Nanopower IoT Power Supply Accurately Monitors Battery Discharge

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The Internet of Things, or IoT, refers to the growing number of interconnected devices that monitor everything from heart rates to room temperatures or building occupants. New applications are created every day to measure and report all types of data via wireless local networks which in turn may connect via gateways directly to the Internet. If the pundits are correct, we will soon have the ability to monitor the health and operating status of every appliance in our homes, turn off all the lights, and learn the exact location of our pets, all with a few finger swipes on our smart phones. Ubiquitous wireless monitoring will enable observation and control of our surroundings anytime, anywhere.

On a more utilitarian note, the Internet of Things has also manifested itself in industrial settings in the form of wireless sensors arrayed in vast mesh networks. Such wireless sensor networks are used in factories, industrial sites and on vehicles and machinery around the world to monitor critical parameters and improve safety, reliability and timely maintenance. Regardless of their intended use, such wireless devices all share a common problem: how do they get their power?

Clearly, there are many alternatives to consider. Wireless monitors should be small and unobtrusive, and they should require minimal maintenance. In the IoT world of tomorrow, experts suggest that many of these devices will be self-powered via optimized energy harvesters capable of providing an endless source of power. While such a prospect sounds ideal, and considerable progress has been made to improve the practicality of energy harvesting, solutions today often fall short in terms of size and performance, and there will always be cases where power is needed and no harvestable energy is available. Fortunately, battery technologies exist which are optimized for long lifetime, low average power applications such as those on the IoT spectrum.

Lithium Thionyl Chloride: The Ideal Wireless Sensor Energy Source

IoT applications tend to have similar power and energy requirements. The average power for remote monitors is typically very low, with an occasional need to measure and broadcast data in a bursty fashion. The ideal battery for such applications would therefore favor energy density over power density. In addition, battery self-discharge should be minimized to enable the longest possible operating time and to reduce the need for costly downtime and maintenance to replace batteries. An excellent battery technology for such applications is lithium thionyl chloride (Li-$SOCL_2$). This battery chemistry provides extremely low self-discharge (shelf life of 20 years plus claimed by several suppliers), very high energy density and a relatively high 3.6V typical operating voltage. Li-$SOCL_2$ batteries are widely available from numerous suppliers in many different shapes, sizes and capacities. However, as with most highly specialized technologies, usage comes with a set of trade-offs.

Challenges Using Long Lifetime Batteries

Realizing the lifetime (capacity) benefits of Li-$SOCL_2$ batteries requires particular care when designing the application circuitry. As can be seen in Figure 1, lithium thionyl chloride batteries have a very high output impedance. The chemical reaction that enables extremely low self-discharge and long shelf life (passivation formation) has the unwanted effect of limiting the available output current. Even when the passivation layer has dissipated due to periodic loading of the battery, the peak currents that may be supplied are low compared to other battery chemistries for a given amp-hour capacity rating. With lithium thionyl chloride, high current draw results in not only a reduced operating voltage but also a reduced battery capacity. Operating the battery of Figure 1 with a 100mA DC load results in 9 amp-hours of capacity, considerably below the peak value of 19 amp-hours, which occurs with a 4mA load. Hence, applications requiring momentary high peak currents must employ capacitor storage in parallel with the battery to handle the periodic short-term power bursts, as well as some form of battery current limiting during peak loads in order to maximize available capacity.

