



New Developments in High-Voltage Surface-Mounted MLCCs

High-voltage surface-mounted MLCCs are usually defined as ratings of 500VDC or higher. They are used extensively in power supplies for isolation and filtering both DC and AC voltage. They are particularly important in reducing ripple noise and diverting potentially unsafe transients caused by the switching regulator. Other notable uses are as snubber capacitors in lighting ballasts and recently they have been incorporated in implantable medical devices to protect lower voltage circuitry from induced transients from external defibrillation. However, as voltage increases above 750VDC there are significant issues with surface arcing both between terminals and from other devices mounted on the boards. For these reasons the separations between capacitor terminals and surface mounted devices, both line-of-sight and surface distances are critical to reliable performance. These distances have been defined in UL and VDE requirements for safety rated capacitors and the capacitor performances are defined in standards such as IEC 60384-14, IEC 60950, ENI 132400 and UL 60950. To comply with these requirements distances, larger case size capacitors, such as 1808 and larger, have been developed for use in these applications. Designers have also employed slotted boards, flexible circuits and conformal coating of boards or coated capacitors to retard surface arcing. Other reliability concerns, particularly with larger case size multilayer capacitors are board flexure and piezoelectric stresses both ultimately resulting in cracking leading to component failures. Furthermore, in applications where board space is at a premium producers have had to develop smaller MLCCs capable of reliable operation at higher voltages. This article describes the designs, materials and performance of surface mount multilayer ceramic capacitors to address these issues.

Designs

Many years ago the standard design for MLCCs was found to have problematic performance when tested at voltages above 500VDC in air. Internal breakdown between the active layers and a surface arcing between terminals both resulted in failures. To address the issue of voltage stress in the active area of the capacitor, manufacturers' developed a series "floating electrode" design that effectively had 2 capacitor stacks or more within a single component.

A diagram of this type of design is compared to a standard MLCC in Figure1.

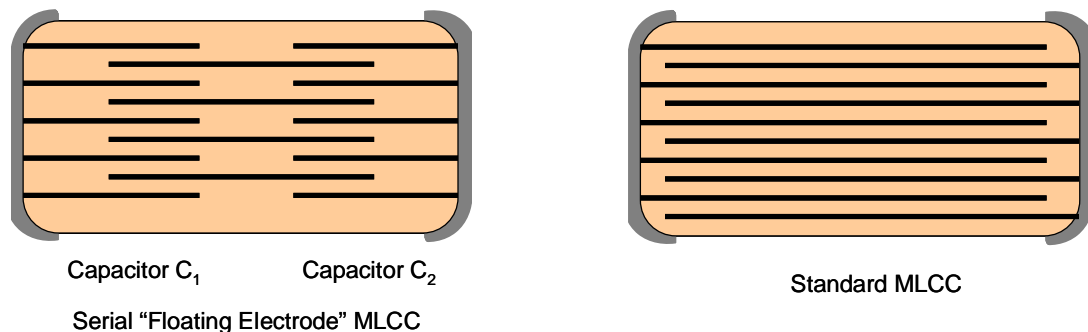


Figure 1. Diagram of Cross-sections of Serial "Floating Electrode" Vs Standard MLCC



The capacitors are typically the same value and so in this case the effective voltage on each capacitor (V_C) is equivalent to the total voltage (V_T) applied to the device divided by the number of capacitors (n):

$$V_C = V_T / n$$

In this way the effective voltage of on each capacitor stack is reduced. Designer of high voltage circuits also use this principle by placing individual capacitors in series to reduce the voltage on each capacitor. However, in both cases the total capacitance (C_T) is reduced:

$$1/C_T = (1/C_1 + 1/C_2 + \dots + 1/C_n)$$

“Floating electrode” serial designs have quite good resistance to surface arc-over. However, one key disadvantage is their lower capacitance compared to standard designs as previously discussed.

Surface-arc-over issues can further be addressed by coating the capacitors. Adding leads and coating with epoxy based resin is an effective solution but the product is no longer surface mountable. More recently coatings have been applied to retain the ability to surface mount but these solutions tend to be expensive and the manufacturing process is complicated. Application of similar coating to the assembled boards can also prevent arc-over occurrence but apart from the additional cost in many cases the resulting coatings do not allow for further soldering during final assembly by the end user.

