Derating Of Tantalum & Niobium Oxide Capacitors

Do you need voltage de-rating in all applications? Or why can't a tantalum be more like a ceramic ?

CONTENT

- INTRODUCTION
- STEADY-STATE RELIABILITY
- DYNAMIC RELIABILITY
- AVX DESIGN AND VERIFICATION
- NIOBIUM VERSES TANTALUM
- EASY TO USE SOFTWARE TOOL

Introduction - Reliability

- Ideal Solid Electrolytic Capacitor – AVX Goal
  - Zero (0) Voltage derating required
  - Zero (0) Impedance circuit use
  - Zero (0) failures

- Design Rules Tantalum (General Industry)
  - When circuit impedance less than 0.1ohm per volt e.g battery line use 0.3 x Vrated, in all other cases use 0.5 x Vrated.

- Design Rules
  - General 50% voltage derating, in very low impedance circuits 70%
  - For below 10v use 80% derate condition

Reliability

- **Reliability Management**

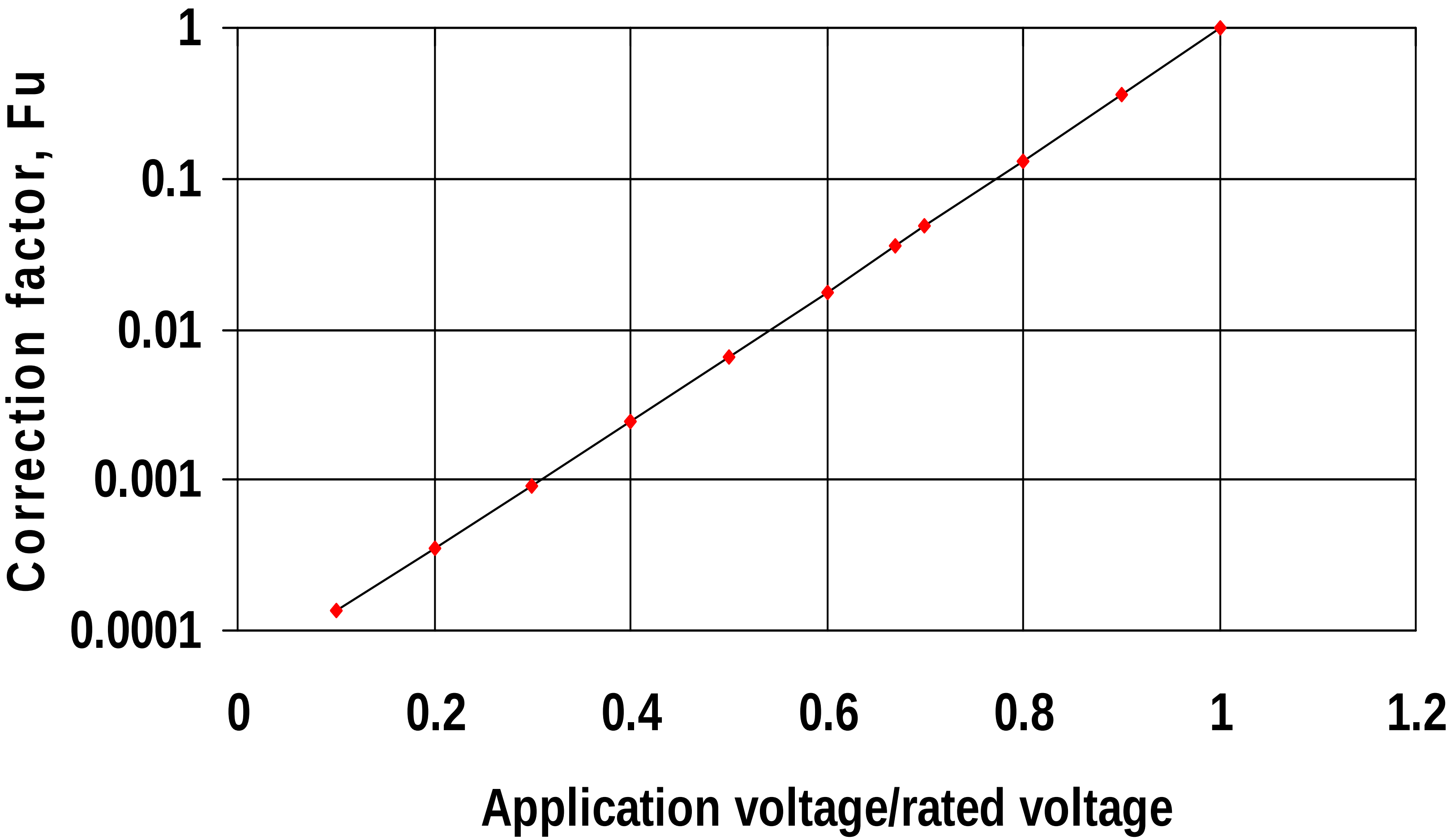
  – Voltage de-rating has a powerful influence on application failure rate for BOTH steady-state and Dynamic reliability.

  – Voltage de-rating to counter the influences of : temperature, base failure rate, circuit impedance (peak currents) and transients.

  – Need for voltage de-rating can be reduced by use of Soft – Start circuits, added series resistance (peak current limited), design control, temperature control, high reliability series capacitors.

