Application Considerations for High Voltage BME Multi-Layer Ceramic Capacitors

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Abstract

High voltage multi-layer ceramic capacitors (MLCC) are used in many types of applications including DC-DC and AC–DC converters as well as for EMI suppression. It has long been known that the application of coatings to surface mounted capacitors can improve resistance to arc-over. However, these coatings are expensive to apply and the resulting circuit is often not compatible with secondary assembly processes needed for final incorporation of the circuit in the product. The DC voltage breakdown performance of high voltage BME X7R MLCCs in both air and inert fluid to mimic an "ideal" coating are evaluated. The ability of these MLCC to sustain high voltage breakdown performance in humid environments is evaluated for both mounted and leaded MLCC. The breakdown failure mechanisms are discussed. In addition the capability of these MLCC to survive high dV/dt pulses such as those experienced during a lightning strike are evaluated since this is also an important consideration in many applications. Based on these results the expected performance of the different high voltage BME X7R MLCC designs in power supply circuits that are not protected using post assembly coatings is assessed.

Introduction

In previous work the development of new high voltage BME X7R MLCC that use shield electrode designs to prevent surface arcing were described[1] so allowing higher capacitances to be realized whilst avoiding the need for conformal coating. The shield designs allow for the miniaturization of high voltage MLCC but concerns persist with respect to the ability of smaller case sizes of any high voltage MLCC design to perform in humid environments in various applications. For this reason the voltage breakdown performance of 1000Vdc rated shielded MLCC are compared to serial capacitor designs in air and 85°C/85% relative humidity. Leads soldered onto MLCC are used in the initial humidity testing to avoid any influence of circuit board pad design or flux contamination that was shown to influence breakdown in the literature[2]. Three different board designs are evaluated for the 0805 case size that has the smallest termination to termination separation to determine voltage breakdown capability in air and humidity. These include a standard design, a trench machined between the pads and a slot machined through the boards between the pads. The performance of 0805 MLCC surface mounted onto boards are evaluated. In addition to this work the peak voltage capability of these MLCC to survive high dV/dt lightening strike pulses using a 1.2 x 50µsec waveform is assessed.

Voltage Breakdown in Air and 85°C/85% Relative Humidity

Four different 1000V rated MLCC were evaluated. Case size 0805 and 1206, 1000pF MLCC that contain 2 capacitors in series as illustrated in Figure 1 showing the cross-section of the 1206. Shielded designs of 0805, 4700pF and 1206, 22000pF, shown in cross-section in Figure 2, were also evaluated.

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CARTS International 2012 Proceedings, pp. 3-12, March 26-29, Las Vegas, NV, USA

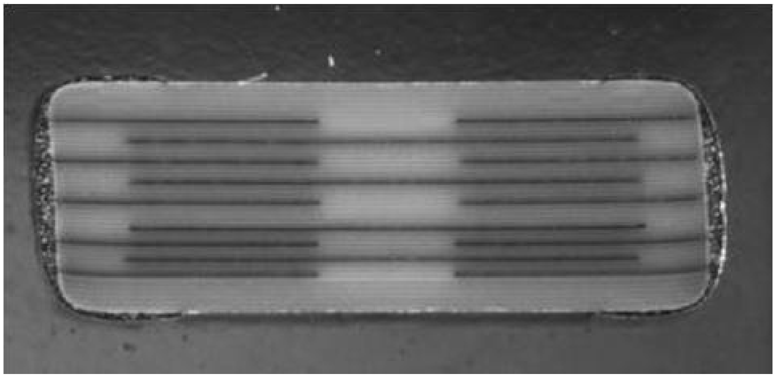


Figure 1. Cross-section of 2-serial 1206, 1000pF, 1000V rated MLCC.

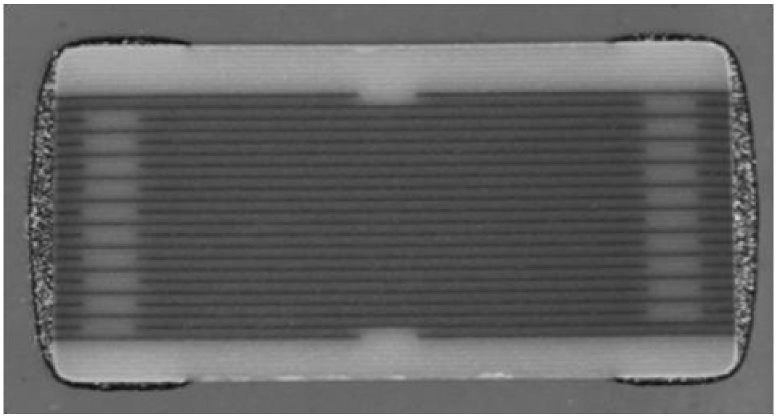


Figure 2. Cross-section of shielded 1206, 22000pF, 1000V rated MLCC.

