The battery and the digital load

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With the move from analog to digital devices, new demands are being placed on the battery. Unlike analog equipment that draws a predictable and steady current, digital devices load the battery with short, high current bursts.

One of the urgent requirements of a battery for digital applications is low internal resistance. Measured in milliohms (mΩ), the internal resistance is the gatekeeper that, to a large extent, determines the runtime. The lower the resistance, the less restriction the battery encounters in delivering the needed power bursts. A high mΩ reading can trigger an early 'low battery' indication on a seemingly good battery because the available energy cannot be fully delivered.

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In this article we examine the current requirements of analog and digital communications devices. Figure 1 provides typical examples of peak current of the analog two-way and digital Tetra radio, as well as the AMP, GSM, TDMA and CDMA mobile phones.

	Two-way Radio	**Tetra Radio**	**AMP Mobile Phone**	**GSM Mobile Phone**	**TDMA Mobile Phone**	**CDMA Mobile Phone**
Type	Analog	Digital	Analog	Digital	Digital	Digital
Peak Power	2-4 Watts	1 or 3 Watts	0.6W	1-2 Watts	0.6-1 Watts	0.2 Watts
Peak current	1.5A at 4W	1 or 3A	0.3A DC	1-2.5A	0.8-1.5A	0.7A
In service since	1962	1997	1985	1986	1992	1995

Figure 1: Peak power requirements of popular global mobile phone systems.
Moving from analog to digital equipment reduces the overall energy need but increases the peak current during load pulses. The wattage varies with signal strength.

Why do seemingly good batteries fail on digital equipment?

Service technicians have been puzzled by the seemingly unpredictable battery behavior when powering digital equipment. With the switch from analog to digital wireless communications devices, particularly mobile communications equipment, a battery that performs well on an analog system may show irrational behavior when used on a digital unit. Testing these batteries with a battery analyzer produces good capacity readings. Why then do some batteries fail on digital devices but not on analog?

The overall energy requirement of a digital mobile phone is less than that of the analog equivalent, however, the battery must be capable of delivering high current pulses that are often several times that of the battery's rating. Let's look at the battery rating as expressed in C-rates.

A 1C discharge of a battery rated at 500mAh is 500mA. In comparison, a 2C discharge of the same battery is 1000mA. A GSM phone powered by a 500mA battery that draws 1.5A pulses loads the battery with a whopping 3C discharge.

A 3C rate discharge is acceptable for a battery with very low internal resistance. However, aging batteries, especially Li-ion and NiMH chemistries, pose a challenge because the mΩ readings increase with use. Improved performance can be achieved by using a larger battery, also known as an extended pack. Somewhat bulkier and heavier, an extended pack offers a typical rating of about 1000mAh or roughly double that of the slim-line. In terms of C-rate, the 3C discharge is reduced to 1.5C when using a 1000mAh instead of a 500mAh battery.

As part of ongoing research to find the best battery system for wireless devices, Cadex has performed life cycle tests on various battery systems. In Figures 2 to 4 we examine NiCd, NiMH and Li-ion batteries, each of which generate a good capacity reading when tested with a battery analyzer but produce stunning differences on a pulsed discharge of 1C, 2C and 3C. These pulses simulate a GSM phone.

A closer look reveals vast discrepancies in the mΩ measurements of the test batteries. In fact, these readings are typical of batteries that have been in use for a while. The NiCd shows 155mΩ, the NiMH 778mΩ and the Li-ion 320mΩ, although the capacities checked in at 113, 107 and 94 percent respectively when tested with the DC load of a battery analyzer. It should be noted that the internal resistance of a new battery reads between 75 to 150mΩ.

From these charts we observe that the talk-time is in close relationship with the battery's internal resistance. The NiCd produces a long talk time at all C-rates. In comparison, the NiMH only works at a lower C-rate. The Li-ion performs better but is marginally at a 3C discharge.

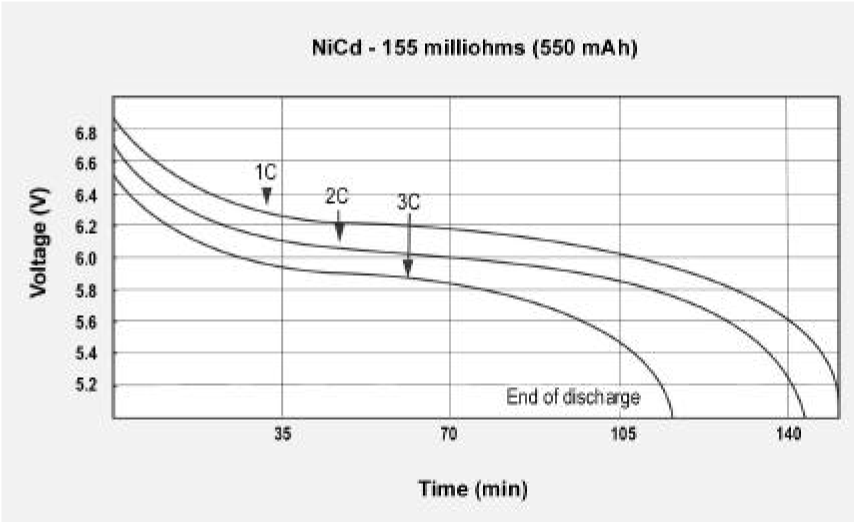

Figure 2: Talk-time of a NiCd battery under the GSM load schedule.
This battery has 113% capacity and 155mÙ internal resistance.

