TECHNICAL PAPER

Tantalum Capacitors: Characteristics and Component Selection

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Abstract:
Capacitors are one of the fundamental building blocks of electrical circuits. Whether they are being used for energy storage, noise filtering, or timing/frequency design, capacitors are important in many common electrical devices. Today, various capacitor technologies are available, each with their own unique benefits and drawbacks, making each type ideal for different applications. Tantalum capacitors offer many interesting characteristics that combine to offer a unique solution to many design problems.

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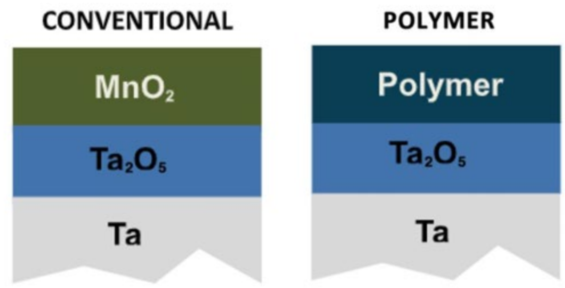
Tantalum Capacitors: Characteristics and Component Selection

INTRODUCTION

Tantalum capacitors are capacitors constructed with tantalum material used to form the anode of the capacitor. Tantalum capacitors are electrolytic capacitors, which means the capacitor is formed by an oxide layer formed on the anode and is thus polarized. A tantalum capacitor includes a tantalum powder anode, a Ta2O5 oxide layer dielectric, and a cathode that can be MnO2 or a solid polymer.



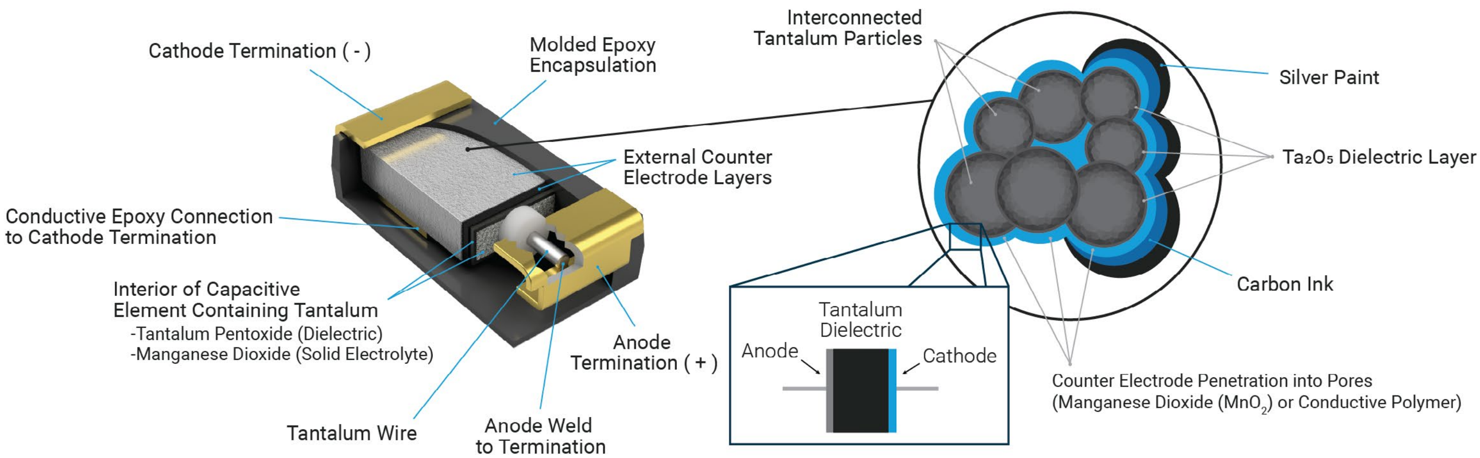


Figure 1: A graphic representation of a tantalum capacitor, which includes a tantalum powder anode, a Ta2O5 oxide layer dielectric, and a cathode that can be MnO2 or a solid polymer.

