Dipped Radial Capacitors

Introduction

KYOCERA AVX offers a broad line of solid Tantalum capacitors in a wide range of sizes, styles, and ratings to meet any design needs. This catalog combines into one source KYOCERA AVX's leaded tantalum capacitor information from its worldwide tantalum operations.

The TAP/TEP is rated for use from -55°C to +85°C at rated voltage and up to +125°C with voltage derating. There are three preferred wire forms to choose from which are available on tape and reel, and in bulk for hand insertion.

KYOCERA AVX has a complete tantalum applications service available for use by all our customers. With the capability to prototype and mass produce solid tantalum capacitors in special configurations, almost any design need can be fulfilled.

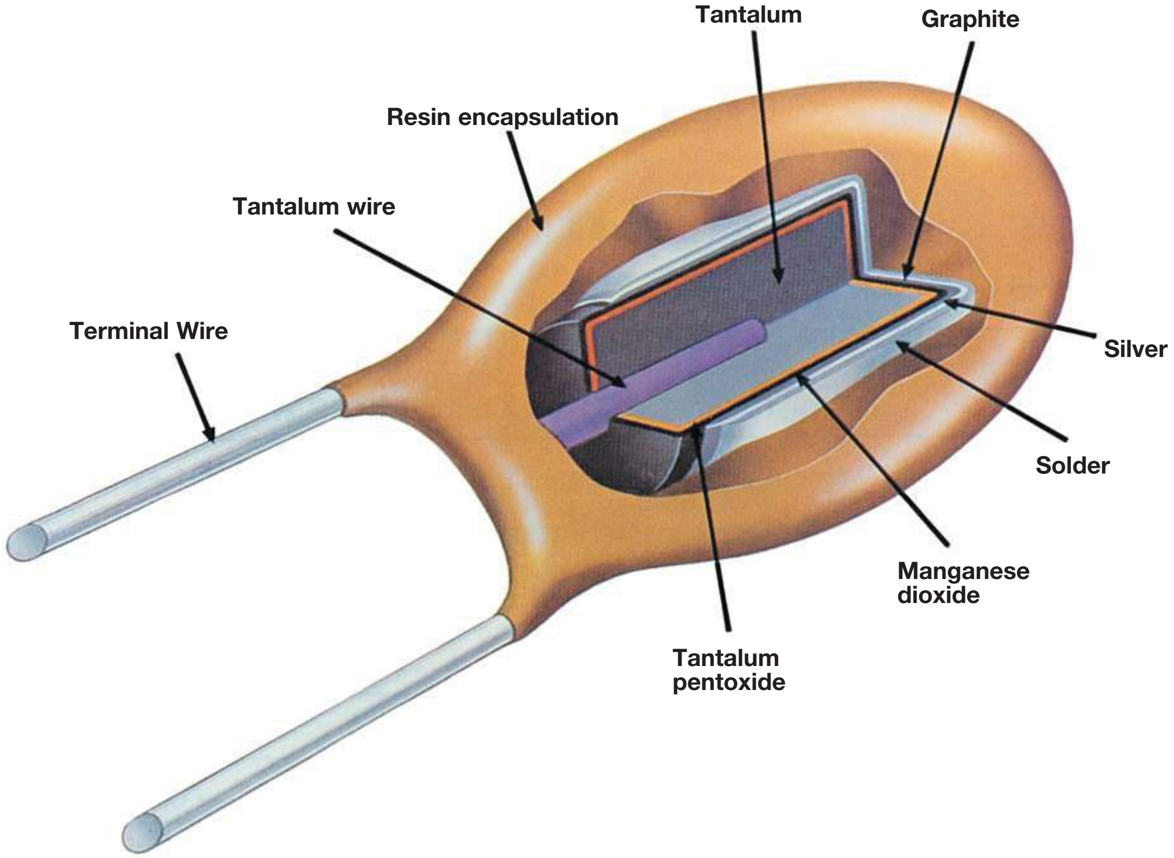
And if the customer requirements are outside our standard testing, KYOCERA AVX will work with you to define and implement a test or screening plan.

KYOCERA AVX is determined to become the world leader in tantalum capacitor technology and has made, and is continuing to make, significant investments in equipment and research to reach that end. We believe that the investment has paid off with the devices shown on the following pages.

DIPPED RADIAL CAPACITORS

SOLID TANTALUM RESIN DIPPED SERIES TAP/TEP

The TAP/TEP resin dipped series of miniature tantalum capacitors is available for individual needs in both commercial and professional applications. From computers to automotive to industrial, KYOCERA AVX has a dipped radial for almost any application.

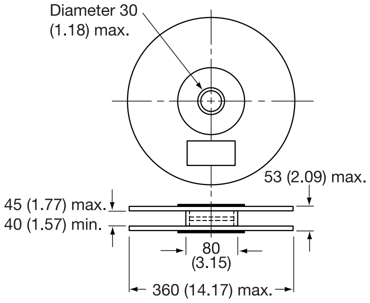


SOLID TANTALUM RESIN DIPPED TAP/TEP

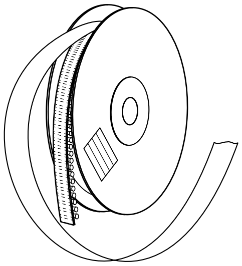
CASE DIMENSIONS: millimeters (inches)

Description	Code	Dimension
Feed hole pitch	P	12.7 ± 0.30 (0.500 ± 0.010)
Hole center to lead	P_1	3.85 ± 0.70 (0.150 ± 0.030) to be measured at bottom of clench
		5.05 ± 1.00 (0.200 ± 0.040) for S wire
Hole center to component center	P_2	6.35 ± 0.40 (0.250 ± 0.020)
Change in pitch	Δp	± 1.00 (± 0.040)
Lead diameter	d	0.50 ± 0.05 (0.020 ± 0.003)
Lead spacing	S	See wire form table
Component alignment	Δh	0 ± 2.00 (0 ± 0.080)
Feed hole diameter	D	4.00 ± 0.20 (0.150 ± 0.008)
Tape width	W	18.0 + 1.00 (0.700 + 0.040) - 0.50 - 0.020)
Hold down tape width	W_1	6.00 (0.240) min.
Hold down tape position	W_2	1.00 (0.040) max.
Lead wire clench height	H	16.0 ± 0.50 (0.630 ± 0.020) 19.0 ± 1.00 (0.750 ± 0.040) on request
Hole position	H_1	9.00 ± 0.50 (0.350 ± 0.020)
Base of component height	H_2	18.0 (0.700) min. (S wire only)
Component height	H_3	32.25 (1.300) max.
Length of snipped lead	L	11.0 (0.430) max.
Total tape thickness	T	0.70 ± 0.20 (0.030 ± 0.001)
		Carrying card 0.50 ± 0.10 (0.020 ± 0.005)

REEL CONFIGURATION AND DIMENSIONS: millimeters (inches)



Manufactured from cardboard with plastic hub.



Holding tape outside. Positive terminal leading.

