

# Aluminium Electrolytic Capacitors Designed for Long Operational Life [125°C rating]

**Leif Eliasson**

KEMET Electronics AB

Skiftesvägen 16, 563 31 Gränna Sweden

E-mail: [LeifEliasson@kemet.com](mailto:LeifEliasson@kemet.com)

## Introduction

The service life for high quality power supplies [e.g. LED Road lighting] and automotive power electronics is often limited by electrolytic capacitors' operational life ( $L_{OP}$ ). Very long life (> 20 years at temperature up to 75°C) is possible to be achieved by choosing capacitors with optimized design. Type of electrolyte, capacitor lid design, sealing method and rubber material quality, are important factors which determine the  $L_{OP}$ .

The contents of this Paper are

- Definition of End of Life for an Al-electrolytic capacitor. End-of-Life (EOL) criteria
- Parameter drift during Operational life ( $L_{OP}$ )  
Examples of measured parametric drift, for different type of electrolytic capacitors.
- Important capacitor's construction parameters with impact on the capacitor's operational life.
  - Type of electrolyte
  - Diffusion of electrolyte
    - Used rubber sealing material
- Conclusions and recommendations

## 1. Definition of End-Of-Life (EOL) for Al-electrolytic capacitors

Normally the EOL criteria are based on parametric drift. Capacitance, dissipation factor, ESR and leakage current are parameters used in defining EOL.

### Example of EOL criteria:

1. Capacitance change ( $\Delta C$ ) larger than  $xx\%$ , in relation to the initial capacitance value ( $C_{init}$ ):  
 $|\Delta C| \div C_{init} > xx\%$ .  
 $xx\%$  is normally given in the range of 10-30%
2. Measured dissipation factor ( $\text{Tan}\delta$ ) larger than  $y.y$  \* (specified dissipation factor):  
 $\text{Tan}\delta \div \text{Tan}\delta_{(\text{specified})} > y.y$   
 $y.y$  is normally given in the range of 1.3 to 3.0  
\*(Normally  $\text{Tan}\delta$  is defined at 100 or 120 Hz).
3. Increased ESR value, ESR larger than  $z$  \* Initial ESR:  
 $\text{ESR} \div \text{ESR}_{init} > z$   
 $z$  is normally given as a factor 2 or 3  
(Normaly ESR is defined at 100 kHz)
4. Leakage current ( $I_L$ ) higher than specified initial value ( $I_{RL}$ ):  
 $I_L \div I_{RL} > 1$   
The  $I_{RL}$  specification differs wildly between manufactures.

For some manufactures, the EOL criteria for ESR may be referred to specified ESR values, and not based on a changing ESR, as in the example above.

**Comments:** When designing-in an electrolytic capacitor it's very important to have a detailed understanding, and detailed information, regarding specified operational life and the EOL criteria.

- Are the electrical parameters at EOL in line with the requirements needed for the application?

## 2. Parametric drift during Operational Life (Lop)

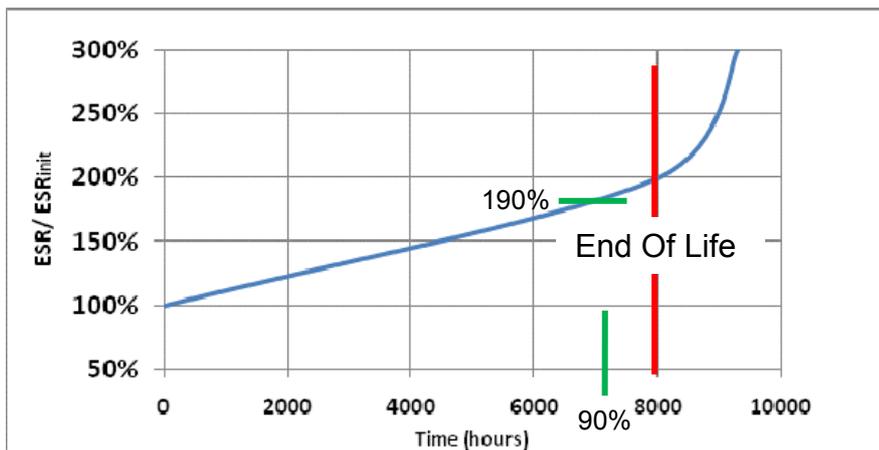
The **ESR** drift during operational life (Lop) is a result of the basic capacitor design. The used electrolyte type has a significant impact on the ESR drift. Also other capacitor materials, like anode foil, capacitor tissue etc. influence the ESR drift.

