

# Life-Limiting Factors in Electrolytic Capacitors (and how to improve them)



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Evox Rifa Passive Components

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## **Electrolytic Capacitors are a Critical Element in Power Electronics Designs**

Different applications in power electronics have different requirements when it comes to selecting electrolytic capacitors. However the one requirement in common in most of these applications is the need for high ripple current capacity. This need is often combined with elevated ambient temperatures. Electrolytic capacitors used for smoothing, energy storage or filtering of a rectified AC voltage will be loaded with an AC ripple current causing a power loss and heating of the capacitor. Since the life of a given electrolytic capacitor is determined by its internal temperature, attention will be given to these issues.

An electrolytic capacitor is one of the most expensive components in a power electronics circuit. For this reason special attention is often paid to the end of life of this component, especially when dealing with capacitor banks that include a number of those capacitors. In most cases the electrolytic capacitor is the life-limiting device. Therefore it is important to understand the factors that can contribute to the capacitor's end the life so that the anticipated lifetime meets the overall reliability requirements.

Several factors can cause electrolytic capacitors to fail, such as severe cold temperatures, heat (soldering, ambient, AC-ripple), high voltages, transients, extreme frequencies or reverse bias. However the most influential factor on the operational life ( $L_{op}$ ) of electrolytic capacitors is heat. Apart from abnormal failures, the life of electrolytic capacitors has an exponential temperature dependency. With non-solid electrolytic solutions the life of the capacitor is determined by how fast the electrolyte solution evaporates, causing degradation in the electrical parameters. Those parameters are the capacitance, leakage current and the equivalent series resistance, ESR.

The temperature rise in the capacitor depends on the ESR and the RMS value of the current flowing through it, in combination with the thermal properties of the device. At some spot inside the capacitor the highest temperature will be found. This is known as the Hot Spot temperature,  $T_h$ . The value of the hot spot temperature is the major factor influencing the operational life of the capacitor. The hot spot temperature is dependent on several factors. Those factors are the outside temperature in the application (the ambient temperature,  $T_a$ )  $R_{th}$ , the thermal resistance from hot spot to ambient, and the power loss,  $P_{LOSS}$ , caused by the AC current. The temperature rise inside the capacitor is linear with the power loss.

When the capacitor is charged and discharged the current flowing through it causes losses in the ohmic resistance. The change in voltage across the dielectric causes losses as well. Add to that the losses caused by the leakage current. These losses result in a temperature rise inside the capacitor.

With that in mind, we can look at how the operational life can be calculated.

$$P_{\text{LOSS}} = (I_{\text{RMS}})^2 \times \text{ESR}$$

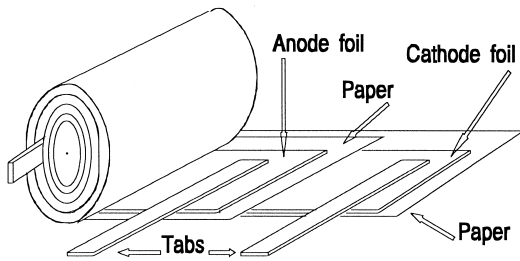
$$T_{\text{h}} = T_{\text{a}} + P_{\text{LOSS}} \times R_{\text{th}}$$

$$L_{\text{OP}} = A \times 2^{(B - T_{\text{h}} / C)} \text{ Hours}$$

B = Reference temperature (typically 85 deg. C.)

A = Life at reference temperature (varies by capacitor diameter.)

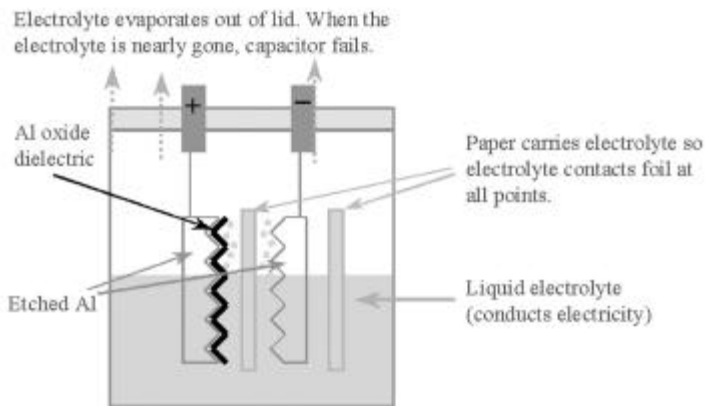
C = Number of degrees temperature rise needed to reduce the life by half.  
(Typically 12 deg. C for screw terminal type capacitors)



In the non-solid electrolytic capacitor, the dielectric is the oxide layer of the anodic foil. The electrolyte acts as the electric contact between the cathode foil and the oxide layer of the anode foil. Paper layers absorbing the electrolyte acts as a spacer between the cathode and anode foils. The foils are connected to the capacitor terminals by aluminum tabs.

