

Aerogel Capacitors: A Unique Low-ESR Supercapacitor

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Aerogel Capacitors

- Unique type of:
 - Supercapacitor
 - Ultracapacitor
 - Electrochemical Double Layer Capacitor (EDLC)
- Aerogel Capacitors have the lowest Equivalent Series Resistance (ESR) of any of these systems

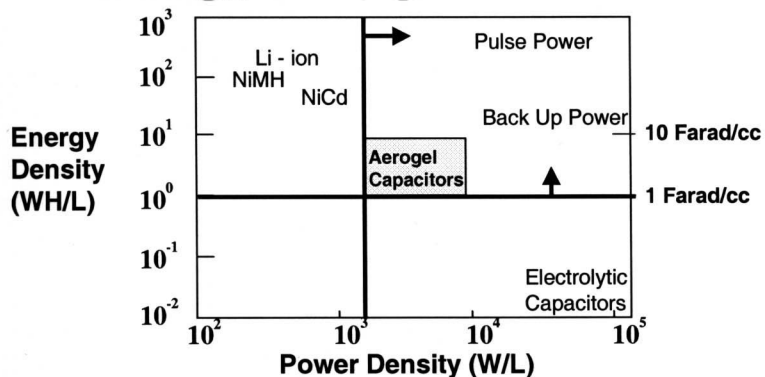
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Energy Storage Devices



Aerogel Capacitors are uniquely positioned between the \$10 billion capacitor market and the \$15+ billion battery market.

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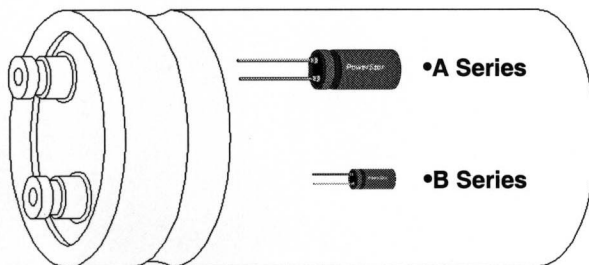
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Aerogel vs. Electrolytic Capacitors

1 F Aluminum Electrolytic Capacitor vs. 1 F **PowerStor** Aerogel Capacitors

A Series to B Series → 1 F/cc to 4 F/cc



Over 2000-5000x reduction in volume!

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Aerogel Capacitors vs. Batteries

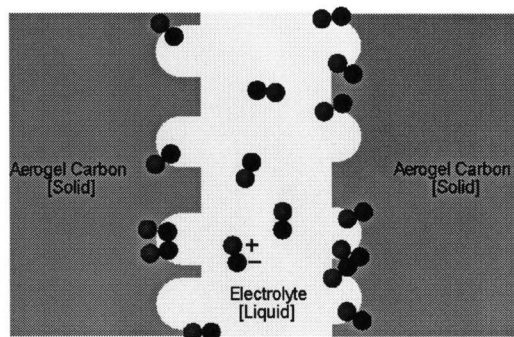
Key Characteristic	Supercapacitor	Batteries
Voltage	+2.5 to +5.5 V DC	+ 1.2 to + 4.2 V DC
Operating Temperature	-40 to 70°C (85°C)	-20 to 60°C
Cycle Life	> 300,000	300 to 1000
Energy Density (Wh/L)	1 to 10	100 to 350
Power Density (W/L)	100 to 10,000	100 to 800
Charge Rate	Seconds to Minutes	Hours

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Aerogel Carbon – Discharged State

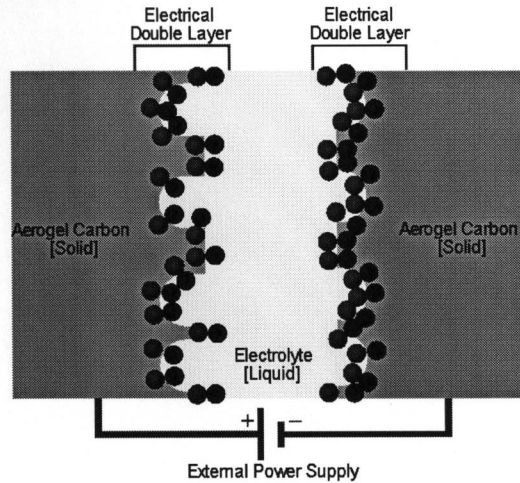


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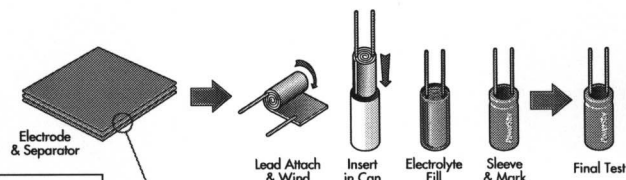
Aerogel Carbon – Charged State



