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Voltage Breakdown Mechanisms in High Voltage Rated, Surface Mount MLCCs

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Abstract

Multilayer ceramic capacitors (MLCCs) exposed to high voltages, around 1000VDC in air, are prone to both surface-arc-over and internal breakdown. In either event failures will result at the instance of surface-arc-over as the circuit is de-stabilized which may cause damage to surrounding components even if the capacitor remains temporarily functional.

The performance of HVArc Guard™ X7R capacitors, that prohibit arc-over occurrence, is compared to conventional MLCC designs using a dielectric withstanding tester, surface acoustic microscopy and high speed photography. The high speed camera fixture developed allows the failure occurrence on applying DC voltage to be closely examined. By coupling this with post examination of voltage failures in cross-sections, the root cause of failures is determined on a case-by-case basis. Cross-section analysis of failures without the benefit of direct observation of the failure event cannot always determine the root cause because of extensive damage and destruction to the components. At higher ramp rates of 3000VDC/second the mechanism of failure for HVArc Guard™ capacitors is internal breakdown not surface-arc-over that is observed in conventional MLCCs.

In addition to the above voltage breakdown tests a series of AC Voltage and surge voltage tests on HVArc Guard™ X7R and C0G (NP0) capacitors are described. These differences in performance are reviewed and the relevance to applications discussed.

Introduction

In previous presentations the properties of conventional high voltage capacitors have been compared to the patented HVArc Guard™ MLCCs for medical (1) and other applications (2). During our continuing development work a high speed camera was used to investigate the failure mechanisms in high voltage MLCCs. The results of this work are presented here together with post failure analysis by cross–sectioning of the parts. In further work the ability of HVArc Guard™ MLCCs to withstand AC and DC voltage was investigated.

Experimental

In some high voltage applications the occurrence of surface-arc-over can cause the capacitor to fail and in turn this can also affect surrounding components. An example of an arc-over is shown for one of our conventional 500VDC rated capacitors in Figure 1. Surrounding components were damaged but are not shown in this picture.

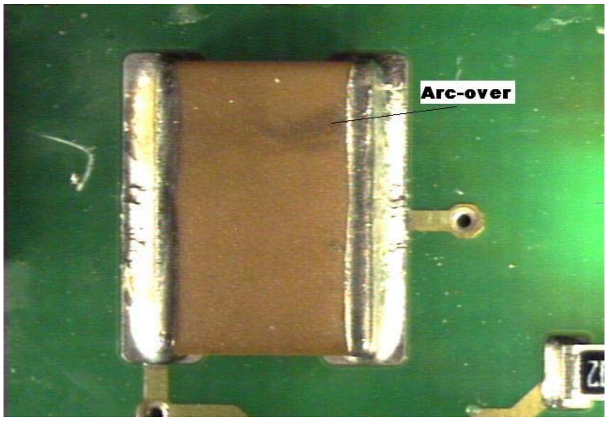


Figure 1. Surface-arc-over failure of a 500VDC rated 100nF, X7R, 1825 MLCC in a customer circuit

The HVArc Guard™ type capacitors were designed to prevent this surface-arc-over failure mode. To better understand the failure modes associated with high voltage capacitors we developed the high speed camera fixture shown in Figure 2.