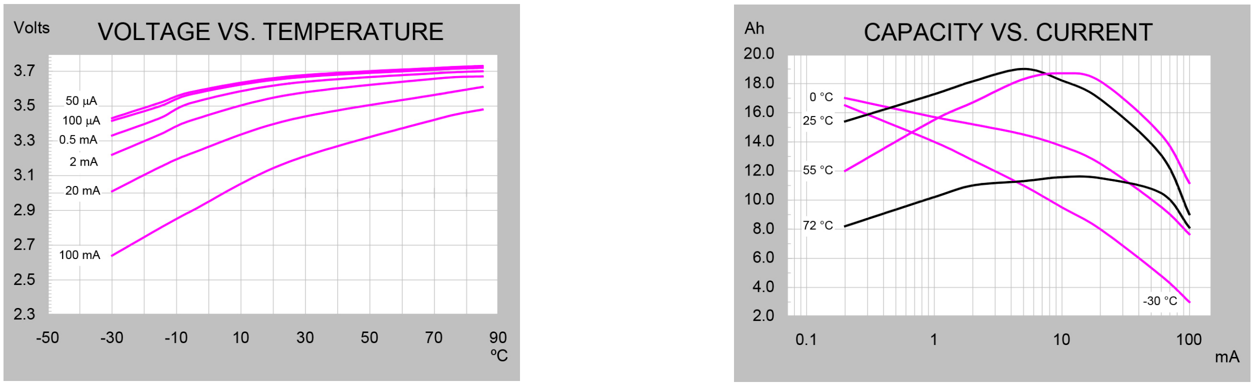

Figure 1. Li-$SOCL_2$ Voltage and Capacity vs. Temperature and Current (source: Tadiran)

The battery current management problem is further complicated if a DC/DC converter is needed to maintain a stable supply voltage for the downstream sensor and communication electronics. DC/DC converters optimized for low power applications generally operate in a Burst Mode® fashion, where the converter remains in a SLEEP state until the output drops below the regulation point, and then large, short duration bursts of current are supplied to the output until regulation is achieved. As previously discussed, such bursty currents are problematic for lithium thionyl chloride as well as other primary battery chemistries, and result in reduced operating life for the system. The ideal IoT power solution would combine a long lifetime battery with a DC/DC converter designed with a battery-friendly current management system.

Nanopower DC-DC Converter with Programmable Peak Input Current

A new product, the LTC3335 (see Figure 2), was designed with these exact requirements in mind. The part is a buck-boost DC/DC converter which generates a fixed, pin-programmable regulated output voltage between 1.8V and 5V from an unregulated input voltage between 1.8V and 5.5V. The part may be used with a wide variety of primary battery sources to regulate an output voltage above, below or equal to the input.

