Cleanliness Requirements: A Moving Target

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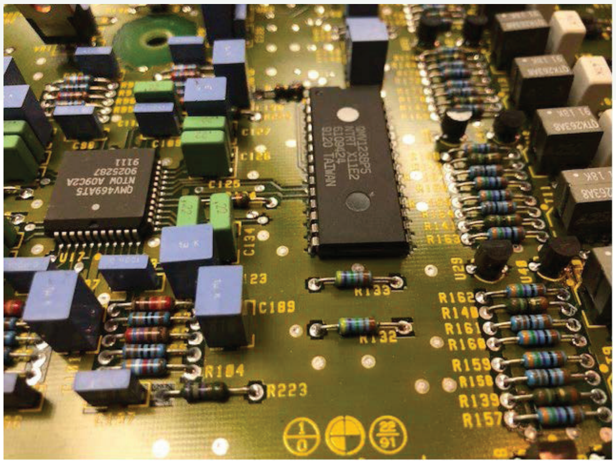


Figure 1: PCBA from 1991 Rosin Flux Solvent Cleaned

Abstract

During the last 25 years, major shifts occurred in the electronic assembly industry, such as the transition to contract manufacturing and reduction or elimination of in house manufacturing, the switch from solvent cleaned rosin fluxes to low solids no-clean fluxes and the big shift from leaded solder to Lead-Free solders.

The preferred method for cleaning high reliability surface mount assemblies was to employ a suitable solvent batch or inline machine, to clean traditional leaded rosin flux wave solder solvent wash process (Figure 1).[1] The fluxes would be reduced from the Printed Circuit Board Assembly (PCBA) with a solvent degreasing process. Visually the board would appear very clean because of the reduction of the amber flux, but when the boards were placed in a water environment the clear flux residue around the leads would turn white. Traditional rosin flux, left a clear film on the board and sealed in the board fabrication and flux activators and visually appeared clean. This is because the solvents used to clean the flux only removed the top 2/3rds off the surface and left a clear film.

PCBA cleanliness was monitored using visual inspection and a ROSE (Resistivity OF Solvent Extraction) test system of a process that meet product validation. The ROSE test measured the amount of equivalent µgrams of NaCl/sq. cm, by immersing the PCBA in a solution of 75% IPA/25% water.[2] This total board average cleanliness reading was a result of the change in the conductivity and the algorithm used to calculate the detectable contamination.[3] IPA was selected as weaker solvent that was in the degreasers to soften the rosin and measure the extractable activators and yet safe to labels and ink ID markings.

The use of this ROSE monitor for historical rosin-based fluxes with solvent cleaned assemblies appeared to meet the needs of the time, but when the entire chemistry of electronic assembly changed, including fluxes (no solids), laminates, soldermask and not cleaning, this tool was not able to correlate to field performance as a predictor of reliability.

Process monitoring of the new no-clean or cleaned processes that passed a ROSE test on the production floor may, or may not, pass during environmental testing, or perform well in the field. As technology has expanded in areas of use, miniaturization and circuit sensitivity, the traditional total board average cleanliness has not correlated to the failure areas that are under a component, between vias, pads, or leads requiring a new definition of cleanlinessProcess monitoring of the new no-clean or cleaned processes that passed a ROSE test on the production floor may, or may not, pass during environmental testing, or perform well in the field. As technology has expanded in areas of use, miniaturization and circuit sensitivity, the traditional total board average cleanliness has not correlated to the failure areas that are under a component, between vias, pads, or leads requiring a new definition of cleanliness and how it is assessed.[4,5] This can be seen in IPC 5702 and 5704 that the IPC recommends that each company determine what level of cleanliness that they require to be included on their print and has not established cleanliness guidelines.[6]

The proliferation of electronics in all aspects of life including medical, wearables, telecom, cell and automobiles is on an exponential growth curve.[7,8] As electronics complexity increases (Figure 2), the spacing between conductors is decreasing and the circuitry is more sensitive to parasitic leakage caused by the presence of semi-conductive ionic and organic materials.

This paper will explore the ever more demanding cleanliness requirements of PCBAs and methods to monitor and assess the cleanliness of electronic assemblies today.

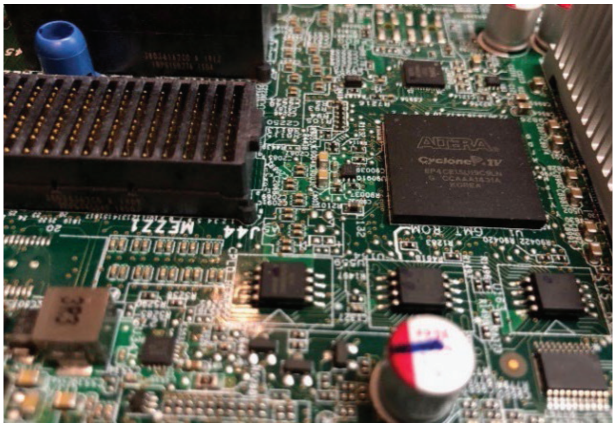


Figure 2: PCBA from 2017 No-clean Assembly

Keywords: Cleanliness, No-clean, ROSE test, Flux Residue, Process, SIR, localized extractions, C3, electrode and IC

Background

It is generally accepted that there is a relationship between the amount and type of surface contamination and the probability of Electrochemical Migration (ECM) or dendritic shorting can occur. Historically, the relationship between the presence of surface contamination and reliability has been evaluated as the average cleanliness across the PCB/PCBA surfaces using a single average value of a processed or bare board using the ROSE value as a monitor for the assembly process (per the IPC 2.3.25 test method).

