Ta SMD capacitors with Polymer Counter Electrode for Space Applications

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ABSTRACT

Solid electrolytic tantalum capacitors utilizing intrinsically conductive polymers as the solid cathode electrolyte have been commercially available since the mid 1990's. Components utilizing this cathode system offer numerous advantages over traditional manganese dioxide based solid electrolytic capacitors, including lower ESR, improved surge current resistance, benign failure mode and lower voltage derating requirements. In 2012 high reliability capacitors employing intrinsically conductive polymer cathodes for military and aerospace markets were successfully developed and marketed.

This paper presents reliability data for low voltage, low ESR tantalum capacitors which use an intrinsically conductive polymer as the cathode. This product was developed in partnership with the European Space Agency. A new ESCC specification, ESCC3012/005 references this new product portfolio. This paper includes the current undergoing qualification testing data for ESA's QPL and further development results in the extended range high voltage, low ESR product portfolio under an on-going partnership agreement with the European Space Agency.

Following the market 'voice of customer' requests this paper finalizes with the initial reliability results for the EIA7343-43 330uF10V with ultra-low ESR according the space ETP testing

INTRODUCTION

Surface Mount technology tantalum capacitors continue to be of preference, being widely used in general electronic industry and new circuits designs due to their unique characteristics of high volumetric efficiency, high long term reliability and stability as well as good process compatibility. During last decades many capabilities were successfully introduced to the market, starting with single digit ESR for decoupling at low and high voltages for input/output in DC/DC and power management. The introduction of design and process improvements allow the evolution in the market from terrestrial to space applications, giving the space application designers the possibility to use the advantages of the technology: (a) stable capacitance in temperature, voltage, over time and in frequency; (b) benign failure mode and (c) high volumetric efficiency.

Back in 2012 KEMET was the 1st to market with Mil-Aero and Space surface mount tantalum polymer technology, T540 and T541 COTS Polymer Electrolytic for High Reliability Applications Series. This product offerings were first in the market with failure rate options, based on KEMET's KO-CAP Reliability Assessment Method, which utilizes accelerated conditions of voltage and temperature applied to board mounted samples to access long term device reliability. Those products are available with DLA drawings from US DoD: Dwg 04051 and Dwg04052 and a specific MIL-PRF Standard for Polymer technology, based in the existing MIL-PRF-55365, is under preparation in USA.

In light of all these advantages, utilizing existing KEMET's advanced polymer technology and following the market trend and latest technology innovations, KEMET started in 2012 with ESA support, a project to *'Develop Ta SMD polymer technology counter electrode for European Space applications up to 50V'*.

This project was developed in two main phases:

- (1) phase addressed the characterization and study of the failure mechanisms of the existing range of capability in the Évora plant, limited to 16V volt ratings built with first generation technology and directed to terrestrial applications, through a comprehensive and detailed Evaluation Test Plan. This allowed us to define the major needs to address the 50V voltage capability compliant with space requirements within
- a (2) phase of the project, and to qualify our existing low voltage portfolio being added to EPPL2 regulated according to specification ESCC3012/005.

In addition, in order to support the customer requirement for an ultra-low ESR with maximum capacitance for POL ('Point of load') solutions KEMET start a new project to release the EIA 7343-43 330uF10V with ESR<10mOhm.

Low voltage applications

As presented in the last October 2016 in the 2nd Space Passive Components Days Symposium, to address and characterize the existing available range, up to 16V, three representative corner types were selected, based on capacitance and rated voltage, covering the spectrum of production as defined in Fig.1.

Capacitance C_n (µF)	Rated Voltage U_R		
	6.3V	10V	16V
33			60, 70
47			70
68		45, 60, 100	
100	45	55, 80	
150	45, 55		

Selected representative corner types for 6.3, 10 and 16V

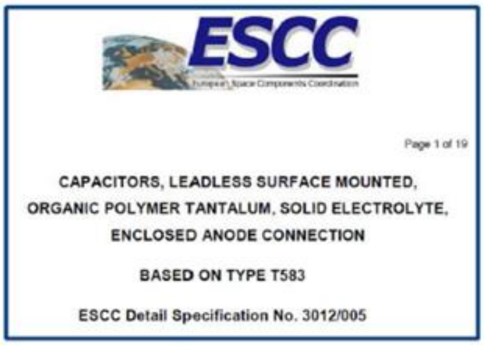
Fig.1. Initial proposal for existing range samples

Considering all the possible failure mechanisms, reliability data available, and testing experience and knowledge such as Military Standards, the R&D team developed an Evaluation Test Program in accordance with ESCC nº 2263000, that allowed the determination of the failure mode mechanisms of this technology in a first phase and proof high voltage capability in a second phase. Step-stress Tests in voltage and temperature to address reliability in maximum operating conditions, operational and accelerated Life tests and moisture resistance testing are part of the challenging evaluation. The ETP Final agreement test package can be found in resume in Fig.2.

