Which Battery Should *You* Use in Your Equipment

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Batteries! Batteries! Batteries! They're everywhere! With several new battery types coming onto the scene in the last 10 years or so, it's hard to keep up with what's available today! And—even more important—how do they differ from one another, and which is best in *your* application?

The tried and true standby batteries for hand-held transceivers, video cameras and portable computers have been nickel cadmium (NiCd). For less-portable applications, sealed lead acid (SLA or gel) cells are often used. Today we have nickel-metal hydride (NiMH), lithium ion (Li-Ion), lithium polymer (Li-Polymer) and reusable alkaline. Each of these types has good and bad features, and selecting the battery for your needs can be a real headache unless you understand those features and how they may apply to your needs. Here, I'll try to shed some light on those subjects.

Selecting the best battery for your particular application can be a compromise between cost and length of service. Here is a description of some of the many types available.

Battery Types[1]

Nickel Cadmium (NiCd)—Mature technology, used where long use life, high discharge rate and reasonable prices are important. Not good where long shelf life is essential.

Nickel-Metal Hydride (NiMH)—Has been around for about 10 years, offers a somewhat better power density than NiCd, but also has a reduced total number of charge/discharge cycles and a lower peak output current (because of higher internal resistance).

Sealed Lead Acid (SLA) or Gel Cells—Best suited for higher-current power applications, or those requiring low current for extended periods of time. The downside of these batteries is their large physical size and weight.

Lithium-Ion (Li-Ion)—A somewhat new technology, really emerging in the last five to seven years, although it has been experimented with for some time. Li-Ion cells provide a much higher power density (power available per unit volume) than NiCd. The downside is that they require very tight control of charge current, charge voltage and discharge to defend against plating metallic lithium inside the battery.

Lithium Polymer (Li-Polymer)—Not commercially available yet, Li-Polymer is a modification of Li-Ion technology and promises to be less expensive to manufacture, but will have a low maximum output current. Best suited for slow drain, low-current applications.

Reusable Alkaline—Cousin to disposable alkaline cells, reusable alkaline cells are good for low-cost and low-power applications. They're known for having a very low self-discharge rate.

That, in a nutshell, is a quick overview of the battery types available today and in the near future. Table 1 summarizes and compares these battery types. Because the Li-Ion technology holds the most promise for amateur and home entertainment use, the remainder of this article focuses on Li-Ion technology, how it works, and the special precautions you must take when using Li-Ion batteries.

What Makes Lithium-Ion Batteries Tick?

Lithium is the lightest of all metals; it also has the greatest –electrochemical potential available. Rechargeable batteries using lithium metal are capable of supplying both high voltage and extraordinary energy density. However, batteries using lithium *metal* have a very severe draw-back. The cells, especially during the charging process, can grow lithium dendrites internally (small slivers of lithium metal grow between the internal electrodes). These dendrites can short the cell and send it into thermal runaway. The cell will get hot enough to melt the lithium metal and will likely explode! For this reason, lithium cells have been limited to small-capacity applications such as watch batteries.

Because of the instability of lithium metal, research shifted to nonmetallic lithium in the form of lithium ions, which are generated by using chemicals such as lithium-cobalt dioxide ($LiCoO_2$). This provides a very stable battery with reasonably high discharge rates, high power density and a low self-discharge rate. On the horizon are other materials, such as amorphous tin-based composites, which will provide even higher power densities, but these are still a few years away.

For safety and battery-life reasons, each battery pack must be equipped with control circuitry to limit the peak voltage of each cell during the charge cycle, and to prevent the cell voltage from dropping too low during discharge.[2] Most of these circuits also properly limit the charging and discharging current and monitor the cell temperature. There are many battery-monitoring microcircuits available that perform all of these functions with a minimal number of

[1]Notes appear on page 42.

