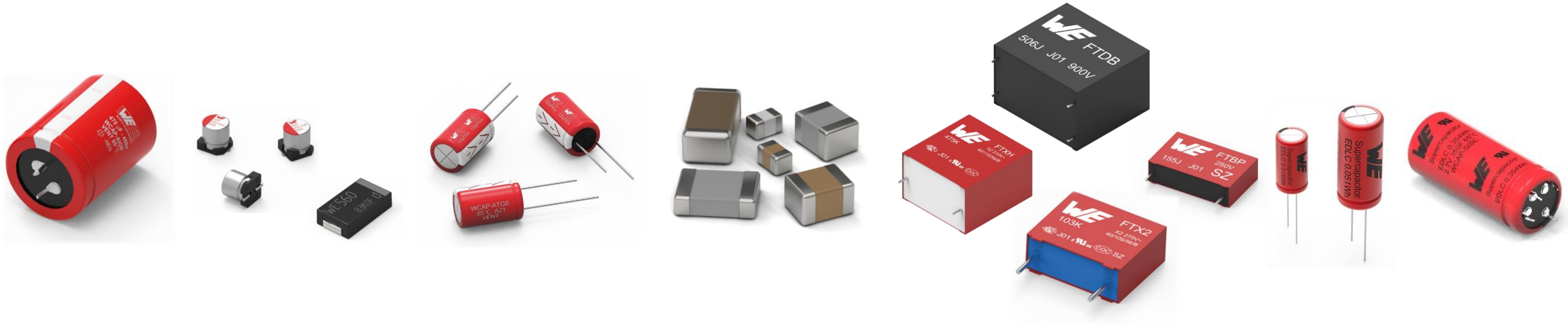

INTRODUCTION TO THE CAPACITOR TECHNOLOGIES AND HOW TO USE THEM

Partnered with Digi-Key Electronics

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TODAY'S SPEAKERS

PRESENTATION
Thomas Frahsek
Business Development Manager

MODERATION
Amelia Thompson
Marketing Department

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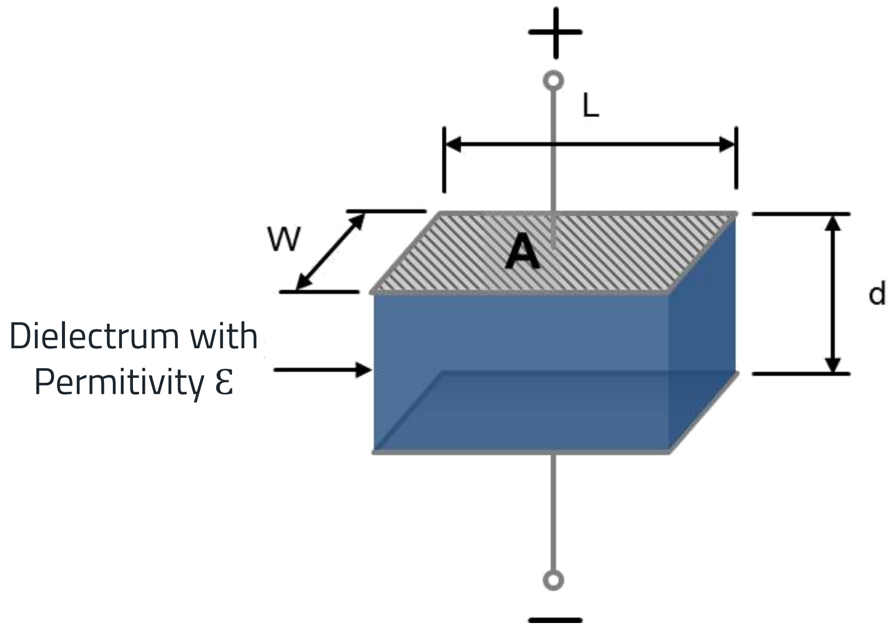
AGENDA

- Technical Basics & Overview
- Technologies
  - MLCC
  - Film Capacitors
  - Aluminum Capacitors
  - Supercapacitors
- Summary
- Questions

BASICS OF CAPACITORS

Overview & Basics of Capacitors

- Construction of a plate Capacitor



$$C = \varepsilon * \frac{A}{d} = \varepsilon_0 * \varepsilon_r * \frac{A}{d}$$

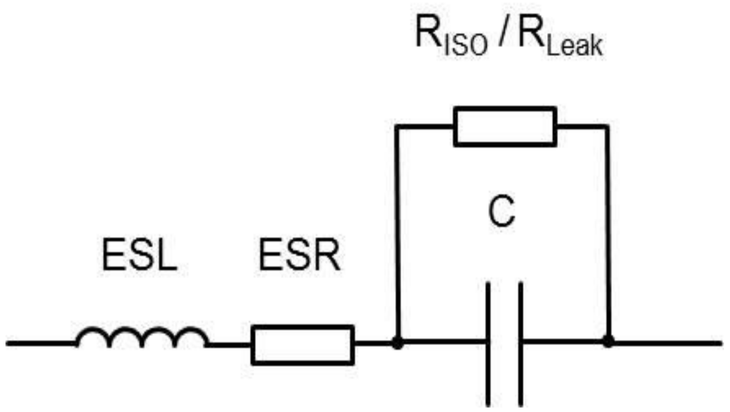
C – Capacitance [F]
A – plate surface
d – plate distance
ε_0- absolute Permittivity
ε_R- relative Permittivity

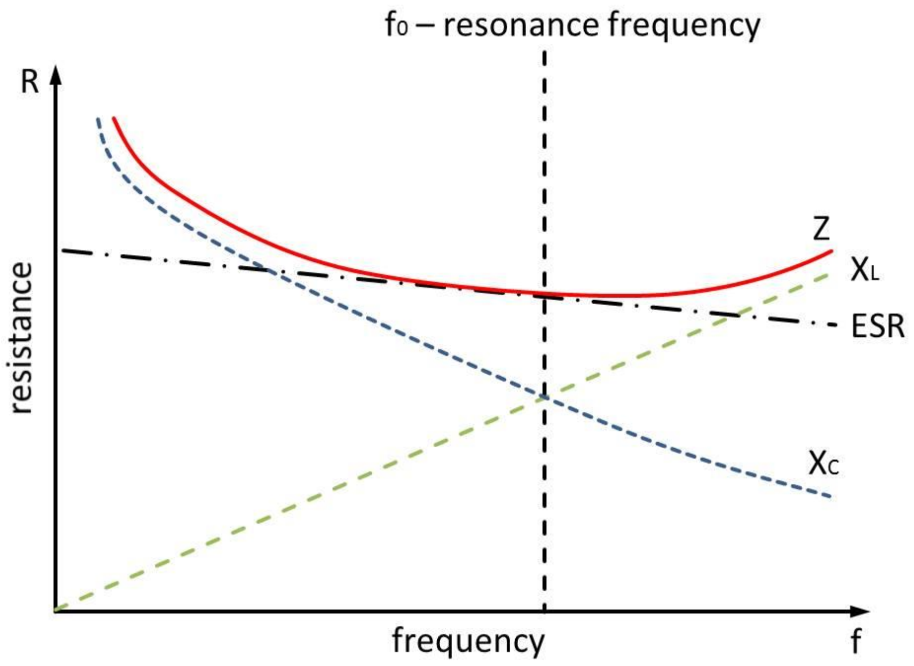
Material	relative Permittivity – (ε_R) (typical values @20°C)
Vaacum	1
Air	1,00059
Paper	1,6...2
Paraffin paper	2
Polystyrene	2,3
Polypropylene	2,5
Polyethylene	2,5 ...4,5
Glass	5
Aluminumoxide	9,3
Tantalumpentoxide	26
Niobiumpentoxide	42
Ceramic Class 1	10...500
Ceramic Class 2	700...>100000

BASICS OF CAPACITORS

Equivalent circuit

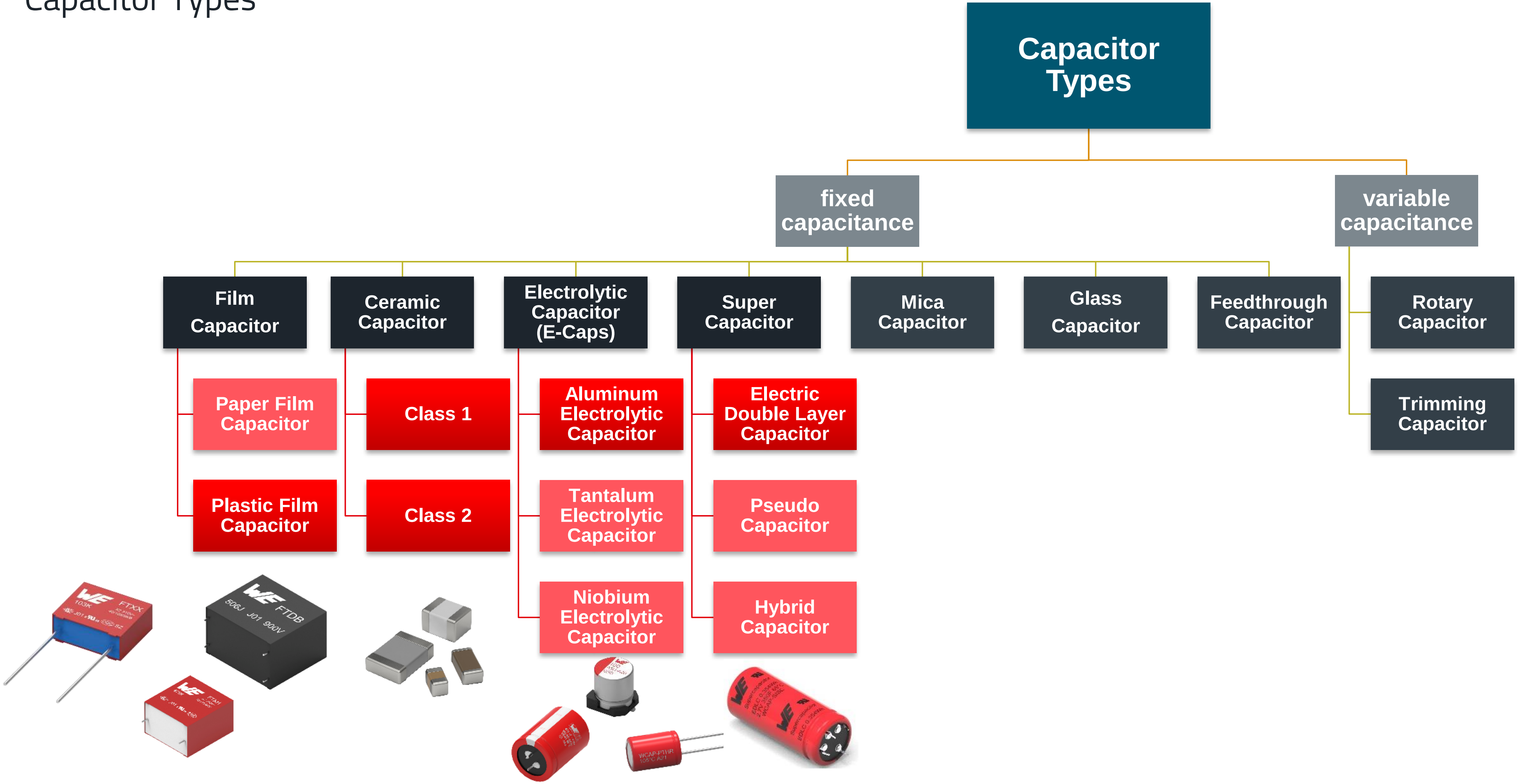
- Every passive component has parasitic side effects next to it main functions





