

# Combination of Spray and Soak Improves Cleaning under Bottom Terminations

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## **Abstract**

The functional reliability of electronic circuits determines the overall reliability of the product in which the final products are used. Market forces including more functionality in smaller components, no-clean lead-free solder technologies, competitive forces and automated assembly create process challenges. Cleanliness under the bottom terminations must be maintained in harsh environments. Residues under components can attract moisture and lead to leakage currents and the potential for electrochemical migration.

Removing flux residues from under bottom terminations is extremely challenging. As components decrease in size, the Z-axis gap height also reduces. When the Z-axis gap is less than 3 mils (75um), the capillary and wetting action of flux during reflow underfills the bottom termination component with flux residue. To clean, the cleaning fluid and mechanical action must reach, wet and dissolve the soil in order to create a flow channel. Once a flow channel is created, the soils under the terminations are effectively cleaned.

The purpose of this research study is to evaluate innovative spray and soak methods for removing low residue flux residues and thoroughly rinsing under Bottom Termination and Leadless Components. Targeted spray nozzles deliver the cleaning agent to the soil. Following this interaction with an agitated soak allows the flux residues to dissolve. Targeted spray nozzles rapidly move the dissolved residues and fully clean residues under terminations. This designed experiment will study process parameters in order to draw inferences from the data findings.

## **Highly Dense Interconnects**

Electronic assemblies have become more compact, more densely populated, and designed with very low standoff bottom termination components. These components have solderable areas under the body of the component or protruding to the edge of the component (Figure 1).<sup>1</sup> Bottom Termination Components (BTC) are similar to BGAs and have descriptive package names such as QFH, DFN, SON, LCA and MLP. Most BTC packages have large ground or power termination pads surrounded by smaller signal terminations. In combination with other leadless components, such as chip cap resistors, capacitors, FETs etc., the terminations are just metalized or pads underneath the package.<sup>2</sup>

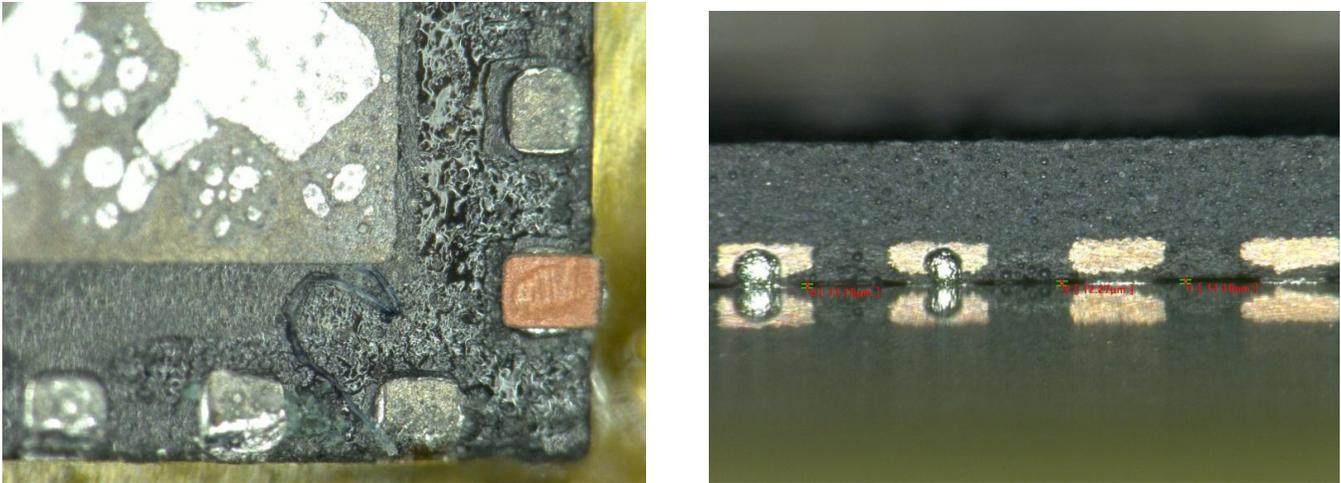


Figure 1: Flux Residues under Bottom Termination Components

Proper cleanliness levels are more difficult to achieve on components with solderable areas under the body of the component. The smaller spacing between conductors yields a larger electronic field, which in conjunction with insufficient cleaning can lead to electrical leakage and/or dendritic growth (Figure 2).<sup>3</sup> Flux residues trapped under the body of the component may lead to electrical shorts and/or intermittent operation of equipment. Tighter lead pitches results in low standoff gaps. Penetrating these gaps to wet and dissolve flux residues requires strong chemical and mechanical forces.

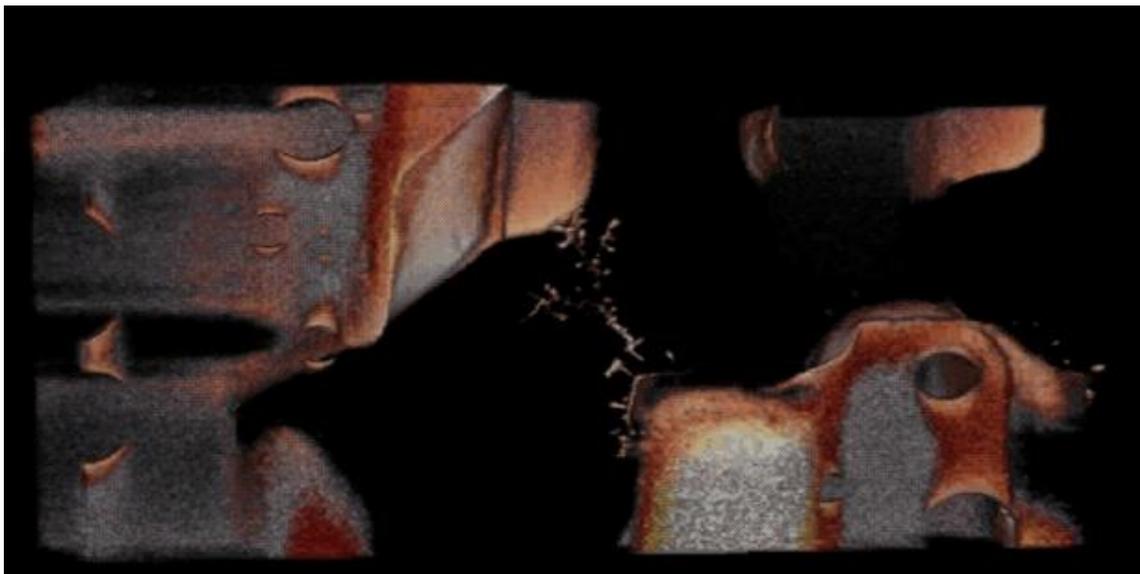


Figure 2: Electrochemical Migration under a Leadless Component<sup>4</sup>

#### Key Elements to Successful Cleaning Highly Dense Interconnects

Numerous factors come into play when designing a cleaning process. One of the first factors to consider is designing the assembly with cleaning in mind. Influential cleaning design factors include open spaces, higher component clearance, optimal soldering conditions, cleanable soils, hermetically sealed components and material compatibility effects. Research data finds that when standoff gaps are sufficient to allow air to penetrate and exhaust during reflow, excessive flux volatiles are burned off with the residue remaining next to the soldered connection. Designing conditions that result in increased gap heights opens the cleaning process window by reducing flux residue levels and creating a flow channel for the cleaning fluid to wet and dissolve flux residues (Figure 3).<sup>5</sup>

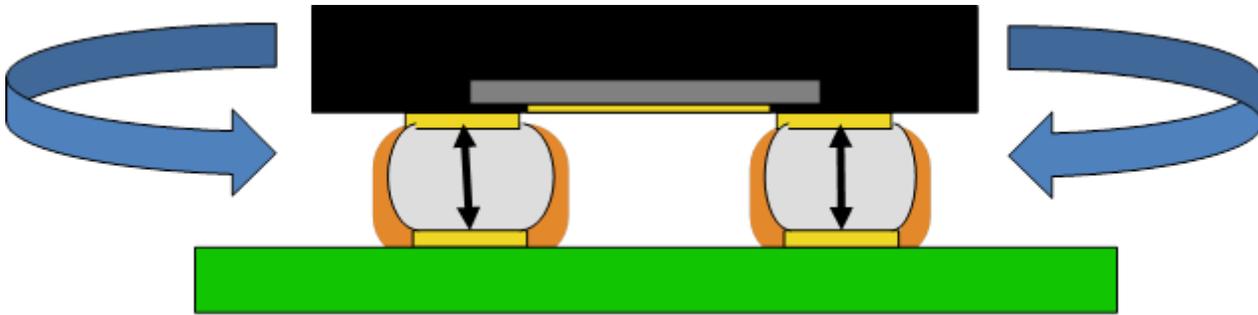


Figure 3: High Standoff Gaps allows for Air Flow and Exhaustion during Reflow

Conversely, when standoff gaps are low, typically less than 2 mils (50um), capillary forces of attraction from the flux residue during reflow accumulates. Air flow and penetration is blocked by the flux residues that are underfilling the under body of the component. This effect underfills the under body with flux residue and blocks all flow channels for the cleaning fluid to wet and dissolve flux residues (Figure 4).<sup>5</sup> To clean the flux residues under the bottom termination, high mechanical forces are needed to penetrate small gaps with the cleaning agent. This requires longer wash time, stronger chemical effects and higher levels of energy.

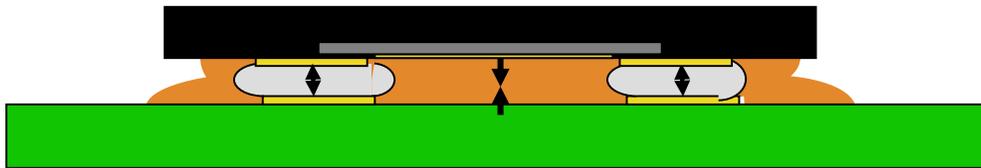


Figure 4: Low Standoff Gaps Prevents Air Flow and Exhaustion during Reflow

Assemblers have a range of solder pastes that fall under the category of water soluble, rosin and low residue no-clean to select from when building the assembly. Additionally, the melting point of the alloy determines the temperature at which the flux residue is exposed. Longer exposure time within the reflow oven at higher temperatures increases the hardness of the remaining flux residue. Hard to clean flux residues require stronger cleaning chemical and mechanical effects to remove. These soil properties increase the time needed to remove flux residues under bottom terminations (Figure 5).

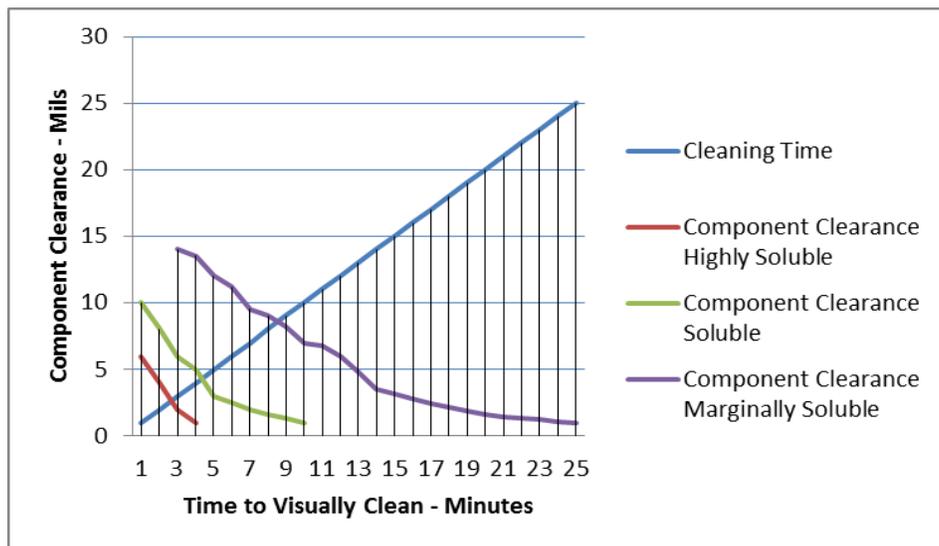


Figure 5: Harder to Clean Soils and Low Standoff Gaps Increase Cleaning Time<sup>6</sup>

### Research Purpose

The cleaning process involves two main components, the cleaning agent and the cleaning equipment. A new advancement in inline cleaning equipment was designed to track the electronic assembly through the wash and rinse chambers so that the cleaning and rinse water barely cover the assembly. This soaking effect brings the assembly to a stable fluid temperature while the board progresses through the wet sections of the cleaning machine. By flooding the assembly, the cleaning agent and rinse water wets the residue. The purpose of this research is study the soaking and dissolution effects provided by the new equipment and how this improves cleaning under bottom termination components.

### Cleaning Equipment Advancement Theory

Traditionally, inline cleaners have used a series of spray bars and nozzles mounted on the top and bottom of a moving conveyor as the sole means to deliver cleaning and rinsing solutions to the circuit board (Figure 6). In this standard configuration the pressures, spray patterns, and the speed of the conveyor can all be adjusted. When these adjustments are optimized for a particular circuit board, cleaning results are good. However, as circuit boards have become smaller and populated more densely with low standoff components, these traditional approaches toward optimizing the cleaning process have reached their limits.

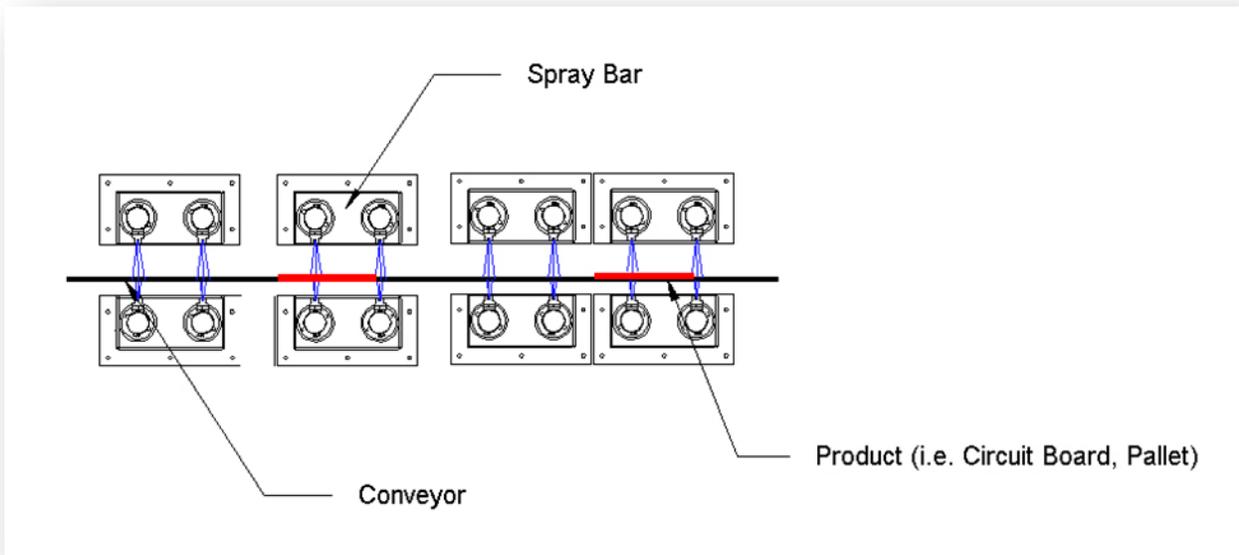


Figure 6: Traditional Spray Bar Only Configuration

The developed equipment is a contained area in the wash and/or rinse sections of an inline cleaner. Within the flood box area, the surface of the circuit board (or other product being cleaned) is completely submersed in an agitated solution. The circuit board is literally flooded with solution while also being sprayed from traditional spray bars (Figure 7).

