UNDERSTANDING AND SELECTING CAPACITORS - FUNDAMENTALS, TECHNOLOGIES AND LATEST TRENDS

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WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

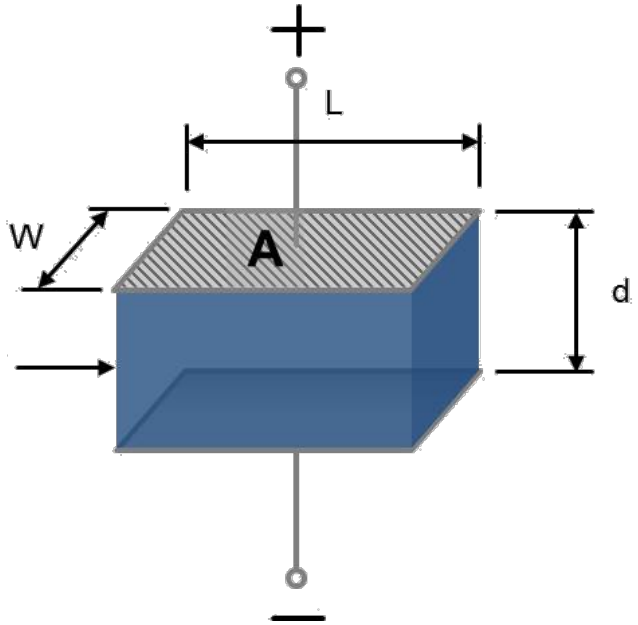
AGENDA

- Technical Basics & Overview
- Technologies
  - MLCC
  - Film Capacitors
  - Aluminum Capacitors
- DC-Link Application
- Summary
- Questions

BASICS OF CAPACITORS

Overview and Basics of Capacitors

- Construction of a plate Capacitor



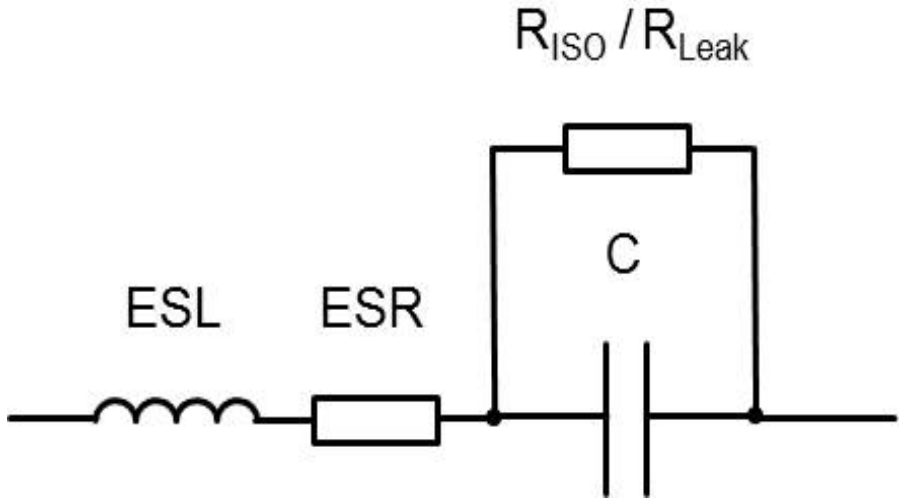
$$C = \varepsilon * \frac{A}{d} = \varepsilon_0 * \varepsilon_r * \frac{A}{d}$$

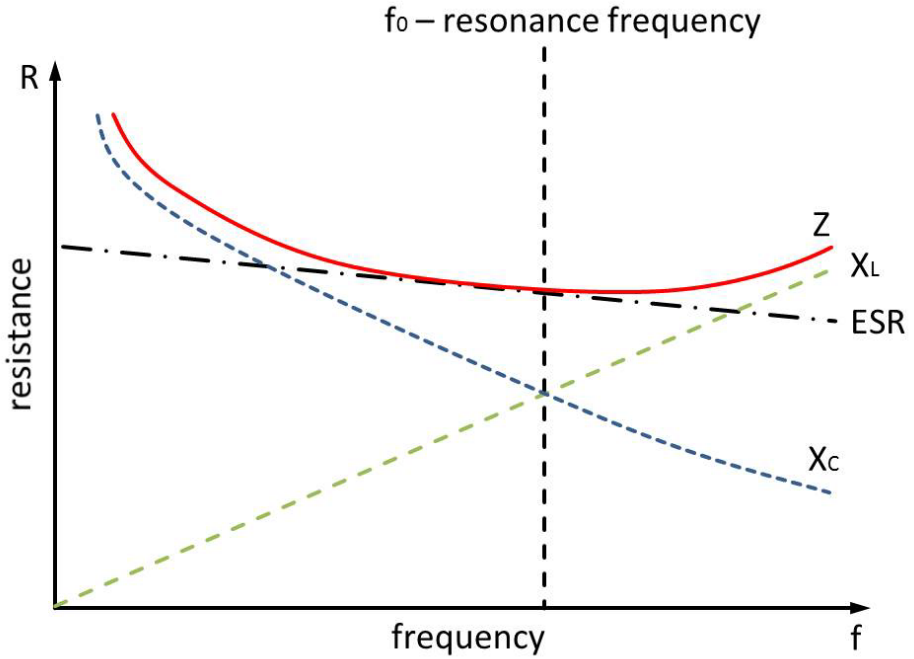
C – Capacitance [F]
A – plate surface
d – plate distance
ε_0- absolute Permittivity
ε_R- relative Permittivity

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

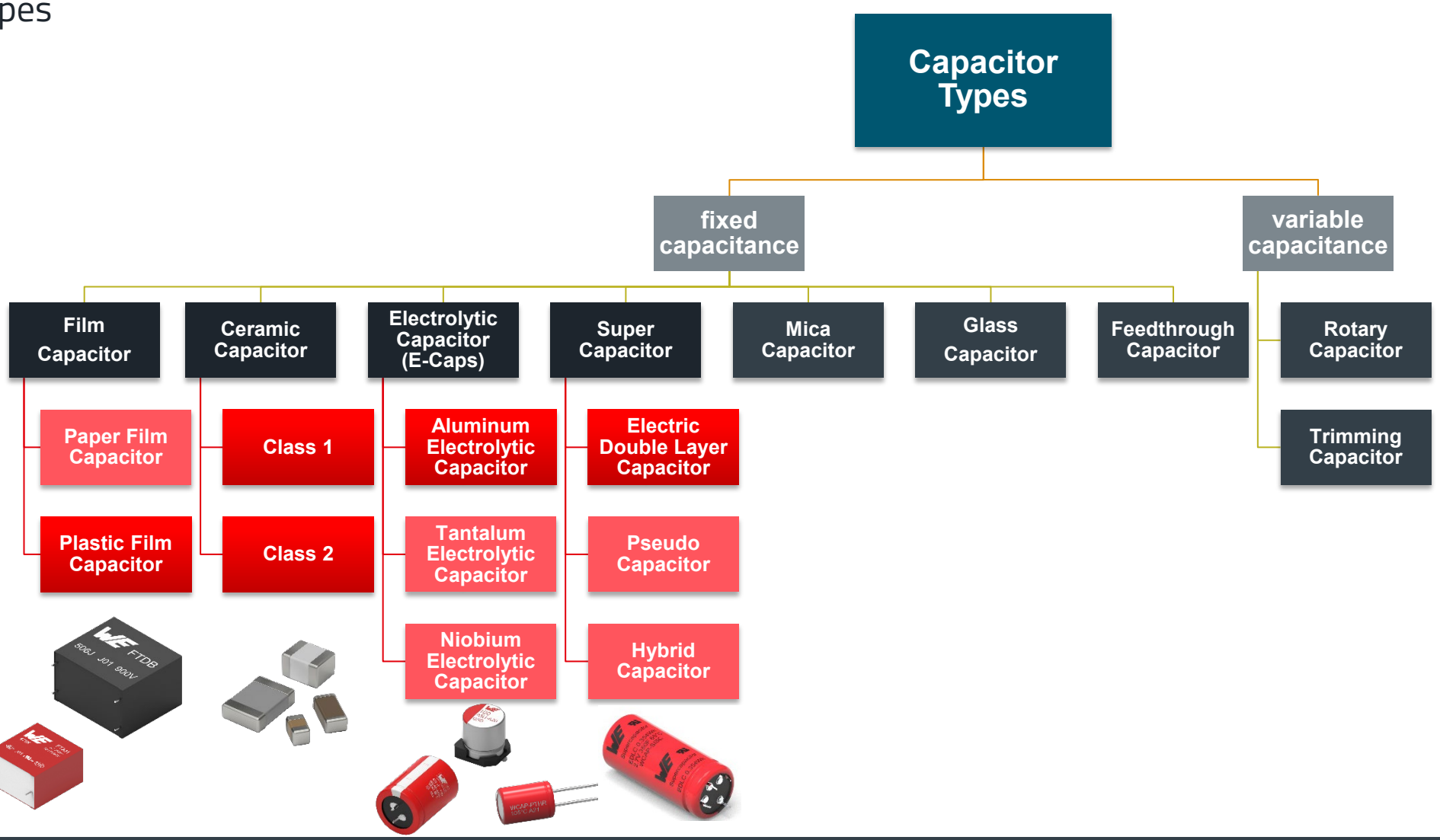
- C – Charge and energy storage
- ESR – Losses, heating and damping
- ESL – High-frequency behavior and switching spikes
- Riso – Leakage