The conduction capability depends on the electrolyte dissociation and viscosity. When the temperature is lowered, the viscosity is increased and thus causing lower ion mobility and lower conductance. When the electrolyte freezes, ion mobility becomes very low leading to very high resistance. On the contrary, excessive heating will accelerate the evaporation of the electrolyte. When the amount of electrolyte is reduced to a critical amount the end of life of the capacitor is reached.

What are the main factors that directly and indirectly contribute to improved life? That's what Evox Rifa answers with their uniquely designed electrolytic capacitors.



The screw-terminal, non-solid electrolytic capacitors offered by Evox Rifa are designed specifically to provide long life in power electronics applications where they are often exposed to very high ripple currents at elevated ambient temperatures.

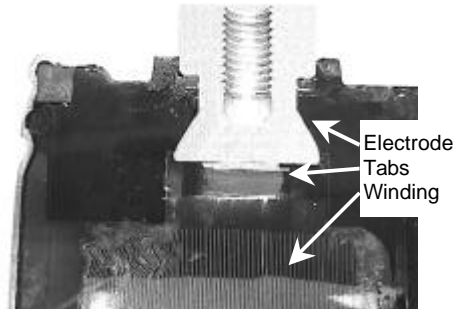
Evox Rifa electrolytic capacitors are designed for operation under severe climatic conditions and for heavy ripple current load. This requires low internal losses and an efficient heat transfer between the capacitor "Hot Spot" and the ambient.

The long life of Evox Rifa electrolytic capacitors is achieved in three ways:

- **Internal heating due to the flow of ripple current in the capacitor is reduced by lowering the ESR. This is accomplished by the use of multiple, laser-welded electrode tabs.**

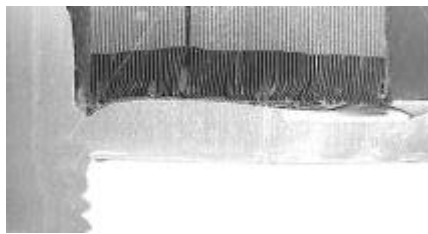
The temperature rise in the capacitor depends on the ESR and the ripple current. ESR is frequency dependent, adding complexity to the power loss calculations. Typically the ESR is lower at higher frequencies though the Evox Rifa design offers a flatter ESR characteristic, resulting in better performance at lower AC frequencies.

One of the main contributors to excessive ESR is the connection between the outer electrodes and the winding, usually made with one or more metal tabs. The more tabs added to the winding, the lower the ESR. However the number of tabs one can add without reducing reliability depends on the process used to connect the tabs to the terminals. With special laser welding that Evox Rifa developed, more tabs can be added and hence lower ESR can be achieved. This means more ripple current capability and less internal heating which means longer life.



This also contributes to a higher shock and vibration resistance, without which one may experience internal short circuits, high leakage currents, capacitance losses, increased ESR and open circuits.

- **The internal heat is efficiently dissipated out the bottom of the can to the equipment chassis via a good mechanical connection between the capacitor winding and the can, and by means of an internal heatsink running through the middle of the winding.**

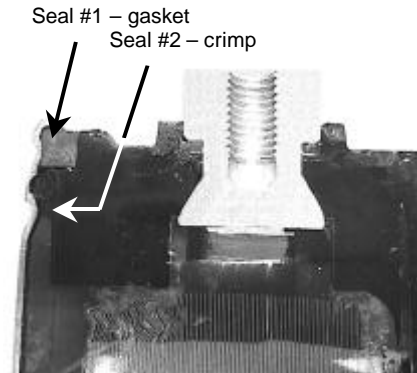


The internal thermal design is of great importance for the reliability and operational life of the capacitor. In the Evox Rifa design the negative foil is extended to make direct contact with the thick base of the capacitor aluminum can. The base then becomes a heat sink to the winding through which heat is

dissipated away from the hot spot. With the “Stud” mounting option, securely mounting the capacitor into a plate (usually aluminum) provides a better overall thermal solution with a lower total thermal resistance,  $R_{th}$ .