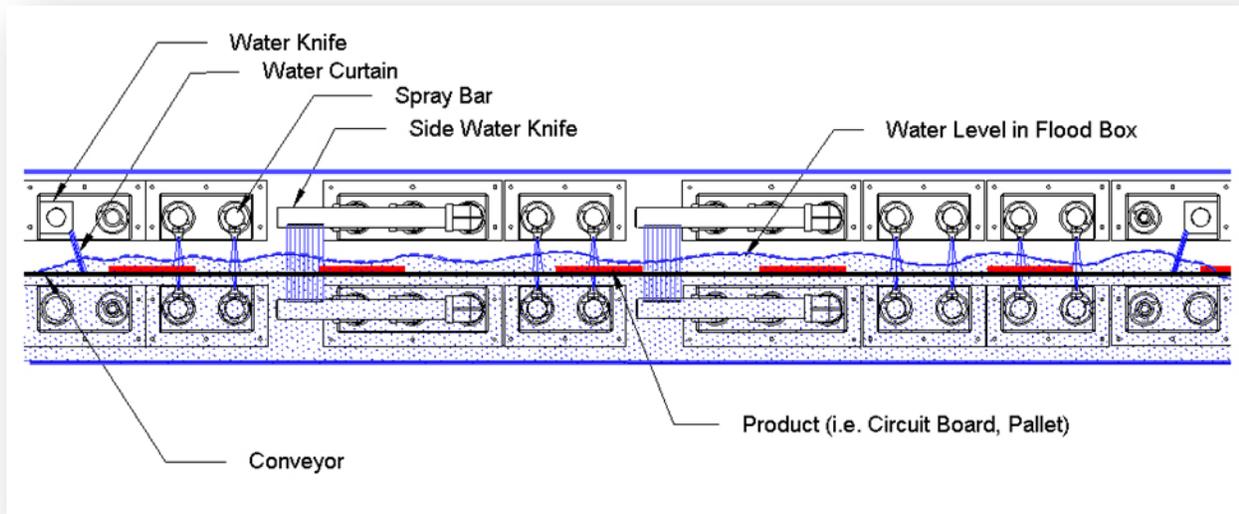


Figure 7: Developed Equipment Section Configuration

This flooding allows the chemical solution to reach everywhere possible on the circuit board. There are no concerns about shadowing from components because the entire board is submersed. Low standoff components are engulfed in the solution so that the cleaning liquid will invade every possible opening for optimal penetration. The wetting effects of the cleaning solution at process temperature soften the residues. When the board is hit with impingement spray, the softened residues are flushed away.

The board is submerged without the raising or lowering of the inline conveyor. The board travels through the flooded section and continues through the remainder of the inline cleaner which may include traditional spray bar sections, isolation sections, and drying sections. This uninterrupted process allows for higher production levels.

### Research Design

The research is designed to study two factors:

1. The removal of flux residues under leadless chip capacitors on 13 solder pastes
2. Ionic cleanliness of both flux residue and rinsing of wash cleaning agent under QFN/BTC quad flat no-lead components

### DOE #1 Methodology

The first designed experiment studied the cleaning efficacy for removing flux residues under leadless chip capacitors. The gap heights on leadless chip caps typically range from 1-3 mils (25-75um) (Figure 8). Due to the low standoff gap, flux residue attractive capillary forces tend to underfill under the body of the component. To clean, the cleaning agent must wet, soften and dissolve flux residue under the body of the component. Low residue no-clean, RMA and water soluble solder pastes were included to provide a range of soft and hard residue conditions.

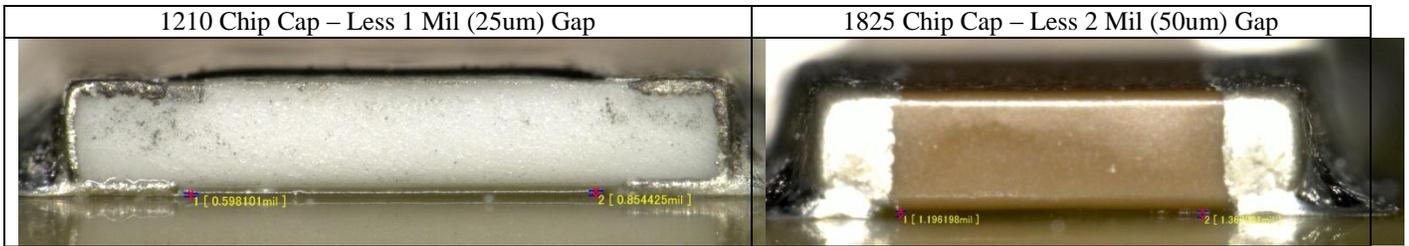


Figure 8: Flux Residues Underfill the Under Body of Leadless Chip Caps

Figure 9 provides a view of the level of flux residues under the body of the components. The components were removed using a flat blade tool.

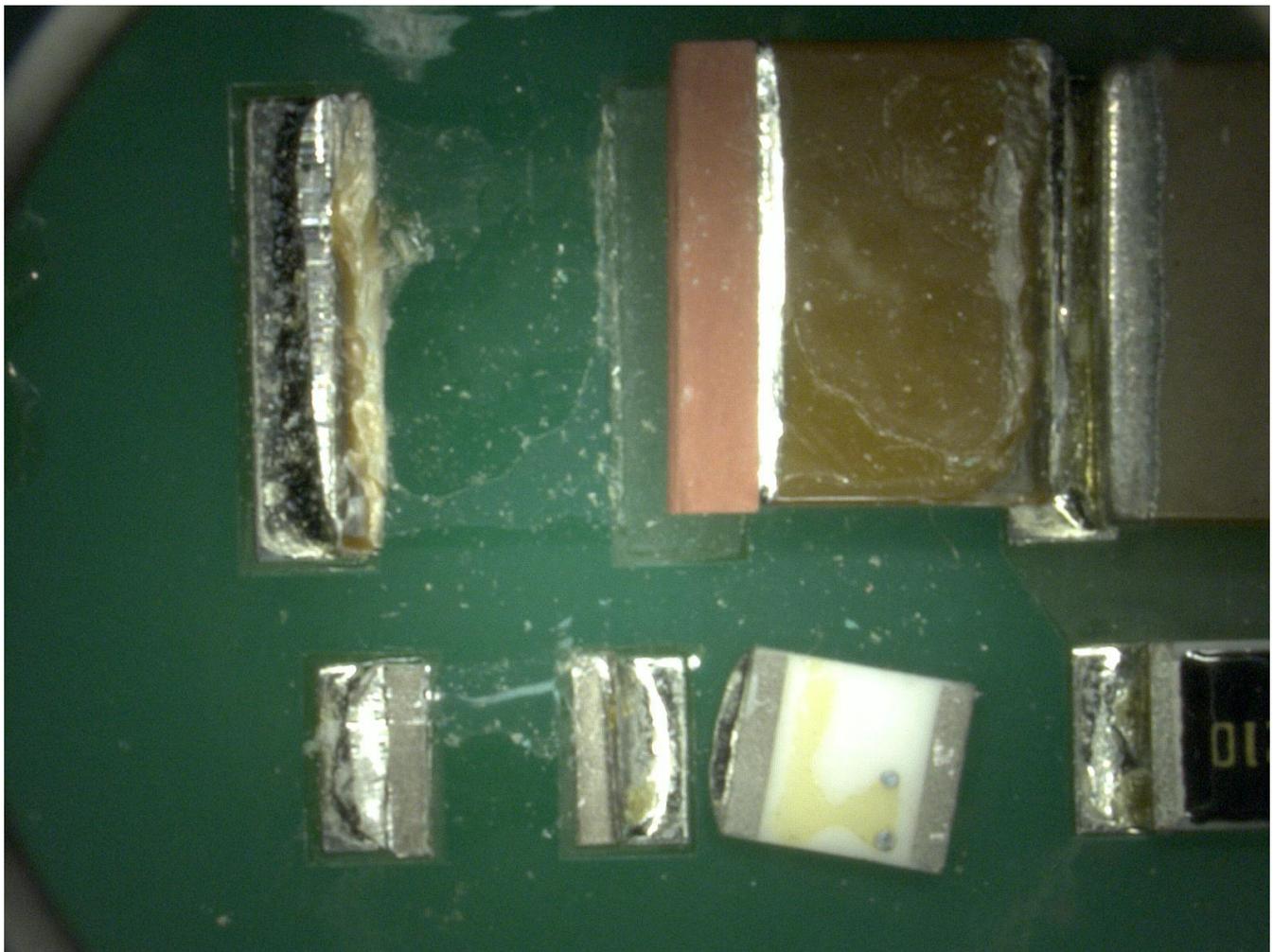


Figure 9: Flux Residues Under the Body of the Component

The combination of the cleaning agent and cleaning machine are critical to dissolving the residue and creating a flow channel under the body of the component. Past research finds that narrow spray patterns provide high deflective forces to move the cleaning agent under the body of the component. To clean hard flux residues, the time in the wash typically requires 10-15 minute exposure time. The new equipment technology submerges the circuit board with the cleaning and rinsing fluids. The liquid layer that barely submerges the board keeps the assembly at temperature while wetting the residues under the body of the component.

The components are sealed on two sides with components placed vertically on the top side of the board and horizontally on the bottom side of the board (Figure 10).

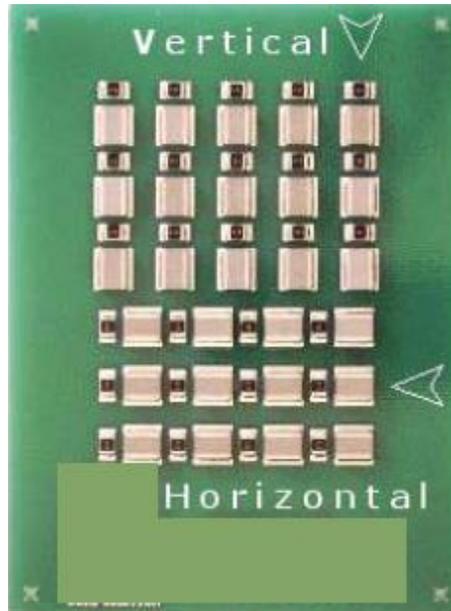


Figure 10: DOE #1 Company Test Vehicle Populated with 1210 and 1825 Chip Caps

- Factors
  - Solder Pastes
    - Tin-Lead Rosin
    - Tin-Lead No-Clean
    - Lead Free Water Soluble
    - Lead Free No-Clean
  - Conveyor Speed
    - 0.5 FPM (feet per minute)
    - 1.0 FPM
    - 1.5 FPM
  - Solder Mask Definition
    - No SM (Solder Mask)
    - NSMD
  - Chip Components
    - 1210
    - 1825
  - Component Placement
    - Vertical
    - Horizontal

### DOE # 1 Data Findings

The response variable for the first DOE measures the mean level of flux residue remaining under the body of components on test vehicles processed through an inline cleaning machine equipped with the new equipment technology (Figure 9). The level of flux residues were graded after removing all components from the test boards. Analysis of Variance was used to examine differences among level means for one or more factors. A main effect is present when different levels of a factor affect the response differently. Each level of the factor affects the response in the same way, and the response mean is the same across all factor levels. Different levels of the factor affect the response differently. The steeper the slope of the line equates to a larger magnitude for that effect.

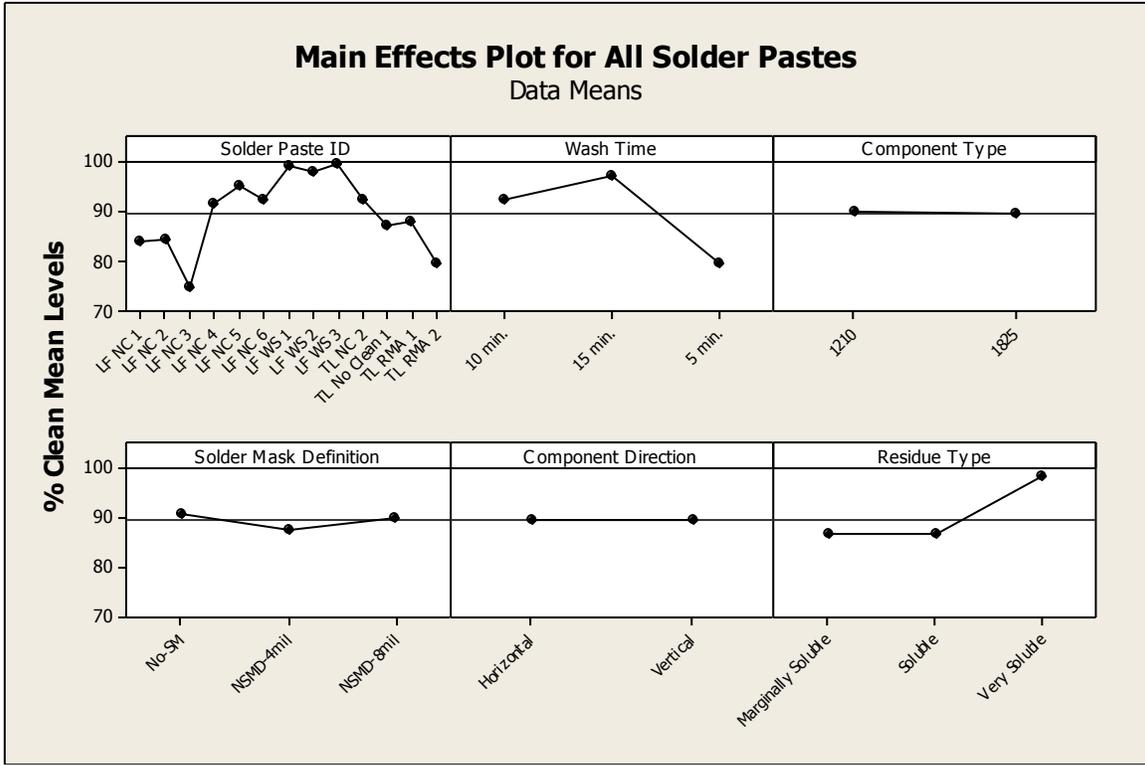


Figure 11: Main Effects for all Solder Pastes

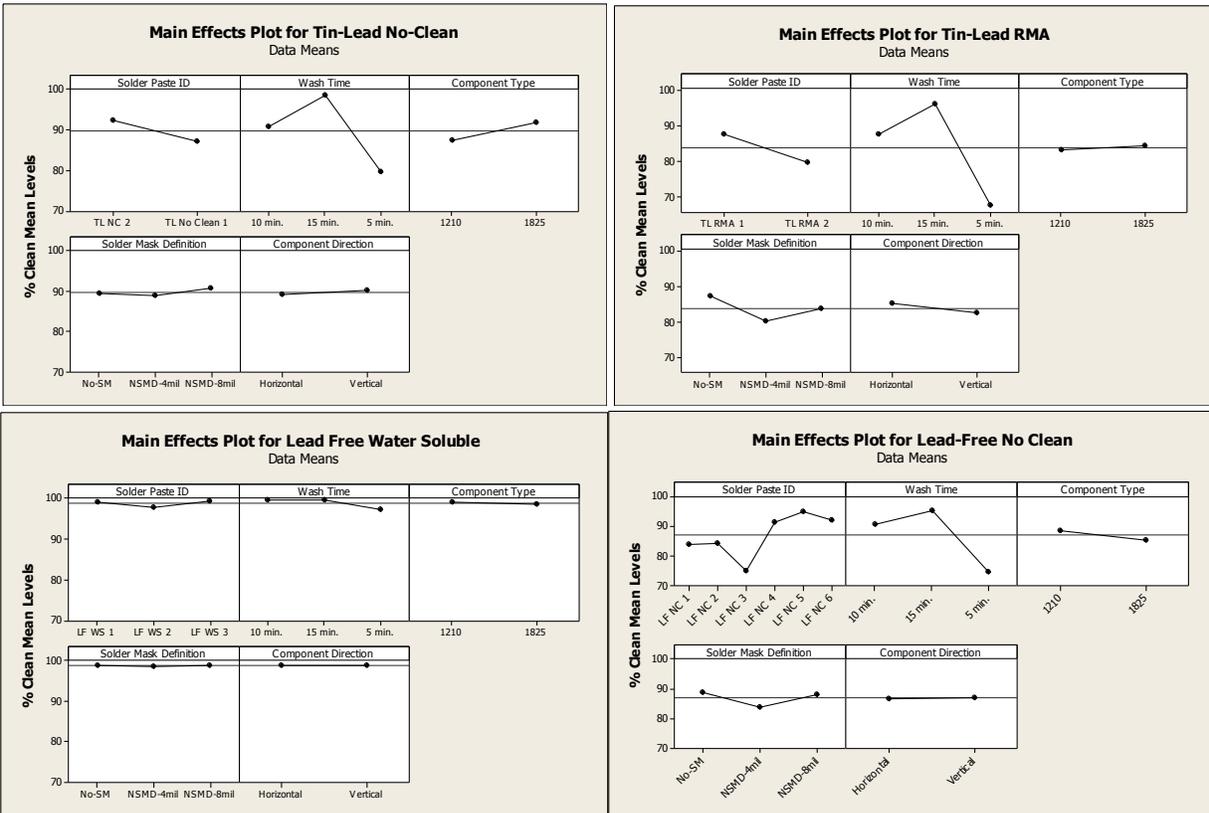


Figure 12: Main Effects for Each Solder Paste Type

## DOE #2 Methodology

The second designed experiment quantified the levels of chloride, bromide and weak organic anions and ammonium cations. Ion Chromatography is an analytical technique used to validate cleaning and rinsing effectiveness. Analytical results were expressed in micrograms per unit area. Acceptable levels can change dependent on the product type, application and environment from which the end product will be used. On highly dense assemblies used for high reliability applications, the acceptable limits are commonly reduced. Failure analysis data is commonly used to develop limits designed to separate good performance from bad performance.