Electrolytic capacitors often have an almost linear increase of ESR vs. time in operation. They can also be designed to have more stable electrical parameters.

### Example:

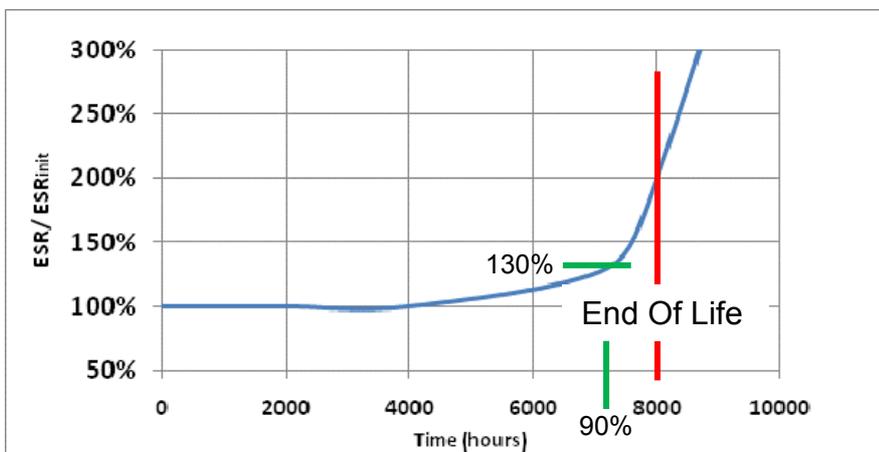
#### Linear parametric drift during operational life:

ESR/ ESR<sub>init</sub>



#### Stable ESR during main fraction of Operational Life (Lop):

ESR/ ESR<sub>init</sub>



When using capacitors with stable ESR, it's not necessary to make the design-in based on the EOL- criteria. With a capacitor characteristic as described in the diagram above, it's suitable to base the design on 130% of specified max initial ESR value. This is a correct base for the design-in, as long as 90% of the specified capacitor's operational life (Lop) is equal or longer than the life requirement for application.

**Dissipation factor (Tanδ)** is normally behaving in a similar way as the ESR. A capacitor with stable ESR normally also have a principally stable Tanδ.

**The capacitance value change** over operational life is normally described by an almost linear function. Capacitance at end of life should therefore be considered in application design (What minimum capacitance is needed for the application?).

**Leakage current** during operational life is normally significantly lower than specified value.

### 3. Parametric drift of PEG124-series of axial electrolytic capacitors (125°C – rating)

The PEG124-series has very stable electrical parameters over operational life (Lop). During the first 90% of the operational life (Lop) the ESR and  $\tan\delta$  are typically stable, or the change is in the range of max  $\pm 30\%$ . In the test result below the ESR and  $\tan\delta$  are showing decreasing values when compared with initial ones during the test period of 7000 hours.