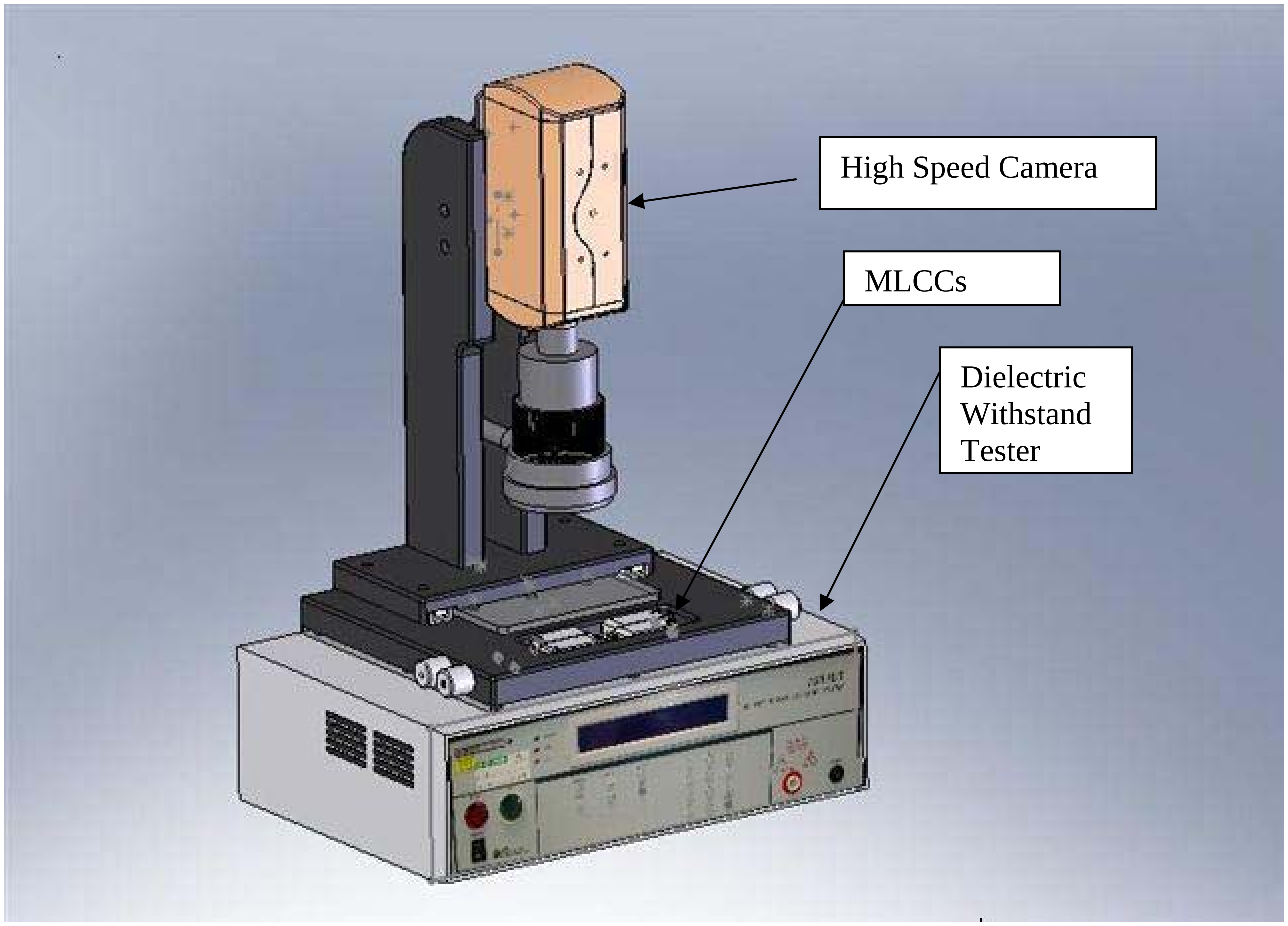


Figure 2. High speed camera fixture

The Vision Research Model 4.3 high speed camera shown in Figure 2, is capable of recording 2200 frames per second. The Associated Research Model 7512 dielectric withstand tester can apply up to 3000VDC per second with a continuous ramp to a maximum voltage of 12000VDC. All the voltage breakdown testing reported in this section was at 3000VDC/second. It is important to note that a standard voltage breakdown test per EIA-198[3] applies 500VDC/second until destruction. MLCCs were place in the spring loaded probes and voltage ramp applied and camera recording is triggered simultaneously. The different types of 1812 case size MLCCs tested in this way are listed in Table 3.