For Reels

Style	Case size	No. of pieces
TAP TEP	A	1500
	B, C, D	1250
	E, F	1000
	G, H, J	750
	K, L, M, N, P, R	500

	A, B, C, D	3000
	E, F, G	2500
	H, J	2000
	K, L, M, N, P, R	1000

For bulk products

Style	Case size	No. of pieces
TAP TEP	A to H	1000
	J to L	500
	M to R	100

AMMO PACK DIMENSIONS

millimeters (inches) max.

Height 360 (14.17), width 360 (14.17), thickness 60 (2.36)

GENERAL NOTES

Resin dipped tantalum capacitors are only available taped in the range of case sizes and in the modular quantities by case size as indicated.

Packaging quantities on tape may vary by ±1%.

SECTION 1: ELECTRICAL CHARACTERISTICS AND EXPLANATION OF TERMS

1.1 CAPACITANCE

1.1.1 Rated capacitance (CR)

This is the nominal rated capacitance. For tantalum capacitors it is measured as the capacitance of the equivalent series circuit at 20°C in a measuring bridge supplied by a 120 Hz source free of harmonics with 2.2V DC bias max.

1.1.2 Temperature dependence on the capacitance

The capacitance of a tantalum capacitor varies with temperature. This variation itself is dependent to a small extent on the rated voltage and capacitor size. See graph below for typical capacitance changes with temperature.

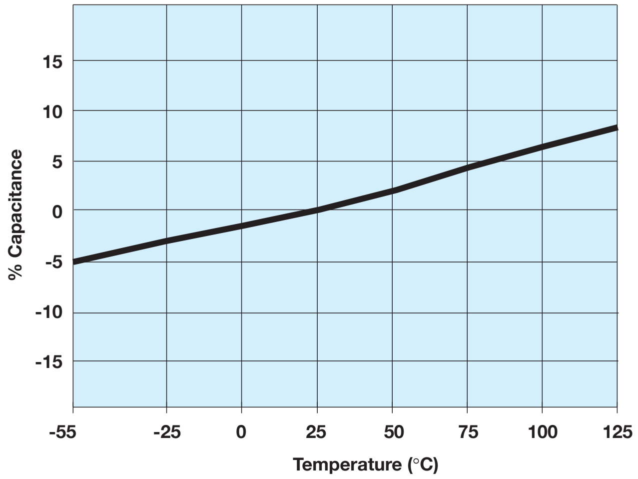
1.1.3 Capacitance tolerance

This is the permissible variation of the actual value of the capacitance from the rated value.

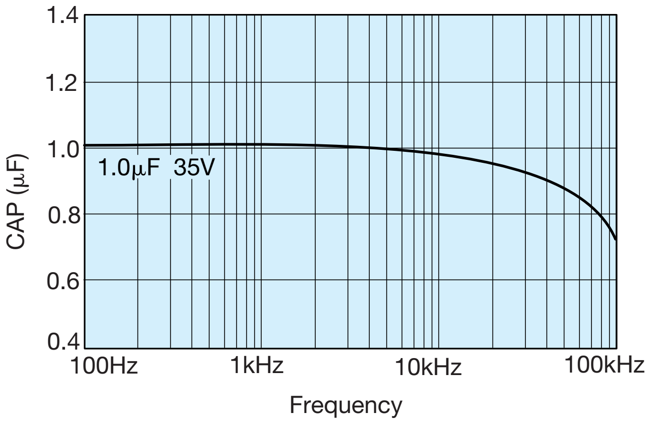
1.1.4 Frequency dependence of the capacitance

The effective capacitance decreases as frequency increases. Beyond 100 kHz the capacitance continues to drop until resonance is reached (typically between 0.5-5 MHz depending on the rating). Beyond this the device becomes inductive.

Typical Capacitance vs. Temperature



Typical Curve Capacitance vs. Frequency



1.2 VOLTAGE

1.2.1 Rated DC voltage (V_R)

This is the rated DC voltage for continuous operation up to +85°C.

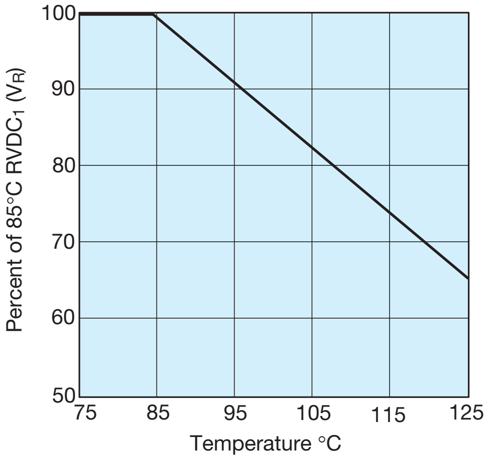
1.2.2 Category voltage (V_C)

This is the maximum voltage that may be applied continuously to a capacitor. It is equal to the rated voltage up to +85°C, beyond which it is subject to a linear derating, to 2/3 V_R at 125°C.

1.2.3 Surge voltage (V_S)

This is the highest voltage that may be applied to a capacitor for short periods of time. The surge voltage may be applied up to 10 times in an hour for periods of up to 30 seconds at a time. The surge voltage must not be used as a parameter in the design of circuits in which, in the normal course of operation, the capacitor is periodically charged and discharged.

Category Voltage vs. Temperature



85°C		125°C	
Rated Voltage (V DC)	Surge Voltage (V DC)	Category Voltage (V DC)	Surge Voltage (V DC)
2	2.6	1.3	1.7
3	4	2	2.6
4	5.2	2.6	3.4
6.3	8	4	5
10	13	6.3	9
16	20	10	12
20	26	13	16
25	33	16	21
35	46	23	28
50	65	33	40

1.2.4 Effect of surges

The solid Tantalum capacitor has a limited ability to withstand surges (15% to 30% of rated voltage). This is in common with all other electrolytic capacitors and is due to the fact that they operate under very high electrical stress within the oxide layer. In the case of 'solid' electrolytic capacitors this is further complicated by the limited self healing ability of the manganese dioxide semiconductor.

It is important to ensure that the voltage across the terminals of the capacitor does not exceed the surge voltage rating at any time. This is particularly so in low impedance circuits where the capacitor is likely to be subjected to the full impact of surges, especially in low inductance applications. Even an extremely short duration spike is likely to cause damage. In such situations it will be necessary to use a higher voltage rating.

1.2.5 Reverse voltage and non-polar operation

The reverse voltage ratings are designed to cover exceptional conditions of small level excursions into incorrect polarity. The values quoted are not intended to cover continuous reverse operation.

The peak reverse voltage applied to the capacitor must not exceed:

10% of rated DC working voltage to a maximum of
1V at 25°C

3% of rated DC working voltage to a maximum of
0.5V at 85°C

1% of category DC working voltage to a maximum of
0.1V at 125°C

1.2.6 Non-polar operation

If the higher reverse voltages are essential, then two capacitors, each of twice the required capacitance and of equal tolerance and rated voltage, should be connected in a back-to-back configuration, i.e., both anodes or both cathodes joined together. This is necessary in order to avoid a reduction in life expectancy.

