Electronic Assembly Rework Best Practices when Building to a No-Clean and Cleaning Conditions

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ABSTRACT
Electronic Assembly reliability must consider process residues and cleanliness. IPC J-STD-001J—Section 8 requires assemblers to qualify soldering and/or cleaning processes that result in acceptable levels of flux and other process residues.

Multiple soldering steps are used to build the assembly. The SMT process is considered the most stable and repeatable. Secondary processes, such as rework, add variability to the assembly process. Flux residue is a common concern when reworking the assembly. Flux can wet and spread outside the area where the rework is taking place. In addition, topical cleaning after rework can also wet and spread active residues outside the area where the rework is taking place. Device failure can occur if these active residues are exposed to climatic conditions.

This research aims to study the electrical effects of flux and process residues following the rework process. Manual soldering, as compared to the use of a rework station, will be evaluated. This study aims to define best practices for assemblers who build to either a No-Clean or Cleaning condition.

Key words: Electronics Assembly; Manual Soldering; Rework and Repair, Flux Residues, Quality and Reliability

INTRODUCTION
This research aims to ensure the reliability and longevity of electronic systems. Manual soldering and reworking of electronic circuitry are highly variable processes that often leave significant amounts of flux residue. Topical cleaning is one method used to remove these flux residues. Regarding manual and rework soldering, we explore the latest research, findings, and advancements in electronic reliability.

Environmental factors such as temperature, humidity, and exposure to flux and process residues are pivotal in determining the reliability of electronic hardware. These factors can accelerate leakage currents and dendritic metal migration, which affects reliability and leads to potential failures that compromise electronic devices' functionality.

PROBLEM STATEMENT
Chemical failures in electronics are typically the result of interactions between process contamination (i.e., flux residue and cleaning residues) and their environment. These interactions can lead to the deterioration of components, ultimately causing system malfunctions.

Topically cleaned flux residues can spread ionic contamination to neighboring components and the area where the cleaning occurred. These residues can lead to moisture ingress when exposed to climatic conditions of temperature and humidity. When the electronic device is turned on, corrosion and conductive pathways can result in intermittent device failure.

To illustrate, a contract manufacturer used a double-sided SIR test board (Figure 1) to develop objective evidence that the rework process resulted in acceptable levels of flux and process residues. The SMT components were soldered with a high-reliability SAC 305 No-Clean Solder Paste, and the TH connector was soldered with a No-Clean selective soldering flux.

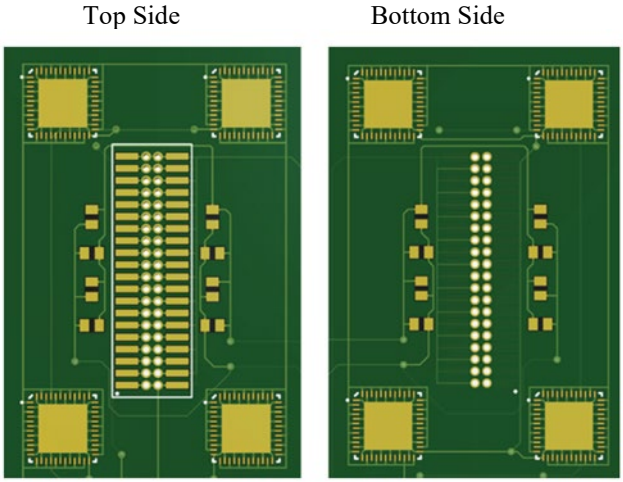


Figure 1: Double-Sided SIR Test Board

The TH connector was reworked using a water-soluble core wire solder. The connector was then topically cleaned using a brush to scrub and dissolve the flux residue. The topical cleaner was reapplied and allowed to evaporate. The test board was SIR tested at 40°C / 90% RH/ 5 Volts Bias/168 hours.

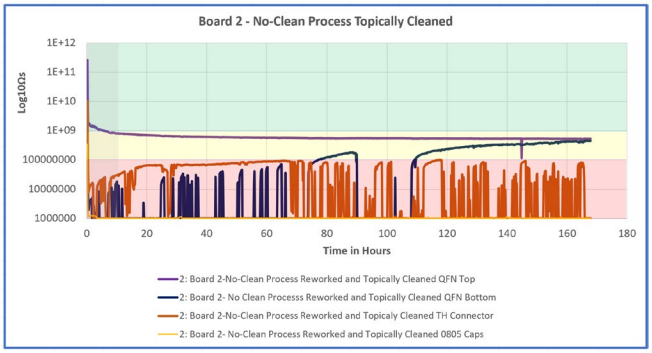


Figure 2: SIR Test Results

The topical cleaning process transferred ionic contamination to components near the cleaning site. The bottom-side QFNs, 0805 caps, and TH connector failed, SIR.