Table 1
Battery Type Comparisons

	NiCd	NiMH	SLA	Li-Ion	Li-Polymer	Reusable Alkaline
Energy density	40-60	60-80	30	100	150-200	80
Cycle life*	500-1500	500	200-500	500-1000	100-150	10
Fast charge time	1 h	2-4 h	8-16 h	3-4 h	8-15 h	2-3 h
Overcharge tolerance	Moderate	Low	High	Very low	N/A	Moderate
Self-discharge (per month)	25%	30%	5%	10%†	N/A†	0.3%
Individual cell voltage	1.25 V	1.25 V	2 V	3.6 V	2.7 V	1.5 V
Maximum load current‡	>2C	0.5-1C	0.2C	1C	0.2C	0.2C
Typical averaged cost (with NiCd being unity)	1.0	1.4	0.5	2.0	0.9 (est)	0.1

*Cycle life is when full capacity decreases from 100% to 80%. For reusable alkaline, it drops to 65%.
†Control and protection circuitry contained within the battery pack typically consume 3% per month.
‡The C specified here refers to the cell's ampere-hour capacity. For example, if a cell is rated at 1.5 Ah and you discharge it at a 1C rate, you will be drawing 1.5 A for 1 hour. If you draw only 0.75 A from it (0.5C), the cell should last for 2 hours.

Table 2
Some Sources for Li-Ion Supervisory Microcircuits

Company Name	*Web Site*	*Part No.*	*Features*	*Functions**
Maxim	**www.maxim-ic.com**	MAX745	Monitors 1 to 4 cells.	charge
		MAX846		charge
Linear Technology	**www.linear.com**	LT1510	Works with NiCd	charge
		LT1511	NiMH or Li-Ion. Get Design Note 111 and App Note 68	charge
Benchmarq	**www.benchmarq.com**	bq2054	Monitors 1 or 2 cells	both
		bq2058	Monitors 3 or 4 cells	both
Temic (Siliconix)	**www.temic.com**	Si9730	Monitors 2 cells	both
National Semiconductor	**www.nsc.com**	LM3420	1 to 4 cells	charge
		LM3620	1 or 2 cells	charge
		LM3621		charge

*Charge = monitors and controls charging of the batteries.
Both = monitors charging of the batteries and monitors the discharge to ensure you don't bring them too low.

additional components, components that are intended to be incorporated into the battery pack itself. (These will be discussed in greater detail a bit later.) By carefully monitoring and controlling all of these parameters, we can virtually eliminate the chance of plating metallic lithium within the battery.

At present, there are two major types of Li-Ion batteries: The *coke* and *graphite* versions. The graphite version has a somewhat flatter discharge curve (with a sharper knee), has a higher peak output current, and its full discharge point is 3.0 V. The coke version must be discharged to 2.5 V (these voltage levels can also vary among manufacturers). Both types are widely used today. Manufacturers are constantly working to improve the chemistry of their Li-Ion batteries.

There are two major advantages of Li-Ion batteries for use by radio amateurs: They can be recharged anytime during their entire discharge cycle, and they can be rapid-charged. In just one hour, they go from fully discharged to 80% of capacity, and are at 100% in just 2.5 hours.

Remaining-Capacity Predictions

Another advantage of Li-Ion is a highly predictable "remaining capacity" indication. Although specific details of the methods used to obtain remaining capacity information are beyond the scope of this story, I will give you an inkling of the two most popular methods.

Analog-to-Digital Conversion

This method uses a low-value series resistor as a current sensor, amplifies that signal, and applies it to the input of an 8 to 16 bit ADC, that provides a dynamic range of about 450:1, producing a digital level that is a fairly precise indication of the battery's output voltage. By knowing the precise discharge curve of the particular cell(s) you are working with, a well defined "remaining time" can be calculated. The main disadvantage of this method is that at low current draw (as during standby), the ADC accuracy is not very good, because it is at the low end of its resolution.

Voltage-to-Frequency Conversion

The second method is similar, but it uses a voltage-to-frequency conversion, and a microcontroller does the calculations for you. This approach also requires a stable clock source, but it can have a dynamic range of more than 4500:1, and will be much more accurate at all levels of usage.