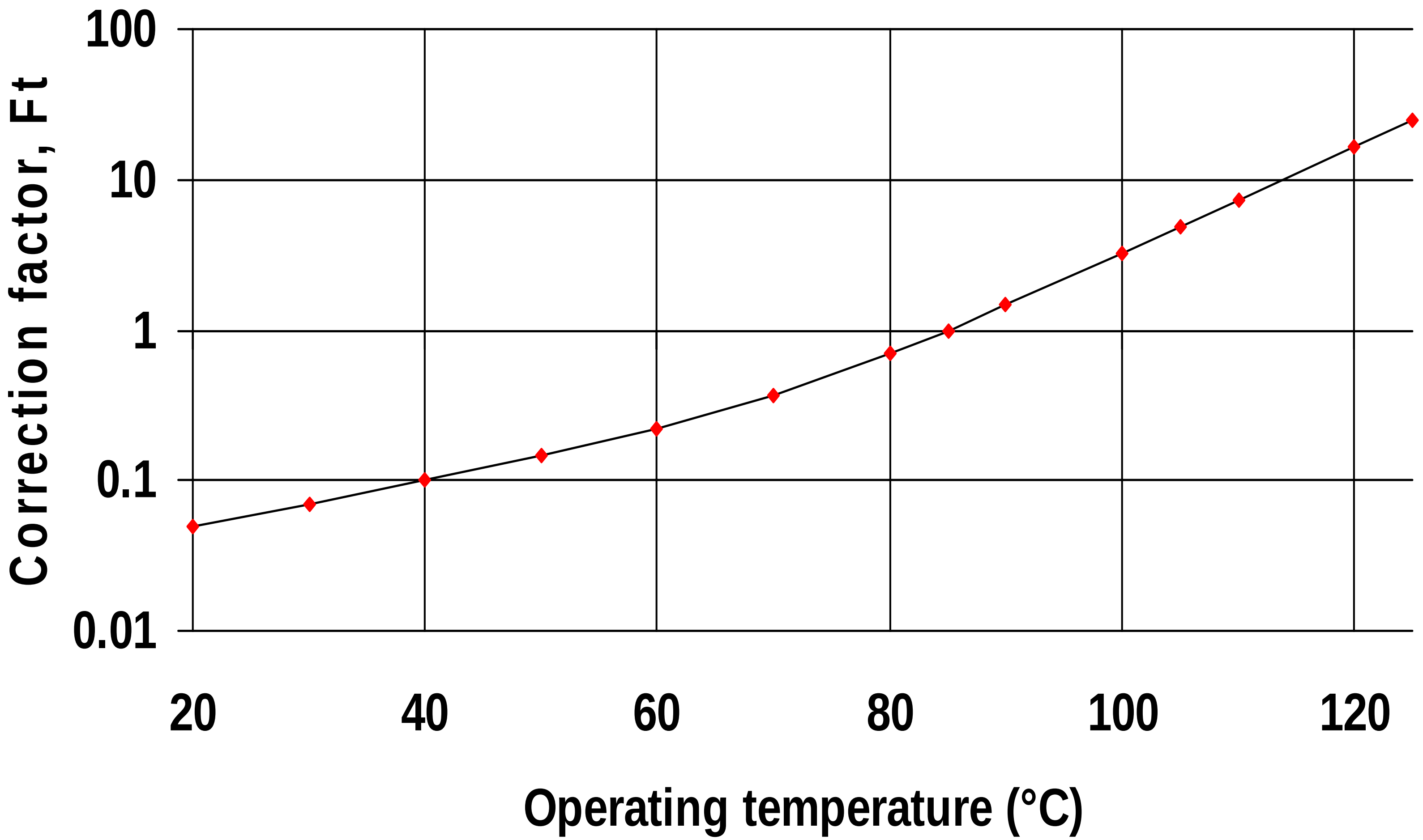
  – Most voltage de-rating is used to prevent failures due to high peak currents

