1.2. Tantalum Capacitor Technology Advantages for Harsh Environment

A Technical Overview Based on Vishay's Innovations

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ABSTRACT

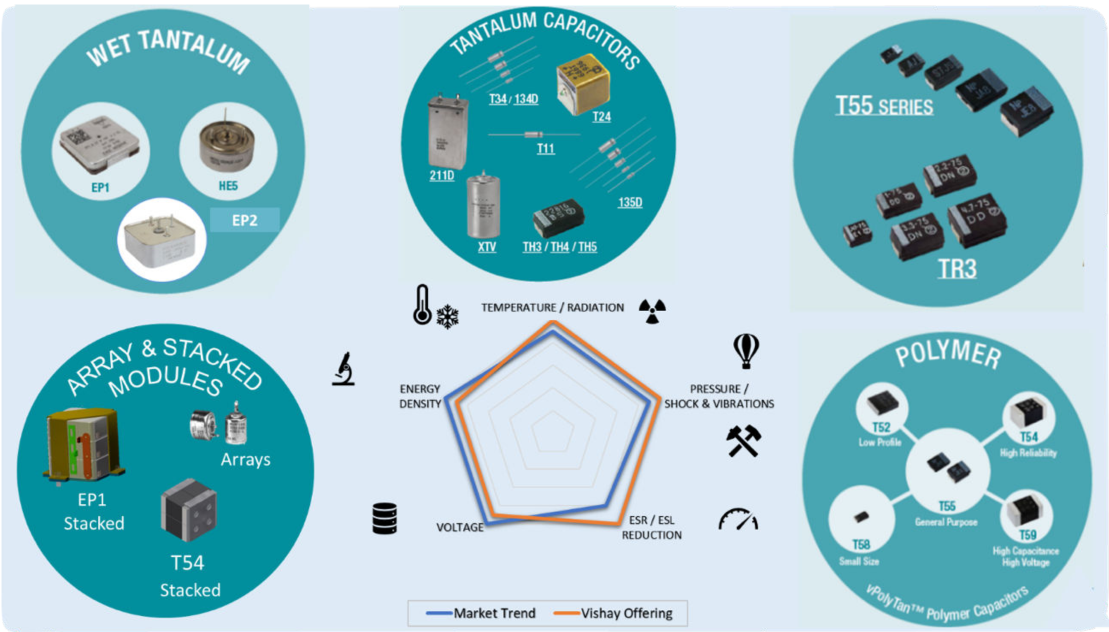
Since the early 1990s, Vishay has pioneered the use of advanced Tantalum anode technology, incorporating techniques such as liquid delubrication, magnesium deoxidation, and anode wire welding. This innovative technology enables the production of defect-free dielectric films, which are crucial for products featuring low DC leakage, long-term reliability, and enhanced resistance to reflow stress.

Additional technological features ensuring stable solder reflow performance include shell formation and beveled pellets.

Vishay's advanced MAP capacitors packaging technology offers approximately a 40% increase in capacity per volume while maintaining stable MSL performance. The MAP polymer capacitors manufacturing process includes in-line testing and HiRel screening which demonstrates robust reflow performance and low, stable DC leakage during life tests. Failure rate assessment according to MIL-PRF-32700 standard will be the next step in reaching established reliability.

Construction and environmental control measures, such as hermetically sealed polymer capacitors, wet capacitors, axial and high energy, further enhance the reliability stability and performance of Vishay's products, allowing the use of specific tantalum series in harsh environments.

1. Introduction



Technological trend

The harsh environment market - encompassing aerospace, military, space, underwater and critical industrial applications - demands electronic components that can operate reliably under extreme temperatures, mechanical stresses, and electrical surges.

Traditional commercial capacitor designs often fall short in delivering stable long-term performance and characteristic when exposed specifically to

- ✓ Very low or high temperature
- ✓ Radiations
- ✓ high shocks and vibration
- ✓ Low or high pressure
- ✓ prolonged electric stress.

Very often, components selection if even more difficult to comply with

- ✓ Design security margin,
- ✓ Redundancy and dissemblance
- ✓ Extra design internal rules
- ✓ Electrical Requirements to keep component in the most appropriate functioning range (for instance AAC extra derating and/or environmental conditions)

To achieve such improvement in te components characteristic, several aspects can be improved

- ✓ Choose the most suitable tantalum technology for the mission profile (Tantalum MnO2 , polymer cathode system or wet construction)
- ✓ "Push the envelope" of CV, keeping reliability at required level but keeping enough room for security margin
- ✓ Improved and innovative manufacturing processes at the component level
- ✓ Use Protective packaging solutions
- ✓ Appropriated testing and screening technics

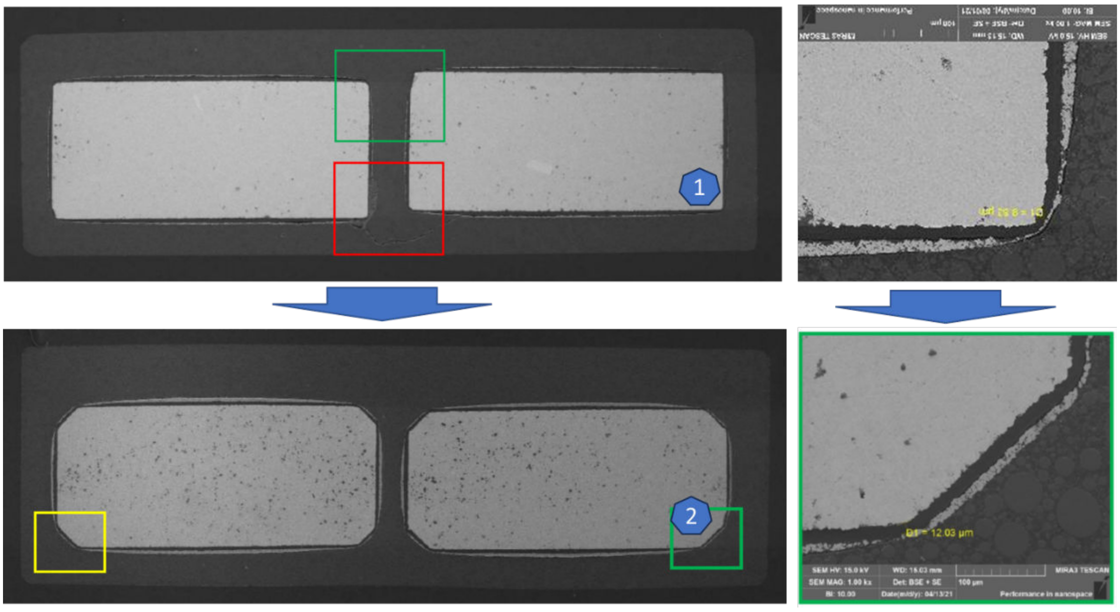
That have resulted in capacitors that not only maintain performance under harsh environment but also exceed the conventional boundaries in energy density and stability.

2. Advanced Tantalum Anode Technology

Process step	Industry practice	Vishay practice	Advantage of Vishay technology	Since
Anode pressing	Sideways pressed rectangular pellets	Top-down pressed beveled pellets	Uniform corner coverage by **polymer cathode** material	2021
Anode delubrication	Thermal [burn-out @ 1000 °C] carbon content ~300 ppm	Our proprietary process guarantees carbon content ≤30 ppm	Defect-free dielectric. Low DC leakage; Long term reliability **MnO2 and Polymer cathode**	
Process	Oxygen content ~5000 ppm	Added proprietary process reduces oxygen content to ~4000 ppm		
Wire attachment	Embedded Good strength attachment	Welded Excellent strength attachment	Improved ability to withstand reflow stress	
Dielectric Formation	Shell Formation of thicker Ta_2O_5 dielectric on outer surface of tantalum anode		Improved ability to withstand reflow and testing stress	MnO_2: 2000 Polymer ≤10V: 2015 Polymer ≥16V: 2020

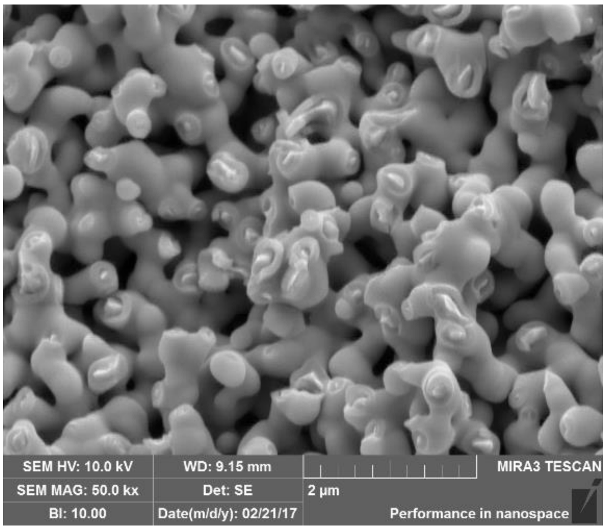
Central to Vishay’s approach is the improvement of Tantalum anode manufacturing. Key innovations include:

- **Top-down pressed beveled pellets:** Majority of short failure occurs at corners, which are most difficult for Polymer coverage. Beveled pellet corners allow Polymer coating with more uniform thickness.

