Isidor Buchmann
Cadex Electronics Inc.
[isidor.buchmann@cadex.com]
[www.buchmann.ca]

Pluses and Minuses of "Smart" Batteries

We charged one of the world's leading experts with explaining, and here's his plug ... er, report.

A speaker at a battery seminar remarked that, "The battery is a wild animal and artificial intelligence domesticates it." An ordinary or "dumb" battery has the inherent problem of not displaying the amount of reserve energy it holds. Neither weight, color, nor size provide an indication of the battery's state-of-charge (SoC) and state-of-health (SoH). The user is at the mercy of the battery when pulling a freshly charged battery from the charger.

Help is at hand. An increasing number of today's rechargeable batteries are being made "smart." Equipped with a microchip, these batteries are able to communicate with the charger and user alike to provide statistical information. Typical applications for "smart" batteries are notebook computers and video cameras. Increasingly, these batteries are also used in advanced biomedical devices and defense applications.

There are several types of "smart" batteries, each offering different complexities, performance, and cost. The most basic smart battery may only contain a chip to identify its chemistry and tell the charger which charge algorithm to apply. Other batteries claim to be smart simply because they provide protection from overcharging, underdischarging and short-circuiting. In the eyes of the Smart Battery System (SBS) forum, these batteries cannot be called "smart."

What makes a battery "smart"? Definitions still vary among organizations and manufacturers. The SBS forum states that a smart battery must be able to provide SoC indications. In 1990, Benchmarq was the first company to commercialize the concept of the battery fuel gauge technology. Today, several manufacturers produce chips to make the battery "smart."

During the early nineties, numerous "smart" battery architectures emerged. They range from the single-wire system to the two-wire system and the system management bus (SMBus). Most two-wire systems are based on the SMBus protocol. Let's look at the single-wire system and the SMBus.

The single-wire bus

The single-wire system is the simpler of the two and delivers the data communications through one wire. A battery equipped with the single-wire system uses only three wires: the positive and negative battery terminals and the data terminal. For safety reasons, most battery manufacturers run a separate wire for temperature sensing. **Fig. 1** shows the layout of a single-wire system.

The modern single-wire system stores battery-specific data and tracks battery parameters, including temperature, voltage, current, and remaining charge. Because of simplicity and relatively low hardware cost, the single-wire enjoys market acceptance for high-end mobile phones, two-way radios, and camcorders.

Most single-wire systems do not have a common form factor; neither do they lend themselves to standardized

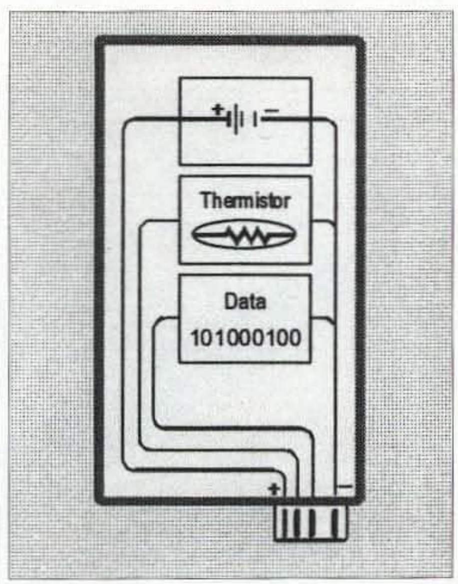

Fig. 1. Single-wire system of a "smart" battery. Only one wire is needed for data communications. Rather than supplying the clock signal from the outside, the battery includes an embedded clock generator. For safety reasons, most battery manufacturers run a separate wire for temperature sensing.

