Quallion Large Battery Pack Technology

Powering Life.

May 2009
Hisashi Tsukamoto, PhD. CEO/CTO Quallion LLC
Quallion Milestones

1998
- Company established in Southern California, USA

2001
- Entered Aerospace/Defense market with OGA and CECOM Contracts
- Initiated Development of Primary Chemistries

2002
- Developed 7 new cell designs (4 implantable grade); shipped 30,000 production units; plant reached 6,000 unit per month volume

2003
- Zero-Volt™ technology patented

2004
- SaFE-LYTE™ technology patented
- Registered under ISO 9001 & 13485; Zero-Volt™ technology patented (recertified in December 2004)

2005
- Title III Award; Registered AS9100

2006
- Frost & Sullivan Award for Lithium Ion Power Sources

2007
- Boeing Technology Supplier Award
Origin of Quallion: Implantable Micro Battery

Inductive charging Technology

Miniature Injectable (implantable) neurostimulator

Quallion Battery (2.8mmD, 12mmL, Li-ion)

Powering Life.
High Reliable Li-ion Cells for USG Satellite

QL075KA

<table>
<thead>
<tr>
<th></th>
<th>QL075KA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>173.7.0 (mm)</td>
</tr>
<tr>
<td>Width</td>
<td>80.9 (mm)</td>
</tr>
<tr>
<td>Thickness</td>
<td>56.2 (mm)</td>
</tr>
<tr>
<td>Weight</td>
<td>1820 g</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>2.7 – 4.1V</td>
</tr>
<tr>
<td>Discharge capacity</td>
<td>72 Ah</td>
</tr>
<tr>
<td>Weight energy density</td>
<td>148 wh/kg</td>
</tr>
<tr>
<td>Zero-Volt™ technology</td>
<td>Applicable</td>
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</tbody>
</table>

*Powering Life.*
QL075KA Cell: Cycle Life
40% DOD Cycle @ R.T.

Capacity retention equation *)

\[(\text{Discharge capacity retention}) = 100 - k \times \sqrt{N_{\text{cycle}}}\]

*) \(k\): constant to determine capacity fading rate
\(N_{\text{cycle}}\): charge and discharge cycle index

75% retention predicted @ 60,000th cycle, 10 years LEO operation

Powering Life.
Zero Volt™ Capability
Cycle Performance after 0V Storage (17 months)
(200mAh model cell)

Storage Condition
For 17 months,
• 100% SOC (3 cells)
• 50% SOC (3 cells)
• 10% SOC (3 cells)
• 0V (3 cells)
(at room temperature)

Cycle condition
• LEO cycle (40% DOD)

Capacity check
• 100% DOD
  at every 500 cycles
  (at 20°C)

No difference in cycle performance
Matrix™ Battery, QL038KM for Little Bird, MH-47, MH-60 and U2

24V Lithium-ion (Lead Acid Replacement)
- 38 Ah capacity
- 0.912Kwh (100wh/kg)
- 9.75Lx8.125Wx5.3H inch
- 24 lbs
24V, 9.5Ah Matrix Battery™ for C-17 Aircraft EBPS

• Qualification Program to Replace Current Ni-Cd System
  • Low maintenance and long life
  • Fully integrated charge control electronics, battery management electronics & BIT/SOC capability
  • -65°F to 160°F (with heaters)
  • Less than 8.5lbs
  • Full charge in 75 minutes over 21V to 32V input range
  • Plug N Play

Powering Life.
QL038KM External Short Test
5 mohm external short with BMU disabled
Passed with no flame or explosion
QL038KM Crush Test
Unit fully charged to 29.4V
Passed with no explosion of fire
Quallion Unique Safety Technology; HAM™ (Heat Absorption Material)
Demonstration of HAM™ Technology

Test Battery-
Sanyo 18650W cell, 10 cells in Parallel connection.
Capacity- 15.0 Ah

Overcharge test condition-
Charge battery pack @6A to 12V, hold voltage @12V till temperature dropping
Battery Failed without HAM™

Connection

Insulation

After Test
Battery was Safe with HAM™

HAM® melted and latent heat stopped thermal run away

Connection

After Test

Insulation

Powering Life.
140V, 28V Battery for the NASA Launch Abort System (LAS) for ARES I

- 140V, 15Ah & 28V, 1.5Ah Lithium-ion Pack
- (378) Commercial 18650 High Power Cells
- 140V Battery is capable of over 220A peak discharge current and 50A peak charge current

70% SOC @ 0°C, 140V Battery Mission Profile
Quallion 24V, 1250A Capable Matrix™ Battery Pack for HMMWV

Less than ½ SLAB Weight and Deep Discharge Capable

Current Lead-Acid Battery
24V, 65Ah, 120lb (2 batteries in series)

Quallion Drop-in Li-ion APU
24V, (78Ah, 98.8Ah, 156Ah), 52lb

Powering Life.
Engine Start Test (Max Current 1100A) at SOC 70%

- Peak current ~ 1100A in first 20ms
- Two peaks 500A during the first 200ms – similar profile as the lead acid battery

