Making Lithium-ion Batteries Meet MIL-STD-810

MICRO
POWER

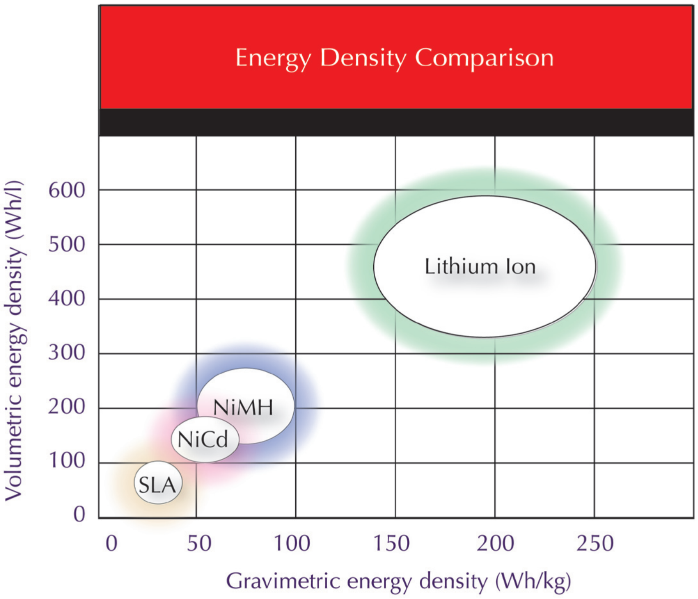
The military standard MIL-STD-810, “Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests” specifies the equipment’s environmental design and test limits that it will experience throughout its service life, and establishes test methods used to measure the effects of the environment on the equipment. MIL-STD-810 Testing addresses a broad range of environmental conditions that include; low pressure for altitude testing, exposure to high and low temperatures, temperature shock (both operating and storage), rain (including wind blown and freezing rain), humidity, fungus, salt fog for rust testing, sand and dust exposure; leakage, acceleration, shock and vibration. MIL-STD-810 is typically specified for military products, but commercial products will commonly reference aspects of MIL-STD-810 as well. Custom batteries can be built to meet all the requirements, but the more challenging requirements for batteries include immersion, shock and vibration, high temperature performance, and low temperature performance. This white paper will focus on overcoming these design challenges for handheld and portable batteries.

SELECTING THE OPTIMAL BATTERY CHEMISTRY

Advances in battery technology have led to increased energy densities over the last few decades. More reactive materials have been employed in order to achieve these advances and active safety circuits are now required to ensure that certain battery chemistries are kept in a stable condition. Common battery chemistries for military batteries, and their associated characteristics, are listed below;

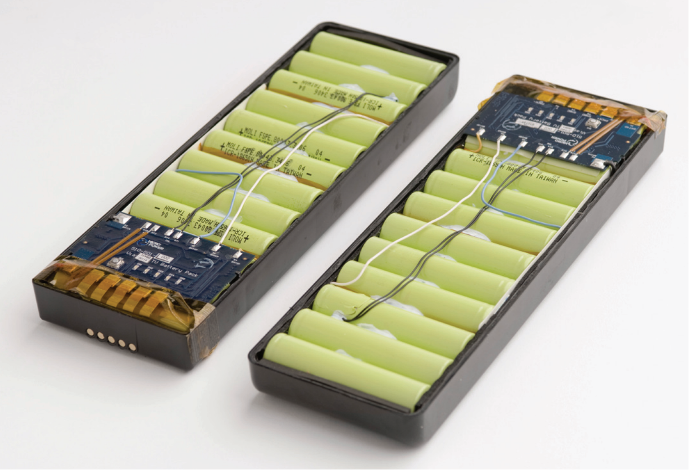
- Rechargeable Sealed Lead Acid (SLA) - SLA Cells utilize concentrated sulfuric acid electrolyte and toxic heavy metal electrodes, and provide a nominal voltage of 1.5 V. SLA Cells are cost effective, but are bulky and heavy for most portable applications. SLA Cells have a wide operating temperature, ranging from – 40 to +70° C. Note that SLA batteries have a liquid electrolyte, so a cracked cell can leak toxic or dangerous fluids.
- Rechargeable Nickel Metal Hydride (NiMH) – NiMH Cells include a nominal voltage of 1.25 V, 500 duty cycles per lifetime, less than 0.5C optimal load current, an average energy density of 100 Wh/kg, less than four-hour charge time, typical discharge rate of approximately 30 percent per month when in storage, and a rigid form factor. NiMH Cells operate effectively between -20 and +60° C. NIMH has a solid solution electrolyte, so leakage due to shock is not an issue.
- Rechargeable Lithium Ion (Li-ion) – Li-ion cell characteristics include a nominal voltage of 3.6 V, 1000 duty cycles per lifetime, less than a 4 C rate load current, an average energy density of 160 Wh/kg, a less-than-four-hour charge time, and a typical discharge rate of approximately 1-3 percent per month when in storage. Li-ion cells operate effectively between -20 and +60° C, Li-ion has a solid solution electrolyte, so leakage due to shock is not an issue. Several varieties of li-ion are available; the older Cobalt Oxide and the newer mixed metal oxide (Nickel, Manganese, and Cobalt), as well as the high rate varieties such as Lithium Iron Phosphate and Manganese Spinel.
- Primary Lithium – Disposable lithium chemistries include Lithium Thionyl Chloride (Li/SOCl2), Lithium Sulphur Dioxide (Li/SO2), and Lithium Manganese Dioxide (Li/MnO2). Primary Lithium cells provide a voltage of 3.6 V, less than 5C optimal load current, an average energy density of 160 Wh/kg, and a negligible self-discharge rate support years of storage. The operating temperature for Lithium primary cells ranges from -40 degrees to +80° C.

