VES16 cells and batteries for LEO & small GEO

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November 2014, NASA Aerospace Battery Workshop
Agenda

1. VES16 Cell design and performances
2. LEO and GEO testing
3. Battery Module design and qualification plan
4. Conclusions
1-VES16 Cell
VES16 chemistry based on Generation 5

- Qualification on July 2011 in the frame of CNES contract

Negative electrode
- Specific LEO graphite blend
- Non-fluorinated binder

Positive electrode
- Li-Ni\textsubscript{x}Co\textsubscript{y}Al\textsubscript{z}O\textsubscript{2}
- Carbon
- PVDF

Electrolyte:
- Carbonate blend
- LiPF\textsubscript{6} based

Mechanical circuit-breaker

3-layer shutdown effect separator
### VES16 cell main features (presented in 2012)

#### Main characteristics

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions (Ø x H)</strong></td>
<td>33 x 60 mm (D-size)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>≤ 115 g</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>0.051 dm$^3$</td>
</tr>
<tr>
<td><strong>Voltage range</strong></td>
<td>[2.7 ; 4.1] V</td>
</tr>
<tr>
<td><strong>Nominal capacity</strong></td>
<td>4.5 Ah on 4.1-2.7V @ C/2, 20°C</td>
</tr>
<tr>
<td><strong>Nominal energy</strong></td>
<td>16 Wh on 4.1-2.7V @ C/2, 20°C</td>
</tr>
<tr>
<td><strong>Av Specific energy</strong></td>
<td>&gt; 150 Wh/kg</td>
</tr>
<tr>
<td><strong>Internal resistance</strong></td>
<td>≤ 35 mΩ @ 20% DoD</td>
</tr>
<tr>
<td><strong>Best cycling temp.</strong></td>
<td>[+10 ; +30] ºC</td>
</tr>
<tr>
<td><strong>Mechanical design margins</strong></td>
<td>EWR &amp; ECSS compliant</td>
</tr>
</tbody>
</table>

- **Positive polarity**
- **Negative polarity**
- **Circuit-breaker**
- **Stainless steel case**
VES16 energy vs discharge rate and temperature

VES16 characterization from -20°C to +50°C, from 2C to C/5:

- Energy vs discharge rate
- Energy vs discharge temperature
### VES16 charge current vs temperature

<table>
<thead>
<tr>
<th>TRP Temp</th>
<th>-20°C</th>
<th>-15°C</th>
<th>-10°C</th>
<th>-5°C</th>
<th>0°C</th>
<th>+5°C</th>
<th>+10°C</th>
<th>+15°C</th>
<th>+20°C</th>
<th>+30°C</th>
<th>+40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Cell Ich</td>
<td>C/20</td>
<td>C/17</td>
<td>C/15</td>
<td>C/12</td>
<td>C/10</td>
<td>C/5</td>
<td>C/3</td>
<td>C/2</td>
<td>C/2</td>
<td>C/2</td>
<td>C/2</td>
</tr>
<tr>
<td>Max Cell I (A)</td>
<td>0.23 A</td>
<td>0.26 A</td>
<td>0.30 A</td>
<td>0.38 A</td>
<td><strong>0.45 A</strong></td>
<td>0.90 A</td>
<td>1.50 A</td>
<td>2.25 A</td>
<td>2.25 A</td>
<td>2.25 A</td>
<td>2.25 A</td>
</tr>
</tbody>
</table>

![Graph showing VES16 charge current vs temperature](image-url)

- TRP Temperature [°C]
- Max Cell Charge Current [A]
2-LEO and GEO Cycling results
Accelerated 20 % DOD 4.05 V 20°C

- 35000 cycles in accelerated conditions on EM and QM cells
- Test conditions:
  - 20 % DOD with charge rate C/3 45 mins, Discharge 1.5 C rate 12 minutes
Real Life test at 20 and 30 % DOD

- Real time test EOCV=4.05 V, 20°C.
- 20 % DOD: charge 65 mins C/5, Discharge 35 mins C/2.9
- 30 % DOD: charge 65 mins C/3, Discharge 35 mins C/1.9
- Less than 20 % energy loss at 50000 cycles for 30%
20 % and 40 % DOD/charge current comparison

