

This document provides basic guidelines for application development using aerogel capacitors, also known as supercapacitors. If questions arise during your development process and are not answered in this document, contact Cooper Bussmann.

Lifetime

PowerStor supercapacitors have a longer lifetime than secondary batteries, but their lifetime is not infinite. The basic end-of-life failure mode for a supercapacitor is an increase in equivalent series resistance (ESR) and/or a decrease in capacitance. The actual end-of-life criteria are dependent on the application requirements. Prolonged exposure to elevated temperatures, high applied voltage and excessive current will lead to increased ESR and decreased capacitance. Reducing these parameters will lengthen the lifetime of a supercapacitor. In general, cylindrical supercapacitors have a similar construction to electrolytic capacitors, having a liquid electrolyte inside an aluminum can sealed with a rubber bung. Over many years, the supercapacitor will dry out, similar to an electrolytic capacitor, causing high ESR and eventually end-of-life.

Voltage

Supercapacitors are rated with a nominal recommended working or applied voltage. The values provided are set for long life at their maximum rated temperature. If the applied voltage exceeds this recommended voltage, the result will be reduced lifetime. If the voltage is excessive for a prolonged time period, gas generation will occur inside the supercapacitor and may result in leakage or rupture of the safety vent. Short-term overvoltage can usually be tolerated by the supercapacitor.

Polarity

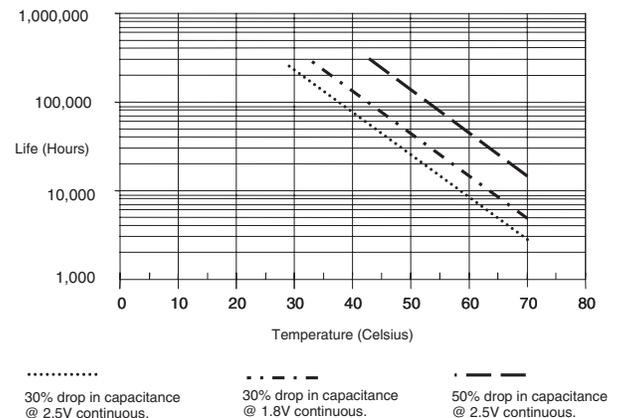
PowerStor supercapacitors are designed with symmetrical electrodes, meaning they are similar in composition. When a supercapacitor is first assembled, either electrode can be designated positive or negative. Once the supercapacitor is charged for the first time during the 100% QA testing operation, the electrodes become polarized. Every supercapacitor either has a negative stripe or sign denoting polarity. Although they can be shorted to zero volts, the electrodes maintain a very small amount of charge. Reverse polarity is not recommended, however previously charged supercapacitors have been discharged to -2.5V with no measurable difference in capacitance or ESR. Note: the longer they are held charged in one direction, the more polarized they become. If reversed charged after prolonged charging in one direction, the life of the supercapacitor may be shortened.

Ambient Temperature

The standard temperature rating for PowerStor supercapacitors is -25°C to 70°C. Temperature in combination with voltage can affect the lifetime of a supercapacitor. In general, raising the ambient temperature by 10°C will decrease the lifetime of a supercapacitor by a factor of two. As a result, it is recommended to use the supercapacitor at the lowest temperature possible to decrease internal degradation and ESR increase. If this is not possible, decreasing the applied voltage to the supercapacitor will assist in offsetting the negative effect of the high temperature. For instance, 85°C ambient temperature can be reached if the applied voltage is reduced to 1.8V per supercapacitor.

At temperatures lower than normal room temperature, it is possible to apply voltages slightly higher than the recommended working voltage without significant increase in degradation and reduction in lifetime. Raising the applied voltage at low temperatures can be useful to offset the increased ESR seen at low temperatures. Increased ESR at higher temperatures is a result of permanent degradation / electrolyte decomposition inside the supercapacitor. At low temperatures, however, increased ESR is only a temporary phenomenon due to the increased viscosity of the electrolyte and slower movement of the ions.

Operating Life vs. Temperature and Charge Voltage



The above plot shows the time taken for capacitance to drop by 30% at 1.8V & 2.5V and by 50% at 2.5V for continuous operation at a given temperature. This can be used to estimate the operating life for specific applications where the minimum allowable capacitance value is known.

Discharge Characteristics

Supercapacitors discharge with a sloping voltage curve. When determining the capacitance and ESR requirements for an application, it is important to consider both the resistive and capacitive

discharge components. In high current pulse applications, the resistive component is the most critical. In low current, long duration applications, the capacitive discharge component is the most critical. The formula for the voltage drop, V_{drop} , during a discharge at I current for t seconds is:

$$V_{drop} = I(R + \frac{t}{C})$$

To minimize voltage drop in a pulse application, use a supercapacitor with low ESR (R value). To minimize voltage drop in a low current application, use a supercapacitor with large capacitance (C value).

An Aerogel Capacitor Calculator program is available online at <http://www.cooperbussmann.com> for predicting electrical requirements and matching these requirements to various supercapacitor configurations / alternatives.

