CapXon

LIFETIME COMPENDIUM

ALUMINUM ELECTROLYTIC CAPACITORS

SOLID CONDUCTIVE POLYMER CAPACITORS

HYBRID CONDUCTIVE POLYMER CAPACITORS

CONTENT

10 FACTS ABOUT CAPXON

Founded 1980
by Victor Lin

Established in Taipei
Taiwan

Family owned and
independent

40 years experience in
electrolytic capacitors

2500 professional
employees

Fully owned factories
1 e-cap and 3 foil factories

ISO9001, ISO14001
and IATF 16949 certified

Patented production
process

Belongs to the TOP 10
manufacturers in e-caps

Production of more than
1 bio pcs per month

TECHNICAL TERMS

Item	Description	SI units
V_R	Rated voltage	V
V_S	Surge voltage	V
V_{Ripple_AC}	Ripple voltage	V
$V_{Reverse}$	Reverse voltage	V
V_A	Application voltage, operating voltage	A
I_R	Rated ripple current, rated alternating current	A
I_A	Application current, operating current	A
I_{A_Max}	Maximum application current, maximum operating current	A
I_{Leak}	Leakage current	A
T_{0_Max}	Upper category temperature	°C
T_{0_Min}	Lower category temperature	°C
T_A	Application temperature, operating temperature	°C
T_S	Capacitor surface temperature	°C
ΔT_0	Core temperature increase by internal heating due to rated ripple current	°C
ΔT_A	Core temperature increase by internal heating due to application ripple current	°C
C_R	Rated capacitance	F
ΔC	Capacitance tolerance	%
C/C_R	Capacitance drift	-
tan δ	Dissipation factor	-
Z	Impedance	Ω
ESR	Equivalent series resistance	Ω
ESL	Equivalent series inductance	H
X_C	Capacitive reactance	Ω
X_L	Inductive reactance	Ω
f	Frequency	Hz
ω	Angular frequency	Hz
λ	FIT = failure in time	-
K_f	Multiplier for ripple current vs. frequency	-
K_T	Multiplier for ripple current vs. temperature	-
K_0	Dielectric constant derating coefficient at high temperature	-
L_0	Specified lifetime at max. capacitor temperature, rated voltage (and rated ripple current)	h
L_A	Expected lifetime at application conditions	h

For further information please contact sales@capxon.org

Aluminum electrolytic capacitors, hereafter called e-caps, are for a good reason the most widely used components in filtering and buffering applications on electronic assemblies. Compared to other capacitor technologies, they feature very high capacitance and small size, acceptable cost of procurement and resistance to voltage surges. They are available in a wide variety of dimensions in SMD and THT styles for printed circuit boards as well as with screw terminals for particularly energy-intensive applications.

Aluminum electrolytic capacitors are divided into three subgroups:

- E-caps with liquid electrolytes
- E-caps with conductive polymer (Solid type)
- Hybrid electrolytic capacitors, the combination of liquid electrolytes with conductive polymer

Fig. 1: CapXon electrolytic capacitors in SMD, THT and with screw terminals

The main differences and characteristics are explained in the CapXon White Paper "Technology of Conductive Polymer and Hybrid Polymer Capacitors.

Significantly, environmental factors such as temperature, humidity, atmospheric pressure, vibration as well as electrical factors such as threshold voltage, AC load, and the duty cycle (time relationship between pulse duration and pulse spacing) determine the life of the capacitor.

The accurate estimation of the lifetime of components is one of the elementary considerations of any electronic assembly. If electrolytic capacitors are not properly designed for the application environment and load, they will inevitably lead to a disproportionate change in their electrical performance or, in the worst case, failure of the capacitor.

The aim of this white paper is to help users to calculate and estimate the expected lifetime of E-caps.

HOW CAN THE TERM 'LIFETIME' AND THE END OF IT BE SUBJECT TO AN E-CAP?

The abundance of existing E-cap manufacturers on the market and the different definitions of terms, make it not easy for the user to perform a direct comparison of the specified life in the datasheets.

The most commonly encountered terms are **ENDURANCE, USEFUL LIFE, LOAD LIFE** or **SHELF LIFE** - but where are the differences?

In manufacturer's datasheets European and US producers mostly used the term "useful life" or "load life" and Asian companies use the definition of lifetime "endurance".

Due to the globalization of the manufacturers, as well as the markets, the above-mentioned descriptions were largely aligned and adopted by all electrolytic capacitor producers.

They describe the capacitors end of life with:

- Maximum permissible upper capacitor temperature T_{0_Max} in °C
- Rated voltage V_R of the capacitor in volts
- **With or without** maximum permissible ripple current I_R in amperes (RMS)

If the capacitor is operated within the parameters, specified by the manufacturer in the datasheet, this means:

The **END OF LIFETIME**

- Overpressure (safety) vent not opened
- Electrolyte did not leak
- Aluminum can (housing) cannot burst
- Capacitor not shorted

However, the following should be noted!

Due to the thermal stress inside the electrolytic capacitor, the electrical variables change. These are capacitance, dissipation factor, ESR and leakage current.

The permissible limits are determined by the manufacturer itself and must be considered in a direct comparison!

Test conditions	Useful Life	Endurance	Shelf Life
Duration time	10000h @ 105°C	5000h @ 105°C	1000h @ 105°C
Applied voltage	Rated DC working voltage V_R and Ripple current I_R		None
After test requirements (+20°C)			
Capacitance change	≤ ±20% of initial measured value	≤ ±10% of initial measured value	
Dissipation factor change	≤ 200% of initial specified value	≤ 130% of initial specified value	
Leakage current	≤ the initial specified value		
Comment			Pre-treatment for measurements shall be conducted after application of DC working voltage for 30min

Table 1: Example of lifetime for the CapXon UL series

CapXon specifies the lifetime of its e-cap series **basically** with the **Endurance** and the **Shelf Life**. In addition, the **Useful Life** is specified for **all** snap-in and screw terminal series, which allows an extended drift of the electrical parameters.

Shelf life is the voltage and currentless storage of the capacitor at maximum permissible temperature. The component reliably maintains its electrical parameters within the permissible limits. Table 1 shows the max allowed changes over 1000 hours of storage, at 105°C.

LOW VOLTAGE E-CAPS (≤ 100V) WITH LIQUID ELECTROLYTE

The title says it already. The capacitor has a liquid electrolyte which works as an energy reservoir. If the electrolytic liquid is now heated by environmental influences, the electrolyte evaporates over time, which in turn leads to a change in the electrical parameters and finally to the end of the lifetime.

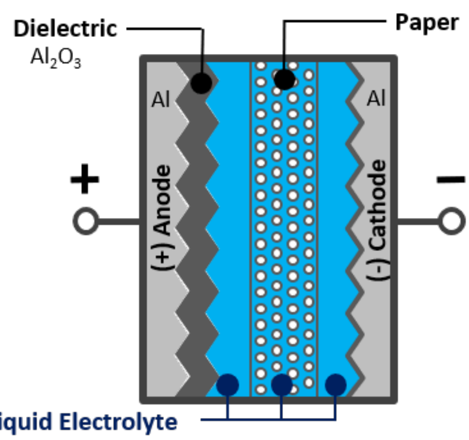


Fig. 2: Construction of an electrolytic capacitor with liquid electrolyte

CALCULATION OF LIFETIME BY MEANS OF AMBIENT TEMPERATURE

In some applications - such as time circuits, etc. - the heat generated by the ESR is not critical because the applied AC current is minimal and negligible. Also, the influence of the applied voltage is small in relation to the temperature, so that the lifetime is calculated based on the Arrhenius equation by means of ambient temperature.

$$L_A = L_0 \cdot K_{Temp} = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}} \quad (1)$$

WITH

L_A Expected lifetime (h) under application conditions

L_0 Specified lifetime (h) at maximum permissible capacitor temperature, rated voltage V_R and (depending on product) rated ripple current I_R. **Datasheet specification**

K_{Temp} Temperature influence

T_{0_Max} Maximum permissible upper category temperature (°C). **Datasheet specification**

T_A Application temperature (°C) of the capacitor

Life is doubled when the temperature of the electrolytic is reduced by 10°C.

CALCULATION OF LIFETIME BY MEANS OF AMBIENT TEMPERATURE AND ADDITIONAL HEATING THROUGH THE APPLICATION CURRENT IN THE CAPACITOR

In most applications, such as switch mode power supplies or converters, however, the electrolytic capacitors are constantly charged and discharged, which, due to the ohmic losses, results in a not insignificant increase in the temperature 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) $$P_V = I_A{}^2 \cdot ESR$$

WITH

P_V Internal power losses (W)

I_A Ripple current flowing in the capacitor (A RMS)

ESR Equivalent series resistance (Ω)

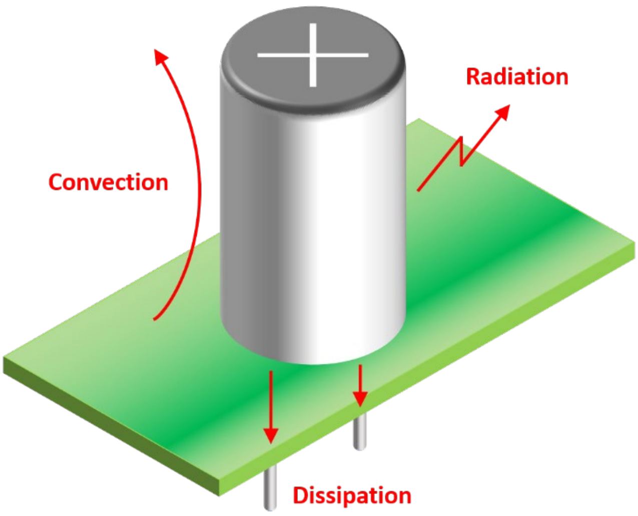


Fig. 3: Thermal output of the e-cap via convection, radiation and dissipation

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.

