



JOHANSON DIELECTRICS INC.

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Arc Season and Board Design Observations

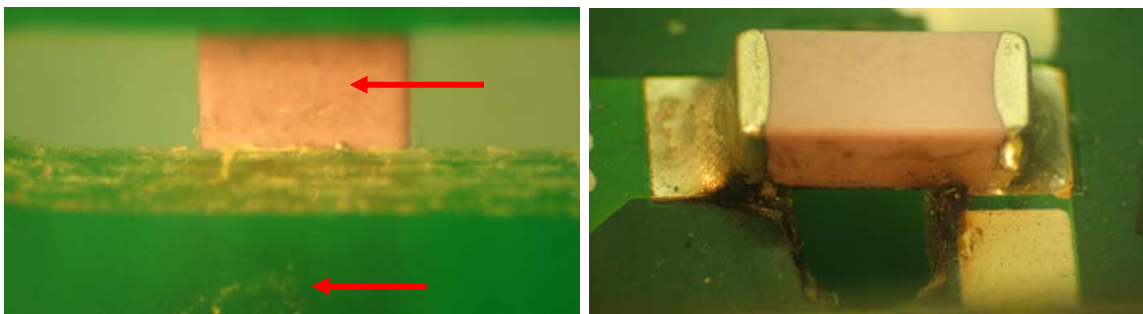
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This years arcing season is just now fading into bad memories as another year is past but knowing that a new season is just a Monsoon away. ARC season is well known to high voltage capacitor vendors and users alike and with the drive to smaller high voltage (HV) components like ceramic capacitors we know that the next season will arrive sooner and last longer. From a vendor's standpoint parts are shipped that meet the published specifications but when the customer mounts those same capacitors on an assembly, high voltage problems can arise. There may be interactions between the board and flux residue, humidity absorption of both the PWB (Printed Wiring Board) and flux residue, what type of flux is used in the solder paste and the high voltage capability of the board itself. These are the areas that need to be investigated.

Field Problems

Problems include test equipment correlation problems, test methods used for HV testing, but the big source of defects appear to be from a combination of the board layout, assembly process, choice of solder paste flux and cleaning where required. A large number of contract manufacturers around the world use water soluble flux solder paste because it is much more aggressive than No-Clean flux allowing for wider reflow process windows and minimizes component solderability problems. Unfortunately organic acids used in water soluble solder paste are very active and if the assembly is not adequately cleaned those flux residues start their damage and are difficult to remove. Now we are faced with high leakage currents, low arc voltages and assembly failures. Add humidity and we have a new ARC season. An interesting ARC season failure is shown in Figure 1. The board was reflow soldered using water soluble solder paste but not completely cleaned. The board design used a 2mm slot beneath 1808 case size high voltage safety capacitors. The use of slots are a typical high voltage board design technique. Complete and thorough cleaning of all flux residues is mandatory when this design technique is used with water soluble flux. There were droplets of flux residue on the assembly bottom and visible flux residues on the bottom of all 1808 size safety capacitors. The burned arc path shown in Figure 1 is along the slot edge in the PWB following flux residues.



a) Flux Residues on Chip & PWB Bottom

b) ARC Path in PWB Slot

Figure 1. Field Failure Due to Water Soluble Flux Residue



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The Experiment

High voltage 1206 3kV 120pF X7R capacitors were mounted on boards with 4 variations of pad/solder mask/slots to evaluate the impact common board layout techniques on AC breakdown voltage. A 5 mil thick stencil was used to replicate the customer environment. Stencil apertures were 95% of the pad area. No-Clean and water soluble solder paste formulations were evaluated to determine the interaction between flux and board layout after reflow soldering and after humidity exposure. An exposure time of 48 hours at 85°C/85%RH was chosen to drive moisture into the board and flux residues trapped beneath the chips. The capacitors were not biased consistent with most high voltage isolation applications typical for smaller safety capacitors.

These capacitors chosen for this experiment are 1206 case size X7R 120pF and are designed for 1500VAC withstanding voltage commonly found in larger safety capacitors. A 107 piece sample of these parts was tested to AC breakdown with the results shown in Figure 1.

