The Benefits of Using High-Reliability Polymer Tantalum Capacitors

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Introduction

With the release of MIL-PRF-32700 for polymer tantalum capacitors, it represents a milestone in the adoption of high-reliability polymer tantalum capacitors in military, defense, and aerospace applications. High-reliability polymer tantalum capacitors continue to set new benchmarks for performance over their manganese dioxide (MnO_2) predecessors. The advancements in polymer electrolyte formulations have enabled these capacitors to offer superior characteristics, including lower equivalent series resistance (ESR), enhanced thermal stability, and higher ripple current capabilities. These improvements not only enhance the efficiency and longevity of electronic systems but also reduce the risk of failure in critical applications, making polymer tantalum capacitors an increasingly preferred choice for designers and engineers seeking to push the boundaries of what's possible in electronics design.

We will provide some manufacturing insights and revisit the technology and processes that go into making a capacitor meet high-reliability standards required by mission critical applications in the defense and aerospace industry. While electrical screening plays a role, creating a robust, high-quality part requires an approach that starts with different mindset on the design of the capacitor itself. We will also reflect on the new reliability assessment method, how it differs from Weibull screening, and why KEMET is including our patented simulated breakdown screening (SBDS) as standard procedure for parts built according to MIL-PRF-32700.

KEMET's T580/T581 series is the first to be qualified to the new MIL-PRF standard and incorporates advancements KEMET has made as a result of 25 years of manufacturing polymer tantalum capacitors. This qualification is a testament to the series' ability to meet the rigorous demands of military applications, offers an easier adoption of these high-reliability capacitors in military projects, and reinforces KEMET's commitment to providing solutions that meet the highest standards of performance and reliability.

Making a High-Reliability Capacitor

The performance of a capacitor starts at design. Material selection, production processes, and testing/screening can be modified to address three parts of the "bathtub curve" to improve the reliability of capacitors as shown in Figure 1 below. The choices made around materials, processes, and tests can improve the life of the capacitor by decreasing early failures, normal lifetime failures, and help to extend the overall life of the capacitor. For tantalum capacitors, we will focus on the material selection of polymer versus MnO_2 capacitors, the conservative anode design and material sets used for the MIL-PRF-32700 qualified capacitors, and the screening processes used internally during production.

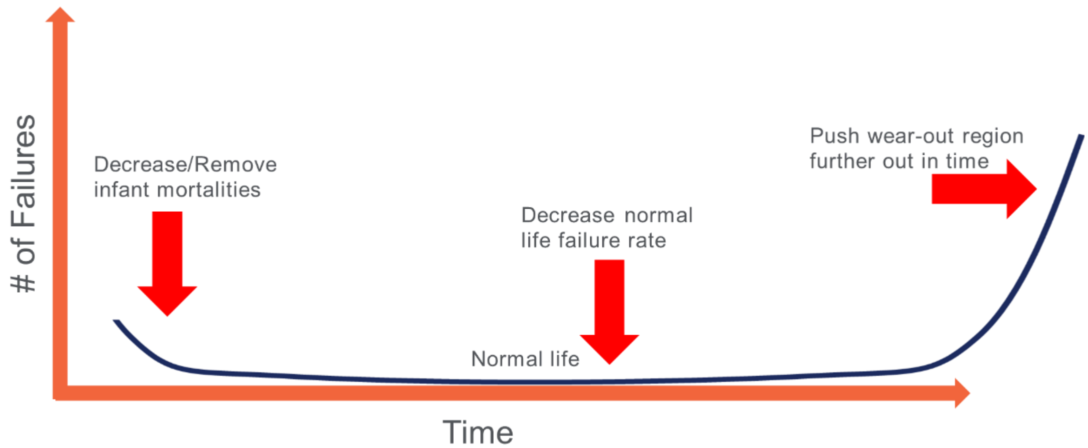

Figure 1. Improvements to the bathtub curve of a passive component

Reliability of Polymer Tantalum vs. Tantalum MnO_2

For MnO_2 capacitors, the tantalum anode is dipped in manganese nitrate at room temperatures which covers the surface and fills in wedges on top of the tantalum pentoxide layer as shown in Figure 2 below. Manganese nitrate is converted to MnO_2 at around 270°C. This conversion process is repeated several times, during which any mechanical forces that might be generated due to the CTE mismatches between the two materials may cause fracturing of the dielectric layer which creates a fault site in which the capacitor may fail in the future. In polymer tantalum capacitors, instead of converting manganese nitrate into manganese dioxide through a high-temperature pyrolytic process, a conductive polymer, poly(3,4-ethylenedioxythiophene) (PEDOT), is used. There are different methods of forming the polymeric cathode, whether that happens prior to coating or *in situ*. In either case, the polymerization process puts less stress on the tantalum capacitor than the MnO_2 formation process since the formation process happens between 25°C and 65°C – much lower than the MnO_2 counterpart.