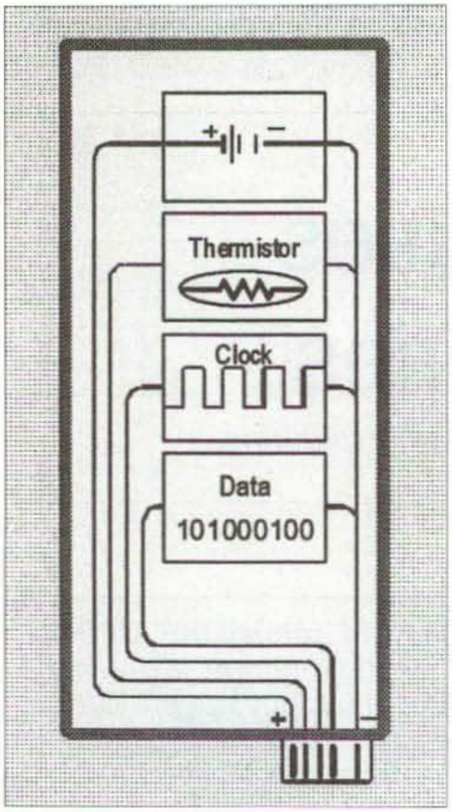

Fig. 2. Two-wire SMBus system. The SMBus is based on a two-wire system using a standardized communications protocol. This system lends itself to standardized state-of-charge and state-of-health measurements.

SoH measurements. This produces problems for a universal charger concept. The Benchmarq single-wire solution, for example, cannot measure current directly; it must be extracted from a change in capacity over time.

On a further drawback, the single-wire bus allows battery SoH measurement only when the host is "married" to a designated battery pack. Such a fixed host-battery relationship is feasible with notebook computers, mobile phones, or video cameras, provided the appropriate OEM battery is used. Any discrepancy in the battery type from the original will make the system unreliable or will provide false readings.

The SMBus

The SMBus is the most complete of all systems. It represents a large effort from the portable electronics industry to standardize to one communications protocol and one set of data. The SMBus is a two-wire interface system: One wire handles the data; the second is the clock. It uses the I^2C defined by Philips as its backbone.

The Duracell/Intel SBS, which is in use today, was standardized in 1993. In previous years, computer manufacturers developed their own proprietary "smart" batteries. With the new SBS specification, a broader interface standard is made possible. This reduces the hurdles of interfering with patents and intellectual properties. **Fig. 2** shows the layout of the two-wire SMBus system.

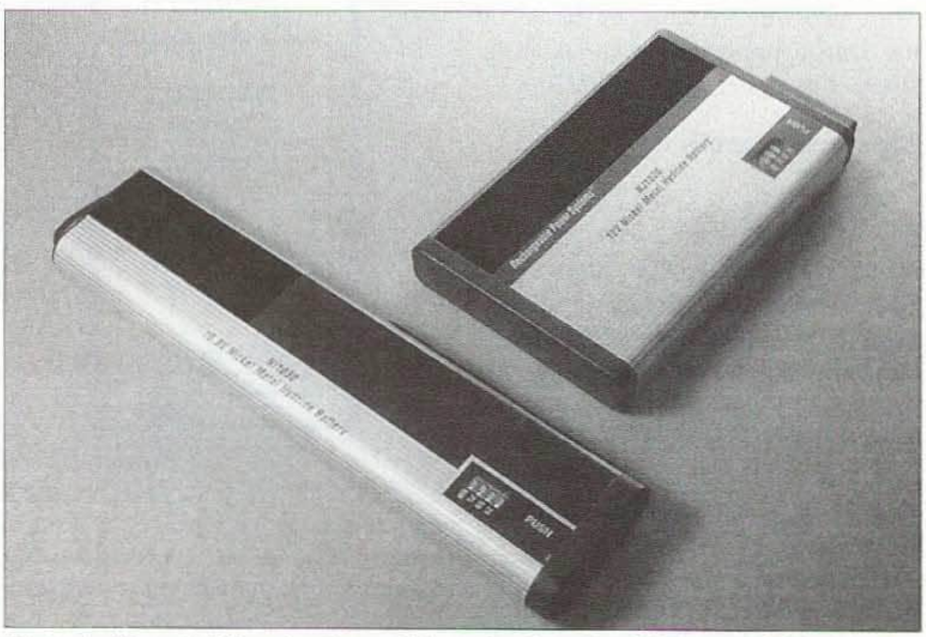

***Photo A.** 35- and 202-series "smart" batteries featuring SMBus. Available in NiCd, NiMH, and Li-ion chemistries, these batteries are used for laptops, biomedical instruments, and survey equipment. A non-SMBus ("dumb") version with same footprint is also available.*

In spite of the agreed standard, many large computer manufacturers, such as IBM, Compaq, and Toshiba, have retained their proprietary batteries. The reason for going their own way is partly due to safety, performance, and form factor. Manufacturers claim that they cannot guarantee safe and enduring performance if a nonbrand battery is used. To make the equipment as compact as possible, the manufacturers explain that the common form factor battery does not optimally fit their available space. Perhaps the leading motive for using their proprietary batteries is pricing. In the absence of competition, these batteries can be sold for a premium price.

