

Introduction

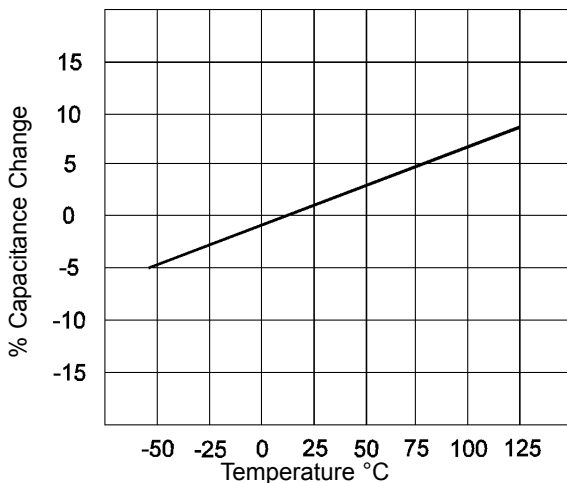
Tantalum capacitors are manufactured from a powder of pure tantalum metal. The powder is compressed under high pressure around a tantalum wire to form a 'pellet'. The riser wire is the anode connection to the capacitor. This is subsequently vacuum sintered at high temperature (typically 1500 - 2000°C). This helps to drive off any impurities within the powder by migration to the surface. During sintering the powder becomes a sponge like structure with all the particles interconnected in a huge lattice. This structure is of high mechanical strength and density, but is also highly porous giving a large internal surface area. The larger the surface area the larger the capacitance. By choosing the powder used to produce each capacitance/voltage rating, the surface area can be controlled. The next stage is the production of the cathode plate. This is achieved by pyrolysis of manganese nitrate into manganese dioxide. The 'pellet' is dipped into an aqueous solution of nitrate and then baked in an oven at approximately 250°C to produce a dioxide coat. This process is repeated several times, varying specific densities of nitrate to build up a thick coat over all internal and external surfaces of the 'pellet'. The 'pellet' is then dipped into graphite and silver to provide a good connection to the manganese dioxide cathode plate. Electrical contact is established by deposition of carbon onto the surface of the cathode. The carbon is then coated with a conductive material to facilitate connection to the cathode termination. Packaging is carried out to meet specifications and customer requirements.

Specifications

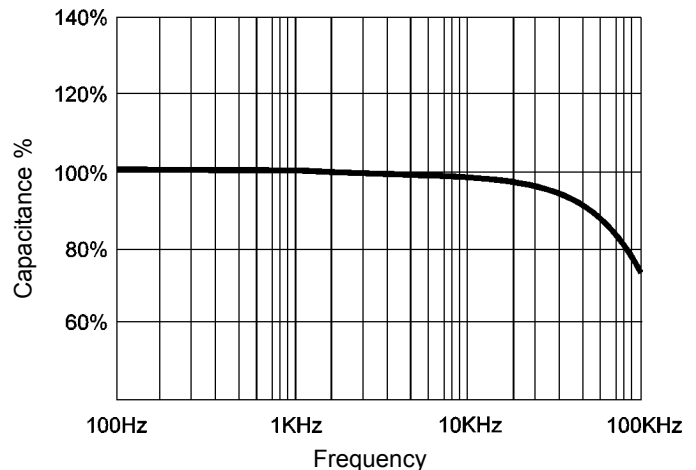
Data relates to an ambient temperature of +25° C

- Operating temperature range** -55°C to +125°C
 2/3 x Vr (linear derating) required for operation above +85°C.
- Capacitance** Nominal rated capacitance is measured at +25°C, 120 Hz source, free of harmonics with a maximum bias of 2.2V d.c. Capacitance decreases with increasing frequency and increases with increasing temperature.

Typical Component
Capacitance vs. Temperature



Typical Component
Capacitance vs. Frequency



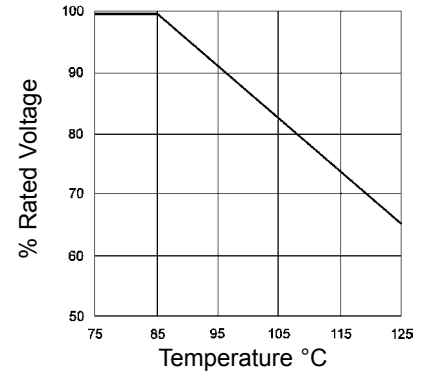
- Capacitance tolerances** E.I.A. standard ±20% and ±10%.
 Tolerance is the permissible variation of the actual value of capacitance from the rated value.
- Stability** $\frac{\Delta C}{C} \leq 12\%$ over the operating temperature range
- Environmental Classification** 55/125/56 (IEC 68-2)

General Performance Information

- **Working DC voltage range - 4 to 50 WVDC**

Rated voltages are the maximum recommended peak DC operating voltages for continuous use from -55°C to +85°C. Operation above +85°C requires linear derating to 2/3 rated voltage at +125°C.

