



# Rutronik Tech Talk

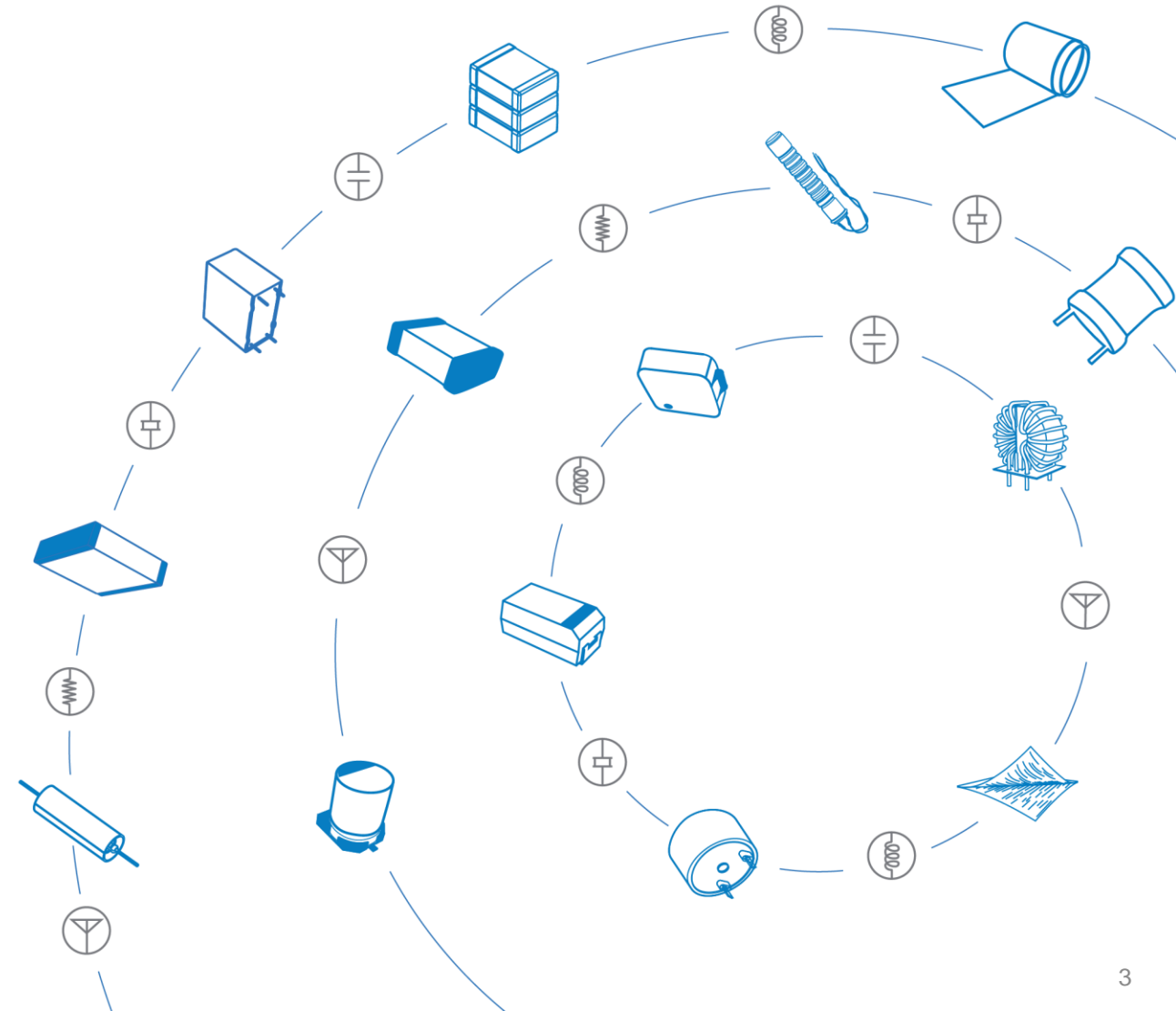
Capacitor Comparison for  
Industry 4.0 Applications

Freitag, 4. März 2022

# Overview

- Capacitor Technologies
- Capacitor Comparison
- Summary and Key Take Away

# Capacitor Technologies



# Electrolytic Capacitors

- Very high Capacitance Values
- Volumetric Efficiency
- Several construction types (SMD, THT, PressFit, ScrewTerminal)
- Solid Polymer and Hybrid Versions with long lifetime



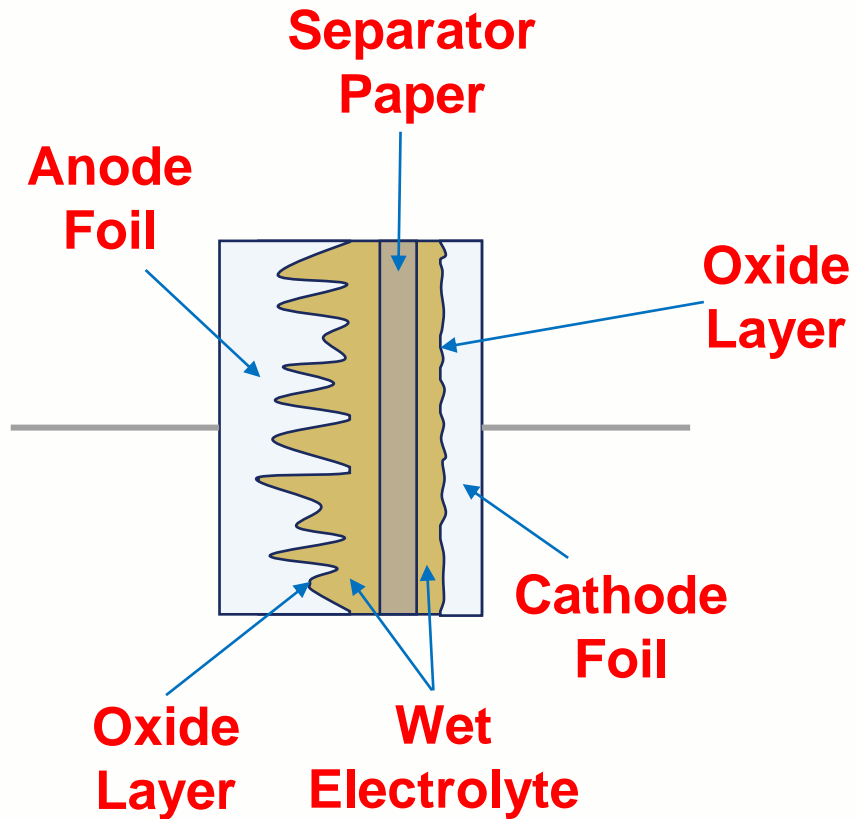
# Hybrid Polymer Capacitors

- Characteristics:
  - Rated Life: 3,000 hours (Rated Voltage, Temperature, and Ripple Current)
  - Operating Temperature: -55°C to 125°C
  - High Vibration up to 30g
  - High ripple current
  - Self-healing behavior
  - Capacitance: 56 & 100  $\mu$ F
  - Rated Voltage: 63 VDC
  - Extreme low leakage current
  - AEC-Q200