Reliability - Voltage De-rating



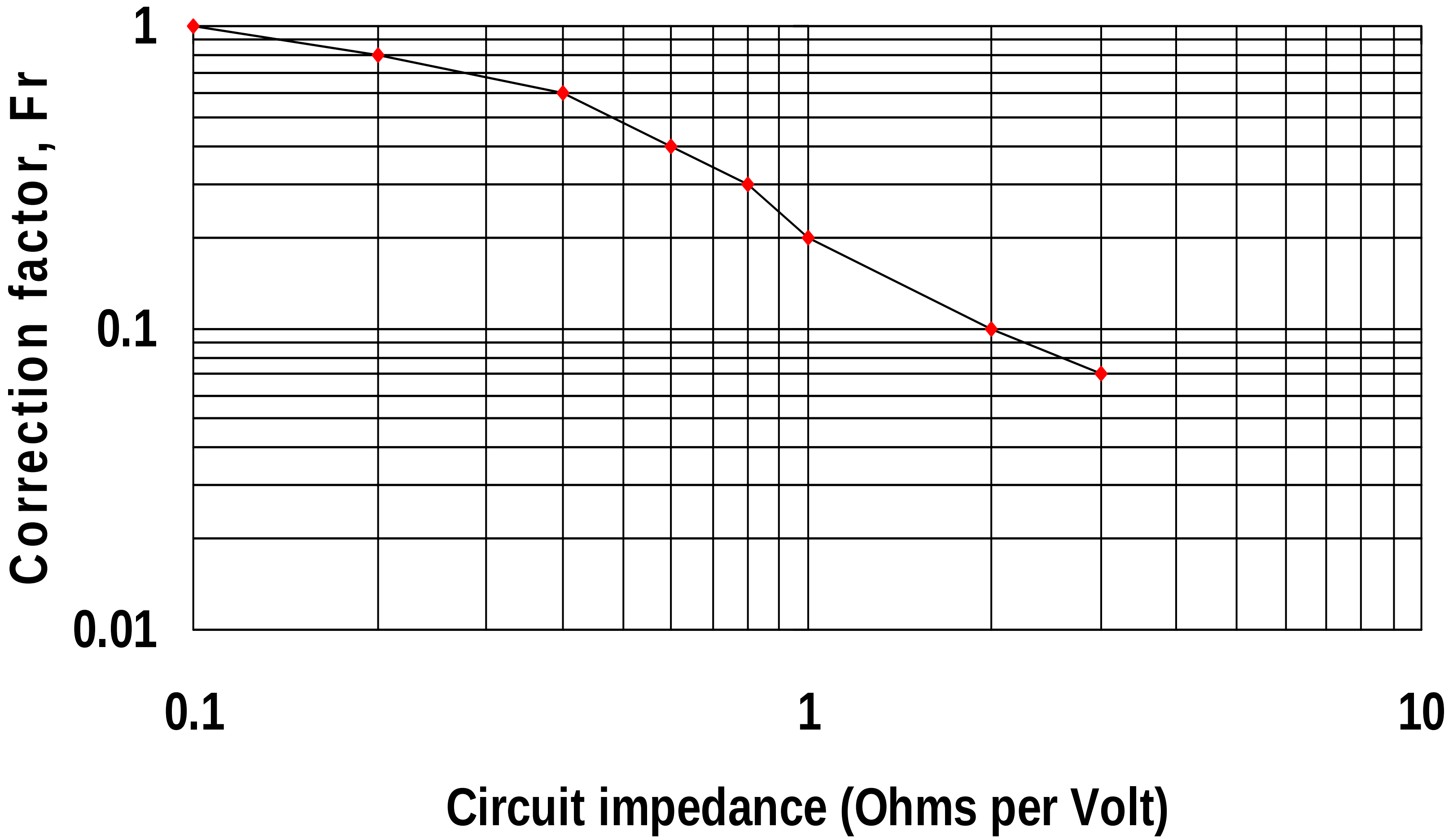
Tantalum Capacitors

Reliability - Temperature



Tantalum Capacitors

Reliability – Circuit Impedance



Tantalum Capacitors

STEADY STATE RELIABILITY

$$F = F_u \times F_t \times F_r \times F_b$$

Fu – correction factor due to voltage derating

4 ranges within 10-100% rated voltage

Ft – correction factor due to operating temperature

2 ranges within temperature range 25/125°C

Fr – correction factor due to series resistance

2 ranges within 0.1-10 Ohms

Fb – basic failure rate level

1%/1000 hours for standard product

EXAMPLE CALCULATION

Application conditions

85°C, 0.1 Ohm/volt, 5 volt rail

basic failure rate

Failure rate = Fu x Ft x Fr x 1%/1000 hours

6.3 volt capacitor

Fu = 0.12, Ft = 1, Fr = 1

F = 0.12 x 1 x 1 x 1%/1000 Hrs
= **0.12 %/1000 Hrs**

MTBF = 10^5/ 0.12
= 833,333 Hrs
= 34,722 days
= **95 Years**

10 volt capacitor

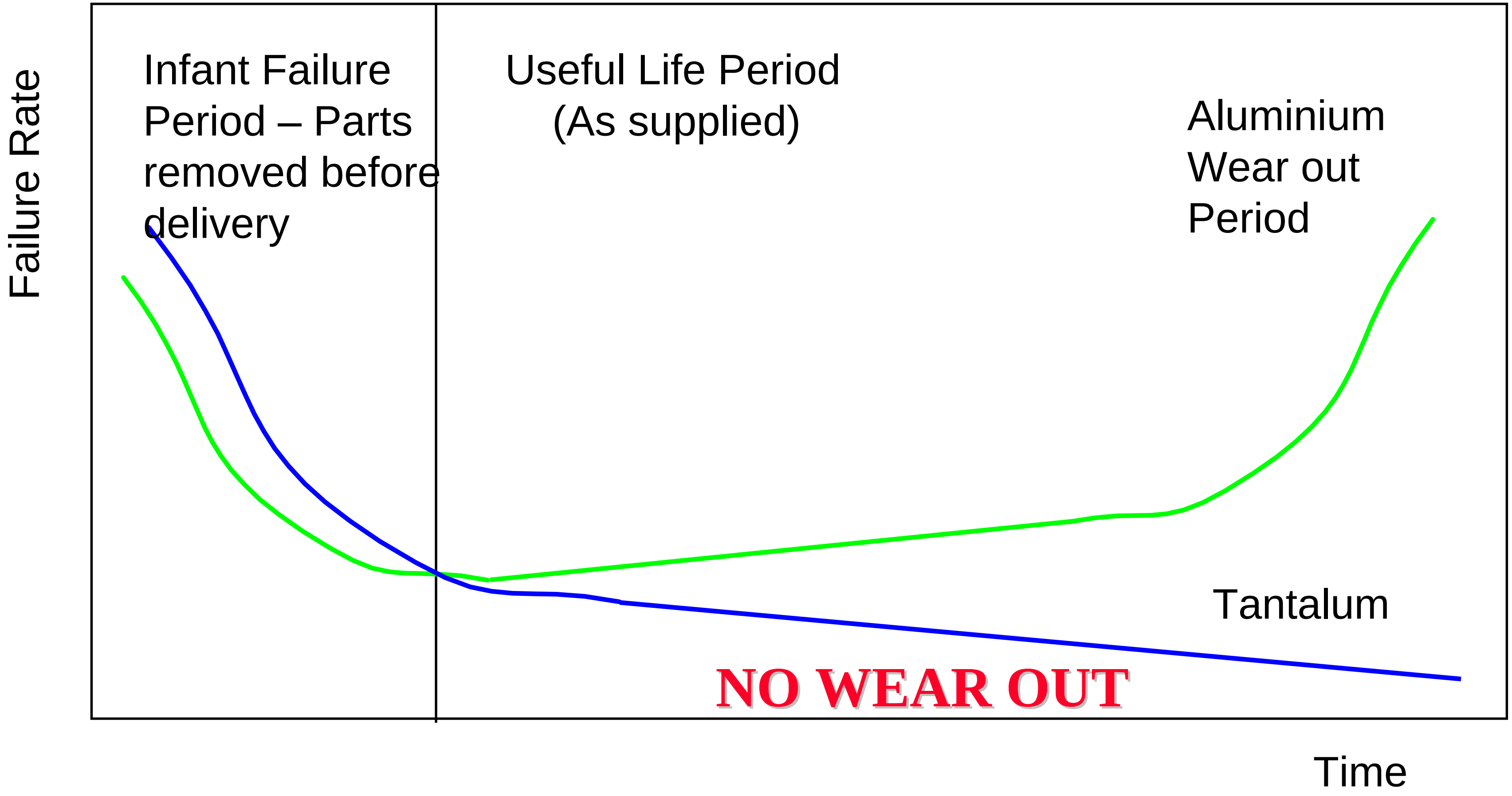
Fu = 0.007, Ft = 1, Fr = 1

F = 0.007 x 1 x 1 x 1%/1000 Hrs
= **0.007 %/1000 Hrs**

MTBF = 10^5/ 0.007
= 14,285,238 Hrs
= 595,238 days
= **1,631 Years**

FAILURE RATE CURVE

STEADY STATE FAILURE RATE



Tantalum Capacitors

Dynamic Reliability

- Why does voltage de-rating play such an important role in both steady-state and dynamic reliability ?
- The role of self-healing in the ‘no wear out’ mechanism
- What occurs if self healing is overcome and becomes a ‘hot-spot’
- Preventative measures
- Risk reduction and elimination

Circuit Impedance

Input Side - Circuit Impedance is very **LOW** **<<< 0.1 Ohms/volt**

Assume **0.1 Ohms** maximum impedance
&
Input Voltage is **4.5V**

$\therefore$ I = V / R = 4.5v / 0.1ohms = 45Amps !!

Can a Tantalum Capacitor take this?

Yes - IF suitable derating is applied

This current is classed as Surge

Very high levels of voltage derating (70%) for Tantalum capacitors should be used on the input if no other solution is possible.