To improve operating reliability select higher voltage ratings (30% to 70% recommended) than the maximum line voltage. This is known as voltage derating. The effects of voltage derating can be seen by referring to the section on reliability, failure rate.



- **Surge Voltage VDC**

Surge voltage includes the sum of peak AC ripple, DC bias and any transients. This is the highest voltage that may be applied to a capacitor for a short period of time. The surge voltage may be applied up to ten times in an hour for periods up to 30 sec. at a time. These values are not intended to apply to continuous operation. 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.

The solid tantalum capacitor has a limited ability to withstand surges due to the fact that they operate at very high electrical stress within the oxide layer. It is important to insure 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. Even an extremely short duration spike is likely to cause damage. In such situations it may be necessary to use a higher voltage rating such as an extended range value and/or a lower ESR device.

Rated Working Volts +85°C	Surge Voltage +85°C	Derated DC Volts +125°C	Surge Voltage +125°C
4	5.2	2.7	3.2
6.3	8	4	5
10	13	7	8
16	20	10	12
20	26	13	16
25	32	17	20
35	46	23	28
50	65	33	40

Solid tantalum capacitors have a self healing ability due to the manganese dioxide semiconducting layer used as the negative plate. In the case of low impedance circuits, the capacitor is likely to be stressed by current surges. Derating the capacitor voltage by 50% or more increases the reliability of the component. In circuits which undergo rapid charge or discharge a protective resistor of 1Ω/V is recommended. If this is impossible, a derating factor of up to 70% is recommended. In such situations a higher voltage may be needed than is available as a single capacitor. A series combination can be used to increase the working voltage of the equivalent capacitor: For example two 22μF 25V parts in series is equivalent to a 11μF 50V part. 1 ohm per volt series resistance 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. 0.1 ohm per volt series resistance is recommended 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.

NOTE: Certain test circuits (i.e. ICT) are likely to subject the capacitors to large voltage and current transients, which will not be seen in normal use. These conditions should be taken into account when considering the capacitor's rated voltage for use. This can be controlled by ensuring a correct test resistance is used.

General Performance Information

- Reverse voltage** A small degree of reverse voltage is permissible for short periods. Limiting reverse voltage excursion to the maximum limits shown will avoid a reduction in the components life expectancy. The maximum allowable reverse voltage is summarized as follows:

25°C	10% of rated voltage not exceeding 1.0 volt
85°C	3% of rated voltage not exceeding 0.5 volt
125°C	1% of rated voltage not exceeding 0.1 volt

The values quoted are not intended to cover continuous reverse operation. They are designed to cover exceptional conditions of small levels into reverse polarity.

Non-Polar operation If higher reverse voltages are unavoidable, 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 cathodes joined together.

- DC Leakage Current** The DC leakage current is the current that, after a three to five minute charging period, flows through a capacitor when voltage is applied. It is dependent upon the voltage applied, the time the voltage was applied and the component temperature. The leakage current increases with increasing temperature. The leakage current decreases when reduced voltages are applied. The DC leakage current is measured at +25°C with rated voltage applied, through a 1000 ohm resistor connected in series in the measuring circuit. Reforming of solid tantalum capacitors is unnecessary even after prolonged periods without the application of voltage.

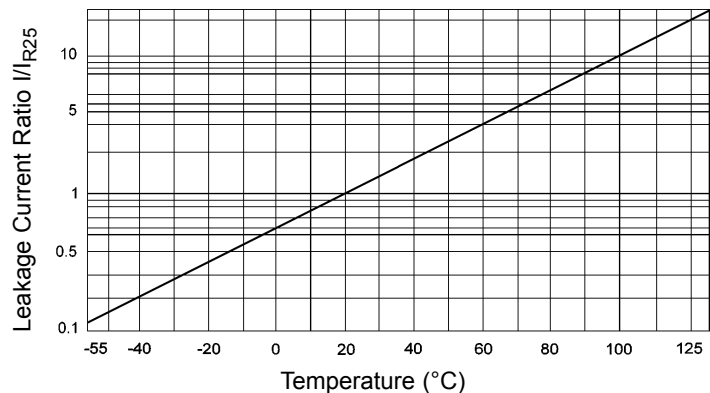
@ 25°C	the DCL values are shown in part number tables
@ 85°C	the DCL should not exceed 10 times the value
@ 125°C	the DCL should not exceed 12 times the value