Voltage breakdown tests at 300V/sec applied were performed on 30 piece samples of all four MLCC in both air and inert fluid. The inert fluid mimics a perfect conformal coating and in this case surface arcing cannot cause a failure. Tin plated leads were soldered onto samples of all 4 MLCC and voltage breakdown testing was performed on 30piece samples in a humidity chamber. In the case of the 1206 MLCC an additional set of samples were tested at 1200V/sec in the humidity chamber to evaluate the potential effect of the higher ramp rate. The voltage breakdown distributions are shown by MLCC in Figures 3-6.

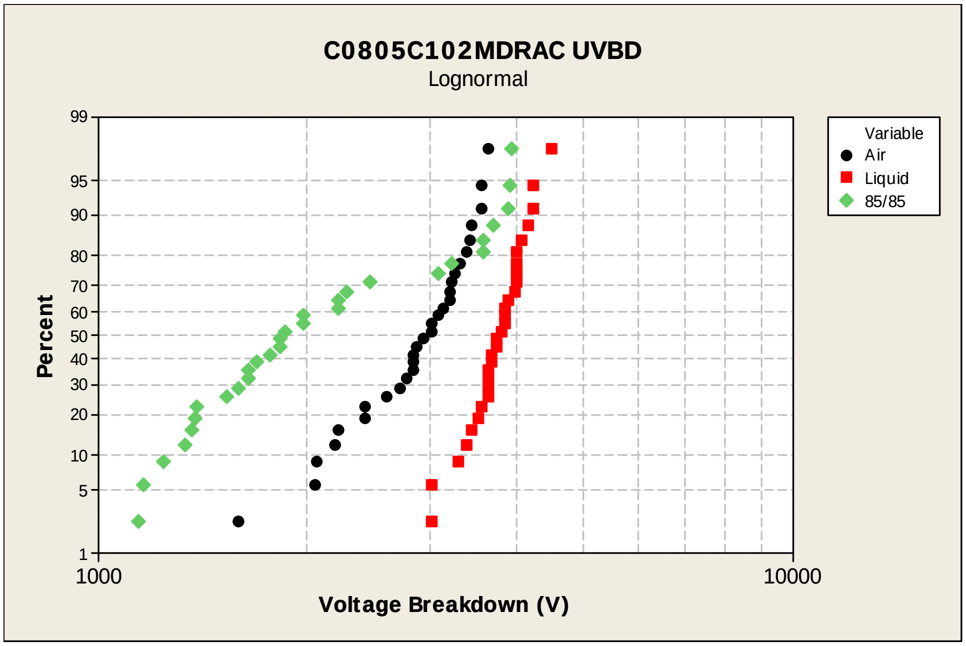


Figure 3. Voltage Breakdown Distributions for 0805, 1000pF, 1000V MLCC with serial design.