BASICS OF CAPACITORS

Capacitor Types

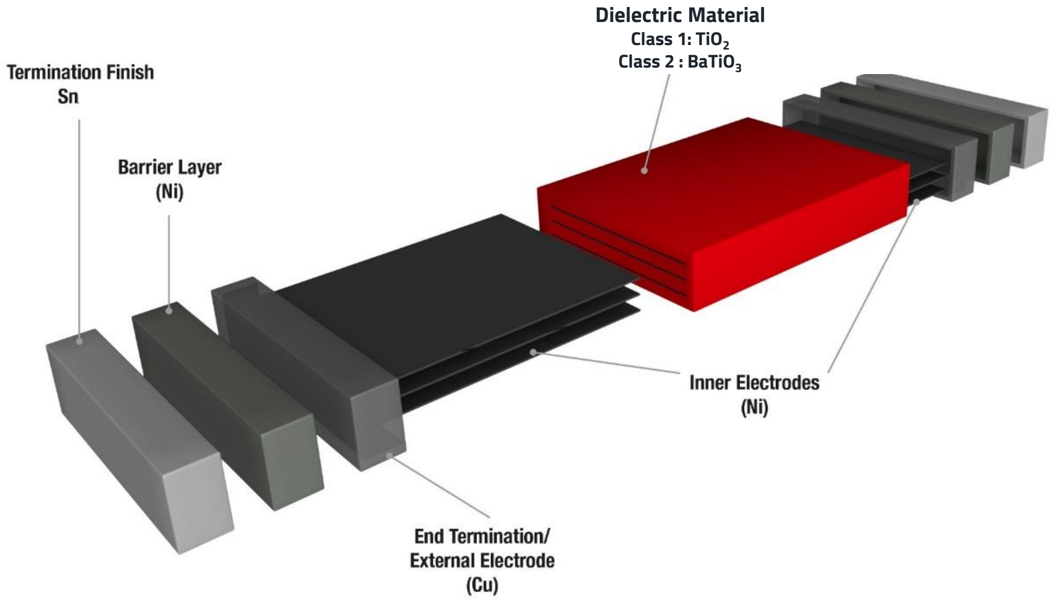


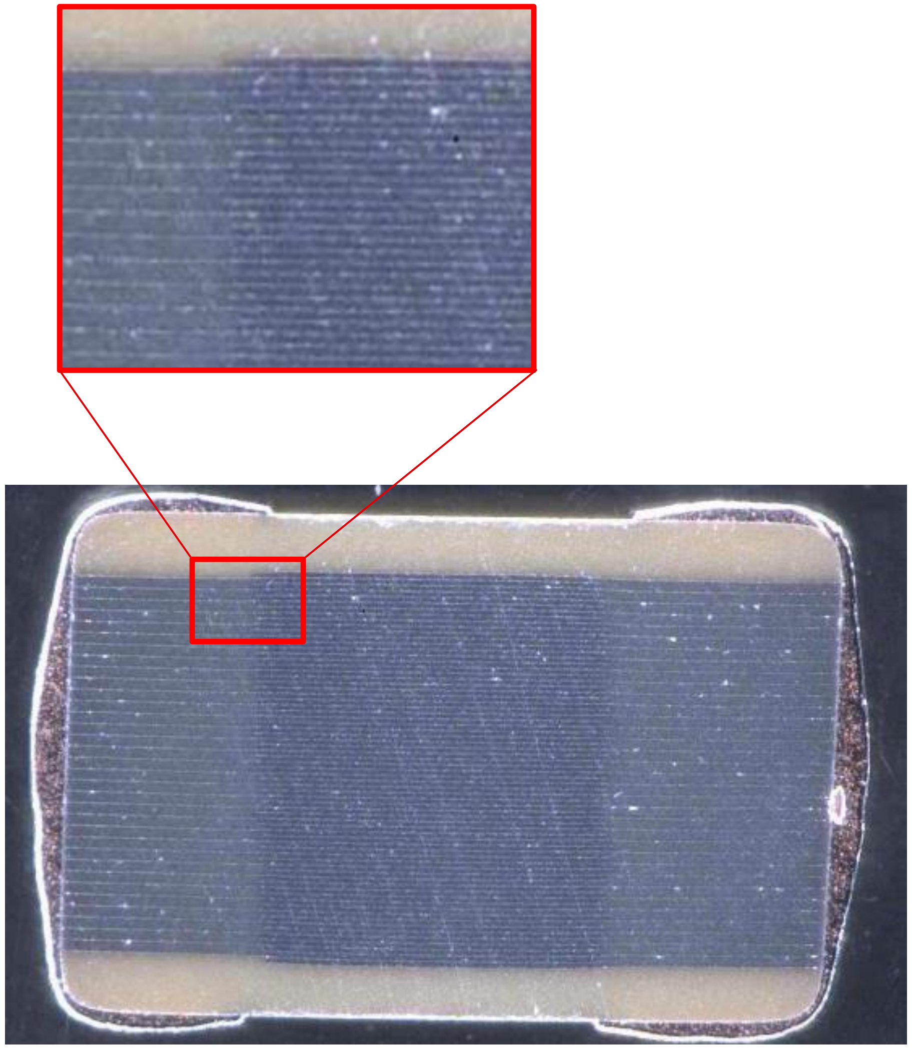
BASICS OF CAPACITORS

Technology	Max. Capacitance	Max. Voltage	Max. Current	Max. Temperature range	Application examples
Aluminum Electrolytic Capacitors	> 1F	ca. 650 V	ca. 0,05 A/µF	85°C up to 150°C	smoothing, storage, DC-Link
Aluminum Polymer Capacitors	> 4 mF	ca. 250 V	Ca. 0,1 A/µF	85°C up to 150°C	smoothing, filtering
Al. Hybrid Polymer Capacitors	> 1 mF	ca. 400 V	Ca. 0,1 A/µF	85°C up to 150°C	smoothing, filtering, DC Link
Film Capacitors	> 8 mF	ca. 3 kV	ca. 1 A/µF	max. 110°C	DC Link, interference suppression, filtering
MLCC	> 100 µF	ca. 10 kV	ca. 10 A/µF	85°C up to 200°C	interference suppression, coupling, filtering
Supercapacitors (EDLCs)	> 350 F	ca. 3.3 V	ca. 0,21 A/F	65° up to 85°C	UPS, storage

MLCC (MULTILAYER CERAMIC CAPACITOR)

Composition of general purpose MLCCs



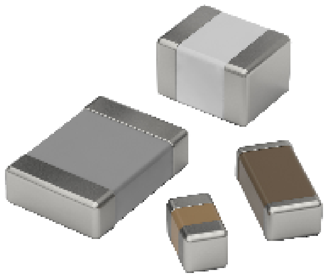


Example cross section of a general purpose MLCC

MLCC (MULTILAYER CERAMIC CAPACITOR)

Class 1 and Class 2 MLCCs

- **Class 1 Ceramic** – (e.g. NP0 / C0G)
  - Relative small Permitivity ε_r >> small capcitance values possible
  - linear temperature dependency
  - Next to no aging
  - Very small voltage dependency
  - Suitable for high frequency applications