(3) $$P_T = \frac{\Delta T_A}{R_{th}} = \Delta T_A \cdot \beta \cdot A$$

WITH

P_T Thermal power (W)

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

R_{th} Thermal resistance of the electrolytic capacitor (K/W)

β Radiation coefficient (W/cm^2 K)

A Surface of the capacitor (cm^2)

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

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. 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 correspondingly large diameters such as snap-in or screw terminals. Please contact your local CapXon office for more information.

b.) Temperature measurement of surface temperature T_S

For this purpose, the surface temperature of the capacitor can T_S and the ambient temperature T_A is first measured and converted to the core temperature increase using a coefficient K_C given for each can diameter, as follows:

(5) $$\Delta T_A = K_C \cdot (T_S - T_A)$$

WITH

K_C Conversion factor core temperature to surface temperature

T_S Surface temperature (°C) of the capacitor during operation

T_A Application temperature (°C) of the capacitor

Diameter (mm)	5 to 8		10	12.5	16	18	22	25
K_C	1.10		1.15	1.20	1.25	1.30	1.35	1.40
Diameter (mm)	**30**	**35**	**40**	**50**	**63.5**	**76**	**89**	**100**
K_C	1.50	1.65	1.75	1.90	2.20	2.50	2.80	3.10

Table 2: Conversion factors - core temperature to surface temperature for different can diameters

By means of the previously described method, the ΔT_A values, including small can sizes such as SMD and THT components, can be determined very well by measurement. The temperature sensor can be attached for the measurement - topside or sideways to the E-cap can.

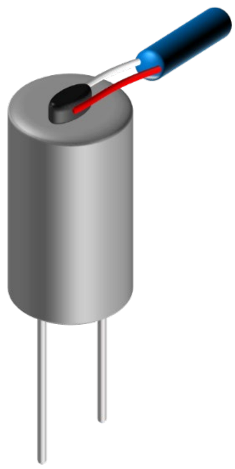


Fig. 5: Measurement of the surface temperature with a temperature sensor mounted on the top side.

c.) Calculation based on reference conditions

In this method, ΔT_A is determined by making a comparison of heat dissipation under application conditions with heat dissipation under reference conditions. CapXon considers an airflow of <0.5m/s for calculations.

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

WITH

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

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

I_A Actual application current (A RMS)

I_R Maximum permissible rated ripple current (A RMS). **Datasheet specification**

K_f Multiplier for rated ripple current compared to frequency. **Datasheet specification**

The permissible nominal ripple current I_R relates to the maximum capacitor temperature T_0 and usually to a frequency of 120Hz, which is twice the mains frequency of 60Hz.

The background is that for low-frequency applications, electrolytic capacitors are used predominantly for smoothing after the mains input rectification.

So-called "low ESR" or "low impedance" types are often used in high-frequency applications, e.g. to be found as an output filter. Their I_R is specified at 100kHz.

Often, the application current I_A is not frequency-equal to the nominal alternating current I_R. In these cases, I_R must be converted to the same frequency as I_A using the AC correction factor K_f. For all CapXon electrolytic series, a table with the ripple current correction factors K_f can be found in the respective data sheet, which allows the calculation of the ratio of I_A/I_R at different frequencies.

V_0 (V) / f (Hz)	60	120	300	1k	10k	50k – 100k
$160 \leq V_0 \leq 250$	0.81	1	1.17	1.32	1.45	1.5
$315 \leq V_0 \leq 600$	0.77	1	1.16	1.30	1.41	1.43

Table 3: Ripple current correction factor for the CapXon UL series

Note:

For low-voltage electrolytic capacitors we recommend under no circumstances to exceed the maximum permissible nominal ripple current I_R. If this is the case, please contact your local CapXon office.

Please note that a ΔT_0 over our specified maximum values - see Table 6 - can overheat the capacitor.

With the ΔT_A values, the heating of the capacitor can be calculated by the ripple current flowing in the application, as shown below. Depending on the used electrolyte and aluminum foil, CapXon differentiates between standard and high-performance series for the low-voltage range ≤ 100V.

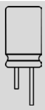
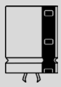
K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{-\frac{\Delta T_A}{10°C}}$	–	SMD (all voltages)		CV, DV, EV, HV, JV, KV, LV, MV, NV, RV, SV, TV
		Radial		GS (≤ 100V), NK, NP, NR, SG, SH, SJ, SK, SM, SR, SS, ST, SW, SY, SZ
		Snap-in		LR

Table 4: Influence of application current on CapXon low voltage standard series

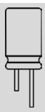
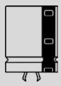
K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{\frac{\Delta T_0 - \Delta T_A}{5°C}}$	–	Radial		FB, FC, FD, FE, FG, FH, GF, GH, GT, KF (≤ 100V), KH (≤ 100V), KM (≤ 100V), KZ, LL, LZ, TE (≤ 100V), TH (≤ 100V), ZH
		Snap-in		HC, HL (≤ 100V), HP (≤ 100V), HU (≤ 100V), LD (≤ 100V), LP (≤ 100V), LT (≤ 100V), LU (≤ 100V)
		Screw terminal		RK, RS

Table 5: Influence of application current on CapXon low voltage high performance series

For all CapXon standard series ≤ 100V, see table 2

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

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

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

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

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.

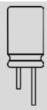
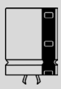
K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{\frac{\Delta T_0 - \Delta T_A}{8°C}}$	$\left(\frac{V_R}{V_A}\right)^{4.4 \cdot K_0}$	Radial		FK, FL, GS (≥ 160V), HY, KC, KF (≥ 160V), KH (≥ 160V), KL, KM (≥ 160V), KS, KY, LE, LY, TE (≥ 160V), TH (≥ 160V)
		Snap-in		HH, HL (≥ 160V), HP (≥ 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

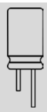
K_{Ripple}	$K_{Voltage}$	Product		
		Type		CapXon series
$2^{\frac{\Delta T_0 - \Delta T_A}{8°C}}$	$\left(\frac{V_R}{V_A}\right)^{2.5}$	Radial		FF, FR, FS, FT, FU, FW, FX

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

For all CapXon series ≥ 160V, except for SMD series, see table 7

$$(9)\quad L_A = L_0 \cdot K_{Temp} \cdot K_{Ripple} \cdot K_{Voltage} = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}} \cdot 2^{\frac{\Delta T_0 - \Delta T_A}{8°C}} \cdot \left(\frac{V_R}{V_A}\right)^{4.4 \cdot K_0}$$

For all CapXon series ≥ 160V, for use in lighting applications, see table 8

$$(10)\quad L_A = L_0 \cdot K_{Temp} \cdot K_{Ripple} \cdot K_{Voltage} = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}} \cdot 2^{\frac{\Delta T_0 - \Delta T_A}{8°C}} \cdot \left(\frac{V_R}{V_A}\right)^{2.5}$$

WITH

$K_{Voltage}$ Influence of the operating voltage

V_R Rated voltage (V) of the capacitor. **Datasheet specification**

V_A Operating voltage (V) in the application

K_0 Dielectric constant derating in high temperature. **See table 9**

Important Remark:
If the operating voltage is less than 80% of the rated voltage (V_R), V_A is 80% of V_R

Ambient temperature of the capacitor T_A	≤ 65°C	≤ 85°C	> 85°C
Correction factor K_0	1	0.85	0.7

Table 9: Correction factor – Dielectric constant derating in high temperature

TOTAL LIFETIME EXPERIENCE WITH CHANGING RIPPLE CURRENT IN THE APPLICATION

If the value of the applied ripple current in the capacitor changes, the life expectancy can be calculated by proportional distribution as follows:

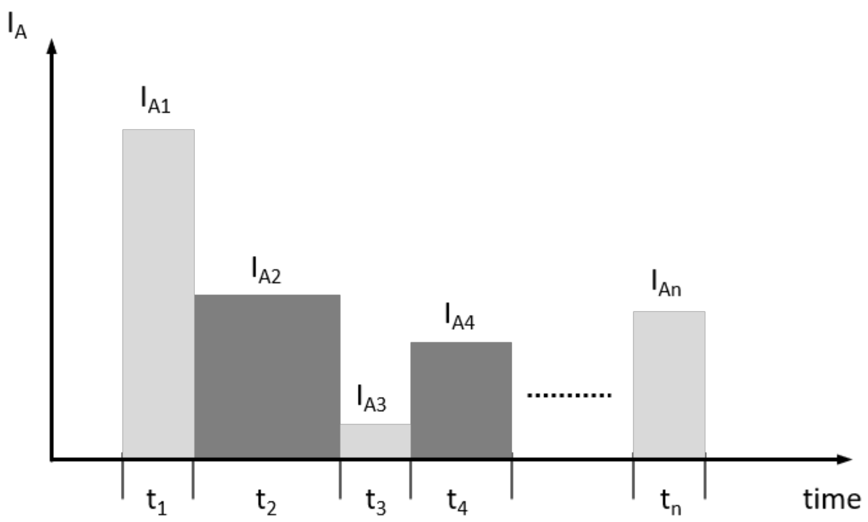


Fig. 6: Example of changing alternating current in the application

$$(11)\quad L_A = L_0 \cdot \frac{t_1+t_2+t_3+t_4 \ldots + t_n}{\frac{t_1}{K_T \cdot K_{I1}} + \frac{t_2}{K_T \cdot K_{I2}} + \frac{t_3}{K_T \cdot K_{I3}} + \frac{t_4}{K_T \cdot K_{I4}} + \cdots + \frac{t_n}{K_T \cdot K_{In}}}$$

WITH

$$(12)\quad K_{Temp} = K_T = 2^{\frac{T_{0\_Max} - T_A}{10°C}}$$

(13) $K_{I1} = K_{Ripple\_1}$

If the ambient temperature can't be determined metrologically, the following equation can be used for the estimation.