Process Capability Analysis for 302R18W121KV

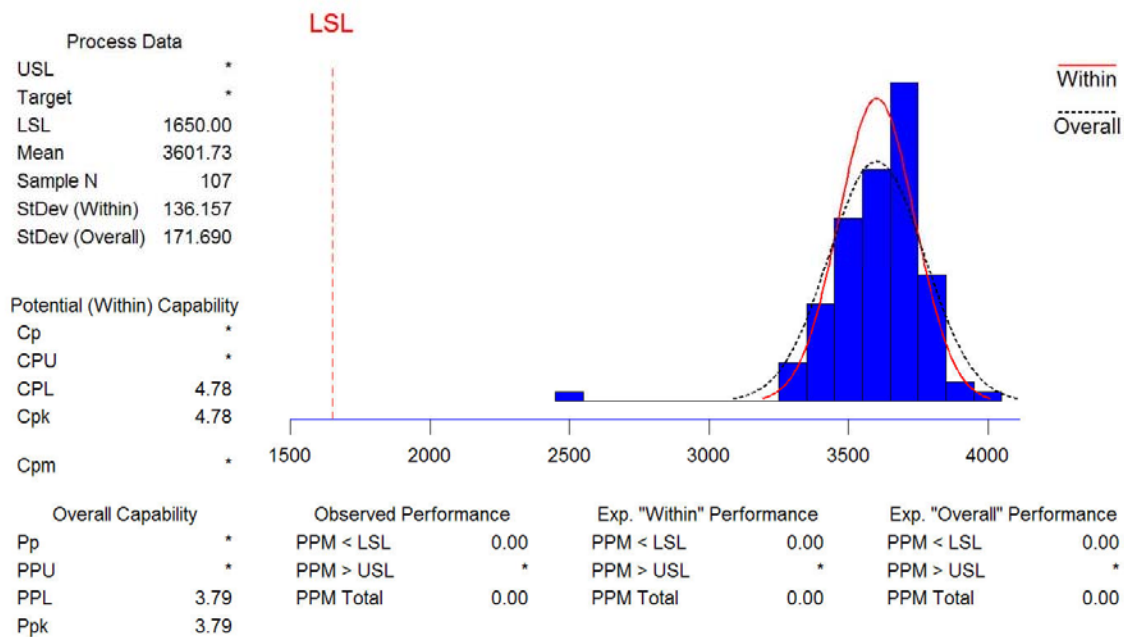


Figure 2. AC Breakdown Results for Test Lot of 302R18W121KV4 Capacitors

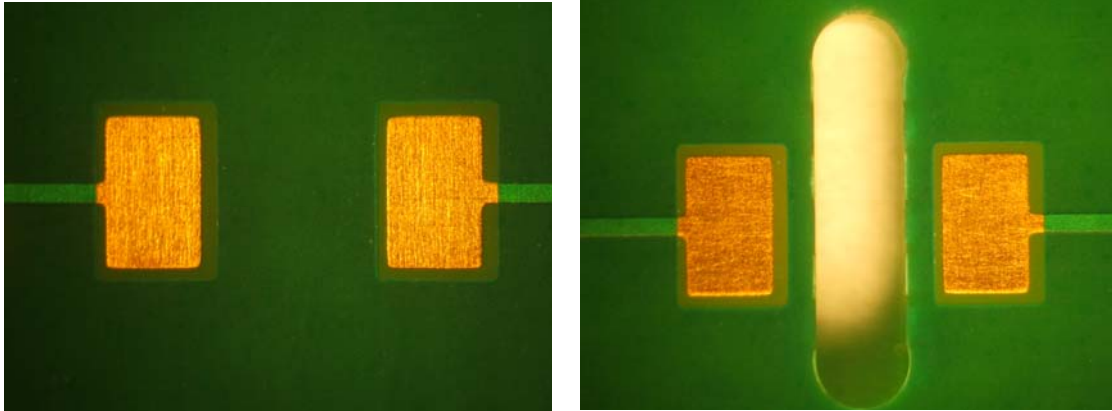
Board layout variations included solder mask between pads, no solder mask between pads, solder mask with a 0.040" (1mm) wide slot between pads and no solder mask with a 0.040" slot between pads. A larger slot was not practical for 1206 sized capacitors because of pad to pad spacing of 0.080" (2mm) was used. Figure 3 shows each layout variation for reference. Removing solder mask from between pads allows solvent access during cleaning when water soluble flux is used and minimizes flux flow between the capacitor pads due to capillary forces during reflow soldering.