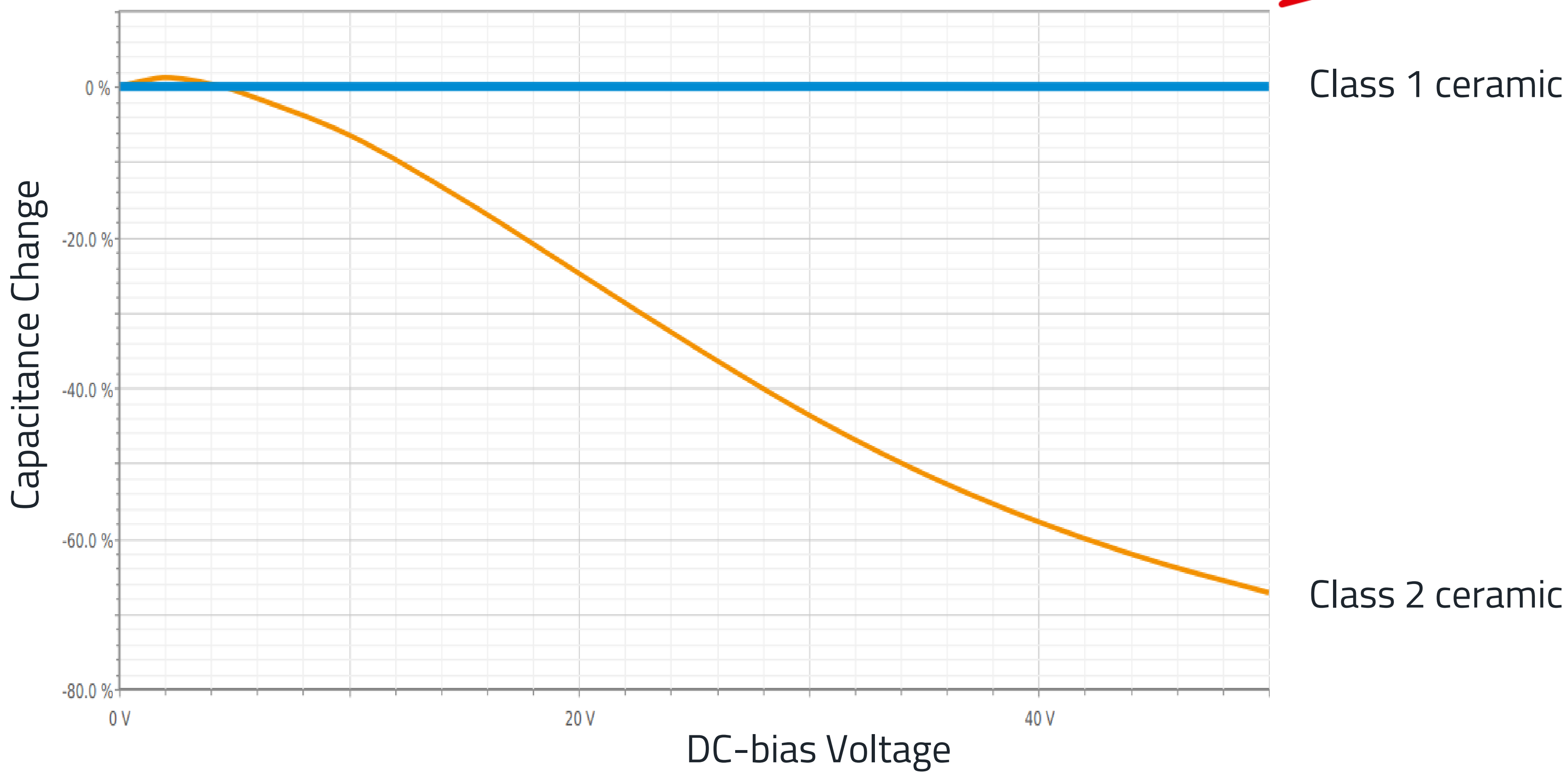


- **Class 2 Ceramic** – (e.g. X7R, X5R, Y5V, ...)
  - Relative high Permitivity ε_r → High capacitance values available
  - Nonlineare temperature dependency
  - Aging
  - High Voltage depency in many cases

MLCC (MULTILAYER CERAMIC CAPACITOR)

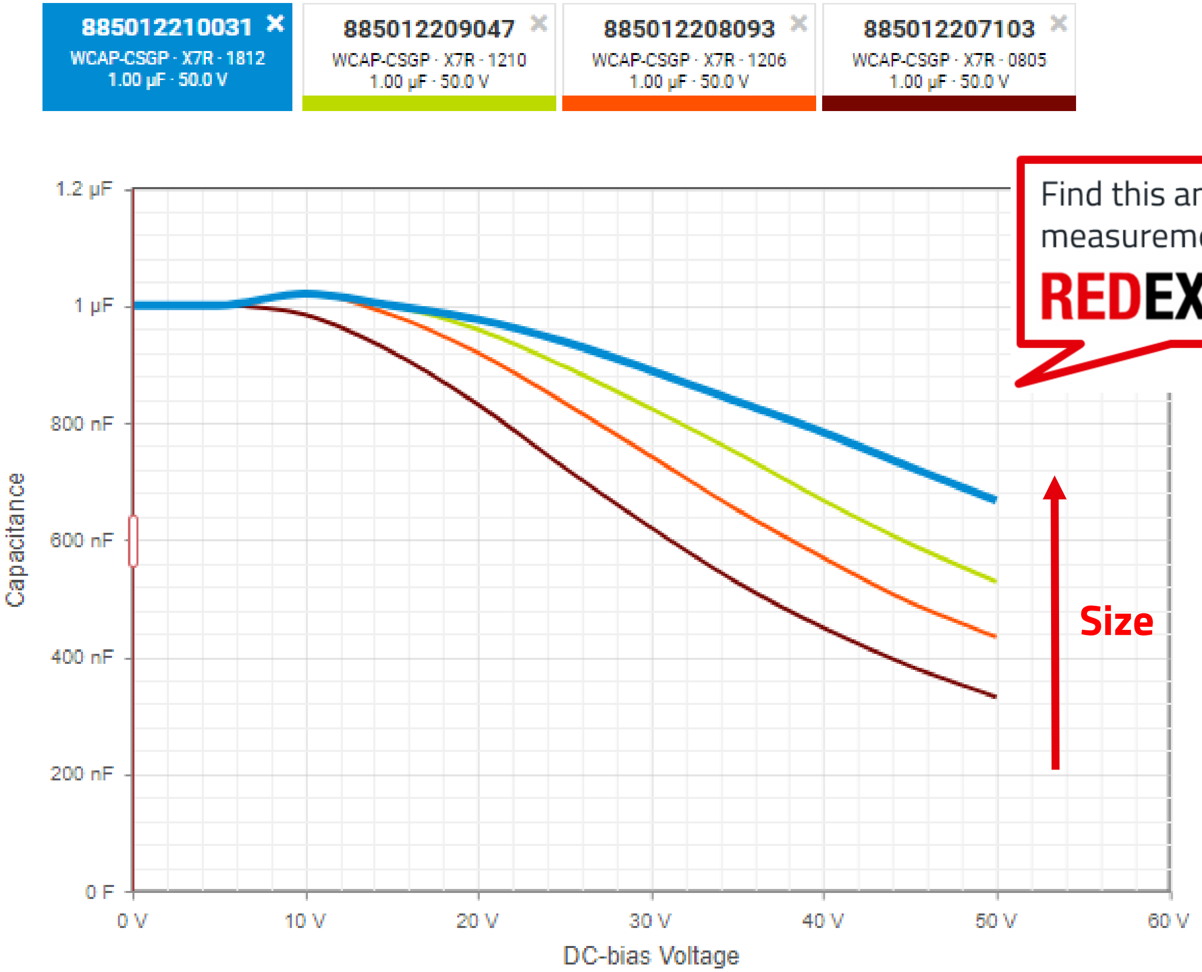
Voltage dependancy of the Capacitance Value (DC-Bias, typical curve)

Find this and more measurements in REDEXPERT®



MLCC (MULTILAYER CERAMIC CAPACITOR)

Voltage dependancy of the Capacitance value (DC-Bias)



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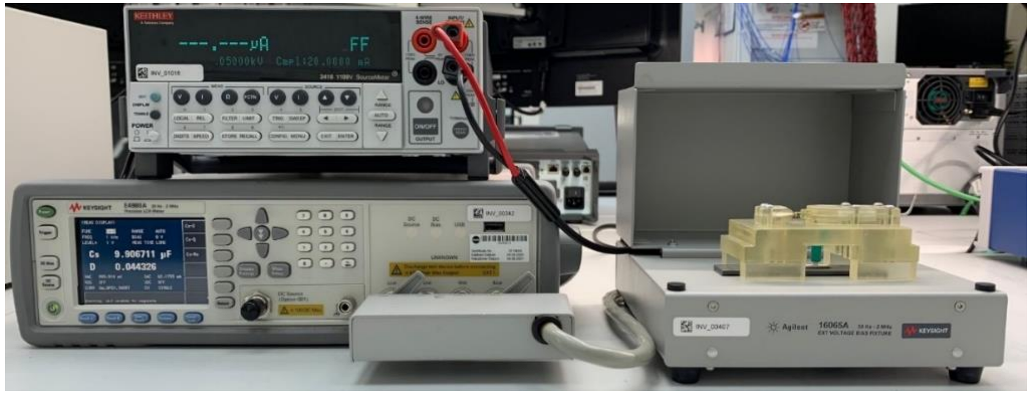
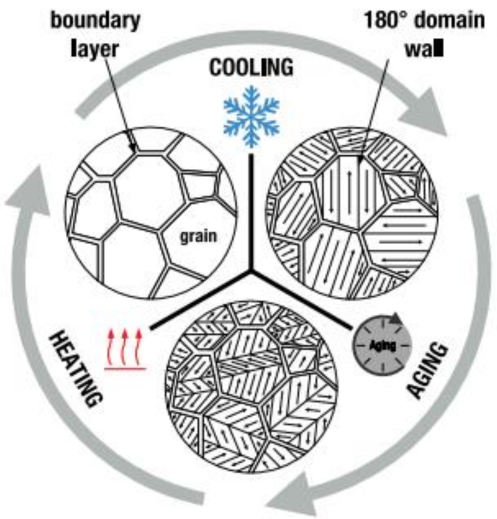


- Capacitance drop affects only Class II Ceramic Capacitors
- Heavily dependent on size
- No specification on the datasheet!
- Only reference curves or simulation models

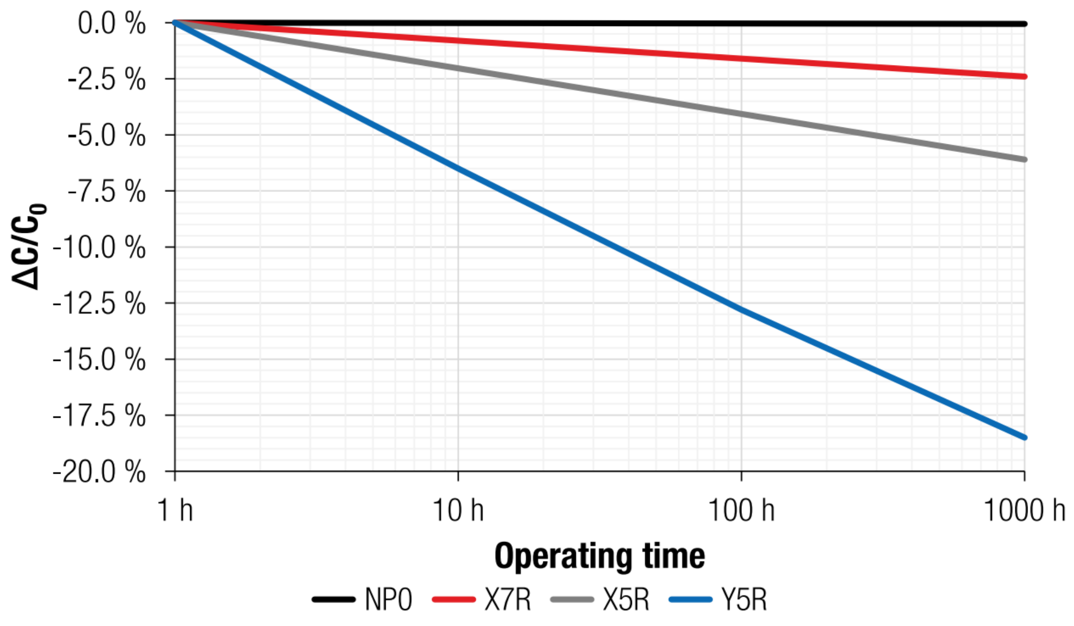
MLCC (MULTILAYER CERAMIC CAPACITOR)