With these historical processes the use of halides (chloride and bromide) in a high solids rosin flux was the norm. This practice was considered acceptable due to the proven cleaning operation that would take place after each flux and soldering operation. Also, any remaining flux with rosin would complex and seal the halide activators and fabrication residues in the remaining flux. Traditionally a small group of fluxes were used and listed as proven materials, meeting the solderability and reliability needs were defined on the Qualified Product List (QPL)[9] for high reliability hardware. These fluxes met the soldering requirements, but cleaning historically was done to meet cosmetic and surface probing reasons, not to mitigate contamination issues, because typically these were not problems (with exceptions for RF issues). ROSE testing was used to catch gross contamination differences (not cleaned samples or poor decreasing system operation). Limits were created based on typical levels that were achievable for military hardware and limits were defined, not based on failures, but what was achievable with hardware performing well in the field.

As technology needs changed the traditional rosin and solvent cleaned systems were replaced to meet environmental and cost reduction requirements of more complex hardware. The use of low solids flux to eliminate the need for cleaning was a great cost reduction opportunity that many manufacturers embraced.

Traditional Testing and Monitoring

Tools used for cleanliness assessment historically are the ROSE test we have discussed, IPC 610 inspection criteria and Surface Insulation Resistance (SIR) testing of the Process residues on test coupons. Testing of electronic hardware has been very generic or minimal for most assembly facilities. SIR has been used by the material suppliers to show that the properly processed material on a coupon can perform well in heat and humidity testing. Higher reliability and military assemblers have used SIR testing to assess the effect of a high temperature and humidity environment on major process changes.

Historically there has been an average ionic residue analysis of an individual PCB/PCBA, array or bare panel diluted in IPA/DI water with a pass/fail criterion of 1.56 µg/cm2 of NaCl equivalents. This was performed on high solids halide activated fluxes (rosin of 18 to 28% solids) cleaned with a solvent giving the value of the total board level of contamination by resistivity of solvent extract that has rarely correlated to electronic hardware field performance. A defined pass/fail limit was needed by military specifications, since this was an achievable value for cleaned assemblies that performed well in the field with a QPL approved flux, they established the limit as their acceptance criteria for this tool. No other research was performed to determine if this correlated to field performance. But this allowed the high reliability community to produce hardware meeting these limits with rosin-based fluxes.

With the shift to lead-free solder and no-clean flux this measurement method is questionable, at best. To begin with, most no-clean fluxes have either a very low number of halides, or preferably, no halides used in their formulation to meet ROL0 composition criteria. Halide residues that are not complexed with rosin or resin are just as or more corrosive as the weak organic acids that are not heated to a benign state as seen in Figure 3 showing dendrites growing under a QFN. Due to no-clean flux residues that were trapped under the QFN sealed in due to the low standoff and not transitioned to a benign state (leaving a soft gooey residue).

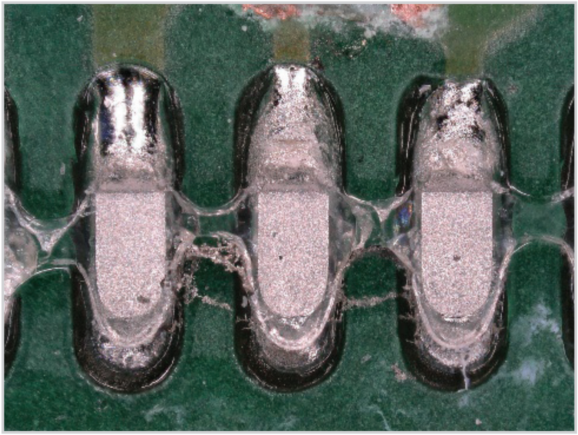


Figure 3:Dendrite under QFN due to high levels of WOA and gooey flux residue with just 3.3v bias failing in the field.

SIR testing allows the process engineer to know that the flux / paste or cored wire, when processed under ideal conditions (on a test coupon with no soldermask) metallization residues or component entrapment areas, would pass the elevated temperature conditions SIR testing. While this is still the test of merit, but it has shortcomings:

1. The test must be run on test coupons, with interdigitated comb patterns. The difference between the process used to assemble test vehicles and actual product may become a significant factor.
2. SIR testing is a good material evaluation and classification tool but doesn't include the bare fabrication residues or mask porosity or any of the critical circuit sensitivity and entrapment of residues under components such as QFNs or large SMT chip components.

The second method, the ROSE test, was developed by the military[10,11]. The test involves the immersion of the PCBA in an ionically clean bath of 75% IPA/25% water. In theory, the sum of ionizable surface contaminants dissolve into the IPA/Water bath and the ions in solution.

Using simple conductivity measurements of the solution before and after exposure, then calculating the delta and converting to a contamination value using an algorithm with fluid, surface area and time variables. The values collected are divided by the surface area of the PCBA to obtain an ion density metric. As compared with the SIR test, this test has inherent advantages, the test can be performed in minutes rather than weeks and it can be done on production hardware as an average total board cleanliness level. Although, if after the test, qualitative analysis is desired on an offending ionic contamination, this is no longer an option to determine what the residue was because some the surface residues have been removed, since it is a recirculating ~5 gallon that passes through a mixed bed resin to remove ionic contamination from solution these residues are lost.

