Characterize and Understand Functional Performance of Cleaning QFN Packages on PCB Assemblies

iNEMI Cleanliness Research Study
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ABSTRACT
Material and Process Characterization studies can be used to quantify the harmful effects that might arise from solder flux and other process residues left on external surfaces after soldering. Residues present on an electronic assembly can cause unwanted electrochemical reactions leading to intermittent performance and total failure. Components with terminations that extend underneath the package can trap flux residue. These bottom terminated components are flush with the bottom of the device and can have small solderable terminations located along the perimeter sides of the package. The clearance between power and ground render high electrical forces, which can propagate electrochemical interactions when exposed to atmospheric moisture (harsh environments).

The purpose of this research is to predict and understand the functional performance of residues present under single row QFN component packages. The objective of the research study is to develop and collect a set of guidelines for understanding the relationship between ionic contamination and electrical performance of a BTC component when exposed to atmospheric moisture and the trade-offs between electrical, ionic contamination levels, and cleanliness. Utilizing the knowledge gained from undertaking the testing of QFN components and associated DOE, the team will establish a reference Test Suite and Test Spec for cleanliness.

Key Words
Bottom Terminated Components, Climatic Reliability, Electrochemical Migration, Leakage Currents, Dendritic Growth, Ionic Contaminants, QFNs

BACKGROUND / CONTEXT
With higher electronic manufacturing demands, contract manufacturers are expanding their offerings to include services in the broader range of a product's life cycle. Shrinking product form-factors, along with higher component I/O densities, will continue to drive higher placement densities[1]. One component notable for trapping harmful residues is the family of bottom terminated leadless components. I/O lands and ground lugs are plated on the underside of the package[2]. When soldering bottom terminated components, blocked outgassing channels can fill the underside of the component with flux residues. No-Clean flux systems should leave benign surface contaminants[5]. The low standoff gap, tight pitch, and mass of solder can increase the levels of flux residue and create a reliability concern.

Contamination that cannot be seen makes it hard for assemblers to project life expectancy[3]. Figure 1 illustrates leakage currents due to ionic contamination trapped under the bottom termination: leakage currents and dendritic growth impact device performance.

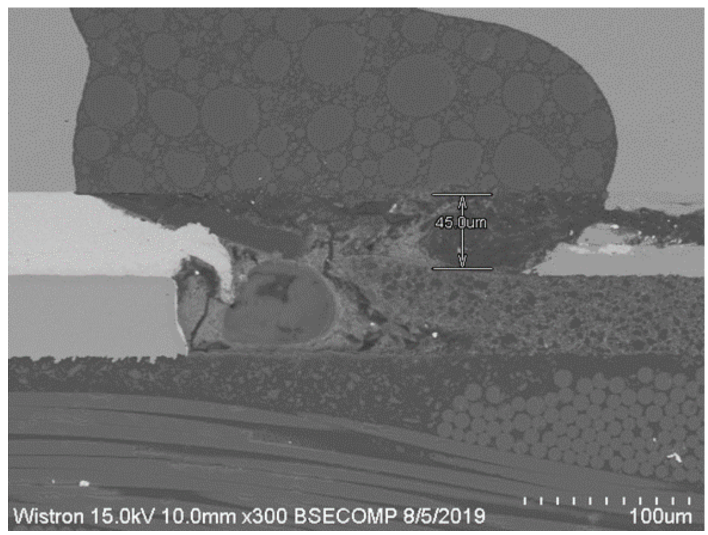

Figure 1: Leakage Currents due to Contamination

Factors that drive cleanliness are diverse[4].

- Materials Selection: Chemistries of materials within the manufacturing process (Solder Pastes, Flux chemistry, wash solution, etc.)
- Processing Parameters: Settings within the manufacturing process (Stencil thicknesses, nozzle pressures, factory environmental conditions, etc.)
- Hardware Selection: Geometric properties of hardware used within the design (component standoff height, termination size, shape, and spacing, PCB conductor thickness, etc.)

Each of these factors can change the properties of surface contamination present on the electronic assembly. Materials characterization followed by methods for controlling the process are vital for reducing variation. Figure 2 highlights factors that can influence the harmful nature of residues left on the printed circuit board after assembly.

Factor	Materials Selection	Processing Parameter	Hardware Selection
Flux Type	X	X	
Reflow Temperature	X	X	
Component Standoff Height			X
Paste Volume	X		X
Venting Paths		X	X

Hardware Selection Can Drive Cleanliness Levels

Figure 2: Cleanliness Factors

WHY DOES OEMs/CMs VALUE CLEANLINESS?

PCB assemblies must have the proper level of cleanliness to prevent unintended leakage current paths in the presence of voltage and moisture which are part of any operating environment. Cleanliness is most important in high voltage power electronics as well as low signal analog and high-resolution mixed-signal applications. For example, detecting the signal in standard diagnostic imaging equipment, the primary digitization of analog signals involves the conversion of accumulated charge on the order of 500-1500 electrons per A-D converter count. The level of signal current flowing from sensor to pre-amplifier to collect this charge can be at nano-ampere levels or less. For these circuits to operate with adequate signal-to-noise-ratio (SNR), leakage current must be kept to absolute minimal values, particularly between the power supply and pre-amplifier circuit nodes. Proper signal integrity ensures maximum resistance between the various circuit nodes over the surface of a PCB assembly.

Another motivation for robust cleanliness is the prevention of corrosion cells and metal migration reactions. Many of the elemental metals such as copper and silver used directly in PCBs, solder contact plating, and solder joints can react with residual ions such as chlorine and weak organic acids (WOA). These contamination reactions have been well documented to show a strong relationship between available ionic levels and electrochemical migration (ECM) activity, including exponential increases in leakage current. For example, a ten times increase in NaCl contamination mass/area has been shown to create over a 100 times increase in leakage current during SIR pattern testing[8].

Cleanliness important can be summarized across industries.

- Military/Defense
  - Products must perform when deployed
  - Failure is not an option
  - When electronics fail, people perish
- Aerospace
  - Dependability in the life-cycle of the aircraft
  - System or component must function under stated environmental conditions for a specified period
- Medical
  - Leakage currents – improper function
  - Operated in an environmentally controlled environment but still have issues with signal integrity
  - Failure can impact human lives
- Power Distribution
  - Grid control
  - Working in a harsh environment (high temperature operating conditions/ high humidity / harsh environment
  - Concerned about ionic failures
- Oil and Gas
  - Deep-sea installation
  - Want the product to be reliable – costly to make repairs
  - Bottom of the seafloor
  - Reclamation is not an option
- Mining
  - High temperature
  - Vibration
  - Temperature
  - Worry about ionic contamination left on the board that could be conductive
- Automotive/Trains
  - High voltage power requirements
  - Extremely harsh environment
  - Vibration & moisture are norms
  - Electric and autonomous vehicles must be reliable

PROBLEM STATEMENT

When it comes to cleanliness requirements, both the OEM and EMS are on their own. Some component types are more problematic to chemical contamination than other component types. The problem is that there is no industry standard for cleanliness across the various components populated on a printed circuit board.

Flux residues and other ionic contaminants left on a printed circuit board assembly (PCBA) during the assembly process are a potential threat to the reliability of electronic devices in service today[5]. When joining metal, wetting is a critical property. The metallurgical bond only occurs in the presence of clean surfaces. Oxide free surfaces is where the flux component plays an important role.

Flux is a chemically active compound that when heated, removes minor surface oxidation[6]. Rosin and resin systems act as an oxygen barrier designed to reduce oxidation of metals during the soldering operation. Solvent and co-solvent blends act as a delivery vehicle for rosin/resin systems and activators. The primary role of activators is to remove surface oxides. Most No-Clean solder pastes use weak organic acid activators that are made up of carboxylic acids (Table 1). Dependent on the soldered alloys, carboxylic acid activators with defined melting and decomposition temperatures are selected.

Table 1: Weak Organic Activators

Carboxylic Acids	**Melting Point ºC**	**Decomposition Point ºC**
Citric acid *	153	175
Adipic acid	152	337
Succinic acid	185-187	235
Malonic acid	135-136	140
Benzoic acid	122.4	249
Malic acid	130	135

The thermal mass of solder and process conditions can vary the soldering temperature under the bottom termination. Variation in the thermal transfer can result in considerable amounts of localized residues. Flux activators that do not correctly outgas and decompose can cause high current leakage when the electronics operated in high humidity conditions[5]. This reduction of surface insulation resistance (SIR) between biased points can cause intermittent and potential mal-function. Active residues like carboxylic acids are hygroscopic and therefore influence the amount of water adsorption under humid conditions. Subsequent dissolution of the active part of the flux into the adsorbed water layer lowers surface insulation resistance followed by detrimental electrochemical processes at biased metallic connections. These mechanisms have a direct impact on the reliability and lifetime of electronics.

QFN I/O pads have a pitch in the range from 0.5mm to 0.3mm. The ground lug is typically greater than 50% of the surface area under the component. The standoff gap ranges from 20-50µms. The high thermal mass of solder and low standoff gap create conditions where the flux has no avenue for outgassing. As a result, the remaining flux can be wet and active, even when using a No-Clean solder paste. Figure 2 illustrates a cross-section of the QFN 48T component.

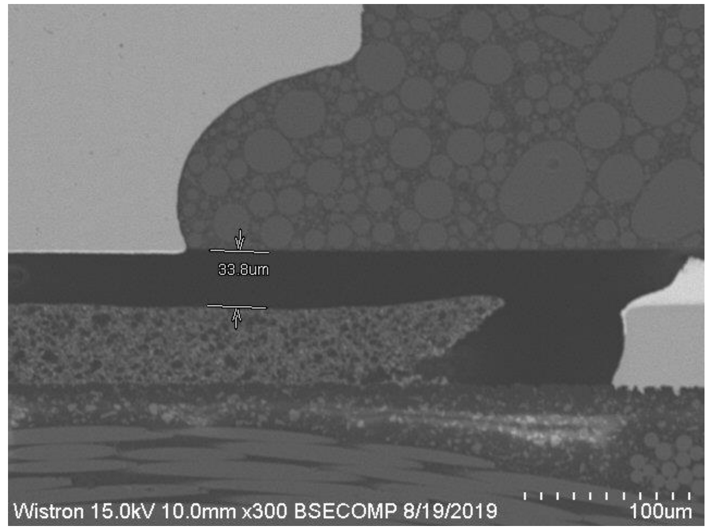

Figure 2: Cross Section of the QFN 48T

TEST METHODS

The ROSE and Ion Chromatography bulk extraction test methods provide information across the entire assembly but not on site-specific components where localized residues are most problematic. SIR (Surface Insulation Resistance) and C3 test methods are better suited for detecting ionic contamination on leadless and bottom terminated components. The IPC B-52 industry-standard test vehicle is designed for material characterization on standard components populated on electronic assemblies. This material and process characterization test vehicle is designed to test for changes in SIR on a representative sample of a printed circuit assembly. Each of these test methods is designed to identify ionic contamination that might arise from solder flux or other process residues left on external surfaces after soldering.

Non-standard leadless and bottom terminated components need to be evaluated for electrochemical reliability. Custom test boards designed with challenging components can detect the activity of these residues under the bottom termination using the SIR and C3 test methods. Sensors routed to the conductive pathways under these bottom terminated components enable electrical testing under temperature, humidity, and bias conditions. Taking this approach to characterize materials, assemblers can evaluate bare board design options, solder paste, and cleanliness effects to determine climatic reliability.