Anions measured within this study that are considered problematic and indicative of flux residues being present under the body of the component are Chloride, Bromide and Weak Organic Acids. One cation was measured that is considered problematic and indicative of cleaning agent trapped under the body of the component. This cation is the ammonium ion. For purposes of this experiment, anions provide a measure for the cleanliness levels of flux residues under the component, and the ammonium cation provides a measure for rinsing the cleaning agent under the component.

Common industry acceptable levels of the anions and cation measured within this experiment are listed in Table 1.

Table 1: Common Industry Acceptable Levels

<b>Anions</b>	<b>Level of <math>\mu\text{g}</math> of the ion per <math>\text{in}^2</math> surface area</b>
Chloride	<6 $\mu\text{g}/\text{in}^2$
Bromide	<12 $\mu\text{g}/\text{in}^2$
Weak Organic Acids	<25 $\mu\text{g}/\text{in}^2$
<b>Cation</b>	
Ammonium	<6 $\mu\text{g}/\text{in}^2$

The QFN (quad flat no-lead)/ BTC test vehicle was fully populated with MLF88 and MLF124 dual row components (Figure 13). A solid ground pad under the body of the QFN/BTC is commonly used by assemblers. On solid ground pads, the flux residue tends to push out into the areas surrounding the component pads. Heavy flux deposits under the body of the component are both active and difficult to clean.

The test boards were processed with the same cleaning agent as used for the cleaning of the boards in DOE #1. The water soluble boards had a wash time of 5 minutes and rinse time of 3 minutes. The no-clean boards had a wash time of 10 minutes and rinse time of 6 minutes.

Via holes were designed within QFN/ BTC ground pads. The thinking behind via holes was to provide an avenue for the flux residue to drain to the back side of the QFN/ BTC ground pad. Via holes provide a path for air to flow and exhaust during reflow. Research data finds that air flow and exhaustion during reflow allow flux volatiles to burn off, which results in lower levels of residue under the body of the component. Via holes could also increase voiding in the ground pad soldered joint.

On the component sites selected for Ion Chromatography analysis, the component was removed using a straight blade. The specific site extractions were done with a localized extraction system and then Ion Chromatography was performed on the extracted solutions.

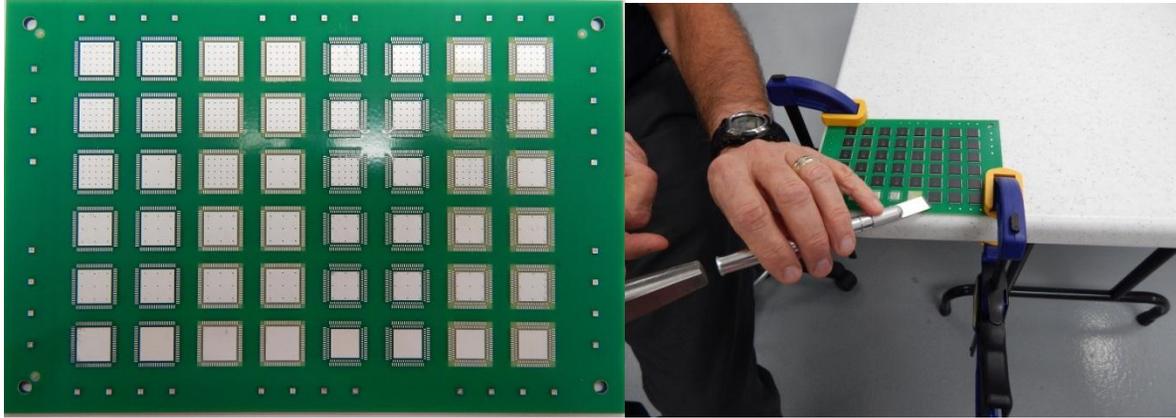


Figure 13: QFN/BTC Test Vehicle / Component Removal Method

Four patterned solder paste ground pad designs were studied (Figure 14). Patterned ground pads provide a path for air to penetrate and exhaust during reflow. If the solder does not coalesce onto the ground pad during reflow, a flow channel for cleaning fluid penetration and exhaustion exists. Properly designed, patterned ground pads can result in less residue under the body of the component which are easier to clean.

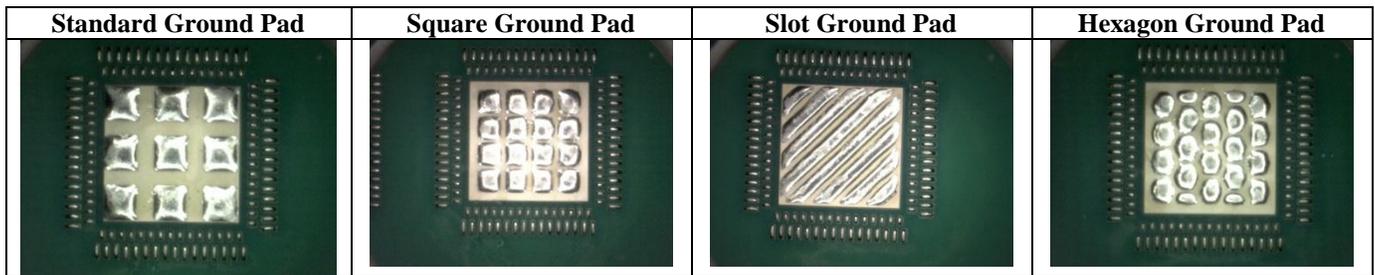


Figure 14: Ground Pad Designs

One Lead-Free No-Clean and one Lead-Free Water Soluble solder paste were factored into the DOE. Non solder mask defined (NSMD) and No-Solder Mask (No-SM) solder mask definitions were factored into the DOE. Eight boards were processed with a total of 160 sites selected for Ion Chromatography analysis. The sites selected for Ion Chromatography are highlighted in yellow as shown in Table 2.

Table 2: Yellow Sites Selected for Ion

	NSMD MLF88	NSMD MLF88	NoSM MLF88	NoSM MLF88	NSMD MLF124	NSMD MLF124	NoSM MLF124	NoSM MLF124
	25 vias 1-1	25 vias 1-2	25 vias 1-3	25 vias 1-4	25 vias 1-5	25 vias 1-6	25 vias 1-7	25 vias 1-8
	25 vias 2-1	25 vias 2-2	25 vias 2-3	25 vias 2-4	25 vias 2-5	25 vias 2-6	25 vias 2-7	25 vias 2-8
	25 vias 3-1	9 vias 3-2	25 vias 3-3	9 vias 3-4	25 vias 3-5	9 vias 3-6	25 vias 3-7	9 vias 3-8
	9 vias 4-1	9 vias 4-2	9 vias 4-3	9 vias 4-4	9 vias 4-5	9 vias 4-6	9 vias 4-7	9 vias 4-8
	9 vias 5-1	9 vias 5-2	9 vias 5-3	9 vias 5-4	9 vias 5-5	9 vias 5-6	9 vias 5-7	9 vias 5-8
Chromatography	Solid 6-1	Solid 6-2	Solid 6-3	Solid 6-4	Solid 6-5	Solid 6-6	Solid 6-7	Solids 6-8

**DOE #2 Data Findings**

The chloride ion, and its salts such as sodium chloride, is very soluble in water. The salts of hydrochloric acid contain chloride ions, commonly referred to as chlorides. Low levels of chloride ions can lead to electrochemical migration. In the presence of monolayers of water, the chloride ions will readily dissolve and form a weak hydrochloric acid solution. This acidic solution dissolves metal ions present in solder alloys. When the part is biased, the positively charged metal ion is attracted to the negative cathode. Over time, the metal ion plates from the cathode to the anode. Eventually the metal dendrite will short out the component leading to part performance issues. Chloride ions contain the highest correlation factor to electrochemical migration effects. The mean  $\mu\text{g}/\text{in}^2$  Chloride ions under QFN/BTC components data findings are listed in Figure 15.

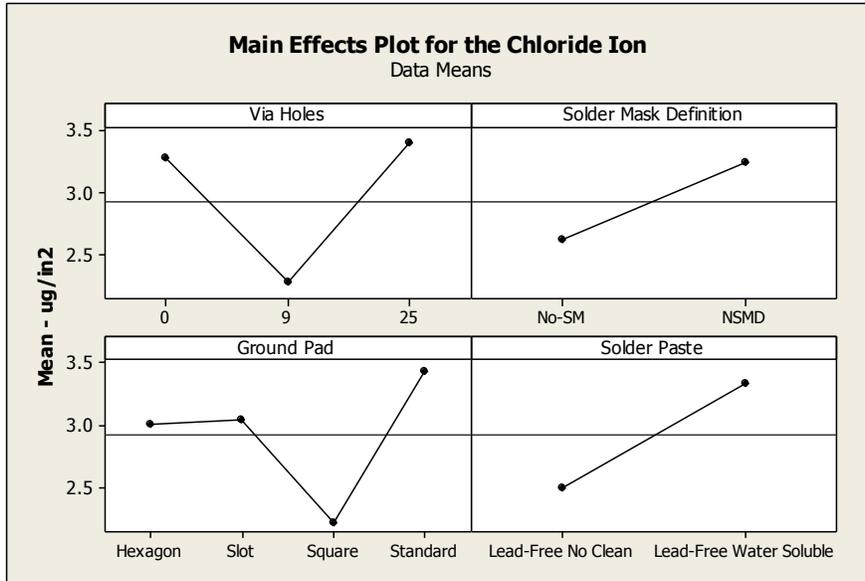


Figure 15: Chloride Ion Data Findings

Brominated flame retardants are organo-bromide compounds that have an inhibitory effect on the ignition of combustible organic materials. The bromide anion, similar to the chloride ion, is deficient of one electron. Bromide ions are also soluble in water. Tetrabromobisphenol A (TBBPA) is a common flame retardant used in printed circuit boards. TBBPA is chemically bound to the resin within the printed circuit board and is less easily released than the chloride ion. As such, the common industry acceptance levels for problematic bromide ion levels toward electrochemical migration are slightly higher than the chloride ion. The mean  $\mu\text{g}/\text{in}^2$  Bromide ions under QFN/BTC components data findings are listed in Figure 16.

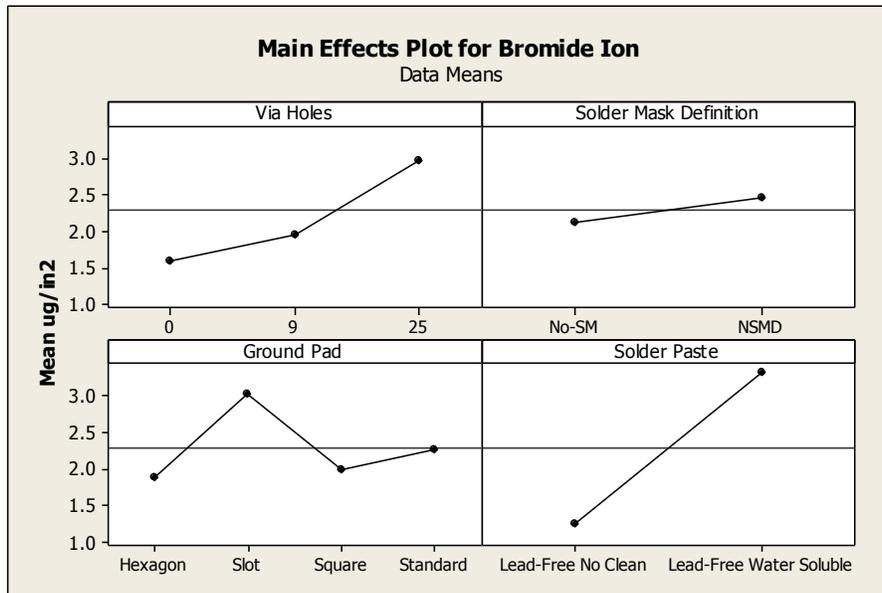


Figure 16: Bromide Ion Data Findings

Carboxylic acids used within flux compositions make up a group of ions referred to as “Weak Organic Acids.” Weak acids do not dissociate completely in water. As such, common industry acceptance levels for the problematic levels of weak organic acid ions are significantly higher than halide ions (chloride and bromide ions). The mean  $\mu\text{g}/\text{in}^2$  Weak Organic Acid ions under QFN/BTC components data findings are listed in Figure 17.

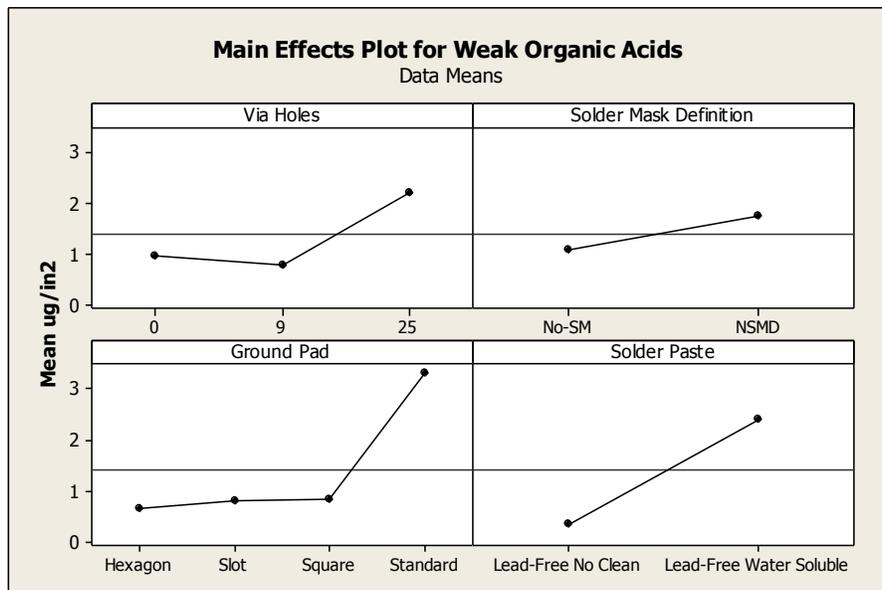


Figure 17: Weak Organic Acids Data Findings

The ammonium ion is a positively charged polyatomic cation with the chemical formula  $\text{NH}_4^+$ . Aqueous electronic assembly cleaning agents are commonly formulated with polar activators that contain the ammonium ion. The ammonium ion levels can be used to measure rinsing effectiveness. When cleaning bottom termination components, rinsing the cleaning agent under very small gaps typically requires sufficient rinse time. High levels of ammonium ions can be an indicator that small levels of cleaning fluid are still present under the component. Data findings for the Ammonium Ion are listed in Figure 18.

