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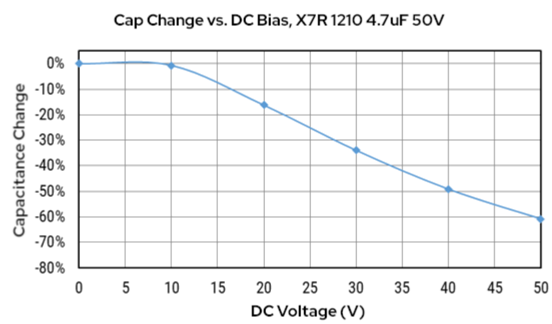
VCC: Capacitance Change vs Voltage in Ceramic Capacitors

Introduction

When purchasing a class II Multilayer Ceramic Capacitor (MLCC) from any manufacturer, the nominal capacitance is specified in the datasheet using specific measurement parameters such as frequency, AC voltage, and DC voltage. When measuring the capacitance per the manufacturer's recommendations, the capacitance should read within the tolerance of the part number that was purchased based on the aging rate. However, under applied DC voltages, there will be a noticeable decrease in capacitance in some cases up to 90% at rated voltage. (See Figure 1)

Figure 1 - Capacitance Change vs. DC Bias X7R 1210 4.7uF 50V



The effect is called VCC or Voltage Coefficient of Capacitance and this Tech Topic will provide a brief overview to help understand Class II and Class III behavior.

What is VCC?

VCC is a phenomenon in Class II and Class III MLCCs where the capacitance will decrease under applied DC voltages. This effect is most noticeable when operating at voltages close to the rated voltage and where high capacitance is a critical parameter in the design. VCC occurs in all Class II and Class III -X7R, X5R, Y5V, Z5U, etc.- capacitors from any manufacturer and is related to the design and material properties of these MLCC.

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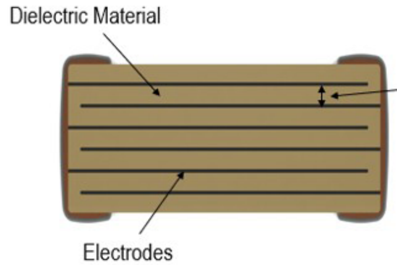
What Causes VCC?

MLCCs are constructed using alternating layers of ceramic dielectric and metal electrodes. Figure 1 shows the calculation of capacitance for an MLCC where the A is the active area of the electrodes, K is the relative dielectric permittivity, N is the number of electrodes, ε_0 is the dielectric permittivity in a vacuum, and d is the dielectric thickness. By increasing either A, K, or N, the net result will be an increase in capacitance

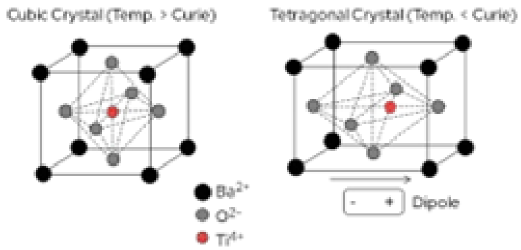
Figure 2 - Cross Section of MLCC



$$C = \frac{\varepsilon_0 * A * K * N}{d}$$

Class II MLCCs are made from Barium titanate ($BaTiO_3$) ferroelectric material which has a crystalline structure containing Barium, Titanian, and Oxygen atoms. Above its curie point (~130°C) $BaTiO_3$ has a cubic crystal structure but as it cools down below its curie point, it transitions into a tetragonal shape. See Figure 3. The effect is an immediate spontaneous polarization of the material, forming dipoles which arrange into domain regions. The creation of the dipole is due to the shift of the titanium ion within the crystal lattice structure causing an electric field to exist. The arrangement of the domain regions within the dielectric are randomly scattered throughout the material in which there is no net electric polarization of the material. The electric fields of each of the dipoles cancel each other out into a neutral state. The result of the spontaneous polarization of the material is a high permittivity which gives Class II and III MLCCs their high capacitance. During a capacitance measurement using small AC voltages, the titanium ion is free to move with the alternating electric field.

