

FAILURE ANALYSIS – USING ION CHROMATOGRAPHY AND ION CHROMATOGRAPHY/MASS SPEC (IC/MS)

Terry Munson,
Foresite, Inc.
IN USA
TerryM@Foresiteinc.com

Abstract

Since the 1980s the electronics industry has utilized ion chromatography (IC) analysis to understand the relationship of ions, and some organics, to product reliability. From component and board fabrication to complete electronic assemblies and their end-use environment, IC analysis has been the de facto method for evaluating ionic cleanliness of electronic hardware. Typical ions accounted for include chloride, bromide, nitrate, sulfate, weak-organic acid (WOA), sodium and ammonium. Environmental and other concerns have driven the industry to adopt myriad flux formulations, which has created a need to further differentiate weak-organic acids beyond what a typical IC system using conductivity can provide.

By utilizing an Ion Chromatography/Mass Spectroscopy (IC/MS) system optimized for organic separation, we can use the same IC column technology for the typical suite of anion/organic species, then run the sample through a quad-pole mass spectrometer which provides the molecular weight assessment of organics for over two dozen channels. This capability is critical to our failure analysis work at Foresite, as it allows for identification of specific organic acids and flux activators. This information can aid in identifying specific residue sources (e.g. board fabrication, SMT paste flux, waver solder liquid flux, hand solder flux or a completely different, possibly unauthorized, source.

Key Words: Ion Chromatography, IC/MS, chloride, sulfate, weak organic acid, spot extraction.

Introduction

Changes in technology and electronic assembly techniques have been dramatic over the last thirty years. Electronic assembly from the 1950s through the 1990s for low- and high-reliability hardware used very similar materials and processes: rosin-based flux with halide activators, in conjunction with tin-lead solder, used in wave-, reflow- or hand-soldering processes and subsequently solvent cleaned (Freon™ or 1,1,1-Trichloroethane). This worked well for decades on high-reliability technology, but then the Clean Air Act of 1987 banned most solvent cleaners that were used. This was a dramatic disruption to the industry which allowed technology drivers (high-volume manufacturers) to create new approaches. Initial introduction of rosin-free no-clean fluxes, as well as water-soluble fluxes with no rosin content, used with historically reliable tin-lead systems and reflow temperatures around 184 °C, fared well. Then a bigger change occurred: by removing lead from solder systems, reflow temperatures can be pushed beyond 230 °C. In conjunction with increased heat stress, the lack of insulative rosin provides a host of opportunities for performance degradation. Large recalls due to contamination or corrosion issues were rare during several decades of rosin fluxing/solvent cleaning. During the 1980s and early 90s, high-

reliability hardware was built with mixed-technology processes similar to what is built today with little or no reliability issues of the leaded solder joints and rosin/solvent cleaned assembly processes. During the transition to no-clean assembly (low- or no-solids fluxes), both proper processing of the flux system and cleanliness of all materials in the assembly suddenly became critical. Circuit-performance issues, dendritic growth, electrical leakage, and insulative residues are all more likely with no cleaning process. As technology continually advanced and new, smaller surface-mount component packaging was introduced and flourished during the mid-90s such as QFN, PQFN, bottom-terminated DIP, large power FETs, and LED technology. Increased power density demands mean many packages have a large soldered ground pad under the component. This creates a standoff height that is virtually non-existent in some packages, which is prone to trapping active flux residues. These residues may absorb enough moisture over time to facilitate electrical leakage, which can be fatal to sensitive circuits. Technology has become so pervasive that the typical citizen's daily life would literally grind to a halt without it. We are amid a surge of technology that is putting massive computing power in everything. But, as the next technology leaps require smaller, denser, stacked interconnects with lower power consumption and higher frequencies, cleanliness becomes more critical to performance, and more difficult to ensure.

Technology and assembly have made significant changes over the last 25 years, especially in chemical processes.

Traditional processes (Fig 1) used rosin-based flux and solvent cleaning – and rarely failed due to cleanliness issues. Changes to no-clean (Fig 2) (low-solids, no rosin) fluxes and Lead-free solder alloys with their

higher temperatures, require cleaning of aggressive, water-soluble fluxes (H1) with saponified, high-pressure inline wash processes, or no-clean fluxes that are not halide-free (ROL1) using more aggressive flux activators to have better soldering with little or no rosin. The IPC test methods for cleanliness monitoring have not been updated to keep up with the process and material changes and specifications have become guideline documents, with the drive back to the OEM to establish cleanliness levels needed to meet the reliability requirements to be put on the product print.

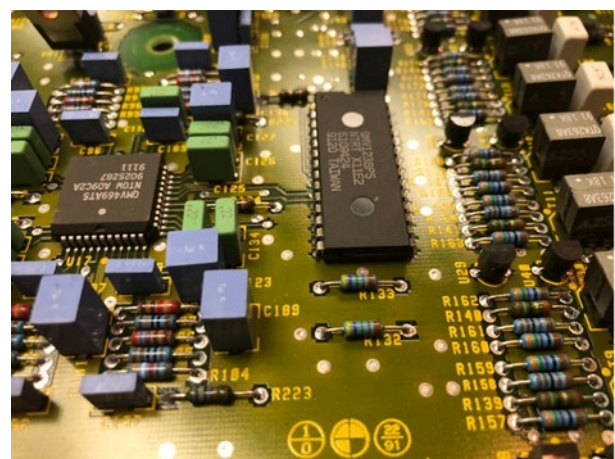


Figure 1. PCBA from 1991 Rosin Flux/SnPb solder and solvent

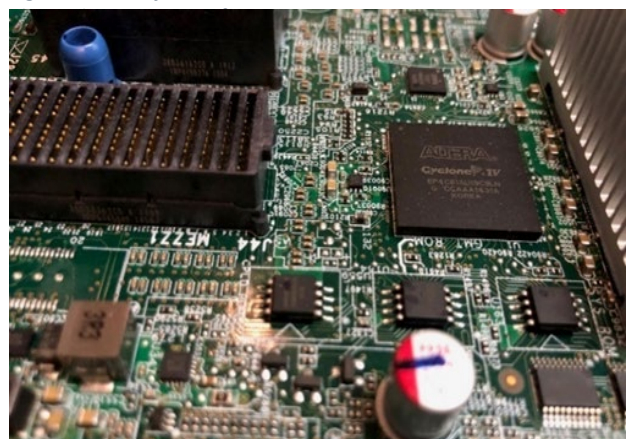


Figure 2. PCBA from 2017 SAC 305 No Clean Assembly at 50x magnification

Cleanliness = Residue Impact on Reliability

It is generally accepted that there is a causal relationship between the amount and type of surface contamination and the probability of electrochemical migration (ECM) or a dendritic short (Fig 3 and Fig 4) will occur. But many do not understand that the corrosion cell required to propagate a dendrite requires three critical elements;

- 1) Adequate moisture to bridge biased points, causing de-plating and a saturated solution of metal salts.
- 2) Voltage difference (> 1.5 V) to drive plating deposition from anode to cathode.
- 3) Conductive or corrosive residue to accelerate the reaction of de-plating and metal salt formation. Flux residues and high-humidity end-use environments are typically a part of the recipe. See the images on Figure 6 to see the progression of a short.

