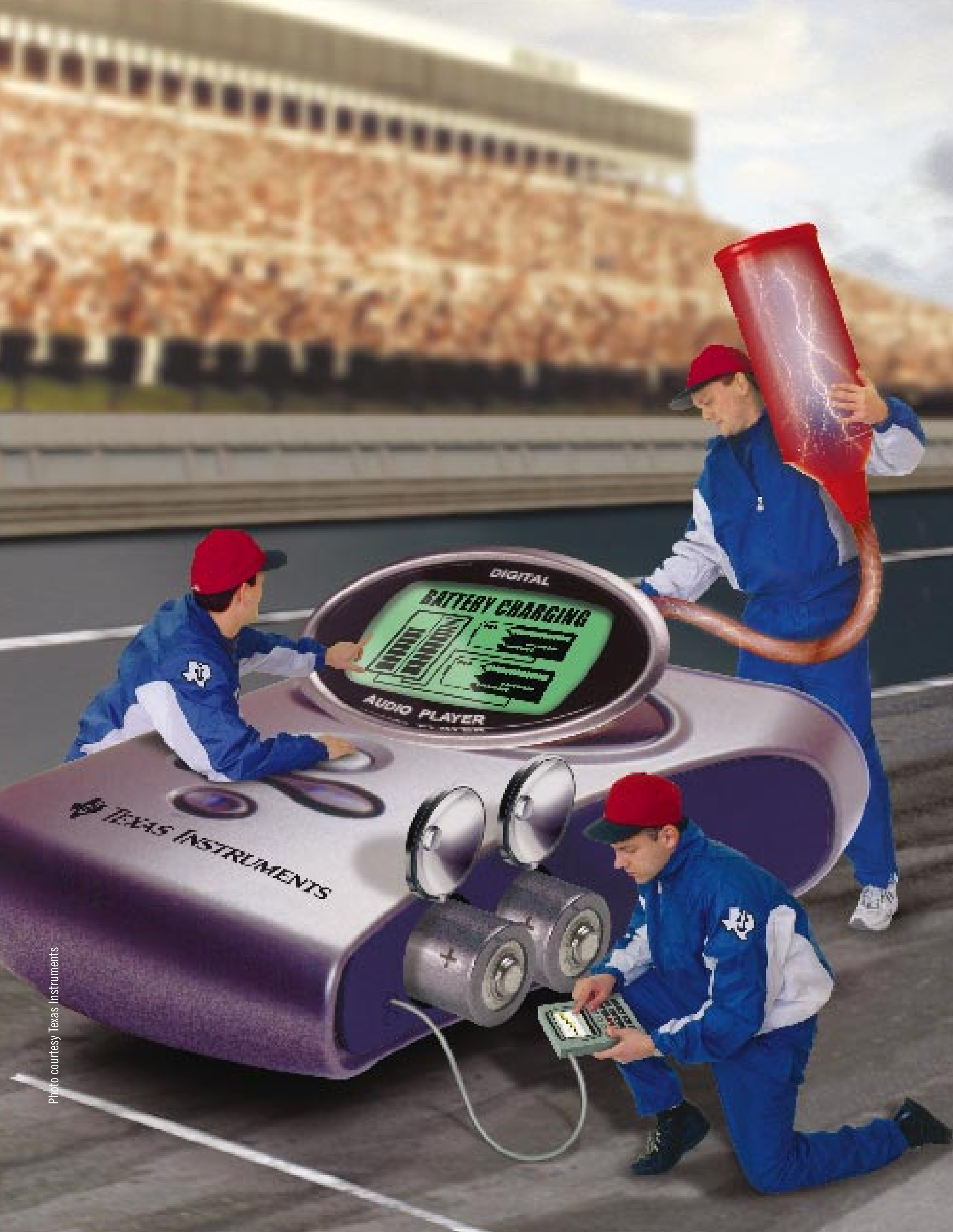


Photo courtesy Texas Instruments

coverstory *By Joshua Israelsohn, Technical Editor*

WEB EXCLUSIVE

Don't let poor battery management make an ash out of your product. See three .avi videos that depict the dangers of mistreating lithium cells in the online version of this article at www.ednmag.com/ednmag/reg/2001/01182001/02cs.htm

Battery management included

ALL THE FEATURES AND FUNCTIONS YOU DESIGN INTO YOUR PORTABLE PRODUCT DON'T MEAN A THING WHEN THE BATTERIES LOSE THEIR ZING. BEFORE YOUR CHIPS ARE DOWN, CONSIDER THE LITTLE CHARGE-CONTROL DEVICES THAT CAN HELP KEEP YOUR PRODUCTS GOING...AND GOING...AND GOING...