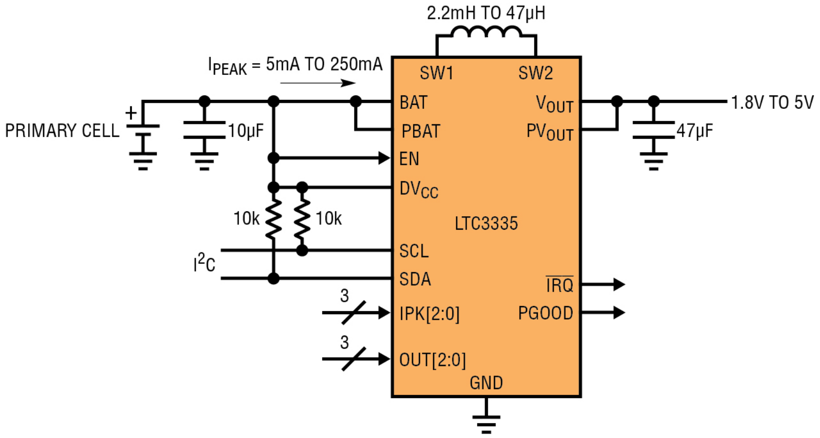

Figure 2. LTC3335 Nanopower Buck-Boost DC/DC with Programmable Peak I_{LIM}

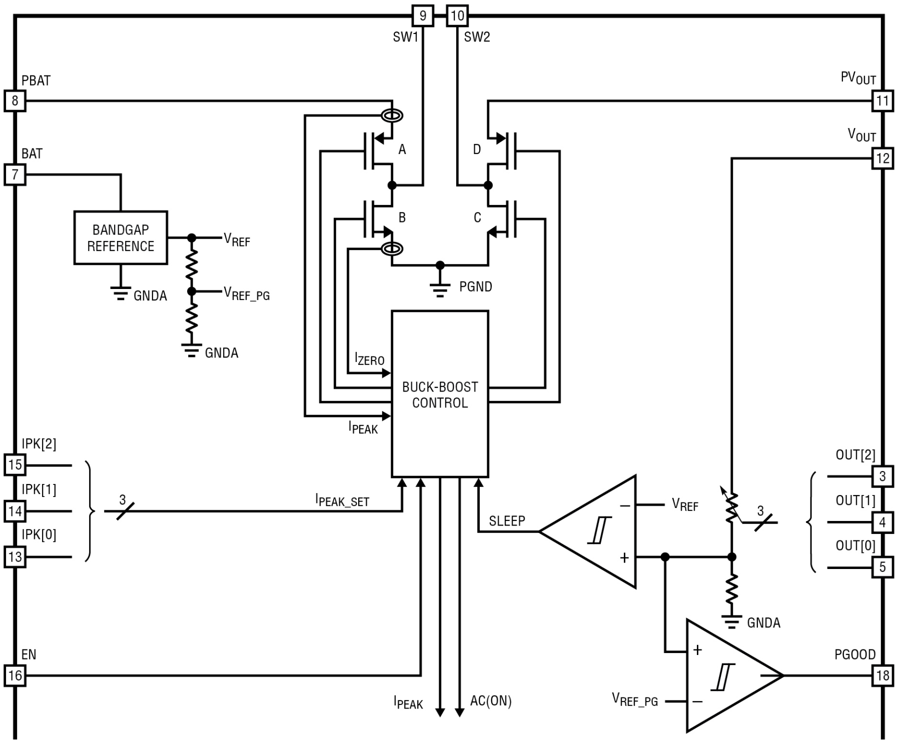

Figure 3. LTC3335 DC/DC Block Diagram

The LTC3335 is unique among buck-boost converters in requiring only 680nA of input quiescent current to maintain a regulated output. In addition, the part includes 8 programmable peak input current settings from as low as 5mA up to 250mA in order to accommodate the input current limitations of a wide range of primary cell batteries, including lithium thionyl chloride, without any external current limiting.

The LTC3335's DC/DC operation is relatively straightforward (see Figures 2 and 3). If the output voltage is above the regulation point, the part enters a SLEEP mode with only the output monitoring circuitry active. Once the load forces the output voltage to drop below its regulation point, the DC/DC converter is enabled and power is transferred from input to output using a four switch monolithic full bridge converter. Once the DC/DC converter is enabled, switches A and C turn on, allowing current to flow from the battery through an external inductor connected between pins SW1 and SW2. Once the programmed peak current (I_{PEAK}) is reached, switches A and C turn off and switches B and D turn on, allowing the current flowing in the inductor to charge the output capacitor connected to the PV_{OUT} pin. Current continues to flow in switches B and D until it reaches zero. If at this point the output is above the regulation point, the part returns to SLEEP mode until the output drops out of regulation. Otherwise, another cycle AC/BD switch cycle commences. With such low quiescent current and synchronous operation, the LTC3335 achieves power conversion efficiency above 80 percent with load currents as low as 10µA, a common average load level for a wide variety of wireless sensors. In addition, peak input currents may be reduced to the minimum value necessary to support the average power consumption, thereby maximizing battery lifetime and capacity.

Additional Challenge: Estimating Remaining Battery Capacity

Despite efforts to minimize load currents and maximize battery life, applications are ultimately area constrained, and batteries will need replacement at some point. In a low cost portable device, monitoring the discharge status of the battery and estimating the remaining capacity may be a low priority. Either the battery outlasts the usable life of the product, or the consequences of going off-line to change the battery are minimal. However, in the case of a critical sensor in a factory automation system or rail car safety monitor, unforeseen downtime to replace a dead battery represents an unacceptable expense.

