

# Low ESR SMD Tantalum Capacitors for Aerospace Applications

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## ABSTRACT

This article presents improvements in the stability parameters of tantalum surface mounted capacitors with manganese dioxide and conductive polymer cathodes. Improved construction now means SMD tantalum capacitors with lower ESR and higher capacitance can meet the demanding criteria of aerospace products and therefore have the potential to significantly reduce the payload of mission-critical power supplies. The new series of lower ESR and higher capacitance SMD tantalum capacitors has been recently added to EPPL2, referencing a new ESCC specification, ESCC3012/004. Placing the capacitor into a hermetically sealed SMD case filled with an inert substance also allows better stability to be achieved. Long term stability testing performed on such hermetically sealed capacitors has proved that both studied types - manganese dioxide capacitor and conductive polymer capacitor - have better stability. The safe working temperature of hermetically sealed capacitors is 230°C with a manganese dioxide cathode and 175°C with a polymer cathode. The hermetically sealed SMD tantalum capacitor with polymer electrode has been developed in a project with the ESA to be the future high capacitance, reliable, space capacitor.

## INTRODUCTION

One common trend in switch-mode power supplies, micro-processors, and digital circuit applications is the reduction of noise while operating at higher frequencies. This functionality is influenced by the quality and ESR of output capacitors. In many cases, output capacitors are used in parallel to increase capacitance value and reduce ESR. The new generation of lower ESR capacitors may be of critical importance for space applications, as the same output ripple current can be achieved with fewer components occupying less space. Alternatively, a higher power output power supply can be made within the same dimensions. In addition, output capacitors may be a mission-critical part of a main power supply, thus quality and reliability is of primary focus.

Tantalum surface mounted capacitors with a solid electrolyte have been the favourite capacitor technology choice in many electronic devices for more than five decades, thanks to high stability, reliability and volumetric efficiency. Traditional cathode material - manganese dioxide - provides good mechanical robustness, relative temperature and humidity stability that suits the most demanding applications including aerospace, defense and medical. Currently there is no range of specific low ESR tantalum SMD capacitors qualified at QPL ESCC level. The existing QPL ESCC 3012/001 has a limited CV and no low ESR offering so far. European space manufactures have to rely on MIL standard CWR 29 or low ESR COTS+ products screened per MIL standards.

One of the main ways to reduce the ESR of conventional large case MnO<sub>2</sub> SMD solid tantalum capacitors is to use a multi-anode concept (i.e. use more node elements within one capacitor body). Such devices have been tested by CNES in cooperation with ESA. Testing similar to ESA ESCC 2263000 evaluation test procedures were performed on commercial versions of 12 low ESR types (including multi-anode types) in a range from 4.7µF to 470µF and between 6.3V to 50V. Results confirmed that this approach was viable for developing reliable, of extended range, low ESR, miniaturized tantalum capacitors. Based on the study, a QPL qualification process has been started within AVX to add a new range of low ESR and HiCV products as a new specification, ESCC3012/004. The QPL process is scheduled to complete in July 2013.

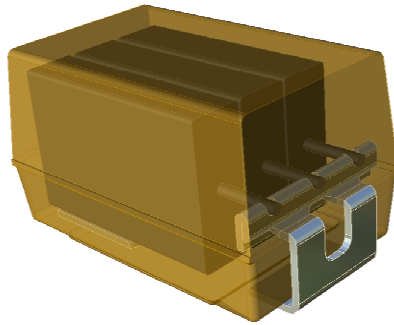
The two major disadvantages of the MnO<sub>2</sub> tantalum capacitors are the thermo runaway failure mode and relatively high ESR. Both of these issues have been overcome by using conductive polymers (PEDOT, PPY) as a cathode material. In addition, newly developed technologies using dispersed PEDOT are pushing the maximum levels of rated voltages of tantalum capacitors with solid electrolyte up to 125V. On the other hand, conductive polymer capacitors show some significant sensitivity to external conditions such as humidity, mechanical stresses and high temperature. These organic

compounds can also exhibit degradation at elevated temperatures, especially in presence of oxygen or humidity [1,2]. Such changes can include oxidation, morphology changes or other mechanisms of degradation which all lead to a reduction of the cathode conductivity, resulting in increased ESR or a drop in capacitance. This is why conductive polymer technology has so far been considered as a technology that is not yet mature and hence, excluded from qualification to top aerospace QPL levels..