(14) $T_A = T_S - \frac{\Delta T_A}{K_C}$

WITH

T_A Ambient temperature (°C) of the capacitor

T_S Surface temperature (°C) of the capacitor can during operation

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

K_C Conversion factor core temperature to surface temperature (see table 3)

NOTE

- **Minimum temperature for T_A is 40°C**
- **Maximum allowable core temperature increase ΔT_A for SMD and radial styles is 15°C. See details in table 9 to 11**
- **Maximum permissible core temperature increase ΔT_A for snap-in and screw terminal style is 35°C. See details in table 12 to 14**

Surface temperature T_s (°C)	≤ 65	75	85
Core temperature rise ΔT_A (°C)	15	15	10

Table 10: Maximum permissible core temperature increase for 85 ° C - SMD and radial series

Surface temperature T_s (°C)	≤ 85	95	105
Core temperature rise ΔT_A (°C)	15	10	5

Table 11: Maximum permissible core temperature increase for 105 ° C - SMD and radial series

Surface temperature T_s (°C)	≤ 105	115	125
Core temperature rise ΔT_A (°C)	15	10	5

Table 12: Maximum permissible core temperature increase for ≥ 125 ° C - SMD and radial series

Surface temperature T_s (°C)	≤ 45	55	65	75	85
Core temperature rise ΔT_A (°C)	30	25	20	15	10

Table 13: Maximum permissible core temperature increase for 85 ° C - snap-in and screw terminal series

Surface temperature T_s (°C)	≤ 45	55	65	75	85	95	105
Core temperature rise ΔT_A (°C)	35	30	25	20	15	10	5

Table 14: Maximum permissible core temperature increase for 105 ° C - snap-in and screw terminal series

Surface temperature T_s (°C)	≤ 65	75	85	95	105	115	125
Core temperature rise ΔT_A (°C)	35	30	25	20	15	10	5

Table 15: Maximum permissible core temperature increase for ≥ 125 ° C - snap-in series

CALCULATION EXAMPLE - OUTPUT FILTER CAP - IN A SWITCH MODE POWER SUPPLY

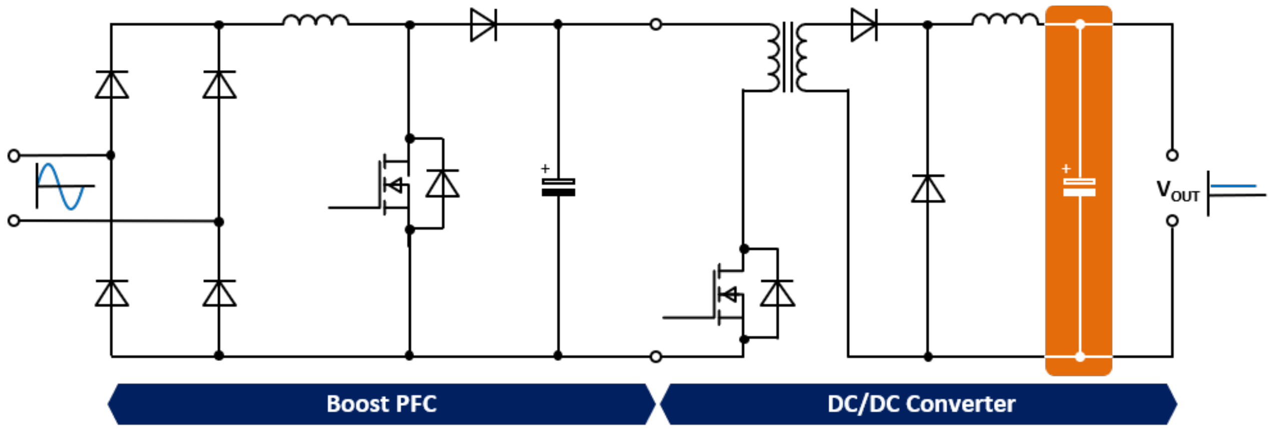


Fig. 7: Principal diagram for switching mode power supply with active PFC and galvanically isolated output

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

CALCULATION STEPS

a.) Average currents I_{Eff} considering the ripple current correction factors

Frequency (Hz)	50 (60)	120	400	1k	10k	≥ 50k
Ripple current correction factor K_f	0.63	0.78	0.87	0.91	0.98	1

Table 18: Ripple current correction factor for the CapXon GF Series

Average current: $I_{Total\_RMS} = \sqrt{\left(\frac{I_{A\_1}}{K_{f1}}\right)^2 + \left(\frac{I_{A\_2}}{K_{f2}}\right)^2 + \ldots + \left(\frac{I_{A\_n}}{K_{fn}}\right)^2}$

Mode 1: $I_{Total\_Mode\_1} = \sqrt{\left(\frac{1.5A}{0.98}\right)^2 + \left(\frac{1A}{1}\right)^2 + \left(\frac{0.8A}{1}\right)^2 + \left(\frac{0.6A}{1}\right)^2} = 2.08A$

Mode 2: $I_{Total\_Mode\_2} = \sqrt{\left(\frac{1.8A}{0.98}\right)^2 + \left(\frac{1.2A}{1}\right)^2 + \left(\frac{0.9A}{1}\right)^2 + \left(\frac{0.7A}{1}\right)^2} = 2.47A$

Stop: $I_{Total\_Stop} = \sqrt{\left(\frac{0.05A}{0.9}\right)^2} = 0.06A$

Standby: $I_{Total\_Standby} = \sqrt{\left(\frac{0.05A}{0.9}\right)^2} = 0.06A$

b.) Period of one operating cycle

Time: $t_{Cycle} = t_{Mode\_1} + t_{Mode\_2} + t_{Stop} = 300s + 180s + 120s = 600s$

Total time: 600s · 200,000 cycles = 33333h

Designation	Maximum capacitor ambient temperature T_A	Operating time during the 200,000 cycles
Mode_1	70°C	16667h
Mode_2	70°C	10000h
Stop	70°C	6667h
Cycle time	**70°C**	**33333h**
Standby time	**45°C**	**54267h**
Desired lifetime		**87600h**

c.) Actual application current of the capacitor during operation

$$I_{Total\_Cycle} = I_A = \sqrt{\left(I_{TM\_1} \cdot \sqrt{\frac{t_{M\_1}}{t_{Cycle}}}\right)^2 + \left(I_{TM\_2} \cdot \sqrt{\frac{t_{M\_2}}{t_{Cycle}}}\right)^2 + \left(I_{T\_Stop} \cdot \sqrt{\frac{t_{M\_Stop}}{t_{Cycle}}}\right)^2}$$

$$I_{Total\_Cycle} = I_A = \sqrt{\left(2.08A \cdot \sqrt{\frac{300s}{600s}}\right)^2 + \left(2.47A \cdot \sqrt{\frac{180s}{600s}}\right)^2 + \left(0.06A \cdot \sqrt{\frac{120s}{600s}}\right)^2} = 2\text{A}$$

GF561M035G250ETA is a low voltage "high performance type. Therefore, for the lifetime, equation 6 is valid.

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

d.) Temperature influence (temperature factor) K_{Temp}

Cycle: $K_{Temp} = 2^{\frac{T_{0\_Max} - T_A}{10°C}} = 2^{\frac{105°C - 70°C}{10°C}} = 11$

Standby: $K_{Temp} = 2^{\frac{T_{0\_Max} - T_A}{10°C}} = 2^{\frac{105°C - 45°C}{10°C}} = 64$

e.) Core temperature rise ΔT_A due to internal heating due to application current

Cycle: $\Delta T_A = \Delta T_0 \cdot \left(\frac{I_A}{I_R \cdot K_f}\right)^2 = 5°C \cdot \left(\frac{2A}{2.04A \cdot 1}\right)^2 = 4.8°C$

Standby: $\Delta T_A = \Delta T_0 \cdot \left(\frac{I_A}{I_R \cdot K_f}\right)^2 = 5°C \cdot \left(\frac{0.06A}{2.04A \cdot 1}\right)^2 = 0.004°C$

ΔT_0 see table 4

f.) Application current influence (ripple current factor) K_{Ripple}

Cycle: $K_{Ripple} = 2^{\frac{5°C - 4.8°C}{5°C}} = 1.03$

Standby: $K_{Ripple} = 2^{\frac{5°C - 0.004°C}{5°C}} = 1.99$

g.) Lifetime in the application L_A

Cycle: $L_A = L_0 \cdot K_{Temp} \cdot K_{Ripple} = 5000h \cdot 11 \cdot 1.03 = 56650h$

Standby: $L_A = L_0 \cdot K_{Temp} \cdot K_{Ripple} = 5000h \cdot 64 \cdot 1.99 = 636800h$

Considering the influence factors **Cycle** and **Standby**, the lifetime in the application L_A is calculated as follows:

Total:

$$L_A = L_0 \cdot \frac{(t_{Cycle} + t_{Standby})}{\frac{t_{Cycle}}{K_{Temp} \cdot K_{Ripple}} + \frac{t_{Standby}}{K_{Temp} \cdot K_{Ripple}}}$$

$$L_A = 5000h \cdot \frac{33333h + 54267h}{\frac{33333h}{11 \cdot 1.03} + \frac{54267h}{64 \cdot 1.99}} = 132924h = 15.2a$$

Under the given use conditions, the e-cap, with an expected lifetime of 15.2 years, meets the desired requirement of at least 10 year's lifetime.

DETERMINATION OF USEFUL LIFE BY GRAPHIC WAY - LIFETIME NOMOGRAM -

CapXon has extensive knowledge of the long-term use of its electrolytic capacitors due to its nearly 40 years of experience in the development and production of aluminum electrolytic capacitors.

Numerous test results and a great deal of know-how are contained in the lifetime nomograms, which graphically illustrate the relationship between the service life of an aluminum electrolytic capacitor and the two variables influencing its temperature. The nomograms can be found in the respective datasheets of our snap-in and screw terminal electrolytic capacitors.

