TECHNICAL INFORMATION

BESTCAP®: A NEW GENERATION OF PULSE DOUBLE LAYER CAPACITORS

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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 it's endurance under different environmental conditions. Specific applications are shown for illustrative purposes.

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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 1

BestCap® Parts come in three sizes:
20 x 15 mm
28 x 17 mm
48 x 30 mm

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:

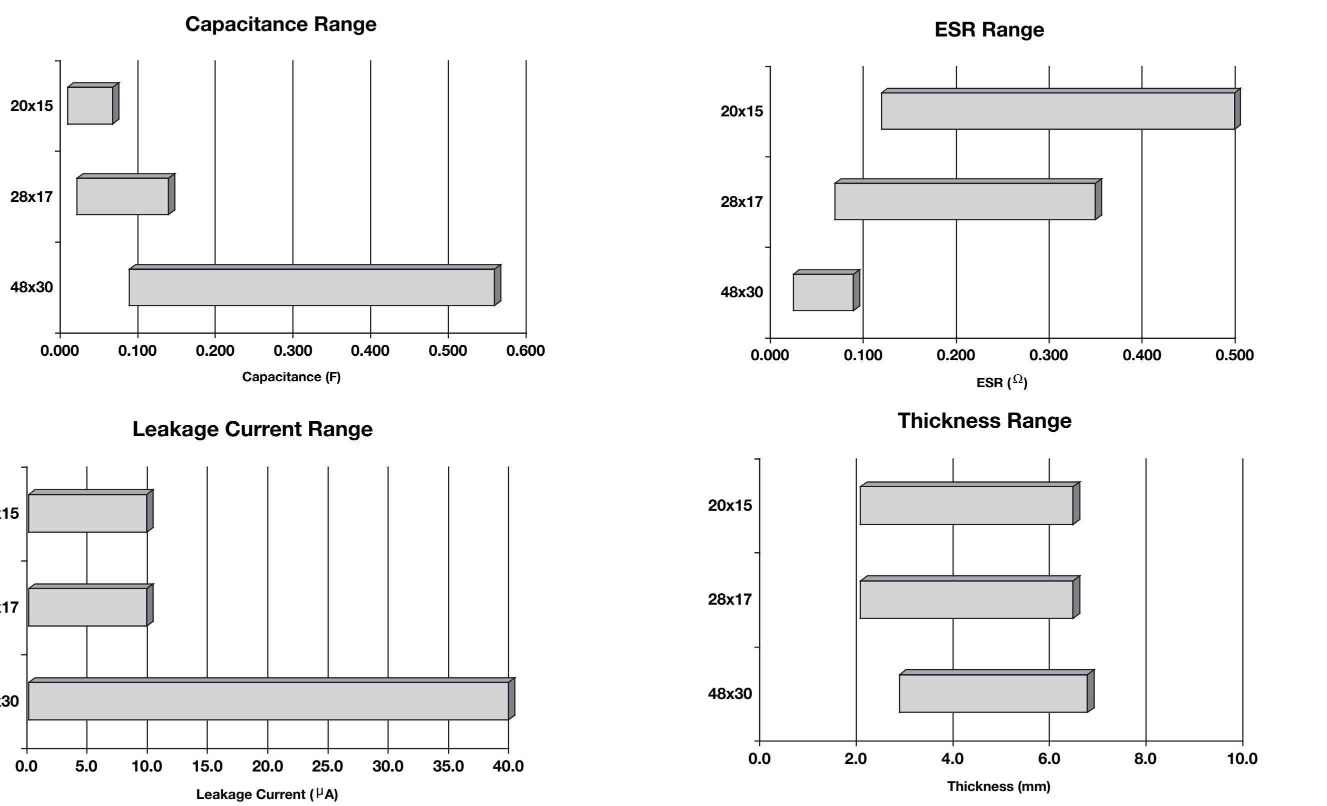


Figure 1 (a-d)

Reliability of BestCap® 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 75ºC, 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).