## NEW LOW ESR SMD TANTALUM CAPACITORS

### 1] TES series - New Range of Low ESR, HiCV SMD Capacitors

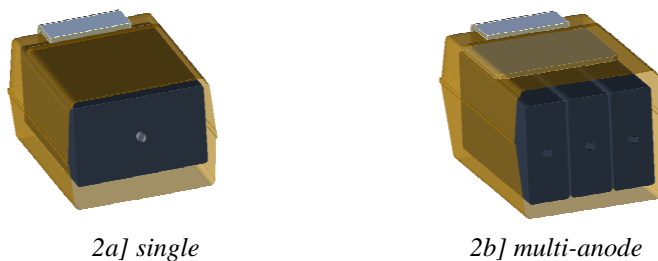
One way to significantly reduce the ESR of tantalum capacitors has been to use a multi-anode approach where more anode elements are used within one capacitor body [ref.4-9] – see Fig.1.



*Fig.1. Multi-anode Construction*

MnO<sub>2</sub> technology provides excellent field performance, environmental stability and high electrical and thermal stress resistance over a wide voltage range from 2.5V to 50V. These capacitors are designed for operation in temperatures up to 125°C.

The overall surface area of a tantalum capacitor anode, particularly its surface-to-volume ratio, is one of the key parameters that define its ESR value - the higher the overall surface area, the lower the ESR.



*Figure.2. Anode design in cross section*

The single anode (Figure 2a) is the standard used for general capacitor designs because of its cost versus performance efficiency. A multi-anode design (Figure 2b) offers the lowest possible ESR. The downside of this approach is a higher manufacturing cost when compared to a single anode solution.

Apart from the afore-mentioned differences between single anode and multi-anode capacitor technologies, there are two additional advantages of the multi-anode concept:

1] Due to a better thermal dissipation of multiple anodes compared to single anodes, the multi-anode capacitor can be loaded to higher continuous current and is also more robust against current surges as heat is dissipated more efficiently. When compared to the single anodes of the same case size, the power dissipation of conventional multi-anodes is higher.

2] Compared to single anode devices, the volumetric efficiency (the active zone) of multi-anode capacitors is lower which can lead to a presumption that multi-anodes cannot achieve the same Capacitance times Voltage (CV) factor. In practice, thinner anodes are easier to process and are better penetrated by the second MnO<sub>2</sub> electrode system, which allows higher CV tantalum powders to be used. Therefore the same or even better CV can be achieved with multi-anode technology.

Mirror Multi-anode Construction

Conventional tantalum multi-anodes mostly use three to five anodes inside one body in a vertical configuration as shown in Fig 3a]. This is practical from a manufacturing point of view, however from the ESR standpoint this solution is inferior to a horizontal layout – see Fig.3b] where thinner flat anodes can reduce the ESR even further. The cost of the multi-anode design grows exponentially with number of anodes. The three anodes currently used in most designs are close to the optimum cost versus ESR ratio.