1.2.7 Superimposed AC voltage (V_{rms}) - Ripple Voltage

This is the maximum RMS alternating voltage, superimposed on a DC voltage, that may be applied to a capacitor. The sum of the DC voltage and the surge value of the superimposed AC voltage must not exceed the category voltage, V_c. Full details are given in Section 2.

1.2.8 Voltage derating

Refer to section 3.2 for the effect of voltage derating on reliability.

1.3 DISSIPATION FACTOR AND TANGENT OF LOSS ANGLE (TAN D)

1.3.1 Dissipation factor (DF)

Dissipation factor is the measurement of the tangent of the loss angle (Tan δ) expressed as a percentage.

The measurement of DF is carried out at +25°C and 120 Hz with 2.2V DC bias max. with an AC voltage free of harmonics. The value of DF is temperature and frequency dependent.

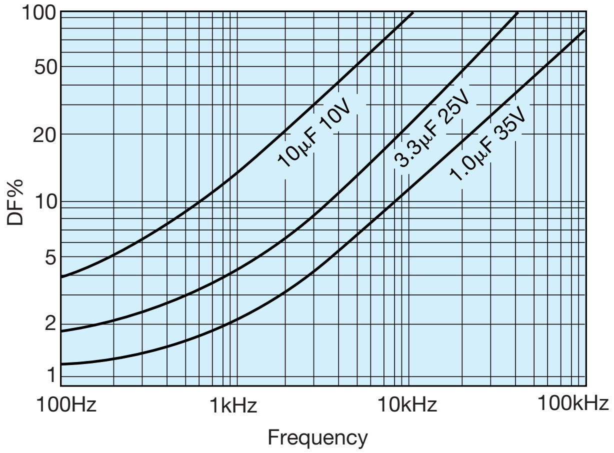
1.3.2 Tangent of loss angle (Tan δ)

This is a measure of the energy loss in the capacitor. It is expressed as Tan δ and is the power loss of the capacitor divided by its reactive power at a sinusoidal voltage of specified frequency. (Terms also used are power factor, loss factor and dielectric loss, Cos (90 - δ) is the true power factor.) The measurement of Tan is carried out at +20°C and 120 Hz with 2.2V DC bias max. with an AC voltage free of harmonics.

1.3.3 Frequency dependence of dissipation factor

Dissipation Factor increases with frequency as shown in the typical curves below.

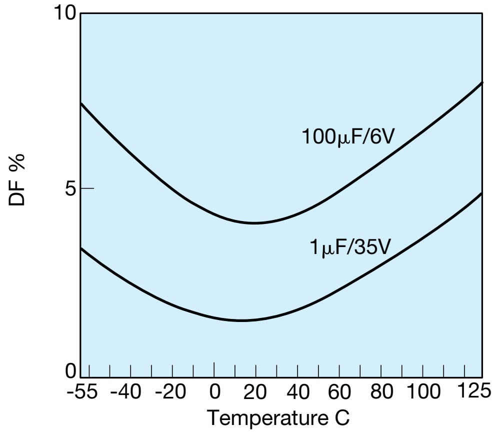
Typical Curve-Dissipation Factor vs. Frequency



1.3.4 Temperature dependence of dissipation factor

Dissipation factor varies with temperature as the typical curves show to the right. For maximum limits please refer to ratings tables.

Typical Curves-Dissipation Factor vs. Temperature



1.4 IMPEDANCE, (Z) AND EQUIVALENT SERIES RESISTANCE (ESR)

1.4.1 Impedance, Z

This is the ratio of voltage to current at a specified frequency. Three factors contribute to the impedance of a tantalum capacitor; the resistance of the semiconducting layer, the capacitance, and the inductance of the electrodes and leads.

At high frequencies the inductance of the leads becomes a limiting factor. The temperature and frequency behavior of these three factors of impedance determine the behavior of the impedance Z. The impedance is measured at 25°C and 100 kHz.

1.4.2 Equivalent series resistance, ESR

Resistance losses occur in all practical forms of capacitors. These are made up from several different mechanisms, including resistance in components and contacts, viscous forces within the dielectric, and defects producing bypass current paths. To express the effect of these losses they are considered as the ESR of the capacitor. The ESR is frequency dependent. The ESR can be found by using the relationship:

$$\mathrm{ESR} = \frac{\mathrm{Tan}\ \delta}{2\pi f C}$$

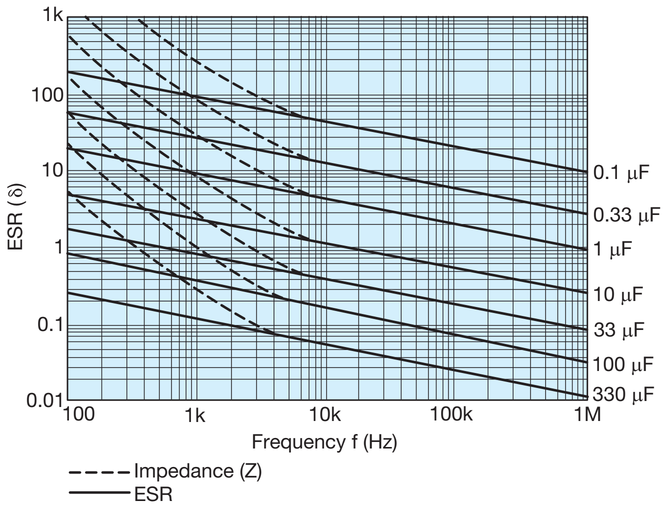
where f is the frequency in Hz, and C is the capacitance in farads. The ESR is measured at 25°C and 100 kHz.

ESR is one of the contributing factors to impedance, and at high frequencies (100 kHz and above) is the dominant factor, so that ESR and impedance become almost identical, impedance being marginally higher.

1.4.3 Frequency dependence of impedance and ESR

ESR and impedance both increase with decreasing frequency. At lower frequencies the values diverge as the extra contributions to impedance (resistance of the semiconducting layer, etc.) become more significant. Beyond 1 MHz (and beyond the resonant point of the capacitor) impedance again increases due to induction.

Frequency Dependence of Impedance and ESR



1.4.4 Temperature dependence of the impedance and ESR

At 100 kHz, impedance and ESR behave identically and decrease with increasing temperature as the typical curves show. For maximum limits at high and low temperatures, please refer to graph opposite.

1.5 DC LEAKAGE CURRENT (DCL)

1.5.1 Leakage current (DCL)

The leakage current is dependent on the voltage applied, the time, and the capacitor temperature. It is measured at +25°C with the rated voltage applied. A protective resistance of 1000 is connected in series with the capacitor in the measuring circuit.

Three minutes after application of the rated voltage the leakage current must not exceed the maximum values indicated in the ratings table. Reforming is unnecessary even after prolonged periods without the application of voltage.

1.5.2 Temperature dependence of the leakage current

The leakage current increases with higher temperatures, typical values are shown in the graph.

For operation between 85°C and 125°C, the maximum working voltage must be derated and can be found from the following formula.

$$V\ max = \left(1 - \frac{(T-85)}{120}\right) \times V_R\ \text{volts}$$

where T is the required operating temperature. Maximum limits are given in rating tables.