TEST Nr	Evaluation Test Program Test Description	Precedence	Status
2Bi	Voltage Step Stress Test (VSST)	---	OK
2Bii	Temperature Step Stress Test (TSST)	2Bi	OK
2Biii	High Inrush Current Step Stress Test (SSST)	---	PASS
2Ci	Solderability / Adhesion	---	PASS
2Cii	Solderability /Humidity Sequence	---	PASS
2Cii	Moisture Resistance	---	PASS
3	Steady State Accelerate Life Test (T1/V1, T2/V2, T3/V3)	2Bi/ 2Bii	PASS
4	Operational Life Tests	---	PASS
5	Storage	---	PASS

Fig.2. Low Voltage ETP Final agreement and results

Taken in consideration of the good results achieved with the existing range samples, a small low voltage portfolio regulated by ESCC Details Specification nr. 3012/005 was proposed and approved for publication in European Preferred Part List (EPPL) – part2 issue 30. This same portfolio Fig3. is undergoing further testing for QPL qualification describe in Fig 4 with finalization date planned in end of CY2018.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CAPACITORS, LEADLESS SURFACE MOUNTED, ORGANIC POLYMER TANTALUM, SOLID ELECTROLYTE, ENCLOSED ANODE CONNECTION

BASED ON TYPE T583

ESCC Detail Specification No. 3012/005

Capacitance C_n (µF)	Rated Voltage U_R		
	6.3V	10V	16V
33			60, 70
47			70
68		45, 60, 100	
100	45	55, 80	
150	45, 55		