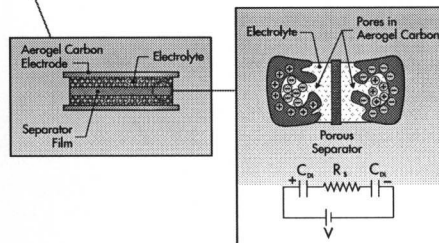
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Aerogel Capacitor Processing



- **Active Material is Aerogel Carbon:**
- Very uniform pore-size distribution
- High usable surface area
- 5 to 10 x higher electrical conductivity than conventional carbons



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Capacitance or ESR?

- In most applications, either Capacitance or ESR is more critical.



B, M, and S Series



- In main power and memory backup (hold-up power) applications, high capacitance is required to ensure adequate run-time



A and F Series



- In pulse power applications, low ESR is critical to decrease V_{drop} during high-current pulse

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Key Parameters

- V_w (V): *Working(Charge)Voltage*
- V_{min} (V): *Minimum Voltage*
- t (sec): *Discharge Time in Seconds*
- I (A): *Current in Amperes*
- C (F): *Capacitance in Farads*
- W (J): *Energy in Joules (W-sec)*
- ESR (Ω): *Measured at 1-kHz AC in Ohms*
- R (Ω): *Internal Resistance (DC) in Ohms*

Note: The application requirements can be calculated from the first four parameters using the PowerStor Aerogel Capacitor Calculator available at www.cooperet.com

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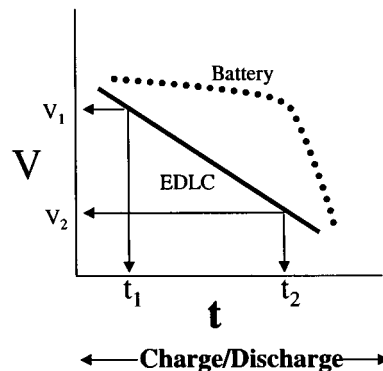
Charge/Discharge Profiles

$$Q = C V$$

$$dQ/dt = I = C dV/dt$$

$$E = 1/2 C (V_1^2 - V_2^2)$$

$$C = \frac{I \times (t_2 - t_1)}{(V_1 - V_2)}$$



Supercapacitors have intrinsically sloping
charge/discharge curves compared to batteries

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Memory Backup (Hold-Up) and Main Power Applications

- Energy (in Joules) required can be calculated:

$$W = I V_w t$$

$$\text{and as } W = \frac{1}{2} C (V_w^2 - V_{min}^2)$$

- We calculate required capacitance (in Farads):

$$C = (2 I V_w t) / (V_w^2 - V_{min}^2)$$

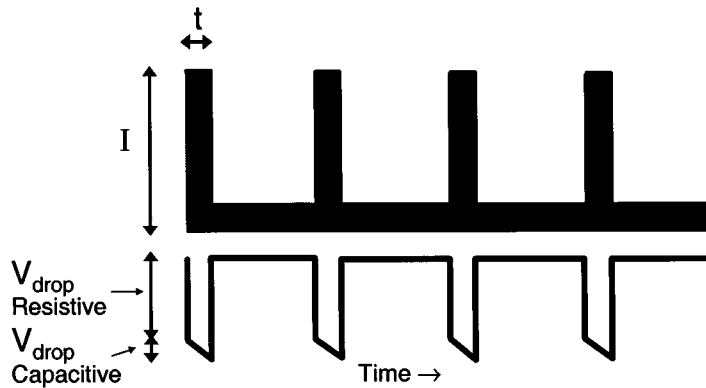
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Pulse-Power Profile



Large voltage drops arise during high current pulses

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Pulse-Power Applications

- $R(\text{estimated}) = V_{\text{drop}} / I$
- Choose correct capacitor(s) based on R and Working Voltage
- V_{drop} with capacitor can be calculated:

$$V_{\text{drop}} = I (R + t / C)$$
- V_{drop} components:
 - Resistive = $I (R)$
 - Capacitive = $I (t / C)$