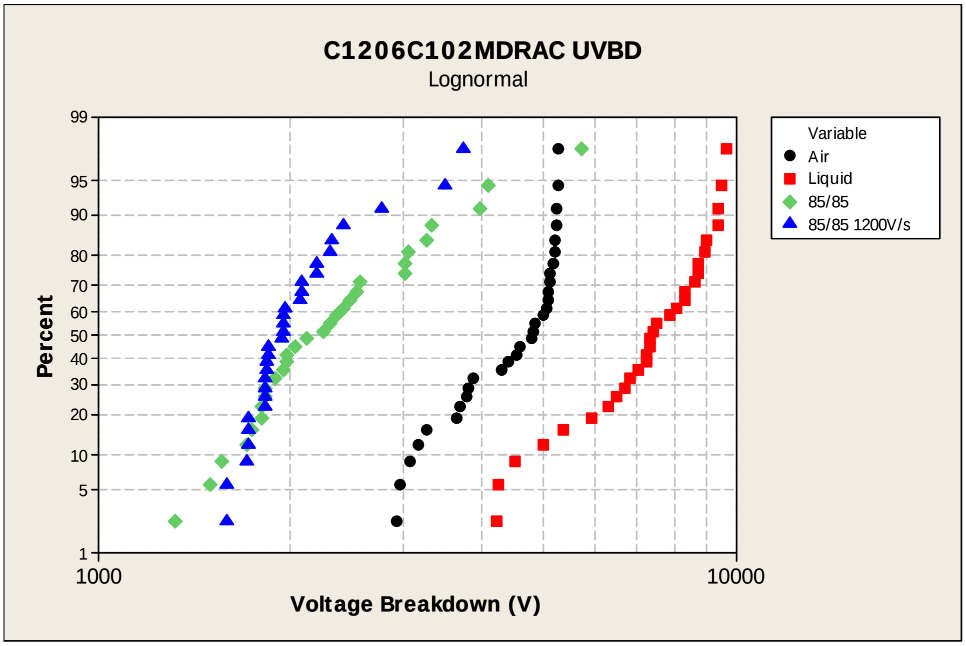


Figure 4. Voltage Breakdown Distributions for 1206, 1000pF, 1000V MLCC with serial design.

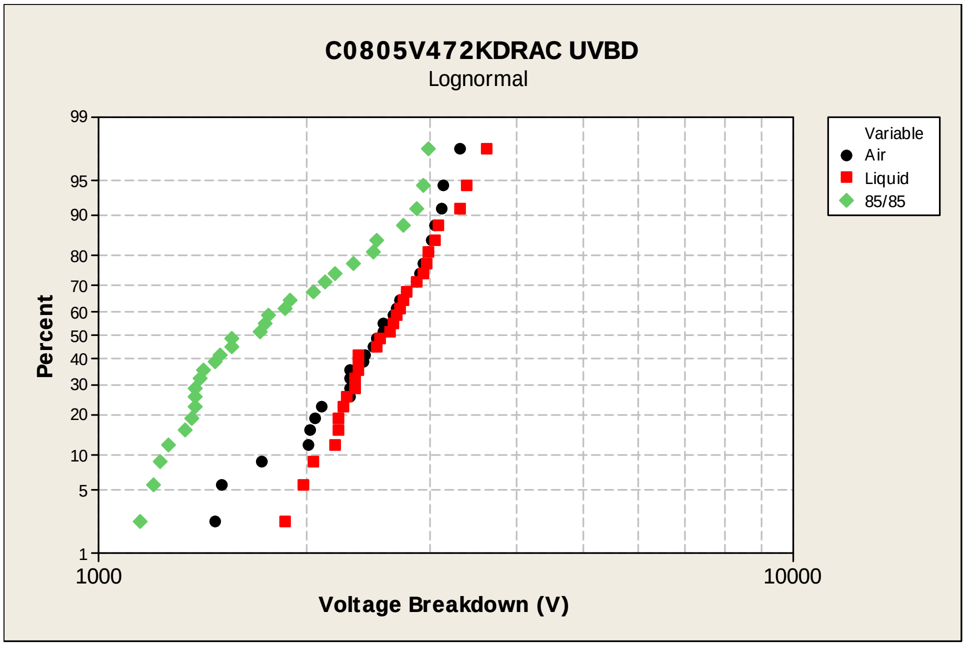


Figure 5. Voltage Breakdown Distributions for 0805, 4700pF, 1000V MLCC with shield design.