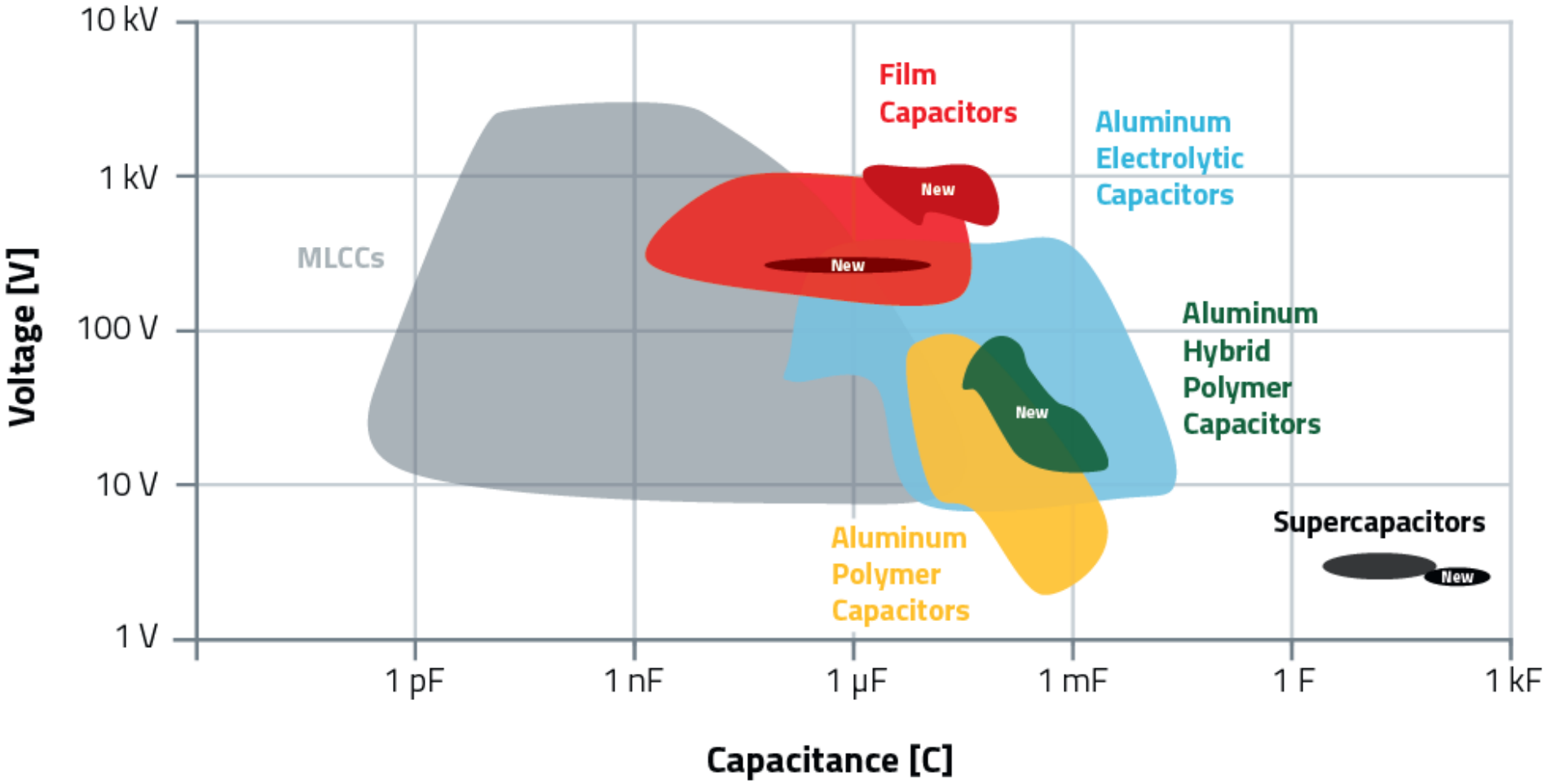
BASICS OF CAPACITORS

Capacitor Types



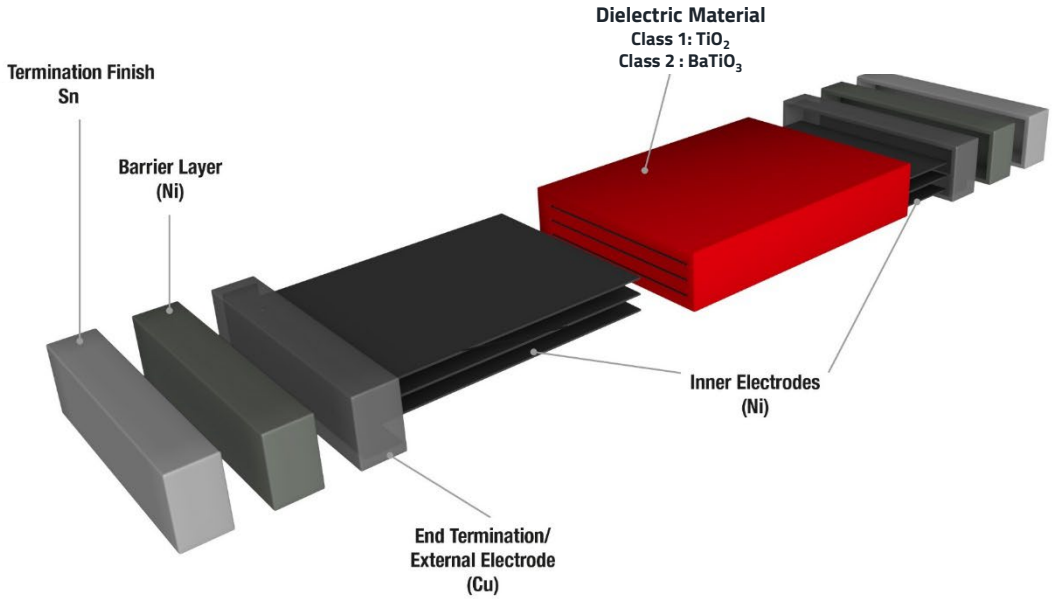
BASICS OF CAPACITORS

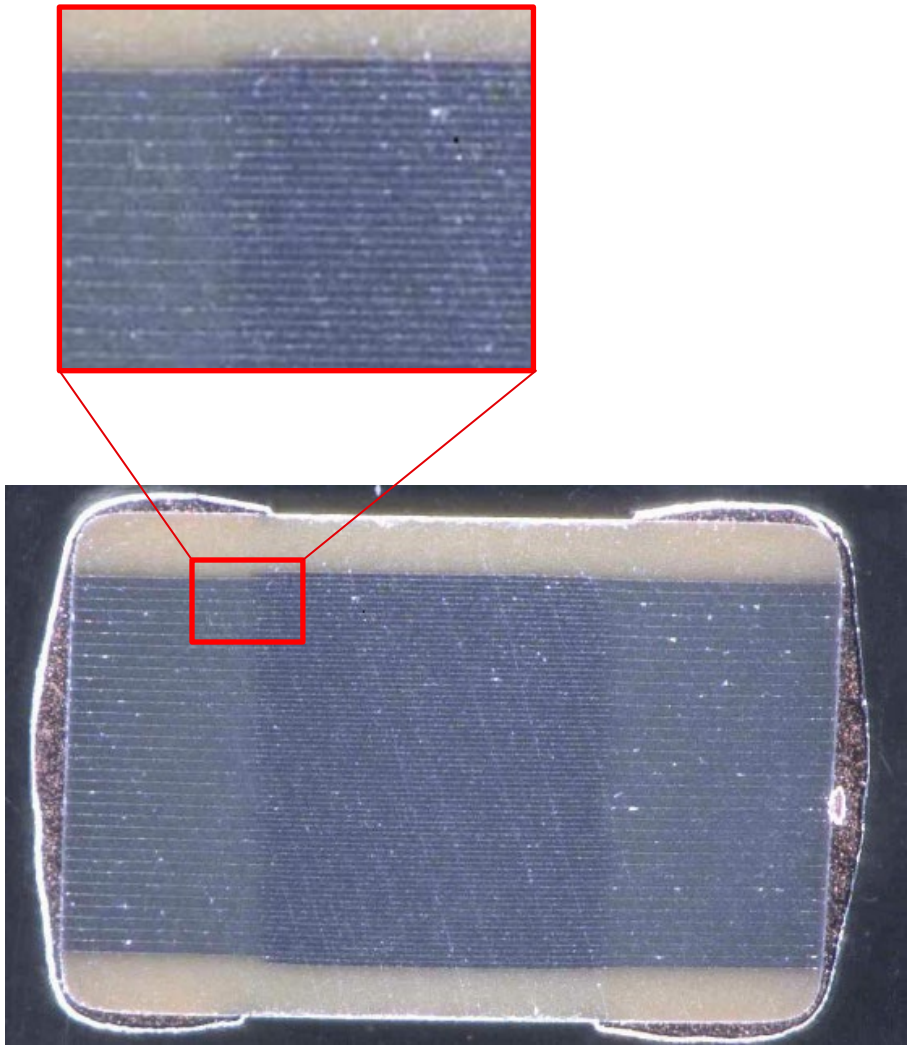
Overview



MLCC

Composition of General Purpose MLCC

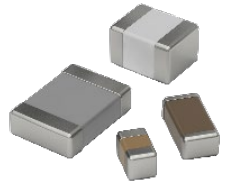




Example cross section of a general purpose MLCC

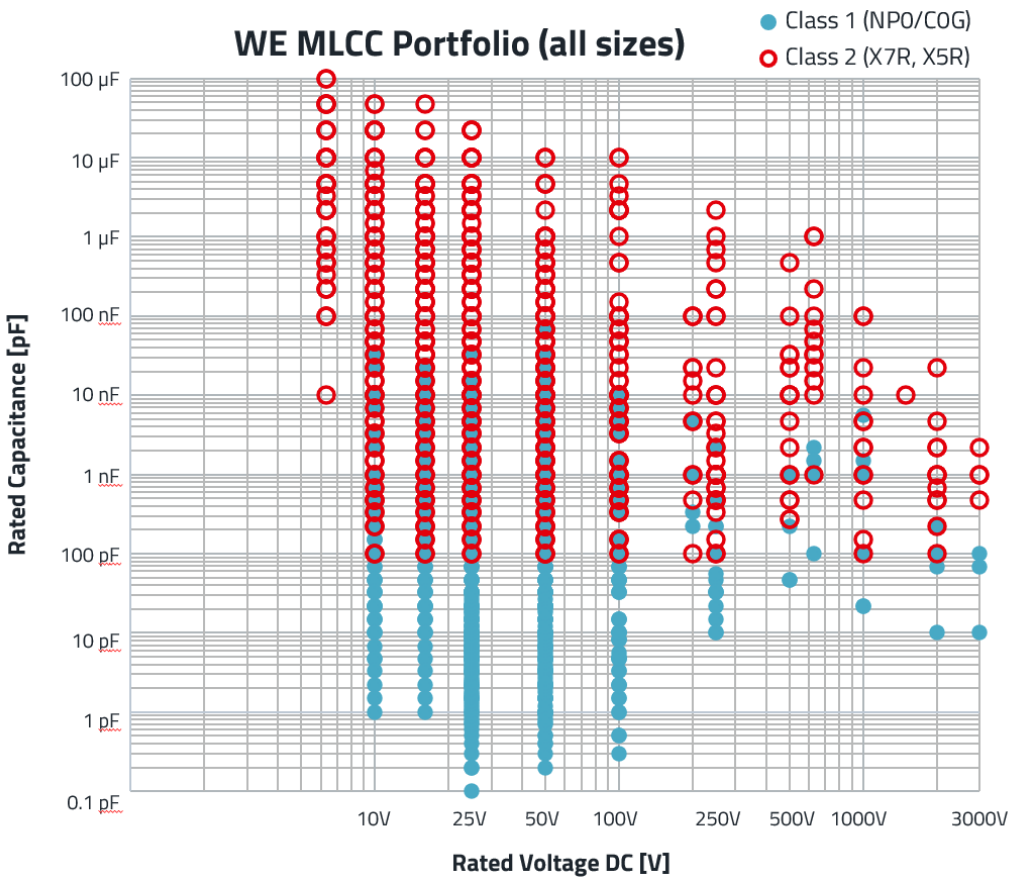
MLCC

Class 1 and Class 2 ceramics



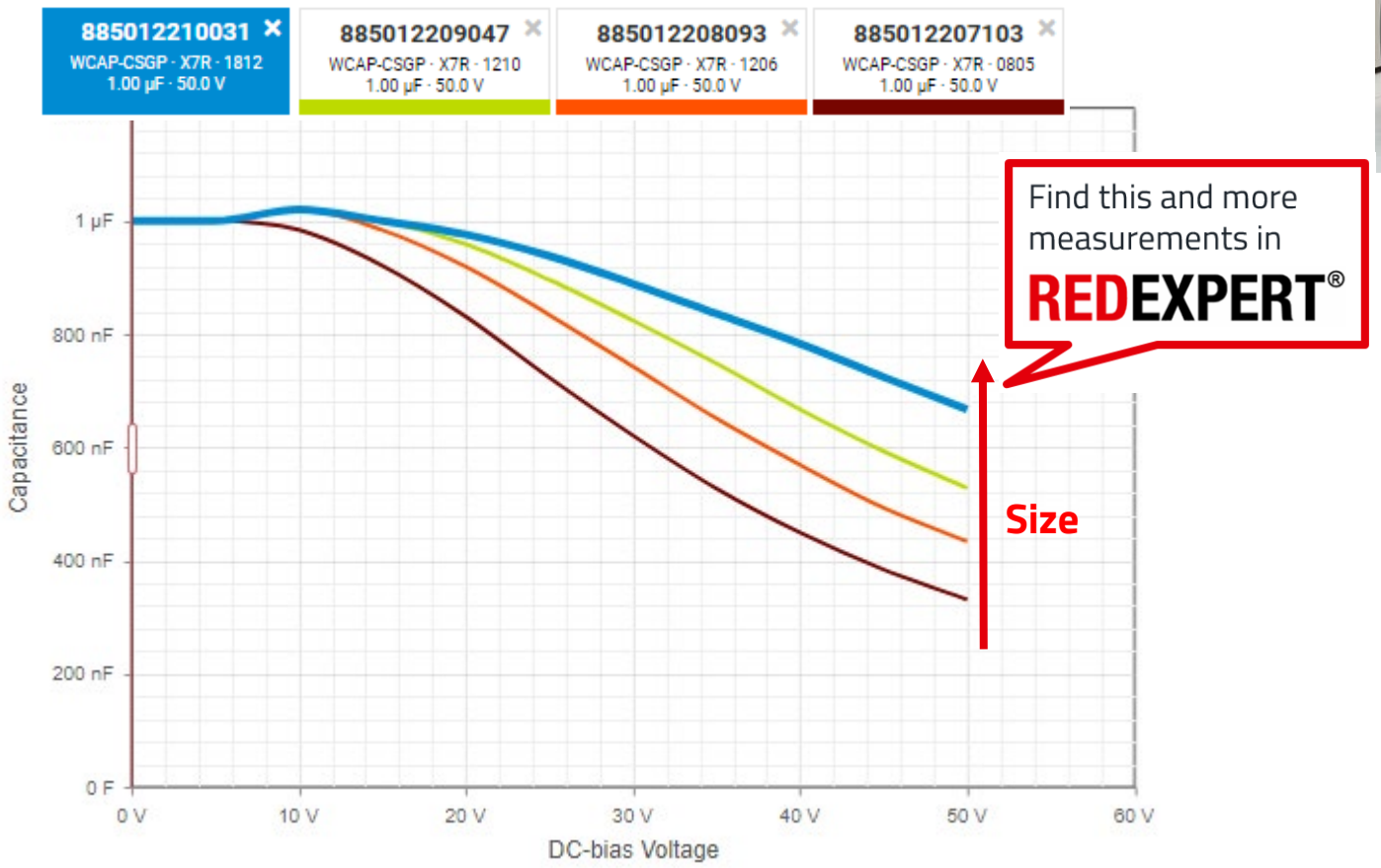
- **Class 1 Ceramic** – (e.g. NP0 / C0G)
  - Relative small Permitivity ε_r >> small capcitance values possible
  - linear temperature dependency
  - Next to no aging
  - Very small voltage dependency
  - Suitable for high frequency applications

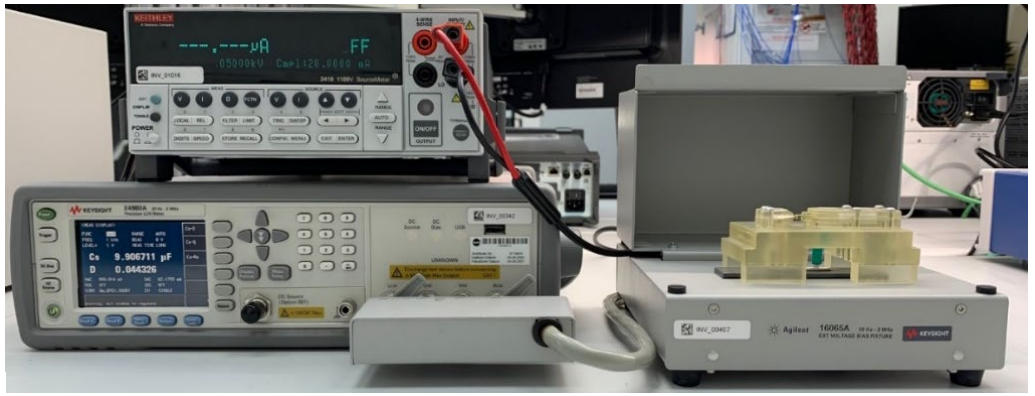
- **Class 2 Ceramic** – (e.g. X7R, X5R, Y5V, ...)
  - Relative high Permitivity ε_r → High capacitance values available