1.5.3 Voltage dependence of the leakage current

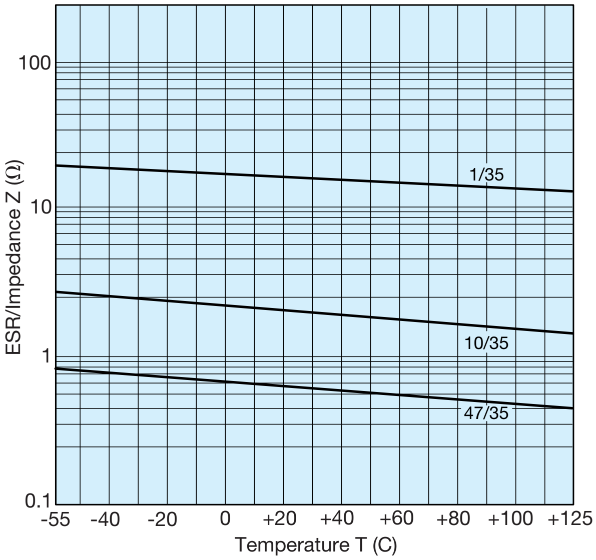
The leakage current drops rapidly below the value corresponding to the rated voltage V_R when reduced voltages are applied. The effect of voltage derating on the leakage current is shown in the graph.

This will also give a significant increase in reliability for any application. See Section 3 for details.

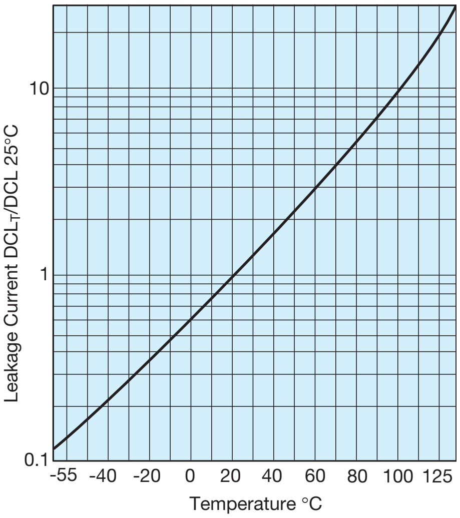
1.5.4 Ripple current

The maximum ripple current allowance can be calculated from the power dissipation limits for a given temperature rise above ambient. Please refer to Section 2 for details.

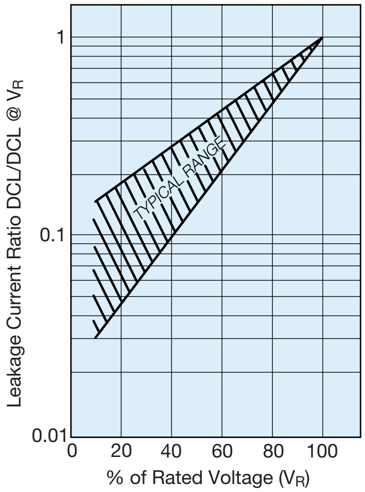
Temperature Dependence of the Impedance and ESR



Temperature Dependence of the Leakage Current for a Typical Component



Effect of Voltage Derating on Leakage Current



SECTION 2: A.C. OPERATION — RIPPLE VOLTAGE AND RIPPLE CURRENT

2.1 RIPPLE RATINGS (AC)

In an AC application heat is generated within the capacitor by both the AC component of the signal (which will depend upon signal form, amplitude and frequency), and by the DC leakage. For practical purposes the second factor is insignificant. The actual power dissipated in the capacitor is calculated using the formula:

$$P = I^2R = \frac{E^2R}{Z^2}$$

I = rms ripple current, amperes
R = equivalent series resistance, ohms
E = rms ripple voltage, volts
P = power dissipated, watts
Z = impedance, ohms, at frequency under consideration

Using this formula it is possible to calculate the maximum AC ripple current and voltage permissible for a particular application.

2.2 MAXIMUM AC RIPPLE VOLTAGE (EMAX)

From the previous equation:

$$E_{(max)} = Z\sqrt{\frac{P_{max}}{R}}$$

where P_{max} is the maximum permissible ripple voltage as listed for the product under consideration (see table).

However, care must be taken to ensure that:

1. The DC working voltage of the capacitor must not be exceeded by the sum of the positive peak of the applied AC voltage and the DC bias voltage.
2. The sum of the applied DC bias voltage and the negative peak of the AC voltage must not allow a voltage reversal in excess of that defined in the sector, ‘Reverse Voltage’.

2.3 MAXIMUM PERMISSIBLE POWER DISSIPATION (WATTS) @ 25°C

The maximum power dissipation at 25°C has been calculated for the various series and are shown in Section 2.4, together with temperature derating factors up to 125°C.

For leaded components the values are calculated for parts supported in air by their leads (free space dissipation).

The ripple ratings are set by defining the maximum temperature rise to be allowed under worst case conditions, i.e., with resistive losses at their maximum limit. This differential is normally 10°C at room temperature dropping to 2°C at 125°C. In application circuit layout, thermal management, available ventilation, and signal waveform may significantly affect the values quoted below. It is recommended that temperature measurements are made on devices during operating conditions to ensure that the temperature differential between the device and the ambient temperature is less than 10°C up to 85°C and less than 2°C between 85°C and 125°C. Derating factors for temperatures above 25°C are also shown below. The maximum permissible proven dissipation should be multiplied by the appropriate derating factor.

For certain applications, e.g., power supply filtering, it may be desirable to obtain a screened level of ESR to enable higher ripple currents to be handled. Please contact our applications desk for information.

2.4 POWER DISSIPATION RATINGS (IN FREE AIR)

TAP/TEP – Resin Dipped Radial

Case size	Max. power dissipation (W)
A	0.045
B	0.05
C	0.055
D	0.06
E	0.065
F	0.075
G	0.08
H	0.085
J	0.09
K	0.1
L	0.11
M/N	0.12
P	0.13
R	0.14

Temperature derating factors	
Temp. °C	Factor
+25	1.0
+85	0.4
+125	0.09

SECTION 3: RELIABILITY AND CALCULATION OF FAILURE RATE

3.1 STEADY-STATE

Tantalum Dielectric has essentially no wear out mechanism and in certain circumstances is capable of limited self healing, random failures can occur in operation. The failure rate of Tantalum capacitors will decrease with time and not increase as with other electrolytic capacitors and other electronic components.

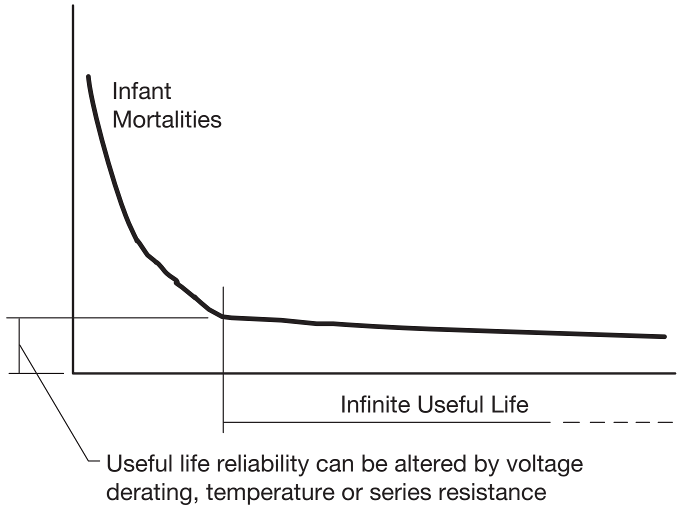


Figure 1. Tantalum reliability curve.

