As originally published in the SMTA Proceedings

# Process Characterization that Results in Acceptable Levels of Flux and Other Residues

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**Abstract**
Surface Insulation Resistance (SIR) testing is a standard method used to characterize soldering and cleaning processes that result in acceptable levels of flux and other residues. Several different materials are used to assemble printed circuit cards. Residues can be present on the assembly from solder flux, solder paste, solder wire, underfill materials, adhesives, staking compounds, temporary masking materials, cleaning solvents, conformal coatings and more. Miniaturization of components increases risk due to tighter pitch, low standoff gaps, and residues trapped under the component termination.

In recent years, analysis of residues and their effects has shifted from a global examination of ionic residues (i.e. the entire assembly) to a more site-specific examination of spot or local contamination. The majority of an assembly surface may have acceptable levels of residues, with problem areas confined to a few components. Therefore, it was the desire to advance the state of the art in SIR testing and design cost-efficient test components and test vehicles that would allow an assembler to examine these problem point-sources of contamination. The goal of this research study was to design and evaluate an economical test board and laminate based components which mimic challenging components, and compare them to an accepted industry standard assembly, the IPC-B-52 standard test assembly.

**Introduction**
With the advent of IPC J-STD-001 Rev G, Amendment 1, manufacturers can no longer rely on a simple Resistivity of Solvent Extract (ROSE) test to determine if electronic hardware is acceptably clean or unacceptably dirty. Modern electronics and modern material sets have made the use of ROSE an obsolete practice. The new protocols rely on more advanced methods of residue characterization, not only characterizing the chemical nature of the residue(s) but evaluating the impact of the residue on electrochemical reliability. While many "standard" boards exist in the industry, most do not have component sets or materials of construction, which approximate modern electronic assemblies. A commonly used test board for characterizing manufacturing materials and processes is the IPC-B-52 test assembly, shown in Figure 1 below. This test assembly, when manufactured and tested by IPC-9202, has provided many assemblers with objective evidence of process acceptability for J-STD-001 in the past. Additional information on this board/assembly may be found in IPC-9203.

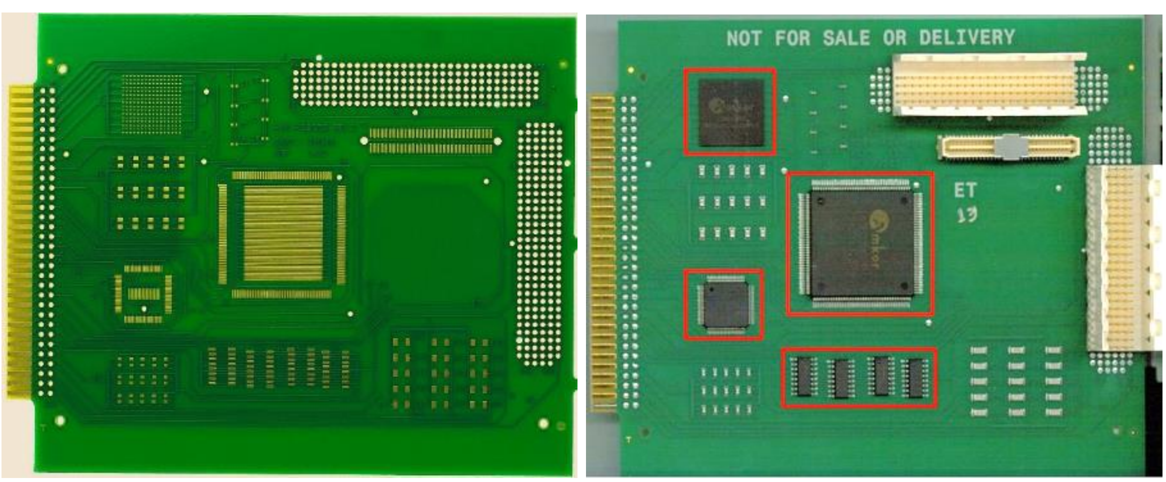



**Figure 1. IPC-B-52 Test Assembly**

This test assembly makes use of several special components, referred to as Mechanical Dummies (MD). These are components custom manufactured with no internal dies or wire bonds, as the presence of these internal structures can compromise surface insulation resistance (SIR) testing under humid conditions. The components outlined in red in Figure 1 are the custom components. Consequently, such custom parts are often long lead items for ordering and have an associated high cost.

