

The background features two fighter jets flying over a dense layer of white clouds. The entire scene is bathed in a deep blue light. A trail of white, glowing digital particles or data points curves across the lower portion of the image, starting from the left and moving towards the right, passing behind the jets.

Aluminum & Tantalum Capacitors

Training for CMSE 2026

presented by: Jerard Jose, Product Marketing
Vishay

Glossary of Terms

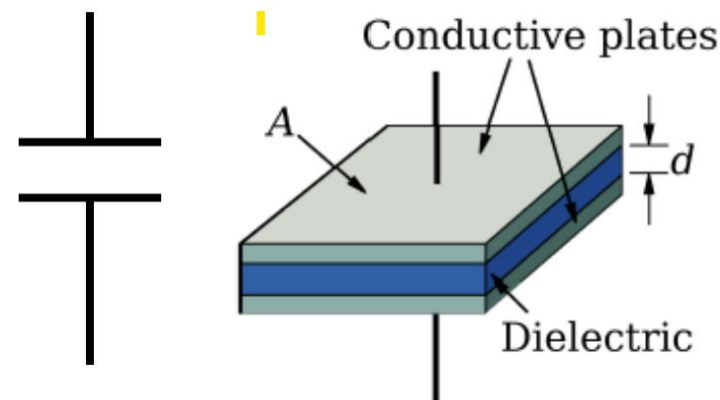
- **Capacitance:** the ratio of the amount of electric charge stored on a conductor to a difference in electric potential.
- **Charge (Q):** electrical charge stored in a capacitor measured in units of Coulomb
- **Dielectric Constant:** the factor by which the electric field between the charges is decreased relative to vacuum.
- **Passive Component:** an electrical component that does not generate power, but instead dissipates, stores, and/or releases it.
- **Active Component:** a device that has an analog electronic filter with the ability to amplify a signal or produce a power gain.
- **Impedance:** the effective resistance of an electric circuit or component to alternating current, arising from the combined effects of ohmic resistance and reactance.

Glossary of Terms

- **Equivalent Series Resistance (ESR):** a value representing the loss of useful energy in a simple electronic circuit consisting of a resistor and an ideal (perfect) capacitor. Technically speaking, the energy is not lost but is usually dissipated as undesirable heat.
- **Equivalent Series Inductance (ESL):** an effective inductance that is used to describe the inductive part of the impedance of certain electrical components
- **Insulation Resistance (IR):** the total resistance between any two points separated by electrical insulation.
- **Self-Resonance Frequency (SRF):** is the frequency at which the impedance of the capacitor becomes zero
- **Dissipation Factor:** Power loss in a capacitor when an AC signal is applied (ESR/X_c)
- **Voltage Coefficient of Capacitance (VCC):** expresses the capacitance drift under applied DC voltages.
- **Temperature Coefficient of Capacitance (TCC):** expresses the capacitance drift over a certain temperature range.

What is a Capacitor?

- Passive Component with two conductors separated by a dielectric.
- Conductors can be Tantalum, Aluminum and other metals.
- Dielectrics can be Ceramic, Plastic, Paper, Tantalum Oxide, Aluminum Oxide, etc.
- Does not dissipate (much) energy.
- Stores energy as an electric field.



$$C = \frac{\epsilon A}{d}$$

Equation: capacitance (F)

$$Q = CV \quad i = C \frac{dv}{dt} \quad E = \frac{1}{2} CV^2$$

Equation:
charge (C)

Equation:
current (A)

Equation:
energy (W)

C – Capacitance (Farads)
 ϵ – Absolute Dielectric Permittivity (F/m)
 A – Conductor Surface Area (m)
 d – Thickness of Dielectric (m)

Why are there different types of capacitors?



Ceramic



Film



Tantalum



Aluminum Electrolytic

Mechanical & Materials

- Terminations
- Size
- Cost
- Dielectric Constant

Electrical

- Polarity
- Voltage (AC / DC)
- Frequency
- Capacitance
- Current
- Parasitic(s) (DF / ESR / ESL)

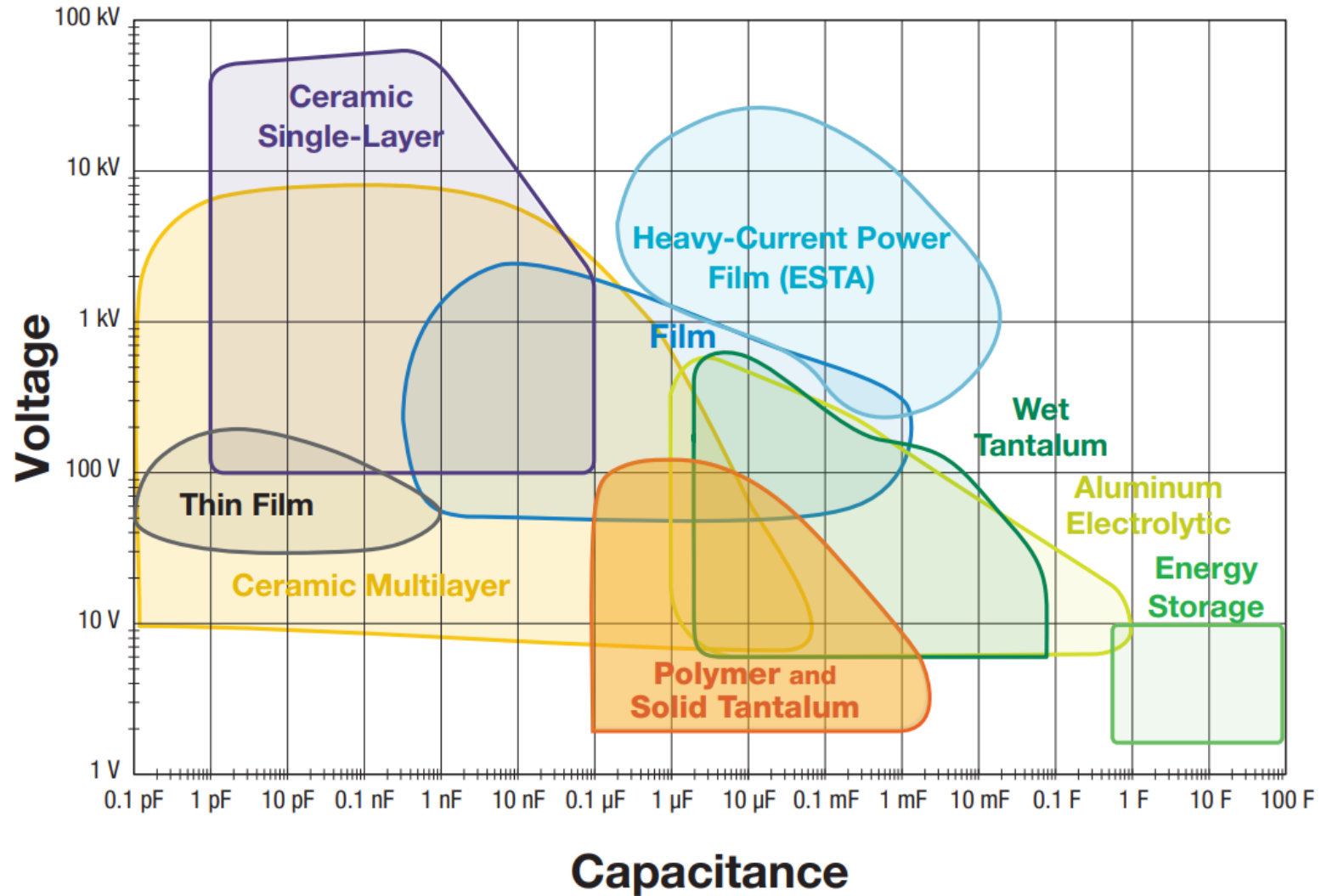
Environmental

- Temperature Range
- Moisture & Humidity
- Shock & Vibration
- Lifetime
- Reliability (FIT & MTBF)

| COMPARISON OF CAPACITOR DIELECTRIC CONSTANTS | |
|--|-----------------------------------|
| DIELECTRIC | ϵ DIELECTRIC CONSTANT |
| Air or vacuum | 1.0 |
| Paper | 2.0 to 6.0 |
| Plastic | 2.1 to 6.0 |
| Mineral oil | 2.2 to 2.3 |
| Silicone oil | 2.7 to 2.8 |
| Quartz | 3.8 to 4.4 |
| Glass | 4.8 to 8.0 |
| Porcelain | 5.1 to 5.9 |
| Mica | 5.4 to 8.7 |
| Aluminum oxide | 8.4 |
| Tantalum pentoxide | 26 |
| Ceramic | 12 to 400K |

$$C = \frac{\epsilon A}{d}$$

Vishay's Capacitor Solutions



Capacitor size

Rating: 1 μ F 100VDC



Tantalum

150D / M39003/01
MnO₂
Max T: +125°C
Volume: 105mm³



~ 9x size

Film

MKT373 (Compact size)
Max T°: +105°C
Volume: 963 mm³



~ 3x size

Aluminum Electrolytic

MAL213229108E3
10,000 hours life
Max T°: +85°C
Volume: 300 mm³



~ 1/5 size

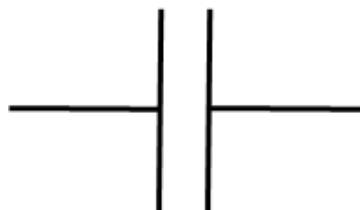
Ceramic

VJ1210Y105KXBTW1BC
Type II - X7R
Max T +125°C
Volume: 18 mm³

Dielectric Comparison Table

| CHARACTERISTIC | MLCC C0G / NP0 | MLCC X7R | MnO ₂ TANTALUM | POLYMER TANTALUM | WET TANTALUM | ALUMINUM ELECTROLYTIC | EDLC | PP FILM | PPS FILM | PET FILM | PEN FILM |
|--|-------------------|-------------------|---------------------------|-------------------|-------------------|-----------------------|------------------|-------------------|-------------------|-------------------|-------------------|
| Temperature range | -55 °C to +125 °C | -55 °C to +125 °C | -55 °C to +200 °C | -55 °C to +125 °C | -55 °C to +230 °C | -55 °C to +150 °C | -40 °C to +85 °C | -55 °C to +125 °C | -55 °C to +125 °C | -55 °C to +125 °C | -55 °C to +125 °C |
| Delta capacitance with temperature | 0 ppm ± 30 ppm | ± 15 % | ± 10 % | ± 10 % | +30 % to -50 % | +25 % to -30 % | Negligible | ± 1.5 % | ± 1.5 % | ± 5 % | ± 5 % |
| DC voltage coefficient at V _{R} | Negligible | -20 % to -50 % | Negligible | Negligible | Negligible | Negligible | Negligible | Negligible | Negligible | Negligible | Negligible |
| Aging rate (%/dec. h) | Negligible | 1 % to 3 % | n/a | n/a | n/a | n/a | n/a | Negligible | Negligible | Negligible | Negligible |
| Dissipation factor (%) | 0.1 | 2.5 | 8 | 8 | 8 | > 5 | n/a | 0.05 | 0.2 | n/a | 0.8 |
| ESR - relative | Low | Moderate to high | High | Low to moderate | Moderate to high | High | High | Very low | Very low | Low | Low |
| Dielectric absorption (%) | 0.6 | 2.5 | 0.5 | 0.5 | 0.5 | n/a | n/a | 0.05 | 0.2 | 0.5 | 1 |
| Capacitance range | 0.1 pF to 0.1 μF | 100 pF to 47 μF | 0.1 μF to 2,200 μF | 1 μF to 2,800 μF | 1 μF to 96,000 μF | 0.1 μF to 1 F | 1 F to 3,000 F | 100 pF to 100 μF | 100 pF to 10 μF | 1000 pF to 10 μF | 1000 pF to 10 μF |
| Capacitance tolerance | 1 % to 10 % | 5 %, 10 %, 20 % | 5 %, 10 %, 20 % | 5 %, 10 %, 20 % | 5 %, 10 %, 20 % | 20 % | -20 % / +50 % | 5 %, 10 %, 20 % | 2.5 %, 5 %, 10 % | 5 %, 10 % | 5 %, 10 % |
| Failure mode | Short | Short | Short | Short | Short | Short, open | Open | Open | Open | Open | Open |
| Self healing | No | No | Limited | Limited | Yes | Limited | No | Yes | Limited | Yes | Yes |
| Reliability | High | Moderate | High | High | High | Low | Low | High | High | High | High |
| Piezoelectric effect | No | Yes | No | No | No | No | No | No | No | No | No |
| Resistance to thermal and mechanical shock | Low | Moderate | High | High | High | Moderate | Moderate | High | High | High | High |
| Polar | No | No | Yes | Yes | Yes | Yes | Yes | No | No | No | No |

Capacitors, Inductors and Resistors



Capacitors

- Block DC Current
- Allow AC Current to Pass easier as Frequency Increases
- Capacitors Store Energy



