Ta SMD capacitors with Polymer Counter Electrode for Space Applications

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ABSTRACT

Solid electrolytic tantalum capacitors using conductive polymers as the solid cathode electrolyte have been commercially available since the mid 1990's and continuously adopted by increased demand applications. This cathode system offers numerous advantages over traditional manganese dioxide based solid electrolytic capacitors, including lower ESR (Equivalent Series Resistance), improved surge current resistance, benign failure mode and lower voltage derating requirements. For the past several years KEMET has worked with European Space Agency support to develop and release to market the T583 Series, as detailed in specification ESCC3012/005.

Following the last application requirements KEMET started the development of single digit equivalent series resistance product. This paper presents the latest in line electrical characterization and ETP (Evaluation Test Plan) results.

INTRODUCTION

The general trend of new market and design in applications require ever lower ESR, high capacitance and high reliability. To achieve such capabilities, we directed our efforts on the multi-anode approach (Fig.1), taking entire advantage of its cumulative charge storage characteristics, cathode material and geometry of the paths within its elements.

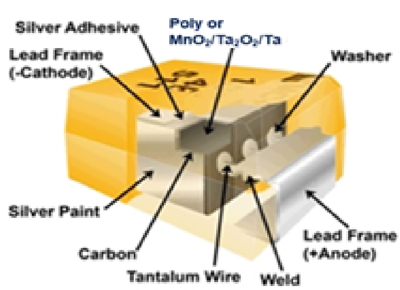

Fig.1. Multianode Virtual Cross Cut

The deepest capacitive element is the one that defines the worst or highest resistive connection to these elements and is the first element to stop responding at increasing frequencies, continuing to the outermost capacitive elements.

In this way, the KEMET Multianode design composed by a three-pellet structure will allow us to reduce the resistance connecting these capacitive elements to the external contacts of the device, reducing the penetration depth to the deepest capacitive element by one-third compared to the single anode structure. Therefore the three pellets in paralel will act as resistors in paralell, offering an effective resistance of one-third of each individual element (Fig.2).

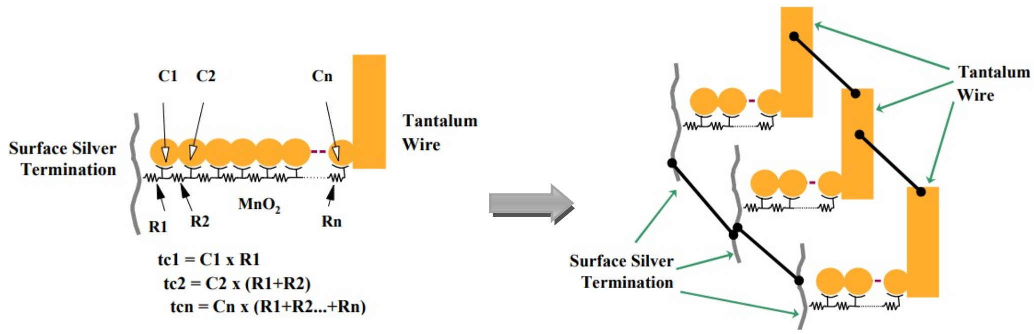

Fig.2. Capacitive Structure Model for Single and Multianode

In addition, the use of low resistivity conductive polymer as material for the cathode system will turn it in the perfect combination for low ESR and high capacitance, with better performance in frequency and the inherent benefit of "no ignition" known to polymer technology.

To support the market requirement for an ultra-low ESR with maximum capacitance for POL ('Point of load') solutions KEMET started a new project to release the EIA 7343-43 330uF10V with ultra-low ESR targeting ESR≤15mOhm. This new PNR (Part Number) has a similar base design and manufacturing process as the previously qualified EPPL (European Preferred Part List) T583 Series under detailed Specification ESCC3012/005, building on the knowledge and technology of the earlier design, with the main difference being the assembly of multiple anodes – 3 in this specific case. Fig 3 outlines the experimental plan and milestones of this project.