THE TASK OF DESIGNING a reliable portable power source is not nearly so formidable as it was just a few years ago. Thanks to a parade of charge controllers, protectors, and other battery-management products, you can find readily available parts and reference designs to support many power-system architectures. These parts range from simple all-analog circuits to mixed-signal devices sophisticated enough to report on battery health and keep track of operating history.

Whatever sort of projects you work on, chances are good that your portable power-source requirements share important attributes with one or two of the most common and best-documented applications (see **sidebar** "Applications cut the cord"). Using the demands of your market and a little product-line history as guides, you can often estimate key system parameters early in your design cycle. These terms may include peak and average currents, maximum battery-pack dimensions, and minimum battery run-times, all of which can help you focus on the best power-source candidates (see **sidebar** "Better living through chemistries"). Single-point comparisons serve well as rough guides (**Table 1**, **Reference 1**). However, their applicability is limited to fixed conditions of discharge rate, discharge depth, and temperature, so you

should examine the parametric nature of any specification critical to your application, particularly with regard to the temperature range you expect your product to experience in both operating and standby modes.

Battery-management components go beyond just charge control, providing cell protection and "fuel-gauge" functions depending on how sophisticated a power-source interface you require. At this end of the spectrum, many devices are equipped with circuitry sufficient to acquire, process, and communicate current operating conditions, performance history, and pack-specific information among the various entities that have use for the information.

SIMPLY CHARGE IT

The four common chemistries require different recharge algorithms and give different indications when they have completed the charge cycle (**Table 2**). Just as deep discharging most chemistries reduces cycle life, overcharging can do the same. Li-ion cells, particularly attractive for their outstanding charge density, demand high accuracy of charge circuits, typically allowing a tolerance of only ±50 mV during the constant-voltage phase of the recharge cycle.

Most secondary cells tolerate trickle charging for long periods. The simplest charging strategy, therefore, uses a small linear regulator circuit in conjunction with a series pass element and a current-sense resistor (**Figure 1**). Versions are also available with small PWMs that use similar application circuits but reduce the pass transistor's power dissipation. Circuits such as these are available from a number of vendors and with a range of auxiliary features for charging single and stacked Li-ion cells or nickel-chemistry cell stacks (**Table 3**). They use an adaptive method that adjusts the charger's behavior according to the battery's state of charge.

A charger of this type starts by testing the battery for deep discharge, which it determines by comparing the battery's

AT A GLANCE

- ▷ Neither a no-brainer nor rocket science, choosing the best chemistry requires a deliberative comparison between battery attributes and your design's power-source demands.
- ▷ Lithium chemistries are perhaps the best supported by semiconductor manufacturers, but they're the most demanding of battery management, too.
- ▷ Many battery-management components will work with multiple chemistries, though some require trimming or scaling components.
- ▷ Batteries pack an enormous amount of energy into a very small space–some more than 12,000 joules per cubic inch. Battery management doesn't just extend battery lifetimes; it protects the portable product and, in some cases, your customer.

TABLE 1–BATTERY ATTRIBUTES BY CHEMISTRY

	SLA	NiCd	NiMH	Li-ion (coke)	Li-ion (graphite)
Mass energy density (Whr/kg)	30	40	60	90	90
Volumetric energy density (Whr/l)	60	100	140	210	210
Operating voltage (V)	2	1.2	1.2	3.6	3.6
Lifetime* (cycles)	500	1000	800	1000	1000
Self-discharge rate (%/month)	3	15	20	6	6
Discharge profile	Slightly sloping	Flat	Flat	Slightly sloping	Sloping
Internal resistance	Low	Very low	Moderate	High	Highest
Maximum discharge rate (C**)	5	10	3	2	2

Notes:
*80% rechargeable.
**C=the battery's rated capacity per hour.