The useful life reliability of the Tantalum capacitor is affected by three factors. The equation from which the failure rate can be calculated is:

$$F = F_U \times F_T \times F_R \times F_B$$

where F_U is a correction factor due to operating voltage/ voltage derating

F_T is a correction factor due to operating temperature

F_R is a correction factor due to circuit series resistance

F_B is the basic failure rate level. For standard leaded Tantalum product this is 1%/1000hours

Operating voltage/voltage derating

If a capacitor with a higher voltage rating than the maximum line voltage is used, then the operating reliability will be improved. This is known as voltage derating. The graph, Figure 2, shows the relationship between voltage derating (the ratio between applied and rated voltage) and the failure rate. The graph gives the correction factor F_U for any operating voltage.

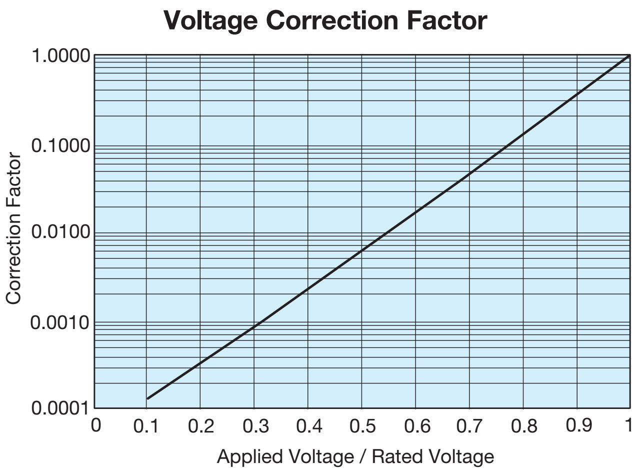


Figure 2. Correction factor to failure rate F for voltage derating of a typical component (60% con. level).

Operating temperature

If the operating temperature is below the rated temperature for the capacitor then the operating reliability will be improved as shown in Figure 3. This graph gives a correction factor F_T for any temperature of operation.

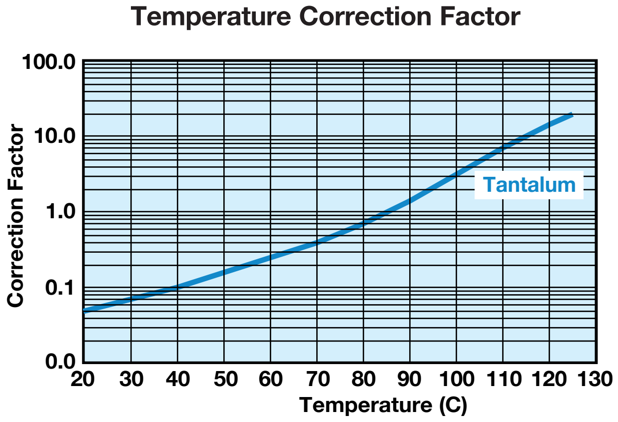


Figure 3. Correction factor to failure rate F for ambient temperature T for typical component (60% con. level).

Circuit Impedance

All solid tantalum capacitors require current limiting resistance to protect the dielectric from surges. A series resistor is recommended for this purpose. A lower circuit impedance may cause an increase in failure rate, especially at temperatures higher than 20°C. An inductive low impedance circuit may apply voltage surges to the capacitor and similarly a non-inductive circuit may apply current surges to the capacitor, causing localized over-heating and failure.

The recommended impedance is 1Ω per volt. Where this is not feasible, equivalent voltage derating should be used. Table I shows the correction factor, F_R, for increasing series resistance.

Table I: Circuit Impedance

Correction factor to failure rate F for series resistance R on basic failure rate F_B for a typical component (60% con. level).

Circuit Resistance ohms/volt	FR
3.0	0.07
2.0	0.1
1.0	0.2
0.8	0.3
0.6	0.4
0.4	0.6
0.2	0.8
0.1	1.0

Example calculation

Consider a 12 volt power line. The designer needs about 10μF of capacitance to act as a decoupling capacitor near a video bandwidth amplifier. Thus the circuit impedance will be limited only by the output impedance of the boards power unit and the track resistance. Let us assume it to be about 2 Ohms minimum, i.e., 0.167 Ohms/Volt. The operating temperature range is -25°C to +85°C. If a 10μF 16 Volt capacitor was designed-in, the operating failure rate would be as follows:

a) F_T = 0.8 @ 85°C

b) F_R = 0.7 @ 0.167 Ohms/Volt

c) F_U = 0.17 @ applied voltage/rated voltage = 75%

Thus F_B = 0.8 x 0.7 x 0.17 x 1 = 0.0952%/1000 Hours

If the capacitor was changed for a 20 volt capacitor, the operating failure rate will change as shown.

F_U = 0.05 @ applied voltage/rated voltage = 60%

F_B = 0.8 x 0.7 x 0.05 x 1 = 0.028%/1000 Hours

3.2 DYNAMIC

As stated in Section 1.2.4, the solid Tantalum capacitor has a limited ability to withstand voltage and current surges. Such current surges can cause a capacitor to fail. The expected failure rate cannot be calculated by a simple formula as in the case of steady-state reliability. The two parameters under the control of the circuit design engineer known to reduce the incidence of failures are derating and series resistance.The table below summarizes the results of trials carried out at KYOCERA AVX with a piece of equipment which has very low series resistance and applied no derating. So that the capacitor was tested at its rated voltage.

Results of production scale derating experiment

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%

As can clearly be seen from the results of this experiment, the more derating applied by the user, the less likely the probability of a surge failure occurring.

It must be remembered that these results were derived from a highly accelerated surge test machine, and failure rates in the low ppm are more likely with the end customer.

A commonly held misconception is that the leakage current of a Tantalum capacitor can predict the number of failures which will be seen on a surge screen. This can be disproved by the results of an experiment carried out at KYOCERA AVX on 47μF 10V surface mount capacitors with different leakage currents. The results are summarized in the table below.

Leakage Current vs Number of Surge Failures

	Number tested	Number failed surge
Standard leakage range 0.1 μA to 1μA	10,000	25
Over Catalog limit 5μA to 50μA	10,000	26
Classified Short Circuit 50μA to 500μA	10,000	25

Again, it must be remembered that these results were derived from a highly accelerated surge test machine, and failure rates in the low ppm are more likely with the end customer.

KYOCERA AVX recommended derating table

Voltage Rail	Working Cap Voltage
3.3	6.3
5	10
10	20
12	25
15	35
≥24	Series Combinations (11)

For further details on surge in Tantalum capacitors refer to J.A. Gill's paper "Surge in Solid Tantalum Capacitors", available from KYOCERA AVX offices worldwide.

