Supercapacitors for Pulse Applications

Eli Alon, CTO

Supercapacitors USA 2012 conference

Cellergy, a Subsidiary of PCB TECHNOLOGIES

Get Power – Run Longer
Agenda

- Company Profile
- Core Competency
- Automated Production Line & technology highlights
- Applications
- Which data should an engineer know when selecting a SC for a specific application?
  - Performances of Cellergy SCs
  - Accelerated testing, cycle life and life time of supercapacitors
- SCs for Energy Harvesting (in Appendix)
- Why select Cellergy products?
In certain applications electronic devices need to deliver high current pulses.

In most battery operated devices - using primary batteries - driving such currents is many times impossible.

In Energy Harvesting (EH) systems - supercapacitors are used for energy storage, mostly eliminating the need for batteries and batteries replacement.

SCs buffer the high power load from the low power source in a small form factor.

Get Power – Run Longer
Get Power – Run Longer

EDLC & Battery Coupling

Voltage Drop with and without SC

Battery Only

Battery Coupled With SuperCapacitor
Cellergy develops & manufactures flat, thin, bi-polar low ESR Pulse Super Capacitors based on it’s own IP.

Automated Line developed by Cellergy specific for its products is implemented for volume manufacturing.

Current product lines are for the industrial & consumer electronics industry (mainly for battery operated devices).

4 form factor groups are manufactured (different size).
About us

- Founded in 2002, privately held
- Acquired by PCB Technologies in 2007
- R&D and manufacturing site in Migdal Ha’emek, Israel
- Patented wafer-printing technology
- Production floor area - 1,200m²
- Production capacity (current) – 15M pcs/year
- Quality system – ISO 9001:2000
- Products – RoHS and REACH certified
- **Frost & Sullivan award for Super-Capacitors technology innovation in 2010**
Core Competency

Patented Screen Printing Technology and automated manufacturing line of Super-Capacitors (EDLCs):

- High capacitance
- Low ESR
- High power density
- Low leakage current
- Small footprint (from 12x12.5mm and 10x15 mm)
- Environmental friendly (no harmful solvents)
- Robust construction
- Cost effective
- Tailor made

Get Power – Run Longer

Wafer – inside view during production stage
Automated Production Line

Production line

Wafer – inside view during production stage

Wafer of 12x12.5 mm cells (400 cells)

Wafer of 28x17 mm cells (144 cells)

Get Power – Run Longer
Applications

Get Power – Run Longer

Consumer
- Digital Camera
- Wireless Toys

Commercial
- RFID
- AMR
- SSD
- Energy Harvesting
- GPRS Module
- Elec’ Lock
- PDA
- Wireless Speakers

Medical
- Micro Pump
- Remote Communication

More...

Cellergy

Get Power – Run Longer
Cellergy’s Product Lines

- **CLK Cx2**
  - 12 x 12.5
  - 17 x 17.5
  - 28 x 17.5

- **CLG**
  - 12 x 12.5
  - 17 x 17.5
  - 28 x 17.5
  - 48 x 30.5

- **CLC LCx1/2**
  - 12 x 12.5
  - 10 x 15
  - 17 x 17.5
  - 28 x 17.5

**Work Temp.**
- -40°C to +85°C
- -40°C to +70°C
- -40°C to +70°C

Get Power – Run Longer
Which data should an engineer know when selecting a SC for a specific application?

- Voltage
- Capacitance, ESR
- Max Leakage current
- Thickness/Size
- Working (storage) temperature range
- Life (cycle) time
- Environment
- Vibration & shock conditions
- Permitted voltage Drop
- Battery data
- Pulse characteristics (current, pulse width, duty cycle)
# Products range - Line Card of 12x12.5 products

**CLG : Standard**

<table>
<thead>
<tr>
<th>PN</th>
<th>Nominal Voltage</th>
<th>ESR (mΩ)</th>
<th>Capacitance (mF)</th>
<th>Max Allowed LC (µA)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Pitch (mm)</th>
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**CLC : Low Leakage**

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## Products Range

### Line card of 12 x 12.5mm

#### CLG: Standard

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<th>ESR</th>
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<td>(µA)</td>
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# Products range - Line Card of 28x17.5

## CLG: Standard

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<th>ESR (mΩ)</th>
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## CLK: Extra Capacitance

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Get Power – Run Longer
# Products Range

**Line card of 28 x 17.5mm**

## CLG: Standard

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<th>Nominal Voltage</th>
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## CLK: High Capacitance

