Defusing Battery Fuel Gauge Misconceptions -- How Wireless Handsets and Other Products Can Benefit From Accurate Battery Monitoring

Most hand-held products lack accurate battery-charge monitors ("fuel gauges") because of the misconception that an accurate fuel gauge is difficult to achieve. This article debunks the myths and discusses how to accurately monitor charge at all temperatures, charge and discharge rates, and aging conditions.

A battery "fuel gauge" monitors the charge remaining in rechargeable batteries, as used in portable applications such as wireless and cellular telephone handsets, PDAs, and MP3 players. Accurate fuel-gauging allows hand-held systems to get the most out of their batteries, allowing system designers to specify smaller batteries while reducing the risk of data loss and enhancing customer satisfaction.

New devices, such as those which combine PDA and cellular handset capability, are a good example of devices that can profit from a good fuel gauge. Unlike their larger counterparts, PC notebooks, they are not likely to use smart-battery standards which include fuel gauging. But they are likely to need fuel gauges to prolong operation between charges and protect volatile data.

The DS276x, DS277x, DS274x and DS275x products are an easy way to accurately monitor usable battery life.

Misconception 1: Accurate Battery Information Does Not Increase the Run Time.

The increase in memory requirements of wireless handhelds means that application programs and user files are stored in volatile RAM memory. A loss of battery power would destroy files that the user created or purchased. Some systems use rechargeable coin batteries to power the memory when the main battery is empty or disconnected, but even the largest of these cells has only a 25mAh capacity and does not hold the memory longer than 1 day. Typical coin cells, moreover, hold less than 5mAh and are exhausted in a matter of hours. Therefore, data-centric wireless handhelds must be shut down before the main battery is completely discharged, thus ensuring sufficient reserve capacity to preserve the memory contents until a charger is connected. Most users require a batteryusage minimum of 5 days, but prefer 10 days or more.

Ideally, the battery used on feature-rich handsets or wireless PDAs should be shut down with 100mAh to 200mAh remaining from its 900mAh to 2000mAh fuel capacity.

As an example, assume an application requires 150mAh reserve capacity. The +20° C curve in Figure 1 shows that choosing a cutoff voltage of 3.5V leaves the appropriate amount of capacity in the cell. However, the 0° C and +40° C curves do not correlate. If the battery is cold (0° C on the curve), the voltage is depressed. Using 3.5V as the cutoff results in over 400mAh for reserve and less than 600mAh for run time. Conversely, when the battery is warm, the voltage is elevated. Less than 100mAh is available for reserve (+40° C on the curve).