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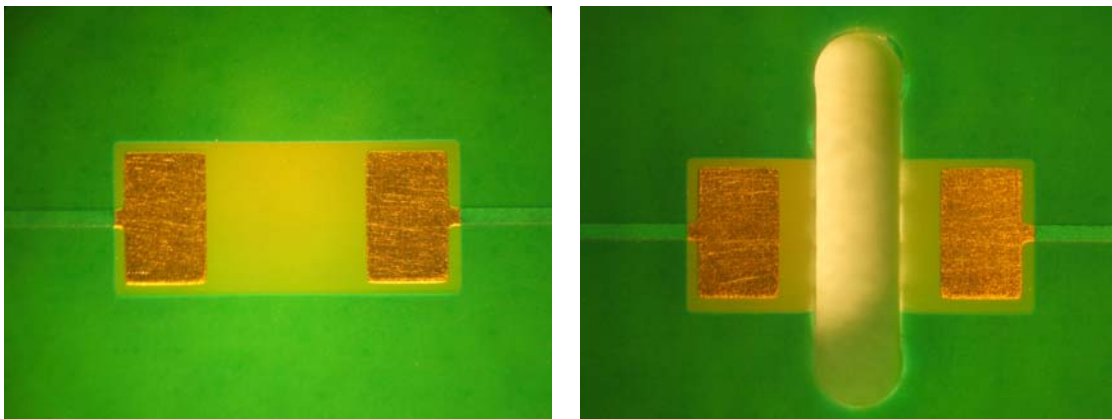
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Square pads were used as they are most commonly encountered on end customer's boards. Additionally square pads are the easiest to draw in board layout programs. Each evaluation board had 80 positions for each pad/solder mask/slot variation for increased confidence levels in the results. Bare board arcs were from pad corner to opposing pad corner as expected as square pad corners will have the highest electric field gradients.



a) Solder Mask between Pads

b) Solder Mask & Slot between Pads



c) No Solder Mask between Pads

d) No Solder Mask but Slot between Pads

Figure 3. Evaluation Board SMT Pad Variations

Two different solder paste and flux chemistries were used in these experiments and are listed in Table 1. These were chosen as they were readily available and are typical of solder pastes commonly used during board assembly.

Table 1. Solder Paste Used in Experiments

Paste Description	Type of Paste
ROL0 ANSI/J-STD-004	No-Clean
ORH0 ANSI/J-STD-004	Water Soluble



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The experimental procedure consisted of exposing both bare boards and assemblies to AC breakdown. A bare board as received was tested for AC breakdown voltage distribution. A second evaluation board had Sn63 No-Clean solder paste stenciled on the pads and reflowed. Those results are listed in Appendix 1 and are used as a baseline for comparisons with capacitors mounted to boards with different fluxes and humidity exposure. What is interesting is that the board AC breakdown capability significantly increased after exposure to reflow soldering temperatures. After components were soldered to the boards and exposed to 48 hours of 85°C/85%RH those breakdown voltages returned to values consistent with the bare board in an as received condition. Real world assemblies will absorb moisture after soldering and depending on where the assemblies are manufactured, stored and the 48 hours of humidity exposure the results inline with the board in its as received condition. The data for the bare board and those with capacitors solder to it is consistent with reflow soldering drying out the assembly.

Appendix 2 lists AC breakdown results for capacitors reflow soldered to an evaluation board with No-Clean solder paste, tested approximately 18 hours after reflow soldering and an assembly that was exposed to 85°C at 85% RH for 48 hours and then tested 1 hour after the board was removed from humidity exposure. Appendix 3 has assembled board breakdown results approximately after two hours after cleaning. This assembly used water soluble solder paste. The other breakdown data is for an assembly with capacitors and water soluble solder paste, reflow soldered, cleaned and exposed to 85°C/85% RH for 48 hours. This assembly was tested to breakdown within 2 hours of humidity exposure. Table 2 is a summary all of the AC breakdown results shown in the appendices.

