# SIR Test Vehicles – Comparison from a Cleaning Perspective

Naveen Ravindran, M.S.Ch.E., Umut Tosun, M.S.Ch.E.
ZESTRON Americas
Manassas, VA

**Abstract**
PCB design has evolved greatly in recent years becoming ever more complex. Board density is increasing, component standoff heights are decreasing and long term reliability requirements are greater than ever, particularly for Class III products. Given the quality and reliability demands for complex PCBs, manufacturing processes are qualified; that is, the PCB design, including component and solder paste/flux selection, material compatibility and process steps, must meet the long term reliability requirements demanded and quality standards desired. As a result, cleaning is becoming a mandatory step within the manufacturing process.

Analytical tests are key elements to any qualification process. Through the IPC, numerous tests have been developed and have become industry standards. In particular, IPC-TM-650, method 2.6.3.7 or SIR (Surface Insulation Resistance) is frequently used regardless of the solder paste/flux type. Per the specification, this test can quantify the deleterious effects of fabrication, process or handling residues on SIR in the presence of moisture. Measuring changes in surface resistance is a standard way of testing cleanliness and long-term reliability of a test board or complete process assembly based on industry standards.

There are numerous test vehicle options available to the industry for conducting SIR analysis. This study was designed to compare different SIR test vehicles, from a cleaning perspective, in order to determine which test vehicle is tougher to clean and therefore challenge the cleaning process.

The three (3) test vehicles selected were the IPC-B-52, IPC-B-36 and the SMTA Saber. Each test vehicle was populated with specific components. The authors chose to reflow the test vehicles with water soluble solder paste only, since the high activity flux in the water soluble paste would increase the chance of SIR failure if left partially cleaned.

Multiple test vehicles were prepared. Cleanliness verification and validation was completed by visual inspection underneath all components as well as by performing SIR tests. All test vehicles were cleaned prior to reflow and ion chromatography was conducted on selected test vehicles initially to ensure they were free of any ionics. An inline cleaning process was used for all cleaning trials.

**Keywords:**
Surface Insulation Resistance, Qualification Process, PCB Cleanliness Assessment, Reliability

**Introduction**
Why employ SIR testing in the first place? As the complexity of PCBs increases, so does required product reliability. As an OEM or CM, SIR has become a standard test mechanism by which to qualify a process. Essentially, SIR testing is performed for one of three reasons [1]:

- As part of a qualification or classification of a product
- To evaluate or control a process
- To compare materials or processes

Considering the purpose of SIR, and the fact that numerous vehicles are available for conducting the test, what criteria should be used to select the SIR test vehicle? One must note that each vehicle includes different component types and in one case, enables evaluating through hole fluxes in addition to surface mount solder paste/flux.

Even though numerous SIR test vehicles are available, only a select few are used to assess effectiveness of a cleaning process. In order to provide the best opportunity for a differentiating result, the authors chose a high activity water soluble flux. Furthermore, they chose to clean the boards using a spray-in-air inline cleaning system with DI-water. As the selected solder paste was water soluble, using DI-water for the cleaning media was expected to result in cleanliness assessment meeting industry standards.

The study was designed in two phases whereby through Phase 1, the authors would establish cleaning process operating parameters and through Phase 2, utilize the Phase 1 cleaning parameters to prepare the vehicles for the SIR analysis. In Phase 1, the authors chose to assess cleanliness by visual inspection underneath all component types. In order to ensure variation in the cleaning results, the test protocol developed included operating the conveyer belt at speeds ranging from 1 ft/min to 4 ft/min. Ideally, the authors attempted to establish cleaner operating parameters resulting in a "best case" or fully cleaned under all component types and "worst case" or partially cleaned residues under all component types.

In the Phase 1 trials, the authors anticipated that DI-water alone would not fully clean underneath the components at the accelerated conveyor belt speeds [2]. Thus, as a comparator, the authors chose to duplicate the cleaning trials using an engineered aqueous based cleaning agent within the cleaning process.

Within the Phase 2 trials, the authors chose the best case and worst case cleaning trial parameters to prepare the test vehicles for the SIR analysis.

**Methodology**

The main objective of the study was to compare three commonly used SIR test vehicles that are available within the industry focusing on the ease and/or difficulty of cleaning them under similar process conditions. Based on the cleanliness results achieved, the effect if any on SIR test results for each vehicle type would be assessed.