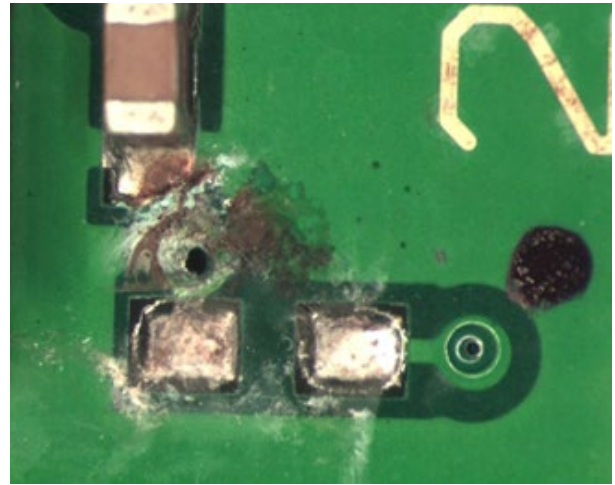


Figure 3. Dendrite shorting via and capacitor pad with 5 volts due to fluid trapped in via.

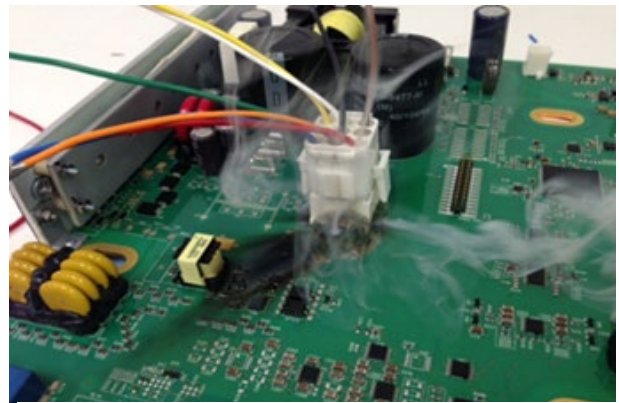


Figure 4. Dendrite under connector due to poorly cleaned water-soluble flux in high humidity condition and high voltage.

Time lapse of a Copper Dendrite growing

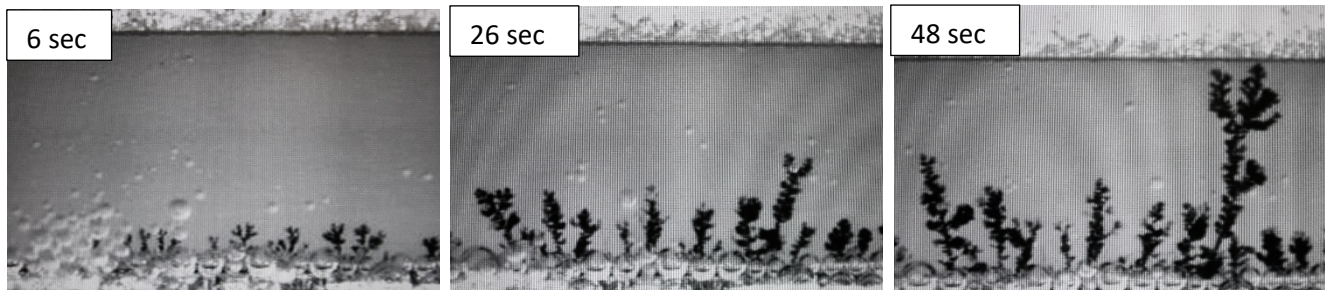


Figure 6. Time lapse images of a copper dendrite growing with 5 volts between traces 0.13 mm apart with MSA plating residue.



Figure 6. Fluid bridging a 0.13 mm space but no dendrite but a measurable short.

Figure 5. shows a 5-volt bias between anode and cathode and enough moisture to bridge the spacing, a current leakage path of 20 - 250 mA causes intermittent circuit performance. As a precursor to dendrite formation, white flux or hazing of the flux is a sign of moisture presence. Leakage without dendrite still causes failures.

Traditional Cleanliness Testing

- ROSE Testing (Resistivity of Solvent Extract)
 - IPC TM 650 2.3.25¹ – Performed on Product – entire assembly in gallons of IPA/DI water solution to get an average cleanliness level.
- SIR Testing (Surface Insulation Resistance)
 - IPC TM 650 2.6.3.7² – Performed on Coupons – bare copper / precleaned coupons – biased and monitored.
- Ion Chromatography (IC)³
 - IPC TM 650 2.3.28 – Performed on Product - bag extraction of the entire assembly in minimal volume of IPA/DI water.

These are all useful tests but have limitations. And the biggest limitation is that they average the cleanliness (residue) effect over the entire board or comb location. Dendrite and leakage shorts occur pad-to-pad or hole-to-hole and not over the

entire board. ROSE testing was primarily developed in the 1960s for testing of rosin flux and solvent cleaning (the IPC TR-583⁴ report from the ionic conductivity task group committee stated that the new fluxes did not react the same and that the systems were not a predictor of field performance released in 2002). SIR developed in the 1980s utilizes test coupons that are not truly representative of the cumulative effect of PCB, component and process cleanliness. Ion Chromatography, which I developed in the mid-1990s using total board extractions, again averaging the total area of the board and not evaluating the effect of processes, like selective soldering or flux entrapment under QFN packages.

