Tantalum Wet Electrolytic Capacitor

Technical Summary and Application Guidelines

INTRODUCTION

The structure of a Tantalum Wet Electrolytic Capacitor consists of four main elements: a primary electrode (anode), dielectric, a secondary electrode system (cathode) and a wet (liquid) electrolyte. The first, positive electrode (the anode) is a very high surface area structure made of pure tantalum metal. As with anodes prepared for surface mount devices, they are made by pressing and sintering pure tantalum powder together with an embedded tantalum wire (for later electrical contact) into, in this case, a cylindrical pellet of extremely high internal surface area capable of achieving high Capacitance at a given rated voltage. Next, the dielectric, a highly resistive insulating layer, is formed. The dielectric material is a thin film of tantalum pentoxide (Ta_2O_5) created by electrolytic oxidation of the anode surface, a process which grows the film over all of the internal surface area of the anode. The second electrode (cathode) is an extremely high surface area material actually applied to the inside surface of the pure tantalum can that provides the external housing for the device. The cathode system in wet capacitors provides good mechanical robustness and excellent contact with the liquid electrolyte, which is the functional connection between anode and cathode. All are contained within the can which s hermetically sealed, with an external anode lead connected to the embedded anode wire, and an external cathode lead connected to the can.

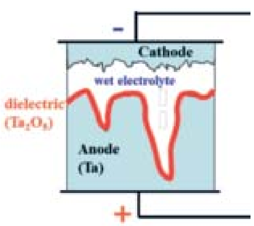


Figure 1 a. Basic Tantalum Wet Electrolytic Capacitor System

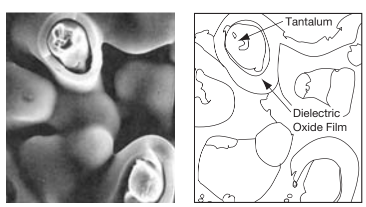


Figure 1 b. Typical Formed anode pellet structure

Wet tantalum capacitors have been utilized for many years in high energy storage applications where volumetric efficiency and high reliability are essential requirements. The first wet tantalum capacitors were developed in the middle of 20th century and comprised a tantalum anode surrounded by an electrolyte inside a silver case with an epoxy end seal.

This design was problematic in that it could be prone to leakage of the electrolyte through the epoxy seal. It also had a limited ability to withstand any reverse voltage. The silver case material was later replaced by pure tantalum, which provided more stable performance characteristics over a wide range of applications.

The use of a tantalum case made it easier to construct a tantalum glass-to-metal end-seal that could be laser-welded to the tantalum can, thus making a fully hermetic capacitor. This construction addressed the risk of fluid leakage from the part and improved overall reliability.

The original design also included the use of a porous, high surface area tantalum sleeve inside the case which acted as the cathode system. The design with tantalum sleeve was adopted by MIL-PRF-39006 and remains the qualified standard tantalum wet capacitors (**AVX TWC series family**).

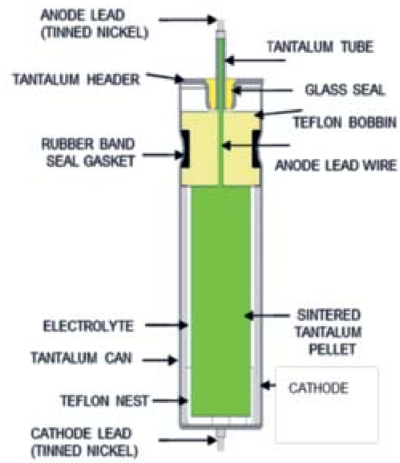


Figure 2. Typical Wet Tantalum Capacitor Construction

Because the bulk of the capacitance attainable is strongly dependent on the area of the cathode, alternative cathode systems, directly coated onto the interior of the tantalum can, were developed, such as used by **AVX TWA series family**. This system not only increases the overall area of the cathode, but also increases the internal volume available for the anode, thus significantly increasing the potential capacitance/voltage ratings available in each case size. The disadvantage of the alternative cathode system is a limited reverse voltage capability.