The SIR test vehicles used were the IPC-B-52 (Figures 1-3), IPC-B-36 (Figures 4-6) and the SMTA Saber (Figure 7). Each vehicle was screened using lead-free water soluble solder paste, 6 mil stencil and reflowed per the manufacturer's recommendation. For the SIR evaluation, each coupon type was populated as follows:

1. IPC-B-52 Rev B populated with:
   a. QFP160
   b. 0402SMC
   c. 0603SMC
   d. 0805SMC
   e. 1206SMC

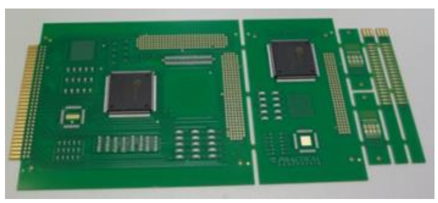


**Figure 1. IPC-B-52**

Figures 2 and 3 are representative pictures of low standoff chip cap components:


**Figure 2. 0402 component**

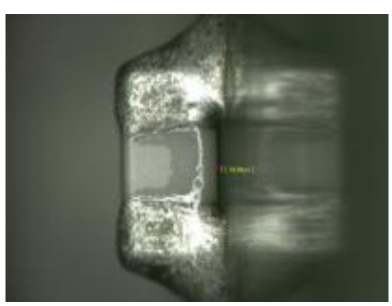


**Figure 3. 0402 component standoff: 20 microns or 0.8 mil**

2. IPC-B-36 populated with:
Four (4) 68LCC components

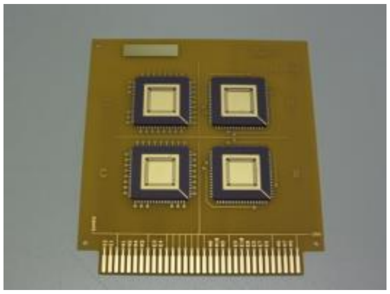


**Figure 4. IPC-B-36 populated with 68LCC components**

68LCC components

i. The 68LCC components were chosen for this board. The PLCC68 has a much higher standoff height and will not challenge the cleaning process.
ii. Patterns 1, 3, 5, 7 are comb structures located in the middle of the LCC component area.
iii. Patterns 2, 4, 6, 8 are external locations which could be on the perimeter of the component or between the leads of the component.

Figures 5 and 6 are representative pictures of standoff heights of PLCC and LCC components:

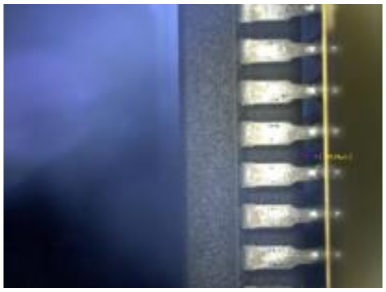


**Figure 5. PLCC68 component standoff: 550 microns or 22 mil**

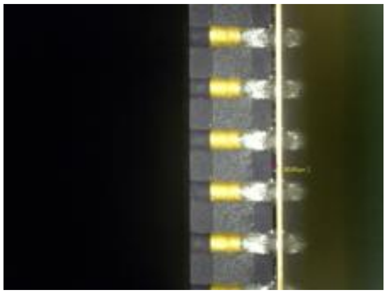


**Figure 6. 68LCC component standoff: 80 microns or 3.2 mil**

3. SMTA Saber Test board (Rev E) populated with:
a. QFP208
b. QFP100
c. 0402SMR
d. 0603SMR
e. 0805SMR
f. 1206SMR
g. PLCC68

**Figure 7. SMTA Saber Test Board**

Standoff measurements could not be made on the Saber board due to the orientation of the chip components.

All SIR test vehicles were populated at Rochester Institute of Technology (RIT) and returned to the ZESTRON Technical Center for cleaning and evaluation. All SIR tests were completed by NTS, an independent testing lab.

The study was conducted in two phases:

- Phase 1 Trials: Determine cleaning process operating parameters resulting in fully cleaned and partially cleaned coupons as verified through visual inspection underneath all components
    - Eight (8) coupons of each type or 24 coupons in total
- Phase 2 Trials: Utilize results from Phase 1 trials for best case and worst case cleaning scenarios and assess cleanliness through SIR analysis for each coupon type
    - Three (3) coupons of each type or 9 coupons in total

**Phase 1 Visual Analysis**

Through these trials, the authors identified the wash process parameters that would result in partially and fully cleaned vehicles as determined through visual analysis. In order to assess cleanliness, all components were sheared off enabling visual assessment underneath the components.