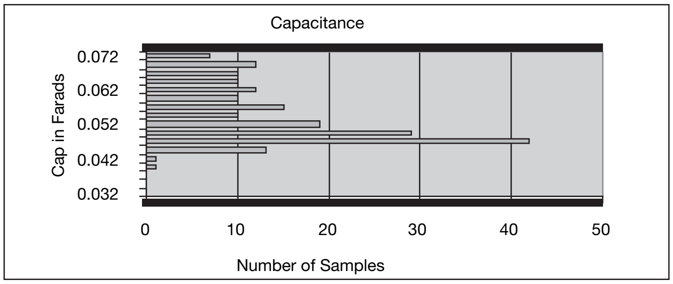
Table 2

Test	Test Method	Parameter	Limits
Initial Capacitance Measurement	Discharge cells with a constant current after a full charge noting voltage and time. C = I * dt/dv	Capacitance (Cap)	+80% / -20% of rated Cap
Initial DCL Measurement	Apply rated voltage. Note current after exactly 3 hours.	Leakage Current (DCL)	Within Limit
Initial ESR Measurement	Measurement frequency @ 1kHz; Measurement voltage @ 10 mV	Equivalent Series Resistance (ESR)	+20% / -50% of typical value
Load Life	Apply rated voltage at 75ºC (A series BestCap), 70ºC (B series BestCap) or 60ºC (C series BestCap) for 1000 hours. Allow to cool to room temperature and measure Cap, DCL and ESR.	DCL Cap ESR	< 2.0x rated max. > 0.7x rated < 3.0x rated
Shelf Life	Maintain at 75ºC (A series BestCap), 70ºC (B series BestCap) or 60ºC (C series BestCap) for 1000 hours Allow to cool to room temperature and measure Cap, DCL and ESR.	DCL Cap ESR	< 1.5x rated max. > 0.7x rated < 2.0x rated
Humidity Life	Maintain at 40°C / 95% RH for 1000 hours. Allow to cool to room temperature and measure Cap, DCL and ESR.	DCL Cap ESR	< 2.0x rated max. > 0.7x rated < 1.5x rated
Leg pull strength	Apply an increasing force in shear mode until leg pulls away	Yield Force (A and L leads only)	Not less than 25 pounds shear
Surge Voltage	Step 1 Apply 125% of the rated voltage for 10 seconds 2 Short the cell for 10 minutes 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°C and then hold for 30 min. 2 Ramp oven up to 75ºC (A series BestCap), 70ºC (B series BestCap) or 60ºC (C series BestCap) and then hold for 30 min. 3 Repeat 1 and 2 for 100 cycles	DCL Cap ESR	< 1.5x rated max. > 0.7x rated < 1.5x rated
Temperature Characteristics	Step / Temp / Time 1 / -20°C / 4 hours Measure Cap, ESR, DCL 2 / -10°C / 4 hours Measure Cap, ESR, DCL 3 / 0°C / 4 hours Measure Cap, ESR, DCL 5 / 25°C / 4 hours Measure Cap, ESR, DCL 6 / 40°C / 4 hours Measure Cap, ESR, DCL 7 / 60°C / 4 hours Measure Cap, ESR, DCL 8 / 70°C (A and B series ONLY) / 4 hours Measure Cap, ESR, DCL 9 / 75°C (A series ONLY) / 4 hours Measure Cap, ESR, DCL	DCL 70°C Cap ESR -20°C -10°C 60°C	 < 10x rated Not less than –30% Within +400% Within +300% Within +30%
Thermal Shock	Step 1 Place cells into an oven at –20°C for 30 minutes 2 Move cells into a 75ºC (A series BestCap), 70ºC (B series BestCap) or 60ºC (C series BestCap) oven for 30 minutes 3 Repeat 1 and 2 for 100 cycles	DCL Cap ESR	< 2.0x rated max. > 0.7x rated < 2.0x rated max.
Vibration	Step 1 Apply a harmonic motion that is deflected 0.03 inches 2 Vary frequency from 10 cycles per second to 55 cycles at a ramp rate 3 Vibrate the cells in the X-Y direction for three hours 4 Vibrate the cells in the Z direction for three hours 5 Measure Cap, ESR and DCL	DCL Cap ESR	< 2.0x rated max. > 0.7x rated < 2.0x rated max.

