Hermetic Space Grade Tantalum Polymer Capacitors: Performance Update

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Abstract

Advances in Tantalum capacitor technology and manufacturing have resulted in a continuous flow of significant device improvements in bulk capacitors. The introduction of polymer systems has further accelerated those performance parameters to a new level. The final step towards ideal performance has been achieved by hermetic tantalum polymer packaging.

These developments come at a time where the capacitors resulting performance characteristics closer match next generation semiconductor power rails and systems.

A comprehensive summary of current state of the art flight grade tantalum polymer capacitors is shown and compared to traditional tantalum solutions. Component weight, volume and maximum current rating are highlighted.

Next, the construction and performance of hermetic tantalum polymers are documented in detail with recent up-screening data illustrating movements into high reliability at higher voltages & temperatures than previously considered. The impact to flight systems is presented along with predictions made summarizing future evolutions of tantalum polymer capacitors.

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Advances in Tantalum capacitor technology and manufacturing have resulted in a continuous flow of significant device improvements in bulk capacitors. The introduction of polymer systems has further accelerated those performance advances to a new level. The final step towards ideal performance has been achieved by hermetic tantalum polymer packaging.

These developments come at a time where the capacitors resulting performance characteristics closer match next generation semiconductor power rails and systems.

A comprehensive summary of current state of the art flight grade tantalum polymer capacitors is shown and compared to traditional tantalum solutions. Component weight, volume and maximum current rating are highlighted.

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Introduction

Bulk capacitors have always played a role in flight electronics. Bulk capacitors have served as a low frequency filter capacitor that could help hold up voltage and maintain voltage stability during discontinuous loads. However, flight electronic loads are getting more complex in nature due to the desire of increased functionality in all levels of spacecraft.

These complex loads require bulk capacitors to provide higher levels of di/dt across a broader frequency spectrum. Active devices such as FPGA's and high power GaN HEMTs demand capacitors to provide high quality power in small, efficient, reliable flight grade bulk capacitors.

Traditional tantalum MnO_2 capacitors have served the purpose of bulk capacitors in flight electronics for decades due to their high stability, high reliability and volumetric efficiency. MnO_2 capacitors have documented performance and reliability characteristics such as those covered in MIL-PRF-55365. Multiple manufacturers have gone beyond the performance requirements of Military specifications and have introduced Space grade screening to provide increased assurance of reliable flight performance. One example is Kyocera-AVXs SRC9000 specification which has various options for screening capacitors to levels associated with space grade flight electronics [1] or the ESCC specifications. Additionally, a wet tantalum technology exists which a higher temperature and voltage operating ranges to the MIL-PRF-55365 document and are documented in MIL-PRF-39006.

Another example is the Defense Logistics Agency (DLA) recently issued a tantalum polymer performance specification. That document is Mil-PRF-32700 and it has multiple slash sheets calling for individual or multiple anode stacks within a component package.

If a comparison were to be drawn between traditional non-hermetic tantalum polymers, hermetic tantalum polymers and wet MnO_2 on a high level, we could recap each technologies characteristics in table 1.

Non Hermetic Polymer	**Hermetic Polymer**	**Traditional MnO_2 Tantalum**
Solid – Polymer electronic conduction	Solid – Polymer electronic conduction	Solid – MnO_2 electronic conduction
Non hermetic	Hermetic	Non hermetic
Low ESR >/= 6mOhm	Low ESR 40mOhms to 150mOhms	ESR >/=10 mOhms
Voltage range 2.5v to 125v	Voltage range 10v to 100v	Voltage range 2.5v to 50v
Temperature range -40°C to + 150°C	Temp. Range -40°C to + 125°C	Temperature Range -40°C to +200°C
Capacitance Range 0.47uf to 1500uf	Capacitance Range 22uf to 330uf	Capacitance Range 0.1uf to 3300uf
DCL 0.1CV to 0.01CV	DCL 0.1CV	DCL 0.01CV to 0.001CV
MSL 3, 4, 5	MSL 1	MSL 1 to MSL 3

