Frequently asked questions regarding:

ESR Performance with Temperature

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Abstract
This application note will highlight some frequently asked questions regarding ESR performance with a focus on the effects of temperature. Effects of temperature includes the effects of both external and internal factors.

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Q1. ***What is ESR?***
A1. The theoretical treatment of devices such as capacitors tends to assume they are *ideal* or "perfect" devices, contributing only capacitance to the circuit. However, all physical devices are constructed of materials with finite electrical resistance which means that physical components contain some resistance in addition to their other properties.

ESR is the real resistive component of the complex impedance $Z(\omega) = R + j X(\omega)$ of the device. This complex impedance can involve several relatively minor capacitances. These small deviations from the ideal behavior of the device can become significant when it is operating under certain conditions, i.e. high frequency, high current, or temperature extremes.

ESR is often represented in the mathematical relationship:

$ESR = DFX_c = DF/2\pi fC$ (EQ 1)

Q2. ***What are the physical components of ESR?***
A2. ESR is physically composed of two parts. The first is the pure electrical resistance, Re, which consists of the terminal and internal electrodes. The second is due to the ferro-electric ceramic material. Further details on the model for MLCC ESR can be found in the TDK application note "ESR Modeling for TDK Capacitors"

Q3. ***How much difference is there in ESR between different value MLCCs?***
A3. When comparing different dielectric material, generally speaking, Class I dielectrics yield lower ESR compared to Class II dielectrics with all other variables being the same. Class I dielectrics, however have lower dielectric constants and therefore can not offer the high capacitance values you can achieve with class II dielectrics.

High value ceramic capacitors typically have a high internal electrode layer count. If you consider each layer of the MLCC as a resistor, the circuit model for the inner electrodes is equivalent to several resistors in parallel. Since resistors in parallel reduce in value, it follows that higher layer count MLCCs result in lower ESR. This, of course, is assuming all other parameters are equal.

Q4. ***How do different stresses or bias affect ESR?***
A4. There are a number of stress and bias factors that are important to consider for circuit design. Electrically, ESR is affected by the frequency of the circuit. This is evident in the formula for ESR shown in EQ 1. Other stresses such as voltage and temperature do not affect ESR.

Figure 1 shows an example of ESR stability with temperature. In Figure 1, both Impedance and ESR are measured at room temperature and 125^{O}C. Graphs show no difference in ESR or Impedance with temperature.

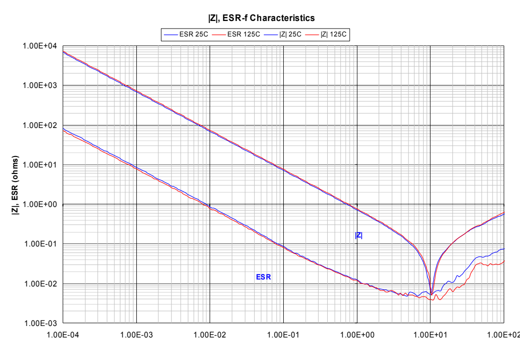

Figure 1. |Z|/ESR at 25^{O}C and 125^{O}C.

Figure 1 shows that ESR does not change with temperature. This does not, however, imply that temperature is not an important factor in circuit performance.

Q5. ***What affect does temperature have on performance?***
A5. Temperature itself does not have any affect on ESR. Temperature does affect capacitor performance. The temperature characteristic of the material defines the maximum rated operating temperature of the capacitor. For example, a X7R is defined to operate up to 125^{O}C while a X5R is defined to operate up to 85^{O}C.

Ripple current indicates the maximum allowable current due to self heating. Ripple current is a function of ESR. Where all this comes together is that although ESR is not affected by temperature, the temperature of the circuit does limit the amount of ripple current the capacitor can handle.

Simply stated, the total temperature of your circuit environment plus the self heating (i.e. ripple current) of the capacitor combined can not exceed the maximum rated temperature of the capacitor. For example, for an X7R, if the circuit operating temperature is 100^{O}C, the ripple current can not introduce more than 25^{O}C of self heating.

Q6. ***What considerations should be taken in account when designing circuits?***
A6. One point stressed in this paper is that ESR itself is not affected by temperature. Frequency response graphs such as the one in Figure 1 shows that ESR does not change with temperature but it does show that ESR changes with frequency. If ESR is a critical parameter for the operation of a circuit, then the design engineer needs to consider two parameters. The first parameter is the operating frequency of the circuit. The second parameter is the overall temperature of the component which includes the external temperature around the component as well as the internal self heating due to current level.

Q7. What can I do if the total temperature (external plus internal) exceeds the maximum rated temperature for the MLCC?
A7. If the circuit runs hot and there is significant ripple current then one or both factors needs to be reduced. The Design Engineer needs to investigate all options to reduce the circuit temperature. To address the external temperature aspect, this may require something as simple as adding heat sinks and cooling fans. Electrically, the Design Engineer needs to reduce the ripple current. One consideration is to add smoothing circuits to reduce the ripple current level. Another option is to add several MLCCs in parallel to distribute the current.

Specific solutions really depend on the exact circuit as well as use conditions for the module.

Q8. What other resources does TDK offer to discuss ESR or ripple current?
A8. TDK has written several FAQ style papers addressing ESR. A few examples which covers a broad range of topics are listed here.

1. How should I measure SRF
2. Modeling Technique for MLCCS
3. ESR Modeling for TDK Capacitors
4. Ripple Current

For further information please contact TDK main or local sales offices in your area or visit our web sites:

More Web sites:

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