ESR calculations for electrolytic capacitors at lower temperatures

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Electrolytic capacitors are widely used in automotive electronics. The devices are exposed to a wide temperature range from −40°C to +125°C. Electrolytic capacitors' properties at “hot” temperatures are well-explored thanks to the Arrhenius Law (see related article, "Determining end-of-life, ESR, and lifetime calculations for electrolytic capacitors at higher temperatures").

At the same time the "cold" range has almost no theoretical background, although the ESR (equivalent series resistance) value of electrolytic capacitors at low temperatures is of great importance. This article suggests an empirically-derived formula and offers an online calculator for determining electrolytic capacitor ESR at the lower end of the temperature range.

The Arrhenius equation does not return optimal results between +40°C and +20°C, and does not work at all at below +20°C, which makes the formula inapplicable for low temperatures. This is why there are almost no theoretical publications covering this low temperature range. Multiple results are obtained empirically. A reliable formula can facilitate the design endeavors of many engineers.

Tedious exploration of manufacturer datasheets and other materials allowed the author's design team to derive a semi-empirical formula that describes the dissipation factor tanδ behavior at temperatures within the temperature range of +20°C to −40°C and below. The tanδ is linearly tied with the ESR, and therefore the resulting formula is applicable to the ESR, too. This formula was verified on a few tanδ plots obtained from the Nichicon dissipation factor versus temperature tests, which were done for capacitors of various capacitances and rated voltage values.

The formula is:

\[
\tan\delta = \tan\delta_0 \times 1.025^{2(T_0-T)/10}
\]

where \(\tan\delta_0\) is the dissipation loss at +20°C, provided by the manufacturer.

\(T_0 = +20^\circ\text{C},\)

\(T = \text{operational temperature of the capacitor}.\)

This formula allows determining the ESR at low temperatures and therefore the strength capability of electrolytic capacitors:

As the \(\text{ESR} = (\omega \times C)^{-1} \times \tan\delta\)

and capacitance does not change significantly with the temperature change, one can deduce that the
ESR changes at the same rate with respect to temperature as the dissipation factor tanδ does. Therefore the following formula holds true:

$$ESR = ESR_0 \times 1.025^{2(T_0-T)/10}$$

where $ESR_0$ is the ESR at $+20°C$ and $ESR$ is the ESR at temperature lower than $+20°C$

For example, a 330 μF 63V Nichicon capacitor BT series has $ESR_0 = 0.068\Omega$. What would its value be at $−40°C$?

$$ESR_{−40} = 0.068 \times 1.025^{2(20−(−40))/10} = 0.068 \times 4.856 = 0.33\Omega$$, which is close to the value obtained from the manufacturer's plot.

The following javascript-based calculator executes these equations:

**Low-Temp ESR calculator**