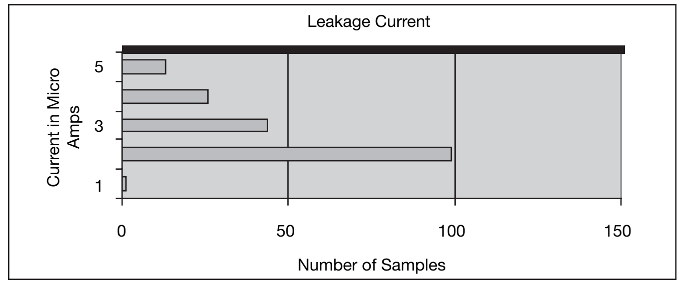
These test procedures involve monitoring capacitance (Farads), leakage current (μA) and ESR (milli-ohms or mΩ).

Figures 2 - 10 show examples of typical results of such tests.

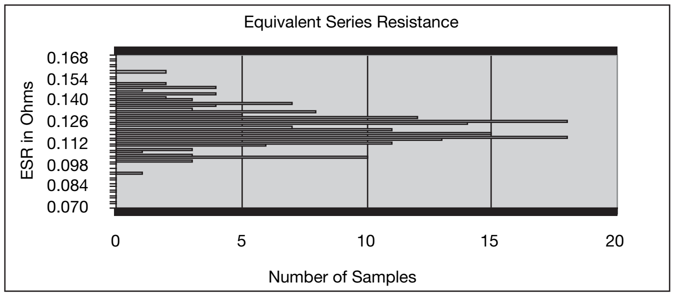
Figure 2 shows initial electrical results: Capacitance, Leakage and ESR data



Average = 0.054 Std. Dev. = 0.009



Average = 2.4 Std. Dev. = 1.1

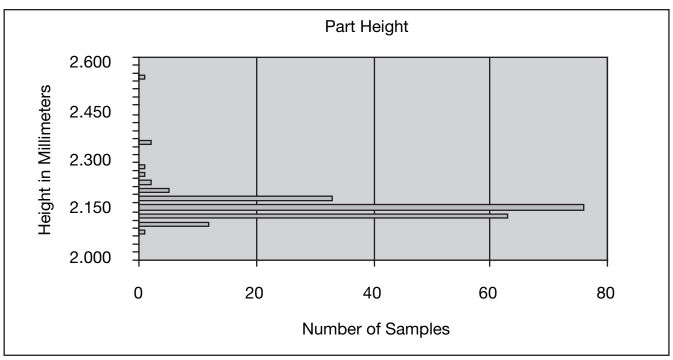


Average = 0.121 Std. Dev. = 0.012

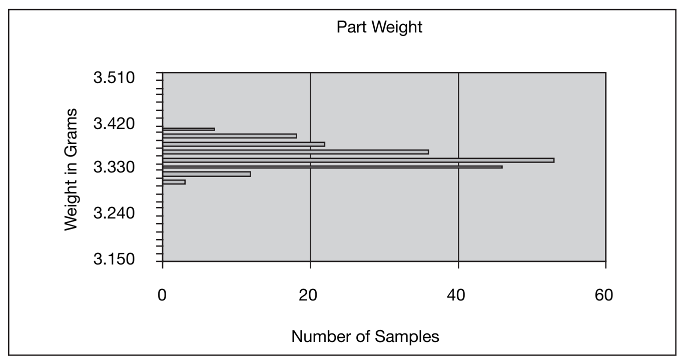
In all the data shown above and in subsequent figures, the solid lines in the capacitance and ESR graphs show the upper and lower control limits, and the solid line in the leakage current graph shows the upper control limit.