Tantalum capacitors are made by pressing the tantalum powder and forming it into a pellet through sintering. Tantalum capacitors are beneficial because they form an extremely thin dielectric, as little as 20 - 400 nm thick. This pellet is porous, like a solid sponge, so when the dielectric layer is formed in the next step (anodic oxidation), the thin oxide layer is formed over a great deal of surface area. This allows tantalum capacitors to have a much higher capacitance and voltage per volume (CV/cc) than other technologies.

Tantalum Capacitors: Characteristics and Component Selection

INTRODUCTION CONTINUED

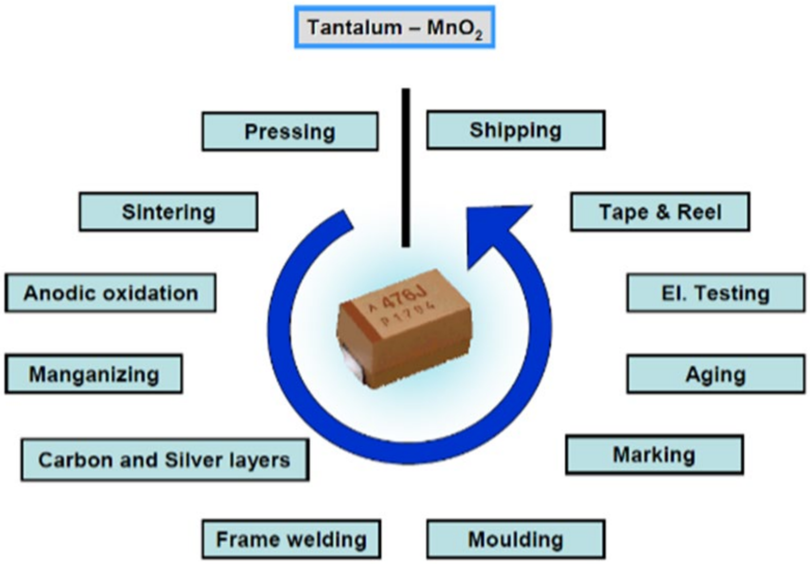


Figure 2: A process flow chart for tantalum capacitors.

Tantalum capacitors offer max CV values many times higher than typical capacitor technologies commonly used today.

Capacitor	Package	Max CV
Tantalum Capacitor	SMD	63.0mFv/mm3
Aluminum Can	Cylindrical	11.8uFv/ mm3
Aluminum Polymer	Stacked SMD	10.5uFv/ mm3

Comparing Tantalum to Other Common Capacitor Technologies

TANTALUM VS ALUMINUM CAN

The primary structural difference between tantalum and aluminum can capacitors (other than the materials used) is the electrolyte. The electrolyte is a solid material in a tantalum capacitor, and a liquid in an aluminum can capacitor. The conductivity of the liquid electrolyte is very dependent on temperature, meaning all of the critical parameters of aluminum can capacitors (capacitance, ESR, leakage current, DF, and even rated voltage) are unstable over broader temperature ranges. The liquid electrolyte can even dry out over time, resulting in a shorter expected lifetime. By contrast, tantalum capacitors utilize a solid electrolyte that does not dry out, is much more stable over temperature, and has a significantly longer life expectancy.

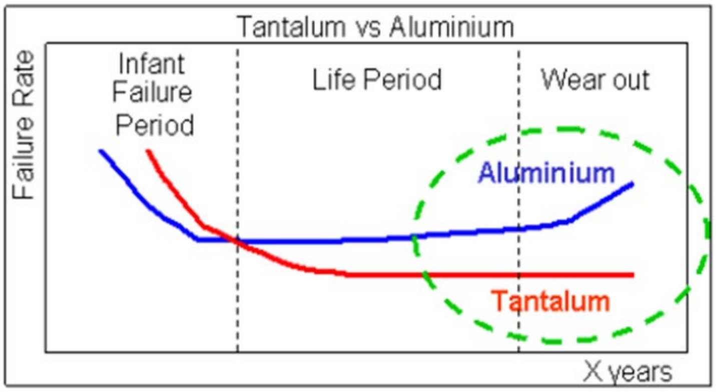


Figure 3: A visual based on the mathematical model of the failure rate VS time.