  - Nonlineare temperature dependency
  - Aging
  - High Voltage depency in many cases



MLCC

Voltage dependancy of the Capacitance value (DC-Bias)



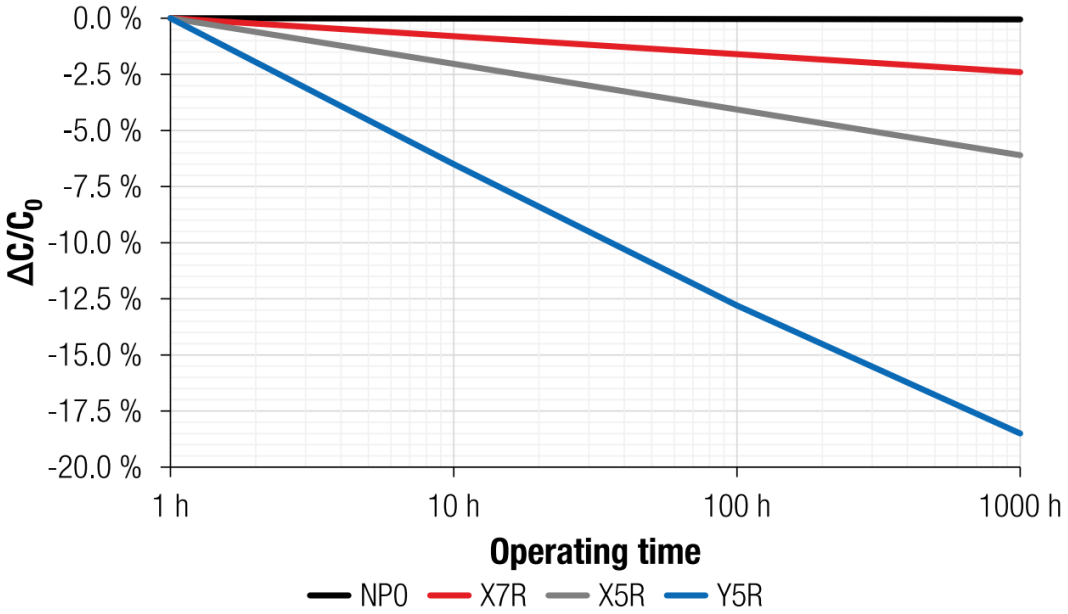


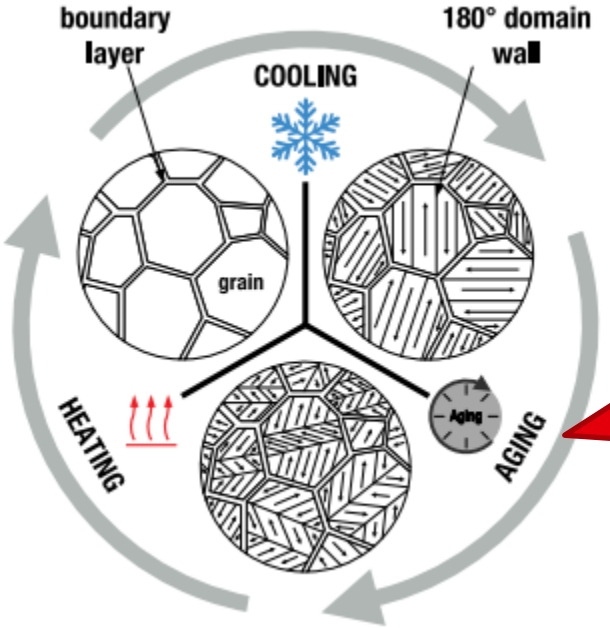
- Capacitance drop affects only Class II Ceramic Capacitors
- Heavily dependent on size
- No specification on the datasheet!
- Only reference curves or simulation models

MLCC

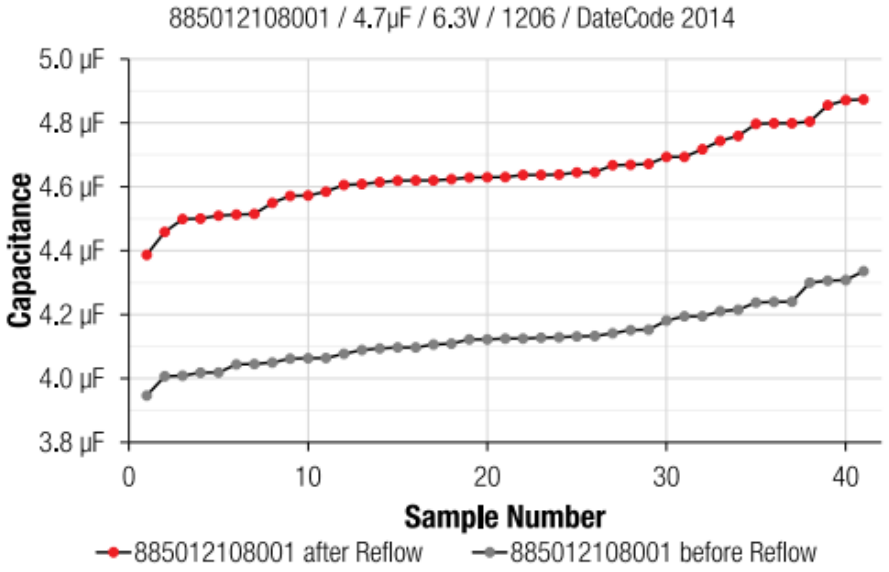
Aging of MLCCs

- 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

Capacitance yield of Class 2 ceramics

MLCC

LT Spice Models with DC Bias + RE Selection

- Example
  - you need 0402/0603/0805 MLCC with an application voltage of 24 VDC
  - you want to select the part with max. Capacitance under these constraints!
- Visit the MLCC Module in RedExpert, set Filters for Size: 0402, 0603, 0805, Vr>30V