Some Changes in the Last 25 Years

- No-clean, low solids ROL0 halide free. With low flux activation only working with very solderable boards and components.
- No-clean, low solids ROL1 with halides due to the need for greater flux activation.
- Lead-free solders – tin rich alloys without the lead in soldering driving the temperature much higher.
- PQFN, PowerFET, Flip Chip, mBGA & low standoff packages and selective wave soldering pallets that trap and isolate flux under the pallet (Fig 7).
- Denser spacing and greater circuit sensitivity
- Cleanliness monitoring and inspection
- Technology used in greater environmental extreme's and

autonomous conditions, such as drones, transportation, robotic rescue systems, as well as pipeline cleaning and inspection systems.

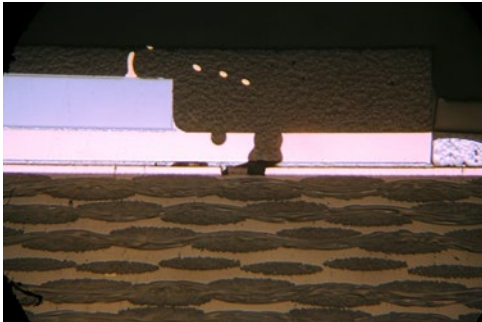


Figure 7. Cross Section of QFN with a 0.25mm gap reduced to 0.008mm gap

Where do Residues Come from that Cause Performance Problems (Short List)

- Board Fabrication (etchants, plating, tap water rinsing or river water, DI cascade forward dirty tanks)
- Component Fabrication (plating, handling, water rinsing, ingress paths)
- Flux (paste, wave, cored, flux pen/bottle)
- No-Clean Processes (reflow, selective wave, wave, fountain, robotic, laser, hand-solder)
- Cleaning Processes (water quality, saponifier residue, flux and soap trapped residues)
- Conformal Coating (trapping residues in and allowing moisture and sulfur to pass)
- Staking Compounds (outgassing of curing material)
- Temporary Maskants (leaving residues that can be high in chlorine or sulfate post soldering)

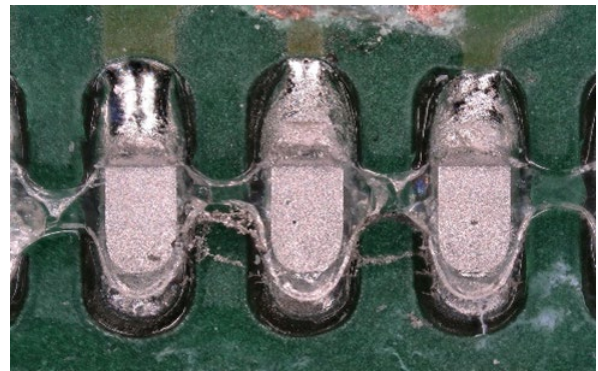


Figure 8. Dendrite growing under cleaned QFN.

Since these sources of contamination are residues from the gross process steps, it could be expected that the residues could be uniform across the entire board, but they are typically not. Differences in component standoff, lead spacing, circuit sensitivity, constant-biased monitoring circuits, etc. define higher risk areas of an assembly that are more susceptible to localized residues (Fig 8, 9, and 10). Residues from selective or hand-soldering operations can also cause localized circuit performance issues, while remaining essentially undetectable when averaged over the surface area of the entire assembly.

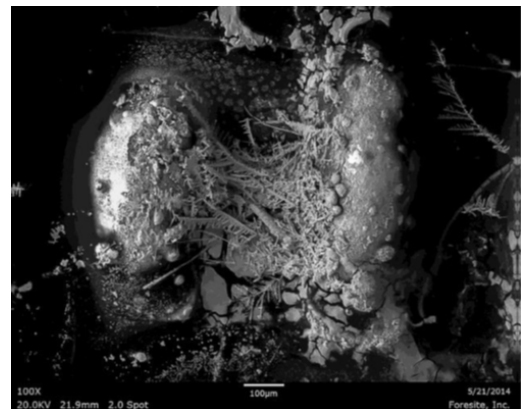


Figure 9. Dendrites from housing contamination on exposed areas of the hardware where coating is thin or not present.

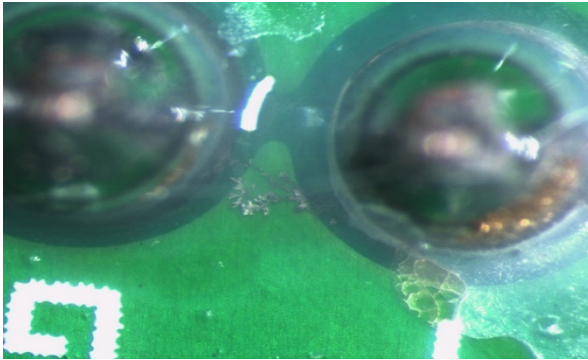


Figure 10. Dendrite growing under conformal coating from selective soldering operation.

We have looked at the issues of stray voltage and dendrite shorting of fielded hardware so the question is how can the failures be looked at with different tools to understand if the contamination is from the fabrication or assembly process? Using traditional tools to look at the ionic and organic contamination average the entire board contamination and won't separate the fluxes from the failure area and many request analyses by SEM/EDS, or FTIR. So, let's look at these systems for a minute

SEM/EDS elemental detection is a specific electronic beam raster of a micron area to identify elements such as tin, copper, bromine, calcium, silica, carbon and oxygen. If the concentration is greater than 1.5-2Wt% the element is detectable that is removed by the EDX electron beam. So, if the residue is thin it will burn through the surface residue and not be detectable by the EDS system, we find that if the EDS is detecting 1.5-5% there are 1000s of ug/in² by ion chromatography/with a C3 localized extraction. Since the EDS does not speciate the organic residues and classifies them as carbon it is difficult to know what the source of carbon is in a failure. Dendrites will cause thermal events and bromine from the flame retardant are released and the copper and

tin which are part of the dendrite will be present but not what caused the dendrite to form. Since the failure was a no clean flux

FTIR of failure analysis is difficult due to the presence of carbon and organic bonds as well as the fact that there was flux applied to the area and that the FTIR is not able discern between a benign no clean flux or a partially heated flux that is still moisture absorbing and conductive.