PURPOSE OF THE STUDY

The purpose is to research residue effects under the QFN bottom terminated component. The data will be used to develop a test method that allows an OEM and their Contract Manufacturer to predict and understand the functional performance of highly dense electronics operated in humid conditions. Cleanliness will be monitored using electrical and chemical effects under bottom terminated components.

This study will evaluate the impact of ionic contamination using SIR surface insulation resistance, Ion Chromatography, and C3 test methods. The team will test the correlation between these three methods.

- Gain a better understanding of cleanliness
- What is applicable?
- What is the the best practice for both the OEM and EMS?

Parameters to build around

- No-Clean and Water Soluble Solder Pastes
- SIR test structure
- QFN component bottom terminated component
- Vary parameters
- Subject the test to different properties
- Custom designed test board that allows for many variables to be included in the test plan
- The value of cleanliness must be related to cost of cleaning

EXPERIMENTAL

The objective of this DOE is to quantify the effects that certain PCBA materials (solder flux), processes (cleaning), and designs (solder mask) have on the reliability of an end PCBA. Cleanliness will be objectively measured by:

- SIR performance
- Ionic Contamination monitoring
  - Ion Chromatography (IC)
  - Cleanliness underneath a component (C3)
- Visual methods
  - Visible corrosion
  - Visible flux residue
  - Dendrite length

Table 2: DOE Design

	Experiment	1	2	3	4	6
	Purpose	Bare Board	No clean Soldered, Not Cleaned	No Clean Soldered, Cleaned	Water-soluble, Not Cleaned	Water-soluble, Cleaned
Parameters	Single-row QFN components		x	x	x	x
	Conformal coating (Acrylic)		x	x		
	Visual Inspection (surface)		x	x	x	x
	Visual inspection (components removed)		x	x	x	x
	SIR measurement		x	x	x	x
	Harsh environment (40C/85% RH)		x	x	x	x
	Ion chromatography	x	x	x	x	x
	C3 (localized extraction) followed by Ion chromatography	x	x	x	x	x

Test Board

QFN component: QFN48T.5-F-ISO (48-Leads, Body 7x7mm, Pitch 0.5mm)

- Four quadrants
- Solder mask definition is different for each of the quadrants

- Studied bare board design options
- Allows the design engineer to determine the impact of
  - Standoff height
  - Flux entrapment under the bottom termination
  - Flux outgassing
  - Ionic contamination

The levels tested are as follows:

- Test board held constant
  - FR4 Laminate
  - Liquid Photo-imageable solder mask
  - Immersion silver
- QFN four Quadrant SIR Test Board
  - Q1: SMD
  - Q2: NSMD
  - Q3: No-SM
  - Q4: NSMD Solder Mask Webs with Thermal Vias
- Solder Paste (flux-bearing materials)
  - Water – Soluble (SAC305)
  - No-Clean (SAC305 R0L0)
- Cleaning Agents
  - Engineered aqueous for No-Clean Solder Paste
  - DI water for the Water-Soluble Solder Paste

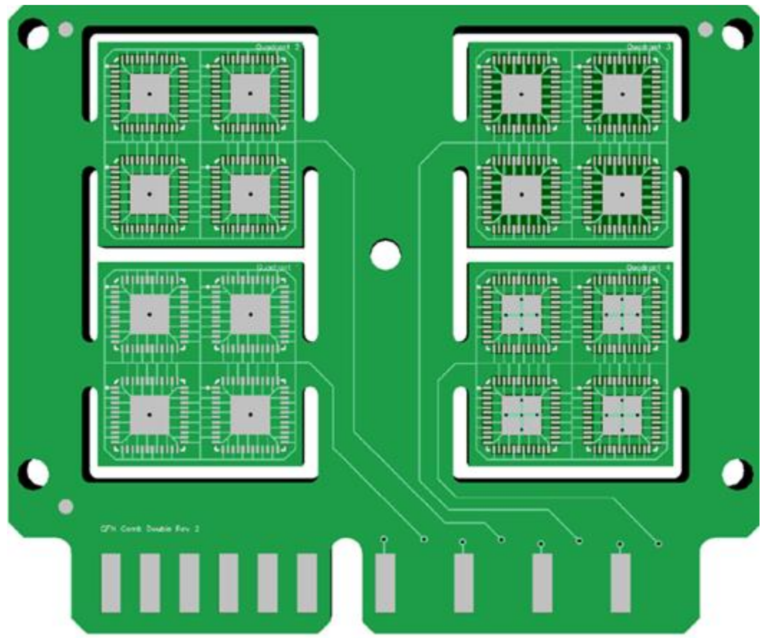

Figure 3: QFN Test Board

Table 3: Response Variables

Response variable (units)	normal operating level & range	meas. precision, accuracy How known?	relationship of response variable to objective
Surface Insulation Resistance, SIR ($\log_{10}\Omega$)	No well-defined "normal" operating range. Current wisdom is that the value should be $\geq 8 \log_{10}\Omega$; Measurement range is $6 \log_{10}\Omega \approx 11 \log_{10}\Omega$	Measure prior to presenting DOE.	SIR is a direct electrical measurement of reliability. The mean and standard deviation of SIR will be determined. With the design and objectives selected, a quantitative model is not possible, but the conditions yielding a maximum SIR value will be
Corrosion Index (µA/s)	Get from Foresite	Get from Foresite	Get from Foresite
Ionic Contamination ($\mu g/cm^2$)	There is no well-defined "normal" level, although the ions should be minimal.	Measure prior to presenting DOE.	Ionic contamination is another measurement of cleanliness and reliability. Each individual ion and the total ionic contamination value will be used in the model.
Visible flux residue	Uncleaned PCBAs should have the maximum flux residue; cleaned PCBAs should have little to none	Visual Criteria (compare to scale)	Visible flux residue indicates a potential reliability issue
Visible corrosion	There should be no visible corrosion.	Visual Criteria (compare to scale)	Visible corrosion indicates the potential for electrochemical failure
Dendrite length (%)	Ranges from 0-100% of the distance between two conductors. Any value greater than 20% is a failure	Dendrite length and conductor spacing is measured either optically or via X-ray methods. Accuracy is $\pm 10\mu m$	Dendrite growth is indicative of electrochemical failure. When dendrites span the distance between conductors by more than >20% this is a failure.

DATA FINDINGS

The data findings of each of the responses will be summarized.

- SIR (5V, 40°C, 90% RH, 168 hours)
- C3 – QFNs were removed and Extracted followed by IC analysis
- IC – Extraction of the four individual quadrants on the test board (This was done to provide a closer value of ions present under the QFN components)

Bare Boards

Ion Chromatography (IC) and C3 site-specific extraction followed by IC was run on four bare boards to evaluate board cleanliness. Notice how the C3 extraction has a lower value than the full quadrant extraction. Keep this value in mind as this trend will change when there is a component placed onto the board.

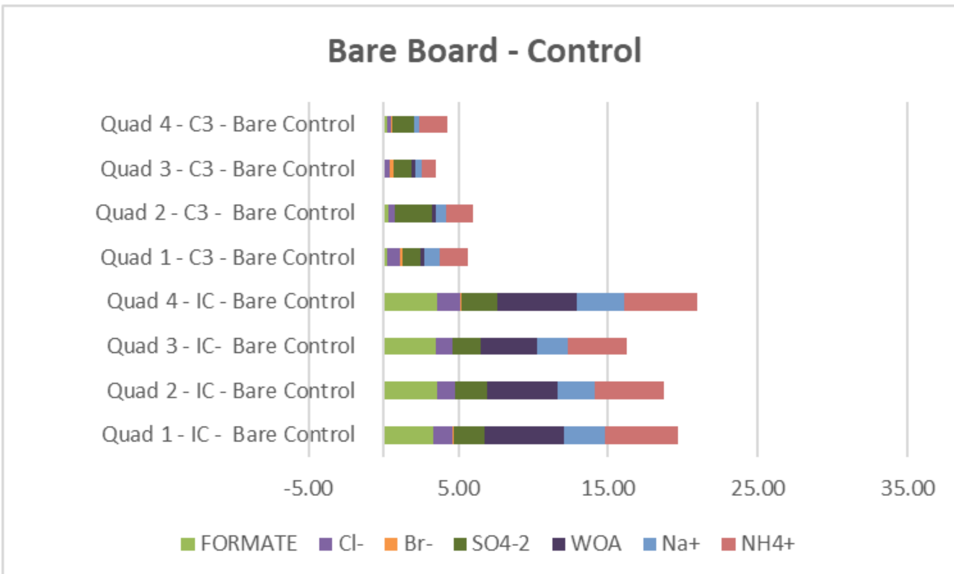

Figure 4: Bare Board Cleanliness

Test Boards Built with No-Clean Solder Paste

<u>Not Populated – No-Clean Solder Paste – Not Cleaned</u>

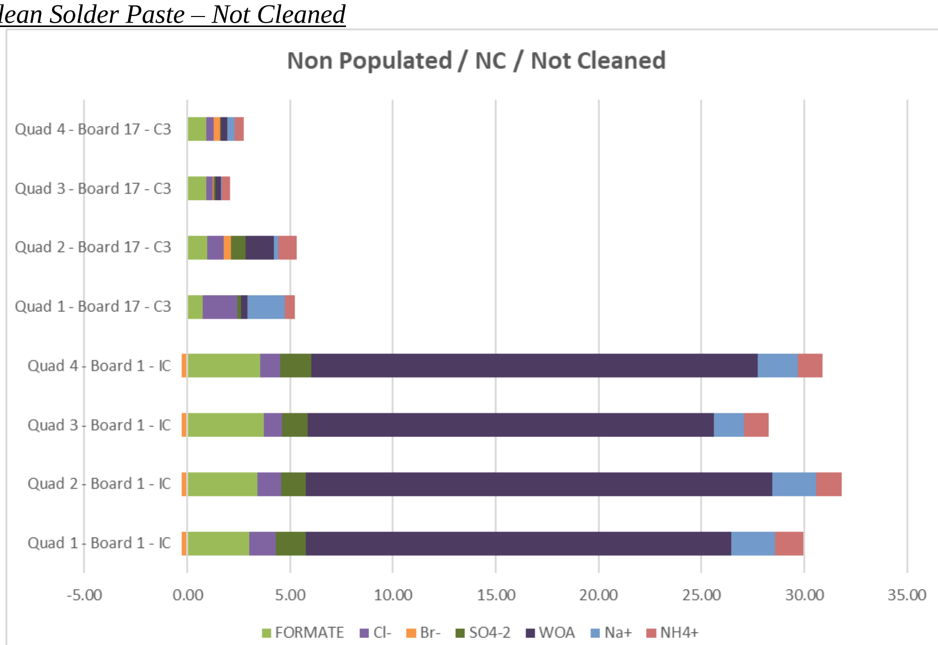

Figure 5: IC and C3 Extraction followed by IC on a No-Clean Solder Board, Not Populated and Not Cleaned

SIR Data Findings of the No-Clean Solder Paste – Not Populated – Not Cleaned
All channels passed SIR. There is a fair amount of ion movement over the time that the test was run.