The cleaning process parameters were selected based on the authors' field experience. With the exception of conveyor belt speed, all inline cleaning parameters remained constant for all trials. Reference Table 1 for cleaning process parameter details:

**Table 1. Cleaning Process Parameters**

| | |
|---|---|
| **Wash Stage** | |
| Equipment | Spray-in-air inline cleaner |
| Cleaning Agent | • DI-water<br>• Dynamic Surfactant Cleaning Agent (5%) concentration |
| Wash Spray Configuration | 8 spray bars standard intermix |
| Pre-Wash Pressure (Top/Bottom) | 50 PSI / 40 PSI |
| Wash Pressure (Top/Bottom) | 75 PSI / 60 PSI |
| Wash Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| Wash Temperature | 140°F / 60°C |
| Chemical Isolation Pressure (Top/Bottom) | 30 PSI / 25 PSI |
| **Rinsing Stage** | |
| Rinsing Agent | DI-water |
| Rinse Pressure (Top/Bottom) | 80 PSI / 70 PSI |
| Rinse Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| Rinse Temperature | 140°F / 60°C |
| Final Rinse Pressure (Top/Bottom) | 25 PSI / 25 PSI |
| Final Rinse Temperature | Room Temperature |
| **Drying Stage** | |
| Drying Method | Hot Circulated Air |
| Drying Temperature (D1) | 160°F |
| Drying Temperature (D2) | 180°F |
| Drying Temperature (D3) | 180°F |

Four (4) conveyor belt speeds were considered for each vehicle type. Thus, a total of twenty-four (24) populated test vehicles were required for this phase of the study. In total, eight (8) trials were conducted. Reference Table 2 for details.

**Table 2. Belt Speeds**

| Trial # | Cleaning Agent | Wash Temperature (°F) | Belt Speed (ft/min) | Board Type |
|---|---|---|---|---|
| 1 | DI-water | 140 | 1 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 2 | | | 2 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 3 | | | 3 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 4 | | | 4 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 5 | Chemistry A (5%) | 140 | 1 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 6 | | | 2 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 7 | | | 3 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |
| 8 | | | 4 | IPC-B-52 |
| | | | | IPC-B-36 |
| | | | | SMTA Saber |

Within Phase 1 of this study, eight (8) fully populated vehicles of each type were cleaned utilizing the spray-in-air inline cleaning system. Four (4) coupons were cleaned with DI-water and four (4) with aqueous based cleaning agent.

**Phase 1 Results**

The components were sheared off of all test vehicles followed by an evaluation of cleanliness underneath components. Overall cleanliness percent of the board was taken as the percent of components that were completely clean underneath. Thus, a fully cleaned surface was determined to be "best case" and highest percent residues remaining underneath component were determined to be "worst case."

- Best case: Settings that yield 100% cleanliness result for all test vehicle types
- Worst case: Settings that yield the lowest cleanliness result for all test vehicle types

Once determined, the "best case" and "worst case" process settings were used for cleaning each vehicle type for Phase 2 of the study.

**Visual Inspection Results**

Once cleaned, all components were sheared off and through visual inspection, each test vehicle was graded for the percent cleanliness achieved. Reference Table 3.

**Table 3. Visual Inspection Results**

| Trial # | Cleaning Agent | Temperature (°F) | Belt Speed (ft/min) | IPC-B-52 Test Vehicle | | IPC-B-36 Test Vehicle | | SMTA Saber Board | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Surface | Under Components | Surface | Under components | Surface | Under Components |
| 1 | DI-water | 140°F | 1 | ++ | 100.00% | ++ | 87.50% | + | 100.00% |
| 2 | | 140°F | 2 | ++ | 100.00% | ++ | 31.25% | + | 97.25% |
| 3 | | 140°F | 3 | ++ | 94.81% | - | 0.00% | - | 91.74% |
| 4 | | 140°F | 4 | ++ | 62.34% | - | 0.00% | - | 66.06% |
| 5 | Aqueous Cleaning Agent (5% conc.) | 140°F | 1 | ++ | 100.00% | ++ | 100.00% | ++ | 100.00% |
| 6 | | 140°F | 2 | ++ | 100.00% | ++ | 100.00% | ++ | 100.00% |
| 7 | | 140°F | 3 | ++ | 100.00% | ++ | 100.00% | ++ | 100.00% |
| 8 | | 140°F | 4 | ++ | 100.00% | ++ | 100.00% | ++ | 100.00% |

It was observed, that all the boards cleaned using the low concentration cleaning agent (Trials 5-8) were fully clean. However, differences in cleaning performance could be noted with boards cleaned using only DI-water (Trials 1-4) as depicted in Figure 8:

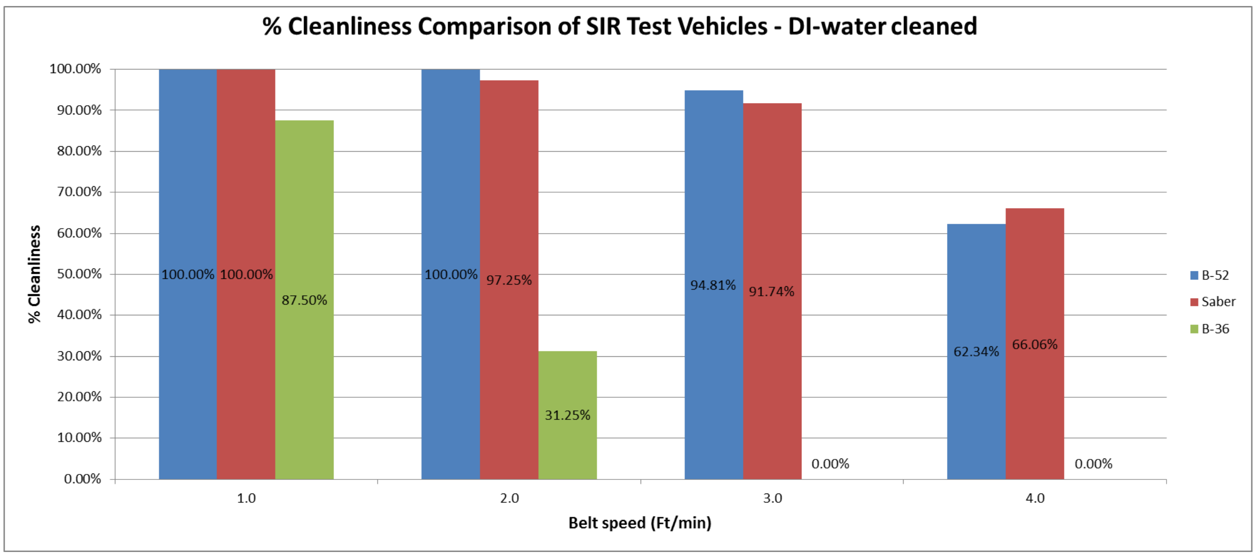



**Figure 8. Cleaning Comparison of SIR Test Vehicles: Cleaned with DI-water**

Representative pictures of the residues noticed in Trial 4 on all the board types are below:

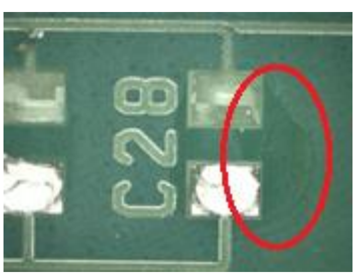



**Figure 9. IPC-B-52: 0805 Components**

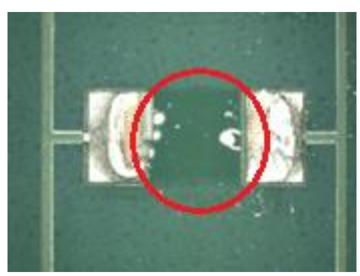


**Figure 10. IPC-B-52: 1206 Components**

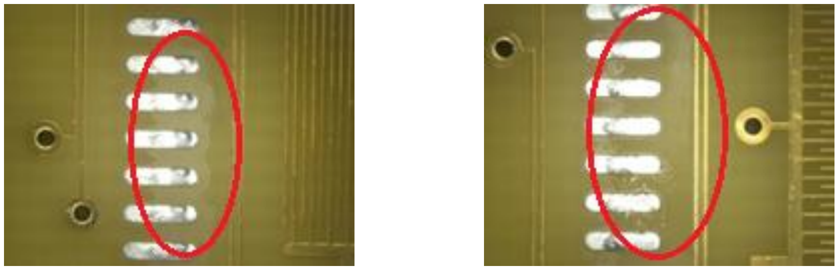


**Figure 11. IPC-B-36 Boards**

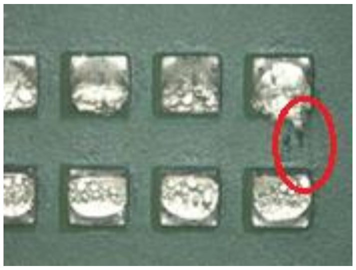


**Figure 12. SMTA Saber Boards – 0603 Components**

**Figure 13. SMTA Saber Boards – 0805 Components**

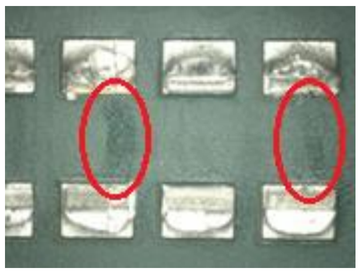


**Figure 14. SMTA Saber Boards – 1206 Components**

**Observations – Visual Inspection Results**

- The IPC-B-52 test vehicles were the easiest to clean, with no residues noticed on the surface, even at the fastest belt speed. Underneath components, residues were mainly noticed on the 1206 and 0805 components in Trials 3 and 4. Complete cleanliness undercomponents could be attained at belt speeds as high as 2 ft/min with the B-52 boards.
- The IPC-B-36 board is the most difficult to clean. Thus, 100% cleanliness could not be achieved even at the reduced conveyor belt speed of 1 ft/min with just DI-water. Additionally, residues could be seen on the surface at the faster belt speeds.
- The SMTA Saber boards showed signs of staining on the solder mask even at 1 ft/min. However, this could be paste dependent and is not considered as a measure of the difficulty of cleaning this board. Underneath components, residues were noticed mainly on the 1206, 0805 and some 0603 components. Results indicated 100% cleanliness undercomponents with DI-water at 1 ft/min.
- 100% cleanliness was achieved for all trials with all vehicles using aqueous cleaning agent

**Phase 2 – SIR Testing**

Prior to proceeding with the Phase 2 trials, and preparing the coupons for SIR analysis, the bare test vehicles were cleaned utilizing the inline cleaning system and the engineered aqueous based cleaning agent. A cleanliness assessment was conducted on two (2) test vehicles of each type using ion chromatography to ensure they were free of any ionics. All cleaned vehicles were placed in ESD bags until processing.