Comparing Tantalum to Other Common Capacitor Technologies

TANTALUM VS MLCC

Multi-layer ceramic capacitors (MLCC) are non-polarized capacitors that are prevalent surface-mount components in many designs. MLCC devices have some drawbacks, which can make tantalum capacitors a better option in many systems.

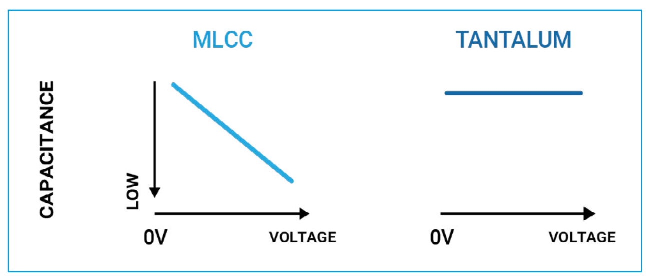
First, ceramic materials have a piezo-electric effect, so MLCC devices share this characteristic. Materials with piezo-electric characteristics physically move or vibrate when electrical signals are applied, and/or create electrical signals when physical pressure is applied. This effect can cause ceramic capacitors to “sing” or “hum” when electrical signals are used, varying by frequency harmonics. Tantalum capacitors do not have a piezo-electric effect.

Next, MLCC devices have a DC bias characteristic, meaning the actual capacitance of the capacitor varies with the voltage level applied to the capacitor. Tantalum capacitors are not susceptible to DC bias.

Finally, as mentioned above, all of the tantalum capacitors’ parameters are very stable over a wide range of temperatures, from -55 to 125°C, and even up to 175°C. MLCC devices have many different grades for different temperature groupings, such as X5R, X7R, and NP0. Tantalum capacitors, being stable over wide ranges of temperatures, do not.

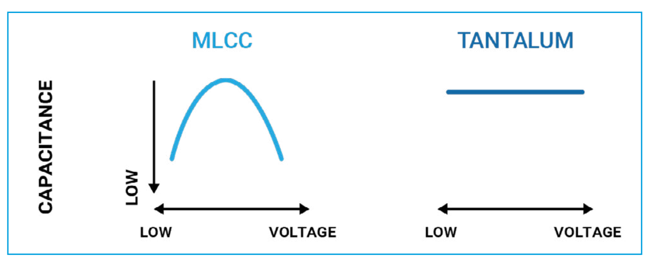
DC BIAS VOLTAGE

In an MLCC, capacitance decreases as bias voltage applied increases. Tantalum capacitors do not vary with bias voltage, and they are physically smaller than the same capacitance MLCC devices.



TEMPERATURE

In an MLCC, capacitance is susceptible to temperature, decreasing at low and high temperatures. Tantalum capacitors show stable capacitance across all rated temperatures.



AC VOLTAGE (NOISE)

In an MLCC, the substrate vibrates when an AC voltage or noise is applied. This vibration can cause audible noise. Tantalum substrates do not vibrate, so they cannot create audible noise.

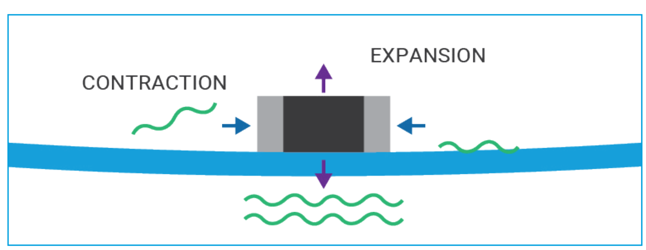


Figure 4: A graphic comparing MLCCs to tantalum capacitors.