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<td>Test Method</td>
<td>Limits</td>
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<tr>
<td>1</td>
<td>Initial capacitance</td>
<td>Charge to rated voltage for 10min. discharge at constant current, ( C=\frac{Id}{dv} ) (details in the page 19)</td>
<td>(+80% / -20%) of rated value</td>
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<tr>
<td>2</td>
<td>Initial leakage current</td>
<td>Charge to rated voltage 12 hr measure current (details in the page 19)</td>
<td>Within Limits (refer to max. LC values in line card table)</td>
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<tr>
<td>3</td>
<td>Initial ESR</td>
<td>Measure @ 1 KHz. Voltage 20mV amplitude, (details in the page 19)</td>
<td>(+20% / -50%) of rated value</td>
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<tr>
<td>4</td>
<td>Endurance</td>
<td>1000 hrs at 70°C at rated voltage (500 hrs at 70°C for 12x12 foot print products) Cool to RT measure: ESR.LC.C</td>
<td>LC (&lt; 3.0x) rated value&lt; 0.7x\rated value&lt; 3.0x\ rated value</td>
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<td>Humidity life</td>
<td>1000 hrs at 40°C 90-95% humidity no voltage Cool to RT measure: ESR.LC.C</td>
<td>LC (&lt; 1.5x) rated value&lt; 0.9x\ rated value&lt; 1.5x\ rated value</td>
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<tr>
<td>6</td>
<td>Lead pull strength</td>
<td>In accordance with JIS C5102.S.1</td>
<td>LC (:) rated value\ Cap (:) rated value\ ESR (:) rated value</td>
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<tr>
<td>7</td>
<td>Surge voltage</td>
<td>Apply 15% voltage above rated voltage for 10 sec short cells 10 seconds repeat procedure 1000 times measure ESR.LC.C</td>
<td>LC (&lt; 2.0x) rated value\ Cap (&gt;) 0.7x rated value ESR (&lt; 2.0x) rated value</td>
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<tr>
<td>8</td>
<td>Temperature cycling</td>
<td>Each cycle consist of following steps: 1) Place supercapacitor in cold chamber ((-40C)) hold for 30 min 2) Transfer supercapacitor to hot chamber ((+70C)) in 2 to 3 minutes. 3) Hold supercapacitor in hot chamber for 30 min Number of cycles: 5</td>
<td>LC (&lt; 1.5x) rated value\ Cap (&gt;) 0.9x rated value ESR (&lt; 1.5x) rated value</td>
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<td>9</td>
<td>Vibration</td>
<td>Frequency = 10 to 55 Hz Amplitude of vibration: 0.75 mm 2 hours each in three directions. (Total 6 hours)</td>
<td>LC (:) rated value\ Cap (:) rated value\ ESR (:) rated value\ No visual damage</td>
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<tr>
<td>No.</td>
<td>Item</td>
<td>Test Method</td>
<td>Limits</td>
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<tr>
<td>1</td>
<td>Initial Capacitance</td>
<td>Charge to rated voltage for 10min. Discharge at constant current, $C=\frac{ldt}{dv}$</td>
<td>+80% / -20% of rated value</td>
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<tr>
<td>2</td>
<td>Initial Leakage Current</td>
<td>Charge to rated voltage 12hr. Measure current</td>
<td>Within limits</td>
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<tr>
<td>3</td>
<td>Initial ESR</td>
<td>Measure @ 1KHz, Voltage 20mV amplitude</td>
<td>+20% / -50% of rated value</td>
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<td>4</td>
<td>Endurance</td>
<td>1000hrs at 70°C at rated voltage 500hrs at 85°C at rated voltage (CLK)</td>
<td>LC &lt; 3.0x , Cap &gt; 0.7x ESR &lt; 3.0x</td>
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<td>5</td>
<td>Humidity life</td>
<td>1000hrs at 40°C, 90-95% humidity no voltage. Cool to RT, measure ESR, LC, C</td>
<td>LC &lt; 1.5x , Cap &gt; 0.9x ESR &lt; 1.5x</td>
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<td>6</td>
<td>Robustness of Termination</td>
<td>In accordance with IEC 62391-1 and subject to test Ub: Bending of IEC 60068-2-21, method 2: two or more bends in an angle of 90° in the same direction</td>
<td>LC &lt; 2.0x , Cap &gt; 0.7x ESR &lt; 2.0x No visual damage</td>
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<td>7</td>
<td>Surge Voltage</td>
<td>Apply 15% voltage above rated voltage for 10sec, short cells 10sec, repeat procedures 1000 times measure</td>
<td>LC &lt; 2.0x , Cap &gt; 0.7x ESR &lt; 2.0x</td>
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<td>8</td>
<td>Temperature cycling</td>
<td>Each cycle consist of the following steps: 1. Place SC in cold chamber (-40°C) and hold for 10min 2. Transfer SC to hot chamber (+70°C) in 2-3min 3. Hold SC in hot chamber for 30min (repeat cycle 5 times)</td>
<td>LC &lt; 1.5x, Cap &gt; 0.9x, ESR 1.5x</td>
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</table>

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Temperature Characteristics

ESR, Capacitance & LC vs. Temperature
Capacitance vs. Frequency CLG03PxxxL12

Capacitance vs. Frequency CLG03xxxLxx double

Get Power – Run Longer
Reliability

- Life time
- Cycle life
- Accelerated testing
- Endurance test
- Models for correlation
- Promises vs. reality
Endurance tests

Includes voltage enhancement

ESR – 65mΩ
Capacitance – 120mF
LC - 20µA

Get Power – Run Longer
Why life time of SC is not indefinite?