Graphic A illustrates an energy density comparison.



Graphic A: Li-ion provides the best volumeric and gravimetric energy performance

As presented in Graphic B, the main components of a typical Li-ion battery pack includes; 1) the cells, 2) the Printed Circuit Board Assembly (PCA) providing the intelligence of the system, 3) a custom plastic enclosure, 4) external contacts providing a physical electrical interface with the host device, and possibly 5) insulation or internal frame/carrier used to absorb external shock.



Graphic B: A battery pack consists of cells, printed circuit board, external contacts, and enclosure

IMMERSION AND SHOCK

Most ruggedized equipment is specified to withstand 30 minutes of immersion in three meters of water. To ensure a watertight seal between the two halves of the plastic pack enclosure, ultrasonic welding is recommended to join plastic case surfaces. Unlike alternative methods of sealing enclosures, such snap-tight seals, watertight seals are possible. Ultrasonic welding ensures the enclosure is resistant to shock or impact, as the resultant joint strength can match the strength of the welded material.

A material such as Polycarbonate-Siloxane copolymer offers good notched impact at lower temperatures, is flame retardant, and is ductile at lower temperatures for improved impact properties. This allows some of the impact energy to be absorbed by the enclosure and not transmitted to the cells and PCA within the enclosure.

If the battery enclosure design does not accommodate ultrasonic welding due to wall thickness or inability to create an acceptable weld joint, then adhesives can be used to seal the pack. Materials based on semi-crystalline polyamides (Nylon) with a 30-40 % glass filler offer the following characteristics; non-conductive, impact resistant from shock and vibration, high levels of stiffness and strength, good dimensional stability, little warpage, low water absorption, minimal subsequent change in property values through any absorption of moisture, and good chemical resistance. Hence, a 30-40% glass filled semi-crystalline co-polymer resin can be challenging to weld due to the high glass content. Given the challenges with ultrasonic welding this material, and the difficulty with creating a water tight and impact resistant weld joint, gluing is typically recommended.

HIGH TEMPERATURE PERFORMANCE

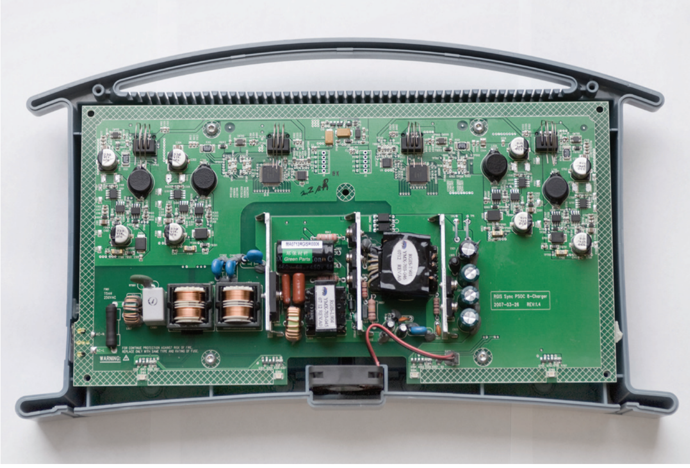
Upper temperature extremes provide challenges. Primary Lithium batteries can easily discharge in temperatures up to 80 C. Since they are not recharged, one does not have to worry about overheating during charge. Most Li-ion batteries can be charged and discharged up to 60 C, so thermal monitoring and heat dissipation within the battery pack is critical for high temperature operation. If a pack is to be used in high temperature environments, then specific design principles should be applied to that pack design.