Table 2. Summary of all Breakdown Test Mean Value Results (Volts)

Pad Layout	Bare Bd.	NC Bd.	NC Caps	NC 85/85	WS Caps	WS 8585
Solder Mask	2552	2952	3002	2682*	2522	2327
SM/Slot	2615	3341	3075	3099	2622	2515
No SM	2406	3098	3097	2957	2624	2487
No SM/Slot	2619	3254	3150	3222	2859	2756

Bare Bd.	Bare board as received
NC Bd.	Bare board reflow soldered with No-Clean solder paste
NC Caps	Board w/capacitors reflowed w/No-Clean solder paste
NC 85/85	No-Clean solder paste w/caps after 48 hour exposure to 85°C/85%RH
WS Caps	Board w/capacitors reflowed w/water soluble solder paste
WS 85/85	Water soluble solder paste w/caps after 48 hours of 85°C/85%RH

* There were some breakdown values below the specification limit of 1500VAC and broad distribution of breakdown voltages



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Observations

Examining both the mean of the breakdown voltages and the actual distributions shown in Appendices 2 and 3 are revealing. Solder mask between pads was consistently the poorest performer in AC breakdown testing in these experiments. Slots between pads were consistently the best performers as expected. No solder mask between pads was comparable with the layout option of solder mask and a slot between the capacitor pads. Figures 4 and 5 are the distributions for No-Clean solder paste with no solder mask between pads and water soluble solder paste with solder mask between pads with a 0.040" (1mm) slot. Both assemblies underwent 48 hours exposure at 85°C/85%RH.

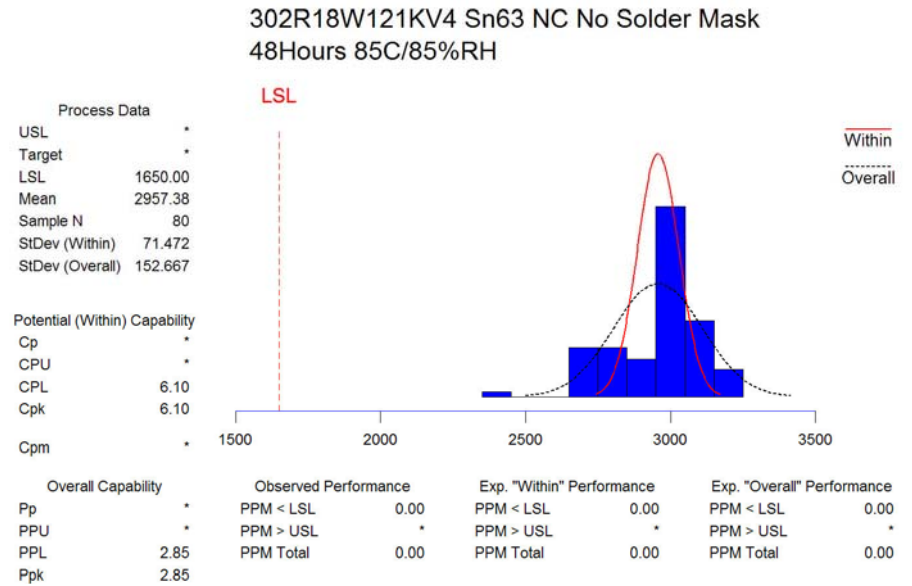


Figure 4. AC Breakdown Distribution 48 Hours 85°C/85%RH Exposure
No-Clean Solder Paste, No Solder Mask
302R18W121KV4 Sn63 WS No Solder Mask
w/Slot 48 Hrs 85C/85%RH

