All About
Batteries

by Carl Moreland

Battery Basics

Detectors these days are much lighter compared to 25 years ago, and incredibly lightweight compared the tube clunkers of the 1950's. I have an old Fisher two-box from I guess the 40's or 50's - it's made of plywood and each box has three monster batteries, three of which are a 45 volt batteries for powering the tube cathodes. Those are a tad hard to come by these days (they can be found!) so I made my own, and low and behold the old Fisher still works! Weighs a ton, tho.

Even into the 70's and early 80's, when everything was not only transistorized but being integrated on to chips, detectors were requiring massive battery packs. My 70's Relic Master uses 17 (!) C-cells, and even the later 6000/D uses 14 AA cells. Part of the reason for this is that detector circuitry often requires dual supply voltages, one positive and one negative. That accounts for two battery packs in many older detectors. Some detectors, like the old Compass', had a third battery for just the audio. Most of these old detectors used clusters of standard 1.5-volt batteries. The reason for having so many batteries in each pack is to get the desired voltage. A 6-cell pack of AA's delivers 9 volts - OK, but why not use one of those smaller, lighter 9-volt batteries? Now we have to look at power.

Power is equal to volts times current. If a detector draws 100 milliamps (mA) from a 9 volt battery then somewhere it is dissipating 900 milliwatts (mW) of power. Some of it in the form of useful electromagnetic energy in the coil and the rest in the form of useless heat. Producing heat is unavoidable, but some designs are better than others.

Most of us know that batteries are rated in voltage, such as 1.5 volts for an 'AA' cell. How long they will last is usually stated by their amp-hour (A-h) rating. This number basically tells us how long the battery can deliver a certain level of current (amps) at a useful voltage. Ferinstance, a 1 A-h battery can deliver 1 amp for 1 hour, or 100 mA for 10 hours, or 10 mA for 100 hours. In other words, take the amp-hour rating of the battery, divide by the current consumption of your electronic gizmo, and you will find out how long your battery will last. Well, not really. We'll see why not in a minute.

Connecting like batteries in series will boost the overall voltage, but do nothing for the current capacity. Two 1.5v, 1 A-h cells in series gives 3v, still with 1 A-h of capacity. Conversely, connecting like batteries in parallel will maintain the same voltage and increase the available amp-hours. Parallel connection is not recommended because even like cells do not have exactly the same voltage, and stronger cells will dump current into the weaker cells. This will waste power and in severe cases, such as mismatching battery types, can damage batteries.

The reason a 9-volt pack of AA's are used instead of a square 9-volt battery is that the AA pack has a much higher A-h rating, so they will last longer. And for some people that's a selling point with metal detectors: "Model X will run for up to 50 hours on a single battery pack." I've never swung a detector for 50 straight hours and I never plan to. Personally, I don't mind swapping out batteries every so often as long as it doesn't require breaking out a toolbox. And popping in a square 9-volt is easier than a big rack of AA's. Easier to carry in the field, too.

But the A-h rating doesn't tell the whole story. Batteries also have an internal resistance, due to the electrolyte used. As you try to pull more current from a battery the voltage will start to drop. Current flow also generates heat, and heat can reduce battery efficiency. So a battery that has a 1 A-h rating might deliver 100mA for 10 hours but not last an hour while delivering 1 amp. In fact, it might not even deliver 1 amp at all, at least not at any useful voltage. Some battery types deliver high current better than others, and some are less sensitive to temperature extremes.

The voltage output of a battery is not necessarily the same as its rating, especially at high current rates, and it drops off even more as the battery discharges. It is not unusual for a 1.5 volt alkaline cell to have 1.2 volts when delivering a decent current, and 1 volt or less near death. One question might be, how do circuits deal with this variation in battery voltage? Most use an internal voltage regulator that outputs a lower but constant voltage. A circuit might have a 5 volt regulator powered by a 9-volt battery, so it will run quite happily until the battery is just about exhausted. Most any circuitry can easily be designed to run on 5 volts, and some on less.