Powering Life.
450A-30 Seconds Pulse Discharge Test at SOC 40%
Quallion Matrix™ Module
48V, 9.5Ah, 0.456Kwh*, 78x115x260mm

* Standard Module (Whr and W capability varies in energy module and power module)
Voltage Sensing, Current Measuring and Temperature Monitoring

Lead wire (14) for voltage sensing

Thermistor

Powering Life.
One Mechanical Configuration can bring Multiple Performance Varietals

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Capacity (mAh)</th>
<th>Weight (g)</th>
<th>1KHz AC Impedance (mili ohm)</th>
<th>Wh/kg</th>
<th>W/kg</th>
<th>Wh</th>
<th>KW</th>
<th>Max. discharge current (A)</th>
<th>Kg</th>
<th>Remark</th>
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<tr>
<td>18650 F3</td>
<td>2500</td>
<td>47</td>
<td>45</td>
<td>197</td>
<td>390</td>
<td>600</td>
<td>1.2</td>
<td>25</td>
<td>4.3</td>
<td>Highest Energy</td>
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<tr>
<td>18650 F1</td>
<td>2100</td>
<td>47</td>
<td>58</td>
<td>165</td>
<td>330</td>
<td>500</td>
<td>1</td>
<td>21</td>
<td>4.2</td>
<td>High Energy</td>
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<tr>
<td>18650 Y</td>
<td>1900</td>
<td>43</td>
<td>40</td>
<td>162</td>
<td>970</td>
<td>460</td>
<td>1.4</td>
<td>29</td>
<td>4.1</td>
<td>Energy/Power Balance Model</td>
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<tr>
<td>18650 W</td>
<td>1500</td>
<td>44</td>
<td>28</td>
<td>125</td>
<td>1600</td>
<td>360</td>
<td>3.6</td>
<td>75</td>
<td>4.2</td>
<td>High power</td>
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<tr>
<td>18650 SA</td>
<td>1200</td>
<td>41</td>
<td>25</td>
<td>108</td>
<td>2200</td>
<td>289</td>
<td>4.8</td>
<td>100</td>
<td>4</td>
<td>Highest Power</td>
</tr>
</tbody>
</table>

Cell MBD pack
Modular Design for Flexible Performance, Flexible Shape and Inexpensive Cost

16-20T Manned Ground Platforms
- Resupply
- SUAV Carrier
- NLOS
- Reconnaissance and surveillance
- APC, C2, CV, RV

Unmanned Air Platforms
- SUAV
- Organic Air Vehicle OAV
- TUAV

Combat Robots
- Armed reconnaissance

Soldier Robots
- Tracked
- Legged
- Mule

BLOS/LOS
Mortar
NetFires

Powering Life.
96V -1.83Kwh Matrix™ System

Central Control Unit (500V capable)

2S X 2P Matrix™
1C Discharge Curves

Charge: 1C 109.2V CCCV C/20CA cutoff at R.T.
Discharge: 1C to 78V at R.T.
5C Discharge Curves

Very small temperature deviation in the packs
BMU in the Matrix™ Module

Block Diagram for Each Battery Pack

- Power Supply
- SW
- 5V Voltage sense
- GND
- 13.5V
- 2.5V
- Protection Circuit
- Thermistor
- 5V(Internal)
- Fuel Gauge MPU
- Coulomb Counter
- Isolator
- Batt+
- Batt-
- 5V(External)
- SMBus
- CLK Data
- Short Detection (TBD)
- Output Enable
- Data GND (External)
- Current Sense Resistor

Powering Life.
Matrix™ Battery System with Matrix™ Module

Block Diagram for All System

Central Controller

Port Expander

Serial Communication I2C or CAN

Power Supply

TBD

Balancing Circuit

Confidential

Powering Life.
Quallion Unique High Power and Low Temperature Capability: 18650 HP

At -40°C, 30C rate discharge capable

- **Electrical Characteristics**
  - Nominal Capacity = 900 mAh
  - Operating Range = -40°C to +71°C
  - Chemistry = NCA/MCMB

- **Physical Characteristics**
  - Diameter = 18.1 mm
  - Height = 65.4 mm
  - Volume = 66.7 cc
  - Weight = 39 g

- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - USG T3 program enables Quallion to produce Cathode NCA and Anode MCMB in-house by 2012
30C Discharge Data Comparison

- **26650-SOA (Olivine System)**
- **18650-SOA (NMC System)**
- **Quallion 18650 HP**

Discharge at 30CA down to 0.5V

**Capacity Retention (%)**

**Temperature (degC)**

*Powering Life.*
Storage of Quallion HP Cell at +71°C/2 Weeks

Discharge Capacity (Ah)

Capacity Recovery After Storage

Initial Capacity
Capacity Remaining
Post-Storage Capacity
Discharge Temperature data of Quallion HP Cell at 30C Rate

Charge: 1C, 4.2V CCCV C/20 cutoff at RT
Discharge: 30 C to 0.5 V at Different temperature

Powering Life.
Matrix™ Technology: Modular Design for Flexible Performance, Flexible Shape and Inexpensive Cost

COTS cell (non-domestic, most inexpensive)
Quallion: US Domestic Battery Company with Unique Material, Cell and Battery Capability

Powering Life.