Know a Battery's State-of-Charge By Counting Coulombs

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Introduction

Once considered dated technology, non-rechargeable (or "primary") battery cells are experiencing a rebirth. Even though they are not rechargeable, these primary cells, such as the Li-SOCl2 (Lithium-Thionyl Chloride), can still provide advantages for the user, including high energy density, instant readiness, low self-discharge, reasonable lifetimes and environmental friendliness (relatively easily disposable). These cells are commonly found in a variety of applications in which swapping out the batteries is impractical, costly, or where proximity/location/access is difficult. These include military, asset tracking, remote monitoring and wireless sensor networks. These batteries are routinely offered in a variety of chemistries with the 2 most popular being alkaline and Lithium (Li) based.

In comparison, rechargeable (or "secondary") cells offer a different set of benefits (even if they have an initially higher cost), and come in a variety of chemistries such as lead-acid, Nickel and Li-ion. Their advantages include reusability, economical to use (as the cost of a charging system can be spread out over many usage cycles), and good power density (the ability to deliver energy quickly). However, these cells are not considered environmentally friendly and have the potential disadvantage of low energy density (think of this as the amount of stored energy) depending on the system configuration. See Figure 1.

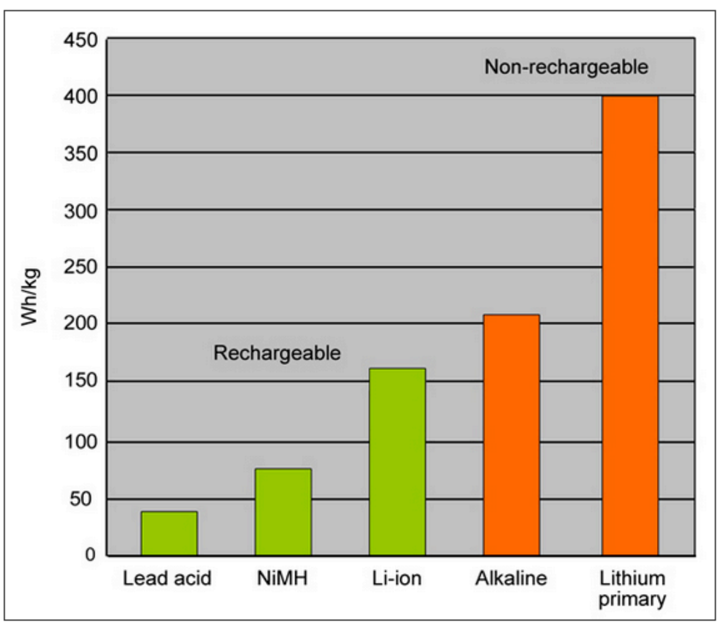

Figure 1. Energy Density of Rechargeable vs. Primary Cell Batteries
Source: Battery University

Remote location applications offer a set of conditions more conducive to primary cells - such as using a small load current over a long period of time - where replacing the battery is both costly and impractical.

Primary Cell Run Time Considerations

Despite all of their advantages, primary cells have some characteristics which are not favorable in some applications – particularly those which cannot afford any down time due to a completely discharged battery. In these instances, ascertaining the remaining run time based on the battery's state of charge ("SoC") is of paramount importance. Some primary cells tend to have very flat discharge curves, such as those of the Lithium Thionyl Chloride cell, shown in Figure 2.

This characteristic makes the remaining cell capacity very difficult to determine or predict.