Filters: Size = 0603, 0805, 0402 | $V_R \geq 30.0$ V

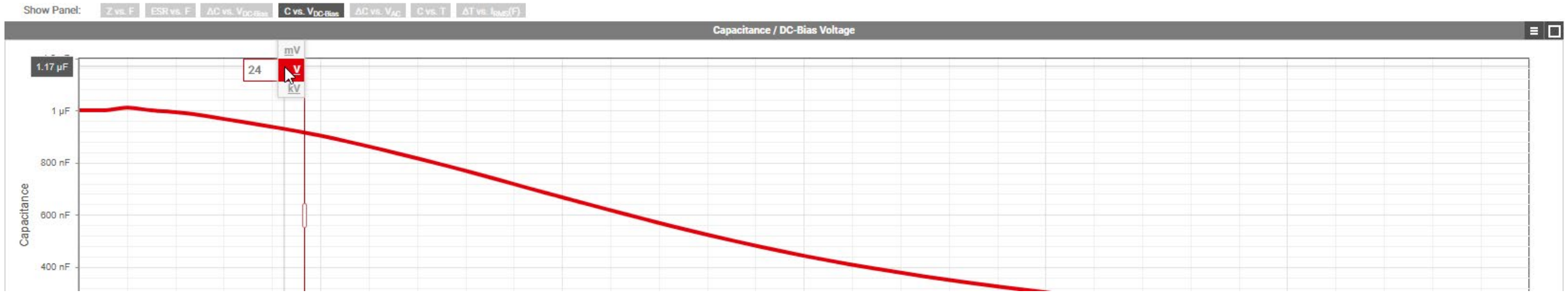
100 / 304 items

Order Code	Spec		Series	Description	Size	I...	Ce...	C	Tole...	V_R	R_{iso}	DF	Q	T_{min}	T_{max}	TCC	Length	Width	Height	R_S	L_S
885012207103R			**WCAP-CSGP**	**General Purpose**	**0805**		**X7R**	**1.00 µF**	**±10 %**	**50.0 V**	**> 100 MΩ**	**10 %**		**-55.0 °C**	**125 °C**	**±15%**	**2.00 mm**	**1.25 mm**	**1.25 mm**	**5.31 mΩ**	**28**
885012207098R			WCAP-CSGP	General Purpose	0805		X7R	100 nF	±10 %	50.0 V	> 5.00 GΩ	2.5 %		-55.0 °C	125 °C	±15%	2.00 mm	1.25 mm	0.800 mm	17.6 mΩ	40
885012206114R			WCAP-CSGP	General Purpose	0603		X7R	10.0 nF	±10 %	100 V	> 10.0 GΩ	2.5 %		-55.0 °C	125 °C	±15%	1.60 mm	0.800 mm	0.800 mm	61.4 mΩ	45
885012206095R			WCAP-CSGP	General Purpose	0603		X7R	100 nF	±10 %	50.0 V	> 5.00 GΩ	3.0 %		-55.0 °C	125 °C	±15%	1.60 mm	0.800 mm	0.800 mm	15.8 mΩ	31
885012206089R			WCAP-CSGP	General Purpose	0603		X7R	10.0 nF	±10 %	50.0 V	> 10.0 GΩ	2.5 %		-55.0 °C	125 °C	±15%	1.60 mm	0.800 mm	0.800 mm	35.9 mΩ	34
885012206083R			WCAP-CSGP	General Purpose	0603		X7R	1.00 nF	±10 %	50.0 V	> 10.0 GΩ	2.5 %		-55.0 °C	125 °C	±15%	1.60 mm	0.800 mm	0.800 mm	258 mΩ	41
885012207130			WCAP-CSGP	General Purpose	0805		X7R	470 nF	±10 %	100 V	> 200 MΩ	10 %		-55.0 °C	125 °C	±15%	2.00 mm	1.25 mm	1.25 mm	11.0 mΩ	90

MLCC

LT Spice Models with DC Bias + RE Selection

- Example
  - you need 0402/0603/0805 MLCC with an application voltage of 24 VDC
  - you want to select the part with max. Capacitance under these constraints!
- Visit the MLCC Module in RedExpert, set Filters for Size: 0402, 0603, 0805, Vr>30V



MLCC

LT Spice Models with DC Bias + RE Selection

- Example
  - you need 0402/0603/0805 MLCC with an application voltage of 24 VDC
  - you want to select the part with max. Capacitance under these constraints!
- Visit the MLCC Module in RedExpert, set Filters for Size: 0402, 0603, 0805, Vr>30V
- A new column appears! Filter it by C(VDC-Bias @ 24 VDC)!
- 885012207103 is the best solution!

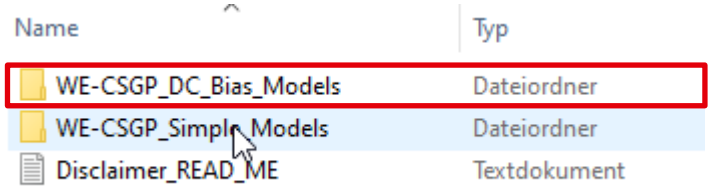
Filters: Size = 0603, 0805, 0402 | $V_R \geq 30.0$ V

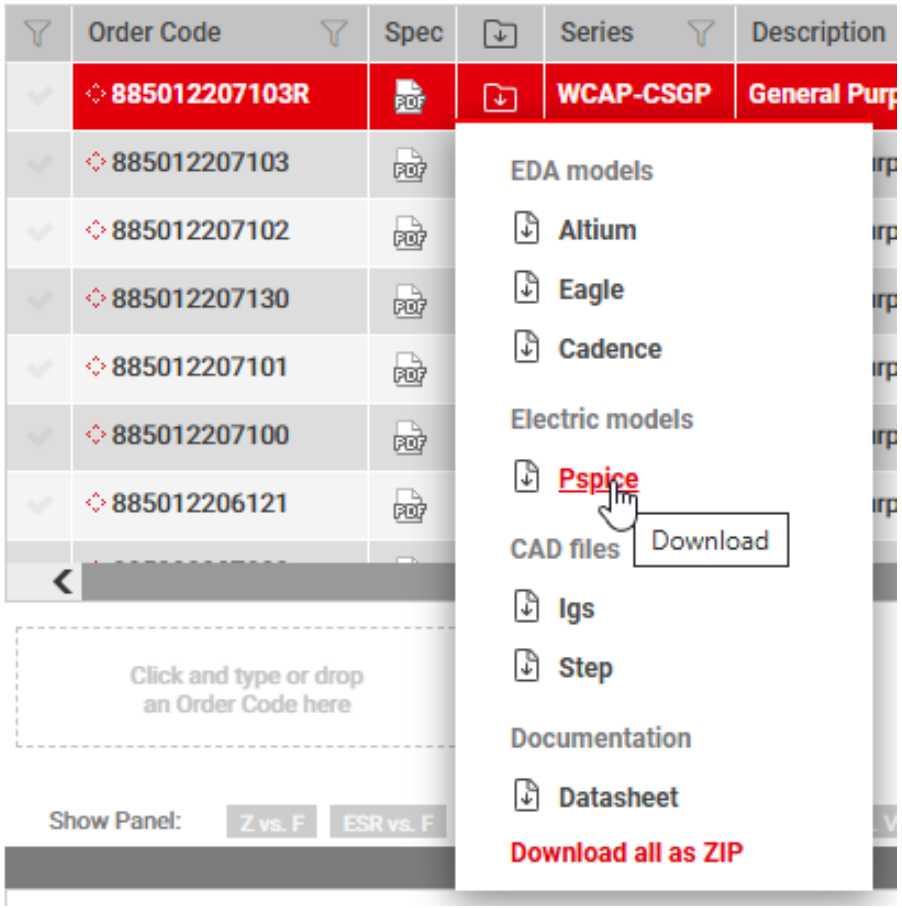
Order Code	Spec		Series	Description	Size	I...	Ce...	C	Tole...	V_R	R_{iso}	$C(V_{DC\text{-}Bias})$ @24.0 V...
885012207103R	PDF		WCAP-CSGP	General Purpose	0805		X7R	1.00 µF	±10 %	50.0 V	> 100 MΩ	570 nF
885012207103	PDF		WCAP-CSGP	General Purpose	0805		X7R	1.00 µF	±10 %	50.0 V	> 100 MΩ	570 nF
885012207102	PDF		WCAP-CSGP	General Purpose	0805		X7R	470 nF	±10 %	50.0 V	> 1.10 GΩ	385 nF
885012207130	PDF		WCAP-CSGP	General Purpose	0805		X7R	470 nF	±10 %	100 V	> 200 MΩ	295 nF
885012207101	PDF		WCAP-CSGP	General Purpose	0805		X7R	330 nF	±10 %	50.0 V	> 1.50 GΩ	257 nF

MLCC

LT Spice Models with DC Bias + RE Selection

- Did you know?
- We have also implemented the DC-Bias Capacitance values in the Spice Library!
- Download it in Red Expert
- Customer can then select between Standard Models and between Models with DC Bias behavior:

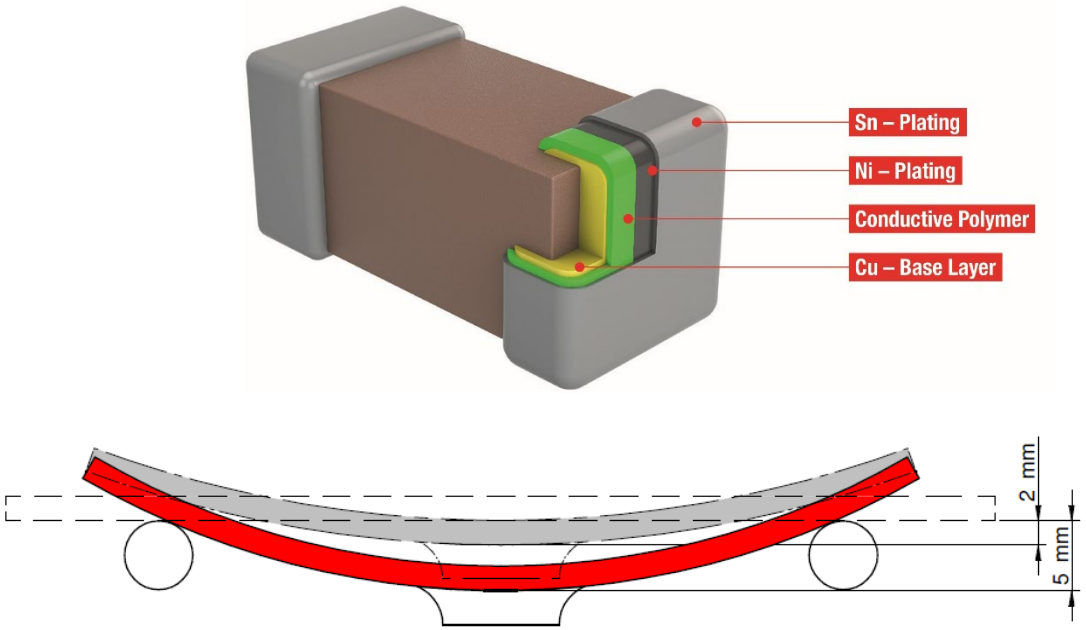




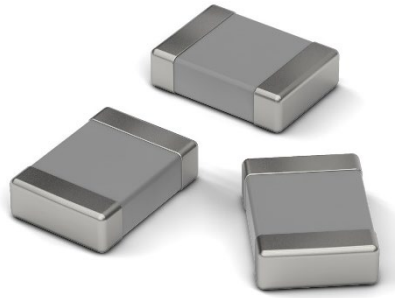
MLCC

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

- Soft Termination



- Safety capacitors (Y2/X1 and X2)



MLCC

Available series

Available Series:

WCAP-CSGP
General Purpose

WCAP-CSMH
Mid and High Voltage

WCAP-CSRF
High Frequency

WCAP-CSST
Soft Termination

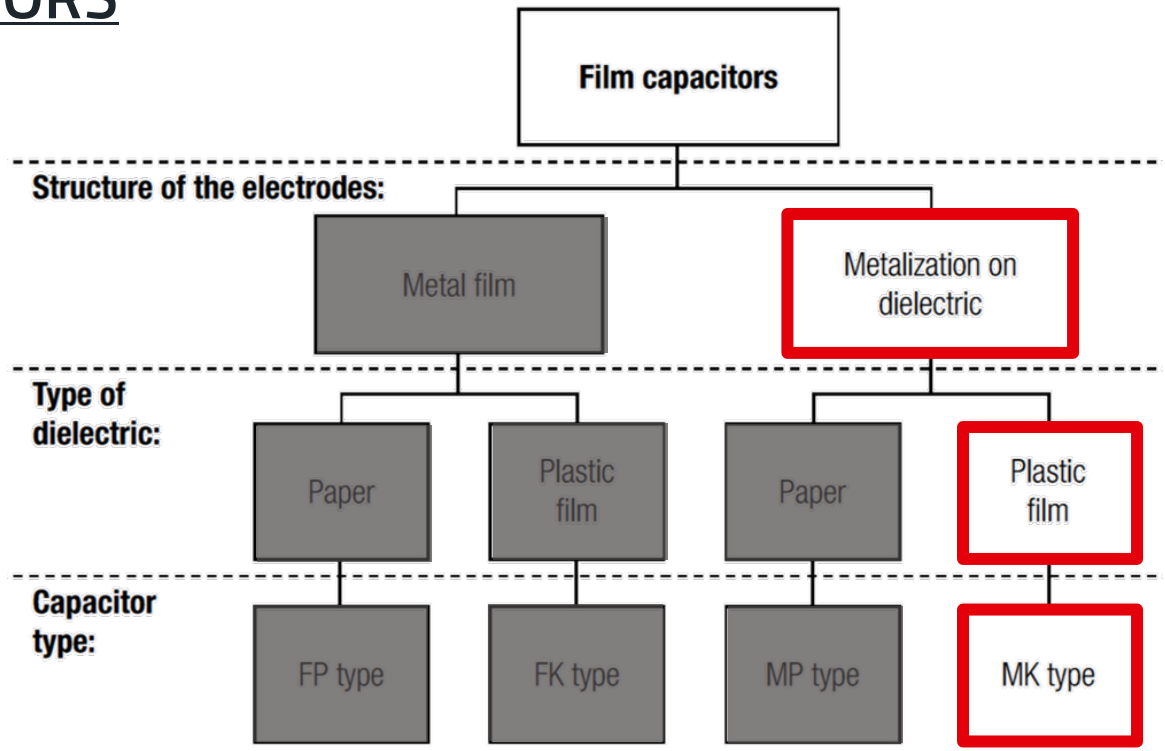
WCAP-CSSA
Safety Capacitors (X1/Y2, X2)

Characteristics:

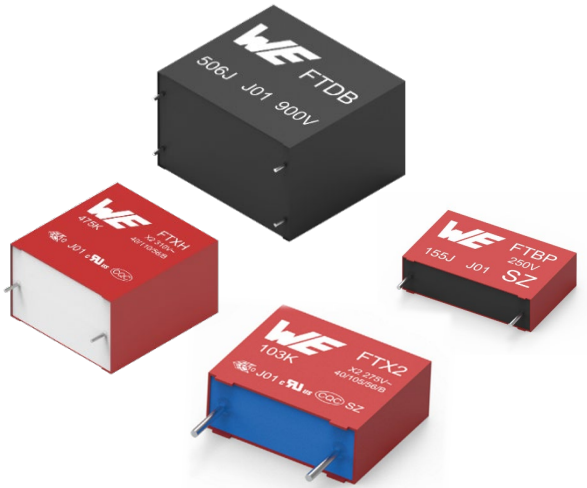
Type	Series	Capacitance	Voltage	Size	Operating Temperature (°C)
General Purpose	WCAP-CSGP	0.5 pF – 100 µF	6.3 – 100 V_{DC}	0201 – 2220	-55 up to +125
Mid and High Voltage	WCAP-CSMH	10 pF – 2.2 µF	200 – 3000 V_{DC}	0603 – 2220	
High Frequency	WCAP-CSRF	0.2 pF – 33 pF	25 & 50 V_{DC}	0201 & 0402	
Soft Termination	WCAP-CSST	220 pF – 2.2 µF	16 – 2000 V_{DC}	0603 – 1210	
Safety Capacitors	WCAP-CSSA	33 pF – 4.7 nF	250 V_{AC}	1808 – 2220	

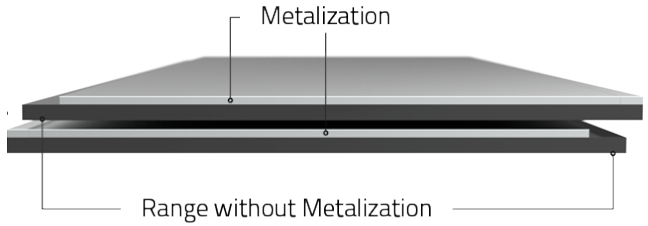
FILM CAPACITORS

Construction



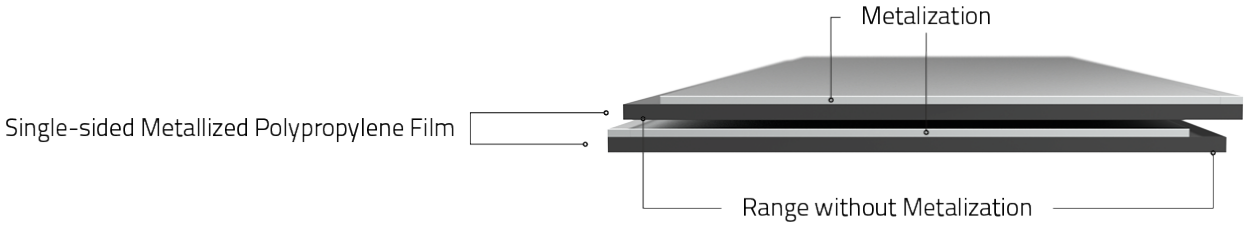
Dielectric	Code for the FK capacitor	Code for the MK capacitor
Polyester (PETP)	KT	MKT
Polycarbonate (PC)	KC	MKC
Polypropylene (PP)	KP	MKP
Polystyrene (PS)	KS	MKS