- Real time test with EOCV=4.05 V, 20°C
  - 20 % DOD : charge 65 mins C/5, Discharge 35 mins C/2.9
  - 40 % DOD : Charge 65 mins C/2.5 Discharge 35 mins C/1.45
- VES16 can sustain LEO mission at 40 % DOD
LEO – VES16 SLIM model vs real-time life-test
LEO – VES16 SLIM model vs real-time life-test

4.05V EoCV, 20%DoD, +20°C

- 14% losses at 50k cycles

4.05V EoCV, 30%DoD, +20°C

- 20% losses at 50k cycles

4.05V EoCV, 20%DoD, +30°C

SLIM model predictions at 4.05V EoCV, +20°C

- 5% DOD
- 10% DOD
- 20% DOD
- 30% DOD
4C rate Discharge Peak capability

- 20% DOD LEO standard plus 4 C rate peaks, limited impact on degradation.

![Graphs showing EOD VES16 Cell Voltage evolution under ten 4C - 15 sec. discharge pulses per orbit in LEO Cycling at ≈19%DoD and VES16 Accelerated LEO Life-Tests with 3C, 3.5C & 4C radar pulses at ≈20%DoD @20°C.]
**VES16 performances at extended low temperature**

- Charge at -20°C and various current
- Discharge at +20°C and C/2

VES16 cycling performances in LEO at 0°C
750 cycles (completed)

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**Graphs and Data**

- Voltage (V) vs. Capacity (Ah)
- Voltage (V) vs. Energy (Wh)
- Resistance (mOhm) vs. Cycle Number (RI 5 sec)

**Key Points**

- Charge at -20°C and various current
- Discharge at +20°C and C/2
- VES16 cycling performances in LEO at 0°C
- 750 cycles (completed)

**Graph Details**

- Voltage Range: 2.7 V to 4.1 V
- Capacity Range: 0 Ah to 5 Ah
- Energy Range: 2.7 Wh to 4.1 Wh
- Resistance Range: 0 mOhm to 25 mOhm
- Cycle Number Range: 0 to 750

**Legend**

- C/10, C/20, C/30, C/40, C/50
- 10% DOD, 15% DOD, 20% DOD
Accelerated GEO cycling at 80% DoD, 20°C, EOCV = 4.05 V and 4.075 V: Voltage loss ~45mV from season 1 to season 35.
GEO – Synthesis of life-test at 60, 70 & 80% DoD

- VES16 cycling performance in GEO:
  - Accelerated GEO life-test w/o solstice (worst case compared to real-time or semi-accelerated life-test) 60, 70, 80% DOD; EOCV = 4.05 and 4.075 V
  - Very good stability of end-of-discharge voltage (EoDV) during 23rd discharge (72 min)
GEO – synthesis of check-up at 60, 70 & 80% DoD

- VES16 cycling performance in GEO:
  - Accelerated GEO life-test w/o solstice (worst case compared to real-time or semi-accelerated life-test)
  - Energy loss: ~2% loss after 30 seasons (15 years of GEO cycling)

Variation of energy in check-up

Variation of internal resistance at 40%SoC in check-up
3- Battery Module Designs and qualification
Battery modules design range

- Voltage steps: from 6S to 10S / Capacity steps: 4P, 5P / 6P, 8P
- Building blocks and modular approach for LEO and GEO missions
- Including autonomous balancing system
- Others configuration & customization possible on request

Double deck modules

Single deck modules
Battery modules design range

- Cells connected in **serial-parallel** (SP) architecture with tabs & bus bars
- Re-use Saft flight proven **mechanical resining assembly** btw plates
- Modular **balancing circuit on each string** (SBS)
- Cells individual **voltage access**, thermal **sensors**, heaters...