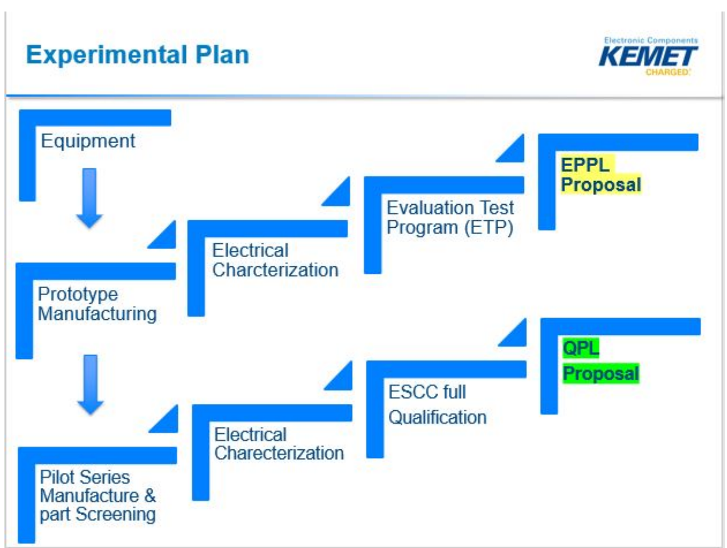

Fig.3. Multianode T584 Series Experimental Plan

This paper will be sharing preliminary results and evaluation test program data of prototype batch with PNR: T584X337M010AHE010P000.

IN-LINE DATA

As presented in September 2107 in the 1st Passive Components Networking Symposium, in Brno, Czech Republic, prototyping for EIA 7343-43 330uF10V in Mutianode construction approach was started and has now available all in-line data. Some sample pictures are shared on Fig.4.

Fig.4. Multianode T584X337/010 Samples Pictures

Intermediate electrical measurements were performed before assembly, to individual anodes as an indicator and first control of the parts electrical quality. The data of this test, also referred to as Solid Test Measurements, is the first evaluation possible on the complete solid unmounted capacitor, allowing us to have a good indication of the 3 anodes assembled future electrical behavior, as we can observe on the plot graphs below.

This intermediate evaluation of the batches is done by sampling, and the values measured are within expectation, with good distributions and very few failures or outliers, allowing us to move forward to assembly -Fig.5.

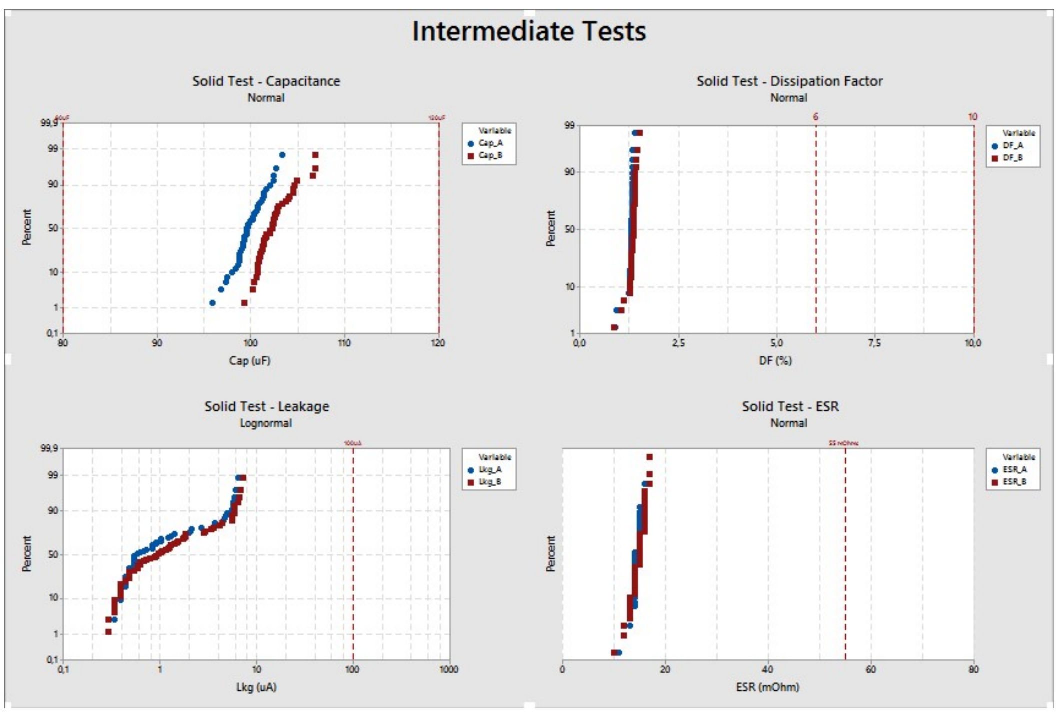

Fig.5. Multianode T584X337/010 Series Intermediate Measurements

At the end of line, 100% electrical screening is performed to remove non-conforming unit. Hot in-rush (surge) and hot leakage tests are conducted followed by room temperature screening of capacitance, DF, ESR and leakage. All screens employ a guard band to insure product surviving the screens are reliable.

Table 1 has a summary of the electrical performance of the batch at end of line with the mean values achieved for the electrical characteristics measured for the first prototype batch of Multianode X 330uF 10V tested.

