Real World Experience - Key Topics

- Saft Background
- Improved Target Acquisition System
  - Lithium Battery Box
- Battery Life
  - Expectations vs. Experience
  - Life Limiting Factors
- Fielded Lessons
  - Expecting the Unexpected
- New Developments
SDD is a division of Saft America, Inc., a subsidiary of the Saft Group, headquartered in Bagnolet, France.

Saft is a multinational company specializing in the manufacture and development of high tech batteries for industry.
Dedicated to manufacturing advanced Li-ion cells and batteries for Space and Defense applications

<table>
<thead>
<tr>
<th>Type of Cell</th>
<th>VL4V</th>
<th>VL12V</th>
<th>VL22V</th>
<th>VL34P</th>
<th>VL52E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>34</td>
<td>47</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Case length (mm)</td>
<td>156</td>
<td>152</td>
<td>174</td>
<td>174</td>
<td>200</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>0.33</td>
<td>0.64</td>
<td>0.96</td>
<td>0.94</td>
<td>0.99</td>
</tr>
<tr>
<td>Capacity (Ah)</td>
<td>5.5</td>
<td>12</td>
<td>22</td>
<td>33</td>
<td>52</td>
</tr>
<tr>
<td>Specific Energy (Wh/kg)</td>
<td>50</td>
<td>74</td>
<td>84</td>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td>Energy Density (Wh/L)</td>
<td>138</td>
<td>175</td>
<td>200</td>
<td>280</td>
<td>430</td>
</tr>
<tr>
<td>Power (W/kg)</td>
<td>3600</td>
<td>6000</td>
<td>6350</td>
<td>1900</td>
<td>N/A</td>
</tr>
<tr>
<td>18 sec pulse at 50% SOC</td>
<td>60C</td>
<td>100C</td>
<td>100C</td>
<td>15C</td>
<td>1C</td>
</tr>
<tr>
<td>Continuous Discharge Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Saft supplies the battery for Raytheon’s Improved Target Acquisition System used with the TOW Missile.

Battery powers weapon sight / targeting unit (ITAS)

More than 1500 batteries have been fielded for combat use. Systems in Iraq and Afghanistan (TRL-9).

Raytheon has recognized Saft with the Supplier Excellence Award three years in a row due to our performance on this program.
ITAS - Lithium Battery Box

- Production began in 2004 - the first production for a large Lithium-ion system.
- Improvements over former AgO/Zn technology:
  - Increased Operational Readiness
    - No activation charge needed
  - Charging time < 6 hours
  - Operating time > 16 hours
  - Total life > 3-5 years
  - Reduced service cost
- Only required field maintenance is periodic charging
- Battery specs:
  - 28 V, > 80 Ah
  - 65 lbs
  - Energy = 2.5 kWh

ITAS cell pack: 8S, 2P configuration
### ITAS - High Energy Cell Design

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>kg</td>
<td>1.0</td>
</tr>
<tr>
<td>Volume</td>
<td>L</td>
<td>0.48</td>
</tr>
<tr>
<td>Charge Voltage</td>
<td>V</td>
<td>4.1</td>
</tr>
<tr>
<td>Capacity (4.1V-2.5V, 25°C, C/7)</td>
<td>Ah</td>
<td>52</td>
</tr>
<tr>
<td>Specific Energy (4.1V-2.5V, 25°C, C/10)</td>
<td>Wh/kg</td>
<td>185</td>
</tr>
<tr>
<td>Energy Density (4.1V-2.5V, 25°C, C/10)</td>
<td>Wh/L</td>
<td>385</td>
</tr>
<tr>
<td>Peak Discharge Current (RT, Complete)</td>
<td>A</td>
<td>52</td>
</tr>
<tr>
<td>1kHz AC Impedance</td>
<td>mΩ</td>
<td>0.8</td>
</tr>
<tr>
<td>Terminal-to-Terminal Length</td>
<td>mm</td>
<td>208</td>
</tr>
<tr>
<td>Diameter</td>
<td>mm</td>
<td>54</td>
</tr>
</tbody>
</table>

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**VL52E Rate Capability @ 25°C from 4.1V to 2.5V**

![Graph showing VL52E rate capability at 25°C from 4.1V to 2.5V with various C-rates and corresponding voltage levels.](image-url)
ITAS - Battery

- Robust
  - Shock
  - Vibration
  - UN Transportation
  - Waterproof to 36” but floats
    - EMI, EMC, NBC qualified
- Designed for one man lift
- Ergonomic Connector access
- Simple user interface
- Designed for 36” drop cold
  - 32 drops for qual - no leaks
- Made to fit the space in HMMWV behind passenger seat
ITAS - Flange Panel Front Controls