The problem is …

- Flux residues leave behind ionic residues
- Operators perform manual soldering
- Liquid flux bottles are standard on the operator's bench
- Flux residues can be heavier near the soldering site
- Topical flux cleaners are used to remove the flux residue
- Residues from topical cleaning can wet neighboring components
- Improperly cleaning and rinsing leaves pockets of active flux residues
- Harsh climatic conditions can result in leakage currents and ECM

HYPOTHESIS

H_1: Manual and/or Rework of electronic hardware should be cleaned in production cleaning hardware using a wash/rinse/dry cleaning process.

RESEARCH QUESTIONS

1. When should a Rework Station be used?
2. On No-Clean assemblies, is the flux residue benign and reliable?
3. How much flux residue is present after rework?
4. Is topical cleaning a suitable cleaning method?
5. How hard is the flux residue to clean?
6. Should the board be cleaned using an automated process?

EXPERIMENTAL METHODOLOGY

A double-sided mixed-technology SIR test board was selected for this study. The SMT components (QFN and 0805 Caps) were soldered using a standard SMT process. The SM/TH connector was soldered using a rework station. The back-side TH connector and 0805 caps were manually soldered. The bottom-side QFNs were planned to be soldered using the rework station but were not soldered due to an issue with the component stencil.

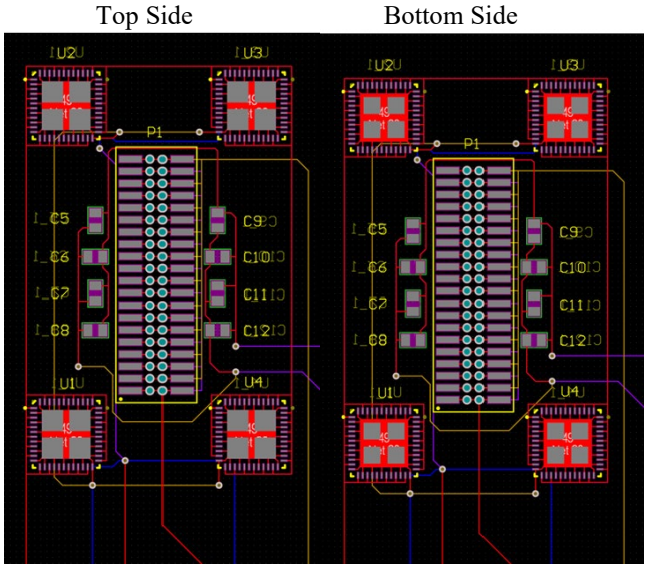


Figure 3: Test Board

Table 1: DOE Test Matrix

Board #	Solder Paste	Liquid Flux	Thru Hole solder	Good Topical Clean	Bad Topical Clean	Inline Clean	Categories Evaluated	SIR	IC+C3	Rework Flux + SIR
1	no	No	No	N/A	N/A	N/A	Bare Boards Group	Yes	Yes	No
2	no	No	No	N/A	N/A	N/A		Yes	No	No
3	No-Clean SAC 305	Yes	Yes	Yes	No	Yes	Good Topical Clean	Yes	Yes	Yes
4	No-Clean SAC 305	Yes	Yes	Yes	No	Yes		Yes	No	Yes
5	No-Clean SAC 305	Yes	Yes	Yes	No	No		Yes	Yes	No
6	No-Clean SAC 305	Yes	Yes	Yes	No	No		Yes	No	Yes
7	No-Clean SAC 305	Yes	Yes	No	No	Yes	No Topical Clean	Yes	Yes	No
8	No-Clean SAC 305	Yes	Yes	No	No	No		Yes	Yes	No
9	No-Clean SAC 305	Yes	Yes	No	No	No		Yes	No	Yes
10	No-Clean SAC 305	Yes	Yes	No	Yes	Yes	Bad Topical Clean	Yes	Yes	No
11	No-Clean SAC 305	Yes	Yes	No	Yes	No		Yes	Yes	No
12	No-Clean SAC 305	Yes	Yes	No	Yes	No		Yes	No	No