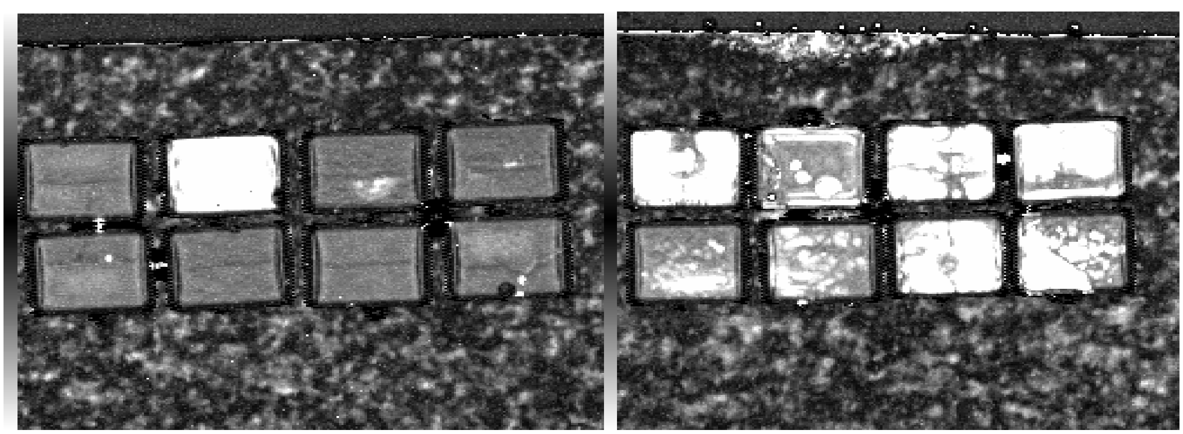
MLCC Design	Dielectric Type	Capacitance (nF)	Rated Voltage (VDC)	Fired Active Thickness (μm)	Number of Actives
Conventional	X7R	100	500	56	23
HVArc Guard™	X7R	100	500	66	25
HVArc Guard™	X7R	150	1000*	48	28
HVArc Guard™	C0G(NP0)	22	1000*	28	67

* Prototypes

Table 3. Types of 1812 MLCCs tested

The conventional design 1812, 100nF 500VDC rated X7R capacitors were split into two groups. The first group was not conformal coated and the second group was conformal coated. Both groups of capacitors were subject to a ramp rate of 3000VDC/second using an Associated Research dielectric withstand tester The non-coated group capacitors showed arc–over at approximately 1200VDC and the ramp was halted due to the instruments arc-over detection function. Although no external physical defects were present, post insulation resistance measurements showed that 37% of the non-coated parts had unacceptable insulation resistance. The conformal coated group of capacitors failed at approximately 3660 VDC and had signs of external damage. The insulation resistance for 100% of the coated capacitor failures was severely low.

The two groups of capacitors were then subject to scanning acoustic microscopy (SAM). The images of Figure 4 show white light spots where the capacitors internal structural integrity is compromised. The uncoated capacitor group on the left shows at least 5 pieces damaged after the arc-over event. This level of failure detection by SAM is higher than that realized by electrical measurements alone. The conformal coated capacitors on the right have extreme interior damage.



Air **Conformal Coated**

Figure 4. Scanning acoustic microscopy images of VBD failures of 1812 case size X7R 100nF 500VDC rated MLCCs

Samples of these same MLCCs were tested in the high speed camera fixture. The predominant mode of failure was confirmed as surface-arc-over and cross-sections showed some cracking from the part surface (Figure 5.).