- Virtually unlimited cycle life of supercapacitors (>100,000’s of cycles)
- Supercapacitors should have an almost indefinite life, because the EDLC is charged and discharged by electrostatic adsorption and desorption of ions on the electrodes whose process involves mass transfer without a chemical reaction.
- However, the actual life of an EDLC is finite, such that its performance begins to slowly degrade and is significantly deteriorated at some point.
- Aging is visible mainly by increase in ESR and by capacitance loss.
Life time Definitions

The time until the capacitor exhibits an explicit failure such as:

- package rupture with electrolyte leakage
- time to development of internal short
- the time until reaching poor performance that is defined as a failure

Voltage and temperature, not charge/discharge cycling, are the two major factors that affect SC life.
Reason for deterioration of SC

- Side reactions during charge/discharge (Faradic process)
  - Between electrolyte ions and Carbon
  - Of electrolyte ions with different impurities
- Cells depletion (electrolyte drying) – by diffusion mechanism
- Electrochemical decomposition of the electrolyte
  - May generate gas evolution (over-pressure in the cell)
- Closing of the pores access (clogging of pores)
- Oxidation of the carbon surface
- Delamination due to temperature cycling causing increase in ESR and eventually failure
- Enhanced aging at high temperatures or voltage
Life time models & accelerated testing

**Model I: Constant load test extrapolation (Kutz et. Al 2006)**

Assuming same degradation process at short time and extrapolated time
(no accelerated testing used)

Expected life time at RT
From extrapolation > 300 years

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Life time models & accelerated testing

Model II: Arrhenius – Eyring life relationship (Miller et al. 2006)

$$\tau = A \cdot \exp\left(\frac{B}{T}\right) \cdot \exp(D \cdot V) = A \cdot \exp\left(\frac{B}{T} + D \cdot V\right)$$

where

- $\tau$ is the component’s life
- $T$ is the absolute temperature in Kelvin
- $V$ is the applied voltage
- $A$, $B$, and $D$ are constants.

Expected life time at RT From extrapolation ~7 years

(Gualous et al. 2010)
Life time models & accelerated testing

**Model III: The ten-degree rule**

A 10°C decrease in temperature will double the life of a cell.
A 0.1V decrease in voltage will double the life of a cell.

\[
\frac{\tau_T(V)}{\tau_{T_0}(V_0)} = 2^{\frac{(T_0-T)}{10}} \times 2^{\frac{(V_0-V)}{0.1}}
\]

1000 Hrs. at 70C correlates to 2.6 Year (at constant voltage).
Comparison of ESR Endurance test

CLG04P050L28 vs. Other companies products

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Comparison of **Capacitance** Endurance test

**CLG04P050L28** vs. Other companies products

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Comparison of **LC Endurance test**

**CLG04P050L28 vs. Other companies products**

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Endurance test

Is it really an accelerated test for life time?

An accelerated test is useful only if **no different failure mechanism appears** in both; the item under the accelerated condition and similar item in normal use.

But what we see is:

- Different capacitance decrease “patterns”
  RT vs. elevated temperature (70°C) – not shown in the presentation
- Endurance test usually is done at upper level of allowed temperature, where different phenomena may happen compared to normal use temperature
  - High vapor pressure
  - Swelling and de-swelling >> may cause mechanical delamination
- Results don’t follow the model...
Endurance tests can be used for measuring the performance at elevated temperature or as comparison between different SCs:

- higher robustness >> Better endurance performance >> longer life time (probably)

For Life time predictions >> need a new model

No valid model for life time of low energy supercapacitors exists (in capacitance range up to 1F). Correlation between endurance tests and life time not proved.
Why select Cellergy Super-Capacitors

- Very wide product offering enables perfect-fit to various applications
- Patented automated line enables high flexibility in tailor-made products and shorten delivery lead time
- Better Endurance performance of Cellergy Supercapacitors than of some of its competitors
- Very fast response time
- Green products – no harmful substances
- No need for balancing resistors Vs. Organic Super capacitors
- Cost effective
Cellergy

Thank You

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