Following cleaning, two (2) test vehicles of each type were sent to RIT for assembly and returned to the ZESTRON Technical Center for cleaning and further analysis. One (1) cleaned bare test vehicle of each type was not populated and used as a control for the SIR comparison tests.

The fully populated vehicles, two (2) of each type, were cleaned utilizing the best case and worst case scenarios and subjected to SIR analysis. SIR analysis was conducted in accordance with IPC TM-650 Method 2.6.3.7.

**Phase 2 Results**
Phase 2 results include both IC and SIR analysis. The IC results are detailed in Table 4.

**Table 4. Ion Chromatography Results**

| | Ionic Species | Maximum Contamination Levels | B-36 #1 | B-36 #2 | Saber #1 | Saber #2 | B-52 #1 | B-52 #2 |
|---|---|---|---|---|---|---|---|---|
| ANIONS | Fluoride ($F^-$) | 3 | 0 | 0.0850 | 0 | 0 | 0.0016 | 0 |
| | Acetate ($C_2H_3O^-_2$ ) | 3 | ND | ND | ND | ND | ND | ND |
| | Formate ($CHO^-_2$) | 3 | ND | ND | ND | ND | ND | ND |
| | Chloride ($Cl^-$) | 3 | 0.1617 | 0.0341 | 0.2219 | 0.2388 | 0.1479 | 0.1250 |
| | Nitrite ($NO_2^-$) | 3 | ND | ND | ND | ND | ND | ND |
| | Bromide ($Br^-$) | 2.5 | 0.0431 | 0.0507 | 0.0028 | 0.0072 | 0.0268 | 0.0277 |
| | Nitrate ($NO_3^-$) | 3 | 0.0448 | 0.0501 | 0.8946 | 0.7664 | 0.0713 | 0.0926 |
| | Phosphate ($PO_4^{2-}$) | 3 | ND | ND | ND | ND | ND | ND |
| | Sulfate ($SO_4^{2-}$) | 3 | 0.0262 | 0.0329 | 0.1196 | 0.1092 | 0.0704 | 0.0957 |
| | WOA (Weak Organic Acid) | N/A | ND | ND | ND | ND | ND | ND |
| CATIONS | Lithium ($Li^+$) | 2 | 0.0006 | 0.0003 | 0.0007 | 0.0003 | ND | ND |
| | Sodium ($Na^+$) | 2 | 0 | 0 | 0.4280 | 0.3574 | 0.1308 | 0.0923 |
| | Ammonium ($NH_4^+$) | 3 | 0.0209 | 0.0140 | 0.6782 | 0.6572 | 0.3968 | 0.4041 |
| | Potassium ($K^+$) | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Magnesium ($Mg^{2+}$) | 1 | 0 | 0 | 0.6000 | 0.3077 | 0.0202 | 0.0028 |
| | Calcium ($Ca^{2+}$) | 1 | 0.0116 | 0 | 0.5045 | 0.2323 | 0 | 0 |

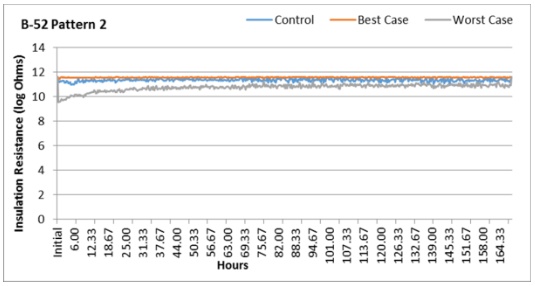
As all test vehicles passed IC analysis, the authors could be assured that the test vehicles were ready to be populated in preparation for SIR analysis. Two (2) vehicles of each coupon type were populated and one unpopulated test vehicle of each was set as “control” for SIR analysis.

Based on the results of the Phase I testing, cleaning process operating parameters from Trial 4 and Trial 5 were selected to represent the “worst case” and “best case” scenarios respectively. SIR results are detailed in Table 5 and Figures 15-32.