An added bonus of increasing the derating applied in a circuit, to improve the ability of the capacitor to withstand surge conditions, is that the steady-state reliability is improved by up to an order. Consider the example of a 6.3 volt capacitor being used on a 5 volt rail. The steadystate reliability of a Tantalum capacitor is affected by three parameters; temperature, series resistance and voltage derating. Assuming 40°C operation and 0.1Ω/volt of series resistance, the scaling factors for temperature and series resistance will both be 0.05 (see Section 3.1). The derating factor will be 0.15. The capacitors reliability will therefore be

$$\begin{aligned}\text{Failure rate} &= F_U \times F_T \times F_R \times 1\%/1000 \text{ hours}\\ &= 0.15 \times 0.05 \times 1 \times 1\%/1000 \text{ hours}\\ &= 7.5\% \times 10^{-3}/\text{hours}\end{aligned}$$

If a 10 volt capacitor was used instead, the new scaling factor would be 0.017, thus the steady-state reliability would be

$$\begin{aligned}\text{Failure rate} &= F_U \times F_T \times F_R \times 1\%/1000 \text{ hours}\\ &= 0.017 \times 0.05 \times 1 \times 1\%/1000 \text{ hours}\\ &= 8.5\% \times 10^{-4}/ 1000 \text{ hours}\end{aligned}$$

So there is an order improvement in the capacitors steadystate reliability.

3.3 RELIABILITY TESTING

KYOCERA AVX performs extensive life testing on tantalum capacitors.

- 2,000 hour tests as part of our regular Quality Assurance Program.

Test conditions:

- 85°C/rated voltage/circuit impedance of 3Ω max.
- 125°C/0.67 x rated voltage/circuit impedance of 3Ω max.

3.4 Mode of Failure

This is normally an increase in leakage current which ultimately becomes a short circuit.

SECTION 4: APPLICATION GUIDELINES FOR TANTALUM CAPACITORS

4.1 SOLDERING CONDITIONS AND BOARD ATTACHMENT

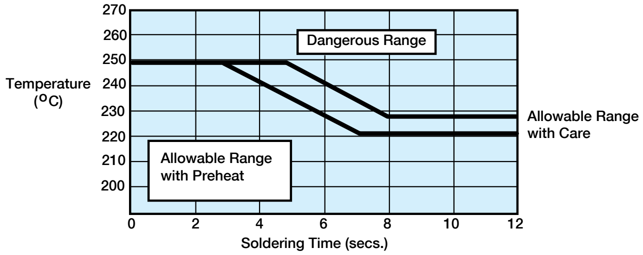
The soldering temperature and time should be the minimum for a good connection.

A suitable combination for wavesoldering is 230°C - 250°C for 3 - 5 seconds.

Small parametric shifts may be noted immediately after wave solder, components should be allowed to stabilize at room temperature prior to electrical testing.

KYOCERA AVX leaded tantalum capacitors are designed for wave soldering operations.

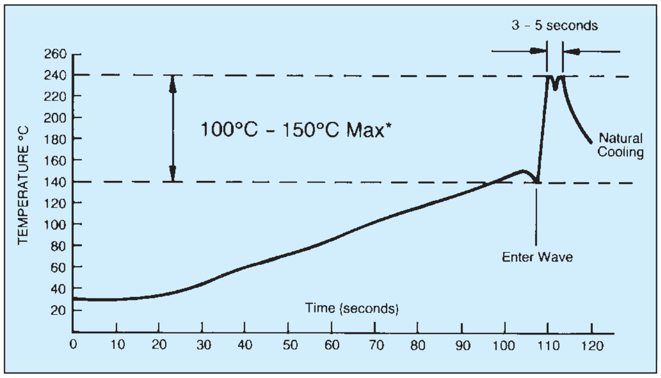
Allowable range of peak temp./time combination for wave soldering



4.2 RECOMMENDED SOLDERING PROFILES

Recommended wave soldering profile for mounting of tantalum capacitors is shown below.

After soldering the assembly should preferably be allowed to cool naturally. In the event that assisted cooling is used, the rate of change in temperature should not exceed that used in reflow.



*See appropriate product specification

SECTION 5: MECHANICAL AND THERMAL PROPERTIES, LEADED CAPACITORS

5.1 ACCELERATION

10 g (981 m/s^2)

5.2 VIBRATION SEVERITY

10 to 2000 Hz, 0.75 mm or 98 m/s^2

5.3 SHOCK

Trapezoidal Pulse 10 g (981 m/s^2) for 6 ms

5.4 TENSILE STRENGTH OF CONNECTION

10 N for type TAR, 5 N for type TAP/TEP.

5.5 BENDING STRENGTH OF CONNECTIONS

2 bends at 90°C with 50% of the tensile strength test loading.

5.6 SOLDERING CONDITIONS

Dip soldering permissible provided solder bath temperature ≤270°C; solder time <3 sec.; circuit board thickness ≥1.0 mm.

5.7 INSTALLATION INSTRUCTIONS

The upper temperature limit (maximum capacitor surface temperature) must not be exceeded even under the most unfavorable conditions when the capacitor is installed. This must be considered particularly when it is positioned near components which radiate heat strongly (e.g., valves and power transistors). Furthermore, care must be taken, when bending the wires, that the bending forces do not strain the capacitor housing.

5.8 INSTALLATION POSITION

No restriction.

5.9 SOLDERING INSTRUCTIONS

Fluxes containing acids must not be used.

QUESTIONS AND ANSWERS

Some commonly asked questions regarding Tantalum Capacitors:

Question: If I use several tantalum capacitors in serial/ parallel combinations, how can I ensure equal current and voltage sharing?

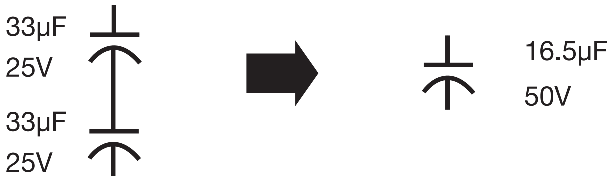
Answer: Connecting two or more capacitors in series and parallel combinations allows almost any value and rating to be constructed for use in an application.

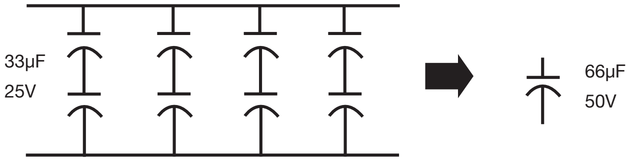
For example, a capacitance of more than 60µF is required in a circuit for stable operation. The working voltage rail is 24 Volts dc with a superimposed ripple of 1.5 Volts at 120 Hz.

The maximum voltage seen by the capacitor is $V_{dc} + V_{ac} = 25.5V$

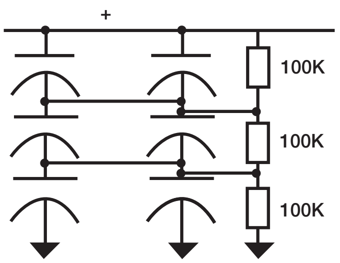
Applying the 50% derate rule tells us that a 50V capacitor is required.