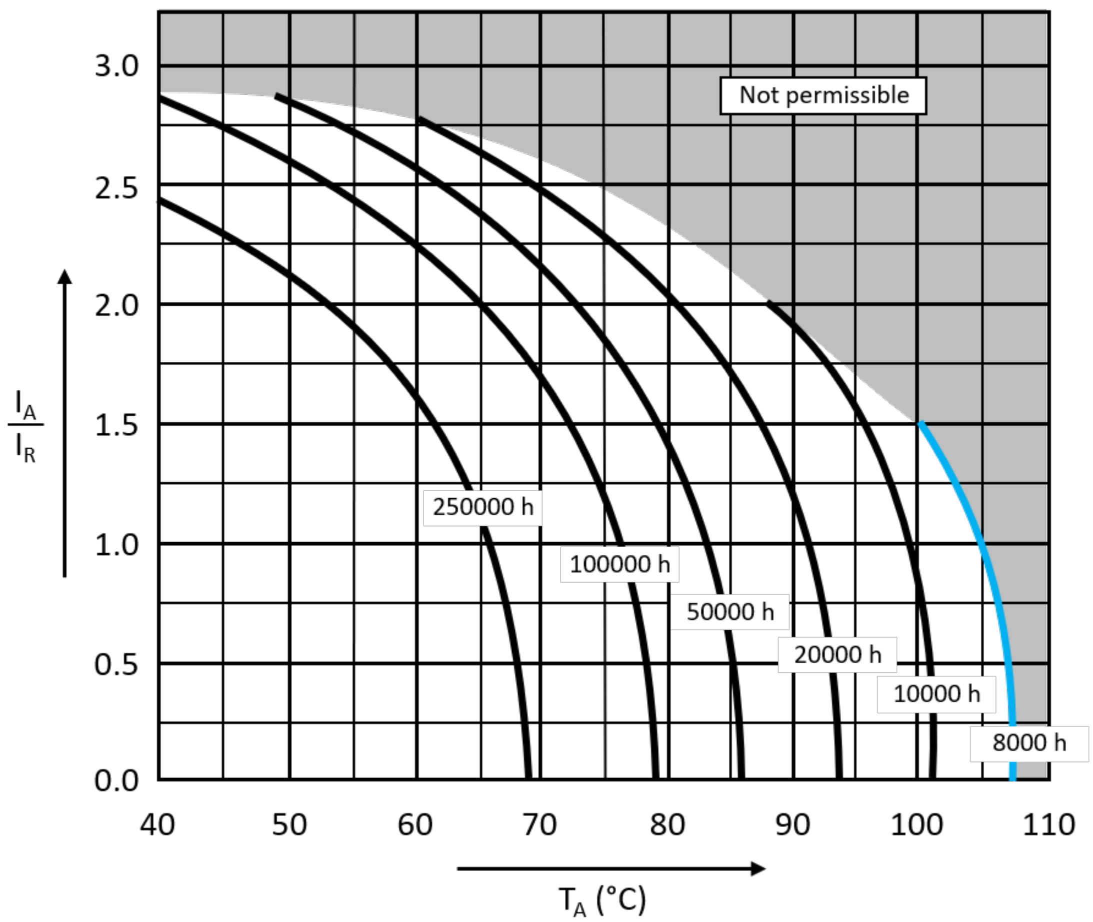


Fig. 7: Nomogram for the CapXon RH series with a useful life of 8000h at 105°C

The abscissa represents the ambient temperature T_A in relation to the ordinate, with the ratio of application current to rated current I_A/I_R.

From the nomogram, it is relatively easy to read the ripple current I_A required in an application and/or the desired useful life.

METHODE

1. Definition of the ambient temperature T_A in the application
2. Calculate the ratio of the actual application current I_A to the maximum permissible nominal ripple current I_R of the e-cap
3. Determine the point of intersection between the calculated ratio I_A/I_R and the ambient temperature T_A
4. Reading the useful life using the lifetime curve taken

NOTE

In the above steps, the frequency characteristic of the alternating current is not considered. Frequently, the application current I_A is not the same frequency as the nominal ripple current I_R. In these cases, I_A must be converted to the same frequency as I_R by means of the ripple current correction factor K_f. K_f can be found in the relevant data sheet of the selected series for a wide range of frequencies.

APPLICATION EXAMPLES

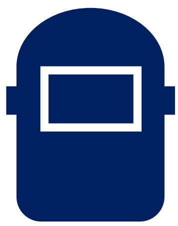
The following examples show how varied the lifetime nomogram can be used.

EXAMPLE 1 Calculation of the required lifetime using the electrical data of a screw terminal e-cap - RH series

Fig. 8: CapXon screw terminal e-cap of the RH series

User requirement - Capacitor discharge welding

Application current 1:	I_{A_1} = 20A (RMS) at 120Hz
Application current 2:	I_{A_2} = 16A (RMS) at 4kHz
Ambient temperature:	T_A = 60°C, constant
Desired lifetime:	> 40.000h
Selected type:	**RH222M450SA20A**



Rated capacitance C_R	Rated voltage V_R	Rated current I_R	Dimension Ø x L	Useful life
2200µF	450V	9.2A at 120Hz/105°C	63.5mm x 120mm	8000h at 105°C

Table 19: Main parameter RH222M450SA20A

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) $$I_{Equ} = \frac{I_A}{K_f}$$

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

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

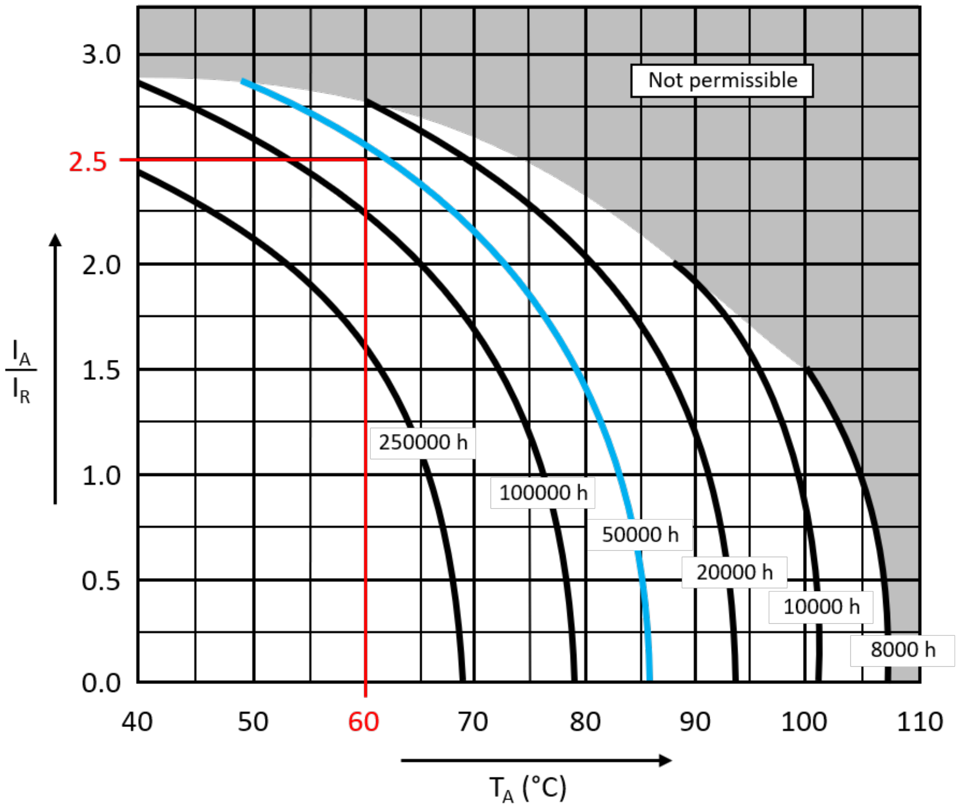


Fig. 9: Nomogram for the CapXon RH series with intersection point for the application example

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.

APPLICATION EXAMPLES

EXAMPLE 2 Calculation of the required application current and selection of a suitable electrolytic capacitor

User requirement - Power supply

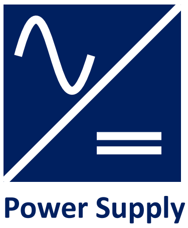
Application current at the output: I_A = 16A (RMS) at 10kHz

Output voltage: V_{OUT} = 24V DC

Application temperature: T_A = 70°C, constant

Desired lifetime: > 7 years = 61,320h

Chosen series: HU-series with a useful life of 5000h at 105°C



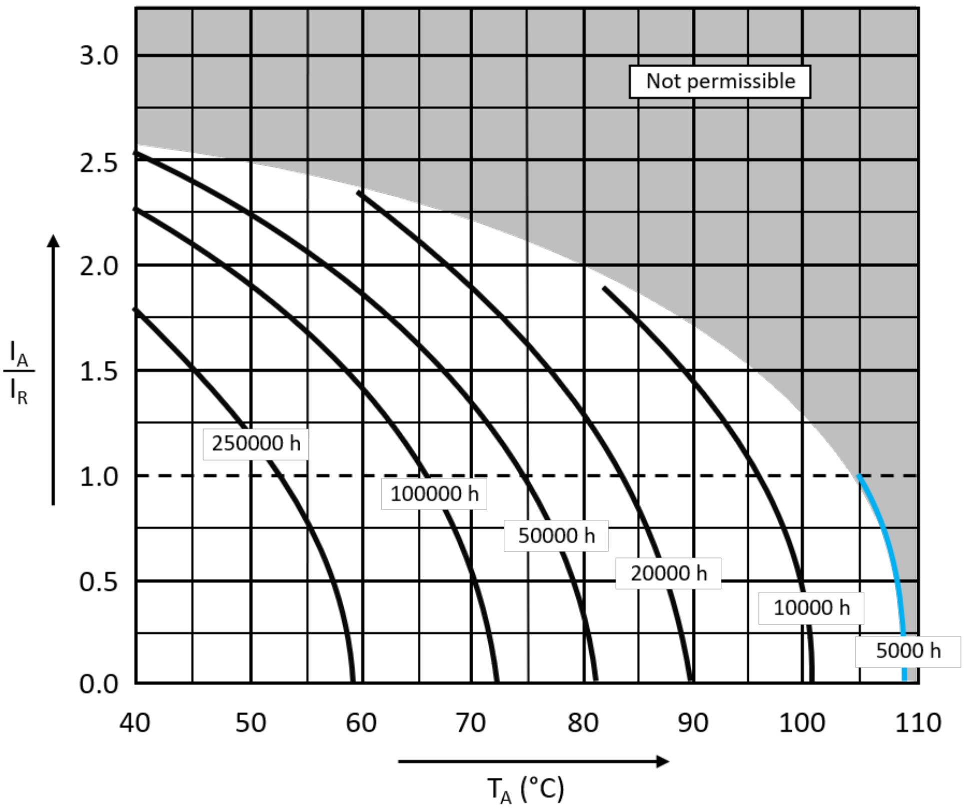
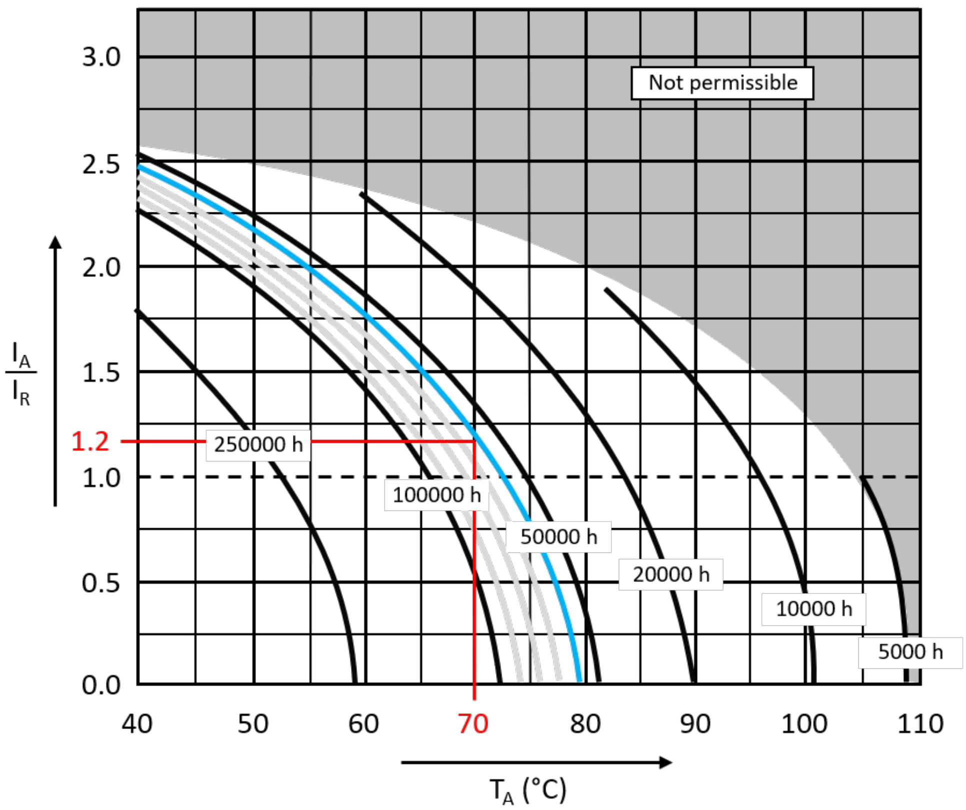


