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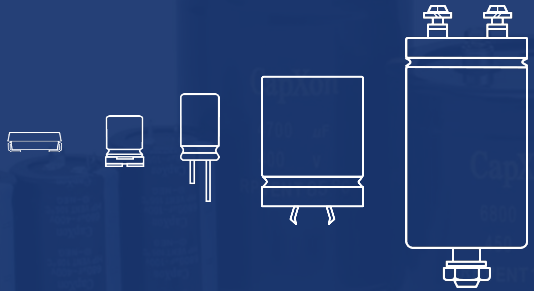
E-Cap technologies for WBG solutions



CapXon - Manufacturer for professional
aluminum electrolytic, conductive polymer and hybrid electrolytic capacitors as well as etched and formed aluminum foil

Short Introduction

M.Eng. & M.A.

Stephan Menzel

Senior Key Account Manager

Oversea Sales Division

Background:

- More than 15 years of work experience in passive components & electronics industry
- Expertise in global sales & product marketing, industrial engineering and quality management
- At CapXon in charge for North America Sales and defined Key Accounts in Europe & US

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The Challenges of WBG for E-Caps

>> **Higher voltage levels**

>> **Higher switching frequencies and so AC ripple frequencies**

>> **Higher ambient temperatures in application**

>> **High reliability requirements**

↳ **The E-caps need to deliver way higher performance as before**

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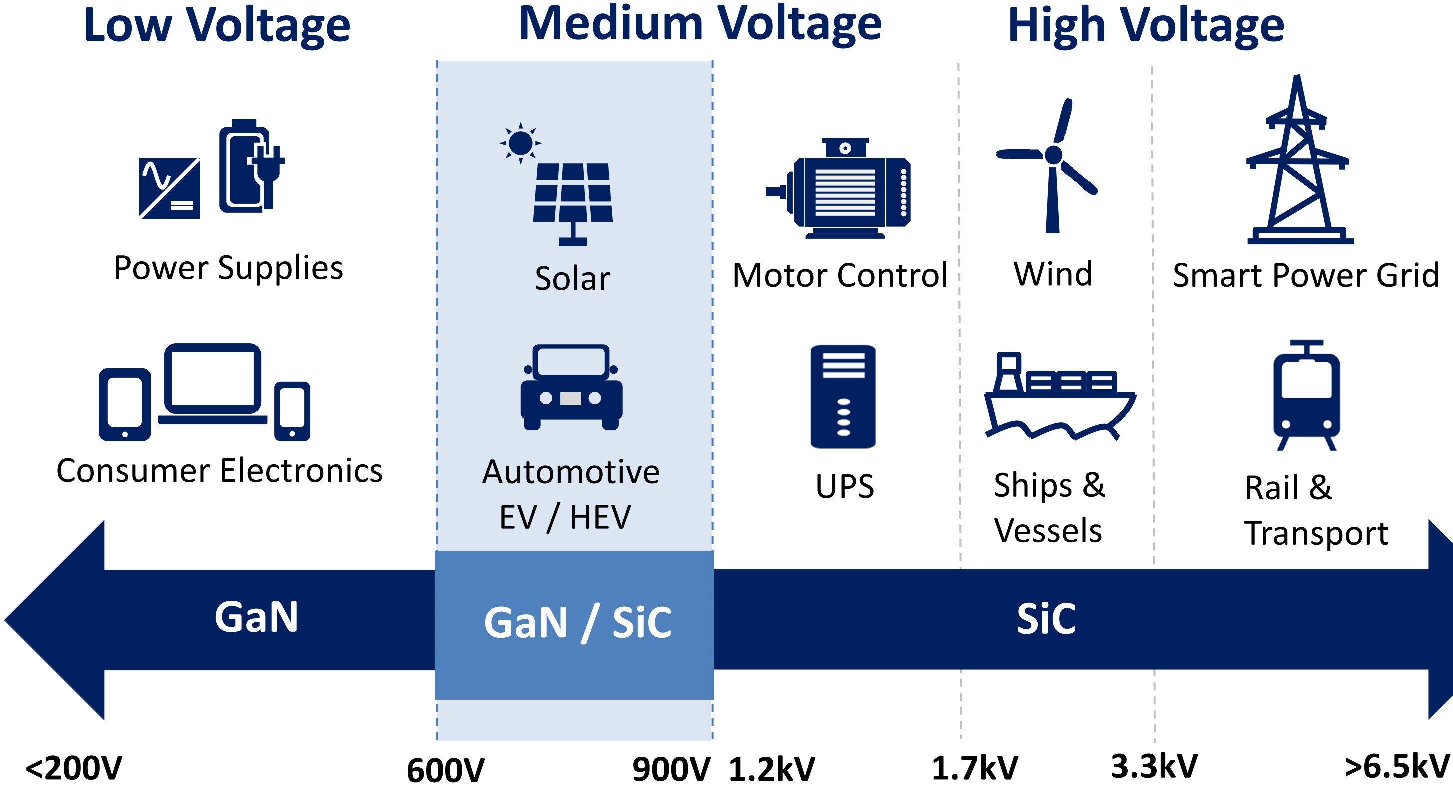
GaN vs. SiC per Market / Voltage Range



