Abstract:

BestCap®, a new generation of Double Layer Capacitors (DLCs) have been developed to deliver low ESR, high power pulses, or provide back-up power in some applications. These capacitors have values of 10 to 560 mF, voltage ratings of 3.5 to 12 volts and ESR values of 20 to 500 mW.

This paper describes the electrical properties of the BestCap® and its endurance under different environmental conditions. Specific applications are shown for illustrative purposes.
**BESTCAP®: A NEW GENERATION OF PULSE DOUBLE LAYER CAPACITORS**

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**Introduction:**

Double Layer Capacitors (DLCs), also known as electrochemical or supercapacitors, have been produced in the last twenty-five years as an excellent compromise between batteries and electronic or dielectric capacitors such as ceramic, tantalum or film capacitors. In general, these DLCs have high Equivalent Series Resistance (ESR) and high loss of capacitance when used in pulse power applications.

BestCap® capacitors, a new generation of low ESR DLCs, have successfully addressed these two limitations (high ESR and loss of capacitance in the kHz frequency range) by utilizing proton conducting polymer separators, nano-particle carbon electrodes, unique current collectors and other design features. In this paper parameters of these BestCap® devices will be presented, results of reliability testing will be shown and a few applications will be outlined.

**Low ESR BestCap® Devices:**

BestCap® parts are available as prismatic, low profile devices, typically with thickness between 1.6 to 7.5 mm, and the size (length x width) as small as 20 x 15 mm and as large as 48 x 30 mm. Table 1 below shows the three sizes of BestCap® product now available:

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>BestCap® Parts come in three sizes:</td>
</tr>
<tr>
<td>20 x 15 mm</td>
</tr>
<tr>
<td>28 x 17 mm</td>
</tr>
<tr>
<td>48 x 30 mm</td>
</tr>
</tbody>
</table>

**Range of Key parameters of BestCap®:**

These non-polar, environmentally friendly DLCs are built with a variety of voltage ratings from 3.3 to 12 volts. Figures 1 (a-d) show the range of the four parameters, capacitance, ESR, leakage current and thickness, available in these three sizes:

![Capacitance Range](image1)

![ESR Range](image2)

![Leakage Current Range](image3)

![Thickness Range](image4)
Reliability of BestCap\textsuperscript{®} parts is assessed by testing parts for initial characteristics at room temperature and then by testing them under various environmental test conditions. Table 2 lists these tests, including the load and shelf life (with and without DC bias voltage) for up to 1,000 hours at 60, 70 and 75\(^\circ\)C, cycle life and humidity testing, thermal shock, temperature cycling, vibration and surge voltage. Parts are selectively tested for up to 4,000 hours under load life, and for up to 10 million cycles (parts are tested continuously for about 8 months).