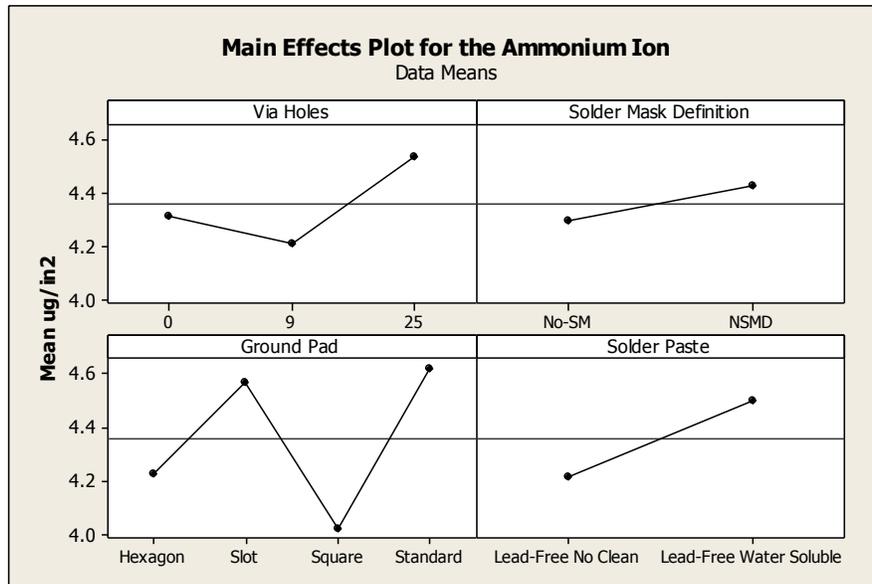


Figure 18: Ammonium Ion Data Findings

### Inferences from data findings

The first DOE studied the visual levels of flux residue under chip capacitors. The components were sealed on two sides with flux residues underfilling the under body of the component. The components were placed both vertically and horizontally onto the test vehicle. For each factor within the designed experiment, the inferences from the data findings found:

- Wash Time: Three wash times were included within the DOE. On marginally soluble flux residues, longer wash time is needed to totally clean under all components on the circuit board. The higher the dissolution rate of the residue into the cleaning agent, the time required in the wash is lower.
- Solder Pastes: Thirteen solder pastes were included within the DOE.
  - Eutectic Tin-Lead No-clean solder pastes ~ 2 solder pastes studied
  - Eutectic Tin-Lead RMA solder pastes ~ 2 solder pastes studied
  - Lead-Free SAC 305 No-clean solder pastes ~ 6 solder pastes studied
  - Lead-Free SAC 305 Water Soluble solder pastes ~ 3 solder pastes studied

The static cleaning rate (rate at which the residue dissolves in the cleaning agent in the absence of impingement force) of the solder pastes flux residues within the cleaning agent varies depending the molecular structure, residue hardness, heat exposure during reflow and match of the flux residue composition with the cleaning agent. Water soluble flux residues typically have a higher static cleaning rate and typically dissolve within the cleaning agent faster than do lead-free and rosin flux residues. Eutectic lead-free and rosin flux residues typically have a higher static cleaning rate over lead-free no clean flux residues. Refer to Figure 5, which correlates cleaning time with the residue properties.

The data found that highly soluble lead-free mean water soluble visual flux residues under the body of components were cleaned very well using the new equipment technology. Less wash time was required to totally remove flux residues. Solder mask definition and/or component direction did not factor into cleaning efficacy.

The data found the removal of mean eutectic tin-lead no-clean visible flux residues under the body of components were 80% clean at 5 minutes of wash exposure, 90% clean at 10 minutes of wash exposure and 99% clean at 15 minutes wash exposure. When cleaning harder to dissolve flux residues, longer wash times are needed to break the flux dam, breakthrough the dam,

create a flow channel and totally clean the under body of the component. From experience in cleaning these component types, the new equipment technology performed very well.

The data found the tin-lead RMA mean visible flux residues under the body of the components were 70% clean at 5 minutes of wash exposure, 85% clean at 10 minutes wash exposure and 97% clean at 15 minutes wash exposure. The data findings indicate that the dissolution of the RMA flux was slightly slowed compared with the eutectic Tin-lead flux residues in this study. The findings can vary dependent on the solder paste and cleaning agent. Again, the new equipment technology performance was good.

The data found the lead-free no-clean mean visible flux residues under the body of the components were 75% clean at 5 minutes of wash exposure, 90% clean at 10 minutes wash exposure and 96% clean at 15 minutes wash exposure. The data found that some of the solder pastes were harder to clean than other solder pastes studied. Past studies find that lead-free no clean solder pastes, due to their higher molecular weights and reflow temperatures, are harder to clean. The new equipment technology performance was again good.

- Solder Mask Definition: The data found that removal of solder mask from under the body of the component cleans slightly better than Non-Solder Mask Defined pads. Design for cleaning testing finds that both removal of solder mask under the body of the component and next to the pad have positive cleaning effects.<sup>8</sup> The data findings with past research findings were similar in this area.
- Component: The 1210 chip cap is typically more challenging to clean than the 1825 chip cap. The gap height for the 1210 is typically less than 2 mils (50um), whereas the gap height for the 1825 chip cap is typically 3-4 mils (75-100um). Even though the 1825 has more surface area under the body of the component, the higher gap improves cleaning effects. The data within this study found that some solder paste residues are harder to clean under the 1210 chip cap while some of the solder paste residues clean similarly.
- Direction: The data found minor cleaning differences between the vertical and horizontal component positions. The directional results indicate that the new equipment technology overcomes any concerns with shadowing issues.

The QFN/BTC test board was used to test ionic cleanliness and rinsing under the body of the components. One hundred and sixty extractions were performed. Table 3 lists a summary of the statistics from all extractions.

Table 3: Ion Chromatography Statistical Summary

Variable	Solder Paste	N	Mean (µg/in <sup>2</sup> )	SE Mean	Std. Dev.	Minimum
Chloride Ion	Lead-Free No Clean	79	2.506	0.252	2.240	0.589
Chloride Ion	Lead-Free Water Soluble	80	3.338	0.224	2.000	0.867
Bromide Ion	Lead-Free No Clean	79	1.247	0.101	0.895	0.103
Bromide Ion	Lead-Free Water Soluble	80	3.319	0.475	4.245	0.034
Weak Organic Acid Ions	Lead-Free No Clean	68	0.3776	0.0361	0.2975	0.1200
Weak Organic Acid Ions	Lead-Free Water Soluble	71	2.395	0.689	5.810	0.130
Ammonium Ion	Lead-Free No Clean	79	4.2177	0.0595	0.5286	2.4136
Ammonium Ion	Lead-Free Water Soluble	80	4.498	0.111	0.991	3.047

The water soluble ion levels were slightly higher on average than were the ions from the No-Clean flux residue. This is not unexpected since water soluble activators are highly ionic.

Chloride ions, considered to be the ion of greatest concern for propagating dendritic growth, is a common by-product of flux residue, plating salts and handling. Removal of chloride ions is critically important to increasing mean time to failure. Common industry acceptable levels for the Chloride Ion are stated at 6 µg/in<sup>2</sup>. Dependent on the product design and

reliability standard for the specific application from which the printed circuit board will be used, the acceptable level could be lower than  $6 \mu\text{g}/\text{in}^2$ . The levels detected were significantly lower than the stated acceptable levels.

Bromide ions are also considered to be problematic for propagating dendritic growth. A common source of Bromide ions is from flame retardants within the bare board. The bromide ion, chemically bound to the resin within the circuit board, is less easily released and bonded with water. As such, the acceptable level of Bromide ion is commonly stated at  $12 \mu\text{g}/\text{in}^2$ . The levels detected were significantly lower than the stated acceptable levels.

Weak Organic Acid ions are a by-product of flux residues. These weakly acidic ions do not completely dissociate in water. The levels detected were significantly lower than common industry acceptable levels of  $25 \mu\text{g}/\text{in}^2$ .

Ammonium cations can be found in flux residues and residual cleaning agent trapped under a component. When cleaning boards highly populated with bottom termination components, the ammonium ion can be an indicator of rinse quality. Inline cleaning tools typically have shorter rinse sections following the wash. Limited rinse exposure on tightly gapped compounds, such as the QFN/BTC used in this study, can potentially leave behind some residuals that make up the cleaning agent. Common acceptable industry levels for the ammonium ion are  $6 \mu\text{g}/\text{in}^2$ . The rinse time for the lead-free water soluble solder paste was 3 minutes and for the lead-free no-clean solder paste it was 6 minutes. The marginally higher levels may indicate that a longer rinse time may be needed. Even so, the detected level for the ammonium ion was less than the common acceptable industry level.

The ion chromatography data indicates that the new equipment technology is an effective technology for cleaning flux residues and ionic contaminants from under the body of Bottom Termination Components.

## **Conclusions**

The new equipment technology is a novel technology for cleaning under the body of Bottom Termination Components. The data finds that the new equipment technology is effective at cleaning both flux residues and ionic contamination under the body of the component. Placing a light layer of cleaning and rinsing fluids over the surface of the printed circuit board creates desirable properties. One of those properties comes from the soaking action of the cleaning agent onto the residue. The soaking action softens the flux residue and when bombarded with spray impingement rapidly displaces the flux residue. Cleaning agent pooled onto the surface of the board lowers surface tension, which helps penetration under tightly gapped components.

Another key benefit of the new equipment technology is reduced need for coherent spray jets. Coherent spray jets deliver the cleaning agent at higher pressures onto the printed circuit board. The pressurized spray jets provide strong deflective forces for penetrating and moving the cleaning agent under the component. A tradeoff of coherent jets is the ability to undercut labels, remove part marking and potentially affect other material compatibility effects. With the new technology, fan sprays are used, which provides less impact to the board. As a result, material compatibility effects may be less.

Rinsing is another area of concern when cleaning under the body of Bottom Termination Components. The new equipment technology can improve rinsing. The cleaning agent is attracted to water. With a layer of water covering the surface of the board within the rinse section, removal of the cleaning agent under Bottom Termination Components can be improved. Since rinse sections are relatively short on inline cleaning machines, the addition of the flooded technology can be highly beneficial to assuring that residual cleaning agent is rinsed from under the component.

## References

1. SMART Group. (Nov. 5, 2010). Bottom Termination Component. Retrieved from Electronic Product Design and Test <http://www.epdtonthenet.net/article.aspx?ArticleID=37819>
2. Prasad, R. (April 24, 2009). Problems and Promises of BTCs: Bottom Termination Components. Axiom Electronics. Retrieved from <http://www.axiomsmt.com/index.php/2009/04/problems-and-promises-of-btcs-bottom-termination-components/>
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4. Travis, J. (2013, Oct.). Dendrites. Nordson Dage – Yestech.
5. Bixenman, M., Lee, D., Vuono, B. and Stach, S. (2013). QFN Design Considerations to Improve Cleaning. SMTAI Technical Conference, Fort Worth, TX.
6. Bixenman M. (2013, Oct). Cleaning and Contamination Process Guide. Global SMT Packaging. Retrieved from [http://www.globalsmt.net/smt/index.php?option=com\\_content&view=article&id=20643&Itemid=396](http://www.globalsmt.net/smt/index.php?option=com_content&view=article&id=20643&Itemid=396)
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8. Bixenman, M. and Lee, D. (2012, Sep). Cleaning Medical Electronics. MEPTEC/SMTA Medical Conference. Phoenix, AZ.

# Combination of Spray & Soak Improve Cleaning

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# Agenda

- Abstract
- Highly Dense Interconnects
- Cleaning under Bottom Terminations
- Research Purpose
- Research Design
- Inferences from Data Findings
- Conclusions



NEW IDEAS ... FOR NEW HORIZONS

**MARCH 25-27, 2014**

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# ABSTRACT

# PCB Market Forces

- Market forces
  - Smaller components
  - No-clean lead-free soldering
  - Bottom Terminations
  - Cleanliness
  - Reliability of the final product

# PCB Cleaning

- Removing flux residues
  - Extremely challenging
  - Z-axis gap heights reducing
  - Flux capillary action underfills bottom termination
- Cleaning fluid and mechanical action
  - Penetrate
  - Wet
  - Create a flow
  - Dissolve all flux residues

# Purpose of the Research

- Evaluate innovative spray and soak methods
  - Cleaning efficacy under bottom terminations
- Designed Experiments
  - Flux removal efficiency
    - Eutectic Tin-Lead Solder Pastes
    - Lead-Free Solder Pastes
  - Ionic Residues Present under Bottom Terminations
    - QFN Test Vehicle
    - Site Specific Analysis



NEW IDEAS ... FOR NEW HORIZONS

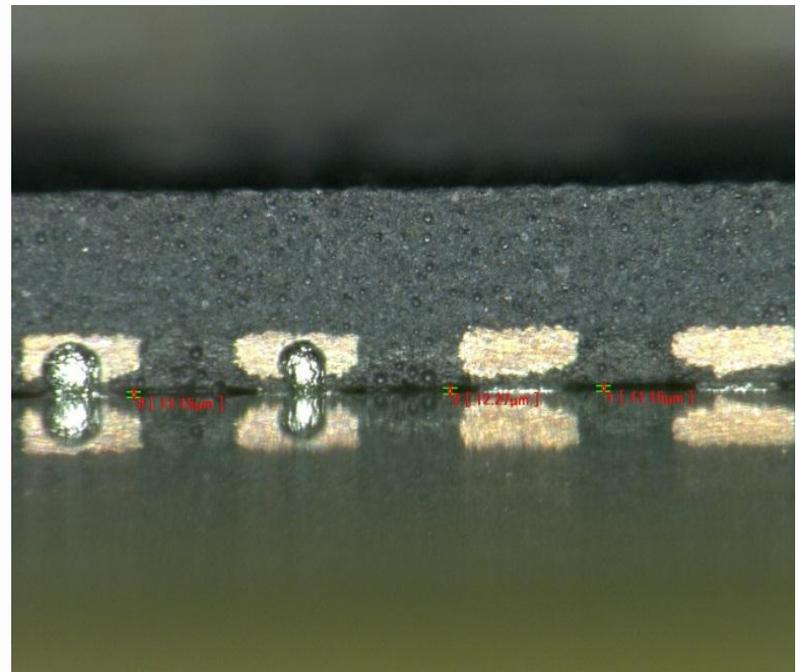
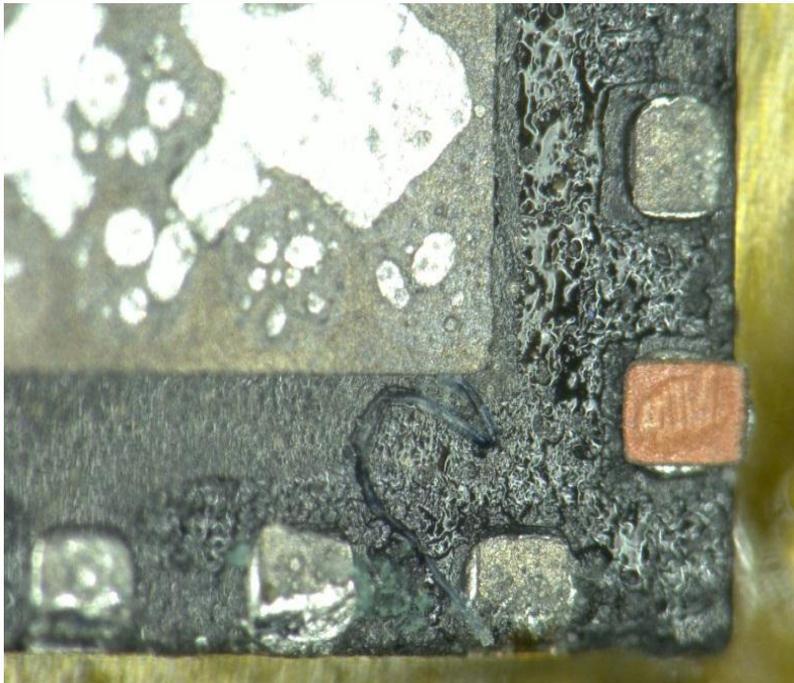
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# HIGHLY DENSE INTERCONNECTS