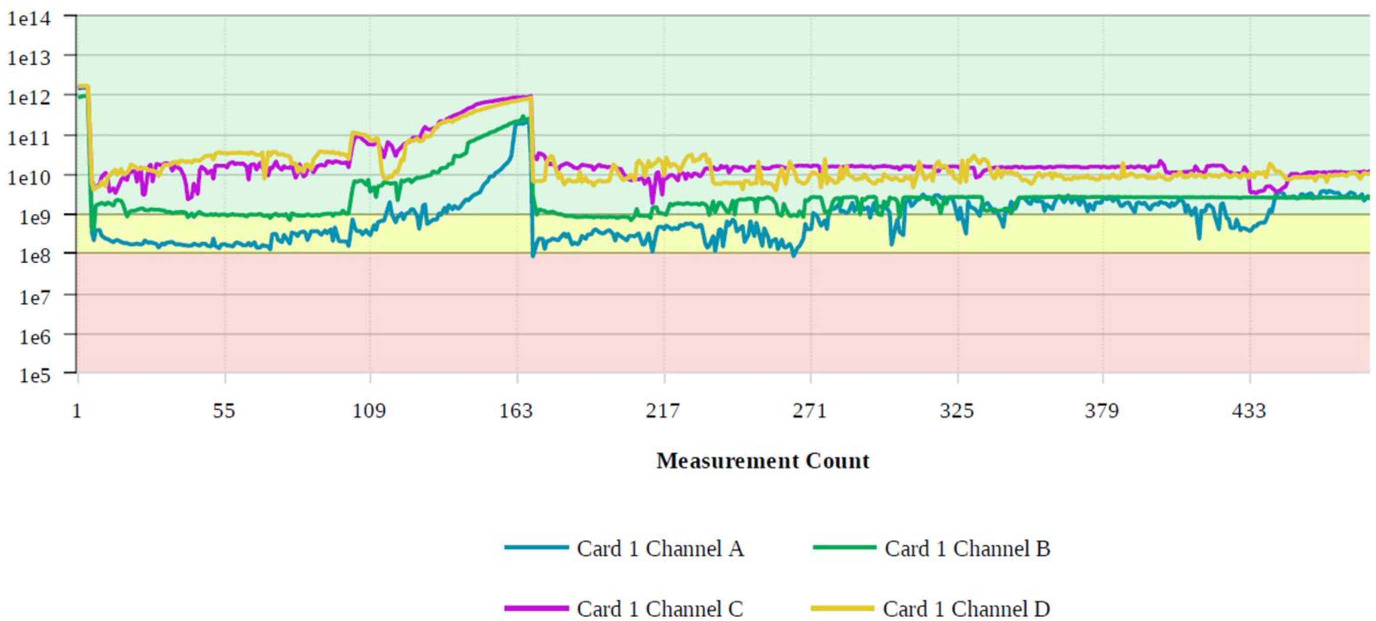

Figure 6: Test Board Soldered with the No-Clean Solder Paste, Not Cleaned and No Components Placed

<u>*Non-Populated – No Clean Solder Paste – Cleaned*</u>
Cleaning the board after soldering lowered ionic contaminants. When no component was placed, C3 extraction was lower.

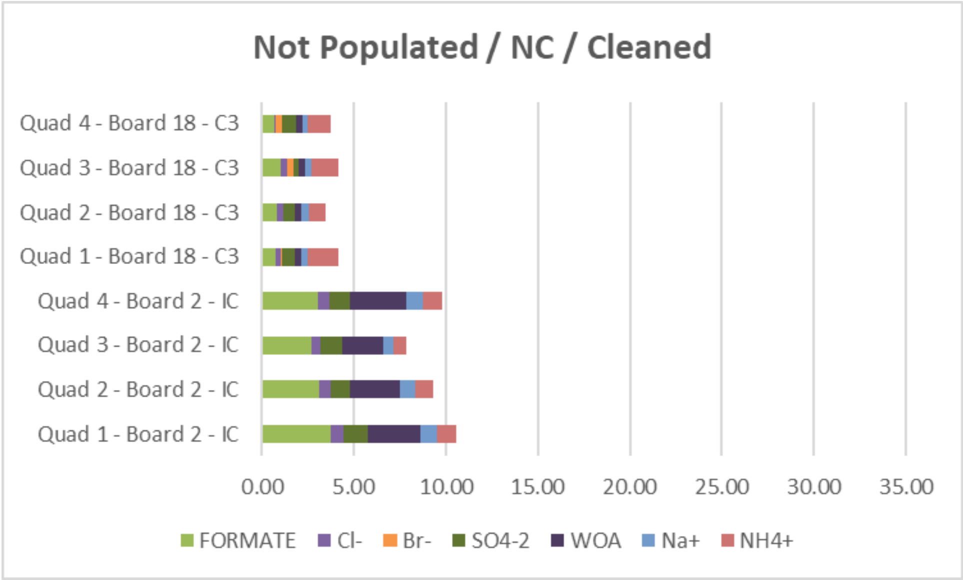

Figure 7: IC and C3 Extraction followed by IC on a No-Clean Solder Board, Not Populated and Cleaned

SIR Data Findings of the No-Clean Solder Paste – Not Populated – Cleaned
SIR values came in at 11.5-12 Log Ω's and were stable over the test duration.

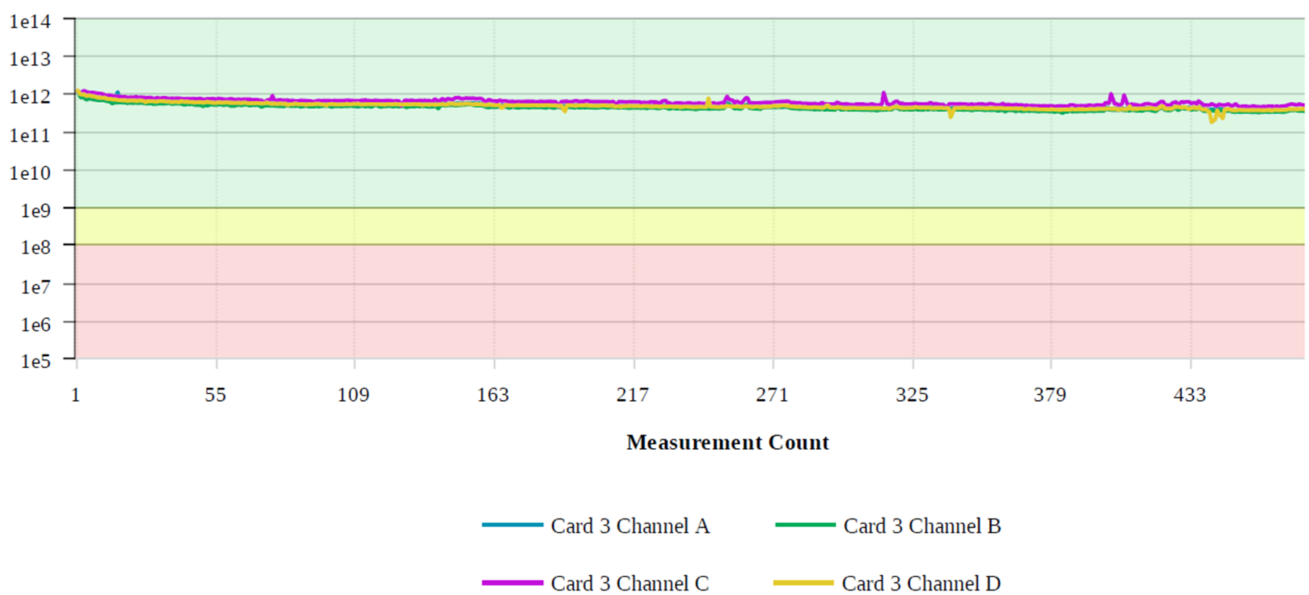

Figure 8: Test Board Soldered with the No-Clean Solder Paste, Cleaned and No Components Placed

<u>Populated – No-Clean Solder Paste – Not Cleaned</u>
The weak organic acids were higher when performing the C3 extraction than IC extraction of each quadrant. When running the C3, the QFN is removed, followed by the site-specific C3 extraction. This is an indicator, that flux outgassing channels are blocked. Channel 4, patterned with thermal vias in solder mask webs performed better.

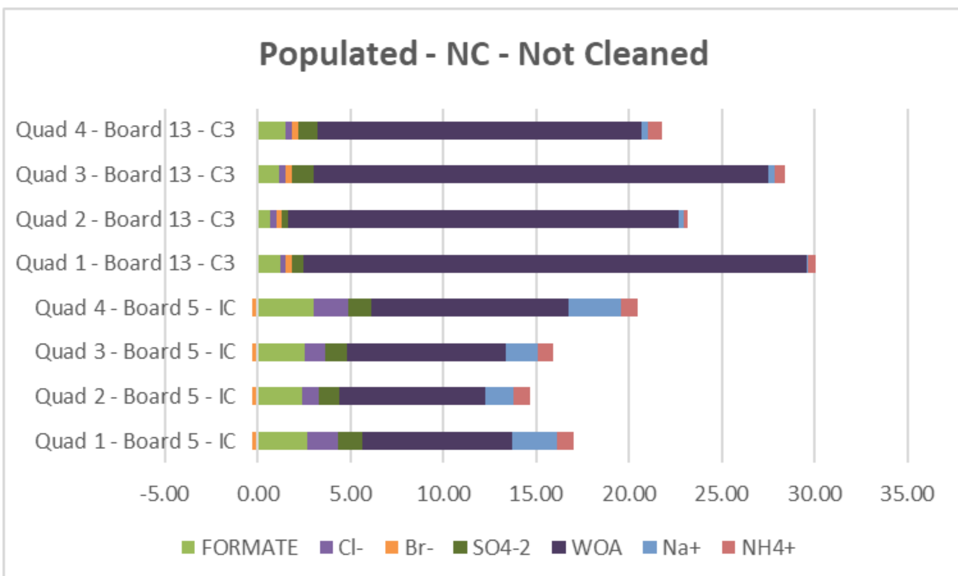

Figure 9: IC and C3 Extraction followed by IC on a No-Clean Solder Board, Populated and Not Cleaned

SIR Data Findings of the No-Clean Solder Paste – Populated – Not Cleaned
All channels passed SIR testing with values ranging from 9.4 – 10 LogΩ's. The decade rise of SIR between reading 109 and 163 was due to a drop in relative humidity within the chamber.

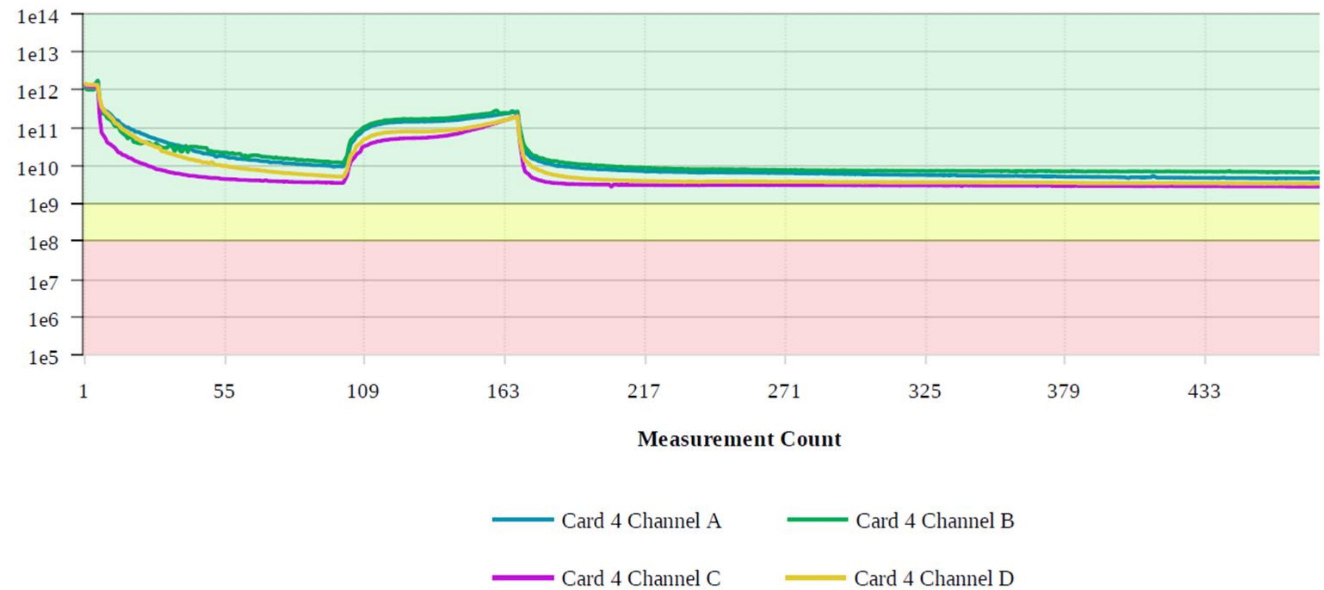

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Figure 10: Test Board Soldered with the No-Clean Solder Paste, Not Cleaned and Populated

<u>*Populated – No-Clean Solder Paste – Cleaned*</u>
Ionic contamination levels were lower on cleaned boards.