Table1. - Multianode T584X337/010 Electrical Performance

Electrical Performance	
Parameters	T584X337M010AHE010P000
KO Batch #	
Lkg mean (µA)	45,25
Cap mean (µF)	300,36
DF mean (%)	1,54
ESR mean (Ω)	0,0079

As part of our characterization, a sample from the batch was submitted for SMT – (Surface Mount Test). This test consists of a mounting process in which LCDR (Leakage, Capacitance, DF and ESR) are measured before and after the mounting process. The SMT consist of assembling finished parts on a PCB (Print Circuit Board) that is passed through a reflow oven 2 times. The reflow profile and peak temperatures are in accordance with EIA specifications for Sn/Pb solders. Electrical readings are performed before and after the reflow cycles, and the results are reviewed and analyzed. Figure 6 present the graphical result of those measurements.

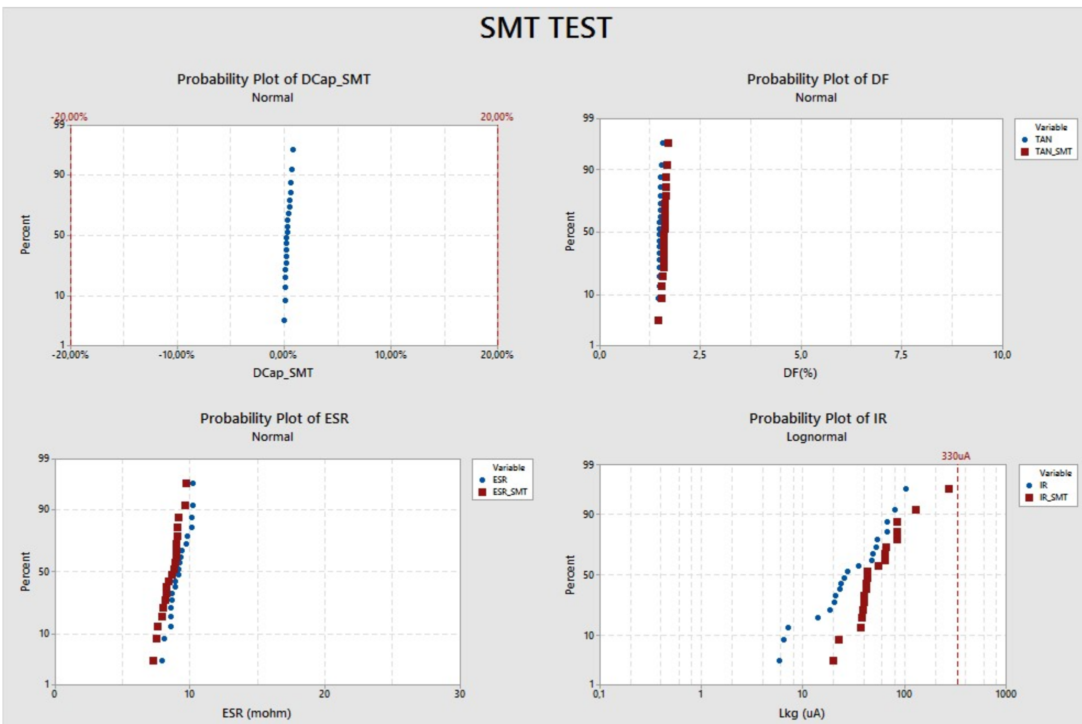

Fig.6. Multianode T584X337/010 Series SMT Test

ELECTRICAL CHARACTERIZATION

Similar to the single anode qualification, 3 additional standard conformity check procedures tests were carried out to provide a more complete characterization of the parts produced, prior to moving to the ETP Phase. These tests were:

- SSST Test (Step Stress Surge Test);
- Cap and ESR over a range of frequencies;
- Electrical characterization over a range of temperatures.

SSST is a low resistance, high current test that subjects the components to increasing voltages until failure. This is a destructive supplementary test that is a good indicator of dielectric stability.

This test consists of determining the voltage at which the dielectric breaks down under high surge current conditions. This behavior will give us a prediction on the reliability of the parts for the application voltage defined. Finished parts are assembled on a PCB that is submitted to 2 Sn/Pb reflow cycles, and the board is then submitted to test. Figure 7 is a percentile plot of the cumulative % of pieced exhibiting breakdown versus the voltage at which the breakdown occurred.