Temperature Dependence of the Leakage Current

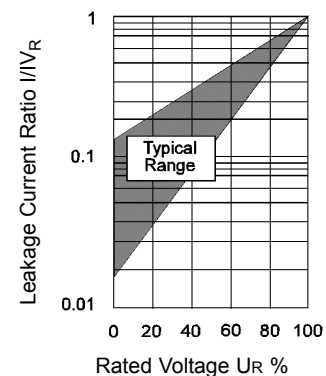
For operation between +85°C and +125°C, the maximum working voltage must be derated and can be found from the following formula.

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

T is the required operating temperature.



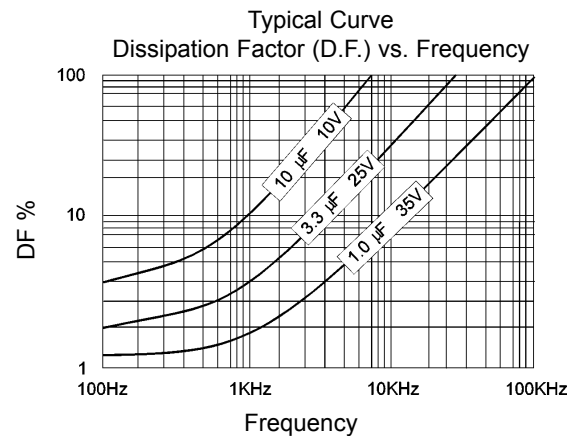
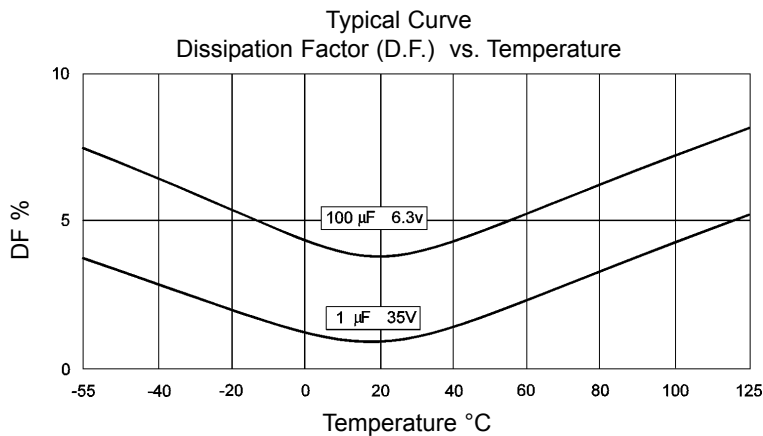
Voltage Dependence of the Leakage Current The leakage current drops rapidly when reduced voltages are applied. The effect of voltage derating on leakage current gives a significant increase in reliability for any application.



General Performance Information

- **Tan δ (at 120 Hz/25°C) (DF)**

Tangent of Loss Angle is a measurement of the energy loss in the capacitor. Terms also used are power factor, loss factor, quality factor, "Q" (the reciprocal of DF) and DF which is the measurement of Tan δ expressed as a percentage. Tan δ is the power loss of the capacitor divided by its reactive power at a sinusoidal voltage of a specified frequency. Measurement is carried out at +25°C and 120Hz with 2.2V DC bias max., with an a.c. voltage free of harmonics. The value of Tan δ is temperature and frequency dependent. DF increases with increasing frequency. DF loses its importance at higher frequencies where impedance and ESR are the normal parameters of concern.



Tan δ (DF) values are indicated in part number tables. The values shown in the part number tables are the limits met by the component after soldering onto the substrate.

$$\text{Tan } \delta \text{ (DF)} = \frac{R}{X_c} = 2\pi fCR$$

Tan δ (DF) = Dissipation factor
 R = ESR (ohms)
 X_c = Capacitive reactance (ohms)
 f = Frequency (Hertz)
 C = Series capacitance (Farads)

- **Impedance** Impedance 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 semiconductor layer; the capacitance value and the inductance of the electrodes and terminations. At high frequencies the inductance of the terminations becomes a limiting factor. The temperature and frequency behavior of these three factors of impedance determine the behavior of the impedance. The impedance is measured at +25°C and 100KHz. There is unavoidable inductance as well as resistance in all capacitors. At some point in frequency, the reactance stops being capacitive and becomes inductive. This frequency is the self resonant point and typically falls between 0.5 - 5MHz depending on the rating. In solid tantalum capacitors, resonance is damped by the ESR and a smooth transition from capacitive to inductive reactance occurs. Total Impedance of the capacitor can be viewed as:

Below resonance - The vector sum of capacitive reactance. $\left(X_c = \frac{1 \text{ ohm}}{2\pi fc} \right)$ and ESR

Above resonance - The vector sum of inductive reactance. $(X_L = 2\pi fL)$ and ESR

f = frequency, Hertz C = capacitance, farad L = inductance, Henries

- **ESR** Equivalent Series Resistance (ESR) is the preferred high frequency statement of the unavoidable resistance appearing in tantalum capacitors. Maximum limits for 100 kHz ESR are listed in the part number tables. NOTE: Nemco LSR series is specifically designed for low ESR performance. 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 measured at +25°C and 100KHz. The ESR is frequency dependent and can be found by using the relationship; $\text{ESR} = \frac{\text{Tan } \delta}{2\pi fC}$

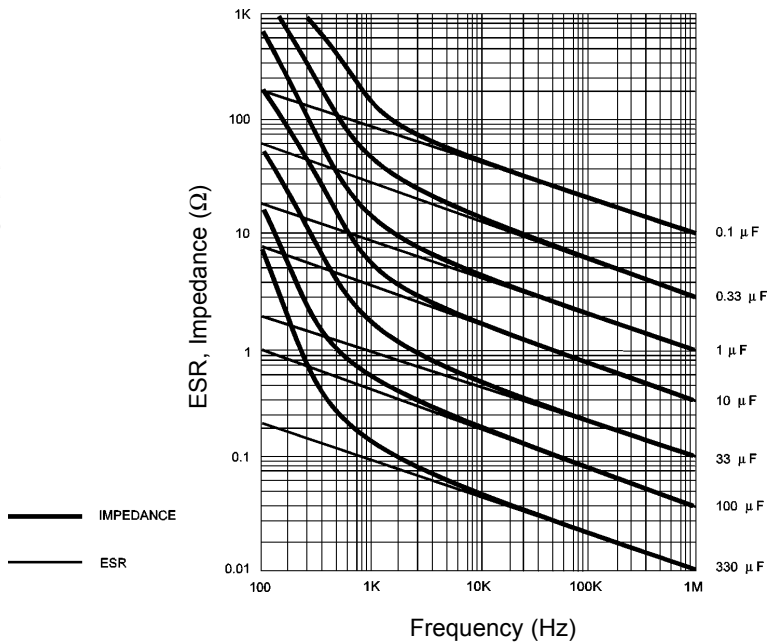
Where f is the frequency in Hertz, and C is the capacitance in farads.

ESR is one of the contributing factors to impedance. At high frequencies (100KHz and above) it becomes the dominant factor. ESR and impedance become almost identical, impedance being only marginally higher.

● **Frequency Dependence of Impedance and ESR**

ESR and impedance decrease with increasing frequency. At lower frequencies the extra contribution to impedance due to the reactance of the capacitor becomes more significant. Beyond the resonant point of the capacitor, impedance again increases due to the inductance of the capacitor.

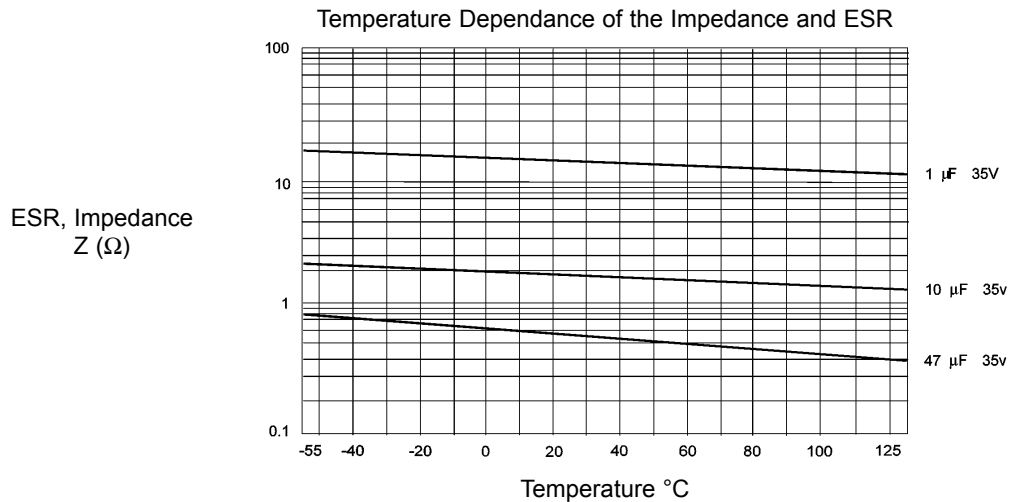
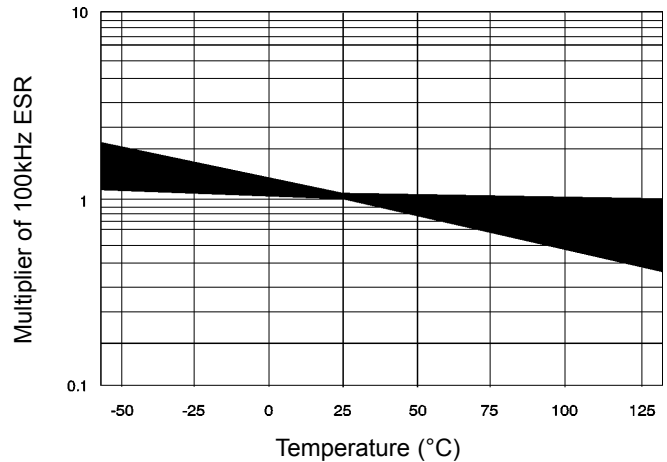
Typical response curve to frequency.