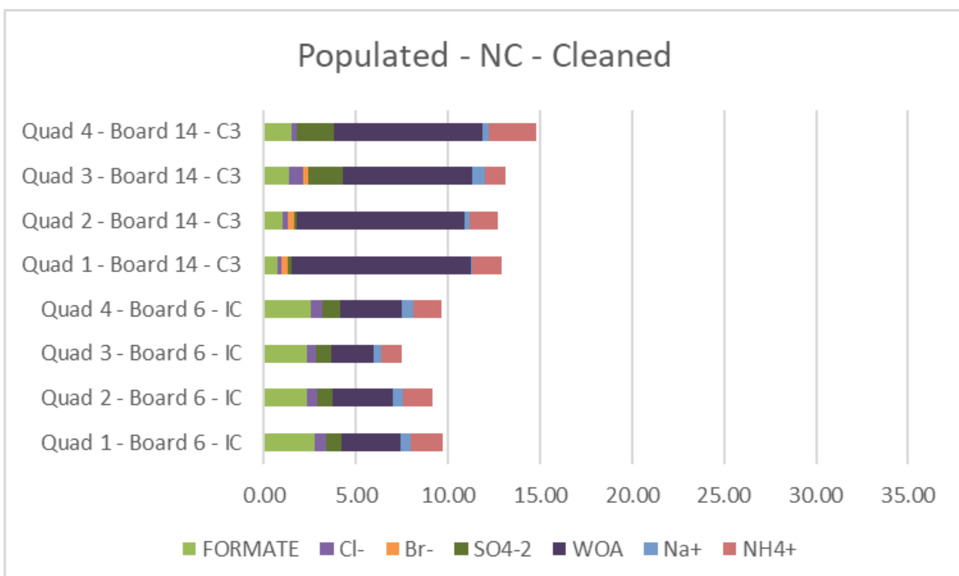


Figure 11: IC and C3 Extraction followed by IC on a No-Clean Soldered Board, Populated and Cleaned

SIR Data Findings of the No-Clean Solder Paste – Populated – Cleaned
SIR values on a cleaned board were over a decade higher.

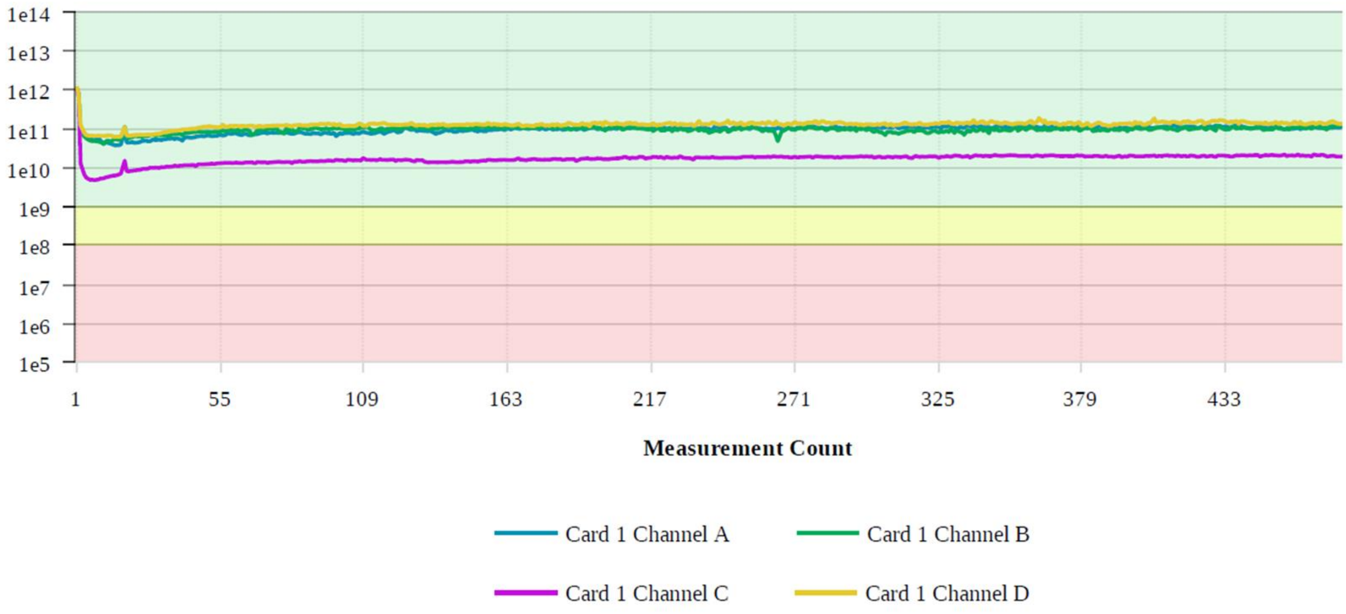


Figure 12: Test Board Soldered with the No-Clean Solder Paste, Populated, and Cleaned

SIR Data Findings of the No-Clean Solder Paste – Populated – Not Cleaned - Conformally Coated

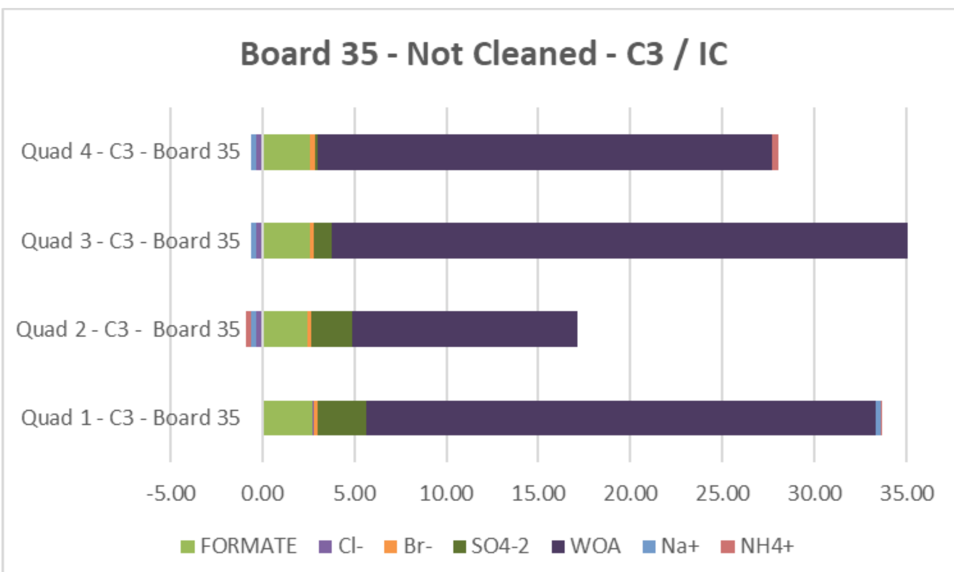


Figure 13: C3 Extraction followed by IC on a No-Clean Soldered Board, Populated, Not Cleaned, and Conformally Coated

SIR Data Findings of the No-Clean Solder Paste – Populated – Not Cleaned - Conformally Coated
Conformal coating on Not Cleaned board soldered with No-Clean paste resulted in stable and acceptable results.

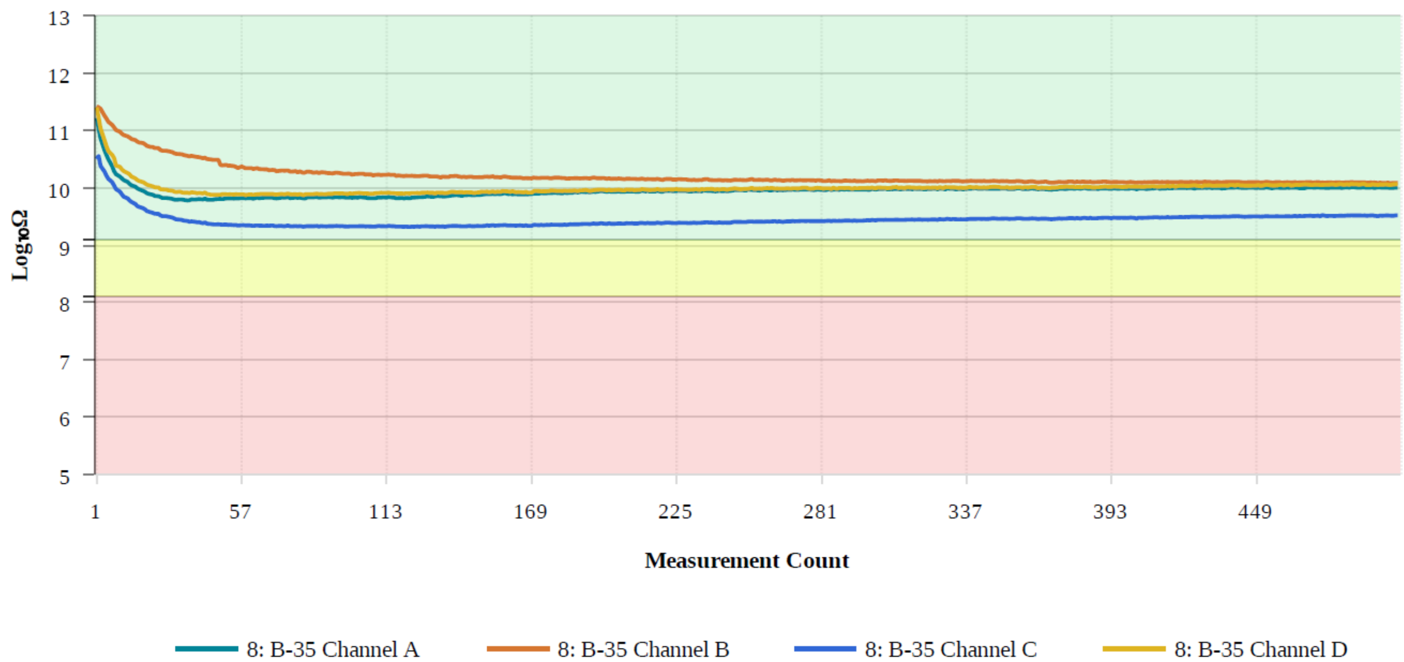


Figure 14: Test Board Soldered with the No-Clean Solder Paste, Populated, Not Cleaned, and Conformally Coated