The objective behind the SMBus battery is to remove the charge control from the charger and assign it to the battery. With a true SMBus system, the battery becomes the master and the charger serves as a slave that must follow the dictates of the battery. This is based on concerns over charger quality, compatibility with new and old battery chemistries, administration of the correct amount of charge currents, and accurate full-charge detection. Controlled charging makes sense when considering that some battery packs share the same footprint but contain different chemistries.

The SMBus system allows new battery chemistries to be introduced without the charger becoming obsolete. Because the battery controls the charger, the battery manages the voltage and current levels, as well as cutoff thresholds. The user does not need to know which battery chemistry is being used.

An SMBus battery contains permanent and temporary data. The permanent data is programmed into the battery at the time of manufacturing and includes battery ID number, battery type, serial number, manufacturer's name, and date of manufacture. The temporary data is acquired during use and consists of cycle count, user pattern, and maintenance requirements. Some of the temporary data is being

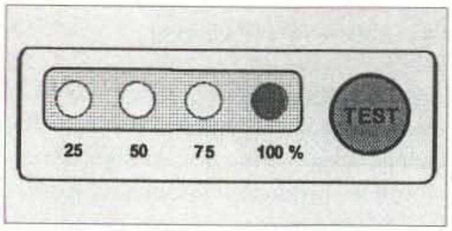

Fig. 3. State-of-charge readout of a "smart" battery. Although the state-of-charge is displayed, the state-of-health and its predicted runtime are unknown.

replaced and renewed during the life of the battery.

The SMBus is divided into Level 1, 2, and 3. Level 1 has been eliminated because it does not provide chemistry-independent charging. Level 2 is designed for in-circuit charging. A laptop that charges its battery within the unit is a typical example of Level 2. Another Level 2 application is a battery that contains the charging circuit within the pack. Level 3 is reserved for full-featured external chargers.

External Level 3 chargers are complex and expensive. Some lower-cost chargers have emerged that accommodate SMBus batteries but are not fully SBS-compliant. Manufacturers of SMBus batteries do not fully endorse this shortcut. Safety is always a concern, but customers prefer these economy chargers because of lower price.

Serious industrial battery users operating biomedical instruments, data collection devices, and survey equipment, use Level 3 chargers with full-fledged charge protocol. No shortcuts are applied. To ensure compatibility, the charger and battery are matched and only approved packs are used. The need to test and approve the marriage between a specific battery and charger is unfortunate, given that the "smart" battery is intended to be universal.

Among the most popular SMBus batteries for portable computers are the 35 and 202 form factors. Manufactured by Sony, Hitachi, GP Batteries, Moltech, Moli Energy, and many others, these batteries work (should work) in all portable equipment designed for this system. **Photo A** shows the 35- and 202-series "smart" batteries. Although the 35 has a smaller footprint than the 202, most chargers accommodate both sizes. A non-SMBus ("dumb") version with the same footprint is also available.

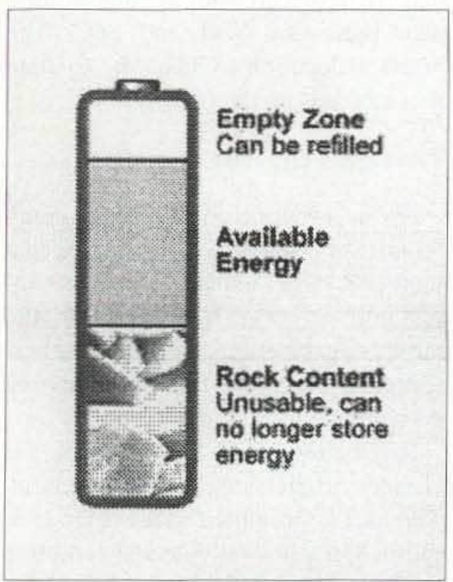

Fig. 4. Battery charge capacity. Three imaginary sections of a battery consisting of (top to bottom) available energy, empty zone, and rock content. With usage and age, the rock content grows. Without regular maintenance, the user may end up carrying rocks instead of batteries.