#### Evaluation of electrical parameters.

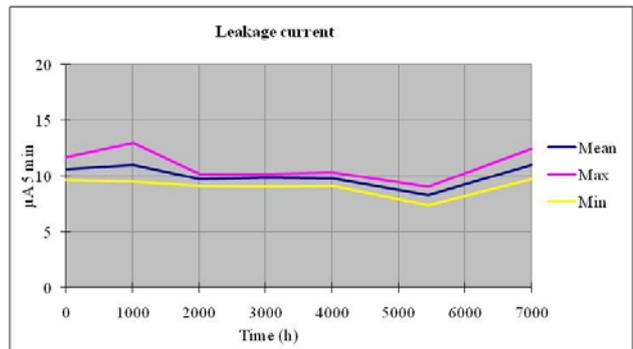
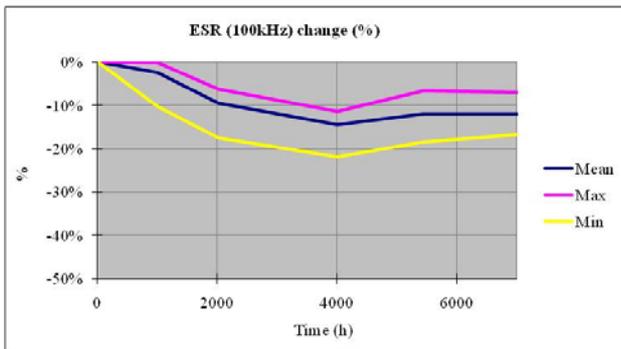
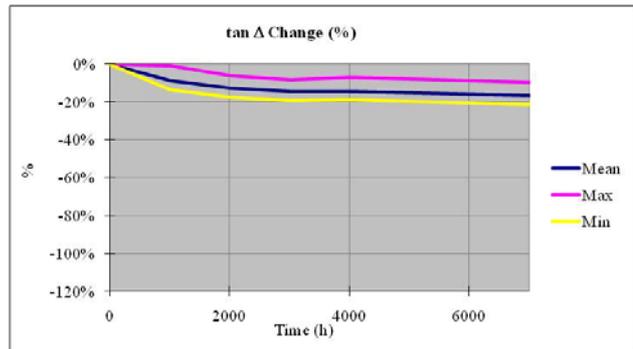
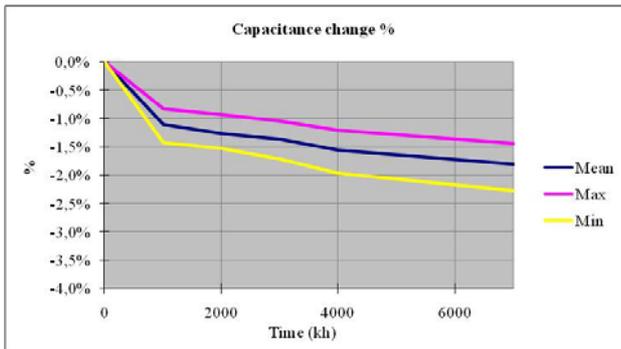
PEG124KL427FQ (2700 $\mu$ F, 40V, D20x46 mm)

**Endurance test, 7000 hours, 40VDC, 125° C, 30 capacitors.**



Initial measured values:

Cap (100Hz) ( $\mu$ F)			$\tan \delta$ (100Hz) (%)			ESR (100Hz) m $\Omega$			ESR (100kHz) m $\Omega$			IL (5 min) $\mu$ A		
Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
2727	2805	2683	4,2	4,4	3,8	24,5	26,0	22,5	10,6	11,6	10,4	10,6	11,7	9,6



#### Comments:

- The diagrams above describe a typical parametric behaviour of the PEG124(125°C)- series.
- The capacitance drop is in this case max 2.7% after 7000 hours at 40V, 125°C.
- $\tan\delta$  and ESR are lower than initial values during the whole test period.

After 7000 hours, all electrical parameters are well within the specification for new capacitors. It's not necessary to make a design-in based on the EOL criteria for the ESR (or  $\tan\delta$ ). Our recommendation is to base the design on 130% of specified max initial ESR value (please see also page 2).

The test results allow us to define the end of life criteria (PEG124):

$$|\Delta C| / C_{init} > 15\%$$

$$\tan\delta / \tan\delta_{(specified)} > 1.3$$

$$ESR / ESR_{init} > 2.0$$

$$I_L / I_{RL} > 1$$

#### 4. Parametric drift, single ended capacitor (from a popular high end supplier), 2200µF, 35V, D18x35,5 mm

The specified operational life at 125°C is 10 k hours.