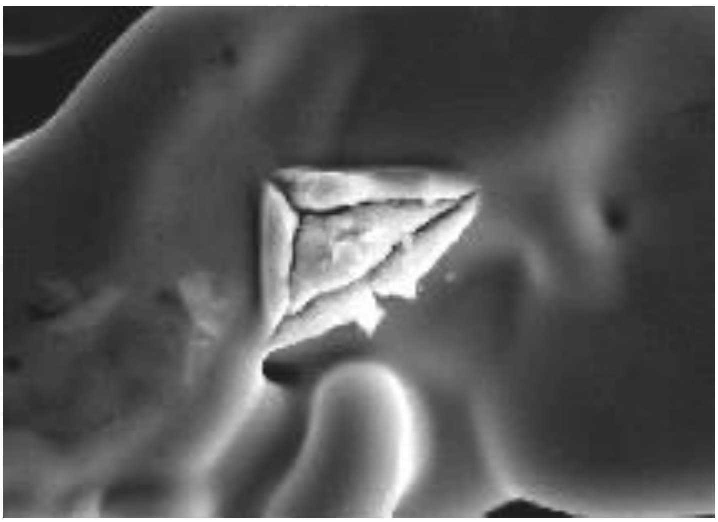


- **Liquid Delubrication:** Rather than relying on thermal burn-out methods that typically leave behind approximately 300 ppm of carbon content, Vishay’s proprietary liquid delubrication process reduces carbon contamination to ≤30 ppm. This significant reduction minimizes the defect density in the Ta_2O_5 dielectric layer.
- **Magnesium Deoxidation:** An additional process step lowers the oxygen content from ~5000 ppm to ~4000 ppm. This optimization ensures that the anodization process forms a uniform, high-quality dielectric film.

These steps allow the formation of defect-free dielectric films that are crucial for achieving low DC leakage, extended reliability, and improved performance during thermal reflow processes.



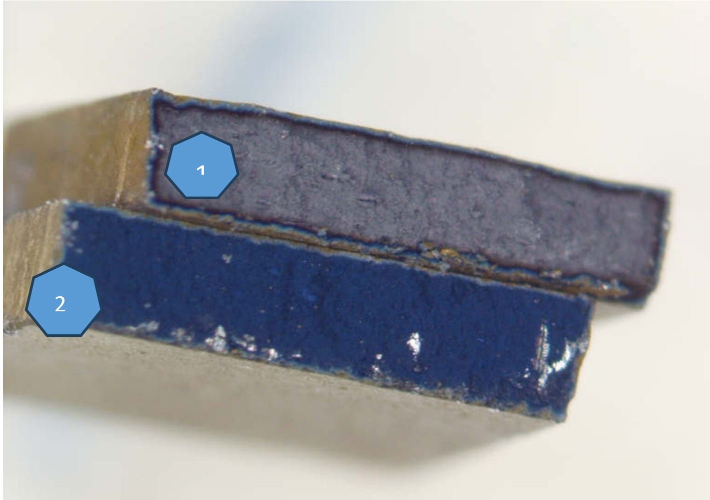
Typical appearance of crystals in Ta2O5 dielectric



Defect-free Ta2O5 dielectric formed over high CV

Defect-free Ta_2O_5 dielectric formed over high CV sintered Ta slug by anodization at 50 V. No crystals were found.

- **Anode Wire Welding:** By moving away from simple embedding techniques and adopting a welded attachment strategy, the mechanical strength of the capacitor is enhanced, which improves reflow stress tolerance.
- The outer surface of Ta_2O_5 dielectric of tantalum anode is most exposed to thermo-mechanical and electrical stresses of reflow mounting and testing. **Shell Formation** forms thicker dielectric layer on this outer surface at relatively high voltage (1.5-3 times higher than regular Formation voltage) resulting in more robust tantalum anode capable of withstanding stresses.



1. *Fractured anode after Shell formation (top) with thick outer dielectric layer formed at 50V. Grey inner portion has no dielectric yet.*
2. *Fractured anode after completion of regular formation (bottom) of the inner portion at 24V for a 6.3V rated capacitor.*

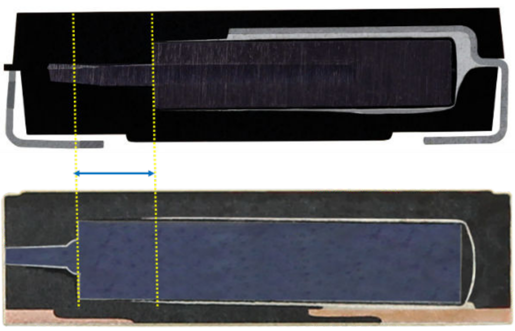
3. Packaging technologies

Process step	Industry practice	Vishay practice	Advantage	Since
Packaging technology	Molded Chip packaging	MAP Chip packaging	40% increase in capacitive element volume!	EIA ≤3528:2006 EIA 7343: 2017 U.S. Patent No. 7,161,797
	Polymer	Hermetic SMD T27	9x9x9 mm SMD Hermetic stable parameters in time	Based on T22 Space qualified
	Wet	High shock and vibration EP2	1.4"x1.4" high energy >2 J/cc	Protected by U.S. s 10,176,930, 10,600,576 and 10,614,963. Additional patents may be pending in the U.S. and/or elsewhere.

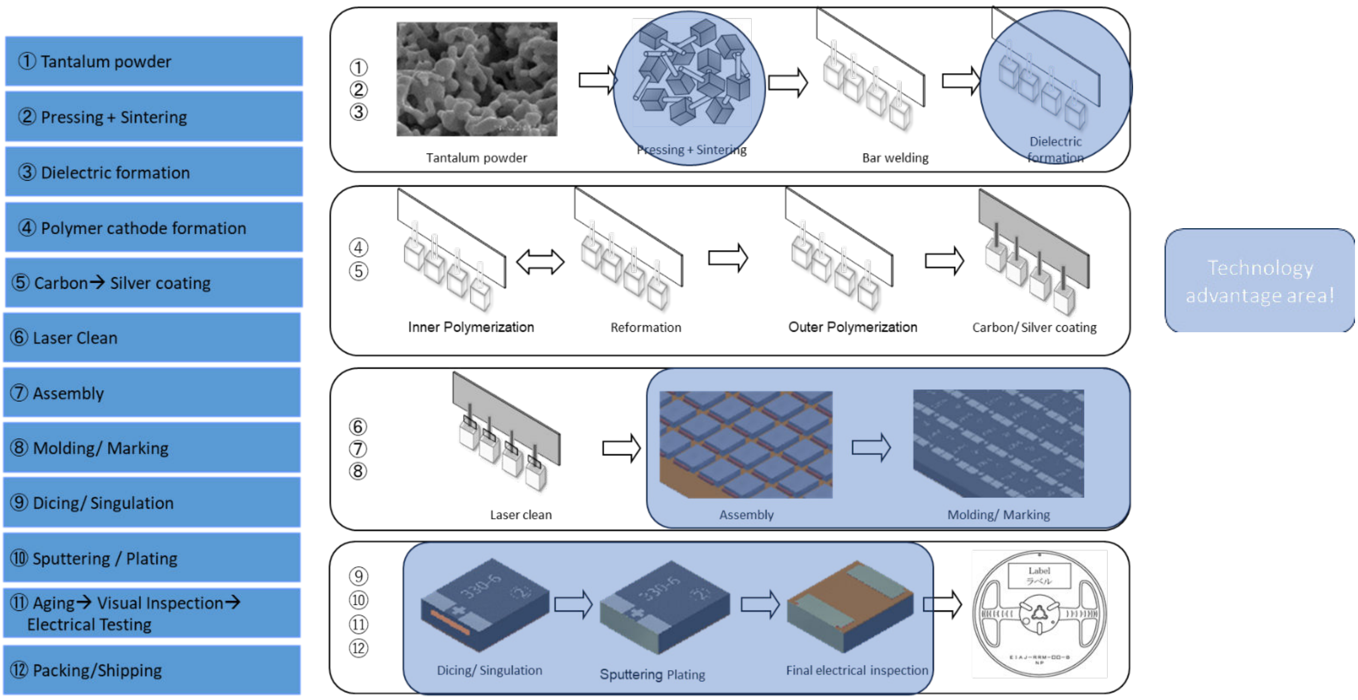
MAP Multiple Array Packaging

A major highlight is Vishay's MAP chip packaging technology, which provides approximately a 40% increase in the effective capacitive element volume without compromising Moisture Sensitivity Level performance.