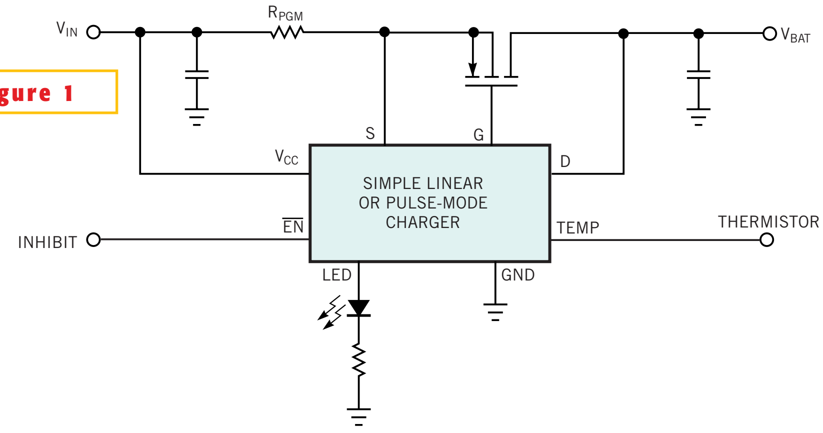
TABLE 2–COMPARISON OF RECHARGE REQUIREMENTS

Standard charge	SLA	NiCd	NiMH	Li-ion (coke)	Li-ion (graphite)
Current* (C)	0.25	0.1	0.1	0.1	0.1
Voltage (V)	2.27	1.5	1.5	4.1**	4.2**
Time (hours)	24	16	16	16	16
Temperature range (°C)	0 to 45	5 to 40	5 to 40	5 to 40	5 to 40
Termination	None	None	Timer	None	None
Fast charge					
Current (C)	1.5	1	1	1	1
Voltage (V)	2.45	1.5	1.5	4.1**	4.2**
Time (hours)	1.5	3	3	2.5	2.5
Temperature range (°C)	0 to 30	15 to 40	15 to 40	10 to 40	10 to 40
Primary termination methods	I_{MIN}***, ΔTCO	dT/dt, −ΔV	Zero dV/dt, −ΔV Slope inflection, ΔTCO	I_{MIN}+timer***, dT/dt, ΔTCO	I_{MIN}+timer, ***dT/dt, ΔTCO
Secondary termination methods	Timer, ΔTCO	TCO, timer	TCO, timer	TCO, timer	TCO, timer

Notes:
*C=the battery's rated capacity per hour.
**Li-ion's charge-termination voltage tolerance is ±50 mV.
***I_{MIN} is the minimum current-termination threshold.

terminal voltage with the charger's internal threshold. If the battery voltage is below the threshold, the charger enters a precharge mode in which it limits its current to some fraction of the resistor-programmed maximum charge current, I_{PGM} (**Figure 2**). The current limit caps the power dissipation in the pass device (usually a PMOS or PNP transistor) and prevents the circuit from driving excessive currents into an unhealthy cell. Most chargers clamp the current to a fixed fraction of the programmed charge current. The ratio of clamped current to programmed current, which some manufacturers refer to as the k factor, varies from model to model and from manufacturer to manufacturer. Common values range from about 0.6 to 0.1. Other models, such as National Semiconductor's LM3622, allow you to independently program both current levels with two resistors.

Figure 1



Simple linear or pulse-mode chargers require only a few external parts.

Once the cell voltage rises to the test threshold, some chargers switch to the programmed constant current, and others enter a fold-back mode. Devices that switch over to a constant-current mode, such as Linear Tech's LTC1732, TI's BQ2057, and NSC's LM3622 offer faster charging but require greater dissipation in the pass device. Devices employing the fold-back method, such as Analog Devices' ADP3820 and TelCom's TC3827, allow the charge rate to increase as the cell continues to approach the end-of-charge voltage. At the low end of the supply range, where overheads are small, the fold-back mode operates the pass transistor at less than constant dissipation as the charge current increases from k to one times the programmed charge rate. With larger supply overheads, these circuits can reach or even exceed constant dissipation in the pass element with increasing charge current. Depending on your product's supply range and the charger you choose, the pass transistor's maximum dissipation may be in the clamped precharge region or at the transition between the fold-back and constant-voltage regions. A quick examination of the operating conditions in both areas will help you properly size the pass device.

