Reliability of SuperCapacitors: Paper 1

Unique Performance at 85°C & Self-Balancing

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Introduction

Increasing use of supercapacitors on printed circuit boards (PCBs) is requiring a further understanding of the reliability of these components. As the use of these types of devices increases, the emphasis on reliability will become critical as sub-ppm failure rates are critical for minimizing and, in fact, eliminating rework of the PCBs in these applications. A broader understanding of the reliability of these devices will assist in reaching this goal.

In this first of many publications, a study of our supercapacitor modules tested at 85°C at various applied voltages, at or below the rated voltage, will demonstrate the impact of voltage on reliability.

Reliability Basics

Unlike the usual testing of electrostatic capacitors which allows the use of higher voltages (V) and temperatures (T) as acceleration factors, electrochemical devices like supercapacitors and batteries offer limited opportunities to use these techniques. One of the key requirements for use of V and T for acceleration is that their corresponding mechanisms should stay the same; unfortunately, this is not the case for electrochemical devices. Using higher voltages and temperatures than the supercapacitor is rated for will cause the failure mechanism to change, thus these conditions are not representative of normal operating conditions. Because of these limitations, these family of devices may be tested at or below the maximum rated temperature and/or voltage only, and is made possible by testing the devices under test (DUTs) for larger number of device hours by increasing test time (t). An alternative approach is to test the devices at or below the rated V and T, and ensure that the mechanisms do not change and data can be used to estimate the failure rates. Similar testing for electrochemical devices for the last 12 years has permitted our team to establish some rules of thumb which can be verified by cross-checking the results to validate these guidelines. These guidelines will be utilized as we further the understanding of this family of components. Failure rate F has been shown to follow the relationship:

$$F \propto V^n \cdot e^{\frac{-Q}{kT}}$$

where V is the voltage, n is the voltage exponent, Q is the activation energy in eV, and k is the Boltzmann constant.

Basic Guidelines for SuperCap use in Circuits

It is very important to understand that lifetime of supercapacitors is a function of both voltage and temperature. Without gaining an understanding of the operating conditions, recommending any type of capacitor or estimating lifetime becomes useless. Reiterating, the rated voltage and rated operating temperature range of a supercapacitor should never be exceeded. This leads to accelerated failure of the supercapacitor and can cause permanent damage to the entire circuit.

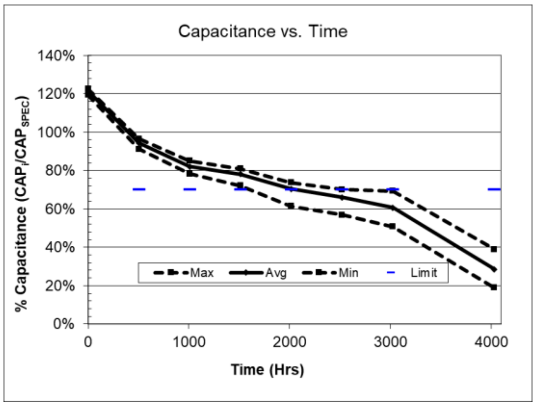
One of the main limitations to standalone supercapacitors among energy storage devices are their rated voltages are comparatively lower than replacement options such as batteries. To combat this issue, supercapacitors are placed in series to attain a desired voltage. Anytime capacitors are used in series, it tends to create a voltage imbalance during the charge and discharge cycle – thus keeping the voltage across each capacitor at or below rated voltage is key to lengthening the lifetime of all components. Balancing circuitry is possible in a variety of tactics: passive balancing with a resistor across a capacitor or with a diode, active balancing with an IC chip for example, or by using a buck-boost converter with a single large capacitor to scale up the voltage. In any case it requires adding nonessential components that could ruin constrained footprints and load current.