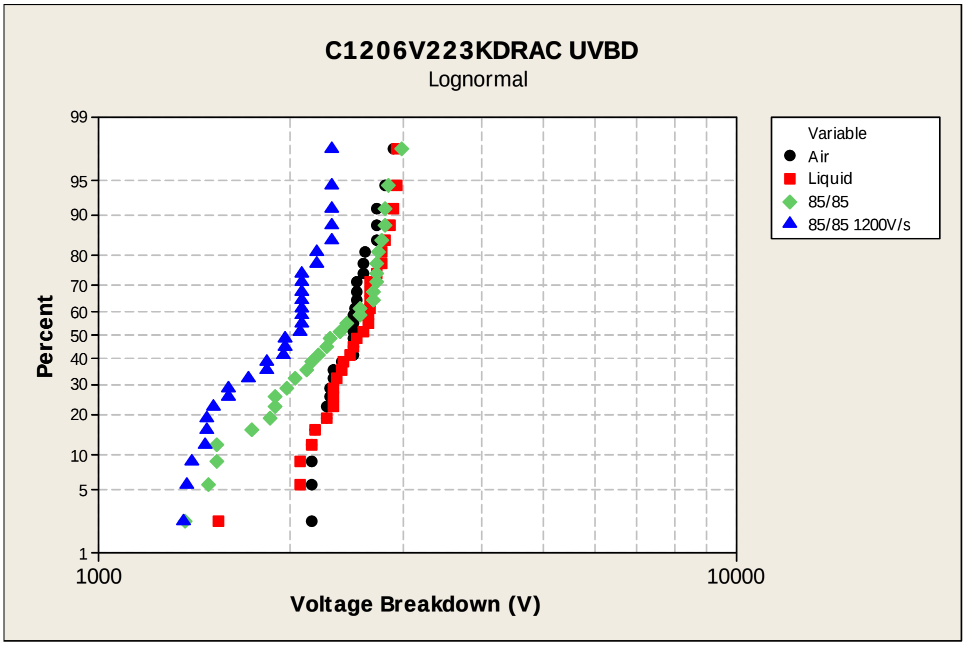


Figure 6. Voltage Breakdown Distributions for 1206, 22000pF, 1000V MLCC with shield design.

The average, standard deviations, maximum and minimum voltage breakdowns associated with these distributions are summarized in Table 1.

	C0805C102MDRAC			C0805V472KDRAC			C1206V223KDRAC				C1206C102MDRAC			
	Air	Liquid	85/85	Air	Liquid	85/85	Air	Liquid	85/85	85/85 1200V/s	Air	Liquid	85/85	85/85 1200V/s
Min	1590	3030	1140	1470	1860	1150	2160	1540	1370	1360	2940	4230	1320	1590
Max	3660	4500	3950	3330	3630	3000	2910	2940	3000	2330	5270	9680	5750	3740
Avg	2904	3781	2219	2515	2616	1827	2472	2516	2303	1907	4458	7396	2453	2075
Stdev	516	336	935	481	435	569	207	313	478	324	809	1595	937	496

Table 1. Summary of Voltage Breakdown Results.

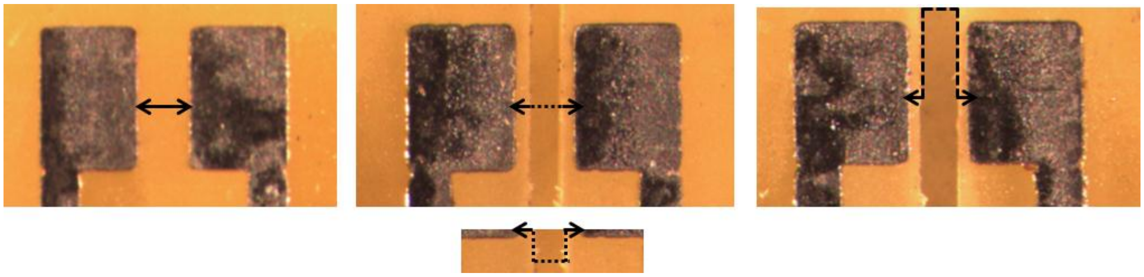
The distributions show a clear difference between the serial and shield high voltage designs when tested in air and inert fluid. Inert fluid suppresses failures due to arcing as explained in previous literature[3]. In the case of the shield designs the distributions in air and fluid are very similar with average voltage breakdown close between air and fluid. These results are consistent with those previously reported for these types of shielded design[1]. The serial designs tested in inert fluid have a significantly higher breakdown voltage than in air. The average breakdowns in air were 2904 and 4458 V for 0805 and 1206 compared to 3781 and 7396V in fluid respectively. The very high breakdown in fluid of the 1206, 1000pF MLCC indicates that this is a very robust design with high voltage capability once arcing is not a factor. Although the breakdown performance in air is acceptable for the serial designs the results in fluid indicate that arcing plays a significant role with respect to breakdown in these designs unlike the shield designs where these distributions are very similar. The minimum voltage breakdown in air for the 2 different 0805 MLCC are close, 1590V for the serial design compared to 1470V for the shield.

In all 4 cases testing in humidity 85% relative humidity/85°C reduced the breakdown voltage. Interestingly the minimum breakdown recorded for similar case sizes are very close although the average values have more variation. Furthermore increasing the ramp rate to 1200V/sec in the humidity testing of 1206 sized parts increased the number of parts failing at lower voltages so the average breakdowns decrease compared with the standard humidity test at 300V/sec but the minimum values recorded are similar for and in the case of the 1206 1000pF the higher ramp rate breakdown was above the lower ramp rate.