Comparison of non-hermetic Tantalum Polymer, Hermetic Tantalum Polymer and traditional MnO_2 Tantalum Technology
Table 1

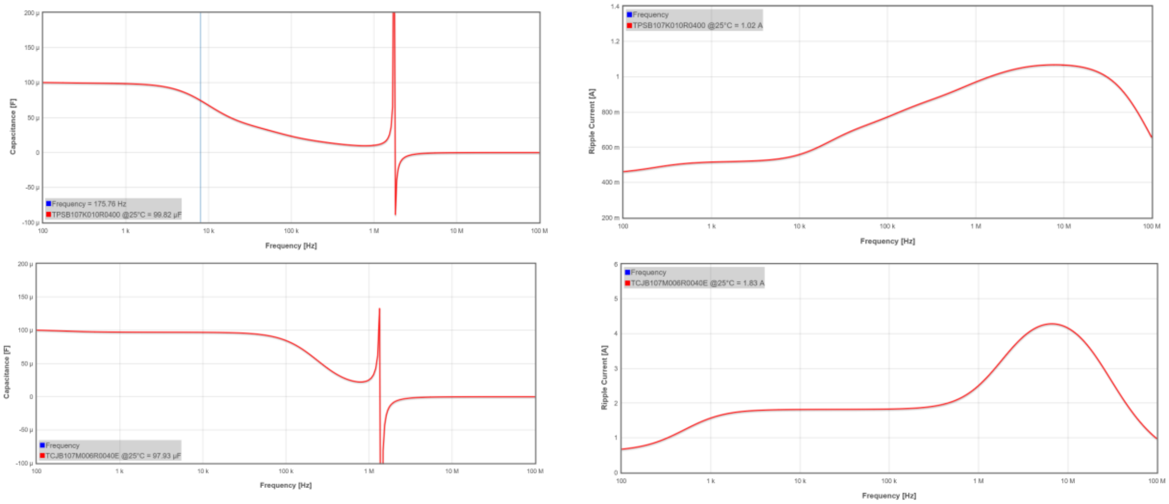
MnO_2 and Tantalum Polymer capacitors

Just like standard MnO_2 capacitors, Tantalum Polymer capacitors are miniature bulk capacitors that are available in a variety of quality levels and case sizes. A key feature of Tantalum conductive polymer capacitors is improved ESR over traditional MnO_2 Tantalum capacitors. Polymers exhibit approximately 1/8th the ESR of standard tantalum devices and therefore can handle much higher ripple current of MnO_2 devices.
A comparison of current capability and ESR of two equivalent case size, voltage rating and value capacitors is shown below in figure 1. This comparison shows the increased ripple current capability of Tantalum Polymers when compared to MnO_2 technology across a broad frequency spectrum.

A common real world 5V application is another good way to demonstrate a B case MnO_2 capacitors ripple rating to that of a similar case size polymer. This example is based upon a Tantalum MnO_2 B case 100uf 10V capacitor which exhibits a single point ripple capability of 460mA. The corresponding B case 100uf 6V Tantalum Polymer exhibits 1800mA of ripple at the same frequency data point. It is important to note that an A case Tantalum polymer can be considered to replace the B case MnO_2 since the A case Tantalum Polymer exhibits a 1000mA capability. This example also shows the impact of case size on a components ripple current capability.