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

Figure 3: Physical Characteristics

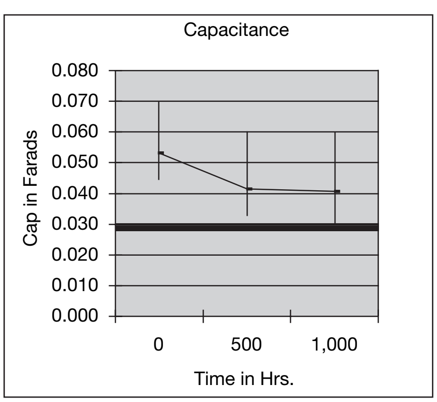


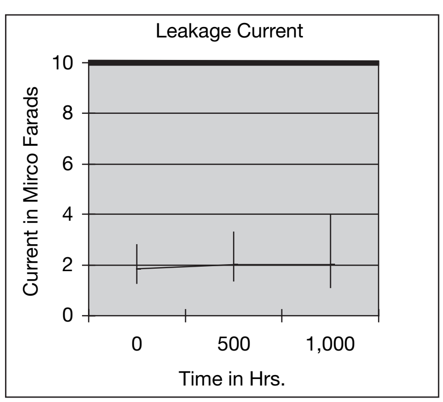
Std. Dev. = 0.044



Average = 3.34 Std. Dev. = 0.023

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





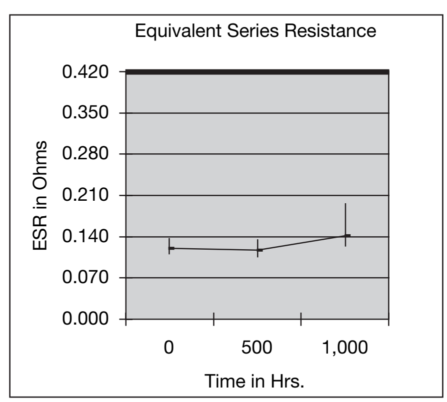


Figure 5: Shelf Life (max. rated temperature applied)

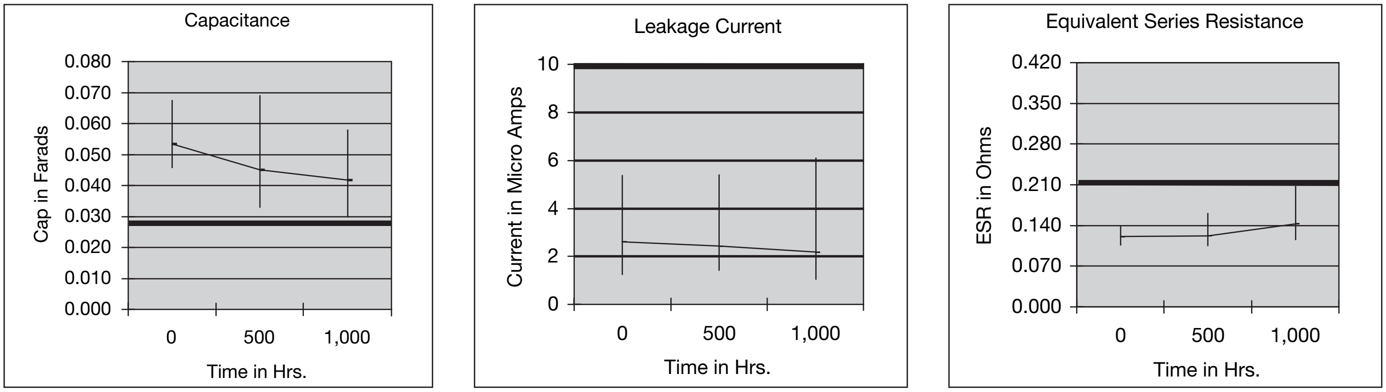


Figure 6: Humidity Life (40°C temperature and 95% humidity applied)