The key benefits of wet tantalum electrolyte systems are:

- Large case sizes capable of offering high Capacitance values at high operating voltages.
- Wide operational temperature ranges -55 to 125ºC, with special designs up to 230ºC
- Wide working voltage range up to 125V
- High volumetric efficiency.

Disadvantages compared to solid tantalum series are:

- Lower electrolyte conductivity resulting in higher ESR.
- Reduced capacitance and increased ESR at low temperatures.
- Risk of hydrogen generation.
- Higher material and manufacturing cost.

Compared to solid tantalum technologies e.g. (MnO_2 or polymer electrolyte), wet tantalum capacitors exhibit a higher surge current capability with a higher breakdown voltage (BDV) close to their dielectric formation voltage. This results in capacitors that require less voltage derating.

Their lower electrolyte conductivity results in a greater capacitance drop with frequency, suiting wet tantalum electrolytic capacitors ideally to high reliability bulk capacitance applications.

SECTION 1
ELECTRICAL CHARACTERISTICS AND EXPLANATION OF TERMS

1.1 CAPACITANCE

1.1.1 Rated Capacitance

Capacitance is measured at 120Hz and 25°C with 2.0V DC bias applied. A small reduction in capacitance level (<2%) may be observed at rated voltage.

1.1.2 Capacitance Tolerance

This is the permissible variation of the actual value of the capacitance from the rated value. For additional reading, please consult the AVX technical publication “Capacitance Tolerances for Solid Tantalum Capacitors”.

1.1.3 Temperature dependence of capacitance.

The capacitance of a tantalum capacitor varies with temperature. This variation itself is dependent to a small extent on the case size and rating as shown in Figure 1.1.3; capacitance limits for individual ratings at -55°C, +85°C and +125°C are given in the data sheet.

1.1.4 Frequency dependence of capacitance.

Capacitance levels decrease with increasing frequency. Figure 1.1.4a across shows the typical capacitance versus frequency behavior of a TWC series (conventional tantalum sleeve) design. Figure 1.1.4b illustrates typical capacitance characteristics versus frequency for several different ratings of the TWA series (wet system with alternative cathode).