Inductors

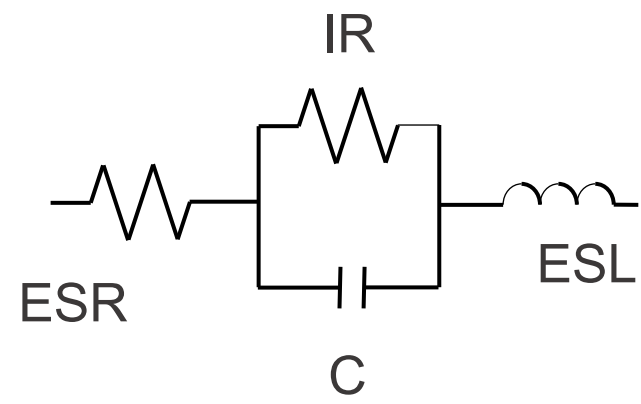
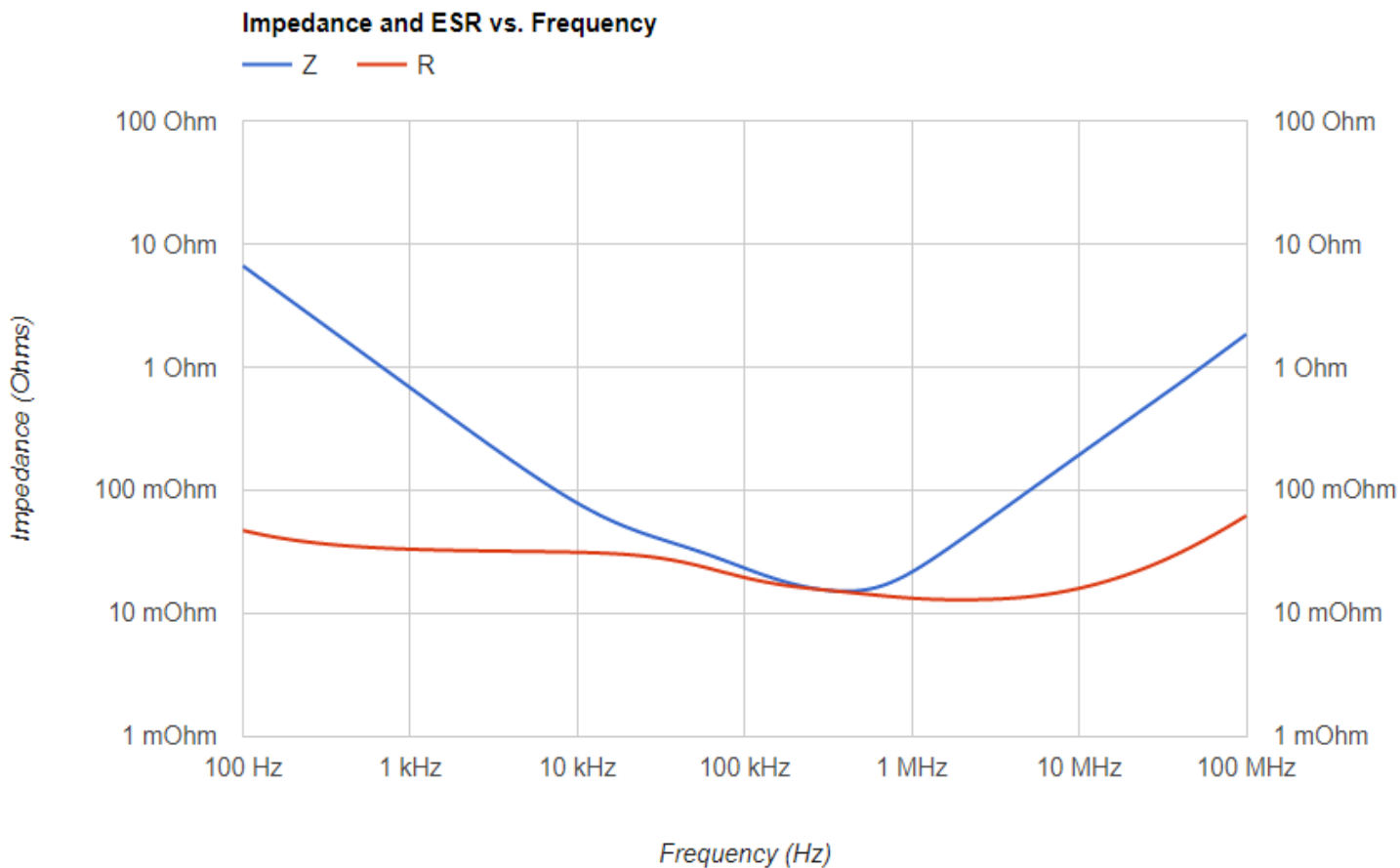
- Allow DC Current to Pass
- Block AC Current; more as Frequency Increase
- Inductors Can Store 1 Cycle of AC Current



Resistors

- Impede both AC and DC Current
- Resistors Dissipate Energy

Capacitor Equivalent Circuit



ESR (Ohms)

$$X(c) = \frac{1}{2\pi f c}$$

Equation: Capacitive Reactance X(c)

$$X(L) = 2\pi f L$$

Equation: Inductive Reactance X(L)

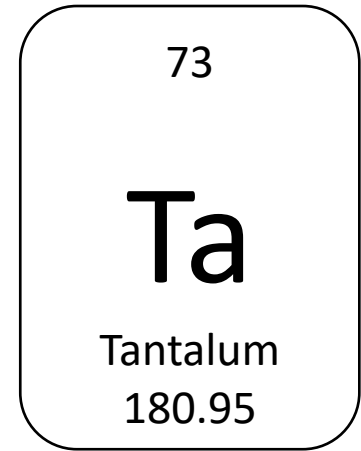
$$Z = \sqrt{ESR^2 + (X_C - X_L)^2}$$

Equation: Impedance Z

Tantalum Capacitors

What Is Tantalum?

- **Discovered in 1802** by Anders Ekeberg, Sweden
- Chemical element, silver-gray metal. Atomic number 73. **High density, high melting point (3269 °C), high resistance to acids**
- **Commonly found as an oxide mineral in combination with columbium (same as niobium) ore – known as “tantalite.”** Largest sources are in Africa, Australia, Brazil, Canada, China, and Thailand
- **Complex multi-step chemical and metallurgical process** used to convert tantalite into capacitor-grade tantalum powder
- Besides the capacitor industry, **tantalum metal in various forms is used in the chemical industry, electronics, aerospace, and nuclear equipment**



History of Tantalum Capacitors

The first tantalum capacitors built as wet tantalums using tantalum foil

1930's

Bell Labs invented the solid tantalum capacitor in the early 1950's.

1950's

Sprague Electric innovated the design to commercially manufacture these in 1954, the "drops"

1954

Tansitor Electronic developed their first wet tantalum capacitors with wound tantalum foils and wet electrolyte in 1955 for the military.

1955

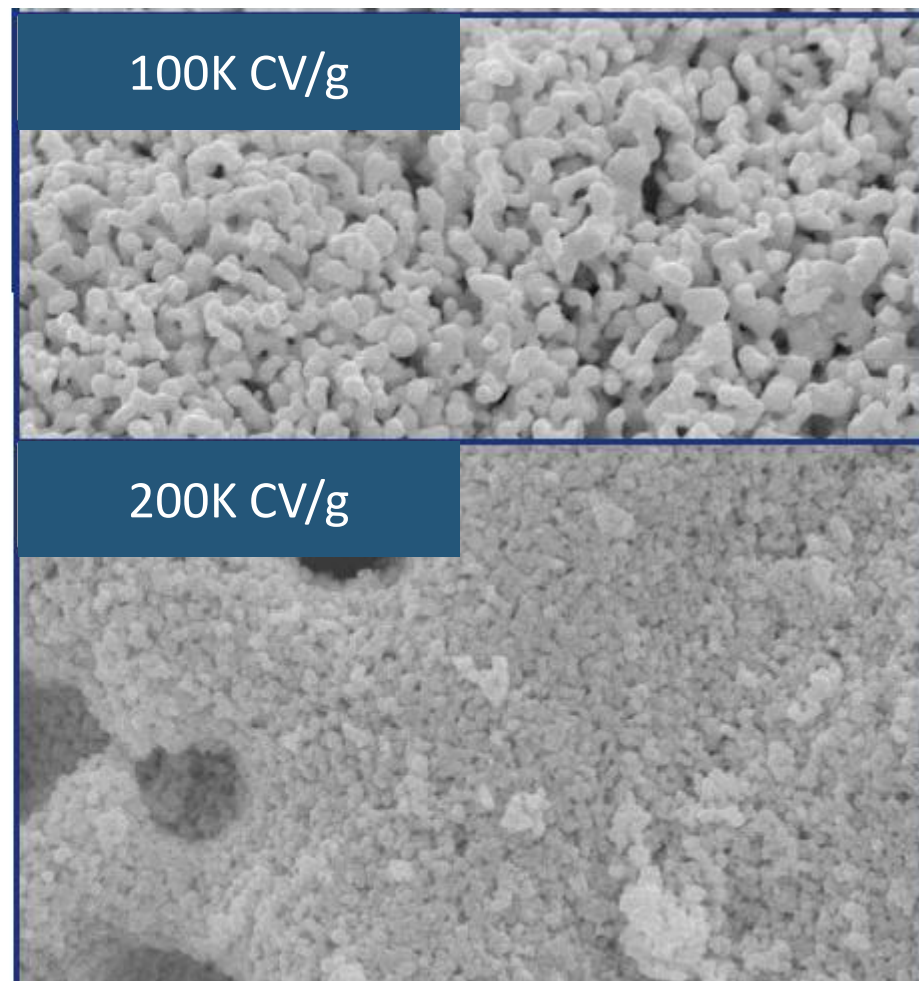
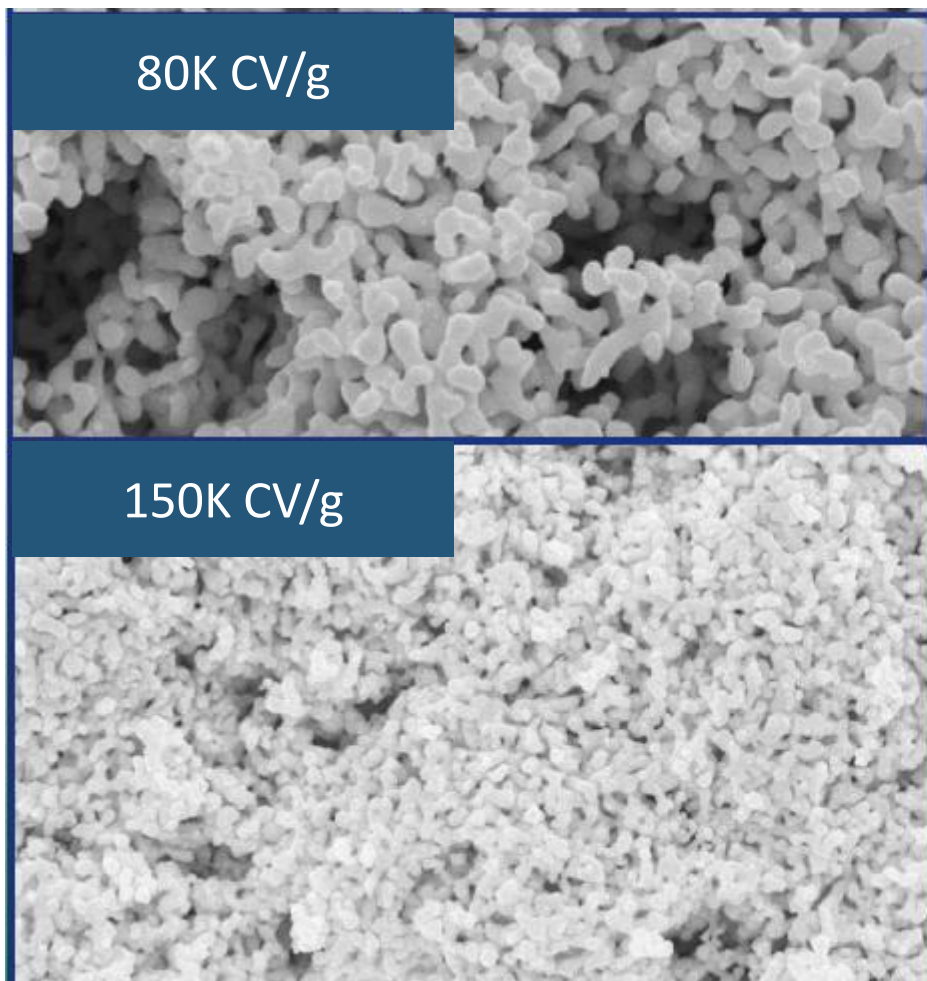
Conductive polymers were developed in 1975, dramatically reducing parasitic resistance. NEC introduced polymer tantalums in 1993, with Sanyo close behind in 1997.

1975



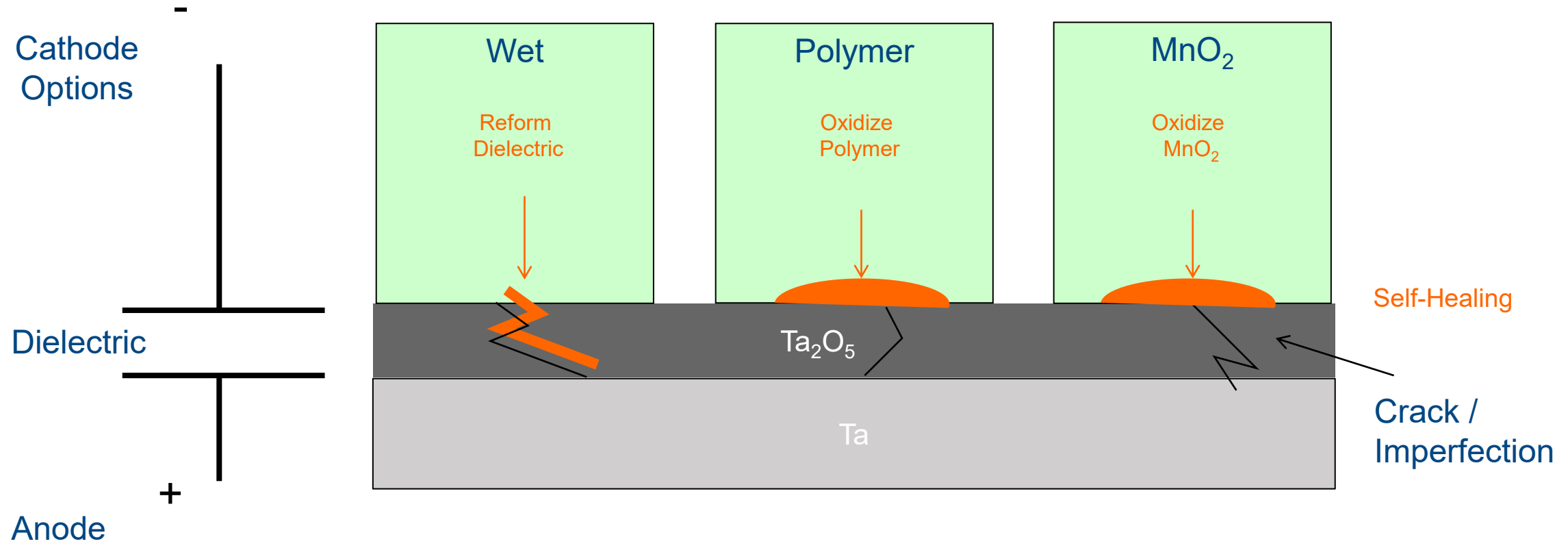
Tantalum Powder Surface – Volumetric Efficiency

For a given volume of tantalum material, the smaller the particle size (higher CV/g), the larger the surface area (A).