This test method was performed on PCBAs where in theory the cleaning process was to remove all flux residue containing ionic contamination. Some of the issues with this test method are discussed by H. Manko. A summary of these issues are listed below:

1. This method allows only for an overall assessment of the total ionizable contaminants on the surface without yielding any specific information on the distribution of the contamination.
2. The character of that solvent used (a mixture of alcohol and water) and its volume are such that the solubility and the ionization potential of most materials become obliterated.
3. Masking by non-ionic, non-soluble materials. The measuring method is admittedly only sensitive to surface contamination. It also only detects ionizable materials which are coated or imbedded in alcohol soluble non-ionic materials.

Manko does go on to say, "Even though the objections raised to the test are formidable, it is an extremely valuable and indispensable tool for the industry." Again, this was published in 1979 in the midst of the rosin-based flux and solvent cleaning technology timeframe, no-clean and water soluble low solids fluxes were not developed as seen today until the early 1990s.

IPC also published a technical report, IPC-TR-583, "An In-Depth Look at Ionic Cleanliness Testing," which was first published in 1993 and then updated in 2002. The stated goal of the technical report,

> *"...is to give users of cleanliness test equipment a better understanding of ionic cleanliness testing. How much does solvent temperature influence the final cleanliness results? How critical is the 75% isopropanol to 25% water ratio?"*

Where the objective is to understand the limits of "cleanliness" testing, there is no attempt to correlate the lack of ionic cleanliness with the probability of causing a product fail. The report did an excellent job of determining the potential sources of variability and error that may occur during the test. The conclusion of the report is telling:

> *"...While they (cleanliness test methods) are suitable for use in process control, current ionic conductivity/resistivity test methods and equipment are not accurate analytical tools and should only be used for monitoring relative changes in cleanliness... Pass/fail limits and equivalency factors are not valid applications for current ionic conductivity/resistivity test methods and equipment due to the accuracy and precision problems noted above."*

In an environment where this test method was developed for fluxes that were intended to be cleaned, with Sn/Pb based solders, paraphrasing what the IPC Technical report states, ROSE testing with its shortcomings may be marginally acceptable for process control, it is not consistent enough and cannot be calibrated well enough to be used for pass/fail testing of a product. To state their conclusion more clearly, the test is not accurate and precise enough to be used as a test to determine the acceptability or rejectability of a product, whether from a cleanliness perspective or from a perspective of predictive reliability.

The Paradigm Shift

To summarize, using ROSE testing on product which is processed through a cleaning process, is less than ideal, and by the subject matter experts in the field, with its numerous problems, was utilized since it was the only process control test available for this application. Fast forward to today, the product has gone through a major change; with respect to ionic and organic contamination, a quantum leap from the QPL fluxes of old. It has been demonstrated that in no-clean flux, the materials, products and by-products are corrosive and conductive. And yet, processed properly, no-clean fluxes are reliable. Why does this matter? ROSE testing was designed for a product that went through a clean process to remove all, or nearly all, of the flux and conductive residues. Now, in addition to all the issues, variability and weaknesses of ROSE testing already mentioned for PCBAs that were intended to have process flux removed through a cleaning process, with no-clean flux residue with its ionics remaining on the product, this is a state that ROSE testing was never intended to test.

We must decide, since all the chemical processes (fabrication and assembly) have changed dramatically (no QPL), how PCBA cleanliness should be defined and how should it be monitored to assess the production process is in control, with and without cleaning operations, to predict product reliability?

What is expected of the PCBA cleanliness? = To predict electrical field performance in relation to the fabrication and process residues.

It is not the particle and debris cleanliness testing for metal/plastic parts (per ISO 16232-1 to 10). That is a separate issue that is growing in understanding but does not work on a PCBA with a pressure wash and collection system to determine the surface debris of a metal or plastic housing.

Definition of Ionic / Organic Cleanliness

The definition of cleanliness has been defined in the IPC 610 Rev. G section 10.6.2 & 3 as visible residue that must be proven to be benign for class 1-3. Visible debris is a defect for class 1 – 3.

With respect to PCBAs function and reliability, what does cleanliness mean? There are PCBAs processed with no-clean flux that pass system level test at time zero but fail in application due to aging and interaction with the environment. How are residues tested and measured with respect to cleanliness, which may change in the application environment?

PCBAs are made from both additive and subtractive photo/chemical processes that leave residues from each step of fabrication and assembly. In order for ionic residue to cause a system to fail, by ECM or parasitic leakage, the ionic residue needs to span between non-common adjacent conductors; pad-to-pad, hole-to-hole, lead-to-lead... of each assembly. What are the key processes that impact the residues on a finished assembly?