For hybrid module, the more flexible height control keep the same height between active and associated capacitors.

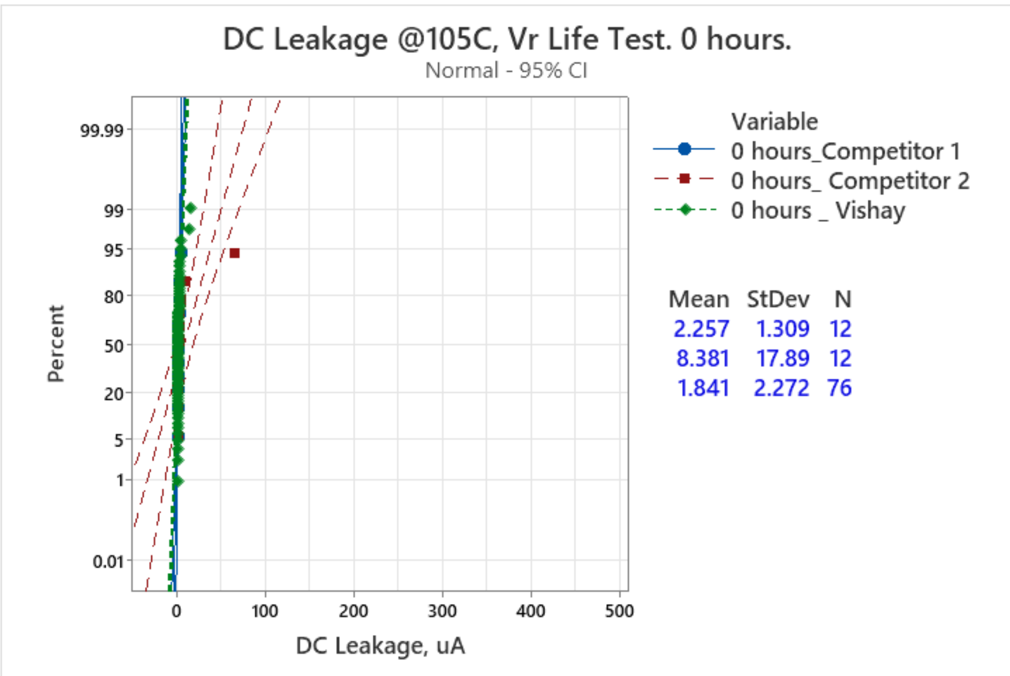


Molded vs MAP array packaging +40% increase in capacitive element

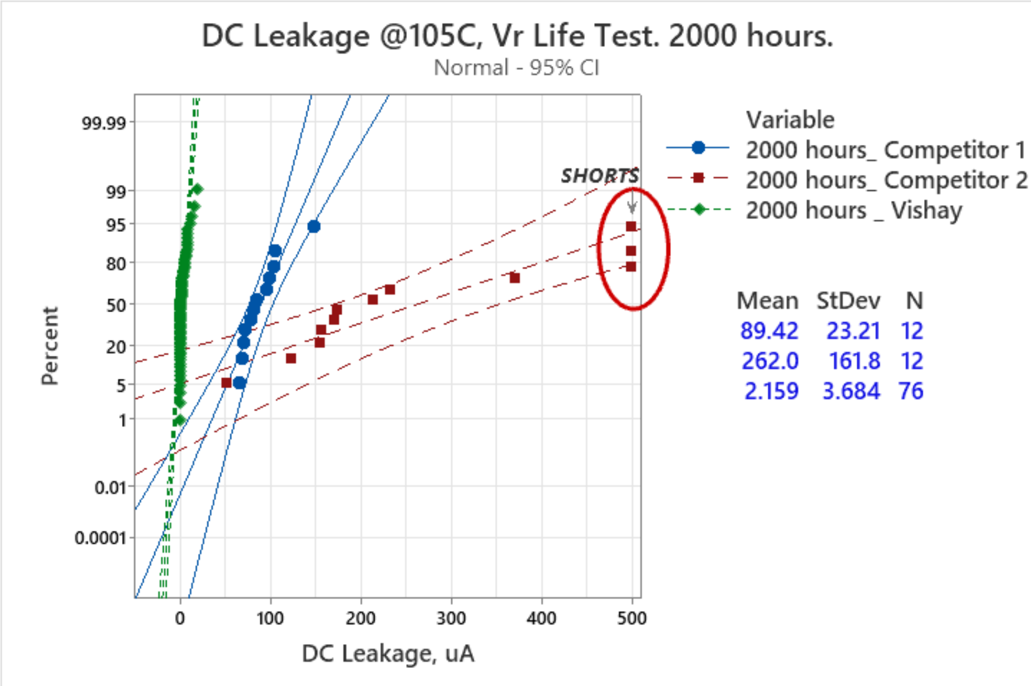


MAP manufacturing Process

The integration of Anode technology into advanced packaging further solidifies the reliability of these components after Reflow stress and DCL stability during life test of T52 polymer capacitors when compared to similar competitor parts.



0 Hours: Similar DC Leakage values for all three manufacturers.



2000 Hours [after Life test]:

Almost unchanged DC Leakage values for Vishay parts vs Orders of magnitude DCL increase and short failures for Competitors

4. PRODUCTION TESTING AND HIREL SCREENING PROCESS.

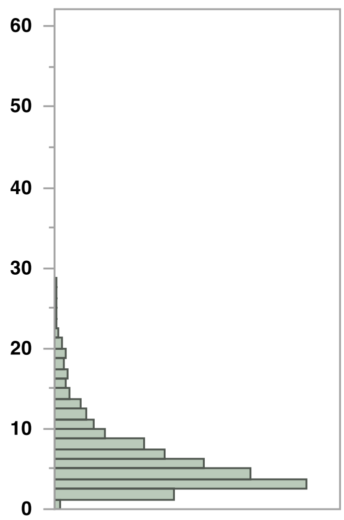
Standard High reliability testing includes

- ✓ Reflow condiiotnning
- ✓ Surge current testing (MIL type)
- ✓ Accelerated voltage conditioning
- ✓ Thermal shock
- ✓ Patented Statistical DCL Screening at Elevated Temperature and Voltage

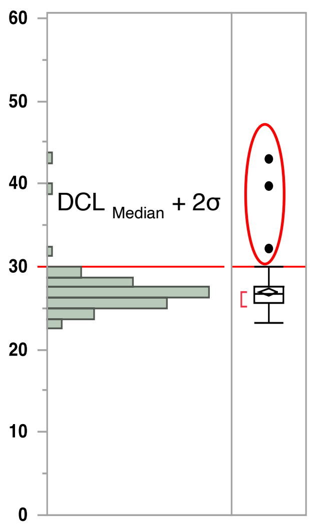
- **<u>Statistical DCL Screening at Elevated Temperature and Voltage (Patent No.: US 10,381,166 B2 (45) Date of Patent: Aug. 13, 2019) process steps</u>**

- ✓ 100 % electrical test at Vr, room temperature, with [Avg + 3σ] statistical limit: much lower than 0.1 CV (450 uA)
- ✓ Hot DCL sample test at elevated temperature and voltage > Vr. Test voltage derived from BDV distribution
- ✓ Statistical analysis of sample test to define new HDCL test limit [Med, sigma]