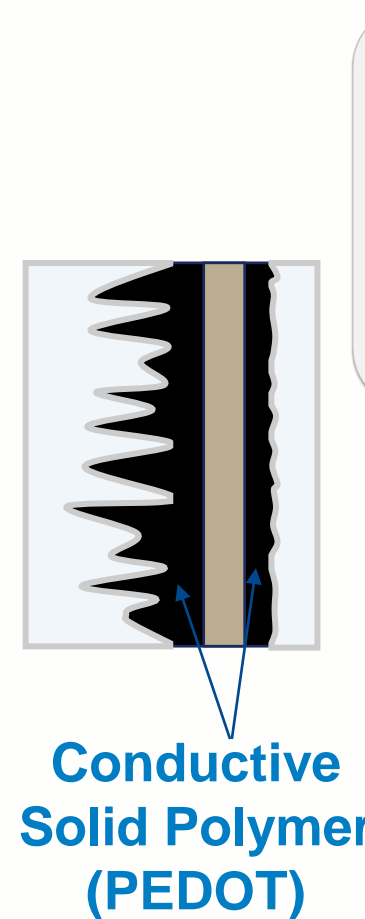


# Aluminum Block Diagram

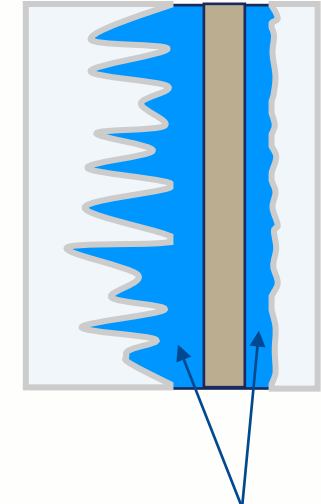
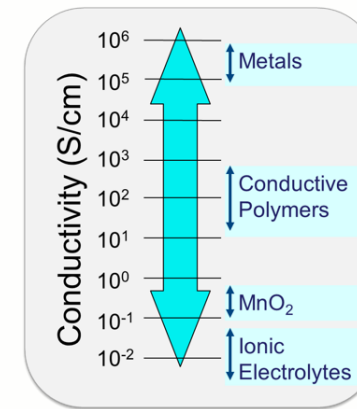
## Aluminum Electrolytic



## Solid Polymer Aluminum



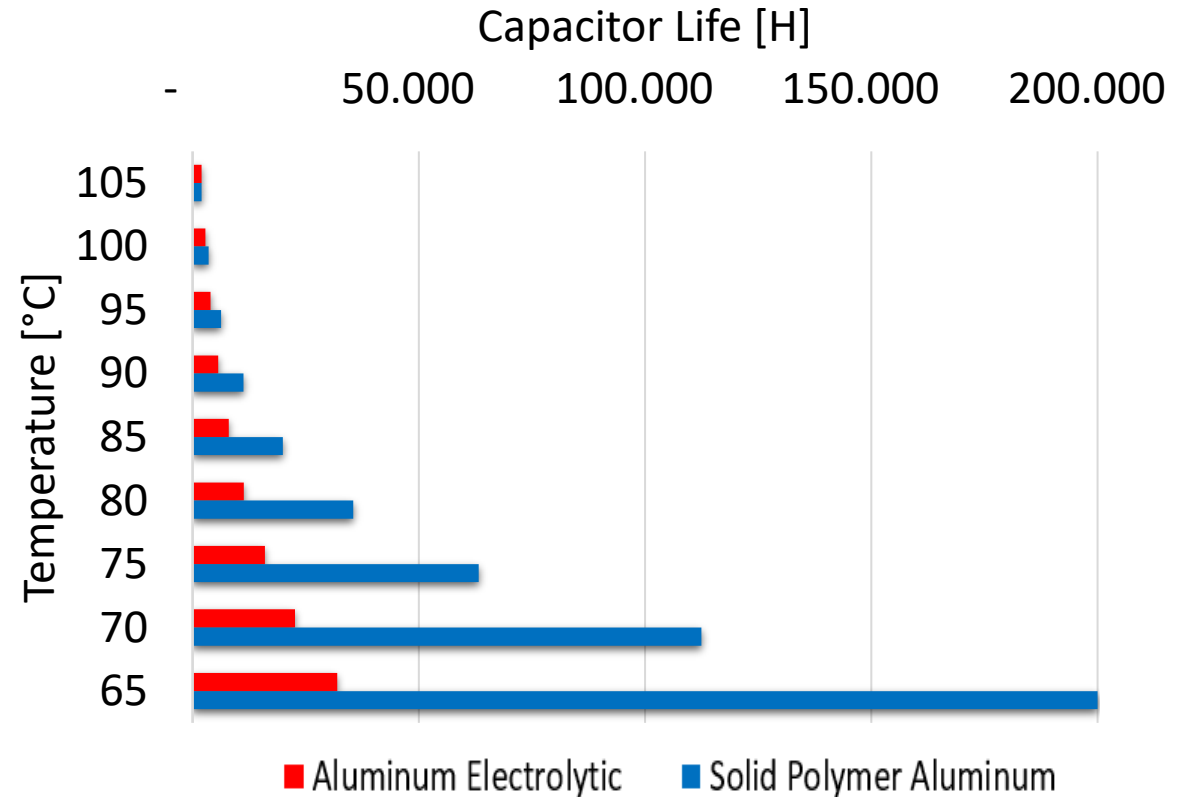
## Hybrid Aluminum



**Conductive Solid Polymer + Wet Electrolyte**

# Aluminium Polymer Capacitors

- Life Time Calculation
  - For the same 20°C decrease, the life expectancy of an aluminium electrolytic increases by a factor of 4, while an aluminium polymer capacitor increases by a factor of 10\*

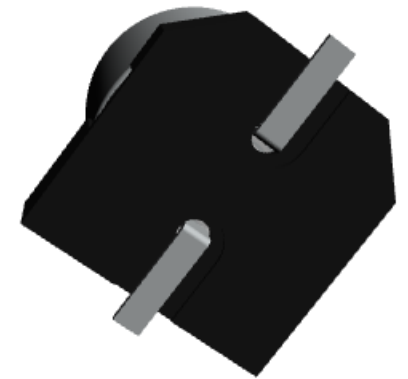
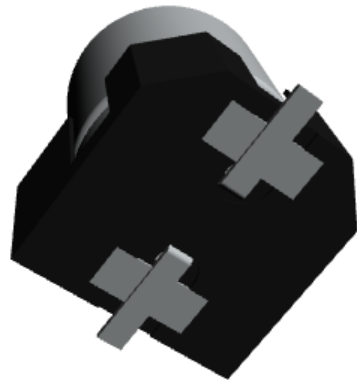


$$L_{\text{calc.}} = L_{\text{opr}} \times 2^{\frac{T_0 - T_{\text{amb}}}{10}}$$

$$L_{\text{calc.}} = L_{\text{opr}} \times 10^{\frac{T_0 - T_{\text{amb}}}{20}}$$