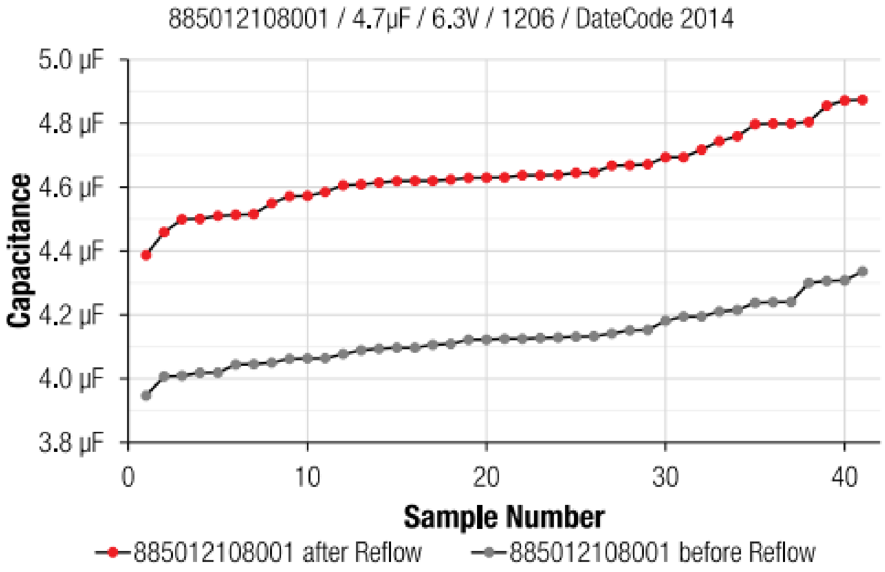
Aging of MLCCs

- Aging process due to changes in crystal structure
- Decreased permittivity cause capacitance loss
- Class 1 (NP0) no aging
- Class 2 has different aging
- Behavior depends on ceramic materials



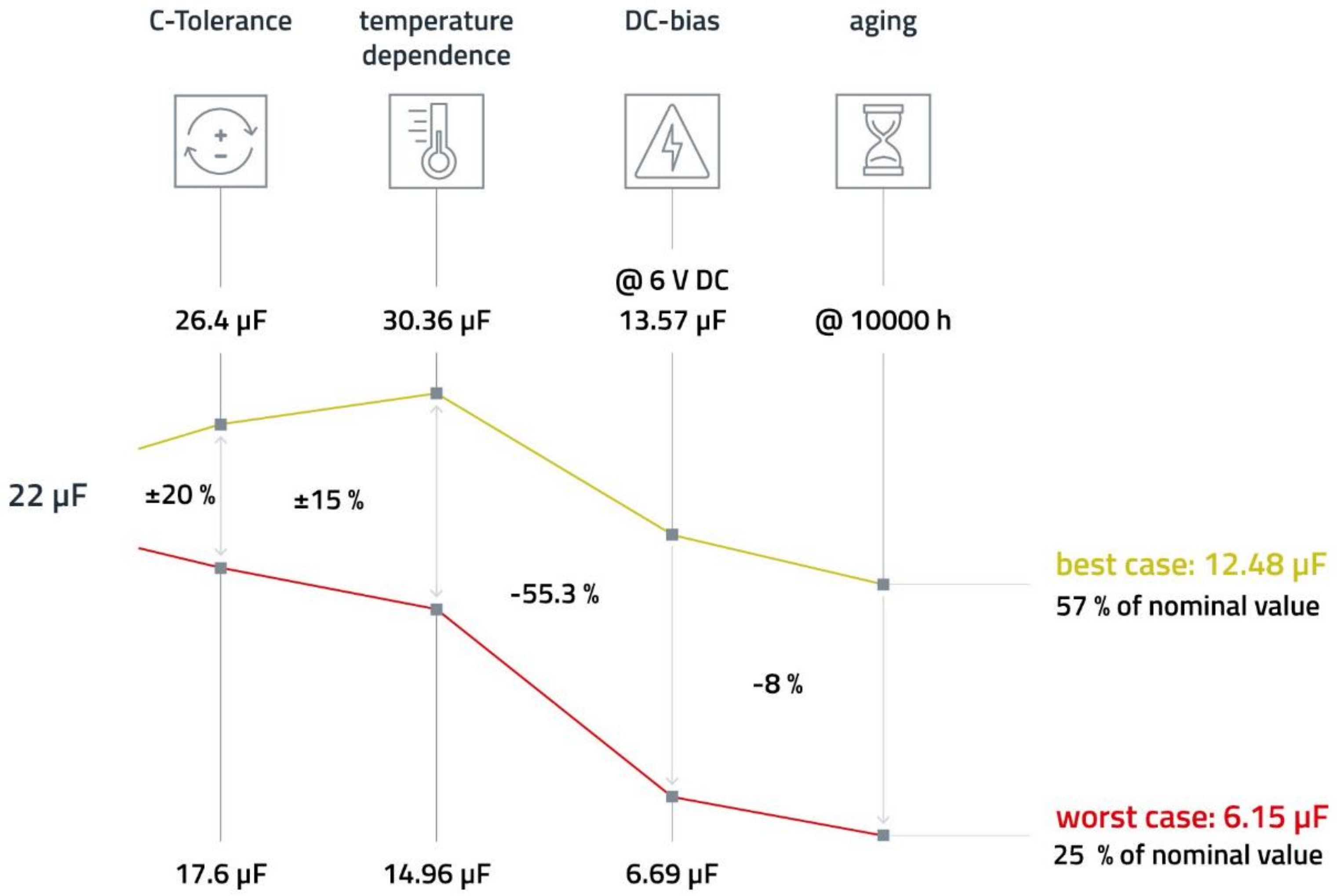
Check the **Application Note SN011** for more information about MLCC Aging





MLCC (MULTILAYER CERAMIC CAPACITOR)

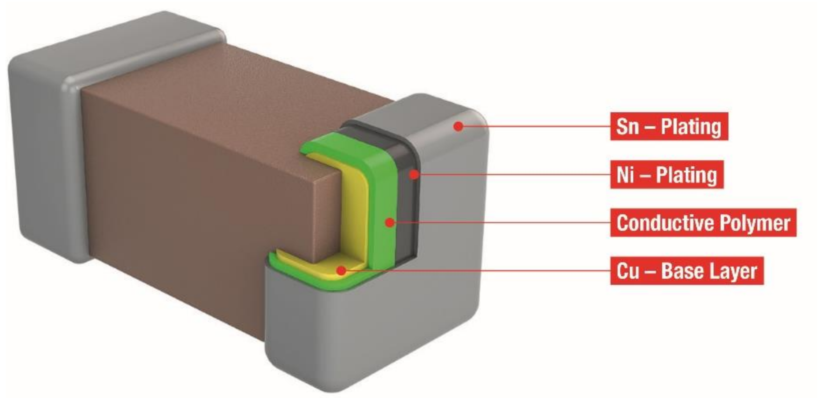
Capacitance yield of Class 2 ceramics

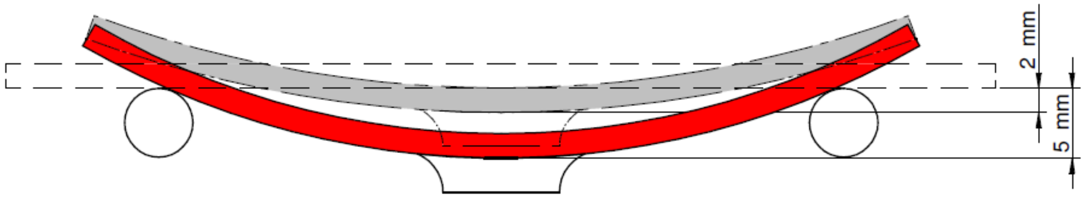


MLCC (MULTILAYER CERAMIC CAPACITOR)