In order to address these shortcomings HVArc Guard[®] capacitors were developed that use a patented arrangement of internal electrodes to prohibit surface-arc-over. Although this arrangement does not reduce the voltage on the internal active like the serial designs in many cases the effective active overlap area is increased by over 300% allowing the higher capacitances and further miniaturization of capacitors.

In the HVArc Guard design the shield electrodes surround the active electrodes to form a barrier between the charge on the terminations and the active layers. The resulting electric field prohibits termination to termination arcing and increases dc voltage breakdown levels. The shield electrodes occupy only a small volume leaving the remainder for the active electrodes thereby increasing available capacitance.

Board Flexure

As mentioned in the previous section soldering leads and coating is used extensively to produce high voltage parts. In addition to leads, frames can be used to package multiple capacitors for higher capacitance and increased compliancy. Although the addition of a gull wing frame adds significantly to the cost of the part it also eliminates the occurrence of board flexure. Until recently there was no effective way to increase the compliancy of the termination on surface mounted devices, this is no longer true. By using silver loaded epoxy polymer terminations the occurrence of failure during board flexure can be retarded increasing the reliability. This option is now available for both high voltage serial designs in our OMD-Cap range as well as for the HVArc Guard capacitors. The difference in failure rate during board flex testing of normal and polymer terminations on the same HVArc Guard capacitor is shown in Figure 2.

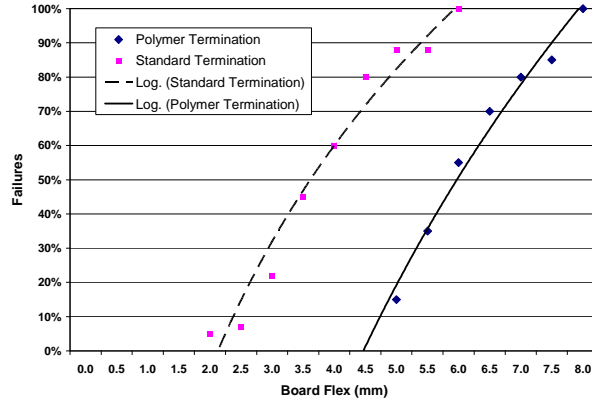


Figure 2. Flexure Failure Rate of Standard and Polymer Terminations on HV Arc Guard, 1812, 150nF, X7R

Materials

High voltage capacitors are typically manufactured in both X7R and C0G dielectrics. These designations describe the temperature coefficient of capacitance by EIA as +/-15% and +/-30PPM/°C respectively in the temperature range -55 to +125°C. C0G capacitors are also referred to by the more general terminology, NP0 (negative positive zero). However, it is critical to note that capacitance measurements are made at 1Vrms, 1 kHz and a broad range of materials can be described by these designations. For many power supply applications it is essential to know the capacitance at a specific voltage. An important distinction between X7R and C0G (NP0) capacitors; on applying DC voltage X7R capacitors will loose significant capacitance whereas C0G (NP0) capacitances will remain relatively unchanged. This occurs because of the fundamental difference in the ferroelectric X7R materials with remnant polarization compared to the paraelectric nature of C0G (NP0) dielectrics. In practical terms although X7R MLCCs are capable of much higher capacitances, their capacitance is significantly reduced on applying DC voltage. An example of this is shown in Figure 3.

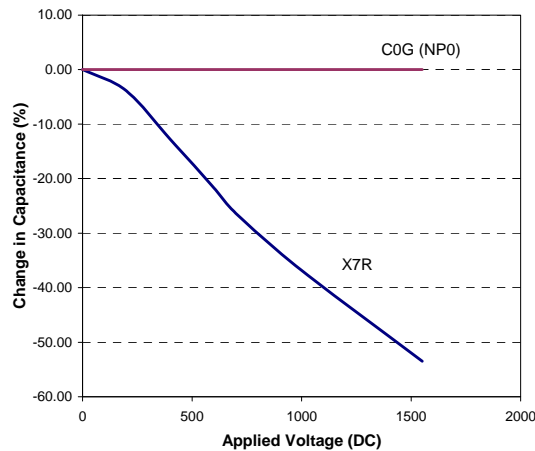


Figure 3. Voltage Coefficient of Capacitance for 1206, 1500VDC rated X7R (OMD-Cap) and C0G (NP0) (HV Arc Guard)



Designers must therefore take into consideration the available capacitance under the application voltage when sourcing the multilayer capacitors.

