

## DC-LINK CAPACITORS FOR DC-CHARGER APPLICATIONS

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Technical Project Engineer for Capacitors & Resistors

**WÜRTH ELEKTRONIK** MORE THAN YOU EXPECT



**WÜRTH  
ELEKTRONIK**  
MORE THAN  
YOU EXPECT

## AGENDA

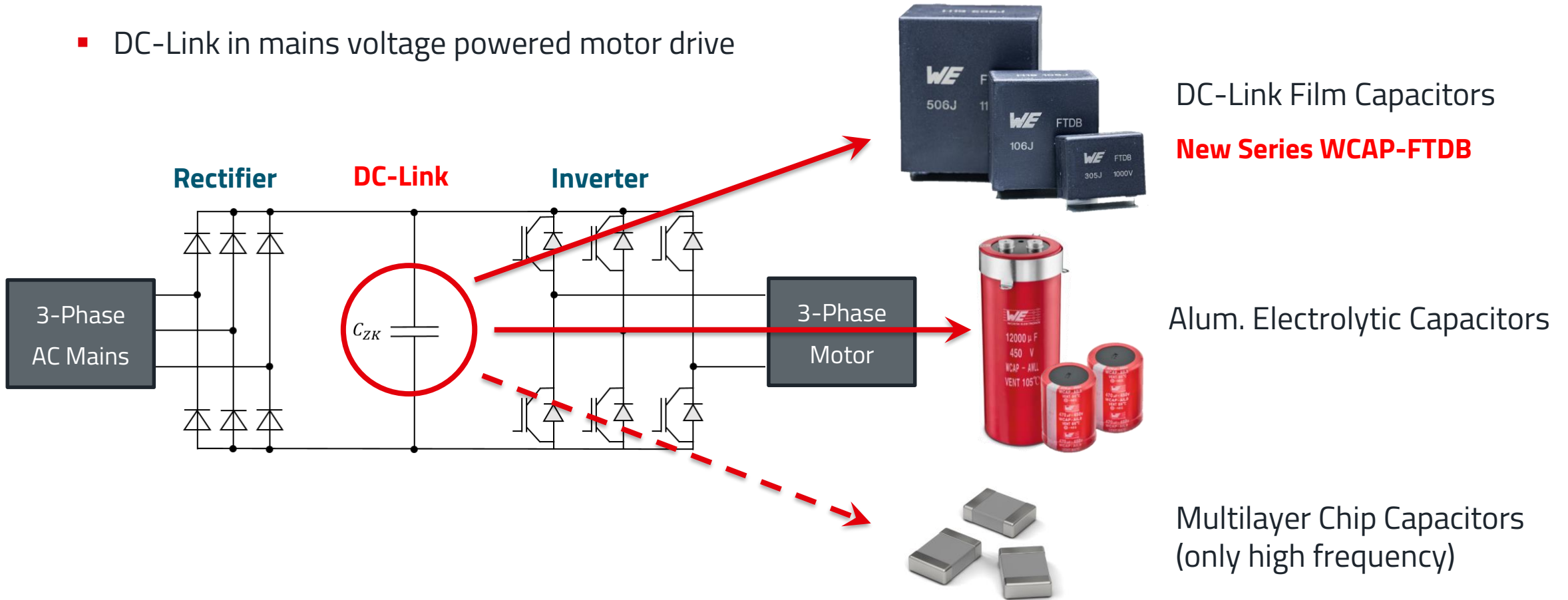
- DC-Link Applications
  - General Overview
  - 25 kW DC Charger (onsemi)
- DC-Link Capacitors
  - Film Capacitors
  - Aluminum Electrolytic Capacitors
  - Comparism
  - Approaches for the capacitance value
  - Maximum Capacitor ripple current at a specific frequency and temperature
- Other important selection criteria



# DC-LINK APPLICATIONS

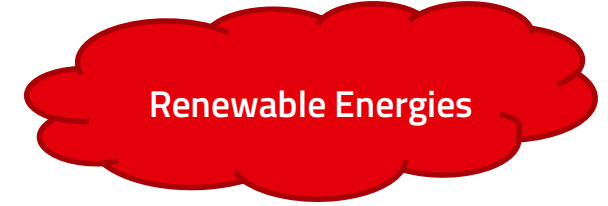
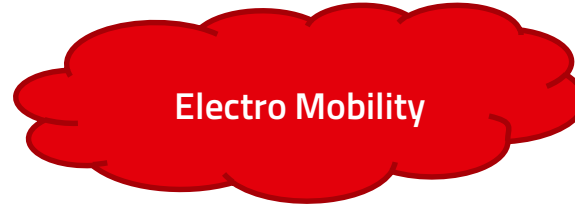
## DC-Link Capacitors

- DC-Link in mains voltage powered motor drive



# DC-LINK APPLICATIONS

## DC-Link Capacitor Applications



Electro Mobility

Renewable Energies

On-Board Chargers (OBC)