Fig. 10: Nomograph for the CapXon HU series with a useful life of 5000h at 105°C

The first step is to calculate the lifetime multiplier, which is determined as follows:

Lifetime multiplier: $$\frac{Desired\ useful\ life}{Spec.\ useful\ life\ at\ max.\ temperature} = \frac{61320h}{5000h} = 12.3$$

Using the nomogram, the corresponding ratio I_A/I_R on the ordinate can now be read at an ambient temperature of 70°C and the calculated lifetime multiplier. See the blue lifetime curve for the factor 12.3.



Ratio I_A/I_R: $\frac{I_A}{I_R} = 1.2$

Consequently, at 70°C ambient temperature a ripple current 20% higher than the nominal rated ripple current, specified in the datasheet, is allowed.

Frequency (Hz)	50 (60)	120	300	1k
Ripple current correction factor K_f	0.88	1	1.07	1.15

Table 21: Ripple current correction factor for the CapXon HU series with rated voltages ≤ 100V

In order to calculate the nominal alternating current I_R required by the electrolytic capacitor, the ratio I_A/I_R and the influence of the application frequency - 10kHz - must be considered.

Required ripple current: $I_R = \frac{1}{I_A/I_R} \cdot \frac{I_A}{K_f} = \frac{1}{1.2} \cdot \frac{16A}{1.15} = 11.6A$

Selected type: 4 pieces HU682M050N450A connected in parallel to supply the required rated ripple current.

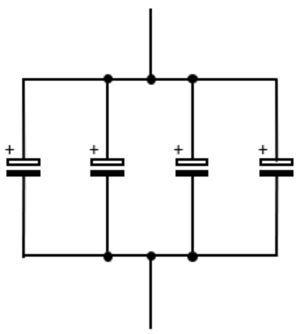


Fig. 9: HU series CapXon snap-in e-cap

Rated capacitance C_R	Rated voltage V_R	Rated current I_R	Dimension Ø x L	Useful life
680µF	50V	3.37A at 120Hz/105°C	25mm x 45mm	5000h at 105°C

Table 22: Main parameter HU682M050N450

SOLID CONDUCTIVE POLYMER CAPACITORS (SOLID TYPE E-CAPS)

Unlike liquid electrolytic capacitors, solid conductive polymer capacitors use the properties of conductive plastic, the polymer. Expressed in a simple way, the solid polymer replaces the liquid electrolyte.

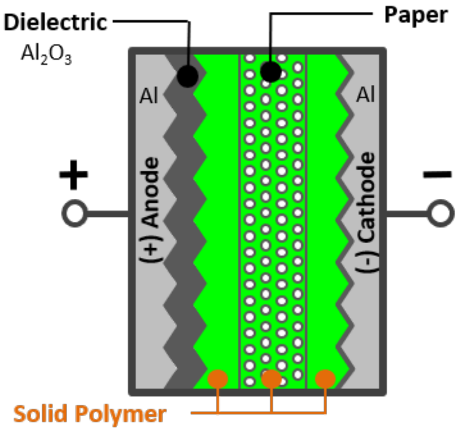


Fig. 10: Structure of an electrolytic capacitor with conductive polymer

The essential feature compared to liquid electrolytes is the significantly higher electrical conductivity of the material - 1,000 to 10,000 times higher - and the resulting, very low equivalent series resistance (ESR) of a few milliohms.

Polymer capacitors, despite their small dimensions, are capable of being loaded with very high ripple currents, which predestines them primarily as output filters.

For polymer capacitors, the solid electrolyte **can't dry out**, either by the ambient temperature or the temperature rise in the capacitor. Only the influence on materials due to the temperature in the component and conversion of the conductivity limit the lifetime, which is much higher than that of electrolytic capacitors.

The Arrhenius Rule is not used for polymer capacitors and is replaced by lab tested rule. So, calculation isnot in the 10 ° C steps as known from liquid electrolytes, but in a modified form.

CALCULATION OF LIFETIME BY MEANS OF AMBIENT TEMPERATURE

For electrolytic capacitors with solid conductive polymer we apply:

$$(17)\quad L_A = L_0 \cdot K_{Temp} = L_0 \cdot 10^{\frac{T_{0\_Max} - T_A}{20°C}}$$

The lifetime increases tenfold when the temperature of the e-cap is reduced by 20°C.

WITH

L_A Expected lifetime (h) under application conditions

L_0 Specified lifetime (h) at rated voltage and rated ripple current **within the maximum capacitor temperature T_0**.
Datasheet specification

K_{Temp} Temperature influence

T_{0_Max} Maximum permissible upper category temperature (°C). **Datasheet specification**

T_A Application temperature (°C) of the capacitor

CALCULATION OF THE LIFETIME BY MEANS OF AMBIENT TEMPERATURE AND ADDITIONAL HEATING THROUGH THE APPLICATION CURRENT IN THE CAPACITOR

Due to their very low ESR, polymer capacitors are mainly used in switching applications with high frequencies, usually in the high kilohertz range
(≥ 50kHz). The recharge losses, despite the low ESR, lead to a temperature rise in the component, which can be determined in the following way.

$$(18)\quad L_A = L_0 \cdot K_{T+R} = L_0 \cdot 10^{\frac{T_{0\_Max} - T_S}{20°C}}$$

WITH

L_A Expected lifetime (h) under application conditions

L_0 Specified lifetime (h) at rated voltage **within the maximum capacitor temperature T_{0_MAx}**.
Datasheet specification

K_{T+R} Temperature and application current influence

T_{0_Max} Maximum permissible upper category temperature (°C). **Datasheet specification**

T_S Surface temperature (°C) of the capacitor can during operation

(19) $T_S = T_A + \Delta T_A$

WITH

T_A Actual application temperature (°C)

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

NOTE

Under no circumstances may the surface temperature be exceeded. A ripple current flowing in the capacitor causes heating of the component and thus additional, thermal losses. This, together with the ambient temperature, causes a reduction of the oxidation in the conductive polymer chains.

Ignoring the maximum temperature causes irreversible damage to the polymer and leads to an increase in the ESR and dissipation factor tanδ, leading to complete loss of electrical conductivity.

The heating of the ripple current flowing in the capacitor must be measured and must not exceed 5°C. The surface temperature should be reduced according to the heating generated by the ripple current.

INCREASE ΔT_A

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

This can be done in different ways:

a.) By means of temperature measurement of surface temperature T_S

For this purpose, the surface temperature of the capacitor housing T_S and the ambient temperature T_A is first measured and converted to the core temperature increase using a coefficient K_C given for each housing diameter, as follows:

(20) $\Delta T_A = K_C \cdot (T_S - T_A)$

WITH

K_C: Conversion factor core temperature to surface temperature

T_S: Surface temperature (°C) of the capacitor can during operation

T_A: Application temperature (°C) of the capacitor

DETERMINATION OF THE CORE TEMPERATURE

Diameter (mm)	4	5	6.3	8	10
K_C	1.1	1.1	1.1	1.1	1.15

Table 23: Conversion factors - core temperature to surface temperature for different can diameters

By means of the previously described method, the ΔT_A values, including small can sizes such as SMD and THT components, can be determined very well by measurement. The temperature sensor can be attached for the measurement - topside or sideways to the E-cap can.

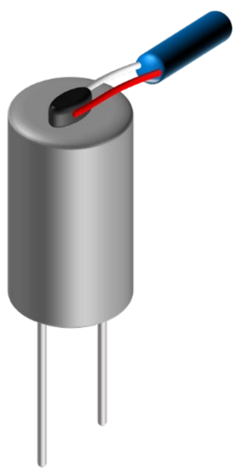


Fig. 11: Measurement of the surface temperature with a temperature sensor mounted on top.

b.) By calculation based on reference conditions

In this method, ΔT_A is determined by making a comparison of heat dissipation under application conditions with heat dissipation under reference conditions. CapXon uses an airflow of <0.5m/s.

