

An update on high temperature tantalum capacitor technology

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Abstract

Developments and improvements in the materials, design and manufacturing of tantalum bulk capacitors have resulted in new case sizes, improved ESR, higher operating voltages and temperatures.

This work discusses the basic design and manufacture of hermetic tantalum and wet tantalum capacitors and the resulting high temperature performance offered by each technology.

Specifically, hermetic sealed tantalum capacitors offer a novel set of design options for the high temperature designer. This technology, exhibits superior stability when exposed to high temperatures, high humidity, and ambient atmosphere. The device is impervious to the typical capacitance drop common to high temperature capacitor operation. Thus they enable potentially significant size reductions, lower component counts, and reliability improvements in extremely high temperature applications, such as down-hole oil drilling.

Both electrical and physical comparisons are made between the characteristics of bulk stacked ceramic capacitors, hermetic tantalum and wet tantalum devices across an operating range of -55°C to +230°C. Lifespan and recommended de-ratings are presented.

Key words

Hermetic Tantalum, MnO₂ Tantalum, Stacked Ceramic Capacitor, Tantalum Polymer, Wet Tantalum

I. Introduction

Passive components can potentially represent up to 70% of PCB footprint in today's electronic systems. A large to the majority of the 70% PCB area is occupied by capacitors since they are among the most widely used passive components. Those statements also hold true for electronics operating in high temperature applications.

For the sake of this paper, high temperature electronics will be considered to range from 180°C to 300°C. Those temperatures can generally be considered to represent applications such as those in oil logging, jet aircraft, nuclear power generation, and other industrial applications.

Typically, Multi Layer Ceramic Capacitors (MLCCs) and tantalum capacitors are chosen for use in high temperature electronics based upon weighted comparisons of reliability, electrical performance, size and cost.

All of these capacitor technologies have advanced significantly in recent years in terms of electrical performance and reliability, but tantalum devices may have

the most advances and specially advances that match the needs of end circuits.

It is because of this that tantalum capacitors have received a large amount of interest from the design community lately due to the increased power demands of complex semiconductors. Those demands place more importance on bulk capacitors in power trees due to higher di/dt and tighter power regulation needs.

An example of the importance of high quality power can be shown in a simple low noise instrumentation amplifier [1]. This IC might be used to measure small signals in the presence of large common-mode voltages at high temperatures.

This IC needs a stable DC voltage since noise on the supply pins adversely affects performance. Typically a 0.1 µF MLCC capacitor is placed as close as possible to each supply pin, and a 10 µF tantalum capacitor is used for bulk/low-frequency characteristics. In this specific example, the tantalum might be shared by another IC and has fewer concerns for physical proximity to the load but,

many cases require the high temperature bulk capacitor to be as close as possible to the IC. Tantalum capacitors' multiple case sizes and generally high capacitance density give designers many options to place a bulk capacitor close to the desired circuit.

II. Tantalum capacitor technology

Tantalum capacitor technology has been proven to exhibit excellent reliability, robustness and offers stable parameters in a wide range of small case sizes that are easy to place and process in assemblies. These capacitors are accepted as a technology available in various quality grades ranging from consumer to automotive as well as enterprise to Established Reliability/High Reliability. Detailed performance criteria are outlined in MIL-PRF-55365, which is a widely accepted and referred to specification from the Defense Logistics Agency.

The evolution of solid tantalum capacitors started with standard tantalum capacitors progressing from consumer applications and quickly being adopted in more demanding higher reliability applications such as auto & military. The high temperature market recognized this material system to hold great promise since end applications commonly involved strong shock & vibration along with extreme temperature cycling. It was understood that all materials used within tantalum capacitors would exhibit adequate thermal and mechanical stress as not to become a point failure.

Tantalum capacitors then progressed to professional grade devices capable of meeting expectations for automotive electronics reliability and operation up to 175°C. As those 175°C devices design, processes and materials expanded, even higher-temperature tantalum-based capacitors were developed using solid MnO₂ technology and extending operating temperatures up to 200°C. Work was later performed on creating high temperature pellets that would be sealed inside of SMT hermetic packages and create Tantalum capacitors capable of operation up to 230°C.