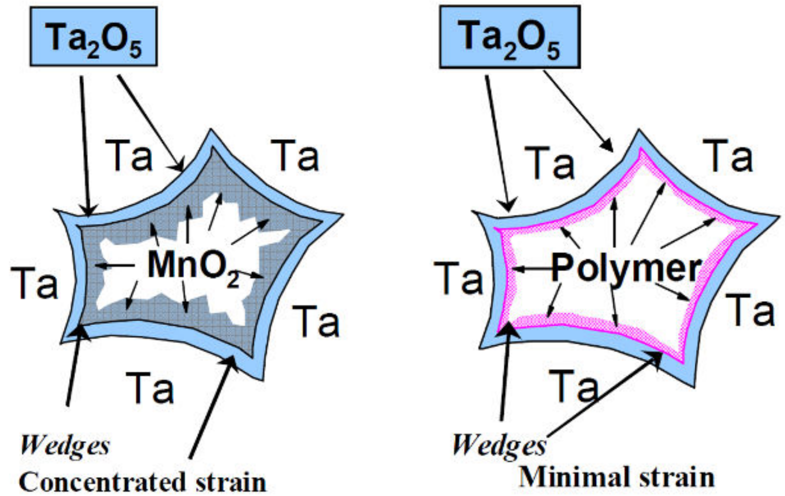

Figure 2. Visualization of strains on the tantalum pellet from MnO_2 (left) and polymer (right)

To measure the reliability differences, both types of capacitors were subjected to voltage pulses of increasing magnitude from a low impedance source. The thought was that the stress level or voltage across the dielectric is the trigger mechanism for the breakdown, and that the current pushes the capacitor into failure.

The method, in short, was that the initial pulse train voltage was set to half the rated value, with a final voltage of four times the rated voltage. Voltage steps were selected based on the start-to-stop range, ensuring a full test sequence within 15 to 40 steps, with increments of 0.1, 0.5, 1, 2.5, or 5 VDC. The power supply delivered high current, maintaining tens of amperes. Each capacitor input was isolated and buffered by a 12,000-uF bank for high charge currents. The pass-fail criterion was a voltage measurement across the capacitor just before discharge. If the voltage was within 95% of the set value, it passed. Failure voltage was recorded, and testing continued until all units failed or the maximum voltage of 4x the rated value was reached. A 5% differential was used to prevent false failures from high-leakage units. [1]

	MnO_2 (27Batches)	Ta-Poly KO V_R>10VDC	Ta-Poly KO V_R<=10VDC	Alum-Poly AO
100 PPM FR % V_{Rated}	68%	126%	197%	235%
@50% V_{Rated} FR(PPM)	9	0	0	0
@80% V_{Rated} FR(PPM)	458	4	1	0
@90% V_{Rated} FR(PPM)	1,700	12	2	0
@100% V_{Rated} FR(PPM)	6,310	35	8	0

Figure 3. Failure rates in PPM based on SSST data.

Results showed that the 100-PPM failure rates were around 68% of rated voltage (V_R) for the tantalum MnO_2 capacitors while it reached 126% and 197% of the higher voltage and lower voltage polymer tantalum capacitors, respectively. The failure rate projection was 9 PPM for MnO_2 at 50% V_R, 4 PPM for high voltage polymer tantalum at 80% V_R, and 2 PPM for low voltage polymer tantalum at 90% V_R.

Material Sets and Screening for High-Reliability Polymer Tantalum Capacitors

In the new MIL-PRF-32700, meeting biased humidity requirements has become official for polymer tantalum capacitors for military applications (Figure 4). We take advantage of advancements with the epoxy casing coming from the automotive industry and stainless-steel lead frames to mitigate damage that arises from corrosion over time. Additionally, we continue to use conservative anode designs and trusted powder sources to ensure that we meet the long-term reliability requirements expected from this series of products.