Once the cell reaches the end-of-charge voltage, which does *not* signal the end of the charge cycle, the circuit operates as a constant voltage source that holds the battery voltage within the charger's rated accuracy. In this mode, the battery simply draws less and less current until it reaches full charge. Some circuits of this type monitor the battery current and terminate the charge current when it falls below a set threshold, usually a fixed fraction of the programmed charge current. Other devices include a time-out mechanism that ends the charge after a fixed duration independent of the battery's charge state. Because Li-ion batteries are available with either coke or graphite anodes with 100-mV difference in their end-of-charge voltage, these parts come in either 4.1 or 4.2V versions, or they provide some means of configuring the constant-voltage section, usually by pin-strapping. Several models also charge NiCd and NiMH stacks but often need external scaling resistors. Some models also require an externally supplied charge-termination signal.

Although these parts all follow the same basic charge algorithm, internally

ACRONYMS

Li-ion: lithium-ion
NiCd: nickel-cadmium
NiMH: nickel metal-hydride
PWM: pulse-width modulator
SBS: smart battery system
SLA: sealed lead acid
SMBus: system-management bus

TABLE 3–A REPRESENTATIVE SAMPLE OF SIMPLE CHARGERS FOR COKE- OR GRAPHITE-ANODE LI-ION BATTERIES

	Manufacturer	Model	Accuracy (%)	Inhibit	Time-out	Temperature input	LED out	Equivalent stack (no. of Li-ion cells)	Price
Linear	Analog Devices	ADP3820	1	X				One	92 cents (10,000)
	Linear Technology	LTC1732	1		X		Two	One	$2.15 (1000)
	National Semiconductor	LM3622	1.20					Two	95 cents (1000)
	TelCom	TC3827	1	X			One	One	99 cents (5000)
	Texas Instruments	BQ2057	1			X	One	Two	$1.57 (1000)
Pulse	Linear Technology	LTC1730CGN	1	X	X	X	Three	One	$2.50 (1000)
	Maxim Integrated Products	MAX1737	0.75	X	X	X	Two	Four	$2.85 (1000)
	On Semiconductor	CS5362	1	X				One	$2 (10,000)
	Texas Instruments	BQ2000	0.75		X	X	One	One	$1.87 (1000)

they are quite different. These dissimilarities lead to differences in external-component specifications and charger performance. The parts also differ in how completely their manufacturers characterize them for operation over a range of electrical and environmental conditions and by the auxiliary features they offer. For example, one part might provide only basic functions but come well-characterized for a host of real-world conditions, such as line-transient response and ripple rejection. The manufacturer of another part may less thoroughly characterize performance, leaving you to determine and characterize the attributes most important to you, but offer attractive features, such as a temperature-sensor input for battery packs with built-in thermistors, status LED outputs, time-out functions, or charge-inhibit inputs. The thermistor and charge-inhibit inputs are particularly helpful if you want to implement microprocessor-controlled charge-cycle termination.

PUTTING THE PEDAL TO THE METAL

To get the lead out of the charge cycle, if not necessarily out of the battery, fast chargers need to accurately detect an end-of-charge condition, or they can reduce the pack's cycle life. Because many end-of-charge-detection schemes require a comparison of measurements made over a time interval, these parts often require at minimum a control interface to a host microcontroller if not a small on-chip state machine or processor core (**Figure 3**). Most chargers demand little of the processors, so many of these chips can economically implement end-of-charge-detection methods for multiple chemistries—a handy trait if you're designing a charge-management subsystem for a product family. Manufacturers may ship top-of-the-line models with Li-ion, and more modestly priced versions may use a less expensive chemistry, such as NiMH.