C3 / IC Data Findings of the No-Clean Solder Paste – Populated – Cleaned - Conformally Coated

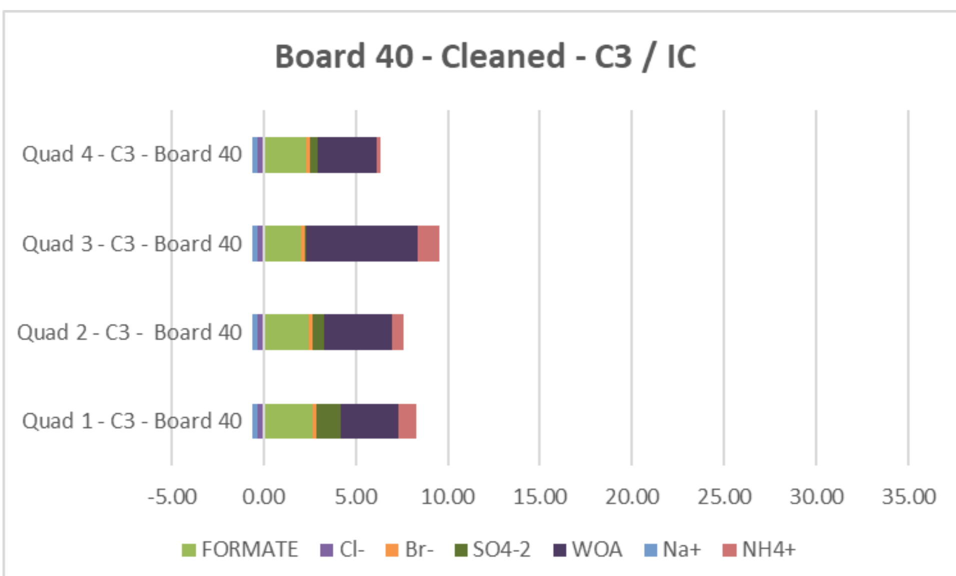


Figure 15: C3 Extraction followed by IC on a No-Clean Soldered Board, Populated, Cleaned, and Conformally Coated

SIR Data Findings of the No-Clean Solder Paste – Populated – Cleaned - Conformally Coated
The data finds that the No-Clean solder paste, cleaned and conformal coated resulted in high SIR. The values approxicate 2 decades improvement in circuit resistance.

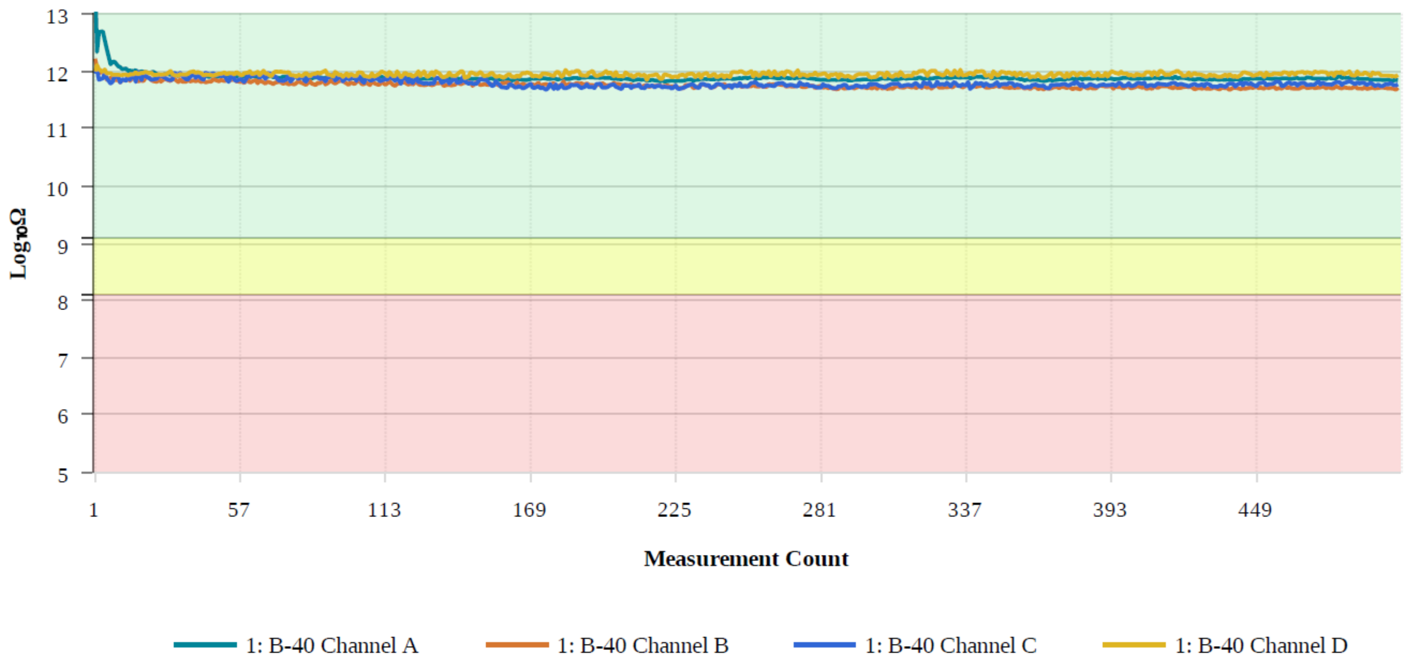


Figure 16: Test Board Soldered with the No-Clean Solder Paste, Populated, Cleaned, and Conformally Coated

Test Boards Built with Water Soluble Solder Paste
SIR Data Findings of Water Soluble Solder Paste – Not Populated – Not Cleaned
The ionic contamination was much higher for the Water Soluble boards. The scale for the total ionic contamination went to a maximum of 35µg/in^2 for the No-Clean solder paste to 120 µg/in^2 for the Water-Soluble solder paste.

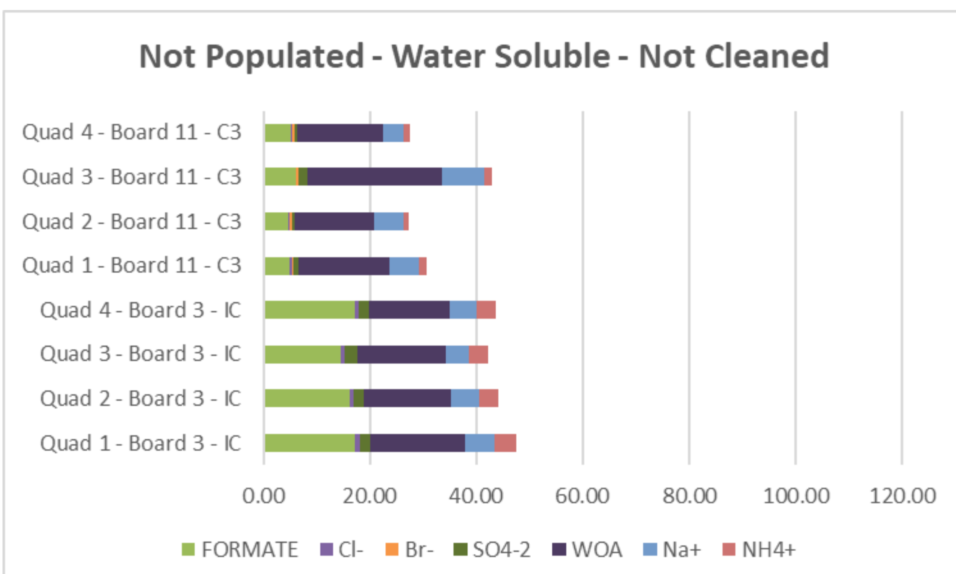


Figure 17: IC and C3 Extraction followed by IC on a Water-Soluble Solder Board, Not Populated and Not Cleaned

SIR Data Findings of the Water-Soluble Solder Paste – Not Populated – Not Cleaned
All channels failed SIR.

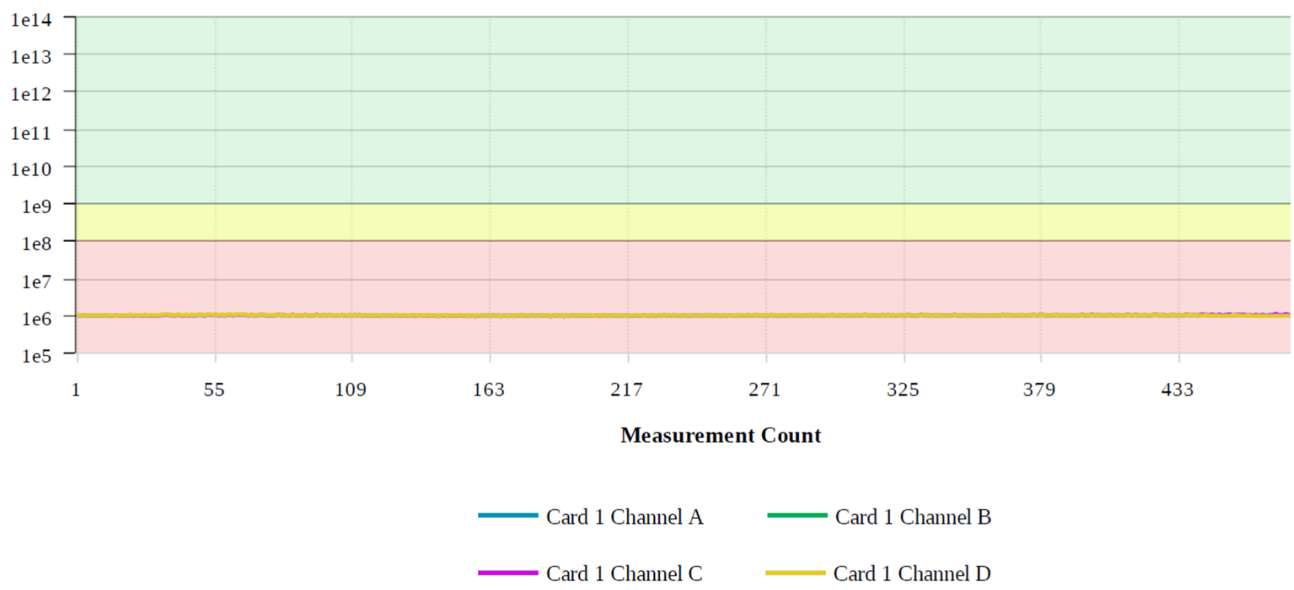


Figure 18: Test Board Soldered with the Water-Soluble Solder Paste, Not Cleaned and No Components Placed

Non-Populated – Water Soluble Solder Paste – Cleaned
Cleaning the board after soldering lowered ionic contaminants. When no component was placed, C3 extraction was lower.