This work was designed to determine the MLCC voltage breakdown capability in these different environments. The use of leads to make the connection to the parts in humidity testing does not reduce the surface creepage distance between terminals. However, in surface mount applications the potential effect of different board designs must be evaluated. For this reason the performance of different FR4 test boards in these environments were evaluated as described in the following section.

Circuit Board Voltage Breakdown Capability

The voltage breakdown performance of three distinct types of 0805 circuit boards was evaluated in air and 85% relative humidity/85°C. These included a standard board shown in Figure 7 made of 0.06" (1.52mm) thick FR4 with a separation of 0.03" (0.76mm) between pads. A trench was machined between pads at a depth of approximately half the board thickness to increase the creepage distance between pads to approximately 0.09" (2.28mm). A third type of test board was made by machining slots completely through the boards to further increase creepage distance to approximately 0.14" (3.56mm).



Standard **Trenched** **Slotted**

Figure 7. 0805 Circuit Board Layouts

Samples of all three board types were tested through voltage breakdown in air and humidity using 10pcs per test. These results are shown in Figures 8 and 9.

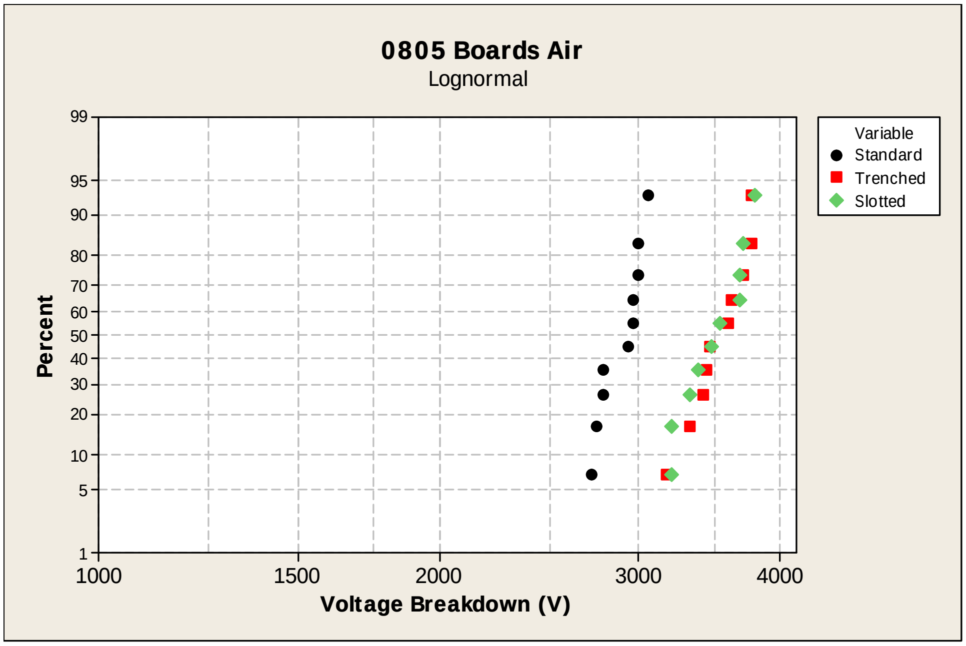


Figure 8. Circuit Board Voltage Breakdowns in Air

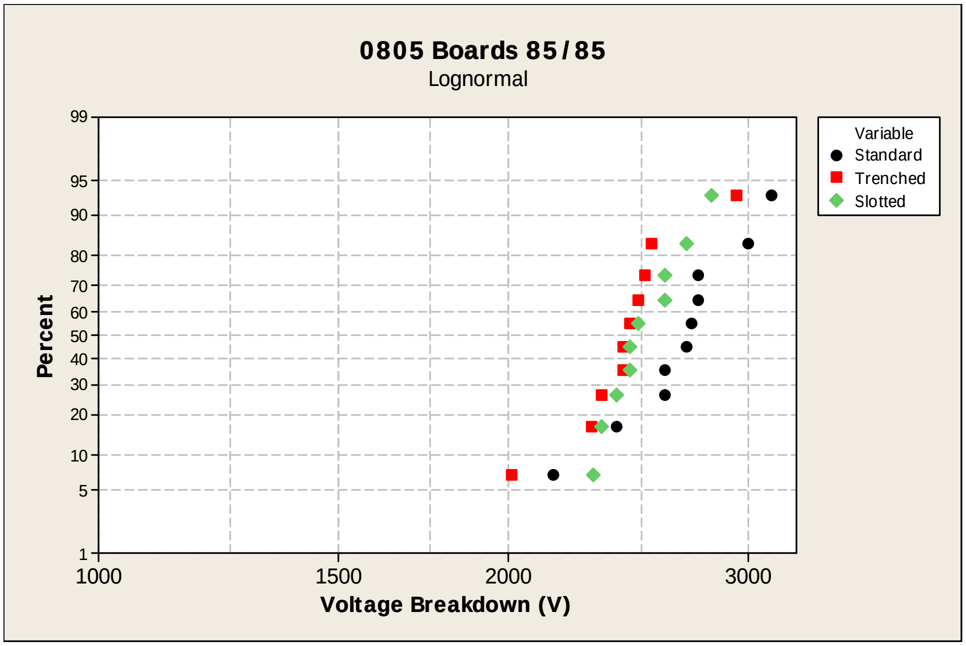


Figure 9. Circuit Board Voltage Breakdowns in 85% relative humidity/85^{o}C

The voltage breakdown in air increased for the 0805 circuit boards that were trenched and slotted compared to the standard board. In humidity the trenched boards had a lower voltage breakdown performance. The reason why performance deteriorated in humidity is not clearly understood at this time but it would appear that the presence of the trench increases susceptibility towards arcing. In all cases the minimum voltage breakdown in air or humidity were ≥ 2000V so higher than 1000V 0805 MLCC measured with under these conditions. The breakdown associated with surface mounted 0805 MLCC on these boards is therefore expected to dominate the breakdown distributions.

Surface Mounted 0805

The 0805 MLCC were surface mounted (30pcs of each type) and tested on the standard board in air and humidity to test the aforementioned hypothesis and the Voltage Breakdown Distributions are shown in Figures 10 and 11.

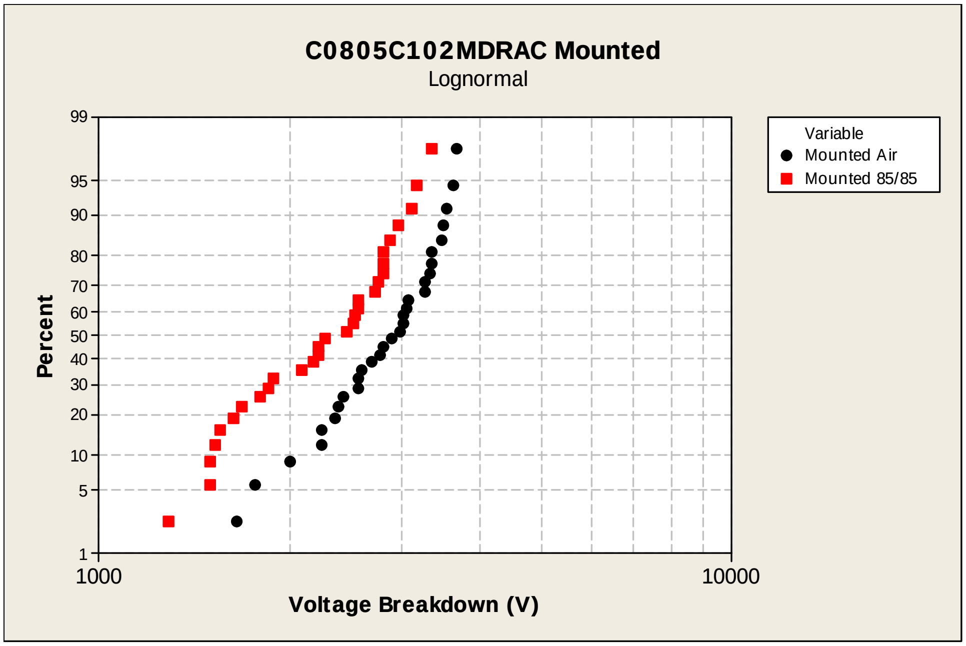


Figure 10. Voltage Breakdown Distributions for Surface Mounted 0805, 1000pF, 1000V MLCC with serial design.