# Aluminium Polymer Capacitors

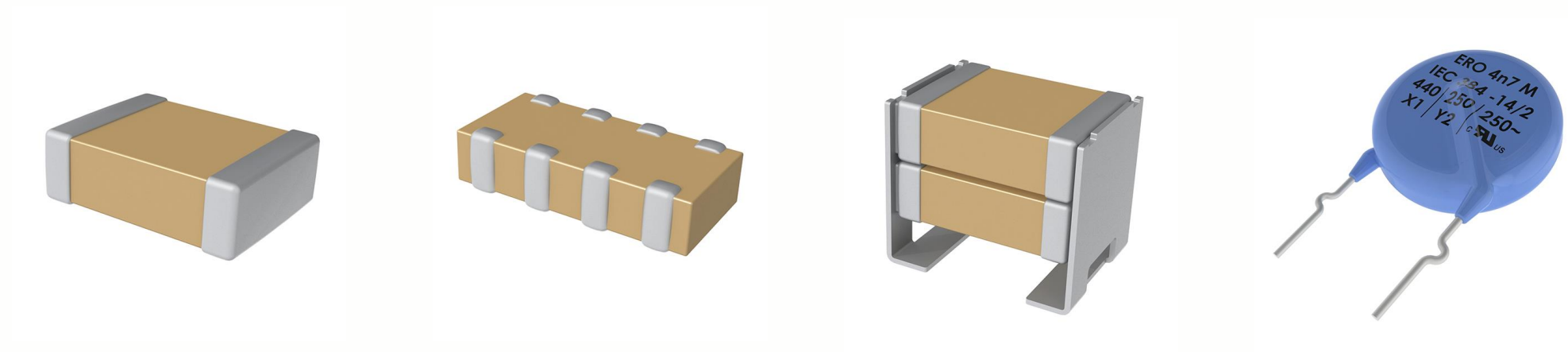
- Anti Vibration Socket
  - Taller base provides better support for part
  - Extra "dummy" terminals for stronger attachment to PCB
  - 30g Vibration capability
  - Only available with AEC-Q200 parts and 10mm diameter





# Ceramic Capacitors

- Smallest size SMD capacitors
- High voltage values
- Suitable for High Frequency Applications
- THT and Safety Versions available



# MLCC Aging

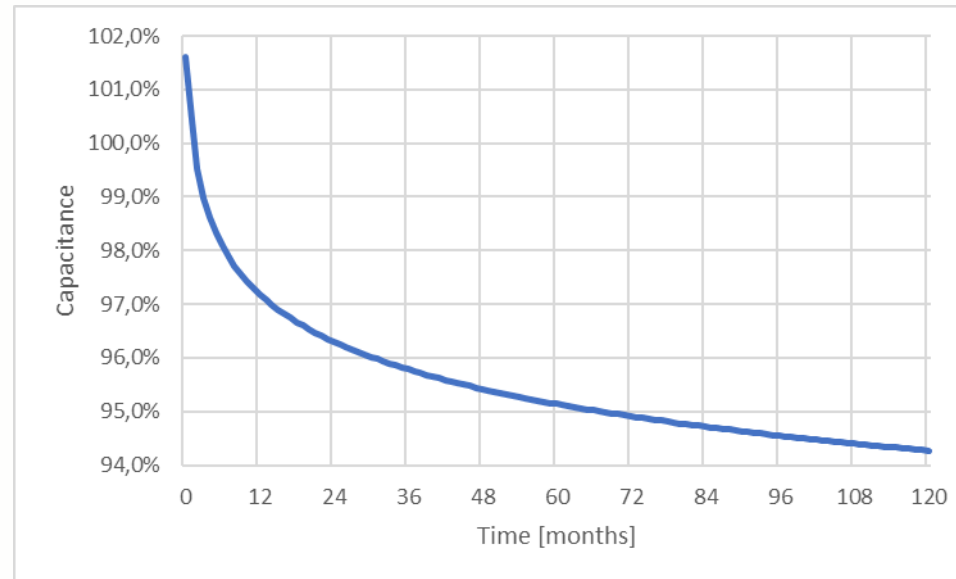
- Aging is the decrease of Capacitance over time
- Aging starts after heating above  $\sim 130^{\circ}\text{C}$  (Soldering)
- Reversible
- Capacitance measurements (including tolerance) are indexed to a referee time of 48 or 1,000 hours
  - C0G - 0% capacitance loss per decade hour
  - X7R - 3% capacitance loss per decade hour
  - X5R - 5% capacitance loss per decade hour

# MLCC Aging

- X7R Aging
  - After 1.000hrs (~42days) - 100% Capacitance
  - After 10.000hrs (~417days) - 97% Capacitance
  - After 100.000hrs (~11years) - 94,1% Capacitance
- X5R Aging
  - After 48hrs - 100% Capacitance
  - After 10.000hrs (~417days) - 88,8% Capacitance
  - After 100.000hrs (~11years) - 84,3% Capacitance

# MLCC Aging

- X7R Aging (in months)



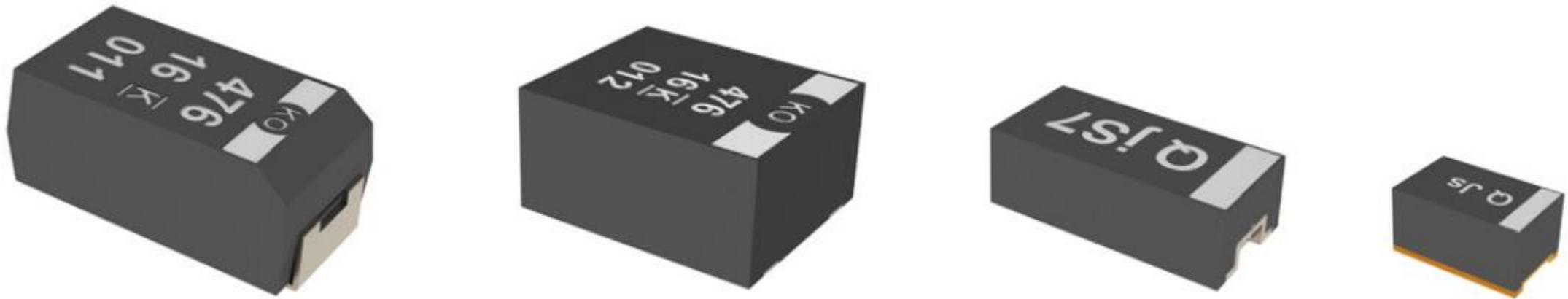
- Most significant capacitance losses within the first 36 months after the last soldering

# MLCC Aging

- X7R Capacitance Loss after
  - 1yr (8760hrs) - 97,2% Capacitance
  - 10yrs - 94,3% Capacitance
  - 100yrs (~KEMET founding) - 91,4% Capacitance
  - 2022yrs (Birth of Jesus) - 87,9% Capacitance
  - 65Myrs (end of Dinosaurs) - 76,6% Capacitance
  - 13,8Byrs (Big Bang) - 71,4% Capacitance