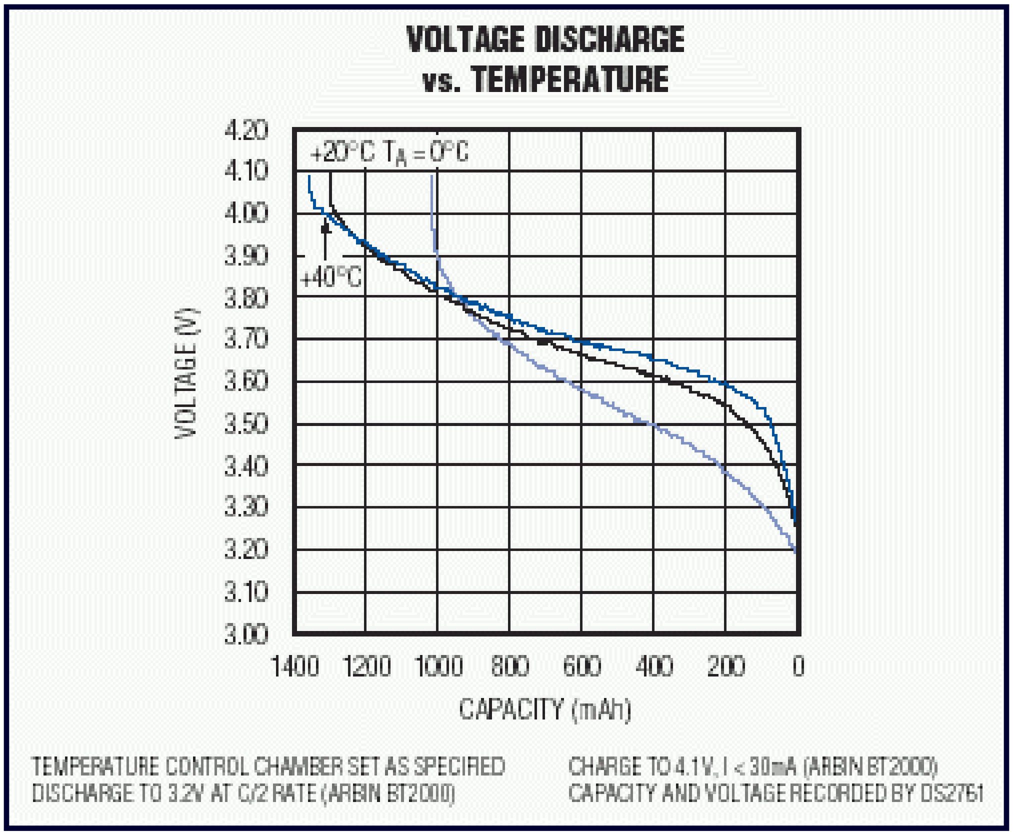

Figure 1. Voltage discharge profile varies with temperature. If the battery is cold, voltage is depressed. If the battery is warm, voltage is elevated.

Variations in the load current also have a significant effect. The curves in Figure 2 show the voltage profiles resulting from three discharge rates: C/2, C/5, and C/10, where C equals the charge capacity of the cell. This shows that reserve capacity resulting from a 3.5V cutoff varies from <100mAh for C/10 to >200mAh for C/2. Increasing the cutoff voltage to 3.6V to ensure sufficient reserve with a C/10 load condition varies the reserve from 150mAh to 400mAh over the three discharge rates. Thus, trying to increase the reserve capacity by increasing the cutoff voltage brings a large penalty.

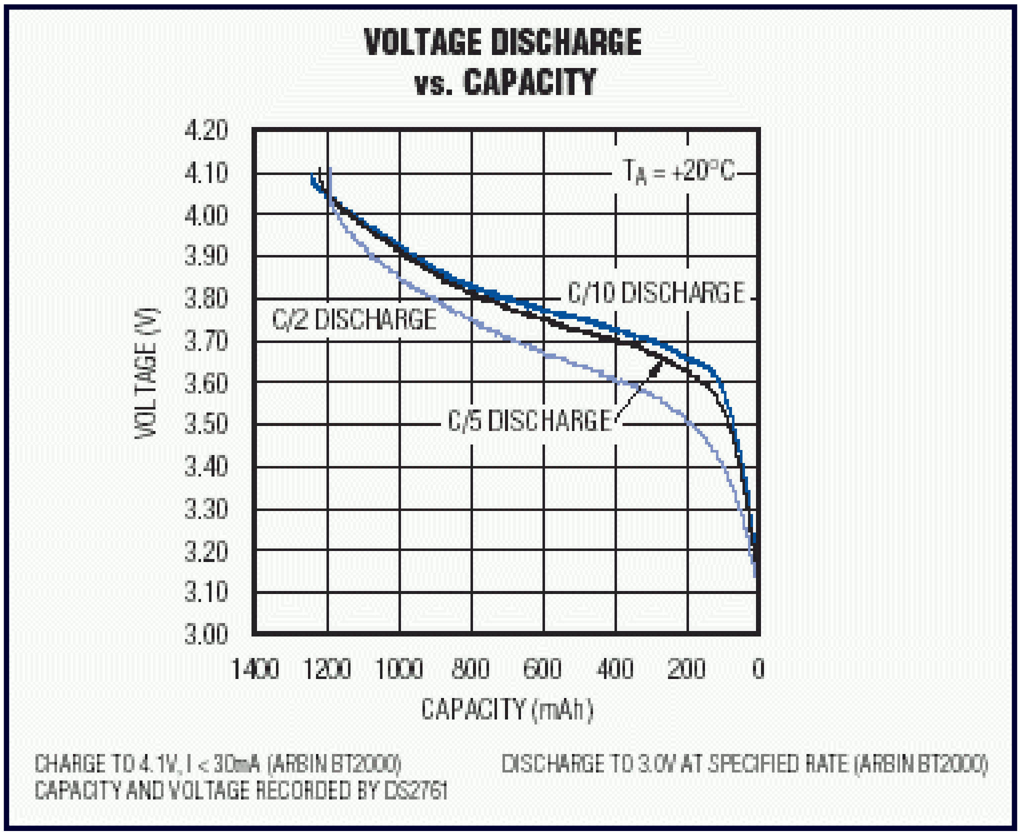

Figure 2. Voltage profile varies with discharge rate. Increasing the cutoff voltage decreases the reserve capacity.

Although not as dramatic, the aging of battery cells also changes the voltage profile. Aging varies from cell to cell and significantly by manufacturer. Moreover, subjecting a cell to shallow discharge cycles has a different effect than full discharge cycles. Figure 3 shows that a permanent loss of 150mAh from full battery capacity occurs over 500 cycles. This is an example of a cell performing particularly well under this stress. The effect on reserve capacity is 50mAh to 75mAh, based on aging from repeated fulldischarge cycling.