✓ Perform hot DCL test for entire lot with [Med + 2σ] statistical limit

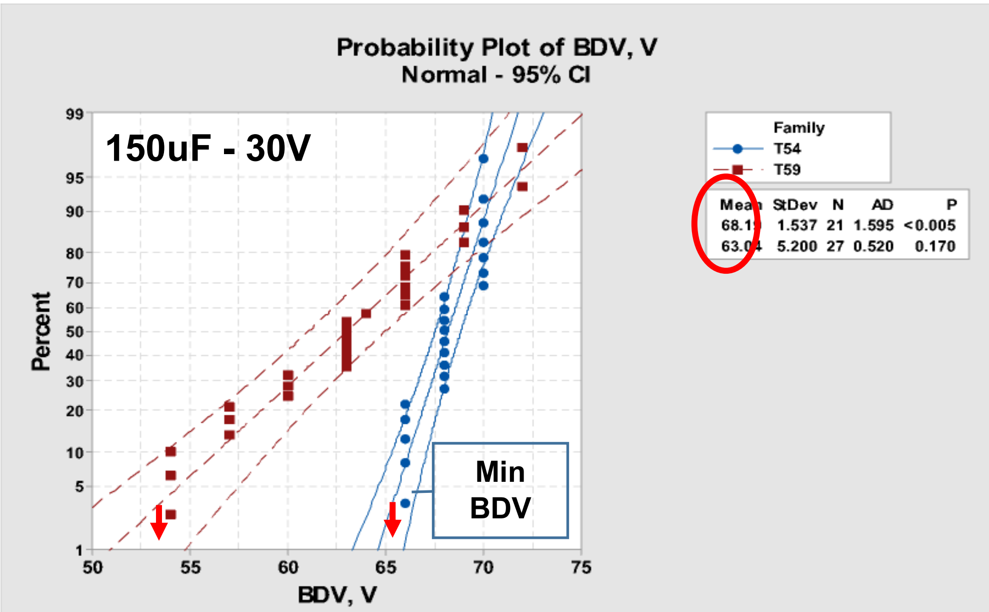


100 % electrical test @ Vr, RT DCL, uA



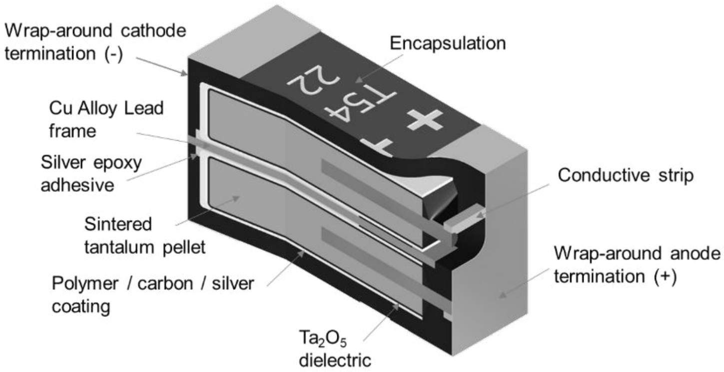
Hot DCL Test : Hidden outliners removed

T54 150 µF - 30V EE

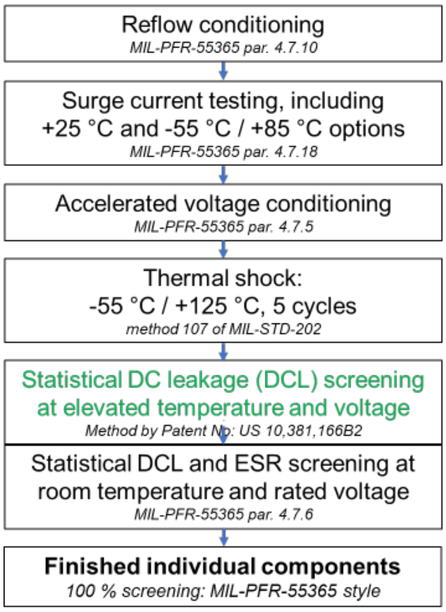


BDV *Significantly higher* ***T54 150 µF - 3 V EE***

5. Anode technics, MAP structure and screening methods applied to T54 double anode polymer

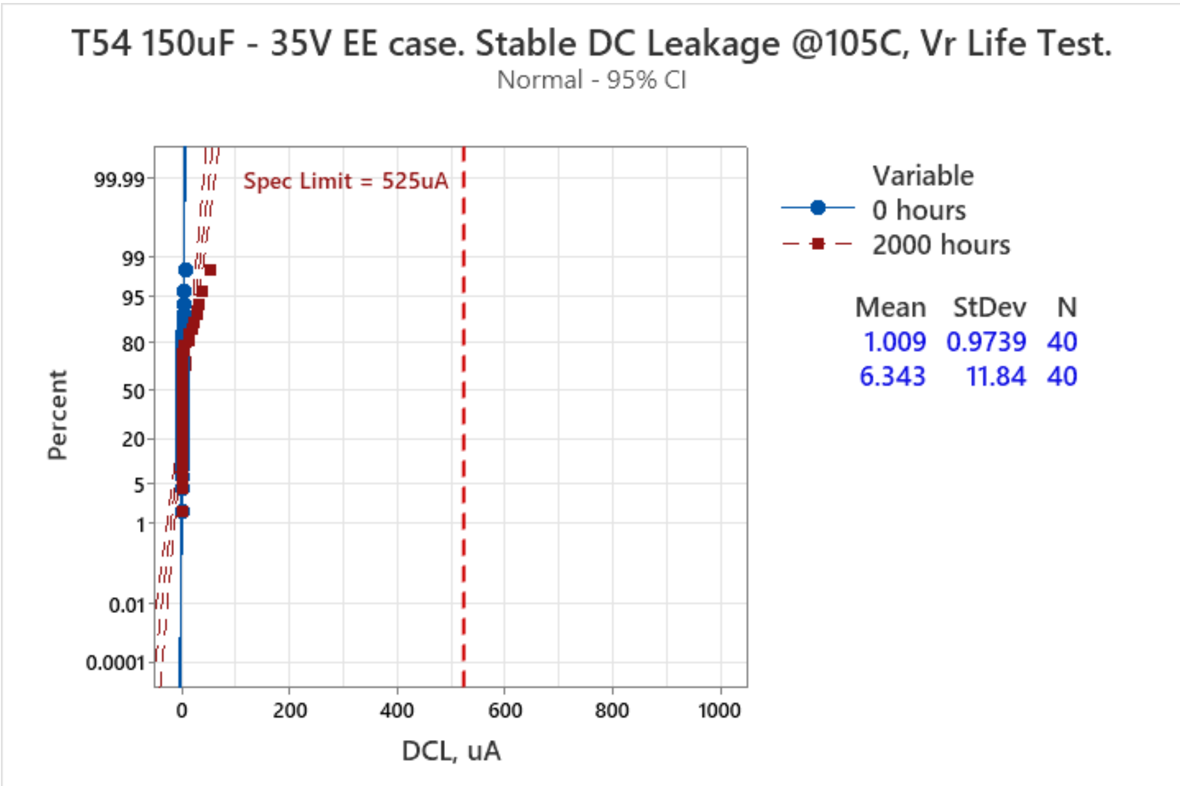


T54 Internal construction



T54 test regime

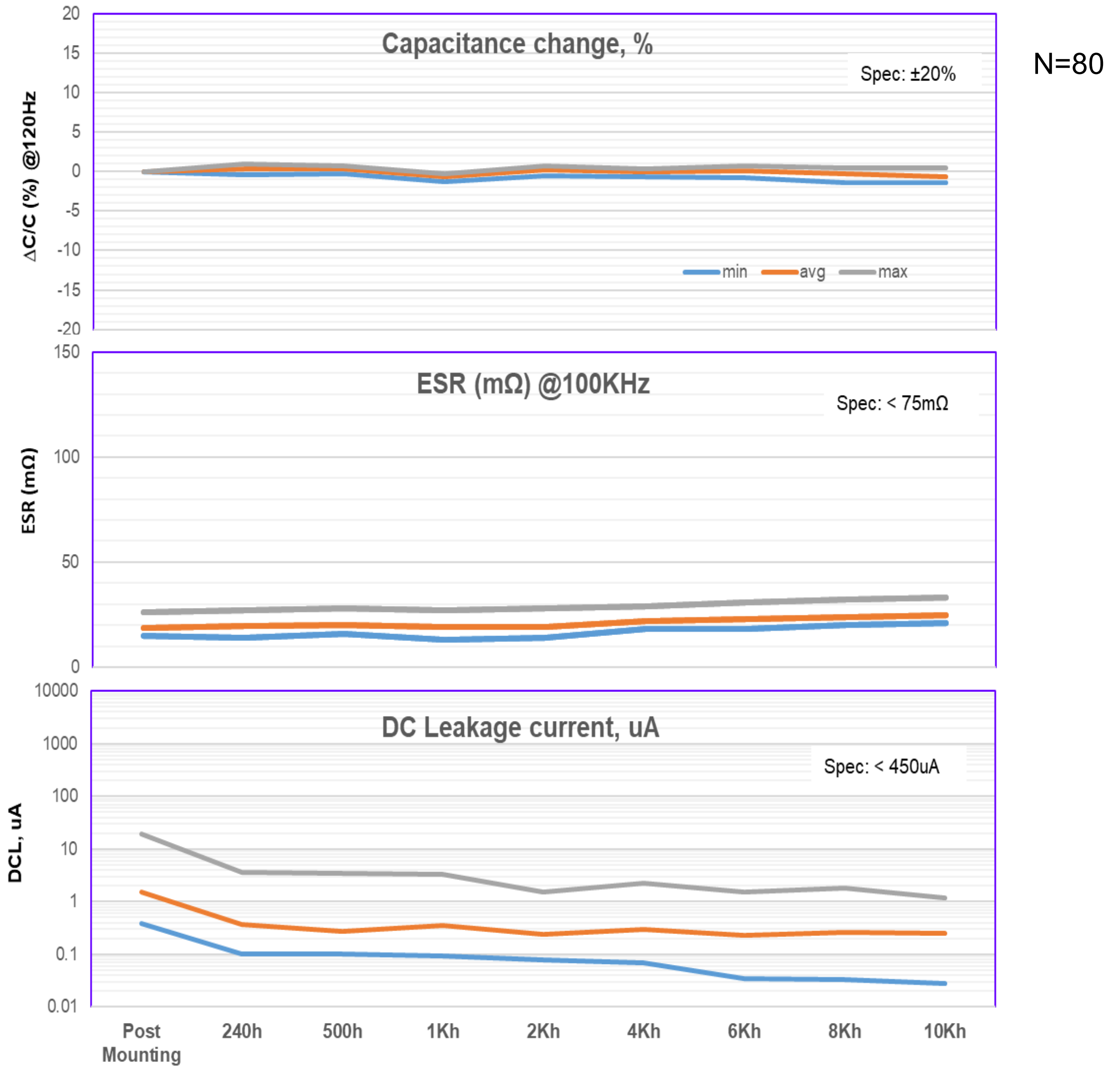
All this results in stable DCL demonstrated by T54 150/35V Life test graphs.