Reliability

- <u>Improvements made by AVX include :</u>

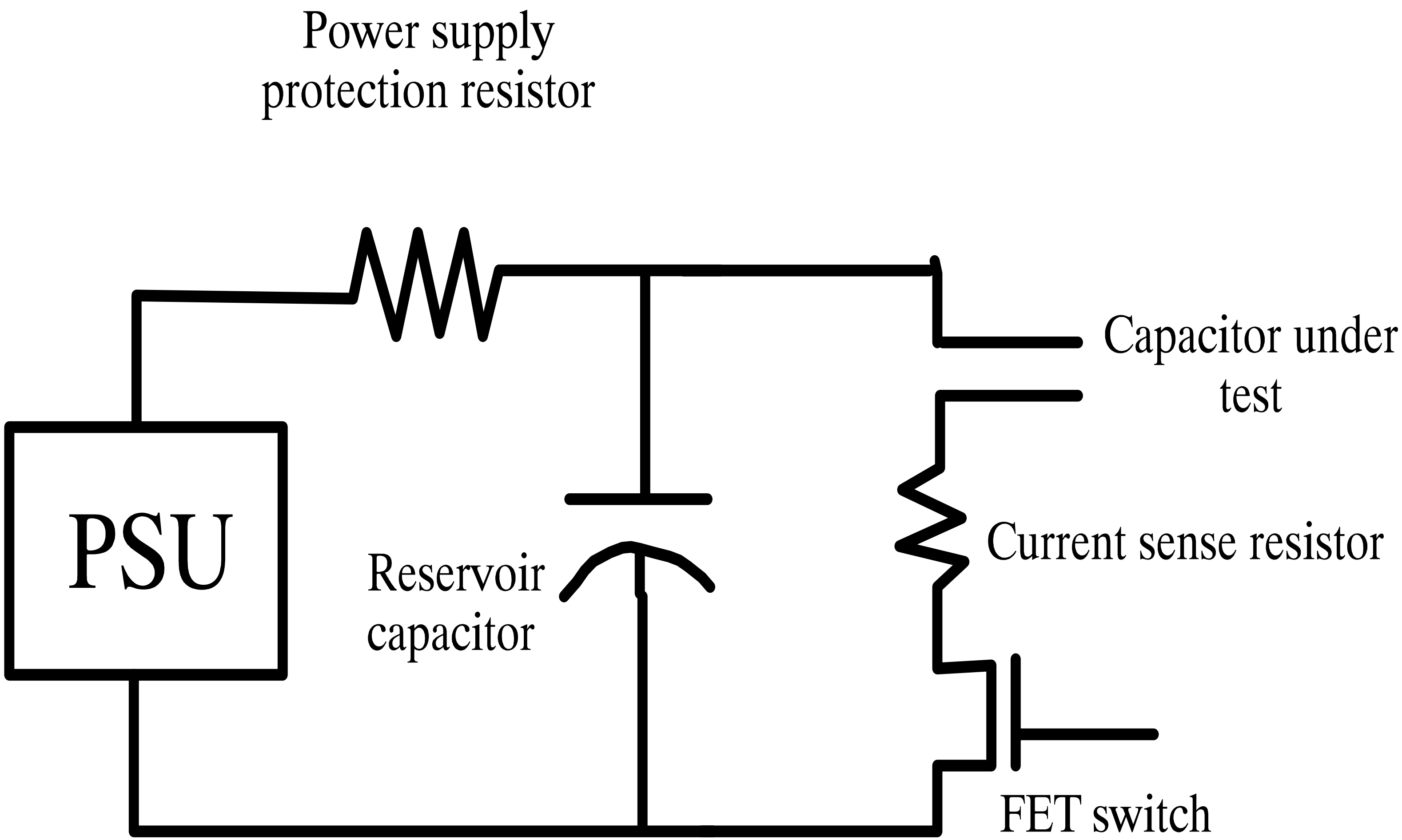
- Surge robust designs
  - Slurry Manganese for even current distribution over the anode
  - Hi purity tantalum anodes for low defect density dielectric
  - High strength anodes – good thermal conductivity
  - Shell Formation – high localised dielectric thickness on anode surface to reduce localised electrical field strength

- **<u>Verification of design and process</u>**
  - 100% very low impedance (high current) burn-in
  - 100% Dynamic Surge – high peak current and current monitor

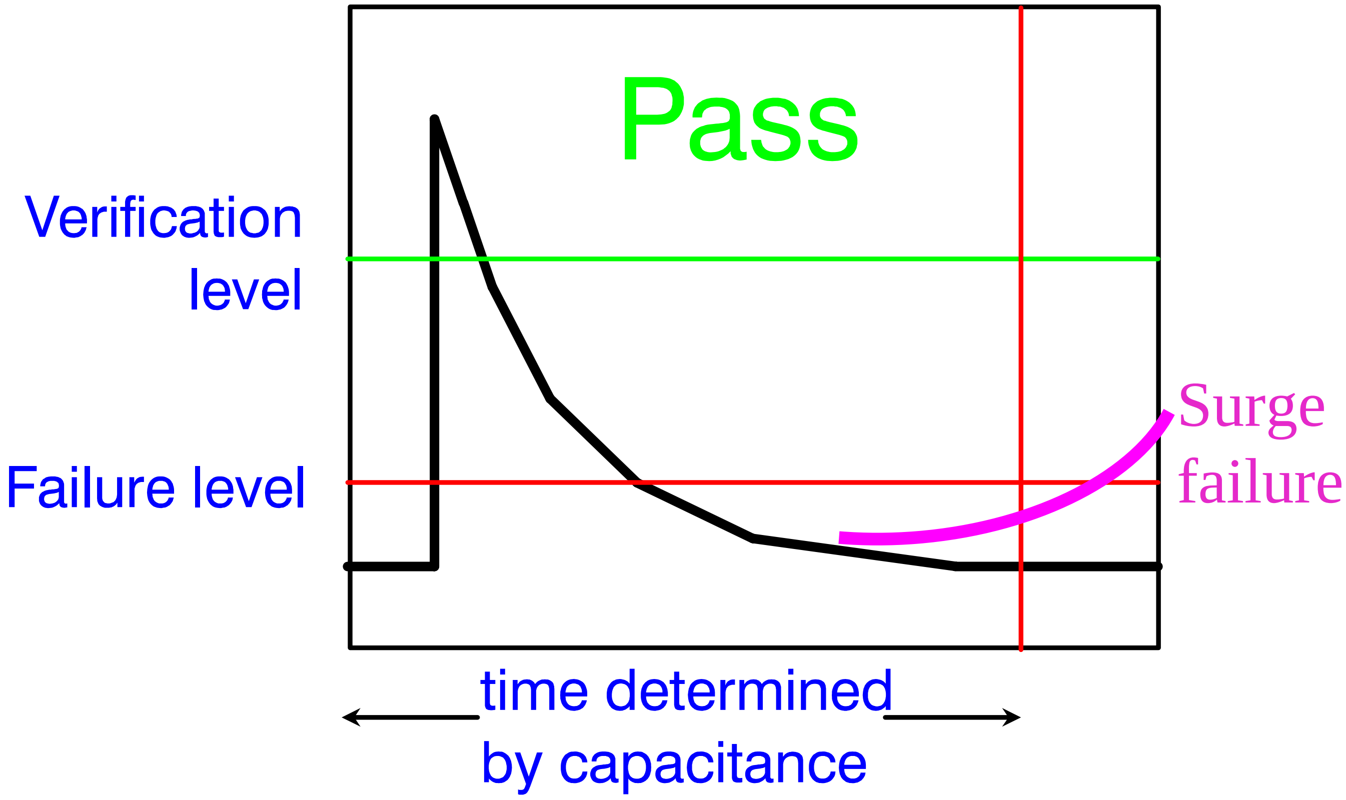
Dynamic Surge Current Test

- Fast turn on gives large instantaneous current
- Capacitors fail at first power up in a low impedance circuit (probability of failure significantly reduces with following power up)
- Test failures - NOT field issue if the in house test condition are in excess of worst field conditions