High-Performance  
Power Supplies

UPS / Backup Inverters

Motor Drive

EV-Chargers

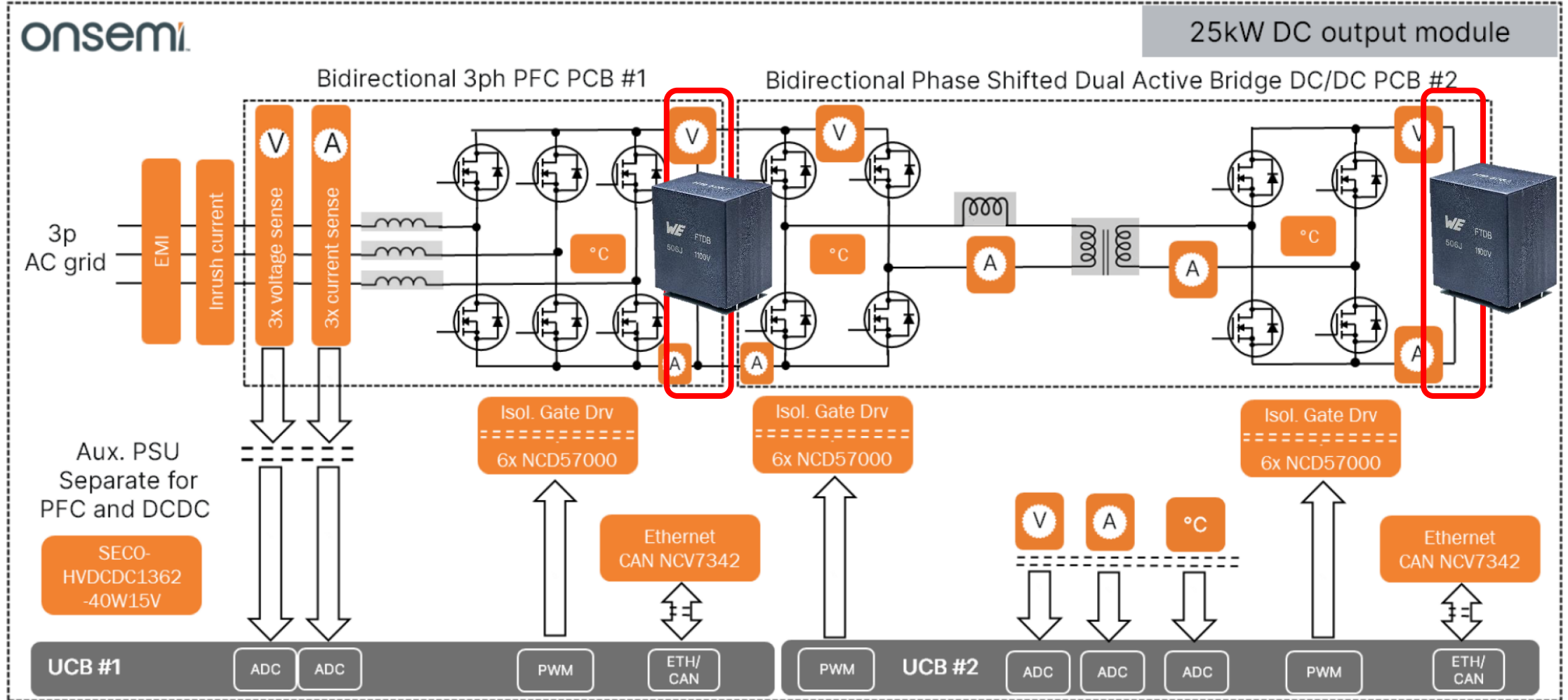
Solar Inverter

PFC Circuits



# DC-LINK APPLICATIONS

Onsemi Reference Design - 25 kW Fast DC Bidirectional Charger incl. PFC

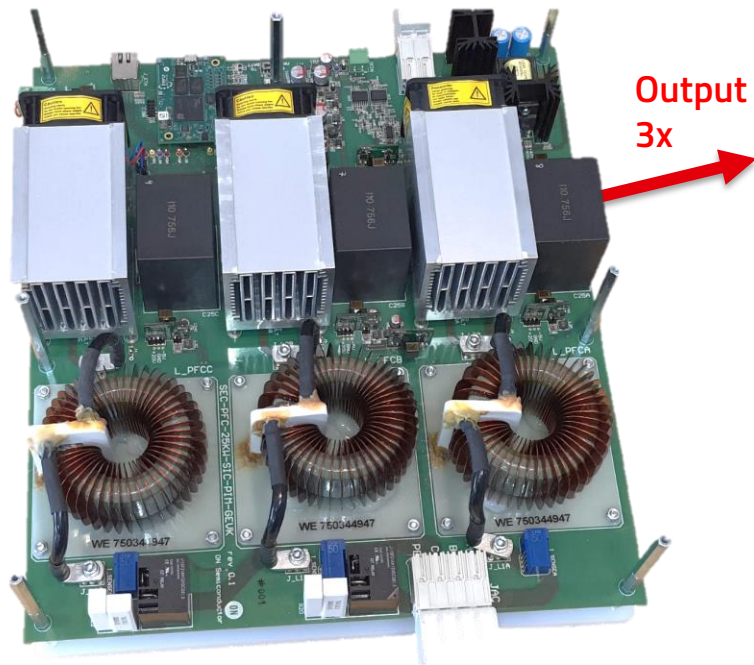


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# DC-LINK APPLICATIONS

Onsemi Reference Design - 25 kW Fast DC Bidirectional Charger incl. PFC

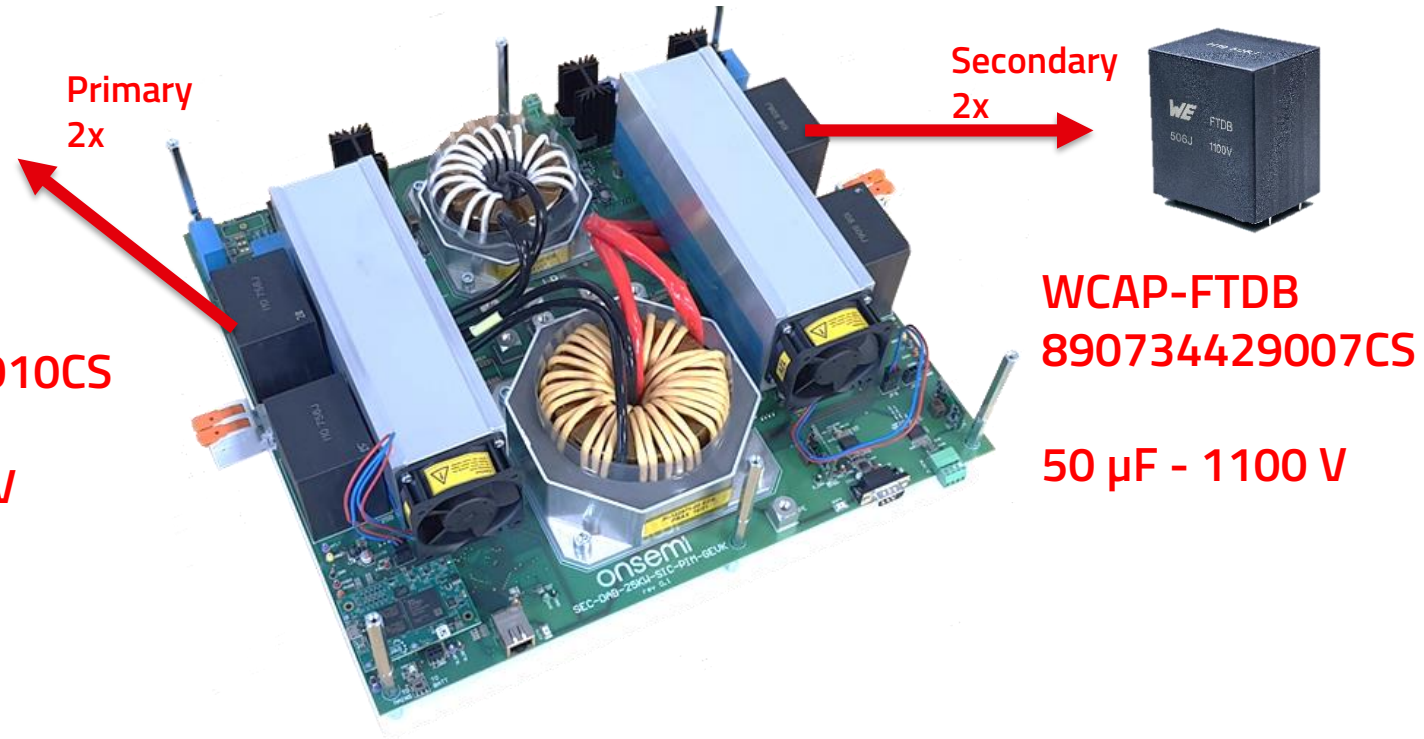
## 3-Phase Rectifier + PFC



Output  
3x

WCAP-FTDB  
890724429010CS  
75  $\mu$ F - 900 V

## Bidirectional DC-DC – Dual Active Bridge (DAB)



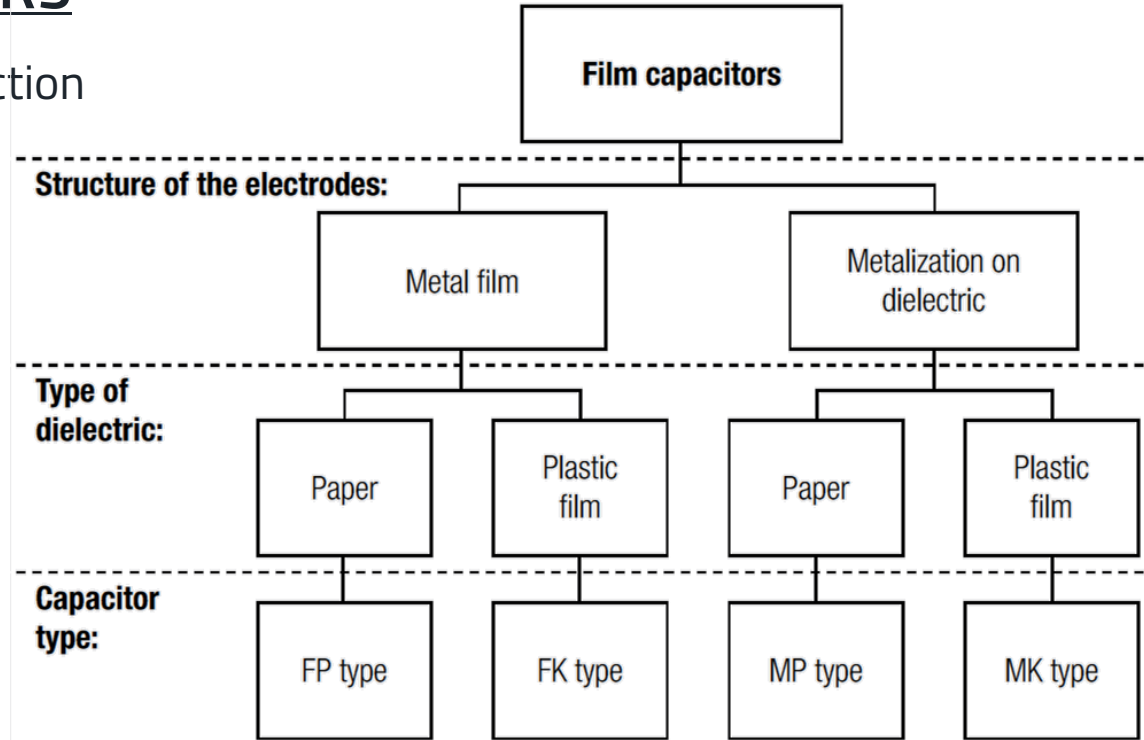
Primary  
2x

Secondary  
2x

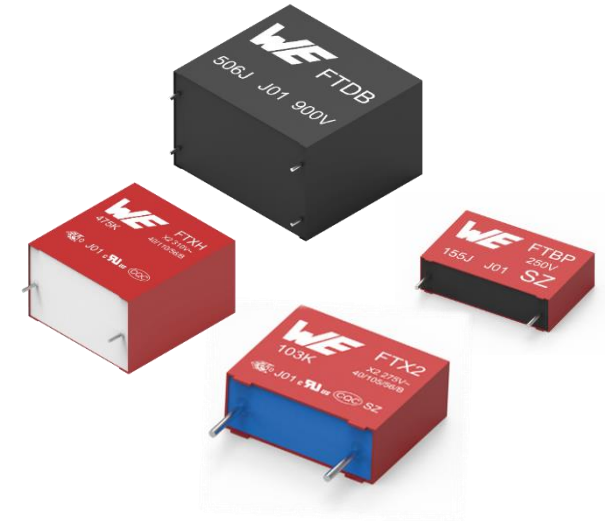
WCAP-FTDB  
890734429007CS  
50  $\mu$ F - 1100 V