Polymers offer the additional advantage of a lowered drop in capacitance at higher frequencies due to faster charge response ability (see figure 1). The polymers lower de-rating coupled with a higher ability to handle inrush currents allow polymers to use its CV more efficiently on a case size comparison to Tantalum MnO2 technology. Examples were generated from AVX simulation software found at:

https://spicat.kyocera-avx.com/product/tan/chartview/TPSB107K010R0400
https://spicat.kyocera-avx.com/product/tan/chartview/TCJB107M006R0040E



Comparison of current capability between MnO_2 Tantalum (TPSB107K010R0400) and Tantalum polymer (TCJB107M006R0040E)
Figure 1

From a mechanical point of view, both Tantalum & Tantalum polymers, come in a large range of small case sizes which translates into a capability of tantalum polymer bulk capacitors to be placed at ideal PCB locations – typically close to the load thereby minimizing loop inductance. Figure 2 defines the capacitors inductance (ESL) by case size and can assist designers in selecting the ideal physical sized device for a given applications [2].

A = 1.8	G = 1.8	P = 1.4	V = 2.4	4 = 2.2
B = 1.8	H = 1.8	R = 1.4	W = 2.2	5 = 2.4
C = 2.2	K = 1.8	S = 1.0	X = 1.8	8 = 2.2
D = 2.4	L = 1.0	T = 1.0	Y = 2.4	
E = 2.5	N = 1.4	U = 2.4	Z = 1.8	

Comparison of Tantalum Polymer, Traditional MnO2 Case Inductance (nh)
Table 2

On a relative basis, Tantalum Polymers also exhibit improved energy density compared to tantalum capacitors. As an example – a TCJ A case polymer exhibits an in circuit energy storage capability of 1.15 mJ and a TPS B case size exhibits 1.2mJ. However, the A case polymer component dimensions are 3.2 x1.6 x 1.6 mm high whereas the B case size is 3.5 x 2.8 x 1.9mm. The A case polymer represents a volume of ~8.2 cubic mm and the B case MnO_2 part has ~ 28.6 cubic mm.

This feature creates further flexibility for designers to find reasonably sized bulk capacitors in small case sizes with reduced component height. Currently, case size dimensions can range from 0402 to 2924 and heights can be as low as 0.55mm.
The weight of Tantalum Polymer and Tantalum capacitors is similar on a case size to case size basis and ranges from 5.7mg in an F38 M case size to approximately 2200mg in a TCH package.

As we have shown, Tantalum polymers have no weight or size disadvantage and in fact offer energy density improvements relative to traditional tantalum capacitors. Further, Tantalum Polymers have a broader voltage range of 2.5V to 125V, Lower de-rating required: 90% rated voltage / 10% voltage de-rating for products rated up to 10V and 80% rated voltage / 20% voltage de-rating for products rated 16Vr and higher and a benign failure mode if shorted.

Tantalum polymers have two main differences users should be aware of when compared to traditional Tantalum capacitors [3].

The first is that non hermetic polymers carry a moisture sensitivity level rating of 3 or higher. Tantalum polymers are shipped in moisture barrier bags with HIC and desiccant to identify and control moisture levels [4]. The parts can be processed under normal/industry standard processing. Reflow assembly follows JEDEC 020 requirements and a maximum of 3 reflow cycles with a peak temperature of 260°c.

Moisture affects polymer performance in two ways. One is that, during the reflow process, moisture presence in molding resin and in polymer cathode (steam) creates internal pressure on polymer layers throughout the reflow mounting process and immediately affects device performance and reliability. The other effect is that, during long-term exposure, excess moisture initiates a degradation of the polymer cathode material, which accelerates with increasing levels of temperature and voltage. This can result in a drop in conductive polymer conductivity (increased ESR) and create a shift in capacitance, which is generally non-recoverable.

