Circle 522

Li-Ion Battery Protection Circuit Draws Only 4.5 µA

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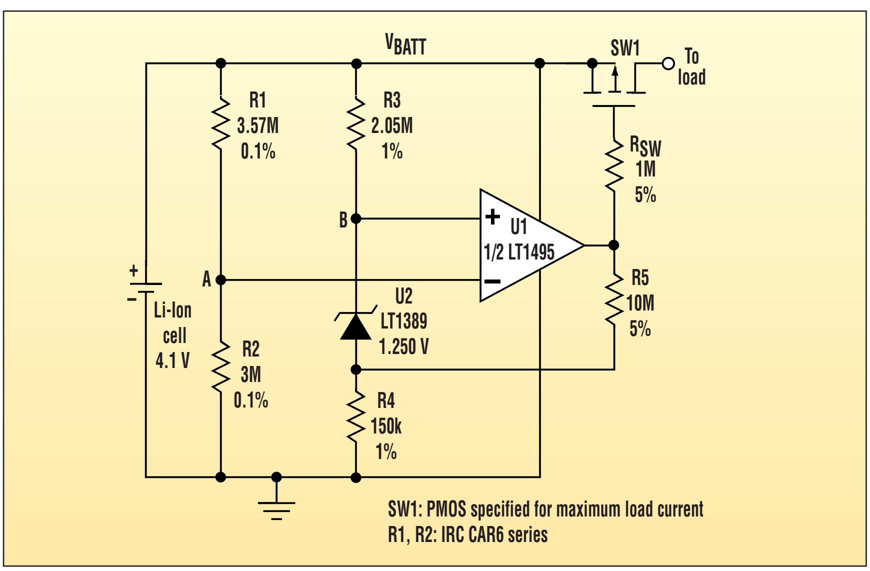
Figure 1 shows an ultra-low-power, precision undervoltage-lockout circuit. The circuit monitors the voltage of a Li-Ion battery, disconnecting the load to protect the battery from deep discharge when the battery voltage drops below the lockout voltage.

Storing a battery-powered product in a discharged state while the battery is low puts the battery at risk of being completely discharged. During the discharged state, current to the protection circuitry also discharges the battery. If the battery discharges below the recommended end-of-discharge voltage, the battery performance degrades, cycle life shortens, and the battery dies prematurely. In contrast, if the lockout voltage is set too high, the maximum battery capacity isn't realized.

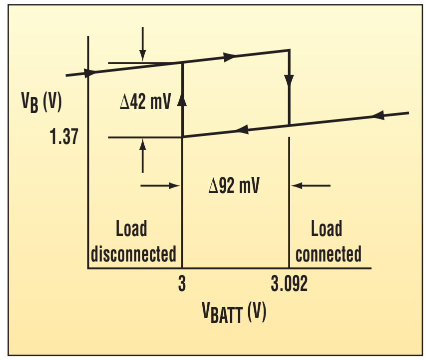
The low-battery mode of operation is indicated when, for instance, a cell phone automatically powers down after the battery-low indicator has been flashing for some time. If the phone is misplaced in this condition and found months later, the protection circuitry shown in Figure 1 won't over-drain and damage the battery. That's because the protection circuitry takes less than 4.5 µA of current. At this low current, the time taken by the Li-Ion battery to reach its end-of-discharge voltage is greatly extended.

For other protection circuitry that typically requires higher currents, the rate of self-discharge is faster, allowing the battery voltage to drop below the safe limit in a shorter time. Note that if the battery is allowed to self-discharge below the safe limit, the resulting capacity loss that occurs is unrecoverable .

The circuit is set up for a single-cell Li-Ion battery, where the lockout voltage (the voltage at which the protection circuit disconnects the load from the battery) is 3.0 V. This voltage, set by the ratio of R1 and R2, is sensed at node A. When the battery voltage drops below 3.0 V, node A falls below the threshold at node B, which is defined as:



1. This ultra-low-power, undervoltage lockout circuit disconnects the load to protect the Li-Ion battery from deep discharge and its associated permanent loss of battery capacity.



2. To avoid oscillation, R5 is added to provide hysteresis around the trip point.

$$V_B = 1.25\text{ V} + I \times R4 = 1.37\text{ V}$$

where $I = (V_T - 1.25\text{ V})/(R3 + R4) = 800$ nA and V_T = lockout voltage.

The output of U1 will then swing high, turning off SW1 and disconnecting the load from the battery. However, once the load is removed, the battery voltage rebounds and will cause node A to rise above the reference voltage. The output of U1 will then switch low, reconnecting the load to the battery and causing the battery voltage to drop below 3.0 V again. This cycle will repeat itself and oscillation occurs.

To avoid this condition, R5 is added to provide hysteresis around the trip point. When the output of U1 swings high to shut off SW1, node B is bumped up to 42 mV above node A, preventing oscillation around the trip point. Using the formula below, the amount of hysteresis for the circuit is calculated to be 92 mV. Hence, V_{BATT} must climb back above 3.092 V before the battery is connected.

$$\text{Hysteresis} = V_B' \times R1/R2 + V_B - V_T$$

where:

$V_B' = (V_{OMAX} - I \times R4) \times R4/R5 + V_{REF} + I \times R4$
V_T = lockout voltage
V_{OMAX} = maximum output swing (high) of U1 when V_{BATT} is equal to the lockout voltage

Consult the battery manufacturer regarding the maximum ESR at the maximum recommended discharge current. Multiply the two values to get the minimum hysteresis required.

The worst-case voltage-monitor accuracy is better than 0.4%. Interestingly, the battery's longevity and capacity are directly related to the depth of discharge. More cycles can be obtained by partially rather than fully discharging the Li-Ion battery, and, conversely, more use time can be obtained by fully discharging a Li-Ion battery. Cutting off the load at the perfect end-of-discharge voltage would ideally result in the best of both cases.

To perform this task requires an accurate overall system. For example, if the optimum lockout voltage is to be set at 3.1 V, a system with 5 % overall accuracy would yield ±155 mV, cutting off at either at 2.945 V or 3.255 V. At a lockout voltage of 3.255 V, the maximum capacity isn't obtained. In addition, the operating range is reduced, with the fully charged battery voltage being 4.1 V.

With a 0.4% overall accuracy, the lockout voltage would be at 3.088 V or 3.112 V, more than 12 times better accuracy and optimally achieving the highest capacity. Furthermore, the load is kept disconnected with only 4.5 µA consumed by the protection circuit. Thus, the protection circuit also assists in preventing deep discharge of the battery. ❒