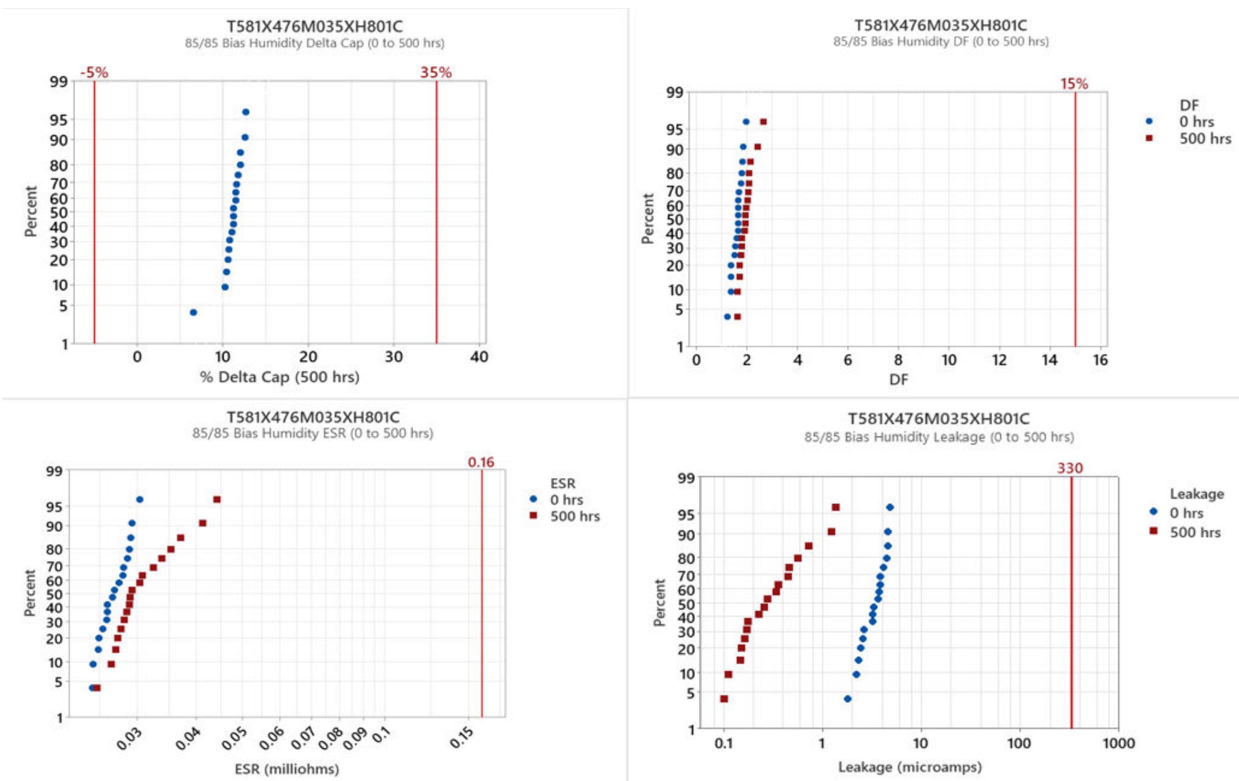

Figure 4. Results from biased humidity testing for MIL-PRF-32700

At KEMET and particularly with the T580/T581 series, we employ the use of a patented technology called Simulated Breakdown Voltage Screening where we determine a representative breakdown voltage of a batch of capacitors and apply a non-destructive amount to the entire population without damage to its dielectric. This screening identifies hidden defects in the dielectric, providing the highest level of dielectric testing. Figure 5 shows a step in the screening process that removes weaker parts of the population from the batch which results in a clear improvement of the overall breakdown voltage of the batch (Figure 6). We expect that the breakdown voltage of the remaining capacitors will be greater than 2x rated voltage, as compared to Weibull Graded parts with breakdown voltages as low as 1.25x rated voltage. Also, this is done without inducing wear out sometime associated with Weibull Grading. [2]