**Table 2**

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Method</th>
<th>Parameter (Cap)</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capacitance Measurement</td>
<td>Discharge cells with a constant current after a full charge noting voltage and time. (C = \frac{I \cdot dt}{dv})</td>
<td>Capacitance (Cap)</td>
<td>+80% / -20% of rated Cap</td>
</tr>
<tr>
<td>Initial DCL Measurement</td>
<td>Apply rated voltage. Note current after exactly 3 hours.</td>
<td>Leakage Current (DCL)</td>
<td>Within Limit</td>
</tr>
<tr>
<td>Initial ESR Measurement</td>
<td>Measurement frequency @ 1kHz; Measurement voltage @ 10 mV</td>
<td>Equivalent Series Resistance (ESR)</td>
<td>+20% / -50% of typical value</td>
</tr>
<tr>
<td>Load Life</td>
<td>Apply rated voltage at 75(^\circ)C (A series BestCap), 70(^\circ)C (B series BestCap) or 60(^\circ)C (C series BestCap) for 100 hours. Allow to cool to room temperature and measure Cap, DCL and ESR.</td>
<td>DCL, Cap, ESR</td>
<td>&lt; 2.0x rated max, &gt; 0.7x rated, &lt; 3.0x rated</td>
</tr>
<tr>
<td>Shelf Life</td>
<td>Maintain at 75(^\circ)C (A series BestCap), 70(^\circ)C (B series BestCap) or 60(^\circ)C (C series BestCap) for 1000 hours. Allow to cool to room temperature and measure Cap, DCL and ESR.</td>
<td>DCL, Cap, ESR</td>
<td>&lt; 1.5x rated max, &gt; 0.7x rated, &lt; 2.0x rated</td>
</tr>
<tr>
<td>Humidity Life</td>
<td>Maintain at 40(^\circ)C / 95% RH for 1000 hours. Allow to cool to room temperature and measure Cap, DCL and ESR.</td>
<td>DCL, Cap, ESR</td>
<td>&lt; 2.0x rated max, &gt; 0.7x rated, &lt; 1.5x rated</td>
</tr>
<tr>
<td>Leg pull strength</td>
<td>Apply an increasing force in shear mode until leg pulls away</td>
<td>Yield Force (A and L leads only)</td>
<td>Not less than 25 pounds shear</td>
</tr>
</tbody>
</table>
| Surge Voltage | Step 1: Apply 125\% of the rated voltage for 10 seconds  
Step 2: Short the cell for 10 minutes  
Step 3: Repeat 1 and 2 for 1000 cycles | DCL, Cap, ESR | < 1.5x rated max, > 0.7x rated, < 1.5x rated |
| Temperature Cycling | Step 1: Ramp oven down to –20\(^\circ\)C and then hold for 30 min.  
Step 2: Ramp oven up to 75\(^\circ\)C (A series BestCap), 70\(^\circ\)C (B series BestCap) or 60\(^\circ\)C (C series BestCap) and then hold for 30 min.  
Step 3: Repeat 1 and 2 for 100 cycles | DCL, Cap, ESR | < 1.5x rated max, > 0.7x rated, < 1.5x rated |
| Temperature Characteristics | Step 1: Measure Cap, ESR, DCL  
Step 2: Measure Cap, ESR, DCL  
Step 3: Measure Cap, ESR, DCL  
Step 4: Measure Cap, ESR, DCL  
Step 5: Measure Cap, ESR, DCL  
Step 6: Measure Cap, ESR, DCL  
Step 7: Measure Cap, ESR, DCL  
Step 8: Measure Cap, ESR, DCL  
Step 9: Measure Cap, ESR, DCL  | DCL, Cap, ESR | < 10x rated, Not less than –30\% |
| Thermal Shock | Step 1: Place cells into an oven at –20\(^\circ\)C for 30 minutes  
Step 2: Move cells into a 75\(^\circ\)C (A series BestCap), 70\(^\circ\)C (B series BestCap) or 60\(^\circ\)C (C series BestCap) oven for 30 minutes  
Step 3: Repeat 1 and 2 for 100 cycles | DCL, Cap, ESR | < 2.0x rated max, > 0.7x rated |
| Vibration | Step 1: Apply a harmonic motion that is deflected 0.03 inches  
Step 2: Vary frequency from 10 cycles per second to 55 cycles at a ramp rate  
Step 3: Vibrate the cells in the X-Y direction for three hours  
Step 4: Vibrate the cells in the Z direction for three hours  
Step 5: Measure Cap, ESR and DCL | DCL, Cap, ESR | < 2.0x rated max, > 0.7x rated, < 2.0x rated max. |

These test procedures involve monitoring capacitance (Farads), leakage current (\(\mu\)A) and ESR (milli-ohms or m\(\Omega\)).

Figures 2 - 10 show examples of typical results of such tests.
Figure 2 shows initial electrical results: Capacitance, Leakage and ESR data

**Capacitance**
- Capacitance in Farads
- Number of Samples
- Average = 0.054    Std. Dev. = 0.009

**Leakage Current**
- Current in Micro Aamps
- Number of Samples
- Average = 2.4    Std. Dev. = 1.1

**Equivalent Series Resistance**
- ESR in Ohms
- Number of Samples
- Average = 0.121    Std. Dev. = 0.012

In all the data shown above and in subsequent figures, the solid lines in the capacitance and ESR graphs show the upper and lower control limits, and the solid line in the leakage current graph shows the upper control limit.