(21) $\Delta T_A = \Delta T_{0\_Max} \cdot \left(\frac{I_A}{I_R \cdot K_f}\right)^2$

WITH

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

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

I_A Actual application current (A RMS)

I_R Maximum permissible rated ripple current (A RMS). **Datasheet specification**

K_f Multiplier for rated ripple current versus frequency. **Datasheet specification**

Upper capacitor temperature T_{0_Max}	105°C	≥ 125°C
Temperature rise ΔT_0	20	20

Table 24: Maximum permissible core temperature rise due to the permissible rated alternating current

The permissible nominal ripple I_R refers to the maximum capacitor temperature T_{0_Max} and a frequency of 100kHz.

Frequently, the application current I_A is not frequency-equal to the nominal alternating current I_R. In these cases, I_R must be converted to the same frequency as I_A using the ripple current correction factor K_f. For all CapXon polymer series, a table with the ripple current correction factors K_f can be found in the respective data sheet, which allows the calculation of the ratio of I_A/I_R at different frequencies.

Frequency (Hz)	120 ≤ f < 1k	1k ≤ f < 10k	10k ≤ f < 100k	100k ≤ f < 300k
Ripple current correction factor K_f	0.05	0.3	0.7	1

Table 25: Ripple current factor for the CapXon PH series

HYBRID CONDUCTIVE POLYMER CAPACITORS

Like solid conductive polymer capacitors with conductive polymer, hybrid conductive polymer capacitors also rely on a solid polymer, which essentially determines the electrical properties. These are low ESR, high ripple load capacity and very good long-term stability of all electrical parameters. As a special feature, hybrid capacitors contain an additional electrolyte film in order to optimally connect the open-pore structure of the dielectric located on the aluminum foil and the conductive polymer.

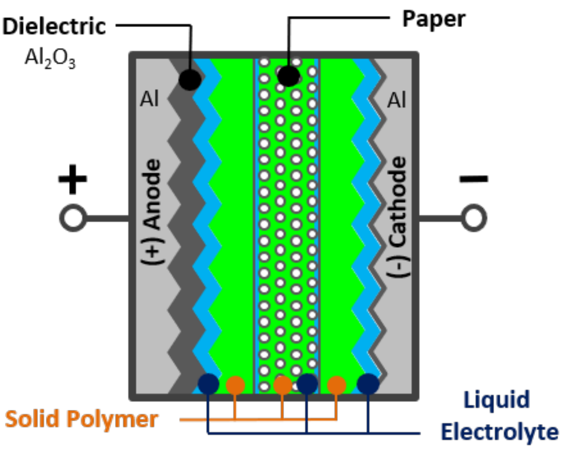


Fig. 12: Construction of a hybrid polymer electrolytic capacitor

The electrolyte film additionally contained in the hybrids combines optimally between the open-pored structure of the aluminum oxide dielectric present on the aluminum foil and the polymer electrolyte. This creates a larger effective capacitor surface area than the solid polymer types.

The electrolyte of hybrid conductive polymer capacitors maintains the reformation of the aluminum, thus reducing the increase in leakage current.

Since the electrolyte consists of a solid material, the polymer and on a electrolyte moisture film, is spoken of a hybrid.

Due to their low ESR, hybrid polymer capacitors are mainly used in switched applications with high frequencies, usually in the high kilohertz range (≥ 50kHz). The recharge losses, despite the low ESR, lead to a temperature increase in the component, which can be determined in the following way.

(22) $$L_A = L_0 \cdot K_{T+R} = L_0 \cdot 2^{\frac{T_{0\_Max} - T_S}{10°C}}$$

WITH

L_A Expected lifetime (h) under application conditions

L_0 Specified lifetime (h) at maximum upper capacitor temperature, voltage and rated ripple current. **Datasheet specification**

K_{T+R} Temperature and application current influence

T_{0_Max} Maximum permissible upper category temperature (°C). **Datasheet specification**

T_S Surface temperature (°C) of the capacitor can during operation

(23) $$T_s = T_A + \Delta T_A - 5°C$$

WITH

T_A Actual application temperature (°C)

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

NOTE

Under no circumstances may the surface temperature be exceeded. A ripple current flowing in the capacitor causes heating of the component and thus additional, thermal losses. This, together with the ambient temperature, causes a reduction of the oxidation in the conductive polymer chains.

Ignoring the maximum temperature causes irreversible damage to the polymer and leads to an increase in the ESR and dissipation factor tanδ, leading to complete loss of electrical conductivity.

The heating of the ripple current flowing in the capacitor must be measured and must not exceed 5°C. The surface temperature should be reduced according to the heating generated by the ripple current.

DETERMINATION OF THE CORE TEMPERATURE INCREASE ΔT_A

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

This can be done in different ways:

a.) By means of temperature measurement of surface temperature T_S

For this purpose, the surface temperature of the capacitor housing T_S and the ambient temperature T_A is first measured and converted to the core temperature increase using a coefficient K_C given for each housing diameter, as follows:

(24) $$\Delta T_A = K_C \cdot (T_S - T_A)$$

WITH

K_C: Conversion factor core temperature to surface temperature

T_S: Surface temperature (°C) of the capacitor can during operation

T_A: Ambient temperature (°C) of the capacitor

Diameter (mm)	5	6.3	8	10
K_c	1.1	1.1	1.1	1.15

Table 26: Conversion factors - core temperature to surface temperature for different can diameters

By means of the previously described method, the ΔT_A values, including small can sizes such as SMD and THT components, can be determined very well by measurement. The temperature sensor can be attached for the measurement - topside or sideways to the E-cap can.

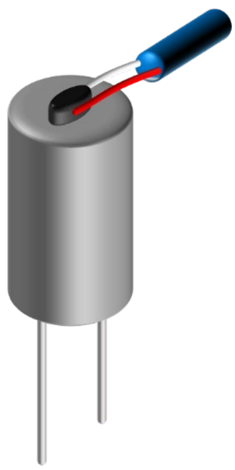


Fig. 13: Measurement of the surface temperature with a temperature sensor mounted on top

b.) By calculation based on reference conditions

In this method, ΔT_A is determined by making a comparison of heat dissipation under application conditions with heat dissipation under reference conditions. CapXon uses an airflow of <0.5m/s.

(25) $$\Delta T_A = \Delta T_0 \cdot \left(\frac{I_A}{I_R \cdot K_f \cdot K_{IR}}\right)^2$$

WITH

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

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

I_A Actual application current (A RMS)

I_R Maximum permissible rated ripple current (A RMS). **Datasheet specification**

K_f Multiplier for rated ripple current versus frequency. **Datasheet specification**

K_{IR} Multiplier for rated ripple current versus ambient temperature. **Datasheet specification**

Upper capacitor temperature T_{0_Max}	60°C	85°C	105°C	125°C	135°C
Ripple current correction factor K_{IR}	2.65	2.00	1.90	1.42	1.00
Temperature rise ΔT_0	35	20	18	10	5

Table 27: Maximum permissible core temperature rise due to the permissible rated alternating current of AN series

The permissible nominal ripple I_R refers to the maximum capacitor temperature T_{0_Max} and a frequency of 100kHz.

Frequently, the application current I_A is not frequency-equal to the nominal alternating current I_R. In these cases,

I_R must be converted to the same frequency as I_A using the ripple current correction factor K_f. For all CapXon polymer series, a table with the ripple current correction factors K_f can be found in the respective data sheet, which allows the calculation of the ratio of I_A/I_R at different frequencies.

Frequency (Hz)	120 ≤ f < 1k	1k ≤ f < 10k	10k ≤ f < 100k	100k ≤ f < 300k
Ripple current correction factor K_f	0.1	0.3	0.6	1

Table 28: Ripple current correction factor for the CapXon AN series

RULE OF THUMB FOR SIMPLE AND QUICK LIFETIME ESTIMATIONS

As rule of thumb it is possible to make a life-time consideration using Arrhenius's law. That a doubling of the lifetime is achieved with 10°C temperature reduction of the electrolytic capacitor. Due to its liquid electrolyte film, the lifetime calculation for hybrid polymer capacitors also follows the 10-degree rule

With **solid conductive polymer capacitors**, the solid electrolyte can't dry out, either by the ambient temperature or the temperature rise in the capacitor. Only the influence of materials due to the temperature in the component and the conversion of the conductivity limit the service life. The Arrhenius rule is mot applied to solid conductive polymer capacitors and lab based rule is applied. The lifetime increases **ten-times** when the temperature of the capacitor is reduced by 20°C.

Technology	CapXon Part number	V_R	C_R	Size Ø x L	ESR at 100kHz	I_{LEAK} after 2 min	I_R (RMS)	Temperature range	Endurance
Aluminum Electrolytic	GF271M016F115A	16V	270µF	8 x 11.5mm	**120mΩ**	**43µA**	**600mA**	-55 to +105°C	3000h
Hybrid Conductive Polymer	AS271M016F090P	16V	270µF	8 x 9mm	**26mΩ**	**43.2µA**	**2000mA**	-55 to +105°C	7000h
Solid Conductive Polymer	PL271M016F115P	16V	270µF	8 x 11.5mm	**9mΩ**	**864µA**	**5600mA**	-55 to +105°C	2000h

Aluminum Electrolytic

$$L_A = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}}$$

10°C reduced 2 x lifetime

Endurance calculation

3000h@105°C

95°C	6000 h
85°C	12000 h
75°C	24000 h
65°C	**48000 h**

Hybrid Polymer

$$L_A = L_0 \cdot 2^{\frac{T_{0\_Max} - T_A}{10°C}}$$

10°C reduced 2 x lifetime

Endurance calculation

7000h@105°C

95°C	14000 h
85°C	28000 h
75°C	56000 h
65°C	**112000 h**

Solid Conductive Polymer

$$L_A = L_0 \cdot 10^{\frac{T_{0\_Max} - T_A}{20°C}}$$

20°C reduced 10 x lifetime

Endurance calculation

2000h@105°C

95°C	6325 h
85°C	20000 h
75°C	63246 h
65°C	**200000 h**

Table 29: Application of Rule of Thumb and Comparison of Lifetime, ESR, I_{LEAK} and I_R

COMPONENT RELIABILITY DATA

In this section, the main parameters for predictive reliability and availability calculations are explained and in which way CapXon can provide you with such data.

