Modern battery technology distinguishes military handhelds – and presents significant design challenges

By Robin Sarah Tichy, PhD

Numerous challenges await designers of reliable, portable power systems for use in rugged, mobile military applications such as Multiband Inter/Intra Team Radios (MBITR). Robin presents information on innovations in cell chemistries, power management electronics, enclosure designs, and safety strategies that address these challenges.

Electrical design engineers need to understand new power technologies on the horizon as they develop portable devices for military applications. The battery pack – embedded in the portable device – is fundamental to functionality, and a high-performance battery can differentiate a product in the handheld military market. Battery packs for ruggedized portable devices must operate in both extremely hot and cold environments. Many devices – such as handheld radios, telemetry monitors, weather stations, test equipment, missiles, rockets, and satellites – are used in harsh environments.

The building blocks of a battery pack

Figure 1 shows the main components of a typical battery pack, including:

➔ The cells providing the primary energy source
➔ The Battery Management Unit (BMU) providing system intelligence for advanced functions such as fuel gauge calculations on remaining cell capacity, protection circuitry, thermal sensors used to monitor internal pack temperature, LEDs that indicate pack or cell status, and a serial data bus that communicates to the host device
➔ A custom plastic enclosure typically produced in an injection mold
➔ External contacts providing a physical electrical interface with the host device
➔ Insulation used to absorb external shock, as well as retain or dissipate heat generated with the pack

All these elements can be customized when designing a battery pack for extreme environments such as those seen by an MBITR radio; however, the cells are critically affected by extreme temperatures, and this is a particular challenge.

Li-ion batteries offer many attractive advantages over other rechargeable chemistries, including a much higher energy density, lighter weight, longer cycle life, superior capacity retention, broader ambient-temperature endurance, and higher current tolerance. Over the past 10 years, the fundamental materials on which Li-ion is based have not changed much. New safety schemes have been developed and energy density increased by stuffing more and more material into the same size can. Li-ion is more environmentally friendly than the other chemistries, and modern designs are very safe. Li-ion has decreased in cost because of the economies of scale driven by consumer products such as laptop and cell phones. Often a Li-ion solution is at cost parity with a Ni-metal hydride solution because the higher operating voltage, 3.6 V versus 1.2 V, allows for a lower cell count. Thus, many applications that require multiple cells in a series will migrate to Li-ion batteries as have the MBITR radios, which require three Li-ion cells in series. All Li-ion batteries

The “whys” and “wherefores” of the Sony battery recall

By Jeffrey VanZwol

As of October 2006, Sony has recalled 9.6 million batteries worldwide, including 250,000 of its own VAIO batteries. The battery recall affected some, but not all, Sony customers who purchased batteries September 2004 through October 2006. Affected customers of Sony Energy Devices – the world’s second-largest rechargeable battery cell manufacturer – included Dell, Apple, Gateway, Fujitsu, Toshiba, and Sony VAIO. The recall arose because microscopic metal particles in the 18650 battery cells (18 mm x 65 mm) came into contact with the cell’s internal elements, leading to a short circuit within the cell.

In response to the global awareness of the Sony battery recall, several industry groups are expediently upgrading standards for Li-ion battery packs, including IEEE 1625, UL 1642 and 2054, and ANSI C18.2M, Part 1-2001 specifications.

Jeffrey VanZwol is marketing director at Micro Power Electronics, Inc. He can be reached at jvanzwol@micro-power.com.
are not created equal. Therefore, proper cell selection and careful battery pack design are of particular importance when the device is exposed to rugged conditions.

**The importance of the usage profile**

Proper choices, with respect to the BMU and battery chemistry, will determine the reliability of an MBITR radio or any other military device. Manufacturers typically specify cell performance at an ideal constant current rate of 1/5 of the battery’s capacity per hour and +20 °C external temperature. However, most portable devices are expected to operate in a range from -20 °C to +40 °C. Military requirements are often -40 °C to +80 °C, and there are higher, pulsating currents; therefore, testing the performance profile of cells and the assembled battery pack in simulated use is necessary to ensure reliability. The first step in ensuring a proper battery choice is to fully describe the “real-world usage profile” of the device. The usage profile includes temperature ranges, discharge profiles, charging regimens, expected shelf life, and transportation requirements and should account for foreseeable misuse as well as intended use. For example, temperature extremes can cause similarly rated cells from different manufacturers to demonstrate widely varying performance results, such as voltage output and runtimes. Shelf life plays a critical role in the selection of the appropriate cell chemistries, so the self-discharge rate of the cell chemistry may be the determining factor in selecting the optimal chemistry.