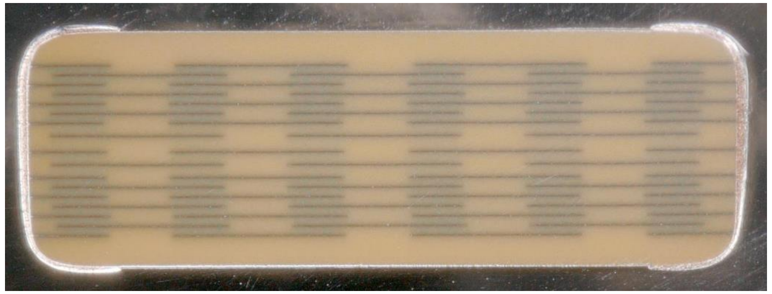
Special Cases

Soft termination Capacitor



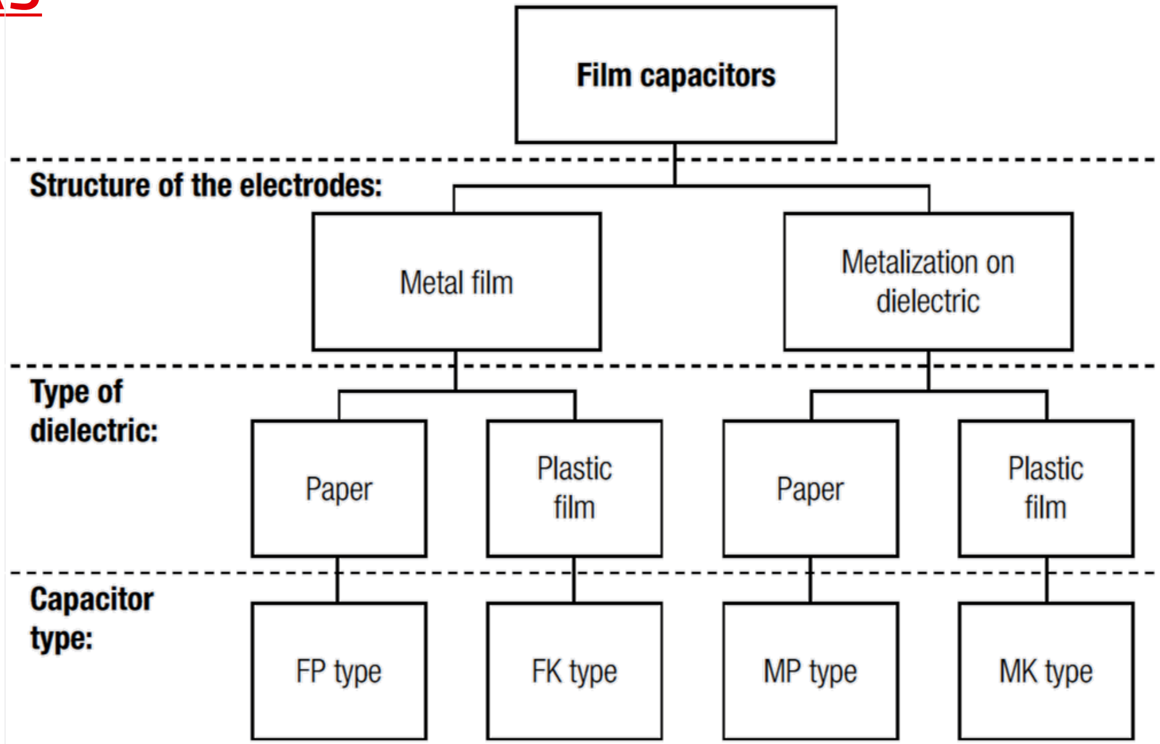


Safety Capacitors for power supply application (X1/X2/Y2)



FILM CAPACITORS

Construction

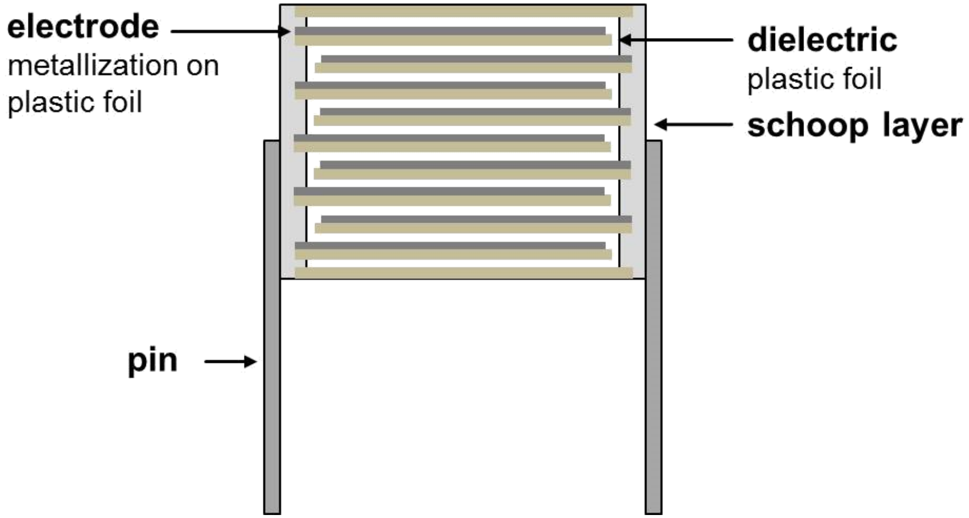


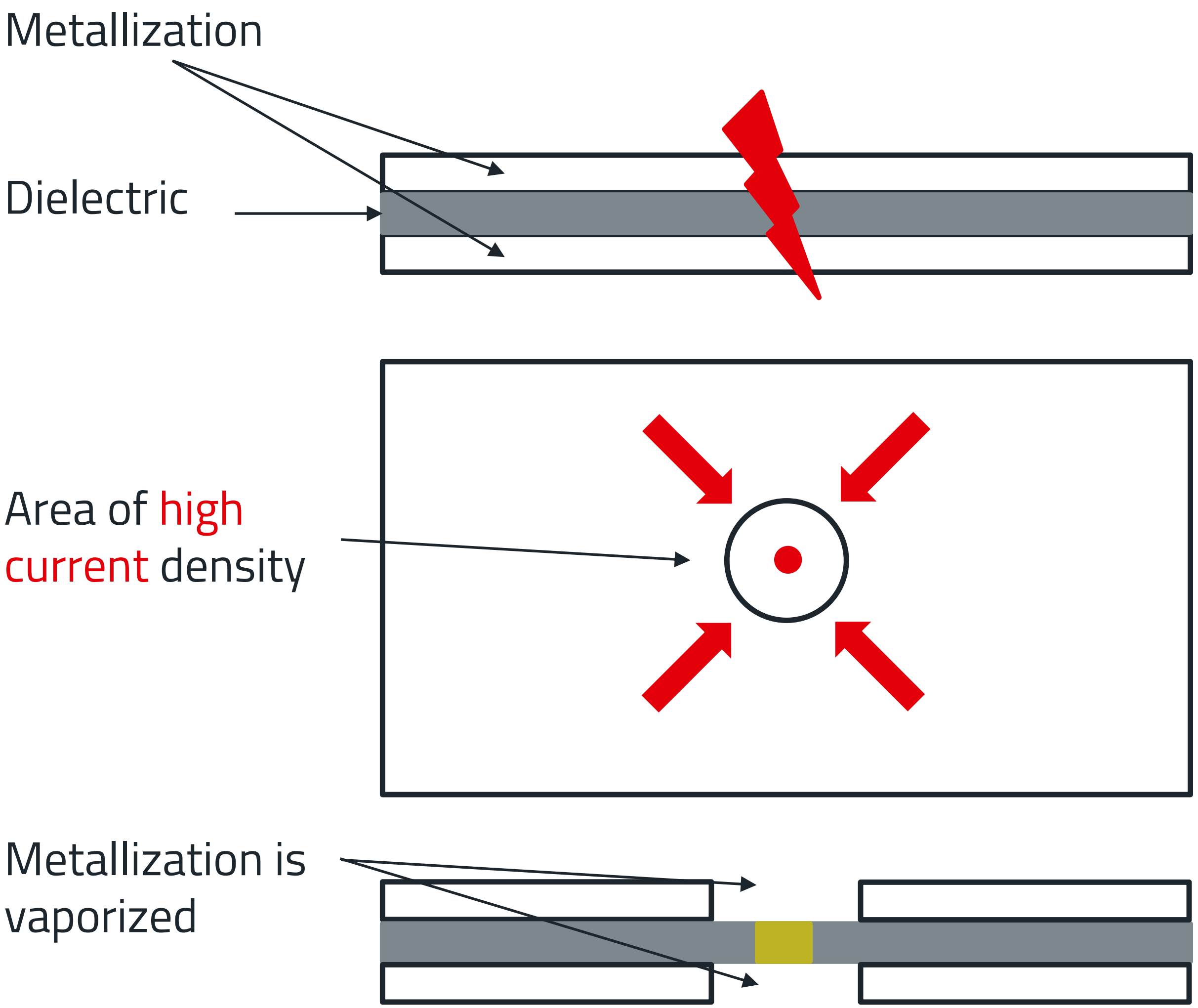
Dielectric	Code for the FK capacitor	Code for the MK capacitor
Polyester (PETP)	KT	MKT
Polycarbonate (PC)	KC	MKC
Polypropylene (PP)	KP	MKP
Polystyrene (PS)	KS	MKS

FILM CAPACITORS

Construction and Selfhealing

- Construction

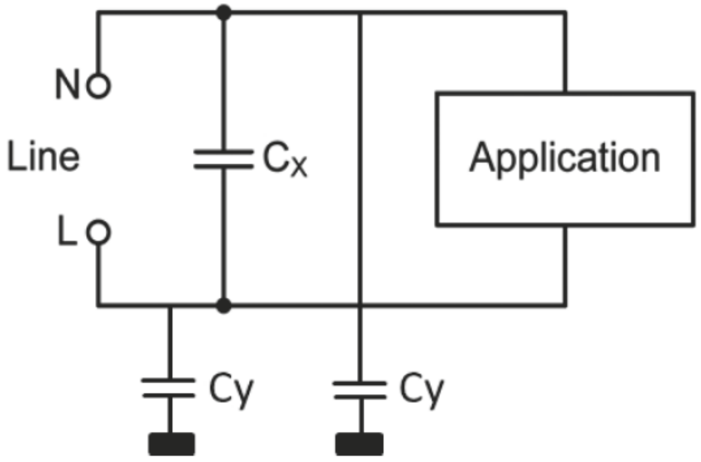




FILM CAPACITORS

AC- Safety Film Capacitors

- X-Capacitors
  - Application protection against voltage peaks of the power grid
  - Network protection against voltage peaks of the application
  - Filtering of differential mode interferences



- Y-Capacitors
  - Capacitance value normally < 6,8 nF → why?
  - In medical equipment we usually forgo the Y- Capacitor, due to defined limitation of leakage current
  - Filtering of common mode interferences

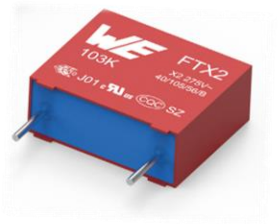
- Safety Classes according IEC 60384-14 / UL 60384-14:

Safety Class	Max. Impulse according IEC- 60384-14
X1	4kV (C≤ 1µF)
X2	2,5 kV (C≤ 1µF)
Y1	8 kV
Y2	5 kV