# DC-LINK CAPACITORS

## 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



# DC-LINK CAPACITORS

Film Capacitors - new series WCAP-FTDB



## Würth Elektronik WCAP-FTDB DC-Link Series

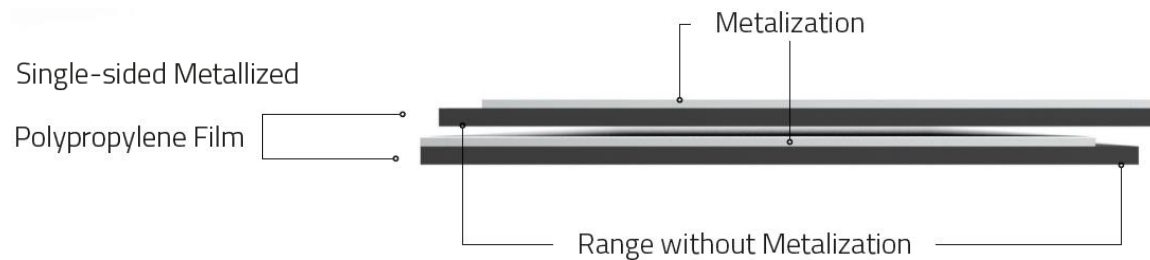
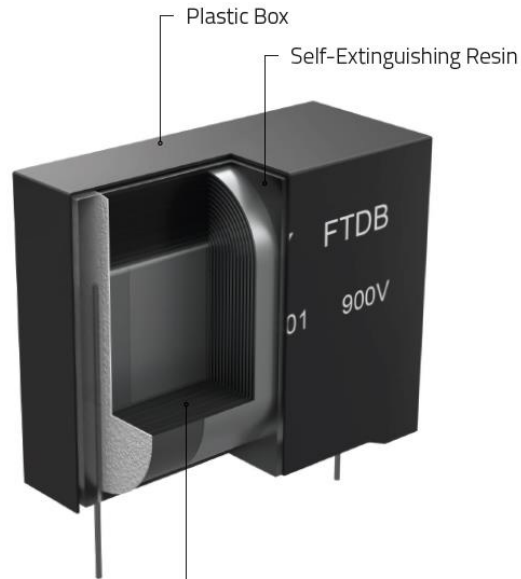
- Boxed THT - MKP Film Capacitors
  - Capacitance: 1  $\mu\text{F}$  up to 75  $\mu\text{F}$
  - Voltage: 500  $V_{\text{DC}}$  up to 1200  $V_{\text{DC}}$
  - MKP: Polypropylene metallized film
  - 24x Standard part numbers in catalogue and ex-stock
  - Temperature:  $-40^{\circ}\text{C}$  up to  $105^{\circ}\text{C}$
  - Pitch / Pin distance: 27.5, 37.5 and 52.5 mm
  - High ripple current capability
  - Self-healing properties
  - Very long expected load life



# DC-LINK CAPACITORS

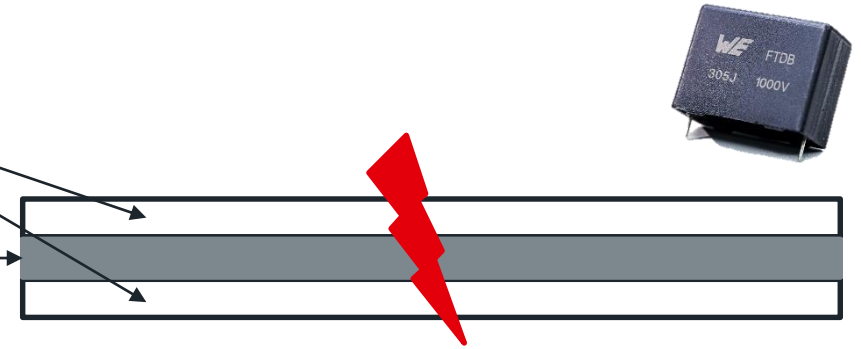
## Film Capacitors - Construction and Selfhealing

### Construction

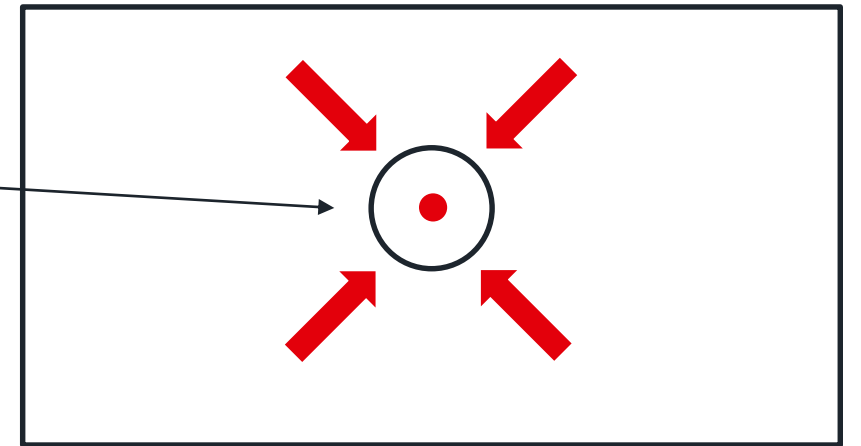


Metallization

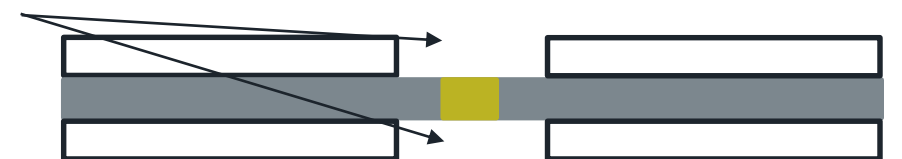
Dielectric



Area of high current density



Metallization is vaporized



# DC-LINK CAPACITORS

## Film Capacitors - Rated current derating

### Electrical Properties:

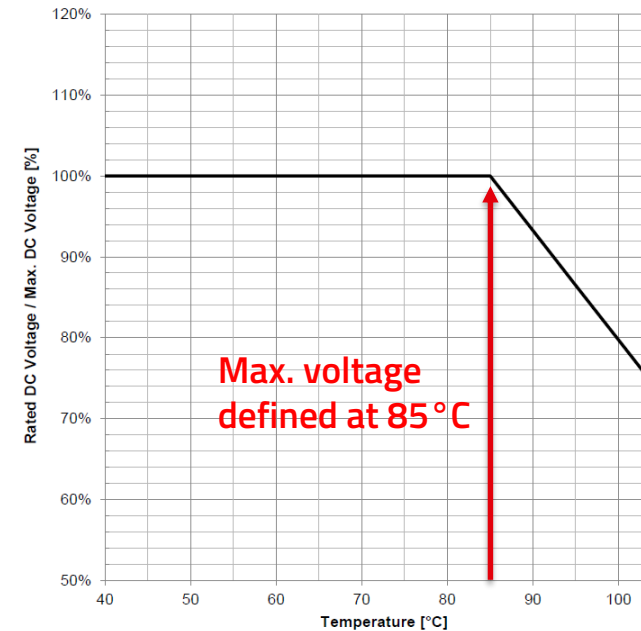
Properties		Test conditions	Value	Unit	Tol.
Capacitance	C	1 V/ 1 kHz ± 0.2 kHz	75	µF	±5%
Rated Voltage	V <sub>R</sub>	up to 85 °C	900	V (DC)	max.
Rated Voltage	V <sub>R</sub>	@ 105 °C	657	V (DC)	max.
Insulation Resistance	R <sub>ISO</sub>	1 min @ 100 V (DC)	133.33	MΩ	min.
Dissipation Factor	DF	@ 1 kHz	0.31	%	max.
Dissipation Factor	DF	@ 10 kHz	3	%	max.
Rate of Voltage Rise	dV/dt		15	V/µs	max.
Dielectric Strength Pin to Pin		10 sec.	1350	V (DC)	max.
Dielectric Strength Pin to Case		10 sec.	2800	V (AC)	max.
ESR	R <sub>ESR</sub>	@ 10 kHz	4.7	mΩ	typ.
Ripple Current	I <sub>RIPPLE</sub>	10 kHz @ 70 °C	25.7	A	max.
Peak Current	I <sub>Peak</sub>	$\hat{i} = C[\mu\text{F}] \cdot dV/dt$	1125	A	max.