Figure 3 - $BaTiO_3$ above and below Curie Point



When DC voltage is applied to the MLCC, an electric field would be present throughout the dielectric and the titanium ion would now be influenced by both the DC electric field and AC electric field. As the DC voltage increases, the titanium ion becomes “locked” into place preventing it from being influenced by the AC voltage thus reducing the dielectric constant of the material. This results in a measurable drop in capacitance in the MLCC.

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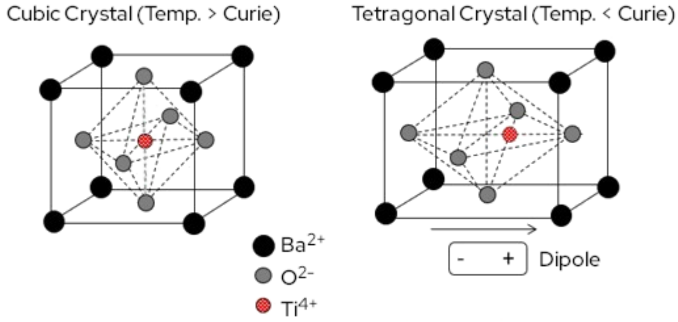
Figure 4 - $BaTiO_3$ under the influence of an electric field



Factors Influencing VCC

Not all Class II and Class III MLCCs will have the same level of capacitance loss versus DC voltage. Some MLCCs may lose 10% capacitance at rated voltage while another MLCC of the same case size may lose 90% at rated voltage. There are two factors that influence VCC:

1. Applied Voltage – As voltage increases on an MLCC, higher electric fields are present on each active layer. Therefore, as voltage increases, capacitance loss also increases.
2. Dielectric Material – Class II and III MLCCs are made from Ba-TiO3 material but also include other materials such as dopants to improve performance, quality, and processing. Formulation differences between ML-CCs can have a significant impact on VCC.
3. Design – MLCCs are constructed using alternating layers of ceramic dielectric and metal electrodes. The dielectric thickness (separation between the electrodes) can range from 10µm down to below 1µm. As the dielectric thickness decreases, the electric field on each of the MLCC layers increases thus increasing the effect of VCC.

Considerations Necessary for Designing in Class II and III MLCCS

For a given class II and III MLCC dielectric the active thickness required for reliable performance is critical. In order to miniaturize, MLCC formulations have been developed with reliable performance in thinner and thinner layer thicknesses. However, although their reliability is good, as the active layer thickness is reduced at a given applied voltage, the electric field on each active layer increases. This results in higher VCC as the parts are miniaturized. It is therefore critical for designers to understand the VCC implications in the circuit when attempting to move to a smaller case size.

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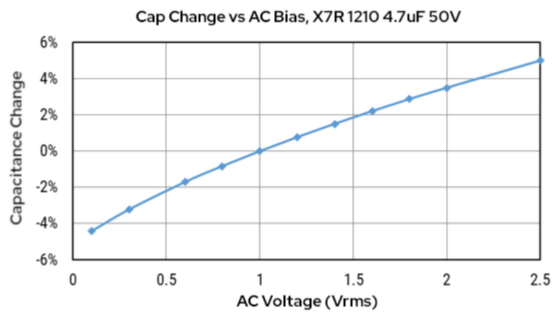
What About AC Voltage?

Similar to DC voltage, the presence of AC will cause an electric field to appear across the dielectric layers on the MLCC. The magnitude of the electric field on each layer is proportional to the peak AC voltage across the MLCC. The result of this is a change in capacitance versus AC voltage as seen in figure 5. If a DC VCC was applied to a component operating under similar AC conditions, the following chart would be shifted downward to account for the applied DC voltage.

Figure 5 - Capacitance Change vs. AC Bias X7R 1210 1.7μF 50V



Measurement Considerations for Capacitance

As seen in figure 5, the capacitance changes as a function of applied AC voltage. Due to this phenomenon, it is critical to make sure during a capacitance measurement, the AC voltage of the meter is set to the value specified in the MLCC datasheet.

What About Class I MLCCs?

Class I MLCCs are made from CaZrO3 dielectric which is a paraelectric material. Therefore, Class I MLCCs are considered to be very stable and have effectively no capacitance shift with DC or AC voltage.

Want to find out more?

For more information about EIA Classification (Class I, II, and III), take a look at this article available:
Here’s What Makes MLCC Dielectrics Different