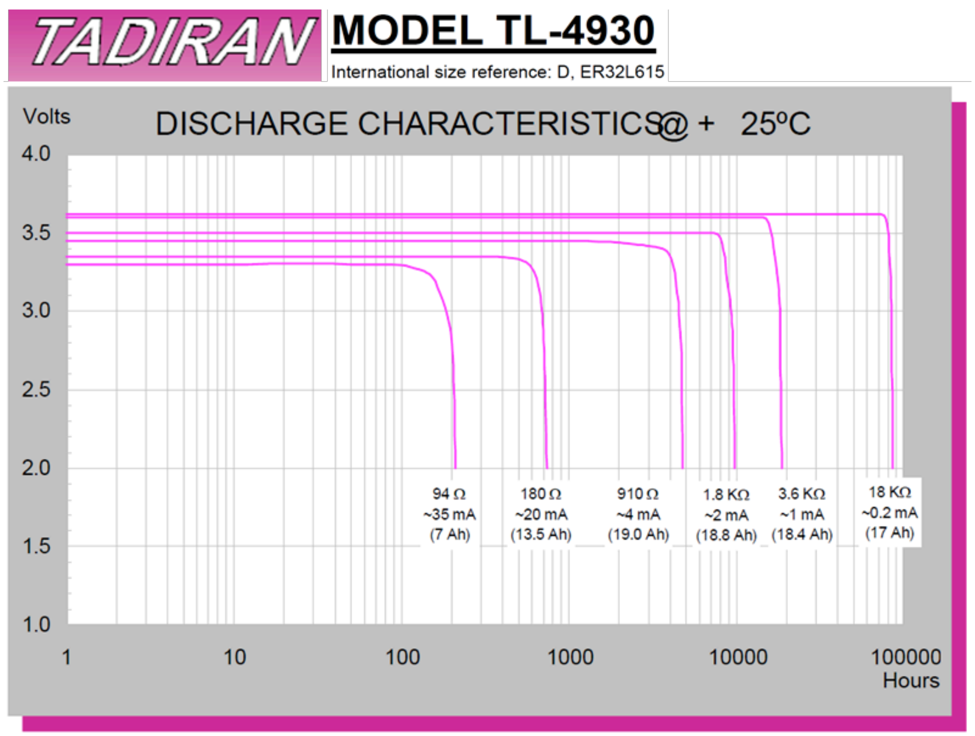

Figure 2. Discharge Curve for Tadiran Model TL-4930 Primary Cell
Source: The Tadiran Company

Ideally, a simple cell voltage measurement should be adequate to estimate a battery's state of charge. However, a flat discharge curve means you can't infer much of anything by measuring the battery voltage until the cell is about 99% dead. This common voltage measurement method for determining SoC works fine for many chemistries, but not for Lithium Thionyl Chloride or other batteries which have flat discharge curves.

Another method for estimating the state of charge involves applying a load and measuring the voltage drop, then comparing the data to an equivalent series resistance

(ESR) drop lookup table which differs by battery type. A complicating factor in this method is that battery ESR tends to have a strong dependence on temperature. Therefore, in order to use this approach with even a remote sense of accuracy requires precise knowledge and measurement of battery temperature. Otherwise, changes in observed battery ESR due to changes in SoC will be indistinguishable from changes in ESR due to variations in temperature.

Another indirect way to "measure" SoC is to characterize the load conditions very well and then measure the total operating time for each battery. For example, many users replace all the batteries on a fixed time schedule which corresponds to 40% of SOC or some pre-determined level. But, this does not maximize battery run time. Also, if there is a board fault or some other condition that causes the load to be 2-3x higher than expected, then this "open loop" method falls apart as battery run time will decrease quickly.

By contrast, another more accurate method is called "coulomb counting", where the coulombs are measured as they outflow from the cell. Traditionally, the cost to implement this coulomb counting method has been expensive, so it has been seldom applied. However, it is very effective and provides the only accurate measurement of the Coulombs consumed from a battery. If the battery's initial capacity is known and or specified, then the remaining capacity can be accurately determined based on the Coulomb count.

Other Primary Cell Challenges

Primary cells do not like excessive inrush current, but this limitation can be mitigated by a DC/DC regulator that has programmable peak input current. Furthermore, primary cells have high internal resistance – a characteristic that causes voltage collapse under load, thus lighter loads are better suited for these cells. Moreover, these cells tend to have low power density and cannot deliver their energy very quickly. As a result, they are better suited for long-life, light load situations, not ones that require fast or large energy bursts. Finally, a DC/DC regulator IC that draws excessive quiescent current to operate will drain the battery of capacity, thereby negatively affecting run time, another potential system drawback. To mitigate these effects, a micropower – or even better – a nanopower regulator, could be used to minimize current draw and maximize battery run time.