# Tantalum Capacitors

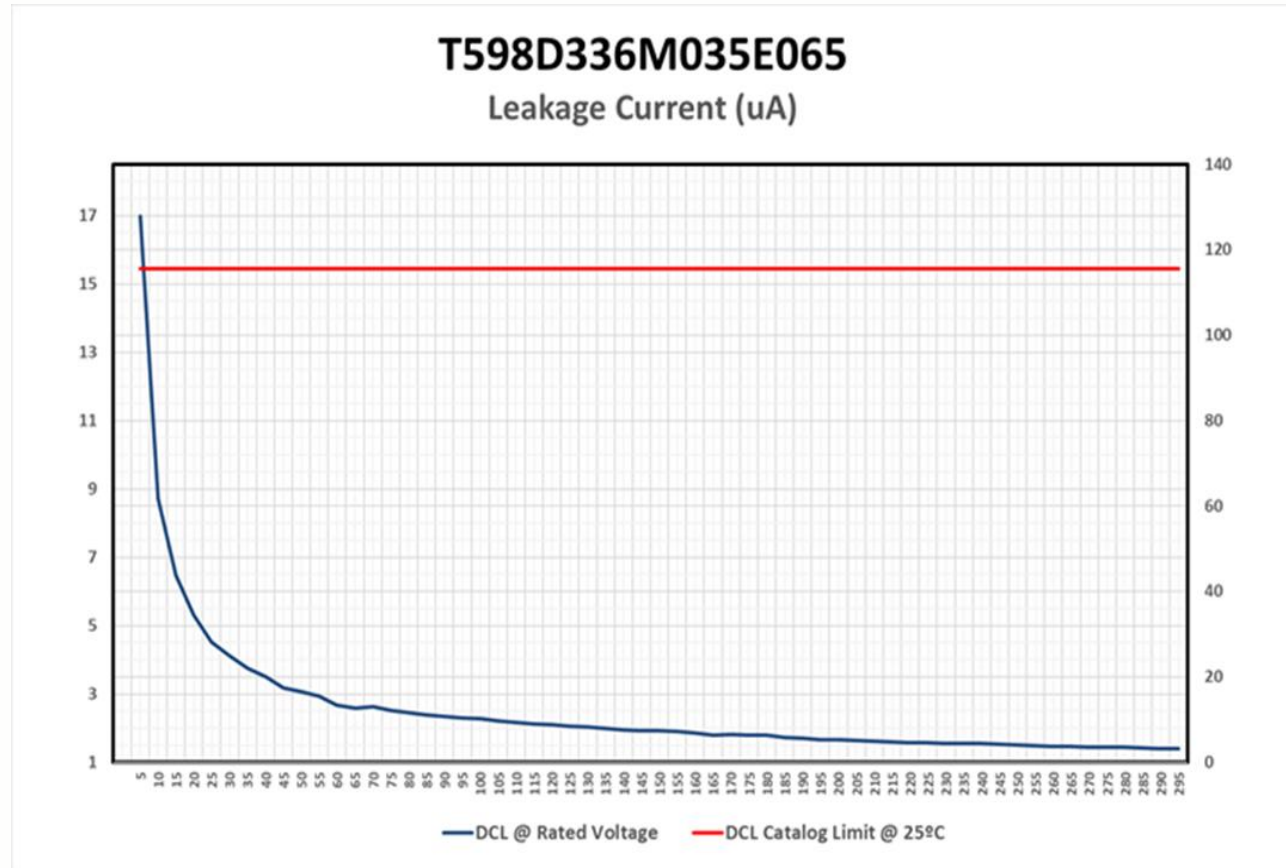
- Most stable capacitor series
- Small size SMD capacitors
- High capacitance values
- No lifetime limitation



# DC Leakage Current

- Real Measurement vs. Datasheet

$$DCL = 0.1 \cdot C \cdot V = 0.1 \cdot 33\mu F \cdot 35 = 115\mu A$$




# DC Leakage Current

- Conclusion:
  - LC is at its highest at first, and then reduces due to healing under voltage application
  - LC saturates after 5 to 10 mins
  - 0.1CV is taken as the worst case LC estimate: based on historical data and its Gaussian Distribution
  - Production and material improvements have ensured a much lower actual leakage current in real time implementation



# Lifetime

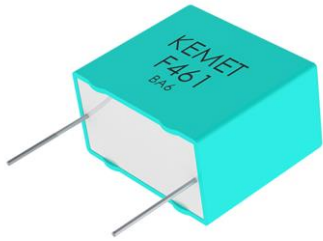
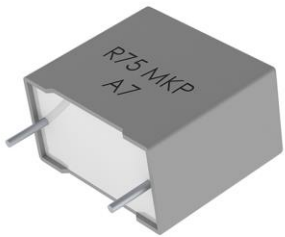
- Lifetime is the „*forbidden word*“ for passive components! 
- Polymer Tantalum Capacitors have the best technology for long lifetime
- Polymer Tantalum Capacitors have no
  - Aging Effect (MLCC)
  - Dry Out (Wet Electrolytics)
  - Life Time Limitation (Film Capacitors)

# Lifetime

- Calculation Example:
  - Application: 12V / max 90°C
  - T520 series / 16V / 125°C capacitor
  - $Life_{U_a, T_a} = 2000hrs \cdot 5109,57 = 10.219.131hrs = 1166years$
  - 10% lower Application Temperatur → **300%** longer life time: 3.639years
  - 20V Cap instead of 16V → **3550%** or 35x longer life time: 41.444years

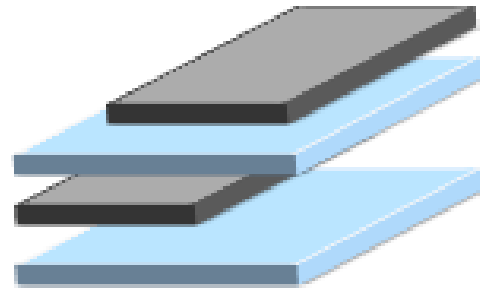
# Film Capacitors

- High Voltage, high Capacitances
- Fail Open, Self Healing
- Suitable for EMI Safety Applications



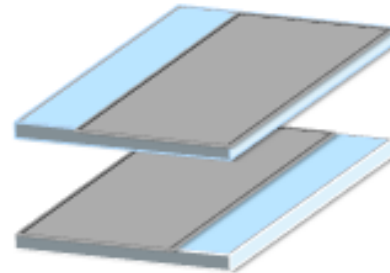
# Film Capacitor Basics

- Film/Foil employs a method where two electrodes (thin metal foils) are separated by a plastic film (dielectric)
- Advantages
  - High insulation resistance
  - High  $dv/dt$
  - Excellent current carrying and pulse handling
  - Good capacitance stability



# Film Capacitor Basics

- Metalized Film employs two plastic films which are chemical vacuum deposited with aluminium
- The Vacuum deposited aluminium provides an extremely thin metal layer (10nm to 20nm)
- The Metallization process can occur on a single side or both sides of the dielectric material
- Advantages:
  - High volume efficiency
  - Good self-healing properties
  - Higher Capacitance (per volume)
  - Less moisture ingress