FAILURE RATE λ

The failure rate λ describes the frequency which components possibly fail. The failure rate describes how many defects can be expected, if you run the application in operation for a certain time.

The failure rate can be calculated as following:

(26) $$\lambda = \frac{n}{N * t}$$

n … Number of defect components

N … Number of tested components

t … Amount of operating hours

FAILURE CRITERIA

Capacitors will show certain wear-out phenomenon's by aging and so as times goes by the capacitors can possibly change their electrical performance.

As soon as the component is no longer fulfilling their electrical spec, stated features or with customer agreed parameters, the status of capacitor is seen as in failure mode or defect. This does not necessarily mean that the application will fail. An essential influence are the design and dimensioning by customer, which lead to major impact on possible failure modes and fail criteria for the application itself.

All given data by CapXon is just concerning the failure mode cases of the single component and is not representing the complexity of complete applications, assembled systems nor full electronic PCB boards.

BATHTUB CURVE

It's a widely used model within the reliability engineering to describe the expected failure rates over the whole application lifetime / product life cycle.

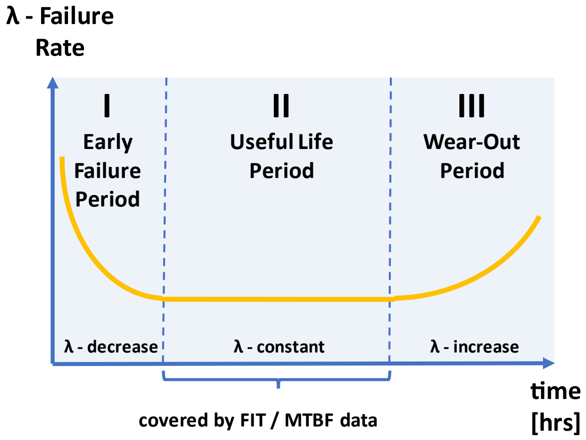


Fig. 14: Bathtub curve

The Bathtub Curve states the failure rate behaviour within the three different product life cycle stages. These are the Early Failure Period, the Useful Life Period and the Wear Out Period.

With production control, monitoring and quality assurance, it is possible to reduce the early failures to a best possible minimum.

Failures within the Useful Life Period, which are described as FIT or MTBF value, are defined as events of coincidence and are not representing any systematic or epidemic failures.

FIT – FAILURES IN TIME

FIT - Failures In Time is the common way to describe the expected failure rate for electronics.

The FIT values describe certain failure rate within the useful life period and provides the basis for calculations, assumptions and extrapolation of reliability and availability to gather the understanding for expected failures / defects. These calculated figures are used to decide whether the component is a proper choice for the desired use case. Additionally, it need to be clarified whether redundancies are necessary and which redundancies are needed to fulfil the desired mission profile of an application.

The unit FIT defines the expected amount of failures per application hour.

(27) $$1\ FIT = \frac{10^{-9}}{h} = \frac{10^{-9} failures}{per\ operating\ hour}$$

So as higher the stated FIT value is, as higher the statistical chance of defect is.

Please find the following example of a failure rate test determined by a useful life test:

- Number of failures n = 2
- Number of tested components N = 10 000
- Operating hours t = 20 000 h

(28) $$\lambda = \frac{n}{N*t} = \frac{2}{10\,000*20\,000h} = 10\ FIT$$

(29) $$10\ FIT = \frac{10^{-8}}{h} = \frac{0.001\%}{1\,000h}$$

MTBF – MEANTIME BETWEEN FAILURES

It's the predicted elapsed time between inherent failures of an electronic system during normal operation. The MTBF can be calculated as arithmetic mean / average time between failures of a system.

Assuming a constant failure rate, the MTBF can be easily calculated by reciprocal value of the Failure Rate λ**:**

(30) $$MTBF = \frac{1}{\lambda}$$

MTBF is just a different way to describe the failure rate and can be easily converted to FIT and vice versa:

(31) $$MTBF = \frac{10^9 h}{FIT} = \frac{114\,000\ years}{FIT}$$

(32) $$FIT = \frac{10^9 h}{MTBF} = \frac{114\,000\ years}{MTBF}$$

The **MTBF** values are just covering the useful life period (flat middle section) of the bathtub curve. Because of this, a FIT or MTBF value can't be extrapolated to estimate the service lifetime for a component. FIT or MTBF values doesn't cover the higher failure rates of the wear-out period, where the expected failure rate would be higher due to occurring wear-out phenomenon's.

LIFETIME TESTS

Due to the fact that all electrolytic capacitors show aging behaviour and a possible drift of electrical parameters over usage time, lifetime tests are performed by manufacturers to describe the related reliability and performance of a certain capacitor. Different product series as well as the single product itself can provide very different lifetime performance. So, these test results are given to select the proper product in relation to the applied stress profile of application to gain the desired application performance within the whole product life cycle.

There are various names (e.g. Endurance, Load Life, Useful Life, Operational Life, Life Expectancy, Shelf Life, …) and different lifetime tests that are existing within the industry. Please kindly check the specific test specification and given data for the capacitor before design-in.

Sadly, there is no standardized naming and test criteria existing, given by any international accepted standard committee for all the lifetime tests, which are applied to electrolytic capacitors. Customers need to compare competitor products carefully with each other to see if test specifications are similar or different.

Please see particular datasheets for the specific test results and criteria of an individual product of CapXon.

Again, please note that the criteria of failure are given by the test specification limits of the dedicated lifetime test and as soon as a component is not fulfilling these given limits, it is rated as a failure. So, failure does not necessarily mean defect or breakdown of application. It is just describing that the drift of electrical performance is bigger than the checked limits of the particular test. It doesn't matter whether the measured C value is lower as the allowed test limit or the component is in a failure mode of open circuit, both cases are treated the same as a failure. Design and dimensioning of application will arrange how much drift of electrical parameters can be accepted for the individual capacitor. For example, when the rate of capacitance change is becoming critical within the application is defined by customer design. The lifetime tests are in place to provide a common and industry-wide comparable performance index of the capacitors.

As manufacturer, we can state and check how fast a drift of capacitance and further parameters will happen. Dimensioning within application design will set how long an error-free operation is possible. A proper dimensioning can enlarge the acceptable drift and so the lifetime performance. But be aware, if it is not done properly or component is overstressed, it also can shorten the expected lifetime performance. Please be aware to check dimensioning and drift estimation to assure your product performance for the desired lifetime. For support with lifetime estimations and dimensioning, we are pleased to support you and feel free to get in touch with our technical support.

In the following section CapXon's lifetime tests, which are performed with our products, are described in detail.

ENDURANCE

The Endurance test of the product checks the performance of its electrical parameters, such as capacitance change, leakage current and dissipation factor on their behaviour over time at a predetermined test setup of electrical stress and ambient condition.

Depending on the product series, the Endurance test is performed according to one of the settings below:

Setting 1 - applying Endurance test:

- max. Temperature
- V_R - Rated Voltage

Setting 2 - applying Endurance test:

- max. Temperature
- V_R - Rated Voltage
- I_R - Rated Ripple

Setting 1 is in accordance to the IEC 60364-4 / JIS 51001-4 test criteria and Setting 2 is enlarging the electrical stress setup with additional appliance of IR, to get a more representative result in comparison to possible real-life application stress.

The Endurance test is performed within product qualification at the stage of internal product validation and is repeated periodically for product requalification.

USEFUL LIFE

To get more representative understanding of lifetime performance for typical capacitor use, the useful life test represents such criteria.

The applied electrical stress is like the Endurance test - Setting 2. The test specification limits are wider as the endurance test specification, but as described the applied electrical stress stays similar. So, a larger acceptable drift of electrical parameters results in a larger expected lifetime. This represents the operational frame which is set by customer at dimensioning the capacitor specification for their application and the possible borders of an error-free operation.

Also, we state a FIT value related to the useful life test. These failure rate describes the deviation / possibility of occurrence of failures within the useful life period when the settings of useful life test are applied. This is related to the middle section of the bathtub curve the so-called useful life period (see above Figure 14 - Bathtub Curve of Product Reliability).

In the datasheet you will find the following phrase:

Failure Rate (during useful Life): 0.01%/1000h with a confidence level of 60%. As a result, this is like a 100 FIT:

(33) $$\lambda = \frac{0.01\%}{1000h} = 100\ FIT$$

$$\lambda = 100\ \frac{failures}{h} * 10^{-9}$$

Example:

If you have 8000 components running in applications for 5000 hours with the test conditions applied like the useful life test, you can estimate the number of components that show a higher drift as given by the useful life test spec borders as follows:

- Number of components N = 8000
- Operating hours t = 5000 h

(34) $$\lambda = \frac{n}{N*t}$$

(35) $$n = \lambda * N * t = \frac{0.01\%}{1\,000h} * 8\,000 * 5\,000h = 4$$

This means that when there are 8000 pcs in operation for 5000 hours at the maximum possible operating conditions (max. temp., V_R & I_R similar to useful life test criteria) an amount of 4 products (with a confidence level of 60%) can be expected to show a higher drift as given in the test spec.

SHELF LIFE

The Shelf Life test simulates the aging of the capacitor, if it is just stressed with ambient temperature without any electrical load. The shelf life is not defining the possible storage time of the capacitor but just to describe the aging situation before mounting / PCB assembly.

The Shelf Life test criteria shall be satisfied, if the capacitor was restored to 20°C and following a conditioning by voltage treatment in accordance with 4.1 of JIS 5101-4 was applied, before measuring the capacitor.