T54 150uF-35V [7343-43] EE case Polymer Tantalum Capacitor: Advantages of Vishay Anode Technology provide low and stable DC Leakage @105C Vr Life Test.

MAP structure will allow a better volumetric efficient

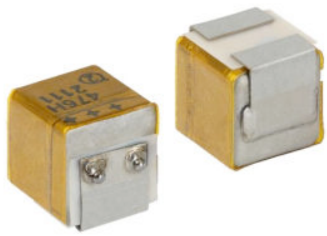
- ✓ Higher derating if required
- ✓ Less component and less FIT failure calculation
- ✓ Lower weight (including total CB saved weight
- ✓ Lower ESL for high frequency filtering
- ✓ Very robust construction



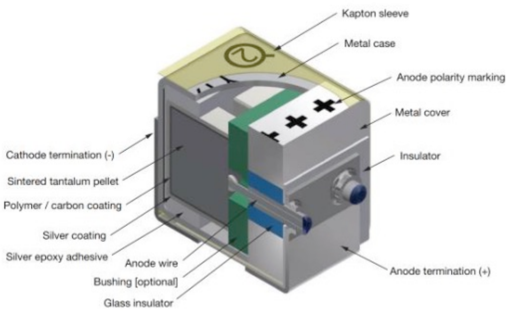
T54 150uF - 30V EE: 10,000h LOAD LIFE TEST @85⁰C, Rated Voltage

□ <u>Hermetic SMD packaging for T27 vPolyTan™ Hermetically Sealed Polymer Surface-Mount Chip</u>

When stability of electrical parameter is paramount in the application and extrem stability and predictability is expected, an hermetic protection can be added to control electrical parameters more tightly and prevent any characteristic drift in the component and in the application. Usage of existing and proven solutions and technology help the part qualification.



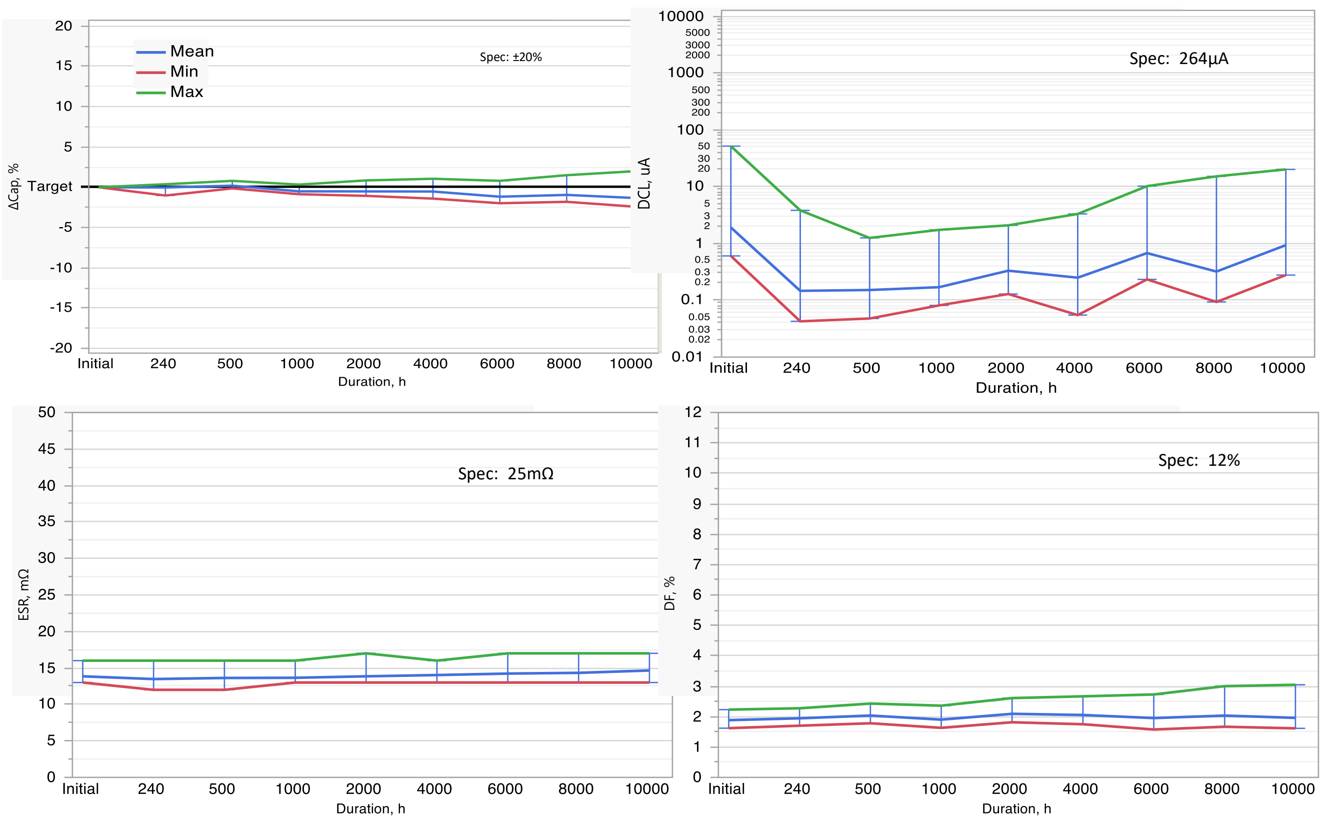
Mechanical and electrical Design based on enclosureT22 wet tantalum [DLA 19001] and Anode on T54 [DLA 20021]