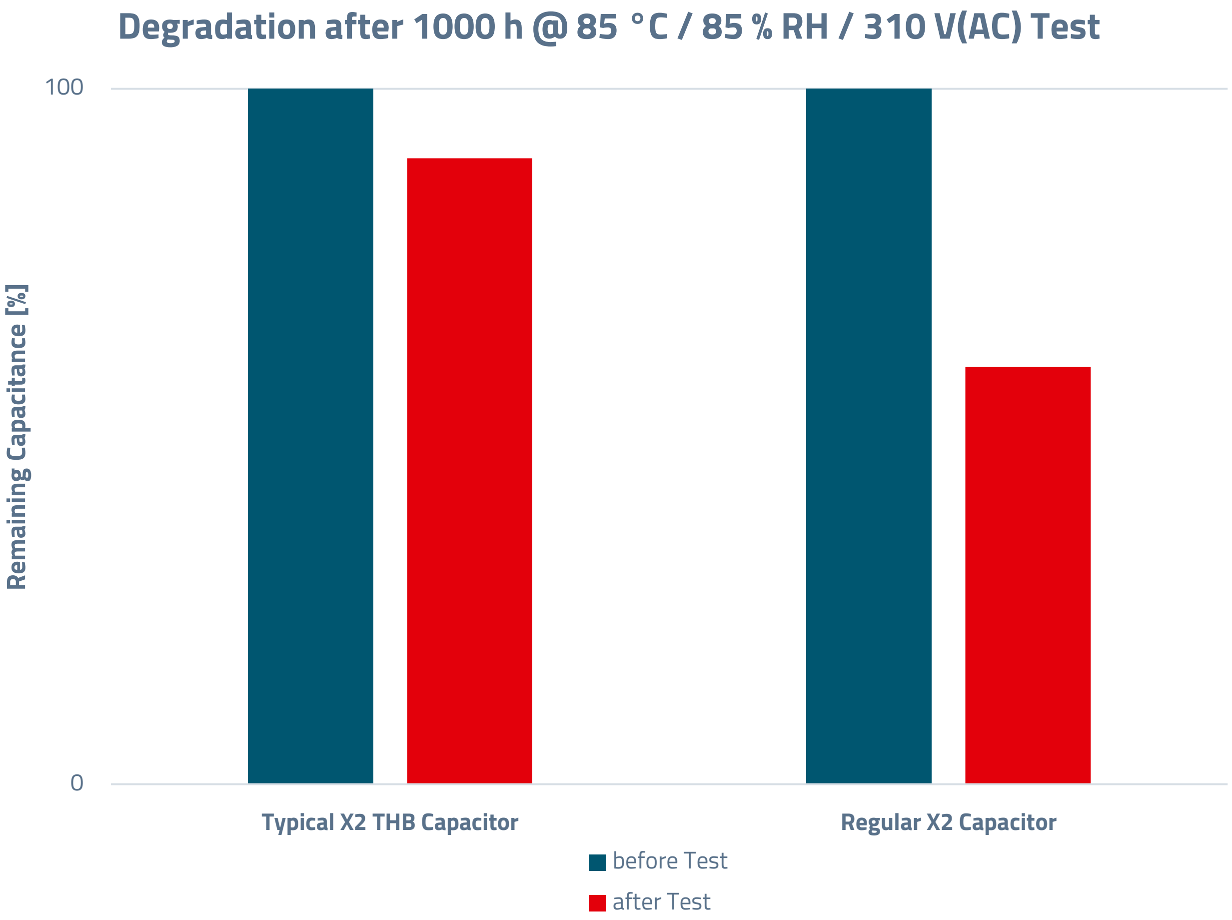
FILM CAPACITORS

THB X2 Capacitors

- Standard X2 Capacitor:
  - Cost effective
  - Sensitive to humidity & temperature
  - Comparable small sizes



- THB X2 Capacitor:
  - Very low moisture absorption
  - Slightly bigger sizes than regular X2 Film Capacitors
  - Very good for long lifetimes

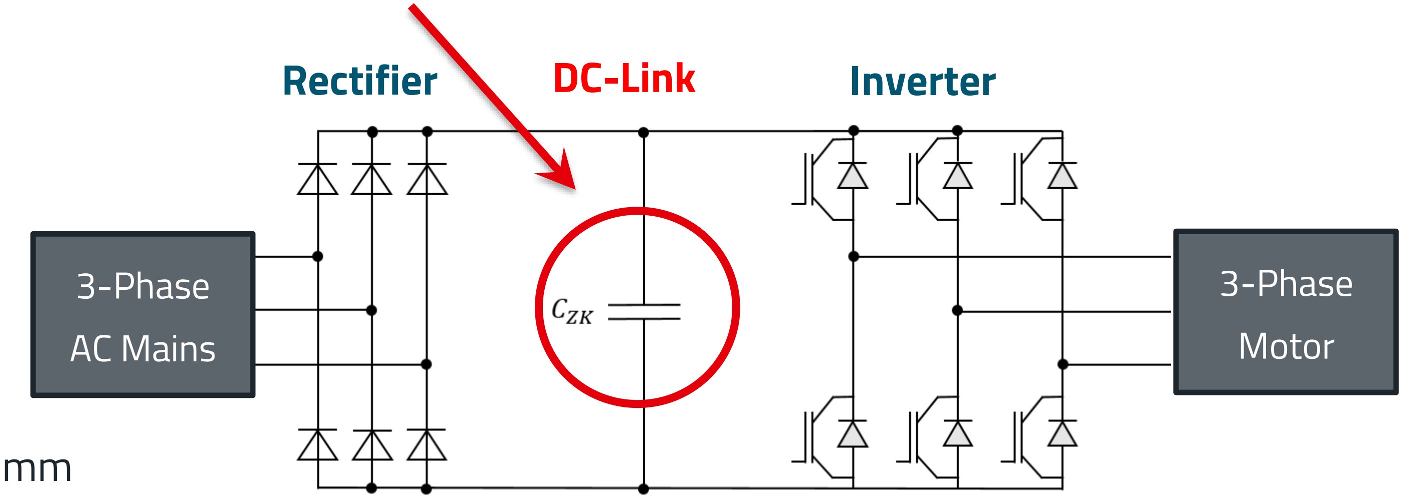


FILM CAPACITORS

DC Link Capacitors

WCAP-FTDB DC-Link Series

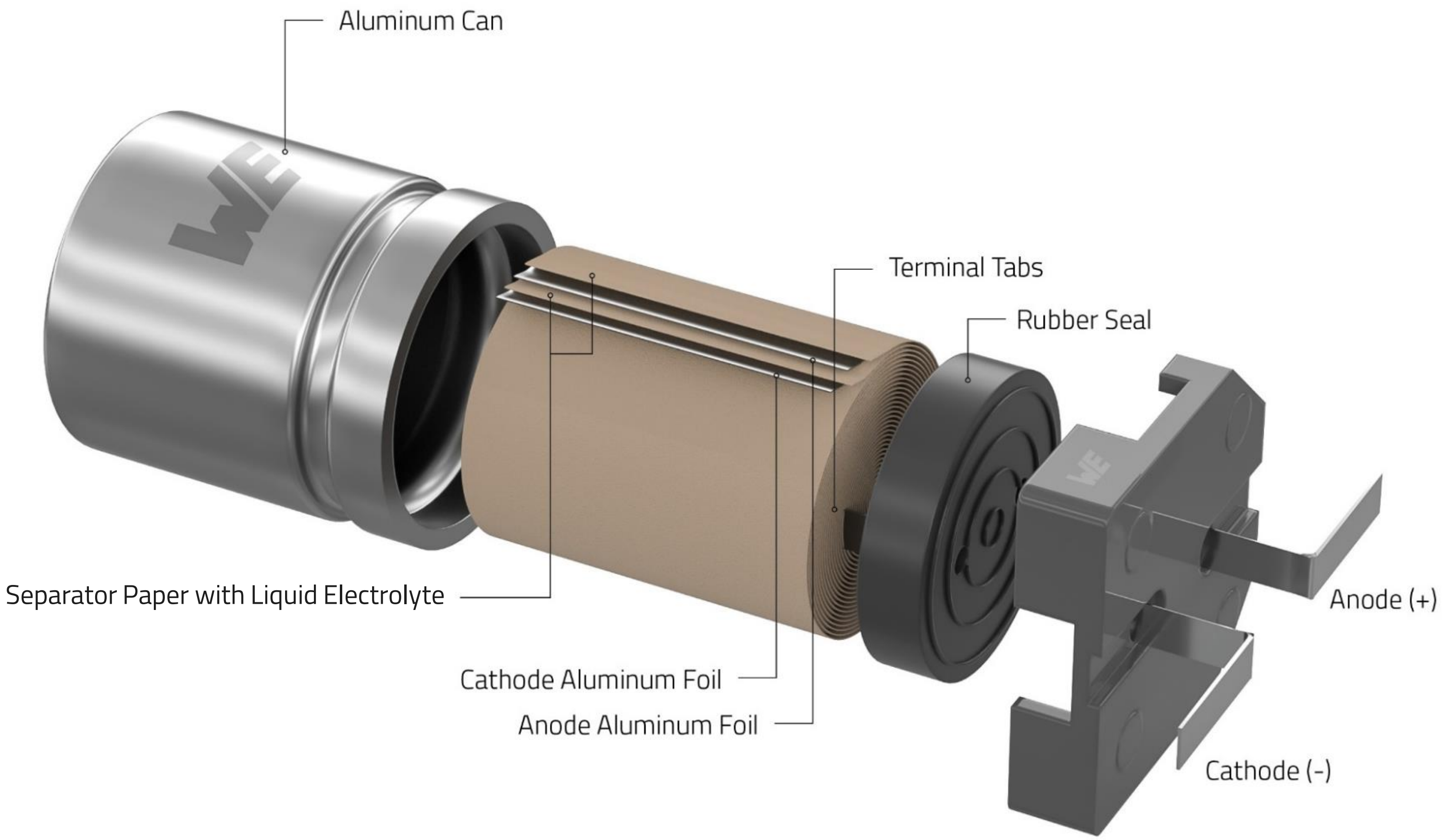
- Boxed THT - MKP Film Capacitors
  - Capacitance: 1 µF up to 75 µF
  - Voltage: 500 V_{DC} up to 1200 V_{DC}
  - MKP: Polypropylene metallized film
  - Temperature: -40 °C up to 105 °C
  - Pitch / Pin distance: 27.5, 37.5 and 52.5 mm
  - High ripple current capability
  - Self-healing properties
  - Very long expected load life