As was mentioned previously there are many materials from many manufacturers' that meet these TCC designations of X7R or C0G (NP0). These materials in combination with various designs do not all perform the same way under applied dc voltage. The available capacitance at any given voltage must be vastly different depending on the manufacturer. Higher voltages can couple with the ferroelectric domains in X7R dielectric resulting in a mechanical stress on the component. This "Piezoelectric Stress" can lead to movement in the z-direction of the capacitor of microns. This is of course the principle behind piezoelectric actuators but in the case of MLCCs successive voltage spikes can lead to stress cracks and failures. To address this issue for these 2000VDC ratings and above X7R dielectrics with reduced piezoelectric coupling should be used. The effect of reducing the coupling coefficient is to increase the breakdown withstanding voltage. as shown in Figure 4.

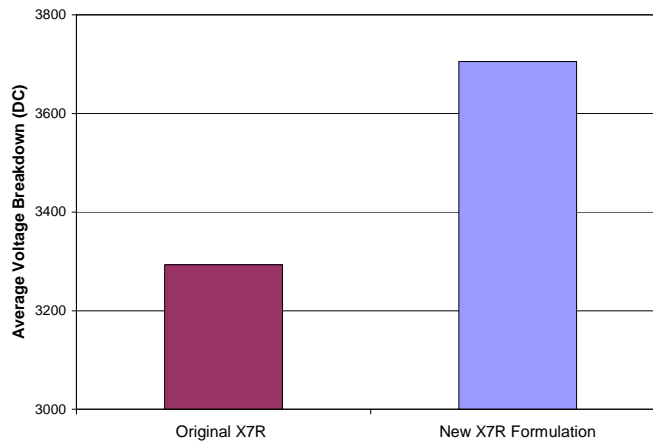


Figure 4. Average Voltage Breakdown of 1812, 4.7nF X7R capacitors

These designs have exactly the same active thickness and "floating electrode" type design. The only difference is in the X7R dielectric modification of the new formulation that has reduced coupling with the applied voltage. This new formulation is used in our high voltage OMD-Cap offering.

AC Voltage Considerations

In many applications AC power handling and the ability to withstand AC voltage is critical. One typical way to measure this is by applying AC ripple voltage at various high frequencies until the capacitor temperature increases by 20°C above ambient. However, once again there are important differences between X7R capacitors where the remnant dipoles move with the applied field that cause heating and C0G (NP0) capacitors where the temperature is not increased in this way.

Another AC capability metric is performed by applying a 60Hz AC voltage ramp up to a peak of 6kV over a 30 second period until dielectric breakdown occurs. The results of this type of testing is compared to DC voltage breakdown on applying 500Vdc/second to destruction for 1000Vdc rated 1206 X7R, HVArc Guard[®] capacitors.

The DC voltage failures occur well above the 1000VDC rating. Failures due to AC voltage occur around 1000VAC but the distribution of failures is very narrow compared to DC voltage.



Environmental Considerations

As mentioned in the previous sections coating of capacitors or boards can prevent surface arcing and also act as a barrier to humidity. To test the susceptibility of HV Arc Guard components to failure induced by humidity 1210 case size, 1000VDC rated MLCC samples were voltage breakdown tested at ambient conditions of 23.8°C/53.3%RH and elevated temperature/humidity of 85°C/85% RH.

Although the average voltage breakdown of the X7R was significantly lowered at 85/85 the COG (NP0) was hardly affected. Therefore the COG (NP0) appears to be less susceptible to failures caused by humidity but in both cases breakdown was well within allowable levels even in high humidity. The components tested in both environmental conditions had breakdown levels well above rated voltage.

Summary

By using new materials and designs, reliable, surface mountable, high voltage MLCCs have been developed to offer power supply designers smaller, higher value capacitors that have no need for coating. Furthermore, these benefits coupled with the ability to use bare board assembly allows power supply manufacturer's to realize significant cost savings.

Acknowledgements

Thanks to Pat Gormally, Paul Coppens, John Jiang, Vito Coppola and Alice Witcher for their contributions and our useful discussions during the preparation of this article.