- **Board Fabrication** (Etchants, water rinsing with tap or pond water, temporary masks)
- **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) See figure 4.
- **Staking Compounds** (outgassing of curing material)
- **Housing/Enclosure/Heatsink** (plastic release agents, such as unreacted polymer precursors, such as adipic acid, used to make nylon, and metal processing residues)

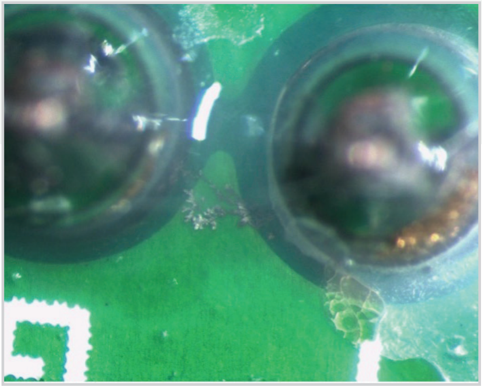


Figure 4: The cleanliness of the area between leads, pads, vias or across the body of a component are the locations where ECM shorting (dendrites) and parasitic leakage occur even under conformal coating.

Dendrites can grow under, through and over conformal coatings, figure 4 shows dendritic shorting that occurred in the field of a smart sensor in a controlled humidity housing with a vent which allowed the enclosure to breath. In this case we found high levels of WOA, reacting with the silicone coating (a thin layer at the surface with cure inhibition due to interaction with flux residue) to set up the corrosion cell causing the dendrite to form. This was not excess flux over the total board but a pocket of flux on the bottom side from a pin-in-paste reflow solder process that did not heat activate the flux completely on the bottom side during reflow since reflow is designed to fully heat the top side primarily.

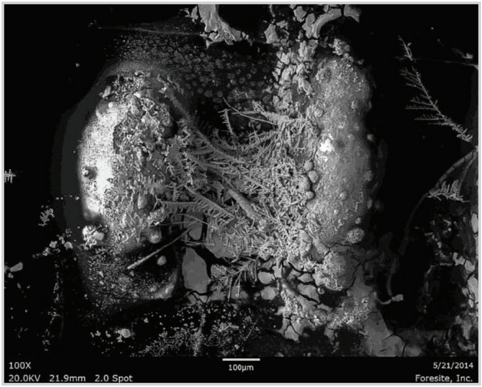


Figure 5: Dendrites only grew between power to ground pads on a non-populated component location with coating that exposed the solder pads showing that the dendrites only grew where there was the opportunity to transfer housing contamination.

Contamination does not always come from the assembly but the housing that protects the surface as seen in figure 5 where two unpopulated pads partially covered with conformal coating with exposed solder that grew dendrites in a powered high humidity qualification test where the housing (plastic) transferred high levels of contamination to the surface of the coated sample causing dendritic growth.

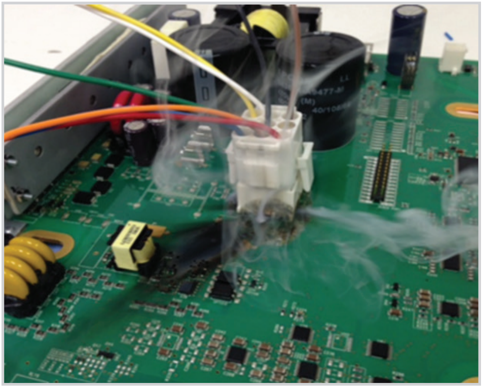


Figure 6: WSF soldered and cleaned with inline cleaner and passed ROSE testing.

PCBAs do not fail due to random contamination spread over the entire board but by contamination that resides between leads, vias, under and inside components, connectors and inner layers. The location and state of the ionic residue matters. There can be a large amount of flux residue spread over the entire board, and the board may never fail. However, a little flux in the wrong place can cause a PCBA to fail. See figure 6 for an example of an assembly that passed the ROSE test but failed in the field. The connector trapped flux from a high-pressure water cleaning only cleaning system and ROSE testing showed acceptable levels of contamination; less than 1.2 μg/cm^2 of NaCl equivalents.

How do we move from cleanliness as a single ionic density value for the total assembly to quantifying cleanliness on the specific areas on the PCBA, where if ionic contamination is present between non-common conductors, it will cause the PCBA to electrically fail?

Electronic hardware/systems are and have been experiencing increased corrosion/shorting/intermittent performance that cause system and hardware failures, since the move away from rosin based high solids flux over the last 15 years. These failure locations are not over the entire board surface, but only in specific areas (pad to pad, via to pad, lead to lead, hole to hole or trapped under a component). Some of these failures are from external environmental contaminants (i.e. sulfur, water ingress, condensing moisture and component EOS) but the greatest impact has been on process/fabrication residues causing failures. It becomes important to understand what residues from fabrication/manufacturing are impacting field performance and not just blame the fielded conditions. The failure rates can be as high as 1-4% in many cases, but the intermittent performance and the features that just stop working are ever growing issues and this is included in the returns that are identified as "No Trouble Found" (NTF) that fail in the field but work when returned to the test bench. Much of the cause behind these failures are the driving conditions of the consumer electronics industry using the greatest number of components, and materials and 70-80% of industry has been using no clean fluxes.

These failures are occurring on a wide range of electronics (consumer toys, garage door systems to automotive and cloud servers and everything in between) under coating's, potting's, inside sealed systems, inside NEMA enclosures and in controlled environments, indicating that there is a greater impact on field performance from manufacturing residues than the environments that the hardware is designed to operate in.