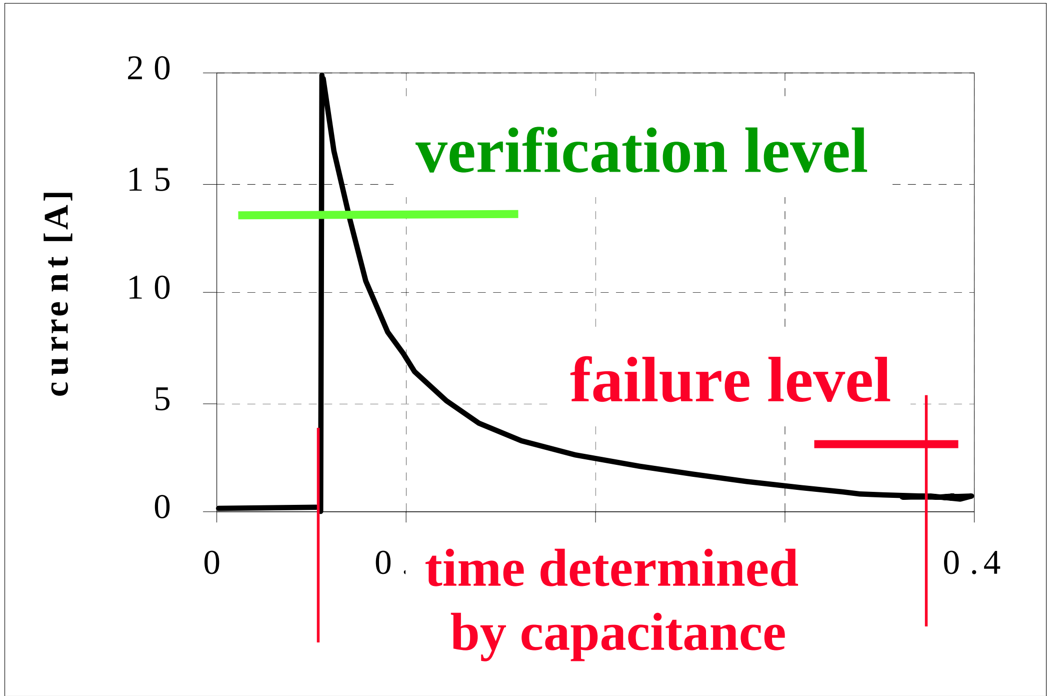
Dynamic Surge Current Test Circuit



Dynamic Surge Current Test Monitoring



AVX 100% Surge Test

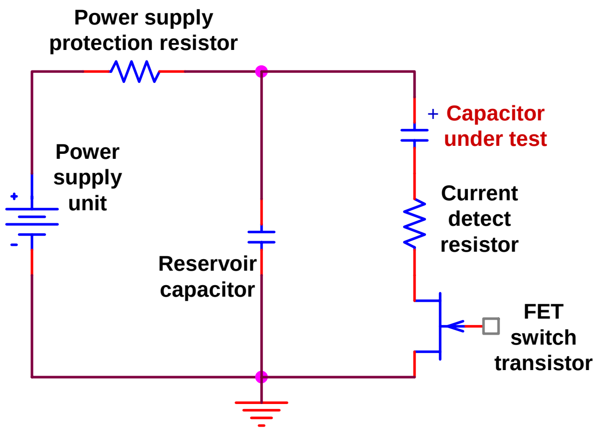


$$I_{P\max} = \frac{1.1xUr}{(1+ESR)}$$

guaranteed total test series resistance Rs

Series	Rs Ohm	Surges min
NOJ, TAJ	1	1x
NOS, TPS, THJ	0.7*	2x

* future 0.45 Ohms

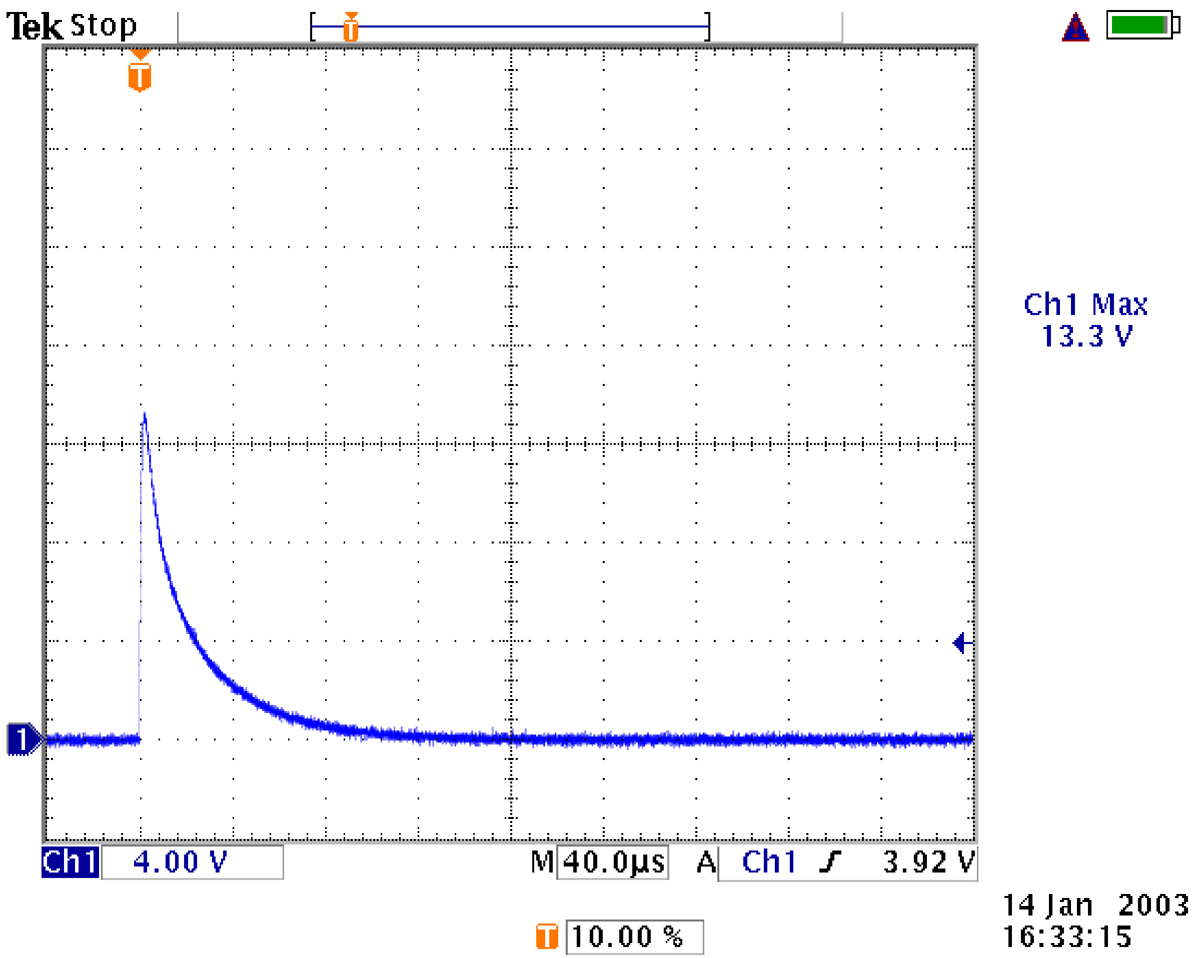


DYNAMIC MONITORING

Actual ‘Hard Surge’ Profile

TAJE47/35

SURGE = 78,23A



Niobium versus Tantalum

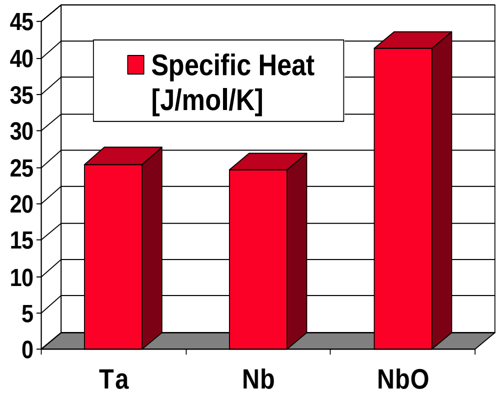
NEW PRODUCT – NIOBIUM OXIDE CAPACITOR

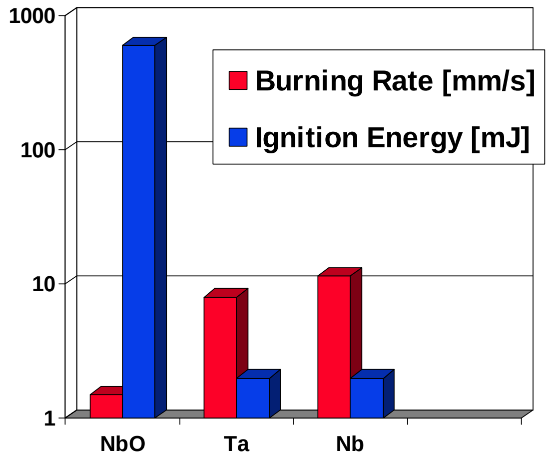
OxiCap™

Parameter	TANTALUM	NIOBIUM	NIOBIUM OXIDE
Dielectric	Ta_2O_5	Nb_2O_5	Nb_2O_5
CV	standard	lower-same*	lower-same*
Rated Voltage	2.5 – 50V	4 – 16	2.5 – 10v
Cap tolerance	+/-10%	+/-10% (20%)#	+/- 20%
DCL	0.01CV	0.01 – 0.04CV#	0.02CV (0.01*)
ESR (same anode design)	standard	comparable	comparable
DF	standard	same/higher	same/higher
Ignition Resistance	low	low	very high
Temperature Range	-55 / +125c	-55 / +125 (105)#	-55 / +125c
Basic Reliability	1%/1000hrs	same	0.2%/1000hrs

Niobium versus Tantalum

Higher overloading possible on NbO OxiCap^{TM} capacitor





DERATING

DC/DC power input rating recommendation*			
Rail Voltage	Rated Voltage		
	Ta	Nb	NbO
3.3V	6.3V	6.3V	4V
5V	10V	10V	6.3V

* at temperature up to 85°C

20% derating sufficient on NbO OxiCap^{TM} capacitor

Surge Performance OxiCap^{TM} v Tantalum

Superior :

- By Design
- By Material Characteristics
- By Performance Measure

OxiCap™ Surge Vs Tantalum

Parameter	End Value	Tantalum	Niobium	Nb Oxide
Powder		Ta metal	Nb metal	NbO
Dielectric	electrical properties	Ta_2O_5	Nb_2O_5	Nb_2O_5
Thickness [10^{-9}m/V]	CV	1.7	2.5	2.5
Dielectric Constant [-]	CV	27	41	41
Formation ratio		3:1	4:1	4:1

OxiCap^{TM} Surge Vs Tantalum