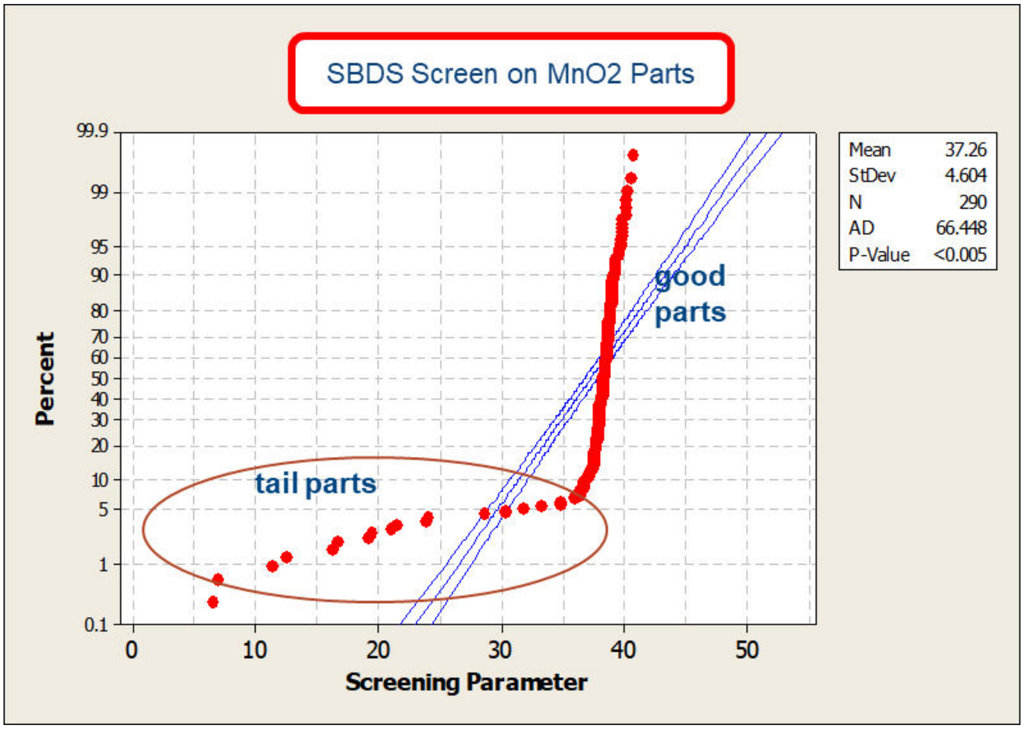

Figure 5. Screening process for SBDS

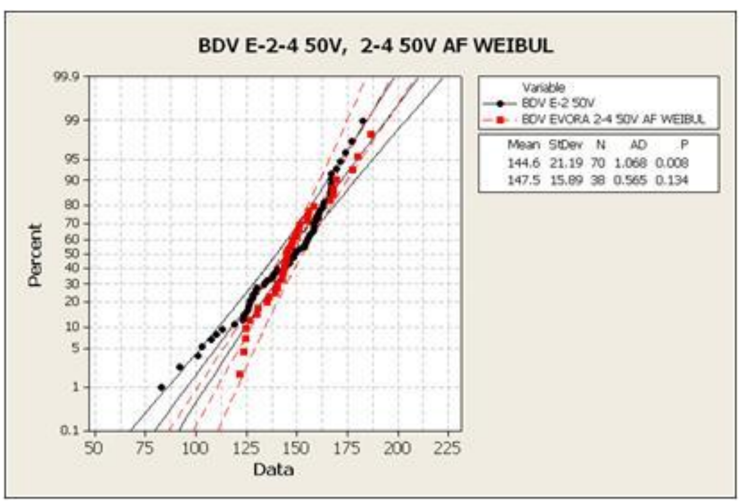

Figure 6. Breakdown voltages for a batch of 50V MnO_2 capacitors

Conclusions

High-reliability tantalum capacitors are typically manufactured under stringent process controls that ensure the highest level of performance and durability. This includes more rigorous control over the materials used (such as the tantalum powder and dielectric formation) and tighter tolerances for key electrical parameters such as capacitance, leakage current, and equivalent series resistance (ESR). High-reliability capacitors are usually subjected to stricter quality assurance (QA) processes, including extensive in-line testing and post-manufacturing screening to catch any defects before the product reaches the customer.

Commercial-grade tantalum capacitors, on the other hand, are manufactured to meet the general specifications required for consumer or less critical applications. While they are still reliable in typical conditions, they are not expected to have the same performance in the extremes of the environments (high temperatures, mechanical stress, radiation exposure, etc.) that high-reliability capacitors are designed for. They may have a wider tolerance range and less rigorous testing protocols, leading to reduced overall reliability in demanding applications.

In some cases, commercial-grade tantalum capacitors can be subjected to additional screening to weed out units with latent defects, a process known as "up-screening." While screening can identify commercial-grade capacitors that may meet high-reliability requirements, it cannot change the fundamental design or materials of the capacitor. Up-screening can identify units that meet short-term reliability requirements, but it may not guarantee long-term reliability under harsh conditions. High-reliability capacitors are designed from the ground up to endure long operational lives in challenging environments, something that up-screening alone cannot fully ensure.

KEMET's T580/T581 series is an ideal choice that takes advantage of all the improvement described in this paper. With the first group of 35V now available, this qualification will extend and support the polymer tantalum capacitor adoption in a market where performance and reliability are key factors. The release of the MIL-PRF and the T580/T581 series shows that polymer tantalum capacitors have achieved a mature stage have been adopted in this demanding market space. This technology has been used in ground, airborne and space devices for more than a decade.

[1] "Derating Review of Ta-MnO2 vs. Ta-Polymer vs. Al-Polymer vs. NbO-MnO2", Prymak et.al., 2004 CARTS

[2] "High Reliability Principles and Verifications in Solid Ta Capacitors", Freeman et.al., 2014 CARTS