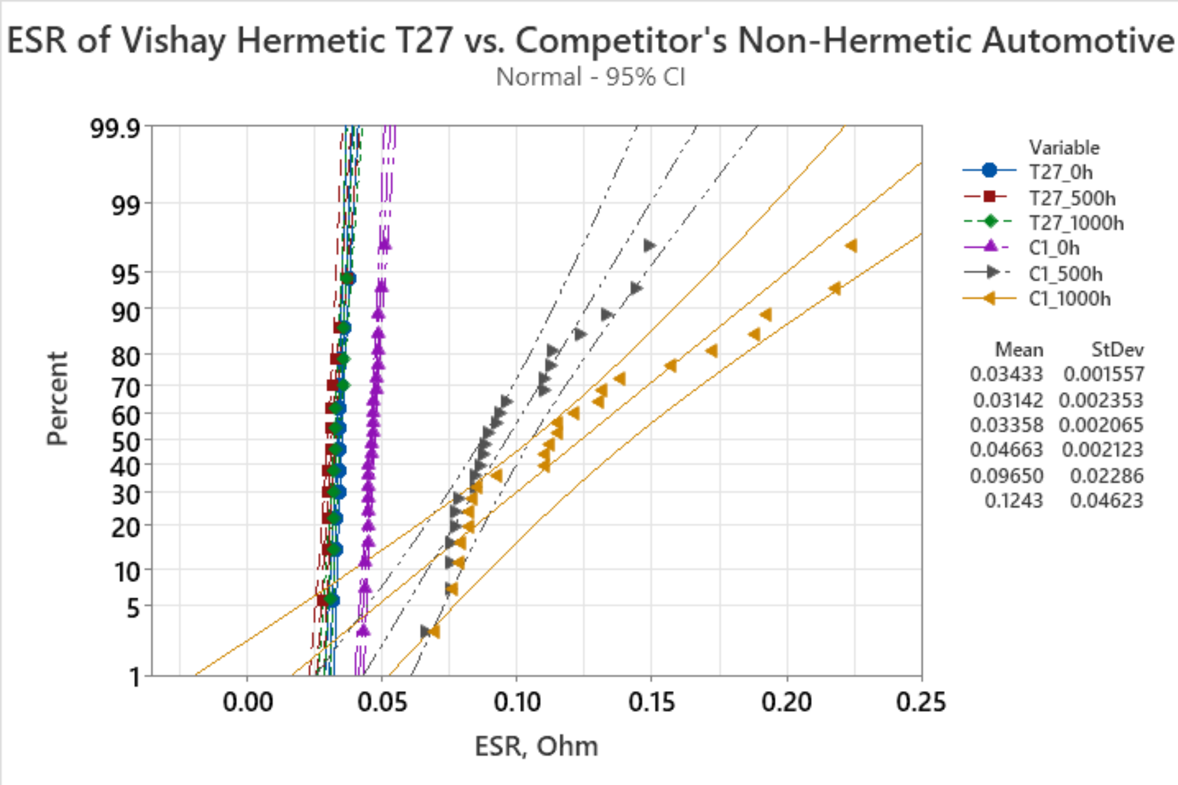
T27 Internal construction

10µF 50v Molded Automotive vs T27 47µF 50v

Using Advanced anode manufacturing and proprietary process (liquid delub, welded anode wire, crystal free anode) provides stable DC leakage performance throughout 10,000 hours of Life test. Hermetic sealing prevents conductive polymer conductivity loss due to Thermo Oxidation and therefore **better parametric stablility and predictable behaviour** of component may be obtained during design and longer missions.



Stability electrical parameters 330µF-16V D-Case: 10,000h Load Life Test @85°C, Rated Voltage



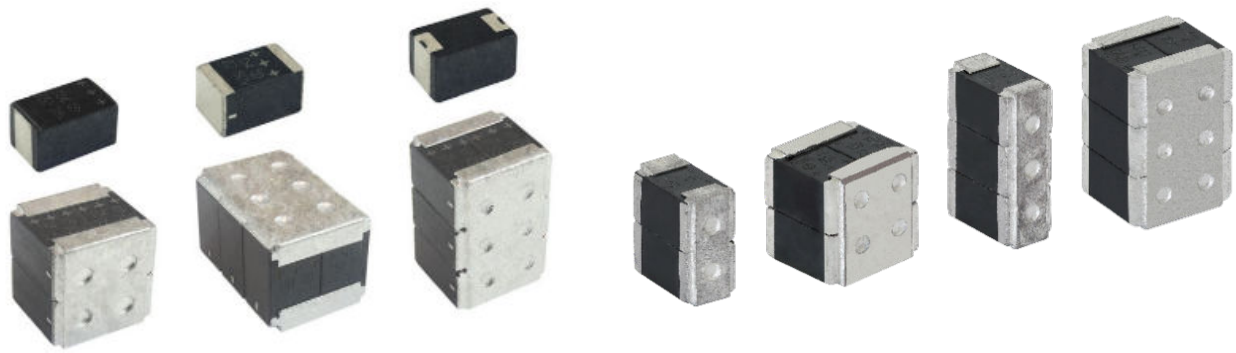
Unchanged ESR Vishay T27 @85°C / 85%RH, Vr, 1000hours Biased Humidity test

6. Modules and Custom assembly

When voltage, derating, capacitance value or low enough ESR cannot be reached using single component an assembly can be designed, tested and used directly by customer. That is MAP T54 stacked standard offering.

The major advantages are:

- ✓ Fully tested in production as a single unit, rather than implemented by customer at the board level and tested only at the end of the finished product process
- ✓ More flexibility in the design and the board layout (some modules can be closer to the point of load
- ✓ Scalable in the future without complete redesign
- ✓ Serial association made easy to reach higher voltages
- ✓ Large case EE to 6E from 2800µF 16v up to0µF 75v for GaN and radar module applications



Product	T54 EE -single	T54 E2 Stack	T54 E3 Stack	T54 E4 Stack	T54 E6 Stack
Footprint [*metric*]	7343 - 43	8044 - 89	8044 - 130	8089 - 89	8089 -130

T54 stacked configuration and MAP polymer flexibility Profile in inches (millimeter)

7. Extreme temperatures

Tantalum MnO2 technology process still preferable in high temperature environment compared to polymer cathode system.

125°C can now be proposed as a standard max temperature for products dedicated to harsh environment with some limited range at 150°C from some manufacturers.

High Temperature usage would have two major impacts:

- **Reliability**

FR is impacted by temperature of continuous functioning: extra derating and design can keep that expect within the reliability expected

Element of the component may not be suitable for above 125°C functioning: some range has been developpe to tackle this constraint:

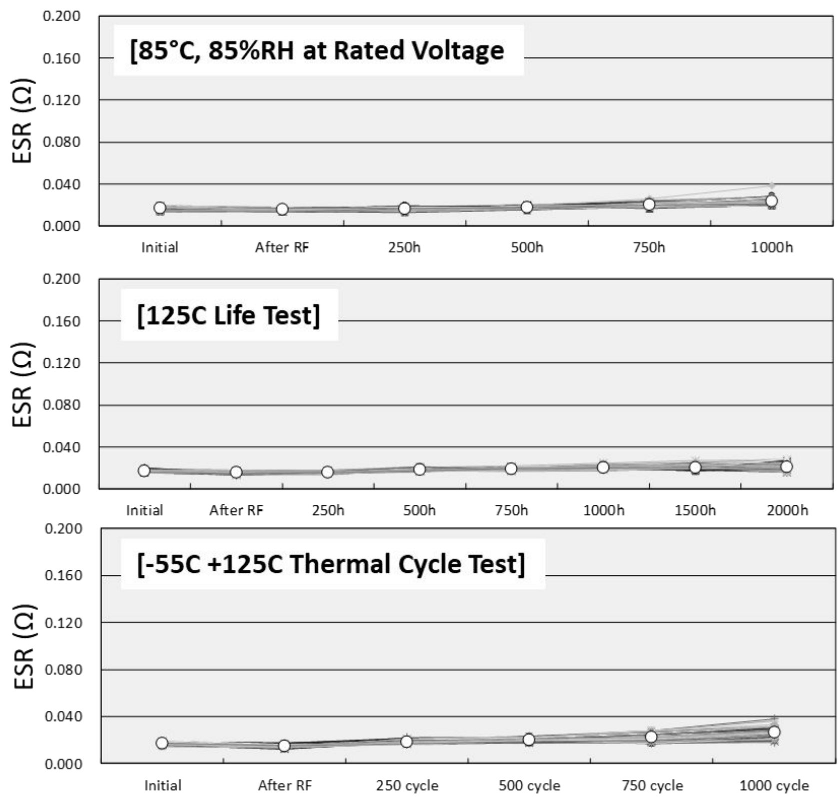
- Polymer

Main issue with high temp is accelerated thermal oxidation of polymer leading to loss of conductivity and ESR increase

It is extremely difficult to comply to above 125°C design and long term reliability. Some ratings are available from manufacturer sat 150°C but the range and voltages are more limited.

The focus is to propose 125C capability for many polymers products and T54 products. That correspond to many harsh AECQ Automotive active and passive range of product.

T51 is Vishay dedicated AECQ200 Automotive product range which is 125C capable offering stable ESR during critical reliability tests.



T51D 220uF-10V (25mΩ) Automotive product: stable ESR critical reliability tests

- Tantalum MnO_2

TH3, TH4 and TH5 can work continuously at 150, 175 and 200°C. They have been developed for automotive and oil drilling industry with specific temperature profile exceeding 125°C

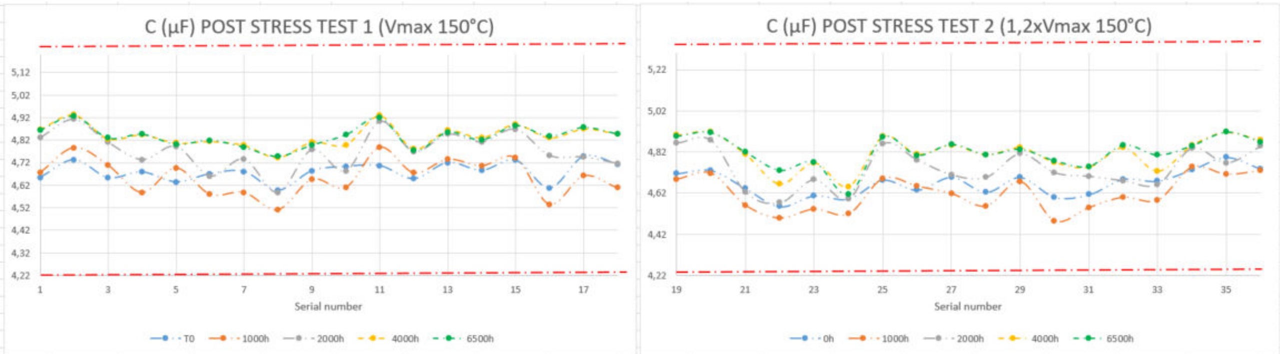
These 175 and 200°C are specifically design products, using improved material selection and high stress test regime, improved rbase reliability

TH3 150°C is used in harsh environment to create some design margin or limited over 125°C time.

