Derating Tantalum Capacitors Depends On The Cathode System

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ABSTRACT

There are a wide range of capacitor dielectrics, each providing unique features that make them the preferred choice in a specific application. Over time, materials and manufacturing innovations increase the capacitance and voltage capabilities of the various dielectrics technologies. This can expand the optimal areas of usage for a given capacitor, and sometimes means the replacement of another device family due to the overall circuit requirements. Other more significant technical developments / modifications of the various dielectrics technologies are usually focused on addressing a specific technical need or minimizing specific parameters that limit usage in a particular application.

Both, solid tantalum and wet tantalum capacitors, feature excellent energy density and reliability. Wet tantalums are particularly suitable for higher voltage applications operating in extreme environments. Application usage, however, always depends on important specification and operating requirements, as well as cost. These two technologies (solid and wet tantalums) are typically used in quite different markets according to their performance characteristics. Often considered a limiting factor, the voltage derating of solid tantalum capacitors with manganese dioxide cathode has been addressed during the development of alternative polymer cathode for solid tantalum capacitors. The latter also offer much lower ESR and non-burning failure mode. Polymer tantalum capacitors require a much lower voltage derating, which significantly expands their usable capacitance and voltage capability for a given circuit. The result is either fewer polymer tantalum capacitors being used and a smaller footprint. The tantalum polymer capacitor is becoming the “best” solution, depending on the application and specifications. The derating differences of these three kinds of tantalum capacitors with different cathode systems will be explored in this paper.

SOLID TANTALUM AND POLYMER TANTALUM COMPARISON

Performance and reliability are the basic building blocks of any piece of equipment. Understanding the conditions of use and the reasons for derating capacitors will simplify decision making when comparing capacitor technologies during the selection process.

Tantalum capacitor manufacturing and testing processes are designed to ensure only high quality parts are shipped into the marketplace. However, subsequent PCB assembly processes can thermally stress the devices and this may result in a lower breakdown threshold for the specific units in the future. Statistically, this would typically impact the device during power-on or a transient event. Normally, short transients and power-on should not impact the long term reliability of the part in an application once self-healing is allowed to occur.

Solid tantalum capacitors should never be operated at or above their rated voltage due to their susceptibility to damage and their catastrophic failure mode. For this reason, voltage derating is a critical factor when evaluating device reliability.

Reliability is usually expressed as a percentage of failures per 1000 h of operation. Tantalum capacitors used at or near their rated voltage typically experience a 1 % failure rate (FR) per 1000 h of operation. It should be noted that most solid tantalum capacitors failures occur during a “power-on” event, and this is NOT included in this “operating” failure rate calculation.

This basic failure rate (Fb) when considering an application will need to be adjusted / corrected to take into account the specific operating conditions. The EIA handbook provides information on the various correction factors for reduced voltage (Fu), lower temperature (Ft), and series resistance (Fr). Lower values for these factors can significantly reduce failure rates.

Putting all these factors together, a graphical calculator (see Fig. 1 below) has been created to allow engineers to evaluate the relative impact of each correction factor based on conditions. For example, take the operating temperature of 40 °C and applied voltage of 60 % V_R to find the failure rate correction factor of about 0.00001.

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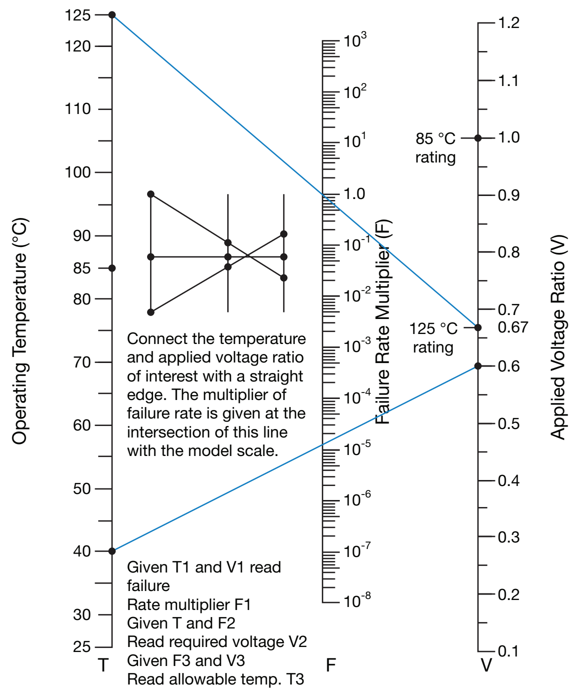