Example: **6.3 Volt capacitor**

Tantalum	3 x 1.7 x 6.3	=	32 nm
OxiCap^{TM}	4 x 2.5 x 6.3	=	63 nm

I.e. 2 x dielectric thickness for same rated voltage

NB : Electrical Field Stress on the dielectric is 50% reduced.

OxiCap^{TM} Surge Vs Tantalum

<u>Example:</u> 6.3 Volt Tantalum Vs 4V OxiCap^{TM}

Tantalum	3 x 1.7 x 6.3	=	32 nm
OxiCap^{TM}	4 x 2.5 x 4	=	40 nm

I.e. Still 25% thicker dielectric for OxiCap v Tantalum

OxiCap^{TM} Surge Vs Tantalum

<u>Example:</u> 6.3 Volt Ta Vs 4V OxiCap^{TM}

Used on a 3.3v power rail, the Electrical Field Strength is

Tantalum	3.3v/32nm = 103kV/mm
OxiCap^{TM}	3.3v/40nm = 82kV/mm

Electrical Field Strength on the OxiCap is still less than for tantalum despite the difference in 20% v 50% derating

OxiCap^{TM} Surge Vs Tantalum

<u>Example:</u> 10 Volt Ta Vs 6.3V OxiCap^{TM}

Used on a 4.2v power rail, the Electrical Field Strength is

Tantalum	4.2v/51nm = 82kV/mm
OxiCap^{TM}	4.2v/63nm = 67kV/mm

Electrical Field Strength on the OxiCap is still less than for tantalum despite the difference in 20% v 50% derating

OxiCap™ Surge Vs Tantalum

Hard current pulse results: **(Same current)**

	Cycle			
	1st	2nd	3rd	4th
D 220uF 6V Tantalum	0.121	0.010	0.000	0.000
D 220uF 4V OxiCap™	0.000	0.000	0.000	0.000

OxiCap^{TM} Surge Vs Tantalum

Parameter	**End Value**	**Tantalum**	**Niobium**	**Nb Oxide**
Powder		Ta metal	Nb metal	NbO ceramic
Density [g/cc]	weight, drop test, CV	16.4	8.6	7.3
Ignition Energy [mJ]	**resistance to burn**	2	2	600
Burning Rate [mm/s]	burning speed	11.5	8	1.5
Specific Heat [J/mol/K]	**load resistance**	25	25	40

Nb : The higher amount of energy needed to increase the temperature of Oxide reduces the tendency to easily develop hot spots which in turn can lead to thermal breakdown and short-circuit.

Failure Mode

Typical Breakdown Voltage (4V part):