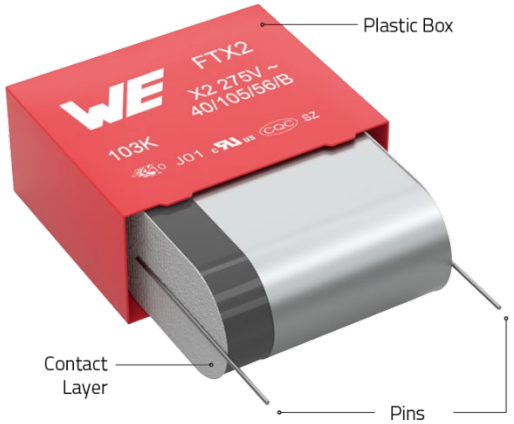


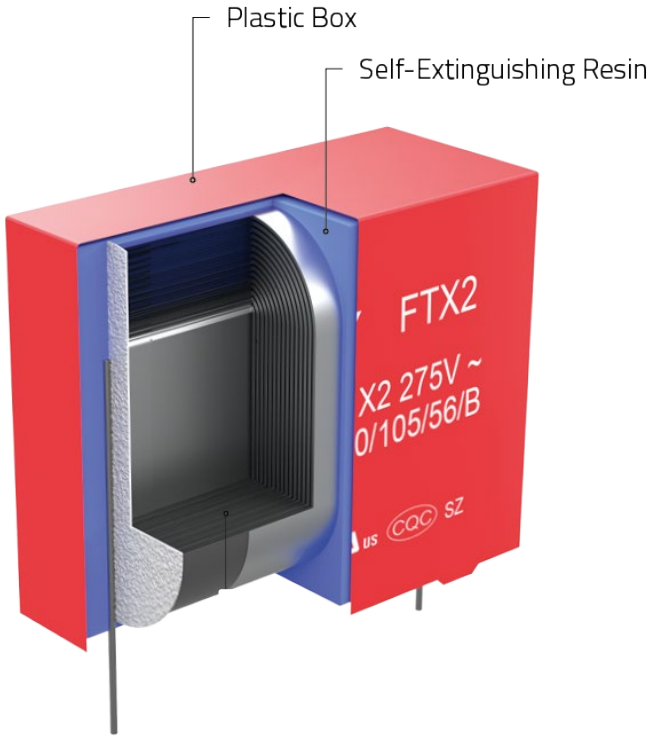


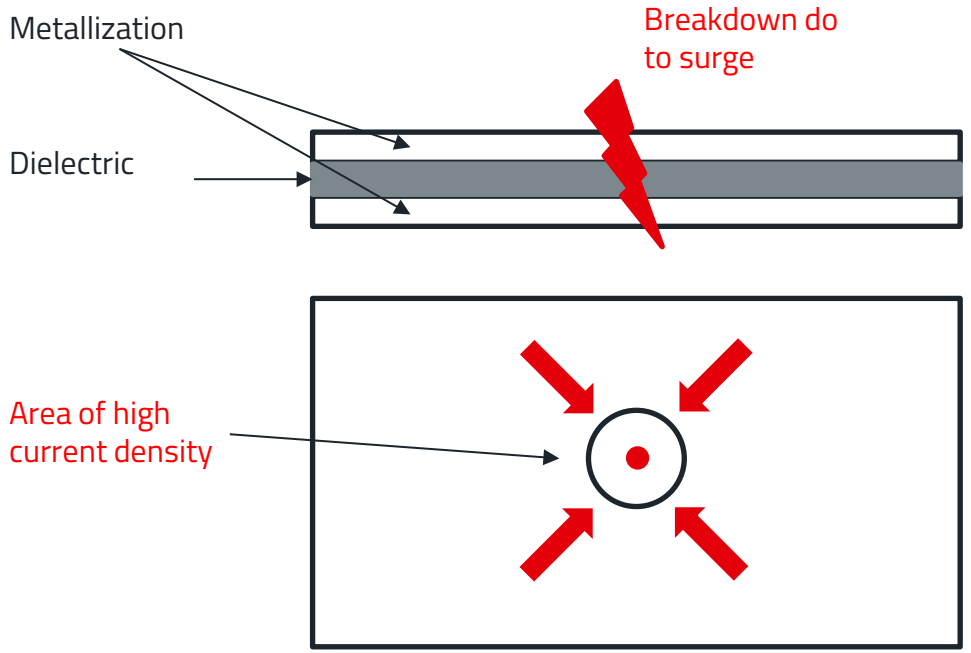
FILM CAPACITORS

Construction and self healing process



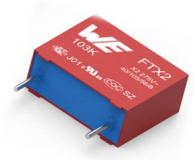




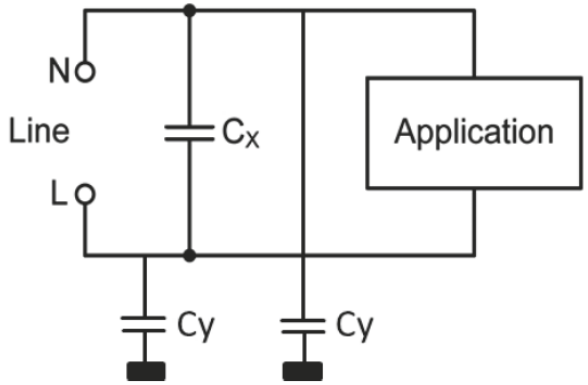


FILM CAPACITORS

AC-Safety Film Capacitors



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



- Y-Capacitors
  - Filtering of common mode interferences
  - Capacitance value normally less than a few nF
  - Limited capacitance to reduce leakage current to earth

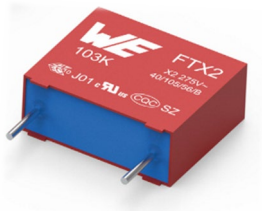
- Safety Classes according IEC 60384-14 / UL 60384-14:

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

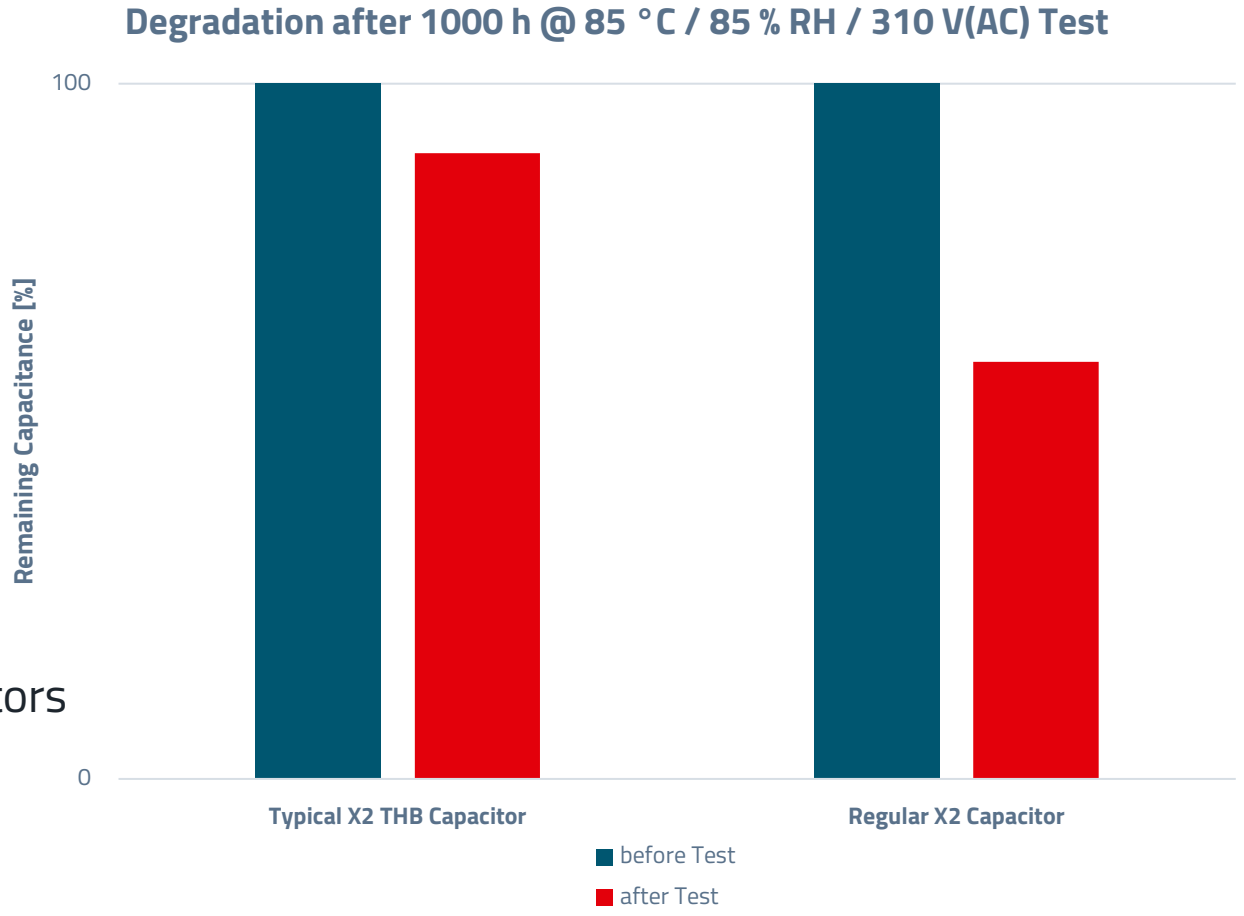
FILM CAPACITORS

THB X2 Capacitors

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



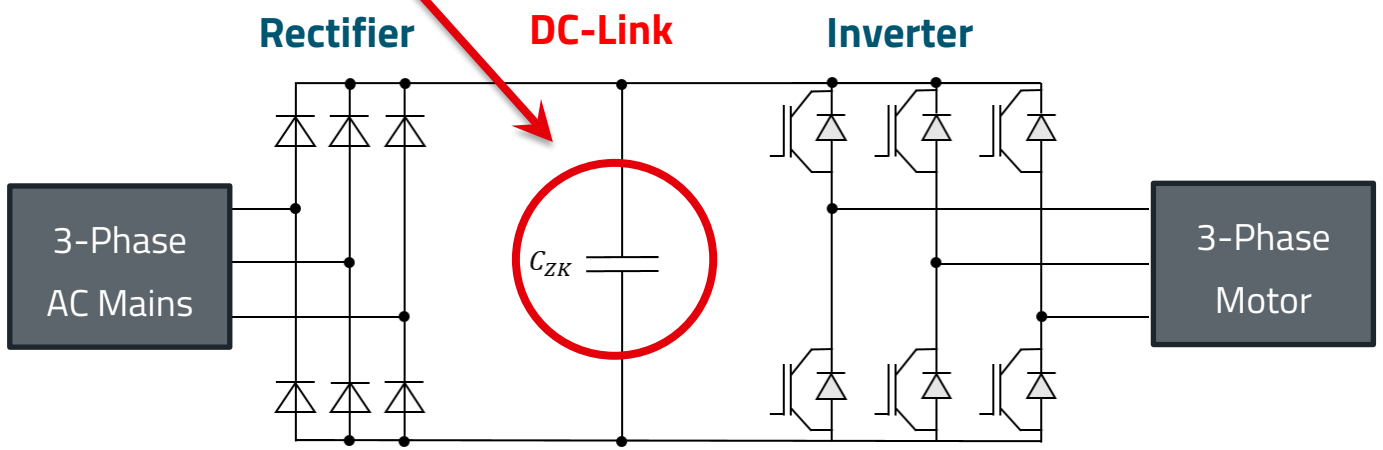
- THB X2 Capacitor:
  - Very low moisture absorption
  - Slightly bigger sizes than regular X2 Film Capacitors
  - Very good for long lifetimes



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

FILM CAPACITORS

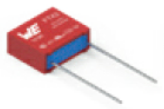
Available series

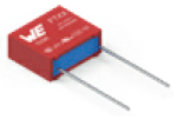
Available Series:


WCAP-FTBE
General Purpose +85°C


WCAP-FTBP
General Purpose +105°C


WCAP-FTDB
DC-Link


WCAP-FTX2
Interference Suppression Class X2, 275 V_{AC}


WCAP-FTXX
Interference Suppression Class X2, 310 V_{AC}


WCAP-FTXH
Interference Suppression THB* Class X2, 310 V_{AC}


WCAP-FTY2
Interference Suppression Class Y2/X1 300/330 V_{AC}

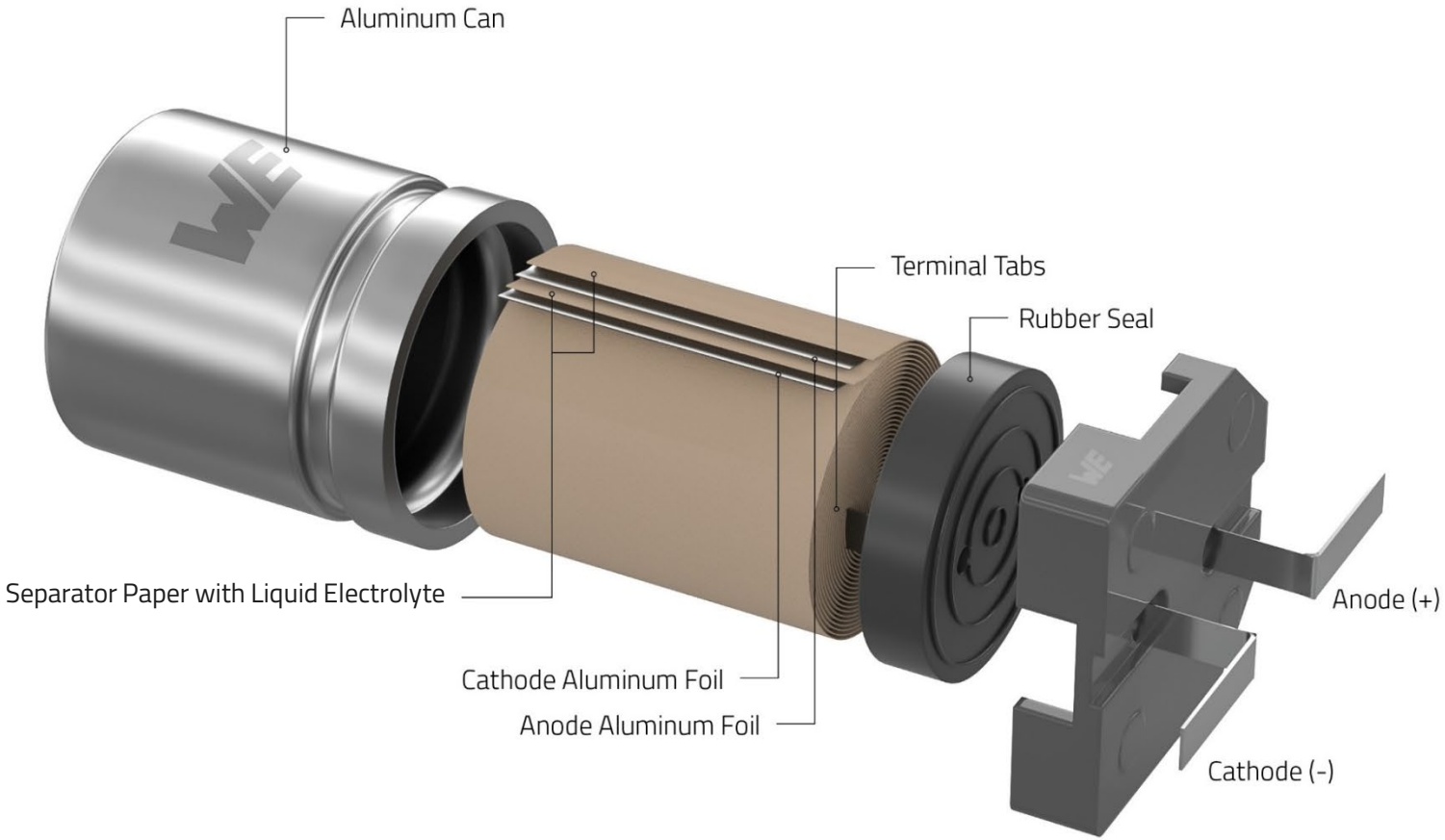
Characteristics:

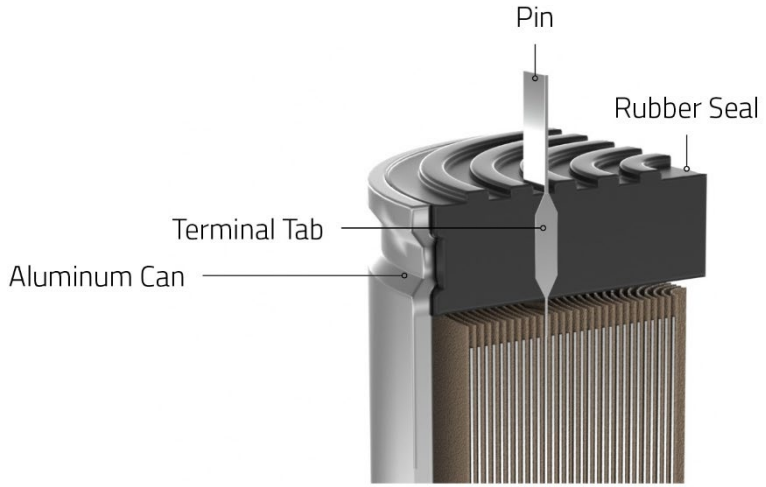
Type	Series	Capacitance	Voltage	Pitch (mm)	Operating Temperature (°C)
General Purpose	WCAP-FTBE, WCAP-FTBP	10 nF – 6.8 µF	100 – 1000 V_{DC}	7.5 – 37.5	-40 up to +105
DC-Link	WCAP-FTDB	1 µF – 75 µF	500 – 1200 V_{DC}	27.5 – 52.5	-40 up to +105
Interference Suppression					
Class X2	WCAP-FTX2, WCAP-FTXX	5.6 nF – 10 µF	275 & 310 V_{AC}	7.5 – 37.5	-40 up to +105
THB* Class X2	WCAP-FTXH	33 nF – 10 µF	310 V_{AC}	15 – 37.5	-40 up to +110
Class Y2/X1	WCAP-FTY2	1 nF – 470 nF	Y2: 300 / X1: 330 V_{AC}	10 – 27.5	-40 up to +110

