost as possible, while maintaining maximum functionality. Minimum self-discharge and a hibernation mode is needed, so the equipment is ready to go after extended storage – even wireless connectivity is increasingly expected. With the high-power/high-value applications incorporating strings of large batteries, active cell balancing is also likely to be required to ensure cell states of charge are equalized, run-time is maximized and stress minimized.

Integrated solutions

To implement all of these features, an integrated solution is attractive and Qorvo [4] has designed parts for the application that focus on the higher cell count, higher voltage systems that are currently inadequately served by other suppliers. The Qorvo approach is to leverage technology in the existing range of power application controller (PAC) ICs using ARM® Cortex® processors--the M0 clocked at 50 MHz or M4F at 150 MHz, suiting lower- and higher-end applications respectively. The M4F has 128 kB flash memory and 32 kB SRAM - four times the storage of the M0 variant, as well as more general purpose I/O pins. Both have SPI, UART and I^2C/SMBus interfaces, while the M4F also features a CAN interface.

Two BMS devices are initially available, the PAC22140 with the M0 processor and the PAC25140 with the M4F (**Figure 3**).

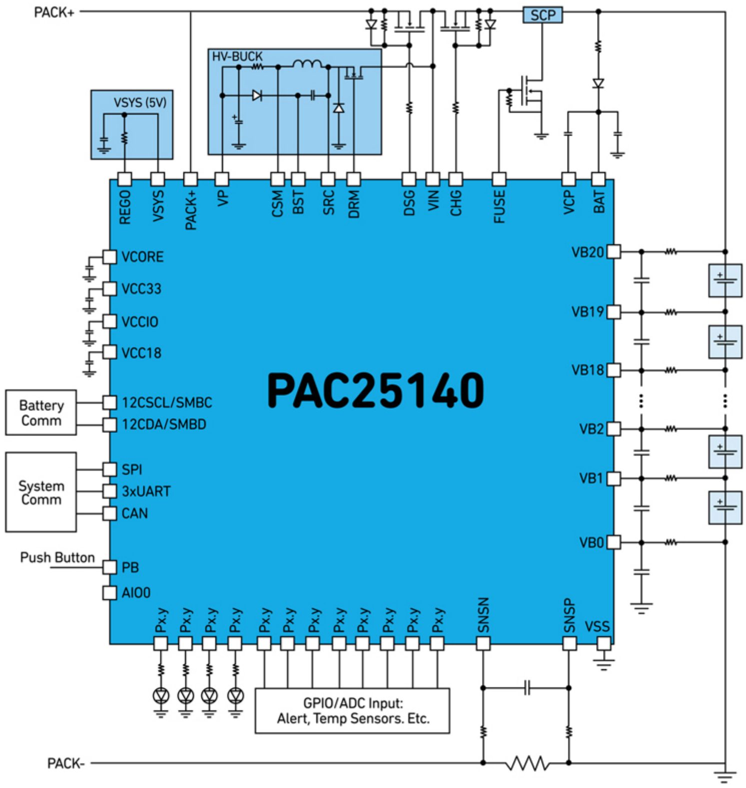

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Figure 3: The PAC25140 integrated BMS from Qorvo

Both solutions are optimized for 20-cell systems and can support down to 10-cell systems with monitoring and balancing for individual cells. Gate drives are provided for the necessary external protection MOSFETs in the high current path, which allow charge/discharge control and cut-off as necessary under overload or short-circuit conditions. Both controllers include a boost converter so that a gate drive voltage can be generated higher than the battery value, enabling cost-efficient N-channel MOSFETs to be used. Features also include:

- Fully firmware programmable industry-standard ARM architecture
- Support for artificial intelligence (AI) and machine learning (ML) using TinyML [AC1] (coming in January)
- Analog interfaces for measurement of cell voltage, current and temperature with high-resolution ADCs
- Fast hardware shut down to avoid any delays through the processor and minimize stress on the battery and BMS under fault conditions
- Individual cells can be in the range of 1.8 V to 4.7 V and are not limited to Li-ion
- Programmable cell under- and over-voltage monitoring
- Cell voltage is measured with 16-bit accuracy in a 5-ms ADC conversion time
- Cell balancing is achieved with internal FETs for each cell which can sink up to 50 mA
- Hibernate current is less than 3 µA at 80 V with various timed or event-driven wakeup options

A particular feature of both devices is the programmable gain of the differential current sense interface. This can be tailored to the application so that signal level and accuracy is optimized, like with high gain at low current values. In high-current applications, the gain can be set lower to keep the full-scale voltage within bounds or, equivalently, left higher with a smaller sense resistor to minimize dissipation. A typical value for the sense resistor is sub one-milliohm and can even be formed from PCB tracking with appropriate temperature compensation of the measured value.

Both devices incorporate the complete power supplies to support the system, which include buck and linear regulators for internal and external auxiliary rails for applications like a low-energy Bluetooth™ module.

Firmware is flexible

Firmware is included in the Qorvo BMS parts for comprehensive charge/discharge control and monitoring, along with algorithms for cell balancing and coulomb counting. Unlike other proprietary solutions, users can develop their own firmware to suit the end application, and, for many, the ARM instruction set will already be familiar. In simple applications, the PAC22140 device will be more than powerful enough, but the PAC25140, with its increased processor speed and memory, opens up the possibility of more functionality and deeper data analytics and fault logging. With the push to have more intelligence, TinyML can be supported to provide a better user experience and potentially the ability to 'learn' the battery characteristics over time, to better predict SOC and SOH (coming in January).

The devices are in compact 9 x 9 mm and 10 x 10 mm QFN packages respectively (**Figure 4**), and full support is available from Qorvo, with software and hardware development kits, a windows GUI for configuration and monitoring, and full documentation.

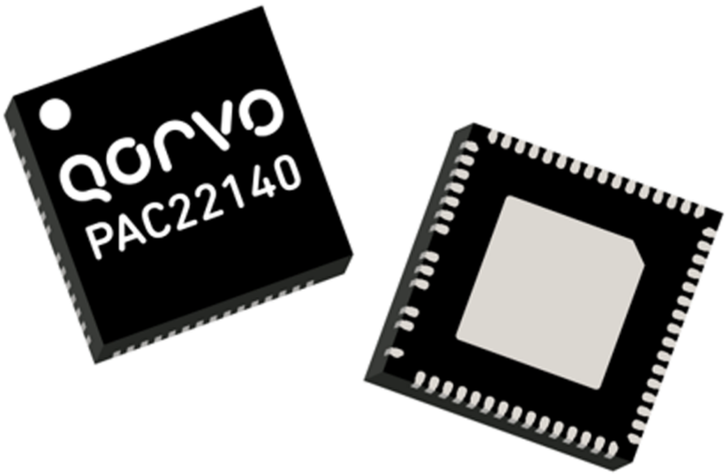

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Figure 4: An example Qorvo PAC series integrated battery management IC

Conclusion

High-performance integrated battery management systems are now available with the functionality, size and price point to incorporate into mass-market portable devices with up to 100 V Li-ion battery strings. As a particular advantage, the flexibility and configurability of the Qorvo parts enable product designers to add their own differentiating features. Watch for further releases of variants in the PAC range to suit an even wider range of applications.

Qorvo

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