Negatives of the "smart" battery

The "smart" battery has some notable downsides, one of which is price. An SMBus battery costs about 25% more than its "dumb" equivalent. In addition, the "smart" battery was intended to simplify the charger, but a full-fledged Level 3 charger costs substantially more than a regular dumb model.

A more serious drawback is maintenance requirements, better known as capacity relearning. This is needed on a regular basis to calibrate the battery. The engineering manager of Moli Energy, a large Li-ion cell manufacturer, commented, "With the Li-ion we have eliminated the memory effect, but are we introducing digital memory with the SMBus battery?"

Why is calibration needed? The answer is to correct the tracking errors that occur between the battery and the digital sensing circuit during use. The most ideal battery use, as far as fuel-gauge accuracy is concerned, is a full charge followed by a full discharge at a constant IC rate. In such a case, the tracking error would be less than 1% per cycle. In real life, however, a battery may be discharged for only a few minutes at a time and commonly at a lower C-rate than IC. Worst of all, the load may be uneven and vary drastically. Eventually, the true capacity of the battery no longer synchronizes with the fuel gauge and a full charge and discharge is needed to "relearn" or calibrate the battery.

How often is calibration needed? The answer lies in the type of battery application. For practical purposes, a calibration is recommended once every three months or after every 40 short cycles. Long storage also contributes to errors because the circuit cannot accurately compensate for self-discharge. After extensive storage, a calibration cycle is recommended prior to use.

Many batteries undergo periodic full

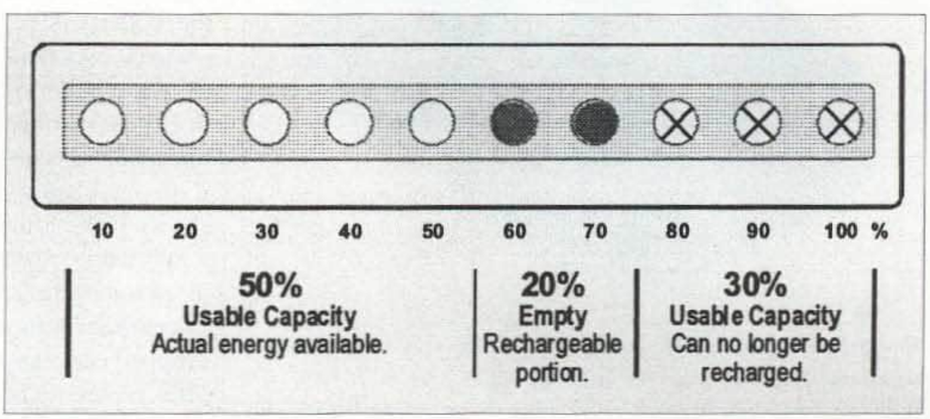

Fig. 5. Tri-state fuel gauge. The Battery Health Gauge reads the "learned" battery information available on the SMBus and displays it on a multicolored LED bar. The illustration shows a partially discharged battery of 50% SoC with a 20% empty portion and an unusable portion of 30%.

discharges as part of regular use. If this occurs regularly, no additional calibration is needed. If a full discharge reset has not occurred for a few months and the user notices the fuel gauge losing accuracy, a deliberate full discharge on the equipment is recommended. Some intelligent equipment advises the user when a calibrating discharge is needed. This is done by measuring the tracking error and estimating the discrepancy between the fuel gauge reading and that of the chemical battery.

What happens if the battery is not calibrated regularly? Can such a battery be used in confidence? Most "smart" battery chargers obey the dictates of the chemical cells rather than the electronic circuit. In this case, the battery will fully charge regardless of the fuel gauge setting. Such a battery is able to function normally, but the digital readout will become inaccurate. If not corrected, the fuel gauge information simply becomes a nuisance.