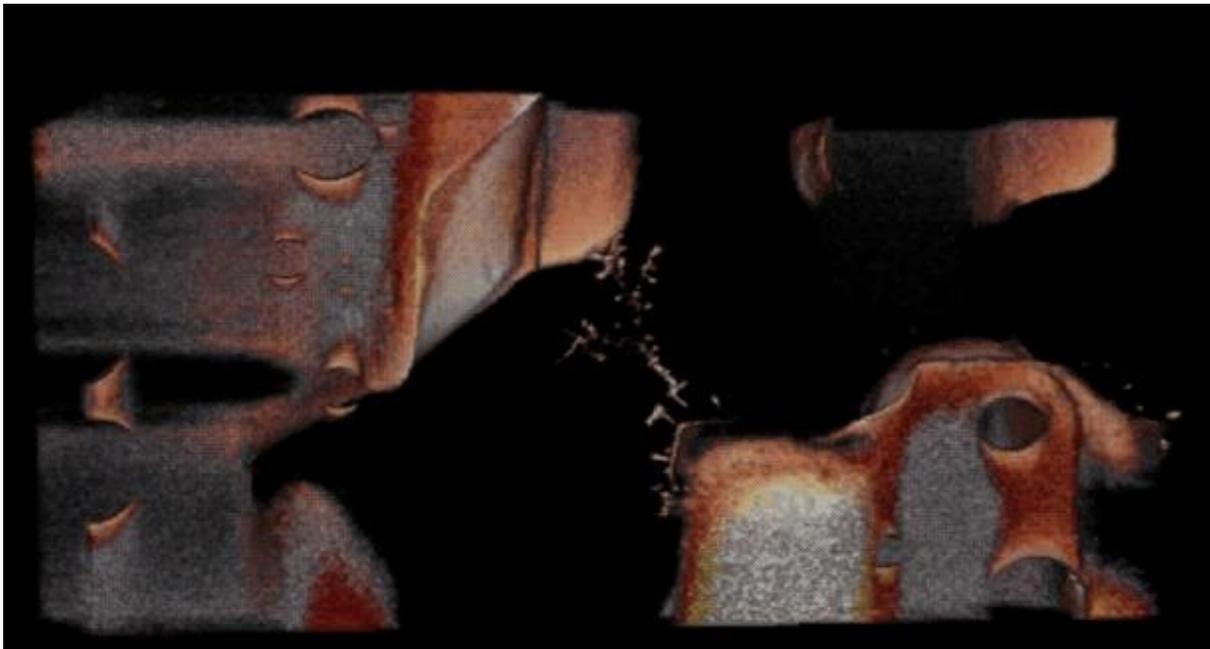
# Bottom Termination Components

- Solderable areas under component body
- Protrude to the edge of the component



# Smaller Spacing between Conductors

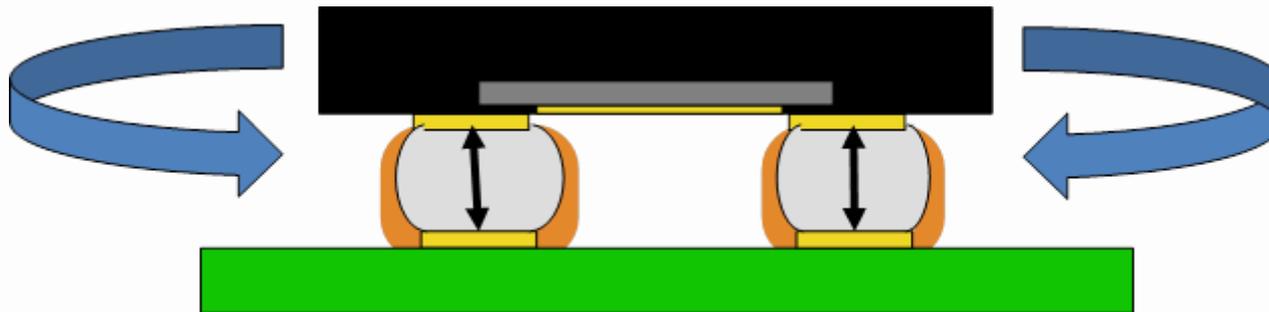
- Yields a higher electric field
- Low levels of ionic contamination problematic



# **CLEANING UNDER BOTTOM TERMINATIONS**

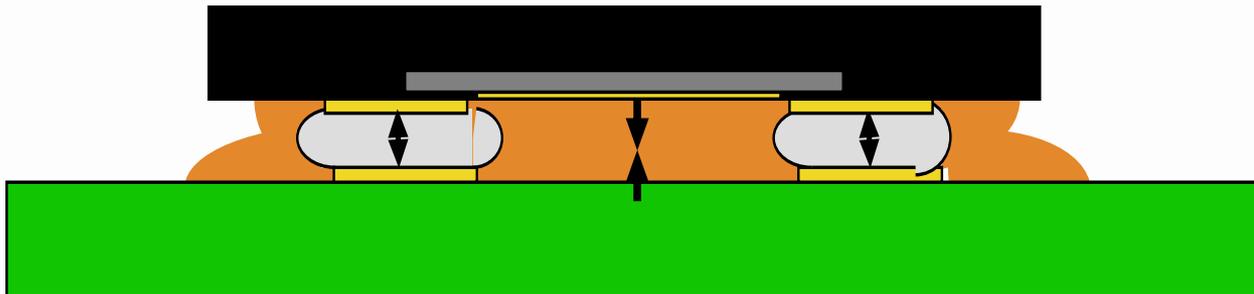
# Standoff Gaps

- Z-Axis over 3 mils
  - Airflow penetration and exhaustion
  - Flux volatiles escape
  - Low flux residue levels under terminations



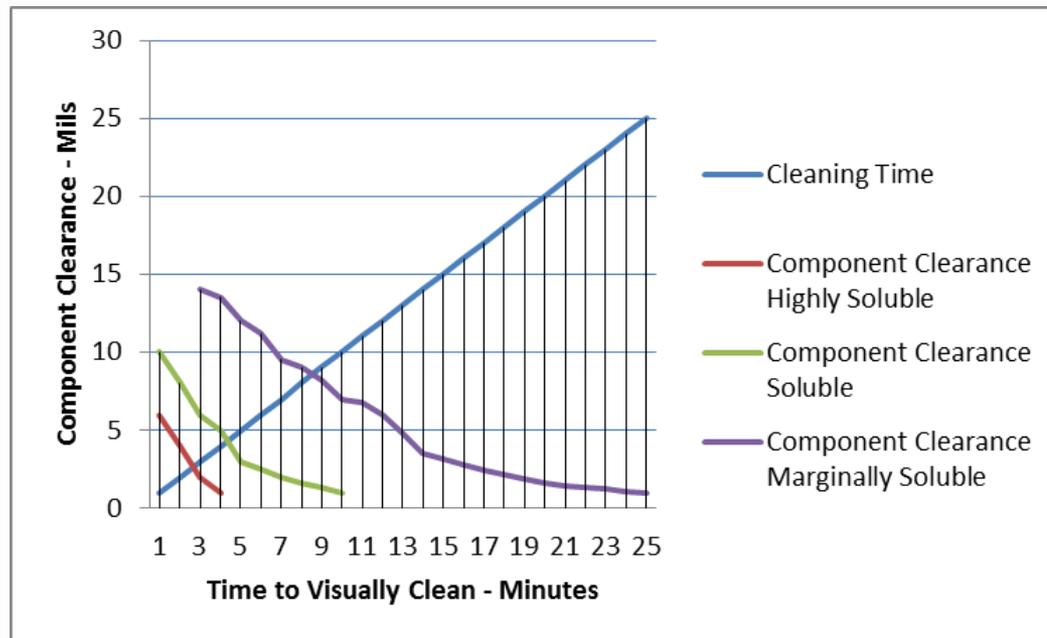
# Low Gaps

- Z-Axis under 2 mils
  - Capillary action of flux attracts
  - Flux volatiles do not escape
  - Flux underfills component



# Flux Residue

- Harder residues require
  - Longer wash times
  - Higher levels of energy to clean



# RESEARCH PURPOSE

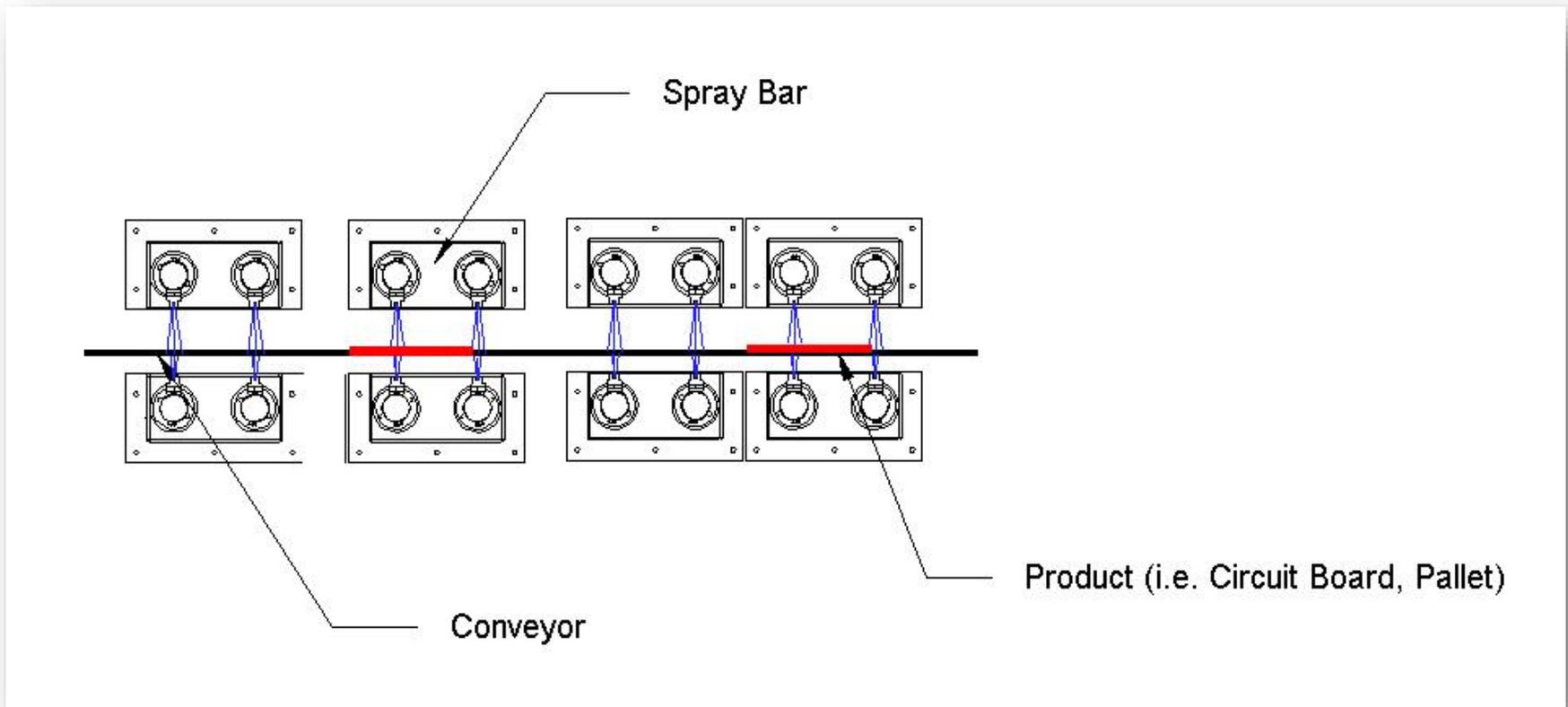
# Cleaning Process

- Two Critical Factors
  - Cleaning agent
  - Cleaning machine
- Purpose of the study
  - Cleaning efficacy study of Flood+Spray Impingement System Configuration

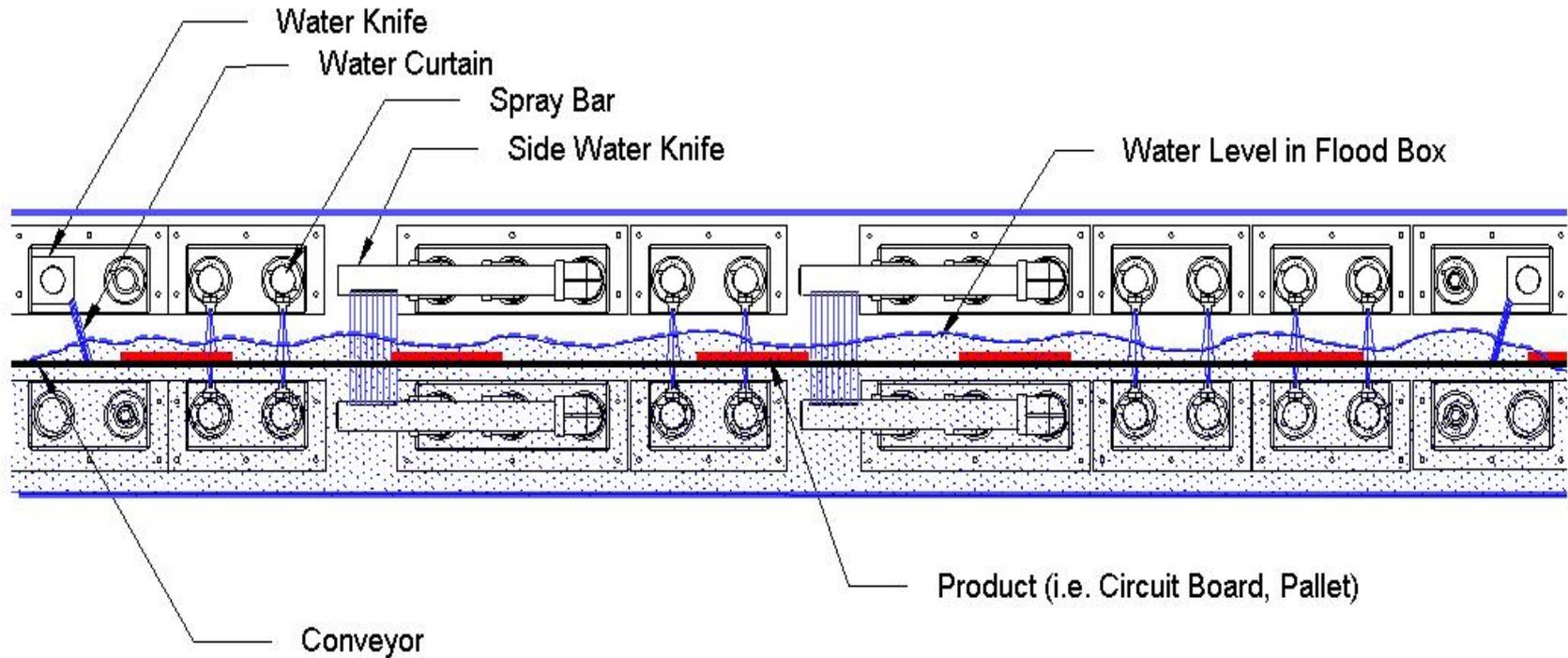
# Cleaning Equipment Advancement Theory

- Combination of soak & spray impingement
  - Soak
    - Wet flux residues
    - Hold PCB to process temperatures
  - Spray-in-Air impingement
    - Penetrate
    - Flow channel under bottom terminations
    - Dissolve flux residues

