2011 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY (P&M) MINI-SYMPOSIUM
AUGUST 9-11 DEARBORN, MICHIGAN

LARGE FORMAT LI ION REPLACEMENT PACKS FOR LEAD ACID APPLICATIONS

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ABSTRACT

Quallion has developed the Matrix™ Battery Design, a modular power system, to support military applications. This design allows for low cost designs, reliance on commercial vendor sources for cells, advanced safety and flexible choice of chemistry and battery form factors. Design and power capability of an 1.86Kwh APU battery pack for HMMWVs and a 1.11 Kwh pack for aircraft will be presented.

INTRODUCTION

Quallion's proprietary Matrix™ Battery System offers an innovative, modular, fully scalable approach to large format Li Ion battery manufacturing. The system simultaneously links commercial-grade cells in parallel and series, thereby reducing cost, increasing flexibility, and improving reliability. Quallion's Matrix™ pack design also includes an imbedded protection circuit and FET switches.

Picture 1. Quallion Matrix™ Battery Module.

The following summarizes the key benefits of the Quallion Matrix™ Battery System:

Survivability-Quallion's Matrix™ Battery Design can accommodate multiple cell failures within the module while still delivering voltage and power to the application. In addition, in a multi module battery assembly, strategic placement of the modules can allow for elimination of individual module units (e.g., in the event the vehicle sustains damage) and the battery will continue to operate.

Safety – The small cell approach and the Matrix™ Battery Design offers greater safety during pack assembly, handling and maintenance as well as during operation. Individual cells failures do not result in catastrophic battery failure.

Design Flexibility – The small-cell approach meets all battery size requirements, but is ideally suited for the truck vehicle environment where active cooling systems may vary.

Cost Effective Solution – Commercial grade 18650 cells cost less than 1% that of custom large cell designs. Modularization allows for product standardization across multiple applications, thereby achieving economies of scale.

Elimination of Cumbersome Control Electronics – The Matrix™ Battery Design allows for autonomous cell balancing within the module thereby eliminating the need for individual cell balance control.

Focus on a Single Cell Size – The small-cell approach allows a single cell type or cell design to be used in all batteries. This allows in-depth characterization of the cell to be used reducing technical risk associated with a larger number of designs. Focus on a single cell also creates a more stable production system increasing reproducibility and further reducing technical risk.

Reliability – A small capacity cell is easier to make than a large capacity cell. Technical risk is lowered by virtue of the fact that there is less to go wrong. For example,

winding of a small length of electrode into a coil pack is more accurate that winding a long length of electrode.

Thermal Management – A small cell enjoys a more uniform thermal gradient throughout the cell. Large cells often experience hot spots during high power drains since I^2R heat is not easily removed from the center of the cell and often caused degradation of the electrolyte components and hence irreversible damage.

Built-In Technology Improvement Roadmap – As the commercial cell manufacturer continues to enhance its cell design, the benefits will automatically flow down to the module battery design without the requirement of costly NRE redesign efforts (e.g., commercial cell manufacturers typically achieve a 5% cell capacity increase annually without impacting cell form factor).

QUALLION'S LITHIUM ION MATRIX™ BATTERY TECHNOLOGY

The traditional approach to building a large battery (i.e. >1 kWh) is to design a large capacity cell and connect the required number in series to attain the design voltage. If a parallel connection of two or more of these large capacity cells is needed, some level of control electronics is required to balance the cells correctly. This approach continues to be applied to the lithium ion systems by several companies are proposing for the PHEV, EV and HEV markets. Quallion has developed an alternative approach to building a large lithium ion battery. Our approach involves using a large number of small capacity lithium ion cells (e.g. 1.5 Ah to 2.9 Ah) in series and parallel to produce the required voltage and capacity.

Quallion's Matrix™ approach to lithium ion batteries is unique to the market. The concept is based on arrays of small cells arranged in series to establish voltage, and strings of cells configured in parallel to establish capacity. The advantage of this approach is nominal use of control electronics and cell redundancy for efficient increases in reliability and survivability.

TRADITIONAL BATTERY CONFIGURATIONS

Traditionally, in creating a battery there are 2 possible formats to connect cells together. These are shown in **Figure 1**.

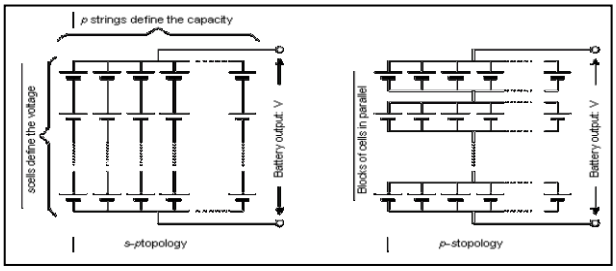


Figure 1. Traditional way to connect cells in series and parallel.

In the s-p format, cells are first connected in series to form 'strings'. The number of cells in the string determines the battery voltage. For example, if 16 cells are used, the string has a nominal operating voltage of 57.6V and operates between 67.2V and 40.0V. Secondly, a number of strings can be connected in parallel. The number of parallel strings determines the battery capacity. In this way, the capacity of the battery can be adjusted in increments of the single cell capacity. In practice, the battery is divided into a series of separate modules consisting of, for example, 10 strings connected in parallel (i.e. 20 Ah of capacity in the case of a 2 Ah cell). Each module voltage equals the individual cell voltage. Several modules are then connected together in series or parallel to complete the full battery.

The Matrix™ Battery Design

Quallion's approach to building batteries is rooted in improving safety, reliability and survivability. Instead of utilizing the conventional battery s-p formats discussed above, Quallion connects its cells in a "Matrix" that interlinks all the cells in a given module, as shown in **Figure 2**.