##### Evaluation of electrical parameters.

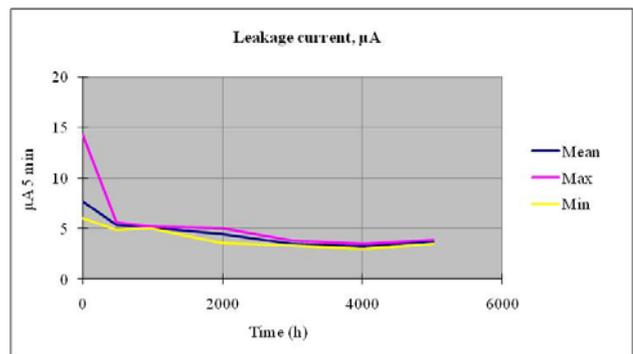
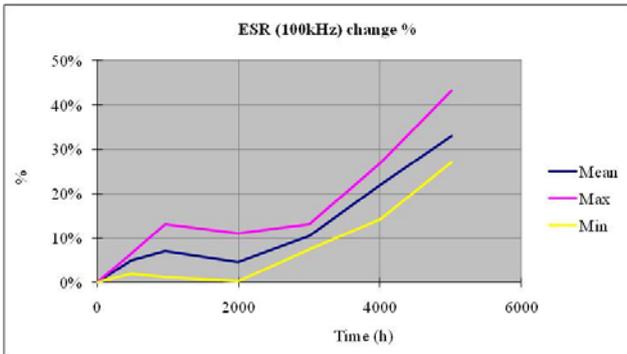
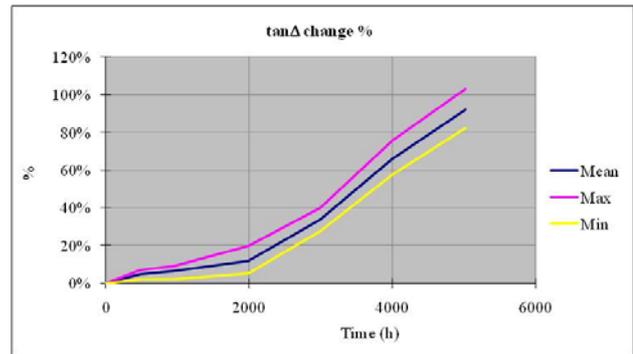
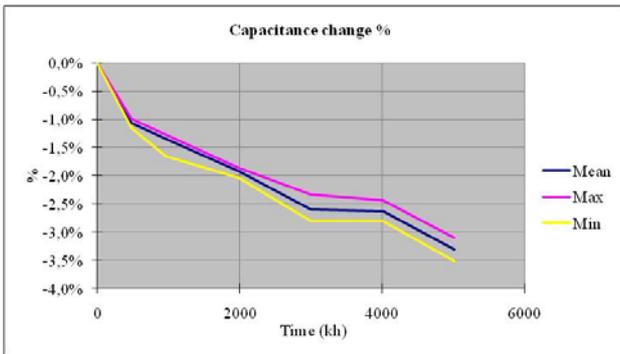
Single ended (2200µF, 35V, D18x35,5 mm)

Endurance test, 5000 hours, 35 VDC, 125° C, 30 capacitors.



Initial measured values:

Cap (µF)			tan δ (%)			ESR (100Hz) mΩ			ESR (100kHz) mΩ			IL (5 min) µA		
Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
1949	1956	1942	3,9	4,1	3,8	32,2	33,7	31,5	22,6	23,0	22,1	7,6	14,2	6,0



##### Comments:

- The diagrams above describe typical parametric behaviour of a capacitor with in principle a linear increase of Tanδ and ESR.
- The capacitance drop is in this case max 3.5% after 5000 hours at 35V, 125°C.
- Tanδ is approximately double the initial value.

The given Lop specification, (10 k-hours) will probably be fulfilled (see end of life criteria below), but it is very important to be aware of the parametric drift. It's important to consider the end of life (EOL) criteria's already at design in.

Defined end of life (EOL) criteria given by the manufacturer for the tested single ended capacitor:

$$|\Delta C| / C_{init} > 30\%$$

$$\text{Tan}\delta / \text{Tan}\delta_{(\text{specified})} > 3.0$$

$$\text{ESR} / \text{ESR}_{init} \text{ not specefied}$$

$$I_L / I_{RL} > 1$$

## 5. Important capacitor construction parameters with impact on the capacitor' operational life

- Type of electrolyte
  - Ethylene Glycol (EG) or Gamma-butyrolactone (GBL)-based electrolyte.
  - Thermal stability of the used substances
- Gasket/ lid, electrolyte diffusion (function of temp.)
- Amount of electrolyte
- ESR-value
- Thermal parameters for the Capacitor

### Type of electrolyte

Gamma-butyrolactone based electrolytes are in general resulting in a higher grade of temperature stability. The parameter change vs. time, for capacitors using GBL-based electrolytes, is in general lower compared with capacitors using EG-based electrolytes. Also the used acid/ base combination and chemical additives have a significant influence on the capacitor performance and parametric stability. Capacitors rated at 125°C or at higher temperatures, are normally using GBL-based electrolytes.