These products are somewhat larger and more expensive, but, depending on the constraints of your application, the

APPLICATIONS CUT THE CORD

Rechargeable batteries have found their way into a remarkably broad range of applications, many that place serious demands on various aspects of battery performance and management. Markets have richly rewarded companies that have met the challenge to cut the power cords off their products and still turn in good performance. The solution isn't as simple as slapping a battery into a case and a wall wart into a box. The different demands those applications place on batteries and their interface electronics can cover quite a range in their own right.

For example, cell-phone and laptop-computer designers need to squeeze the last minute out of a battery even if performance measures, such as SNR or speed, suffer some (but not too much). These devices don't demand just long per-charge runtimes. The battery-cycle life, negatively affected by deep discharging, is another key performance issue in these markets. The end of a battery's life spells the end of the product's life for many mobile phones because the replacement cost of the power source exceeds half the replacement cost for the entire device. The residual cost of getting the latest features and technology is so small that many customers find it compelling. Even though laptop batteries, for which retail prices average more than $100 for NiMH and more than $180 for Li-ion, constitute less than 10% of the total equipment cost, one of the largest areas of customer complaints in that market is limited battery-cycle life (**Reference A**).

Portable-power-tool designers need to deliver useful torque even at the risk of a slightly shorter discharge cycle. Batteries and battery-management devices must provide larger currents in this application than in most others. They also need to provide for rapid charging to minimize the number of spare packs that a job site requires (**Reference B**). Other applications, such as remote data acquisition, on the other hand, may have very low average current requirements but may place great value on a low self-discharge rate and wide operating-temperature range. With only a solar-electric panel as a long-term charge source, load-management functions and access to battery-status information may be as important as the battery's charge-capacity-versus-temperature curve.

The battery systems that film and professional-video crews use must meet stiff demands for reliability and capacity and, here again, do so over a range of environmental conditions. These industries simply will not tolerate either missing a shot because a battery pack didn't last until the lunch break or having an entire cast and crew standing around waiting for batteries to be swapped out of various cameras, audio recorders, mixers, and portable lighting systems. Here, the predictable performance and ruggedness of batteries and charging systems are more important than the price or mass charge density—within reason.

Applications that put human life at risk demand the utmost from battery-system reliability. Medical, law-enforcement, and military systems tolerate no failure and may even require provisions for swapping batteries without losing functionality or stored data.

Whatever your small-battery-system requirements, they likely share important traits with one or more well-characterized applications. Most of the semiconductor manufacturers listed in the **sidebar** "For more information" have lots of online information to help you choose the architecture that best suits your purposes. Reference designs are commonly available. However, remember to pay close attention to those places where your requirements deviate from those of the references. As with any energy-storage device, you must design battery-interface circuits with enough margin to both handle the full range of storage and operating conditions and to safely survive predictable nonstandard conditions.

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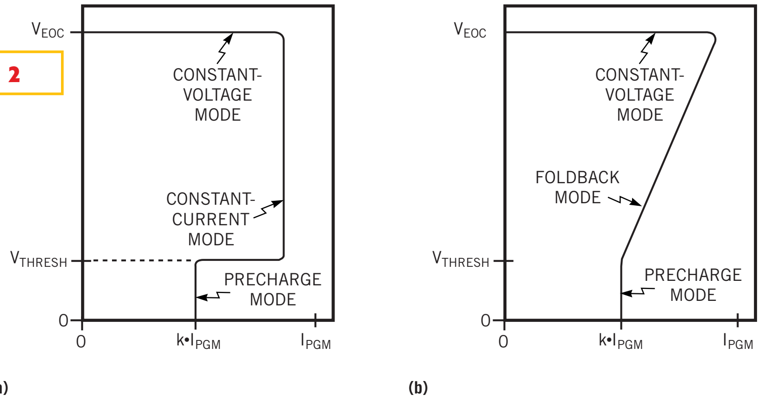
B. *The New Video Battery Handbook*, Bauer, Anton.

Notes
Also charges NiCd or NiMH
0.7% accuracy grade available at higher cost; different versions for single and stacked cells
Different versions for single and stacked cells
Graphite anode (4.2V) only
Also charges NiCd or NiMH

added flexibility and potential performance improvement may be worth it. Simple versions of this charger type are roughly half again more expensive, with typical package options including SOs and TSSOPs in the 16- to 20-pin range. Some require only a resistor, a couple of bypass capacitors, and occasional attention from the processor to form a quick, chemistry-agnostic charger. Others require more external circuitry but form a more complete system with on-chip measurement capabilities.