### General Information:

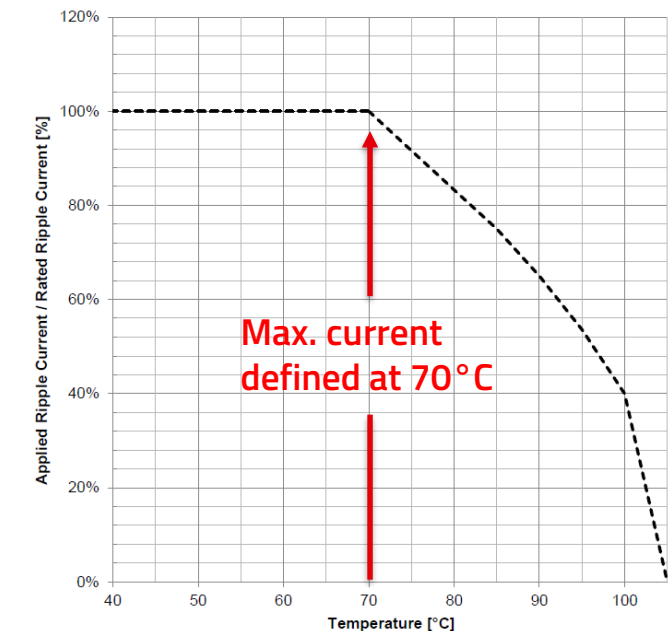
DC-Link Capacitor; wound type; boxed; MKP-Metallized Polypropylene	
Operating Temperature	-40 up to +105 °C
Storage Conditions (in original packaging)	5 °C up to + 35 °C; 10 % up to 75 % RH
Maximum Selfheating (Rated)	15 °C
Moisture Sensitivity Level (MSL)	1
Climatic Category	40/85/56
Test conditions of electrical properties: +20 °C, 35 % RH if not specified differently	
FIT according to separate documentation	



Voltage Derating:



Current Derating (Typical Curve):



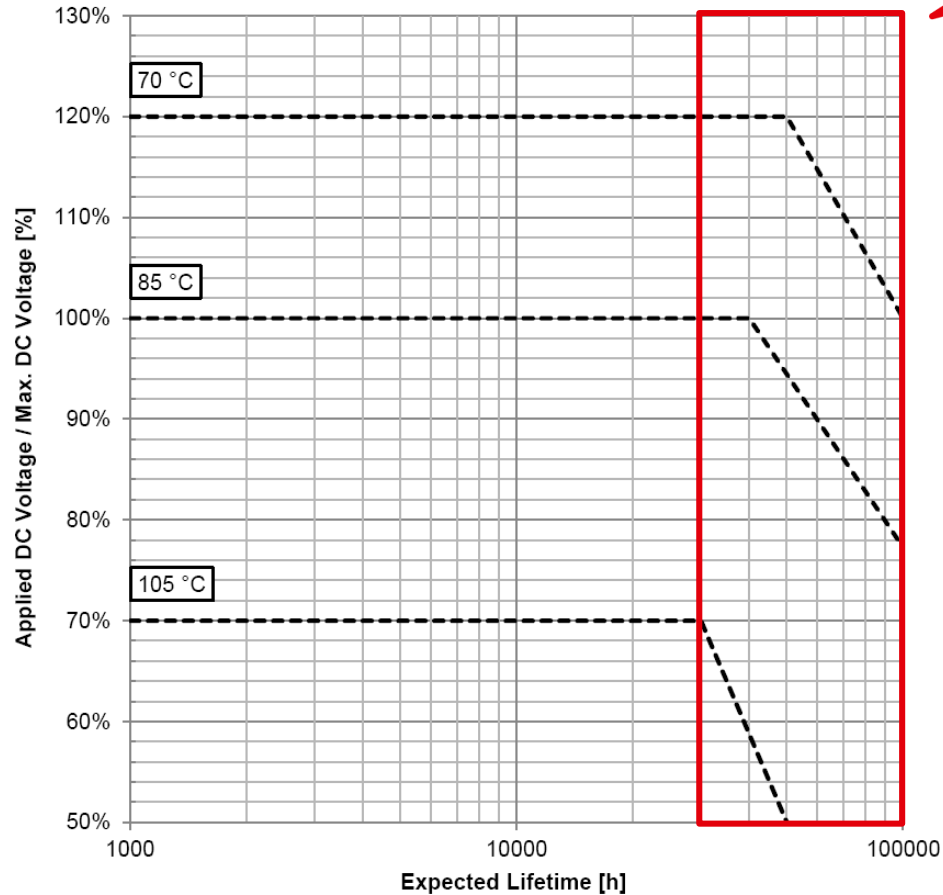
# DC-LINK CAPACITORS

## Film Capacitors - Lifetime and Voltage (de)rating



Find this and more measurements in  
**REDEXPERT®**

Lifetime (Typical Curve):

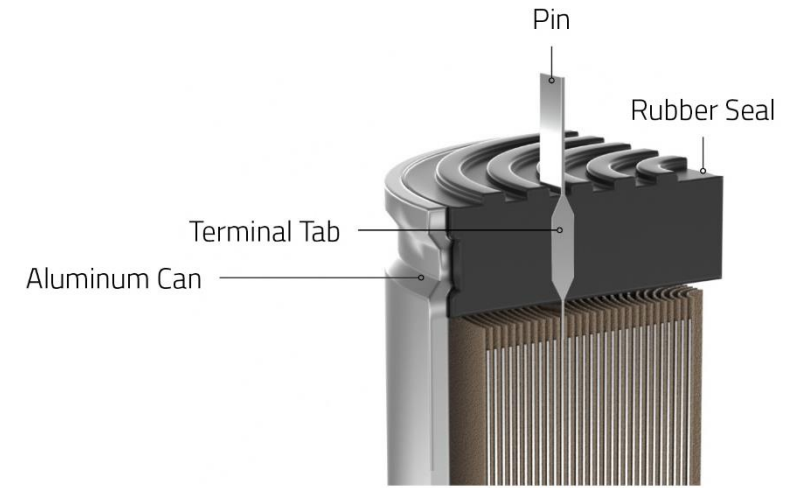
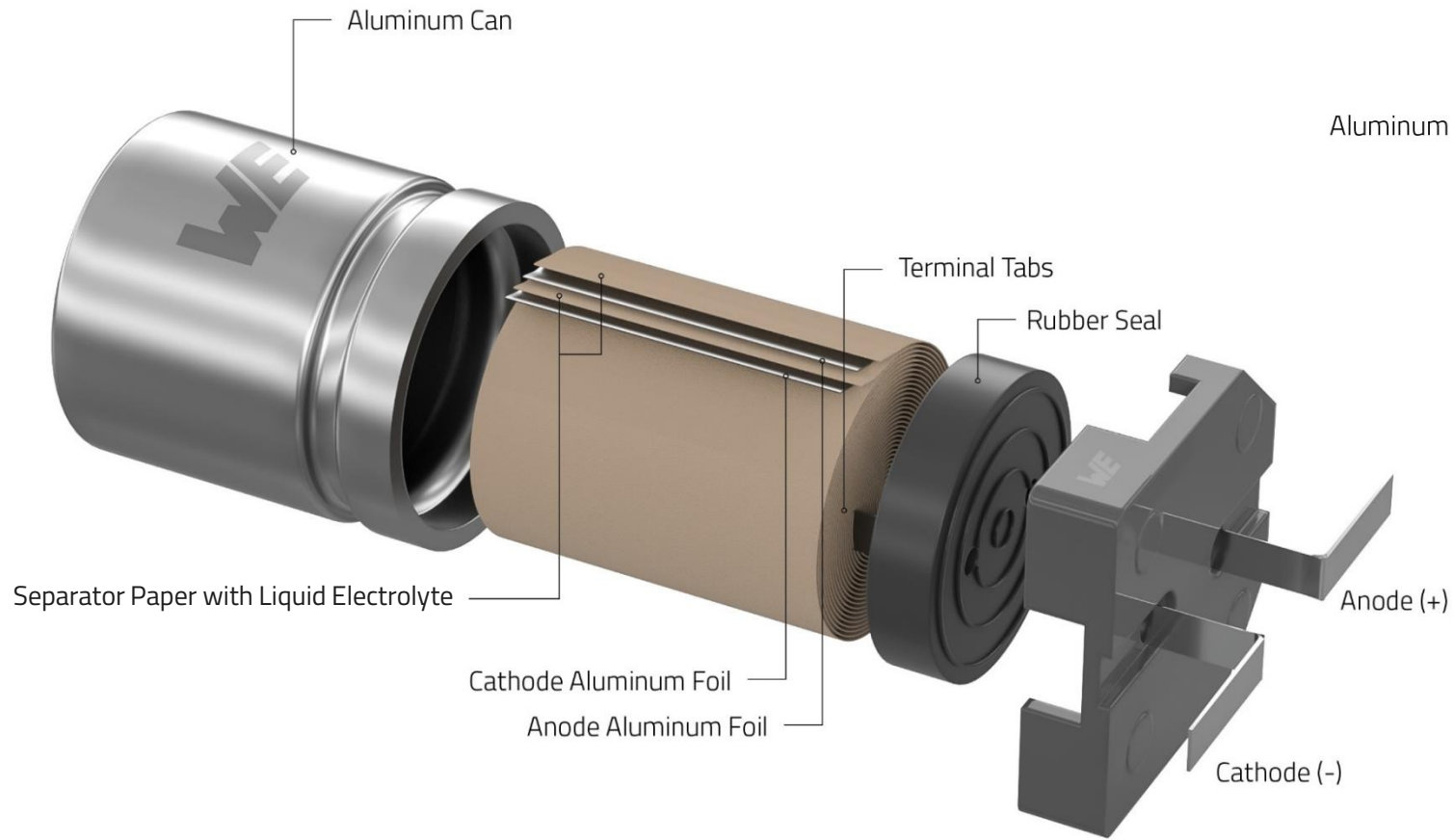