The IPC-B-52 test assembly was designed in the 2001-2002 time frame, with component technologies typical for that time. One of the more challenging components in present-day manufacturing is bottom terminated components (BTCs) such as Quad Flat Pack No-Leads (QFNs). These devices have a very low standoff height and are very difficult to clean under them. In addition, earlier work [1] has shown that flux residues under these components may not fully react during reflow operations, leading to an electrochemical failure cell.

The IPC-B-52 standard assembly does not presently contain BTC components. The B-52 test board contains a defined area where complex components can be added. Figure 2 is a modified version of the B-52 assembly with QFNs [3] added to test flux residues under these challenging components.

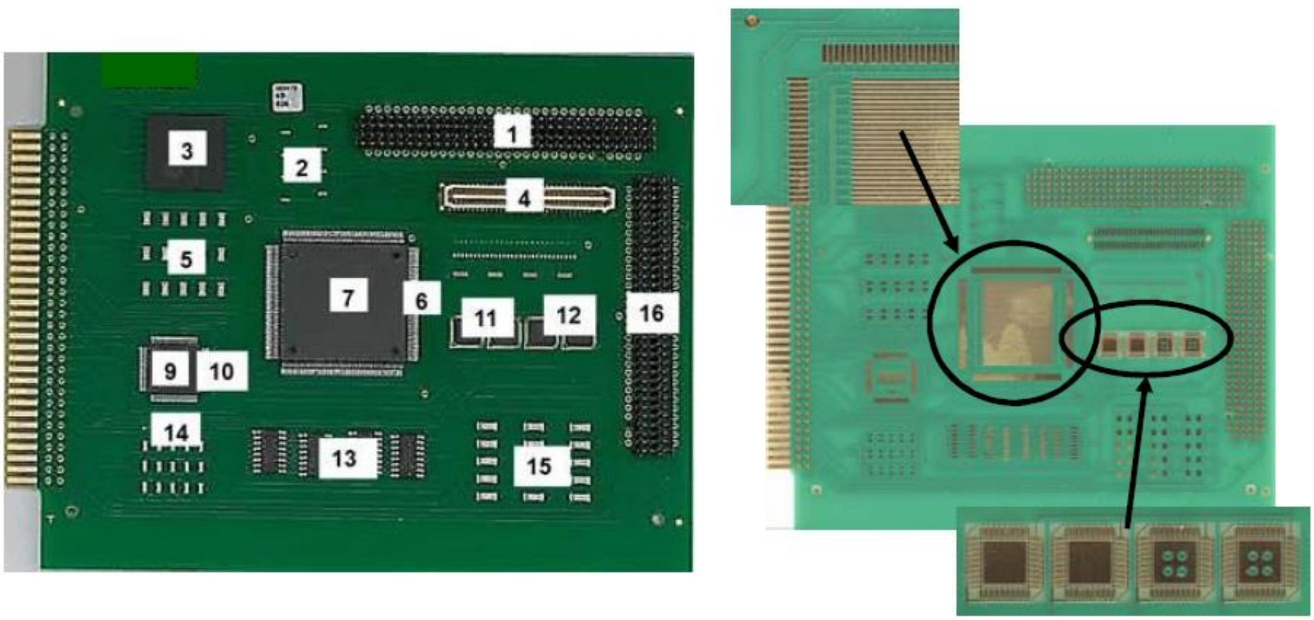



**Figure 2: Modified B-52 Test Board Example**

However, IPC-9202 and the IPC-B-52 test assembly are not the only way to generate objective evidence that assembled hardware has an acceptable residue condition. Soldering Technology International (STI) and Kyzen Corporation, in a joint venture called Magnalytix, worked on developing a series of standard test substrates and a standardized test equipment, which would allow an electronics assembler, who may not be aware of the subtleties of SIR testing, to examine aspects of their manufacturing process and thereby generate objective evidence of residue acceptability. More information on the development of those test substrates and test systems can be found in the reference section of this paper. Collins Aerospace has served as a beta test site for these alternate test vehicles and for the custom SIR test system, outlined in this paper.

## Goals of the Research

One key consideration for all of these SIR test systems is the cost of an assembled test vehicle. In many cases, especially for small volume shops, an expensive test assembly limits the amount of testing that can be done. One of the high-cost drivers of an IPC-B-52 test assembly is the custom mechanical dummy (MD) parts. Could a more economical component be used in place of the MD parts, while giving comparable performance to the industry standard IPC-B-52 MD performance?