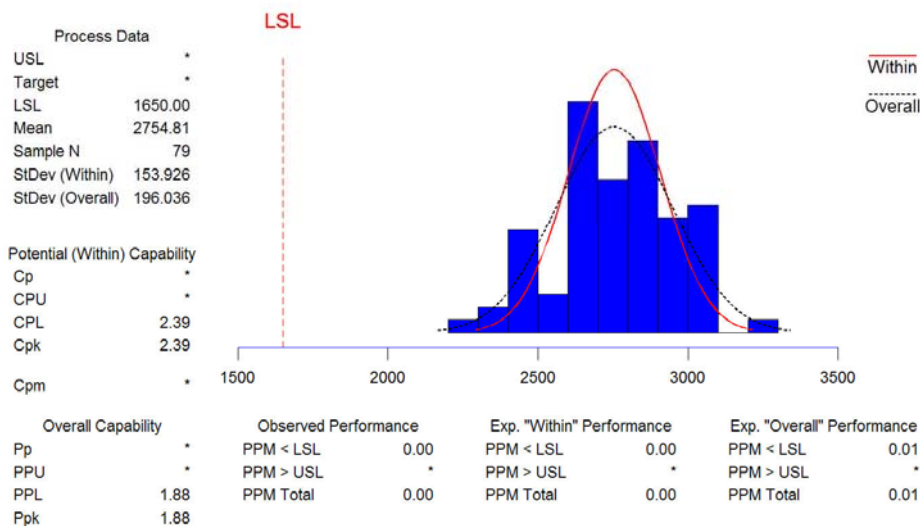


Figure 5. AC Breakdown Distribution 48 Hours 85°C/85%RH Exposure



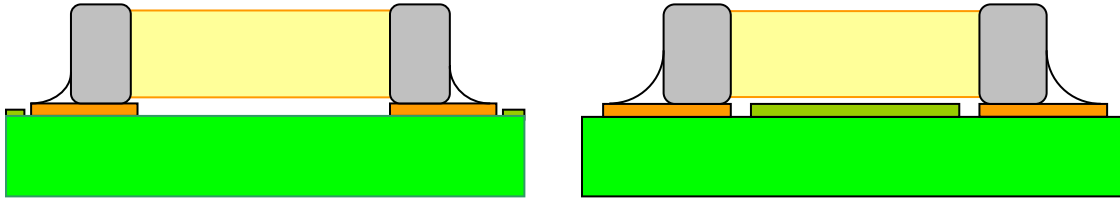
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Water Soluble Solder Paste, No Solder Mask with 1mm Slot

PWB Layout Suggestions

The data are consistent with eliminating high voltage slots where allowed and removal of solder mask between pads. Figure 6 represents a chip soldered to pads with and without solder mask showing the added gap between chip bottom and PWB surface.



a) No Solder Mask between Pads b) Solder Mask between Pads

Figure 6. Solder Mask Layout Options

Flux residues are trapped between capacitor bodies and solder mask during reflow soldering when the flux is liquid. This is due to capillary forces wicking the flux between the solder mask and capacitor body. Figure 7 shows three parts removed from a board that suffered ARC season defects. The flux is clearly visible in this photo. The parts were removed by placing the assembly on a hot plate and were plucked off using tweezers when the solder reflowed. These particular boards had a 2mm slot between pads but failed 1500VAC during HiPot testing. Bottom side of capacitors showing flux residues trapped between capacitor bodies and solder mask. The flux flow stopped at the PWB slot and has arrows pointing to the flux gaps.