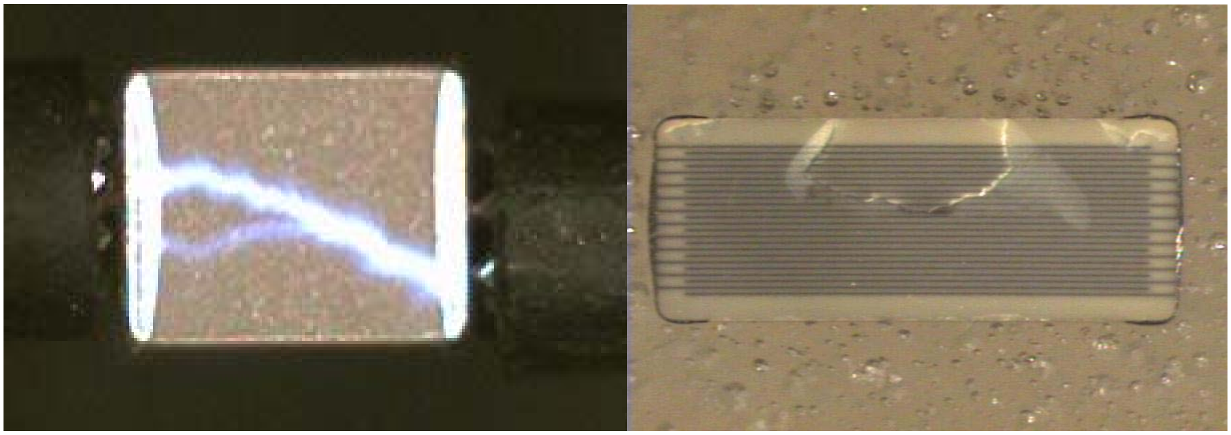


Figure 5. Surface-arc-over in 1812 case size X7R 100nF 500VDC rated MLCC and post test cross section showing surface cracking

This failure mechanism in air can be compared to the VBD failures observed in the conformal coated parts. A typical failure is shown in Figure 6 together with a cross-section of the extensive internal damage associated with this failure.

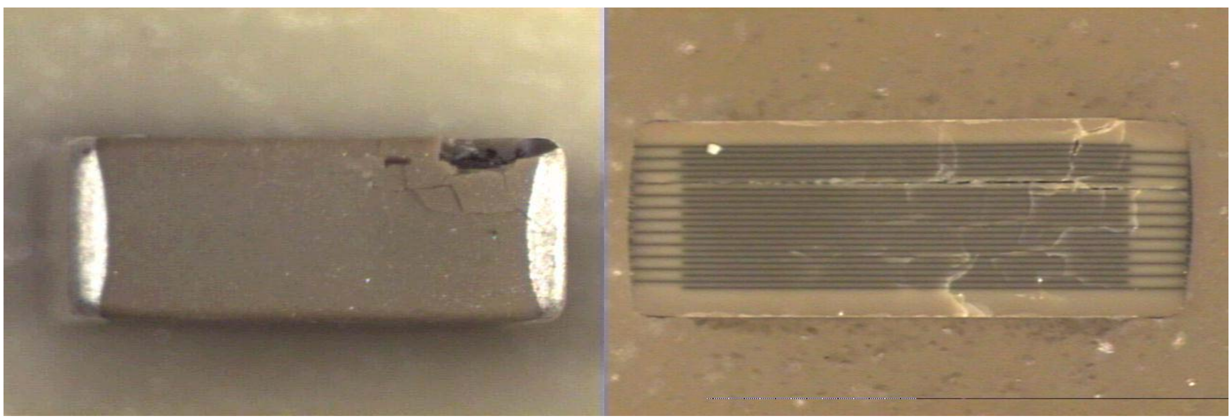


Figure 6. Voltage breakdown of conformal coated 1812 case size X7R 100nF 500VDC rated MLCC showing external damage and post-test cross section showing internal cracking

The HVArc Guard™ 1812 case size X7R 100nF 500VDC rated MLCCs have an average voltage breakdown in air of 2560VDC. The HVArc Guard™ MLCCs are designed not to fail by surface-arc-over so the failure mechanism in these parts was examined using the high speed camera fixture. A typical result is shown in Figure 7 together with a post test cross-section of the failure site.