Figure 2



Some chargers implement a constant-current/constant-voltage algorithm (a), and others put less stress on the external pass transistor at the expense of charge time by using a current-fold-back mode (b).

Most parts in this category charge Li-ion (coke or graphite), NiCd, and NiMH. Some support SLA packs as well. Several chargers offer configuration options that allow you to use them with as many as four Li-ion cells or with stacks of as many as 12 NiCd or NiMH cells. Because chargers in this class offer a range of capabilities, you need to consider how the various measurements and charge-control tasks distribute between the charger and the other parts of your design. What looks like a complicated and expensive component may turn out to be the cheapest and simplest option if it solves your measurement problems while metering out the charge.

As was the case with the simple linear chargers, microprocessor-controlled chargers offer a range of optional features in addition to basic functions. Examples include the $1.40 (100,000) Si9731 from Siliconix in a 16-pin TSSOP, which reduces the external parts count to two bypass capacitors and a resistor for single lithium cells or three-cell NiCd or NiMH stacks. The $2.80 (1000) ADP3801 in a 16-pin SO from Analog Devices drives an external switch to select between two packs of one, two, or three Li-ion cells each. The 3801 also provides for a ±10% battery-voltage trim, enabling precise matching to the chemistry of your choice. Maxim equips its $1.65 (1000) MAX1679 in an eight-pin μMAX8 with an on-chip state machine, forming one of the smallest chargers available but limited to single Li-ion cells.

GAUGING PROGRESS

A universal charger system needs to determine a good deal of information to optimally control a battery's charge cy-

BETTER LIVING THROUGH CHEMISTRIES

Most portable electronic devices use one of four basic battery chemistries: NiCd, NiMH, Li-ion, or SLA. Although sources disagree on the precise figures, it appears that applications that SLA packs traditionally served have largely moved toward NiCd, which now accounts for roughly 70% of the batteries in applications for which the two compete. For the rest of the small secondary (rechargeable)-battery market in which NiMH and Li-ion are alternatives, NiCd accounts for roughly 50% of cell sales, but the three will likely fall into parity during the coming decade (**Reference A**).

For applications such as portable power tools that demand high current capability, NiCd's low internal resistance and fast-charge capability make it preferable to NiMH and Li-ion. Its high capacity and long cycle life are superior to small sealed-lead-acid batteries as well (**Reference B**).

For applications less demanding of current delivery, NiMH batteries offer better energy density–40% by volume and 50% by weight-at the expense of reduced cycle life, a greater self-discharge rate, and a more complex charging algorithm. The additional energy density derives from the greater porosity of the metal-hydride electrode.

Precise direct comparisons are difficult for several reasons. First, a number of significant variations exist within a given chemistry. For example, in Li-ion cells, both cost and capacity depend on whether the cathode is formed with lithium-cobalt oxide, lithium-nickel oxide, or lithium-manganese oxide (**Reference C**). Other variations affect internal resistance, flatness of the discharge curve, and even end-of-charge voltage. Second, different mechanical forming methods used in the fabrication of battery elements also impact battery performance. NiCd cells built with sintered cathodes can accommodate faster charge rates, have lower internal resistance, and exhibit longer cycle lives than cells built with pressed or pasted cathodes (**Reference B**). Third, batteries, though structurally simple, exhibit parametric nonlinear behaviors. For example, a battery's self-discharge rate is a function of both the current state of charge and the temperature. If your product requires long battery standby in extreme environments, you should research candidate chemistries' behaviors and not assume that linear extrapolations lead to accurate predictions.