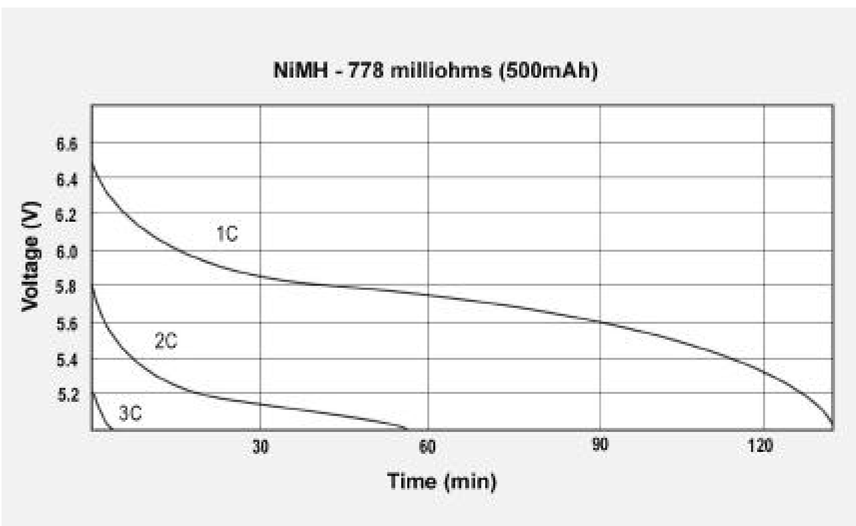

Figure 3: Talk-time of a NiMH battery under the GSM load schedule.
This battery has 107% capacity and 778mÙ internal resistance.

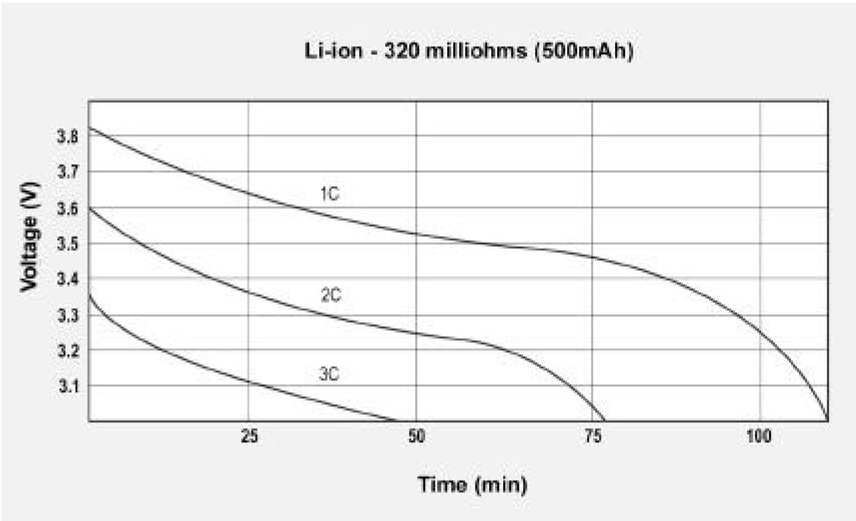

Figure 4: Talk-time of a Li-ion battery under the GSM load schedule.
This battery has 94% capacity and 320mÙ internal resistance.

How is the internal battery resistance measured?

A number of techniques are available to measure the internal battery resistance. One common method is the direct current (DC) load test, which applies a discharge current to the battery while measuring the voltage drop. Voltage over current provides the internal resistance.

The alternating current (AC) method, also known as the conductivity test, measures the electrochemical characteristics of a battery. This technique applies either a fixed frequency, or a frequency range from 10 to 1000Hz to the battery terminals. The impedance level affects the phase shift between voltage and current, which reveals the condition of the battery. Some AC resistance meters evaluate only the load factor and disregard the phase shift information.

Cadex uses the discreet DC method to measure internal battery resistance. Added to the Cadex *7000 Series* battery analyzers, a number of charge and discharge pulses are applied, which are scaled to the mAh rating of the battery tested. Based on the voltage deflections, the battery's internal resistance is calculated. Known as *Ohmtest*™, the mΩ reading is obtained in five seconds.

Neither of the three methods is dead accurate. The discrepancies are reasonably small on a good battery but the readings get more diverse on weaker packs. Figure 5 compares the accuracy obtained using the three methods.