- Aging depends on voltage and temperature
- High air humidity will always accelerate the degradation of the metallized film
- MKP Film Capacitor Aging
  - Capacitance drop
  - ESR /  $\tan \delta$  increase
  - Leakage current increase
- Combination of C drop and ESR rise may increase self heating and accelerate aging

# DC-LINK CAPACITORS

## Aluminum Electrolytic Capacitors

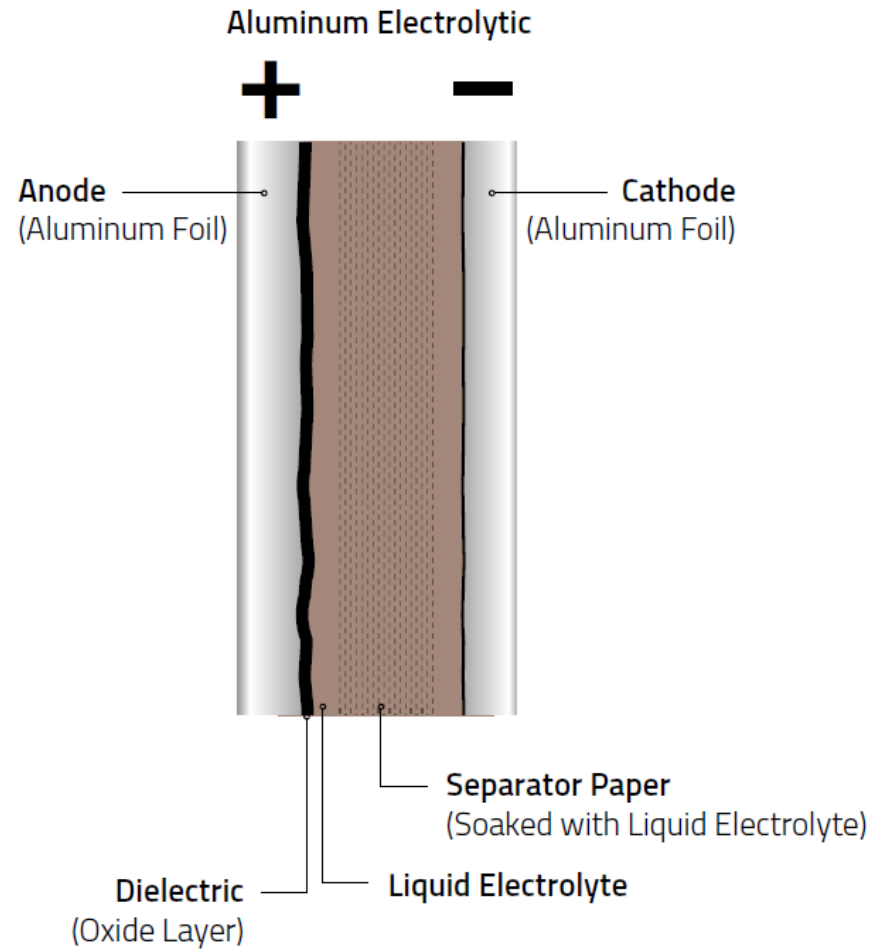
- Construction of an Aluminum Electrolytic Capacitor:





# DC-LINK CAPACITORS

## Aluminum Electrolytic Capacitors – Inner Structure



# DC-LINK CAPACITORS

## Aluminum Electrolytic Capacitors – Lifetime Calculation with WE

- Arrhenius [4]:
  - $L_{Al.} = L_0 2^{\frac{T_{Max} - (T_x + \Delta T)}{10}} \left(\frac{V_r}{V_{max}}\right)^{V_x}$
- Temperature influences the lifetime:
  - Ambient temperature
  - Ripple current and frequency
- Applied Voltage
- Consult us
  - Specific Mission Profiles
  - Samples with Temperature Sensor (Only for special Projects)



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< **Expected Lifetime**

SELECTION

**Actual Operating Temperature**  
T 20°C

**Applied Frequency**  
f 1 kHz

**Applied Voltage**  
V 0 V

**Applied Ripple Current**  
I<sub>r</sub> 0 A

Do not apply Ripple Current filter

**861140384001**

Maximum Expected Lifetime of  
**13 years**

# DC-LINK CAPACITORS

## Film vs. Aluminum DC Link Technology

### Film DC Link Capacitor

- High RMS current capabilities
  - Several  $A_{RMS}$  per  $\mu F$
- Rated voltages up to 1,200 V
- No liquid inside
- Long storage and load life
- Self-healing properties



### Aluminum Electrolytic Capacitor

- High capacitance values
  - Highest capacitance per volume unit ( $\mu F / mm^3$ )
  - Highest capacitance per dollar ( $\mu F / \$$ )
- Relatively high ESR internal resistance
  - Depends on the part 1 mA/ $\mu F$ ...20 mA/ $\mu F$  or higher
- Rated voltages up to 650 V
  - Series connection possible for higher voltage level



# DC-LINK CAPACITORS

## Calculation – DC-Link film vs Aluminum Electrolytic Capacitor

- Design requirements
  - $V_{DC}$  Bus voltage
  - Rated power
  - Switching frequency
- Other design parameters or constraints
  - Load/Motor inductance
  - Voltage ripple  $V_{RMS}$
  - Current ripple  $I_{RMS}$
  - Total capacitance
  - Expected load life
  - Size
  - ...

Design criteria **different** for each technology

### Film Capacitors



High  $I_{RMS}$   
Low C



High Lifetime

High  $V_{RMS}$

### Alum. Electrolyte



High C  
Low  $I_{RMS}$



Low voltage ripple  $V_{RMS}$

Start-up Issues?  
Safety Issues?

For the same  
Space & Cost

Result



# DC-LINK CAPACITORS

Approaches for the Capacitance value

Formula	(20)	(21)	(22)	(23)
	$\frac{P_{Load}}{12f_{grid}(V_{dc}^2 - (V_{dc} - V_{dc,pp})^2)}$	$\frac{P_{Load}}{240V_{dc,pp}V_{ph}f_{grid}}$	$\frac{I_{d,pp}}{2\pi f_d V_{dc,pp}}$	$\frac{V_{dc}}{32L_N V_{dc,pp} f_{pwm}^2}$
$C_{dc-Link,min} [\mu F]$	3,271.56	1,132.24	76.67	22.77
Reference	[1]	[2]	[2]	[3]

- Impedance based Design
- Other design requirements may lead to higher C-value
  - C-Value depends strongly on the load!
  - Fault-ride-through
  - Higher capacitance may be required for storage of regenerated energy