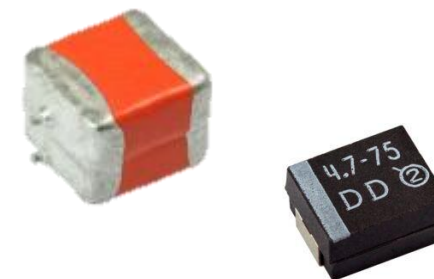


Three Tantalum Capacitor Classes:

Solid (MnO_2), Polymer & Wet



Tantalum capacitor types: major characteristics



Wet Tantalum

Highest Energy Density
Shock and Vibration
No wear out

Voltage Range:
10V to 125V
Capacitance Range:
1 μ F to 96,000 μ F

Polymer

Low ESR
Low Voltage Derating
Benign Failure Mode

Voltage Range:
2.5V to 75V
Capacitance Range:
1 μ F to 2,800 μ F

Solid Tantalum

Proven reliability
Low DCL
Small footprint

Voltage Range:
2V to 125V
Capacitance Range:
0.027 μ F to 2,200 μ F

Tantalum vs Polymer Technology Differences

➤ MnO₂

- Low Price Commodity Product
- Low DCL (.01 CV)
- Stable Over Lifetime and Temperature
- No DC Bias
- High Temp (up to 175C)



➤ Polymer

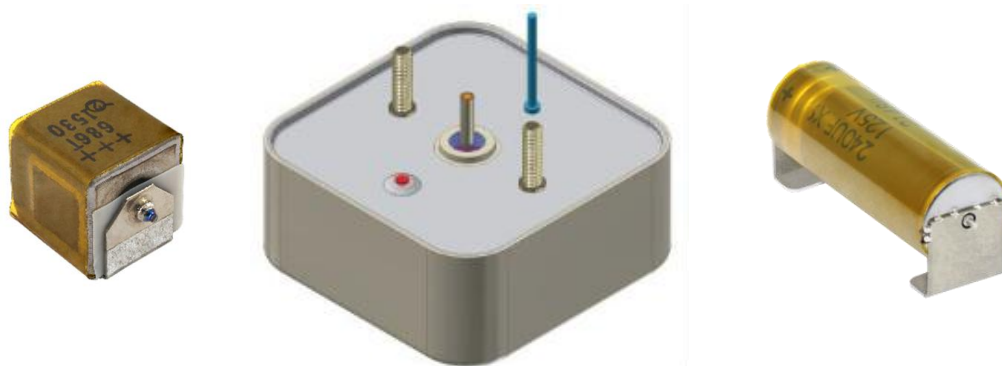
- No Burn Failure Mechanism
- Low ESR (6 mohm)
- Low Series Inductance
- Lower Derating than MnO₂ (80% Working Voltage)
- High Reliability
- Stable Over Lifetime and Temperature
- No DC Bias










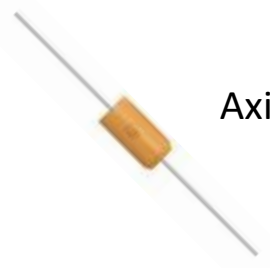

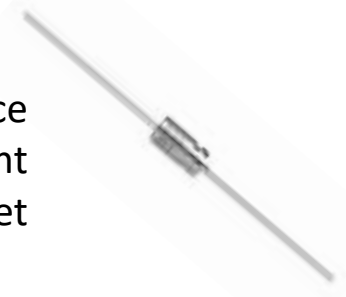





Tantalum vs Polymer Technology Differences

➤ Wet

- Best in class volumetric efficiency; Energy densities up to 2J/cc
- Lower Derating (100% Working Voltage)
- Wide voltage range; 10V-125V
- All Tantalum, hermetically-sealed case; No humidity related wear out mechanism
- No Burn Failure Mechanism
- Harsh Mechanical Environments (500g Shock, 80g Vibration, 300 cycle thermal shock)



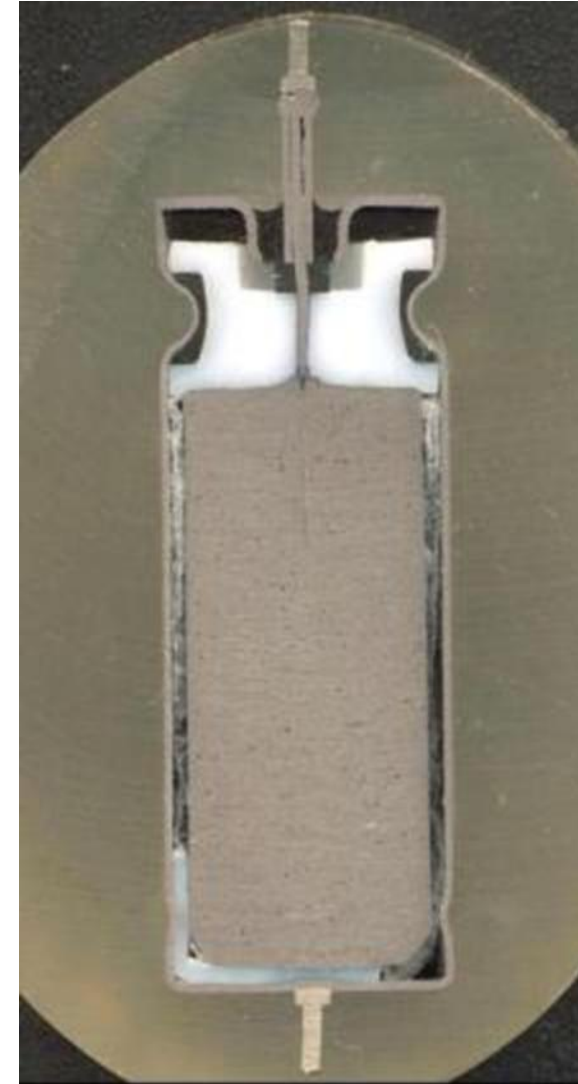
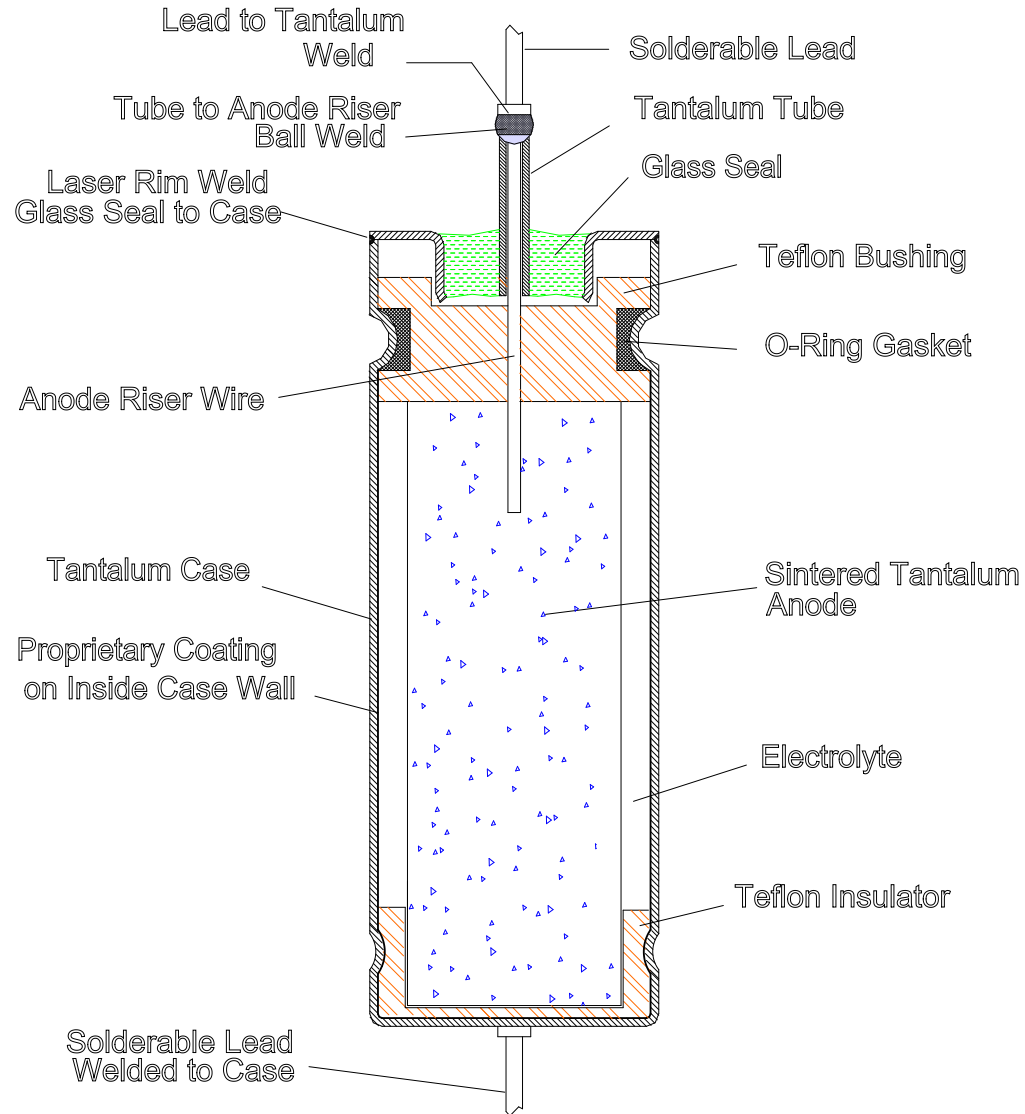
Various packaging and lead styles of tantalum capacitors.

| | | | | | | | | | |
|---|------------------|---|----------------------------|--|--------------------------------|---|--------------------------------|---|-----------------|
|  | Molded Polymer |  | Molded MnO ₂ |  | Radial Dipped MnO ₂ |  | High Energy Wet |  | High Energy Wet |
|  | Microtan Polymer |  | Microtan MnO ₂ |  | Axial Molded MnO ₂ |  | Surface Mount Wet |  | Axial Wet |
|  | Hermetic Polymer |  | Conformal MnO ₂ |  | Hermetic MnO ₂ |  | Radial Molded MnO ₂ |  | SMD Axial Wet |

Why Choose Wet Tantalum Capacitors

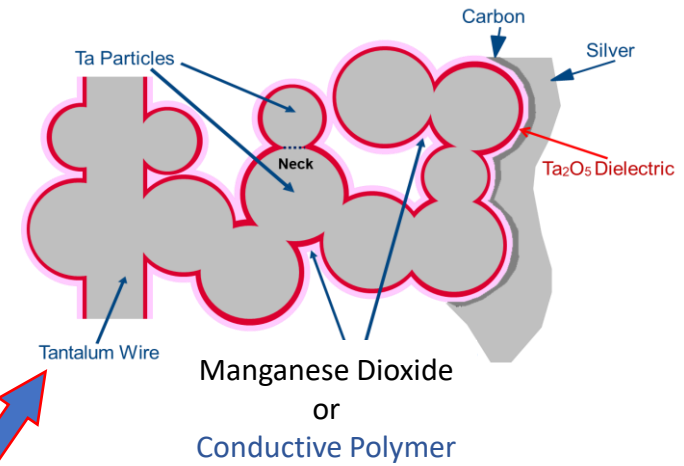
- Best in class volumetric efficiency; Energy densities up to 2J/cc
- Wide voltage range; 10V-150V
- All Tantalum, hermetically-sealed case; No humidity related wear out mechanism
- Non-burning failure mode
- Available in surface mount and axial designs
- No wear-out mechanism; qualified for
 - 10,000hrs; MIL products; established reliability
 - 2,000hrs; 85C at RV, 125°C at 67% RV
 - 1,000hrs at 200°C at 50-60% RV
- Capable to withstand harsh mechanical conditions/environment suitable for various AMS applications
 - 300 cycles thermal shock -55°C +125°C
 - 500g Shock
 - 80g high frequency vibration
 - 54g random vibration