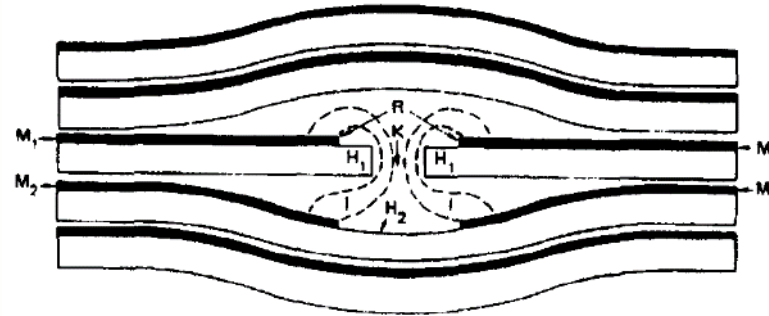
# Self Healing

- Process

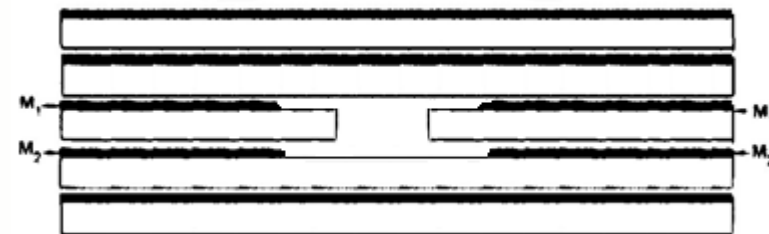
1. Failure



2. Evaporization



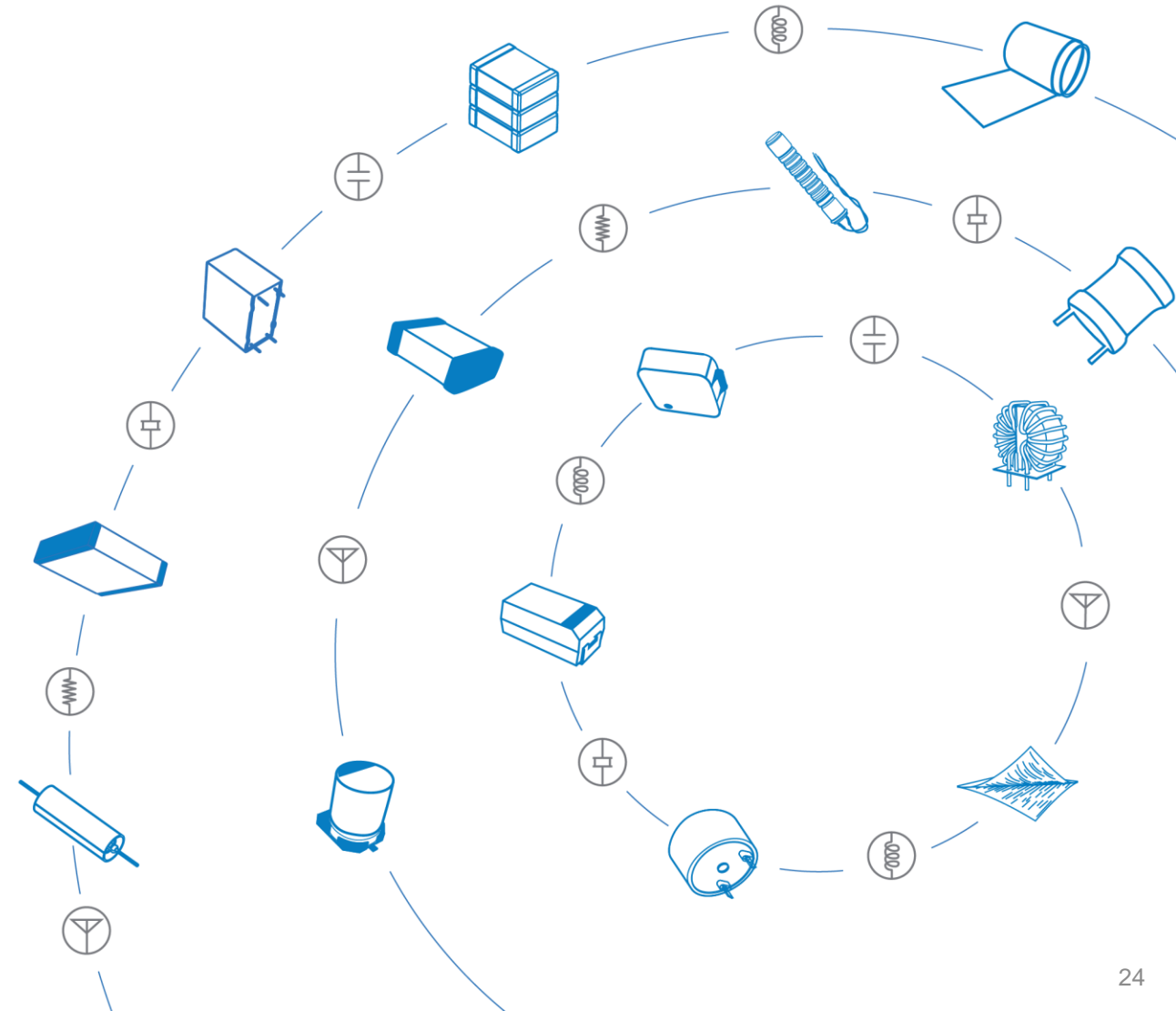
3. Isolated Area



# Self Healing

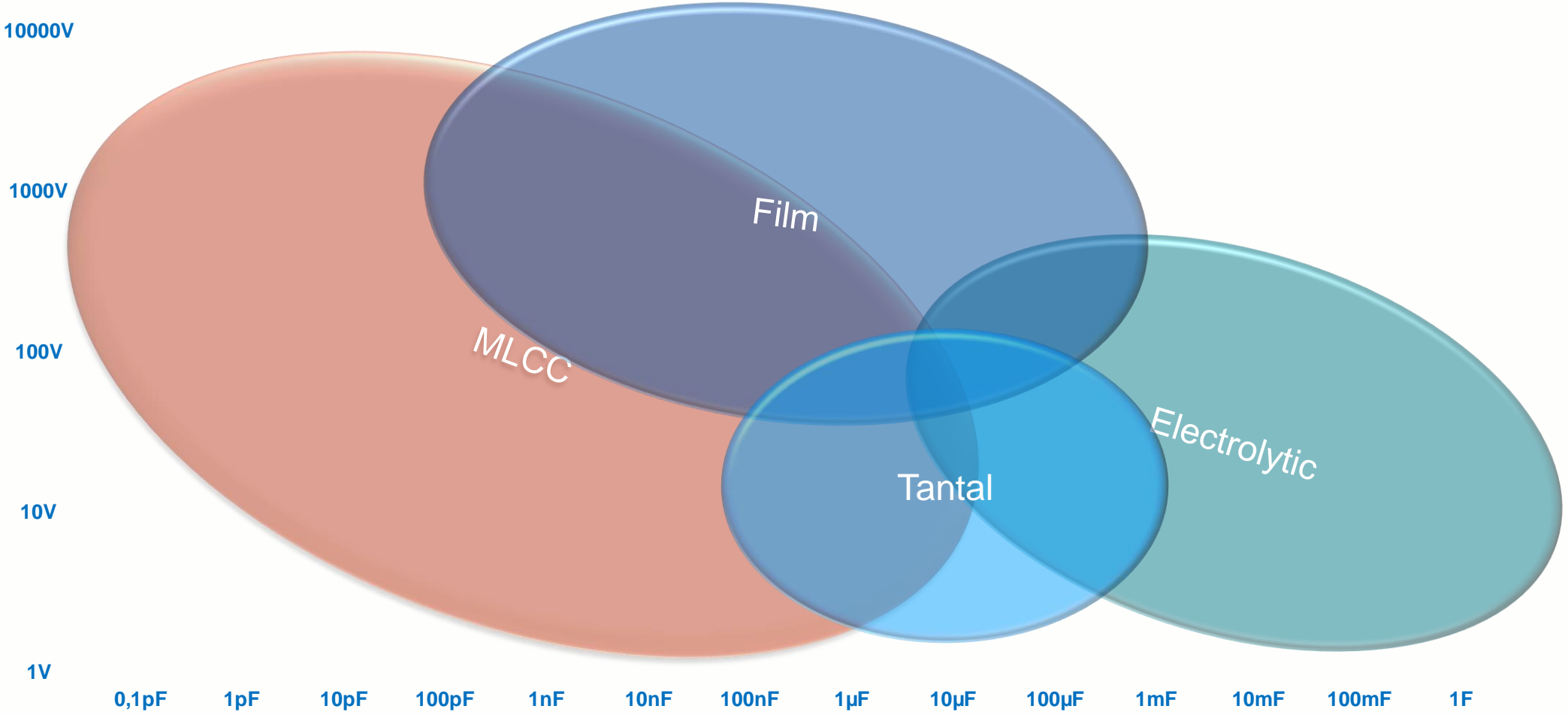
- Capacitors with metallized film have an excellent self healing property
  - In metallized film capacitors the metal layer is very thin
  - In case of dielectric breakdown, the energy released by the arc discharge evaporates the thin metal coating
  - This results in insulation restoring
  - Capacitor has only a small capacitance drop ( $\ll 1\%$ )
- Capacitors can be used in safety applications

