IMPROVE SSD PERFORMANCE WITH ULTRACAPACITOR POWER BACKUP

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Maxwell Industry Involvement

**Transportation**
- Auto
- Bus
- Rail

**Renewable Energy**
- Wind
- Solar
- Smart Grid

**Industrial**
- Cranes
- Fork Lifts
- Mining
- Construction

**Electronics**
- Solid State Disk Drive
- UPS
Ultracapacitor Basics

- Ultracapacitors, Electric Double Layer Capacitors, Supercapacitors are synonyms
- Operating principle
  - An electronic charge accumulator having extreme capacitor plate specific area and atomic scale charge separation distance.
  - No chemical reactions
- Performance
  - 100k to >1M charge/discharge cycles
  - Up to 15 year DC life

Graphic: IEEE Spectrum, Jan 2005
Electrode

Intellectual Property:
- ~ 55 Patents
- ~ 20 Patents pending

Thickness of Helmholtz layer ~ 1nm
Carbon powder surface area up to 3,000m²/g

Capacitors up to 3,000F
Fundamental Materials

Basic material is carbon

Charred Carbon → Grind → Activation → Activated Carbon → Coating → Rolling → Kneading → Pasting → Maxwell Electrode
Maxwell offers a variety of sizes and configurations of ultracapacitors.

<table>
<thead>
<tr>
<th>Specification</th>
<th>PC Series</th>
<th>HC Series</th>
<th>BC Series</th>
<th>K2 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance (F)</td>
<td>10</td>
<td>1–150</td>
<td>310–350</td>
<td>650–3,000</td>
</tr>
<tr>
<td>Rated Voltage (V DC)</td>
<td>2.5</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>ESR, DC (mohm)</td>
<td>180</td>
<td>14–700</td>
<td>2.2–3.2</td>
<td>0.29–0.8</td>
</tr>
<tr>
<td>Leakage current (mA)</td>
<td>0.04</td>
<td>0.006–0.5</td>
<td>0.3–0.45</td>
<td>1.5–5.2</td>
</tr>
<tr>
<td>Emax (Wh/kg)</td>
<td>1.4</td>
<td>0.9–4.3</td>
<td>5.2 – 5.9</td>
<td>4.1 – 6.0</td>
</tr>
<tr>
<td>Pmax (W/kg)</td>
<td>660</td>
<td>2400 - 7000</td>
<td>9500 – 14,000</td>
<td>12,000 – 14,000</td>
</tr>
</tbody>
</table>
Power and Energy Density – Ragone Plot

Source: ElectronicDesign.com
November 15, 2007
Ultracapacitor Aging Behavior

- Ultracapacitors exhibit a gradual decline in performance over time
  - Decrease in capacitance
  - Increase in ESR
- “End of Life” becomes a defined point – not an actual failure
- Maxwell defines EOL when one of two things happen:
  - Decrease in capacitance below 70 - 80% of rated value
  - Increase in ESR to 200% of rated value
- In practice, the decrease in capacitance is usually the limiting factor
- Parts still function, but these parameters are degraded
- Decrease in performance must be accounted for when doing initial system design
Lifetime Model

Mean Service Life vs. Temperature

Cell Voltage
- 2.40
- 2.50
- 2.60
- 2.70

Time

Temperature (°C)
Need for Backup Power in Enterprise SSDs

- SSDs used for
  - Computation Intensive Applications
  - Online Transaction Processing (OLTP)
  - Database Warehousing
  - Image Processing
- Faster Input/Output performance a key metric
- Larger DRAM caches improve performance
  - More backup power required
Enabling Higher Write IOPS

Host Writes Data to SSD

SSD Stores Data in DRAM

Acknowledged

Is Flash Space Available?

Yes

Write Data to Flash

No

Identify an Available Block and Erase

FAST

MEDIUM SPEED

SLOW
Typical SSD Architecture

- Host
- I/F Connector
- Interface Controller
- Flash Controller
- DRAM Controller
- DRAM Cache
- Encryption
- Power Mgmt
- Ultracapacitor
- Voltage Regulator
- Flash Array

Example

- Backup Requirement = 3W
- Minimum Backup Time = 2 seconds
- Starting Voltage = 2.2V
- Ending Voltage = 1.1V
- Required Energy
  - $3W \times 2 \text{ seconds} = 6J$
- Minimum Capacitance
  - $\frac{(2 \times 6)}{(2.2^2 - 1.1^2)} = 3.3 F$
Simulation Schematic

\[ V_1 \quad R_1 \quad V_2 \]

\[ R_2 = V(v2)^2/P \]

\[ .tran 0 10 0 .01 \]
\[ .ic V(v1)=2.2 \]
\[ .param P=3 \]
Simulation Results

- C = 7.2 F
- R = 360 mΩ
- Requirement not met
Simulation Results

- C=5F
- R=120mΩ
- Requirement met
Keys to a Successful Design

- Manage temperature carefully
  - Dominant stressor for ultracapacitor life
- Ensure that power requirements are within the capability of device ESR
- De-rate capacitance and ESR to end-of-life values
- Pay close attention to specification details
  - All 10F ultracapacitors are not equal
A Current Implementation
Future Trends

- Ultracapacitor technology is relatively new
- As applications grow, improvement is likely in:
  - Cost
  - ESR (Power Density)
  - Operating Voltage (Energy Density)
Conclusions

- Inclusion of DRAM cache in Enterprise SSD requires backup power
- Ultracapacitors are accepted devices to provide required backup capability over SSD life expectancies
- Attention to pertinent device parameters can ensure successful performance