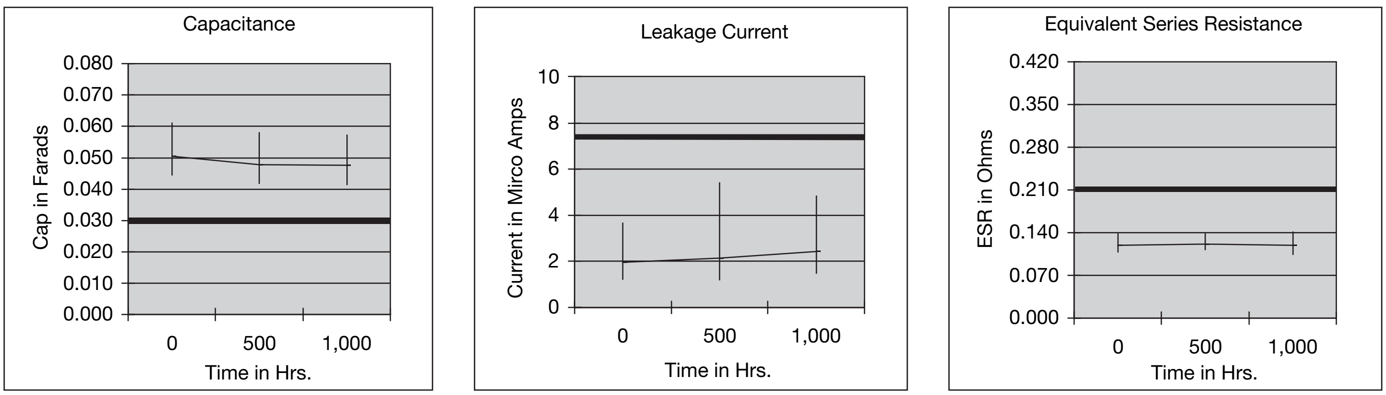


Figure 7: Surge Voltage (125% rated voltage for 10 seconds)

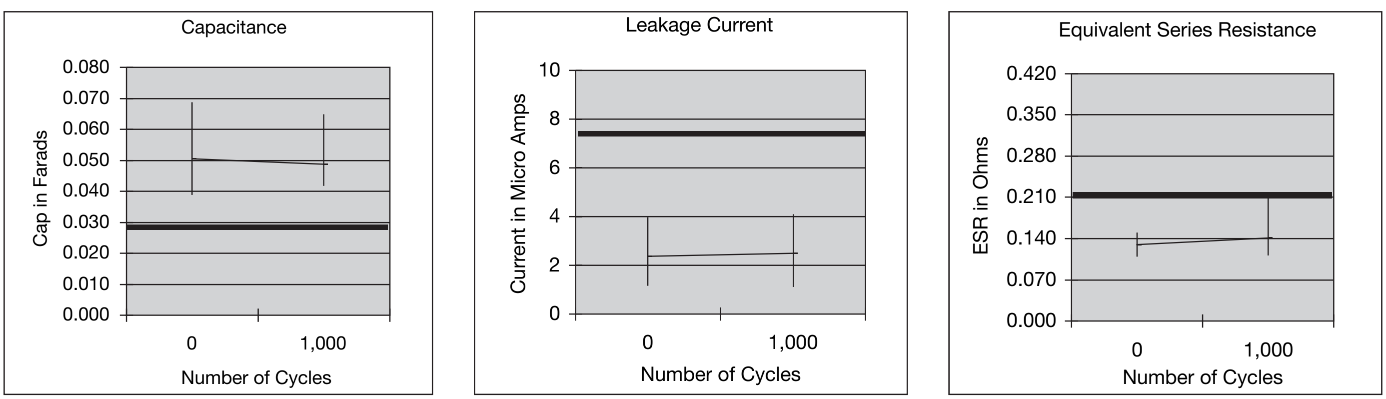


Figure 8: Temperature Cycling (min to max temp. cycling, slow transition)