Therefore, the effects of environmental conditions are designed into the operating system and have been validated to function in these conditions, but with many more recalls, poor electrical and intermittent performance increased failure rates, and no trouble found returns. It becomes clear that the biggest unknown variable is the amount of contamination in these specific areas (between leads, on components or inside the PCB) causing poor performance issues are from the manufacturing process and it is not just flux residues, all fluxes when properly processed (no-clean and water-soluble fluxes) leave protective, non-reactive or no residues. What we have seen since the 1990s is that there are pockets of contamination from the bare board fab, fluxes trapped under components, fabrication etchants, plating solution, poor rinse water quality, HASL flux residues rinsed with tap water, all are key contributing factors to system failures, with every increasing circuit sensitivity.

Analysis of these specific areas as a cleanliness monitor should be it is important to realize and understand that combined effects of manufacturing electronic systems in specific areas. To accomplish this our extraction and testing technique must be equal to the effects of humidity in the field, creating conditions that ionize residues creating conductive pathways through the residues, and importantly not removing or reacting the bound residues that create pockets of protection and entrapment from available moisture.

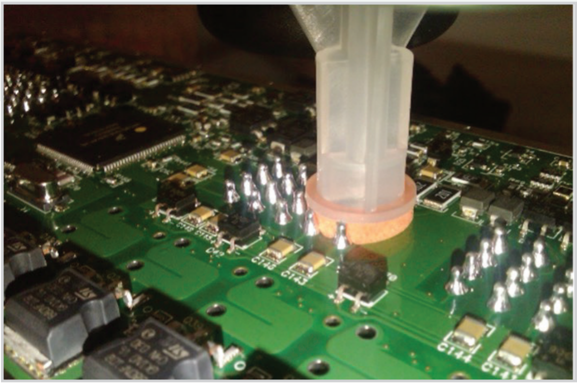


Figure 7: Area of isolation with the localized test cell to assess residue pad to pad, hole to hole.

A New Definition of Cleanliness Monitoring (localized assessment) – Is the extraction of a specific area (pad to pad, via to pad, lead to lead, hole to hole) that is the collective effects of PCB and component fabrication, assembly flux / cleaning or not, of the primary and secondary processing systems, it is a specific area measurement of ionic / organic residues that have a functional effect on circuit and system performance see figure 7. Using a localized extraction method (that assesses electrical corrosivity of the solution) in conjunction with detailed analysis of the ionics/organic residues through ion chromatography and ion chromatography/mass spec to identify and quantify these residues from key process steps and component entrapment areas.

Process Monitoring Localized Cleanliness = Σ^{primary} (a + b + c + d) + $^{\text{secondary}}$ (e + f + g + h + i) as a predictor of field performance = chemical effects from fab and assembly collectively at a specific location (understanding that some chemical effects such as rinses are beneficial as a reduction effect)

Primary Cleanliness (both additive and subtractive effects come from each process)

a) **PCB fabrication chemical effects**

- Beginning at inner layer etchants, soldermask porosity and filler, final metallization, and rinse water quality at each process step.

b) **Component fabrication chemical effects**

- Plating residues, rinse water quality and thousands of parts produced and rinsed an hour.
- Rinse water quality ranges from tap to DI but with bath loading and no monitors it is difficult to determine the cleanliness of rack, barrel or cut-strip plating systems.

c) **Process Assembly chemical effects**

- SMT 1 and 2 paste flux and thermal profile (water soluble flux –highly active or No-Clean halide free
- Wave solder flux / selective pallet/ robotic soldering (water soluble flux or No-Clean halide free/ROL0 or ROL1)
- Selective pallet residue transfer to next board and droplets of flux concentrate from vent in oven or at wave solder vent stacks.
- Environmental conditions production floor (debris and particles from open storage)
- Environmental conditions air/humidity quality (humidity mister spraying tap water)
- Dust and debris in trays and racks that are made up of conductive fibers from ESD smocks and wrist straps

d) **Cleaning or No-Cleaning chemical effects**

- Cleaning solvent, water, or saponifier with high or low pressure in-line
- Cleaning batch water / saponifier (randomness of the cleaning)
- Cleaning entrapment of the water / flux / saponifier
- No-Clean flux residues are benign when they have high enough heat for long enough for the volume to create a benign residue.
- No-Clean flux vapors traveling to connector pin surface causing insulation problems.
- No-Clean flux trapped under a large chip SMT component or QFN package.

Primary Cleanliness = the residues at the pad, via, PTH, and space between the architecture on the board

Secondary Processes Cleanliness Effects (both additive and subtractive effects come from each process)

e) Rework and Repair chemical effects

- Hot Air / gas removal of component
- Cleaning of the solder surface and flux removal
- Rework flux and soldering iron residues
- Localized cleaning and residue transfer to nearby areas

f) Touch up with soldering iron chemical effects

- Localized residues from soldering iron
- Additional liquid flux or cleaning residues

g) Staking / Underfill compounds chemical effects

- Residues from primary and secondary curing
- Reactions with flux residues in entrapment areas

h) Coating and Potting compound chemical effects

- Residues from primary and secondary curing
- Reactions with flux residues in entrapment areas
- Inhibition of coating cure due to flux residues that were not benign causing leakage and corrosion (dendrite) formations

i) Foam pad, Thermal heatsinks/pads, housings and enclosure chemical effects –

- Residue from foam cells (high sulfur can cause creep corrosion)
- Thermal pads can outgas silicone and absorb moisture and heatsink process residues
- Housings – plastic mold release are typically conductive and corrosive