- Two Mil spec connectors with connector covers
- BIT lights (BAT, ELEC)
  - BAT = Cell Pack
  - ELEC = Electronics
- Display Intensity Control
  - On (low) / On (high) / Off
- Charge Indicator
- State of Charge LEDs
- Power Switch integral 35A Circuit Breaker
- Override Switch
Battery Life

- Battery life based on few major factors
  - Fundamental Electrochemistry - Specific chemistry gives life potential
  - Calendar Time / Temperature - Lower temperature gives longer life
  - Discharge Depth and Rate - Shallower / slower cycles give longer life
- Methods to determine life take time - cycles and calendar time
- Two data sources - Lab / Field
Battery Life - Definitions

- Battery life defined for given application
  - Typically when battery delivers 80% of new capacity

- Lithium-ion - General Life / Technology
  - No memory effect as in some other chemistries
  - Does have low rate self discharge
  - Self discharge will vary from cell to cell
  - Overcharge is chief systems concern
Battery Life - Saft Lithium Ion (NCA)

Calendar Life Comparison

Temperature (C)

Calendar Life (yrs)

- P155
- P181

Battery Life - Calendar Stability at Temperatures

VLE cells with storage at 100% SOC (4V)

Years of storage @ 100% SOC

C/3 discharge

5.25 years
Battery Life - VES140 Cell for Space

- Space program calendar life testing of Li-ion cells
  - Cells were very similar to ITAS cells
- Actual > 6 years of storage performed
- Storage done at several different voltages and two different temperatures - 10°C and 30°C on float and on Open Circuit Voltage
- Capacity and impedance measured periodically

<table>
<thead>
<tr>
<th>Storage Condition</th>
<th>Capacity Loss per Year</th>
<th>Remaining Runtime after 10 Years (20 hours at start)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0V and 10°C (50°F)</td>
<td>0.5%</td>
<td>95% / 19 hours</td>
</tr>
<tr>
<td>4.0V and 30°C (86°F)</td>
<td>1.2%</td>
<td>88% / 17.6 hours</td>
</tr>
</tbody>
</table>
Battery Life - VES140 Cell for Space

4.0V & 10°C (50°F)  
0.5% per year

4.0V & 30°C (86°F)  
1.2% per year

CAPACITY measured at 25°C (77°F)
14A Discharge Current
Batteries SN0064 and SN0187 tested at Saft after 3+ Years uncontrolled use (transit, operational use, etc)

Battery Capacities were 90.7 Amp Hours and 93.3 Amp Hours

- Battery test
  - ITAS simulation discharge at room temperature (C/18 rate)
  - Capacities were above nameplate capacity for new units
- Original Cell Capacities were checked
  - Manufacturing data from July and December 2004.
  - Capacities were roughly 45 Amp Hours at medium discharge rate (C/3 rate) - Equivalent to 90 Amp Hours in a battery

Very low capacity loss after 3+ years uncontrolled use - Roughly 3% in July 2004 unit / No loss in December 2004 unit
Battery Life - Limiting Factors

- Electrochemistry - Not the limiting factor?
  - Life of more than 4 years (and counting) demonstrated

- Connectors - Mate / Unmate Cycles
  - Expected number of cycles for MIL-38999

- Interior Components - Foam / Adhesives
  - Degrade over time

- Physical Abuse
  - Case damage
  - Lack of charging
Fielded Lessons - Alternate Uses

- Supporting the Warfighter!

Warfighter

ITAS LBB (in supporting role)
Fielded Lessons - Systems Function

- ITAS LBB contains complete system functionality
  - Overcharge Protection (Primary Function)
    - Multiple Layers
    - Fully independent circuits
  - Cell Balancing
  - Communication with maintainer
- Lesson: Overcharge protection has been a complete success
  - No failure - ever!
- Once circuit is in place, what other features can be enabled?
# Fielded Lessons - Systems Function

[Image of a software interface with various parameters and metrics]