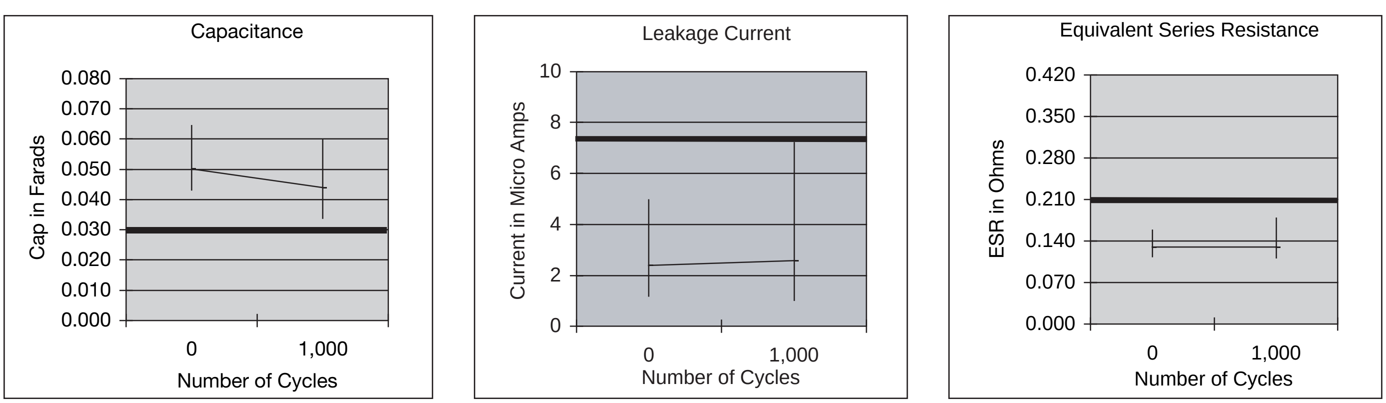


Figure 9: Thermal Shock (min to max temp. cycling, rapid transition)