# Traditional Spray Impingement



# Configuration





NEW IDEAS ... FOR NEW HORIZONS

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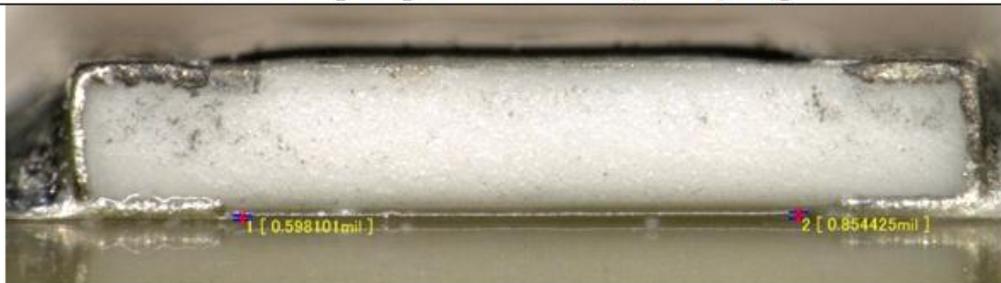
LAS VEGAS, NEVADA

# RESEARCH DESIGN

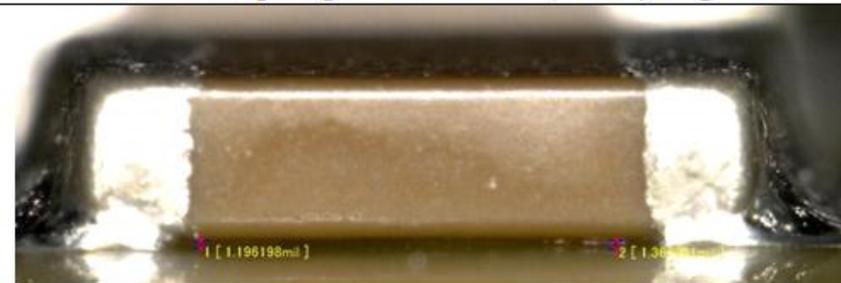
# DOE #1

- Study cleaning efficacy for removing
  - Flux residues under leadless chip capacitors
    - 1210 < 2 mil gap
    - 1815 < 4 mil gap

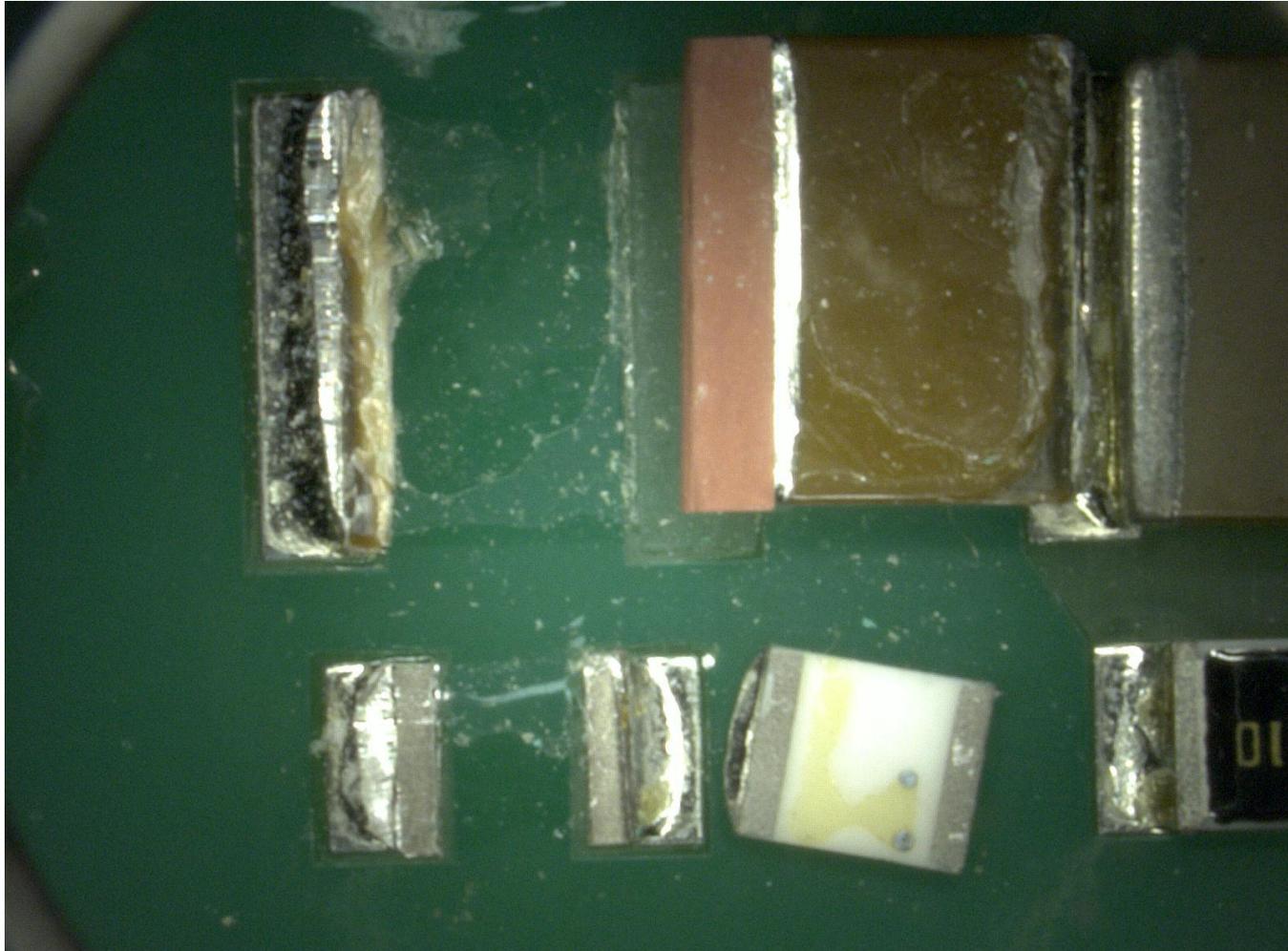
1210-Chip-Cap--Less-1-Mil-(25um)-Gap



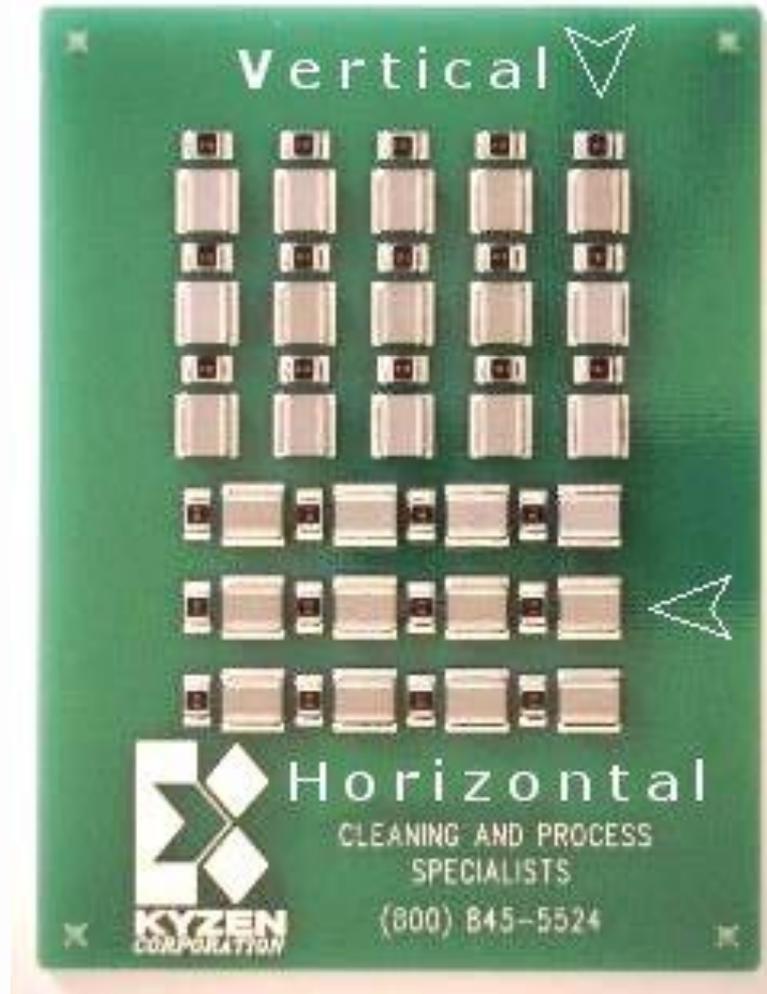
1825-Chip-Cap--Less-2-Mil-(50um)-Gap



# Flux Residue Under Terminations



# Test Vehicle



# DOE #1 Factors

— → Solder Pastes · · →      →      →      →

- → Tin-Lead-Rosin
- → Tin-Lead-No-Clean
- → Lead-Free-Water-Soluble
- → Lead-Free-No-Clean

— → Conveyor Speed

- → 0.5 FPM (feet per minute)
- → 1.0 FPM
- → 1.5 FPM

— → Solder Mask Definition

- → No SM (Solder Mask)
- → NSMD

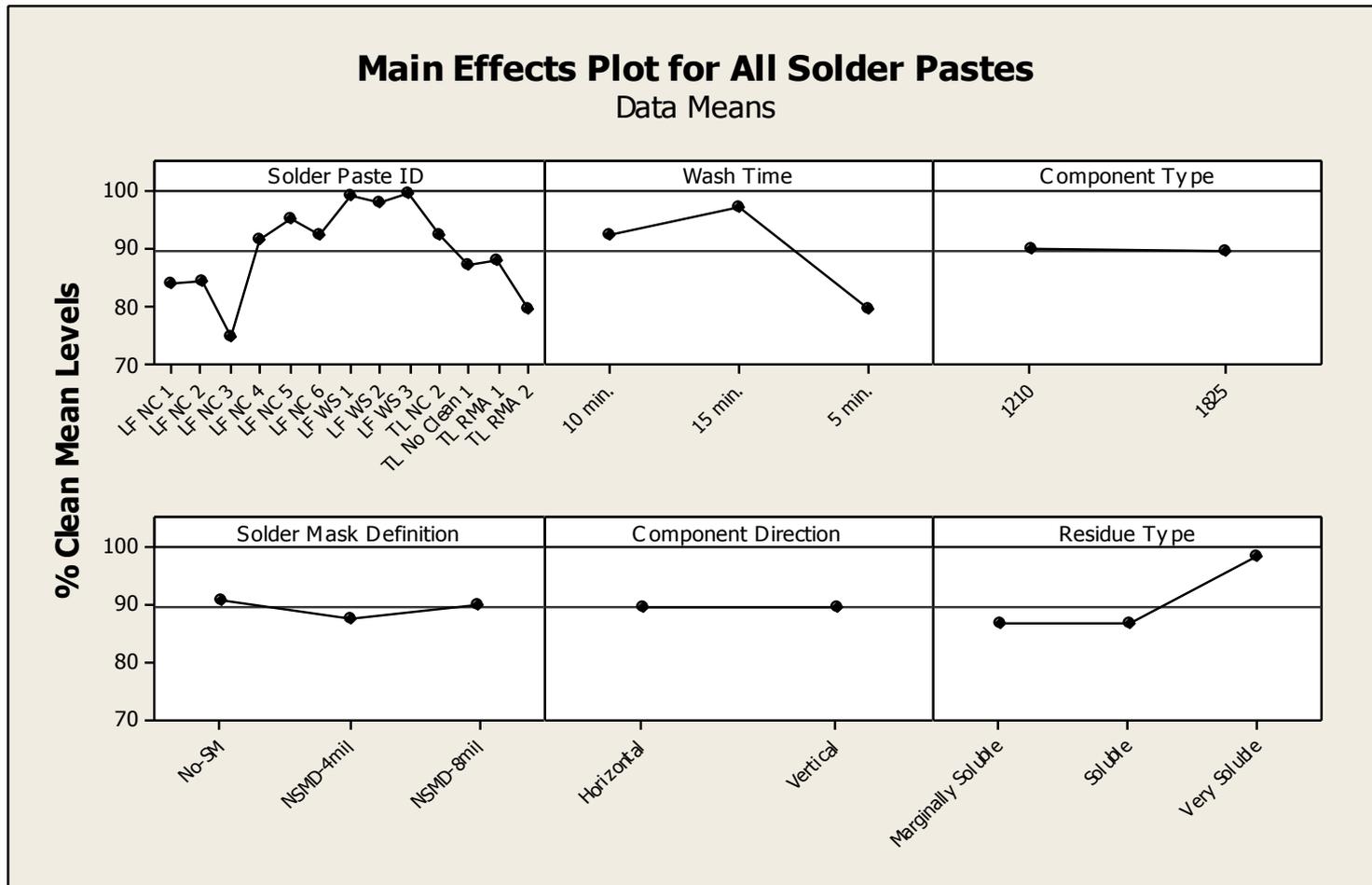
— → Chip Components

- → 1210
- → 1825

— → Component Placement

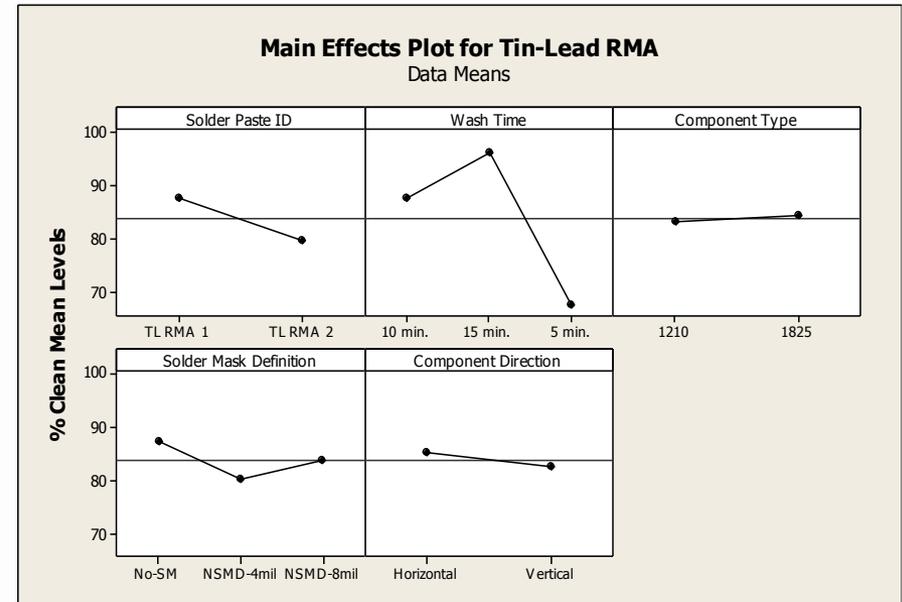
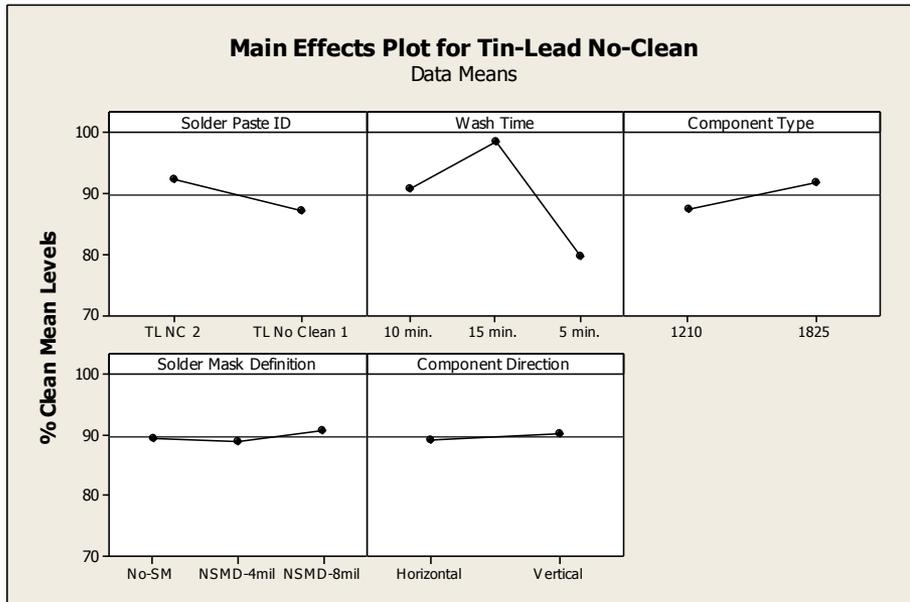
- → Vertical
- → Horizontal