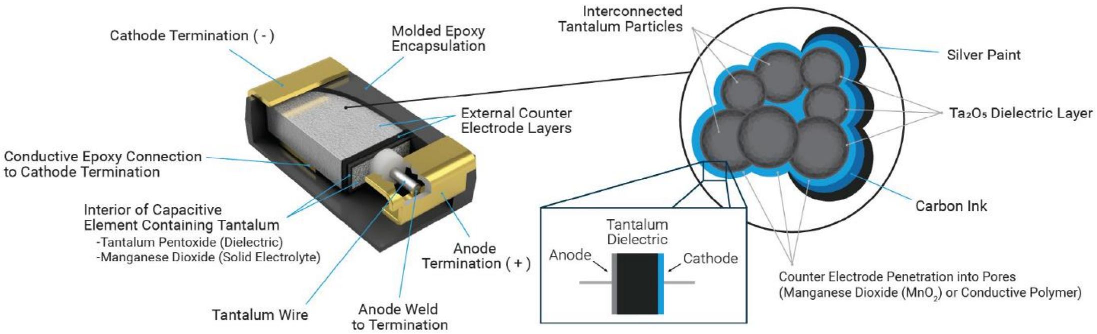
However, TCH (hermetic-case tantalum polymers) sufficiently isolate the polymer material system where this characteristic is of little concern.

Even with MSL 3 rating, Tantalum Polymers pose no long term reliability threat to end systems given great progress achieved in the performance of non-hermetic packages. Non hermetic Tantalum polymers have achieved AEC Q200 rating and agency flight acceptance/drawing in multiple non hermetic packages. An example of agency accepted and flown non hermetic tantalum polymer is the TCS series device. The TCS series has been qualified by ESA for the supply of leadless surface mounted solid organic Polymer Tantalum Capacitor – Detail Specification 3012/006. TCS devices are manufactured in the European Union, within ESA qualified plant in accordance to ESCC 3012. Statistical screening along with accelerated ageing is utilized to improve basic reliability and deliver capacitor with an operating temperature range of - 55 to +105°C with low ESR and a capacitance /voltage range of 22 - 470µF / 6.3 - 35V.

The second main difference is Anomalous charging current (ACC). ACC is a temporary increase in the DC leakage of conductive polymers that occurs during initial charging, typically when a device has experienced excessive drying. Anomalous charge currents can be detrimental to circuits, which need rapid charging immediately after reflow or at low/ambient temperatures. ACC effects can return to normal leakage current range within minutes, or hours of initial appearance. There are multiple way around ACC – the first being waiting for leakage currents to return to normal after the reflow assembly operation. Another method is to realize that the magnitude of ACC is part number dependent and reducing ACC can be achieved with specific part number and family selection.

Polymer Capacitor Construction

Tantalum polymer capacitors are created by utilizing a conductive polymer in the cathode of the tantalum capacitor as shown in Figure 2. The anode wire is tantalum and a porous pellet of tantalum powder is pressed onto the anode wire. The resulting structure is sintered into a monolithic block and a Ta_2O_5 dielectric is formed. A conductive polymer layer is deposited onto that structure and with added processing a tantalum conductive polymer capacitor is created. This insert is then welded/conductive epoxied onto a lead frame and then over-molded to create a finished capacitor. As previously mentioned, TCS series capacitors utilize advanced molded material systems and processes in order to create a highly isolated capacitor ‘insert’.



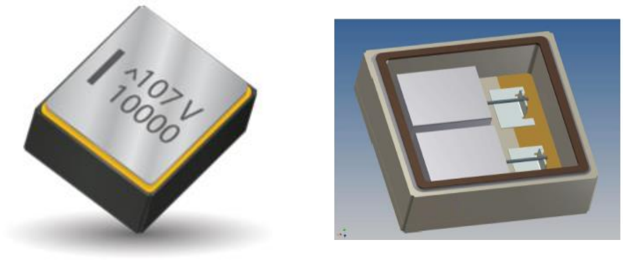
Non hermetic Tantalum polymer construction

Figure 2

Though TCS tantalum polymers offer improved moisture resistance stability and performance, efforts were taken to create a fully hermetic Tantalum polymer to ensure even higher reliability and stability capacitors by eliminating any possible effects of external environment humidity and moisture. The hermetic package allows for an inert atmosphere to eliminate oxidation and morphology changes that could lead to an increase in ESR through reduced cathode conductivity and loss of capacitance.