Definitions

1. Bare Boards Group
   a. SIR Test Board as Received from the Bare Board Supplier
2. Good Topical Clean
   a. A mixture of IPA, Ethyl Alcohol, and Methyl Alcohol
   b. Cleaning mixture is in a container that is dispensed through a pressure tube with a brush to scrub the area being cleaned.
   c. The cleaning fluid is left on the surface and allowed to evaporate.
   d. Two test boards are not processed further after the topical cleaning.
   e. Two test boards are cleaned using an aqueous-engineered cleaning fluid processed through an inline cleaner.
3. No Topical Clean
   a. Two of the test boards were not cleaned after rework.
   b. One of the test boards was cleaned using an aqueous-engineered cleaning fluid processed through an inline cleaner.
4. Bad Topical Clean
   a. Ethyl alcohol cleaning fluid.
   b. The cleaning fluid was in a dispenser with a small pump that could be pushed down to leave a pool of fluid at the top of the dispenser can. A brush is used to dip into the pool of the cleaning liquid and applied it to the area being cleaned.
   c. Two test boards are not processed further after the topical cleaning.
   d. Two test boards are cleaned using an aqueous-engineered cleaning fluid processed through an inline cleaner.

DATA FINDINGS

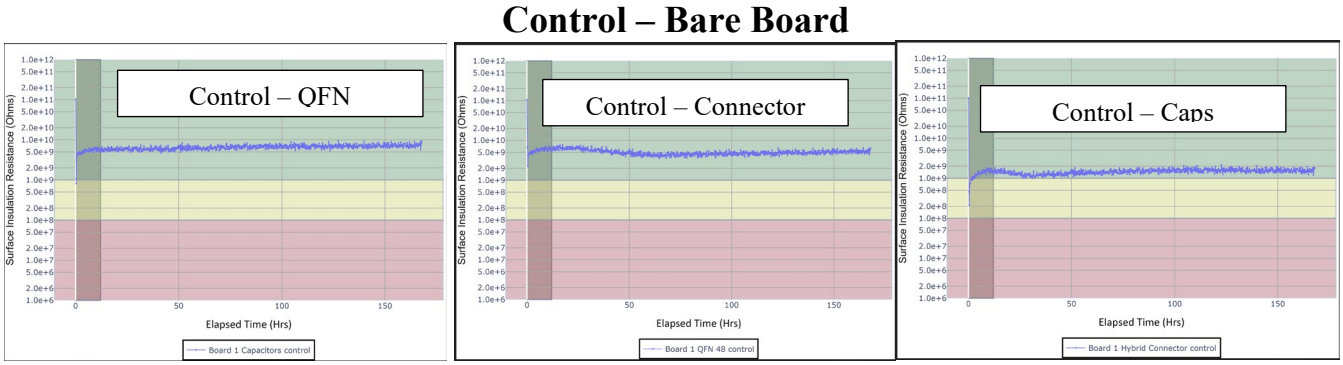


Figure 4: Control SIR Charts

Table 2: Control IC Data

Anions									
Board #	Category	Location	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
Values Recorded in: µg/in^2									
		Recommeded Limits	1.00	3.00	3.00	6.00	3.00	3.00	3.00
Board 1	Control	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 1	Control	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*

Cations								
Board #	Category	Location	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium
Values Recorded in: µg/in^2								
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00
Board 1	Control	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.57**
Board 1	Control	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	**0.98**	*n.d.*	**0.86**

			Weak Organic Acids						
Board #	Category	Location	Acetate	Formate	Succinate	Adipate	Phthalate	MSA	Total
			Values Recorded in: µg/in^2						
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00	18.00
Board 1	Control	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 1	Control	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00