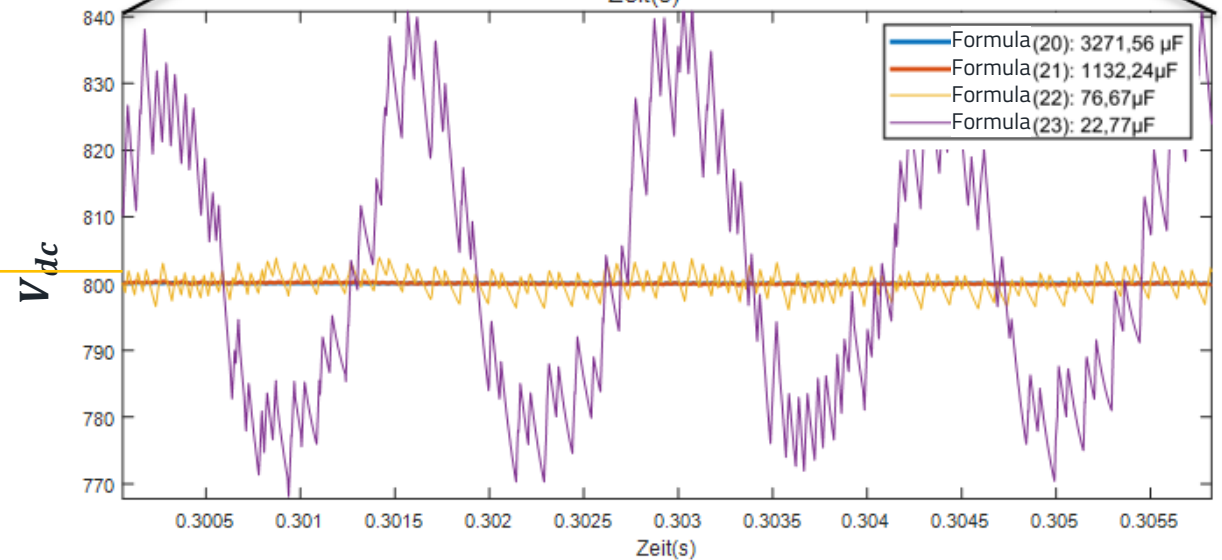
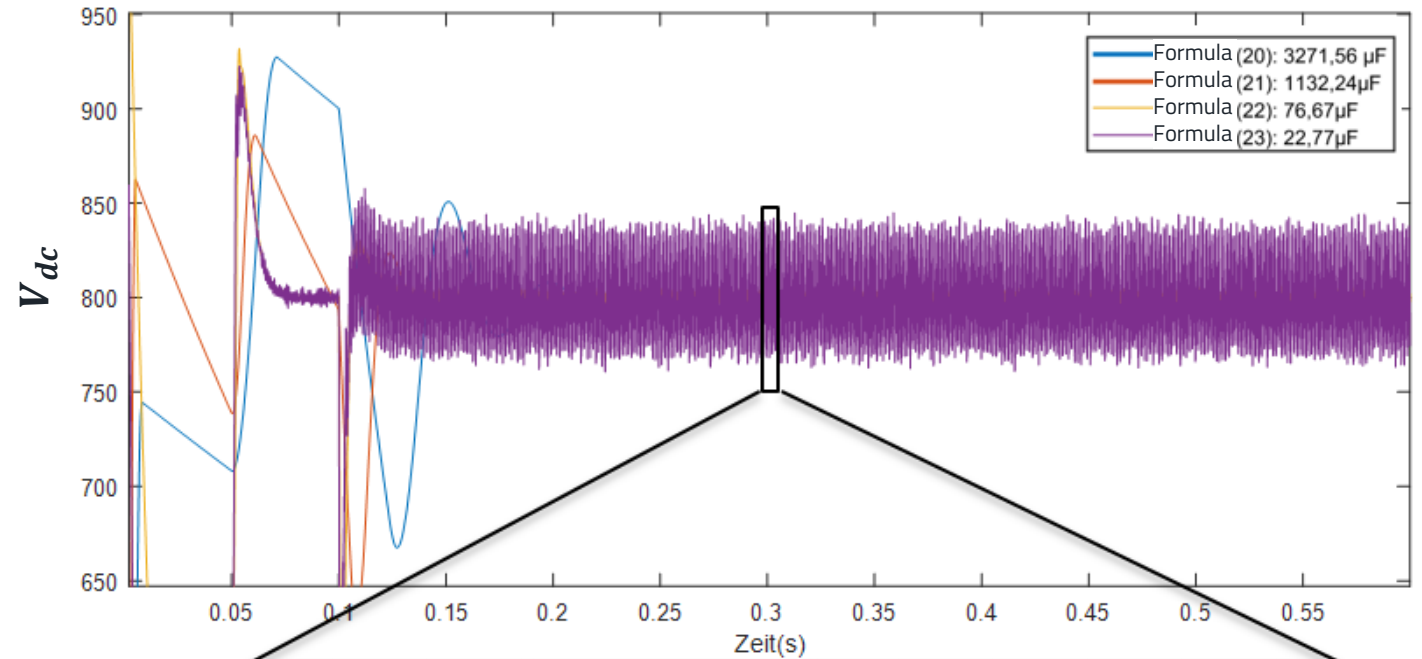
Only for reference!

# DC-LINK CAPACITORS

Approaches for the Capacitance value

$$C_{dc-Link} \geq \frac{I_{d,pp}}{2\pi f_d V_{dc,pp}}$$

Only for reference!

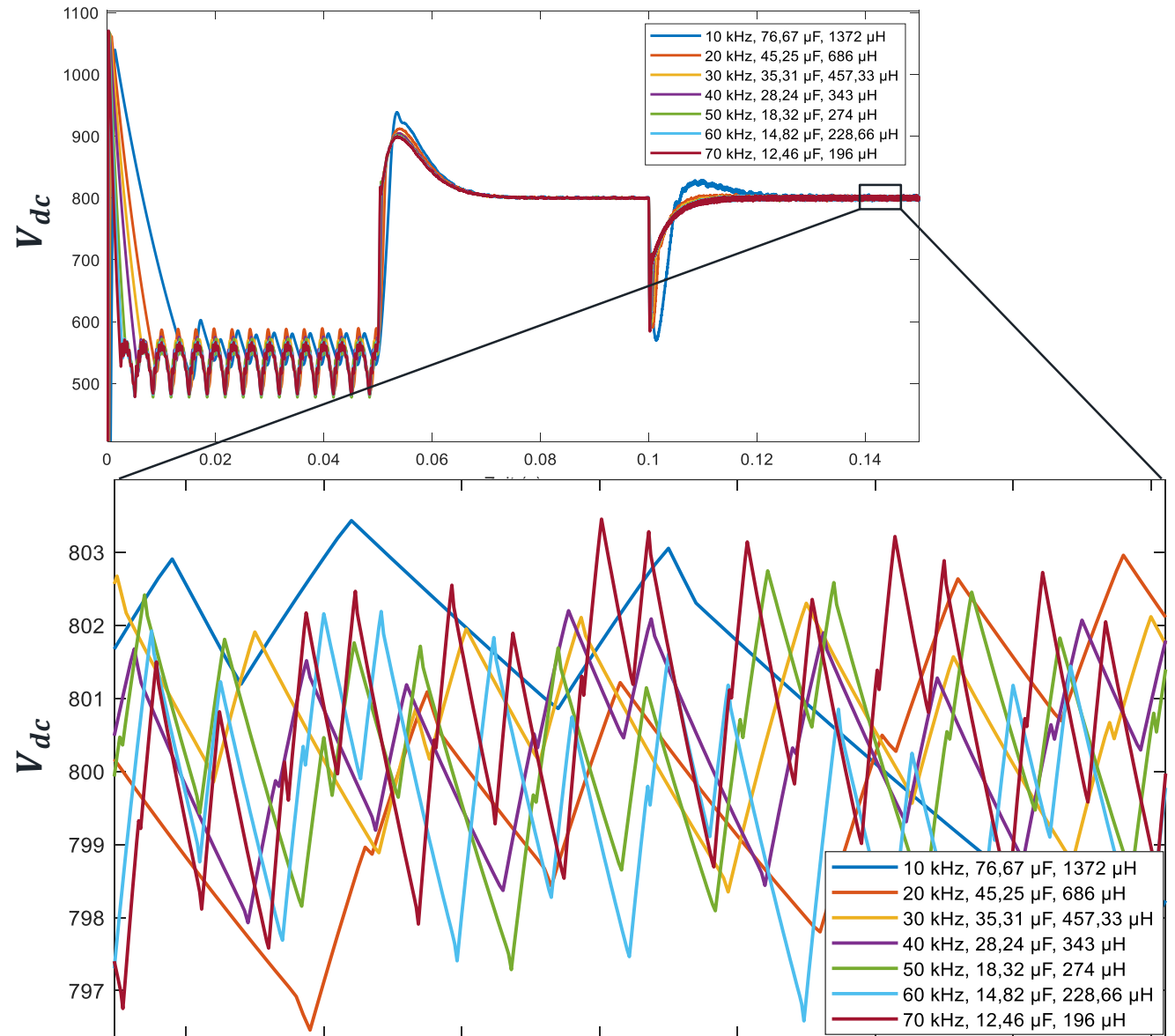


# DC-LINK CAPACITORS

## Approaches for the Capacitance value

- Calculation of the Capacitance values for different Frequencies
  - Vienna Rectifier
  - **Constant Load!**
  - Reduction of the Inductance value for each Frequency
- Calculation of the Capacitance value by:
  - $C_{dc-Link} \geq \frac{I_{d,pp}}{2\pi f_d V_{dc,pp}}$
- Target: 1% Voltage Ripple

Only for reference!



# DC-LINK CAPACITORS

Determining the maximum Capacitor ripple current at a specific frequency and temperature

**REDEXPERT** Aluminum Electrolytic / Aluminum Polymer Capacitors

🔗
🛒
🌐
☰ MENU

57 items

**Expected Lifetime**

**SELECTION**

Actual Operating Temperature  
T

Applied Frequency  
f

Applied Voltage  
V

Applied Ripple Current  
I<sub>r</sub>

Do not apply Ripple Current filter

Filters: Not Internal V<sub>R</sub> ≥ 400 V Maximum I<sub>R</sub> ≥ 2.70 A

Order Code	Series	V <sub>R</sub>	C	Technology	Series Description	I@65°C @10 kHz...	Spei
861141386028	WCAP-AI3H	400 V	1.00 mF	Alum. Electrolytic	Snap-In - Long Life +105°C	6.65 A	
861141485033	WCAP-AI3H	450 V	470 µF	Alum. Electrolytic	Snap-In - Long Life +105°C	6.10 A	
861011487027	WCAP-AIG8	450 V	560 µF	Alum. Electrolytic	Snap-In - General Purpose +8...	5.75 A	
861141486026	WCAP-AI3H	450 V	680 µF	Alum. Electrolytic	Snap-In - Long Life +105°C	5.52 A	
861141486025	WCAP-AI3H	450 V	560 µF	Alum. Electrolytic	Snap-In - Long Life +105°C	5.40 A	