There were four goals identified for this joint research:

1. Do test cards, all other factors being equal, processed with the laminate dummies (LD) provide the same SIR performance as test cards processed with the mechanical dummies?
2. Can the SIR test system distinguish between LD and MD?
3. Can the laminate dummies serve as a cost-efficient replacement for the mechanical dummies on the IPC-B-52?
4. Can the Magnalytix B-52 Legacy 1 test assembly serve as an acceptable alternative to the IPC-B-52 test assembly?

To address these questions, the Magnalytix B-52 Legacy 1 test card was designed and is shown as Figure 3.

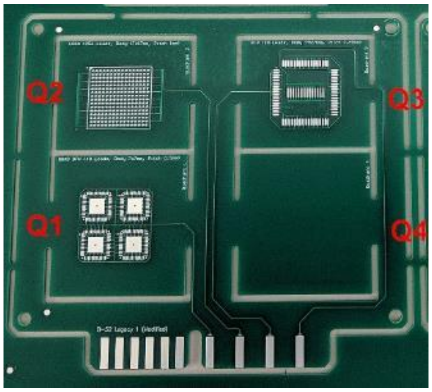



**Figure 3. B52 Legacy 1 Card**

This test card was single-sided, 0.062 inches thick multifunctional FR-4 laminate, with an IPC-SM-840 Class H qualified solder mask. The surface finish was immersion silver.

The test patterns in Quadrant 1 (Q1) were used in previous research that characterized SIR performance under BTCs. The test pattern in Quadrant 2 (Q2) was identical to the ball grid array (BGA) test pattern on the IPC-B-52 test assembly. The two test patterns in Quadrant 3 (Q3) were identical to the QFP80 test pattern and the comb pattern under the QFP80, found on the IPC-B-52 test assembly. There was no active circuitry or components in Quadrant 4 (Q4). These test boards were fabricated in a 4-up panel by a qualified fabricator.

SIR test data is geometry dependent. Therefore, having patterns that exactly duplicate the geometry of the B-52 patterns should produce equivalent SIR performance.

The MD components, with no internal dies or wire bonds, were readily obtained from vendors who provide these parts. Figure 4 shows the top side and board side of the mechanical dummies (top row) and the laminate dummies (bottom row). The laminate dummy concept was to build non-electrical mechanical representative dummy parts that can be low-cost substitutes, which replicate the cleanliness state of actual parts for SIR test evaluation and validation.

