Determining end-of-life, ESR, and lifetime calculations for electrolytic capacitors at higher temperatures

Gregory Mirsky - August 20, 2008

This article shows how the Arrhenius equation is the basis for developing useful characteristics for electrolytic capacitors for temperatures greater than 20°C. For determining ESR at temperatures below 20°C, see the author's article, "ESR calculations for electrolytic capacitors at lower temperatures."

1. Temperature range of $T \geq 20^\circ C$

An electrolytic capacitor's ESR (equivalent series resistance) contains a frequency-dependent dielectric loss $R_{ox}$ due to the dissipation factor $D_{ox}$ of aluminum oxide and a temperature-dependent loss $R_{sp}$ due to the electrolyte-impregnated paper and the liquid electrolyte in the etched pits or tunnels of the foil.

$$ESR = R_{ox} + R_{sp}$$

Where $R_{ox}(f) = \frac{D_{ox}}{2 \times \pi \times f \times C}$

$D_{ox}$ has a typical value of 0.015

$$R_{sp}(T) = R_{sp}(25^\circ C) \times 2^{\left[-\frac{(T - 25)}{A}\right]^B}$$

The possible temperature range is limited by $25^\circ C = &100^\circ C$ but extrapolation to $125^\circ C$ seems to be acceptable.

Coefficients $A$ and $B$ depend on the electrolyte type, and for a typical electrolyte-spacer, ethylene-glycol-based system the values are:

$A = 40$ and $B = 0.6$.

Hence, it is possible to determine the ESR at any temperature within the range of $25^\circ C$ to $125^\circ C$. The $R_{sp}$ value at normal temperature is usually provided by a capacitor manufacturer.

Although ESR goes down with temperature increase, the ripple current may produce excessive heat even at elevated temperatures, adding up to the high environmental temperature. The temperature increase $\Delta T$ due to the ripple current $I_{rip}$ can be calculated from

$$\Delta T = (I_{rip})^2 \times \tan\delta/(\beta \times \omega \times A \times C)$$
Where $A$ is the surface area of the can case, $m^2$

$$A = \frac{\pi}{4} \times D \times (D + 4L),$$

where: $D =$ can diameter, $L =$ can length, all in m

$C$ is the capacitance value, $F$

$\omega$ is the cyclic frequency, $s^{-1}$

$\beta$ is the heat transfer constant, which the manufacturer should know, $W/(K \times m^2)$

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$\beta$ may have value between 7 and 13 $W/(K \times m^2)$ and has a slight negative temperature coefficient. Therefore, one can determine the ESR at any temperature within the 25°C to 125°C range.

2. Lifetime calculation at $T \geq 20°C$

In datasheets for its aluminum electrolytic capacitors, Hitachi AIC Inc. recommends determining the capacitor lifetime $L$ using the Arrhenius formula as

$$L = L_0 \times 2^{(T_m - T)/10} \times (V_m/V)^{2.5}$$

where $L_0$ is the manufacturer-rated endurance at maximum temperature $T_m$, hours

$T$ is the operating temperature of the capacitor, $C$

$V_m$ is the maximum manufacturer-rated capacitor voltage, $V$

$V$ is the operating voltage, $V$

For example: a device has a time-versus-temperature profile as follows:

2000 hrs between -40°C and +68°C
2560 hrs between +68°C and +81°C
15380 hrs between +81°C and +107°C
600 hrs between +107°C and +125°C

It is necessary to determine the endurance period for an electrolytic capacitor below.

For the middle of the "hottest" range the Nichicon BT series 470 μF, 80V electrolytic capacitor will have an endurance period of:

$$L_{110} = 5000 \times 2^{(125 - 110)/10} \times (80/55)^{2.5} = 36,085 \text{ hrs.}$$

And the capacitor will use up "only" 600 hrs.

For the longest third range:

$$L_{107} = 102,065 \text{ hrs. That is, the endurance percentage is } 15,380/102,065 = 15\%. $$
For the second range:

\[ L_{41} = 263,026 \text{ hrs, and the endurance percentage is: } \frac{2560}{263,026} = 0.97\% \]

For the maximum temperature:

\[ L_{125} = 5000 \times 2.55 = 12,758 \text{ hrs. That is, the endurance percentage is } \frac{600}{12,758} = 4.7\%. \]

For the lowest temperature:

\[ L_{68} = 645,654 \text{ hrs. That is, the endurance percentage is } \frac{2000}{645,654} = 0.31\%. \]

In order to simplify the formula handling it is reasonable to use a logarithmic scale, and after a series of manipulations obtain

\[ \log L = \log L_0 + 0.03 (T_m - T) + 2.5 \log (V_m/V) \]

where \( \log \) is a decimal logarithm.

In order to adapt this formula to different capacitors operating at different voltages, one can plot graphs similar to those provided by Nichicon, which depict capacitors' lifetime dependence on temperature as a series of straight lines having spacing corresponding to the operating voltage and lifetime at maximum temperature and rated voltage.

**Reference**


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