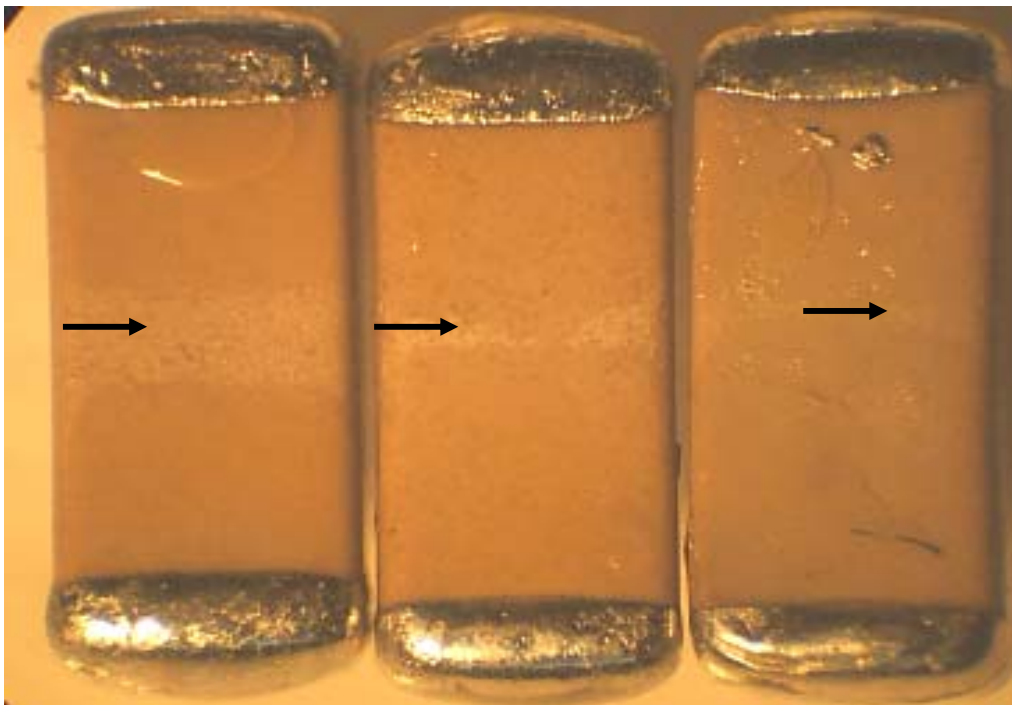


Figure 7. Bottom Side of Capacitors Showing Trapped Flux Residue Leading to Failure



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In addition to eliminating solder mask between pads, the pads themselves should have radiuses instead of rectangular corners. All arcs emanated from pad corners due to those locations having the highest electric field gradients when exposed to high voltage fields. Adding a radius at each corner will reduce field gradients aid in high voltage performance. Suggested pad radiuses are shown in Figure 8.

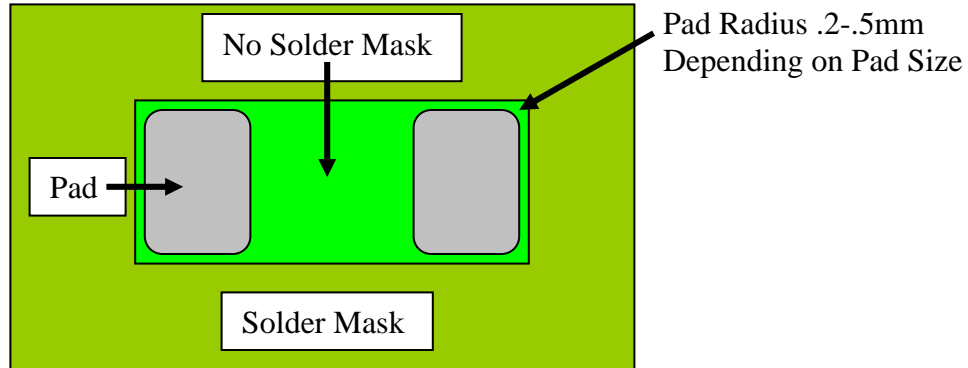


Figure 8. High Voltage Surface Mount Pad Radius Suggestions

Summary

The data are consistent with cost savings by eliminating slots where possible by eliminating solder mask between pads. There is the additional benefit of creating cleaning access if water soluble solder paste is used in board assembly. And finally spreading out field gradients by adding a radius to pads can aid in improving AC breakdown performance. Each layout suggestion needs to be evaluated in new designs as each design will have unknown quirks.

As a side note high voltage components should never have traces beneath the component body and voltage creepage requirements to eliminate arcing to adjacent components and traces.

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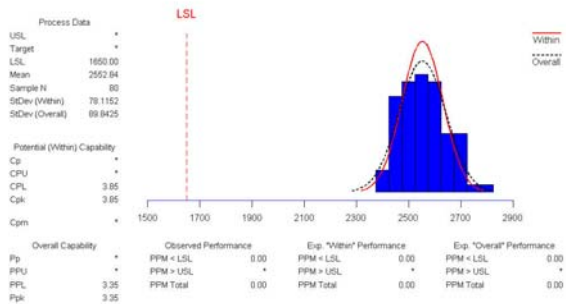


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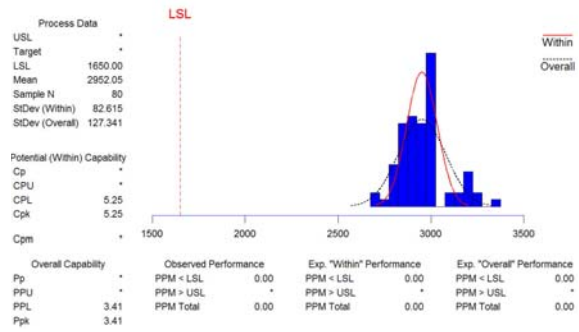
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Appendix 1. Bare Board and Sn63 NC Solder Paste AC Breakdown Results