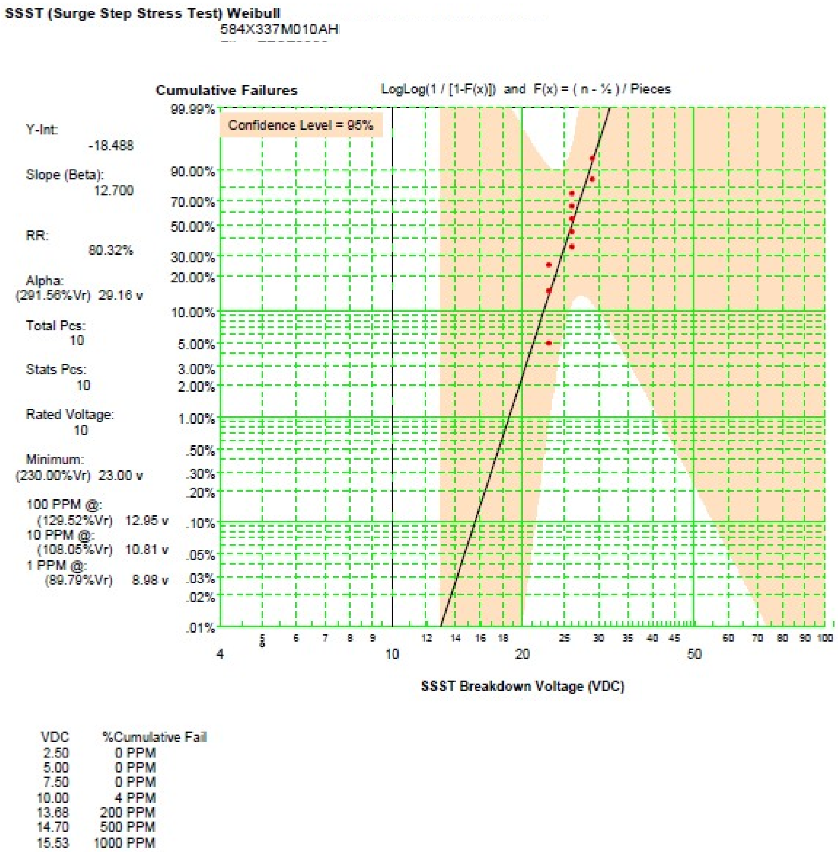

Fig.7. Multianode T584X337/010 SSST Testing

The PNR evaluated presented a very good SSST behavior within expectation, with the first failure approximately two times higher than the rated voltage, consistent with the behavior of the single anode.

For measurements in frequency, capacitance is typically measured at 120Hz and 25ºC with up to 1volt rms applied. The behavior of the batches in frequencies from 100Hz to 100 kHz was measured for 5 parts, and as expected, the parts exhibit the typical polymer Ta Cap behavior of Capacitance in frequency, presenting quite stable values along the frequency range up to 100 KHz- Fig.8. This known behavior is a result of the high conductivity of the organic polymer conductive coating, combined with the previously described advantages of a multianode construction. This characteristic is of interesting advantages of this design for high frequency applications.

ESR was measured from 100Hz to 10MHz at 25ºC. As expected the ESR is higher at low frequencies, decreasing with increasing frequency up to 100KHz and remaining low and stable at higher frequencies – Fig.9. This profile results from the higher contribution of oxide losses to ESR at lower frequencies, which become smaller with increasing frequency.

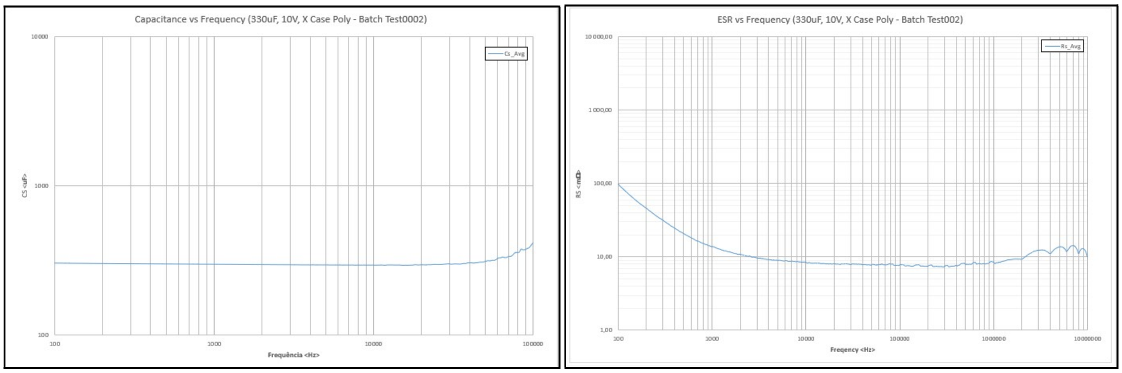

Fig.8 & 9 -. Multianode T584X337/010 Frequency Testing for Capacitance and ESR.

Mounted Capacitors were subjected to extreme temperatures testing at a succession of continuous steps. To characterize the behavior at the recommended operation range temperatures (-55ºC min to 105ºC max) random parts were selected and submitted to our Lab facility. The main Electrical Characteristics were plotted for several conditions against Room Temperature to easily evaluate the impact of temperature, and from a general point of view, the PNR evaluated presented behavior similar and consistent with the previously evaluated single anode form T583 Series. - Fig 10.

