Keywords: ML, rechargeable lithium, secondary batteries, single-piece modules, SPM

APPLICATION NOTE 3954

Characteristics of Manganese Lithium (ML) Batteries

Dec 21, 2006

Abstract: This study of Manganese Lithium (ML) batteries provides some of the basic electrical characteristics required to support nonvolatile memory devices. The Maxim single-piece NVSRAM modules with an ML battery serve as examples.

Introduction

This article details the characteristics of Manganese Lithium (ML) rechargeable (secondary) coin cell batteries, as applied in nonvolatile memory backup applications. Data will be presented to: 1) measure the initial battery capacity; 2) characterize the battery charging profile; 3) determine the effects of repetitive charge/discharge cycles upon the battery capacity; and 4) understand the implications of self-discharge when using secondary coin cells.

As a prerequisite, it is recommended that the reader be familiar with the basic characteristics of primary lithium coin cells as utilized in memory applications. For more information on lithium cells and battery capacity, please see application note 505, "Lithium Coin-Cell Batteries: Predicting an Application Lifetime."

Battery Capacity Measurements

For this experiment, a discrete circuit was constructed to isolate the lithium consumption phase of the classic discharge model, as presented in application note 505. The battery manufacturer will typically specify a maximum discharge rate based on the chemistry and physical cell sizing. **Figure 1** illustrates the basic discharge circuit.

To measure battery capacity, monitor and record the battery voltage across a known load (R_L) for the amount of time required to discharge the cell to an effective 2V cut-off voltage (also referred to as 100% depth-of-discharge).

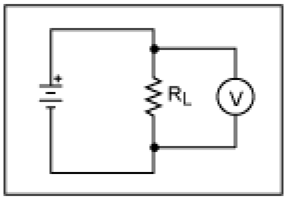

Figure 1. Basic diagram of a discharge circuit.

With primary batteries, this discharge can be executed one time. Once depleted, the cell must be discarded/replaced. With rechargeable batteries, this discharge function can be executed multiple times, thus extending the product's service lifetime.

A discrete circuit was also defined to control the charge cycle for the ML-chemistry batteries. The battery manufacturer will recommend a current-limiting series resistance (R_{CL}), based upon the specific chemistry and physical cell sizing. The diode is to prevent accidental battery discharge, in case the power source fails during the charge cycle. **Figure 2** illustrates the basic charging circuit.

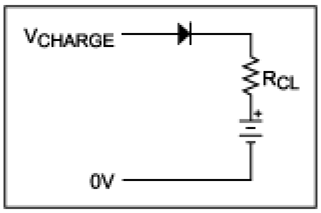

Figure 2. Charge circuit for an ML battery.

"As Received" Capacity

With primary batteries, there is a single capacity value to measure. The "As Received" condition is the best that primary cell will ever be. Maxim utilizes the As Received condition as the standard—a benchmark capacity level at which either a primary or secondary cell should remain throughout the manufacturing process for memory products.

According to the battery manufacturer, the ML2020R cells are approximately 60% charged upon shipment. Fully charged ML2020R cells will be discussed later in this article.

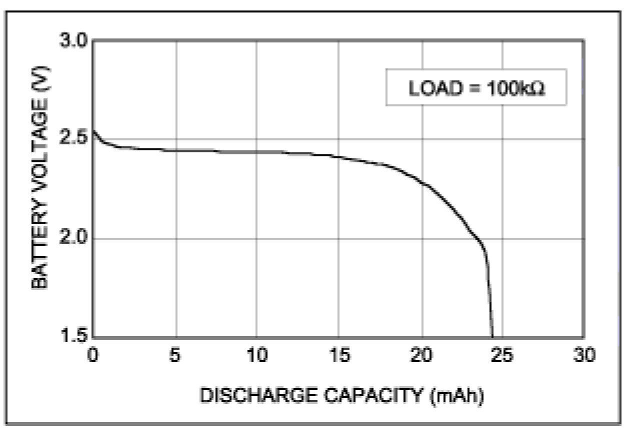

Figure 3. ML2020R "As Received" capacity.

As a result of this discharge evaluation, the ML sample demonstrated an average capacity of approximately 23mAh, or about 75% of full capacity. (See **Figure 3**.)

Battery Charging

The simplicity of the ML charger circuit (Figure 2) makes monitoring the battery charge cycle quite easy, as the ML cell will attempt to reach equilibrium with the input supply voltage after some time. By monitoring the battery voltage, the charging current, and the time, those characteristics can be illustrated.

As we already measured the capacity of the cells As Received, a new sample was selected to characterize the initial battery charge cycle. **Figure 4** illustrates the changes in closed-circuit voltage and capacity added during the charge. No further voltage change was observed after ~80 hours. Capacity added was 5.7mAh on the sample monitored.