Buck-Boost Converters

The number of power rails in today's feature-rich electronic devices has increased while operating voltages have continued to decrease. Nevertheless, many of today's systems still require 3V, 3.3V or 3.6V rails for powering low power sensors, memory, microcontroller cores, I/O and logic circuitry. Traditionally these voltage rails have been supplied by step-down (buck) switching regulators or low-dropout regulators (LDOs). However, these types of ICs do not capitalize on the battery cell's full operating range, thereby shortening the device's potential battery run time. Therefore, when a buck-boost converter is used (it can step voltages up or down) it will allow the battery's full operating range to be utilized. This increases the operating margin and extends the battery run time as more of the battery's useful capacity is attained, especially as it nears the lower end of its discharge profile.

Buck-Boost Converter with Coulomb Counter
It is clear that a DC/DC converter solution that solves the primary cell system application requirements, as well as the associated issues already discussed, should have the following attributes:

1) A buck-boost DC/DC architecture with wide input voltage range to regulate Vout through a variety of battery-powered sources and their associated voltage ranges
2) Ultra-low quiescent current, both in operating mode and shutdown, to increase battery run time
3) The ability to efficiently power system rails
4) Capably count coulombs accurately without significantly affecting IC quiescent current (battery consumption), to determine remaining battery state of charge
5) Current limiting for attenuating inrush currents thus protecting the cells
6) Small, lightweight and low profile solution footprints
7) Advanced packaging for improved thermal performance and space efficiency

Fortunately, a recent product introduction from Linear Technology, the nanopower LTC3335 buck-boost converter with integrated coulomb counter, has all of these attributes already. The device was designed for primary battery applications that need really low quiescent current and also need to know something about remaining battery capacity. Or, where potential battery component or load leakage may be detected by the coulomb counter as a check for system faults. See Figure 3 below.