Construction of hermetic Tantalum Polymer capacitors is relatively straight forward.

The same tantalum polymer insert can be used in creating hermetic tantalum polymer capacitors with the slight difference being the lead frame configuration. The hermetic tantalum polymer makes use of the tantalum polymer capacitor insert, welded onto a different shaped lead frame which sits on metallized pads inside the internal cavity of a hermetic ceramic package. The specific hermetic package chosen utilizes a J lead Undertab connection with either a C or L shape metal lead. See figure 3. Once the capacitor inset connections are completed, an internal filler material may be applied along with finishing steps of an inert dry atmosphere, metal lid welding and marking. The resulting packaged device passes the shock & vibration requirements MIL-STD-202 Method 213 – condition (shock) and MIL-STD-202 Method 204, Condition D (vibration). The device also passes MIL-STD-883Method 220, Condition A, Particle Impact Noise Detection (PIND) tests.



Hermetic Tantalum Polymer Construction

Figure 3

Hermetic Tantalum Polymer performance test results

Significant testing programs were initiated to characterize hermetic tantalum capacitors using both direction from NASA and ESA test requirements.

NASA

NASA document EEE-INST-002 exists with a purpose of providing Instructions for EEE Parts Selection, Screening, Qualification, and De-rating [5].

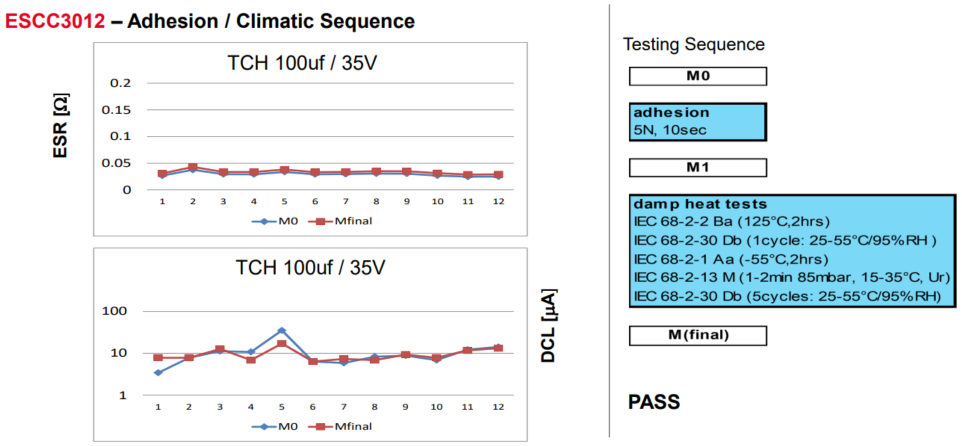
Specifically, the document establishes baseline criteria for selection, screening, qualification, and de-rating of EEE parts for use on NASA GSFC space flight projects. The EEE section chosen was for tantalum capacitors under level 2 requirements.

The performance level or grade of capacitor performance in this document range from Level 1 - highest reliability, to level 3 - lowest reliability level. Level 2 parts have reduced manufacturing control and testing but significant requirements exist. Level 2 parts can be for use on missions with low to moderate risk, balanced by cost constraints and mission objectives. Level 2 active parts shall be reviewed for radiation hardness, and radiation testing is required when information is not available. The typical mission duration for level 2 programs varies from 1 to 5 years. TCH devices have successfully met the requirements for flight and have proven successful in many programs. Added details can be found in the KAVX Space Parts Working group session.