We propose a different approach, on we have been doing for 7-8 years and found it very effective. When using standard Ion chromatography there are limitations especially with the ever-growing list of organic acids that are being used in the more aggressive no clean and water-soluble fluxes. These weak organic acids (WOA) flux activators are being blended to meet solderability needs first and how well they transition to benign fluxes after the soldering is complete. Fluxes not cleaned must make this transition from a conductive moisture absorbing residue demonstrated in previous Pan Pac papers, to a benign insulative residue while the fumes during reflow and wave solder are shielded away from connector contacts and other daughter cards or they can transfer these residues to the contact surfaces causing corrosion and insulative issues later in the field.

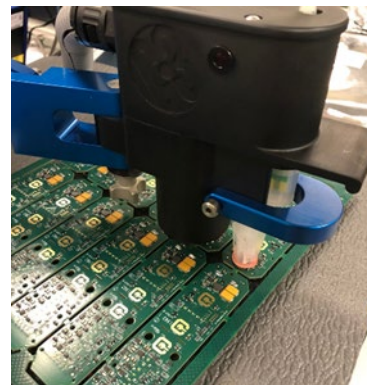


Figure 11. Localized extraction tool to isolate extraction area

Foresite investigations will take a three phased approach:

1. *Isolate a specific area (Fig 11) with a steam extraction using a tool designed for this specific extraction of a 0.1 in² area that will allow for solubilization of ionic and organic residues on the surface and subsurface of the PCBA component and plastic surfaces. By using the localized extraction tool, we will collect a uniform volume of extraction solution (2.2 mls) from a specific area (0.1 in²) that will always be the same so comparing areas of a PCBA that failed vs that didn't fail or top side vs bottom side residues. This specific tool will also evaluate how corrosive the residues extracted from the board surface with a sacrificial copper electrode at 0.13 mm spacing with a 10v bias. Each 2.2 ml volume of extracted residue is placed in an autosampler vial to be tested*
2. *Using an autosampler to schedule the sample run in the Ion Chromatography system to determine the anions and cations, as well as the general Weak Organic Acids that are difficult to speciate all the different WOAs from each other using just conductivity analysis. Knowing that residues like methane sulfonic acid (MSA) is difficult to separate from acetate or formate depending on the column and eluent. This allows a quick 17-minute run for the primary anions, cations, and WOA results.*
3. *Using the same vial of extraction solution in a second autosampler, the sample was then analyzed by an IC/MS spec system with both conductivity separation and mass spec (MS) detection using a quad pole detector. This MS detection allows for the analysis by mass weight of the species detected creating separation of the organic acids, MSA, chlorate, citrate.*

<u>Anion</u>	<u>Other species identified by IC/MS</u>	<u>by IC only (anion)</u>
1.	Chloride	Chloride
2.	Chlorate	co-eluate with chloride
3.	Citrate	co-eluate with Acetate
4.	MSA (methane sulfonic acid)	co-eluate with Formate
5.	Nitrate	Nitrate
6.	Nitrite	Nitrite
7.	Bromide	Bromide
8.	Bromate	co-eluates with bromide
9.	Sulfate	Sulfate
10.	Sulfite	co-eluate with sulfate
11.	Fluoride	Fluoride
12.	Acetate	Acetate
13.	Formate	Formate
14.	Phosphate	Phosphate

Table 1. IC compared to IC/MS for common anions

Anion Weak Organic Acids identified by IC/MS

1. Propionate
2. Glycolate
3. Butyrate
4. Oxalate
5. Lactate
6. Malonate
7. Thiosulfate
8. Maleate
9. Succinate
10. Benzoate
11. Glutarate
12. Malate
13. Adipate
14. Tartrate
15. Phthalate

by IC only (anion)

- co-eluate with succinate
- co-eluate with succinate
- co-eluate with succinate
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- co-eluate with succinate
- co-eluate with succinate
- co-eluate with succinate
- Succinate***
- co-eluate with succinate
- co-eluate with succinate
- Malate***
- Adipate***
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- co-eluate with succinate

Table 2. IC compared to IC/MS for common Weak Organic Acids (WOA)