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B. Bauer, Anton, *The New Video Battery Handbook.*

C. *Designer's Guide to Charging Li-ion Batteries*, Analog Devices, 1998.

TABLE 4—REPRESENTATIVE SAMPLE OF BATTERY-PROTECTION CIRCUITS

Manufacturer	Model	Equivalent stack (no. of Li-ion cells)	Price	Package
Maxim Integrated Products	MAX1666X	Four	$2.75 (1000)	20-pin QSOP
On Semiconductor	NCP345*	One	50 cents (12,000)	Five-pin TSOP
On Semiconductor	MC33351A	Three	$1.62 (10,000)	20-pin TSSOP
Siliconix	Si9730	Two	$1.40 (100,000)	Eight-pin SO
Texas Instruments	UCC3952	Four	$1.73 (1000)	16-pin TSSOP
Texas Instruments	UCC3957**	One	$2.35 (1000)	16-pin SSOP

Notes:
*Supports nickel-based chemistries and larger stacks with use of external resistors.
**Includes on-chip pass devices.

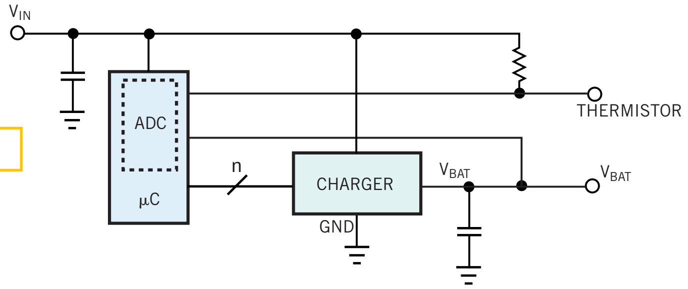
cle. This data includes a host of pack-specific information, such as chemistry, cell-stack size, initial state of charge, and cell temperature. Additionally, the processor needs to track the recent measurement history to calculate dT/dt, dV/dt, $-\Delta V$, or slope inflection (d^2V/dt^2), as required by the various end-of-charge strategies. With different chemistries requiring different termination methods, the design must manage the charge recipes and the measurement and control resources distributed among the processor, charger, and often an external ADC.

Not only overcharging, but also deep discharging reduces a battery's cycle lifetime. Many of the largest applications for small secondary packs also require some level of battery-status indication for the operator. Ironically, the best performing chemistries make this job all the harder. Flat discharge curves eliminate voltage as a useful indicator of remaining capacity. So, in applications where NiCd batteries have replaced SLA or better performing Li-ion chemistries and constructions have replaced lesser ones, charge systems lose the ability to assess the battery's current condition by simply measuring the terminal voltage under load.

The other method of assessing a battery's remaining capacity integrates both the charging and the discharging battery current. Several chip makers that offer this function refer to it as coulomb counting. Similar to other applications that integrate very-low-frequency phenomena, this function is sensitive to measurement offsets and must periodically eliminate the effects of accumulated errors in the measurement and, in this case, correct for misestimates of the battery's self-discharge losses. Coulomb counters require battery-pack characterization data over the full range of charge, discharge rates, and operating temperatures. A gauge usually stores this information in EEPROM so that the characterization can reflect the specific pack the gauge monitors, not an aggregate of all packs of a given type. The system can also update the data during the pack's lifetime based on measurements stored from previous charge and discharge cycles and thereby properly compensate for cell aging.

Accurate battery gauges have enabled

Figure 3



Adding a processor to the architecture enables chargers to operate at higher charge rates without the risk of overcharging.

FOR MORE INFORMATION...

For more information on products such as those discussed in this article, go to our information-request page at www.rscahners.ims.ca/ednmag/. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

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www.analog.com
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Dallas Semiconductor
www.dallassemiconductor.com
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Linear Technology
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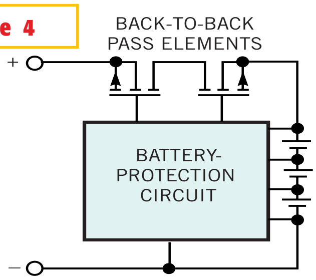
SUPER INFO NUMBER
For more information on the products available from all of the vendors listed in this box, enter No. 320 at www.rscahners.ims.ca/ednmag/.