ESA

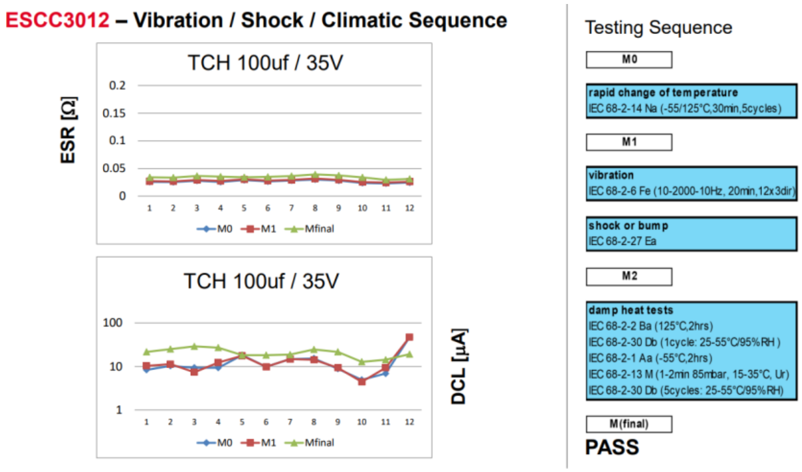
Further testing was performed in accordance to European Space Components Corporation (ESCC) ESCC Generic Specification No. 3012. This specification defines the general requirements for the qualification approval, procurement, lot acceptance testing (LAT), and delivery of Capacitors, Leadless Surface Mounted, Tantalum, Solid Electrolyte, and Enclosed Anode Connection for space applications.
Results of testing to ESCC 3012 specification has confirmed the reliability and performance to test requirements. Excerpt test performance results follow [6]:

Robustness of terminations: Components mounted in accordance to approved processing procedures and then subjected to a shear of 5 N for 10 ±1s seconds. This was followed by exposure to 125°C for 2 hours, followed by temperature cycle of 22 to 55°C at 95% RH. Followed by a - 55°C 2 hour dwell, 1.2 minute 85mBar, 15-35°C, U exposure and 5 cycles of 25-55°C 95% RH exposure. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 4.



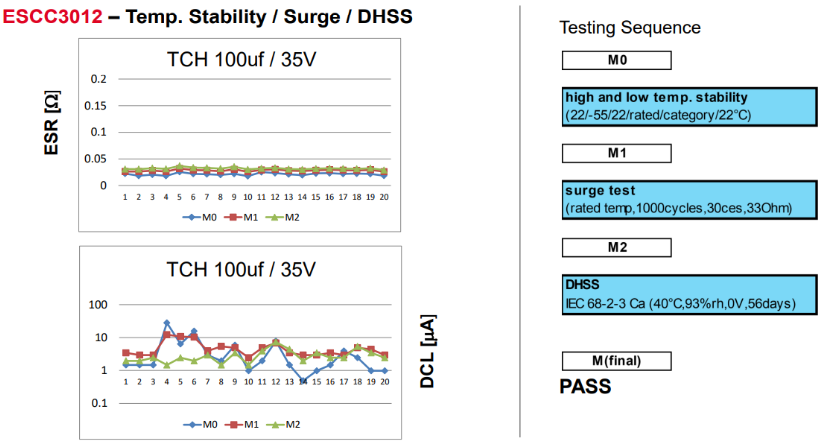
ESCC 3012 – Adhesion / Climatic Sequence - 100uf 35v test results
Figure 4

Vibration / Shock / Climatic Sequence: TCH 100uf 35v parts were mounted in accordance with accepted methods and subjected to a rapid change of temperature from -55 to 125°C for 30 minutes to completed 5 cycles. The devices were then subjected to 10-2000 hz 12 sweep cycles in each axis for 20 minutes. Shock test comprised of a half sine, 500m/S^2 peak acceleration, 11 second duration tests. A total of 3 shocks in each direction of the three mutually perpendicular axis (18 impulses total). Damp heat testing followed at a 2 hour 125°C exposure, followed by 1 cycle of 25-55°C 95%RH, a two hour -55°C dwell, followed by 1-2 minute 85mbar 15-35 °C Ur and 5 cycles of 25-55°C 95% RH exposure. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 5.