LIFETIME TEST EXAMPLES

Example 1 **-** Useful Life, Endurance (Setting 1) and Shelf Life tests of SMD types – HV Series:

Lifetime Test		
Endurance 105°C (V_R applied)	Test	**2 000 hours**
	△C/C	≤ ±30% of initial measured value
	tanδ	≤ 300% of initial specified value
	I_{Leak}	≤ the initial specified value
Shelf Life 105°C (None)	Test	**1 000 hours**
	△C/C	≤ ±30% of initial measured value
	tanδ	≤ 300% of initial specified value
	I_{Leak}	≤ the initial specified value
Resistance to Soldering Heat	The capacitors shall be kept on a hot plate maintained at 250°C for 30 seconds. After removing from the hot plate and restored at room temperature, they meet the characteristic requirements listed below	
	△C/C	Within ±10% of initial value
	tanδ	Less than specified value
	I_{Leak}	Less than specified value

Example 2 - of Useful Life, Endurance (Setting 2) and Shelf Life tests of Radial types – GF Series

Lifetime Test			
Endurance 105°C (V_R & I_R applied)	Test	**2 000 hours**	ø D 5 ~ 6.3 mm
		3 000 hours	ø D 8 mm
		5 000 hours	ø D ≥ 10 mm
	△C/C	≤ ±20% of initial measured value	
	tanδ	≤ 200% of initial specified value	
	I_{Leak}	≤ the initial specified value	
Shelf Life 105°C (None)	Test	**1 000 hours**	
	△C/C	≤ ±20% of initial measured value	
	tanδ	≤ 200% of initial specified value	
	I_{Leak}	≤ the initial specified value	

Example 3 - of Useful Life, Endurance (Setting 2) and Shelf Life tests of Snap In types – HU Series:

Lifetime Test		V_R ≤ 100V	V_R > 100V
Useful Life 105°C (V_R & I_R applied)	Test	**5 000 hours**	**8 000 hours**
	△C/C	≤ ±30% of initial measured value	≤ ±20% of initial measured value
	tanδ	≤ 300% of initial specified value	≤ 200% of initial specified value
	I_{Leak}	≤ the initial specified value	≤ the initial specified value
Endurance 105°C (V_R applied)	Test	**3 000 hours**	
	△C/C	≤ ±15% of initial measured value	≤ ±10% of initial measured value
	tanδ	≤ 130% of initial specified value	≤ 130% of initial specified value
	I_{Leak}	≤ the initial specified value	≤ the initial specified value
Shelf Life 105°C (None)	Test	**1 000 hours**	
	△C/C	≤ ±15% of initial measured value	≤ ±10% of initial measured value
	tanδ	≤ 130% of initial specified value	≤ 130% of initial specified value
	I_{Leak}	≤ the initial specified value	≤ the initial specified value

Example 4 - Useful Life, Endurance (Setting 2) and Shelf Life tests of Screw types – RK Series:

Lifetime Test		
Useful Life 105°C (V_R & I_R applied)	Test	**4 000 hours**
	△C/C	≤ ±45% of initial measured value
	tanδ	≤ 300% of initial specified value
	I_{Leak}	≤ the initial specified value
Endurance 105°C (V_R applied)	Test	**2 000 hours**
	△C/C	≤ ±15% of initial measured value
	tanδ	≤ 130% of initial specified value
	I_{Leak}	≤ the initial specified value
Shelf Life 105°C (None)	Test	**1 000 hours**
	△C/C	≤ ±15% of initial measured value
	tanδ	≤ 130% of initial specified value
	I_{Leak}	≤ the initial specified value

TELCORDIA SR-332

This industry-wide accepted standard provides data and tools for reliability predictions of components, devices or full hardware units of electronic equipment. Telcordia (formerly Bellcore). With the given figures and data, it is possible to assure system availability and to gather the desired system reliability.

FIT & MTBF DATA OF CAPXON PRODUCTS

CapXon provides FIT & MTBF values based on Telcordia SR332 standard for all components. From our perspective, it provides more reliable prediction because it is more specific and detailed than MIL-217 or Siemens SN 29500.

Please find the FIT values for CapXon components and application-based reliability prediction calculations on the following page.

The table of SMD / RADIAL / Snap-In is covering all Electrolytic Technologies – Liquid, Solid and Hybrid Electrolytic Capacitors in SMD & Radial.

The table of Screw capacitors is just concerning Liquid Aluminum Electrolytic Capacitors.

Mounting Type	SMD / Radial / Snap-In					
Electrical Stress	100%		75%		50%	
Opera-ting Temp. [°C]	λ [FIT]	σ [FIT]	λ [FIT]	σ [FIT]	λ [FIT]	σ [FIT]
≤ 30	1,19	0,28	0,65	0,15	0,36	0,08
35	1,52	0,35	0,84	0,19	0,46	0,11
40	1,94	0,45	1,06	0,25	0,58	0,14
45	2,45	0,57	1,34	0,31	0,74	0,17
50	3,07	0,71	1,68	0,39	0,92	0,22
55	3,82	0,89	2,10	0,49	1,15	0,27
60	4,72	1,10	2,59	0,60	1,42	0,33
65	5,80	1,35	3,19	0,74	1,75	0,41
70	7,09	1,65	3,89	0,91	2,14	0,50
75	8,61	2,01	4,73	1,10	2,59	0,60
80	10,40	2,42	5,71	1,33	3,13	0,73
85	12,50	2,91	6,86	1,60	3,76	0,88
90	14,94	3,48	8,20	1,91	4,50	1,05
95	17,78	4,14	9,76	2,27	5,35	1,25
100	21,05	4,90	11,55	2,69	6,34	1,48
105	24,82	5,78	13,62	3,17	7,47	1,74
110	29,13	6,78	15,99	3,72	8,77	2,04
115	34,05	7,93	18,69	4,35	10,26	2,39
120	39,65	9,23	21,76	5,07	11,94	2,78
125	45,99	10,71	25,24	5,88	13,85	3,23
130	53,15	12,38	29,17	6,79	16,01	3,73
135	61,20	14,25	33,59	7,82	18,43	4,29
140	70,24	16,36	38,55	8,98	21,15	4,93
145	80,34	18,71	44,09	10,27	24,20	5,64
150	91,60	21,33	50,27	11,71	27,59	6,43

Table 30: FIT values for SMD, Radial, Snap-In

Remark: Above values are only valid within the max. specified temperature range of the particular component. All given FIT data is meant for lifetime predictions only and is not representing any warranty.

For particular products (e.g. screw capacitors) within the datasheet, further FIT or MTBF data is added and in such a case, this substitutes the general information stated above.

Mounting Type	Screw terminal					
Electrical Stress	100%		75%		50%	
Opera-ting Temp. [°C]	λ [FIT]	σ [FIT]	λ [FIT]	σ [FIT]	λ [FIT]	σ [FIT]
≤ 30	34,20	24,43	18,77	13,40	10,30	7,36
35	43,85	31,32	24,06	17,19	13,21	9,43
40	55,78	39,84	30,61	21,87	16,80	12,00
45	70,42	50,30	38,65	27,61	21,21	15,15
50	88,27	63,05	48,44	34,60	26,59	18,99
55	109,88	78,48	60,30	43,07	33,09	23,64
60	135,88	97,06	74,57	53,27	40,93	29,23
65	166,99	119,28	91,65	65,46	50,30	35,93
70	203,99	145,71	111,95	79,97	61,44	43,89
75	247,76	176,97	135,97	97,12	74,62	53,30
80	299,26	213,76	164,24	117,31	90,14	64,38
85	359,57	256,84	197,34	140,96	108,30	77,36
90	429,86	307,04	235,91	168,51	129,47	92,48
95	511,39	365,28	280,66	200,47	154,03	110,02
100	605,57	432,55	332,34	237,39	182,39	130,28
105	713,89	509,92	391,79	279,85	215,02	153,59

Table 31: FIT values for Screw types

λ - Mean Component Failure Rate

σ - Standard Deviation of Component Failure Rate

CALCULATION OF FIT VALUE FOR APPLICATION CASE

By using the given Telcordia SR-332 figures and by the assumption that the failure rate follows a gamma distribution, the FIT value can be calculated with given mean λ and standard deviation σ (see section tables 30 & 31) and desired UCL - Upper Confidence Level as follows:

$$shape\ \kappa = \left(\frac{\lambda}{\sigma}\right)^2$$

$$scale\ \theta = \frac{\sigma^2}{\lambda}$$

The desired FIT value for the application case is the P% quantile of the gamma distribution and it can be calculated by the inverse cumulative gamma distribution with the shape κ and scale θ parameters as follows:

$$\lambda_{P\%UCL} = G^{-1}(90/100; \kappa; \theta)$$

If the shape κ parameter is >100 the FIT can also be calculated by using the P% quantile of the normal distribution, by inverse cumulative distribution of normal distribution with mean λ and standard deviation σ:

$$\lambda_{P\%UCL} = N^{-1}(P/100;\ \lambda; \sigma\ )$$

Customer need to define which UCL is desired for the reliability prediction for their application case (typical values for UCL are e.g. 60%,90%, 95%, 99%).

CALCULATION EXAMPLE

Example 1:
GF Series – Radial type
Aluminum Electrolytic Capacitor

@ 70°C and 75% electrical stress
Upper Confidence Level (UCL) = 90%

Values according to table 30:
λ= 3.89 FIT / σ= 0.91 FIT

$$shape\ \kappa = \left(\frac{3.89}{0.91}\right)^2 = 18.27$$

$$scale\ \theta = \frac{0.91^2}{3.89} = 0.21$$

$$\lambda_{90\%UCL} = G^{-1}\left(\frac{90}{100}; 18.27; 0.21\right)$$

$$\lambda_{90\%UCL} = 5.02\ FIT$$

In Microsoft Excel you can solve this with the following formula:

International / American Excel Version:
=GAMMAINV(0.9,18.27,0.21)

European Excel Version:
=GAMMAINV(0,9;18,27;0.21)

Example 2:
RG Series - Screw type
Aluminum Electrolytic Capacitor

@ 60°C and 75% electrical stress
Upper Confidence Level (UCL) = 90%

Values according to table 31:
λ= 74.57 FIT / σ= 53,27 FIT

$$shape\ \kappa = \left(\frac{74.57}{53.27}\right)^2 = 2.01$$

$$scale\ \theta = \frac{0.91^2}{3.89} = 38.05\ FIT$$

$$\lambda_{90\%UCL} = G^{-1}\left(\frac{90}{100}; 2.01; 38.05\right)$$
$$\lambda_{90\%UCL} = 148.57 FIT$$

In Microsoft Excel you can solve this with the following formula:

International / American Excel Version:
=GAMMAINV(0.9,2.01,38.05)

European Excel Version:
=GAMMAINV(0,9;2,01;38,05)

IATF 16949

AEC-Q200

ISO 9001

ISO 14001

QC 080000

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