**861141386028**

Maximum Expected Lifetime of  
**7.86 years**

**Endurance Conditions**

Capacitance Drop  
≤ ±15% of initial value

Dissipation Factor  
≤ 175% of the initial specified value

Leakage Current  
≤ the initial specified value

Show Panel: Z vs. F ESR vs. F I<sub>RMS</sub> vs. F I<sub>RMS</sub> vs. T

**Expected LifeTime**

**Multiplier Factor for Ripple Current / Frequency**

**Multiplier Factor for Ripple Current / Temperature**

20

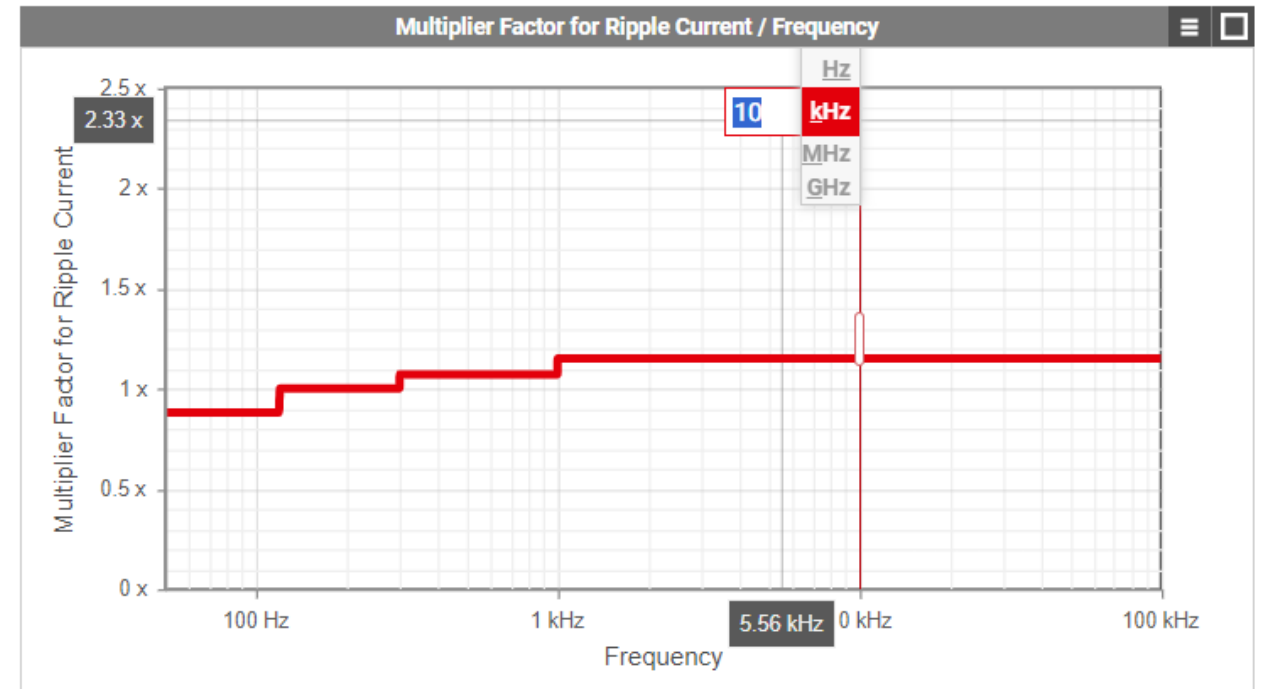
DC-LINK CAPACITORS FOR DC-CHARGER APPLICATIONS  
DIGITAL WE DAYS 2023 | LUH | 18.10.2023



# DC-LINK CAPACITORS

Determining the maximum Capacitor ripple current at a specific frequency and temperature

- Use case
  - 23 Arms @ 10 kHz @ 65 °C
- 1st Step
  - Filter for mechanical Dimensions, etc.
- 2nd Step
  - Enter the Frequency

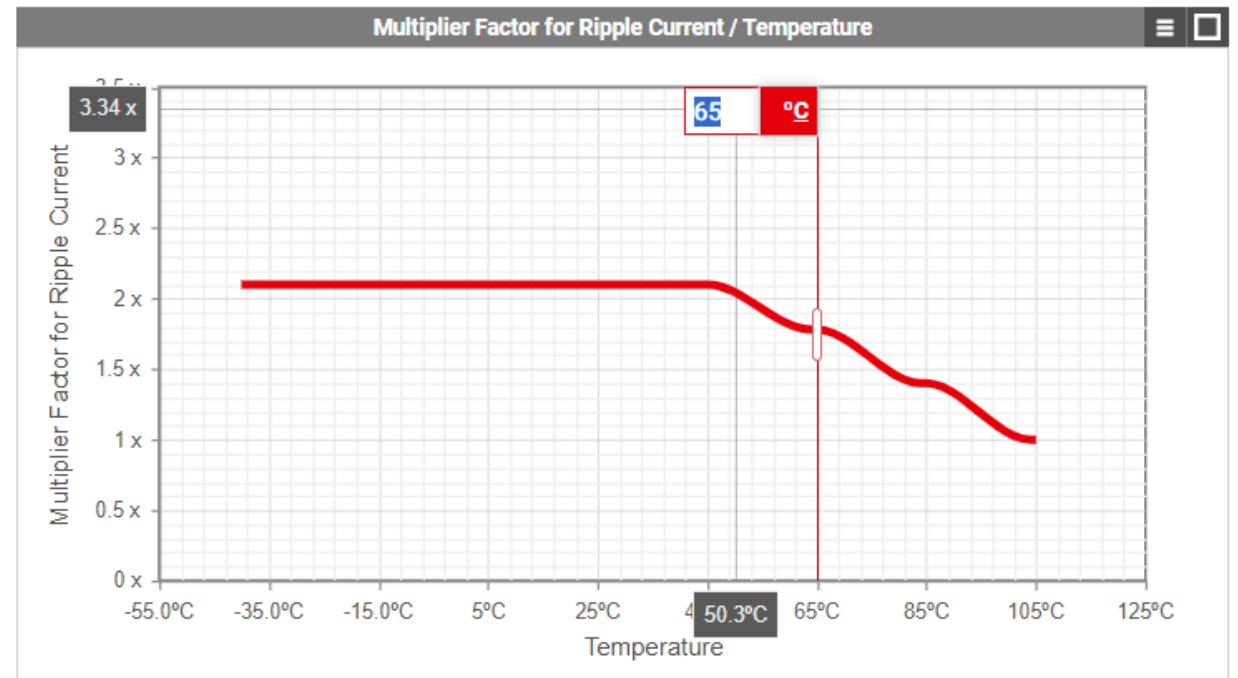


# DC-LINK CAPACITORS

Determining the maximum Capacitor ripple current at a specific frequency and temperature

- Use case
  - 23 Arms @ 10 kHz @ 65 °C

- 3rd Step
  - Enter the Temperature



# DC-LINK CAPACITORS

Determining the maximum Capacitor ripple current at a specific frequency and temperature

- Use case
  - 23 Arms @ 10 kHz @ 65 °C
- 4th Step
  - Filter your parts and check the lifetime!

**WE** WÜRTH ELEKTRONIK **REDEXPERT** Aluminum Electrolytic / Aluminum Polymer Capacitors

Filters: Not Internal

Lifetime Calculator



	Order Code	Series	V <sub>R</sub>	C		Technology	Series Description	I@65°C @10 kHz...
✓	862011291005	WCAP-AWG8	350 V	8.20 mF		Alum. Electrolytic	Screw Type - General Purpo...	29.4 A
✓	861011086027	WCAP-AIG8	200 V	1.50 mF		Alum. Electrolytic	Snap-In - General Purpose +8...	8.65 A
✓	861141386028	WCAP-AI3H	400 V	1.00 mF		Alum. Electrolytic	Snap-In - Long Life +105°C	6.65 A
✓	861220786020	WCAP-AIE8	63.0 V	6.80 mF		Alum. Electrolytic	Snap-In - Long Life +85°C	6.38 A
✓	861020786030	WCAP-AIG5	63.0 V	10.0 mF		Alum. Electrolytic	Snap-In - General Purpose +1...	6.34 A
✓	861010786001	WCAP-AIG8	63.0 V	6.00 mF		Alum. Electrolytic	Snap-In - General Purpose +8...	6.31 A

# DC-LINK CAPACITORS

## Bank Design Example

- Example
  - 23 Arms @ 10 kHz @ 65 °C
  - Min. 76  $\mu\text{F}$  @ End of Life
  - Required  $V_r = 880\text{ V}$  in total
  - Min. 10 years Life Expectancy
  - **Only Standard parts**
  - Selected solutions for Alum. Electrolytic and Film Capacitors **by volume**

Only for reference!

PN		C [ $\mu\text{F}$ ]	C <sub>total</sub> [ $\mu\text{F}$ ]	Series x parallel	Volume [l]	ESR <sub>total</sub> @ 10 kHz [m $\Omega$ ]	$\approx P_{Loss}$ [W]
<b>861141485033</b>		470	<b>940</b>	2 x 4 = 8	0.253 l	47.4	25.1
<b>890724429005CS</b>		50	100	1 x 2 = <b>2</b>	<b>0.209 l</b>	<b>1.3</b>	<b>0.7</b>



# OTHER IMPORTANT SELECTION CRITERIA

## Operating load conditions

### Ripple Voltage

- For the WCAP-FTDB film capacitor the maximum peak voltage  $V_{peak+}$  shall not be greater than the rated voltage  $V_R$  according to the temperature derating of the rated voltage  $V_R$ . The peak-to-peak value of the ripple voltage  $V_{p-p}$  should not be greater than  $0.3 \cdot V_R$  according to the temperature derating of the rated voltage  $V_R$ . The rated voltage of the capacitor may need to be reduced for different operating temperatures. See voltage derating curve within this datasheet.