Charge Methods

Supercapacitors can be charged using various methods including constant current, constant power, constant voltage or by paralleling to an energy source, i.e. battery, fuel cell, DC converter, etc. If a supercapacitor is configured in parallel with a battery, adding a low value resistor in series will reduce the charge current to the supercapacitor and will increase the life of the battery. If a series resistor is used, ensure that the voltage outputs of the supercapacitor are connected directly to the application and not through the resistor, otherwise the low impedance of the supercapacitor will be nullified. Many battery systems exhibit decreased lifetime when exposed to high current discharge pulses.

The maximum recommended charge current, I , for a supercapacitor where V_W is the charge voltage and R is the supercapacitor impedance is calculated as follows:

$$I = \frac{V_W}{5R}$$

Overheating of the supercapacitor can occur from continuous overcurrent or overvoltage charging. Overheating can lead to increased ESR, gas generation, decreased lifetime, leakage, venting or rupture. Contact the factory if you plan to use a higher charge current or higher voltage than specified.

Self Discharge and Leakage Current

Self discharge and leakage current as essentially the same thing measured in different ways, due to the supercapacitor construction there is a high impedance internal current path from the anode to the cathode. This means that in order to maintain the charge on the capacitor a small amount of additional current is

required, during charging this is referred to as leakage current. When the charge voltage is removed, and the capacitor is not loaded, this additional current will discharge the supercapacitor and is referred to as the self discharge current.

In order to get a realistic measurement of leakage or self discharge current the supercapacitor must be charged for in excess of 100 hours, this again is due to the capacitor construction. The supercapacitor can be modeled as several capacitors connected in parallel each with an increasing value of series resistance. The capacitors with low values of series resistance charge quickly thus increasing the terminal voltage to the same level as the charge voltage. However, if the charge voltage is removed these capacitors will discharge in to the parallel capacitors with higher series resistance if they are not fully charged. The result of this being that the terminal voltage will fall giving the impression of high self discharge current. It should be noted that the higher the capacitance value the longer it will take for the device to be fully charged, see figure 2 in the Measurement Techniques section for more details.

Series Configurations of Supercapacitors

Individual supercapacitors are limited to 2.5V (P Series reaches 5V using two supercapacitors in series). As many applications require higher voltages, supercapacitors can be configured in series to increase the working voltage. It is important to ensure that the individual voltages of any single supercapacitor do not exceed its maximum recommended working voltage as this could result in electrolyte decomposition, gas generation, ESR increase and reduced lifetime.

Capacitor voltage imbalance is caused, during charge and discharge, by differences in capacitance value and, in steady state, by differences in capacitor leakage current. During charging series connected capacitors will act as a voltage divider so higher capacitance devices will receive greater voltage stress. For example if two 1F capacitors are connected in series, one at +20% of nominal capacitance the other at -20% the worst-case voltage across the capacitors is given by:

$$V_{cap1} = V_{supply} \times (C_{cap1} / (C_{cap1} + C_{cap2}))$$

where C_{cap1} has the +20% capacitance.

So for a $V_{supply} = 5V$,

$$V_{cap1} = 5V \times (1.2 / (1.2 + 0.8)) = 3V$$

From this it can be seen that, in order to avoid exceeding the supercapacitor surge voltage rating of 3V, the capacitance values of series connected parts must fall in a +/-20% tolerance range. Alternatively a suitable active voltage balancing circuit can be

employed to reduce voltage imbalance due to capacitance mismatch. It should be noted that the most appropriate method of voltage balancing will be application specific.

Passive Voltage Balancing

Passive voltage balancing uses voltage-dividing resistors in parallel with each supercapacitor. This allows current to flow around the supercapacitor at a higher voltage level into the supercapacitor at the lower voltage level, thus balancing the voltage. It is important to choose balancing resistor values that provide for higher current flow than the anticipated leakage current of the supercapacitors, bearing in mind that the leakage current will increase at higher temperatures.

Passive voltage balancing is only recommended for applications that don't regularly charge and discharge the supercapacitor and that can tolerate the additional load current of the balancing resistors. It is suggested that the balancing resistors be selected to give additional current flow of at least 50 times the worst-case supercapacitor leakage current (3.3 kΩ to 22 kΩ depending on maximum operating temperature). Although higher values of balancing resistor will work in most cases they are unlikely to provide adequate protection when significantly mismatched parts are connected in series.

Active Voltage Balancing

Active voltage balancing circuits force the voltage at the nodes of series connected supercapacitors to be the same as a fixed reference voltage; regardless of how any voltage imbalance occurs. As well as ensuring accurate voltage balancing active circuits typically draw much lower levels of current in steady state and only require larger currents when the capacitor voltage goes out of balance. These characteristics make active voltage balancing circuits ideal for applications that charge and discharge the supercapacitors frequently as well as those with a finite energy source such as a battery.