so-called intelligent battery systems in which a battery pack, primarily through its gauge chip, communicates with the charger IC and host processor to manage the charge cycle and report on remaining capacity during the discharge cycle. These systems commonly use either the 1-Wire or the SBS/SMBus communications protocol. Representative parts include Dallas Semiconductor's $1.15 (10,000) DS2438 in an eight-pin SO package, a monitor for Li-ion and nickel chemistries, and the $4.22 (1000) BQ2050H in a 16-pin SO package Li-ion monitor from Texas Instruments. Both of these products support 1-Wire systems. SBS/SMBus gauges include the $3.49 (1000) PS331 from PowerSmart in a 28-pin SSOP for Li-ion and nickel batteries and Maxim's $9.40 (1000) MAX1780 in a 48-pin TQFP, a monitor for Li-ion, nickel, and SLA types. Some gauges, such as the PowerSmart and Maxim parts, track as many as four individual Li-ion cells in a stack, making it easy to detect a single unhealthy cell within a pack.

Figure 4



Most battery-protection circuits use external back-to-back MOS devices as pass elements. The circuits monitor voltage, current, and temperature, and they disconnect the battery when they detect unsafe conditions.

SAFETY SAM SEZ

A fuel gauge monitors a battery's condition over repeated charge and discharge cycles. A battery-protection circuit monitors the pack's instantaneous electrical and thermal environment. When the protector detects an overvoltage, undervoltage, overcurrent, or overtemperature condition, it disconnects the battery from its load. A series pair of low R_{ON} MOS devices form the disconnect mechanism. They are wired source-to-source or drain-to-drain so that their parasitic body diodes cannot conduct in either the charge or the discharge direction (**Figure 4**). Protectors monitor the individual cells in a stack to ensure system safety even in the presence of individual unhealthy cells. Like other battery-management functions, numerous protectors are available for various pack sizes (**Table 4**).

A 1-Ahr, 4.2V pack has a theoretical energy storage of more than 15 kJ-equivalent to 1.7 kF (yes, kilofarads) charged to the same potential—an appreciable energy source under fault conditions even if only a fraction of the energy is available in a short interval. Considering the energy-storage levels of modern packs, OEM designers should guard batteries of any chemistry against electrical faults or excess temperature. However, lithium-based chemistries are particularly intolerant. Under extreme fault conditions, lithium batteries plate out highly reactive lithium metal from the electrolyte onto internal electrode surfaces with potentially catastrophic consequences (**Figure 5**). (See also the online version of this article at www.ednmag.com/ednmag/reg/2001/01182001/02cs.htm for three .avi videos depicting the results of Li-ion batteries subjected to gross overcharge.) This warning is not to suggest that lithium or any other battery chemistry is inherently unsafe, but lithium chemistries do demand care, both electrically and physically, in handling.

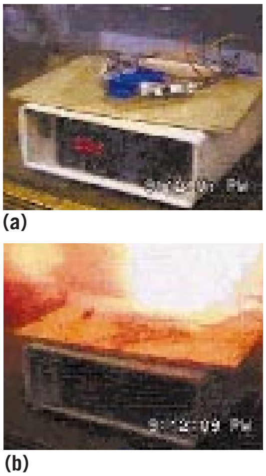


Figure 5 **A Li-ion battery pack with no protection IC (a) subjected to gross overcharging conditions makes a dramatic case for the inexpensive devices (b).**

Several government agencies, including the Federal Aviation Administration, National Transportation Safety Board, and Department of Transportation have explored battery-chemistry safety with renewed interest following a handling accident that resulted in two pallets of lithium-based primary cells catching fire on the tarmac at the Los Angeles International Airport on April 28,1999. The incident is noteworthy because it resulted from simple mishandling, and each time the ground crew thought the fire had been extinguished, it flared up again. Although the DOT recommended new packing, labeling, and handling procedures for both primary and secondary lithium cells, they did not recommend placing lithium cells under the Hazardous Materials Regulations (**Reference 4**).

A WORD ON FINAL STATE

There is little material in a rechargeable battery that recyclers can't reclaim. Few compounds in a battery benefit landfills or groundwater systems. Easy and economic recycling programs allow OEMs and resellers to direct spent cells to where they can do the most good and the least harm. You can get more information about battery-recycling programs from the Portable Rechargeable Battery Association (www.prba.org) and the Rechargeable Battery Recycling Corporation (www.rbrc.org).□

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