Small Cell Supercapacitors

Design and Characteristics
What Is a “Super” Capacitor?

| APowerCap | EVerCAP | Super capacitor |
| BestCap   | DynaCap | SuperCap       |
| DLCAP     | EneCapTen | PseudoCap |
| HY-CAP    |          | Ultracapacitor |

Electrostatic Double-Layer Capacitor (EDLC)
(Electrical) Double Layers

1. IHP Inner Helmholtz Plane
2. OHP Outer Helmholtz Plane
3. Diffuse Layer
4. Solvated Ions
5. Specifically Adsorptive Ions
6. Solvent Molecule
Traditional and EDLC Comparison

Aluminum Electrolytic Reference

Symmetric “Supercapacitor”

Asymmetric “Hybrid Capacitor”

\[ C = \frac{Q}{V} \]

\[ C = \frac{\varepsilon_0 K A}{d} \]

- Surface Area of Carbon
- Inner Helmholtz Layer
Electrode Material
Activated Carbon

Forms the Electrodes

- Tiny low volume pores
- $1\text{g} = 1,000\text{~}2,000\text{m}^2$
- Very conductive
- Made from coconut shells
- Can be synthetic carbon using potassium hydroxide (KOH)
### Electrolytes

#### Acetonitrile
- CH₃CN
- Common for SC
- Dielectric constant: 37
- Burns to HCN
- BP: ~80°C

![Acetonitrile structure](image)

#### Propylene Carbonate (PC)
- C₄H₆O₃
- Dielectric constant: 64
- Destructive effect on graphite
- BP: ~240°C

![Propylene Carbonate structure](image)

#### Sulfuric Acid
- H₂SO₄
- Used in lead-acid batteries
- Dielectric constant: ~100
- BP: 337°C

![Sulfuric Acid structure](image)
Electrolytes
Choosing Aqueous or Organic

<table>
<thead>
<tr>
<th>Capacitance</th>
<th>Price</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 0.47F</td>
<td>Aqueous</td>
<td>Aqueous</td>
</tr>
<tr>
<td>Over 0.47F</td>
<td>Organic</td>
<td>Aqueous</td>
</tr>
</tbody>
</table>
Design
Structure of Aqueous Supercapacitors

Construction Technique

Capacitor – Base Cell

Activated carbon

Porous organic film

Capacitor – Cell Stack

Current Collecting Electrode
Conductive Rubber

Sealing Synthetic Rubber

Separator (Porous Organic Film)
Activated Carbon + Electrolyte
(Dilute Sulfuric Acid)
Structure of Aqueous Supercapacitors

Packaging Techniques

Can Type
- Outer Case
- Base Cell
- Isolation Case
- Sleeve
- Pins

Resin Molded
- Mold Material (PBT)
- Pins
- Base Cell

Surface Mount
- Outer Can
- Base Cell
- Isolation Case
- Plate
- Pins
High Reliability Design

Performance Characteristics & Benefits

KEMET Base Cell (Aqueous Type)

- Activated carbon + electrolyte (Dilute sulfuric acid)
- Collecting electrode rubber (conductive)
- Separator
- Gasket rubber
- Vulcanized bond (Chemical reaction, Integrated)

- Vulcanized Bonding = Strong Bonding
  - Great thermal shock performance
  - Less electrolyte dry up
- Aqueous solution electrolyte
  - Good moisture resistance

Competitor Base Cell (Organic Electrolyte Type)

- Activated carbon + electrolyte (Propylene Carbonate etc.)
- Upper lid (Stainless steel)
- Crimp (mechanical)
- Separator
- Gasket
- Bottom case (Stainless steel)

- Press and seal gasket
  - Weak against thermal shock
  - Fast electrolyte dry up over time
- Organic electrolyte
  - Poor moisture resistance
High Reliability Design

Voltage Margin

KEMET 5.5v Cell Stack

Max voltage of base cell is **1.2V/cell**

For 5.5v: **0.917v** applied per cell

*Gives 24% Margin*

5.5v Cell Stack

Max voltage of base cell is **3.0V/cell**

For 5.5v: **2.750v** applied per cell

*Leaves 8% Margin*

Voltage stresses cause the electrolyte to break down, reducing the life of the supercapacitor.
High Reliability Design

Open Mode Failure

• Open Failure Mode
  – Does not damage circuit
  – No heat generated

• What Happens
  – Gas forms in electrolyte
    • Builds up between electrode and activated carbon
    • Causes electrode separation
  – Increased ESR
    • Creates “open circuit”
  – Electrolyte does not leak out

• Competitive Design
  – Seal breaks down
  – Electrolyte leaks out
    • Internal short
    • Shorts between circuit components