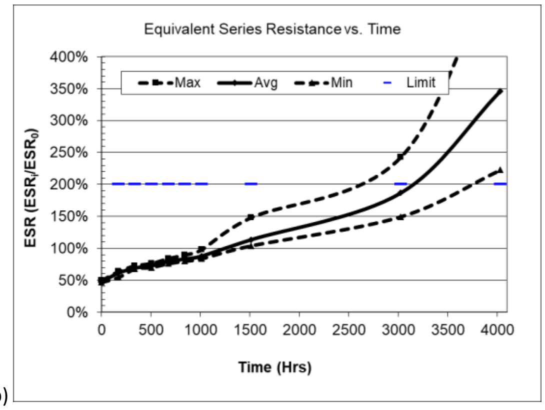
Test Results

AVX SuperCapacitor Modules (SCM Series) are unique in a way that they do not *require* balancing circuitry. The SCM Series is a new series of electrochemical, double-layer, series-connected supercapacitor modules that offer excellent pulse power handling characteristics based on the combination of very high capacitance and very low ESR. The core matching technique deployed in production allows for greater performance and longer lifetimes. Backed by over 4,000 hours of data, AVX has proven balancing can be avoided when creating modules by combining capacitors with similar capacitance, leakage current values, and ESR values. This is on the assumption that the leakage current value was taken when the charging current reaches an asymptotic value – or approximately 72 hours of test time.

Test Data for SCMT22C505MRBA0 (5V, 5F parts) at 85°C:

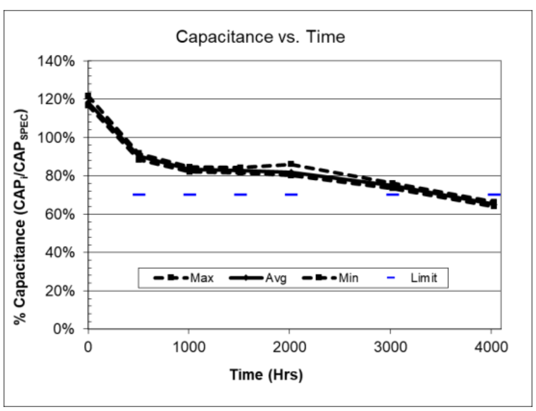
SCM Series parts were tested at various applied voltages and results clearly demonstrate that as the voltage drops the parts actually show decreasing rate of change in capacitance and ESR values become stable with time.

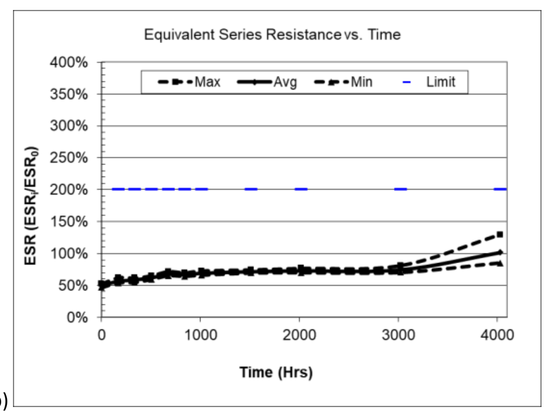
(1a) 

(1b) 

Figures 1a and 1b represent Capacitance vs. Time and Equivalent Series Resistance vs. Time, respectively, for SCMT22C505MRBA0 at rated voltage for 4,000 hours at 85°C.

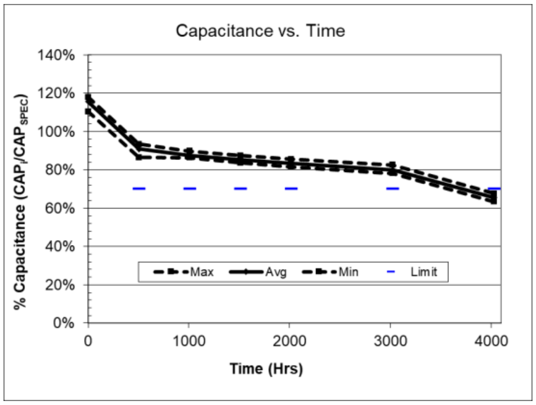
At rated voltage, all SCM Series parts are rated to 65°C maximum. As both Figures 1a and 1b display, the part suffered catastrophic failure at rated voltage and 85°C, verifying that operating within operating voltage and temperature are critical.