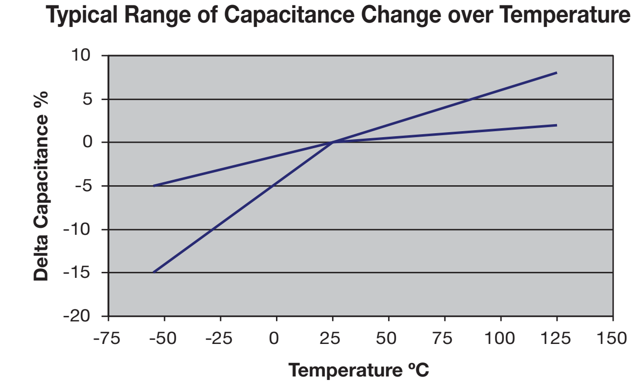


Figure 1.1.3: Typical Capacitance Change Limits vs. Temperature

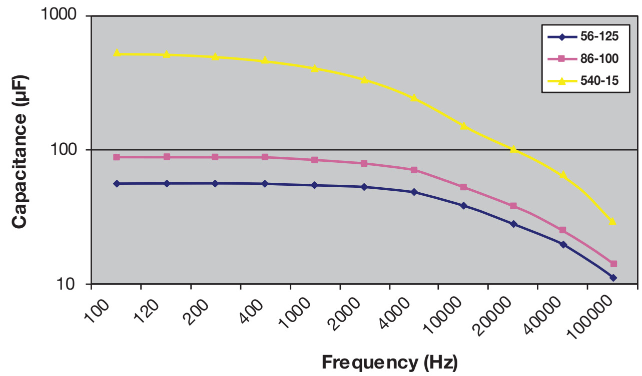


*Figure 1.1.4 a: **TWC** Typical Capacitance vs. Frequency*

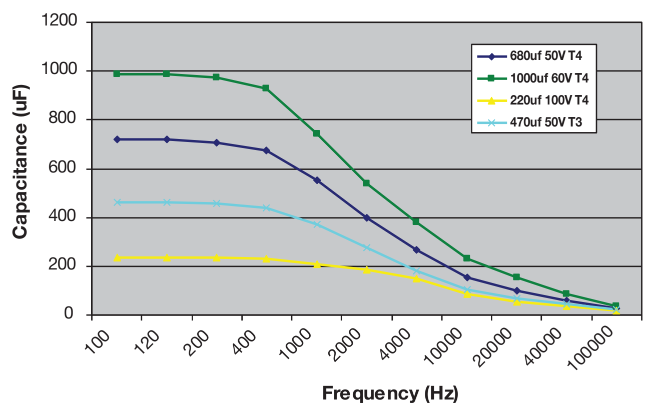


*Figure 1.1.4 b: **TWA** Typical Capacitance vs. Frequency*

1.2 VOLTAGE

1.2.1 Rated DC Voltage (V_R)

This is the maximum continuous DC voltage that the part may be subjected to at temperatures from -55°C to +85°C.

1.2.2 Category voltage (V_C).

This is the maximum voltage that may be applied continuously to a capacitor over its temperature range. It is equal to the rated voltage V_R from -55°C to +85°C, beyond which it is subject to a linear derating, to 2/3

V_R at 125°C See Figure 1.2.1 below for voltage derating with temperature.

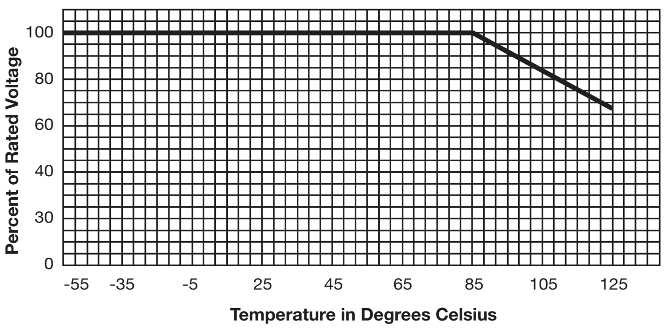


Figure 1.2.1 Voltage Derating over Temperature

The maximum working voltage for temperatures between 85°C and 125°C can also be found from the following formula:

$$V_{max} = \left(1 - \frac{(T - 85)}{125}\right) \times V_R$$

where T is the required operating temperature.

1.2.3 Surge voltage (V_S).

This is the highest voltage that may be applied to a capacitor for short periods of time in circuits with minimum series resistance of 33Ohms. This includes the peak AC ripple voltage in addition to the DC bias voltage.

Table 1.2.3 below illustrates the maximum allowable surge voltage for each voltage rating.

Voltage	
Rated (85ºC) (85ºC)	Surge (85ºC) (85ºC)
6	6.9
8	9.2
10	11.5
15	17.3
25	28.8
30	34.5
50	57.5
60	69.0
75	86.3
100	115.0
125	144.0

Table 1.2.3

85ºC Surge Voltage ratings

<u>TWC Series Family Surge Test:</u>

Typical surge voltage testing consists of 1000 cycles of an applied 30 second surge voltage followed by a 5.5 minute discharge period. Voltage application is made through a resistance of (1,000 ±100) ohms in series with the capacitor. Each surge voltage cycle is performed in such a manner that the capacitor is discharged through a 1 kOhm resistor at the end of 30 seconds of applied voltage. Upon completing the test, the capacitors are allowed to stabilize at room temperature and measured to the following limits:

1. Capacitance shall be within the initial 25°C tolerance
2. DC leakage shall not exceed the initial 25°C limit
3. DF shall not exceed the initial 25°C limit
4. Capacitors shall be visually examined for mechanical damage and leakage of electrolyte.