● **Temperature Dependence of Impedance and ESR**

At 100KHz, impedance and ESR behave identically. Impedance and ESR decrease with increasing temperature. The amount of change is influenced by the size of the capacitor and is generally more pronounced on smaller ratings.

Typical effect of temperature on 100KHz ESR can be seen by applying a multiplier to 100kHz ESR.



General Performance Information

- AC Operation** Ripple ratings for all devices can be calculated with the power dissipation rating and ESR rating of the component. Calculated ripple ratings are based on a free air environment. In an AC application heat is generated within the capacitor by both the AC component of the signal (which will depend upon the signal form, amplitude and frequency), and by the DC leakage. For practical purposes the DCL is insignificant. Permissible AC ripple voltage and current are related to ESR and power dissipation capability. Actual power dissipated can be calculated from the following formula:

$$P = I^2R = \frac{E^2R}{Z^2} \quad (\text{substituting } I = \frac{E}{Z})$$

I = rms ripple current (amperes)

R = equivalent series resistance at specified frequency (ohms)

E = rms ripple voltage (volts)

P = power dissipated (watts)

Z = impedance at frequency under consideration (ohms)

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

Maximum allowable rms ripple voltage or ripple current may be determined taking into account three limiting factors.

- The d.c. working voltage of the capacitor must not be exceeded by the sum of the positive peak of the applied a.c. voltage and the d.c. bias voltage.
- The sum of the applied d.c. voltage and the negative peak of the a.c. voltage must not allow a voltage reversal in excess of that defined in "Reverse Voltage".
- The power dissipated in the ESR of the capacitor must not exceed the power dissipation rating for the case size.

NOTE: Temperature derating factors to power dissipation ratings for case size must be considered in calculations.

RIPPLE CURRENT

$$I_{RMS} = \sqrt{\frac{P_{MAX} T_{DF}}{ESR}}$$

I_{RMS} = rms current (amps)

P_{MAX} = Power Dissipation rating (watts)

T_{DF} = Temperature derating factor

85°C = 0.90

125°C = 0.40

RIPPLE VOLTAGE

$$E_{RMS} = \sqrt{(X_L - X_C)^2 + (ESR)^2} \cdot I_{RMS}$$

E_{RMS} = rms ripple voltage

X_L = $2\pi fh$ f = Frequency (of interest)

h = Inductance (Negligible at Low f)

X_C = $\frac{1}{2\pi fc}$ f = Frequency (of interest)

c = Capacitance (Farad)

ESR = ESR (at f of interest)

I_{RMS} = rms ripple current

General Performance Information

• Power Dissipation

The maximum power dissipation at 25°C has been calculated for the various ranges, and are shown (see Table) 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). For surface mount components, the free air values can be approached by correct thermal management of the board. Operation in confined spaces with no heat sinking may lead to a tenfold reduction in the dissipation required to heat the capacitors to 10°C above their ambient. The ripple ratings are set by defining the maximum temperature rise allowable under worst case conditions, i.e. with resistive losses at their maximum limit. This differential is normally at 10°C at room temperature dropping to 2°C at 125°C. In application (this is particularly critical for surface mount components) circuit layout, thermal management, available ventilation and signal waveform may significantly affect the values. It is recommended that 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. The maximum permissible power dissipation should be multiplied by the appropriate derating factor. For certain applications, e.g. power supply filtering, it may be desirable to obtain a Low ESR device to enable higher ripple currents to be handled. Please contact our technical sales office for discussion.