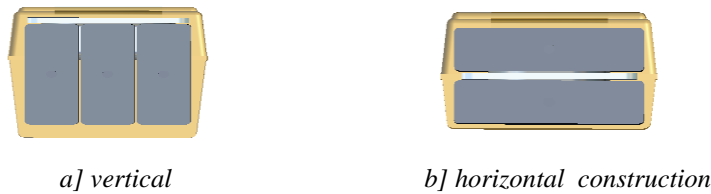


Figure.3. Multi-Anode concept cross section

Individual anodes in the vertical design configuration are connected to the second electrode by a silver glue epoxy to a second electrode lead frame. The same system is used in standard single anode capacitors, therefore the manufacturing technology is similar to the established process and no major investment in new technology flow is required. The horizontal design, on the other hand, requires a “solution” to the problem of connection between the anodes - and costly modifications of established technology. Hence, to date this design has not been used in volume production of the single body multi-anode capacitor. Horizontal designs are used more often in special applications by “stacking” two or more finished capacitors together by soldering or jigging systems into arrays or modules.

ESR differences between horizontal and vertical configurations are shown in Fig. 4. This example is based on theoretical calculation for D case and it shows the estimation of ESR for 2, 3 and 4 anode systems in horizontal and vertical configurations. It can be seen that the two anode horizontal layout has a similar ESR to the three anode system in a vertical configuration. The ESR versus cost value is however better for the horizontal structure.

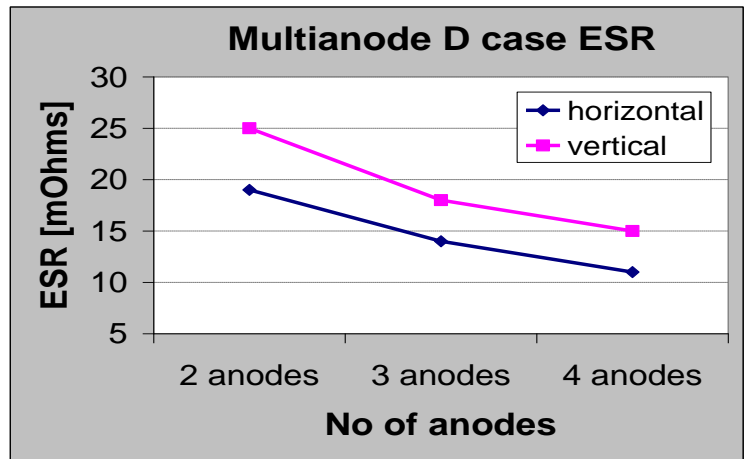


Figure.4. ESR of horizontal and vertical layout

Compared to the horizontal format, the vertical construction has the disadvantage of limited height reduction potential which is currently at 3.5 to 4.5mm. A novel multi-anode construction has been developed using two anodes in horizontal “mirror” configuration – see Fig.5]. The mirror construction uses a modified lead frame shape where the lead frame is in the middle between the two anodes.

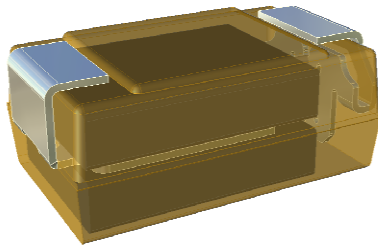


Fig.5. Multi-Anode “Mirror” Horizontal Design

The ESR level of the two anode mirror design is slightly inferior to the three vertical anode equivalent - however the cost versus performance value is better (the 2-anode system is cheaper to make compare to 3-anodes). However, the main benefit achieved is that this configuration enables the reduction of component height of multi-anode designs down to 3.1mm 7343-31 D case size. The other advantage of the mirror design is its symmetrical layout which helps to reduce self inductance ESL.