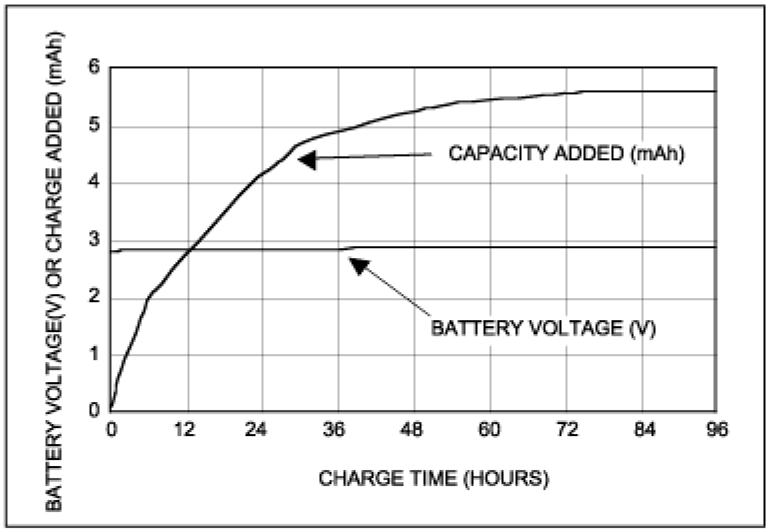

Figure 4. Initial charge profile for a ML2020R battery.

Fully Charged Capacity

A sample of fully charged batteries was subsequently discharged using the same methodology employed in the As Received capacity illustration (Figure 3). To eliminate the uncertainty induced by the test equipment resolution, this sample was allowed to charge for approximately 200 hours prior to beginning the discharge measurements.

As suggested by the summation of the As Received capacity plus the charge added during this extended charge cycle, the fully charged ML2020R cell was found to exceed the typical capacity rating of 30mAh. Capacity added during this slightly extended recharge was calculated to be greater than 7mAh.

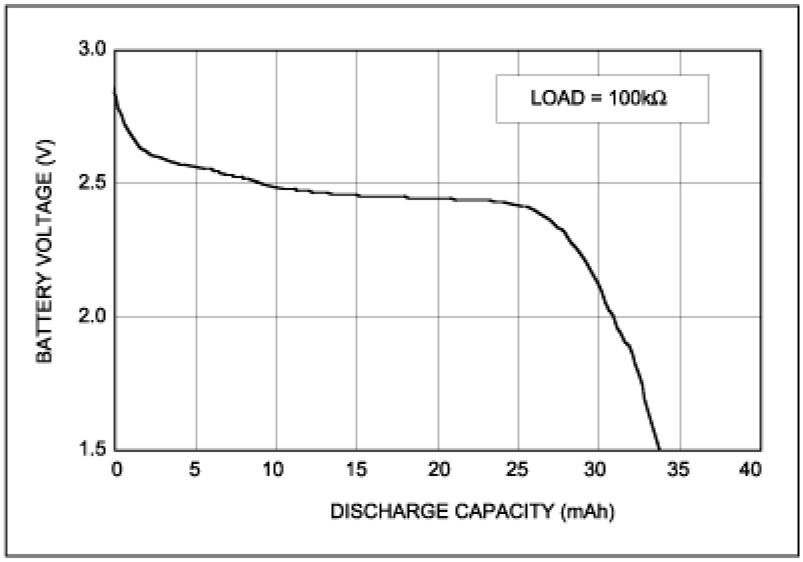

Figure 5. ML2020R capacity after a full charge.

Cycle-to-Cycle Stability

The sample selected in Figure 3 was then repetitively recharged and discharged to ascertain the stability of the battery over a hypothetical system lifetime. The battery manufacturer rated the ML2020R to withstand up to 15 100% depth-of-discharge cycles, or 1000 10% depth-of-discharge cycles.

For this study, all discharge cycles were conducted to 100%, and the initial discharge (As Received condition) was included in **Figure 6** to represent an extended post-manufacturing shelf-life period, which is applicable for field spares. The present accumulative data, through the tenth discharge cycle, required over 18 months of continual study. The conclusion of this experiment is projected for mid-2007.