# Capacitor Comparison





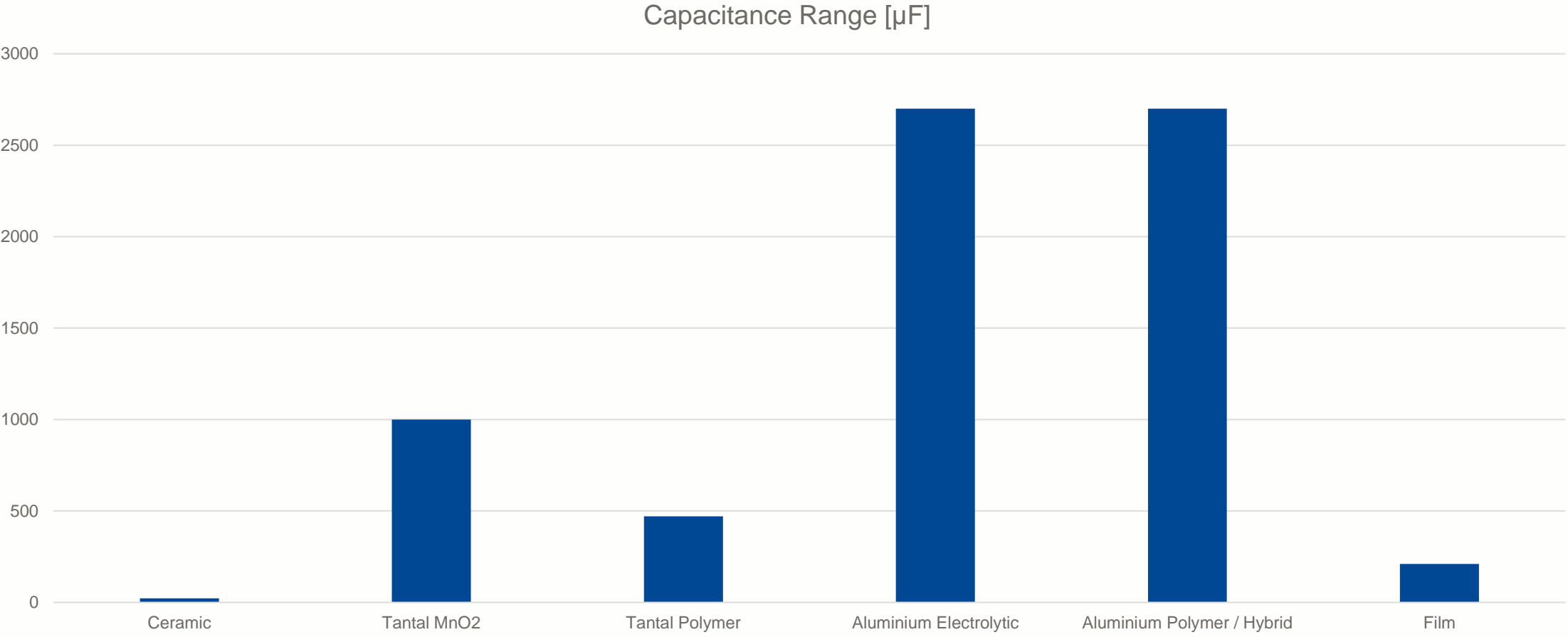
# Capacitor Comparison



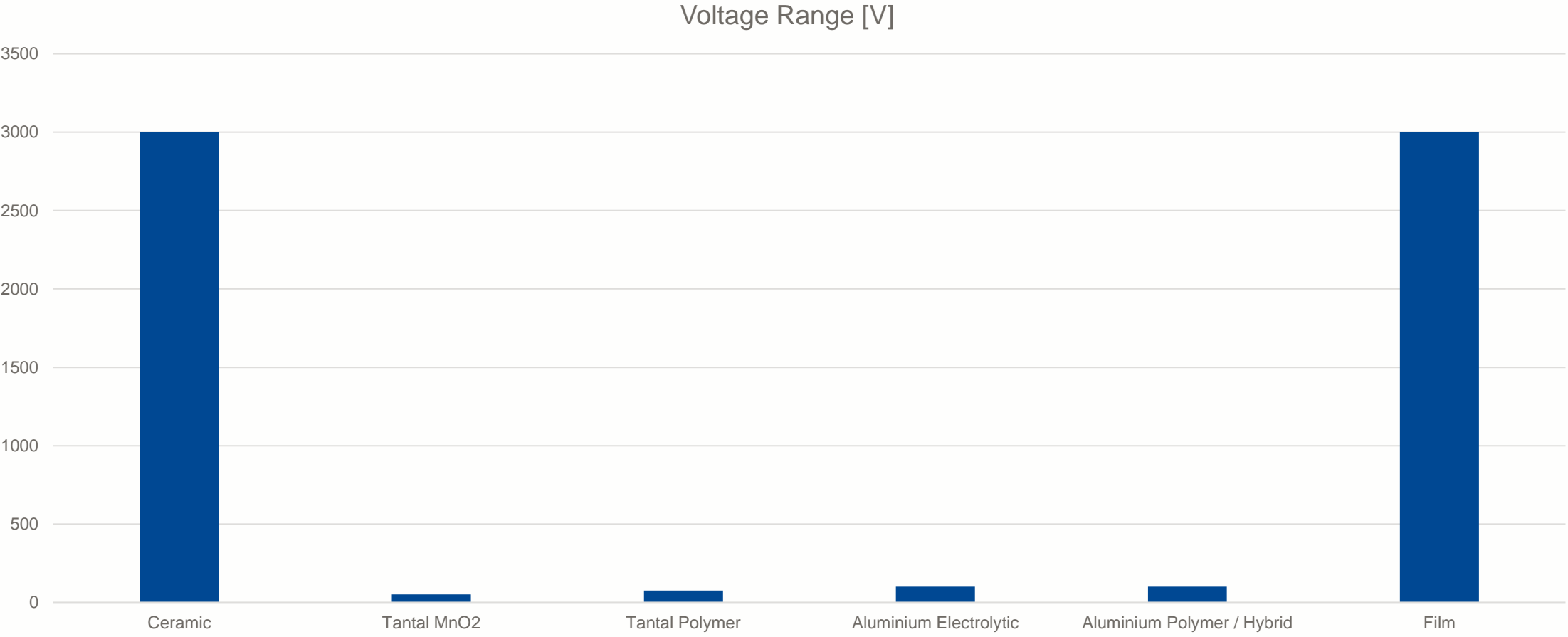
# Capacitor Comparison

- Main Factors:
  - Capacitance & Voltage
- More to consider:
  - Electrical: Frequency, Temperature, ESR, ESL, Leakage Current
  - Mechanical: Size, Height
  - Other: Lifetime, Stability, Solderability,
  - Commercial: Price, Availability, 2nd Source