Fig. 3.ESCC nr 3012/005 and T583Low Voltage available portfolio

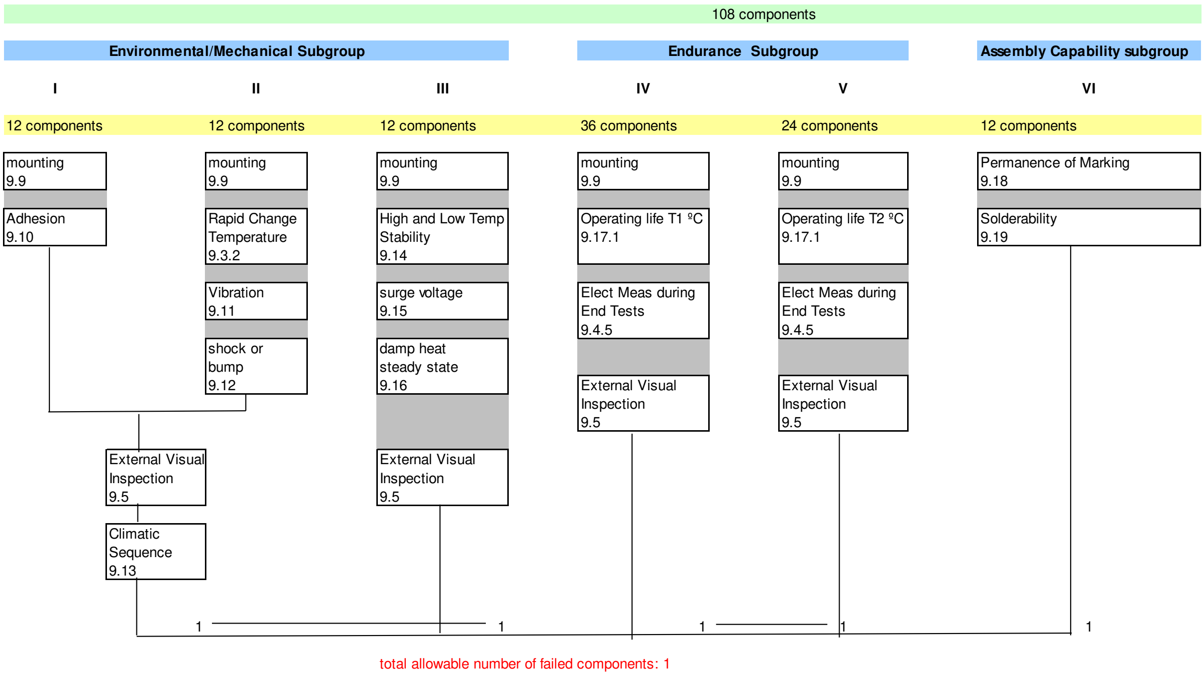

Fig 4. QPL Qualification Process in progress in LV range

Before the QPL testing all the components are subject to a sequence of burn in and electrical characterization at low and high temperature, radiographic inspection and visual inspection as describe in the ESCC Generic Specification 3012. The burn in applied to the parts follow the electric drift measurement B grade. An example of the burn-in performance of the parts is shown in figure 5. Results demonstrate that electrical characteristic are stable after 168h / 85ºCat rated voltage conditions. These parts are now subject to the environmental, mechanical, endurance and assembly capability QPL tests.

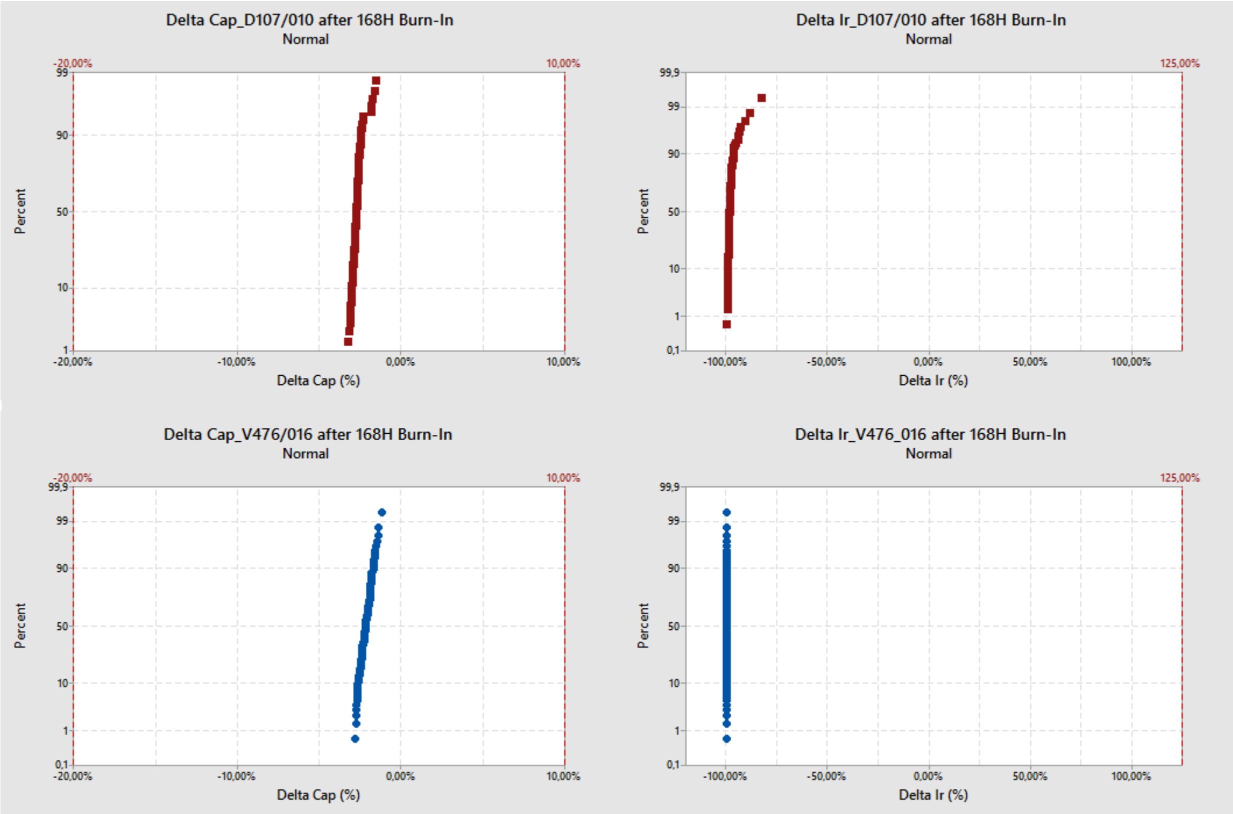

Fig 5. Low Voltage QPL parts – Burn-in Drift Analysis

From all the data retrieved form the ETP, a possible path was defined to overcome the identified weakness and degradation modes of the existing technology, and achieve the development, as intended, of very low ESR Polymer Ta Capacitor for High Voltage.