Diagram of IC / MS system configuration⁵

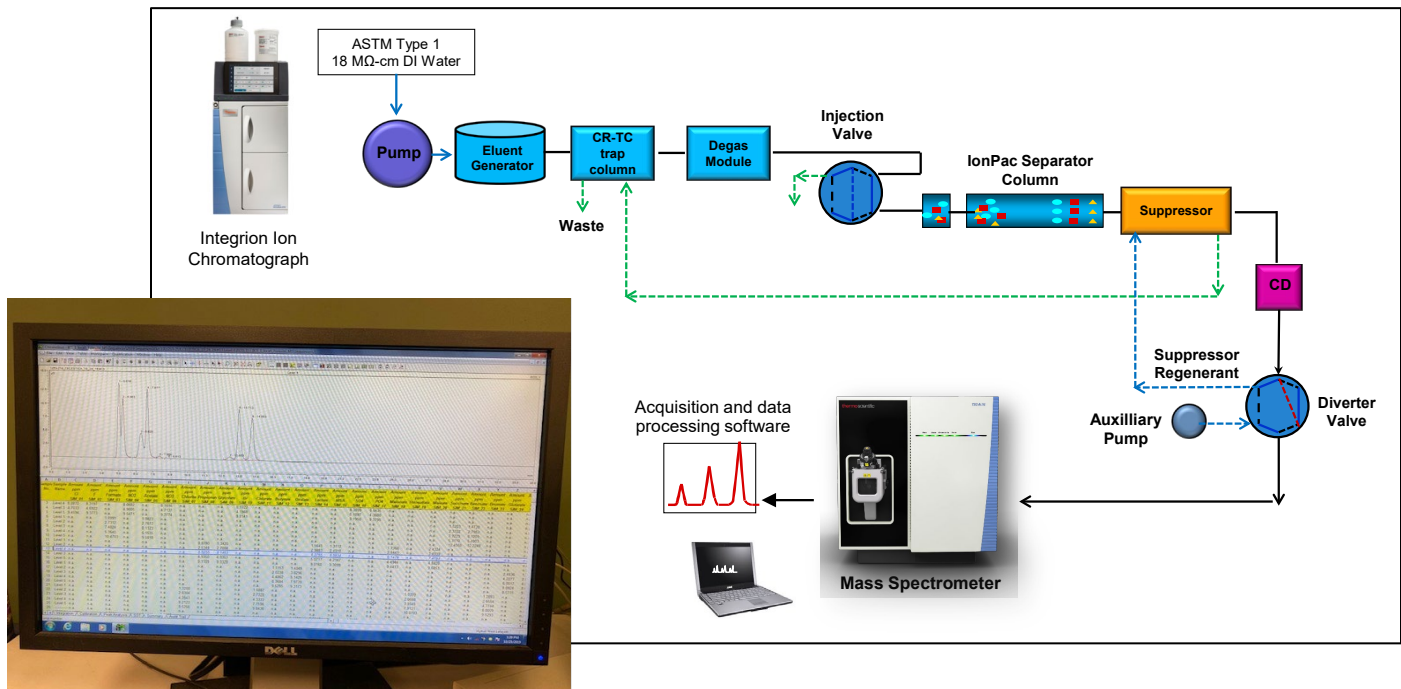


Figure 13. IC/Mass Spec results showing separation and diagram of the system

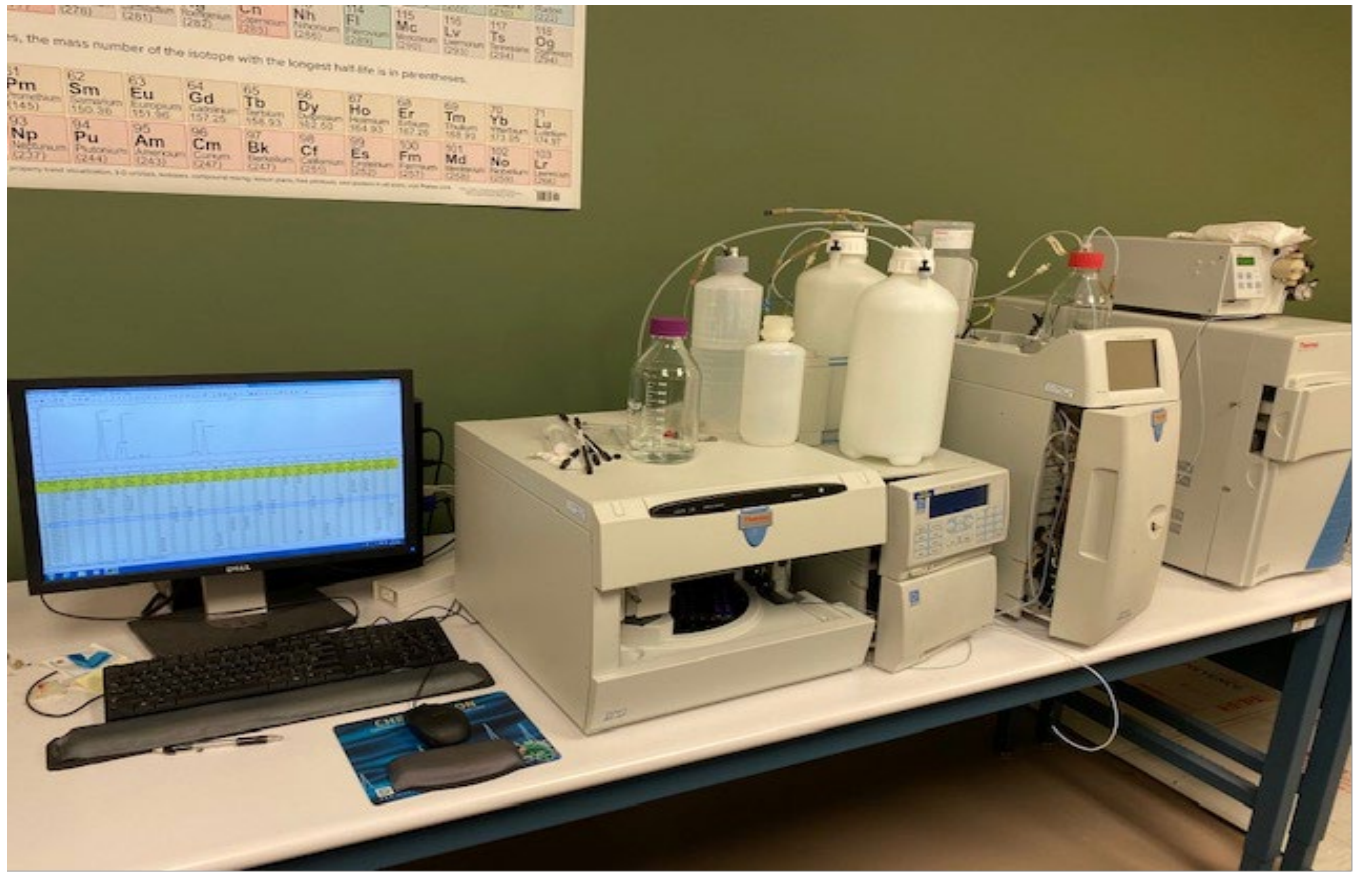


Figure 12. IC/Mass Spec system with autosampler

all values in µg/l		Ion Chromatography / Mass Spec using a Quad Pole Detector																		Total					
Sample Description	Chloride	Acetate	NO3	Chlorite	Br	Chlorate	MnO4	Propionate	Glycolate	Chloride	Butyrate	Oxalate	Lactate	Malonate	Thiosulfate	Maleate	Succinate	Benzoate	Glutarate	Maleate	Aspartate	Tartrate	Pyruvate	WOA	
1	Falco Assembly A - C1 location	2.65	4.16	0	0	144.36	0	0	0	0	0	0	0	5.65	0	0	102.25	0	3.65	0	251.24	0	0	0	362.79
2	Falco Assembly A - R1 location	2.11	3.59	0.02	0	112.36	0	0	0	0	0	0	0	5.98	0	0	121.61	0	4.85	0	301.25	0	0	0	433.69
3	Falco Assembly A - J1 Connector	1.09	1.81	0	0	40.69	0	0	0	0	0	0	0	2.36	0	0	41.26	0	1.59	0	79.52	0	0	0	124.73
4	Good Assembly A - C1 location	0.81	0	0.44	0	0.51	0	0	1.21	0	0	2.35	0	0	0	0	18.65	0	0	0	0	0	0	0	22.21
5	Good Assembly A - R1 location	0.66	0	0.13	0	0.10	0	0	1.06	0	0	1.22	0	0	0	0	15.24	0	0	0	0	0	0	0	17.52
6	Good Assembly A - J1 Connector	0.98	0	0.19	0	0.12	0	0	1.36	0	0	1.67	0	0	0	0	16.88	0	0	0	0	0	0	0	19.91
7	Paste No-Clean 0.1g on foil heated to 150°C	0.51	1.55	0.02	0	0	0	0	3.05	0	0	4.91	0	0	0	0	7.98	0	0	0	0	0	0	0	15.94
8	Touch up / repair flux pen 0.1g of flux on foil dry	0.36	12.63	0	0	0	0	0	0	0	0	0	0	18.65	0	0	245.07	0	37.98	0	562.54	0	0	0	884.24