Many circuits are easier to design with dual voltage supplies, i.e., a positive and a negative supply. Some linear IC's even require dual supplies. So now we need two battery packs, one for positive and one for negative. Or do we? There is a technique to generate a negative voltage from a positive one, called a charge pump. First use an oscillator to make an AC waveform from the positive DC supply, then pump AC current into a capacitor to create a negative AC waveform, rectify and filter. Sounds like a lot of work just to get rid of a battery. Fortunately, there are some cool IC's that do the job easily, the most popular being the LM7660 from National Semiconductor. With this, we can use a single 9 volt battery and end up with +/- 9 volt supplies.

There's no free lunch, and charge pump inverters waste some power in the inversion process. Efficiencies of 80% or better are normal these days, which means if you want to supply 80mA of current to a negative supply you will need to waste 20mA of current in the charge pump. 100mA in, 80mA out, plus some heat. Charge pumps can also be used to increase a voltage, like doubling 9 volts to 18 volts. Again with inefficiencies.

That's it for a background on battery basics. Now let's take a look at some of the batteries that are available, and which ones you might want for your detector.

Battery Technology

Battery technology has progressed quite a bit in the last few years, driven mostly by portable computers and other hi-powered gizmos. In fact, some people call it the 3 "C"s: computers, cell phones, and camcorders. Carbon-cell (Leclanche) batteries were all we had up to 25 years ago and they've been around, virtually unchanged, since the 1890's. Alkaline batteries are the standard now and offer more of those amp-hours. Just recently manufacturers began selling new "super alkalines," such as the Duracell Ultra. One that caught my eye is Energizer Titanium - unfortunately, when you compare its data sheet to the standard Energizer the performance is *identical*, at least for moderate loads. I doubt these new batteries will offer any real improvement in detectors.

There are also rechargeable batteries, such as nickel-cadmium (NiCd), nickel-metal-hydride (NiMH), lithium (Li), and even rechargeable alkaline. Rechargeable batteries have a higher initial cost but save money in the long run, and are very popular with detectorists. Although their capacity looks worse than standard alkaline, they typically perform much better under heavy loads. The following chart compares AA cells for the types mentioned. Note that standard alkaline has the best capacity but that's only true for low to moderate loads, like detectors. The cost of rechargeables is based on 100 charges (25 for the rechargeable alkaline), and does not include the cost of the recharger (usually about 10-20 bucks).

Table 1: 'AA' Battery Comparison

Type	mA-H	Cost per A-H
Li (NR)	2500	$1.00
Zn-C	700	0.28
Alkaline	2700	0.20
Alkaline Recharg.	1600 *	0.04
NiCd	800	0.04
NiMH	1400	0.02

* Initial charge

One thing to note is that NiCds have a lower voltage rating than other batteries. A 6-cell pack will be 7.5 volts instead of 9, and this could degrade performance if the circuitry needs the full 9 volts. But no one designs a circuit that requires a full battery voltage. As already discussed, voltage regulators are used to deal with battery degradation, and most detectors are designed to accept NiCd batteries. Plus, NiCds have a better discharge curve and can actually have a *higher* voltage than alkaline when delivering high current. Figure 1 shows some typical discharge curves for several AA cells.

But NiCds have another problem besides the lower voltage rating. They have *memory*. If they are not completely discharged before recharging they may lose some of their capacity. In other words, they remember if they were not completely discharged and in subsequent cycles may not discharge as deeply. So there is a definite cycle life, and it may depend on how you use the batteries.

Rechargeable alkalines have been out for a number of years, but I don't see that they've caught on in a big way. Battery racks at the local Stuff-Mart are still nearly 100% throw-away alkaline. I latched on to Ray-O-Vac's Renewal batteries when they first came out. You see, I have kids, with lots of battery-operated toys. Unlike NiCds, these don't have memory. However, one problem I've had with Renewal is that one cell might suddenly decide to stop working altogether. Stick it in the recharger and it does nothing. And maybe after only one or two recharges. Other cells seem to last forever and ever. I think there's room for improvement, but still they're way better than constantly buying throw-aways.

NiMH is one of those portable computer batteries that has found it's way in many other gadgets. They've become enormously popular in the last couple of years in gadgets that have extreme current demands. My digital camera has four AA NiMH batteries. Not only do they have more capacity (A-h's) than NiCds, but they are memoryless. So you can recharge them at any point in the discharge cycle. They do have one big problem: they self-discharge. When you buy them new they're generally dead, and after a full charge they may last only a month or two. So before heading out to that remote desert location make sure to top them off.