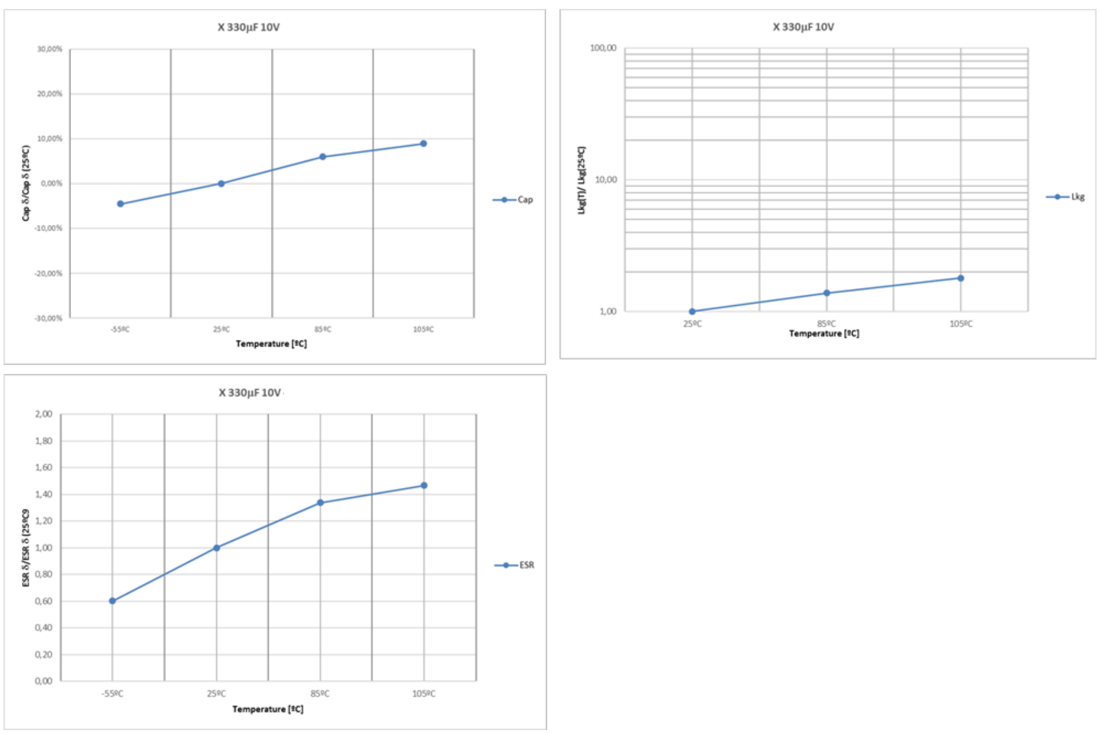

Fig.10 -. Multianode T584X337/010 Temperature Characterization.

Capacitance is mostly dependent of the dielectric and therefore will increase with temperature in accordance with its Capacitance and Voltage Value. A maximum variation of 30% of the initial value is expected at 125ºC. DC leakage is highly dependent on temperature and tends to increase at higher temperatures with specification limits of 10 x Initial Value for 85 and 125ºC. The PNR tested present a maximum increase of 2 x IL (initial limit), well within limits, and showing good stability. For solid electrolytic capacitors ESR is generally determined primarily by the resistance of the electrolyte and the size of the capacitor, but for capacitors exhibiting such low ESR, the contribution from the resistance of the metals present in the construction have a significant contribution to the ESR of the device. A slight increase in ESR is therefore observed.

EVALUATION TEST PROGRAM

The Evaluation Test program for the multianode samples was reviewed and established with our ESA partners. The agreed upon test plan for the multianode design took the performance during ETP testing and electrical characterization for the previously EPPL qualified single anode design (ESCC3012/005) as a baseline. To achieve the for the most relevant and quickest path to qualification the following test plan was defined:

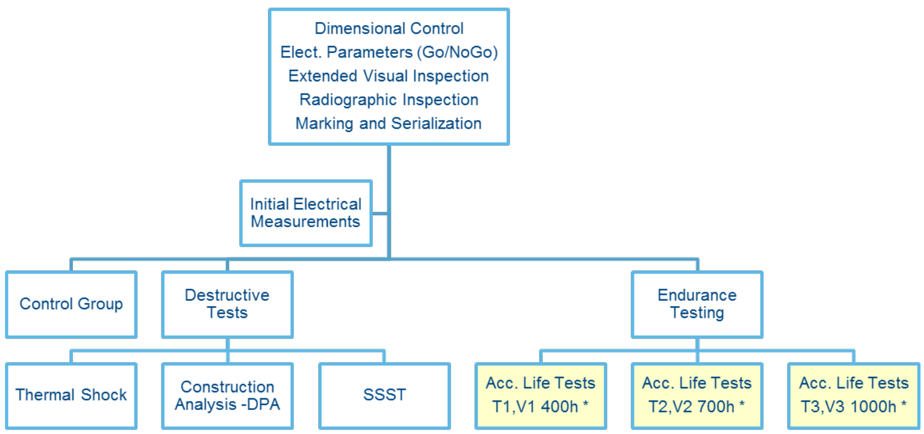

Fig.11 -. Multianode T584X337/010 Agreed Evaluation Test Program (ETP) .