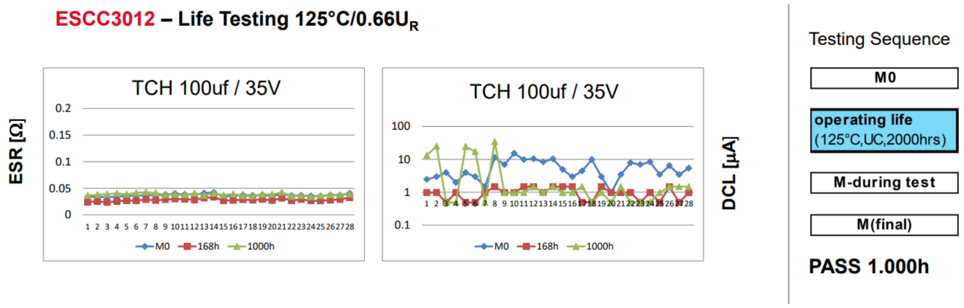
ESCC 3012 – Vibration / Shock / Climatic Sequence - 100uf 35v test results
Figure 5

Temperature Stability / Surge / DHSS Testing consisted of high and low temperature stability testing at 22/-55/22/rated category /22°C tests followed by 1000 surge cycles at rated temperature, 30 ces /33 ohms. DHSS was then performed at 40°C, 93%RH, zero volts for 56 days. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 6.



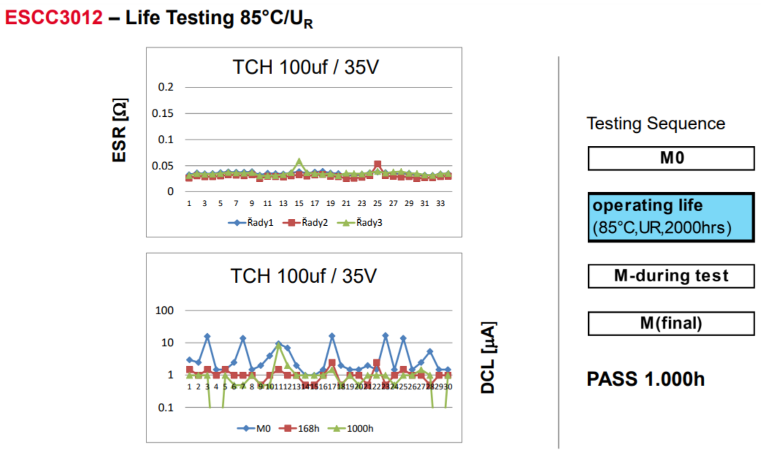
ESCC 3012 – Temperature Stability / Surge / DHSS - TCH 100uf 35v test results
Figure 6

Life Testing occurred at 125°C / 0.66 U_R for 2000 hours. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 7.



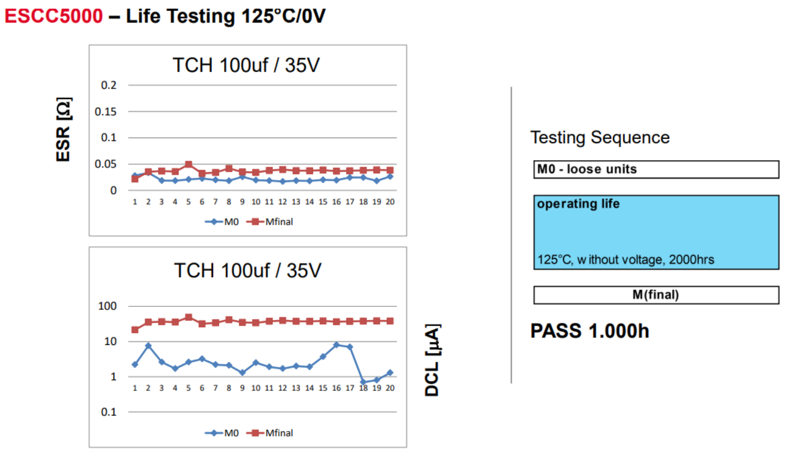
ESCC 3012 – 2000 hour life test at 125°C - 100uf 35v test results
Figure 7

Life Testing occurred at 85°C / 0.66 U_R for 2000 hours. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 8.