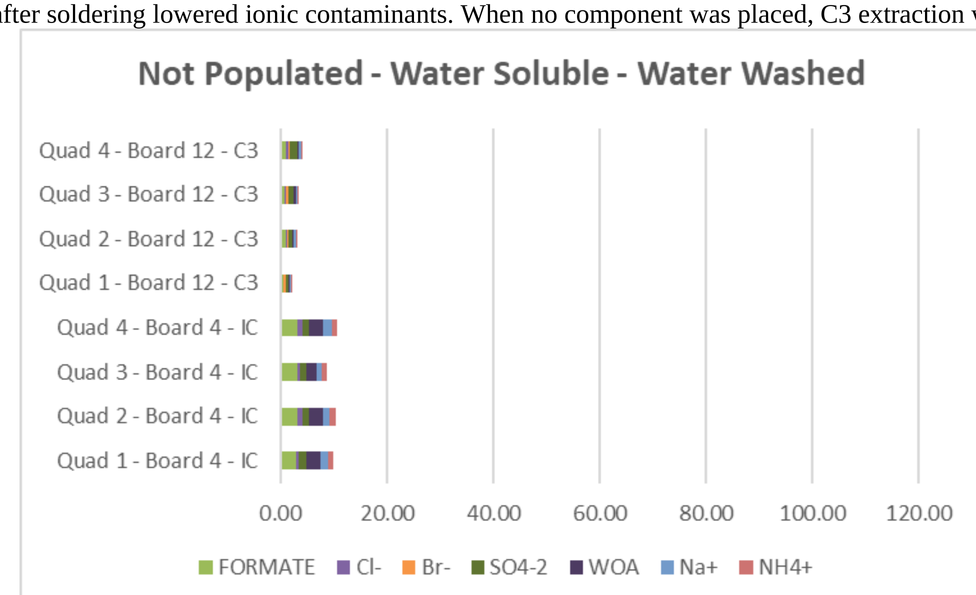


Figure 19: IC and C3 Extraction followed by IC on a Water-Soluble Solder Board, Not Populated and Cleaned

SIR Data Findings of the Water-Soluble Solder Paste – Not Populated – Cleaned
SIR values came in at 11.5-12 Log Ω's and were stable over the test duration.

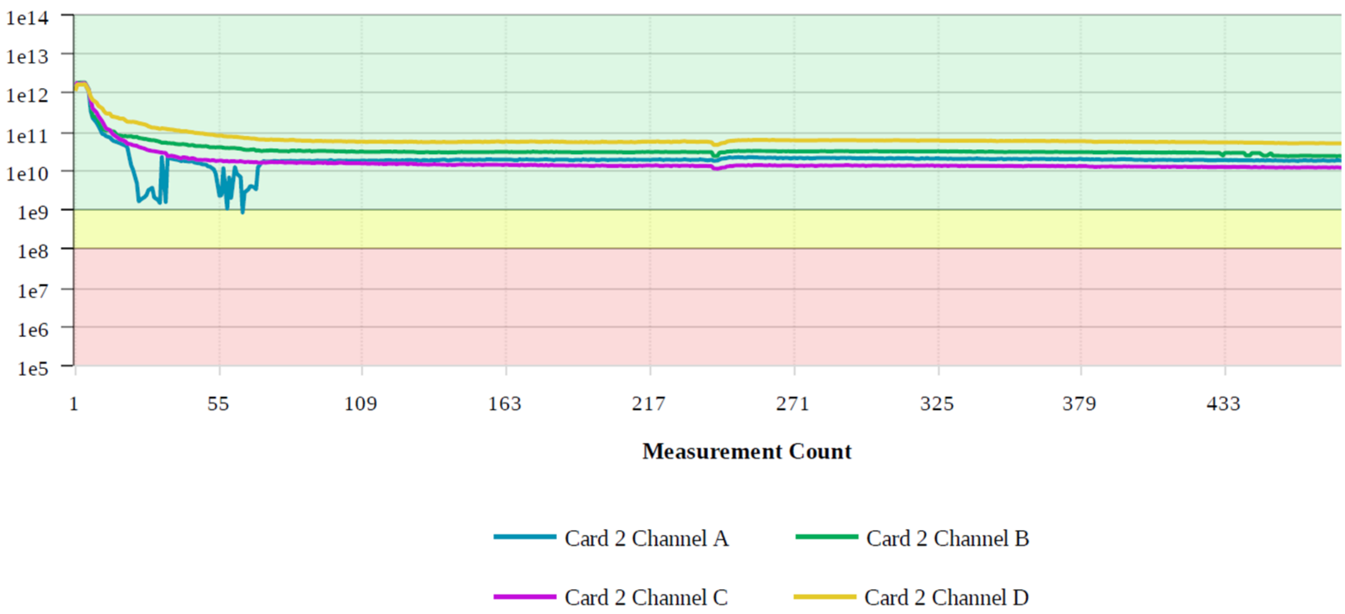


Figure 20: Test Board Soldered with the Water-Soluble Solder Paste, Cleaned and No Components Placed

Populated – Water-Soluble Solder Paste – Not Cleaned

The weak organic acids were higher when performing the C3 extraction than the IC extraction of each quadrant. When running the C3, the QFN is removed, followed by the site-specific C3 extraction. This is an indicator, that flux outgassing channels are blocked. Channel 4, patterned with thermal vias in solder mask webs performed better.

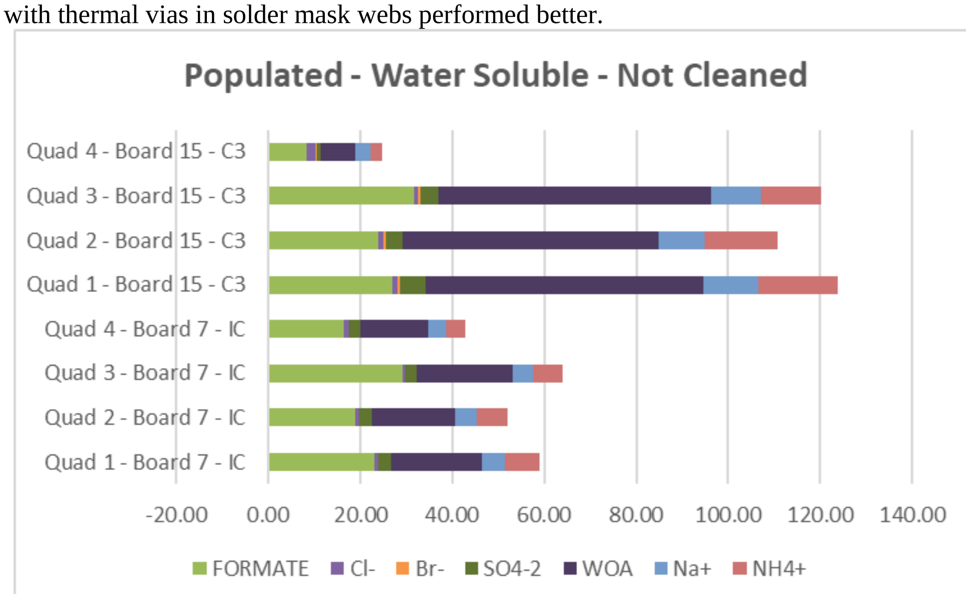
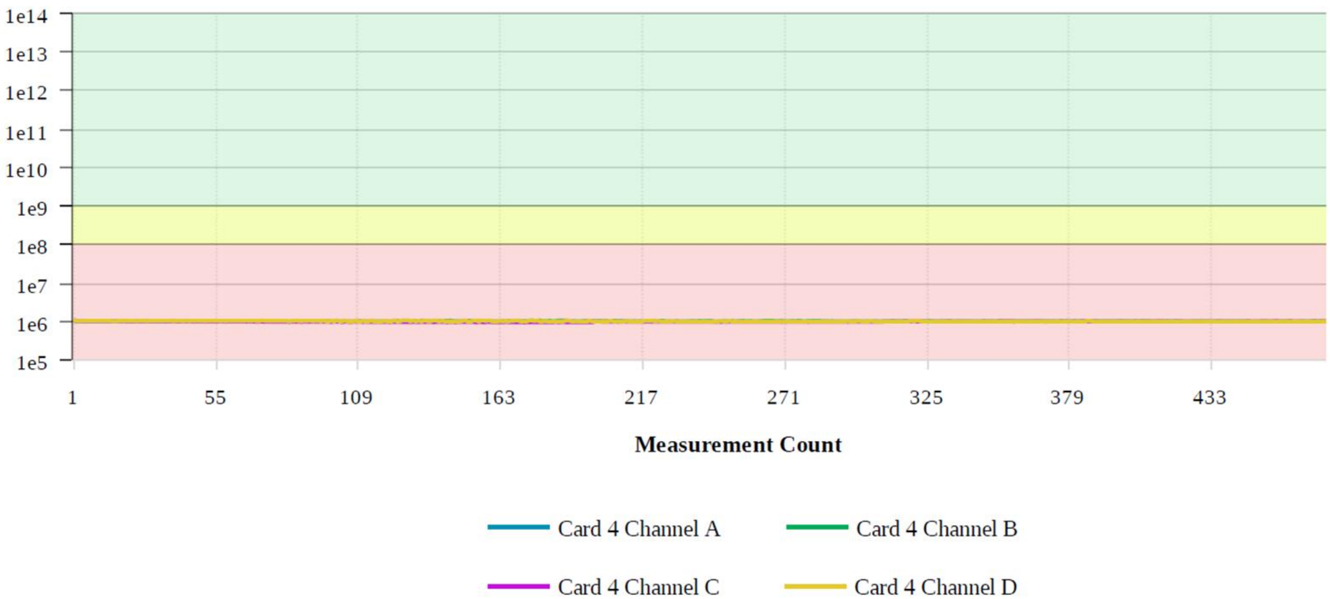


Figure 21: IC and C3 Extraction followed by IC on a Water-Soluble Solder Board, Populated and Not Cleaned

SIR Data Findings of the Water-Soluble Solder Paste – Populated – Not Cleaned
All channels failed SIR testing.



\ **Figure 22:** Test Board Soldered with the Water-Soluble Solder Paste, Not Cleaned and Populated

Populated – Water-Soluble Solder Paste – Cleaned
Ionic contamination levels were lower on cleaned boards.

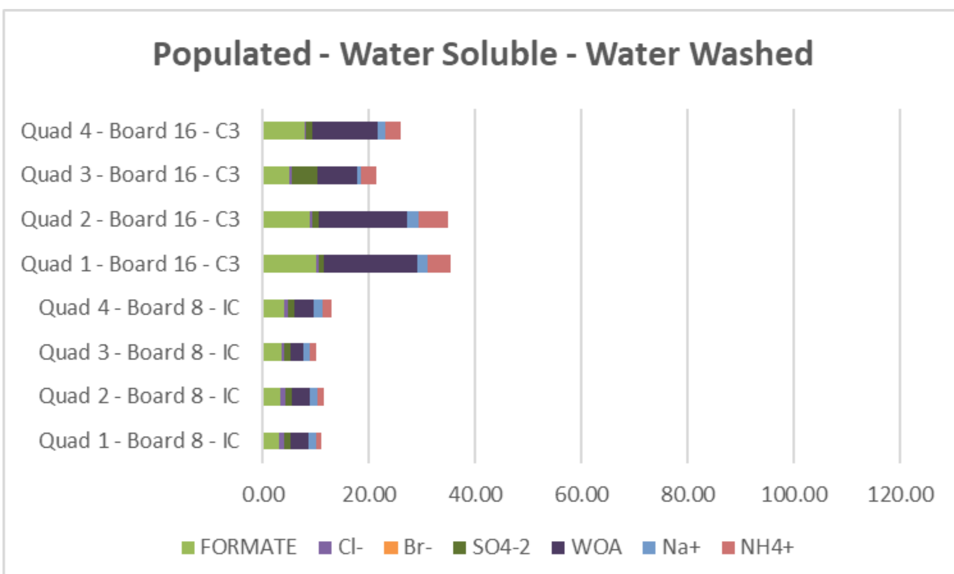


Figure 23: IC and C3 Extraction followed by IC on a Water-Soluble Soldered Board, Populated and Cleaned

SIR Data Findings of the Water-Soluble Solder Paste – Populated – Cleaned
The water-soluble solder paste, populated and water cleaned failed all four SIR channels.