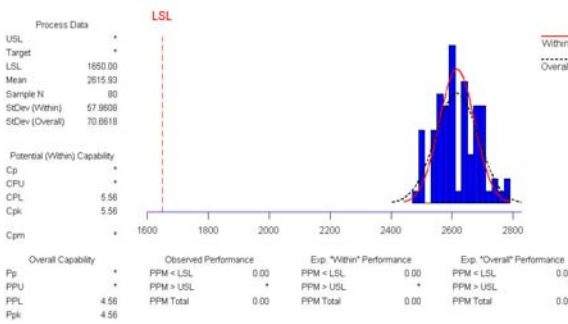
Process Capability Analysis for Solder Mask



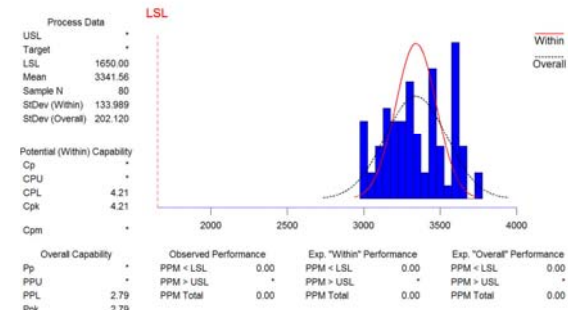
Process Capability Analysis for Sn63 NC Solder Mask



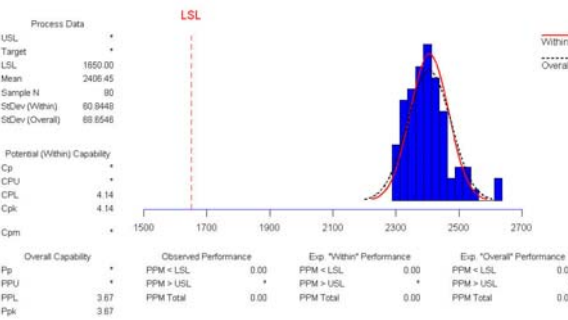
Process Capability Analysis for Solder Mask with slot



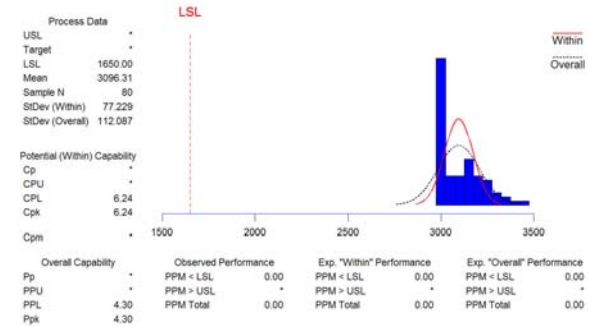
Process Capability Analysis for Sn63 NC Soldmask w/Slot



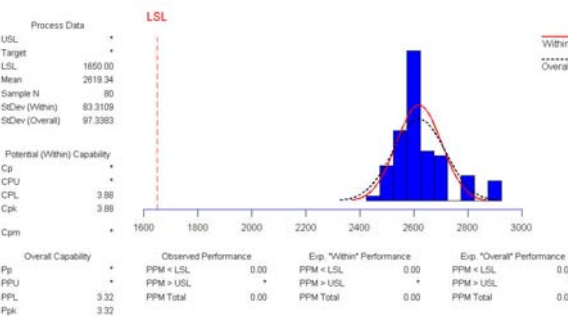
Process Capability Analysis for No Solder Mask



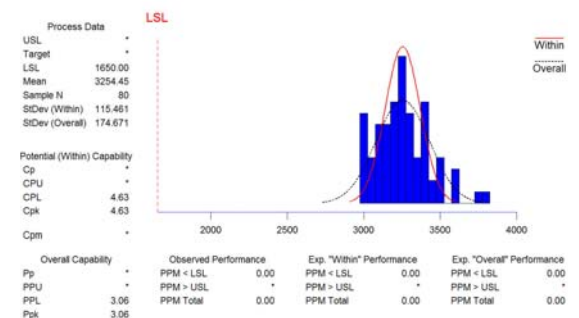
Process Capability Analysis for Sn63 NC No Solder Mask