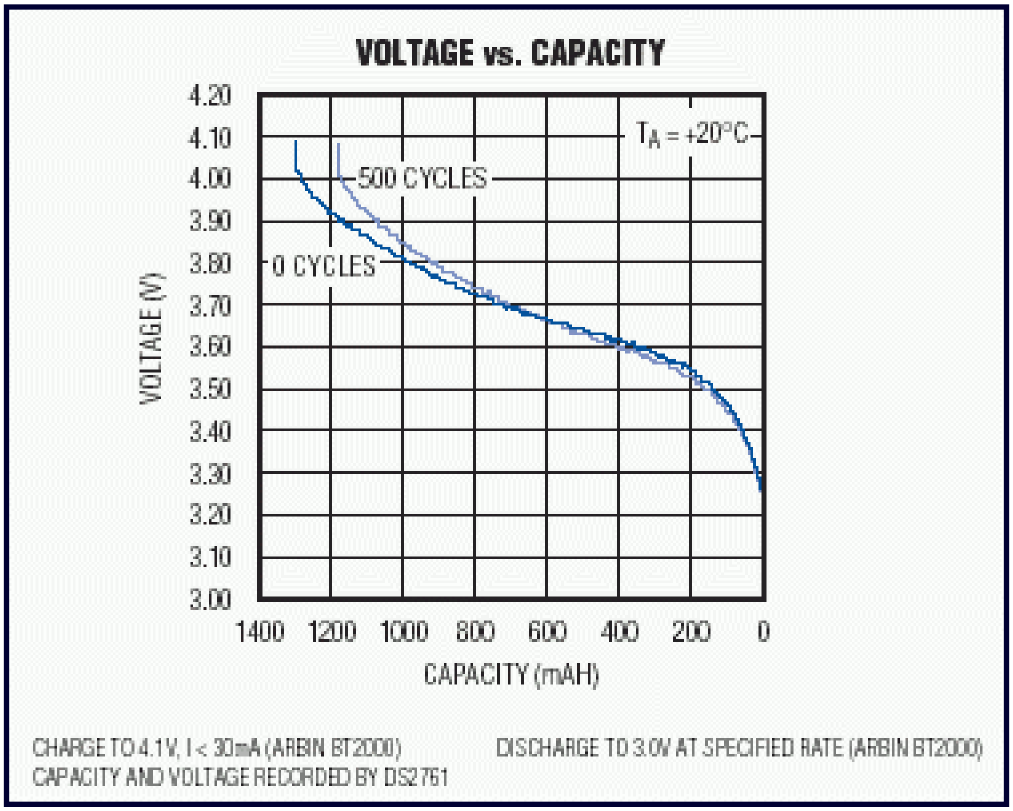

Figure 3. C/2 discharge voltage profile varies with aging. This example shows a particularly good cell performing under this stress.

Flawed Methods of Measuring Capacity

Lookup tables can compensate for the wide variation in terminal voltage due to temperature, discharge rate, and aging. However, this method is error prone and also requires measurements for temperature and current. To be accurate, the current and voltage measurements should be taken simultaneously to ensure that the terminal voltage data coincides with the discharge rate. For this reason, many voltage-based capacity implementations are done without consideration of discharge rate. Using voltage and temperature alone requires a two-dimensional lookup table to store nominal cell characteristics for computing an estimate of remaining capacity. This method yields 20% to 40% error across the full temperature range.

Because the voltage-based method suffers from limited accuracy, a common alternate approach employs a larger battery than necessary. This affects the size of the handheld, which is a critical competitive issue for these devices. Yet another alternative uses a small battery with less run time or higher risk of data loss. The optimal choice includes an intelligent battery monitor (such as those in the DS276x and DS277x families), which increases run time without increasing the size of the handheld or increasing the risk of data loss.

How Intelligent Battery Monitors Work

Intelligent battery monitors typically avoid the lookup of capacity based on voltage, temperature, and current. Instead, the charge flow into and out of the battery is measured. A coulomb counter tracks the charge stored in the battery. Temperature and discharge rate measurements are used to compensate for the cell's ability to deliver stored charge based on a small lookup table that stores the cell characteristics. The DS276x and DS277x families provide all measurement and data storage necessary, with algorithm storage and result computation provided by the host system. A maximum error of 3% can be expected when discharging from full at temperatures <+15° C. A combined error of 5% is achieved over all temperature, load, and age conditions. If the time between full charges increases beyond 2 weeks, input offset errors become more frequent. However, most users fully charge every week. Table 1 shows the key features and performance of battery monitors.

Table 1. Battery monitor features and performance

Device	Measured Parameters*	Current Range (mV)	Current Offset (µV)	Data Storage	Other Features
DS2761	V, T, I	±64	±15	32 bytes EEPROM	Li+ protector
DS2770	V, T, I	±51	±1.6	40 bytes EEPROM	Li+/NiMH charger

*V = Voltage, T = Temperature, I = Time

Misconception 2: Displaying Accurate Battery Information Does Not Benefit Users.

