ESR Modeling for TDK Capacitors

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Abstract

This paper explains the fundamental theory and explanation of how to derive ESR for TDK Mulitilayer Ceramic Capacitors.

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Introduction: In this highly competitive market, most design engineers are given less time to develop, prototype, and test new designs and updates. Computer simulation is becoming a more critical stage in the design process. As a result, the need for a more accurate real world model is needed for components including MLCCs.

TDK has developed an Equivalent Circuit Model Library (ECML) to assist designers in using TDK capacitors in their simulations and prototype builds. The ECML includes SRF, ESL, & ESR among other critical parameters that the design engineer may need.

TDK's equivalent circuit model for a MLCC (Fig. 01) considers the parasitic inductance and parasitic resistance. This paper explains how the Re portion of the model is derived.
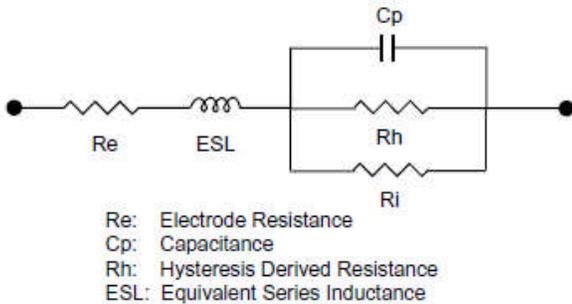

Re: Electrode Resistance
Cp: Capacitance
Rh: Hysteresis Derived Resistance
ESL: Equivalent Series Inductance

Fig. 01: TDK Equivalent Circuit Model of MLCC

Components of ESR

The ESR of a MLCC consists of two parts. The first part is pure *electrical resistance*, Re, which is due to the terminal and inner electrodes (Fig. 02). The second part comes from *dielectric loss* of the ferro-electric ceramic material.
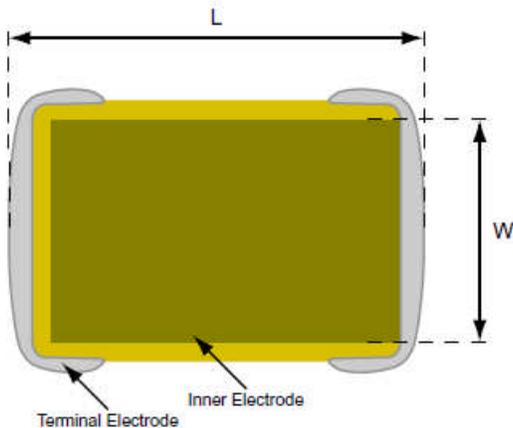

Fig. 02: Top view cross section: Terminal and inner electrode

Re and ESR need to be considered independently. Re is very low for MLCCs and therefore very difficult to measure, especially for high capacitance parts. By measuring the resistivity of the internal electrode, which is relatively high, Re can be obtained for any TDK MLCC. The following details TDK's analysis method.

Re Calculation

Since Re is the electrical resistance of the electrodes, it is also a function of the geometry of the MLCC and the electrode material. Re can be represented by the following:

$$Re = \rho \frac{L}{W\,t\,n} \qquad \text{(Eq. 01)}$$

where

ρ = resistivity of internal electrode
L = total length of MLCC
W = width of internal electrode
t = thickness of internal electrode
n = number of internal electrode