Axial Wet Ta Capacitor Construction

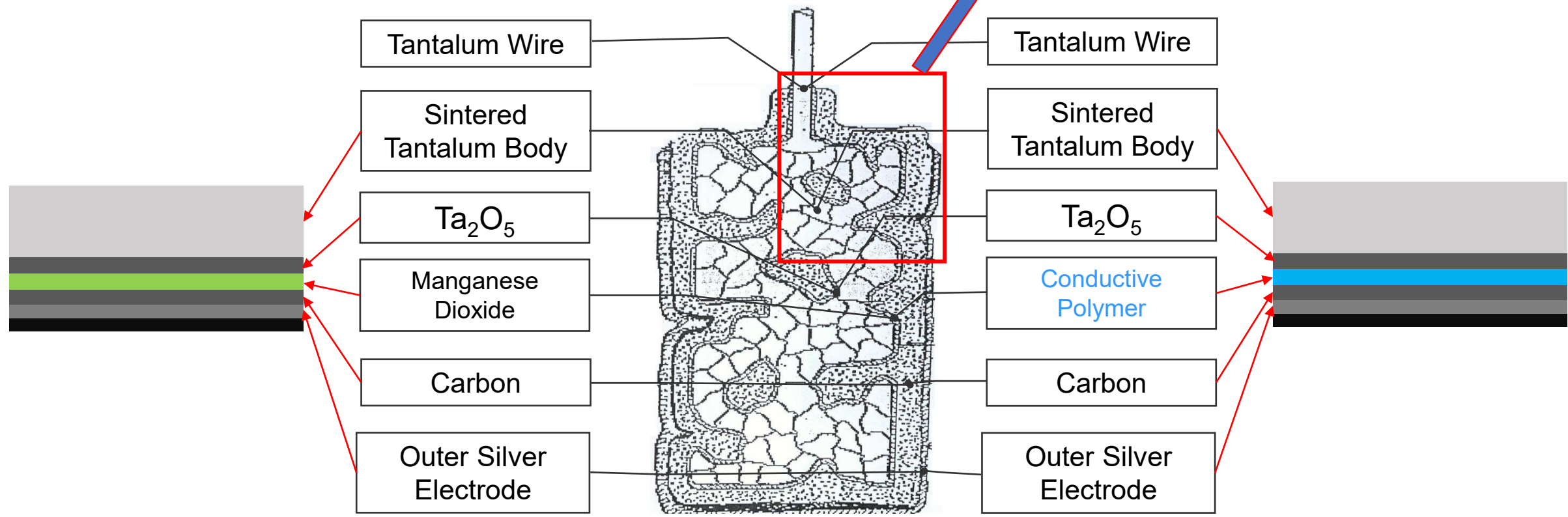


Capacitor Construction

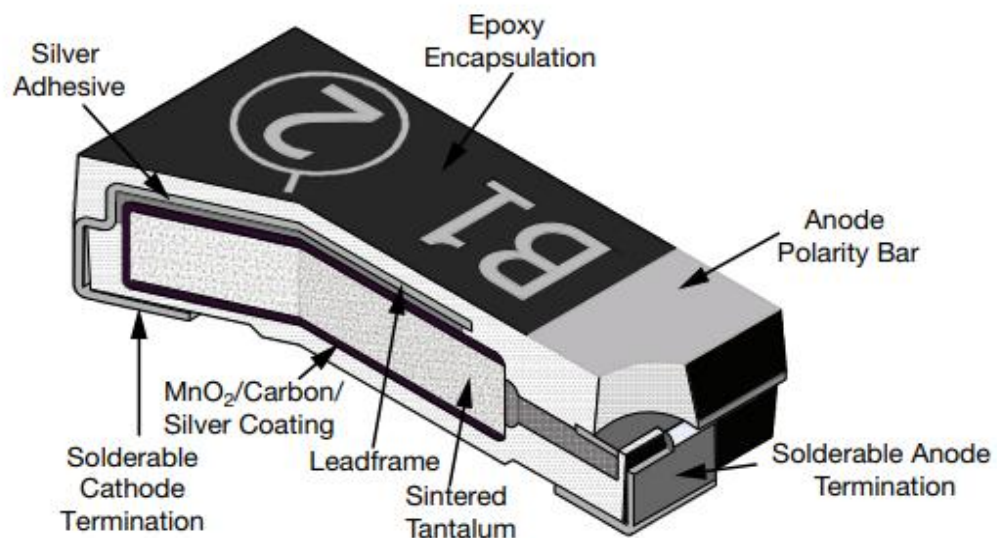
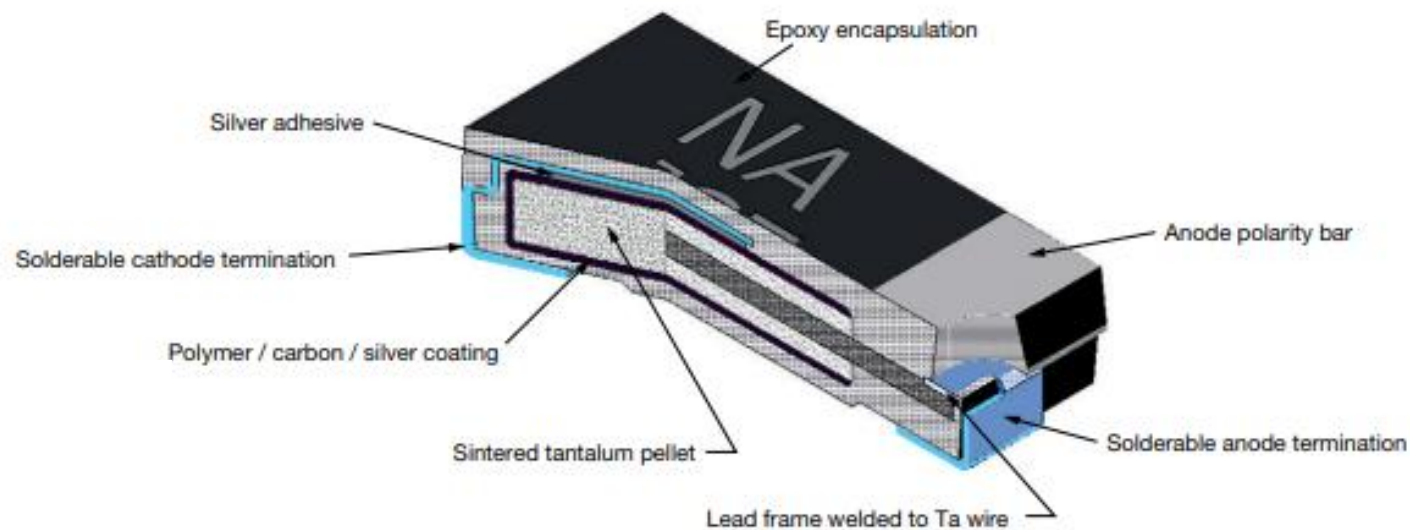
Structure of Solid Tantalum Pellet



Manganese Dioxide
or
Conductive Polymer



Solid Capacitor Construction - Tantalum Capacitor



Vishay's AnodeXpert Tech History

1. Since early 90's Vishay pioneered usage of advanced Tantalum anode technology including:
 - Liquid delubrication
 - Magnesium deoxidation
 - Anode wire welding
2. This advanced Tantalum anode technology allows Vishay to produce defect-free dielectric films essential for reaching:
 - Low DC leakage
 - Long term reliability
 - Improved ability to withstand reflow stress
3. Statistical DCL Screening at Elevated Temperature and Voltage along with MIL-PRF-55365 style screening result in highly reliable products suitable for AMS applications.

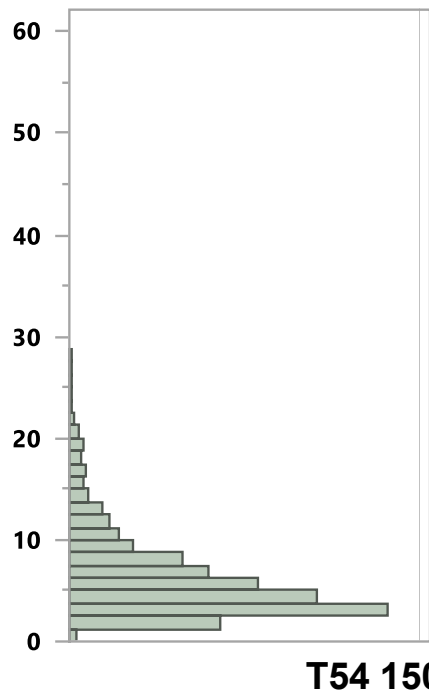
Statistical DCL Screening at Elevated Temperature and Voltage

(Patent No.: US 10,381,166 B2 (45) Date of Patent: Aug. 13, 2019)

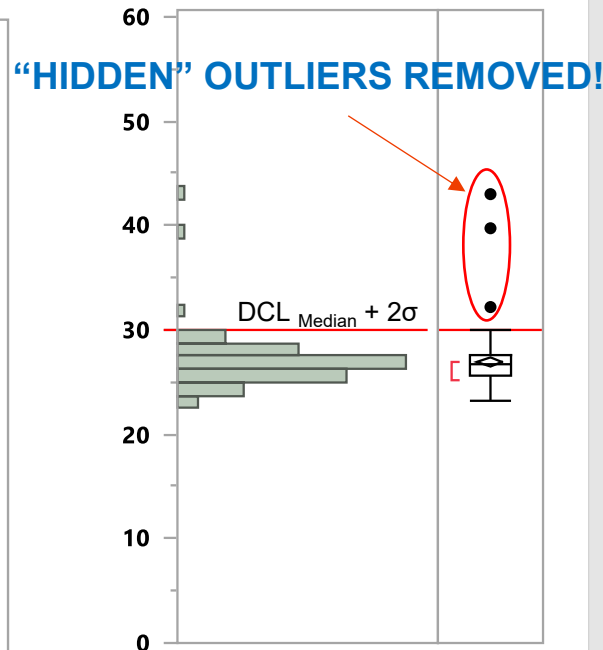
Screening process steps:

- 100 % electrical test at V_r , room temperature, with $[Avg + 3\sigma]$ statistical limit: much lower than 0.1 CV (450 uA)
- Hot DCL sample test at elevated temperature and voltage $> V_r$. Test voltage derived from BDV distribution
- Statistical analysis of sample test in order to define new HDCL test limit $[Med, \sigma]$
- Perform hot DCL test for entire lot with $[Med + 2\sigma]$ statistical limit

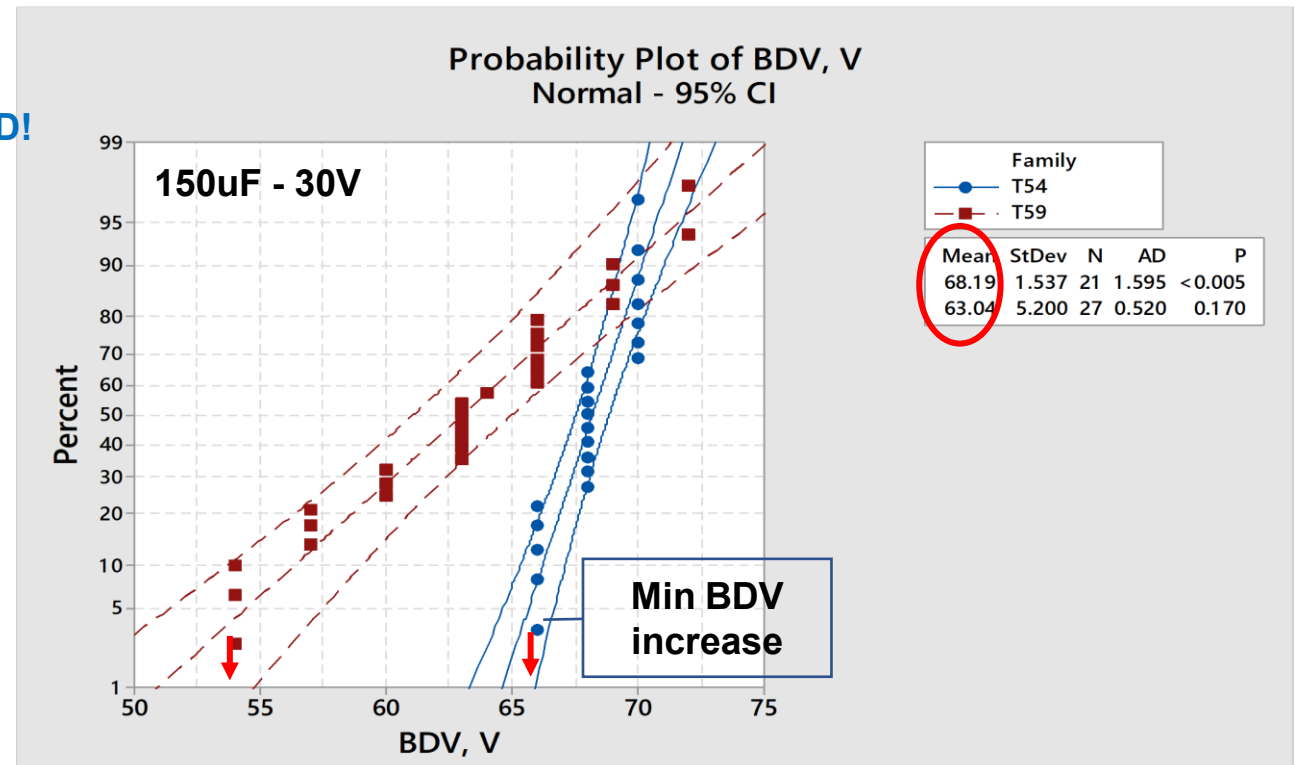
100 % electrical test @ V_r ,
RT DCL, uA



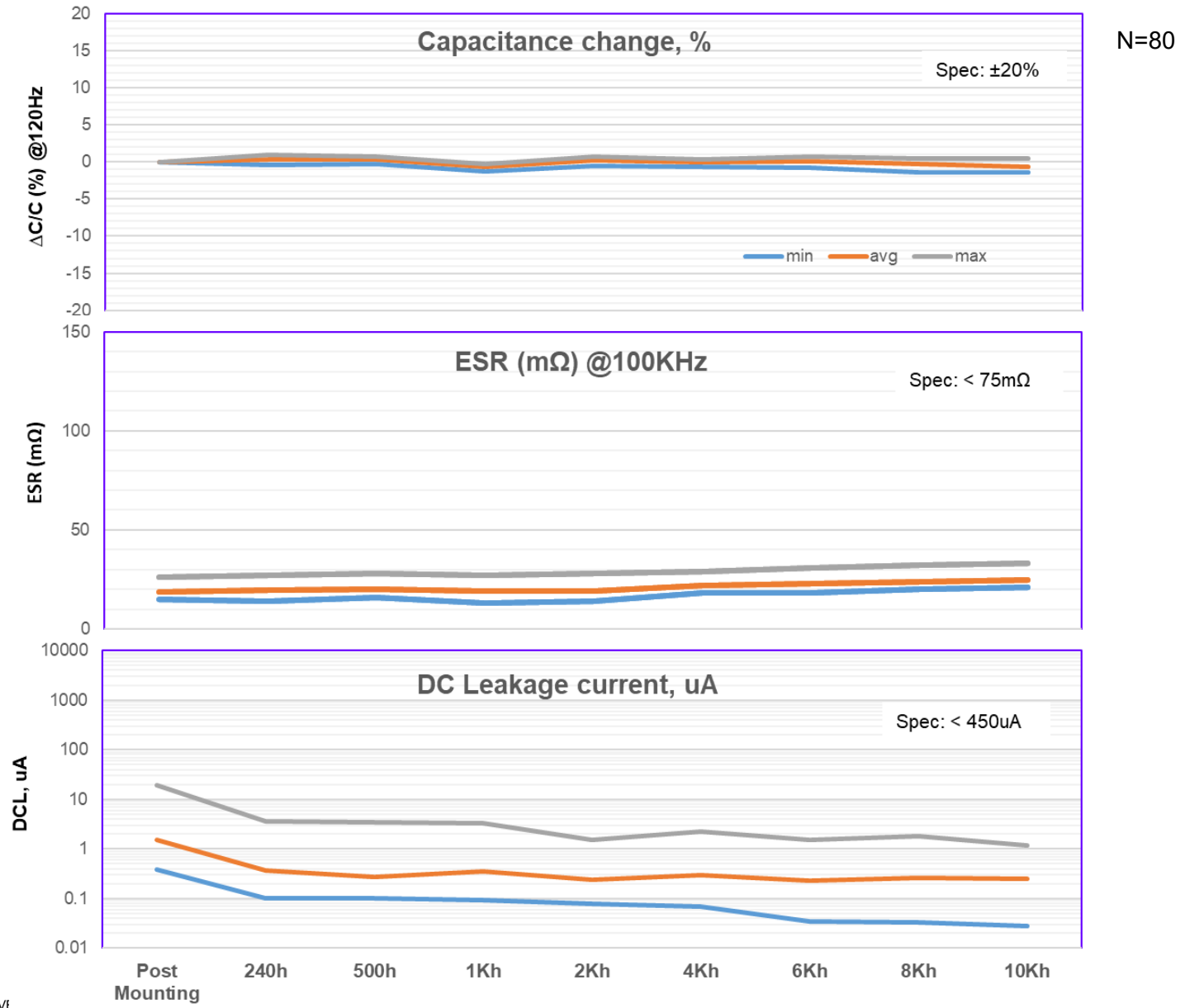
Hot DCL test
DCL, uA



BDV is SIGNIFICANTLY HIGHER!