It was during this transition period that parallel paths were created, introducing improved materials and processes to further reduce the Equivalent Series Resistance (ESR) for improved end-use efficiency.

Conductive Polymer Tantalum

The design of conductive polymer tantalum capacitors is based on similar electrochemistry and design principals as solid MnO₂ tantalum capacitors. Tantalum

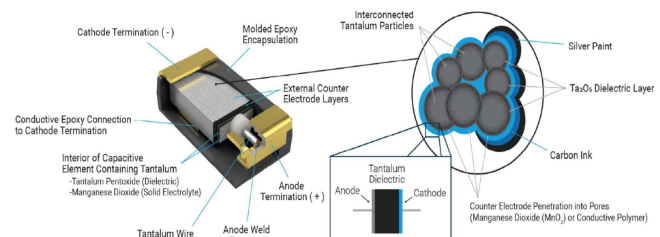
polymer capacitors will exhibit attractive performance features above those of traditional tantalum capacitors. Among those are:

- Significantly lower ESR
- Higher ripple current ratings
- Improved Capacitance retention at high frequency
- Higher energy density (Joules/cc)
- Increased operating voltage
- Lowered voltage de-rating required
- Benign failure mode if short-circuited

From a design point of view, conductive polymer capacitors do have some important performance differences from MnO₂ capacitors. Those are:

- Moisture Sensitivity Level MSL = 3 rating
- Sensitivity to high thermo-mechanical stress
- Higher leakage - DCL
- Possible capacitance & ESR change related to the effects of oxygen and humidity on conductive polymer cathode

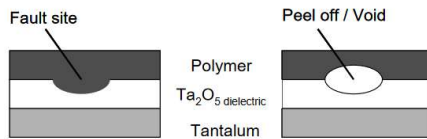
Conductive polymer capacitors utilize a highly conductive polymer on the cathode to reduce the ESR of the capacitor and gain several other advantageous electrical characteristics. A cross-section of an SMT plastic encapsulated tantalum, along with a blow-up of the grains and options for counter electrode material, is shown in Figure 1.



SMT Tantalum Construction
Figure 1

Explaining further, a conventional tantalum capacitor uses MnO₂ as the 2nd electrode (cathode). This material has a relatively high resistivity and impacts the ESR of the capacitor, which in turn, limits the RMS of the capacitor during its operation. The design of a Conductive Polymer Tantalum Capacitor replaces the MnO₂ with an organic material that is a conductive polymer. Polymers exhibit a lower capacitance drop across frequency. Further, the organic conductive polymer cathode promotes a more benign failure mode, as the conductive polymer, unlike MnO₂, is not an oxidation agent. Also, the conductive polymer has a different self-healing process where the failure site is insulated within the defect site when it basically becomes a hot spot that stops further current flow

through the failure site. The failure site isolation is best represented by figure 2 shown below.



Cross section of the self-healing process in polymer
Figure 2

The use of a conductive polymer material system in conjunction with plastic encapsulation has enabled the creation of a high temperature capacitor with low ESR that is AEC Q200 auto grade approved, rated up to 50 volts, and capable of 3x reflow at 260°C.

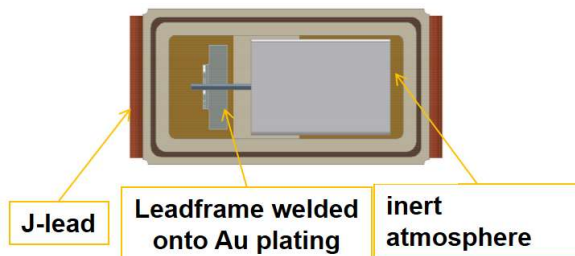
However, work done in conjunction with recent tantalum and tantalum polymer capacitors fundamental R&D has resulted in a traditional tantalum capacitor (MnO₂ based cathode) with an even higher operating temperature – up to 230°C.

Hermetically sealed SMD MnO₂ tantalum capacitor

Several studies were launched to assess the stability of parameters on tantalum surface mounted capacitors at temperatures well above 200°C.