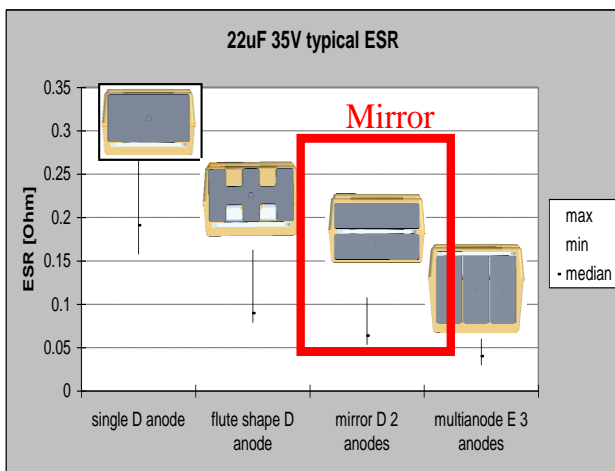


Figure 6 shows a comparison of typical ESR performance of 22 $\mu$ F 35V devices using the different internal design configurations. As described in the previous section, a higher surface area gives better ESR performance. Also the ESR distribution range is much tighter in low ESR designs. Therefore, low ESR parts are recommended for circuits with a bank of parallel capacitors due to a more equal load share among the individual capacitors. It should be also noted that there is no direct comparison in the case of vertical multi-anode as it is available in the taller E case size only, compared to the other designs made in the lower D case size. Three vertical D case size anodes in the vertical multi-anode style would show a higher ESR value compared to the E case size data available for this comparison only.

Fig 6. Typical ESR of different internal anode design configurations

The other benefit of the mirror design lies in its improved power dissipation capability. The heat generated in the anode by ripple current is cooled through leads and tantalum wire by PCB pads. The cooling effect difference is shown in Figure 7.

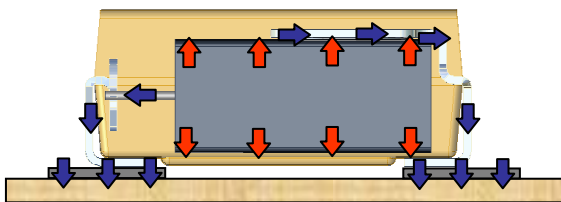


Fig.7a. cooling effect of single anode

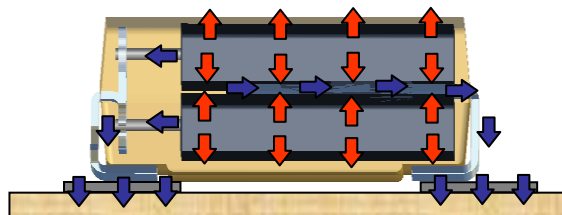


Fig.7b. cooling effect of mirror design

Thus the single anode D case capacitor is capable of continuously dissipating 150mW power compared to 255mW in the mirror D case. This represents ripple current capability of single design 1.0A (D 330μF 10V 150mΩ) with significantly higher 2.7A ripple in the case of mirror design (D 330μF 10V 35mΩ).

The new AVX TES series of low ESR range SMD tantalum capacitors uses single anode construction for small case sizes A,B and C case, mirror construction for D case size and vertical multianode for E case size as the optimum balance between design, low ESR and robustness to achieve the highest performance.

A proposed TES matrix under qualification for QPL per ESCC 3012/004 – see Fig.8

### CAPACITANCE AND RATED VOLTAGE, $V_R$ (VOLTAGE CODE) RANGE (LETTER DENOTES CASE SIZE)

Capacitance		Rated Voltage DC ( $V_n$ ) at 85°C							
μF	Code	6.3V (J)	10V (A)	12V (B)	16V (C)	20V (D)	25V (E)	35V (V)	50V (T)
1.0	105						A(3000)		B(2000)
1.5	155								
2.2	225								
3.3	335					A(2500)		B(1000)	C(1000)
4.7	475				A(2000)		B(1000)	C(600)	D(200)*
6.8	685								
10	106		A(1800)			B(1000)	C(600)	D(120)	E(150)*
15	156								
22	226	A(900)			B(600)	C(400)		D(100)	
33	336		B(650)			C(300)	D(65)	E(65)	
47	476	B(500)			C(350)	D(55)	E(65)		
68	686								
100	107		C(200)		D(55)	E(45)			
150	157	C(300)	D(45)		E(40)				
220	227		D(35)	E(35)					
330	337	D(35)	E(35)						
470	477	E(30)							
680	687								

Available Ratings: ESR limits quoted in brackets (Ohms)

Engineering samples - please contact manufacturer

\*Codes under development - subject to change.