Comparing Tantalum to Other Common Capacitor Technologies

TANTALUM VS ALUMINUM POLYMER

Aluminum polymer capacitors generally use the materials of the aluminum can capacitors, but replace the liquid electrolyte with a solid polymer material. This solid polymer reduces the ESR of these capacitors to the mOhms range, while at the same time providing greater stability of the parameters over temperature, time, voltage, and frequency.

While aluminum polymer capacitors offer technology improvements over traditional aluminum can capacitors, tantalum capacitors still offer some superior parameters. First, tantalum capacitors can achieve even higher CV due to its porous structure. Second, tantalum capacitors can achieve even lower ESR because of their internal structure with parallel layers and multiple anodes. Finally, tantalum capacitors are more resistant to vibration, which is especially important for automotive applications.

In summary, tantalum capacitors offer many technological advantages over other standard capacitors available today.

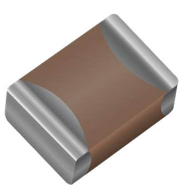
	Strength	Weakness
 **Aluminum**	• Low Cost • Open Circuit Failure Mode • High Cap vs. Voltage Range in Large Case Sizes • Higher Capacitance in Large Case Sizes	• Limited Life Expectancy/Dry Up Mechanism • Poor Stability of Impedance With Low Temperatures • Capacitance Decreases With Time • Lifetime Decreases Over High Ripple Current/ High Temperature • Difficult to Meet 3x Pb-Free Reflow Requirements • Low Profile Issue
 **Aluminum Polymers**	• Low Cost • Extra Low ESR as E Cap. • Low Profile	• Max Voltage/35V • Most Case Sizes is 7343 with Different Height, Hard to be Downsized. • Lower Volumetric Efficiency Compared with Tantalum • Max Temperature/125C
 **Ceramics**	• Low Cost • Very Low ESR - High Ripple Rating Excellent Reliability • Non-Polar • Wide Capacitance & Voltage Range • Surge Robust • Light Weight • Flexiterm/Flexisafe	• Thermal/Mechanical Cracking • High Price for High Capacitance • Capacitance Value Decreases Dramatically with DC/AC Bias and Temperature Variation • Short Circuit Failure Mode • Piezo Effect
 **Tantalum**	• Unlimited Lifetime • Lower Profile (Height) for Height Restrictive Applications • High Long Term Reliability • Stable Electrical Parameters • Self-Healing Mechanism • Wide Temperature Range (up to 230C) • Volumetric Efficiency • No Piezo Effect	• Higher Price for <22uF • Limited to Lower Voltage (125VR Max) • Derating Rules • Tan/Severe Short Circuit Failure Mode • Polymer/Benign Failure Mode • Polymer/Benign Impedance After Overstressed • Weight/Size Constraint • MSL

Figure 5: An explanation of each common capacitor and their strengths and weaknesses.

Tantalum Capacitor Variants

MNO2 TANTALUM

The manganese dioxide tantalum capacitor is the conventional tantalum capacitor construction. MnO2 tantalum capacitors are suitable in terms of stability, reliability and long lifetime. They have no DC bias, no piezo effect, and good volumetric efficiency for applications where space is limited. These parts are used in high-end applications, such as precision equipment, industrial control, medical, military, & aerospace.

POLYMER TANTALUM

Polymer tantalum capacitors are used in new and emerging technologies where the application requires additional safety and low ESR. For example, in portable or handheld devices, safety is a primary concern, while low ESR helps to reduce the size of the circuit implementation and extend battery life. The low ESR also reduces internal heating and extends the lifetime.