T54 150uF - 30V EE: 10,000h Load Life Test @85°C, Rated Voltage



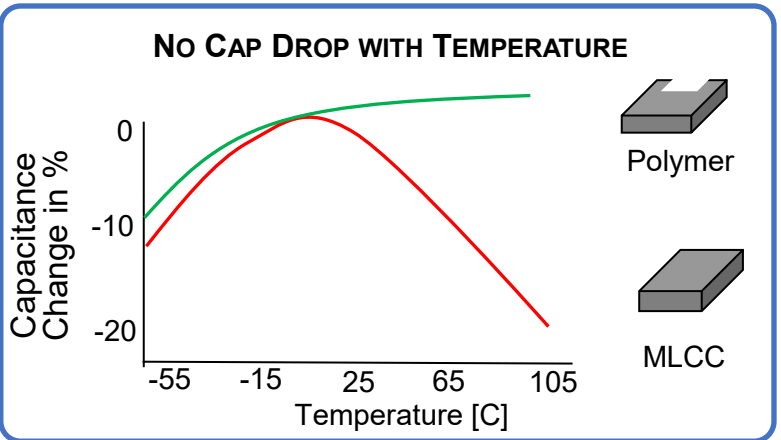
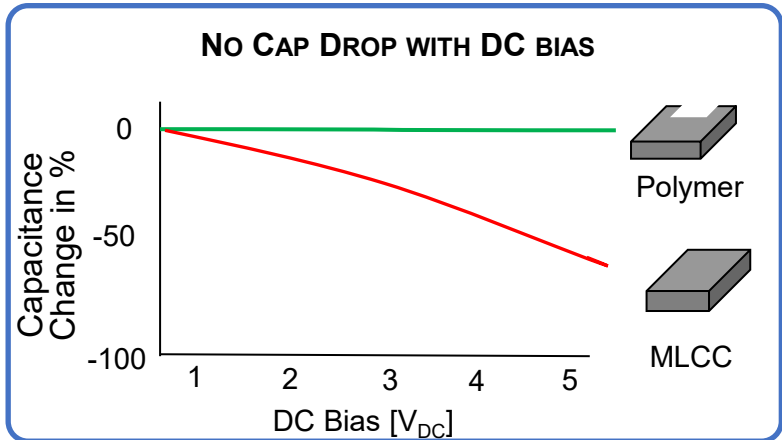
Polymer Advantages Over Other Technologies

DERATING & SIZE

24V: 2x 50V 10uF MnO2 → 1x 35V 22uF Polymer

5V: 1x 10V 220uF MnO2 → 1x 6.3V 220uF Polymer

7343 → 3528



SELF HEALING

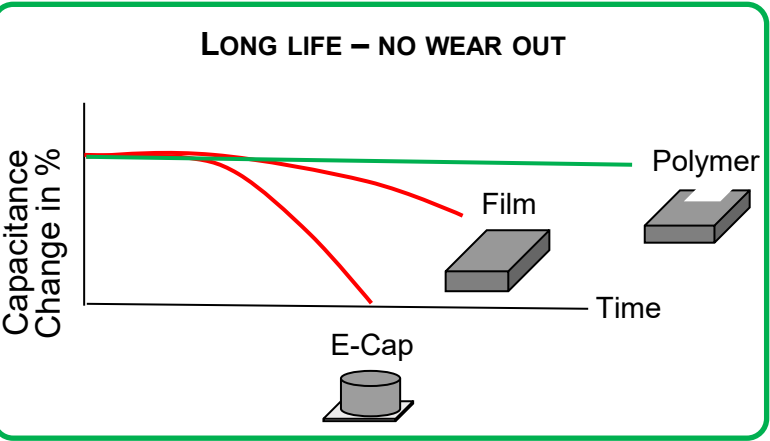
Defect in Dielectric => DCL & Temp increase

Under Heat: Polymer resistance increase => Failure spot electrically **isolated**

SAFETY

MnO2: Flammable

Polymer: Safe Failure Mode



SMALL FOOTPRINT, HIGH DENSITY & LOW PROFILE

E-Cap vs Polymer

Note: Self healing with MnO2 resulting in free oxygen => in case of quick temp. rise, ignition may occur => Fire

NOT SENSITIVE TO BOARD FLEX AND MECHANICAL STRESS

MLCC vs Polymer

NO PIEZO EFFECT NOISE

MLCC vs Polymer

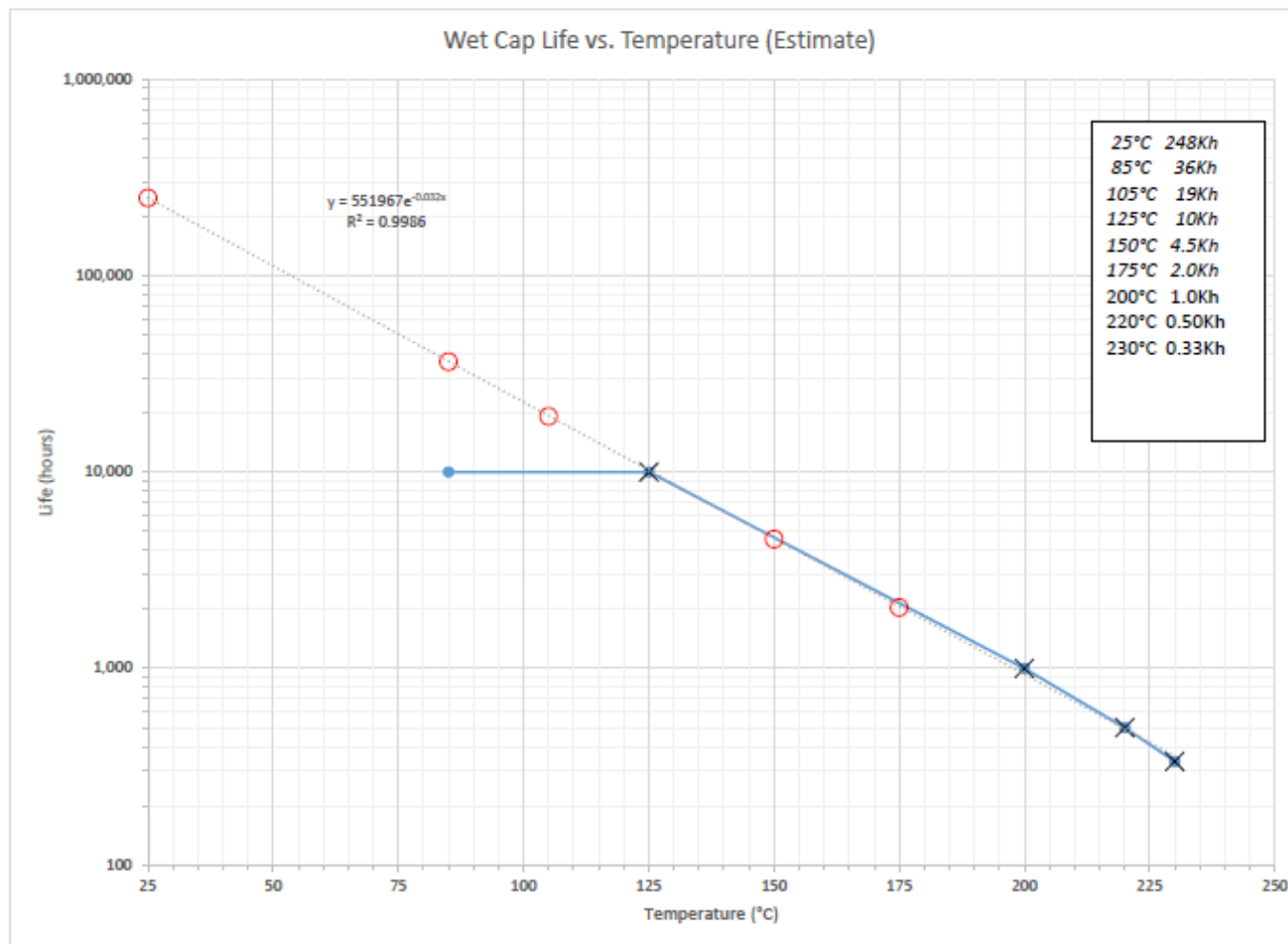
LOW ESR AND ESL

MnO2 vs Polymer

Tantalum Reliability and Derating

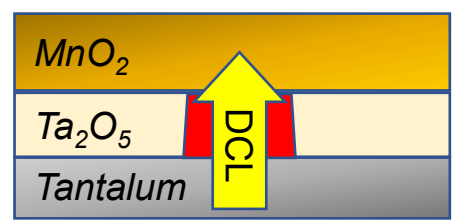
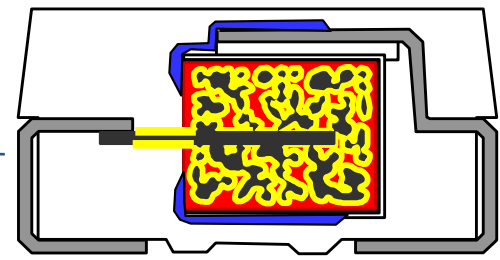
- These two factors, temperature and voltage, are what drive lifetime.
- The cathode system changes the reliability as does the cap series inside that level. An example would be STE vs. M39006. This is not to say that a commercial part can't reach the same level of lifetime, but they are not designed to do so. Derating plays an important factor in lifetime .
- Unfortunately, we cannot say one level of derating fits all tantalums. Each type has it's own rules. While polymer is 20% derate, MnO₂ tantalums is 50% derate and wets are 10-20% derate.
- Application also plays into this, as different uses require more reliability than others.

Wet Tantalum Life Prediction Curve

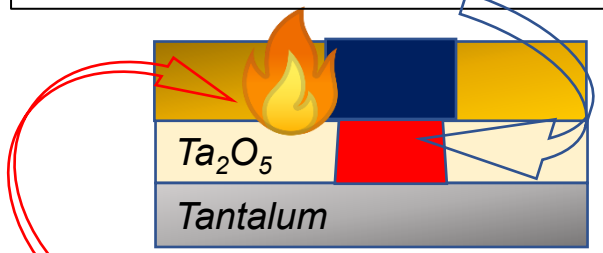


Failure Mechanism of MnO₂ (Conventional Solid Tantalum Capacitor)

MnO₂ Capacitors



- Temperature increase to ~500°C.
- Under heat MnO₂ ---> Mn₂O₃ + O.
- Highly resistive Mn₂O₃ electrically isolates failure area.
- Released Oxygen heals Ta₂O₅ dielectric.

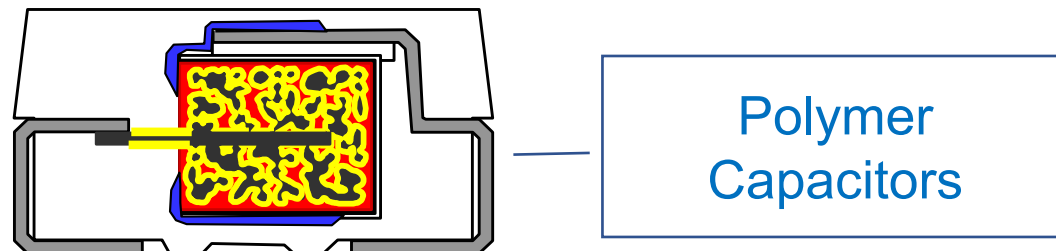


• In case of quick temperature rise the ignition may occur.

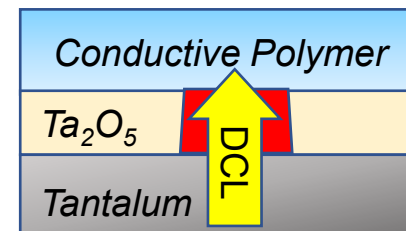
1. Defect in dielectric causes elevated DCL
2. As leakage current increased, local temperature would increase
3. Heat will help self healing on Ta₂O₅ layer and form Mn₂O₃ to isolate failure area
4. As the local temperature could reach 500°C and oxygen exists in the process, quick temperature rise* may trigger ignition

*Quick temperature rise may be caused by overvoltage operations

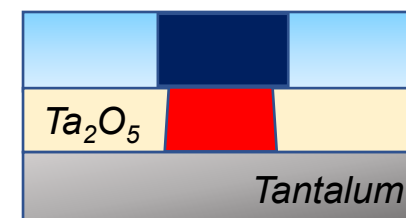
Why Polymer Is Safer – Polymer Self Healing Process



1. Defect in dielectric causes elevated DCL
2. As leakage current increased, local temperature would increase
3. Heat will void the connection of the failure spot and stop the current flow through it
4. As there is no oxygen involved in the process, ignition cannot occur.



- Temperature increase to $\sim 300^\circ\text{C}$.
- Conductive polymer resistance increases under heat.
- Failure spot electrically isolated.



- No Oxygen available in the system, the ignition cannot occur!

Why Derating Is Needed

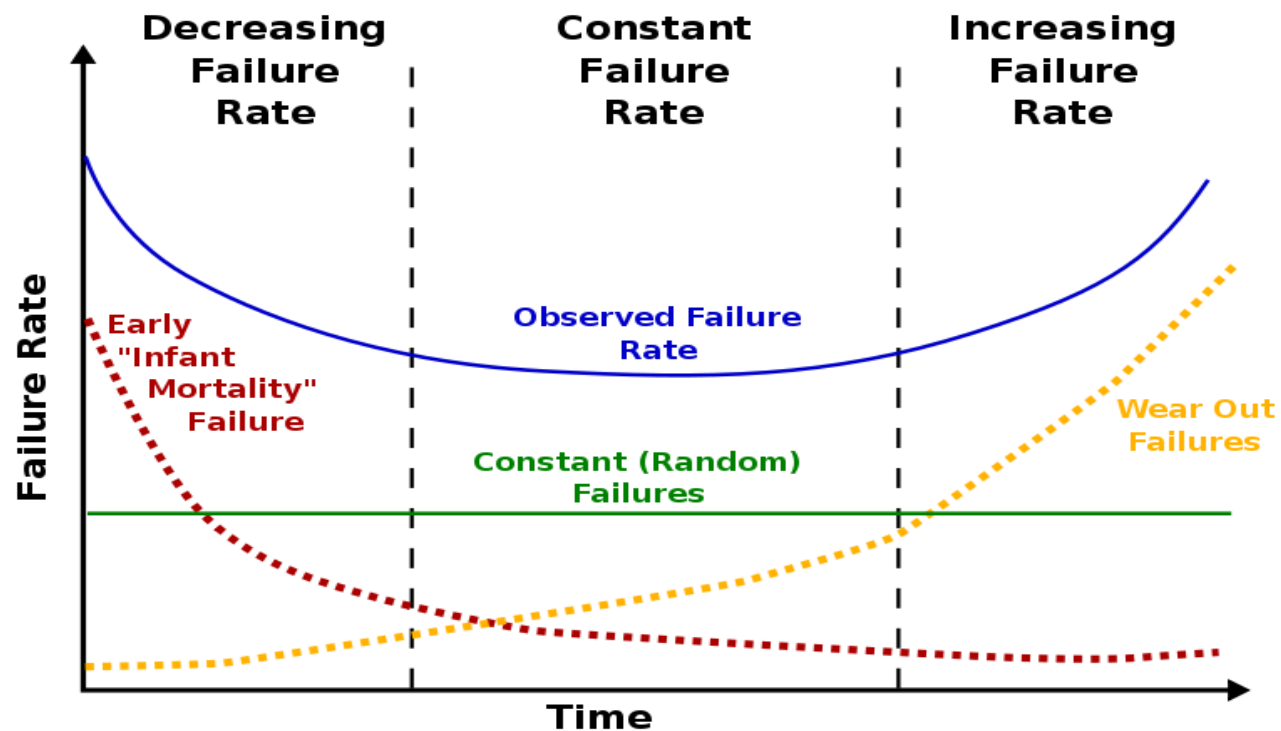
- Technically, all kinds of tantalum capacitors could operate in rated voltage if failure rate @1000hrs is not a concerns to the applications.
- Industrial generally accepts 0.1% failure rate at 1000hrs and to achieve it, derating is needed.
- MnO₂ and Polymer is with different acceleration model due to technology different making the derating different.

| Parameter | Basic Failure Rate | MnO ₂ capacitors | Polymer capacitors |
|---------------------------------------|--------------------|---|-----------------------|
| Reference document | | MIL-HDBK-217F Notice 2 | MIL-PRF-32700 |
| Voltage acceleration model | N/A | $VAF [\pi_v] = \{S/0.6\}^{17} + 1, S = \frac{V}{V_r}$ | $VAF = (V_R/V)^{VRE}$ |
| Voltage Ratio exponent [VRE] | - | - | 16 |
| Derating [V/V _R] | 1 | 0.5 | 0.8 |
| Voltage acceleration factor [VAF] | 1.0 | 23.2 | 35.5 |
| Temperature acceleration factor [TAF] | 1.0 | | |
| Number of units tested (N), pcs | 100 | | |
| Test hour per unit (t), hours | 1000 | | |
| Number of failures (m), pcs | 0 | | |
| Chi-Square @ confidence level (α) | 4.6 | | |
| Confidence level (α) | 0.9 | | |
| Failure Rate FR, % 1000 hours | 2.3% | 0.1% | 0.1% |
| MTTF, years | 4.96 | 115 | 176 |

What is Weibull?