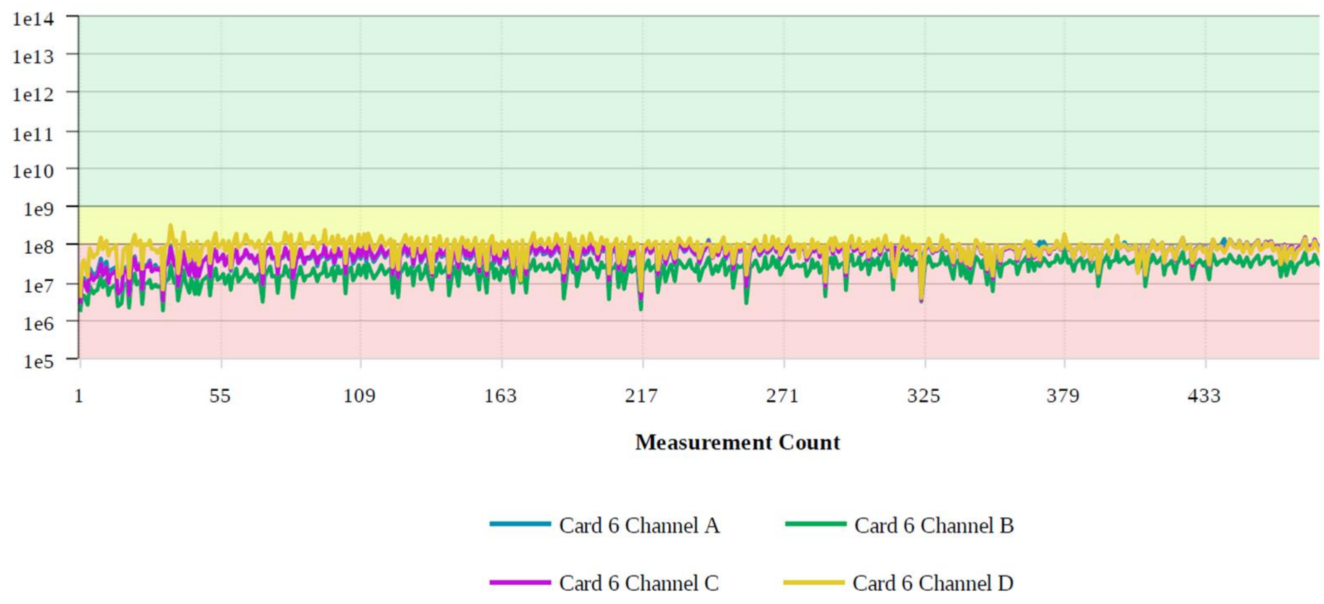


Figure 24: Test Board Soldered with the Water-Soluble Solder Paste, Populated, and Cleaned

STATISTICAL METHODS

Data Preprocessing

Before analyzing the DOE statistically, the data had to be processed. For each quadrant, the mean SIR value was calculated as well as the sum of all ionic species. The mean SIR value was calculated from all SIR measurements performed on a quadrant. One could choose any period to average over, or use other measures, but for the initial analysis of this data set, the mean SIR value over the entire test duration was used. For the SIR data, the total ionic content was used instead of analysis on a per ion basis, although this will be undertaken later. This was done to reduce the amount of analysis and bring the output to a manageable size.

For the IC data, there were two extraction methods utilized: "whole board" extraction in which the quadrant is broken out and submerged in 10% IPA/90%DI water; and C3 extraction in which a component is removed and flipped over onto the pad and steam is introduced to that component only. Due to the size of the DOE, only two IC measurements were made with each method (whole board and C3). This low sample size ($n = 2$), prohibits meaningful statistical comparisons between extraction methods. However, the C3 data was normalized to permit further analysis. As the C3 extraction only extracts ¼ of the total number of components on a quadrant, the ionic contamination amounts (in $\mu g/in^2$) for C3 were multiplied by 4. These were then treated as a replicate measurement for ionic contamination values. While this method is susceptible to statistical outliers, and doesn't account for ionic contamination sources other than those located at the site of the component, this was the best method available without increasing the DOE size.

General Data Analysis Approach

Due to the number of variables studied, as well as the strong suspicion that interactions between factors may be significant a multiway Analysis Of VAriance (ANOVA) was utilized on the mean SIR values and the total ionic contamination levels. Due to the unbalanced nature of the DOE, a Type III Sum of Squares was used[9].

To facilitate the interpretation of the results of this study, as well as any future work, the effect sizes will be reported. Reporting effect sizes, in addition to traditional measures of statistical significance such as p values, allows for results to be better utilized. As effect sizes are generally not utilized in this industry a brief primer is included here, although a more detailed discussion can be found elsewhere[10]. The effect size is a simple way to *quantify the difference* between groups, rather than p value which simply reports that there *was a difference* between groups[11]. For those who wish to understand, in lay terms, effect sizes, the presentation by Coe - *It's the Effect Size Stupid* - is recommended. There are three main advantages that effect sizes have over traditional statistical reporting[12]. First, they represent the *magnitude* of the difference between groups in a standardized metric which does not depend on the scale of the measured value. This allows the practical significance of the findings to be shown, meaning that one can tell if changing a particular setting in a process will result in a large change in the output or a small one. Secondly, by standardizing the results the current study can be compared to *prior studies* (*meta-analysis*). Lastly, when planning *future studies* the effect size can be used for *a priori* power size calculations, meaning that one can determine the average sample size needed to observe a particular effect.

There are many different measures of effect sizes and how to calculate them, and just as many discussions of which effect size or calculation is appropriate for a particular scenario, but much of this is rooted in statistical minutiae[13] and the fact that some early statistical programs used incorrect formulas or terminology[14]. However, there is much agreement in the general methods to use as well as the interpretation[15]. One of the authors (Lober) feels that the partial effect size *partial eta squared* (η_p^2) to be suitable for this study, but could easily accept the use of *eta squared* (η^2) or either *omega squared* (ω^2) or *partial omega squared* (ω_p^2).

Conceptually, and to some extent mathematically, effect sizes and their interpretation can be related to the well-known Pearson Correlation Coefficient (r^2) from regression. Effect sizes, for the four listed above) range between 0 and 1, and a larger number indicates a more significant effect. Effect size interpretations generally use the qualitative terms *small* (< 0.01), *medium* (□ 0.06), and *large* (□ 0.14).

DOE Analysis: SIR

The ANOVA model that best fit the data is presented as Figure 25. It was determined that the solder mask design had no effect on the resulting SIR value, and as such was removed from the model. The type of solder paste (water soluble vs no clean) was predictably the most significant factor impacting the mean SIR value, followed by weather the part was cleaned or not. It was noteworthy that the interaction between cleaned and populated boards was very significant. This indicates that either off gassing from solder or the ability for cleaning agents to penetrate underneath components have a large impact on reliability from an SIR point of view.

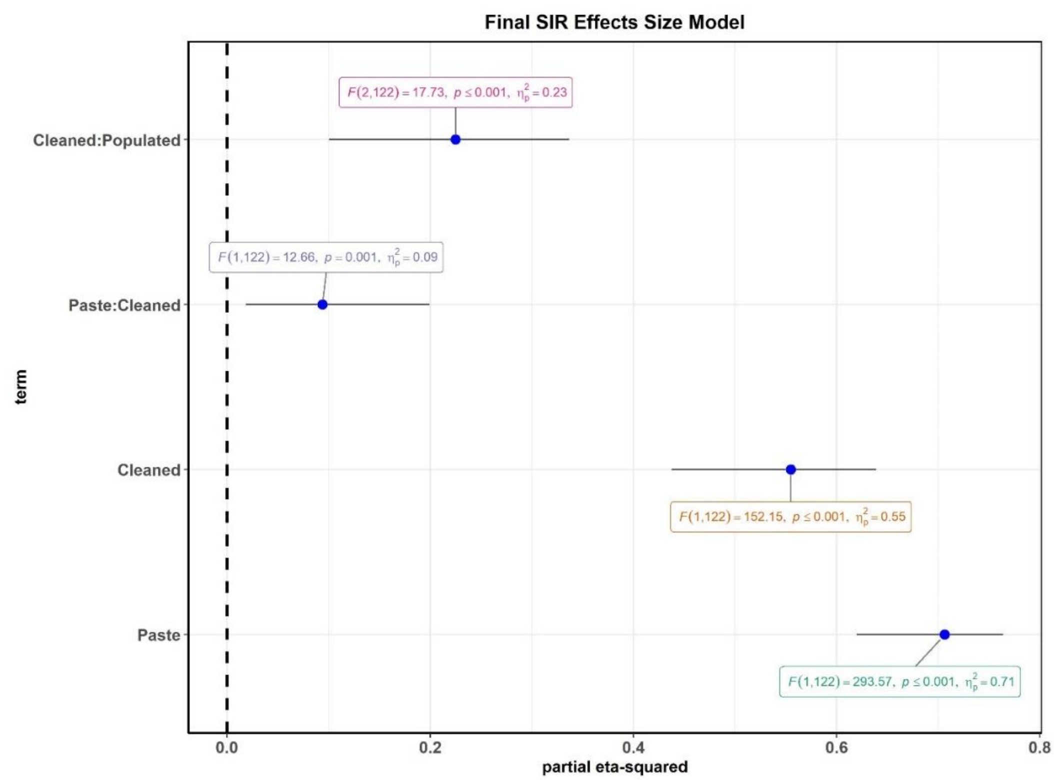


Figure 25: Final Model of SIR Data

DOE Analysis: IC

As noted above, the normalized total IC values were used in the statistical analysis. The model and effect sizes are presented as Figure 26. It is interesting to note that the interaction between solder paste type and cleaning is substantially higher than for SIR data, where as the interaction between cleaning and populated is much smaller, almost to the point of statistical insignificance.