Fig. 1 - Correction factor graphical calculator

Commercial solid tantalum capacitors have typical failure rate of 1 % per 1000 hours. However, for high reliability applications that require a much lower failure rate, the MIL-HDBK-217 standard was established. This included a specification for the derating of capacitor voltage that was a cornerstone of increasing the operating life. This standard dictates the 50 % voltage derating to achieve a 5 FIT to 15 FIT (failures in time) rate. 1 FIT is one failure per billion hours.

Fig. 2 is from the military handbook and shows the effect of temperature on FIT with four curves for rated voltage effect.

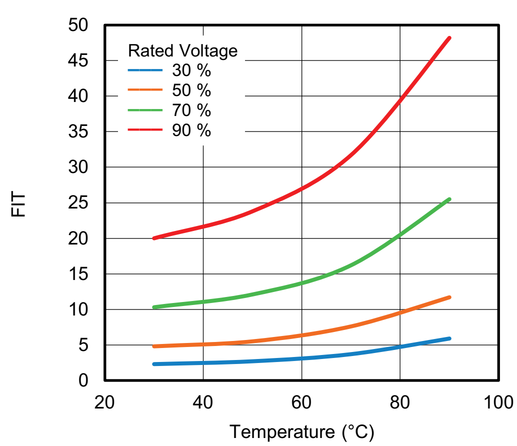

Fig. 2

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Solid tantalum capacitors of all types (molded, conformal, and hermetically sealed), have, for all practical purposes, an unlimited lifespan, provided they are used within the voltage, temperature, and circuit impedance guidelines. This is because there is no dielectric wear out under derated application conditions. Device failures are usually found in the “early life” of the capacitor - for example, at first “turn on” - and the failure occurrences typically decrease over time.

Although factors like temperature, circuit impedance, ripple current, and mechanical stress play a role in overall reliability, no single factor has more effect on component life and operational reliability than applied voltage. Derating this voltage will improve the long term reliability of the device, as well as improve the initial power on performance.

As a comparison (see Fig. 3) the above-mentioned solid tantalum failure over time is significantly different to that of aluminum electrolytic capacitors, which exhibits a “bathtub” curve, where end of life failures will eventually increase with time.

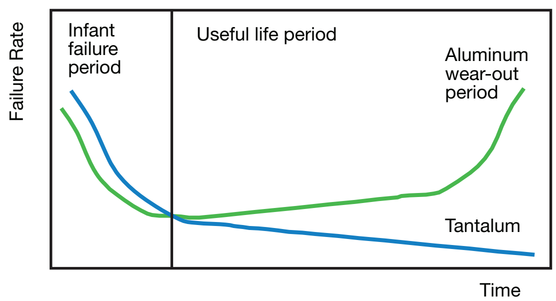

Fig. 3

Due to the impact of voltage derating, all tantalum capacitor manufacturers publish derating guidelines for their parts. For solid tantalum capacitors with MnO_2 electrolyte, Vishay uses the EIA-809 standard as well as the NASA and MIL-STD guidelines to dictate the recommendations shown in the table below. Usually, the application (working) voltage should be about 0.5 of the rated voltage. For rated voltages ≥ 35 V, Vishay recommends an even higher derating ratio.