As temperatures increased, several challenges were encountered due to exceeding the glass transition temperature of epoxies and also other mechanisms related to humidity and oxygen deterioration. Investigations found that a higher electrical parametric stability can be achieved by placing the capacitor into a hermetically-sealed SMD case filled with an inert gas.

A new hermetically-sealed SMD tantalum capacitor structure was designed where the capacitor element is enclosed in a ceramic housing (Figure 3).



Top View Tantalum capacitor pellet encased in hermetic package with J leads
Figure 3

Nitrogen is used inside the hermetic package as an inert gas inner atmosphere to inhibit oxidation of the solid electrolyte.

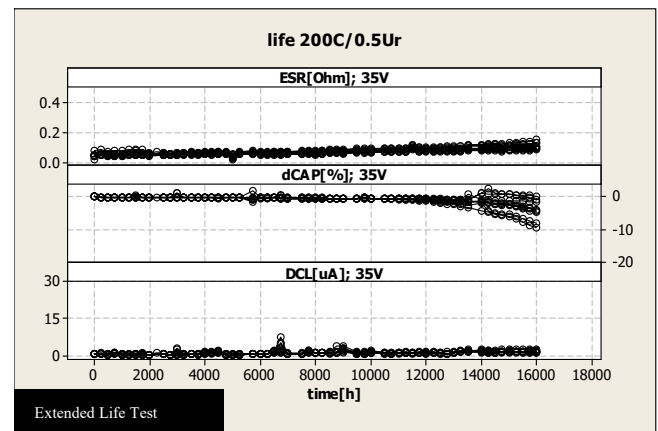
To test mechanical robustness, mechanical shock tests with conditions of 1.500g - 0.5ms, 5x, XYZ planes and also 20g vibration across 10-2,000Hz at 25°C were performed.

Next, an operating life test of 2,000hrs at 230°C and rated voltage, as well as a moisture resistance test of 64 hours duration at 120°C, 85% RH, and rated voltage, were carried out.

Test results showed no failures and these devices have demonstrated proven and excellent performance.

Based on these positive initial results, a formal development and qualification program was started and completed by AVX to create a 230°C high temperature hermetically-sealed tantalum product (THH series).

An excerpt of extended life testing is shown in figure 4. THH series capacitors are currently available with capacitance values spanning 6.8μF to 100μF, voltage ratings spanning 16V to 50V. The THH Series offers designers an alternative to larger size wet tantalum capacitors having sizes as small as 11 x 6 x 2.5 mm.



Hermetic THH series 100μF/35V Capacitance, ESR,
Leakage test 200°C/0.5U_R 16,000hrs

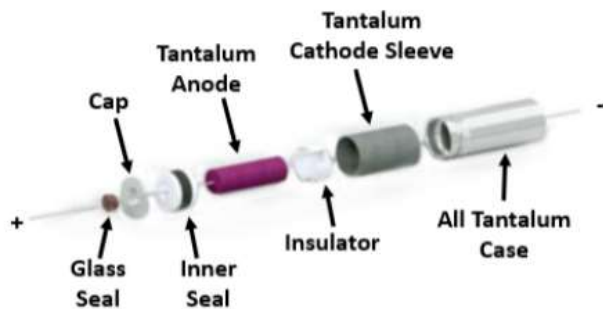
Figure 4

Wet Tantalum Capacitors

Wet tantalum capacitor technology has been in existence for over five decades and offers higher capacitance and higher voltage ratings than solid tantalum capacitors. Wet tantalum technology provides designers with an option for high capacitance, low DCL, and long life, combined with proven mechanical robustness. Wet tantalum capacitors are built by using a tantalum pellet as an anode. The pellet has an insulating dielectric oxide layer on it and then is

surrounded by a liquid used as the cathode. The liquid cathode material is hermetically sealed in a metal can using welding and metal to glass seals.

The individual components used to make a wet tantalum capacitor are shown in figure 5. Individual wet tantalum capacitors can be connected in series/parallel configurations to address applications such as hold up or large pulse discharge. Wet tantalums are available in voltage ratings as high as 125V and, on a comparative basis, exhibit approximately 3 times the capacitance density as aluminum electrolytic capacitors. Wet tantalums, with their hermetic case designs, have a very long life and low DC leakage.