Predicting remaining capacity with many primary cell batteries is often a difficult task, but is especially challenging with lithium thionyl chloride. As shown in the discharge curves in Figure 4, the open circuit voltage for a typical Li-$SOCL_2$ battery remains fixed at a nearly constant voltage until virtually *no* capacity remains in the battery. At this point, the battery voltage drops abruptly. As a result, battery voltage monitoring provides little useful information until battery capacity is very close to zero. Furthermore, both the open circuit voltage and the battery impedance have a strong temperature dependency, so even if measuring such parameters provides sufficient warning to avoid unscheduled downtime, discerning the difference between the knee of the discharge curve and a change in temperature or load is impossible without additional monitoring – all of which consumes unwanted power.

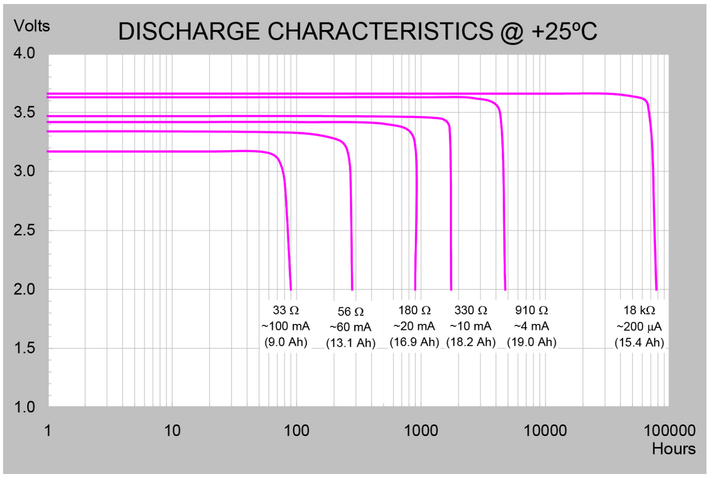

Figure 4. Li-SOCL$_2$ Voltage vs. Output Current (source: Tadiran)

Solution: "Zero" Quiescent Current Coulomb Counter

The most simple and direct way to monitor battery usage is to count the coulombs discharged from the battery. Traditional methods involve continuous monitoring and integration of the battery current, which consumes considerable amounts of power even under no load conditions. However, the LTC3335's power conversion architecture accurately self-monitors the amount of charge passing from the battery to the load each time the DC/DC converter needs to boost the output into regulation. The key difference is that during the DC/DC SLEEP periods, the coulomb counter consumes *zero* current.

Whenever the DC/DC converter is enabled, current flows from the battery only when switches A and C are on. Current in switches A and C will flow until I_{PEAK} is reached, and then switches B and D turn on and the inductor current discharges into the output capacitor as it ramps down to zero. Once the zero current point is detected, the cycle repeats until V_{OUT} is in regulation. With an appropriately chosen inductor, the current from the battery will ramp linearly from zero until the programmed peak current value is reached each time switches A and C are ON, as shown in Figure 5.

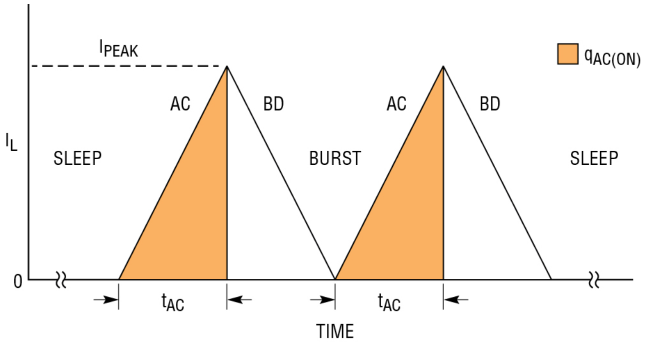

Figure 5. Battery Discharge Measured During Switch AC ON Time

The time required to reach I_{PEAK} in a given AC ON cycle is primarily a function of the battery voltage, inductor value and I_{PEAK} setting. By measuring the amount of time required to reach I_{PEAK}, the number of coulombs transferred during each AC ON cycle may be determined for a given I_{PEAK} setting using the formula below:

$$q_{AC(ON)} = \frac{I_{PEAK} \bullet t_{AC}}{2}$$

The LTC3335 contains an internal timing circuit that periodically measures the AC ON time and outputs an accurate number of coulombs scaled for the selected I_{PEAK} setting each time switches A and C are turned ON. An internal adder and ripple counter tally up the number of times that switches A and C turn ON and multiply this count by the scaled coulombs per AC ON time, $q_{AC(ON)}$. The 8 MSBs of the counter chain are accessible to the user via an I^2C port and represent the total number of coulombs passed from the battery to the load. Scale factors may be chosen via I^2C to accommodate different battery sizes and I_{PEAK} settings, and alarm levels may be selected to alert the system about each sensor's battery consumption. Since the LTC3335's internal coulomb counter must only hold its logic state while the DC/DC converter is in SLEEP mode, the added quiescent current to monitor battery discharge truly approaches *zero*.

Sources of Error and Mitigation

As with most solutions, trade-offs and error sources exist. The LTC3335 coulomb counter, shown in Figure 6, monitors and "measures" the charge that is consumed at the output of the DC/DC converter. This includes 100% of the load current, as well as that portion of the internal switch driver current that is powered from V_{OUT}. However, the quiescent current during SLEEP mode and the V_{IN} current used for switch drive and the DC/DC control circuits active during charge transfer are *not* measured and represent an error source. In general, the part will slightly under-report coulombs discharged. At peak currents above 50mA or so, these errors are quite small (less than 5%), but at the lowest peak current settings, these errors can be substantial (>20% of actual coulombs discharged). Fortunately, for a given set of application conditions, the primary error sources are due to relatively well controlled and predictable characteristics of the IC which enables software error correction to reduce the reported coulomb count error to single digit percent accuracy, even at the lowest peak current settings. Typical curves published in the data sheet may be used to compensate for these errors at the system software level.

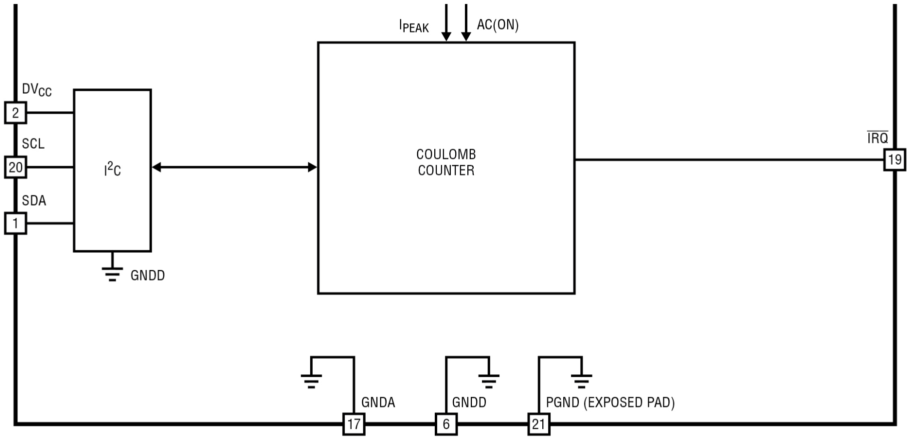

Figure 6. LTC3335 "Zero" Current Coulomb Counter Relies on DC/DC Architecture

The Optimal Wireless Sensor Power Supply

Achieving long operating life, together with reliable operation, is a worthy goal for any wireless application. Choosing which of many available power sources to use requires weighing the trade-offs associated with solution size, operating life, peak power requirements, etc. As wireless sensor use expands into more and more applications involving safety, security or industrial system performance, the need to optimize power consumption and achieve longer operating life becomes imperative. Network reliability grows in importance as well. This includes not only the robustness of the data generation and transfer throughout the network, but also the avoidance of unexpected downtime due to power loss. New DC/DC converters such as the LTC3335 are designed specifically to address the power needs of such systems and optimize energy utilization regardless of battery size and chemistry. However, only the LTC3335 also provides an accurate tally of the number of coulombs transferred from the battery to the load without taxing the battery in the process. This is a rare case of getting something for nothing.