Low Voltage

Power Supplies

Consumer Electronics

Medium Voltage

Solar

Automotive
EV / HEV

Motor Control

UPS

High Voltage

Wind

Ships &
Vessels

Smart Power Grid

Rail &
Transport

GaN

GaN / SiC

SiC

<200V
600V
900V
1.2kV
1.7kV
3.3kV
>6.5kV

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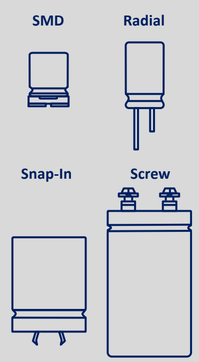
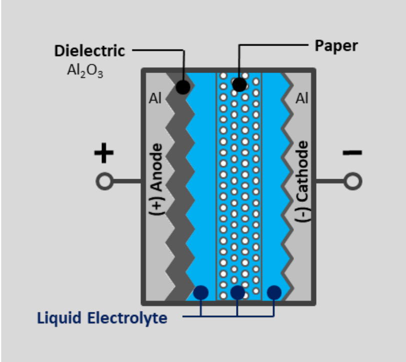
Al E-Cap Technologies

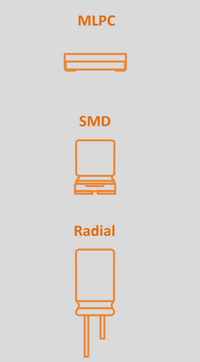
Aluminum Electrolytic

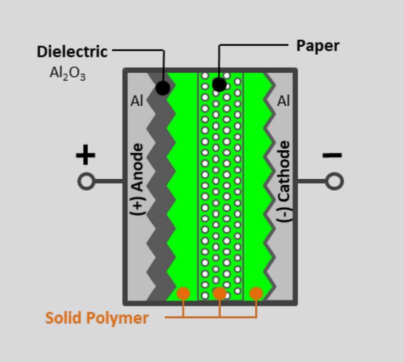




Rated Voltage ▪ V_R	4 VDC to 650 VDC
Cathode Material	Liquid Electrolyte
Self-healing of Dielectric	Yes
Package	Widest range in all sizes
Stability	Reduced performance at low temperature
Lifetime	Limited life at high temperature
Reliability	🚗 AEC-Q200 qualified

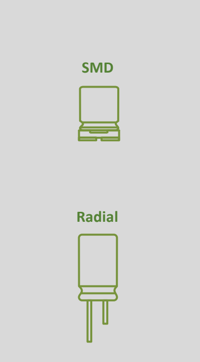
Solid Conductive Polymer

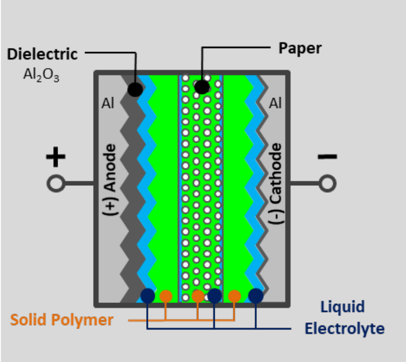




Rated Voltage ▪ V_R	2.5 VDC to 100 VDC
Cathode Material	Solid Conductive Polymer
Self-healing of Dielectric	No
ESR	Ultra-low ESR at high frequency
Stability	Stable for low and high temperature
Lifetime	Very stable and long life – no dry out
Reliability	Only internal standard qualification

Hybrid Conductive Polymer





Rated Voltage ▪ V_R	16 VDC to 400 VDC
Cathode Material	Solid Conductive Polymer & Liquid Electrolyte
Self-healing of Dielectric	Yes
ESR	Very low ESR at high frequency
Stability	Even more stable than liquid type
Leakage current. ▪ I_{LEAK}	Lower leakage current than Solid Conductive Polymer Type
Reliability	🚗 AEC-Q200 qualified