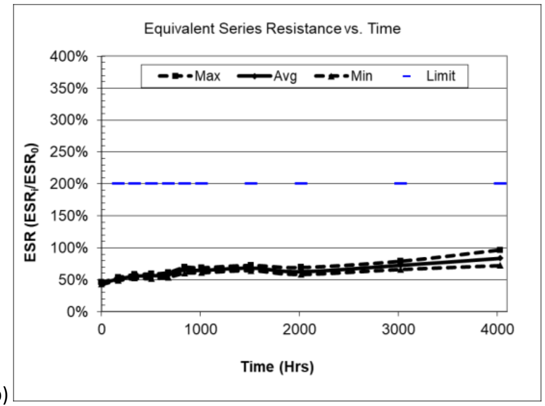
(2a) 

(2b) 

Figures 2a and 2b represent Capacitance vs. Time and Equivalent Series Resistance vs. Time, respectively, for SCMT22C505MRBA0 at 90% rated voltage, otherwise 4.5V, for 4,000 hours at 85°C.

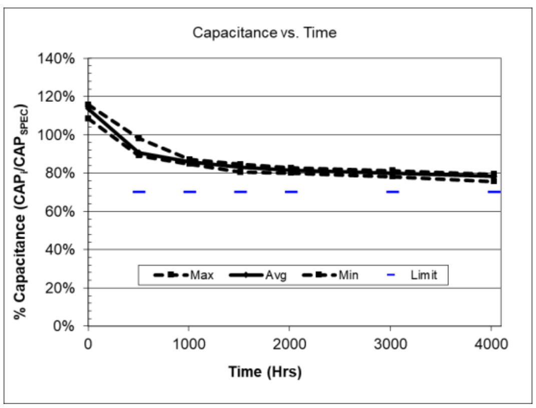
Figures 2a and 2b show that derating to 90% (4.5V) of rated voltage drastically improved the longevity of the part. The 5F part lost 30% of capacitance a little over 3,000 hours and ESR began exhibiting a slow rise at the same mark. It can be safely concluded that this part would survive 85°C operating temperature for 3,000 hours at 4.5V operating voltage.

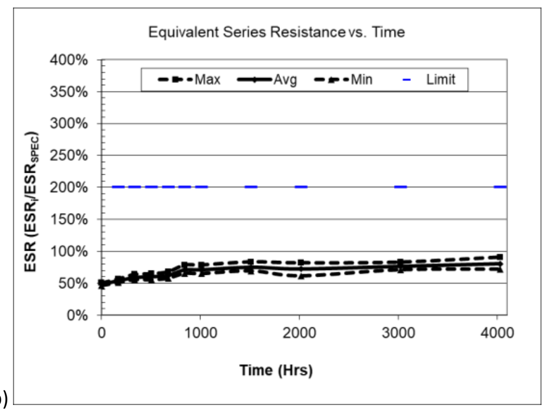
(3a) 

(3b) 

Figures 3a and 3b represent Capacitance vs. Time and Equivalent Series Resistance vs. Time, respectively, for SCMT22C505MRBA0 at 80% rated voltage, otherwise 4.0V, for 4,000 hours at 85°C.

At 80% of rated voltage (4.0V), the part almost passed 85°C testing conditions for 4,000 hours. The ESR curve was encouraging – slow, lethargic rise – however, the capacitance dropped off after 3,000 hours of testing as shown in Figure 3a.

(4a) 

(4b) 

Figures 4a and 4b represent Capacitance vs. Time and Equivalent Series Resistance vs. Time, respectively, for SCMT22C505MRBA0 at 70% rated voltage, otherwise 3.5V, for 4,000 hours at 85°C.

While derating the operating voltage to 70% (3.5V), capacitance reached an asymptotic curve and ESR remained stagnant, as can be seen in Figures 4a and 4b, respectively. SCMT22C505MRBA0 easily passed 4,000 hours of testing at 85°C operating temperature.

Conclusions

Test results clearly indicate that AVX SuperCapacitor Modules, or SCM Series supercapacitors, exhibit unique qualities as they may be used at 85°C and voltages ≤ 4 volts. Additionally, these operating conditions support the use of Li-ion batteries, a feature not offered by any other supplier in the industry.