An additional problem with the SMBus battery is noncompliance. Unlike other tightly regulated standards, the SMBus protocol allows some variations. This may cause problems with existing chargers and the SMBus battery should be checked for compatibility before use. Ironically, the more features that are added to the SMBus charger and battery, the higher the likelihood of incompatibilities.

The need to test and approve the marriage between a specific battery and charger is unfortunate, given the assurance that the SMBus battery is intended to be universal. Ironically, the more features offered on the SMBus charger and the battery, the higher the likelihood of incompatibilities.

The state-of-charge indicator

Most SMBus batteries are equipped with a charge level indicator. When pressing an SoC button on a battery that is fully charged, all signal lights illuminate. On a partially discharged battery, half the lights illuminate, and on an empty battery, all lights remain dark. **Fig. 3** shows such a fuel gauge.

While SoC information displayed on a battery or computer screen is helpful, the fuel gauge resets to 100% each time the battery is recharged, regardless of the battery's SoH. A serious miscount occurs if an aged battery shows 100% after a full charge, when in fact the charge acceptance has dropped to say 50% or less. The question remains: "100% of what?" A user unfamiliar with this battery has little information about the runtime of the pack.

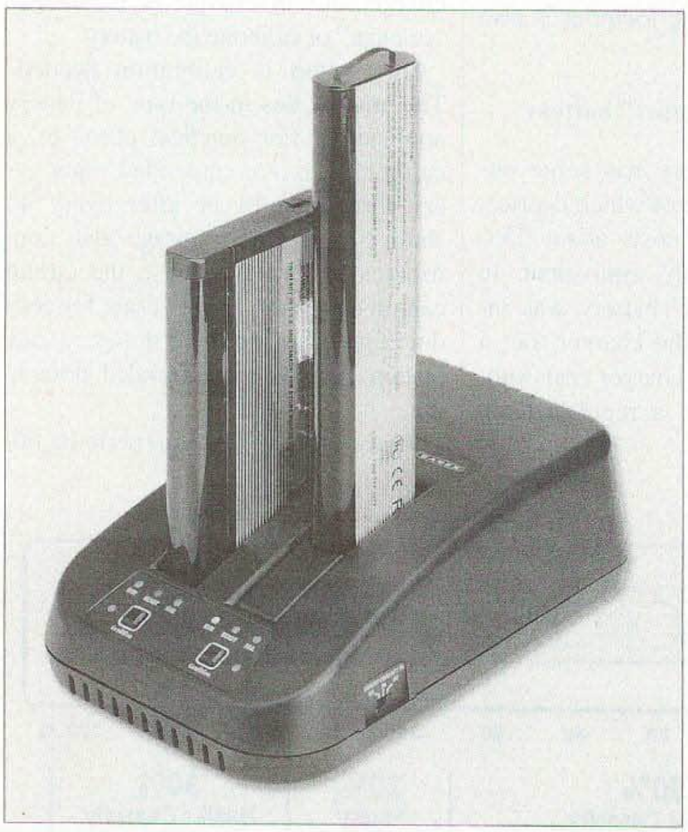

Photo B. *The Cadex SM2+ charger. This Level 3 charger serves as charger, conditioner and quality control system. It reads the battery's true state-of-health and flags those that fall below the set target capacity. Each bay operates independently and charges NiCd, NiMH, and Li-ion chemistries in approximately three hours. "Dumb" batteries can also be charged, but no SoH information is available.*

How can the three levels of a battery be measured and made visible to the user? While the SoC is relatively simple to produce, measuring the SoH is more complex. Here is how it works:

At time of manufacture, each SMBus battery is given its specified SoH status, which is 100% by default. This information is permanently programmed into the pack and does not change. With each charge, the battery resets to the full-charge status. During discharge, the energy units (coulombs) are counted and compared against the 100% setting. A perfect battery would indicate 100% on a calibrated fuel gauge. As the battery ages and the charge acceptance drops, the SoH begins to indicate lower readings. The discrepancy between the factory-set 100% and the actual delivered coulombs on a fully discharged battery is used to calculate the SoH.