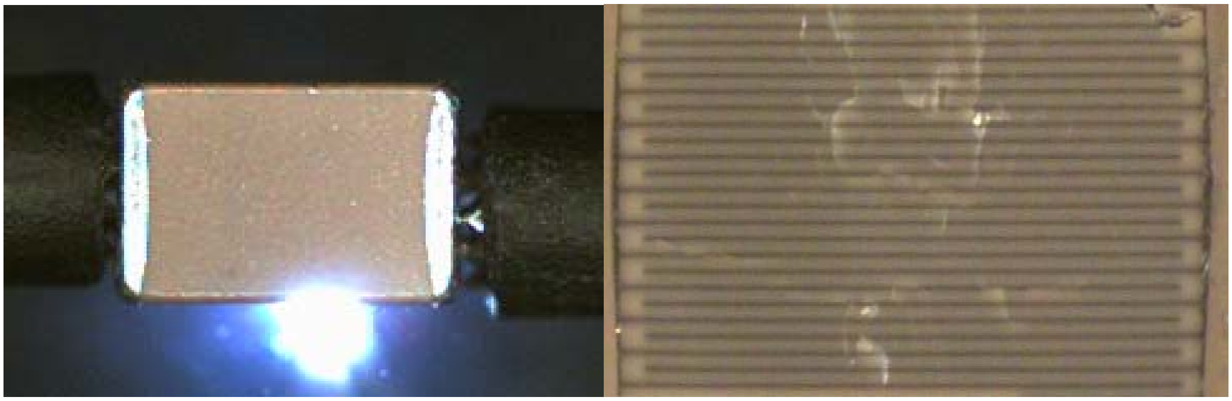


Figure 7. Voltage breakdown of HVArc Guard™ 1812 case size X7R 100nF 500VDC rated MLCC in air and post-test cross section showing failure site

The HVArc Guard™ 1812 case size X7R 100nF 500VDC rated MLCCs do not have the terminal to terminal arcing observed in the conventional MLCC. The high speed camera shows the failure occurrence as a side blow-out and post failure cross-section shows extensive internal cracking around the failure site. To confirm the absence of surface-arc-over in HVArc Guard™ MLCCs, other 1812 X7R and C0G(NP0) MLCCs were tested as shown in Figures 8, 9 and 10 respectively.

Figure 8. Side view of voltage breakdown of HVArc Guard™ 1812 case size X7R 150nF MLCC

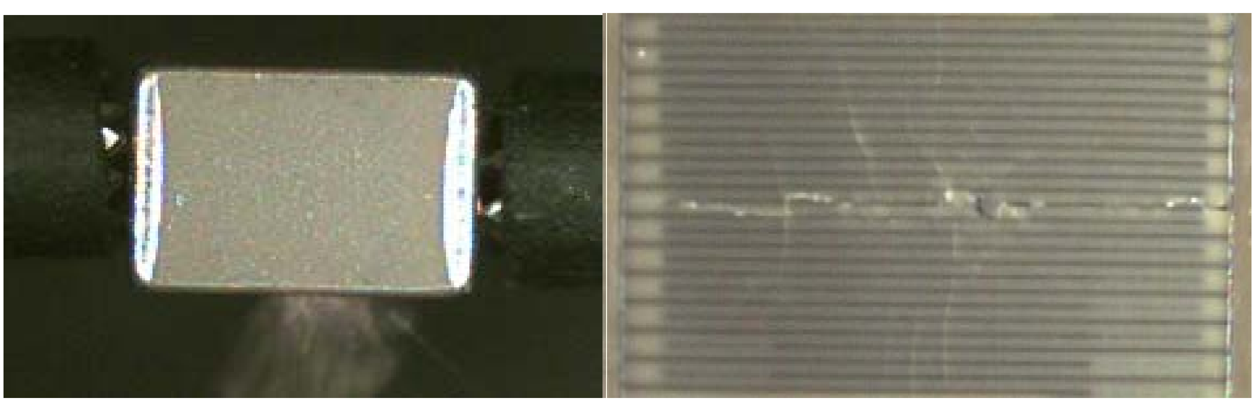


Figure 9. Voltage breakdown of HVArc Guard™ 1812 case size X7R 150nF MLCC showing side blow out and post test cross-section of failure site with extensive internal cracking