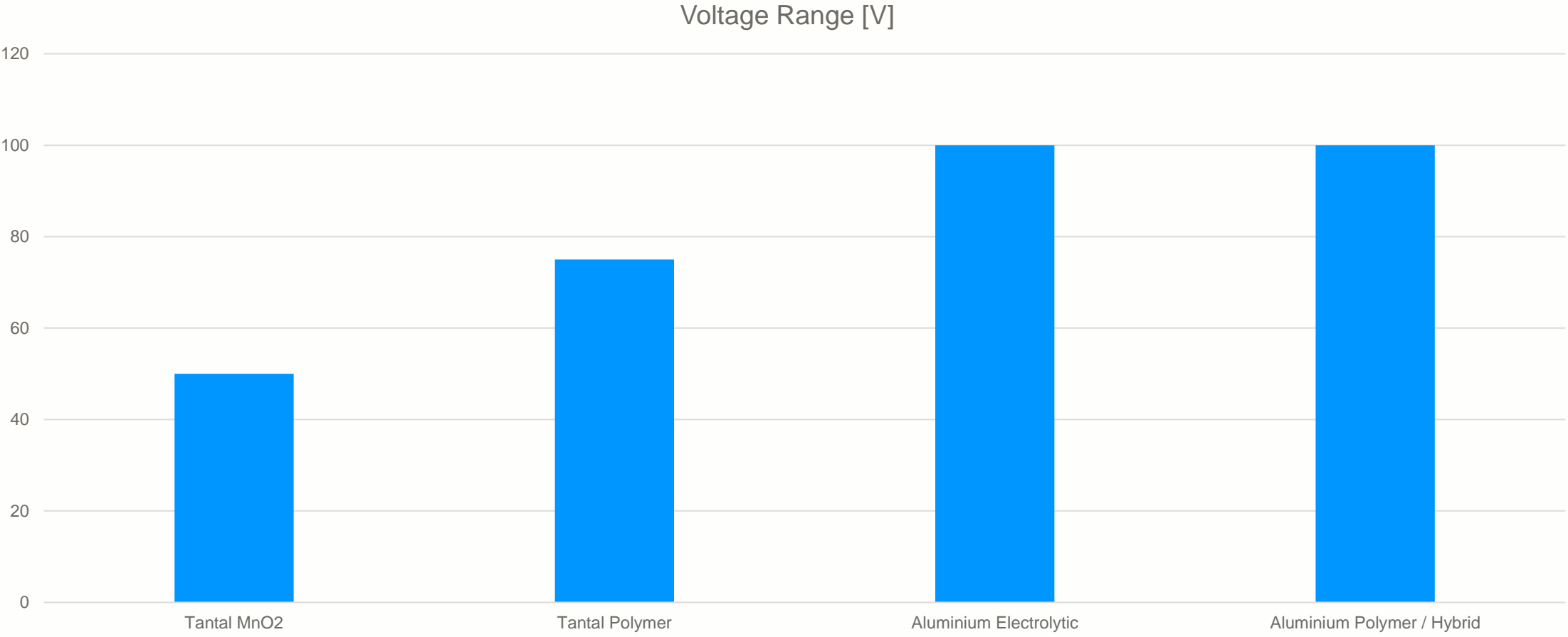
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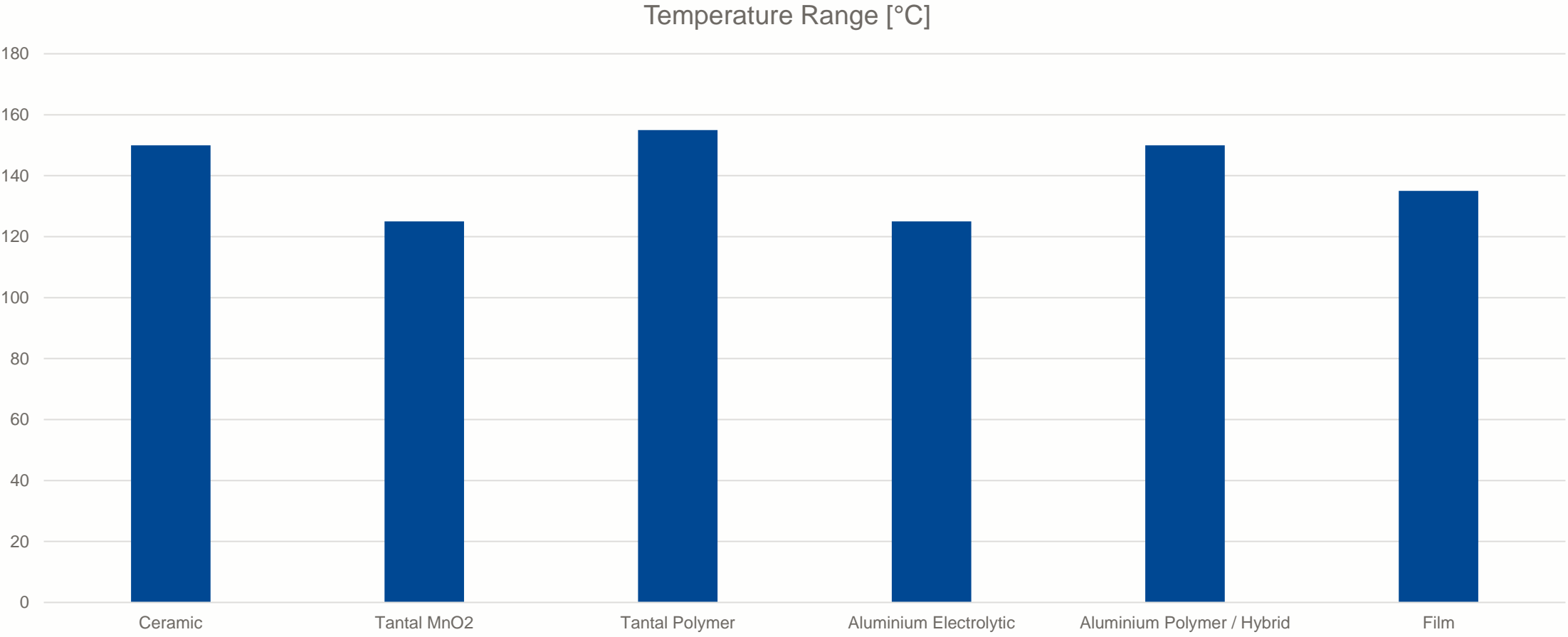
# Capacitor Comparison