Polymer: 11 to 15V OxiCap^{TM}: 18 – 24V

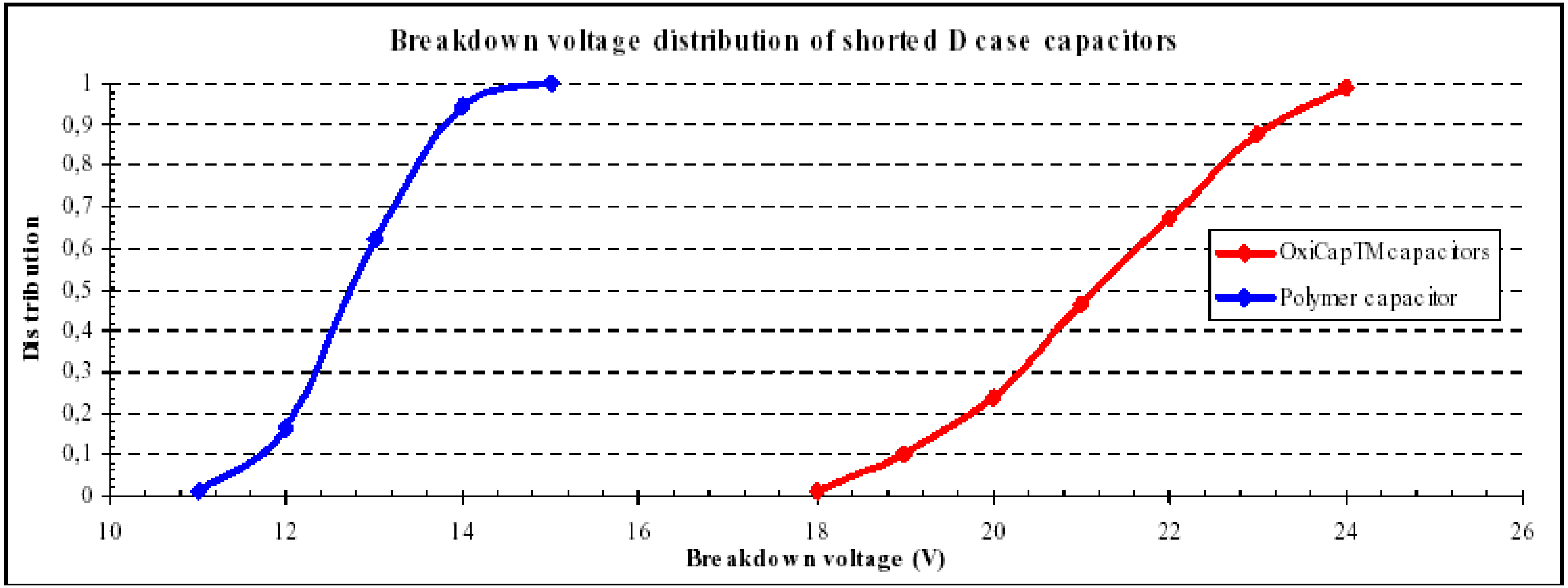


Figure 1: Typical breakdown voltage

Failure Mode

Breakdown resistance is a function of voltage. Resistance measured at 0.5V:

Polymer: 0.3 Ohms to 10kOhms with mean 2Ohms = **low resistance**

OxiCap™: 9 Ohms to 1MOhm with mean 34kOhms = **high resistance**

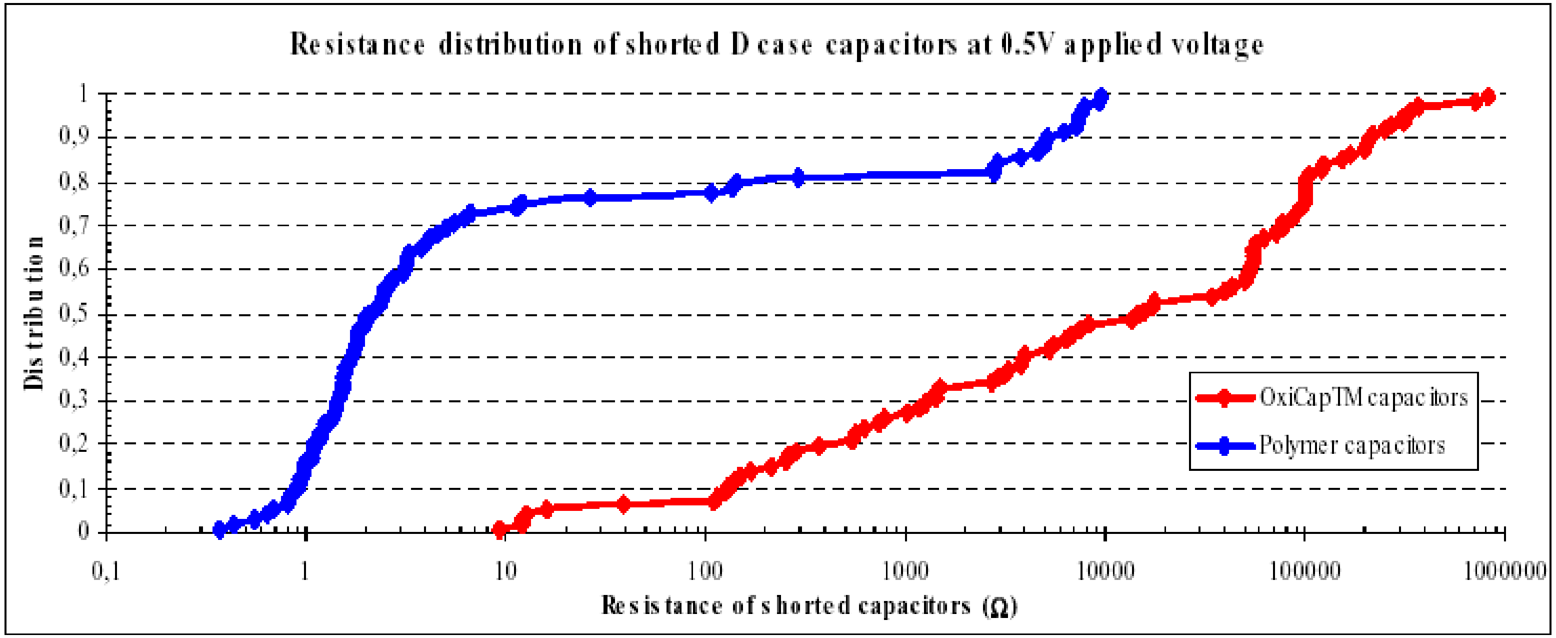


Figure 2: Resistance distribution of shorted capacitors at 0.5V

Failure Mode

Failed OxiCap™ Will Not Burn up to Category Voltage

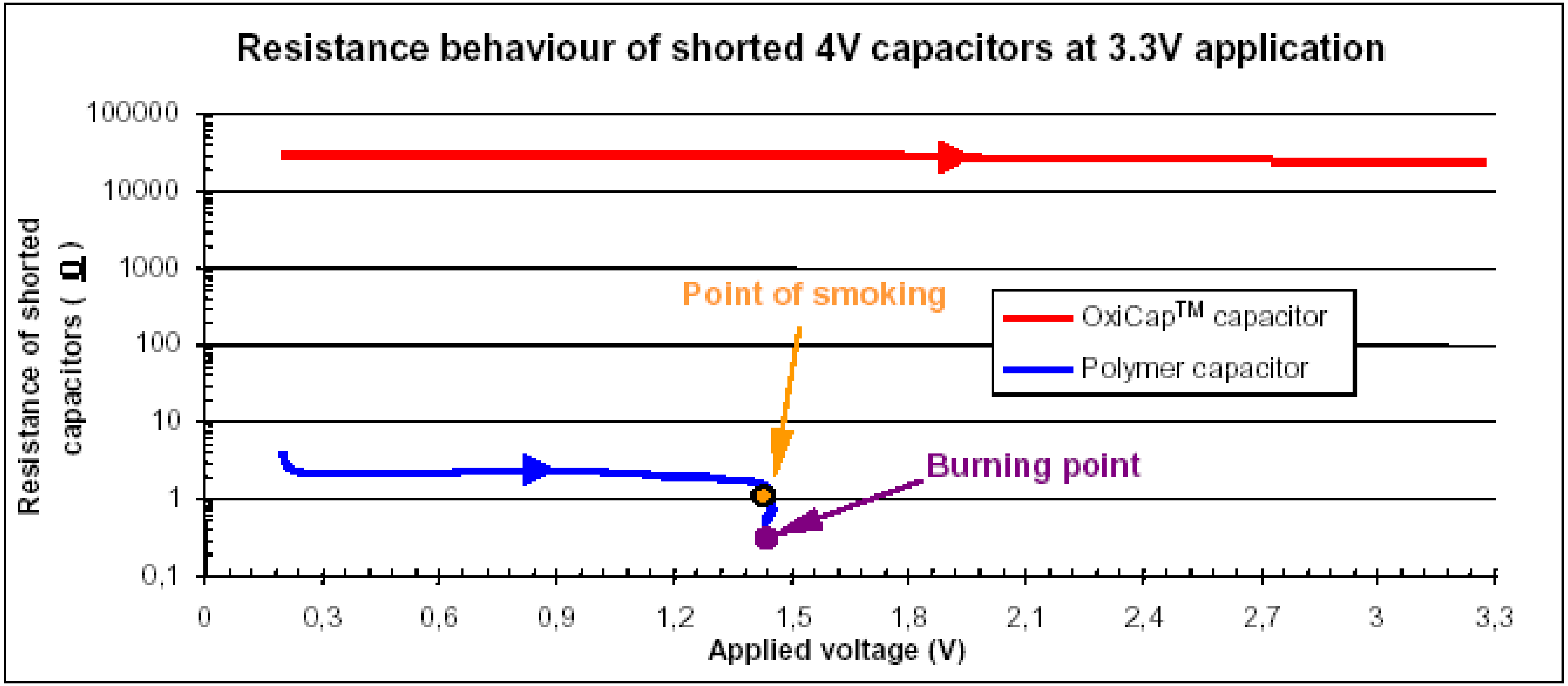


Figure 3: Resistance dependence of shorted capacitors to 3.3V

Failure Mode

Failed OxiCap™ Will Not Burn up to Category Voltage

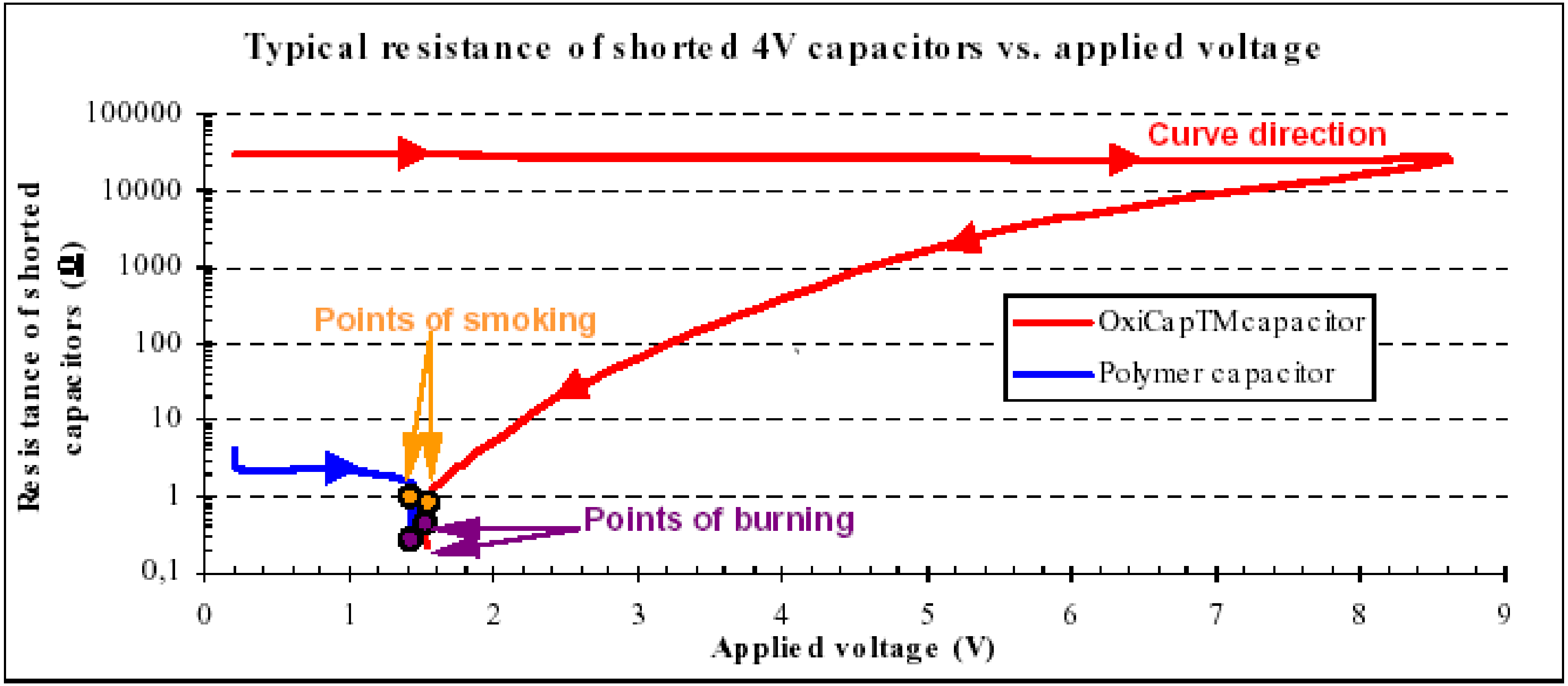


Figure 4: Resistance dependence of shorted capacitors

Reliability Comparisons

reliability %/1000hrs		specification	typical
Tantalum K=27 FR 3:1	TAJ, TPS	1.00%	0.1 - 0.2%
	THJ,TRJ	0.50%	0.10%
	Military	0.10%	0.01 - 0.1%
	TAC	0.10%	0.04%
OxiCapTM K=41, FR 6:1	NOJ	0.50%	**0.01%**
	NOS	0.20%	**0.01%**

SUMMARY (1)

- “Voltage” derating is actually to prevent the failure of the capacitor due to an excess “current”.
- Tantalum capacitors can be used at 80% of their rated voltage, but the MTBF will be lower.
- The less voltage derating applied the higher the leakage current.
- If a tantalum must be used across a low impedance source, consider incorporating a PFET integrator to reduce risk of failure
- 20% derating sufficient for OxiCap™ NbO capacitor
- Select–a–Cap software is ready to advise the correct part number including typical parameters in the application circuit.

SUMMARY (2)

- To provide a higher reliability tantalum series of capacitors for low impedance circuits i.e no voltage de-rating would require :
  - Best in Class Tantalum powders as a design restriction
  - Higher design formation ratio minimum
  - High Shell Formation applied as a design restriction
- To provide verification of performance would require :
  - 100% multiple ‘extra hard’ surge testing
  - 100% ultra low impedance burn in
- Implications
  - Increased cost (less for OxiCap)
  - Reduced range (extended range types not available)
  - Close co-operation with customers