Five parts were sent to ESA facilities to perform Construction Analysis, and the remaining were tested at our Laboratory with all results complete.

SSST Test had already been performed as part of our Electrical Characterization, thus was not repeated (Fig7).

As per ESCC Basic Specification Nº2263000, Thermal Shock was executed on 5 parts, assuring separate chambers equipment, submitting the parts selected to 25 Cycles of 30min steps between -65ºC and +125ºC. Electrical Characteristics were evaluated before and after the test, and at intermediate points of 5 and 15 cycles, with no significant drifts in any of the electrical Characteristics monitored, and no indication of issues in the device construction or materials.

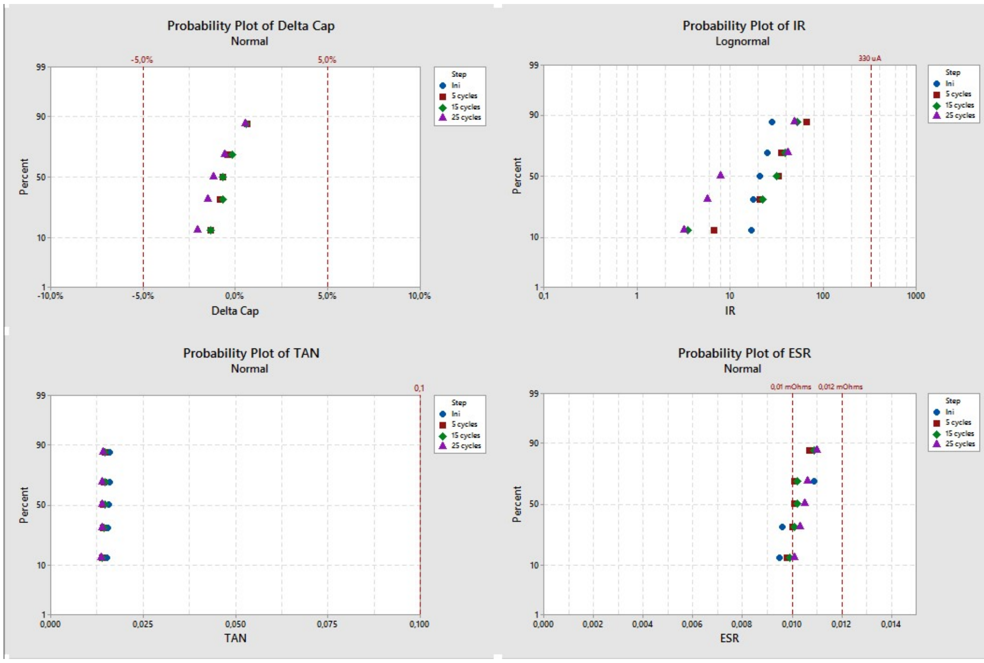

Fig.12 -. Multianode T584X337/010 Thermal Shock

The Steady State Accelerated Life Test (SSALT) were defined to be performed at the same conditions as the one used for the single anode evaluation in order to cover the different conditions and ranges in temperature and voltage and also assure the same performance as the single anode. The three tests were pushed up to 2000hrs, beyond their estimated failure time to better characterize the new design and evaluate the reliability impact of the assembly of the 3 pellets - Fig 13,14 & 15.