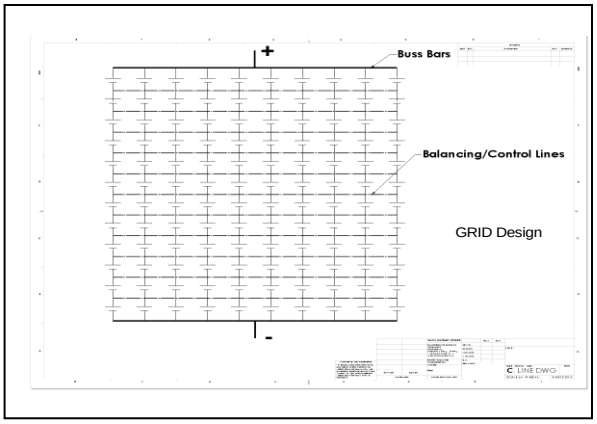


Figure 2. The Quallion Matrix™ Battery Design.

The "Matrix™ Battery Design" (MBD) was developed in 2004 to bring more cost effective lithium ion battery solutions to the military and aerospace markets. Instead of using large 15Ah to 300Ah cells, Quallion developed a method of linking small commercial grade lithium-ion cells in a two dimensional matrix connection. By utilizing this small cell approach, Quallion was able to take advantage of the small cell's strengths over larger cell designs. As cell size increases, the cell's specific internal impedance (ohm/Ah) also increases. As a result, in large energy and power applications, excessive heat can be generated during charge and discharge thereby requiring burdensome thermal management to maintain safety and battery life. This problem can be mitigated by decreasing impedance through use of smaller format cells such as 18650s. In addition to these thermal control benefits, this two dimensional matrix configuration provides autonomous current distribution control, safety and reliability, thus simplifying any charge control and balancing electronics.

MATRIX™ BATTERY DESIGN FAULT TOLERANCE

The following figures represent the reliability of the Matrix™ Battery Design in comparison to the tradition methods. **Figures 3** show the schematic of a 7S-3P packs in which three faults were introduced into the system.

- F1 – Represents a cell with a high self-discharge
- F2 – Represents a cell with a high internal impedance
- F3 – Represents a cell with lower capacity than the other cells in the pack

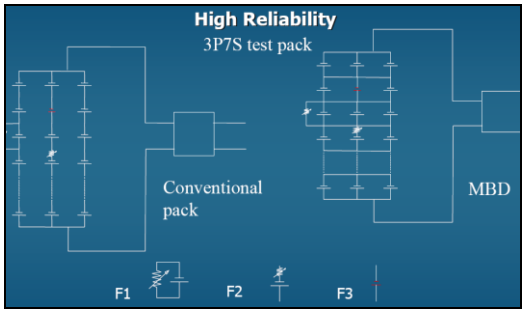


Figure 3. Traditional versus Matrix Battery Design and instruction of faults

As shown in **Figure 4**, during normal pack level charging, the F2 & F3 cell exceeded the control cells EOCV of 4.1V and much lower EODV. The F3 cell was demonstrating the greatest risk by approaching an EOCV of greater than 4.5V & close to 0V for the EODV. Continual cycling at this voltage range greatly reduce pack performance and introduces higher safety risks.

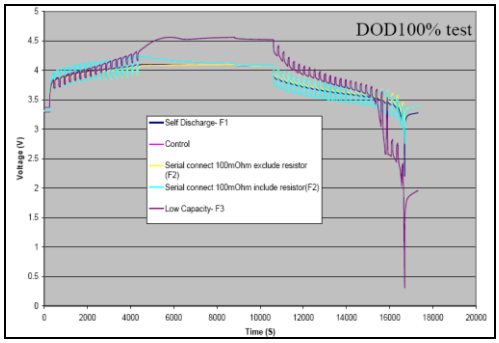


Figure 4. EOCV and EODV of faulted cells in the traditional design.

In comparison, **Figure 5** shows that the same faults associated with the F1-F3 cells EOCV and EODV operating within the safety and performance tolerances of the cell designs in Quallion's Matrix Battery Design configuration.

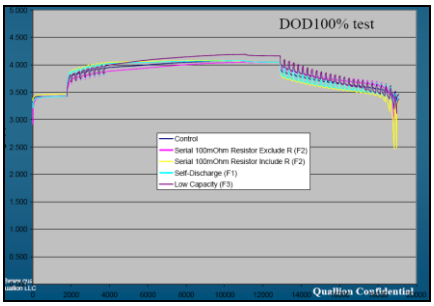
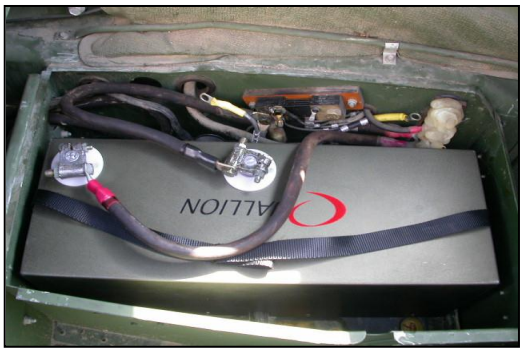


Figure 5. EOCV and EODV of faulted cells in the Matrix Battery Design.

THE QUALLION MATRIX™ MODULE MILITARY APPLICATIONS

The Matrix™ appoach has been incorporated into a number of military battery configurations. To date, Quallion has implemented this technology into UAV prototypes, HMMWV starter batteries and helicopter applications, as shown in Pictures 2 & 3.

Picture 2. Quallion Aviation Lithium-ion Battery.



Picture 3. Quallion Ground Vehicle Lithium-ion Battery.