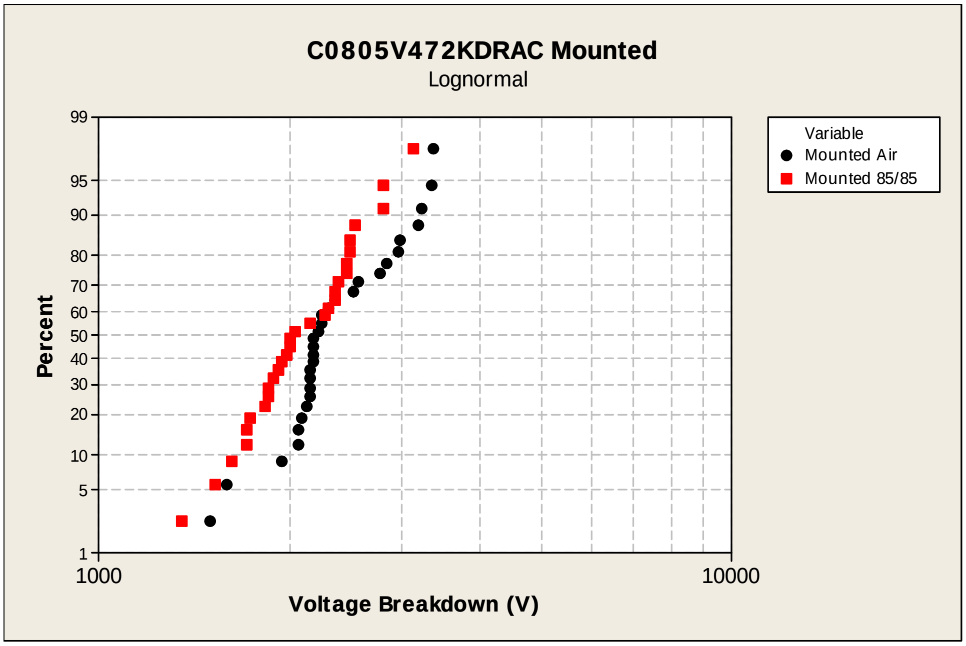


Figure 11. Voltage Breakdown Distributions for Surface Mounted 0805, 4700pF, 1000V MLCC with shield design.

The voltage breakdown for the mounted 0805 samples were lower in humidity than air but still well above 1000V for both the serial and shielded designs so are considered acceptable for uncoated boards. These results are compared to those previously described in air and humidity in Table 2.

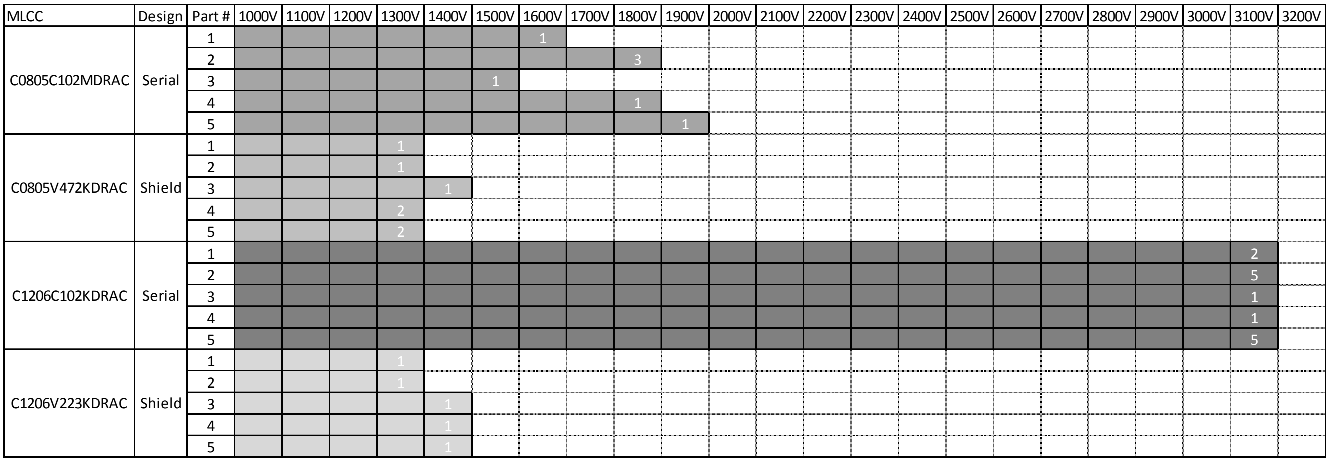
	C0805C102MDRAC				C0805V472KDRAC			
	MLCC		Surface Mounted		MLCC		Surface Mounted	
	Air	85/85	Air	85/85	Air	85/85	Air	85/85
Min	1590	1140	1650	1290	1470	1150	1500	1350
Max	3660	3950	3690	3360	3330	3000	3390	3150
Avg	2904	2219	2859	2313	2515	1827	2403	2138
Stdev	516	935	550	581	481	569	487	417

Table 2. Summary of Voltage Breakdown Results for 0805 Samples.