RECOMMENDED VOLTAGE DERATING GUIDELINES (below 85 °C)	
VOLTAGE RAIL	**CAPACITOR VOLTAGE RATING (V)**
≤ 3.3	6.3
5	10
10	20
12	25
15	35
24	50 or series configuration
28	63 or series configuration
≥ 32	75 or series configuration

When conductive polymer tantalum capacitors were invented, the primary feature of the new cathode system was a much lower ESR than that of existing MnO_2 devices. This was because the conductivity of polymer is orders of magnitude higher than of MnO_2. In addition to the significantly lower ESR, a conductive polymer cathode also features much more benign failure more under voltage stress.

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Both types of tantalum capacitors have a self-healing mechanism, but it is technologically different for MnO_2- and polymer-type capacitors. Cathode system of MnO_2 solid tantalum capacitors, as the formula (MnO_2) suggests, have an oxygen source inside the device. In the event of elevated leakage current, the current flows through the dielectric flaw and generates localized heat, increasing the temperature in the vicinity of the potential failure location. This elevated temperature causes a reduction of the manganese dioxide (MnO_2) to a lower order oxide (Mn_2O_3), which has resistance that is orders of magnitude higher than the original MnO_2. The potential failure site then becomes electrically isolated and the current flow decreases to an acceptable level. The oxygen released in the conversion from MnO_2 to Mn_2O_3 is consumed by the tantalum pentoxide dielectric. However, it is possible that if the temperature rise occurs too quickly, a dangerous ignition event can be triggered.

By comparison, for polymer tantalum capacitors, the localized heating of the potential failure site causes the polymer to become non-conductive, insulating the spot and reducing the leakage current. No oxygen released in such event and if occasional short failure occurs, the parts will not burn. Such benign failure mode allows for more generous derating guidelines:

- 10 % (usage of up to 90 % of rated voltage) for products rated up to 10 V
- 20 % (usage of up to 80 % of rated voltage) for products higher than 10 V

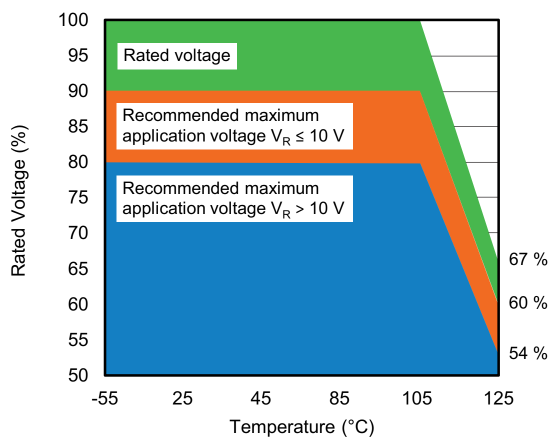

Fig. 4

Polymer tantalum has recently been provided a MIL-PRF-32700 to guide users. The failure rates are defined differently to those of MnO_2 tantalum, as a polymer device has better lifetime performance. They cannot be Weibull graded as we do with MnO_2, because the capacitors do not fail under the Weibull criteria. To better understand the failure rates, HALT testing is used to establish failure rates. The change in material set and production techniques from MnO_2 manufacturing creates this difference in behavior, allowing for a significant reduction in voltage derating recommendations.

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Tantalum capacitors healing mechanism: MnO_2 vs. Polymer