- Weibull is a method for failure rate (FR) prediction, based on representative sample behavior study.
- Conditions
- 1.3 to 1.53 Rated Voltage
- 40 Hours minimum at +85°C
- Benefits
- Eliminates Infant Mortality Failures
- Eliminates Lot to Lot reliability performance variability.
- Only lots with decreasing FR are accepted.

“Bathtub Curve” describes failure rate vs. time of engineered systems (e.g. cars) or components.

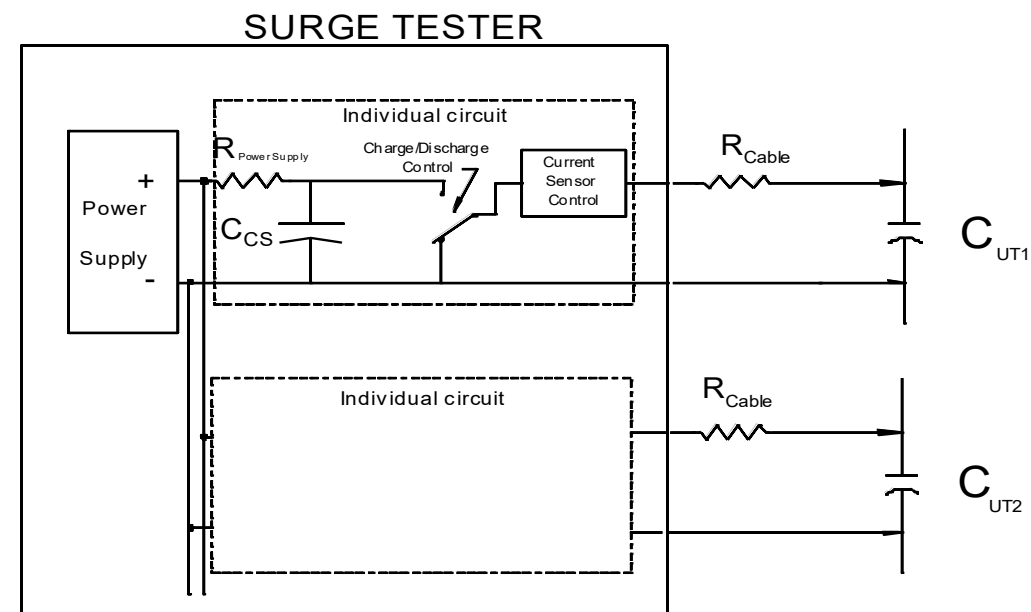


| FRL CODE | % per 1000 hours |
|----------|------------------|
| B | 0.1% |
| C | 0.01% |
| D | 0.001% |

Red line is characteristic for Tantalum capacitors since there is no wear out mechanism for Ta₂O₅ dielectric.

What is Surge Current Screening?

- Benefits
- Promotes “self healing” in dielectric
- Screens out capacitors with excessively weak dielectrics
- “Heal ‘em or kill ‘em”
- Surge Test Conditions
- Full Rated Voltage
- Temperature:
 - +25°C (commercial and Mil)
 - -55°C and +85°C (space)
- Total Circuit Resistance: < 0.5 Ω
- Charge/Discharge Time: 0.1 sec/0.1 sec
- # of Cycles:
 - 3 Cycles (commercial)
 - 10 Cycles (Mil)
 - 10 cycles @ each temp (Space)
- Cap, DF, ESR and DCL are tested 100%



C_{UTn} = Capacitor under test
 C_{CS} = Charge Supply Capacitor
 R_{Cable} = Cable Resistance (<0.1 ohms)

Aluminums

Why Alu-Caps?



- High capacity-per-volume / energy storage at an attractive price
- Relatively insensitive to rough application conditions (self-healing)
- The high capacity allows filtering of switching currents up to about 200 kHz
- Fits well with most switched mode power conversion applications (power supplies, motor control)
 - for filtering and buffering

First Capacitor (1745)

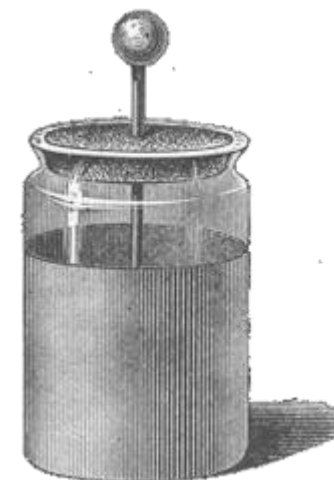
“Leyden Jar - Leidener Flasche”

named after the University of Leyden

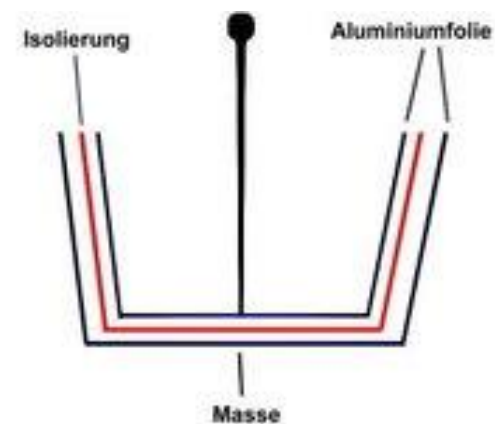
Invented by Ewald Jürgen Georg von Kleist (Germany) and before his discovery became widely known, a Dutch physicist Pieter van Musschenbroek (University of Leyden) independently invented a very similar capacitor in January 1746.

Principle

The device was a glass jar coated inside and out with metal. The inner coating was connected to a rod that passed through the lid and ended in a metal ball. Typical designs consist of an electrode and a plate, each of which stores an opposite charge. These two elements are conductive and are separated by an insulator (e.g., the glass dielectric). The charge is stored at the surface of the elements, at the boundary with the dielectric.



Leyden Jar

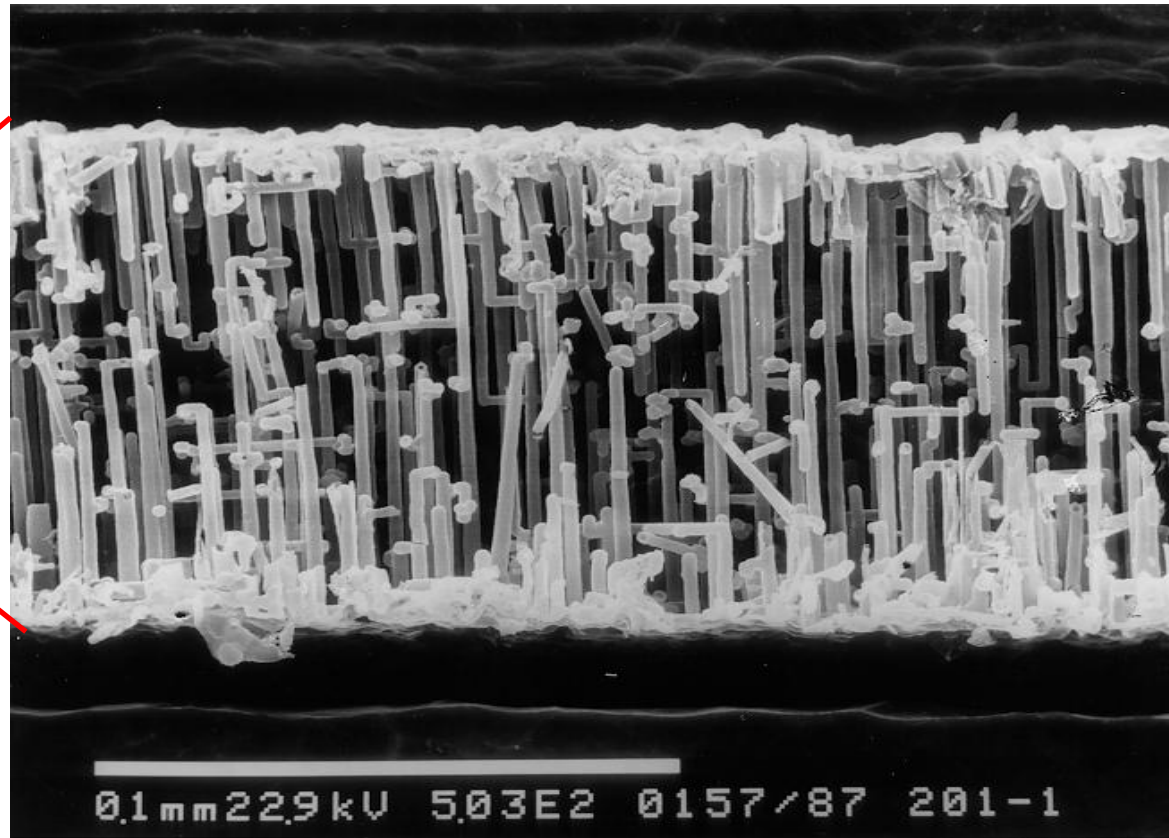
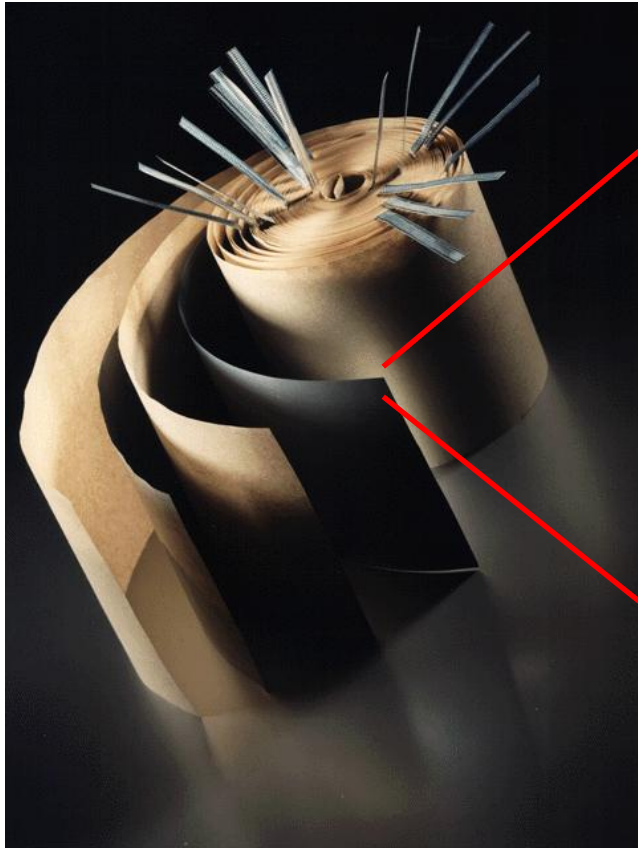


Schematic: Source Wikipedia

Aluminum Product Form Factors



Aluminum Electrolytic Capacitor Basics



Aluminum Capacitor Basics

Area A:

Enlarged by roughening the anode

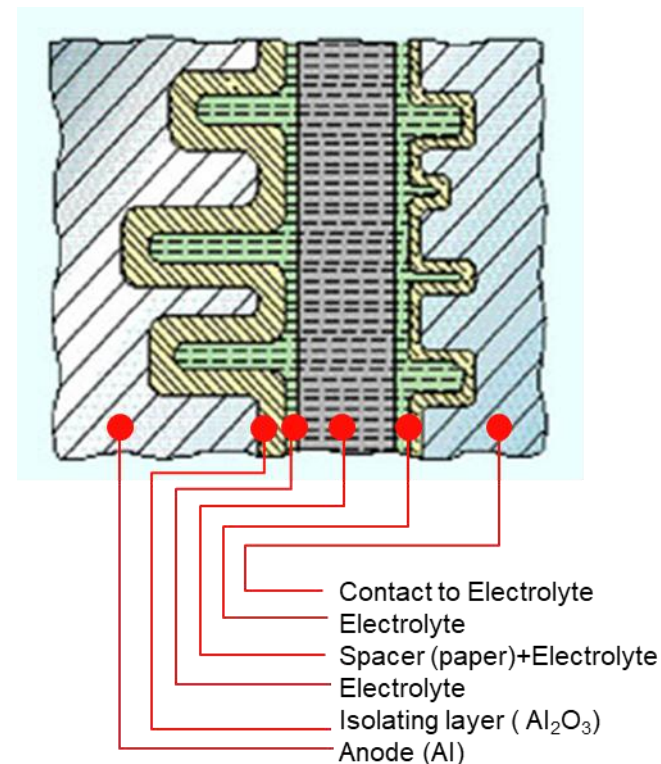
(~ 30 – 120 x)

Distance d:

Oxide layer very thin (~ 1.4 nm/V)

Electrolyte / Electrode:

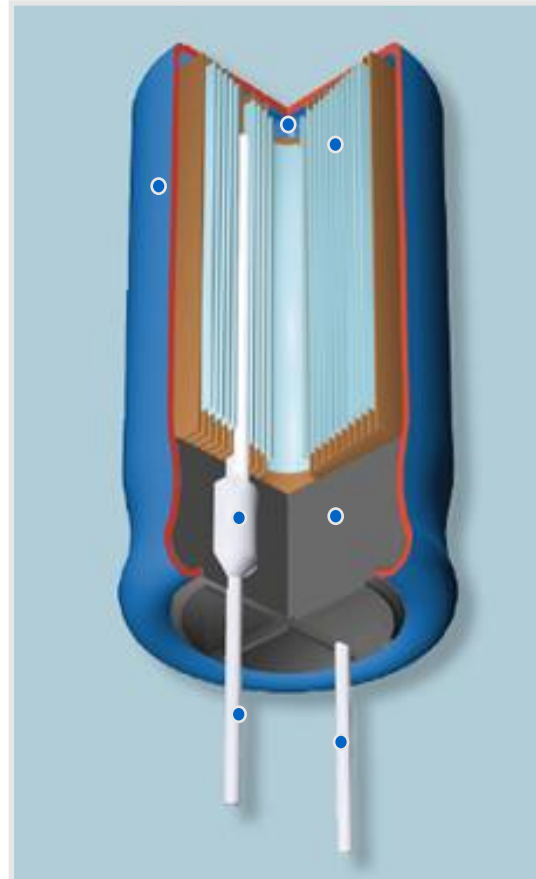
Fluid second plate of the capacitor (cathode) that contacts all the roughened anode surface area



Radial Electrolytic Capacitors

Aluminum can
Insulating sleeve

Aluminum connection
part



cross sectional view

Wound cell, consisting of:

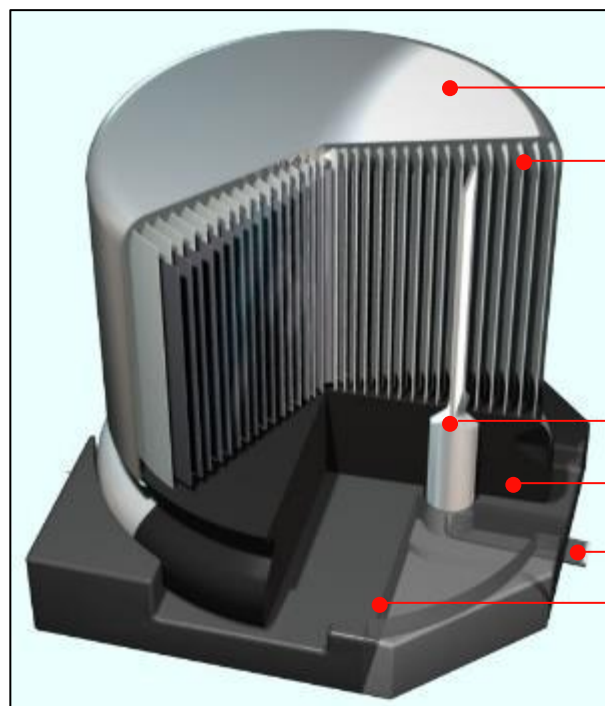
- Aluminum foil anode with aluminum oxide dielectric
- Paper spacer impregnated with electrolyte
- Aluminum foil cathode

Rubber sealing

Anode and cathode lead,
tin plated

Aluminum Capacitors – SMD Configuration

SMD Electrolytic Capacitor (Vertical, V-Chip) – Industry Standard



Case/Can, aluminium nylon(PA)/PET cladded

Capacitor winding:

- anode foil, etched/oxidised aluminium,
- spacer paper, impregnated with electrolyte (high boiling point)
- cathode foil, etched aluminium

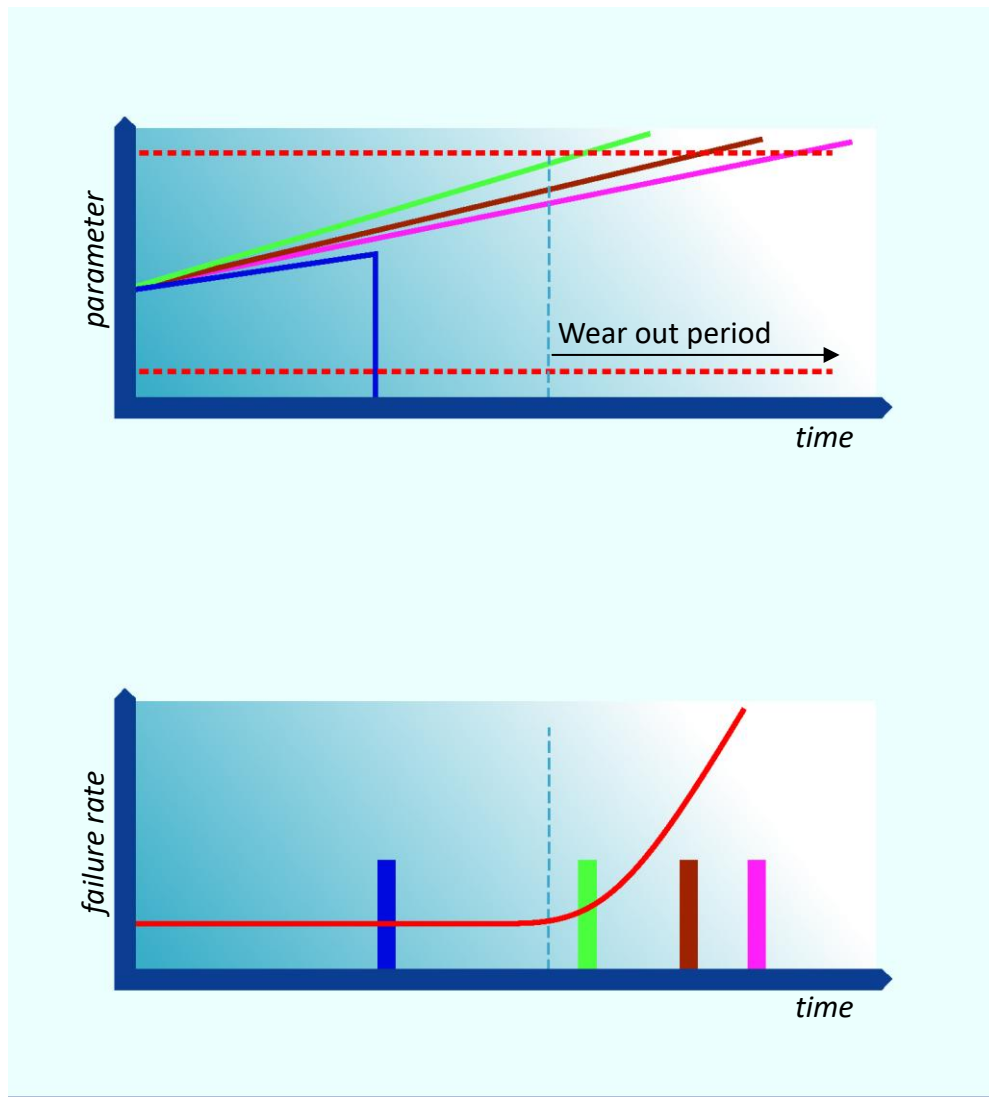
Connecting tab, aluminium

Sealing rubber, temperature resistant

Terminal, tinned steel

Base plate, temperature resistant, with or without dummy terminals (molded lead-frames)

Wear-out



Advise customer!

Wear out period

- components fail due to parameters reaching a limit value
- failures / hr increases over time

When does it start

- drifting parameter differs per technology
- rate of drifting set by conditions in application

End of Useful Life Requirement

Non-operating

- 64 khr / 200 = 320 hr

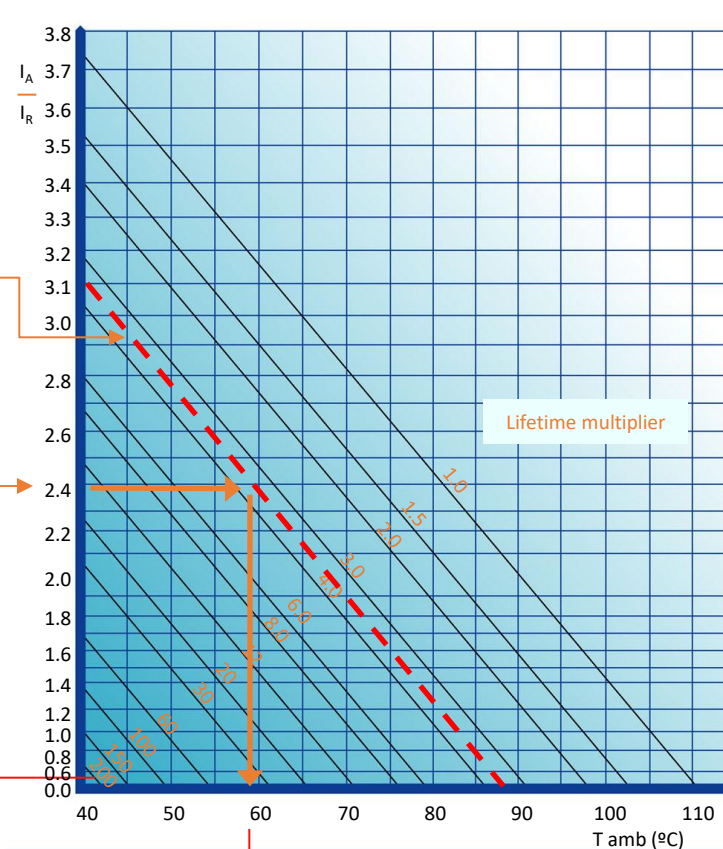
Operating

- 24 khr / (7000 - 320) = 3,6

| Frequency | Multiplier |
|-----------------|-------------------------------------|
| | $U_R = 16 \text{ \& } 25 \text{ V}$ |
| 100 | 0.63 |
| 300 | 0.72 |
| 1 000 | 0.80 |
| 3 000 | 0.88 |
| 10 000 | 0.92 |
| 30 000 | 0.98 |
| $\geq 100\ 000$ | 1.00 |

- $I_{A \text{ RMS}} = 3,0 / 0,98 = 3,1 \text{ A}$
 $\Rightarrow I_A / I_R = 3,1 / 1,3 = 2,4$

- $T_{\text{amb operating}} < 58 \text{ }^\circ\text{C} \checkmark$



Lifetime Calculation Tool

LIFETIME CALCULATOR FOR ALUMINUM CAPACITORS

Ordering Code: ?

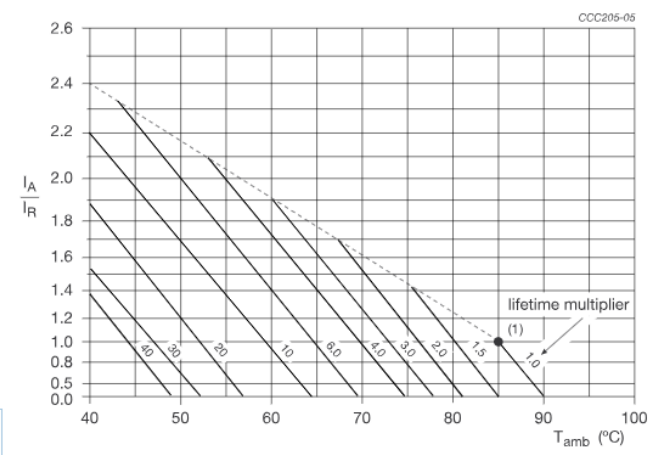
Series Name: ?

Useful Life [h]: ?

Rated Ripple Current [A]: ?

Target Lifetime [year]: ?

Number of Parallel Branches: ?



[Help](#)

[Save as PDF](#)

[Print](#)

- Operating Condition Name
- Off
 - Idle
 - On

| INPUT | | | | | | |
|--|------------------------------------|--------------------------------------|----------------------------------|--------------------------|--------------------------|--|
| Main Frequency of Ripple Current [Hz]: | | <input type="text" value="1000"/> | | | | |
| Ripple Current Multiplier: ? | | <input type="text" value="1.20"/> | | | | |
| Operating Time per Year [h] | Percent per Year [%] | Operating Temperature T_{amb} [°C] | Ripple Current I_1 [A] | Ripple Current I_2 [A] | Ripple Current I_3 [A] | |
| <input type="text" value="4380"/> | <input type="text" value="50.00"/> | <input type="text" value="25"/> | <input type="text" value="0"/> | <input type="text"/> | <input type="text"/> | |
| <input type="text" value="1752"/> | <input type="text" value="20"/> | <input type="text" value="25"/> | <input type="text" value="0.1"/> | <input type="text"/> | <input type="text"/> | |
| <input type="text" value="2628"/> | <input type="text" value="30"/> | <input type="text" value="70"/> | <input type="text" value="10"/> | <input type="text"/> | <input type="text"/> | |

| OUTPUT | | | | | |
|---|-----------|-------------------|---------------------|-----------------|-----------------------------------|
| Operating Time [h] | I_A [A] | Ratio I_A / I_R | Lifetime Multiplier | Error Message | Equivalent Useful Life [h] |
| 43800 | 0 | 0 | 109 | No errors occur | 402 |
| 17520 | 0.08 | 0 | 109 | No errors occur | 161 |
| 26280 | 8.33 | 0.6 | 4.8 | No errors occur | 5475 |
| Lifetime Used by Operating Conditions[h]: | | | | | <input type="text" value="6038"/> |

Capacitor's Lifetime at T_{max} [h]:

Calculated Lifetime of Capacitor in Application: h or yr

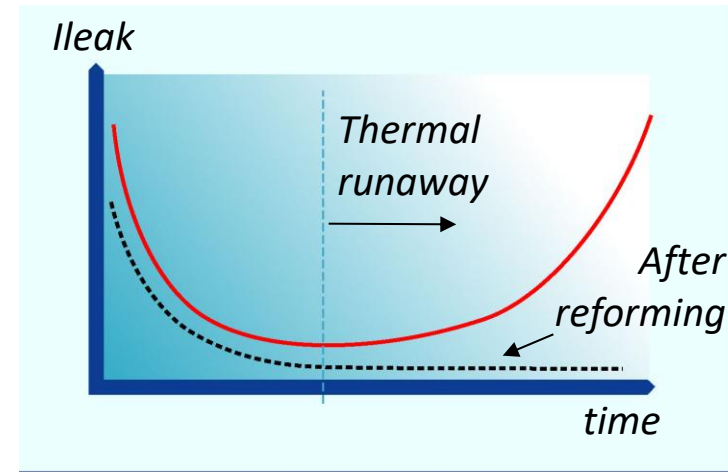
Error Message:

[Store & Compute](#) [Reset](#)

Storage

Storage time exceeded
Oxidation of contact(lead)s
Increased leakage current
(electrolytic capacitor)

Soldering / First switch-on
Solder quality
Overheating ($P_{diss} = U \cdot I_{leak}$)



$$I_{\max}(mA) = \frac{1 \text{ mW}}{\text{mm}^2} \cdot \frac{A_{\text{surf}}(\text{mm}^2)}{U_R(V)}$$

! Solution: Proper storage conditions, Reforming

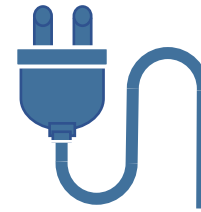
Energy Storage



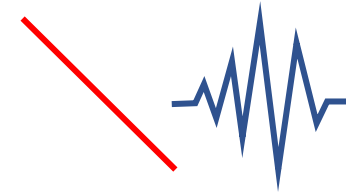
min



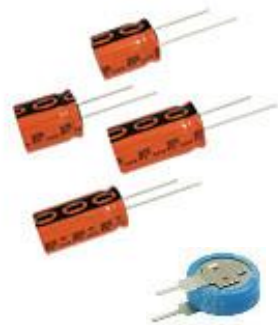
s



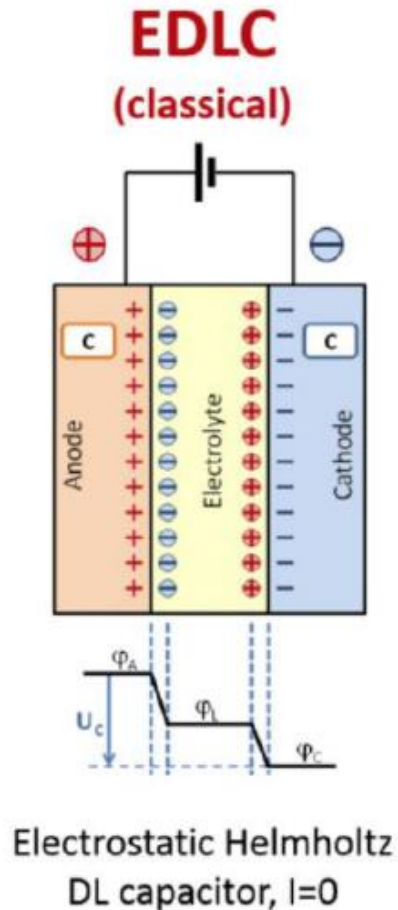
ms



μ s



EDLC Capacitor Basics



- Double Layer Capacitors store energy electrostatically in Helmholtz layers.
- Helmholtz layers are ionic layers on the surfaces of electrically conductive electrodes.
- Ions are from dissociated salts in electrolyte liquids.
- Solid electrodes are usually activated carbons with large surface areas per volume.