#### Cautions and Warnings:

The following conditions apply to all goods within of Würth Elektronik eiSos GmbH & Co. KG:

#### General:

- This electronic component is designed and manufactured for use in general electronic equipment.
- Würth Elektronik must be asked for a written approval (following the certain PPAP level procedure) before incorporating the components into any equipment in the field such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. Where higher safety and reliability are especially required and/or if there is the possibility of direct damage or human injury.
- Electronic components that will be used in safety-critical or high-reliability applications, should be pre-evaluated by the customer.
- Direct mechanical impact to the product shall be prevented as material of the body, pins or termination could flake or in the worst case it could break.
- Avoid any water or heavy dust on capacitors surface, which may cause electrical leakage, damage, overheating or corrosion.
- Würth Elektronik products are qualified according to international standards, which are listed in each product reliability report. Würth Elektronik does not warrant any customer qualified product characteristic, beyond Würth Elektronik specifications, for its validity and sustainability over time.
- The customer is responsible for the functionality of his or her own products. All technical specifications for standard products also apply to customer specific products.
- The component is designed and manufactured to be used within the datasheet specified values. If the usage and operation conditions specified in the datasheet are not met, the body, pins or termination may be damaged or dissolved.
- Do not apply any kind of flexural or compressive force onto soldered or unsoldered component.
- The capacitance tolerance as specified within the datasheet is only valid on the date of delivery and according specified measurement criteria.

#### Product specific

##### Storage conditions

- A storage of Würth Elektronik products for longer than 12 months is not recommended. Within other effects, the terminals may suffer degradation, resulting in bad solderability. Therefore, all products shall be used within the period of 12 months based on the day of shipment.
- Do not expose the components into direct sunlight.
- The storage condition in the original packaging is defined according to DIN EN 61760-2.
- The environment in which the capacitors are operated and stored has to have atmospheric characteristics and must be free of dew condensation and toxic gases (e.g. chlorine, ammonia, sulfur, hydrogen sulphide and hydrogen sulfate).
- Do not expose the capacitor to environments with hazardous gas, ozone, ultraviolet rays or any kind of radiation. Avoid any contact of the capacitor with direct sunshine, saltwater, spray of water or types of oil during storage.

#### reliability.

- Surface temperature including self-heating must be kept below the maximum operating temperature.

#### Operating load conditions

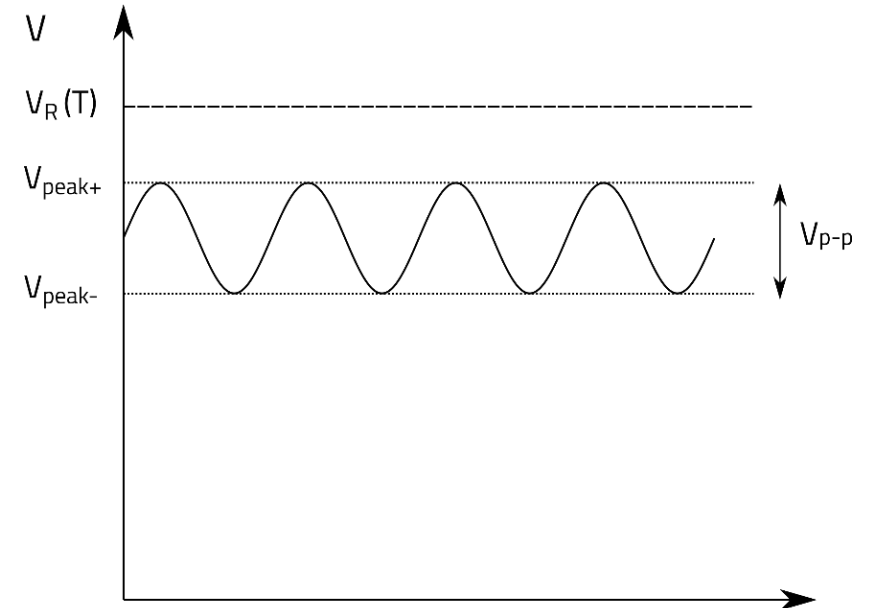
- Due to self-heating the reliability of the capacitor may be reduced, if high frequency AC or pulse is applied.
- Consider carefully possible specific changes of electrical characteristics like capacitance over temperature, voltage and time as well as the specific performance over frequency for the actual use conditions.
- Avoid any overvoltage and do not apply a continuous overvoltage. If an overvoltage is applied to the capacitor, the leakage current can increase drastically. The applied working voltage is not allowed to exceed the rated working voltage of the specific capacitor.
- If film capacitors with safety approvals are operated with a DC voltage exceeding the specified AC voltage, the approvals given on the basis of IEC 60384-14 are no longer valid.
- For the WCAP-FTDB film capacitor the maximum peak voltage  $V_{peak+}$  shall not be greater than the rated voltage  $V_R$  according to the temperature derating of the rated voltage  $V_R$ . The peak-to-peak value of the ripple voltage  $V_{p-p}$  should not be greater than  $0.3 \cdot V_R$  according to the temperature derating of the rated voltage  $V_R$ . The rated voltage of the capacitor may need to be reduced for different operating temperatures. See voltage derating curve within this datasheet.

#### Packaging:

- The packaging specifications apply only to purchase orders comprising whole packaging units. If the ordered quantity exceeds or is lower than the specified packaging unit, packaging in accordance with the packaging specifications cannot be ensured.

#### Soldering

- The solder profile must comply with the Würth Elektronik technical soldering specification. All other profiles will void the warranty.
- All other soldering methods are at the customer's own risk.
- Strong forces which may affect the coplanarity of the component's electrical connection with the PCB (i.e. pins), can damage the part, resulting in void of the warranty.
- Customer needs to ensure that the applied solder paste, the paste thickness and solder conditions are enough to guarantee a sufficient solder result according to the relevant criteria of IPC-A-610.
- Excessive amount of solder may lead to higher tensile force and chip cracking. Insufficient amount of solder may detach the capacitor due to defective contacts.
- Do not use excessive nor insufficient flux.



	CHECKED	VERSION	DATE (YYYY-MM-DD)	GENERAL TOLERANCE	SELECTION METHOD
	FPu	001.000	2022-10-13	DIN ISO 2768-1m	
<b>WÜRTH ELEKTRONIK</b> MORE THAN YOU EXPECT	Würth Elektronik eiSos GmbH & Co. KG EMS & Industrie Solutions Max-Eyth-Str. 1 74638 Waldenburg Germany Tel. +49 (0) 79 42 945-0 www.wue-wl.com eiSos@wue-wl.com			TECHNICAL REFERENCE MDBP525756J500DCPP15040	
	<b>WCAP-FTDB DC-Link Capacitor</b>			ORDER CODE <b>890484429001CS</b>	
SECTYPE	BUSINESS UNIT	STATUS	DATE		
Pitch 1: 52.5 mm; Pitch 2: 20.3 mm	e1Cap	Valid	6/8		

This electronic component has been designed and developed for usage in general electronic equipment only. This product is not authorized for use in equipment where a higher safety standard and reliability standard is especially required or where a failure of the product is reasonably expected to cause severe personal injury or death, unless the parties have executed an agreement specifically governing such use. Moreover Würth Elektronik eiSos GmbH & Co. KG products are neither designed nor intended for use in areas such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. Würth Elektronik eiSos GmbH & Co. KG must be informed about the intent of such usage before the design-in stage. In addition, sufficient reliability evaluation checks for safety must be performed on every electronic component which is used in electrical circuits that require high safety and reliability functions or performance.



# OTHER IMPORTANT SELECTION CRITERIA

- Aging over Lifetime
  - C-Value
  - ESR
  - DF
- Series Connection
  - Overdimensioning of the rated voltage is necessary
  - Balancing is required
- Consult us!



# DC-LINK CAPACITOR: SPECIFICATION AND APPLICATION

## Summary

### Applications



- Power converters
- Renewable Energy
- Onsemi Reference Design - 25 kW  
Fast DC Bidirectional Charger incl.  
PFC

### DC-Link Capacitors

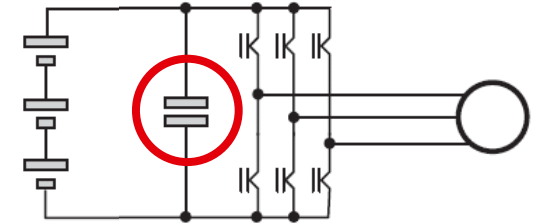


vs.



- Film Capacitors
- Electrolytic Capacitors
- Lifetime
- Selection **REDEXPERT**<sup>®</sup>
- Comparism

### Capacitor Bank



- Capacitance Estimation
- Bank Calculation
- Other important selection criteria

## REFERENCES

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# Questions & Answers



Online Catalogue  
WCAP-FTDB



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