# DOE #1 Data Findings



# DOE #1 Data Findings

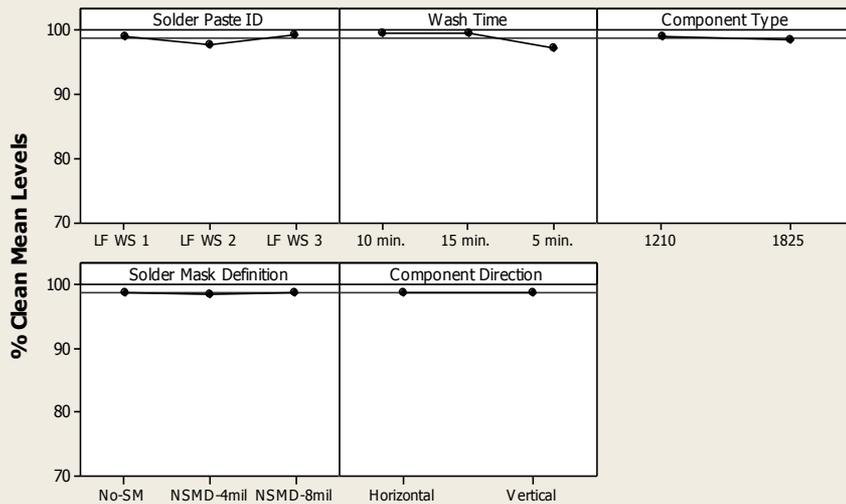
- Tin-Lead Solder Pastes in the Study



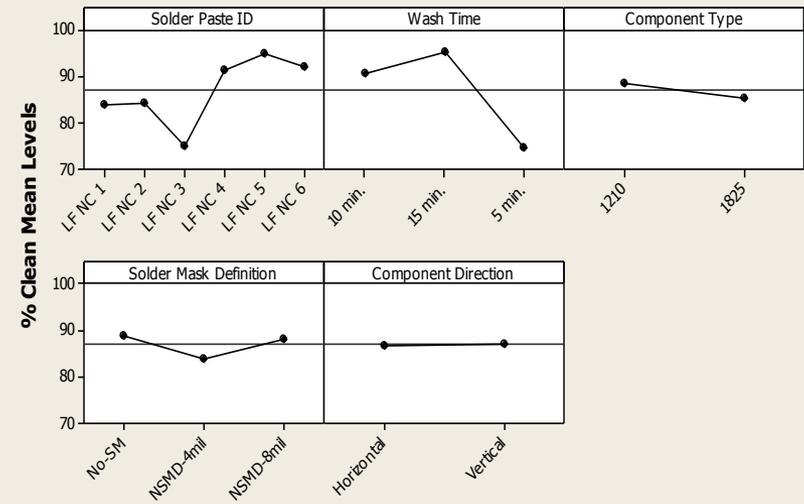
# DOE #1 Data Findings

- Lead Free Solder Paste in Study

**Main Effects Plot for Lead Free Water Soluble  
Data Means**



**Main Effects Plot for Lead-Free No Clean  
Data Means**



## DOE #2

- Ion Chromatography
  - Site Specific
  - Quantify the levels of specific ions
    - Chloride
    - Bromide
    - Weak organic acids
    - Ammonium

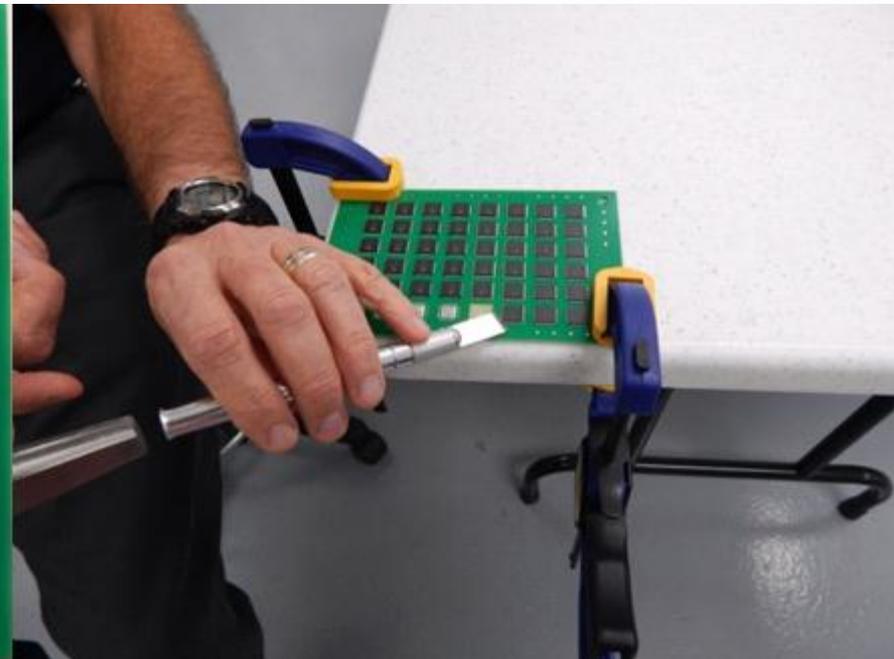
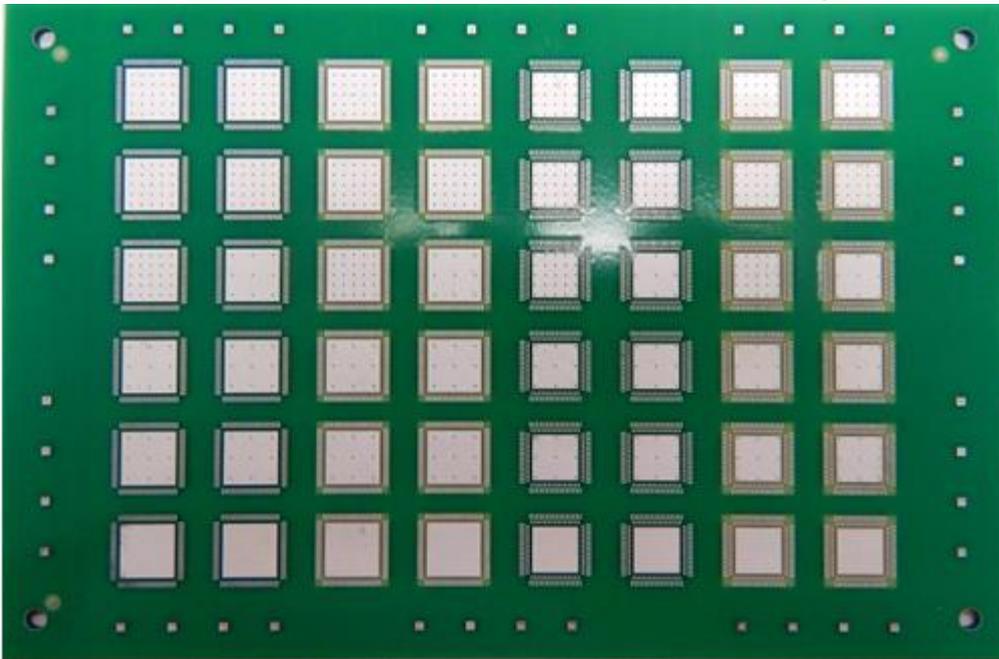
# Industry Acceptable Levels

- Anions in study
  - Correlate with electrochemical migration
- Cation in study
  - Correlate with rinsing under terminations

Anions	Level of $\mu\text{g}$ of the ion per $\text{in}^2$ surface area
Chloride	$<6 \cdot \mu\text{g}/\text{in}^2$
Bromide	$<12 \cdot \mu\text{g}/\text{in}^2$
Weak Organic Acids	$<25 \cdot \mu\text{g}/\text{in}^2$
<u>Cation</u>	
Ammonium	$<6 \cdot \mu\text{g}/\text{in}^2$

# Test Vehicle

- QFN / MLF Components
  - Single and Double Row
  - 4 ground pad designs
  - Via holes in some ground pads

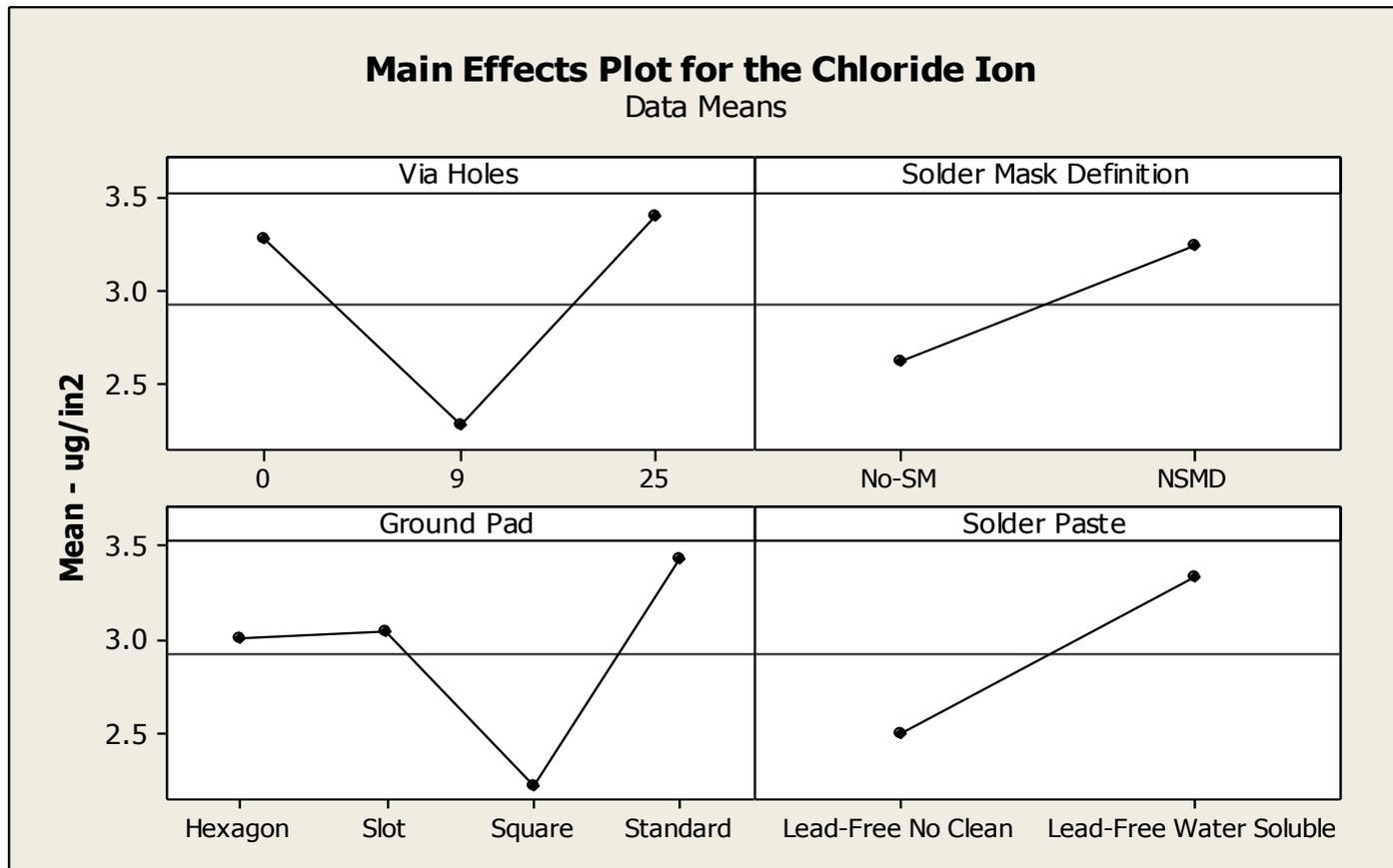


# Site Specific IC Analysis

NSMD MLF88	NSMD MLF88	NoSM MLF88	NoSM MLF88	NSMD MLF124	NSMD MLF124	NoSM MLF124	NoSM MLF124
25 vias 1-1	25 vias 1-2	25 vias 1-3	25 vias 1-4	25 vias 1-5	25 vias 1-6	25 vias 1-7	25 vias 1-8
25 vias 2-1	25 vias 2-2	25 vias 2-3	25 vias 2-4	25 vias 2-5	25 vias 2-6	25 vias 2-7	25 vias 2-8
25 vias 3-1	9 vias 3-2	25 vias 3-3	9 vias 3-4	25 vias 3-5	9 vias 3-6	25 vias 3-7	9 vias 3-8
9 vias 4-1	9 vias 4-2	9 vias 4-3	9 vias 4-4	9 vias 4-5	9 vias 4-6	9 vias 4-7	9 vias 4-8
9 vias 5-1	9 vias 5-2	9 vias 5-3	9 vias 5-4	9 vias 5-5	9 vias 5-6	9 vias 5-7	9 vias 5-8
Solid 6-1	Solid 6-2	Solid 6-3	Solid 6-4	Solid 6-5	Solid 6-6	Solid 6-7	Solids 6-8