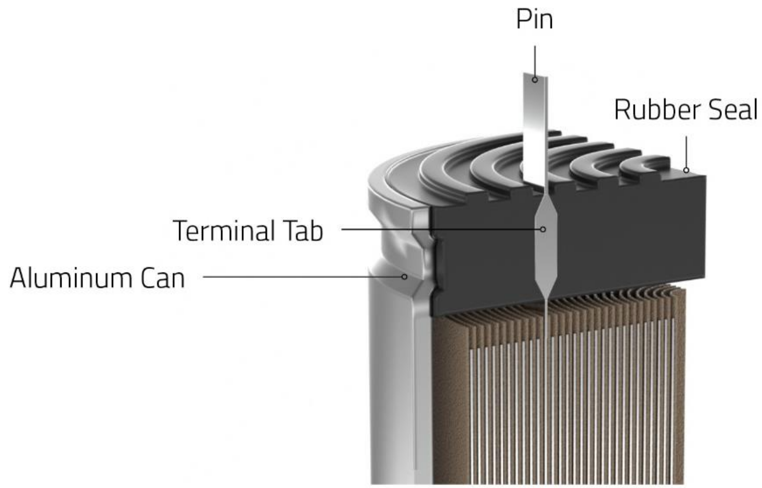


ALUMINUM CAPACITORS

Aluminum Electrolytic Capacitor

- **Construction of an Aluminum Electrolytic Capacitor:**

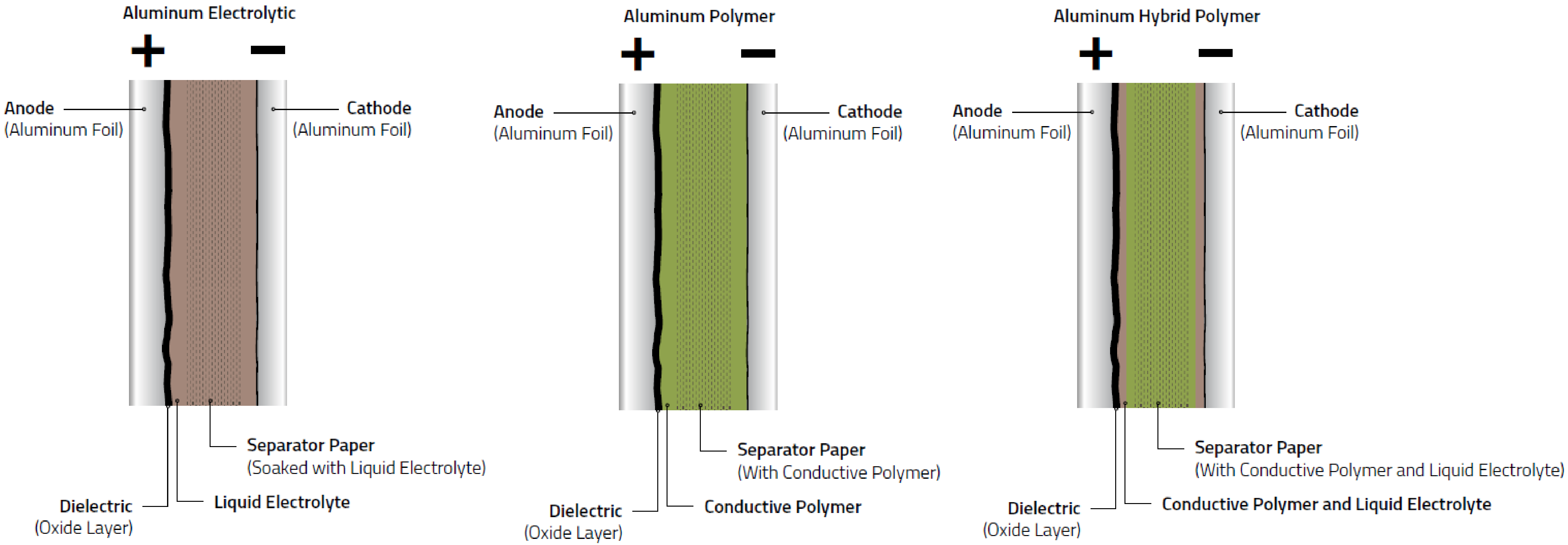




ALUMINUM CAPACITORS

Comparison of the technologies

- Comparison



ALUMINUM CAPACITORS

Aluminum Electrolyte Capacitor

- **Proven technology**
- **Most cost effective**
- **Highest Voltage range** (up to ca. 650V)
- **Highest Capacitance range >> because of biggest max. size**
- **Has certain self-healing properties**
- **Calculation of life expectancy:**

- $$L_x = L_{nom} * 2^{\frac{T_0 - T_a}{10}}$$

for every **10°C** below max. temperatur, the expected lifetime **doubles**

L_x = expected lifetime; T_0 = max. temperature; T_a = Operating temperature

ALUMINUM CAPACITORS

Aluminum Polymer Capacitors

no vent

- **Lower ESR than Electrolyte >> higher possible Ripple current**
- **Cannot dry out (Solid Polymer)**
- **Higher expected lifetime than electrolyte in most cases**
- **Limited in max size**
- **Polymer is stable over temperature till -55°C**
  - **Solid matter shows no phase transition**
  - **Suited for low temperature usage**
- **Increased leakage current**
  - **Consider this for battery-powered applications**
- **Susceptible to vibrations**

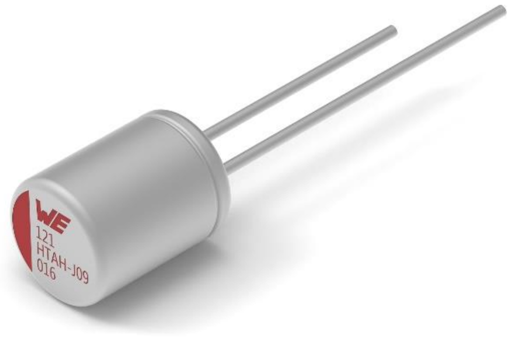
- **Calculated Life expectancy:**
  - $L_x = L_{nom} * 10^{\frac{T_0 - T_a}{20}}$

for every **20°C** below max temperatur, the lifetime increases by the factor **10**

L_x = expected lifetime; T_0 = max. temperature; T_a = Operating temperature

ALUMINUM CAPACITORS

Aluminium Hybrid Kondensatoren



- **Newest Technology**
- **Most difficult too produce**
- **Limited in max. size**
- **Limited rated Voltage**
- **Polymer still works without liquid electrolyte part**
- **Available in smaller cases than Polymer or Electrolyte in some cases**
- **Has certain self healing properties**

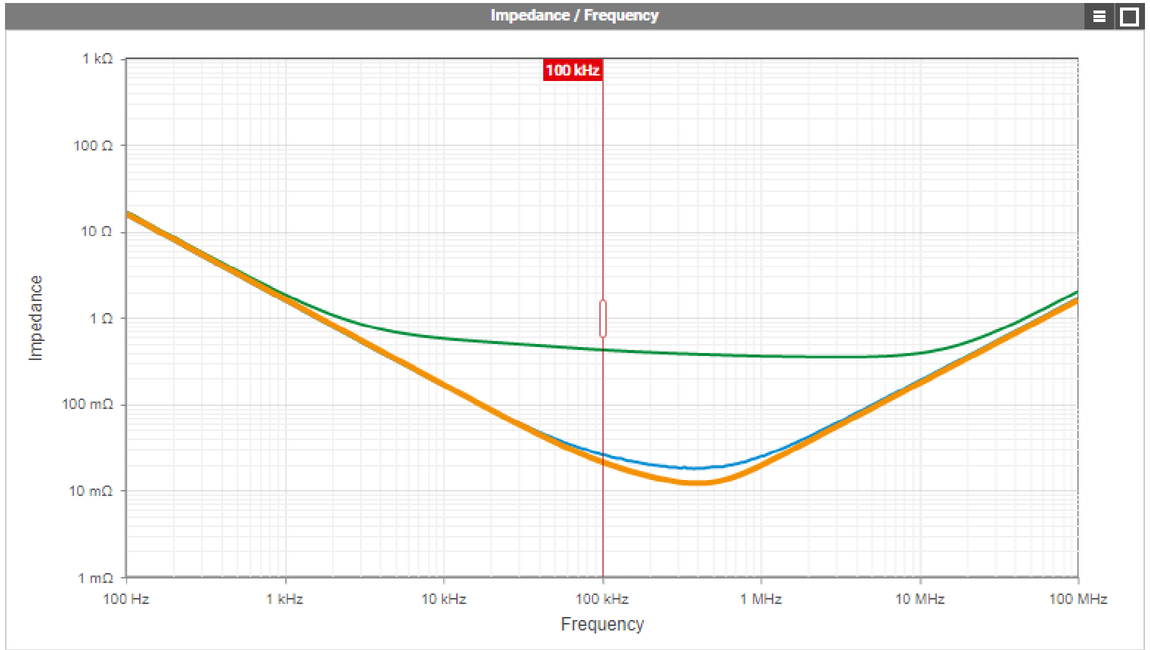
- $L_x = L_{nom} * 2^{\frac{T_0 - T_a}{10}}$ → for every **10°C** below max. temperature, the expected lifetime **doubles**

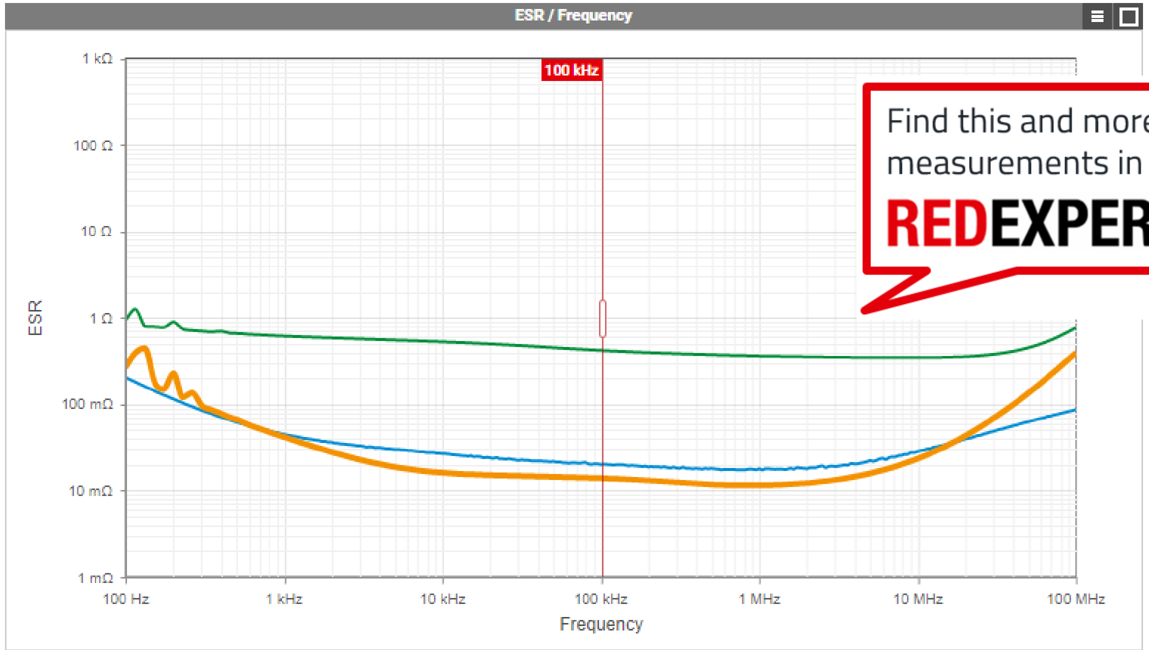
L_x = expected lifetime; T_0 = max. temperature; T_a = Operating temperature