Secondary Cleanliness = primary + secondary (pad, via, PTH, and space between leads) on or near localized area

Fielded Localized Cleanliness = Σ ^{primary} (a + b + c + d) + ^{secondary} (e + f + g + h + i) + ^{Fielded} (j + k + l + m + n)
= chemical effects from fab and assembly collectively at a specific location reacting to the field condition
(understanding the chemical effects on a functional biased hardware in the fielded state)

Fielded Hardware Localized Cleanliness = as an understanding of NTF (no trouble found) and field returns

Primary Contaminants

a) PCB fabrication chemical effects
b) Component fabrication chemical effects
c) Process Assembly chemical effects
d) Cleaning or No-Cleaning chemical effects

Secondary Processes

e) Rework and Repair chemical effects
f) Touch up with soldering iron chemical effects
g) Staking / Underfill compounds chemical effects
h) Coating and Potting compound chemical effects
i) Foam pad, Thermal heatsinks/pads, housings- and enclosure chemical effects –

Fielded Conditions

j) Humidity and temperature cycling chemical effects
k) Functional voltage and circuit electrochemical effects-
l) Environmental gaseous chemical effects
m) Environmental particle chemical effects-
n) Outgassing chemical effects-

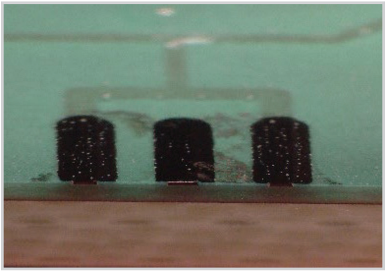
Primary Contaminants

a) PCB fabrication chemical effects

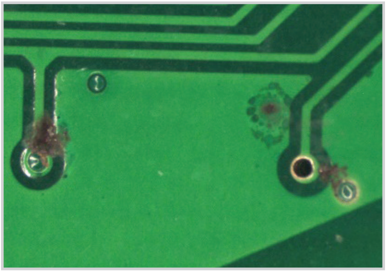
Where do failures occur? Answer, in localized pad-to-pad, via-to-via, PTH-to-PTH and lead-to-lead.

Primary Contaminants

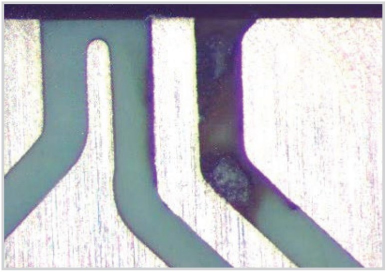
a) PCB fabrication chemical effects



PCB with high sulfur – creep

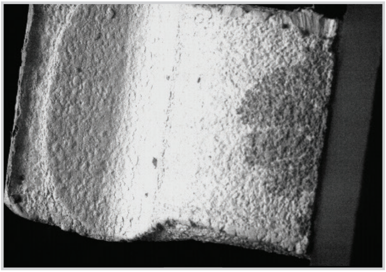


PCB sulfur trapped under

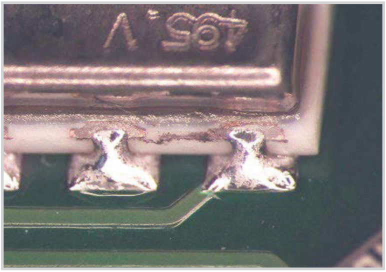


Innerlayer with dendrite CAF

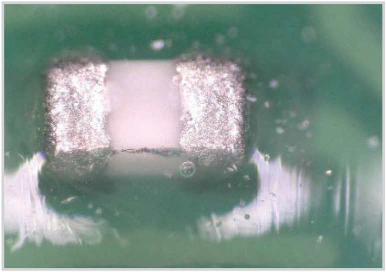
b) Component fabrication chemical effects



Raw SOT 23 with Creep in tape/reel

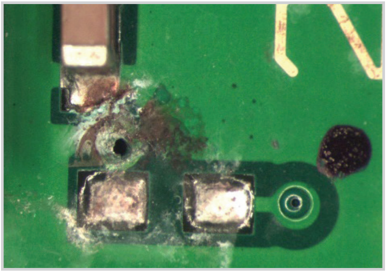


Dendrite on component body only



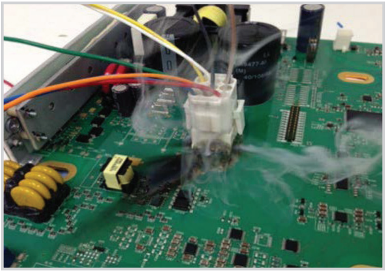
Dendrite on Cap under coating

c) Process Assembly chemical effects

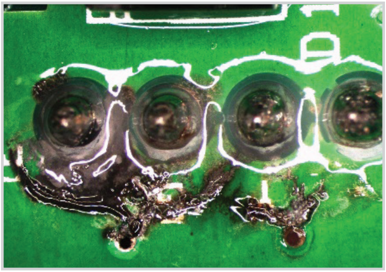


No-Clean selective solder flux in via top side

d) Cleaning or No-Cleaning chemical effects



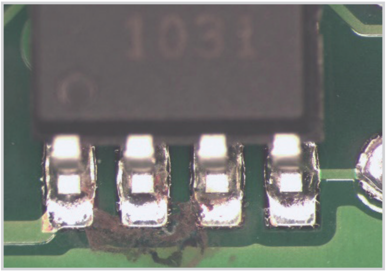
WSF left under connector causing shorting