If high current is flowing through the battery, low voltage cutoff will be reached earlier because of I*R voltage drop. External battery voltage can be modeled as \( V = V_0 - I \times R \) where \( R \) is internal resistance of the battery and \( R \) is dependent on state of charge, temperature, and battery age. Performance of rechargeable Li-ion chemistry starts to suffer as the temperature drops below freezing. As the temperature drops below 0 °C, the battery’s internal impedance increases. The result of this effect is shown in Figure 2, where a 2 A load causes the voltage to droop. This “voltage droop” is more pronounced at -20 °C, and the electrolytic material within the cell will freeze with further temperature declines. Figure 3 demonstrates the importance of well-characterized cells in the design of an MBITR battery pack. In this case, cell 1, the red curve, was chosen by the radio’s manufacturer and performed adequately at room temperature. Also, it seemed to work well at colder temperatures until the user transmitted a radio signal. At that time, the higher current and low temperature combined to make the pack reach its low voltage cutoff of 9 V. Micro Power Electronics tested four cells from two alternate cell suppliers against this specific usage profile, and all were found to be adequate. Although, it should be noted, they all displayed some variability even among the same manufacturer.

On the other hand, extremely high temperature operation provides equal challenges for cells based on lithium chemistry. The upper range of safe operation for Li-ion and lithium primary cells is 60 °C. Cells provide energy through the electrochemical shuttling of lithium ions between the anode and the cathode materials. However, at high discharge rates, this chemical reaction generates heat, and the effects of this heat must be factored into a sound battery pack design. Care must be taken that the combined ambient and generated heats do not take the cells out of the safe operating temperature range. The effects of the generated heat are compounded when numerous cells are assembled into a multicell pack.

To demonstrate the typical temperature rise in a multicell pack, Micro Power has assembled a pack and monitored the temperature rise using our environmental and electrical test chambers. This testing should be performed on packs that must operate near
the upper or lower boundaries of the cell specifications. The pack assembled for the test was a 4S6P (four cells in series, six strings in parallel) Li-ion pack using 18650 (18 mm diameter, 65 mm length) 2.4 A-Hr cells, resulting in a pack that provides 14.4 V and 14.4 A-Hr of capacity. Testing was conducted at a condition of 145 W discharge at 45 °C ambient temperature. Thermistors were placed within the pack core and around the outside edge of the cells. The pack was wrapped in packing material to simulate a plastic enclosure, and an additional thermistor was placed on the outside of the packing material to capture the temperature outside the simulated enclosure. Temperature and performance data were recorded on automated Maccor battery testing equipment.

The results of the testing are presented in Figure 4. The thermistor placed within the cells in the center of the pack registered a core temperature of 65 °C. The two thermistors placed at the edge of the assembled cells registered a perimeter temperature of 64 °C and 65 °C. Note that the temperatures at the core and edge of the pack are similar. Figure 4 also presents a thermal image of the pack during the test, and one can see that the temperature of the interior and edge cells are similar. Finally, the thermistor outside the packing material registered a temperature of 54 °C.

Hence, this test demonstrates that one can expect up to a 20-degree rise in temperature when the pack is in operation, and this can result in a 9-degree temperature rise of the pack enclosure. Note that the temperature changes are dependent on the amount of current drawn from the pack (for example, greater current results in greater heat generation). These temperature increases, both within and outside the pack, must be factored into the design of the battery pack and portable device. This level of testing and analysis should be performed on all pack designs that must operate in low- or high-temperature conditions such as those of an MBITR radio. Intimate knowledge of the usage profile allows the pack to be designed in a way that avoids stressing the pack thermally.