Surface Mount Tantalums			
Case Size	Free Air Max Power Dissipation (W)	Temperature Derating Factors for power dissipation by case size	
A	0.075	Do not use these derating factors when calculating ripple current ratings. Use temperature correction factors.	
B	0.085		
C	0.110		
D	0.150		
H	0.165		
Z	0.250		
		Temp °C	Factor
		+25	1.00
		+85	0.80
		+125	0.16
XL	0.055		
AL	0.065		
BL	0.080		
CL	0.090		
DL	0.125		
R	0.045		

Dipped Radial			
Case Size	Free Air Max Power Dissipation (W)	Temperature Derating Factors for power dissipation by case size	
A	0.045	Do not use these derating factors when calculating ripple current ratings. Use temperature correction factors.	
B	0.050		
C	0.055		
D	0.060		
E	0.065		
F	0.075		
		Temp °C	Factor
		+25	1.00
		+85	0.40
		+125	0.09
G	0.080		
H	0.085		
J	0.090		
K	0.100		
L	0.110		
M	0.120		
N	0.130		
O	0.140		

• Self Inductance Value (ESL) for surface mount devices

The self inductance value can be important for resonance frequency evaluation. This table shows typical ESL values per case size.

Self Inductance Value (ESL)	
Case Size	Typical Self Inductance Value (nH)
A	1.8
B	1.8
C	2.2
D	2.4
H	2.5
Z	2.4
XL	1.4
AL	1.8
BL	1.8
CL	2.2
DL	2.4
R	1.4

- **Reliability** Tantalum capacitors have no known wear-out mechanism and in certain circumstances are capable of self-healing. Random failures can still occur in operation. The failure rate will decrease with time and not increase as with other capacitor types and other electronic components. The reliability of solid tantalum capacitors is dependent upon three key factors which affect the working environment and operating conditions:

- Operating voltage
- Operating temperature
- Circuit impedance

Operational reliability generally increases with reduction of applied voltage and temperature and with an increase of series resistance.

1% per 1000 hours at +85°C, Vr with 0.1Ω / V series impedance, 60% confidence level.

- **Base Failure Rate** Standard tantalum product conforms to Level M reliability (i.e. 1%/1000 hours) at rated voltage, rated temperature (+85°C) and 0.1Ω/volt circuit impedance. This is known as the base failure rate, F_B , which is used for calculating operating reliability. The effect of varying the operating conditions on failure rate are shown.

- **Reliability Assessment**

Operational reliability F in any circuit condition can be deduced from the three previous graphs by multiplying the base failure rate, F_B , for the series by the correction factors, F_U , F_T , and F_R .

Worked example of reliability calculation. For a capacitor with a 16v rating, being operated on a 10v line with 0.8Ω per volt circuit impedance, at a temperature of 50°C, the correction factors given by the previous graphs are as follows:

$$\begin{aligned} F_U &= 0.04 \\ F_T &= 0.1 \\ F_R &= 0.2 \end{aligned}$$

For a series with $F_B = 1\%/1000$ hours, the failure rate F will be

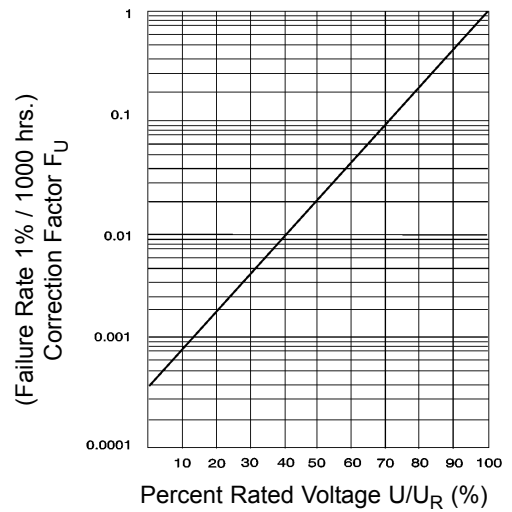
$$\begin{aligned} F &= F_U \times F_T \times F_R \times F_B \\ &= (0.04 \times 0.1 \times 0.2 \times 1)\%/1000 \text{ hours} \\ &= 0.0008\% \text{ per 1000 hours at 60\% confidence level} \end{aligned}$$

It should be noted that the above analysis refers to steady state operating conditions. The failure rate will also be affected by the presence of surges.