By normalization, $\ddot{Re} = \dfrac{Re\,W\,t}{L}$ becomes

$$\ln \ddot{Re} = \ln \rho - \ln n \qquad \text{(Eq. 02)}$$

Re needs to be measured in order to determine the resistivity, ρ, of the electrode material. Since Re is very low for MLCCs, it is very difficult to measure. MLCCs that have a low number of active layers also have a relatively higher Re, which will increase the measurement accuracy. The Re of several MLCCs between 1608 -3216 case sizes are measured and plotted.
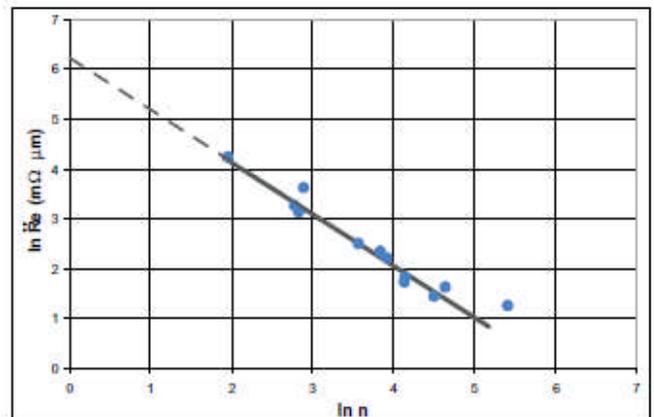

Fig. 03: Plot of Re

Through interpolation, a linear equation is found from the measured data. ρ is determined by taking the y-intercept of the linear equation as shown in Fig. 03.

$$\rho = 4.707 \times E^{-5}\ \Omega\ cm \qquad \text{(Eq. 03)}$$

Re can then be determined by combining Eq. 01 & Eq 03.

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ESR Verification

Measurements are performed using the HP4194A Impedance/Gain-Phase Analyzer and the HP16044A test fixture (Fig. 04 & 05). The HP16044A is used due to the low contact resistance.
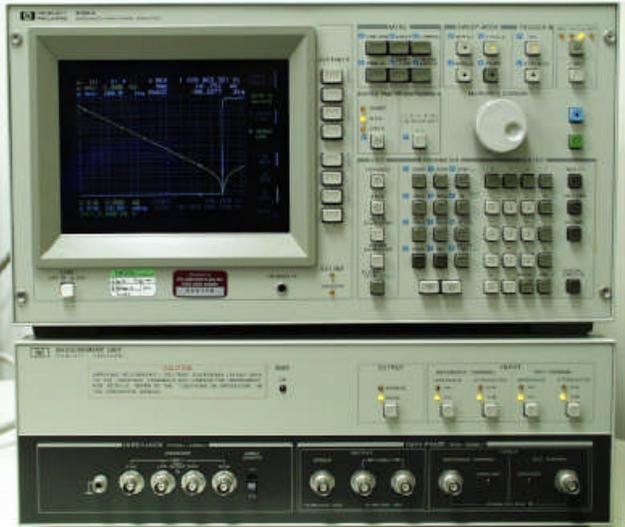

Fig. 04: HP4194A Impedance/Gain-Phase Analyzer

Fig. 05: HP16044E Fixture

The accuracy of the TDK ESR model is verified by comparing the modeled (calculated) ESR with the measured ESR. The following compared modeled vs. measured for a TDK C1608X7R1C104K (Fig. 06).
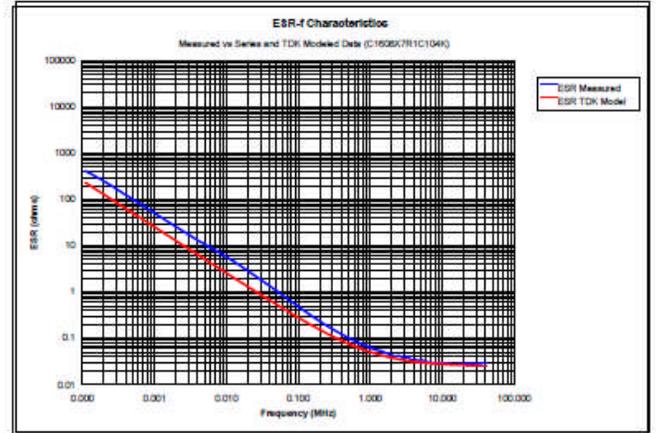

Fig. 06: Modeled vs. Measured ESR

Conclusion

To determine the ESR of a MLCC r is found by measuring the Re from several MLCCs. Once r is found, it is combined with the equation for the Re which is based on the geometry of the MLCC electrode.

ESR is just one parameter that the design engineer uses when performing Spice or equivalent simulations of their designs. The ESR is provided along with other critical parameters in the TDK ECML to aid the design engineer in more accurately simulating real performance.