### Gasket/ lid, electrolyte diffusion (function of temp.)

For Axial and Single-ended type capacitors, using GBL electrolyte, the End-Of-Life (EOL) normally occur as a result of dried out capacitor windings. The Gasket/ lid design have a significant impact on the capacitor's operational life. It's crucial to optimize and limit the electrolyte solvent diffusion to a low level. On the other hand, the diffusion can't be reduced too much. Generated gases (e.g., H<sub>2</sub>) are creating an internal pressure in capacitor housing. Too low diffusion could create parametric drift or even catastrophic failure (due to the generated gas pressure).

### Amount of electrolyte

Single ended and axial capacitors are quite often produced with a minimum amount of electrolyte. This is often limiting the capacitor's operational life. GBL-based capacitor designs achieve an extended operational life, when the capacitor is produced with an additional amount of electrolyte (in addition to the electrolyte impregnated into the winding material). All KEMET axial capacitors are produced with additional electrolyte.

### ESR-value

When a capacitor is operating with a significant level of ripple current, the heat dissipation and the temperature raise is proportional to the capacitor's ESR (at the specific temperature and frequency). An increased temperature of 10-12 °C will reduce the operational life up to 50%.

### Thermal parameters for the Capacitor

The thermal resistance (from capacitor winding to ambient air) has a significant impact on the capacitor's temperature. For conventional mounted capacitors (cooled by natural convection), the capacitor's internal thermal resistance has only a minor impact on the temperature raise. The main factor is the external thermal resistance. It's important that the capacitor is mounted with enough space, not limiting the natural convection by blocking the convection flow. The temperature rise is significantly reduced if the capacitor is mounted on a heat-sink connected to metallic chassis. KEMET series PEG220, PEG225 and PEG226 (axial electrolytic capacitors) are optimised for mounting with heat-sink. When the external cooling is properly managed, the low internal thermal resistance allows removal of the internally generated heat effectively. This increases the ripple current handling capability of the capacitor significantly. The given KEMET series are designed with uniquely low internal thermal resistance.

## 6. PEG124 (125°C) – unique design

The unique PEG124- design secures low electrolyte diffusion. The electrolyte is GBL-based and extremely temperature resistant (identical electrolyte is also used for 150°C rated capacitors).

The unique design results in extremely stable electrical parameters (see pages 2-3)

During the first 90% of operational life (Lop) the Tanδ and ESR change is in the range of max ±30%.



Axial design allows the use of aluminium lid which will not delaminate. The Al-lid is also an efficient diffusion barrier. Specially designed gasket minimizes electrolyte diffusion.

Operational life, PEG124  
Calculated with EOL criteria  
given in section 3 above :

$$L_{op} = A * 2^{((85-T_h) / 11)}$$

D20 mm: A= 97 kh  
D16 mm: A= 64 kh

$$P_{loss} = I_{AC}^2 * ESR$$
$$\Delta T = P_{loss} * R_{th}$$
$$T_h = T_a + \Delta T$$

### *Lop example, PEG 124, D20mm case sizes.*

The operational life specification (Lop) is 8 k-hours at 125°C (capacitor temperature), or 97 k-hours (11 years) at 85°C.

Twenty (20) years operational life is achieved up to 75°C temperature (capacitor temperature).

## 7. Conclusion and recommendations

In applications designed for long service life (e.g., LED Road light applications), it's crucial to design in electrolytic capacitors meeting the application's life requirement. In addition to the information of specified capacitor's operational life (Lop), it's also necessary to have detailed information related to the End-of-Life criteria for the designed in capacitors. **The Given End-of Life criteria by various manufacturers may differ substantially and the given Lop always depends on these.** The Lop, which is defined with tight EOL criteria, can be increased, if wider EOL criteria can be applied.

Operational life of up to 20 years is possible to achieve at ambient air temperature of up to 75°C. KEMET's PEG124(125°C)-series is optimized for extremely long operational life, and has very stable electrical parameters.