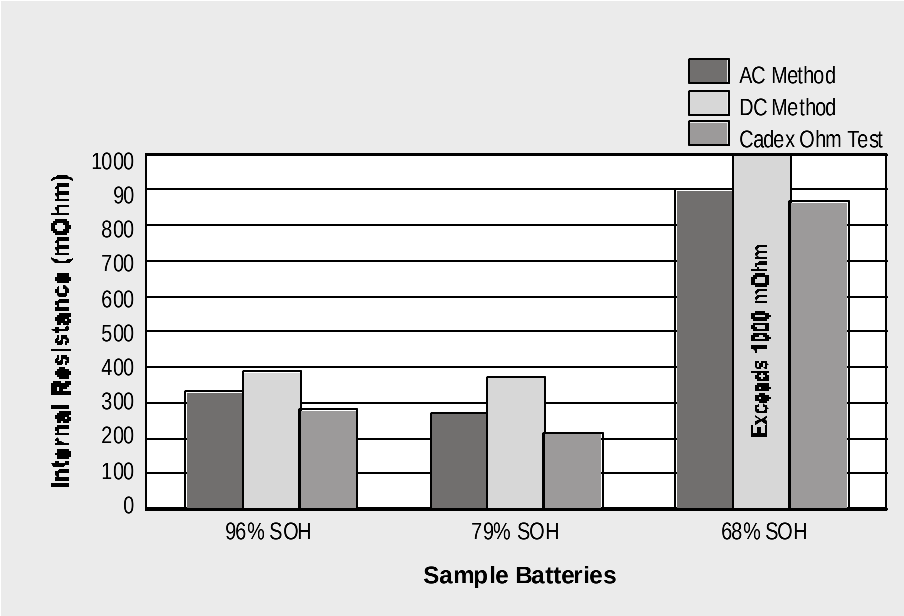

Figure 5: Comparison of the AC, DC and Cadex Ohmtest™ methods.
State-of-health readings were obtained using the Cadex 7000 Series battery analyzer by applying a full charge/discharge/charge cycle.

Resistance measurements alone do not provide a reliable indication on the battery's performance. The mΩ readings may vary widely depending on battery chemistry, cell size (mAh rating), type of cell, number of cells connected in series, wiring and contact type.

When using the impedance method, a battery with a known performance should be measured and its readings used as a reference. For best results, a reference reading should be on hand for each battery type. Figure 6 provides a guideline for digital mobile phone batteries based on impedance readings.

Milli-Ohm	Battery Voltage	Ranking
75-150mOhm	3.6V	Excellent
150-250mOhm	3.6V	Good
250-350mOhm	3.6V	Marginal
350-500mOhm	3.6V	Poor
Above 500mOhm	3.6V	Fail

Figure 6: State-of-health on mobile phone batteries based on internal resistance.
The milliohm readings relate to the battery voltage; higher voltage allows higher milliohm readings.

The milliohm readings are related to the battery voltage. Higher voltage batteries allow higher internal resistance before the system fails because less current is required to deliver the same power. The ratio between voltage and milliohm is not totally linear. There are certain housekeeping components that are always present whether the battery has one or several cells. These are wiring, contacts and protection circuits.

Temperature also affects the internal resistance of a battery. The internal resistance of a naked Li-ion cell measures 50mΩ at 25°C (77°F). If the temperature increases, the internal resistance decreases. At 40°C (104°F), the internal resistance drops to about 43mΩ and at 60°C (140°F) to 40mΩ. While the battery performs better when exposed to heat, prolonged exposure to elevated temperatures is harmful. Most batteries deliver a momentary performance boost when heated.

Cold temperatures have a drastic effect on all batteries. At 0ºC (32ºF), the internal resistance of the same Li-ion cell drops to 70mΩ. The resistance increases to 80mΩ at -10ºC (50ºF) and 100mΩ at -20ºC (-4ºF).

The internal resistance readings work best with Li-ion batteries because the degradation follows a linear pattern with cell oxidation. The performance of NiMH batteries can also be measured with the internal resistance method but the readings are less dependable. There are instances when a poorly performing NiMH battery can also exhibit a low mΩ reading.

Testing a NiCd on resistance alone is unpredictable. A low resistance reading does not automatically constitute a good battery. Elevated impedance readings are often caused by memory, a phenomenon that is reversible. Of course, high internal resistance can have sources other than memory alone.

Summary

Customer demand has compelled manufacturers to equip portable devices with batteries that provide a long talk-time, are small and are light in weight. By packing more energy into a pack, other qualities may be neglected, one of which is internal resistance and longevity.

Predictable low mΩ reading and long service life is found in the NiCd family. This chemistry has been replaced with higher energy dense batteries for many wireless applications. In addition, negative publicity about the memory phenomenon and concerns of toxic metals have caused a shift towards alternative choices.

For many applications, including biomedical devices, power tools and most notably the Tetra system, the NiCd may be the only battery that has the endurance of delivering high pulse current under continuous usage. Other chemistries are simply too fragile. The resistance on a NiMH rises after a few hundred charge/discharge cycles. In comparison, a properly maintained NiCd provides over one thousand cycles.

For many portable devices, the battery is one of the most expensive components. It is also the only part that repeatedly fails during the life of a product. It is therefore prudent that manufacturers do not only focus on high energy density, but also address the issue of longevity. The longer a battery lasts, the fewer batteries are discarded, a win-win situation for business and the environment.

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 battery 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.

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. 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.

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