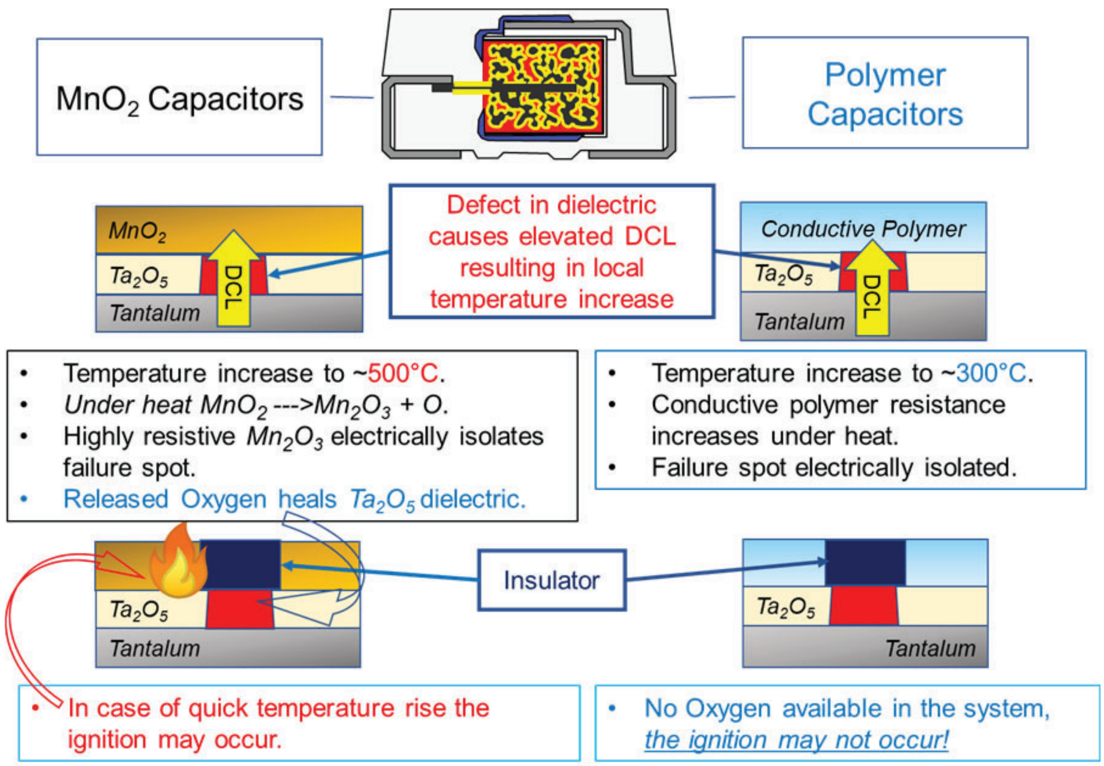

Fig. 5

When comparing these two tantalum capacitor types, a user can see that when used properly and within derated voltage and temperature conditions, both can provide for a very long lifetime.

Example: a life test of 100 samples for 1000 h at the specified temperature and rated voltage predicts FR of 2.3 % / 1000 h and MTTF of five years. This failure rate level would not be acceptable in the majority of applications. Derating of 50 % for MnO_2 capacitors and 80 % for polymer capacitors brings the predicted FR to approximately the same level of 0.1 % and increases MTTF from five years to over 100 years.

Derating is required in order to provide reliable operation of the capacitor under given application conditions. It is also instrumental in prevention of post board mounting and first power on failures.

It is important to distinguish between failure rate and turn-on / surge events. As mentioned earlier, the ability of tantalum capacitors to self-heal means not all events lead to device failure and decreasing FR is typically based on steady-state conditions. Transient / surge events can occur at any time and the high stress may cause failures that are not preventable by the self-healing feature.

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WET TANTALUM CAPACITOR DERATING REQUIREMENTS

Wet tantalum capacitors are a completely different technology that has a liquid cathode electrolyte. This electrolyte provides true self-healing and no contact stresses on the dielectric. Due to their high reliability and long life, they have been widely used in harsh environment applications for many years. They have established reliability with 10 000 h life and are designed to be hermetic, so there are no environmental concerns aside from temperature and shock / vibration. The majority of the initial construction steps are the same as the two solid cathode types.

Healing mechanism in wets:

Due to tiny imperfection (or weak spot) in the dielectric layer, a small, localized breakdown can occur. This breakdown site will experience an increased leakage current. The increased leakage current triggers an electrolytic reaction between the tantalum anode and the electrolyte solution within the capacitor. This reaction reforms the thin oxide layer at the breakdown point, essentially healing the microscopic defect.