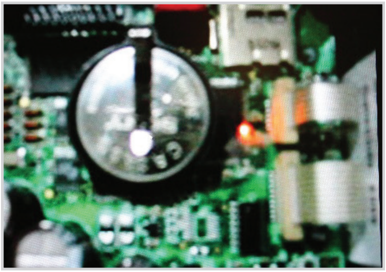
No-Clean Flux under silicone coating

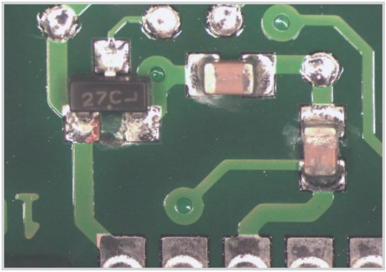
Secondary Processes

e) Rework and Repair chemical effects – Humidity and temperature cycling chemical effects

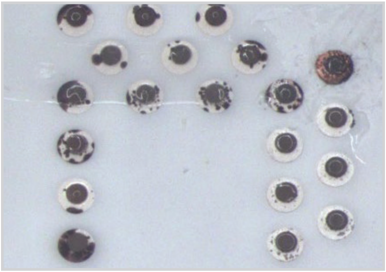


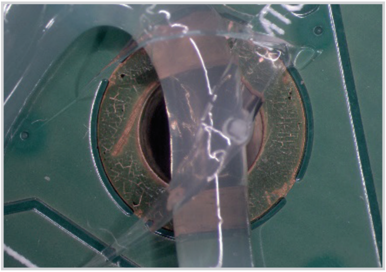
Rework flux brushed to nearby component


No-Clean touch up on micro shorting and fire



No-Clean repair heavy flux shorting


PCBA showing creep corrosion/box sulfur


Staking compound causing copper corrosion


Dendrite growth from plastic housing residue

These are very detailed collective summaries of the residues from the process at each critical location, It is difficult to understand where these contaminants would affect a total board cleanliness measure defined by a single value of general conductivity?

Good electrical performance of the PCBAs is typically defined by the critical power circuits and the range of circuit sensitivity in the operating environment.

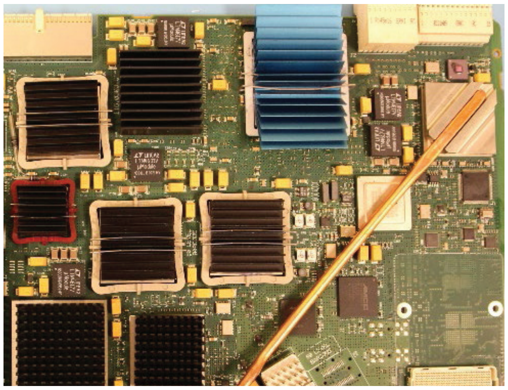


Figure 8: How clean is this PCBA? Mixed Technology Assembly with no-clean Flux with Immersion Silver PCB finish and both SMT reflow and Selective Soldering.

Poor electrical performance with intermittent performance and No Trouble Found (NTF) returns indicating that only critical parts of the circuit may have residues that absorbed moisture causing a non-visible electrical performance problem. Residues found on critical circuits with a high level of circuit sensitivity are typically the first parts of the circuit that start showing intermittent performance.

What has changed in electronics in the past 25 years? The answer is, everything:

1. Higher glass transition, Tg, laminates for lead-free reflow processing at higher temperatures
2. Circuit spacing – tighter with lower standoff and smaller, denser packages, see figure 7
3. New metal finishes (i.e. silver and tin) and new HASL lead-free alloys, see figure 8.
4. Fluxes – from Rosin high solids, QPL to no solids no-clean and water-soluble fluxes with no, or low halides
5. Reflow Temperatures are at least 30 °C, higher and forced zone cooling.
6. Selective wave solder with heavy flux residue build-up on the pallet
7. Rework and touch up flux squirt bottles, flux pens and no-cleaning, and brush cleaning
8. Component packages that sit tight to the boards surfaces (QFN, direct FETS, LEDs and Chip components)
9. With the advent of Internet of Things (IoT) and applications such as autonomous driving vehicles with all their function and sensor arrays, and increased circuit sensitivity, use environments have grown exponentially.
10. Disposable electronics mindset of use for 1-3 years and a change from following high reliability processes to following consumer electronic supply processes with little or no long-term reliability understanding and changes on the fly to meet production needs.

The reality is, defining cleanliness is a moving target; because of all the above listed elements between fabrication, assembly including no-clean and cleaning fluxes, environmental residues transferring from housing and packages, along with uncontrolled environments, the cleanliness requirements are exponentially increasing.