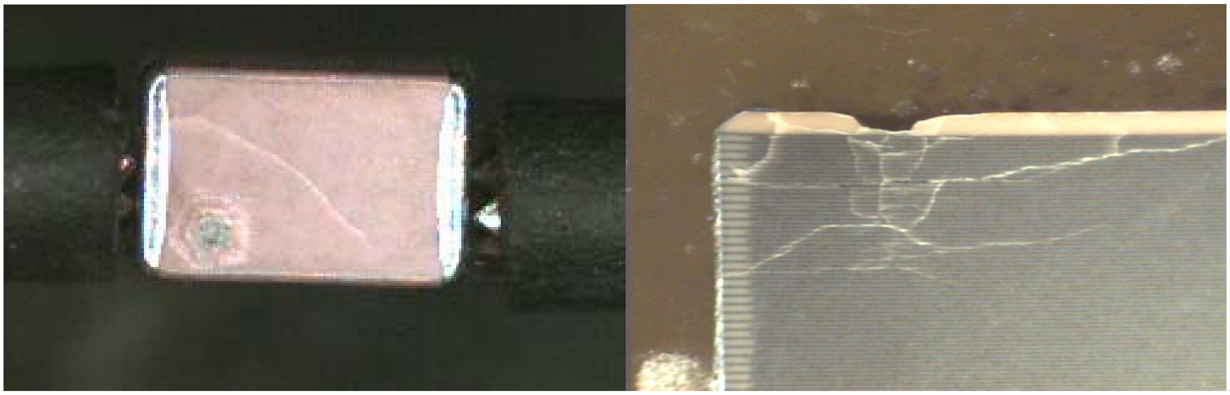


Figure 10. Voltage breakdown of HVArc Guard™ 1812 case size C0G(NP0) 22nF MLCC showing corner blow out near terminal and post test cross-section of failure site with extensive internal cracking

Voltage Breakdown Performance Summary

No surface-arc-over was detected in these HVArc Guard™ 1812 MLCCs and post test cross sectioning confirmed the internal damage associated with failures. The absence of surface-arc-over in the HVArc Guard™ MLCCs results in a higher voltage breakdown in air at 3000VDC/second as shown in Figure 11.