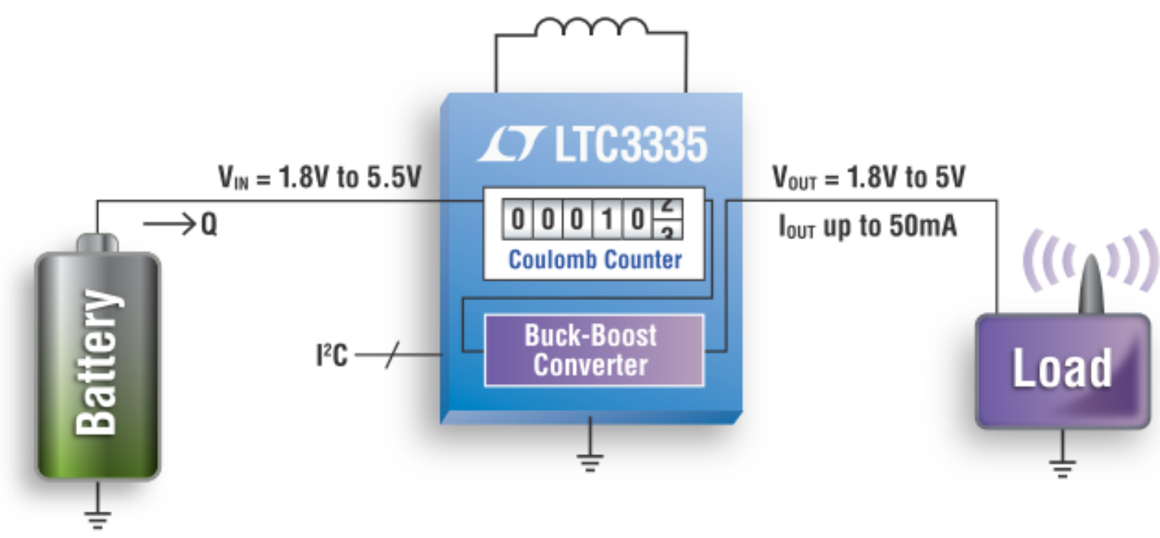

Figure 3. LTC3335 Buck-Boost Converter with Integrated Coulomb Counter

The LTC3335 is a nanopower high efficiency synchronous buck-boost converter with an onboard precision coulomb counter that delivers up to 50mA of continuous output current. With only 680nA of quiescent current and programmable peak input currents from as low as 5mA up to 250mA, the device is ideally suited for a wide variety of low power battery applications, such as those found in wearables and IoT (internet of things) devices. Its 1.8V to 5.5V input range and 8 user-selectable outputs between 1.8V and

5V provide a regulated output supply with an input voltage above, below or equal to the output. In addition, the device's integrated precision (±5% battery discharge measurement accuracy) coulomb counter provides accurate monitoring of accumulated battery discharge in long-life non-rechargeable battery-powered applications which in many cases have extremely flat battery discharge curves. Typical applications include wireless sensors, remote monitors, and Linear Technology's Dust Networks ® SmartMesh® systems. The LTC3335 includes four internal low R_{DSON} MOSFETs and can deliver efficiencies of up to 90%. Other features include a programmable discharge alarm threshold, an I2C interface for accessing coulomb count and device programming, a Power Good output, and 8 selectable peak input currents from 5mA up to 250mA to accommodate a wide range of battery types and sizes. The LTC3335 is available with an operating junction temperature range from -40°C to +125°C in a thermally enhanced, 20-lead 3mm x 4mm QFN package. Figure 4 shows a typical application circuit.

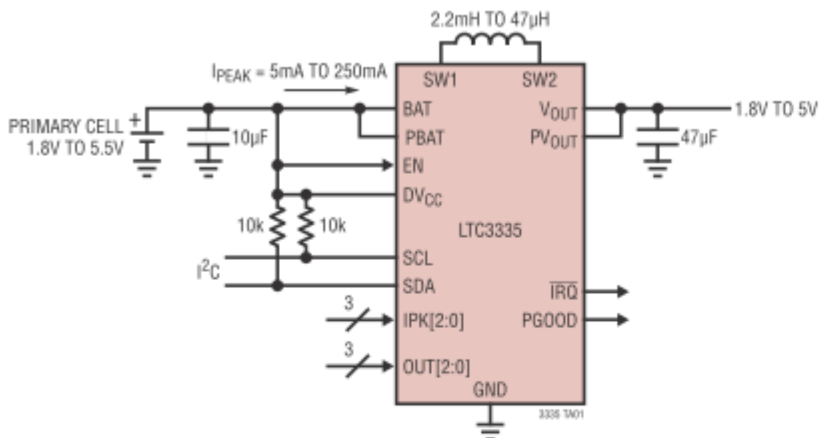

Figure 4. Simplified LTC3335 Application Schematic

Conclusion

Rechargeable "secondary" batteries can be found in a myriad of applications; however there has been resurgence in demand for non-rechargeable primary cell applications, such as military, remote monitoring or wireless sensor systems. Primary cells have many advantages but also have a few characteristics which make them difficult to implement in many designs: flat discharge curves, do not behave well with surges in current, and are better under light load conditions.

Coulomb counting is a reliable technique to predict remaining battery capacity. A buck-boost architecture is advantageous since it regulates Vout when the input is equal to, above or below the output, which maximizes run time when battery-powered. Effectively powering a low-current remote monitoring application can prove very challenging; however**,** Linear Technology offers a portfolio of leading-edge products capable of very high performance at low power levels. One particular device with nanopower consumption, the LTC3335 buck-boost regulator with integrated coulomb counter and current limiting, makes for an extremely compelling solution for a variety of non-rechargeable, light load applications to save battery run time.