Knowing the SoC and SoH, a simple linear display can be made. The SoC is indicated with green LEDs; the empty part remains dark; and the unusable part is shown with red LEDs. **Fig. 5** shows such a tri-state fuel gauge. As an alternative, the colored bar display may be replaced with a numeric display indicating SoH and SoC. The practical location to place the tri-state fuel gauge is on the charger.

The target capacity selector

For users who simply need a go/no go answer, chargers are available that feature a target capacity selector. Adjustable to 60%, 70%, or 80%, the target capacity selector acts as a performance check and flags batteries that do not meet the set requirements.

If a battery falls below target, the charger triggers the condition light. The user is prompted to press the condition button to calibrate and condition the battery by applying a charge/discharge/charge cycle. If the battery does not recover, a fail light indicates that the battery should be replaced. The green ready light at the end of the service reveals full charge and ensures that the battery meets the required performance level. **Photo B** illustrates a two-bay Cadex charger featuring the target capacity selector and discharge circuit. This unit is based on Level 3 and services both SMBus and "dumb" batteries. SoH readings are only available when servicing SMBus batteries.

By allowing the user to set the desired battery performance level, the question is raised as to what level to select. The answer is governed by the applications, reliability standards, and cost policies.

A practical target capacity setting for most applications is 80%. Decreasing the threshold to 70% will lower the performance standard but pass more batteries. A direct cost saving will result. The 60% level may suit those users who run a low budget operation, have ready access to replacement batteries, and can live with shorter, less predictable runtimes. It should be noted that the batteries are always charged to 100%, regardless of the target setting. The target capacity simply refers to the amount of charge the battery has delivered on the last discharge.

Summary

SMBus battery technology is predominantly used for higher-level industrial applications. Improvements in the "smart" battery system, such as higher accuracies and self-calibration will likely increase the appeal of the "smart" battery. Endorsement by large software manufacturers such as Microsoft will entice PC manufacturers to make full use of these powerful features.

"Smart" battery technology has not received the widespread acceptance that battery manufacturers had hoped for. Some engineers go so far as to suggest that the SMBus battery is a "misguided principle." Design engineers may not have fully understood the complexity of charging batteries in the incubation period of the "smart" battery. Manufacturers of SMBus chargers are left to clean up the mess.

One main drawback of the "smart" battery is high price. In the early 1990s, when the SMBus battery was conceived, price was not as critical as it is today. Now, buyers want scaled down products that are economically priced and perform the functions intended. In the competitive mobile phone market, for example, the features offered by the SMBus would be considered overkill.

In spite of teething problems and relative high costs, the "smart" battery will continue to fill a critical market segment. Unless innovative improvements are made and manufacturing costs are drastically reduced, this market will be reserved for high-level industrial applications only.

About the author

Isidor Buchmann is the founder and CEO of Cadex Electronics Inc., in Richmond (Vancouver), British Columbia, Canada. Mr. Buchmann has a background in radio communications and has studied the behavior of rechargeable batteries in practical, everyday applications for two decades.

Continued on page 58

Pluses and Minuses of "Smart" Batteries

continued from page 41

The author of many articles and books on battery maintenance technology, Mr. Buchmann is a well-known speaker who has delivered technical papers and presentations at seminars and conferences around the world.

About the company

Cadex Electronics Inc. is a world leader in the design and manufacture of advanced battery analyzers and chargers, Their award-winning products are used to prolong battery life in wireless communications, emergency services, mobile computing, avionics, biomedical, broadcasting, and defense. Cadex products are sold in over 100 countries.

Note: This article contains excerpts from the second edition book entitled *Batteries in a Portable World — A Handbook on Rechargeable Batteries for Non-Engineers.* In the book, Mr. Buchmann evaluates the batteries in everyday use and explains their strengths and weaknesses in laymen's terms. The 300-page book is available from Cadex Electronics Inc. through [book@cadex.com], tel. 604-231-7777, or most bookstores. For additional information on battery technology, visit [www.buchmann.ca]. 73

The Digital Port

continued from page 46

log program but have not yet looked into its workings. Logs are important to most of us, and I am sure there is one available to answer our needs.