<u>TWA Series Family Surge Test:</u>

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 the design parameter for circuits in which, in the normal course of operation, the capacitor is periodically charged and discharged to.

1.2.4 High Temperature Voltage (V_T)

High temperature capacitor series (TWA-Y and TWC-Y) (designed for operation above 125°C) can be operated at 60% of their rated DC voltage (V_R) at 200°C for a period specified in their individual data sheets. The specialty high temperature TWA-X series is designed to service at extremes 200-230°C. For maximum operating voltage and time at the temperature see the TWA-X series specification.

1.2.5 Reverse voltage and Non-Polar operation.

Tantalum wet capacitors are inherently polar devices with the positive terminal identified on the body of the component. It is advisable to avoid the application of reverse voltage at all times. However, they do have the capability to withstand some reverse voltage as follows:

<u>TWC Series Family Reverse Voltage Operation</u>

TWC series allow limited reverse voltage levels of up to 3V for a maximum of 125 Hours. Capacitors evaluated to these conditions have met the following requirements:

1. DCL shall not exceed 125% of the initial value specified.
2. Capacitance shall remain within the initial tolerance (5%, 10%, 20%).
3. DF shall not exceed the initial limit specified.

<u>TWA Series Family Reverse Voltage Operation</u>

Continuous application of reverse voltage without normal polarization may result in an increase in leakage current.

Reverse voltage ratings are designed to cover exceptional conditions where small level excursions into incorrect polarity may occur. The values quoted do not apply to continuous reverse operation.

Any peak reverse voltage applied to the capacitor must meet the following criteria:

a. The peak reverse voltage must be less than or equal to 1.5 volts and the product of the peak current times the duration of the reverse transient must be less than or equal to 0.05 ampere-second.
b. The repetition rate of the reverse voltage surges must be less than 10 Hz.

Non-Polar Operation

Under conditions where the continuous application of a reverse voltage could occur, two similar capacitors should be used in a back-to-back configuration with the negative terminations having a common connection. This combination will give a total capacitance of approximately one half of the nominal capacitance of each capacitor. Under conditions of isolated pulses or during the first few cycles, the capacitance may approach the full nominal value.

1.2.6 Superimposed A.C. Voltage (Vrms) - 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 peak value of the superimposed ac voltage must not exceed the category voltage, V_C.

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

1.3.1 Impedance, Z.

This is the ratio of voltage to current at a specified frequency. The impedance is measured at -55°C and 120Hz.

1.3.2 Equivalent Series Resistance, ESR.

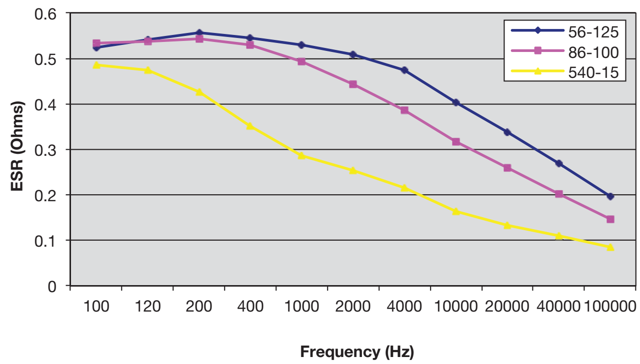
The ESR of a wet tantalum behaves much the same as a solid tantalum capacitor. It will decrease as frequency increases and generally resonance is achieved above 100 kHz. ESR is measured at 120Hz and 25ºC with 2.0V DC bias applied. The ESR is frequency dependent and can be found by using the relationship:

$$ESR = \tan \delta / 2\pi fC$$

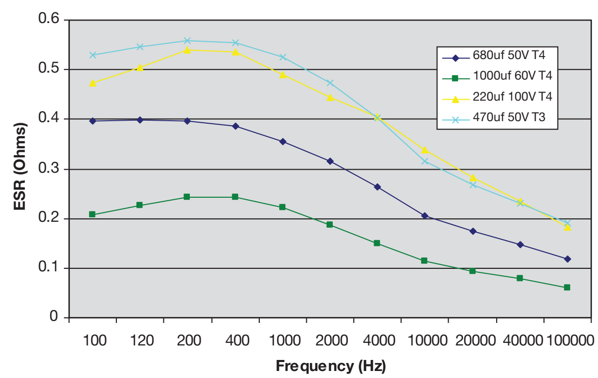
Where f is the frequency in Hz, and C is the capacitance in farads. ESR is one of the contributing factors to impedance, and at high frequencies (10kHz and above) it becomes the dominant factor.