Notes: Voltage ratings are minimum values. AVX reserves the right to supply higher ratings in the same case size, to the same reliability standards.

Fig.8. TES series proposed matrix under qualification for QPL per ESCC 3012/004

### 2] Low ESR Polymer Capacitor in Hermetic Sealing

A new hermetically sealed SMD tantalum capacitor structure has been designed where the capacitor element is enclosed and hermetically sealed within a ceramic housing. In addition, nitrogen is used as an inert gas inner atmosphere inside the hermetic package to inhibit oxidation of the solid electrolyte.

A wide selection of different materials can be used to form the housing, such as metals, plastics, ceramics, etc. Ceramic packaging has been selected for the initial studies due to its solid mechanical robustness and its hermetic sealing capabilities. There is also wide field experience with other electronic components using this type of package for hermetically sealed cases.

The capacitor element is attached to the ceramic housing by a common anode termination. Cathode termination is then formed to make a surface mounted capacitor. The particular configuration of terminations can be customized based on application requirements. Typically, the ceramic housing and the capacitor element have a similar shape so that the capacitor element can be readily accommodated within the interior space to provide maximum volumetric efficiency.

The housing includes a lid that is placed on an upper surface of the side walls after the capacitor element is positioned within the ceramic housing. The lid is typically made of ceramic or metal materials to achieve appropriate hermetic performance.

The package is hermetically sealed after a drying procedure by a seam welding process within an inert atmosphere. In this case, resistance seam welding process produces a weld at the two surfaces (lid/sealing member) in contact along the length of the joint. 100% hermeticity testing is performed on all manufactured parts in order to verify and guarantee sealing quality.

### Results and Discussion

Stability studies have been carried out on tantalum capacitors hermetically sealed under an inert atmosphere in packages, as described in the above section. Both temperature and voltage derating combinations have been the subject of extensive studies for various types of capacitors. Specific results from standard manganese dioxide or high voltage polymeric capacitors are presented as an example of the hermetic sealing effect in the following sections..

Stability testing and analysis of tantalum surface mounted capacitors has been performed on 10 $\mu$ F/35V capacitors. Operating life and moisture resistance have been considered for devices with manganese dioxide cathodes and conductive polymer PEDOT cathodes. Mechanical tests were performed on 100 $\mu$ F/35V capacitors with conductive polymer PEDOT cathode. For life testing purposes, the capacitors were placed in an oven at an appropriate temperature with an applied voltage equal to 50% of the rated voltage. For mechanical testing, capacitors were placed on a vibrating system under appropriate conditions. A detailed description of all test methods is set below.

- A. Operating Life A1: duration 2.000hrs, test temperature 150°C, 0.50  $U_R$
- B. Operating Life A2: duration 2.000hrs, test temperature 175°C, 0.50  $U_R$
- C. Operating Life A3: duration 2.000hrs, test temperature 200°C, 0.50  $U_R$
- D. Operating Life A4: duration 2.000hrs, test temperature 215°C, 0.50  $U_R$
- E. Operating Life A5: duration 2.000hrs, test temperature 230°C, 0.50  $U_R$
- F. Moisture Resistance Test D: duration 64hrs, test temperature 120°C, test humidity 85%,  $U_R$
- G. Mechanical Shock: 1.500g, 0.5ms, 5x, XYZ planes
- H. Vibration: 20g, 10-2.000Hz, test temperature 125°C

Capacitance was measured at 120Hz, 0.5RMS with DC bias of 2.2 volts. ESR was measured at 100kHz. All measurements were performed at ambient temperature to verify whether the part exhibits any degradation. The results are shown in Figures 9-10.