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Charging Aerogel Capacitors

- Aerogel Capacitors can be held at maximum voltage indefinitely
- Aerogel Capacitors can handle very-low to very-high charge currents
 - Limit voltage to:
 - +2.75 VDC for A Series per capacitor in series
 - +2.5 VDC for B Series per capacitor in series
 - +5.5 VDC for M and S Series
 - Small surge voltages acceptable but not recommended
 - As a rule of thumb, maximum current:

$$I_{\max} = \text{Charge voltage} / (5 \times \text{ESR})$$
- Example for a 4.7F A Series device with 30 mΩ ESR:

$$I_{\max} = +2.75 \text{ VDC} / (5 \times 0.03\Omega) = 18.3 \text{ A}$$






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PowerStor Product Roadmap

	Series	Capacitance (F)/ (Voltage)	ESR Range (Ohms)	Applications
	A	0.47 to 10 (+2.75 VDC)	0.015 to 0.15	Low duty cycle pulse power Hybrid battery-capacitor DC/DC converters Solenoids / Motors
	B	1 to 50 (+2.5 VDC)	0.025 to 0.4	High duty cycle pulse power 1.5- and 2-way pagers Main Power – low current
	M	0.1 to 0.33 (+5.5 VDC)	≤ 5	Memory backup, hold-up and battery swap out for CMOS, RAM, μprocessor
	S	0.1 to 0.33 (+5.5 VDC)	≤ 5	Memory backup, hold-up and battery swap out for CMOS, RAM, μprocessor
	F (Q1'01)	TBD (+2.3 or +4.6 VDC)	TBD	Pulse / space constrained GSM Mobile phones PCMCIA cards

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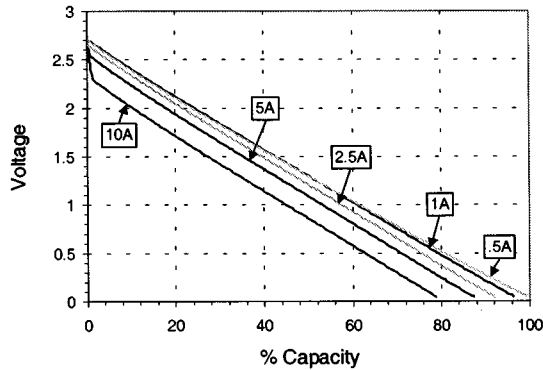
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Discharge Characteristics

High-Power Cylindrical Devices

Discharge Curves (RT)



(10A = 1500 C rate
in battery terms)

High current capability of up to 4000 W/L

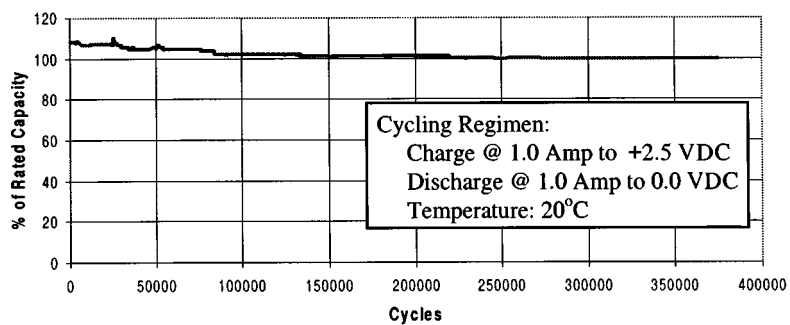
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Aerogel Capacitor Cycle Life

High-Power Cylindrical Devices



Aerogel Capacitors have significantly higher
life cycle than batteries

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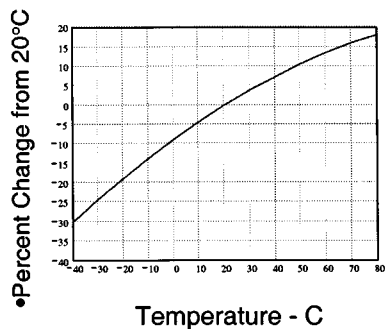


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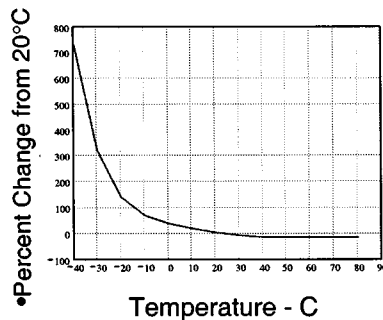
Temperature Characteristics

High-Power Cylindrical Devices

Percent Capacitance
Change Over
Temperature Range



Percent ESR Change
Over Temperature Range



Aerogel Capacitors operate over a wide temperature range

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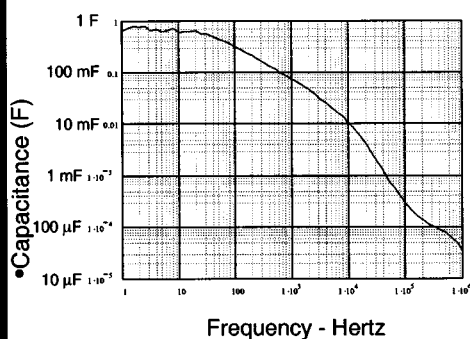
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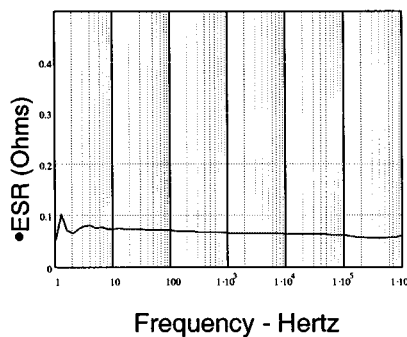
Frequency Characteristics