1.3.3 Frequency dependence of ESR.

ESR and Impedance both reduce with increasing frequency. At lower frequencies the values diverge as the extra contributions to impedance (due to the reactance of the capacitor) become more significant. In the range (1–10) kHz the values of impedance and ESR are almost identical, while at higher frequencies (and beyond the resonant point of the capacitor) impedance again increases due to the inductance of the capacitor.



Graph 1.3.3.a TWC Frequency Dependence of ESR



Graph 1.3.3. b TWA Frequency Dependence of ESR

1.3.5 Temperature dependence of Impedance, Z and ESR.

ESR and impedance vary with temperature, with the most significant changes occurring at low temperature. ESR and Impedance can increase by a factor of 20 to 30 times at the lower limit of -55°C; low temperature impedance limits for each rating are given in the individual data sheets.

At High temperatures ESR levels reduce slightly. ESR is typically halved at +85°C and is reduced to almost a third at +125°C.

1.4 D.C. LEAKAGE CURRENT

1.4.1 Leakage current, DCL.

The leakage current is dependent on the voltage applied, the time over which the voltage is applied and the component temperature. It is measured at +25°C with rated voltage applied. A protective resistance of 1000Ω is connected in series with the capacitor in the measuring circuit. Three to five minutes after application of the rated voltage the leakage current must not exceed the maximum values indicated in the individual data sheet.

Leakage limits are specified for 25ºC and 85ºC with rated voltage applied, and for 125ºC with category (2/3 rated) voltage applied.

Wet tantalum technology is characterized by extremely low leakage current, typically less than 0.0002CV (about 50 times lower than solid tantalum technology).

1.4.2 Temperature Dependence of Leakage current.

Leakage current increases with increasing temperature. In general, there will be a 10 to 12 times increase at 85°C and 125°C respectively. DCL limits for individual ratings at -55°C, +85°C and +125°C are given in the data sheet.

1.4.3 Voltage dependence of the leakage current.

When operated at applied voltages less than the rated voltage, leakage current will be greatly reduced.

When operated at applied voltages less than the rated voltage, reliability in any given application will be increased.

1.5 A.C. OPERATION, POWER DISSIPATION AND RIPPLE CURRENT

1.5.1 A.C. Operation.

In an A.C. application heat is generated within the capacitor primarily by the a.c. component of the signal (which will depend upon the signal form, amplitude and frequency), and secondarily by the DC leakage (for most practical purposes this, second factor is insignificant). The actual power dissipated in the capacitor can be calculated using the formula:

$$P = I^2R$$

rearranged to:

$$I = SQRT\,(P/R) \text{ .....(Eq. 1)}$$

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

The maximum a.c. ripple voltage (Umax) is calculated from Ohms' law:

$$U_{max} = IR \text{ .....(Eq. 2)}$$

Where P is the maximum specified permissible power dissipation.

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 a.c. voltage and the DC bias voltage.
2. The sum of the applied DC bias voltage and the negative a.c. voltage peak must not exceed the reverse voltage specification limit.

1.5.2 Power Dissipation

Power dissipation is a measure of the power required to heat the capacitor to a certain temperature above ambient. Power dissipation is a function of case size and This is used in the above equations to calculate ripple current limits.

1.5.3 Ripple Current.

Ripple current is referenced at 40kHz at 2/3 rated voltage at 85°C and multipliers for applied voltages of different percentages of rated voltage, and for different frequencies, have been calculated over the temperature range from -55°C to 125°C. These are shown in table 1.5.3.