EDLC Supercapacitors - Lifetime calculation

- Arrhenius model
- An Arrhenius approximation is sufficient to describe lifetime t within limits. Commonly used acceleration factors / activation energies for EDLC models

| | |
|-------------|---------------------|
| temperature | $\Delta T_0 = 10K$ |
| voltage | $\Delta U_0 = 0.2V$ |

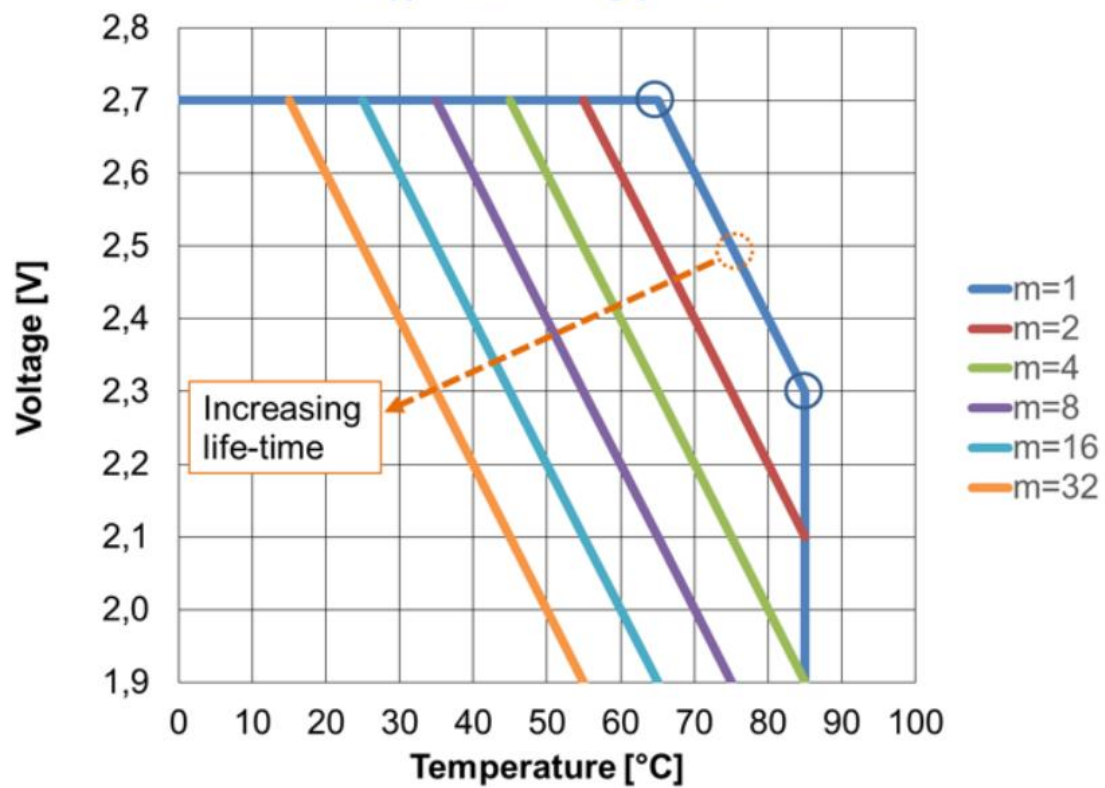
$$t = t_0 * 2^{\frac{T_0 - T}{\Delta T_0}} * 2^{\frac{U_0 - U}{\Delta U_0}}$$

For $U_0=2.7V$ Types: $T < T_0$ and $2.1V < U < U_0 < 2.7V$
respectively

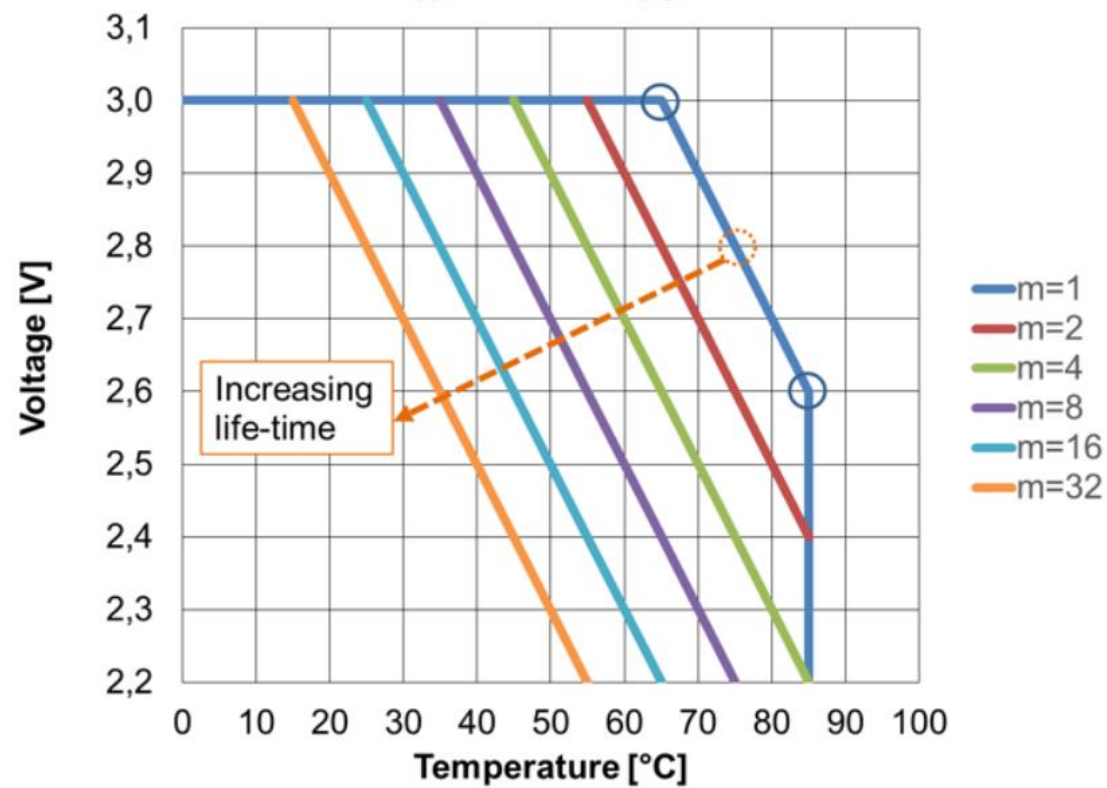
For $U_0=3.0V$ Types: $T < T_0$ and $2.2V < U < U_0 < 3.0V$

Multiplier m of useful life as function of ambient temperature and applied voltage

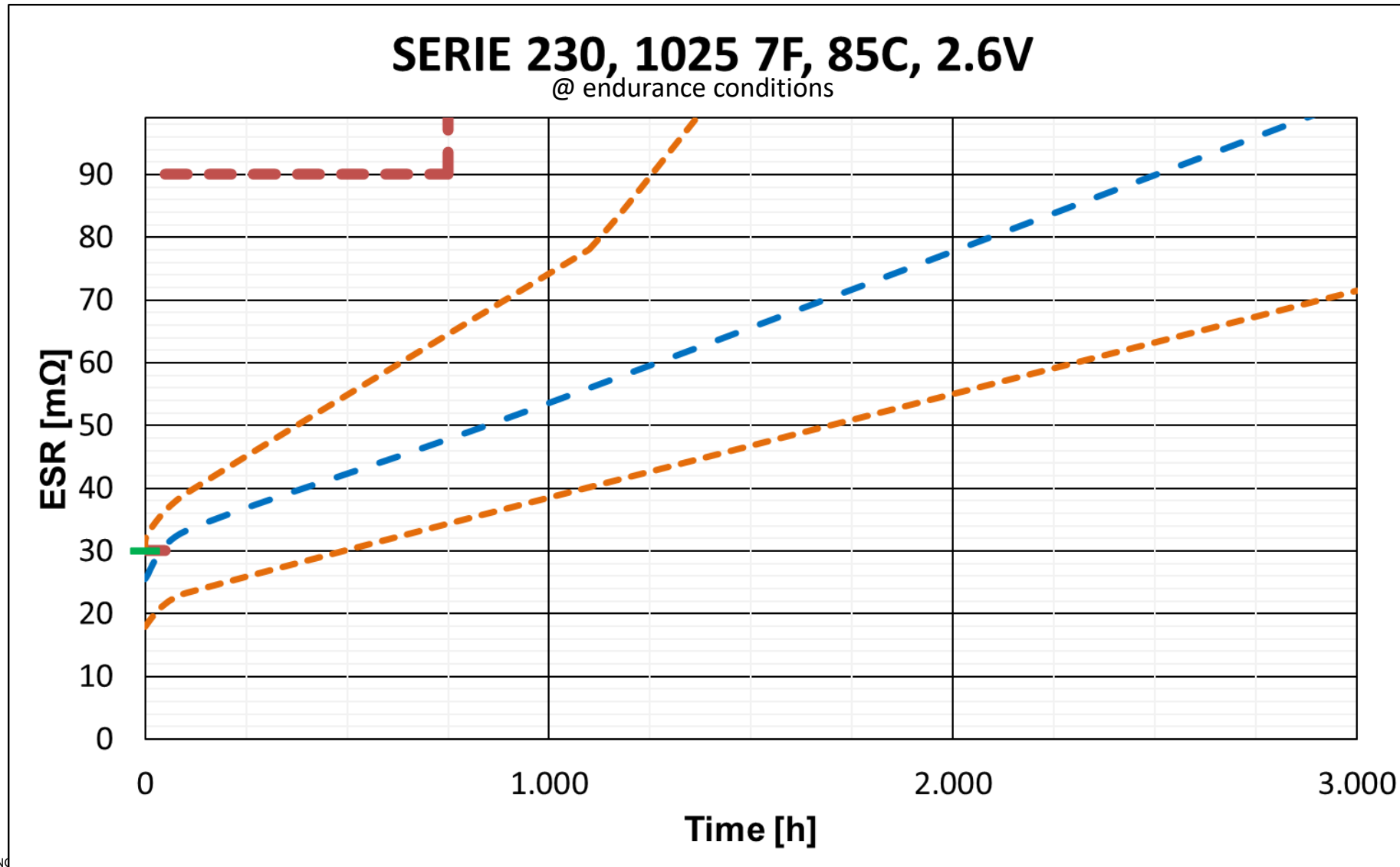
$U_R = 2.7V$ Types



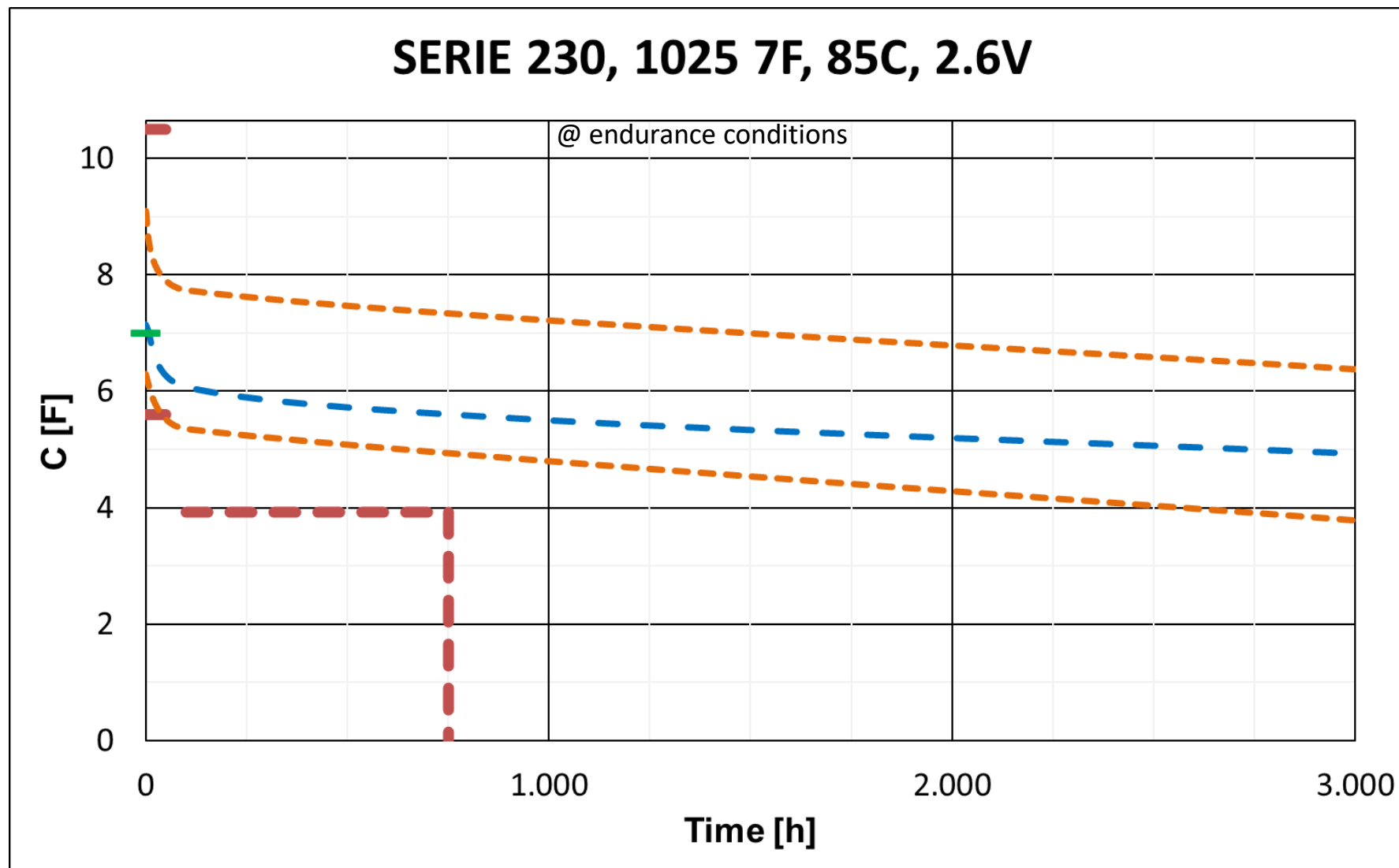
$U_R = 3.0V$ Types



Typical Parameter Drift For EDLC



Typical Parameter Drift For EDLC



Takeaways

Capacitors Are Not Just Simple, Passive Devices

- Tantalums are the most volumetrically efficient, stable capacitor available
- Aluminums are the most cost-efficient solution in terms of capacity density

- Know the strengths and weaknesses of your choice.
- One cannot break the laws of physics.
- Don't Wait To The Last Minute Choosing Your Passives.

The background features a light blue and white abstract pattern of dots and lines, resembling a stylized DNA helix or a network of connections, set against a white background.

Thank you!!!