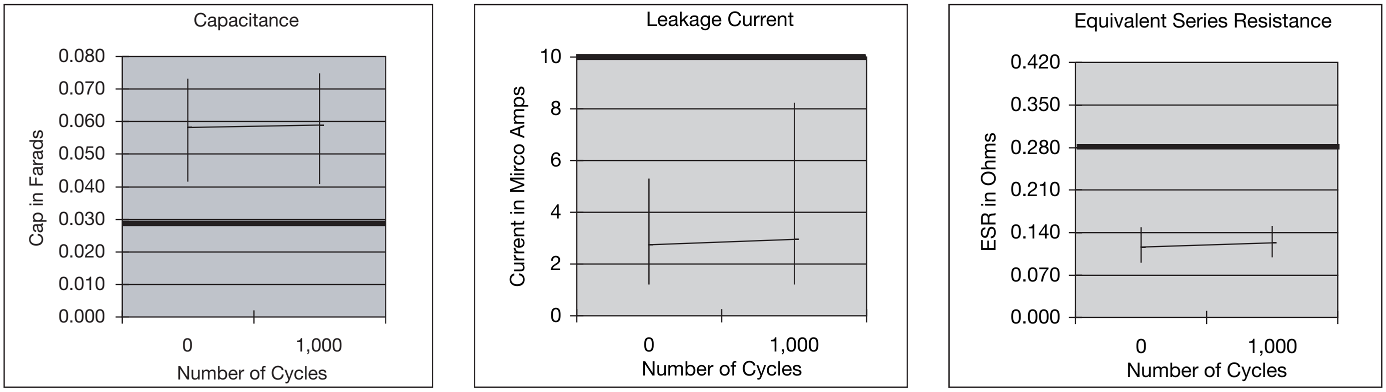
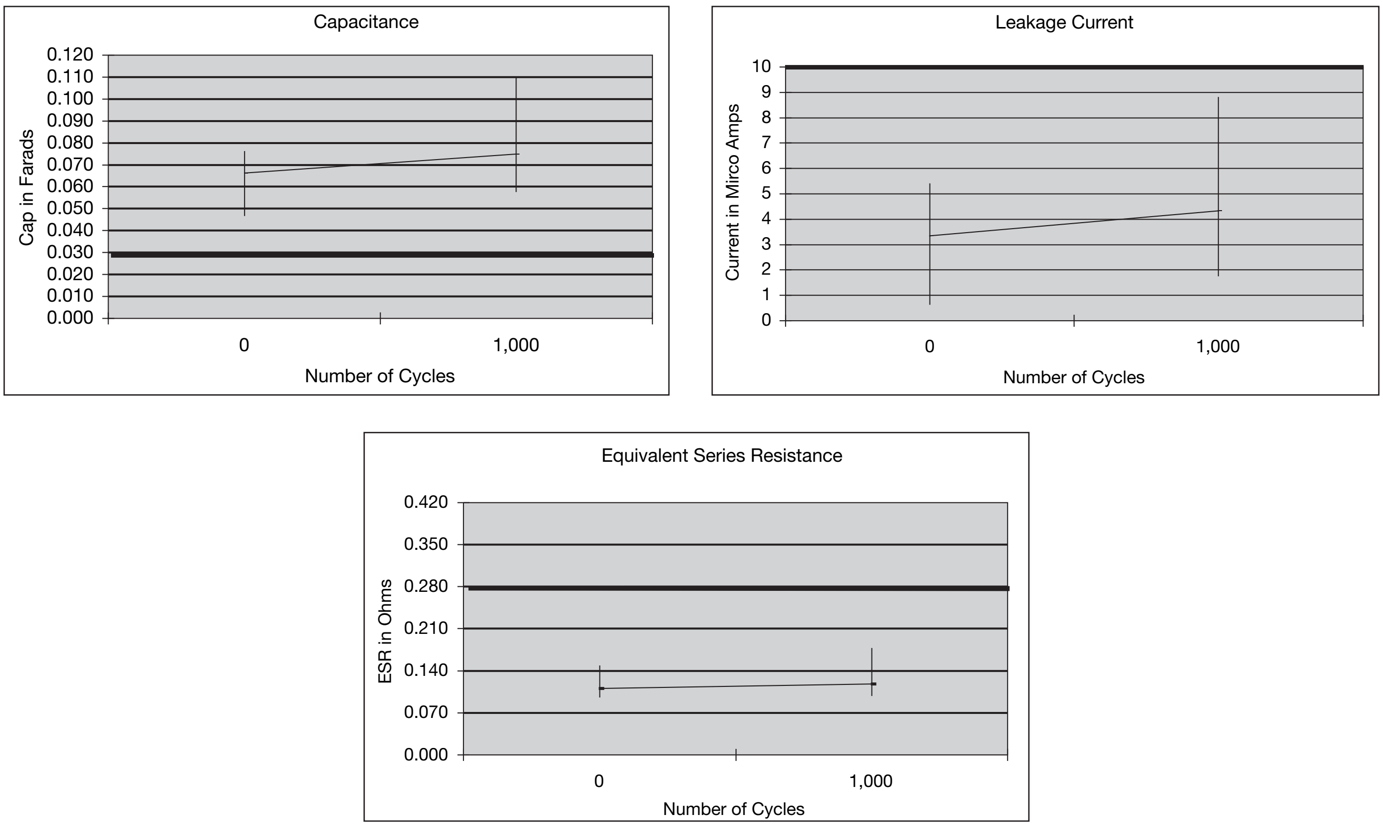


Figure 10: Vibration (10-55Hz, X, Y, and Z axis)



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:

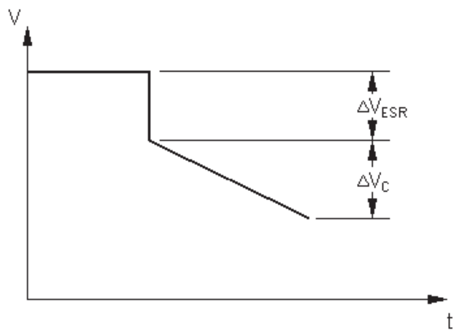


Figure 11: Voltage-Time Relation after Pulse is Initiated

The instantaneous voltage drop, ΔV_{ESR} is directly proportional to the ESR as shown below, where I is the instantaneous current.