Good Topical Clean

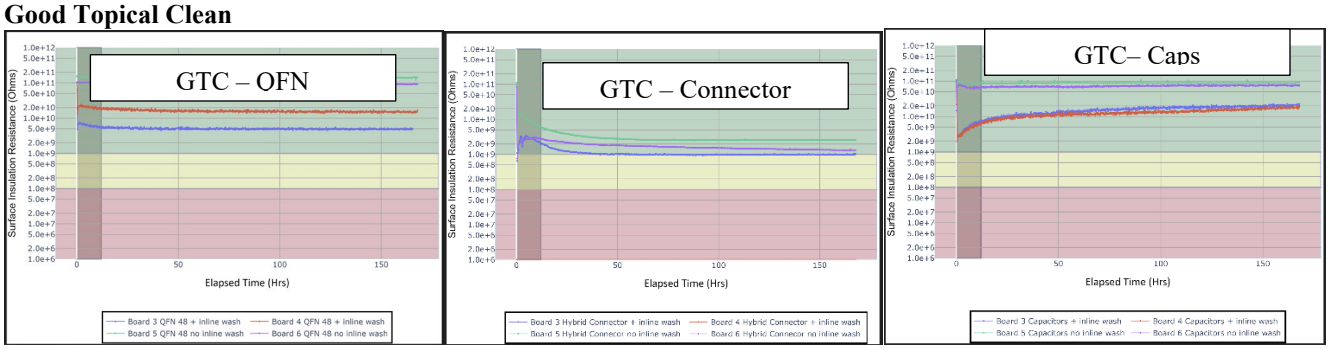


Figure 5: Good Topical Clean SIR Data

Table 3: Good Topical Clean Images

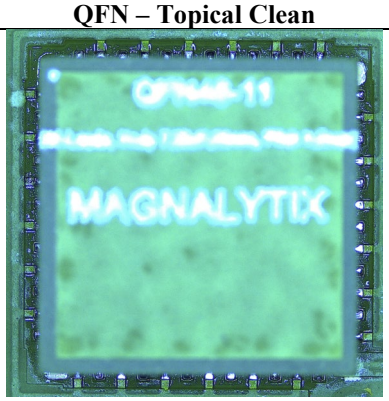
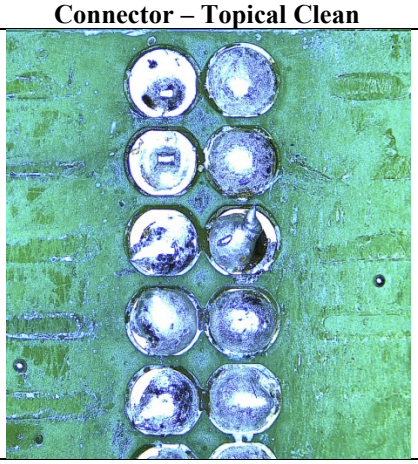
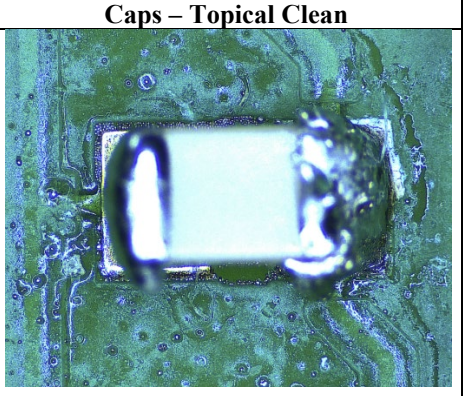
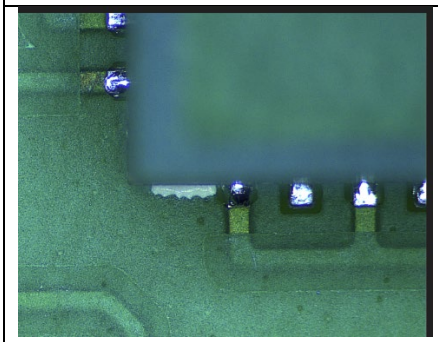
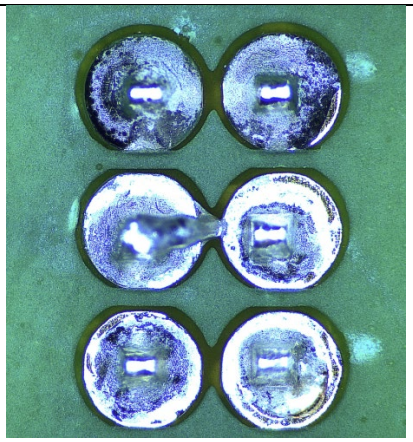
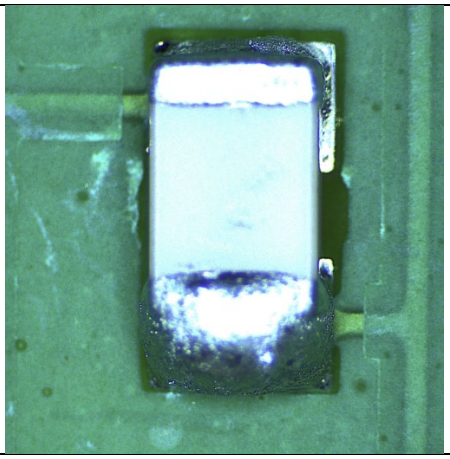
QFN – Topical Clean	Connector – Topical Clean	Caps – Topical Clean
		
QFN – Topical + Inline Clean	**Connector – Topical + Inline Clean**	**Caps – Topical + Inline Clean**
		