It is a common belief among manufacturers that users do not appreciate or are confused by a battery capacity display beyond a few bars or the simplistic image of a battery with three diagonal slices. Many manufacturers believe users are satisfied with simple bar displays that are too coarse to show the real changes in run time. While perhaps true for some voice-only cellular users, this is not true of full-featured, wireless data device users. The latter users are migrating from notebook PCs and are accustomed to a numerical percentage display of available capacity, predicted run time, standby, and charge times.

Some manufacturers are reluctant to display predictive battery capacity data because any assessment of available run or talk time is based on current usage conditions. They cannot factor in changing conditions before they occur. Equipment makers also want to avoid disappointing customers by predicting the wrong run time because the user changed from a low-consumption to a high-consumption mode.

The user base for wireless data devices should not, however, be underestimated. Most are quite familiar with the difference between usage modes, just as they understand that cars get more miles per tank on the highway than in the city, or with a light load vs. a full load. Nor are users confused by changes in run time when they run downloaded third-party software or CompactFlash® add-in hardware on today's hand-held systems.

Battery uncertainty is especially true for the charge in the lower half of the battery. How much battery life really remains in handhelds when all you see is the common three- or four-segment battery display? Because of dropped calls, interrupted data exchange, and lost data files, experience has taught users not to trust the data display. Consequently, some users charge their handhelds when one or two segments of the battery display are gone. With poor accuracy and too few battery display segments, users might revert to more wired transactions. How many wireless data transactions are avoided because the user wants to save the battery power for an emergency voice call later? But intelligent battery monitors display estimated run time, so users are aware of different power consumption modes. The quantitative power estimate of the DS276x and DS277x allows users to choose how to consume the energy stored in each battery charge.

Misconception 3: The Battery Monitor Needs to be Accurate in Standby Mode for Several Months.

This is an issue with the deployment of batteries in new equipment. Batteries are usually shipped from the factory 3 to 9 months before reaching the end user. With the offset performance of battery monitors in the 1.6mV to 30mV range, small offset errors accumulated over several months (thousands of hours) equate to a large percentage of consumed battery capacity. Manufacturers are concerned that the monitor may indicate a dead or full battery, when in reality the capacity is approximately 30%. Until offset errors can be tamed to the submicrovolt range, this situation will persist.

The battery should be fully charged by the user before use. The first full charge is an important step that "forms" the cell and is highly recommended for optimal battery performance. A clear disclaimer in the owner's manual directs customers to fully charge the battery before initial use. A full charge is often recommended if the battery has not been used for several months. Whenever the battery is fully charged, the battery monitor's coulomb count-the accumulated current register (ACR) on the DS276x and DS277x series devices-can be synchronized with the cell.

Misconception 4: Intelligent Battery Monitoring Adds Too Much Cost.

When the first battery monitor solutions reached market, wireless communication served voice-only handsets. PDAs connected through PCs on short-range infrared or serial links. Bluetooth™, Wi-Fi® , and 3G network technologies were under development. An intelligent battery monitor was neither cost effective nor essential.

Because data is now both valuable and vulnerable, situations have changed. Intelligent battery monitors increase run time, enable development of smaller devices, add value to the user's experience, and encourage more wireless activity. When a user spends between $200 and $600 on a wireless hand-held data device and an additional $40 to $100 per month on service fees, what is the value of increased operating time that is accurately displayed? For the hand-held manufacturer competing on size, performance, and cost, is it worth the ability to shrink the newest model? For the wireless operators trying to increase subscriber use of data services, how do you value user confidence that the battery is not rapidly depleted? Only a few industry leaders understand that the value of intelligent battery monitoring far exceeds its cost. Right now, those products outpace the competition in run time and user satisfaction. So, in that sense, they are reaping a reward, not paying a price.

Conclusion

Revolutionary product features often evolve from "nice-to- have" bonus properties to "must-have" core or enabling features. Intelligent battery monitoring is such a feature. With the move to hand-held computing and communications increasing, users will not tolerate an unpredictable estimation of battery capacity represented by only a few visual battery segments. As long as voltagebased solutions prevail, so will larger batteries, larger handhelds, early shutdowns, and low user confidence. Fortunately, however, predicting battery power is now quite reliable. Intelligent battery monitors such as the DS276x and DS277x product lines enable wireless handhelds to evolve like PCs, decreasing size while increasing performance and user confidence.

More Information

DS2761: QuickView -- Full (PDF) Data Sheet -- Free Samples
DS2770: QuickView -- Full (PDF) Data Sheet -- Free Samples