Process Capability Analysis for No Solder Mask with slot



Process Capability Analysis for Sn63 NC No Solder Mask w/Slot

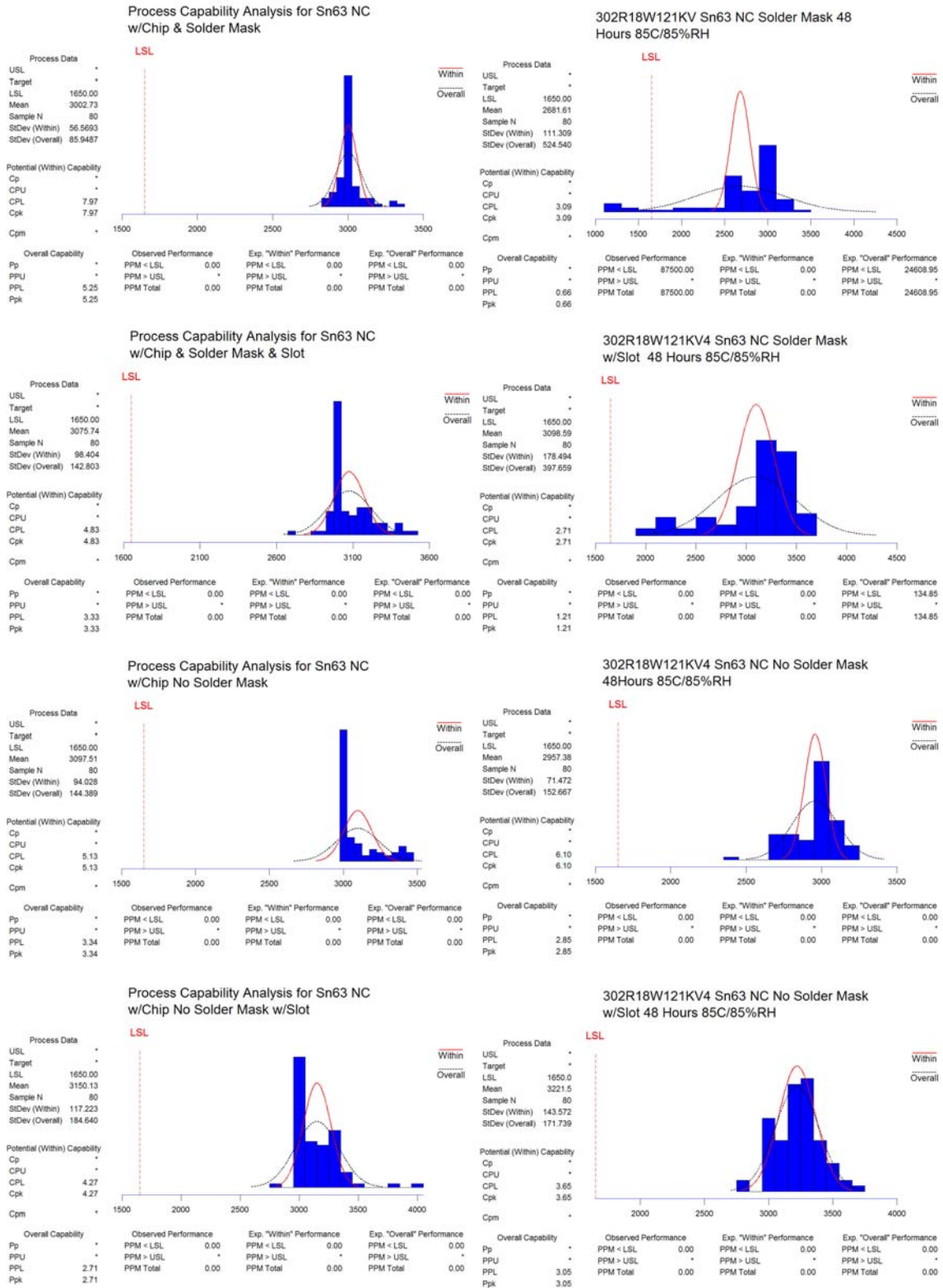




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Appendix 2. AC Breakdown Results for Capacitors Reflow Soldered w/Sn63 No-Clean Flux With and Without Humidity Exposure





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Appendix 3. AC Breakdown Results for Capacitors Reflow Soldered w/Sn63 Water Soluble Flux With and Without Humidity Exposure