KEMET Cell

Coin Based Cell

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Characteristics
Capacitance and ESR Shift

Accelerated Life Test

Capacitance Change

Conditions: 85°C, 5.5V_{DC}, 240H
Capacitance and ESR Shift
Accelerated Life Test

Rate of equivalent series resistance

\[ \Delta \text{ESR/ESR(\%)} \]

- Aqueous
- Organic

Conditions:
- 85°C, 5.5V\text{DC}, 240H

ESR Change

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Organic electrolytes may have significantly higher ESR than aqueous-based systems.
Leakage Current
Multi-Hour Charge

Absorption current turns into leakage current.

\[ I = \frac{V}{1000} \ (A) \]
Discharge Characteristic
Discharge through 1MΩ Resistor

[Graph showing capacitor voltage (V) against discharge time (h) for 70°C and 25°C conditions.]
Life of the Supercap

• KEMET’s definition of the Supercap’s life = 30% decrease in capacitance from its initial capacitance value.
  – Initial capacitance value = capacitance at the time of final inspection during manufacturing process

• Life of the supercap degrades due to gradual evaporation of the electrolyte.

• Life of the supercap is influenced by three factors as follows:
  – Ambient Temperature
  – Voltage
  – Humidity
Aqueous Life Estimation Curve
We define the life time of the Supercap as 30% decreased capacitance from the initial value.
Voltage Impact

The lower the applied voltage, the longer the life of the super capacitor.
High Temperature, Biased Test
Test Condition: 85°C, 5.5V, 240 Hours

KEMET Supercapacitor: Better ESR & Self Discharge Reliability
High Temperature, High Humidity Test
Test Condition: 85°C, 85% RH, No Load, 240 Hours

Capacitance Changing Rate

LC Characteristic (30min value)

ESR Changing Rate (@1kHz)

Self Discharge Characteristic (24Hr value)

Competitor Part: Poor ESR Performance, Poor Self Discharge Performance
How Does the EDLC React When Humidity Enters Into the Base Cells?

**Aqueous Type**

- Input voltage per cell is lower than 1.23V.
- Electrolysis does not occur = No Reaction.

**Organic Type**

- Input voltage per cell is higher than 1.23V.
- Electrolysis occurs = Reaction.

- Humidity = H₂O
- Electrolysis of H₂O occurs at 1.23V
Design Consideration
Design Consideration

• Supercapacitors should not be installed close to the heat source.

• Reverse polarity
  – Please mount the supercapacitor per polarity marking.
  – It does not harm supercapacitor if reverse polarity is applied.
  – There may be electrical charge left on the positive side after charging/discharging during the manufacturing process.

• Applying voltage exceeding the rated voltage
  – Not recommended to avoid electrolyte leakage, gas generation, and physical damage.

• Balancing
  – Series - need voltage balance circuit (passive voltage balance or active voltage balance)

• AEC-Q200
  – There is NO AEC-Q200 standard for Supercapacitors.
  – Please contact PMs for guidance.
Design Consideration

• Use in Smoothing Circuit
  – Not recommended
  – Supercapacitors have large ESR values and may generate heat due to the ripple current.

• Washing, Coating, Potting
  – FM series – washing, coating and potting are OK
  – Can type – washable type is available
    • Please contact KEMET for coating and potting.
  – SMD type – No washing
    • Please contact KEMET for coating and potting.

• Shelf Life
  – 1 year after shipping
  – Not moisture sensitive device (MSL1)
  – Storage condition:
    • +5 to +35°C (typical 25°C) & 20 to 70% (typical 50%) in relative humidity
Supercapacitor Application Guide

**Current**

- 500μA
- 50mA
- 1A
- 10A

**Duration**

- 1s
- 10s
- 10m
- 1 h

- CMOS RAM, μC, Clocks
- Embedded Memory, Backup, Motor Drivers
- Small Electronics
- Power Supplies

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Real Time Clock (RTC) Backup

Main Power Supply

Supercapacitor or Coin Cell Battery

RTC

Support Clock

Xtal

Micro Processor
Small Memory Backup

Main Power Supply

Supercapacitor or Coin Cell Battery

Micro Processor

Memory

Main Load

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Beyond What We Have ...
Under Development
AEC-Q200 Grade 3 (Al Electrolytic Cap) Compatible Capacitor

• There is no AEC-Q200 standard for Supercap

• Targeting AEC-Q200 Grade 3 (Aluminum Electrolytic Cap) applications

• 85°C / 85% RH / 1000 hours capable

SMD type: 5.5V, 0.1F, \( \phi \) 10.5 x H 8.5mm package

Mold type: 5.5V, 0.33F, L15 x W 14 x T 9mm package
Thank You!