When current is introduced (i.e. charged) or removed (i.e. discharged) from a battery, there is an associated temperature increase. The pack circuitry should use a thermal sensor to disconnect the cells at a specified temperature. This upper limit is programmable, so battery packs can be customized for hotter operating environments. This eliminates thermal runaway and overheating.

Placement of circuitry within the pack is critical. The circuit board may have heat generating components, such as a Field Effect Transistor (FET), and improper placement may result in the FET heating the cells. The application of heat to select cells within a pack erodes the longevity and safety of that pack.

Consideration is needed for the position of the pack in relation to any heat generating components, such as high performance processors, operating within the host device. Uneven heating may cause the cells to behave differently from their companions in the pack, thus shortening the pack life and compromising safety.

The final consideration is managing pack performance during the charge cycle. Imagine a vehicle mount charger sitting in the transport bay of a Hummer in the desert. A battery could be dropped into the charging bay directly after use - already warm from discharge - and the charger starts applying charge current to the battery which further heats the battery. Even the charger must be designed to accommodate these high temperature conditions. Variable current charging includes the active monitoring of the cell temperature during the charge cycle. Microcontrollers, embedded with the battery charger, allow the charger to monitor all electrical and environmental aspects of the cells in the pack. These microcontrollers can administer variable charge currents based on available power, cell temperature conditions, and maximum allowable charge current. Cell temperature can be monitored in real time via the communication bus or thermistor pin, and charge current can be regulated until the battery approaches its high temperature limit. If the cells hit their high temperature limit, the charger can be designed to reduce or suspend the charge current. If further prevention of battery heating is required, a fan can be built into the base of the charger to evacuate heat generated by the charger electronics and batteries. Graphic C shows a battery charger with a fan in the base that provides vertical draft to cool electronics and batteries. If needed, this vertical draft can be directed into the base of each of the battery charger cups.



Graphic C: A fan in the charger base provides vertical draft to cool electronics and batteries.

LOW TEMPERATURE PERFORMANCE

Environmental requirements may specify extended operating temperatures down to – 40° C. Rechargeable Li-ion comfortably operates at -20 to + 60° C. When challenged with this requirement, there are several design options to maximize electrical output at low temperatures.

Li-ion comes in several varieties. The newer mixed metal oxide (Nickel, Manganese, and Cobalt) and Lithium Iron Phosphate perform better than Cobalt Oxide at temperatures down to - 30 C. Cell and chemistry selection is critical.

If the battery is mounted in a vehicle and has access to vehicular power, a heater embedded with the pack can warms cells prior to use. The embedded heater can be powered from the main cells within the pack when the temperature drops below – 20 C, or from an external source like vehicle power.   Embedded heaters can heat cells, reduce electrolyte viscosity, and reduce voltage droop or delay prior to use.

The host device can be designed to pulse discharge cells prior to primary discharge, this self-warms the cells via the I2R heating effect. This technique is applicable when the duty cycle is predictable and cyclical (i.e. periodic transmission of telemetry report), rather than a random or haphazard duty cycle (i.e. handheld radio transmission).

Super-capacitors embedded within pack can provide immediate energy to host device while cells warm up to their optimal electrical performance.

Lastly, if these design techniques cannot extend operation of a rechargeable Li-ion pack down to the low temperature requirement, one should again consider utilizing Lithium primary cells to power the device. When assessing Lithium primary formulations, Li/MnO2 provides less voltage droop than Li/SO2 and Li/SOCl2 in cold temperatures.

ABOUT MICRO POWER ELECTRONICS INCORPORATED

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