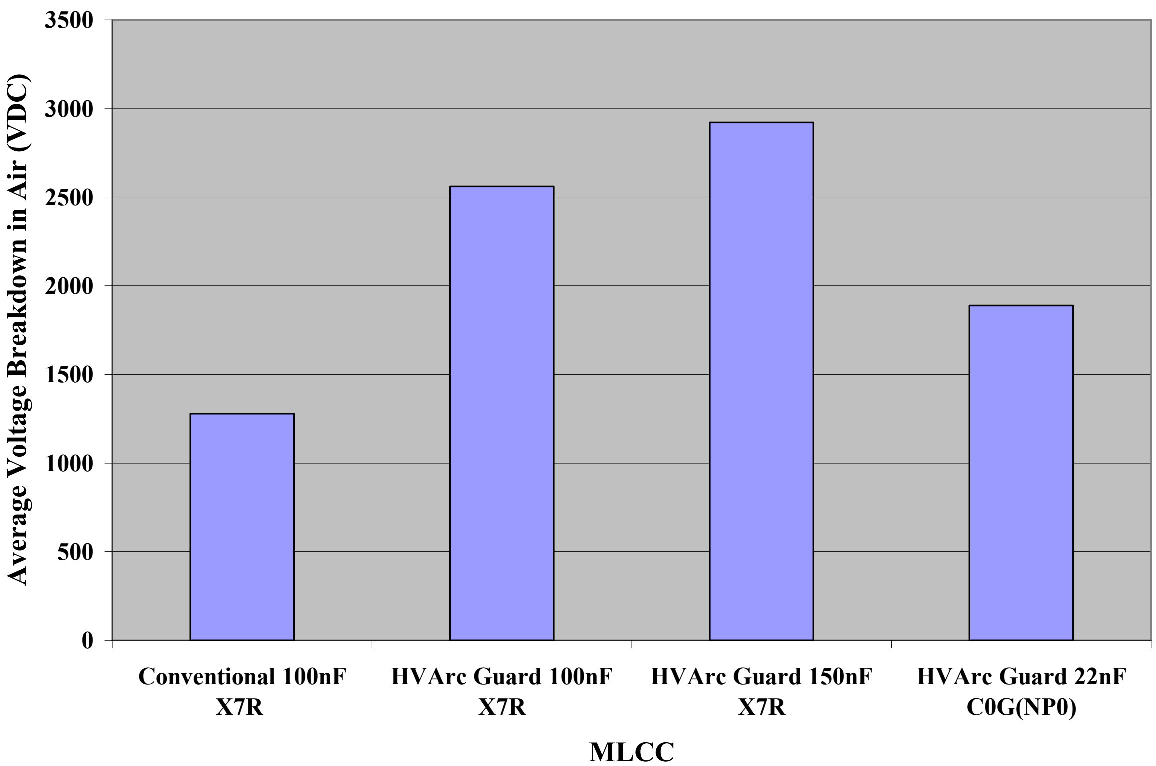


Figure 11. Average voltage breakdown of 1812 case size MLCCs in air

Application Related Testing

High voltage capacitors are typically used in the power sources that must be accurately controlled and regulated. The output of the electronic device could be DC or AC power. Any residual pulsation, called ripple noise, in the output of the power source is undesirable. The high voltage capacitors are used in these circuits to reduce ripple, and to contain potentially unsafe transients due to noise generated by the switching regulator. It is therefore important to recognize differences in performance under different DC ramp rates, high pulse rates (lightening surge) and AC voltage. To determine the capability HVArc Guard™ MLCCs, samples were tested using voltage breakdown per EIA[3] at 500VDC/second, by applying AC voltage at 60Hz and increasing until destruction and surge testing using a rapid voltage pulse as shown in Table 12.

HVArc Guard MLCC	Voltage Breakdown (VDC)	AC Voltage Breakdown at 60Hz (Vrms)	Surge Test, 10x160µs waveform (VDC)
22nF C0G(NP0)	2167	1100	1500
100nF X7R	2385	700	1000
150nF X7R	2396	700	1000

Table 12. HVArc Guard MLCCs voltage capability testing

In the previous section the HVArc Guard™ 22nF C0G(NP0) capacitors had significantly lower voltage breakdown (VDC) when tested at 3000VDC/second than the X7R HVArc Guard™ MLCCs (Figure 11.) but at 500VDC/second (Table 12.) breakdown occurs at a similar voltages. Furthermore the C0G(NP0) MLCCs have significantly higher AC Voltage breakdown and surge capability than the X7R MLCCs so this must be considered for applications where high pulses and AC voltage is expected.

Conclusions

A high speed camera fixture was developed and used to investigate voltage breakdown mechanisms in high voltage capacitors. Conventional high voltage capacitors exhibited extensive surface-arc-over in air and conformal coating was required to prevent this. Voltage breakdown testing in air confirmed that no surface-arc-over occurred in HVArc Guard™ MLCCs. Post failure cross-sectioning of HVArc Guard™ MLCCs showed the failures were consistent with internal damage to the capacitors. Further AC Voltage and surge testing confirmed that the HVArc Guard™ C0G(NP0) has better performance than the X7R capacitors.

References

1. Bultitude, J., Gormally, P., Rogers, J., and Jiang, J., "Surface Mount Multilayer Ceramic Capacitors for High Voltage Medical Applications," Journal of Surface Mount Technology, July - September 2006,Vol. 19. Issue 3, p18-22.
2. Bultitude, J., Gormally, P., Rogers, J., and Jiang, J., "Arc-Over-Resistant Multilayer Ceramic capacitors for High-Voltage Applications," CARTs Europe 2006 Proceedings of the 20th Annual Capacitor and Resistor Technology Symposium, p167-178.
3. Electronic Industries Association document ANSI/EIA-198-1F-2002