



WHITE PAPER

DESIGN CONSIDERATIONS FOR ULTRACAPACITORS

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Maxwell's BOOSTCAP® ultracapacitors are increasingly being utilized in consumer electronics, traction, automotive, telecoms and industrial, with applications including pulse power, bridge power, main power and memory backup. This document provides an overview of some of the key performance characteristics and design issues of BOOSTCAP ultracapacitors. Product datasheets, tools for sizing ultracapacitors to an application, application notes and white papers are available at our website (www.maxwell.com). It is recommended to contact Maxwell for assistance and more detailed information before commencing any design. Maxwell is committed to RoHS compliance and providing product satisfying Directive (2002/95/EC) limiting use of hazardous substances in electrical and electronic components, as well as complying with all relevant safety and quality standard. Please contact Maxwell for more information.

1. Temperature effects and performance changes over time

The performance of Maxwell Technologies ultracapacitors is very stable over a wide operating temperature due to the chemistry and physical make up of the products. An advantage of the ultracapacitors' organic based electrolyte is its low freezing point. This enables the ultracapacitors to be utilized over a wide range of temperatures, with relatively unaffected performance. Plots of capacitance and resistance change as a function of temperature are available on request.

2. Lifetime

Ultracapacitor life is predominantly affected by a combination of operating voltage and operating temperature. The ultracapacitor has an unlimited shelf life when stored in a discharged state. When referring to ultracapacitor life the data sheets reflect the change in performance, typically decrease in capacitance and increase in resistance. The ultracapacitor does not experience a true end of life rather the performance continually degrades over the life of the use of the product.

The typical degradation behavior of the ultracapacitor resembles that of an exponential decay. The majority of the performance change occurs during the initial use of the ultracapacitor and this performance change then levels off over time. The most dramatic effect of the life degradation is on the internal resistance of the device.

In many applications, such as UPS, the ultracapacitors will be maintained at working voltage until needed. Plots are available on request that show the degradation in rated capacitance for ultracapacitors held at typical working voltages for long periods of time, and at different temperatures. To give one example, a 15% reduction in rated

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capacitance and a 40% increase in rated resistance may occur for an ultracapacitor held at 2.5 V after 88,000 hrs at 25 o C. The plots, along with the fact that the influence of temperature has a doubling effect for every 10 o C, can be used to predict the expected performance change for a variety of conditions.

3. Cycling

From cycle testing performed on the products, under typical conditions the product is expected to provide in excess of 1 million duty cycles with an approximate 20% reduction in rated capacitance. More details of the testing and plots of capacitance versus cycles are available on request.

4. Frequency response

Ultracapacitors have a typical time constant of approximately one second. One time constant reflects the time necessary to charge a capacitor 63.2% of full charge or discharge to 36.8% of full charge.

The time constant of an ultracapacitor is much higher than that of an electrolytic capacitor. Therefore, it is not possible to expose ultracapacitors to a continuous ripple current as overheating may result. The ultracapacitor can respond to short pulse power demands, but due to the time constant the efficiency or available energy is reduced.

5. Voltage

Ultracapacitors are capable of operating between their rated voltage and zero volts. Occasional spikes above the rated voltage will not immediately affect the capacitor. Depending on the frequency and duration of voltage spikes the life will be reduced.

Efficient utilization of the available energy and power storage is achieved with the widest operating voltage range use. Most electronics have a minimum voltage threshold for utilization, limiting the effective utilization voltage of the capacitor although there is no limitation in the capacitor itself. Since the energy in the capacitor is proportional to the voltage squared according to $E = \frac{1}{2} C V^2$.

It is possible to utilize approximately 75% of the available energy if the application utilizes from the rated voltage to $\frac{1}{2}$ rated voltage of the capacitor.

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6. Polarity

Unlike many batteries the anode and cathode of an ultracapacitor are comprised of the same material. If the positive and negative terminal and casing are also comprised of similar materials, then theoretically the ultracapacitor has no true polarity.

For manufacturing and consistency purposes the terminals are marked with polarity. It is recommended practice to maintain the polarity although catastrophic failure will not occur if the ultracapacitor is reversed charged for some reason. If the ultracapacitor has been conditioned for charge in a certain direction and then is changed, the life can be reduced due to this conditioning. For the PC5, PC10 and PC55 products the case is comprised of stainless steel. Due to the corrosion potential it is required to maintain the polarity indicated on the products, and reverse polarity will cause accelerated life reduction.

7. Charging

Since the energy storage mechanism of the ultracapacitor is not a chemical reaction, charging/discharging of the ultracapacitors can occur at the same rate. Therefore, the rated current for the ultracapacitor applies for both charge and discharge. The efficiency of charge and discharge are in practical terms the same. A variety of methods are possible for charging of the ultracapacitors. This may be either through constant current or constant power charging via a dc source or through ac charging methods. A separate application note is available discussing different methodologies for ultracapacitor charging.

8. Series connection and balancing

Since the individual ultracapacitor cell voltage is relatively limited compared to the majority of application requirements, it is necessary to series connect the ultracapacitors to achieve the voltage required. Because each ultracapacitor will have a slight tolerance in capacitance and resistance it is necessary to balance, or prevent, individual ultracapacitors from exceeding its rated voltage.

Balancing can be achieved through two different methods, active balancing or passive balancing:

- Active balancing schemes are varied. Maxwell has adopted a balancing methodology based on a linear voltage balancing scheme. This methodology will always attempt

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to balance two adjoining ultracapacitors based on the voltage mismatch between the two ultracapacitors. The maximum current during balancing varies by product. Refer to the product data sheet or product manual for more information.

- Passive balancing implies no variation in the voltage regulation as a function of the ultracapacitor condition. The most typical method of passive balancing utilizes resistors in parallel with the ultracapacitors.

A variety of interconnect methods are employed with the various product offerings. They range from buss bar interconnecting to soldering. In general the larger the cell capacitance the more critical the cell interconnects becomes. The larger capacitance devices have internal resistances on the order of a few hundred microohms. A poor interconnection can have more resistance than the internal resistance of the device itself. Larger devices will generally be required to carry larger currents, thus necessitating reliable interconnects.

9. Efficiency

Unlike batteries, the ultracapacitor has the same efficiency during charge or discharge. This enables the ultracapacitor to be recharged quickly without current limiting as long as the current is within the rated current for the device.

The only efficiency losses associated with ultracapacitors are due to internal resistance of the device resulting in IR drop during cycling. For most uses the ultracapacitor efficiency is in excess of 98%. For high current or power pulsing the efficiency is reduced. Typical efficiency under high current pulses is still greater than 90%.

10. Thermal Properties

For minimum performance influence over the life of the application it is necessary to maintain the ultracapacitor core temperature within the rated temperature range of the device. The lower the temperature is maintained the better for life considerations.

All products are provided with an electrically insulating shrink sleeving around the capacitor body. For this reason and since all current passes through the capacitor terminals, cooling at the capacitor ends or terminals is the most efficient means for cooling of the capacitor.

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Depending on the duty cycle of the application cooling can be accomplished via heat sinks (conduction), air flow (convection) or a combination of the two. Consideration should be made for the duty cycle and resulting capacitor temperature as well as the anticipated ambient temperature the device will be operating under. The combination of the two should not exceed the operating temperature for the ultracapacitor.

More information and advice on thermal performance and design considerations is provided for each product on the data sheet.

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