**THB = Temperature Humidity Bias*

ALUMINUM CAPACITORS

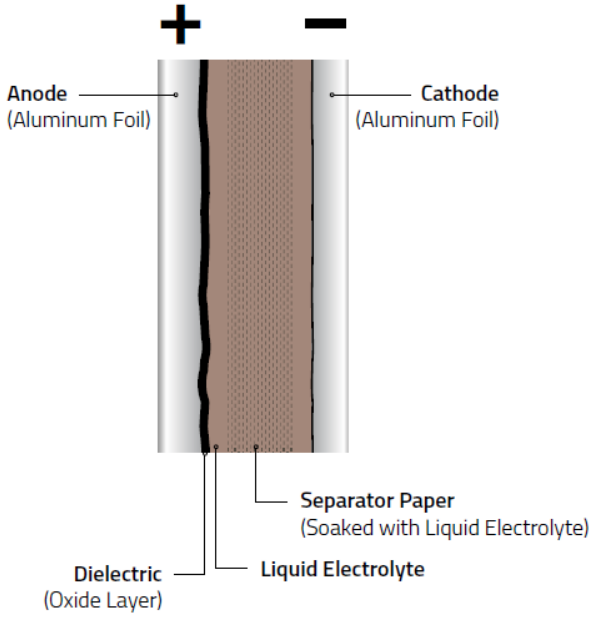
Construction

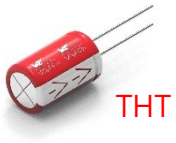




ALUMINUM CAPACITORS

Aluminum Electrolytic





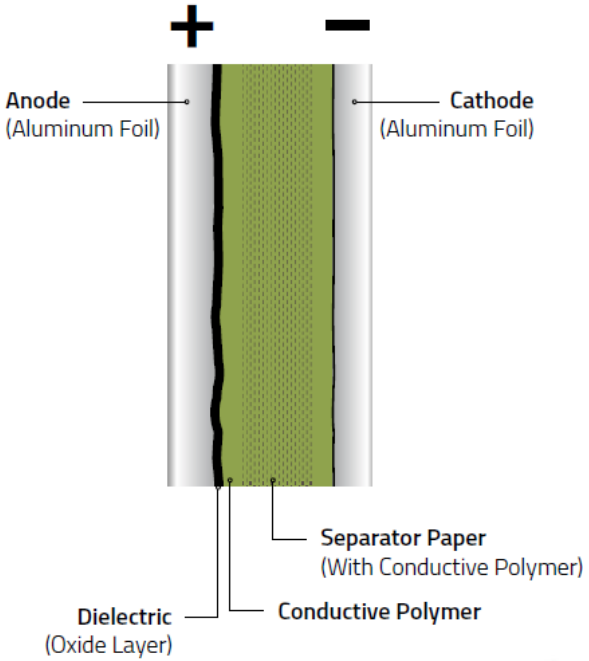
THT Radial

Snap-In THT

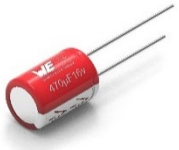
Screw Connection

SMD V-Chip

Aluminum Polymer



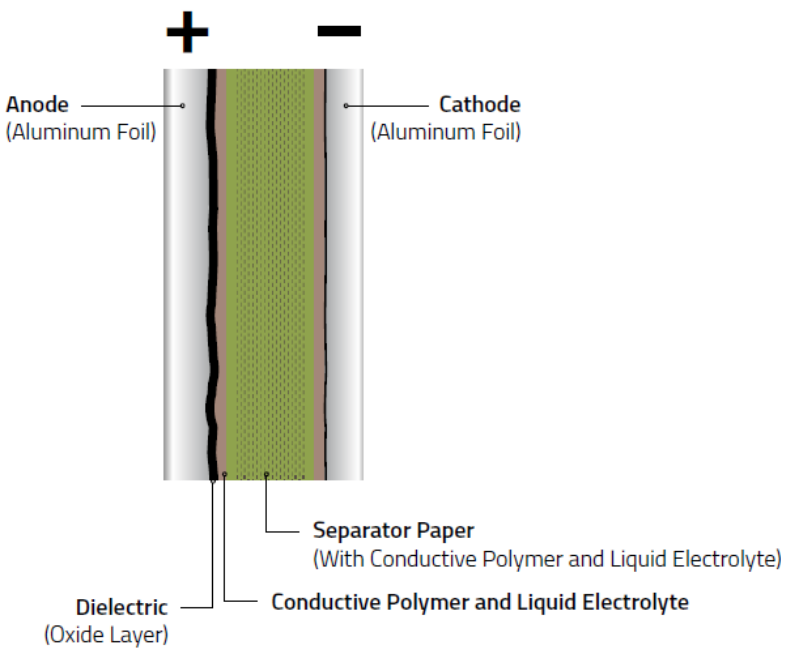
SMD V-Chip



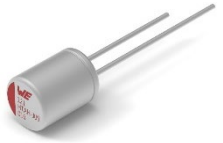
THT Radial

SMD H-Chip

Hybrid Polymer



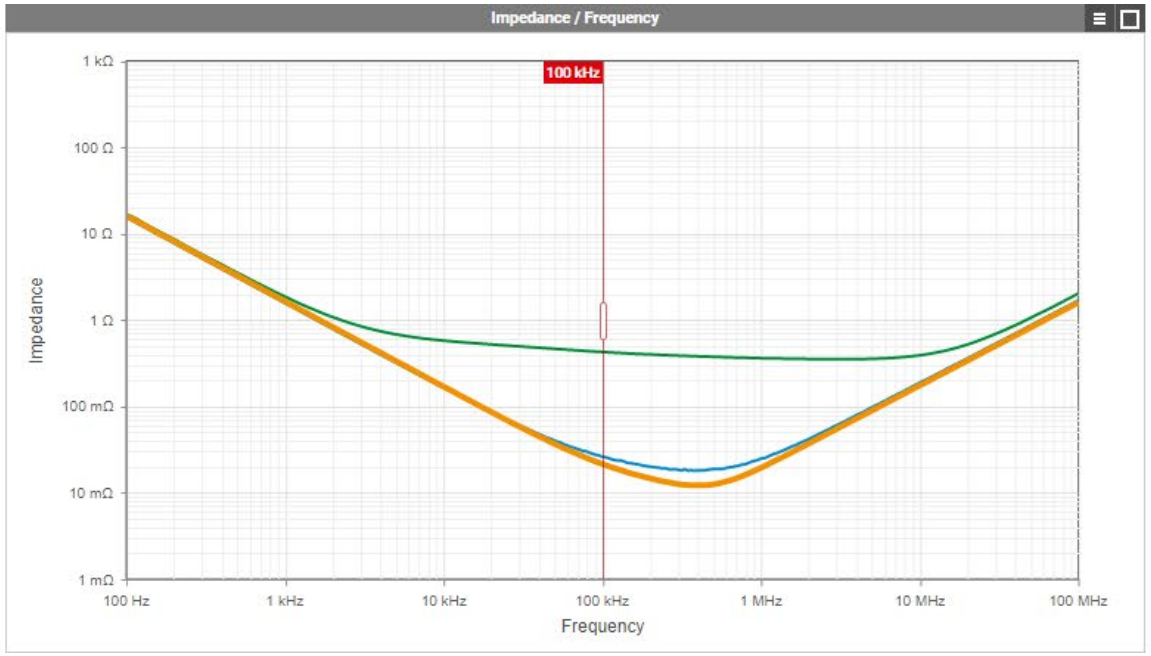
SMD V-Chip



THT Radial

ALUMINUM CAPACITORS

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®

ALUMINUM CAPACITORS

Available series – Aluminum Electrolytic

Available Series:

WCAP-ATXX
Radial THT

WCAP-ASXX
V-Chip SMT

WCAP-AIXX
Snap-In

WCAP-AWXX
Screw

Characteristics:

Type	Series	Capacitance	Voltage (V_{DC})	D x L (mm)	Operating Temperature (°C)	Endurance (h)
Radial THT*	ATG8, ATG5, AT1H, ATET, ATLI, ATUL, ATLL	0.47 – 33,000 µF	10 – 450	5 x 11 – 25 x 51	-55 up to +125	1,000 – 10,000
V-Chip SMT*	ASLI, ASLL, ASLU, ASNP, AS5H	0.47 – 6,800 µF	6.3 – 450	3 x 5.5 – 16 x 17	-40 up to +105	1,000 – 5,000
Snap-In*	AIG8, AIE8, AIG5, AI3H	33 – 10,000 µF	63 – 450	22 x 25 – 40 x 52	-40 up to +105	2,000 – 4,000
Screw	AWG8, AWG5	470 µF – 1 F	16 – 630	35 x 50 – 100 x 240	-40 up to +105	2,000 – 8,000

ALUMINUM CAPACITORS

Available series – Aluminum Polymer

ALUMINUM POLYMER CAPACITORS

More than 300 part numbers available ex stock. More part numbers on request.

Capacitance: max. 3,900 µF
Voltage: max. 100 V_{DC}

Available Series:

WCAP-PTXX
Radial THT

WCAP-PSXX
V-Chip SMT

WCAP-PHXX
H-Chip SMT

Characteristics:

Type	Series	Capacitance (µF)	Voltage (V_{DC})	Dimensions (mm)	Operating Temperature (°C)	Endurance (h)
Radial THT	PTG5, PTHR, PTHT, PT5H	10 – 2,000	6.3 – 100	D x L: 6.3 x 5.2 – 10 x 12.5	-55 up to +125	2,000 – 5,000
V-Chip SMT	PSLC, PSLP, PSHP	4.7 – 2,000	6.3 – 100	D x L: 4 x 5.5 – 10 x 12.4	-55 up to +105	2,000 – 5,000
H-Chip SMT	PHGP, PHLE, PHSE	100 – 560	2 – 6.3	L x W x H: 7.3 x 4.3 x 1.9	-55 up to +105	2,000

ALUMINUM CAPACITORS

Available series – Aluminum Hybrid Polymer

ALUMINUM HYBRID POLYMER CAPACITORS

More than 80 part numbers available ex stock. More part numbers on request.

Available Series:

WCAP-HTG5
Radial THT
General Purpose 105°C

WCAP-HTAH
Radial THT
High Temperature 125°C

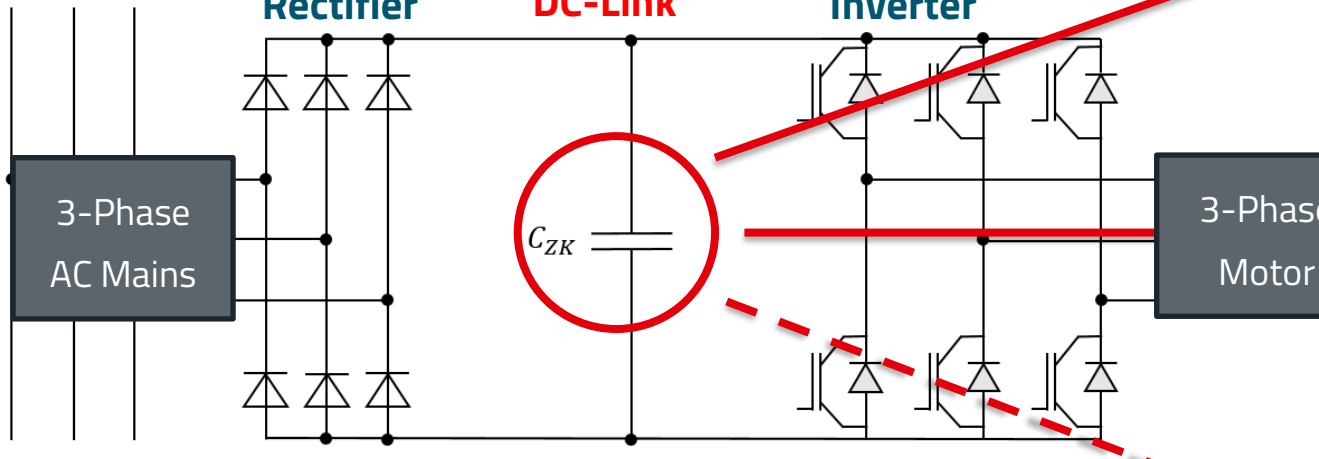
WCAP-HSG5
V-Chip SMT
General Purpose 105°C

WCAP-HSAH
V-Chip SMT
High Temperature 125°C

Characteristics:

Type	Series	Capacitance (µF)	Voltage (V_{DC})	D x L (mm)	Operating Temperature (°C)	Endurance (h)
Radial THT, General Purpose	WCAP-HTG5	10 – 470	16 – 100	6.3 x 8 – 10 x 12.5	-55 up to +105	5,000 – 10,000
Radial THT, High Temperature	WCAP-HTAH	10 – 560	16 – 100	6.3 x 8 – 10 x 12.5	-55 up to +125	2,000 – 4,000
V-Chip SMT, General Purpose	WCAP-HSG5	10 – 560	16 – 100	5 x 5.8 – 10 x 12.4	-55 up to +105	10,000
V-Chip SMT, High Temperature	WCAP-HSAH	10 – 820	16 – 100	5 x 5.8 – 10 x 12.4	-55 up to +125	4,000

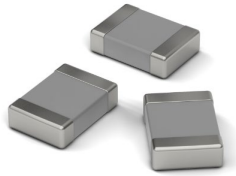
DC LINK APPLICATION



DC-Link Film Capacitors

New Series WCAP-FTDB

Alum. Electrolytic Capacitors



Multilayer Chip Capacitors
(only high frequency)

DC LINK APPLICATION

Film vs. Aluminum in DC Link Technology

General technical comparison

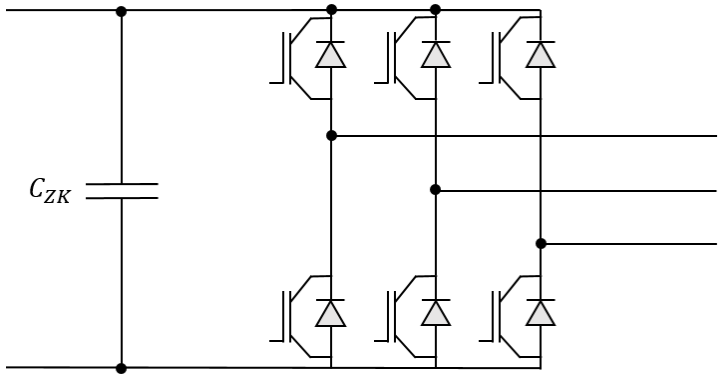
- High RMS current capabilities
  - Several ARMS per µF
- Rated voltages up to 1,200 V
- No liquid inside
- Long storage and load life
- Self-healing properties

- High capacitance values
  - Highest capacitance per volume unit (µF / mm³)
  - Highest capacitance per dollar (µF / $)
- Relatively high ESR internal resistance
  - Depends on the part 1 mA/µF…20 mA/µF or higher
- Rated voltages up to 650 V
  - Series connection possible for higher voltage level

DC LINK APPLICATION

Hybrid Polymer?

DC-Link Requirements	Why Hybrid Polymer?
High RMS ripple current	Low ESR vs. Aluminum Electrolytic
Low ESR to limit self-heating	High ripple-current capability
Stable behavior over temperature	Compact solution for dense inverter layouts
High realiability and lifetime	Liquid electrolytc supports oxide regeneration



	Al-Electrolytic	Hybrid Polymer	Film Capacitor
Pros 👍	Low cost, high capacitance, higher voltages than Hybrid Polymer	Low ESR, high ripple capability, compact, good thermarmal performance	Very low ESR, excellent ripple capability, long life
Cons 👎	High ESR, lower ripple capability, shorter life	Higher cost than Al electrolytic, voltage and size limits	Low capacitance density, large size, higher cost

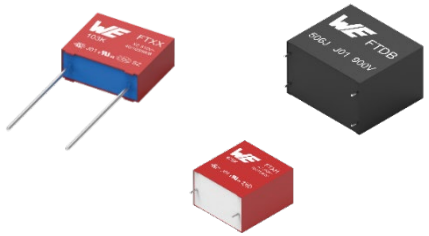
UNDERSTANDING AND SELECTING CAPACITORS

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



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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