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Technology Comparison

++ … best performance

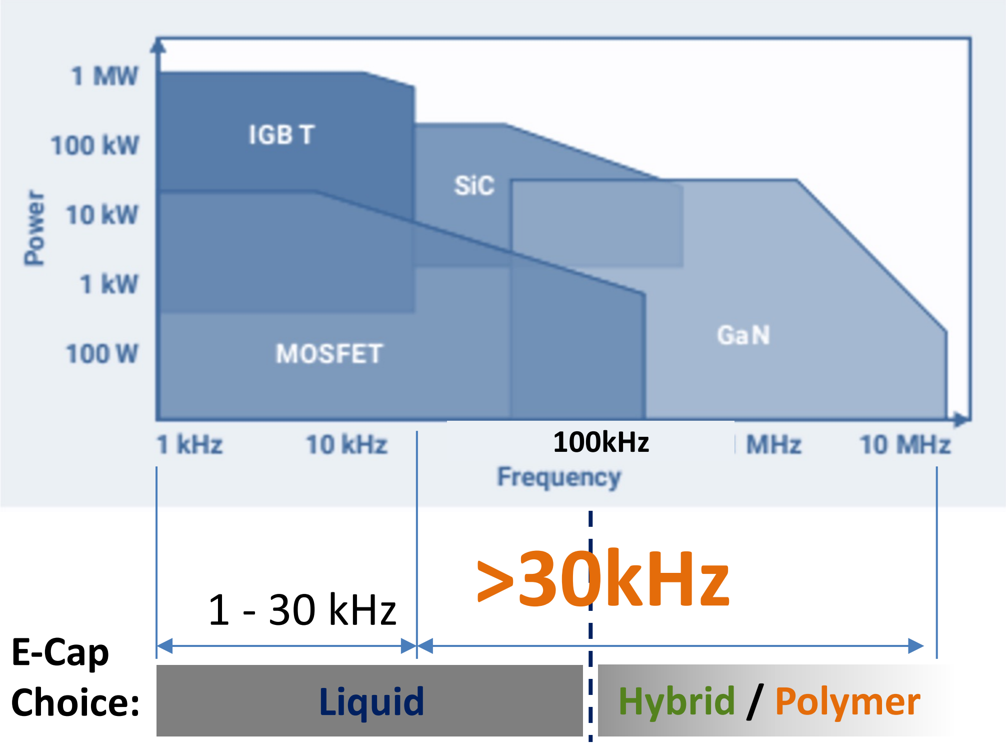
\+ … well performance

● … basic performance

Characteristics	Aluminum Electrolytic Capacitor	Solid Conductive Polymer Capacitor	Hybrid Conductive Polymer Capacitor
ESR at High Frequency	● (120 ~ 1 000 mΩ)	++ (7 ~ 15 mΩ)	+ (20 ~ 30 mΩ)
Leakage Current ▪ I_{LEAK}	++ (0.01*C_R*V_R)	● (0.2*C_R*VR)	++ (0.01*C_R*V_R)
Ripple Current ▪ I_R	● (~ 600 mA)	++ (2 000 ~ 7 000 mA)	+ (2 000 ~ 3 000 mA)
Rated Voltage ▪ V_R	++ (~ 700 V)	● (~ 100 V)	+ (~ 400 V)
Operating Temperature Characteristics	+ (-40 ~ + 125 °C)	+ (-55 ~ + 125 °C)	++ (-55 ~ + 150 °C)
Low Temperature Characteristics	● (-40 ~ + 125 °C)	++ (-55 ~ + 125 °C)	+ (-55 ~ + 150 °C)
Lifetime	● (105 °C / 3 000h)	++ (105 °C / 5 000h)	++ (105 °C / 10 000h)
Failure Mode	+ Open	● Open / Short	+ Open

The Challenge of WBG Frequency Range

Example by TI for SIC / GaN range:



1 - 30 kHz

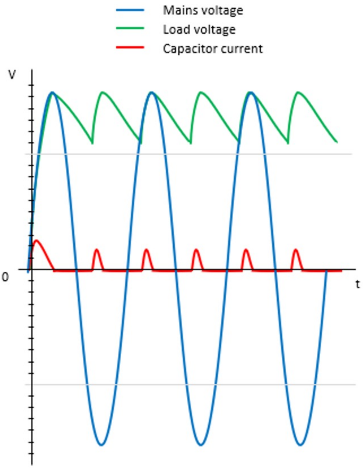
>30kHz

E-Cap Choice:

Liquid

Hybrid / Polymer

- WBG requires caps to handle AC ripple with way higher frequencies
- Cap technologie need to be capable to deal with ripple frequencies of 30kHz and above

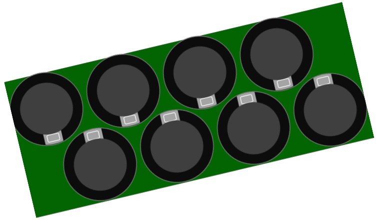


↳ Switching frequency causes high frequency AC ripple

The Challenge of WBG Voltage Range on Output Side

Higher Voltages of newer **WBG applications** can easy ranges from:

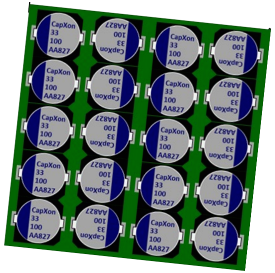
650V – 1800V

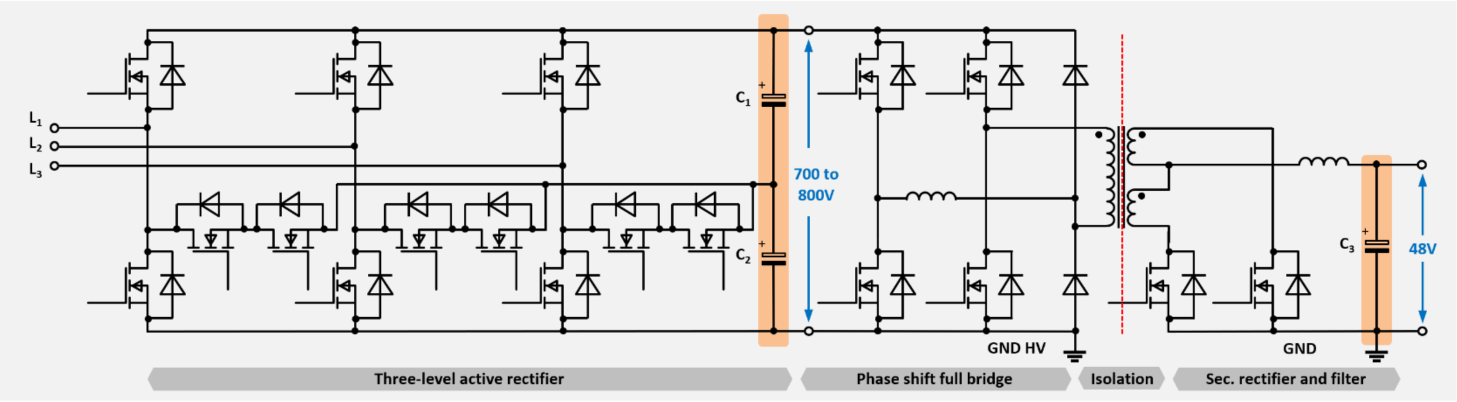


The rated voltage of **E-Caps rated voltage** ranges from:

4V – 650V

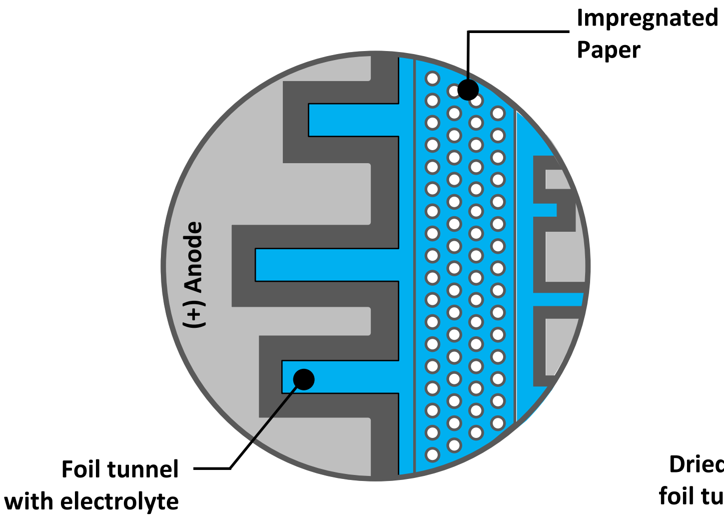
↳ **SiC mostly requires multiple e-caps or banks**





E-Cap Aging due to Temperature & Ripple Stress over Time

New e-cap

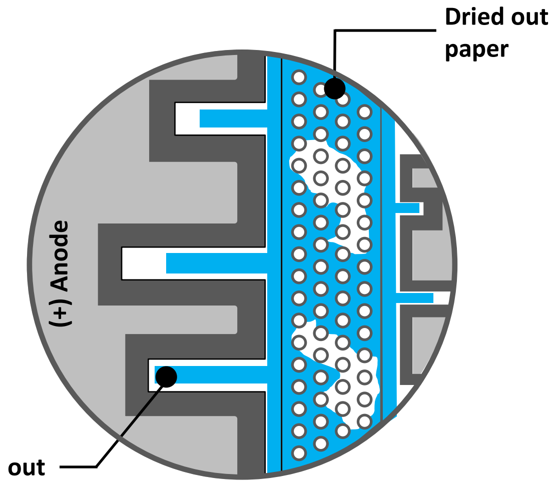


Capacitance ☺

ESR/Impedance ☺

Leakage current ☺

Used e-cap

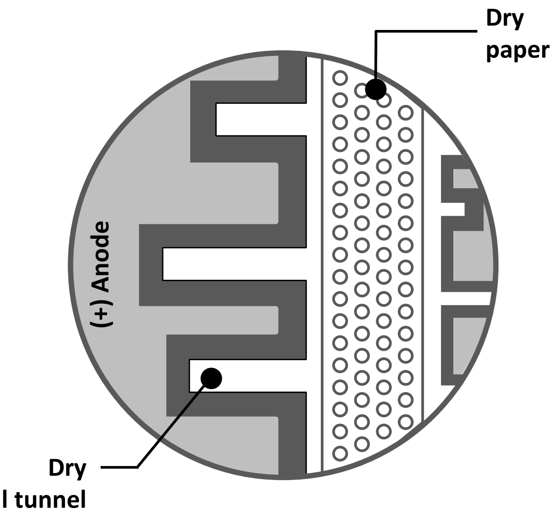


Capacitance 😐

ESR/Impedance 😐

Leakage current 😐

Dry e-cap



Capacitance ☹

ESR/Impedance ☹

Leakage current ☹

END OF LIFETIME

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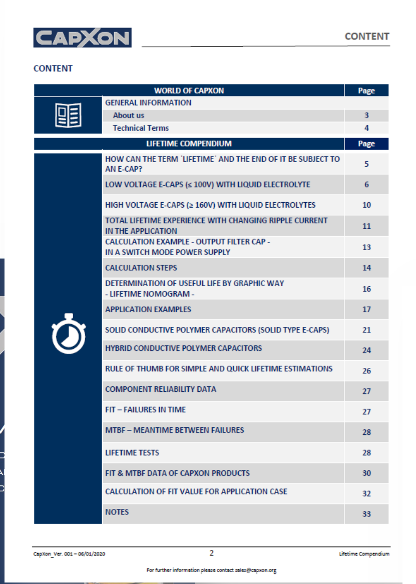
Lifetime Compendium


CAP

LIFETIME
COMPENDIUM

ALUMINUM ELECTROLYTIC CAPAC
SOLID CONDUCTIVE POLYMER CA
HYBRID CONDUCTIVE POLYMER C

Table of Content



CONTENT

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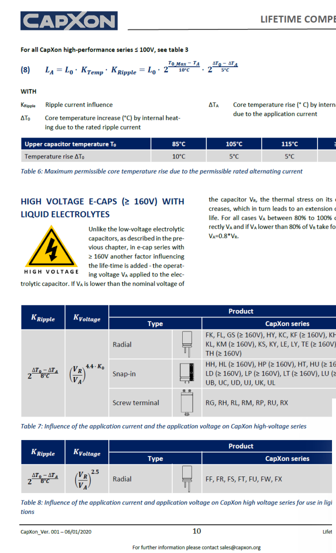
Calculation basis



For all CapXon high-performance series ≤ 100V, see table 3

$$(8)\quad L_A = L_0 \cdot K_{Temp} \cdot K_{Ripple} = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}} \cdot 2^{\frac{\Delta T_0 - \Delta T_A}{5°C}}$$

WITH

K_{Ripple} Ripple current influence

ΔT_0 Core temperature increase (°C) by internal heating due to the rated ripple current

ΔT_A Core temperature rise (° C) by internal heating due to the application current

Upper capacitor temperature T_0	85°C	105°C	115°C	≥ 125°C
Temperature rise ΔT_0	10°C	5°C	5°C	5°C

Table 6: Maximum permissible core temperature rise due to the permissible rated alternating current

HIGH VOLTAGE E-CAPS (≥ 160V) WITH LIQUID ELECTROLYTES

HIGH VOLTAGE

Unlike the low-voltage electrolytic capacitors, as described in the previous chapter, in e-cap series with ≥ 160V another factor influencing the life-time is added - the operating voltage V_A applied to the electrolytic capacitor. If V_A is lower than the nominal voltage of the capacitor V_R, the thermal stress on its dielectric decreases, which in turn leads to an extension of the service life. For all cases V_A between 80% to 100% of V_R take directly V_A and if V_A lower than 80% of V_R take for calculations V_A=0.8*V_R.