$$\Delta V_{ESR} = I * ESR$$

The time dependent voltage drop ΔV_C is inversely proportional to the available capacitance. This is shown in the formula below, where Δt is the pulse duration and C_f is the available capacitance at the frequency of pulse.

$$\Delta V_C = I * \Delta t / C_f$$

The total voltage drop ΔV is the sum of the instantaneous and time dependant 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

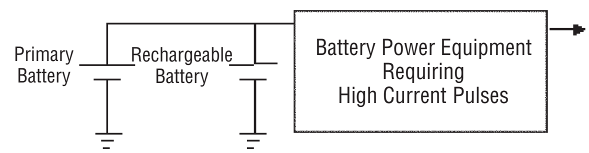
When electronic equipment is powered by a primary (non rechargeable) battery, one of the limitations is the power capability of the battery.

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:



Design using BestCap®

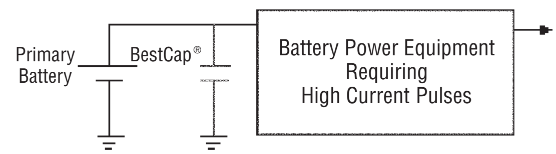


Figure 12

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 (-20ºC).
- 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 3

BestCap® 5.5V 100mF

Pulse	**Votage Drop (mV)** BestCap® Supercapacitor	**Votage Drop (mV)** Rechargeable Battery
250mA / 1msec	25	150
500mA / 1msec	50	220
750mA / 1msec	75	150
200mA / 100msec at -20ºC	232	470

BestCap® 3.5V 560mF

Pulse	**Votage Drop (mV)** BestCap® Supercapacitor	**Votage Drop (mV)** Rechargeable Battery
250mA / 100msec	50	190
500mA / 100msec	100	350
750mA / 100msec	152	190
1500mA / 1msec	43	220
1500mA / 100msec	305	350
750mA / 100msec at -20ºC	172	470

Additional Characteristics	**Best Cap®**	**Rechargeable Battery**
Maximum discharge current (single pulse)	Not limited	5a Maximum
Number of cycles	Not limited	40K to 400K (to retain 80% capacity)

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.

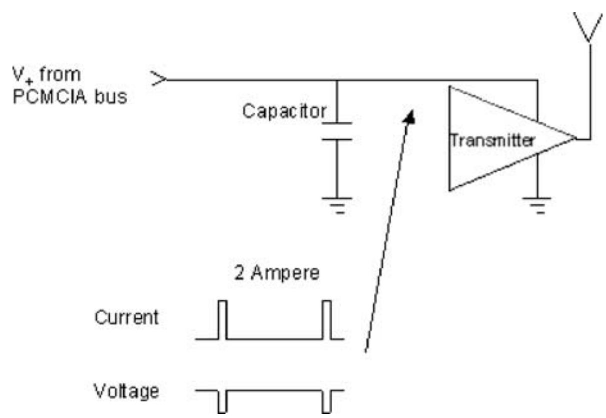
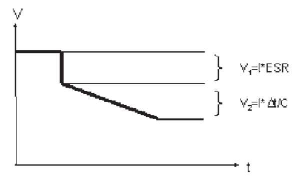


Figure 13

Table 4: The solution

	Solution A	Solution B	
	Chip Tantalum	BestCap® BZ014C353ZSB	BestCap® BZ055B353ZSB
Rated Capacitance (milli Farad)	1	35	35
Capacitance @ 0.5msec pulse (milli Farad)	1	17	17
Working voltage (V)	6.3	4.5	5.5
ESR (milli ohm)	30	120	110
Size (mm)	7.2x6.3x3.8	28x17x2	20x15x4.2
Voltage Drop* (V) GSM pulse	0.9	0.23	0.21
Voltage Drop** (V) GPRS pulse (25% duty cycle)	1.75	0.28	0.26



(1) Calculation:
*V=V1 + V2 = 1.5A*ESR + (1.5A*0.577msec)/C
**V=V1 + V2 = 1.5A*ESR + (1.5A*1.154msec)/C

Figure 14

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 electro-magnetic 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.

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