The surface mounted parts have very similar breakdown to MLCC reported in air and with leads in case of 85% relative humidity/85^{o}C . As expected breakdown of the mounted MLCC is dominated by the capacitor rather than the circuit board. These results indicate that it is not necessary to coat boards to achieve acceptable breakdown performance for these 0805 MLCC but for smaller case size MLCC pad dimensions need to be considered as smaller pad gaps could cause lower voltage breakdowns.

Pulse Capability Testing

This testing was performed on 5 samples of each MLCC type using a 1.2 x 50µsec pulse waveform. Each sample was pulsed 5 x at a peak voltage of 200V and if no failures were detected then the voltage was increased by 100V and then pulsed a further 5 x. The voltage was increased until arcing was observed and the pulse that this occurred on was noted. These results are shown in Figure 12.



MLCC	Design	Part #	1000V	1100V	1200V	1300V	1400V	1500V	1600V	1700V	1800V	1900V	2000V	2100V	2200V	2300V	2400V	2500V	2600V	2700V	2800V	2900V	3000V	3100V	3200V
C0805C102MDRAC	Serial	1	▨	▨	▨	▨	▨	▨	1																
		2	▨	▨	▨	▨	▨	▨	▨	▨	3														
		3	▨	▨	▨	▨	▨	1																	
		4	▨	▨	▨	▨	▨	▨	▨	▨	1														
		5	▨	▨	▨	▨	▨	▨	▨	▨	▨	1													
C0805V472KDRAC	Shield	1	▨	▨	▨	1																			
		2	▨	▨	▨	1																			
		3	▨	▨	▨	▨	1																		
		4	▨	▨	▨	2																			
		5	▨	▨	▨	2																			
C1206C102KDRAC	Serial	1	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2	
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		5	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	5	
C1206V223KDRAC	Shield	1	▨	▨	▨	1																			
		2	▨	▨	▨	1																			
		3	▨	▨	▨	▨	1																		
		4	▨	▨	▨	▨	1																		
		5	▨	▨	▨	▨	1																		

Figure 12. Pulse Test Capability of 1000V Rated MLCC

The shield designs tested had consistent performance with capability above 1200V. The lower capacitance serial designs had higher pulse capability with the 1206, 1000pF showing very high capability of 3000V. High breakdown voltage in air seems to correspond to high pulse capability. These pulse measurements were made at ambient temperatures in air and the effect of humidity and temperature on capability would be interesting to evaluate in the future.

Summary

The voltage breakdown performance of 1000V rated X7R MLCC were evaluated in air, inert fluid and 85% relative humidity/ 85^{o}C. The lower capacitance MLCC with serial designs had very high voltage breakdown in inert fluid that were significantly lowered in air indicating that surface arcing significantly reduces capability in these designs. The shield designs MLCC voltage breakdown in air and fluid was very similar since surface arcing is prohibited in these designs. In humid conditions the breakdown occurs at lower voltages and increasing dV/dt increases the occurrence of failures at lower voltages but the minimum breakdowns were not reduced on increasing the ramp rate to 1200V/sec. The performance of 0805 circuit boards in air and humidity showed higher breakdown than the MLCC so were not expected to influence the minimum breakdowns of assembled MLCC in these environments and this was confirmed in subsequent testing. The pulse test capability of all MLCC were evaluated using a 1.2 x 50µsec waveform and although the lower capacitance serial designs had higher peak voltage capability all the MLCC were > 1000V. Although this study did not assess the long term capability of the parts to perform in humid conditions these results show that it is possible to retain high breakdown performance in surface mounted 0805 MLCC after exposure to humid environments without the use of conformal coatings.

Acknowledgements

The authors would like to acknowledge the support of their colleagues, Kevin Lynn and Wanda Andrews.

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