That can be met when during cooling phase after heavy load on the electronic: automatic gearbox, space launcher.

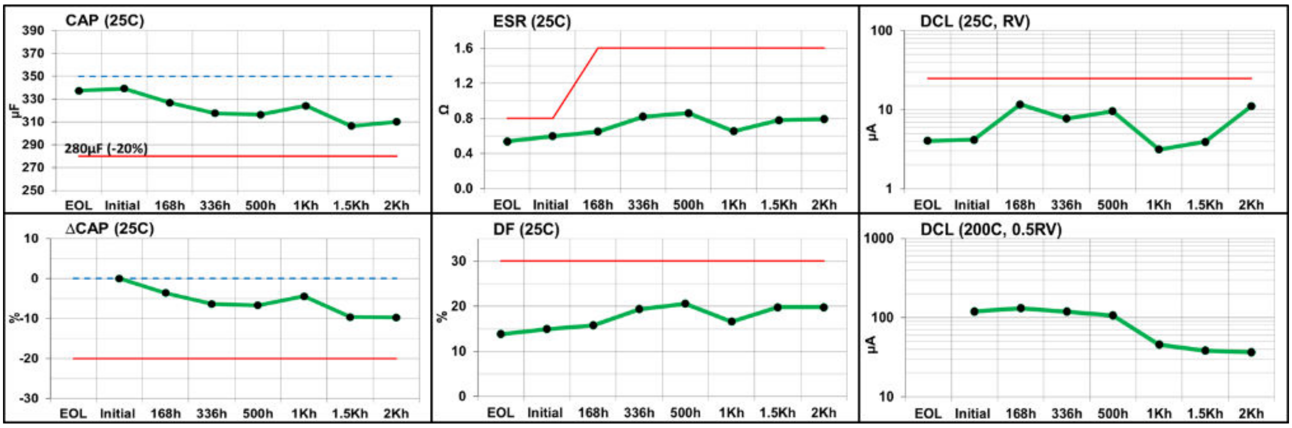
For FADEC that also allow a over specified functioning in case of emergency (fire...)

Data below show the TH3 at 1.2 Rv 150°C demonstrate a very stable capacitance after 6500 hrs, showing long term stability of MnO_2.



- Wet tantalum

This type of capacitors are widely used in High temperature oil drilling design.
They remain the best choice when temperature exceed 150°C and voltage is above 12v with high derating requirements
T34 350µF-125V D-case results below show all electrical parameters stable after 2000 hrs 0.5Vr 200°C.



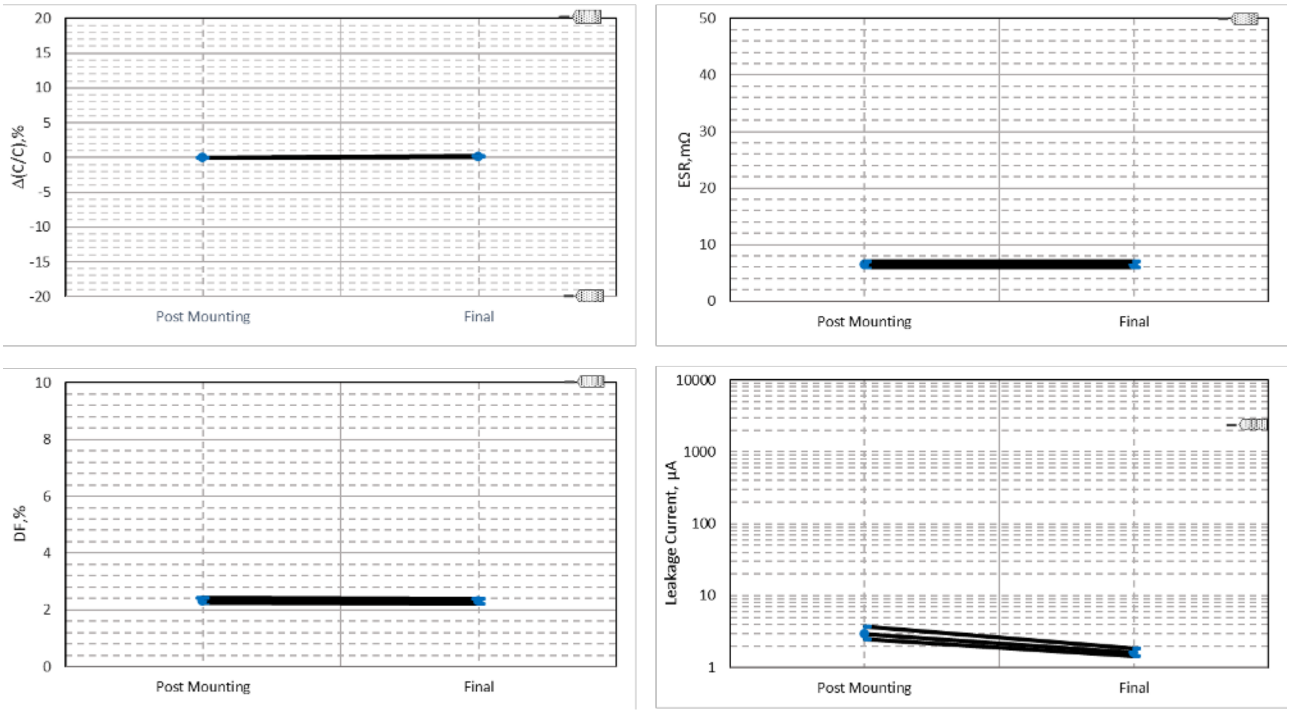
8. Mechanical Stress reliability

Harsch environment will also bring severe necanical stress to the component during part or all the mission
Oil drilling is an obvious exemple
Space is rising the limit with new parameter and requirements:

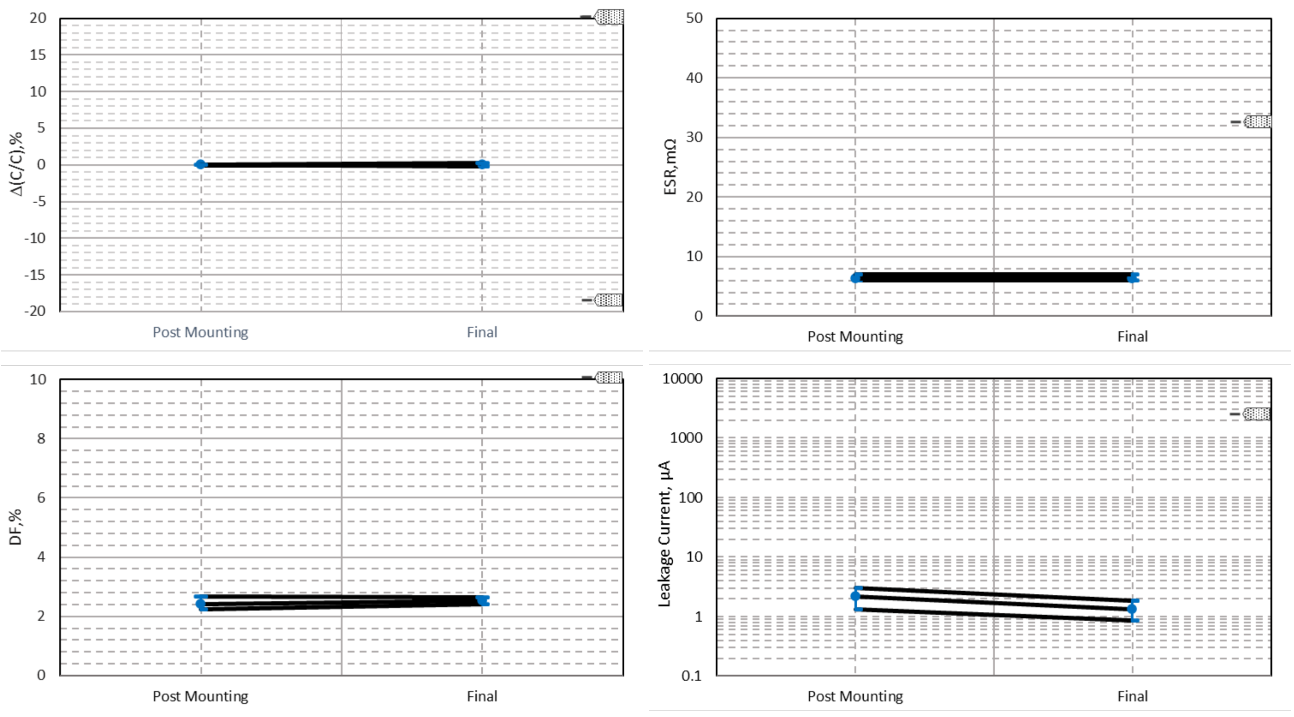
- ✓ Launcher vibration and acceleration
- ✓ Larger solar pannels and vibration
- ✓ More power in a lighter and smaller equipmentwith less buffereing
- ✓

Duration of these stres period will also increase, or become repeatable for reusable equipments.