**Working with new technology**

There are several new technologies available for Li-ion battery pack designers. New materials are improving the cost, capacity, and rate capabilities of cells while new electronics for power management are improving monitoring and efficiency. New choices bring more variability to cell performance, so the usage profile and cell characterization’s importance is increased. Li(CoMnNi)O₂ (NCM) is a safer and less expensive cathode material that will be featured in cells offered by a number of the tier 1 cell suppliers. The new cells will originally be offered in the common 18 mm diameter and 65 mm long size, but eventually they will be offered in both cylindrical and prismatic shapes so that they can be designed into the more restrictive form factor of a handheld device. NCM experiences a significantly lower voltage droop when power is drawn at 0 °C compared to standard cobalt systems, indicating lower cell impedance. Under certain circumstances, the higher internal impedance of the traditional LiCoO₂ cells can work in the user’s favor. The increased I²R heating effectively raises the temperature of the cobalt cell above the ambient, which in turn reduces electrolyte viscosity.

Figure 5 shows that the cobalt cells are capable of yielding more of their stored energy at 0 °C ambient compared to the NCM cell, but the NCM cell might be the safer choice in high ambient temperature conditions. This information gives the battery designer a choice. Depending on the usage profile of the end device, either the standard cobalt cell or the NCM may be a better choice. For example, an application with high-current pulses, such as an MBITR radio, might benefit from the smaller voltage droop of the NCM; for an application requiring a continuous low drain rate at 0 °C, the standard cobalt cell would be a better choice.
Engineers are making great strides in power management technologies that complement novel battery chemistries. The battery schematic shown in Figure 1 depicts the circuit board that controls safety and power management. The battery systems for military applications must incorporate redundant safety systems and reliable protection circuitry because the device’s operation is critical to the military mission. The printed circuit board not only has protection circuitry and thermal sensors, but it also provides the system intelligence for advanced functions such as fuel gauging, cell balancing, and communication via a serial data communications bus. Smart battery systems are the preferred choice for military applications. A valuable smart battery pack feature, to users of MBITR radios, is the pack’s ability to monitor its status, accurately predict its remaining runtime, and communicate its operational status to the host device. Traditional fuel gauges either monitored the voltage or the capacity, and the accuracy was quite limited.

Low-frequency impedance is a critical factor for DC performance of batteries, but low-frequency impedance increases rapidly with battery aging. During the first 100 cycles, low-frequency impedance increases more than twice, as shown in Figure 6. However, battery chemical capacity changes very little during the same period; therefore, the voltage is a very bad indication of the battery’s state of charge for an application with variations in load, such as the MBITR radio. A new “gas gauge” monitors the number of coulombs transferred and opportunistically calibrates with the open circuit voltage of the Li-ion pack. When no load or standby load is applied to the battery, these newer fuel gauges use the voltage-based method to determine starting State Of Charge (SOC) and no-load capacity degradation. When under a subsequent load, the fuel gauge uses a current integration-based method and updates the impedance at every cycle using voltage and current information. Texas Instruments claims an accuracy of 99 percent for its Impedance Track technology. These features allow the end user to intelligently manage device use and avoid unexpected failures or shutdowns.

**Battery packs and today’s mobile military applications**

The military is demanding higher performance, lower weight, longer effective usage times, and absolute reliability from mobile, handheld applications such as MBITR radios. These systems rely on increasingly sophisticated battery packs for their power requirements, yet they present unique design challenges because of the extreme environments to which they are exposed. Design engineers are faced with an array of challenges in designing effective battery systems – from cell and cell pack selection to intelligent power management, from safety concerns to charging systems. Armed with an understanding of these demands, however, designers can make the best choices for battery-supplied power in today’s rugged military applications.

**Robin Sarah Tichy** is technical marketing manager at Micro Power Electronics in Beaverton, Oregon. She has developed an expertise in translating market drivers into technical solutions in the battery and charger industry. Prior to joining Micro Power, Robin applied technical and project management skills to orchestrate and implement solutions to solve vital business problems at Hewlett Packard and International SEMATECH, in the semiconductor, nanotechnology, and MEMS verticals. She holds a PhD from the University of Texas for her work in solid oxide fuel cells.

**Micro Power Electronics**

13955 SW Millikan Way • Beaverton, OR 97005
800-576-6177
rtichy@micro-power.com
www.micro-power.com

![Figure 6](image)