Wet Tantalum Capacitor cross section
Figure 5

III. Tantalum capacitor vs MLCC stability

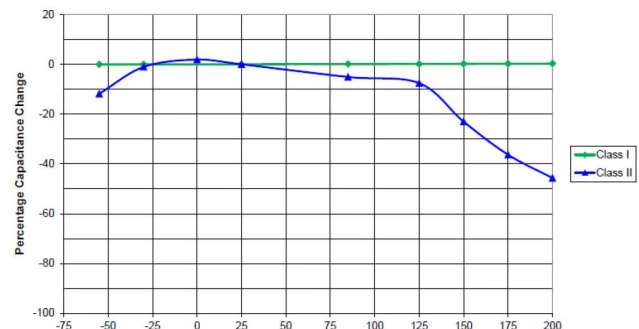
The two most widely used high temperature capacitor types—multilayer ceramic capacitors (MLCCs) and tantalum capacitors—have dramatically different temperature stability characteristics. Capacitance stability is commonly the biggest concern with high temperature capacitors (this, of course, assumes the reliability of both device types is acceptable).

High-temperature capacitors are based on uniquely formulated material systems with the highest of purity. A combination of conservative design rules (typically lower electric field stress across dielectrics) and tightly controlled manufacturing steps help these devices meet intended high temperature electronic end sector performance needs.

Ceramic capacitors intended for -55°C to +150°C are manufactured with dielectrics ranging from C0G (Class 1) and X8R to X8L (Class 2) dielectric materials. These dielectrics provide a highly reliable capacitor with low loss and multiple capacitance stability characteristics over temperature. Capacitors built using C0G dielectrics exhibit capacitance stability of 0 ± 30 ppm/°C.

Capacitors based on X8R material have a capacitance variation of $\pm 15\%$ between -55°C and +150°C. The X8L

material has a capacitance variation of $\pm 15\%$ between -55°C to 125°C and +15/-40% from +125°C to +150°C. A typical comparison of class 1 and class 2 dielectric type MLCC is shown in figure 6.

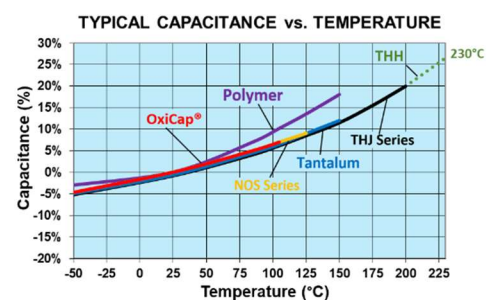


Typical Capacitance vs Temperature Class 1 & Class 2
MLCC

Figure 6

When confronted with a need for large capacitance, designers can gravitate to stacked MLCCs in an effort to increase CV (capacitance/unit volume) without adding to increased board area from an XY point of view. Stacked MLCCs are made by stacking multiple MLCCs vertically or horizontally.

Alternatively, high temperature tantalum capacitors can be used to achieve large capacitance values with a much greater certainty of offering a minimum amount of capacitance in the circuit. Tantalum capacitors' typical capacitance vs temperature stability is shown in figure 7.



Typical Capacitance vs Temperature of Tantalum and
Niobium Oxide Capacitors

Figure 7

III. Conclusion

Advances in tantalum capacitor technology has resulted in miniature high temperature bulk capacitors. Several grades of high temperature capacitors exist, from 175°C auto grade

devices in plastic packages to 200°C capacitors – both in standard MnO₂ tantalum cathode technology. Hermetic Tantalums exist in both standard MnO₂ cathode and Tantalum polymer material systems as they do in wet tantalum construction. High temperature hermetic MnO₂ devices exhibit high reliability and extended lifetime performance at up to 230°C. Hermetic polymer tantalum capacitors have been created that exhibit high reliability at temperature. Future work is centering upon design modifications allowing these devices to be rated at elevated temperatures. Wet Tantalum capacitors continue their evolution into packaged modules through series/parallel packaging schemes.

Acknowledgment

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