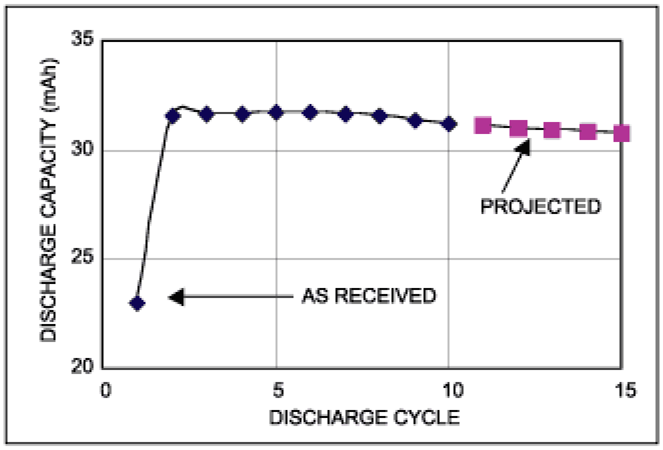

Figure 6. ML2020R capacity vs. discharge cycle.

As an observation, it is noted that all samples show a slight but consistent cyclic capacity improvement (~0.2%), up through the first half of the cell's useful cycle life. That trend then reverses, where subsequent discharge measurements show a ~0.3%/cycle degradation in the capacity.

Using the accumulative charge data in Figure 6, **Figure 7** illustrates the lifetime expectancy of a product using the ML2020R secondary cell, when compared to a "like" product using a BR1225 primary cell.

Although the secondary cell's initial capacity is less than a primary cell, the obvious advantage of using secondary cells is in the much-improved field lifetime of the end system.

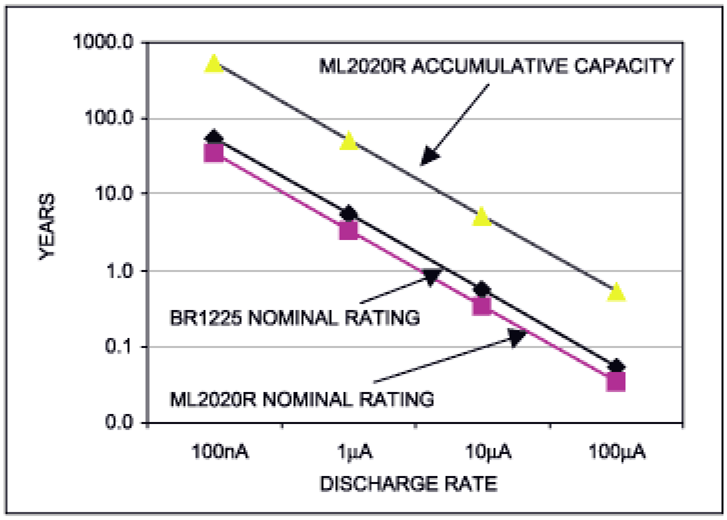

Figure 7. Accumulative lifetime capacity.

Working from the basic battery lifetime calculations found in applications note 505, some assumptions were made that the end system would be powered on for four consecutive days, once every three years, and that the memory component consumes 1µA continuously during battery backup. Therefore, the expected field lifetime comparison shows that a BR1225-based product (48mAh primary cell) should last for ~5.5 years, while a ML2020R-based product (30mAh secondary cell) should function well beyond 50 years.

Self-Discharge

With primary cells, the classic parallel discharge model presented in application note 505 provides a methodology to estimate capacity loss when system V_{CC} power is applied, based upon the self-discharge rate specified by the battery manufacturer. With the ML secondary cells and the float-charger circuit employed in Maxim's NV controller, the battery is being charged whenever V_{CC} power is present, thus negating any concerns of self-discharge after installation.

The only time that the classic self-discharge model can be applied is the shelf-storage time after Maxim's manufacturing. Our "Freshness Seal" circuitry in the nonvolatile controller/charger component prevents any load current consumption prior to the customer's first power application. Therefore, any charge loss during this time would revert to the self-discharge rating from the battery manufacturer.

Conclusions

The sampled ML2020R batteries met or exceeded the manufacturer's expectations of at least a 60% charge upon receipt.

The sampled ML2020R batteries were confirmed to reach a full charge in ≤ 96 hours. The rapid initial rise in the battery voltage during the charge cycle has little relevance to the actual charge capacity added. Accurate charge monitoring requires the inclusion of an ammeter capable of measuring currents of less than 1µA on each individual cell being monitored.

The cycle-to-cycle capacity measurements indicate a ~0.2% cycle-to-cycle improvement in battery capacity through the first eight discharge cycles. After that point, there is a ~0.3% cycle-to-cycle degradation in that capacity. Projected capacity estimates indicate that the manufacturer's capacity rating will be met for all of the 15 full-discharge cycles.

Unlike products containing primary batteries, there is essentially no time where the customer should experience the classic self-discharge phenomenon. When V_{CC} power is applied, the battery is under a constant float charge, thereby negating this historic concern.

The ML2020R rechargeable lithium cell provides a very significant improvement in the expected field service lifetime of products containing this battery technology. Traditional efforts to estimate remaining battery capacity become unnecessary when the charge can be replenished many times during the system's operational life.

More Information
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