![Diagram](image-url)
**SBS : Simplified Balancing System**

- **Purpose:**
  Homogenize cells’ voltage at end of charge to extend cycling life, autonomously

- **Principle:**
  Derive individual cell charge current from a Voltage trigger level

- **Design:**
  One dedicated SBS function per cell, one SBS board per cells string

- **Space environments demonstrated:**
  140krad level, 2000h @ 125°C life test, 3400g shock, 20g sine, 36grms
Battery Qualification Plan

- Extensive characterization phase
  - Electrical characterisation
  - Self discharge study
  - Balancing demonstrations

- Environmental phase
  - Vibrations tests (sine & random)
  - Shock tests
  - Thermal/Vacuum cycling
  - Corona & Magnetic Moment

- LEO life test on 8S4P VES16 battery
ESA Battery Qualification Plan

3 qualification vehicles:

- **QM1**: 2x10S8P
  - Electrical and Environmental tests
  - L x W x H: 406 x 196 x 165 mm³ / 10S8P
  - Mass (Max): 27.6 kg

- **QM2**: 10S5P
  - Environmental tests
  - L x W x H: 376 x 216 x 90 mm³
  - Mass (Max): 7.5 kg

- **QM3**: 8S4P
  - LEO Life tests running
  - L x W x H: 308 x 180 x 90 mm³
  - Mass (Max): 4.9 kg

<table>
<thead>
<tr>
<th>Energy</th>
<th>2,560 Wh at C/3, 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>1520 W for GEO under 70% DoD</td>
</tr>
<tr>
<td></td>
<td>1040 W for LEO under 20% DoD</td>
</tr>
<tr>
<td>L x W x H</td>
<td>406 x 196 x 165 mm³ / 10S8P</td>
</tr>
<tr>
<td>Mass (Max)</td>
<td>27.6 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy</th>
<th>800 Wh at C/3, 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>465 W for GEO under 70% DoD</td>
</tr>
<tr>
<td></td>
<td>320 W for LEO under 20% DoD</td>
</tr>
<tr>
<td>L x W x H</td>
<td>376 x 216 x 90 mm³</td>
</tr>
<tr>
<td>Mass (Max)</td>
<td>7.5 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy</th>
<th>512 Wh at C/3, 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>300 W for GEO under 70% DoD</td>
</tr>
<tr>
<td></td>
<td>205 W for LEO under 20% DoD</td>
</tr>
<tr>
<td>L x W x H</td>
<td>308 x 180 x 90 mm³</td>
</tr>
<tr>
<td>Mass (Max)</td>
<td>4.9 kg</td>
</tr>
</tbody>
</table>
Mechanical successful validation: *Random Vibrations*

- On **10S5P single deck** battery
  - 9.5 Grms in plane & 14.6 Grms vertical

- On **10S8P double deck** battery
  - 11.2 Grms in plane & 13.9 Grms vertical
Battery Qualification Plan

- Mechanical successful validation: *Shock Test*
  - On 10S8P *double deck* battery
  - 3400g from 2000Hz to 10000Hz
  - No frequency drift before/after test
  - No battery degradation

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Battery shock test

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Required spectrum
Battery 10S5P energy tests @ various rates & temperatures
Battery qualification campaign

- SBS balancing efficiency **test** in LEO and GEO:
  - Initial cells unbalance (60mV) within 8S4P QM3 battery
  - Battery **unbalance** recovered after **<15 days** in LEO (<15mV)
4. Conclusions
Conclusions

- VES16 cell performances demonstrated its capability to answer both LEO and GEO missions

- High DOD (up to real 40 %) or high peak power LEO missions are achievable thanks to the specifically chosen negative electrode (with a specific blend)

- VES16 is well adapted for low power GEO satellites with DOD up to 80 %.

- Qualification tests on battery modules are successful.

- 120 VES16 batteries are already delivered or in manufacturing. More in order.

VES16 batteries behave as designed and demonstrated long duration LEO/GEO missions …

Acknowledgments to CNES and ESA to have supported the qualification plan
Philae on Chouryomov-Gerasimenko Comet

- Saft LSH20 Primary Battery powered Philae lander during 60 hours for experiments, analysis, transmission and communications on the Chouryomov-Gerasimenko comet.
- Great success for the Universe evolution understanding