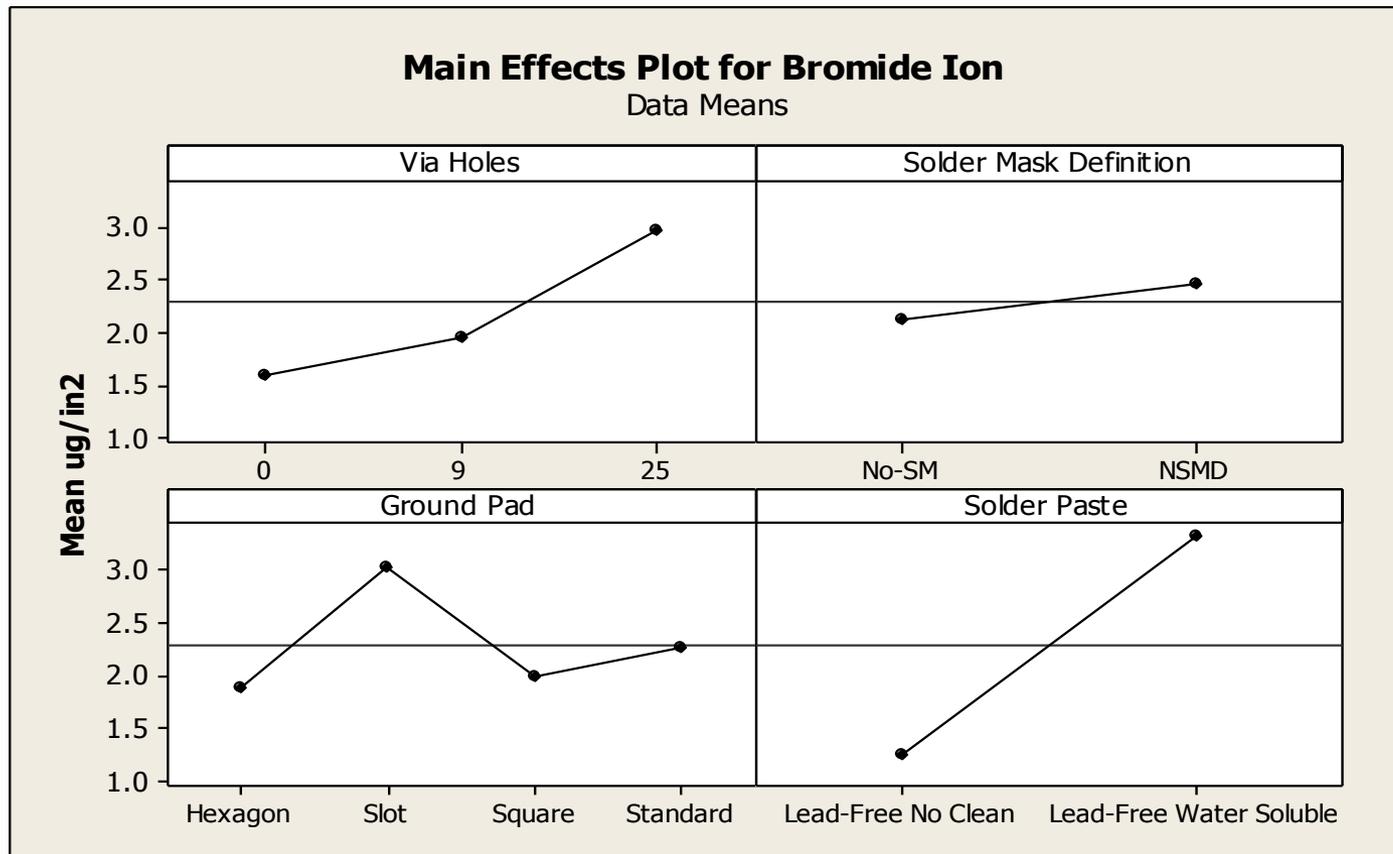
# DOE #2 Data Findings

- Chloride ion



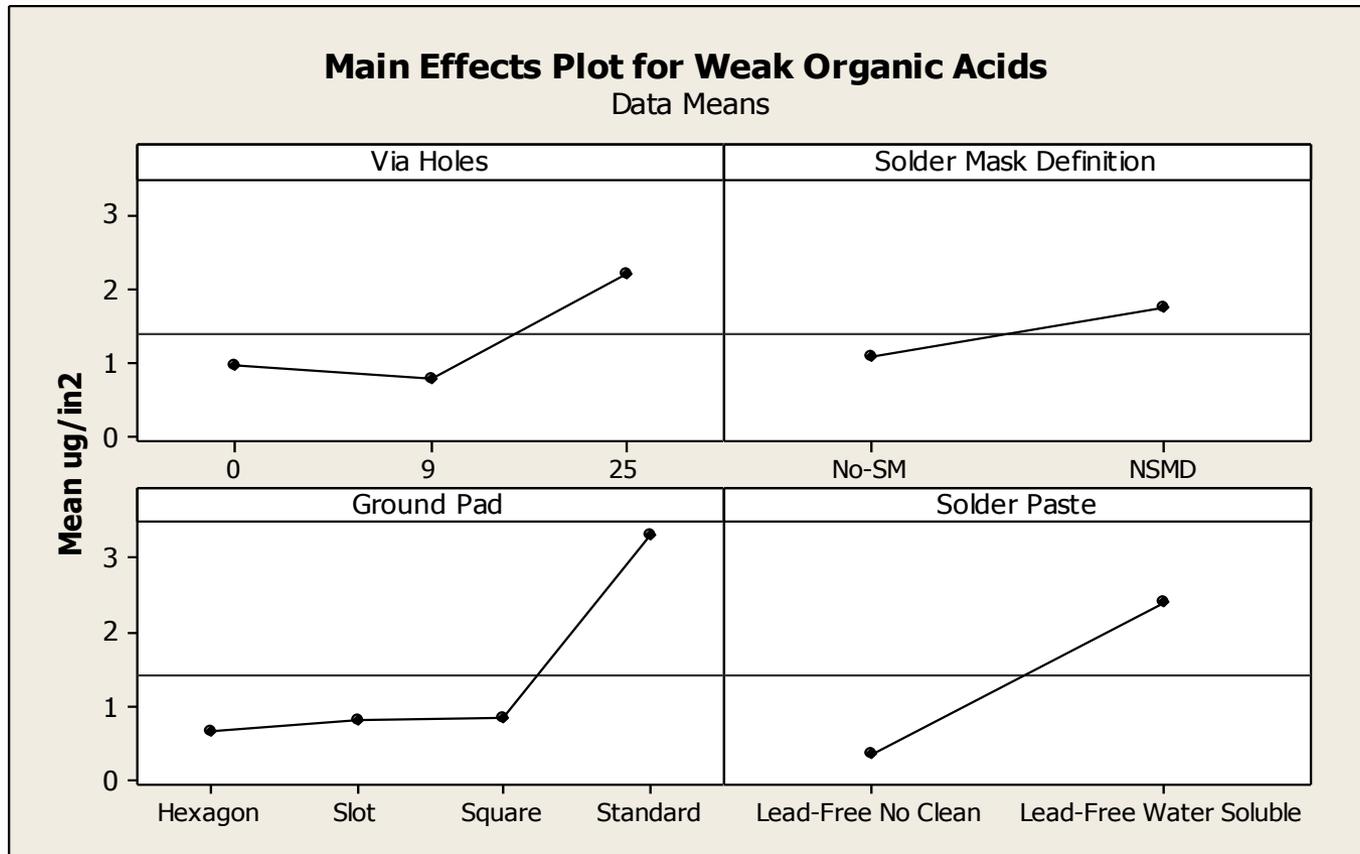
# DOE #2 Data Findings

- Bromide Ion



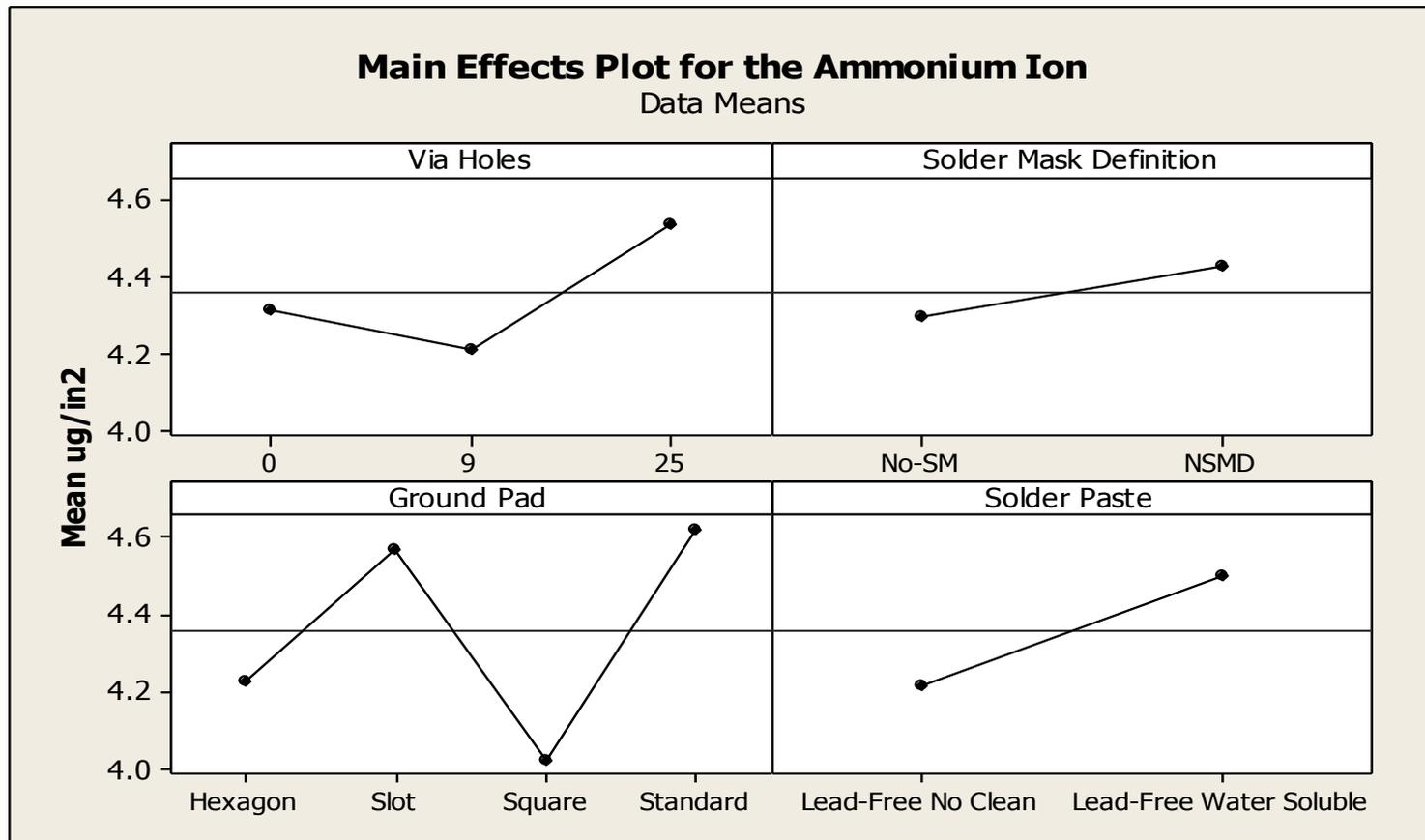
# DOE #2 Data Findings

- Weak Organic Acids



# DOE #2 Data Findings

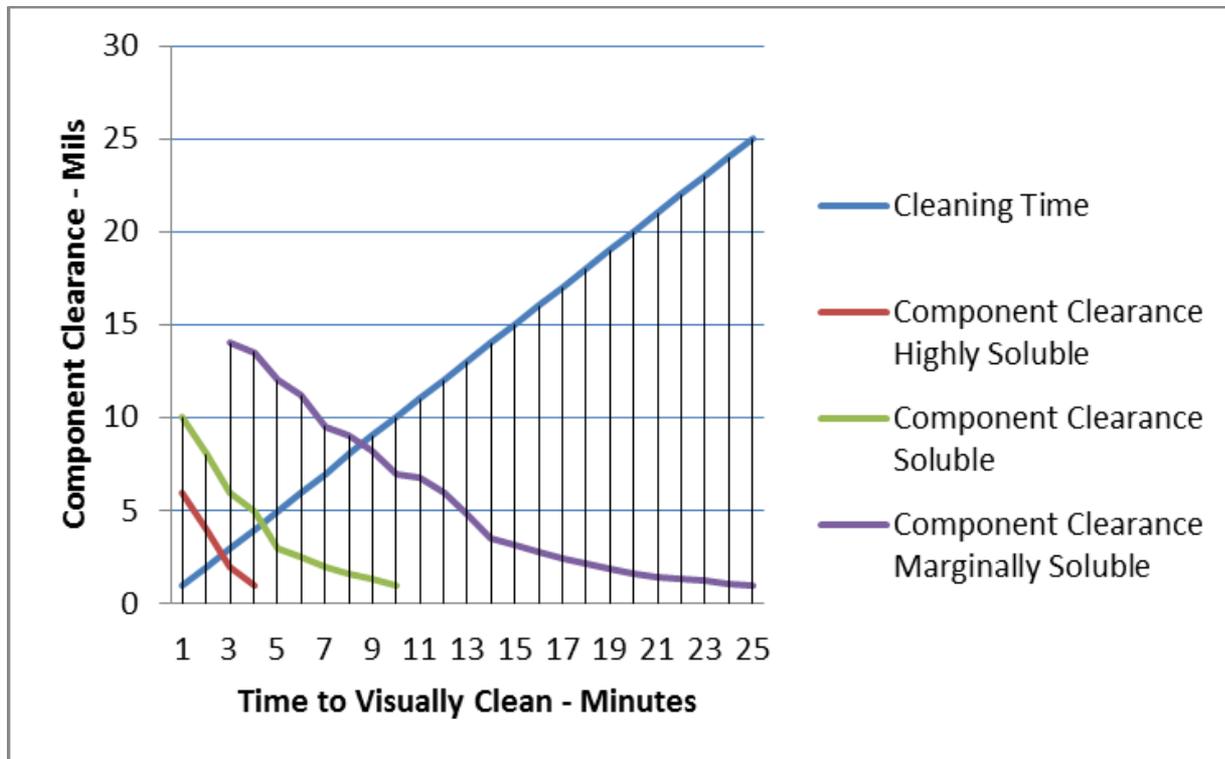
- Ammonium Ions



# INFERENCES FROM DATA FINDINGS

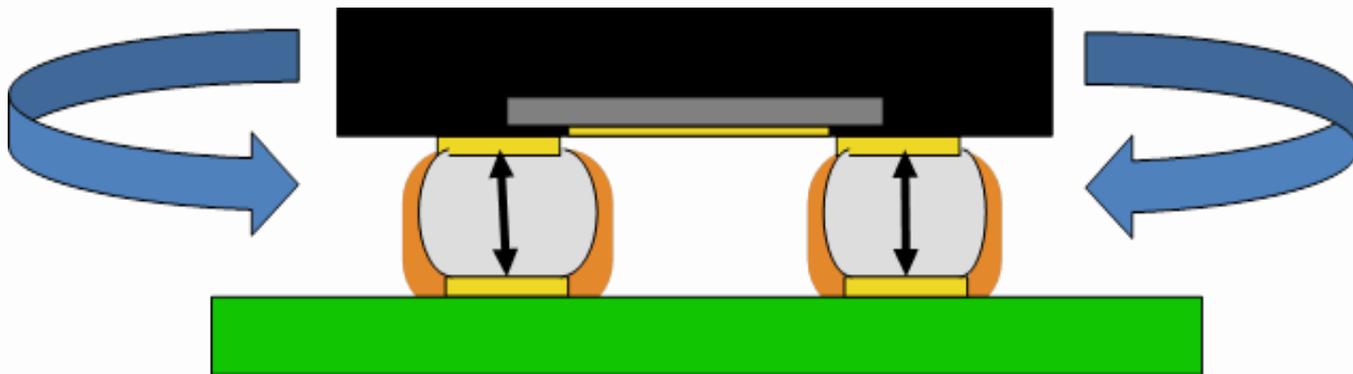
# DOE #1

- Wash time correlates with solubility characteristics of the flux residue



## DOE #1

- High gap heights reduced cleaning time
  - Non Solder Mask Defined
  - No Solder Mask
  - Square ground pad design



# DOE #2

- IC levels below industry acceptable levels
- Indicates
  - Effective cleaning under terminations
  - Effective rinsing under terminations

Variable	Solder·Paste	N	Mean·(µg/in <sup>2</sup> )	SE·Mean	Std·Dev·	Minimum
Chloride·Ion	Lead-Free·No·Clean	79	2.506	0.252	2.240	0.589
Chloride·Ion	Lead-Free·Water·Soluble·	80	3.338	0.224	2.000	0.867
Bromide·Ion	Lead-Free·No·Clean	79	1.247	0.101	0.895	0.103
Bromide·Ion·	Lead-Free·Water·Soluble·	80	3.319	0.475	4.245	0.034
Weak·Organic·Acid·Ions	Lead-Free·No·Clean	68	0.3776	0.0361	0.2975	0.1200
Weak·Organic·Acid·Ions	Lead-Free·Water·Soluble·	71	2.395	0.689	5.810	0.130
Ammonium·Ion	Lead-Free·No·Clean	79	4.2177	0.0595	0.5286	2.4136
Ammonium·Ion	Lead-Free·Water·Soluble·	80	4.498	0.111	0.991	3.047

# Conclusions

# Developed Equipment Spray and Flood Configuration

- Innovative approach
  - Soak (Flooding) improves
    - Wetting
    - Softens residues
    - Board temperature remains consistent through process
  - Spray Impingement
    - Flux dissolve residues from under terminations
    - Flushes wash fluids and ion contamination from under terminations

# Wash /Rinse Times

- Wash Time is a Function of
  - Gap Height
  - Removal properties of the residues
    - Easy to dissolve clean fast
    - Hard to dissolve requires time to solubilize
- Rinse Time is a Function of
  - Gap Height
  - Area under component
  - Shadowing effects

# References

- SMART Group. (Nov. 5, 2010). Bottom Termination Component. Retrieved from Electronic Product Design and Test <http://www.epdtonthenet.net/article.aspx?ArticleID=37819>
- Prasad, R. (April 24, 2009). Problems and Promises of BTCs: Bottom Termination Components. Axiom Electronics. Retrieved from <http://www.axiomsmt.com/index.php/2009/04/problems-and-promises-of-btcs-bottom-termination-components/>
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# Acknowledgements

- Numerous People contributed to the research
  - Dale Lee of Plexus ~ QFN board design
  - Bill Vuono of Raytheon ~ Building QFN boards
  - Staff at Foresite Labs ~ Site specific IC analysis
  - Kevin Soucy and Chelsea Jewell of Kyzen ~ Building chip cap test boards
  - Staff at Technical Devices ~ Cleaning test boards

The authors thank all those behind the scenes that made this research possible.

# Questions

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