In conclusion the reliability to mechanical stress will increase and become more difficult to predict and anticipate. The best strategy in this case at component level will be to increase safety margins and select the most stable product / technology in a given environment and mission profile



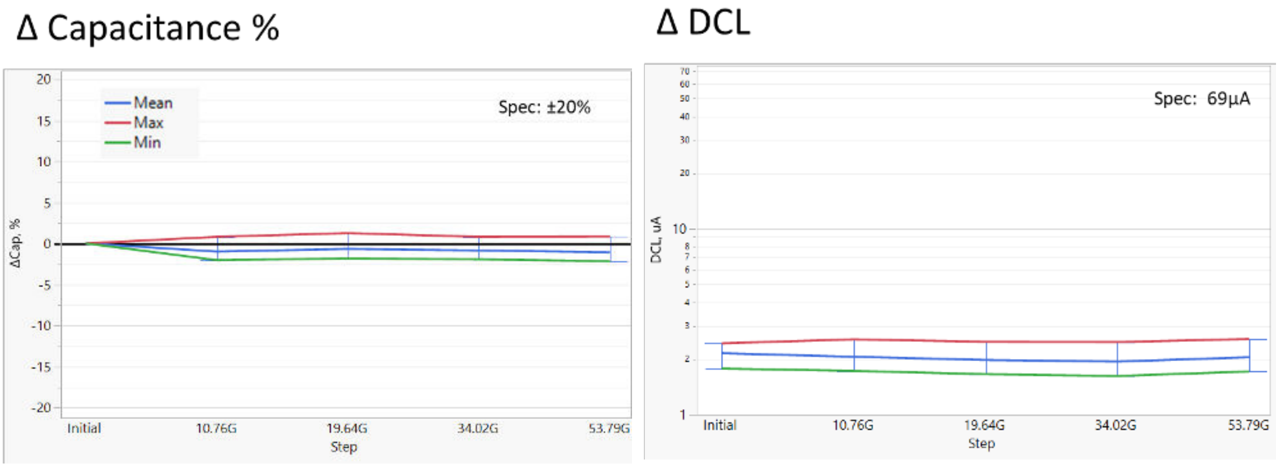
Vibration 20g peak T54E6137M075



Shock 1000g peak T54E6137M075

A vibration proven enclosure solution (like T22/T24 for oil drilling) can also be used like T27 (Hermetically sealled version of T54

Below a T27 test after random mechanical test up to 53G random vibration show no variation of electrical parameters



Electrical parameter stability ***after Random Vibration***

9. FR ASSESSMENT OF POLYMER CAPS

- **Hi-Rel and FR Screening:** The screening process for MnO2 products follows strict protocols (e.g., MIL-PRF-55365), including reflow conditioning, surge current testing, accelerated voltage conditioning, and thermal shock procedures. These tests simulate worst-case operating conditions and provide statistically significant reliability benchmarks.

- **FR assessment for Polymer tantalum capacitors:** WGT is not applicable for Polymer tantalum capacitors [PTC] since their probability of IM failures is much lower than in MnO_2 parts.

Too few, if any, capacitors fail under maximum accelerated test conditions to support the failure rate calculations. Accelerating PTCs enough to cause failures within 10 hours requires applying voltage > 1.53Vr. This violates MIL-PRF-55365 acceleration limit and potentially shortens the lifetime of the treated parts.
PTCs cannot undergo 100% FR grading like MnO_2 parts.

Instead, FR assessment should be performed on each manufacturing lot ordered with given FRL:
- ✓ sample testing under accelerated temperature/voltage
- ✓ FR calculation based on achieved unit-hours, number of rejects and acceleration factors.

Acceleration Factor [AF] that defines capacitor degradation can generally be presented as a multiplier of Voltage and Temperature acceleration factors: $A_F = A_T * A_V$

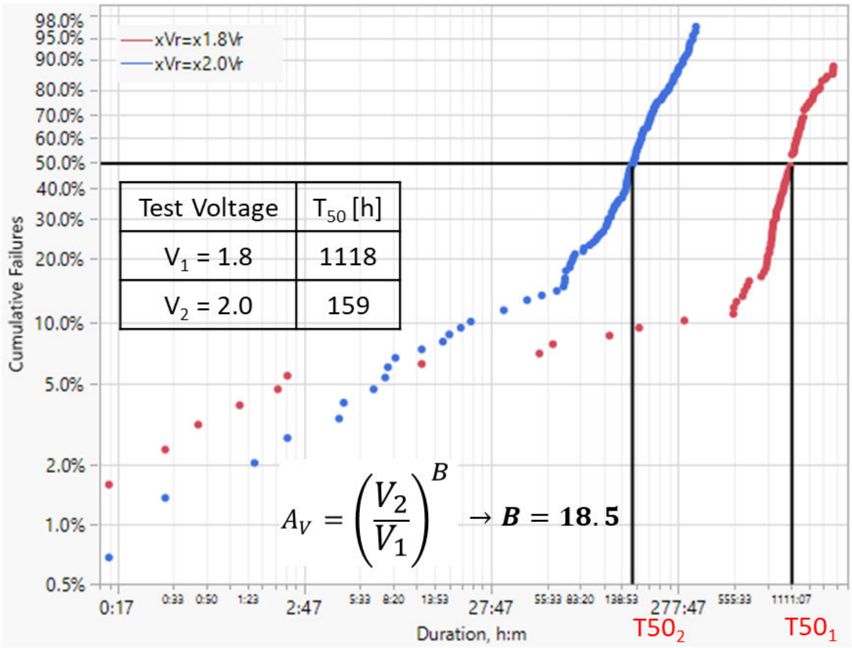
➢ Temperature acceleration described by the Arrhenius model:

$$A_T = e^{\frac{E_a}{k}\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

T : Application temperature
T_0 : Maximum operational temperature at rated voltage
Ea : Activation energy – empirically defined by testing product at a range of elevated temperatures
k : Boltzmann's constant, $8.617E^{-5}$ eV/K

➢ Voltage Acceleration defined by Power law (Prokopowicz-Vaskas) model: $A_V=(V/V_0)^B$

V : Application voltage
V_0 : Max operational [rated] voltage
B : Voltage power factor [or Voltage Ratio Exponent VRE] – empirically defined by testing product at a range of elevated voltages



Av: voltage acceleration factor

B: VRE - voltage ratio exponent

Accelerated testing of T54EE 47uF-35V at 85°C

Reliability assessment per §4.7.12 of MIL-PRF-32700 ***Performed for each lot ordered with FRL.***

- Mounting: minimum of 100 capacitors, 2X reflow.
- Test temperature: between +85°C and +129°C.
- Test Voltage: 1Vr min to 2Vr max.
- Duration of test: depends on the failure rate level desired but a minimum of 100 hours.
- Failure determination: blown-1-amp fuse [in line with each capacitor on test].

Failure rate level calculation:

$$FRL = \frac{Fx10^5}{(N)(T_{test})(A_V)(A_T)}$$

FRL = failure rate level in %/1,000 hours at Vr and +85°C.

F = number of failures. If F=0, 1 failure shall be assumed. **A=Non ER / X=0.1 Y=0.01 Z=0.001 %/1000h**

Ttest = test duration in hours.

AV = voltage acceleration [appendix B].

AT = temperature acceleration factor [appendix B]. AT = 1, if testing @ 85°C

Example: For FRL Z (0.001%/1,000 hrs.), 1 failure is permitted in 10^8 accumulated part hours. If 100 capacitors tested for 100 hours, the product of the AV x AT must be 10^4.

SUMMARY AND CONCLUSIONS

Vishay's advanced Tantalum capacitor technology embodies a comprehensive engineering solution for harsh environments. Through rigorous control of process parameters—from anode preparation using liquid delubrication and magnesium deoxidation to innovative packaging with MAP technology—the resulting capacitors exhibit exceptional reliability, low DC leakage, and robust performance under extreme conditions. These improvements not only meet but often exceed industry standards, making them indispensable in critical applications where performance and longevity are mandatory.

The component manufacturer improvements continues toward higher temperature, longer life time and stable functioning in harsh environments but should be targeted in close communication with future harsh mission designer, other active and passive components specialist to offer the best solution for the application.