Connecting two 25V rated capacitors in series will give the required capacitance voltage rating, but the effective capacitance will be halved, so for greater than 60µF, four such series combinations are required, as shown.





In order to ensure reliable operation, the capacitors should be connected as shown below to allow current sharing of the ac noise and ripple signals. This prevents any one capacitor heating more than its neighbors and thus being the weak link in the chain.



The two resistors are used to ensure that the leakage currents of the capacitors does not affect the circuit reliability, by ensuring that all the capacitors have half the working voltage across them.

Question: What are the advantages of tantalum over other capacitor technologies?

Answer:

1. Tantalums have high volumetric efficiency.
2. Electrical performance over temperature is very stable.
3. They have a wide operating temperature range -55 degrees C to +125 degrees C.
4. They have better frequency characteristics than aluminum electrolytics.
5. No wear out mechanism. Because of their construction, solid tantalum capacitors do not degrade in performance or reliability over time.

Question: If the part is rated as a 25 volt part and you have current surged it, why can't I use it at 25 volts in a low impedance circuit?

Answer: The high volumetric efficiency obtained using tantalum technology is accomplished by using an extremely thin film of tantalum pentoxide as the dielectric. Even an application of the relatively low voltage of 25 volts will produce a large field strength as seen by the dielectric. As a result of this, derating has a significant impact on reliability as described under the reliability section. The following example uses a 22 microfarad capacitor rated at 25 volts to illustrate the point. The equation for determining the amount of surface area for a capacitor is as follows:

$C = ((E) (E^\circ) (A)) / d$

$A = ((C) (d)) / ((E^\circ)(E))$

$A = ((22 \times 10^{-6}) (170 \times 10^{-9})) / ((8.85 \times 10^{-12}) (27))$

A = 0.015 square meters (150 square centimeters)

Where C = Capacitance in farads

A = Dielectric (Electrode) Surface Area (m^2)

d = Dielectric thickness (Space between dielectric) (m)

E = Dielectric constant (27 for tantalum)

E° = Dielectric Constant relative to a vacuum (8.855×10^{-12} Farads x m^{-1})

To compute the field voltage potential felt by the dielectric we use the following logic.

Dielectric formation potential = Formation Ratio x Working Voltage
= 4 x 25
Formation Potential = 100 volts
Dielectric (Ta_2O_5) Thickness (d) is 1.7×10^{-9} Meters Per Volt
d = 0.17 µ meters
Electric Field Strength = Working Voltage / d
= (25 / 0.17 µ meters)
= 147 Kilovolts per millimeter
= 147 Megavolts per meter

QUESTIONS AND ANSWERS

No matter how pure the raw tantalum powder or the precision of processing, there will always be impurity sites in the dielectric. We attempt to stress these sites in the factory with overvoltage surges, and elevated temperature burn in so that components will fail in the factory and not in your product.

Unfortunately, within this large area of tantalum pentoxide, impurity sites will exist in all capacitors. To minimize the possibility of providing enough activation energy for these impurity sites to turn from an amorphous state to a crystalline state that will conduct energy, series resistance and derating is recommended. By reducing the electric field within the anode at these sites, the tantalum capacitor has increased reliability. Tantalums differ from other electrolytics in that charge transients are carried by electronic conduction rather than absorption of ions.

Question: What negative transients can Solid Tantalum Capacitors operate under?

Answer: The reverse voltage ratings are designed to cover exceptional conditions of small level excursions into incorrect polarity. The values quoted are not intended to cover continuous reverse operation. The peak reverse voltage applied to the capacitor must not exceed:

> 10% of rated DC working voltage to a maximum of 1 volt at 25°C.
>
> 3% of rated DC working voltage to a maximum of 0.5 volt at 85°C.
>
> 1% of category DC working voltage to a maximum of 0.1 volt at 125°C.

Question: I have read that manufacturers recommend a series resistance of 0.1 ohm per working volt. You suggest we use 1 ohm per volt in a low impedance circuit. Why?

Answer: We are talking about two very different sets of circuit conditions for those recommendations. The 0.1 ohm per volt recommendation is for steady-state conditions. This level of resistance is used as a basis for the series resistance variable in a 1% / 1000 hours 60% confidence level reference. This is what steady-state life tests are based on. The 1 ohm per volt is recommended for dynamic conditions which include current in-rush applications such as inputs to power supply circuits. In many power supply topologies where the di / dt through the capacitor(s) is limited, (such as most implementations of buck (current mode), forward converter, and flyback), the requirement for series resistance is decreased.

Question: How long is the shelf life for a tantalum capacitor?

Answer: Solid tantalum capacitors have no limitation on shelf life. The dielectric is stable and no reformation is required. The only factors that affect future performance of the capacitors would be high humidity conditions and extreme storage temperatures. Solderability of solder coated surfaces may be affected by storage in excess of 2 years. Recommended storage conditions are: Temperature between -10ºC – +50ºC with humidity 75% RH maximum and atmospheric pressure 860 mbar-1060 mbar. Terminations should be checked for solderability in the event an oxidation develops on the solder plating.

Question: Are any recommendations/limitation for capacitor selection in parallel combination of capacitors?

Answer: Higher performance series TPS, TPM, NOS, TCJ, TCN are designed to provide lower ESR values and make the product more robust against current surges. The design differences make the better performance distribution of parameters, namely ESR is lower and tighter compared to the general purpose TAJ series. The surge current load in a parallel combination of capacitors is therefore shared more evenly amongst the capacitors and thus it is better suited for this application.

In a parallel combination is is strongly recommended to use the low ESR series of Tantalum Capacitors such as TPS, TPM, NOS, TCJ and TCN. Do not combine different series of manufacturers within one parallel combination.

Question: What level of voltage derating is needed for Tantalum Capacitors?

Answer: For many years whenever people have asked a tantalum capacitor manufacturer about what were the safe guidelines for using their product, they spoke with one voice "a minimum of 50% voltage derating should be applied". This message has since become ingrained and automatic. This article challenges this statement and explains why it is not necessarily the case.

The 50% rule came about when tantalum capacitors started to be used on low impedance sources. In such applications, the available current is high and therefore a risk of failure is inherent. Well established by empirical methods and covered in MIL-STD 317, was the fact that the amount of voltage derating has a major influence on the failure rate of a tantalum capacitor (Figure 1). Indeed, from rated voltage to 50% of rated voltage is an improvement in failure rate of more than 100.

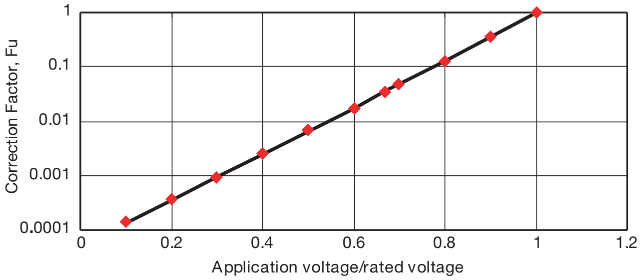
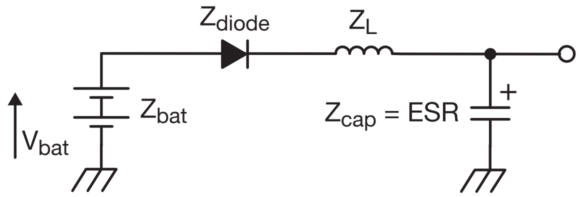


Figure 1

It was also proved that the same was true of dynamic, high current pulse conditions1, hence the recommendation.