- **Electrolyte loss is greatly reduced through the use of a solid phenolic lid with insert-molded terminals, joined to the can with a double-seal employing a special rubber gasket.**

The operational life of long life electrolytic capacitors is dependent on the evaporation of the electrolyte through the seal. As the electrolyte evaporates out of the capacitor over time the capacitor will eventually fail. (This is accelerated by heat.) The Evox Rifa design provides a double sealing system which slows down the evaporation rate, keeping the electrolyte inside the capacitor for the longest possible life.



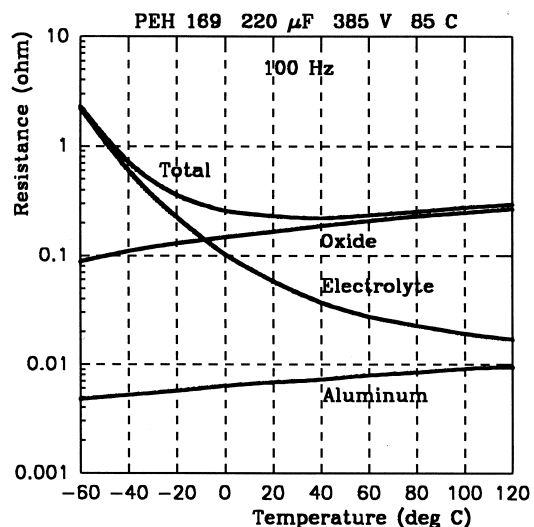
The combination of these features allows for very long life in demanding applications. It is also so that through a good understanding of the application, the design of the capacitors can be optimized to provide the desired combination of ESR, life, size and cost.

### Evox Rifa defines capacitor end of life

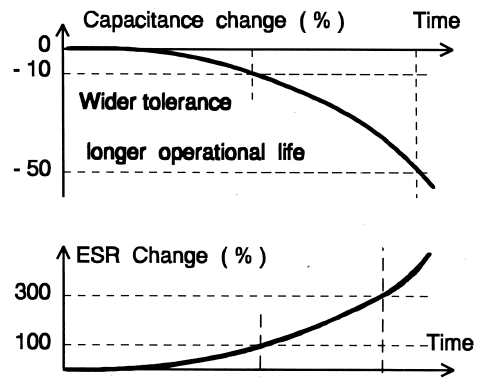
As was discussed earlier, heat is of paramount concern. The hotter the capacitor, the faster the end of life is reached. With an increase in temperature the change in capacitance, electrolyte conductivity, aluminum resistivity, leakage current, chemical instability and corrosion processes increase.

As the capacitor ages, capacitance decreases and ESR increases. Lifetime is defined by the application. In some circuits only small changes in capacitance and ESR are tolerable, which means the capacitor will cause a failure in a shorter time than if the application were more tolerant.

ESR consists of three components. Those are the resistance in the aluminum tabs and foil which increases with temperature, resistance of the electrolyte (oxide layer) that strongly decreases with temperature and the dielectric resistance that decreases with frequency. The last is negligible above 1.5 KHz.



End of life of the capacitor is defined when one or more of the capacitor parameters have changed by a given amount. Those parameters are capacitance (C), ESR, dissipation factor (DF), and leakage current ( $I_L$ ). Different manufacturers define those limits differently depending on their capacitor capabilities. Evox Rifa defines end of life of their electrolytic capacitors when,



$$\Delta C = \begin{cases} 15\% & \text{for } V_r \leq 160 \text{ VDC (} V_r = \text{Rated Voltage).} \\ 10\% & \text{for } V_r > 160 \text{ VDC.} \end{cases}$$

ESR  $\geq$  2 times the initial value.

DF (tan $\delta$ )  $\geq$  1.3 times the rated value.

$I_L \geq$  the rated value.

### Reducing cost

Although specific requirements vary it is usually taken for granted that to handle higher ripple current higher capacitance is needed. This is true to an extent, but varying capacitor technologies among suppliers often affects the capacitance actually needed to achieve a given ripple current and operational life. A higher capacitance may be required from one supplier compared to another depending on the capacitor design.

The design, materials and fabrication processes determine the life time and the reliability of the capacitor. With a good capacitor design this makes it possible to meet the application ripple current requirements with less capacitance than expected, especially in circuits where one can do with less capacitance if it were not for the ripple current load. In other words, the circuit may perform well with a certain C-value except that the high ripple current would cause the operational life to be too low. In this case one must choose an “over-designed” capacitor just to survive the current. With a well-design electrolytic capacitor the need for over-designing is reduced, resulting in potentially considerable cost savings.

For further information contact Evox Rifa.

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