Table 4: Good Topical Clean IC Data

Anions									
Board #	Category	Location	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
			Values Recorded in: µg/in^2						
		Recommeded Limits	1.00	3.00	3.00	6.00	3.00	3.00	3.00
Board 3	Good Topical Clean + Inline Cleaned	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 3	Good Topical Clean + Inline Cleaned	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 5	Good Topical Clean	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 5	Good Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*

Cations								
Board #	Category	Location	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium
			Values Recorded in: µg/in^2					
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00
Board 3	Good Topical Clean + Inline Cleaned	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**0.72**
Board 3	Good Topical Clean + Inline Cleaned	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 5	Good Topical Clean	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**0.69**
Board 5	Good Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.26**

Weak Organic Acids									
Board #	Category	Location	Acetate	Formate	Succinate	Adipate	Phthalate	MSA	Total
			Values Recorded in: µg/in^2						
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00	18.00
Board 3	Good Topical Clean + Inline Cleaned	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 3	Good Topical Clean + Inline Cleaned	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 5	Good Topical Clean	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 5	Good Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	**2.61**	**2.51**	*n.d.*	*n.d.*	**5.12**

No Topical Clean

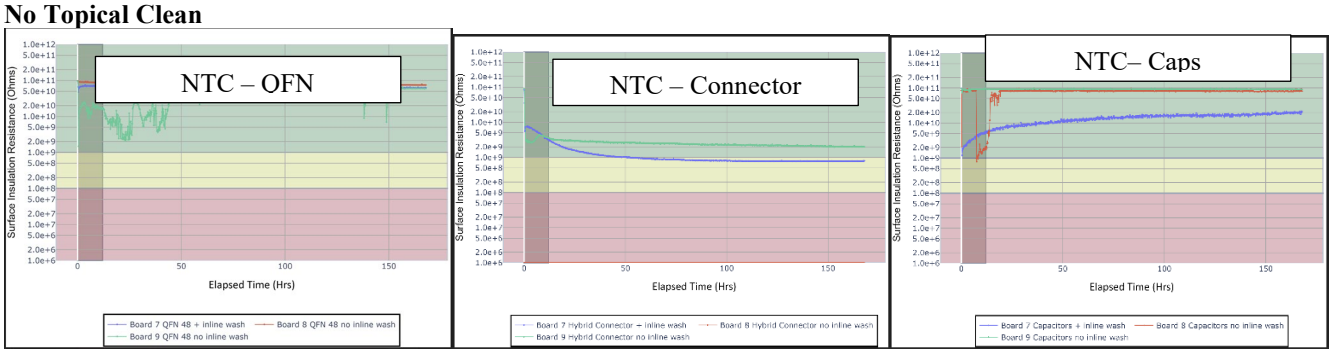


Figure 6: No Topical Clean SIR Data

Table 5: No Topical Clean Images

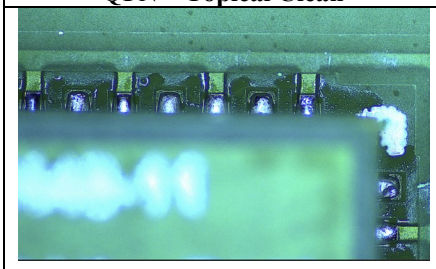
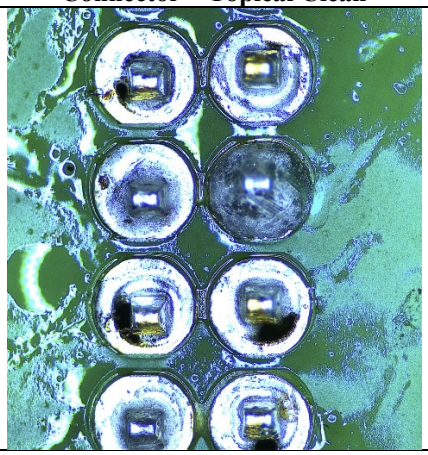
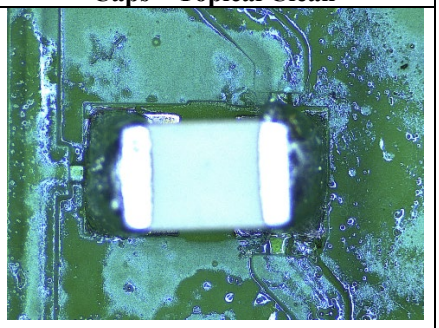
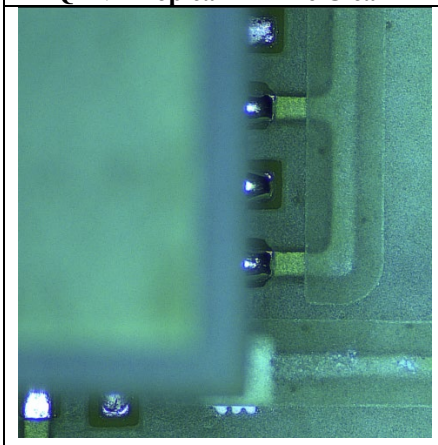
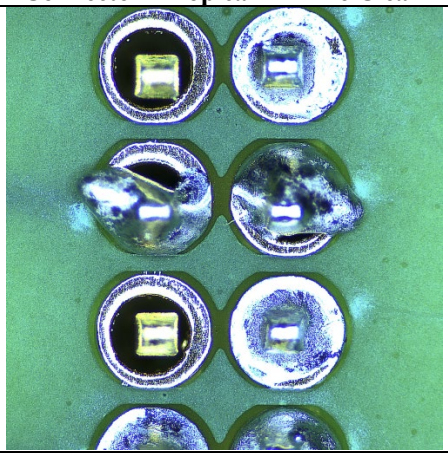
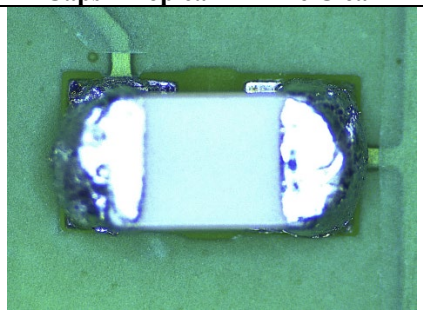
QFN – Topical Clean	Connector – Topical Clean	Caps – Topical Clean
		