K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{\frac{\Delta T_0 - \Delta T_A}{8°C}}$	$\left(\frac{V_R}{V_A}\right)^{4.4 \cdot K_0}$	Radial		FK, FL, GS (≥ 160V), HY, KC, KF (≥ 160V), KH (≥ 160V), KL, KM (≥ 160V), KS, KY, LE, LY, TE (≥ 160V), TH (≥ 160V)
		Snap-in		HH, HL (≥ 160V), HP (≥ 160V), HT, HU (≥ 160V), LD (≥ 160V), LP (≥ 160V), LT (≥ 160V), LU (≥ 160V), UB, UC, UD, UJ, UK, UL
		Screw terminal		RG, RH, RL, RM, RP, RU, RX

Table 7: Influence of the application current and the application voltage on CapXon high-voltage series

K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{\frac{\Delta T_0 - \Delta T_A}{8°C}}$	$\left(\frac{V_R}{V_A}\right)^{2.5}$	Radial		FF, FR, FS, FT, FU, FW, FX

Table 8: Influence of the application current and application voltage on CapXon high voltage series for use in lig tions

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Technical background

ature of the component. To explain and calculate the additional heating, the relationship of the thermal resistance, is the ability of electronic components to dissipate heat.

Like all electronic components, electrolytic capacitors are not ideal components, but have losses that give off in the form of heat under load. For all electronic components, the cooler the component, the longer the expected lifetime.

For e-caps the ohmic losses are grouped under the term "ESR" for Equivalent Series Resistance. These include the ohmic losses resulting from the terminals of the capacitor, the contact connections of the terminals, the contact resistance of the electrode contacting and the dielectric losses, also referred to as dissipation factor tan δ.

$$(2)\quad P_V = I_A{}^2 \cdot ESR$$

WITH

P_V Internal power losses (W)

I_A Ripple current flowing in the capacitor (A RMS)

ESR Equivalent series resistance (Ω)

$$(3)\quad P_T =$$

WITH

P_T Thermal

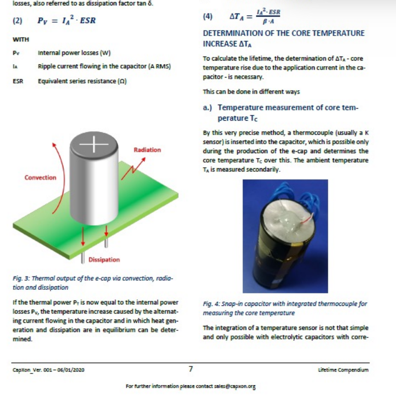
ΔT_A Core te due to t

R_{th} Thermal (K/W)

β Radiation coefficient (W/cm² K)

A Surface of the capacitor (cm²)

$$(4)\quad \Delta T_A = \frac{I_A{}^2 \cdot ESR}{\beta \cdot A}$$


DETERMINATION OF THE CORE TEMPERATURE INCREASE ΔT_A

To calculate the lifetime, the determination of ΔT_A - core temperature rise due to the application current in the capacitor - is necessary.

This can be done in different ways

a.) Temperature measurement of core temperature T_C

By this very precise method, a thermocouple (usually a K sensor) is inserted into the capacitor, which is possible only during the production of the e-cap and determines the core temperature T_C over this. The ambient temperature T_A is measured secondarily.

Fig. 3: Thermal output of the e-cap via convection, radiation and dissipation

If the thermal power P_T is now equal to the internal power losses P_V, the temperature increase caused by the alternating current flowing in the capacitor and in which heat generation and dissipation are in equilibrium can be determined.

Fig. 4: Snap-in capacitor with integrated thermocouple for measuring the core temperature

The integration of a temperature sensor is not that simple and only possible with electrolytic capacitors with corre-

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Application example

CALCULATION EXAMPLE - OUTPUT FILTER

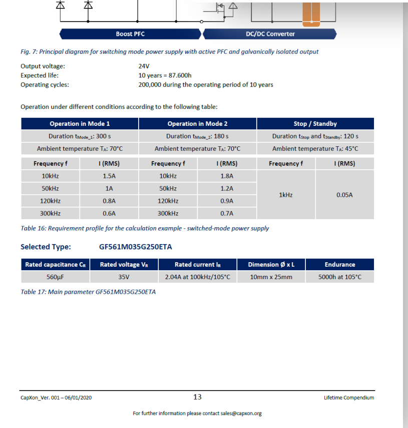

Fig. 7: Principal diagram for switching mode power supply with active PFC and galvanically isolated output

Output voltage:	24V
Expected life:	10 years = 87.600h
Operating cycles:	200,000 during the operating period of 10 years

Operation under different conditions according to the following table:

Operation in Mode 1		Operation in Mode 2		Stop / Standby	
Duration t_{Mode_1}: 300 s		Duration t_{Mode_2}: 180 s		Duration t_{Stop} and $t_{Standby}$: 120 s	
Ambient temperature T_A: 70°C		Ambient temperature T_A: 70°C		Ambient temperature T_A: 45°C	
Frequency f	I (RMS)	Frequency f	I (RMS)	Frequency f	I (RMS)
10kHz	1.5A	10kHz	1.8A	1kHz	0.05A
50kHz	1A	50kHz	1.2A		
120kHz	0.8A	120kHz	0.9A		
300kHz	0.6A	300kHz	0.7A		