High-Power Cylindrical Devices

Capacitance - Frequency
Characteristic, A1020



ESR - Frequency
Characteristic, A1020



Key parameter for Back-up Power

Key parameter for Pulse Power

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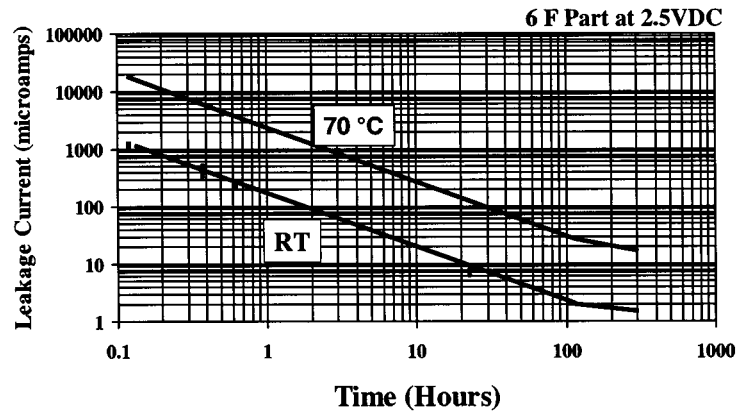
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Typical Inflow Current

Leakage Current = Ultimate Value of Inflow Current

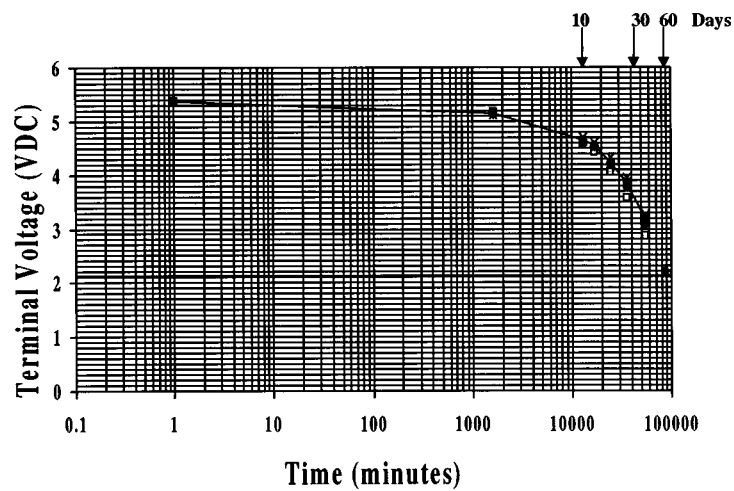


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M & S Series – Self Discharge

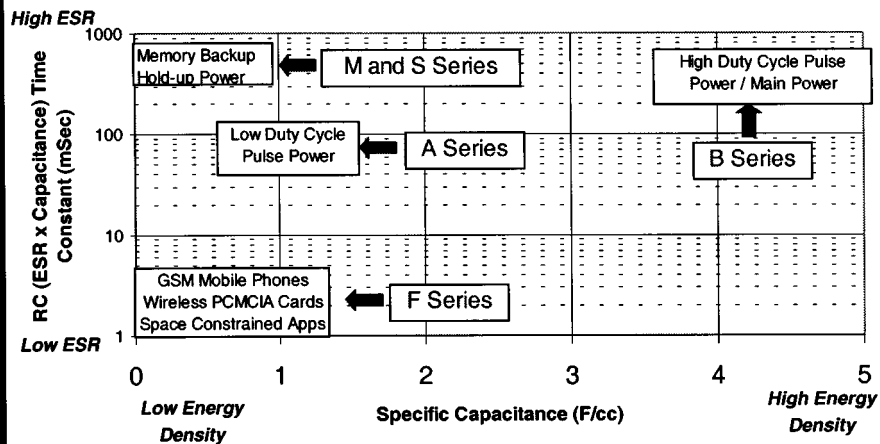


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Product Line for Applications



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Summary

- PowerStor's Aerogel Capacitors have the lowest ESR due to our unique Carbon Aerogel
- PowerStor has developed Aerogel Capacitor product lines for:
 - Memory Backup and Hold-Up,
 - Main Power, and
 - Pulse Power.

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