QFN – Topical + Inline Clean	**Connector – Topical + Inline Clean**	**Caps – Topical + Inline Clean**
		

Table 6: No Topical Clean IC Data

			Anions						
Board #	Category	Location	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
			Values Recorded in: µg/in^2						
		Recommeded Limits	1.00	3.00	3.00	6.00	3.00	3.00	3.00
Board 7	No Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 7	No Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**2.13**
Board 8	No Cleaning	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 8	No Cleaning	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*

Cations								
Board #	Category	Location	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium
			Values Recorded in: µg/in^2					
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00
Board 7	No Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**0.52**
Board 7	No Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**0.92**
Board 8	No Cleaning	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.21**
Board 8	No Cleaning	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.1**

Weak Organic Acids									
Board #	Category	Location	Acetate	Formate	Succinate	Adipate	Phthalate	MSA	Total
			Values Recorded in: µg/in^2						
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00	18.00
Board 7	No Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 7	No Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 8	No Cleaning	Chip Cap	*n.d.*	*n.d.*	**1.72**	*n.d.*	*n.d.*	*n.d.*	**1.72**
Board 8	No Cleaning	Through-Hole Connector	*n.d.*	*n.d.*	**7.32**	**4.55**	*n.d.*	*n.d.*	**11.87**

Bad Topical Clean

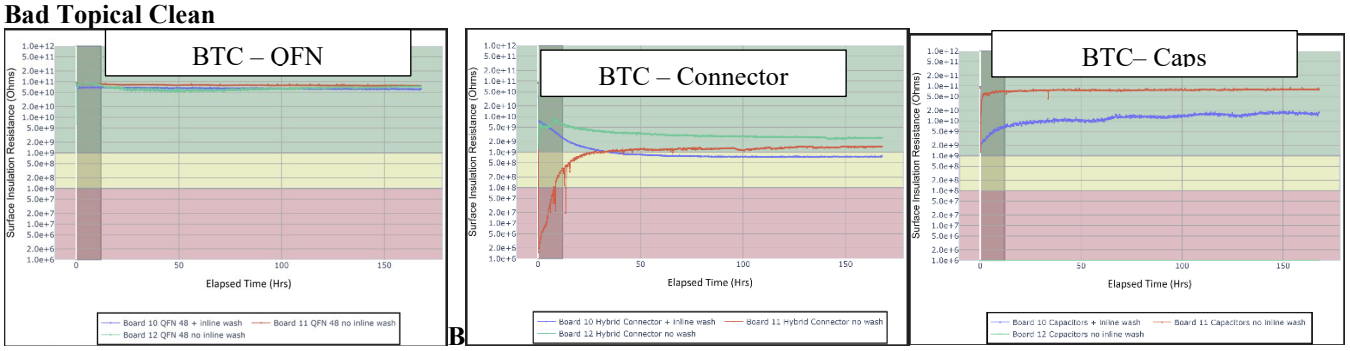
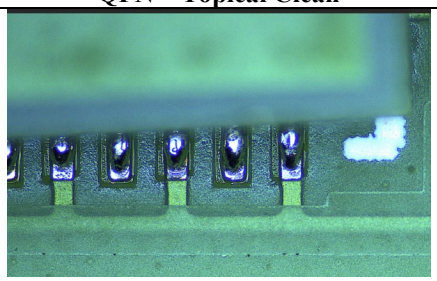
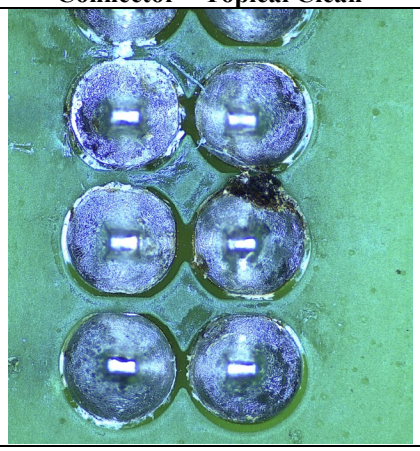
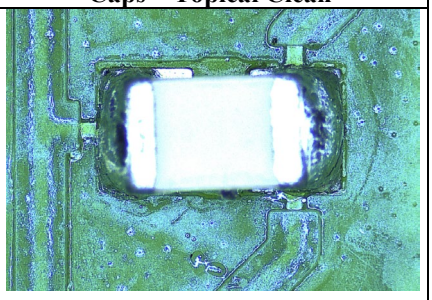