The hermeticity test was conducted using a helium detector, before and after the following individual tests. Maximum helium leakage rate should not exceed  $1 \times 10^{-8}$  atm cc/sec. of helium. Hermeticity was checked before and after all tests to confirm quality of hermetic sealing.

Figures 9 and 10 show electrical results (capacitance and ESR) of tantalum conductive polymer PEDOT surface mounted capacitors with/without hermetic sealing in a ceramic housing at 120°C @  $U_R$  for a duration of 64 hours. It can be observed that the standard capacitors show the typical change of capacitance due to humidity, as well as increased ESR caused by cathode degradation. Capacitors sealed in an inert atmosphere exhibit very small changes of capacitance and ESR, which might be explained by incomplete drying before hermetical sealing.

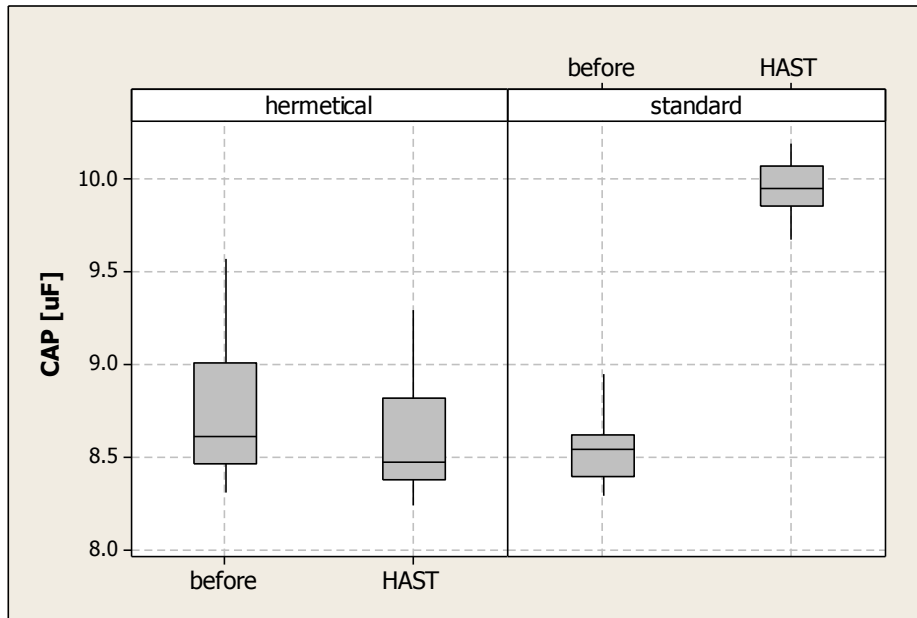


Figure 9 – humidity stability results of capacitance after 64 hours @  $U_R$  of  $10\mu\text{F}/35\text{V}$  capacitors with conductive polymer PEDOT cathode hermetically sealed in ceramic housing vs. capacitors assembled via standard production procedure