One tool has been used to move from the total board average cleanliness to identifying pockets of contamination that we find between leads, around and under SMT components and under µBGA packages. Localized ionics testing can now be performed on circuitry at high risk for ionic contamination. This allows for the production floor to move from a total board average cleanliness to a specific area assessment to monitor the effects of bare PCB, SMT 1, SMT 2, selective wave and rework areas. Using the localized extraction tool to isolate a 0.1 in^2 area with micro burst of hot extraction solution with only a 2.2 ml extract volume,[18] so as not to over dilute the extract. The IPC Technical Report 583 listed volume of eluent as a major source of test variability. Greater amounts of eluent tend to decrease detection limits of ROSE testing. ROSE testing does not capture ionics which are entrapped in crevices, pockets or cavities. Localized ionics testing can test these regions, but it becomes a destructive test. Localized extraction method has limitations. Such as testing areas with flux skinning and flux entrapment under QFN and µBGA samples. However, the advantage of localized ionics testing is that in past work, it has correlated extremely well with SIR tests in predicting what parts fail.[19] If anything, localized ionics testing was more sensitive than SIR testing in its ability to predict a potential failure.

What impacts electrical performance is not just flux residue. There are other sources of ionic contamination. We must understand the multiple chemical, thermal and mechanical processes for each key process step to understand the risk of residues on the PCB surface, subsurface and under and over component surfaces.

If an average temperature for all North America represents an accurate result for your town, the same is true for the effect of the residues on a total board analysis.

See figure 9 showing selective wave solder area, bottom side view with conductive flux residues on SMT parts. The localized test area shows that the residue found in this location shows high levels of WOA (succinic acid) 278.45 µg/in2 and 45.43 µg/in2 of adipic acid using Ion Chromatography Mass Spec analysis. These residues are moisture absorbing, conductive and corrosive.

Figure 9: Conductive flux residues on SMT parts. The region within the red box sees the direct heat of wave solder. The region adjacent to the red box has flux that has not seen the full heat of wave solder, so the flux is still active with WOAs at 312 µg/in2 and failed in 12 seconds under a localized extraction and biased test.

Summary

There are two tests in common use today. The first test usage is historical; the ROSE test. Its intended application was on product which was assembled with fluxes that were designed to be cleaned post soldering process, essentially verifying the effectiveness of the cleaning process. It was never intended to be used on product where flux residues are intentionally left on the PCBA with no or low solids.

The second, a localized ionics extraction tool, designed for either flux chemistries that are cleaned or those that leave residues remaining the PCBAs. Its intended purpose is both a process control and a predictor of reliability of the remaining collective residues.

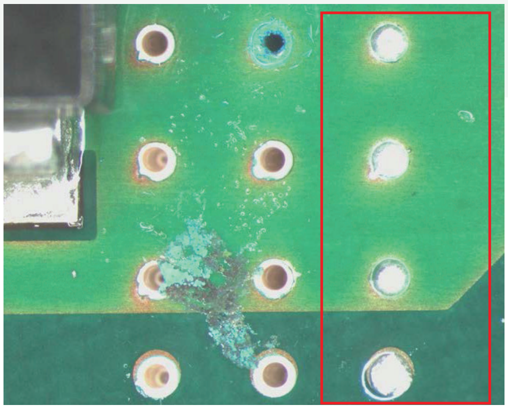


Figure 10: Flux corrosion in the region adjacent to selective soldering, which did not see the heat of the solder operation.

Conclusions:

1. ROSE testing for fluxes intended to be removed through a cleaning process, at best was an inadequate test, but it was the best that was available.
2. Passing or failing a ROSE test does not correlate with whether the device under test will fail in the customer's application.
3. ROSE testing takes an ionic count and averages it over the surface area of the entire assembly, without any regard for localized contamination in high risk areas, or cavities or crevices which cannot be reached and is a weak room temperature extraction of IPA/DI water.
4. ROSE testing was never designed or intended for product which is fabricated using no-clean fluxes.
5. ROSE testing washes away most ionic forms of contamination, so that if a fail occurs, further qualitative analysis is no longer feasible.
6. Localized ionics testing correlates well with SIR testing in its ability to predict the potential for ECM related failures.
7. Localized ionic testing can test specific risk areas, or regions of interest, for their potential to fail in the field.
8. The extraction solution from localized ionic testing can be used in subsequent qualitative analysis (i.e. ion chromatography and IC/MS).

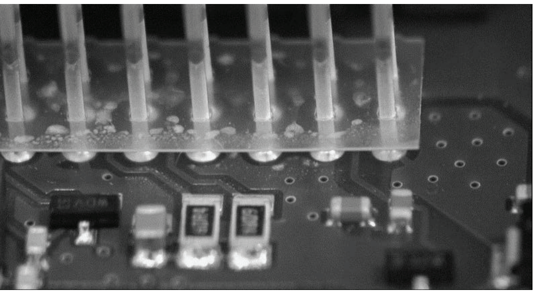


Figure 11: Unreacted, active flux on the secondary solder side from spray and flux vapors.

If ionic cleanliness of a PCBA is to be a predictive projection of an assembly's reliability of a specific location, it must be accepted that it includes the sum of the processes and the impact of the materials (housings, heat sinks and frames...) around the hardware as it reacts to the operating environment (ambient humidity and gases) at the critical circuits; pad-to-pad, hole-to-hole, power-to-ground and their sensitivity to ECM or parasitic leakage issues.

PCBA Reliability is proportional to the sum of reactive residues at the specific area of each of the critical circuits/components, and PCB locations. This means to predict reliability we must understand residues that are on and under the most sensitive components/locations and their possible sources.

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