Table 16: Requirement profile for the calculation example - switched-mode power supply

Selected Type: GF561M035G250ETA

Rated capacitance C_R	Rated voltage V_R	Rated current I_R	Dimension Ø x L	Endurance
560µF	35V	2.04A at 100kHz/105°C	10mm x 25mm	5000h at 105°C

Table 17: Main parameter GF561M035G250ETA

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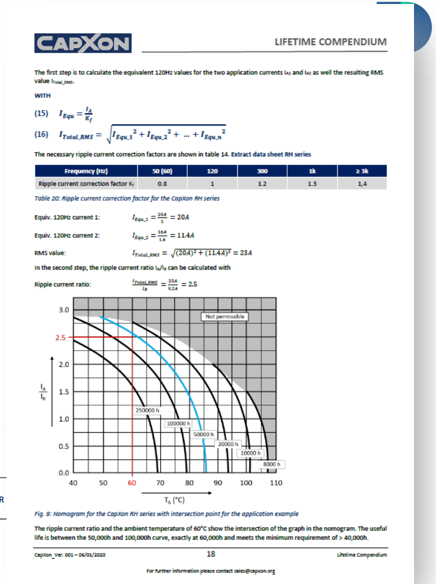
Graphical estimation



The first step is to calculate the equivalent 120Hz values for the two application currents I_{A1} and I_{A2} as well the resulting RMS value I_{Total_RMS}.

WITH

$$(15)\quad I_{Equ} = \frac{I_A}{K_f}$$

$$(16)\quad I_{Total\_RMS} = \sqrt{I_{Equ\_1}{}^2 + I_{Equ\_2}{}^2 + \dots + I_{Equ\_n}{}^2}$$

The necessary ripple current correction factors are shown in table 14. Extract data sheet RH series

Frequency (Hz)	50 (60)	120	300	1k	≥ 3k
Ripple current correction factor K_f	0.8	1	1.2	1.3	1,4

Table 20: Ripple current correction factor for the CapXon RH series

Equiv. 120Hz current 1: $I_{Equ\_1} = \frac{20A}{1} = 20A$

Equiv. 120Hz current 2: $I_{Equ\_2} = \frac{16A}{1.4} = 11.4A$

RMS value: $I_{Total\_RMS} = \sqrt{(20A)^2 + (11.4A)^2} = 23A$

In the second step, the ripple current ratio I_A/I_R can be calculated with

Ripple current ratio: $\frac{I_{Total\_RMS}}{I_R} = \frac{23A}{9.2A} = 2.5$

Fig. 9: Nomogram for the CapXon RH series with intersection point for the application example

The ripple current ratio and the ambient temperature of 60°C show the intersection of the graph in the nomogram. The useful life is between the 50,000h and 100,000h curve, exactly at 60,000h and meets the minimum requirement of > 40,000h.

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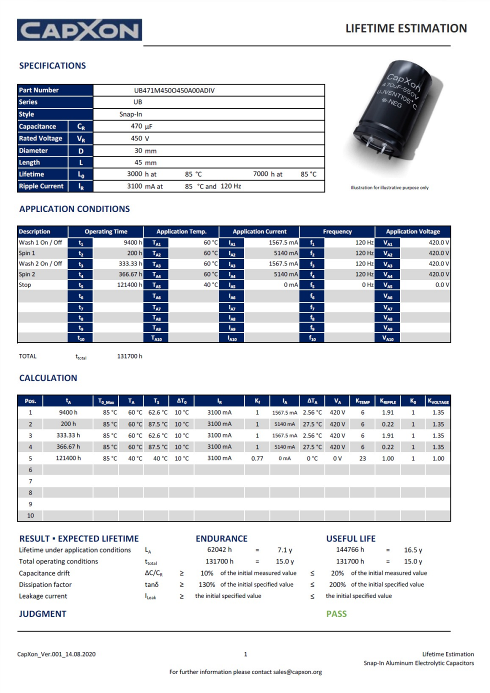
Lifetime Estimation

Application parameters



LIFETIME ESTIMATION

SPECIFICATIONS

Part Number		UB471M450O450A00ADIV
Series		UB
Style		Snap-In
Capacitance	C_R	470 µF
Rated Voltage	V_R	450 V
Diameter	D	30 mm
Length	L	45 mm
Lifetime	L_0	3000 h at 85 °C 7000 h at 85 °C
Ripple Current	I_R	3100 mA at 85 °C and 120 Hz

Illustration for illustrative purpose only

APPLICATION CONDITIONS

Description	Operating Time		Application Temp.		Application Current		Frequency		Application Voltage	
Wash 1 On / Off	t_1	9400 h	T_{A1}	60 °C	I_{A1}	1567.5 mA	f_1	120 Hz	V_{A1}	420.0 V
Spin 1	t_2	200 h	T_{A2}	60 °C	I_{A2}	5140 mA	f_2	120 Hz	V_{A2}	420.0 V
Wash 2 On / Off	t_3	333.33 h	T_{A3}	60 °C	I_{A3}	1567.5 mA	f_3	120 Hz	V_{A3}	420.0 V
Spin 2	t_4	366.67 h	T_{A4}	60 °C	I_{A4}	5140 mA	f_4	120 Hz	V_{A4}	420.0 V
Stop	t_5	121400 h	T_{A5}	40 °C	I_{A5}	0 mA	f_5	0 Hz	V_{A5}	0.0 V
	t_6		T_{A6}		I_{A6}		f_6		V_{A6}	
	t_7		T_{A7}		I_{A7}		f_7		V_{A7}	
	t_8		T_{A8}		I_{A8}		f_8		V_{A8}	
	t_9		T_{A9}		I_{A9}		f_9		V_{A9}	
	t_{10}		T_{A10}		I_{A10}		f_{10}		V_{A10}	