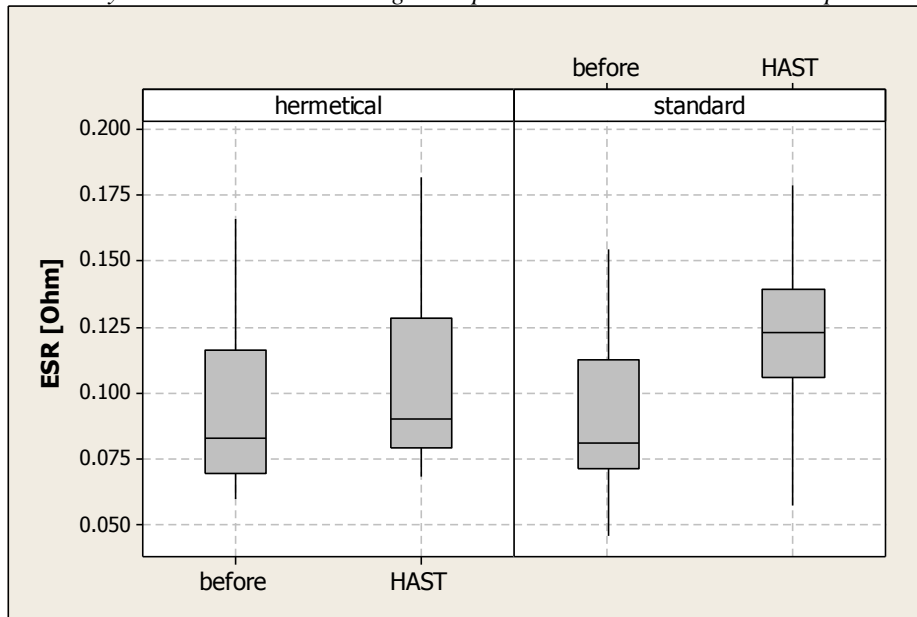


Figure 10 – humidity stability results of ESR after 64 hours @  $U_R$  of  $10\mu\text{F}/35\text{V}$  capacitors with conductive polymer PEDOT cathode hermetically sealed in ceramic housing vs. capacitors assembled via standard production procedure

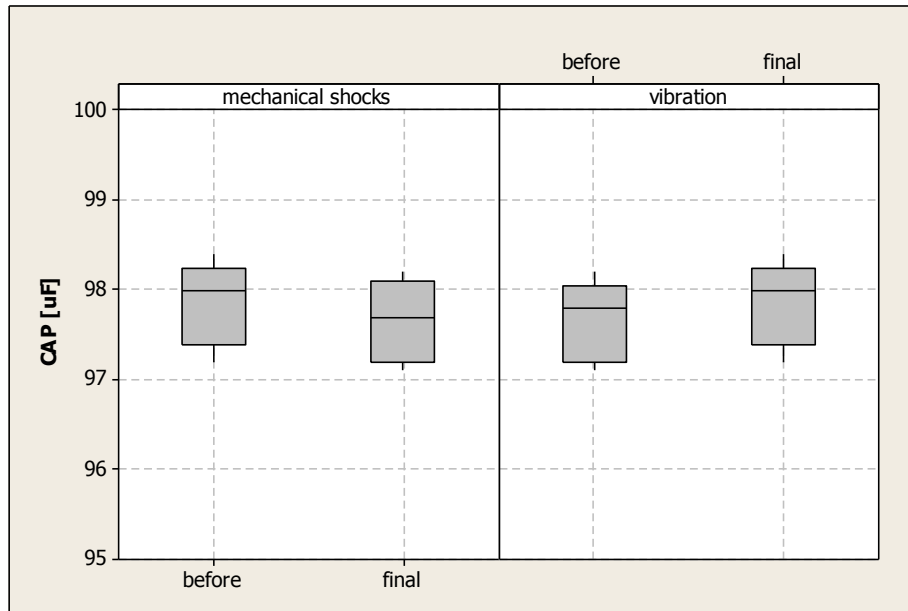


Figure 11 – mechanical stability results of capacitance after 5x 1.500g shock and after 20g vibration testing at 125°C of 100µF/35V capacitors with conductive polymer PEDOT cathode hermetically sealed in ceramic housing vs. capacitors assembled via standard production procedure