NIOBIUM OXIDE TANTALUM

Niobium oxide tantalum capacitors, branded Oxicap® by AVX, offers improved failure mode safety. In the worst-case failure mode, niobium oxide tantalum capacitors fail open, rather than short, which creates a much safer failure mode, preventing severe circuit damage or even fire. In application designs requiring extreme conditions or safe failure, these are the ideal choice. They are limited by rated voltage, with current maximum voltage rating for AVX's Oxicap® topping out at 10V. Example applications include portable devices, petroleum, natural gas, and other applications that might be very sensitive to flames.

Application Information for Tantalum Capacitors

A WORD ON DERATINGS

Generally, polymer and niobium oxide capacitors are voltage derated by 20%, while MnO2 capacitors are derated by 50%. These derating considerations are based on surge or inrush currents.

If the applied voltage to a polymer or niobium oxide capacitor is 10V or lower, a 10% derating can be used. For assistance with determining the proper derating in your design, and calculating the MTBF and FITS data for your application and given deratings, the AVX team can help provide more details, including simulation tools and MTBF calculation formulas.

Application Information for Tantalum Capacitors

MNO2 TANTALUM APPLICATIONS

For most electrical circuit applications, MnO2 tantalum capacitors are a good choice. They have been proven in use for several decades, so their characteristics and reliability are well understood. They have a high volumetric efficiency (CV) and very stable parameters.

MnO2 tantalums are suitable for consumer-grade applications requiring a small physical size and low noise, such as audio and video equipment. They are also useful as a substitute for aluminum can capacitors for industrial applications with long life expectations because they do not dry out. They are also ideal for higher temperature applications such as automotive ECU or fan control, where temperature ratings need to be 150° or 175°C.

Because of the potential for a short circuit failure mode, if that failure will be catastrophic in an application a 50% voltage derating is recommended for MnO2 capacitors. Large scale production testing has validated the benefit of derating.

Capacitance and Voltage	Number of units tested	50% derating applied	No derating applied
47µF 16V	1,547,587	0.03%	1.1%
100µF 10V	632,876	0.01%	0.5%
22µF 25V	2,256,258	0.05%	0.3%

Figure 6: Empirical failure rates with and without derating.

POLYMER TANTALUM APPLICATIONS

Polymer tantalum capacitors have extremely low ESR and a benign failure mechanism, meaning no catastrophic damage is caused. These capacitors are ideal for consumer applications, along with some industrial applications.

Due to their low ESR, polymer tantalums are useful for high current applications and those that require low ripple voltage. For example, 5G partial power supply, GPU, AI, GaN Fast Charger, and some LED lighting applications.

These components are also useful for portable devices such as tablets, smartphones, wearable devices, and portable medical devices, thanks to their low noise, small size, and safe operation.

With the undertab concept structure, polymer tantalum has a lower thickness, which can be applied to some low profile applications, like ESSD, ultrasound fingerprint identification module.

Polymer tantalum capacitors can be sensitive to moisture and temperature, somewhat limiting their application. Most of them are moisture sensitivity level 3 (MSL3), so they require strict controls on the production line. AVX has developed unique processes to develop an enhanced automotive level polymer tantalum capacitor. This is a huge leap forward in technology, making these parts ideal for automotive applications. Based on this new technology, polymer tantalums are now also available for high-reliability applications, like aerospace, military, and COTS-Plus.

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Application Information for Tantalum Capacitors

NIOBIUM OXIDE TANTALUM APPLICATIONS

Niobium Oxide capacitors are used in safety applications. They fail open, high impedance, even after overstressing. Niobium Oxide capacitors are suitable for applications where the voltage is under 10v, like most digital circuits. They also have an option with ultra-low ESR to match up with chipset ports.

Niobium Oxide capacitors can be used as an alternative for MnO2 tantalum capacitors. They have similar electrical and mechanical parameters but offer the improved failure mode safety operation.

AVX Tantalum Capacitors

AVX offers an industry-leading selection of tantalum capacitors — ones that provide excellent solutions for many of today's design challenges. For more details, visit AVX's website and the tantalum products catalog **http://catalogs.avx.com/TantalumNiobium.pdf**.

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