Reverse Voltage Protection

When series connected supercapacitors are rapidly discharged the voltage on low capacitance value parts can potential go negative. As explained previously, this is not desirable and can reduce the operating life of the supercapacitor. One simple way of protecting against reverse voltage is to add a diode across the capacitor, configured so that it is normally reverse bias. By using a suitably rated zener diode in place of a standard diode the supercapacitor can also be protected against overvoltage events. Care must be taken to ensure that the diode can withstand the available peak current from the power source.

Soldering Information

Excessive heat may cause deterioration of the electrical characteristics of the aerogel supercapacitor, electrolyte leakage or an increase in internal pressure.

Follow the specific instructions listed below.

In addition:

- Do not dip aerogel supercapacitor body into melted solder.
- Only flux the leads of the aerogel supercapacitor.
- Ensure that there is no direct contact between the sleeve of the aerogel supercapacitor and the PC board or any other component. Excessive solder temperature may cause sleeve to shrink or crack.
- Avoid exposed circuit board runs under the aerogel supercapacitor to prevent electrical shorts.

Manual Soldering

Do not touch the aerogel supercapacitor's external sleeve with the soldering rod or the sleeve will melt or crack. The recommended temperature of the soldering rod tip is less than 260°C (maximum: 350°C) and the soldering duration should be less than 5 seconds. Minimize the time that the soldering iron is in direct contact with the terminals of the aerogel supercapacitor as excessive heating of the leads may lead to higher equivalent series resistance (ESR).

Wave Soldering

Use a maximum preheating time of 60 seconds for PC boards 0.8 mm or thicker. Preheating temperature should be limited to less than 100°C.

Use the following table for wave soldering on leads only:

Solder Bath Temperature (°C)	Solder Exposure Time (seconds)	
	Recommended	Maximum
220	7	9
240	7	9
250	5	7
260	3	5

Reflow Soldering

Do not use reflow soldering on PowerStor supercapacitors using infrared or convection oven heating methods unless the supercapacitor is specifically rated to withstand reflow soldering temperatures.

Ripple Current

Although PowerStor aerogel supercapacitors have very low resistance in comparison to other supercapacitors, they do have higher resistance than aluminum electrolytic capacitors and are more susceptible to internal heat generation when exposed to ripple current. Heat generation leads to electrolyte decomposition, gas generation, increased ESR and reduced lifetime. In order to ensure long lifetime, the maximum ripple current recommended should not increase the surface temperature of the supercapacitor by more than 3°C.

Circuit Board Design

Do not design exposed circuit board runs under the supercapacitor. An electrical short could occur if the supercapacitor electrolyte leaked onto the circuit board.

Circuit Board Cleaning

Avoid cleaning of circuit boards, however if the circuit board must be cleaned use static or ultrasonic immersion in a standard circuit board cleaning fluid for no more than 5 minutes and a maximum temperature of 60°C. Afterwards thoroughly rinse and dry the circuit boards. In general, treat supercapacitors in the same manner you would an aluminum electrolytic capacitor.

Long Term Storage

Do not store supercapacitors in any of the following environments:

- High temperature and/or high humidity
- Direct contact with water, salt water, oil or other chemicals
- Direct contact with corrosive materials, acids, alkalis, or toxic gases
- Direct exposure to sunlight
- Dusty environment
- Environment subject to excessive shock and/or vibration

Transportation Information

PowerStor supercapacitors are non-regulated by the US DOT (Department of Transport) and IATA. The correct international shipping description is "Electronic Parts – Capacitors".

Emergency Procedures

If a supercapacitor is found to be overheating or if you smell a sweet odor, immediately disconnect any power or load to the supercapacitor. Allow the supercapacitor to cool down, then dispose of properly. Do not expose your face or hands to an overheating supercapacitor. Contact the factory for a Material Safety Data Sheet if a supercapacitor leaks or vents. If exposed to electrolyte:

- Skin Contact: Wash exposed area thoroughly with soap and water.
- Eye Contact: Rinse eyes with water for 15 minutes and seek medical attention.
- Ingestion: Drink milk/water and induce vomiting; seek medical attention.

Note: In general the electrolyte, using the NFPA/HMIS (0 to 4) rating system, has slight (1 out of 4) health and fire hazard and minimal (0 out of 4) reactivity hazard.

Regulatory Information

PowerStor supercapacitors are rated non-hazardous under the OSHA hazard communication standard (29 CFR 1910.1200)

General Safety Considerations

- Supercapacitors may vent or rupture if overcharged, reverse charged, incinerated or heated above 150°C.
- Do not crush, mutilate, nail penetrate or disassemble.
- High case temperature (burn hazard) may result from abuse of supercapacitor.

Disposal Procedures

PowerStor supercapacitors are non-regulated under RCRA Waste Code. Supercapacitors may however be disposed of by a specialized industrial waste processor or by incineration. Use caution when incinerating as the supercapacitor can explode unless it is crushed or punctured prior to incineration. Wear protective gear, such as face shields or goggles, coats/aprons and gloves. Use high temperature to incinerate the supercapacitors as the plastic (poly vinyl chloride) sleeving can produce chlorine gas at lower incineration temperatures.

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