It is also critical that physical characteristics be monitored for these products and typical data are shown below:

**Part Height**
- Height in Millimeters
- Number of Samples
- Std. Dev. = 0.044

**Part Weight**
- Weight in Grams
- Number of Samples
- Average = 3.34    Std. Dev. = 0.023

Figure 3: Physical Characteristics

Figure 4: Load Life (rated voltage and max. rated temperature applied)
Figure 5: Shelf Life (max. rated temperature applied)

Figure 6: Humidity Life (40°C temperature and 95% humidity applied)

Figure 7: Surge Voltage (125% rated voltage for 10 seconds)

Figure 8: Temperature Cycling (min to max temp. cycling, slow transition)
Figure 9: Thermal Shock (min to max temp. cycling, rapid transition)

- **Capacitance**
  - Number of Cycles: 0 to 1,000
  - Values: 0.000 to 0.080

- **Leakage Current**
  - Number of Cycles: 0 to 1,000
  - Values: 0 to 10

- **Equivalent Series Resistance**
  - Number of Cycles: 0 to 1,000
  - Values: 0.000 to 0.420

Figure 10: Vibration (10-55Hz, X, Y, and Z axis)

- **Capacitance**
  - Number of Cycles: 0 to 1,000
  - Values: 0.000 to 0.120

- **Leakage Current**
  - Number of Cycles: 0 to 1,000
  - Values: 0 to 10

- **Equivalent Series Resistance**
  - Number of Cycles: 0 to 1,000
  - Values: 0.000 to 0.420
Applications:

In pulse applications, the capacitor discharges to provide a pulse for the circuit. Two factors are critical in determining the voltage drop: ESR and capacitance. The voltage drop caused by the pulse is made up of two terms as shown in Figure 11 below.

\[ \Delta V_{ESR} = I \times ESR \]

The time dependent voltage drop \( \Delta V_C \) is inversely proportional to the available capacitance. This is shown in the formula below, where \( \Delta t \) is the pulse duration and \( C_f \) is the available capacitance at the frequency of pulse.

\[ \Delta V_C = I \times \Delta t / C_f \]

The total voltage drop \( \Delta V \) is the sum of the instantaneous and time dependent voltage drop as shown below.

\[ \Delta V = \Delta V_{ESR} + \Delta V_C \]

Because of the enormous capacitance at high frequencies combined with low ESR, BestCap® outperforms any other solution in pulse applications.

Two application notes will be illustrated in this paper as examples to demonstrate the “pulse power” capability of BestCap®.

1. Enhancing the Power Capability of Primary Batteries
2. GSM / GPRS PCMCIA modems

1. ENHANCING THE POWER CAPABILITY OF PRIMARY BATTERIES

When electronic equipment is powered by a primary (non rechargeable) battery, one of the limitations is the power capability of the battery.

In order to increase the available current from the battery, while maintaining a constant voltage drop across the battery terminals, the designer must connect additional cells in parallel leading to increased size and cost of both the battery and finished product.

When high power is only required for short periods more sophisticated approaches can be considered. The traditional approach involves using a high power rechargeable battery, charged by a low power primary cell.

A far superior solution, however, is the use of a BestCap® Supercapacitor, which is a device specifically designed to deliver high power.

Traditional Design:

![Diagram of Traditional Design]

Design using BestCap®

![Diagram of Design using BestCap®]

BestCap® Supercapacitor benefits to the designer are:

- Substantially lower voltage drop for pulse durations of up to 100msec.
- Substantially lower voltage drop at cold temperatures (-20°C).
- Discharge current limited only by the ESR of the capacitor

The following analysis compares a primary battery connected in parallel to a Lithium Tionil Chloride, to the same battery connected to a BestCap® Supercapacitor. Various current pulses (amplitude and durations) are applied in each case.