General Performance Information

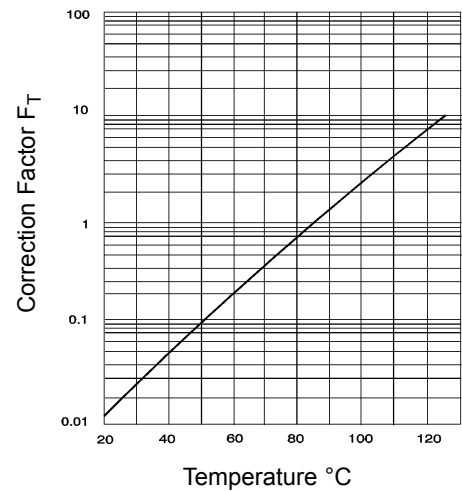
- Operating Voltage/Voltage Derating** If a capacitor with a higher voltage rating than the maximum line voltage is used, then the operating reliability will be improved. This is known as voltage derating. The graph shows the relationship between voltage derating (the ratio between applied and rated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

Effect of applied voltage on basic failure rate for typical component
(60% confidence level).



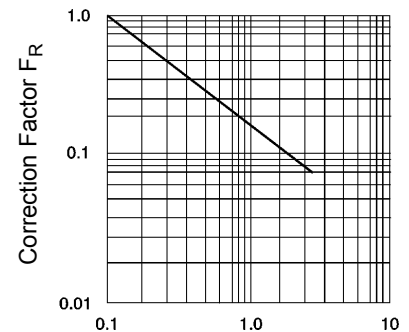
- Operating Temperature** If the operating temperature is below the rated temperature for the capacitor then the operating reliability will be improved as shown. This graph gives a correction factor F_T for any temperature of operation.

Correction Factor to Failure Rate F for Ambient Temperature T
for typical component



- Circuit Impedance** All solid tantalum capacitors benefit from current limiting to prevent burning of the device. A series resistor is recommended for this purpose. A lower circuit impedance may cause an increase in failure rate, especially at temperatures higher than $25^{\circ}C$. An inductive low impedance circuit may apply voltage surges to the capacitor and similarly a non-inductive low impedance circuit may apply current surges to the capacitor, causing localized over-heating and failure. The recommended circuit impedance is 1 ohm per volt. Where this is not feasible, equivalent voltage derating should be used. The graph shows the correction factor, F_R , for increasing series resistance.

Correction Factor to Failure Rate for Series Resistance R on Basic
Failure Rate F_B for typical component



Surface Mount

- Life test** Capacitors are subjected to +85°C at rated voltage and +125°C at 2/3 x rated voltage for 2000 hours with 3 ohms circuit impedance. The capacitors must meet the following limits after stabilizing at 25°C.

capacitance change	within +/-10% of the initial value
Tan δ (DF)	within the initial value
DC leakage current	within 125% of the initial value

- Humidity test** Capacitors are subjected to damp heat at steady state +40°C with 95% relative humidity. The capacitors must meet the following limits after stabilizing at 25°C.

capacitance change	within +/-5% of the initial value
Tan δ (DF)	within 125% of the initial value
DC leakage current	within 125% of the initial value

- Thermal shock** Capacitors are subjected to 5 cycles of 30 minutes at -55°C followed by 30 minutes at +125°C. The capacitors must meet the following limits after stabilizing at 25°C.

capacitance change	within +/-5% of the initial value
Tan δ (DF)	within the initial value
DC leakage current	within the initial value

- Surge Current** Capacitors shall withstand 3 consecutive cycles. The capacitors are charged approximately 4 seconds at rated voltage thru a low circuit resistance of approximately 1 ohm @ +25°C followed by a discharge to below 1% of rated voltage. Post test readings must meet the following criteria:

capacitance change	less than +/-5% of the initial value
Tan δ (DF)	within the initial limit
DC leakage current	within the initial limit

- Surge Voltage** Surge voltages are performed at +25°C, +85°C and +125°C. Capacitors are subject to 1000 cycles of 1.3 x rated voltage for 30 seconds followed by a 30 second discharge period. After stabilizing at room temperature post test readings must meet the following criteria.

capacitance change	less than +/-5% of the initial value
Tan δ (DF)	within the initial limit
DC leakage current	within the initial limit

Radial Dipped

- Life test** Our regular quality assurance program requires capacitors be subjected to +85°C at rated voltage and +125°C at 2/3 x rated voltage for 2000 hours with 3 ohms circuit impedance. The capacitors must meet the following limits after stabilizing for 1 - 2 hours at room temperature.