High voltage applications

The 2nd phase of the project sought to overcome the identified limitation to 16V of the existing Low Voltage range capability portfolio for the Évora plant, assuring a good breakdown Voltage (BDV) performance for application voltages up to 50V, and the reliability required for Space applications.

In order to overcome the identified weakness and degradation modes of the existing technology, a possible path to achieve the development, of very low ESR 25 to 50V polymer Ta Capacitors was defined and agreed with ESA.

Based on existing R&D developments within KEMET, a new hybrid process was studied with the combination of both in-situ polymerization and pre-polymerized solution deposition that through the reduction of the number of local chemical reactions, and consequent defect sites, improves the interface quality between the coating and dielectric, and therefore overcomes the BDV weakness and stabilizes its behavior. Initial results were detailed presented and documented in the reference1.

Samples of extended rated voltage were manufactured (25 to 50V) with this 2nd generation polymerization process and were proposed for evaluation with the target to establish a Qualification roadmap for the 50V extended rated voltage industrialization- Fig.6

	Rated Voltage					
Cap	16	20	25	35	50	63
6,8						
10					D (125mΩ)	
15			D	D (100mΩ)		
22		D	D			
33		D	D (100mΩ)			
47		D				
68						

Legend:

Corners	Parts submitted for ETP testing
	Sister part types

Fig.6 Portfolio for Extended Voltage Range Qualification

The extended range Part numbers started the Evaluation Test Program, according Fig.7 and the results will determine if additional improvements or optimization are required. For the purpose of this discussion are presented some examples of available reliability data and behavior of the tested range under temperature.

TEST Nr	Evaluation Test Program Test Description	Precedence	Status
2A	Thermal Shock	---	PASS
2Bi	Voltage Step Stress Test (VSST)	---	OK
2Bii	Temperature Step Stress Test (TSST)	2Bi	OK
2Biii	High Inrush Current Step stress Test (SSST)	---	PASS
2Cii	Moisture Resistance	---	PASS
3	Steady State Accelerated Life Test (T1/V1, T2/V2, T3/V3)	2Bi/ 2Bii	Not Started
4	Operational Life Tests	---	On-Going
5	Storage	---	On-Going

Fig.7. High Voltage ETP Final agreement and status

Temperature Step Stress as part of group 2B of ETP intend to determine and push to the limit the dielectric. At rated voltage temperature step increase of 168h were performed, results are shown in fig 8.

		Parametric Failures (#)			Catastrophic Failures (#)		
Temperature (ºC)	Hours (h)	33uF25V	15uF35V	10uF50V	33uF25V	15uF35V	10uF50V
105	168	0	0	0	0	0	0
115	336	0	0	0	0	0	0
130	504	0	0	0	0	0	0
155	672	7	3	0	1	3	0
180	840						
		Acceptance Criteria DCL > 1,25IL ESR > 2 IL DF > IL Cap out -20%/+10%			Acceptance Criteria DCL > 10 IL ESR >3 IL DF > 2 IL Delta Cap 3x applicable tolerance		

Fig 8. ETP – 2Bii – Temperature Step Stress Test @ Ur (TSST) for Polymer HV Range (parametric / catastrophic failures analysis)

The cumulative temperature step stress shows that the 3 designs evaluated were inside the acceptance criteria limits up to 130ºC / Ur testing. After subjecting the capacitors +168h at 155ºC the 50V presented no failures and the 25V and 35V show some parametric failures. Those are mainly related to leakage current increases (1,5-2,5xIL). Only the 35V presented 3 parts with leakage current increase o respectively: 10,9, 11,2 and 12,2x IL spec limit. Testing up to 155ºC temperature step generated a limited % of failures < 15%, which is still distant form the 50% rule to allow failure characterization and smaller than the low voltage range evaluation.

Operational life tests are in progress and 85ºC@Ur and 105ºC@0,8Ur. An example of the Leakage current performance at 85ºC@Ur up to complete 2000h and at 105ºC@0,8Ur up to intermediate 500h measurements are shown in the probability plots of Fig 9a and 9b. The results are consistent with similar tested components in KEMET. The population in both cases has an DCL lower than 10uA well inside the specification limit of 82,5uA.