Table 3. IC/Mass Spec system results of C3 extracted samples in µg/in²

Using both Ion Chromatography and IC/Mass Spec, let's look at a couple of case studies that require understanding what caused the contamination of the electronic hardware. Since the boards did not show thermal damage or dendrite growth over the entire board surface, it's critical to isolate the areas of the extraction so that the residues near, and in the specific location

of the damage, can be assessed. This was done using the localized extraction system instead of total board bag extractions.

Case Study #1

This first case study assessed a transportation system lighting control board with 5-volt power applied to the C1 capacitor which failed within 10 minutes of powering on the controller. The result was a thermal event that destroyed the capacitor and burned areas of the PCBA. If a capacitor, with only a 5-volt input supply, is cracked it typically would just destroy the surface of the capacitor and not cause thermal damage to the board and nearby components. This event appears to have been caused by a dendrite short around the capacitor causing the damage. In investigating the residues, we wanted to understand what residues besides bromide (flame retardant released from the laminate) were present originating from fabrication or assembly and/or could have potentially come from an outside source. The investigation included comparing the failed assembly with a 'good' control assembly using the localized extraction system, we were able to isolate three areas on each assembly.

When assessing the failure, we noted that the C1 capacitor was completely removed due to the thermal event. Also noted, under UV light, was the presence of conformal coating on the board surface, therefore each area to be tested (if not thermally damaged) had the coating lifted and

folded back with a clean scalpel for inclusion in the localized extraction of the area.

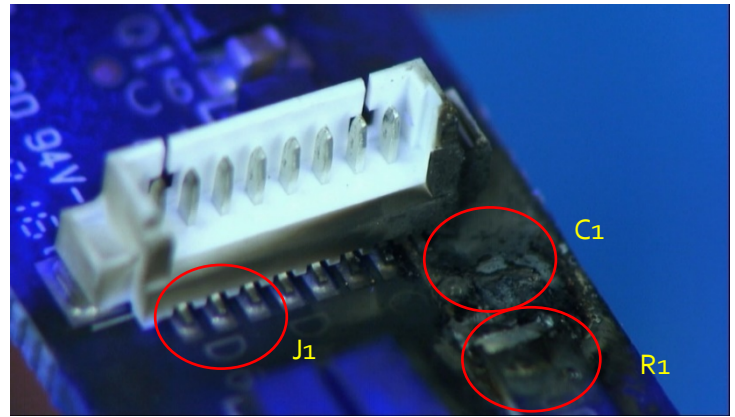


Figure 14. Localized Extraction of the J1, C1 and R1 location- failed

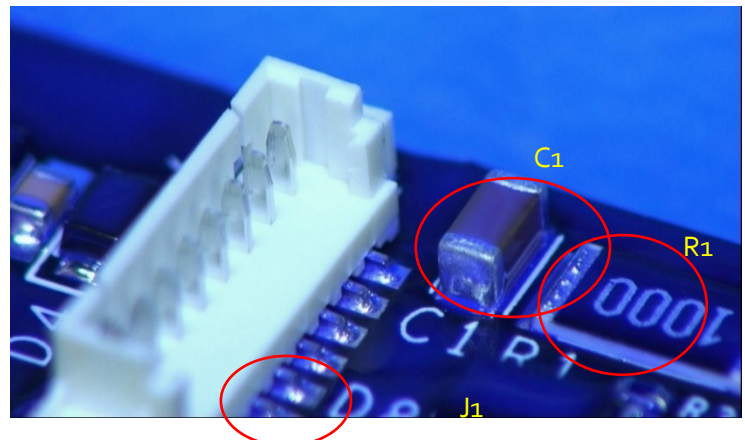


Figure 15. Localized Extraction of the J1, C1 and R1 location- good

all values in ug/in ²		Ion Chromatography (Dionex ICS 3000 at Foresite) n/a = not applicable															C3 Tester			
Sample Description	Fluoride	Acetate	Formate	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate	WOA	MSA	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium	Results	Time(sec)	
Foresite recommended limits for Bare Boards	3	2.5	2.5	2.0	2.5	2.5	2.5	2.5	3.0	n/a	0.5	2	2	2.5	2	n/a	n/a	Clean	>120	
Foresite recommended limits for PCBA (no clean - SMT)	1	3	3	3.0	3	6.0	3	3	3.0	25	1	3	3	3	3	n/a	n/a	Clean	>120	
ID																				
1	Failed Assembly A - C1 location	0	4.51	0	2.51	0	151.98	0	0	2.61	357.98	0	0	144.25	0.65	0	0	4.65	Dirty	1
2	Failed Assembly A - R1 location	0	3.62	0	1.99	0	120.14	0.06	0	1.98	463.65	0	0	169.65	0.29	0	0	6.65	Dirty	1
3	Failed Assembly A - J1 Connector	0	1.61	0	1.26	0	44.32	0	0	1.24	125.35	0	0	54.16	0.54	0	0	4.24	Dirty	7
4	Good Assembly A - C1 location	0	0	0	0.73	0	0.65	0.25	0	2.81	21.62	0	0	2.11	0	0	0	3.21	Clean	159
5	Good Assembly A - R1 location	0	0	0	0.58	0	0.12	0.10	0	1.65	16.54	0	0	1.21	0	0	0	3.26	Clean	180
6	Good Assembly A - J1 Connector	0	0.30	0	1.38	0	0.87	0.15	0	1.72	18.65	0	0	1.41	0.11	0	0	3.07	Clean	179
7	Paste No-Clean 0.1g on foil heated to liqueous	0	1.95	0	0.59	0	0	0.05	0	0.98	16.35	0	0	2.05	0.59	0	0	0	Clean	168
8	Touch up / repair flux pen 0.1g of flux on foil dry	0	11.98	0	0.09	0	0	0	0	0	871.65	0	0	351.27	0.11	0	0	0	Dirty	1