For wet tantalum devices the maximum working voltage is equal to the rated voltage (RV) if they operate in the temperature range of -55 °C to +85 °C. Above 85 °C it decreases linearly to 2/3 x RV at the maximum working temperature of +125 °C. For Vishay series with higher maximum operating temperatures - like the 134D, 135D, T11, T24, and T34 - it will go to 0.5 to 0.6 rated voltage at extreme temperatures. Above +85 °C, it is common to refer to the maximum working voltage as the category voltage. For the ratio between the RV and category voltage, refer to Fig. 6.

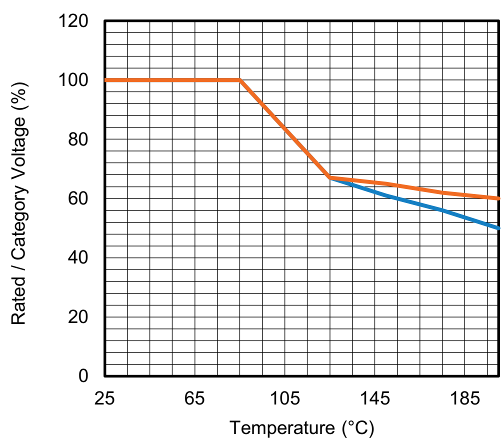

Fig. 6

Although most wet tantalum capacitor series do not require voltage derating when used at or below +85 °C, DC working voltage (bias) should be chosen so that the sum of the DC bias and AC (ripple) voltages does not exceed the RV. For increased reliability, it is recommended to have a 10 % to 20 % guard band, meaning not to exceed 80 % to 90 % of RV at or below +85 °C. At higher temperatures the same ratio should be kept with respect to the category voltage.

To further understand reliability, historic data has been collected for 10 000 h of life at rated voltage for +85 °C. There is also data available for 10 000 h at +125 °C derated voltage and life testing for high temperature operation at +200 °C and even +230 °C. By adding a few more data points, and using the Excel FIT curve calculator, we are even able to reliably predict life at intermediate temperatures along the curve. As a result, we now have an estimated life at intermediate points within the high temperature operational area. See Fig. 7.

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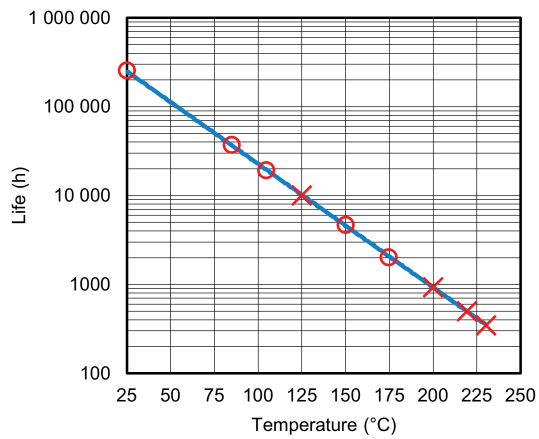

Fig. 7 - Wet Tantalum Capacitor
Life vs. Temperature (fitted curve)

CAPACITOR DERATING REQUIREMENTS

For the highest levels of reliability, mostly space applications, NASA has its own derating rules for capacitors, a minimum of 50 % derating on solids up to 70 °C, not 85 °C, and 30 % up to 110 °C. For wets the recommended derating is 60 % and 40 % accordingly.

CONCLUSION

Choosing the right capacitor, and more specifically the right tantalum capacitor, is critical for success in terms of equipment reliability at first turn-on and over time. Derating should always be considered in order to provide the best overall reliability performance. These derating requirements vary significantly between the three major tantalum electrolytes, based on the cathode system employed. In summary, voltage derating offers the greatest improvement in long term reliability and initial power-on performance. The differences in recommended voltage derating between types are: MnO_2 is 50 %; polymer is 20 %, and wets - 10 % to 20 %.

Correct choice of tantalum capacitor types allows dramatic advantages in board area, weight, and manufacturing cost savings.