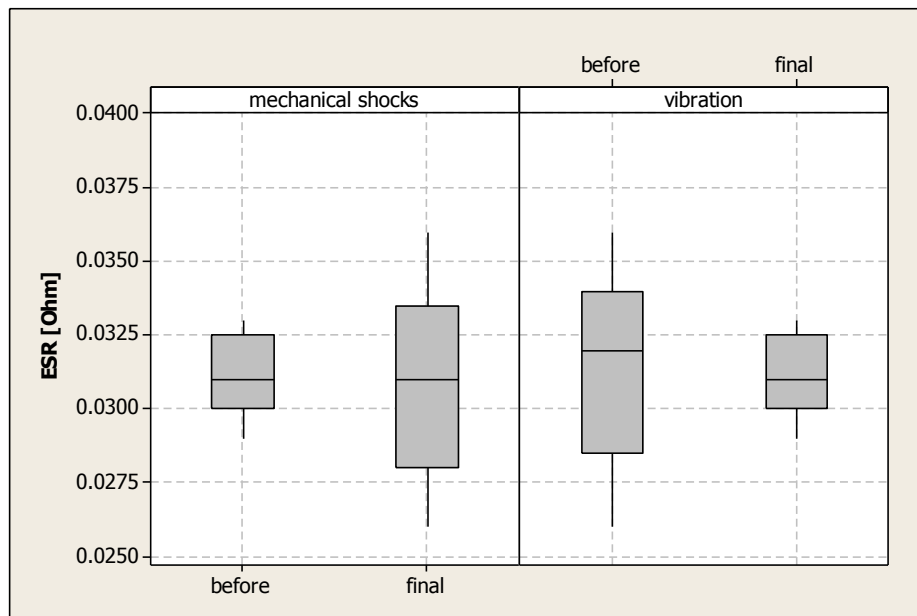
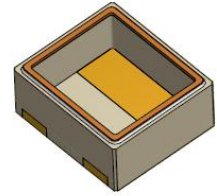


Figure 12 – mechanical stability results of ESR after 5x 1.500g shock and after 20g vibration testing at 125°C of 100µF/35V capacitors with conductive polymer PEDOT cathode hermetically sealed in ceramic housing vs. capacitors assembled via standard production procedure



AVX's TCH hermetically sealed polymer capacitors are available in ESCC 3012/003 CTC21 large case size for maximum capacitance. The first released code is 100 $\mu$ F 35V with maximum ESR of 55m $\Omega$ . Due to the high voltage rating of polymer capacitors, further released codes will be available from 10V up to 100V. 22 $\mu$ F 100V is the first capacitor to provide the excellent reliability of tantalum capacitors that can be operated on 48V power line (standard satellite power rail) with the recommended minimum 50% derating valid for tantalum capacitors.



## SUMMARY & CONCLUSIONS

Significant reduction of flight hardware payload can be achieved by using lower ESR HiCV tantalum SMD capacitors. Designers' choice of aerospace QPL qualified capacitors is currently limited. There are two new series of low ESR tantalum capacitors dedicated to mainly European aerospace applications from a manufacturing base in Europe – Lanskroun, Czech Republic:

**1] EPPL 2 MnO<sub>2</sub> low ESR TES series** currently under QPL qualification process per ESCC 3012/004. The capacitors use designs optimized to achieve maximum CV and lowest ESR with the capability of meeting levels required by demanding aerospace applications.. Large case sizes D and E are based on a multi-anode design that brings the lowest possible ESR and higher ripple current to this technology..

### 2] Hermetically Sealed Polymer Capacitors – TCH series

A new hermetically sealed SMD tantalum capacitor design using a polymer cathode has been introduced in order to bring the key benefit of polymer – lower ESR - to the most demanding applications such as mission critical circuits in space electronics. The hermetic case minimizes influence of humidity so that fluctuations of capacitance due to moisture variation, a weak point of polymer technology, are significantly suppressed. The tests performed on the polymer surface mounted tantalum capacitors hermetically sealed under inert atmosphere have proven to give excellent performance in comparison to the same capacitors moulded in standard epoxy resin. The effect of extreme humidity conditions during HAST test (120°C/85% RH/rated voltage) on ESR was also diminished when a hermetic package was used compared to the standard parts with moulded resin. Mechanical robustness has been tested to comply with 1500g shock and 20g vibration requirements in a project supported by ESA Czech Incentive Project

## ACKNOWLEDGEMENT

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