Table 4. Case Study #1 Results of Ion Chromatography and localized C3 testing in µg/in²

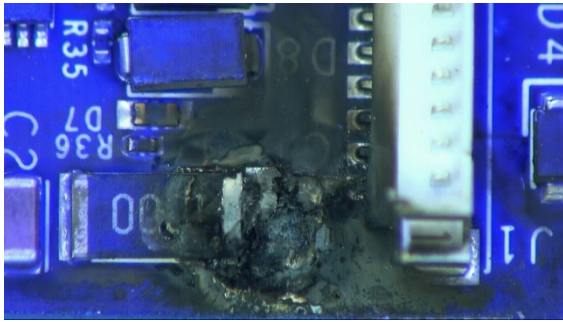


Figure 16. Failed Board under UV light examination – Before localized extraction

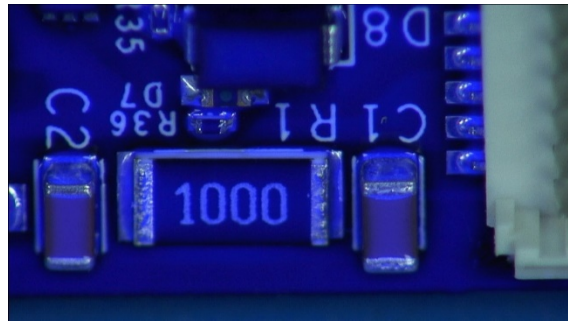


Figure 17. Good Board under UV light examination - Before localized extraction

all values in $\mu\text{g}/\text{in}^2$		Ion Chromatography / Mass Spec using a Quad Pole Detector																				Total			
Sample Description	Chloride	Acetate	NO ₃	Chlorite	Br	Citrate	MSA	Propionate	Glycolate	Chlorate	Butyrate	Oxalate	Lactate	Malonate	Thiosulfate	Maleate	Succinate	Benzonate	Glutamate	Maleate	Adipate	Tartrate	Pyruvate	WOA	
1	Failed Assembly A - C1 location	2.65	4.16	0	0	144.36	0	0	0	0	0	0	0	0	5.65	0	0	102.25	0	3.65	0	251.24	0	0	362.79
2	Failed Assembly A - R1 location	2.11	3.59	0.02	0	112.36	0	0	0	0	0	0	0	0	5.98	0	0	121.61	0	4.85	0	301.25	0	0	433.89
3	Failed Assembly A - J1 Connector	1.09	1.81	0	0	40.69	0	0	0	0	0	0	0	0	2.36	0	0	41.26	0	1.59	0	79.52	0	0	124.73
4	Good Assembly A - C1 location	0.81	0	0.44	0	0.51	0	0	1.21	0	0	0	2.35	0	0	0	0	18.65	0	0	0	0	0	0	22.21
5	Good Assembly A - R1 location	0.66	0	0.13	0	0.10	0	0	1.06	0	0	0	1.22	0	0	0	0	15.24	0	0	0	0	0	0	17.52
6	Good Assembly A - J1 Connector	0.98	0	0.19	0	0.12	0	0	1.36	0	0	0	1.67	0	0	0	0	16.88	0	0	0	0	0	0	19.91
7	Paste No-Clean 0.1g on foil heated to 150°C	0.51	1.55	0.02	0	0	0	0	3.05	0	0	0	4.91	0	0	0	0	7.98	0	0	0	0	0	0	15.94
8	Touch up repair flux pen 0.1g of flux on foil dry	0.36	12.63	0	0	0	0	0	0	0	0	0	0	0	18.65	0	0	245.07	0	37.98	0	562.54	0	0	864.24

Table 5. Case Study #1 IC/Mass Spec system results in $\mu\text{g}/\text{in}^2$

Ion chromatography results are shown in Table 2 below, along with the C3 electrical corrosivity results. The failed assembly indicated high bromide, WOA, and sodium with slightly elevated levels of acetate. This indicates that the chemical signature of the damaged area was not due to outside water or handling contamination, since bromide is present from the thermal damage, we need to assess the WOA and sodium residues from the good assembly in the same locations. Foresite recommends levels below 25 $\mu\text{g}/\text{in}^2$ of WOA for good performance. The raw paste and touch-up fluxes were tested to determine their residue contribution as well. Normal SMT paste does not leave a high WOA or sodium residue signature, but no rework was done in this area of the board so additional analysis is required.

Using the same extraction solution / vials, the samples were transferred to the IC/MS for a 40-minute run-time (vs a 17 min.) per sample to determine what was present in the WOA (a collection of organic acids using succinic as a standard). By determining which organic acids are present in the failed areas, compared to the reference and control (good) samples, we get a clearer picture of the residues present.

We see that the IC/MS allows for a greater separation of the organic residues, providing a better understanding of which activators were used in the different fluxes. As with the IC data, the chloride and nitrate levels are low, and the acetate is slightly elevated on the failed assembly only. Looking at the good assembly, we see that the contamination present from the solder paste flux contains a small amount of propionate and oxalate, with succinate as the primary activator. These levels are similar to the IC conductivity method.

Next, we looked at the failed sample to determine what WOA activators were present. The activators contained malonate, succinate, glutarate, and adipate (with the highest levels), matching the touch up flux. Upon this finding, a discussion with the engineers and operators was initiated to determine if touch up flux was used in this area. From the discussion, it was concluded that no touch up was done; however, brush cleaning was performed on a component (different board location) that had touch up. Brushing was done to a connector area, to remove a couple solder balls, with the same IPA/water brush used to clean the rework area. IC/MS allowed for a more detailed analysis of the residues present in the failure and reference areas, aiding in identifying the sources of contamination that cause leakage, dendrite shorting and thermal events.

Case Study #2

In the second case study, an automotive assembly (6 months in the field), inside a vented case, experienced significant shorting damage to the PCBA with clear fluid flow patterns not typically found on the board surface from normal processing. Areas of the board that failed were directly below the vent filter media, which previously had worked for years on thousands of products in the field. So why did a large number of failures occur all the sudden in similar locations? Our first approach with investigations like this is to document and assess the residue in the area of the failure. We want to determine if this is a process residue (like a dirty brush from rework), residue from internal condensation of the vented unit, or outside residues getting inside.