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Votage Drop (mV)</th>
<th>Votage Drop (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250mA / 1msec</td>
<td>25</td>
<td>150</td>
</tr>
<tr>
<td>500mA / 1msec</td>
<td>50</td>
<td>220</td>
</tr>
<tr>
<td>750mA / 1msec</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>200mA / 100msec at -20°C</td>
<td>232</td>
<td>470</td>
</tr>
</tbody>
</table>

BestCap® 5.5V 560mF

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Votage Drop (mV)</th>
<th>Votage Drop (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250mA / 100msec</td>
<td>50</td>
<td>190</td>
</tr>
<tr>
<td>500mA / 100msec</td>
<td>100</td>
<td>350</td>
</tr>
<tr>
<td>750mA / 100msec</td>
<td>152</td>
<td>190</td>
</tr>
<tr>
<td>1500mA / 1msec</td>
<td>43</td>
<td>220</td>
</tr>
<tr>
<td>1500mA / 100msec</td>
<td>305</td>
<td>350</td>
</tr>
<tr>
<td>750mA / 100msec at -20°C</td>
<td>172</td>
<td>470</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Characteristics</th>
<th>Best Cap® 5.5V 560mF</th>
<th>Rechargeable Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum discharge current (single pulse)</td>
<td>Not limited</td>
<td>5a Maximum</td>
</tr>
<tr>
<td>Number of cycles</td>
<td>Not limited</td>
<td>40K to 400K (to retain 80% capacity)</td>
</tr>
</tbody>
</table>

Table 3
2. BestCap® FOR GSM/GPRS PCMCIA MODEMS

There is an increasing usage of PCMCIA modem cards for wireless LAN and WAN applications.

The PCMCIA card is used as an accessory to Laptops and PDA’s, and enables wide area mobile Internet access, including all associated applications like Email and file transfer.

With the wide spread use of GSM networks, a PCMCIA GSM modem is a commonly used solution. To achieve higher speed data rates, GSM networks are now being upgraded to support the GPRS standard.

The design challenge:

GSM/GPRS transmission requires a current of approximately 2A for the pulse duration. The PCMCIA bus cannot supply this amount of pulsed current. Therefore, there is a need for a relatively large capacitance to bridge the gap.

The capacitor supplies the pulse current to the transmitter, and is charged by a low current during the interval between pulses.

<table>
<thead>
<tr>
<th>Table 4: The solution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Rated Capacitance</td>
</tr>
<tr>
<td>(milli Farad)</td>
</tr>
<tr>
<td>Capacitance</td>
</tr>
<tr>
<td>@ 0.5msec pulse</td>
</tr>
<tr>
<td>(mill Farad)</td>
</tr>
<tr>
<td>Working voltage (V)</td>
</tr>
<tr>
<td>ESP (mill ohm)</td>
</tr>
<tr>
<td>Voltage Drop* (V)</td>
</tr>
<tr>
<td>GSM pulse</td>
</tr>
<tr>
<td>Voltage Drop** (V)</td>
</tr>
<tr>
<td>GPRS pulse (25% duty cycle)</td>
</tr>
</tbody>
</table>

(1) Calculation: 

\[ V = V_1 + V_2 = 1.5A \cdot ESR + (1.5A \cdot 0.577msec)/C \]

It is assumed that during the pulse, 0.5A is delivered by the battery, and 1.5A is delivered by the capacitor.

High capacitance is needed to minimize total voltage drop. A high value capacitance, even with a higher ESR, results in a lower voltage drop in this example. A lower voltage drop reduces the conductive and emitted electromagnetic interference, and increases transmitter output power and efficiency.

**Summary:**

The high capacitance and low ESR of BestCap® supercapacitors provide outstanding performance in pulse applications. Coupled with the wide voltage ratings available, non-toxic materials, and non-polar construction, BestCap® capacitors offer numerous advantages over other capacitor types.