Figure 7: Bad Topical Clean

Table 7: Bad Topical Clean Images

QFN – Topical Clean	Connector – Topical Clean	Caps – Topical Clean
		
QFN – Topical + Inline Clean	**Connector – Topical + Inline Clean**	**Caps – Topical + Inline Clean**

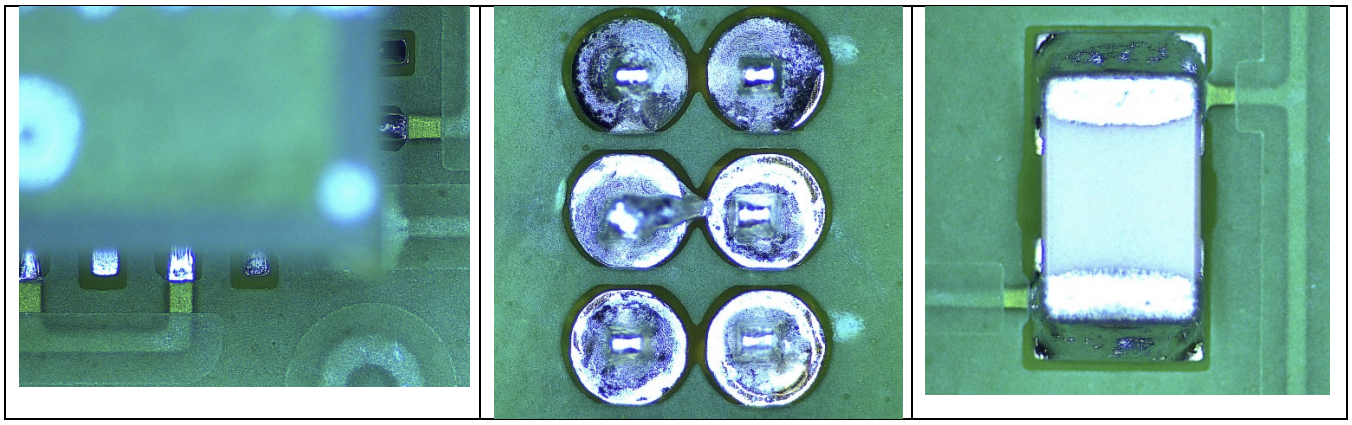


Table 8: Bad Topical Clean IC Data

Anions									
Board #	Category	Location	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
			Values Recorded in: µg/in^2						
		Recommended Limits	1.00	3.00	3.00	6.00	3.00	3.00	3.00
Board 10	Bad Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 10	Bad Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 11	Bad Topical Clean	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Board 11	Bad Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*

Cations								
Board #	Category	Location	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium
			Values Recorded in: µg/in^2					
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00
Board 10	Bad Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**0.92**
Board 10	Bad Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.1**
Board 11	Bad Topical Clean	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.41**
Board 11	Bad Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	**1.76**