**Table 5. SIR Results**

| Board Type | Process settings | Overall Results |
|---|---|---|
| IPC-B-52 | Control | Pass |
| | Best Case settings (Aqueous Cleaning Agent) | Pass |
| | Worst Case settings (DI-water) | Some failures. SIR values lower than Control and Best Case boards in general. |
| IPC-B-36 | Control | Pass |
| | Best Case settings (Aqueous Cleaning Agent) | Pass |
| | Worst Case settings (DI-water) | Some failures. SIR values lower than Control and Best Case boards in general. |
| Saber | Control | Pass |
| | Best Case settings (Aqueous Cleaning Agent) | Pass |
| | Worst Case settings (DI-water) | Pass |

**IPC-B-52 Test Vehicles**



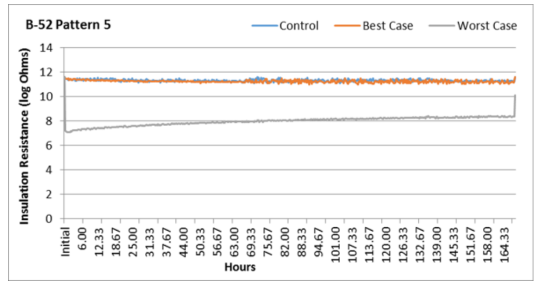
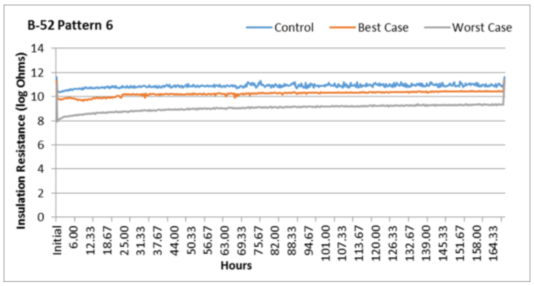




**Figure 15. IPC-B-52 Vehicle: Pattern 2 – Passed**

**Figure 16. IPC-B-52 Vehicle: Pattern 5 – Failed (Worst Case)**



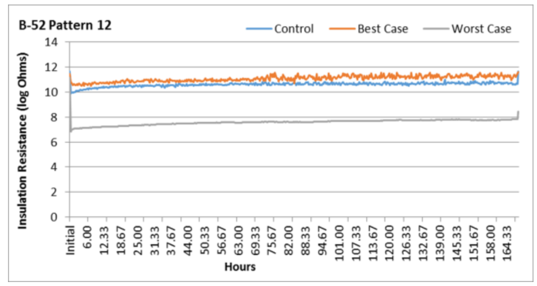




**Figure 17. IPC-B-52 Vehicle: Pattern 6 – Passed**

**Figure 18. IPC-B-52 Vehicle: Pattern 12 – Failed (Worst Case)**

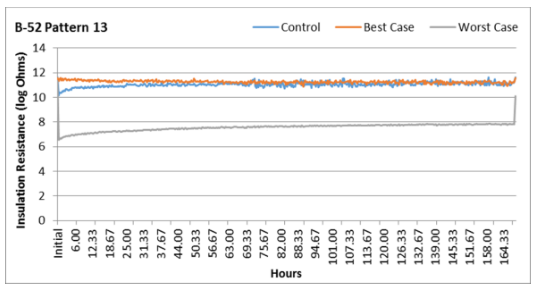
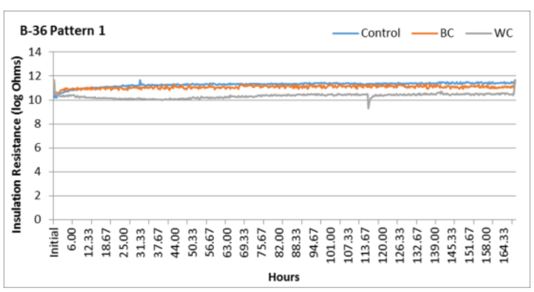



**Figure 19. IPC-B-52 Vehicle: Pattern 13 – Failed (Worst Case)**

**IPC-B-36 Test Vehicles**



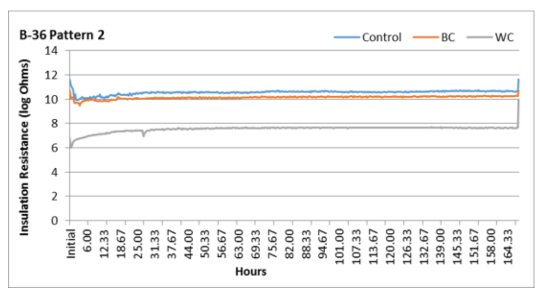
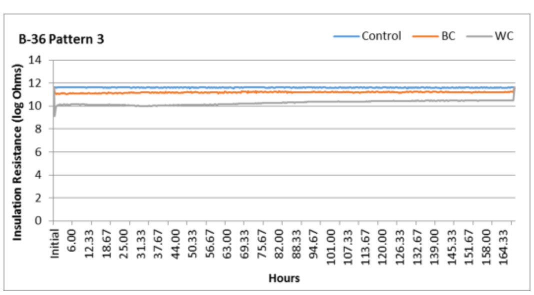