A final battery to consider is lithium which also started out for computers. Lithium is an interesting element, the lightest of all metals. It's very reactive and a bit tricky to make this stuff work in a battery, especially a rechargeable battery. But batteries work by shedding a single electron from the anode material, and lithium's single valence electron is ideal for this task. So in terms of energy capacity to weight ratio, you fundamentally cannot do better than lithium.

The Li batteries sold with laptops are rechargeable lithium-ion (Li-ion) types. Lithium is a 3.6v technology and special things (like using a FeS_2 cathode) have to be done to get 1.5v compatibility. I've recently seen AA Li batteries on the local store racks. You will note that the Li batteries really are lighter than other types, by about 40%. So they are great for detectors, unless you depend on the battery weight to balance the unit. And Li has about the best capacity you can get (Table 1). Unfortunately, they're pretty expensive.

I've not yet seen any other sizes besides AA, but they are surely on the way. Like I said, it's hard to make 1.5v Li cells it's even harder to make large sizes like D cells. Unfortunately, using

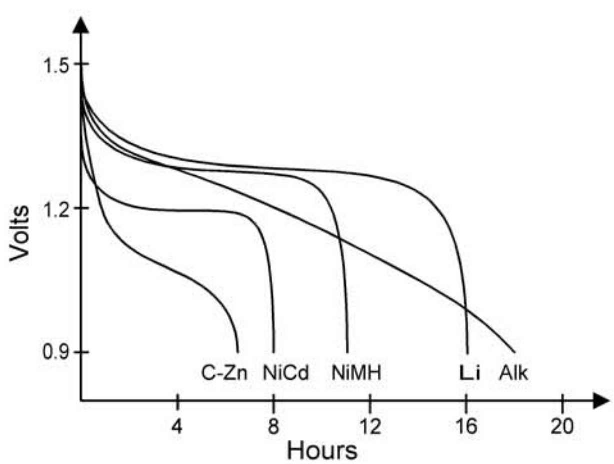

Fig. 1: Discharge curves for different technologies. Note that NiCd quickly plateaus to 1.2v and has an abrupt death, while alkaline has a long, steady discharge.

a FeS_2 cathode to get a lower voltage makes the battery non-rechargeable. Rechargeable 3v and 6v Li batteries are available though, in some pretty nice drop-in packages (especially in the cell phone market) that are becoming standardized. Check the racks at your local Stuff-Mart to see what I'm talking about. Maybe detector manufacturers should consider this as an option. Look for lots of advances in lithium batteries in the near future, perhaps even in electric vehicles.

A final note on recharging. Some types of rechargeable batteries are finicky about the exact way they are charged. Some rechargers now have a special integrated circuit that monitors and controls charge rates, especially for NiMH and Li batteries. So you can't just build up a home brew fixed-regulator-type charger and not expect some potentially bad results. And with non-rechargeables (esp. Li) I wouldn't recommend trying them out in *any* charger. Basically, never do any of the nasty things the package says not to do. Most detectors that have NiMH batteries come with simple wall transformer rechargers, and I know that some people have built successful NiMH pack chargers that are similarly simple. Just watch the charging current so you don't damage the cells.

So what's the best battery technology for detectors? If you don't do a lot of detecting then standard alkaline is probably your best bet. I prefer rechargeables, and would choose Renewals over NiCds - they don't have the quirky memory problem, are cheaper, and easy to find. Just don't discharge them totally dead. But the current best all-around choice for rechargeables would have to be NiMH, especially for high capacity needs like pulse induction. If weight is critical, lithium is a good choice (but expensive), and as lithium technology progresses, it will probably win out.

Resources

1. Duracell
   http://www.duracell.com
2. Eveready Energizer
   http://www.energizer.com
3. Ray-O-Vac
   http://www.rayovac.com
4. *Batteries for Low Power Electronics*, Robert Powers, Proc. of the IEEE, April 1995
5. *All About Batteries*, Stephen Bigelow, Popular Electronics, August 1990