Weak Organic Acids									
Board #	Category	Location	Acetate	Formate	Succinate	Adipate	Phthalate	MSA	Total
			Values Recorded in: µg/in^2						
		Recommended Limits	3.00	3.00	3.00	3.00	1.00	1.00	18.00
Board 10	Bad Topical Clean + Inline	Chip Cap	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 10	Bad Topical Clean + Inline	Through-Hole Connector	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	*n.d.*	0.00
Board 11	Bad Topical Clean	Chip Cap	*n.d.*	*n.d.*	**2.83**	**2.40**	*n.d.*	*n.d.*	**5.23**
Board 11	Bad Topical Clean	Through-Hole Connector	*n.d.*	*n.d.*	**6.08**	**4.85**	*n.d.*	*n.d.*	**10.93**

INFERENCES FROM THE DATA FINDINGS

1. Bare Boards Group
   a. SIR was stable and in the desired performance range over the testing period.
   b. IC – Anions, Cations, and WOA were also within limits except for calcium.
   c. There is no indication of performance issues from the bare boards group.
2. Good Topical Clean
   a. A rework station was used to place the TH/SM connector.
   b. The thru-hold portion and the 0805 caps on the bottom side of the test board were hand-soldered.
   c. A rosin flux at 15% in 85% IPA was used for soldering the thru-hole leads and 0805 components.
   d. The soldering iron transfers high heat, which outgasses and hardens the rosin flux residue.
   e. The visual images following the topical cleaning step left visual flux residues.
   f. SIR was stable and in the desired performance zone.
   g. The C3 instrument was used to take site-specific extractions at the connector and 0805 caps.
   h. IC found high levels of succinate and adipate weak organic acids for one of the topically cleaned test boards.
   i. The test boards that underwent an inline clean process left no visible flux residues and passed both SIR and IC.
3. No Topical Clean
   a. A rework station was used to place the TH/SM connector.
   b. The thru-hold portion and the 0805 caps on the bottom side of the test board were hand-soldered.
   c. A rosin flux at 15% in 85% IPA was used for soldering the thru-hole leads and 0805 components.
   d. The soldering iron transfers high heat, which outgasses and hardens the rosin flux residue.
   e. The visual images following the topical cleaning step left visual flux residues.
   f. SIR generated a series of leakage currents, which were still in the passing zone early in the testing period. As the test continued, SIR was stable and in the desired performance zone.
   g. The C3 instrument was used to take site-specific extractions at the connector and 0805 caps.
   h. IC found high levels of succinate and adipate weak organic acids for non-cleaned test boards.
   i. The test boards that underwent an inline clean process left no visible flux residues and passed both SIR and IC.
4. Bad Topical Clean
   a. A rework station was used to place the TH/SM connector.
   b. The thru-hold portion and the 0805 caps on the bottom side of the test board were hand-soldered.
   c. A rosin flux at 15% in 85% IPA was used for soldering the thru-hole leads and 0805 components.
   d. The soldering iron transfers high heat, which outgasses and hardens the rosin flux residue.
   e. The visual images following the topical cleaning step left visual flux residues.
   f. SIR generated leakage currents at the thru-hole connector, which failed early in the testing period. As the test continued, SIR was stable and in the desired performance zone.
   g. The C3 instrument was used to take site-specific extractions at the connector and 0805 caps.
   h. IC found high succinate and adipate weak organic acids levels in both topically cleaned test boards.
   i. The test boards that underwent an inline clean process left no visible flux residues and passed both SIR and IC.

RECOMMENDED BEST PRACTICES

1. A rework station designed to place SMT components using solder paste should be used.
2. The best practice is a flux-embedded solid core wire without a liquid flux when hand soldering.
3. Soldering materials should meet an R0L0 standard.
4. Never use a water-soluble flux as they are highly active and increase ECM risks.
5. Whenever a liquid flux is used, cleaning should be conducted using a cleaning machine designed to use an aqueous-engineered cleaning agent that processes the boards through a wash, rinse, and dry process.
6. The process should be validated using SIR, C3, and IC test methods.

CONCLUSIONS

Secondary soldering processes have a higher risk of ECM failures. Manual and rework soldering are less controlled processes that increase process variability. From a test lab perspective, we find more failures resulting from rework.

The test data from the designed experiment used for this paper were relatively good, which could give an engineer confidence that rework is relatively safe. Rosin flux that is fully heat-activated is benign. Topical cleaning leaves and spreads residues. When exposed to climatic conditions, there is a high risk of failure occurrences.

Operators often use water-soluble flux because it is easier to clean. However, unless cleaned using an aqueous cleaning process, the residues transferred across the assembly will fail quickly.

We highly recommend using the best practices we documented in this paper. These practices should be documented and operator trained. Validating and qualifying these practices using SIR, C3, and IC is highly suggested.

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