**Figure 20. IPC-B-36 Vehicle: Pattern 1 – Passed**

**Figure 21. IPC-B-36 Vehicle: Pattern 2 – Failed (Worst Case)**



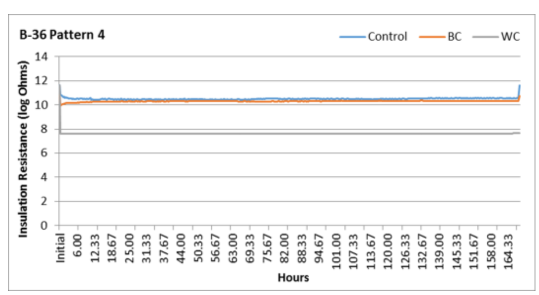




**Figure 22. IPC-B-36 Vehicle: Pattern 3 – Passed**

**Figure 23. IPC-B-36 Vehicle: Pattern 4 – Failed (Worst Case)**

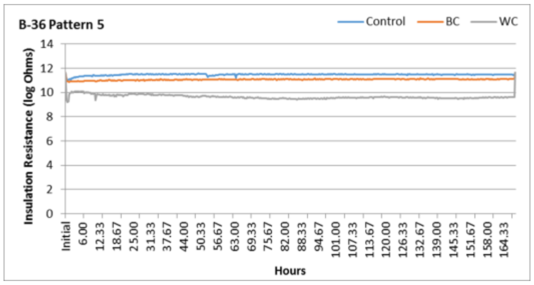



Figure 24. IPC-B-36 Vehicle: Pattern 5 – Passed

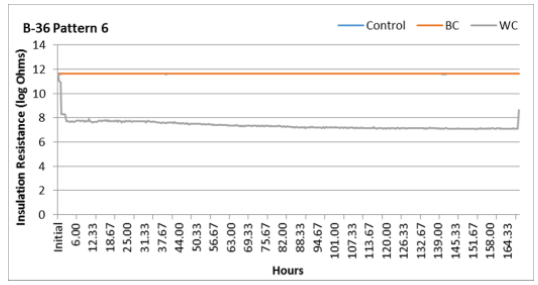



Figure 25. IPC-B-36 Vehicle: Pattern 6 – Failed (Worst Case)

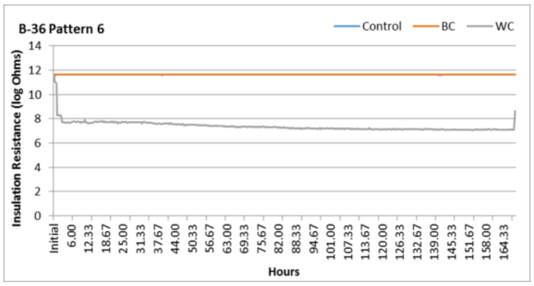



Figure 26. IPC-B-36 Vehicle: Pattern 6 – Failed (Worst Case)

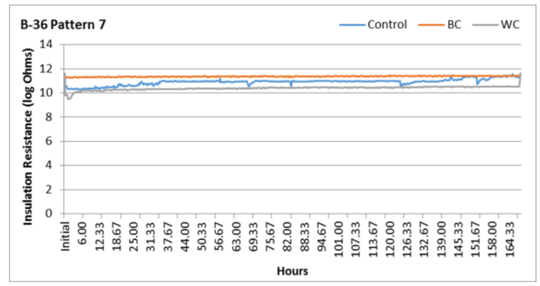



Figure 27. IPC-B-36 Vehicle: Pattern 7 – Passed

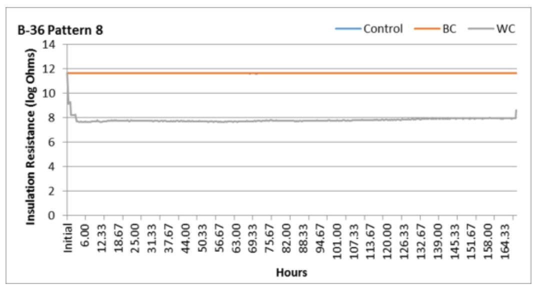



Figure 28. IPC-B-36 Vehicle: Pattern 8 – Failed (Worst Case)