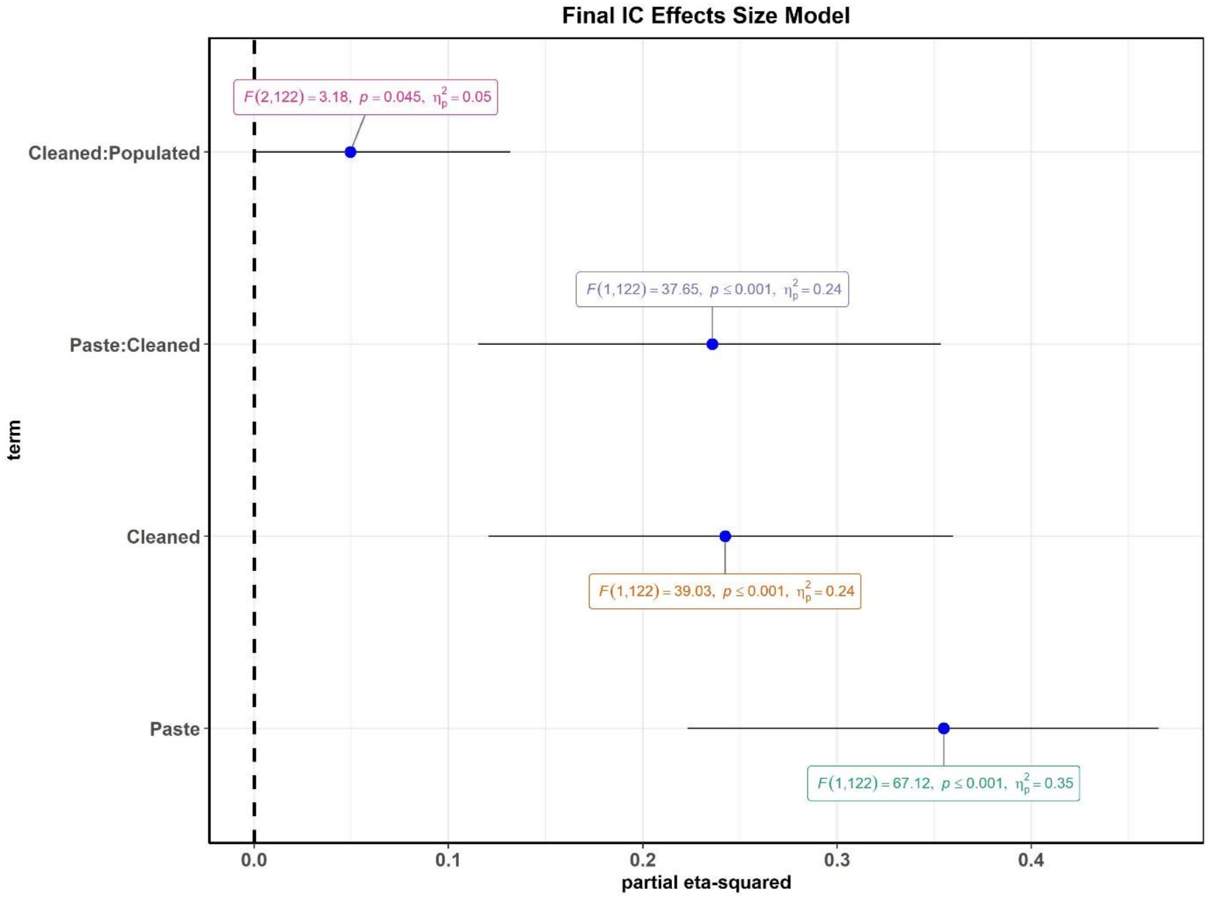


Figure 16: IC Model

DOE Analysis: SIR - IC correlation

The correlation between SIR and IC values is presented as Figure 27 for the no clean solder paste, and Figure 28 for the water soluble solder paste. This was done due the vastly different distribution of the data between solder pate types. The correlation between SIR values and IC values is moderate ($r^2 \approx 0.5$), but this is suspected to be caused by the statistical methods used. The assumptions of Pearson's R is that the variables are unbounded, or at least there is not a significant portion of the data at a bound. This is not the case, especially for boards that had water soluble flux on them. The SIR data is heavily skewed towards the lower bound of the SIR measurement system ($6.0\log_{10}\Omega$) for the water soluble flux. Conversely the no clean SIR data is skewed towards the upper bound of the SIR equipment ($\approx 12\log_{10}\Omega$) and the lower bound of the IC. Elimination of these outliers or a different statistical approach is needed.

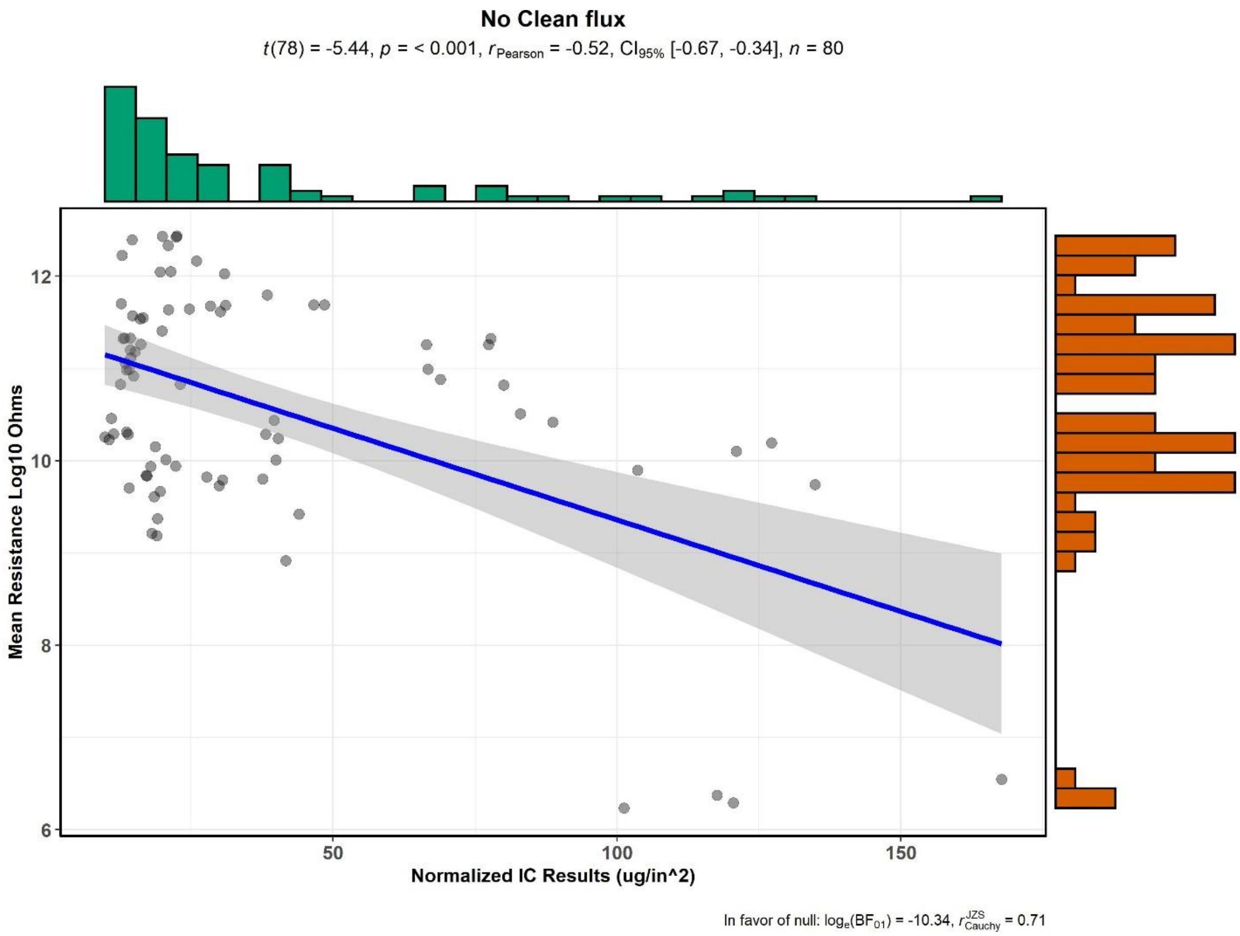


Figure 27: SIR IC Correlation No Clean Flux

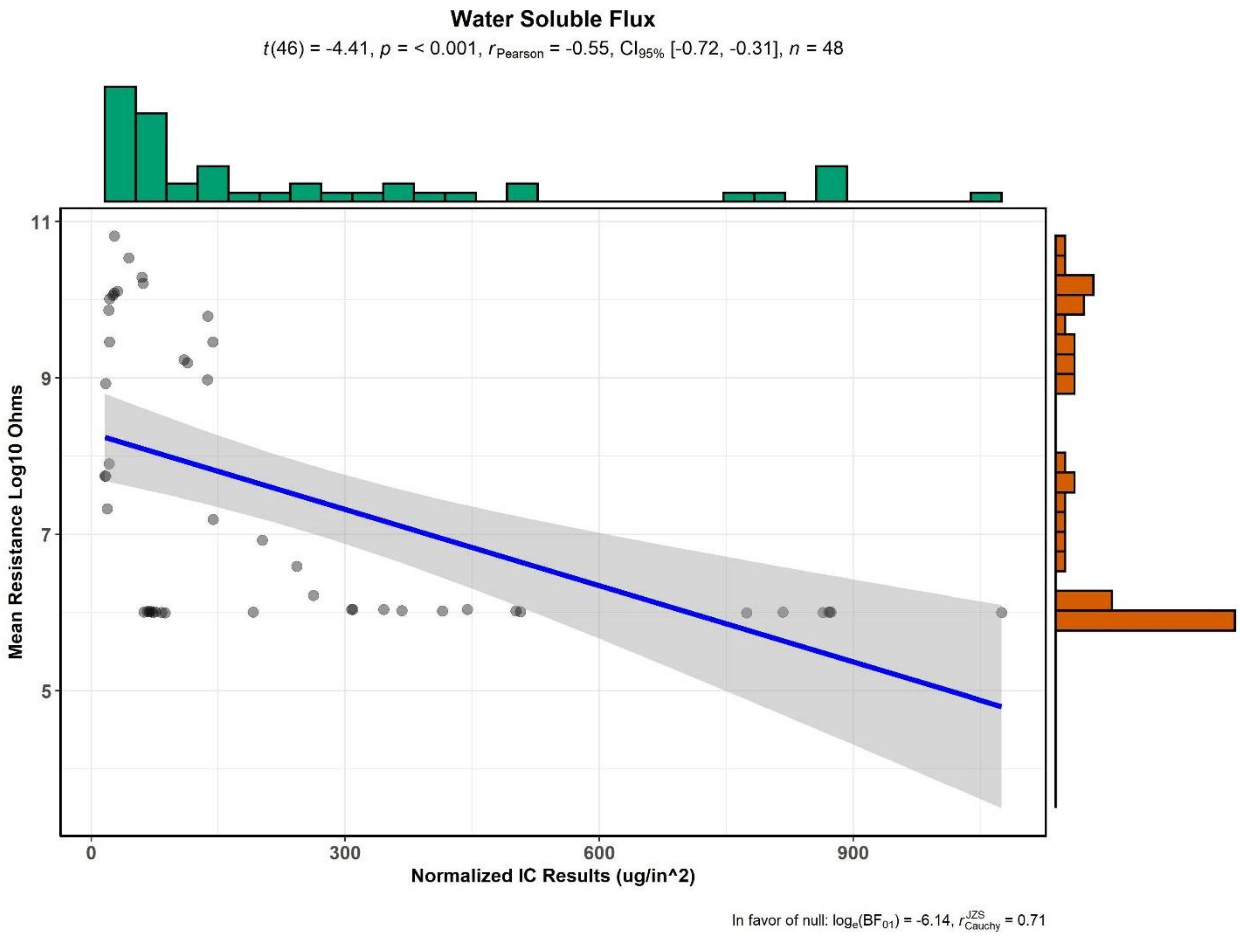


Figure 28: SIR IC correlation Water Soluble Flux

TEST SUITE AND TEST SPEC FOR CLEANLINESS

The Design Phase is the best approach toward developing a test suite and test spec for cleanliness. C3 followed by IC analysis and SIR are effective at analyzing ionic contamination located next to the I/O leads, and from the I/O leads to the ground lug. The quantitative test methods accurately determine the activity of ionic contamination present at the components bottom termination.

The first step is to start with the bare board design. The core issue is the low standoff gap and high thermal mass of solder under these components. Bare board design features that improve outgassing and standoff gap improve reliability.

- Laminates
- CAF / Interior
- Metallization
- Surface Cleanliness
- Solder Mask Definition
- Solder Mash Windows
- Thermal Via
- VIPPO
- Others

Materials characterization of soldering materials, reflow parameters, cleaning agents, cleaning machines and process parameters is the logical second step.

- Solder Pastes
- Wave Fluxes
- Selective Soldering Fluxes
- Reflow Conditions
- No-Clean vs. Cleaning
- Cleaning agents
- Cleaning machines
- Time to clean after reflowing the assembly
- Process Parameters

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