Safely Charging and Discharging Li-Ion Battery Packs

There are a number of microcircuits available today that perform all of the needed functions to properly supervise from one to four cells, and do so with a minimum number of additional components. These are all designed to be built into the battery pack itself, so that charging the batteries involves simply attaching a proper voltage source to two terminals

Table 3
A Few Sources of Li-Ion Batteries

Model No.	*Vendor*	*Voltage*	*mAh Rating*	*Physical Size (inches)*	*Supplier's Web Site*
ICR-18650	NEC	3.7	1500	0.72 dia×2.56 long (cyl)	**www.nec.com**
ICR-17670	NEC	3.7	1300	0.67 dia×2.64 long (cyl)	**www.nec.com**
IMR-18650	NEC	3.8	1350	0.72 dia×2.56 long (cyl)	**www.nec.com**
IMP-220665	NEC	3.8	600	0.87×2.56×0.34 thick (rect)	**www.nec.com**
IMP-341065	NEC	3.8	1550	1.34×2.56×0.39 thick (rect)	**www.nec.com**
Eli-18650	Energizer	3.7	1350	0.71 dia×2.57 long (cyl)	**www.eacnet.com**
UR 18650	Sanyo	3.6	1300	0.71 dia×2.56 long (cyl)	**www.sanyo.ca**
UR 18500	Sanyo	3.6	900	0.71 dia×1.99 long (cyl)	**www.sanyo.ca**
UF 812248	Sanyo	3.6	550	0.87×1.89×0.32 thick (rect)	**www.sanyo.ca**
4/3A	GP Batteries	3.7	1220	0.67 dia×2.64 long (cyl)	**www.gpbatteries.com**
DR201	GP Batteries	10.8	3600	2.09×8.48×0.76 thick (rect)	**www.gpbatteries.com**
DR202	GP Batteries	10.8	3900	3.52×5.89×0.79 thick (rect)	**www.gpbatteries.com**

and the battery pack does the rest! These microcircuits are available from several manufacturers (see Table 2), but here I will discuss the Benchmarq bq2058 circuit in particular.

The Benchmarq device is a bq2058SN, factory set for an overvoltage threshold of 4.25 V. Several other thresholds between 3.4 V and 4.375 V are available, and you can consult their spec sheet for more information. With the addition of 10 resistors, 10 capacitors, a Zener diode and four switching FETs, you can build a complete three or four-cell (10.8 or 14.4 V) Li-Ion battery pack, that draws only 0.7 µA while sleeping (not in use), or 25 µA when the battery is being discharged or charged. The Benchmarq device provides over- and undervoltage and overcurrent protection—essentially everything you need for a complete battery pack. Benchmarq also offers a complete supervisor module with everything but the batteries themselves, fully assembled on a 2.6×0.7 inch PC board (bq2158). You can get a spec sheet from their Web site (see Table 2).

With a battery pack such as described in the Benchmarq data sheet, you could have a 14.4-V battery pack for your H-T that will likely give you twice the operating time, quick recharge capability and long shelf life. A ham's dream come true!

Battery Form Factors and Availability

There are many sources of Li-Ion cells; I have compiled basic information on several of them. Although Sony is probably the world's largest manufacturer of Li-Ion batteries, at this time they have chosen to keep that manufacturing captive and not sell them to outside users. See Table 3 for some basic information on a few of the sources.

Summary

All in all, the hobbyist has several choices today in battery power, and Lithium Ion appears to offer the best overall performance for use in H-Ts and similar electronic equipment. The one "gotcha" you must pay very close attention to is the careful control and monitoring that is necessary during charging and discharging. Luckily, there are several microcircuit manufacturers that can supply ready-to-go solutions to those issues.

Notes

[1] Definitions of battery types are courtesy of the CADEX Web site at **http://www.cadex.com**.

[2] Li-Ion charging characteristics data was courtesy of the Power Conversion and Intelligent Motion Web site at **http://www.pcim.com**.

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