ESCC 3012 – 2000 hour life test at 85°C - 100uf 35v test results
Figure 8

Life Testing occurred at 125°C / 0 U_R for 2000 hours. Passing test results of TCH 100uf 35v device performance in these tests are shown in Figure 9.



ESCC 3012 – 2000 hour life test at 85°C - 100uf 35v test results
Figure 9

The impact of polymers on flight systems & future direction

Data shows hermetic encapsulated tantalum polymer capacitors offer stabile DCL, ESR and capacitance along with increased reliability. As flight semiconductors evolve and enable faster processing the demand for low parasitic loss bulk capacitors will naturally grow. These devices will be used in conjunction with ceramic capacitors to control EMI and ensure voltage rails are within the tolerances demanded by advanced semiconductors.

Future developments will launch from the level of environmental isolation and operating stability obtained from hermetic packaging. Data suggests that higher operating temperatures, higher voltages, and larger capacitors are all possible. An example of hermetic TCH family devices is shown in figure 10. TCH 22uf 10v and 100uf 35 volt devices were placed upon life testing with conditions of 150°C 50% rated voltage. Results are shown for various time durations due to the availability of test chambers.

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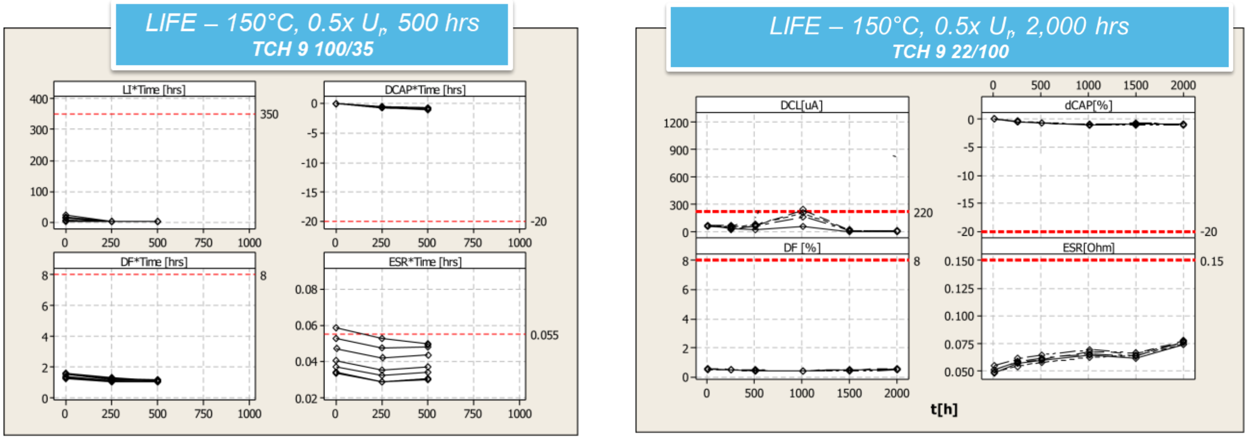

150°C Testing of Hermetic Tantalums

Figure 10

Summary

Tantalum polymer capacitors offer low ESRs (Equivalent Series Resistance) which in turn allow higher ripple currents in smaller packages. The benign failure mode of polymers is attractive as well as the multiple case options and range of product series & reliability levels available. The TCS series non hermetic polymers are a viable choice for flight applications as allowed by end system part use requirements. The emergence of hermetic tantalum polymers achieving high levels of performance and reliability have resulted in use on NASA and ESA hardware. Hermetic Tantalum polymers represent designers an option for a near ideal bulk capacitor voltage stabilization & hold up. Future developments in the area of high temperature hermetic capacitors is expected.

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