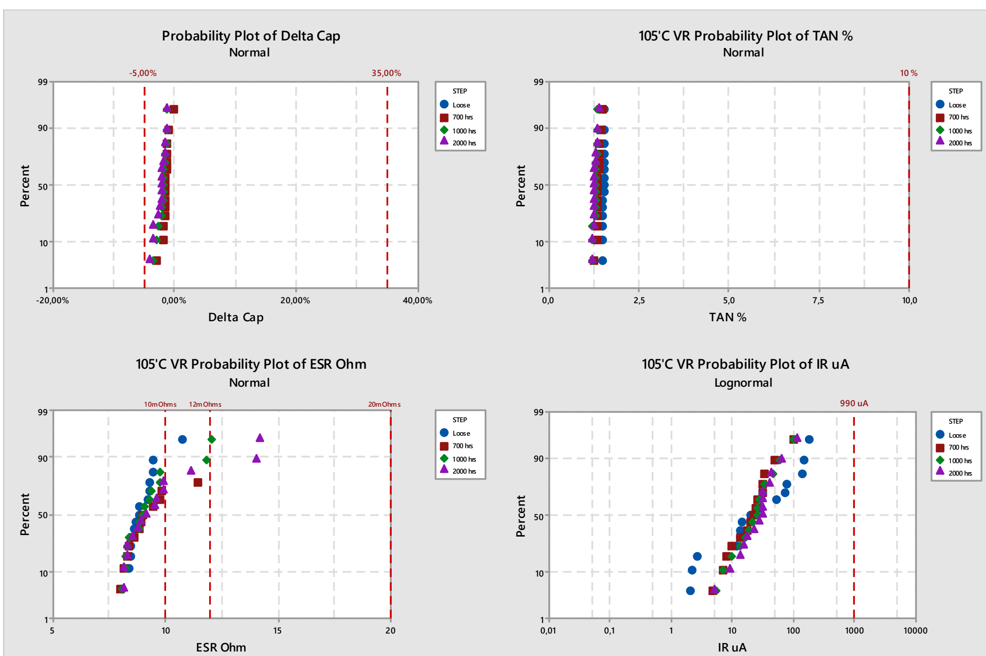

Fig.13 -. Multianode T584X337/010 SSAL T_1V_1

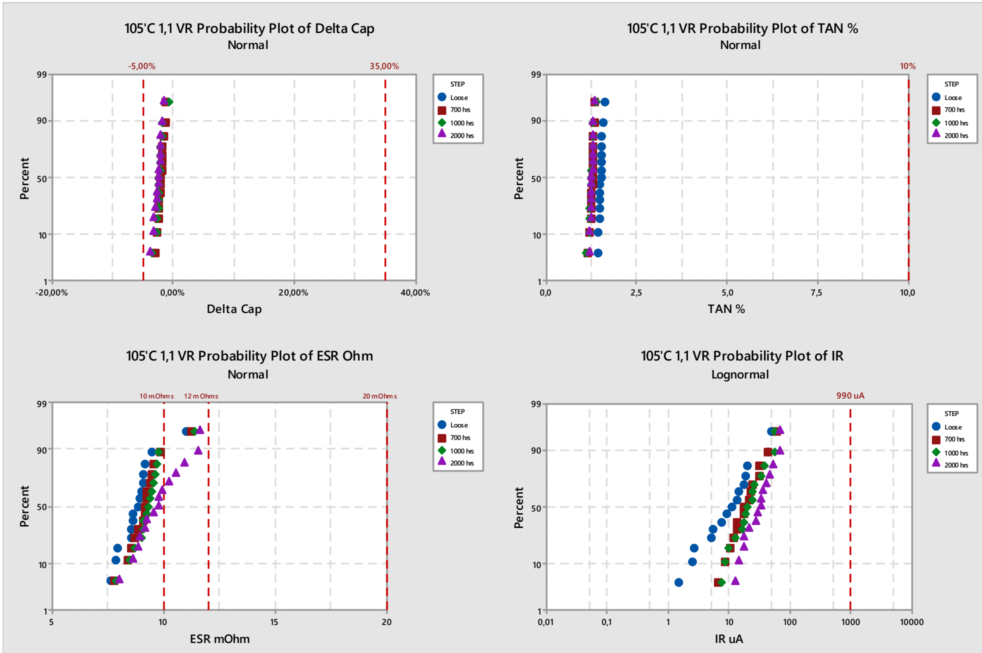

Fig.14 -. Multianode T584X337/010 SSAL T_2V_2

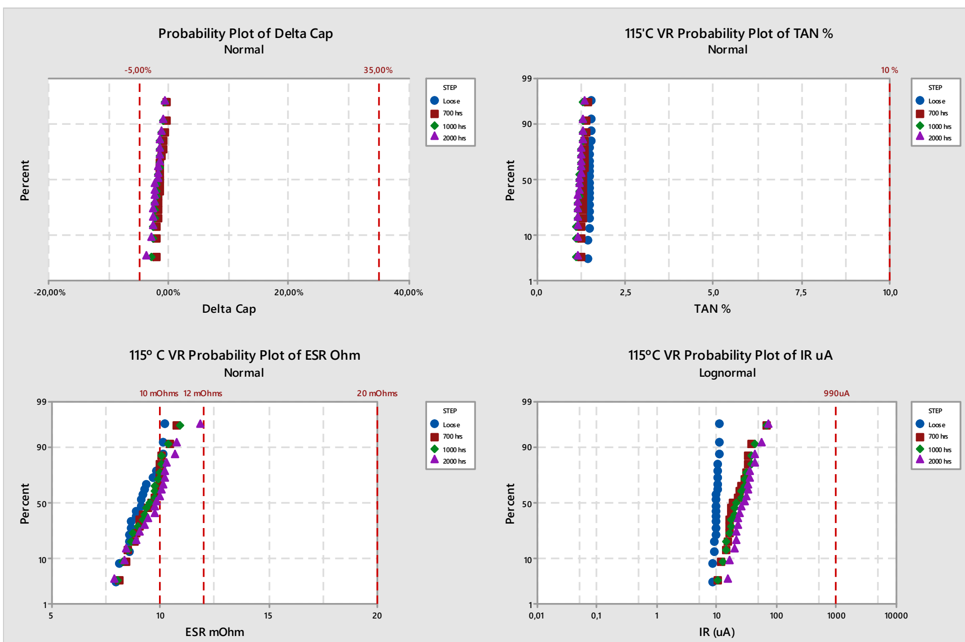

Fig.15 -. Multianode T584X337/010 SSAL T_3V_3

The three SSALT presented a good behaviour up to the estimated failure time, consistent with the single anode reported behaviour. When extended to 1000 & 2000hrs, some expected slight drifts in ESR are reported, presenting nevertheless stability on remaining electrical characteristics, including DC Leakage, result of a good assembly & construction in this model.

Note that the test voltage was maintained during the cool down from elevated test temperature to +25°C and the capacitor was discharged for a minimum of 5 minutes prior to the DC leakage measurements documented above. This practice avoids the Anomalous Charge Current (ACC) effect during DC leakage measurements.

Anomalous Charge Current

ACC is a phenomenon where higher current flows into a capacitor while charging than is predicted by i = c ∗ *dv/dt.* ACC increases the time required to fully charge a capacitor at a constant current, but ACC is not caused by degradation of the capacitor's dielectric. ACC occurs when the capacitor is in a "dry state", with higher impact at lower temperatures. Anomalous Charge Current phenomenon occurs at voltages below rated for only certain designs with specific design criteria, material sets and conductive polymer formulations necessary to achieve specific design goals (higher reliability, smaller size, higher voltage, etc.).