TOTAL t_{total} 131700 h

CALCULATION

Pos.	t_A	T_{0_Max}	T_A	T_S	ΔT_0	I_R	K_f	I_A	ΔT_A	V_A	K_{TEMP}	K_{RIPPLE}	K_0	$K_{VOLTAGE}$
1	9400 h	85 °C	60 °C	62.6 °C	10 °C	3100 mA	1	1567.5 mA	2.56 °C	420 V	6	1.91	1	1.35
2	200 h	85 °C	60 °C	87.5 °C	10 °C	3100 mA	1	5140 mA	27.5 °C	420 V	6	0.22	1	1.35
3	333.33 h	85 °C	60 °C	62.6 °C	10 °C	3100 mA	1	1567.5 mA	2.56 °C	420 V	6	1.91	1	1.35
4	366.67 h	85 °C	60 °C	87.5 °C	10 °C	3100 mA	1	5140 mA	27.5 °C	420 V	6	0.22	1	1.35
5	121400 h	85 °C	40 °C	40 °C	10 °C	3100 mA	0.77	0 mA	0 °C	0 V	23	1.00	1	1.00
6														
7														
8														
9														
10														

RESULT ▪ EXPECTED LIFETIME			ENDURANCE				USEFUL LIFE		
Lifetime under application conditions	L_A		62042 h	=	7.1 y		144766 h	=	16.5 y
Total operating conditions	t_{total}		131700 h	=	15.0 y		131700 h	=	15.0 y
Capacitance drift	$\Delta C/C_R$	≥	10%	of the initial measured value		≤	20%	of the initial measured value	
Dissipation factor	tanδ	≥	130%	of the initial specified value		≤	200%	of the initial specified value	
Leakage current	I_{Leak}	≥	the initial specified value			≤	the initial specified value		

JUDGMENT PASS

CapXon_Ver.001_14.08.2020 1 Lifetime Estimation
Snap-In Aluminum Electrolytic Capacitors
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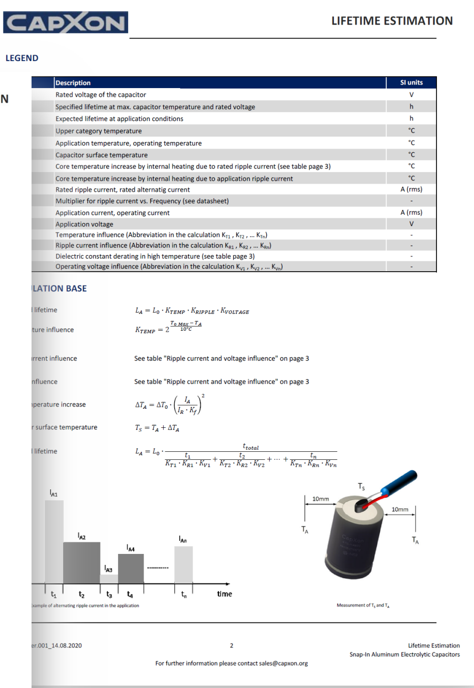
Calculation basics



LIFETIME ESTIMATION

LEGEND

Description	SI units
Rated voltage of the capacitor	V
Specified lifetime at max. capacitor temperature and rated voltage	h
Expected lifetime at application conditions	h
Upper category temperature	°C
Application temperature, operating temperature	°C
Capacitor surface temperature	°C
Core temperature increase by internal heating due to rated ripple current (see table page 3)	°C
Core temperature increase by internal heating due to application ripple current	°C
Rated ripple current, rated alternatig current	A (rms)
Multiplier for ripple current vs. Frequency (see datasheet)	-
Application current, operating current	A (rms)
Application voltage	V
Temperature influence (Abbreviation in the calculation K_{T1} , K_{T2} , … K_{Tn})	-
Ripple current influence (Abbreviation in the calculation K_{R1} , K_{R2} , … K_{Rn})	-
Dielectric constant derating in high temperature (see table page 3)	-
Operating voltage influence (Abbreviation in the calculation K_{V1} , K_{V2} , … K_{Vn})	-

LATION BASE

lifetime $L_A = L_0 \cdot K_{TEMP} \cdot K_{RIPPLE} \cdot K_{VOLTAGE}$

ture influence $K_{TEMP} = 2^{\frac{T_{0\ Max} - T_A}{10°C}}$

rrent influence See table "Ripple current and voltage influence" on page 3

nfluence See table "Ripple current and voltage influence" on page 3

perature increase $\Delta T_A = \Delta T_0 \cdot \left(\frac{I_A}{I_R \cdot K_f}\right)^2$

r surface temperature $T_S = T_A + \Delta T_A$

lifetime $L_A = L_0 \cdot \frac{t_{total}}{\frac{t_1}{K_{T1} \cdot K_{R1} \cdot K_{V1}} + \frac{t_2}{K_{T2} \cdot K_{R2} \cdot K_{V2}} + \cdots + \frac{t_n}{K_{Tn} \cdot K_{Rn} \cdot K_{Vn}}}$