Now let us look more closely at the type of circuits in use. Below is a simple circuit which will be discussed further in this text.



Let us assume this is a 2 cell battery system, therefore

$$V_{bat} = 3.2 \text{ Volts}$$

Also, let us assume

Z_{bat} = 60 mΩ, Z_{diode} = 70 mΩ, Z_{cap} = 120 mΩ, ZL = 70 mΩ

If the "50% rule" was followed, the designer should chose a 6.3V rated capacitor.

The total circuit impedance of the system is 320 mΩ. So by Ohm's law the peak current would be 10 Amps.

This exceeds the test conditions used by KYOCERA AVX to screen its product for high current pulses[1], so a risk of failure exists. Clearly a minimum of a 10 volt rate capacitor is required in this application.

As a general rule of thumb, the maximum current a tantalum capacitor can withstand (provided it has not been damaged by thermomechanical damage2 3 or some other external influence) is given by the equation:

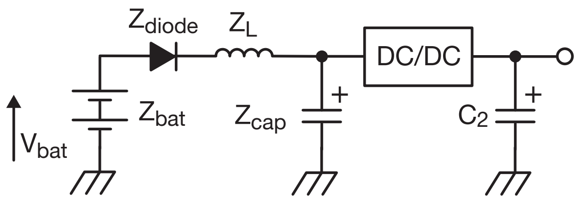
$$I_{max} = V_{rated} / (1 + \text{Catalog ESR})$$

So for example for a 100µF 10V D case capacitor (Catalog ESR = 0.9 Ohms), this would be:

$$I_{max} = 10 / (1 + 0.9) = 5.2 \text{ Amps}$$

In some circuits, because of size restrictions, a tantalum capacitor may be the only option available. If this is the case, KYOCERA AVX recommends a PFET integrator be used to slow the voltage ramp at turn on, which in effect reduces the peak current, and therefore reduces the risk of failure4.

Now, let's consider a continuation of the circuit with the addition of an LDO or DC/DC convertor.



The risk of a high surge current being seen by the capacitor in location C_2 is very small. Therefore if we assume the voltage rail is 2.8 volts and the maximum current seen by C_2 is <1.5 Amps, a 4 volt capacitor could be able to be used in this application.

This all seems like good news, but as always, there are some downsides to using a part nearer to its rated voltage. The first is the steady-state life, or MTBF. The MTBF of a tantalum capacitor is easily calculated from MIL-STD 317 or the supplier's catalog data. An example is given below:

Assume operating temperature is 85°C and circuit impedance 0.1 Ohms/volt (F_T = 1).

For a 10 volt rated capacitor on a 5 volt rated line, the failure rate is:

F_R = 1%/1000 hours x F_T x F_U x F_R
= 1%/1000 hours x 1 x 0.007 (from Figure 1) x 1
= 0.007%/1000 hours

MTBF = 10^5 / F_R
= 14,285,238 hours
= 1,631 years

For a 6.3 volt rated capacitor on a 5 volt rated line, the failure rate is:

FR = 1%/1000 hours x F_T X F_U X F_R
= 1%/1000 hours x 1 x 0.12 (from Figure 1) x 1
= 0.12 %/1000 hours

MTBF = 10^5 / F_R
= 833,333 hours
= 95 years

The second factor to be considered is that the more derating applied to a tantalum capacitor, the lower the leakage current level (Figure 2). Therefore a part used at 50% of its rated voltage will have more than 3 times better leakage levels than one used at 80%.

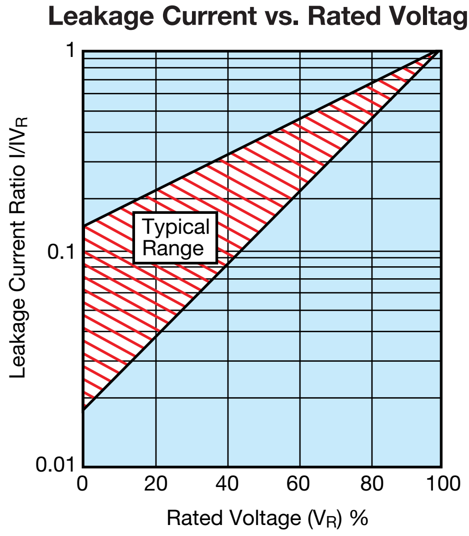


Figure 2

One final point worthy of mention with the introduction of higher reflow temperatures with the introduction of lead-free solders is that voltage derating can help to reduce the risk of failures due to thermomechanical damage during reflow.

To summarize, a tantalum capacitor is capable of being used at its rated voltage or close to it, provided that the user obeys the rules outlined in this document and is prepared for the reduced steady-state life performance and higher leakage current levels this would produce.

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[1] Surge in Solid Tantalum Capacitors, John Gill, KYOCERA AVX Tantalum
[2] IR Reflow Guidelines for Tantalum Capacitors, Steve Warden & John Gill, KYOCERA AVX Tantalum
[3] Mounting Guidelines in KYOCERA AVX Tantalum Catalog
[4] Improving Reliability of Tantalum Capacitors in Low Impedance Circuits, Dave Mattingly, KYOCERA AVX

Question: What does failure rate mean?

Answer: Failure rate is expressed as the number of parts (as a percentage) that can be expected to fail in a given time period under specific conditions of temperature, applied voltage (ratio to rated voltage - usually 1.0) and circuit impedance.

Question: What does ppm mean?

Answer: PPM is defined as 'PARTS PER MILLION' and can be used to express how many parts within a million pieces may fail to the specification.

Question: What is the difference between %/1000hrs and FITs?

Answer: The failure rate as the mathematic quantity can be expressed in several units of measurement - mostly in %/1000hrs or in FITs. FITs are usually used for the high-reliability components where expression in %/1000hrs would be more difficult to read. The conversion is as follows: e.g. 0.01%/1000hrs = 100 FIT for specified conditions ([%/1000hrs] = x 10000 [FIT]).

Question: What are the standards for reliability calculations?

Answer: The standards used in the KYOCERA AVX specification are based on the European norm EN 61709 with the added feature of series resistance in order to better reflect real application conditions. The basic failure rate in the KYOCERA AVX test is given for conditions - 85°C, Vrated, 0.1 Ohm/V. To calculate the actual failure rate for specific conditions you have to consider the influence of different factors which have an impact on reliability - correction factors for temperature (FT), voltage derating (FV),(circuit) impedance (FR) and the base failure rate (Fbase) for the series being used.

Question: Are tantalum capacitors ESD (i.e. Electrostatic Discharge) sensitive devices?

Answer: All tantalum and niobium Oxide capacitors are not ESD sensitive devices.