capacitance change	within +/-10% of the initial value
Tan δ (DF)	within the initial value
DC leakage current	within 125% of the initial value

- Humidity life test** Capacitors shall be capable of withstanding 1000 hours at +55°C with 95% RH and rated voltage applied. The capacitors must meet the following limits after stabilizing for 24 hours at 25°C.

capacitance change	within +/-10% of the initial value
Tan δ (DF)	less than 2X the initial limit
DC leakage current	less than 5X the initial limit

- Thermal Shock Test** Capacitors are subjected to 5 cycles of 30 minute durations at -55°C followed by 30 minutes at +125°C. The capacitors must meet the following limits after stabilizing at 25°C.

capacitance change	within +/-5% of the initial value
Tan δ (DF)	within the initial limit
DC leakage current	within 125% of the initial limit

- Surge Current** Capacitors shall withstand 3 consecutive cycles. The capacitors are charged approximately 4 seconds at rated voltage thru a low circuit resistance of approximately 1 ohm @ +25°C followed by a discharge to below 1% of rated voltage. Post test readings must meet the following criteria:

capacitance change	less than +/-5% of the initial value
Tan δ (DF)	within the initial limit
DC leakage current	within the initial limit

- Surge Voltage Test** Surge voltage tests are performed at +25°C, +85°C and +125°C. The capacitors shall be applied a surge voltage in series with a 33 Ω resistor at a cycle of .5 minutes "on" and 5.5 minutes "off" repeating 1000 times at +85°C. After stabilizing at room temperature the capacitor must meet the following limits.

capacitance change	within +/-10% of the initial value
Tan δ (DF)	within the initial limit
DC leakage current	within the initial limit

General Performance Information

- **Mechanical properties**

Tantalum chip capacitors are mechanically robust, meeting requirements for high speed insertion machines and the needs of most automotive and aerospace applications. The performance specifications:

Acceleration	10 g (98.1 m/s ²)
Vibration severity	10 to 2000 Hz, 0.75mm of 10 g (98.1 m/s ²)
Shock	Trapezoidal Pulse 10 g (98.1 m/s ²) for 6 ms

Adhesion to substrate Nemco chip components meet IEC 384-3. This requires a minimum adhesive to substrate strength of 5 Newtons.

Resistance to substrate bending and expansion Because the component has compliant leads, thermal mismatch between the component and substrate (ceramic, FR4, etc.) or bending of the substrate itself, will not normally give rise to stress at the solder joint and will enhance the temperature cycling capability of the finished board.

Solderability Meets the requirements of IEC 68 2.20 Test Ta and MIL-STD-202, Method 208.

Stand off and glue pad The glue-pad on the PCT and LSR types aid high volume insertion: the surface of the pad is etched to provide a strong mechanical key to the glue, and the reduced clearance allows the use of ultraviolet cured epoxies. For the A, B, and P cases, the stand-off is 0.05±0.05 mm; for C, D, and H cases, it is 0.1±0.1 mm.

Flammability UL Rating UL94 VO, Oxygen Index 35%. Epoxy, Hysol MG 33.

Resistance to board cleaning Nemco tantalum chips have excellent solderability characteristics and are compatible with mildly activated (RMA) or pure resin flux systems. The use of high acidity fluxes must be avoided. The encapsulation and termination materials are resistant to immersion in boiling solvents such as: Freon TMS and TMC, Trichloroethane, Methylene Chloride, Isopropyl alcohol (IPA), etc., up to 50°C. If ultrasonic cleaning is to be applied in the final wash stages the application time should be less than 5 minutes with a maximum power density of 9 mW/cc to avoid damage to terminations. Care should also be taken to ensure that boards are firmly held and that adjacent boards are not allowed to contact each other. Nemco tantalum chips are also compatible with newer aqueous and semi-aqueous processes.

Thermal Management.

The heat generated inside a tantalum capacitor in a.c. operation comes from the power dissipation due to ripple current. The heat will be transferred from the outer surface by conduction. How efficiently it is transferred from this point is dependent on the thermal management of the board.

Power dissipation ratings are based on free-air calculations. These ratings can be approached if efficient heat sinking and/or forced cooling is used.

In practice, in a high density assembly with no specific thermal management, the power dissipation required to give a 10°C rise above ambient may be up to a factor of 10 less. In these cases, the actual capacitor temperature should be established (either by thermocouple probe or infra-red scanner) and if it is seen to be above this limit it may be necessary to specify a lower ESR part or a higher voltage rating.