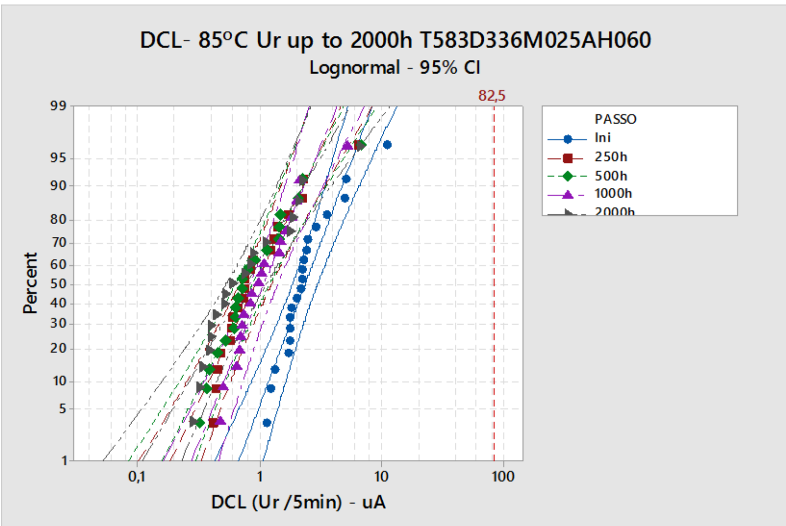

Fig 9a – Life Test – 85ºC@Ur – Leakage current – 7343-31 33uF25V

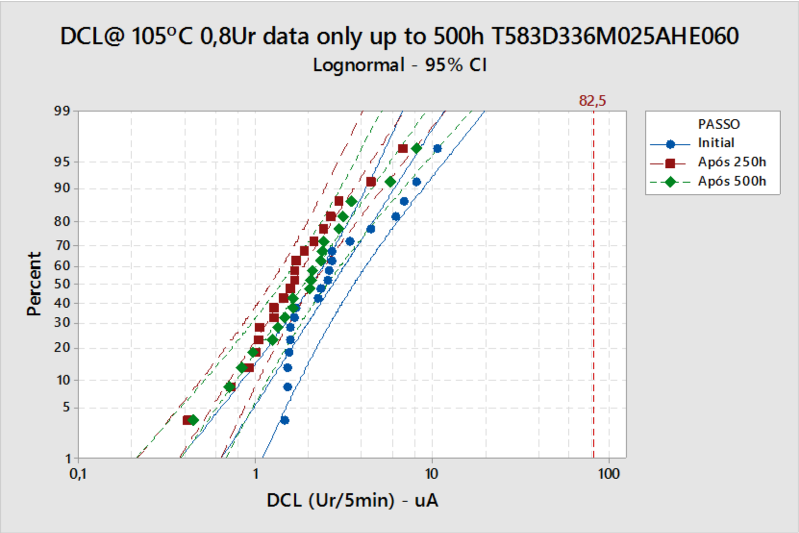

Fig 9b – Life Test – 105°C@0,8Ur – Leakage current – 7343-31 33uF25V

The remaining tests are in progress with finalization expected by the end CY2018.

Multiple Anode Construction Applications

In addition, in order to support the customer requirement for an ultra-low ESR with maximum capacitance for POL ('Point of load') solutions KEMET start a new project to release the EIA 7343-43 330uF10V with ESR<10mOhm. The samples preparation for the MAT Construction – Low Voltage Final agreement, shown in figure 10, are in progress. The initial preliminary electrical characterization results post assembly construction are reported in the figure 11.