xample of alternating ripple current in the application

Measurement of T_S and T_A

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Snap-In Aluminum Electrolytic Capacitors
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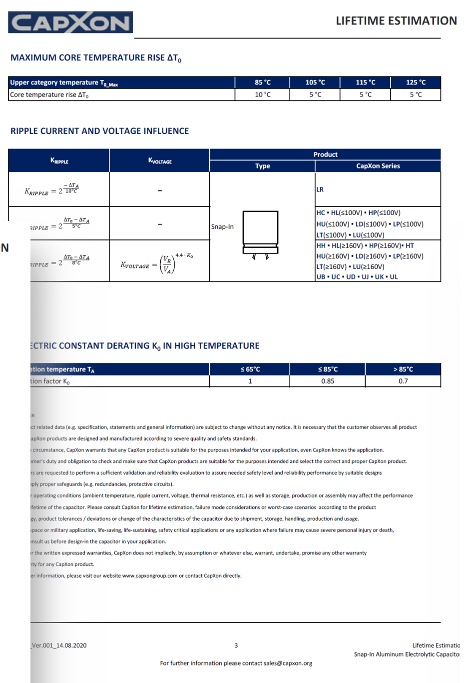
Calculation basics



LIFETIME ESTIMATION

MAXIMUM CORE TEMPERATURE RISE ΔT_0

Upper category temperature T_{0_Max}	85 °C	105 °C	115 °C	125 °C
Core temperature rise ΔT_0	10 °C	5 °C	5 °C	5 °C

RIPPLE CURRENT AND VOLTAGE INFLUENCE

K_{RIPPLE}	$K_{VOLTAGE}$	Product	
		Type	CapXon Series
$K_{RIPPLE} = 2^{\frac{-\Delta T_A}{10°C}}$	–	Snap-In	LR
$_{RIPPLE} = 2^{\frac{\Delta T_0 - \Delta T_A}{5°C}}$	–		HC ▪ HL(≤100V) ▪ HP(≤100V) HU(≤100V) ▪ LD(≤100V) ▪ LP(≤100V) LT(≤100V) ▪ LU(≤100V)
$_{RIPPLE} = 2^{\frac{\Delta T_0 - \Delta T_A}{8°C}}$	$K_{VOLTAGE} = \left(\frac{V_R}{V_A}\right)^{4.4 \cdot K_0}$		HH ▪ HL(≥160V) ▪ HP(≥160V)▪ HT HU(≥160V) ▪ LD(≥160V) ▪ LP(≥160V) LT(≥160V) ▪ LU(≥160V) UB ▪ UC ▪ UD ▪ UJ ▪ UK ▪ UL

ECTRIC CONSTANT DERATING K_0 IN HIGH TEMPERATURE

ation temperature T_A	≤ 65°C	≤ 85°C	> 85°C
tion factor K_0	1	0.85	0.7

ER

ct related data (e.g. specification, statements and general information) are subject to change without any notice. It is necessary that the customer observes all product
apXon products are designed and manufactured according to severe quality and safety standards.
circumstance, CapXon warrants that any CapXon product is suitable for the purposes intended for your application, even CapXon knows the application.
mer's duty and obligation to check and make sure that CapXon products are suitable for the purposes intended and select the correct and proper CapXon product.
rs are requested to perform a sufficient validation and reliability evaluation to assure needed safety level and reliability performance by suitable designs
ply proper safeguards (e.g. redundancies, protective circuits).
r operating conditions (ambient temperature, ripple current, voltage, thermal resistance, etc.) as well as storage, production or assembly may affect the performance
ifetime of the capacitor. Please consult CapXon for lifetime estimation, failure mode considerations or worst-case scenarios according to the product
gy, product tolerances / deviations or change of the characteristics of the capacitor due to shipment, storage, handling, production and usage.
space or military application, life-saving, life-sustaining, safety critical applications or any application where failure may cause severe personal injury or death,
nsult us before design-in the capacitor in your application.
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_Ver.001_14.08.2020 3 Lifetime Estimatio
Snap-In Aluminum Electrolytic Capacito
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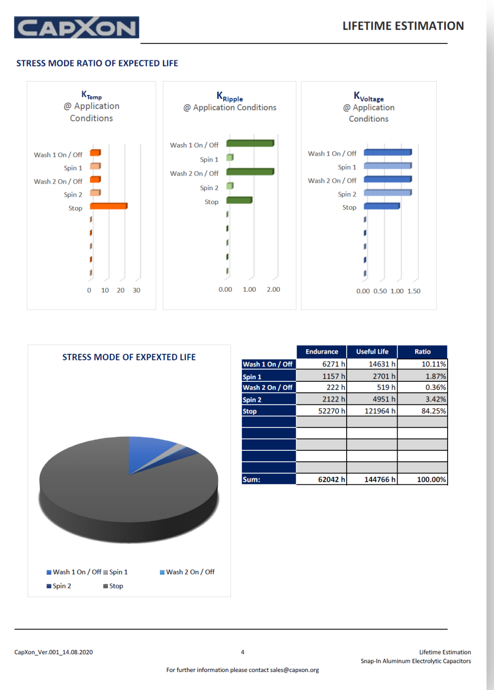
Stress mode ratio of expected life



LIFETIME ESTIMATION

STRESS MODE RATIO OF EXPECTED LIFE

	Endurance	Useful Life	Ratio
Wash 1 On / Off	6271 h	14631 h	10.11%
Spin 1	1157 h	2701 h	1.87%
Wash 2 On / Off	222 h	519 h	0.36%
Spin 2	2122 h	4951 h	3.42%
Stop	52270 h	121964 h	84.25%
Sum:	62042 h	144766 h	100.00%

CapXon_Ver.001_14.08.2020 4 Lifetime Estimation
Snap-In Aluminum Electrolytic Capacitors
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Professional is ...

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