**Saber Boards**

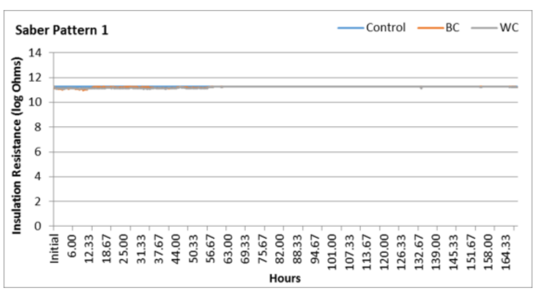



Figure 29. Saber Vehicle: Pattern 1

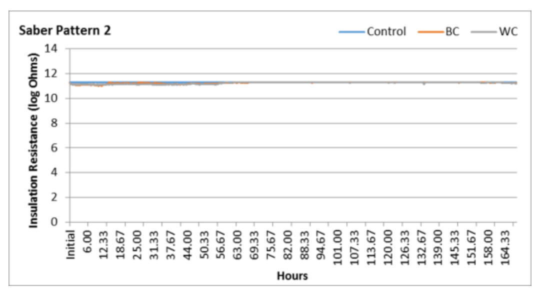



Figure 30. Saber Vehicle: Pattern 2

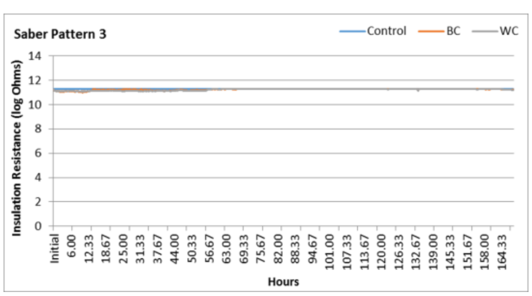



Figure 31. Saber Vehicle: Pattern 3

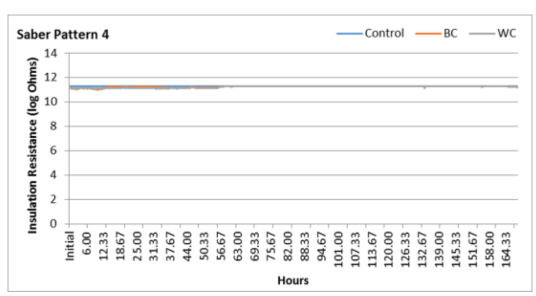



Figure 32. Saber Vehicle: Pattern 4

## Conclusions

Conducting this study using water soluble solder paste enabled the authors to differentiate achievable cleanliness levels of the three (3) different SIR test vehicles. As expected, if residues remain on the board surface, SIR tests yielded failed results. As mentioned in the introduction, the purpose of SIR testing should influence SIR coupon selection. It is interesting to note that utilizing the low concentration aqueous cleaning agent yielded passing SIR results for all coupons cleaned under the "best case" scenario whereas the DI-water cleaned coupons yielded failed SIR results under "worst case" scenarios for IPC-B-52 and IPC-B-36. Additionally the authors noted:

- Differences in visual cleaning results could be noted on boards cleaned with DI-water only.
- The IPC-B-36 test vehicles were found to be the most difficult to clean with residues noticed underneath components even at 1 ft/min with DI-water. Using the aqueous cleaning agent, all coupons were clean at 4 ft/min.
- Saber boards required a conveyor belt speed of 1 ft/min to be 100% clean, whereas the IPC-B-52 test vehicles were completely cleaned at 2 ft/min with DI-water.
- SIR test results showed failures on the IPC-B-52 and IPC-B-36 test vehicles cleaned under "worst case" settings, which was to be expected since these settings resulted in residues undercomponents.
- The Saber board passed the SIR test even under worst case settings. This is due to the fact that the SIR measurements are taken on the QFP component of the Saber board which is an easier component to clean as compared to other components on the board.
- In general, the SIR values for test vehicles cleaned with "best case" settings (with chemistry) were higher than boards cleaned with "worst case" settings (DI-water only).

## Recommendations

As a result of this study, the authors recommend using the IPC-B-36 test vehicles for projects where the goal is to compare cleaning processes. This board provides the most challenging environment to test cleanliness. This can include comparing cleaning agents, cleaning equipment or a combination of both.

Once a cleaning process is established, the IPC-B-52 test vehicles can subsequently be used for the process qualification step since it has various components that may be more representative of the components used on actual production boards. An additional advantage with the IPC-B-52 test vehicles is that the board can be used for testing through-hole fluxes as well.

Although, the Saber boards are not ideal for SIR tests, from a cleaning perspective, the authors recommend that the boards could still be used for visual analysis.

## References

[1] Renee Michaelkiewicz, Janet Green, and Scott Opperhauser, "Surface Insulation Resistance Testing of Soldering Pastes and Fluxes," Pan Pacific Microelectronics Symposium, February 2001.

[2] Umut Tosun, Jigar Patel, Michael McCutchen, "Comparative Cleaning Study to Showcase the Effective Removal of OA Flux Residues," SMTA International, October 2012.

## Acknowledgements

RIT for populating all SIR coupons

StenTech for providing the stencils