# Capacitor Comparison

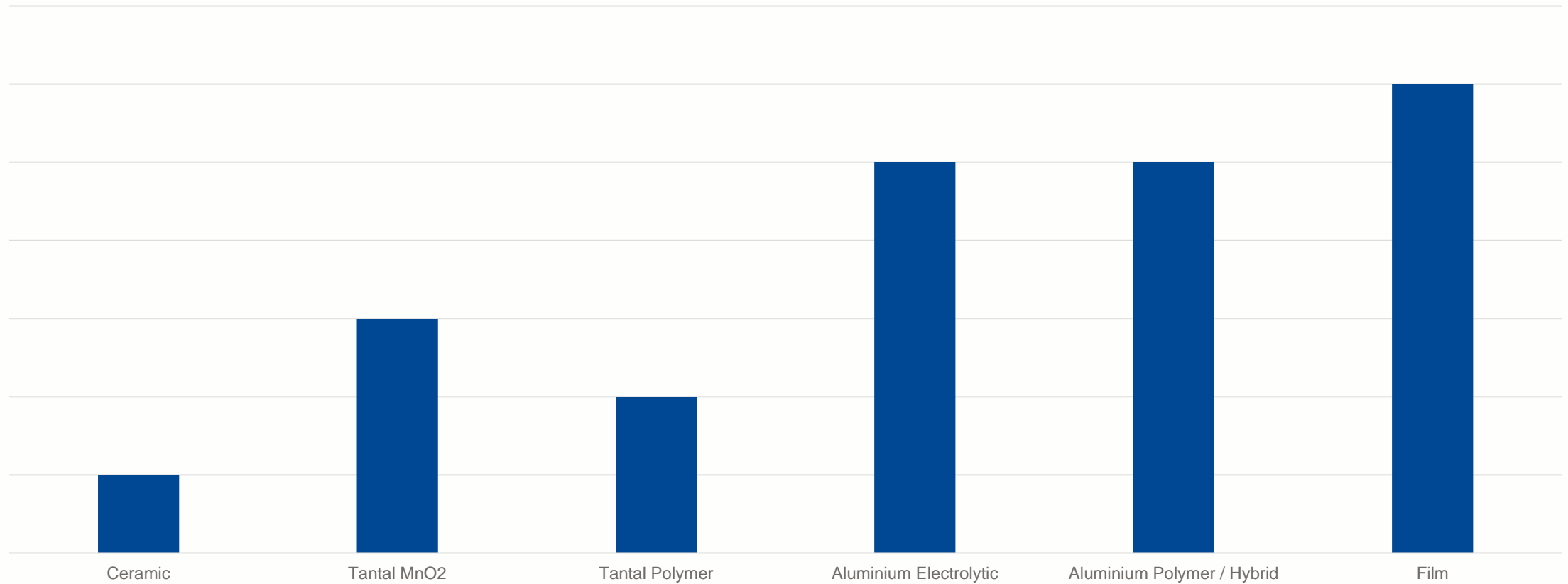


# Capacitor Comparison



# Capacitor Comparison

Mechanical



# SMD Capacitor Comparison

- SMD Capacitor Technology Comparison

Technology	Ceramic	Tantal Polymer	Aluminium Electrolytic (SMD)	Aluminium Polymer (SMD)
Capacitance Range	max. 22 $\mu$ F	max. 470 $\mu$ F	max. 2700 $\mu$ F	max. 2700 $\mu$ F
Voltage Range	max. 3kV <sub>DC</sub>	max. 50V <sub>DC</sub>	max. 100V <sub>DC</sub>	max. 100V <sub>DC</sub>
Size Range (EIA)	<b>0402 - 2220</b>			
Size Range (mm)	1005 - 5750	<b>2012 - 7743</b>	<b>Ø4 – Ø16</b>	<b>Ø4 – Ø16</b>
Lifetime	Good	Perfect	Limited	Good



# SMD Capacitor Comparison

- SMD Capacitor Technology Comparison

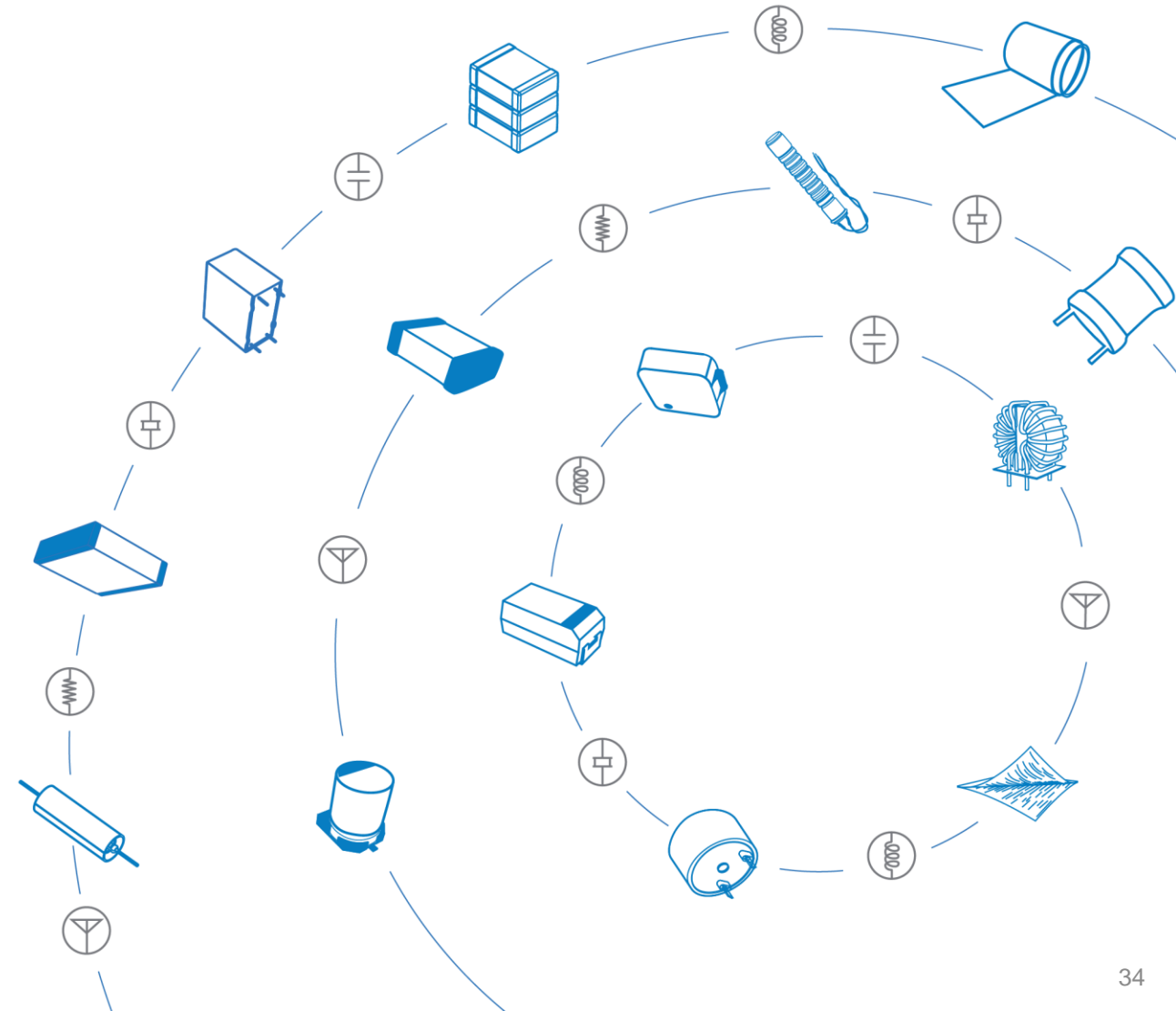
Technology	Ceramic	Tantal Polymer	Aluminium Electrolytic (SMD)	Aluminium Polymer (SMD)
Capacitance Range	max. 22 $\mu$ F	max. 470 $\mu$ F	max. 2700 $\mu$ F	max. 2700 $\mu$ F
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Size Range (EIA)	0402 - 2220			
Size Range (mm)	1005 - 5750	2012 - 7743	Ø4 – Ø16	Ø4 – Ø16
Lifetime	Good	Perfect	Limited	Good
Price per piece <sup>1)</sup>	Low	High	Low	Mid
Price per $\mu$ F <sup>2)</sup>	High	Low	Low	Mid
Price per Volume <sup>3)</sup>	Low	Mid	Low	High

1: 1 $\mu$ F

2: 100 $\mu$ F / 100V

3: 10 $\mu$ F / 100mm<sup>3</sup>

# Summary & Key Takeaways



# Capacitors

Technology	Properties	To be considered
Ceramic	Small Size, High Frequency, High Voltage	Limited Cap Value, Losses, Aging
Film / Paper	Safety, High Current, Pulse Current	Limited Temperature, Size, Lifetime
Electrolytic	High Capacitance, High Voltage, High product variety	Limited Temperature, Limited Lifetime, Dry Out Effect
Tantalum	Very Stable, Small Size,	Limited Voltage, Limited frequency, Peak Pulse behavior

# Summary

- Each technology has properties and benefits
- No technology can ideally replace another one
- For each application there is one perfect capacitor solution
- RUTRONIK or YAGEO Sales and FAE can help to find this solution
- Those who consider everything will make the best and most efficient decision