ACC is observed only if the applied voltage exceeds a 'threshold' voltage. Below this voltage, charging obeys i = c ∗ *dv/dt.* To illustrate ACC, the current required to charge a T584X337/010 at 0, 25 and 45°C at a voltage ramp rate of 120V/sec was measured. The charging current and applied voltage are plotted versus time in Figure 16. Below an applied voltage of approximately 5 volts the charging current for the 3 curves is generally flat and very close to the theoretical charging current of 39.6 mA. At applied voltages above 5 volts the charging current measured at 0°C is observed to increase relative to the theoretical line. The deviation is less noticeable at 25 and 45°C.

For higher voltage ramp rates, the theoretical charging currents are higher and deviations from the theoretical charging current become less noticeable. The potential impact of ACC on circuit performance is dependent on many factors, including circuit design, circuit voltage, and voltage ramp rate. In Space and Military applications, where conservative derating rules are applied, this phenomenon is normally not observed and does not impact the final application.

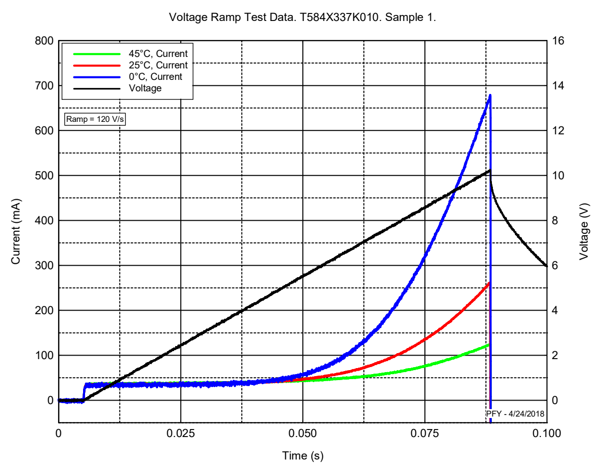

Figure 16. Constant voltage ramp test to illustrate ACC

CONCLUSIONS

With Evaluation Test Program report, and upon on-going Construction Analysis completion, it is KEMET's intent to apply for EPPL-part2, with a new detailed Specification for T584 Series based on existing released 3012/005 (T583 Series). Pilot Series for QPL (Qualified Part List) will then be manufactured and qualified accordingly to close the process.

KEMET will continue its development efforts qualifying needed components of SMD Tantalum technology for space applications with increasing harsh environmental conditions.

ACKNOWLEDGMENTS

The developed work and quick definition for this new series of Ta SMD Polymer Multianode Cap -T584, was only possible through a good support and partnership with ESA technical department.

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