The reference point (40kHz at ²/₃ rated voltage at 85°C) is highlighted in yellow in the table.

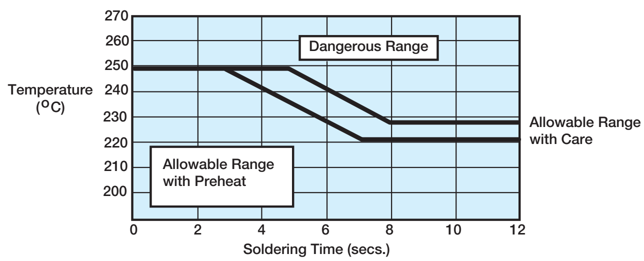
Frequency of applied ripple current		120 Hz				800 Hz				1 kHz			
Ambient still air temperature (°C)		≤ 55	85	105	125	≤ 55	85	105	125	≤ 55	85	105	125
% of 85°C rated peak voltage	100%	0.6	0.39	–	–	0.71	0.43	–	–	0.72	0.45	–	–
	90%	0.6	0.46	–	–	0.71	0.55	–	–	0.72	0.55	–	–
	80%	0.6	0.52	0.35	–	0.71	0.62	0.42	–	0.72	0.62	0.42	–
	70%	0.6	0.58	0.44	–	0.71	0.69	0.52	–	0.72	0.7	0.52	–
	66-2/3%	0.6	0.6	0.46	0.27	0.71	0.71	0.55	0.32	0.72	0.72	0.55	0.32
Frequency of applied ripple current		10 kHz				40 kHz				100 kHz			
Ambient still air temperature (°C)		≤ 55	85	105	125	≤ 55	85	105	125	≤ 55	85	105	125
% of 85°C rated peak voltage	100%	0.88	0.55	–	–	1	0.63	–	–	1.1	0.69	–	–
	90%	0.88	0.67	–	–	1	0.77	–	–	1.1	0.85	–	–
	80%	0.88	0.76	0.52	–	1	0.87	0.59	–	1.1	0.96	0.65	–
	70%	0.88	0.85	0.64	–	1	0.97	0.73	–	1.1	1.07	0.8	–
	66-2/3%	0.88	0.88	0.68	0.4	1	1	0.77	0.45	1.1	1.1	0.85	0.5

Fig. 1.5.3 Ripple current multipliers vs. Frequency, temperature and applied voltage

1.6 SOLDERING CONDITIONS AND BOARD ATTACHMENT

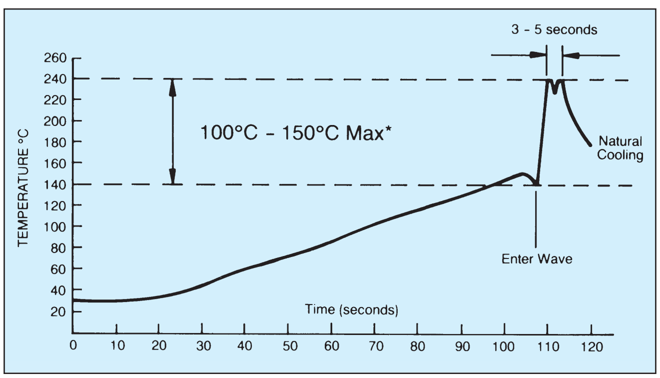
1.6.1 Wave Soldering.

AVX leaded tantalum capacitors are designed for printed circuit board (pcb) attachment via a wave soldering operation. The soldering temperature and time should be the minimum required for a good connection. After insertion into the pcb, the exposed leads can be passed through wave solder, a suitable temperature/time combination being 230°C – 250°C for 3-5 seconds. Figure 1.7.1 illustrates the allowable range of peak temperature versus time for wave soldering.