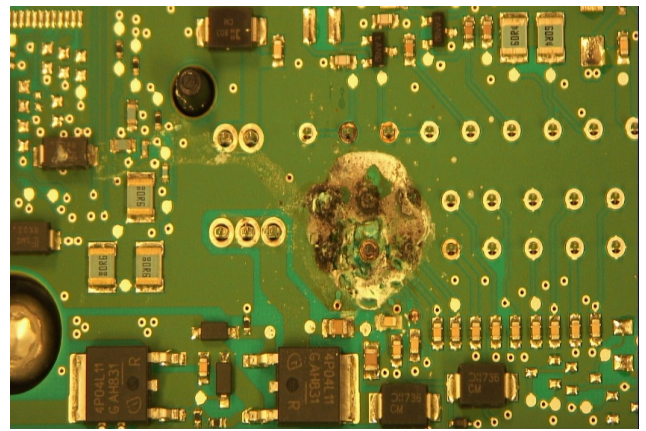


Figure 18. Case Study #2 showing dendrite growth and residues of press fit power connector on the back side of the PCBA

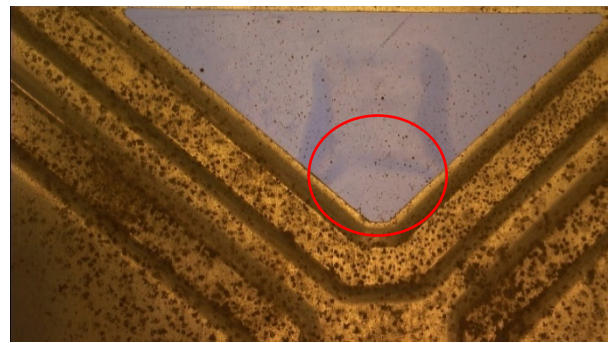


Figure 19. Outside of aluminum cover with square vent covered by a dirt shield (breathable)

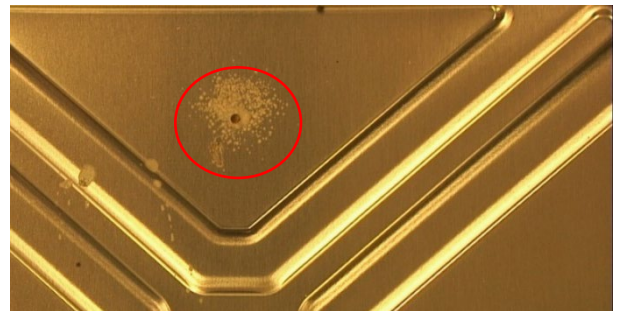


Figure 20. Inside of aluminum cover with vent hole showing fluid spots and condensation points

all values in $\mu\text{g}/\text{in}^2$		Ion Chromatography / Mass Spec using a Quad Pole Detector																		Total						
Sample Description	Chloride	Acetate	NO_3	Chlorite	Br	Citrate	MSA	SO_4	Propionate	Glycolate	Chlorate	Butyrate	Oxalate	Lactate	Malonate	Thiosulfate	Malate	Succinate	Benzoate	Glutarate	Malate	Adipate	Tartrate	Phthalate	WOA	
1 Housing outside vent	3182.20	2933.29	250.41	0	0	0	0	559.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Board Surface Corrosion	4354.87	725.36	80.83	0	0	0	0	460.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Housing inside vent	1934.91	21.39	11.15	0	0	0	0	51.93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Case Study #2 IC/Mass Spec system results in $\mu\text{g}/\text{in}^2$

The results from the IC/MS system (Table 4) indicate no flux activators were present, and the residues originate from the outside automotive environment. Residues appear to be migrating from the outside to the inside surface in the bubbled areas of the vent cover (triangle), then condensing inside causing the PCBA to short and fail at the connector leads.

Below highlights the various sources/processes impacting the performance of electronic hardware, relating to cleanliness and reliability.

Understanding when hardware failures occur, what the root cause is, typically involves more than one variable.

but a scale using a salt standard of gross conductivity) over the entire board/component surfaces with room temperature extractions. Similar to this, Ion Chromatography utilizing total board bag extractions gives a better understanding of the average species detectable by the heated (80 °C for one hour IPA/DI water) extraction, but again this is an average over the entire board and only uses conductivity detection. Using tools that isolate the residue and specific area (with a heated DI water extraction) where failures are occurring (lead to ground under the QFN), then utilizing both IC and IC/MS analysis to detect which residues are present in these areas allows us to gain a better

<u>Primary Residues</u>		<u>Secondary Residues</u>		<u>External Factors</u>
a) PCB fab (external/ Internal)		e) Rework and repair		j) Humidity non-condensing
b) Component fab (external /Internal)	Plus	f) Touch up	In	k) Humidity condensing
c) Process Assembly SMT / Wave		g) Staking / underfill/Temporary mask	Application	l) Fluid from outside sources
d) Cleaning / No-Clean		h) Coatings		m) Gaseous residues – sulfur/chlorine
		i) Foam pad/heatsink housing/ thermal pad		n) Time in the environment
				o) Powered / operations

Conclusions

Due to all the changes in electronic design, size, sensitivity, application and expected reliability, it is vital to understand the variables of cleanliness (residues from key critical steps) on the hardware pad to pad, hole to hole and lead to ground. Using traditional ROSE testing allows for a gross understanding of some small percentage of an average of conductive soluble residues (not NaCl

understanding of failures and whether they are unique or if they originate from manufacturing processes. Or, is it an environmental impact or both? Understanding electronic cleanliness (both when things are working well and when they fail) is critical to identifying how to predict the reliability needs of your specific electronic hardware in your application, it starts with tools that allow you to understand the different chemicals being left on the assembly or in the system that will impact performance.

¹ IPC Test Method TM 650 current revision

² IPC Test Method TM 650 current revision

³ IPC Test Method TM 650 current revision

⁴ Tim Crawford, EMPF and Ionic Conductivity Task Group, IPC TR-583 “An In-Depth Look at Ionic Cleanliness Testing” (1993)

⁵ Alexander N. Semyonov, Thermo Fisher Scientific, “IC-MS: Ion Chromatography – Mass Spectrometry” WP73175 (2019)