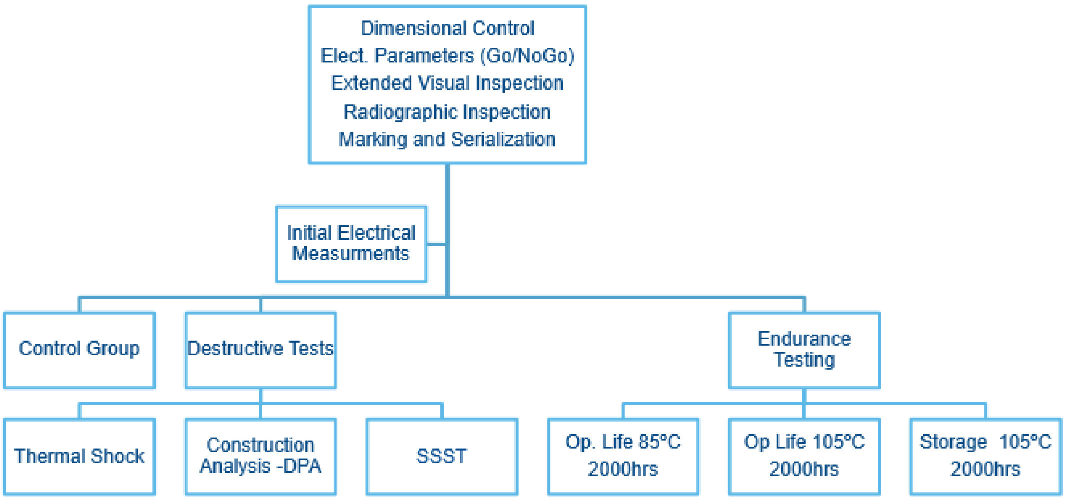

Fig.10. Multiple Anode Construction - ETP Final agreement

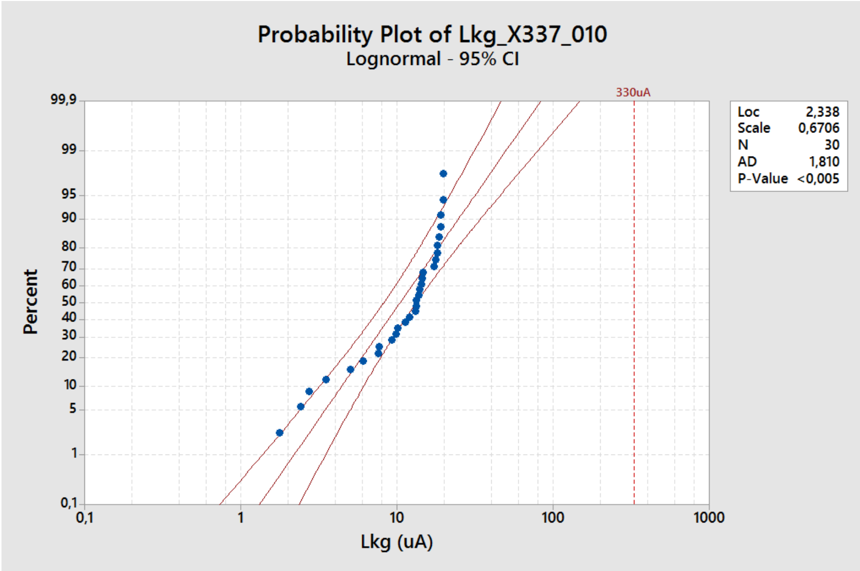

Fig.11a. Electrical Characterization – Lkg - Inline data – After Mechanical Assembly.

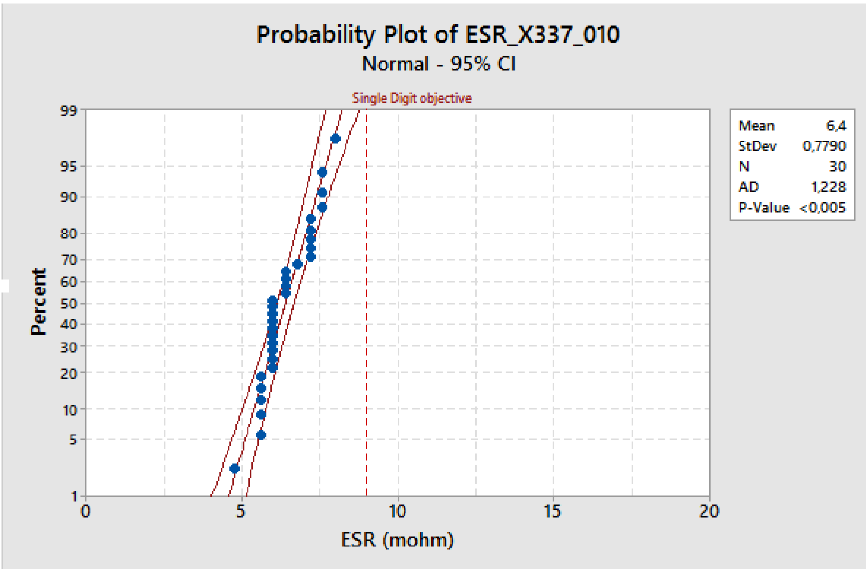

Fig.11b. Electrical Characterization – ESR - Inline data – After Mechanical Assembly.

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

ACKNOWLEDGMENTS

This work, with emphasis to Ta SMD capacitors with polymer counter electrode for High Voltage application was possible through a development project sponsored and supported by ESA and Portugal delegation Space Incentive Program.

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