Graph 1.6.1. Allowable range of peak temp./time combinations for wave soldering

As small parametric shifts may be noted immediately after wave solder, components should be allowed to stabilize at room temperature prior to electrical testing. After soldering. the assembly should 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. A recommended wave solder profile is shown below:



Graph 1.6.2. Recommended Wave Solder Profile

1.7 RELIABILITY CALCULATION

The predicted reliability of a wet tantalum capacitor in an application can be calculated using the equation defined in MIL-HDBK-217 as seen below:

$$\lambda_P = \lambda_b \times \pi_T \times \pi_C \times \pi_V \times \pi_{SR} \times \pi_Q \times \pi_E$$

Failures/10^6 Hours

where:

λ_P = part failure rate

λ_b = base failure rate

π = factors that modify the base failure rate

For wet tantalum capacitors the base failure rate (λ_b) is:

$$\lambda_b = 0.0004$$

The π factors should be determined from the tables that follow which outline the values for each variable as they pertain to individual components and the applications in which they are utilized.

Temperature Factor π_T	
T (°C)	π_T
20	0.91
30	1.1
40	1.3
50	1.6
60	1.8
70	2.2
80	2.5
90	2.8
100	3.2
110	3.7
120	4.1
130	4.6

Capacitance Factor π_C	
Cap (µF)	*π_C
1	1.00
4	1.38
10	1.70
15	1.86
33	2.23
68	2.64
100	2.88
220	3.46
470	4.12
680	4.48
1200	5.11
2200	5.87

*πC = C0.23

Voltage Stress Factor π_V	
Voltage Stress	π_V
0.1	1
0.2	1
0.3	1
0.4	1
0.5	1
0.6	2
0.7	15
0.8	130
0.9	990
1	5900

Quality Factor π_Q	
Quality	π_Q
D	0.001
C	0.01
S, B	0.03
R	0.1
P	0.3
M	1
L	1.5
COTS-Plus	3
Commercial	10

Environmental Factor π_E		
Environmental	π_E Symbol	π_E
Ground, Benign	G_B	1
Ground, Fixed	G_F	10
Ground, Mobile	G_M	20
Naval, Sheltered	N_S	7
Naval, Unsheltered	N_U	15
Airborne, Inhabited Cargo	A_{IC}	12
Airborne, Inhabited Fighter	A_{IF}	15
Airborne, Uninhabited Cargo	A_{UC}	25
Airborne, Uninhabited Fighter	A_{UF}	30
Airborne, Rotary Winged	A_{RW}	40
Space, Flight	S_F	0.5
Missile, Flight	M_F	20
Missile, Launch	M_L	50
Cannon, Launch	C_L	570

Series Resistance Factor π_{SR}	
Circuit Resistance (Ohms/Volt)	π_{SR}
> 0.8	0.66
> 0.6 to 0.8	1
> 0.4 to 0.6	1.3
> 0.2 to 0.4	2
> 0.1 to 0.2	2.7
0 to 0.1	3.3

More information for the definitions of the application environments can be seen in MIL-HDBK-217.

Example Calculation: A 100 VDC 220µF COTS-Plus wet tantalum is being used in a fixed ground environment at 50°C with 60V applied and a series resistance of 0.2 Ohms/Volt.

$\pi_T = 1.6$ $\pi_C = 3.46$

$\pi_V = 2$ $\pi_{SR} = 2$

$\pi_Q = 3$ $\pi_E = 10$

$$\lambda_P = 0.0004 \times 1.6 \times 3.46 \times 2 \times 2 \times 3 \times 10 = 0.26$$

Failures/10^6 Hours

1.8 LONG TERM STORAGE

Higher temperature long term storage of completed circuit card assemblies with capacitors installed can result in an increase in direct current leakage (DCL). This will return to a normal level after a period of electrification. This may also occur during low temperature storage over an extended time period (typically several years). It is recommended that after such a storage period, capacitors should be powered by a soft start / slow voltage ramp to avoid damage to parts with elevated leakage current.

For such long term storage, it is recommended that capacitors are kept in environment below +40ºC and powered every 2 years to keep the DCL at very low level for their entire life time.