## Battery Status
- **Battery Mode**: Normal
- **Power Source**: External
- **SOC**: 100%

## Battery Voltage
- **Battery Voltage**: 0.0 V
- **Cell VSum**: 31.9 V

## FET States
- **Discharge FET**: Open
- **Charge FET**: Open

## Environmental
- **Temperature**: 25°C
- **Heater State**: Off
- **Capacity Remaining**: 90.00 Ah

## Built-In-Test Status
- **BAT Light**: Off
- **ELEC Light**: Off
- **BIT Results**: No Fault

## Cell Information

<table>
<thead>
<tr>
<th>Cell</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.994 V</td>
</tr>
<tr>
<td>2</td>
<td>3.994 V</td>
</tr>
<tr>
<td>3</td>
<td>3.994 V</td>
</tr>
<tr>
<td>4</td>
<td>3.994 V</td>
</tr>
<tr>
<td>5</td>
<td>3.994 V</td>
</tr>
<tr>
<td>6</td>
<td>3.990 V</td>
</tr>
<tr>
<td>7</td>
<td>3.991 V</td>
</tr>
<tr>
<td>8</td>
<td>3.991 V</td>
</tr>
</tbody>
</table>

## VMC Information
- **FCS Cable**: Disconnected
- **Charger Cable**: Connected
- **Charging Status**: Charging
- **Charging Capable**: No
- **Charger On**: On
- **Charger Disable**: True
- **Charger Status**: No Fault

## Cell Summary
- **Max**: 3.995 V
- **Min**: 3.990 V
- **Diff**: 5 mV
- **Avg**: 3.993 V

## Misc
- **Voltage Ref**: 2.492 V
- **Heater Sense**: 0.000 V
- **RS 422 Power**: 5.000 V
- **Est. To Balance**: 00 Days 00 Hrs 00 Mins

## LBB Messages
- (11/29/2007 10:03:29 AM) Attempting to connect to LBB

## Clock
- **11/29/2007 10:06:39 AM**

## Manufactured
- **11/28/2007**

## SW Version
- **2.8**

## SW Date
- **3/23/2004**

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**Saft - 2009 Joint Service Power Expo - 5 May 2009**
Fielded Lessons - Logistic Challenges

- **Battery Charging**
  - Only maintenance needed!
  - Once every 6 months
    - Baseline recommendation
    - Consult Raytheon FSR’s for best practice
  - Lesson: Lead cause of battery return

- **Cell Balance**
  - Handled by LBB system
  - Lesson: Challenge for battery availability

- **Solution - Training and Setting Expectations**
  - Article in “The Preventive Maintenance Monthly” (August 2008)
  - Sharing current information
Fielded Lessons - Logistics - Charging

- Batteries self discharge over time and ensuring a maintenance charge is applied remains a challenge.
- Largest return issue (by far)
- Education of user has helped
- Continued storage at low SOC can lead to irreversible cell damage and require cell replacement
Differences in self-discharge rate lead to voltage differences in the cell packs

Normal self-discharge in cells from 0.2 to 2.0 mV/day

Balancing function during charging corrects for unequal self-discharge - No user intervention needed.

Balancing rate during charge is ~30 mV / day
- Takes time to bring a pack back into alignment
Delta Voltage: Difference between max / min cells
Charging must stop when max cell reaches upper limit (4.1 V)
Other cells not fully charged

(green = wasted capacity)
Fielded Lessons - Logistics - Balancing

- Balancing selectively discharges high cells to match lower ones
- Charging is allowed to continue
- Cells charged more uniformly
- Balancing capability is a key feature of the ITAS LBB. Allowing time for the balancing to work will improve performance.
Fielded Lessons - Battle Damage

- **Enemy Fire**
  - At least three batteries in separate incidents
  - Batteries smoked, vented
  - Not the end of the world!

- **Overwhelming Damage**
  - Bridge collapsed onto one battery
New Developments

Advanced Lithium Power Source
- Development from the ITAS LBB - Performance Heritage
- On board AC and DC charging - Convenient Charging
- Lower Voltage range
- Wider variety of applications - Simple integration

VL52E Cells
(7S2P)

Available Fall 2009
Saft’s High Energy Technology is ideal for use in deployed situations as a high reliability power source.

- The robust cell design allows for high charge and discharge power, low heat generation, and excellent cold temperature performance, all with extended cycle and calendar life.

Saft’s System approach and integrated control electronics provide an unsurpassed total solution for today's field demands

- 100% performance of charging safety system has been a key success.

Large Format Lithium-ion batteries are a success in today’s battlefield!
Saft would like to thank US Army Close Combat Weapons Systems (CCWS) and Raytheon for their continued support and team based approach in providing the best possible power solutions for the US Military.

Saft would also like to thank our customers for continued feedback on battery system performance. This insight allows us to continually update and improve our energy storage solutions.
Questions?
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