ALUMINUM CAPACITORS

Comparison of the technologies

Technology	Capacitance [µF]	Voltage [VDC]	Size [mm]	ESR [mOhm, typ]	RC [mA]	LC [µA]	Temperature range	Endurance [@105°C]	Expected Lifetime [h, @65°C]
Electrolytic	100	16	6.3x6.6	420	255	16 +	-55 to 105	2000	3.65 years max
Hybrid	100	16	6.3x6.6	20.1 +	1300 +	16 +	-55 to 105	10000 +	13 years max +
Polymer	100	16	6.3x6.6	14 + +	2690 + +	400	-55 to 105	2000	13 years max +





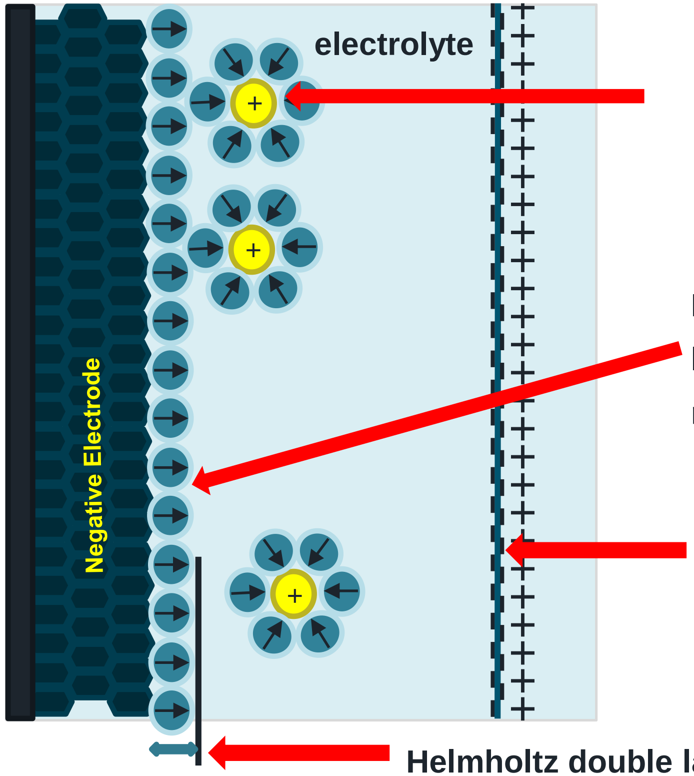
Find this and more measurements in REDEXPERT®

SUPERCAPACITORS

Composition of Supercapacitors

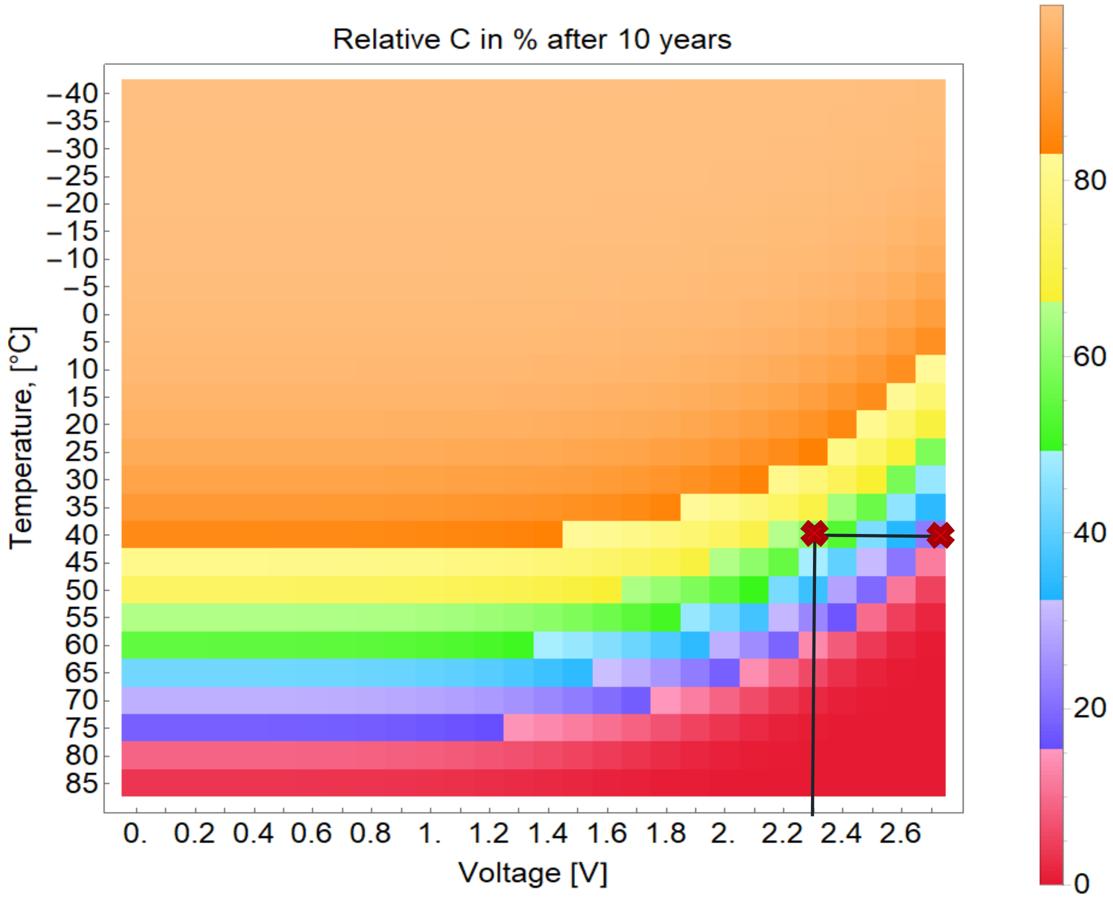
Characteristics EDLCs:
(Electronic Double Layer Capacitors)

- -Very huge capacitance
- -Limited Voltage Range
- -Temperature range 65°C up to 85°C
- -Very low ESR values
- -Comparatively high leakage Currents



SUPERCAPACITORS

Lifetime expectancy of Supercapacitors



Remaining Capacitance after 10 years

For example:

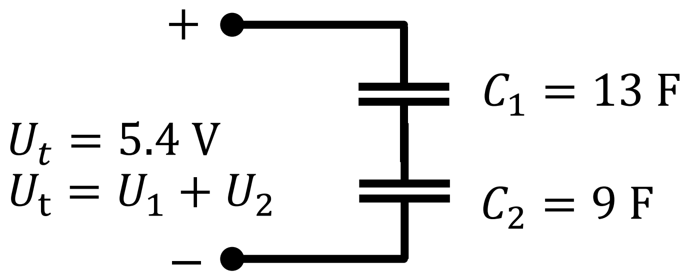
At 2,3 V and 40 °C expected remaining capacitance around 60%

At 2,7 V and 40 °C expected remaining capacitance around 20%

SUPCERCAPACITORS

Balancing

- **Worst Case Scenario:**
  - 2 Supercapacitors with a Capacitance of 10 F (tol.: -10%, +30%) are being put in series and are charged at 5,4 V.)
  - Worst case: $C_2 = 9\ F(-10\%)$, $C_1 = 13\text{ F }(+30\%)$
  - This results in the following Voltage levels:



$$U_2 = \frac{C_1}{C_2 + C_1} U_t$$

$$U_2 = \frac{13F}{9F+13F} 5.4V = 3.19V$$

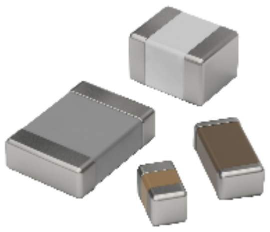
(Caution Overvoltage!)

INTRODUCTION TO CAPACITOR TECHNOLOGIES

Summary

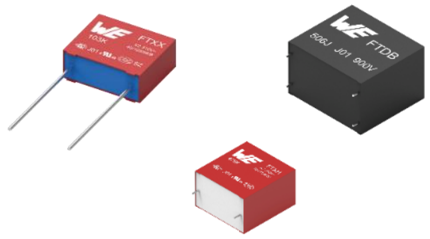
MLCC

- Smallest sizes
- High Voltage available
- Class 1 Ceramic very stable over Temperature, Voltage and Time
- Class 2 Ceramic big capacitance but mind the Capacitance losses
- Safety Capacitors available
- Limit possible cracking with soft termination



Film Capacitor

- Suitable for high Voltage
- Self-healing properties
- Safety Capacitors available
- Sensitive to humidity & temperature

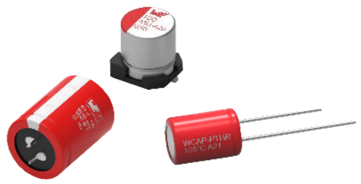


Supercapacitor

- Very high Capacitance
- Strongly adviced Balancing if connected in series

Aluminum Capacitor

- Aluminum Electrolyte
  - Cost efficient
  - Big variety in size
- Aluminum Polymer
  - Suited for longevity applications
  - Low ESR values
  - Not suited for:
    - Battery powered applications
    - High vibration applications
- Aluminum Hybrid Polymer
  - Combines the advantages of both technologies
  - Suited for longevity applications
  - Suited for high temp applications



Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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Thomas.Frahsek@we-online.com