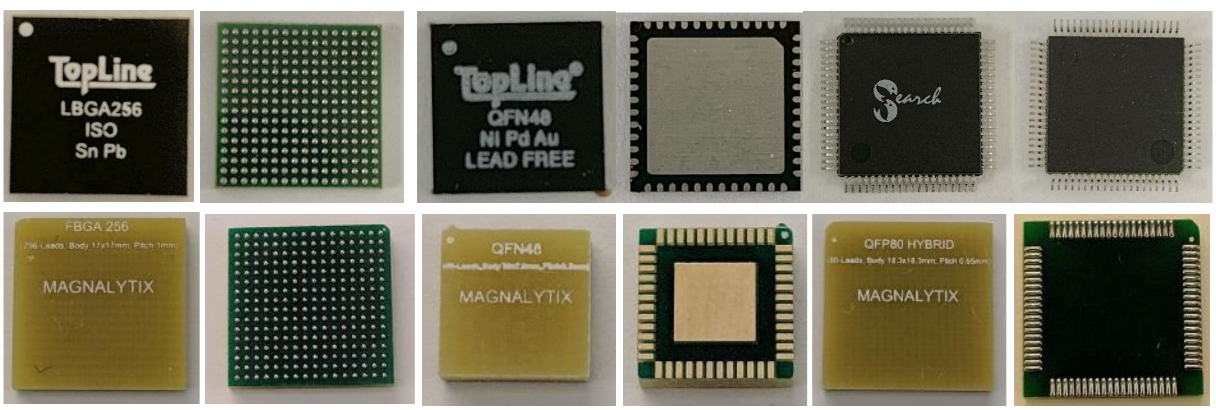



**Figure 4. Laminate Based Dummies**

The design concept was to create a dummy standoff height, which replicated actual component standoffs, allowing for SIR testing that would replicate real world conditions. Additionally, if the standoff heights of the laminate dummies could be made slightly less, creating a tougher cleaning challenge, then SIR testing would show a worse case condition. Example: if SIR data showed you can adequately clean under a component with an 8 mil standoff, then it could be assumed that you can clean adequately under the same component with a 10 mil standoff. This kind of component standoff "tailorability" would open up the test vehicle and SIR testing to test new scenarios not possible with stock mechanical dummies. However, for this to occur, all dynamics of the laminate dummy would need characterization. This research centered on such characterization.

**Component Details**

Mechanical Dummy Components

- Topline FBGA 256 (1mm pitch) – Mechanical Dummy - – 17 mm x 17 mm ( .672 x .672) 1.240 grams / .040 ounces – 1st build - .016 z –axis ball height / 2nd build .016 z-axis ball height
- Topline QFN 48 (.5 MM PITCH) – Mechanical Dummy - 7.0 mm x 7.0 mm (.275 x .275 ) .127 grams / .0044 ounces – 1st build no z-axis bump / 2nd build no z-axis bump in height
- Search QFP 80 (.65MM PITCH ) – Laminate Dummy – Magnalytix – 18mm x 18 mm ( .685 x .685 ) .922 grams / .032 ounces – 1st build .010 z-axis lead height / 2nd .010 z –axis lead height

Laminate Dummies (from Magnalytix)

- FBGA 256 ( 1 MM PITCH) - Laminate Dummy – Magnalytix – 17 mm x 17 mm ( .672 x .672) 1.438 grams / .050 ounces – 1st build - .007 z –axis ball height / 2nd build .012 z-axis ball height
- QFN 48 (.5 MMPITCH )– Laminate Dummy – Magnalytix – 7.5 mm x 7.5 mm (.300 x .300) .271grams / .0095 ounces – 1st build no z-axis bump / 2nd build no z-axis bump in height
- QFP 80 (.65MM PITCH ) – Laminate Dummy – Magnalytix – 18mm x 18 mm ( .715 x .715) 1.533 grams / .053 ounces – 1st build .005 z-axis bump / 2nd .009 z –axis bump in bump height

There were two rounds of experimentation performed in this evaluation. Round 1 testing involved early designs of the laminate dummies, resulting in a lower overall standoff height. Round 2 testing involved a subsequent design that had a higher standoff to improve cleanability. The standoff height of the QFN components was consistent between Round 1 and Round 2 testing.

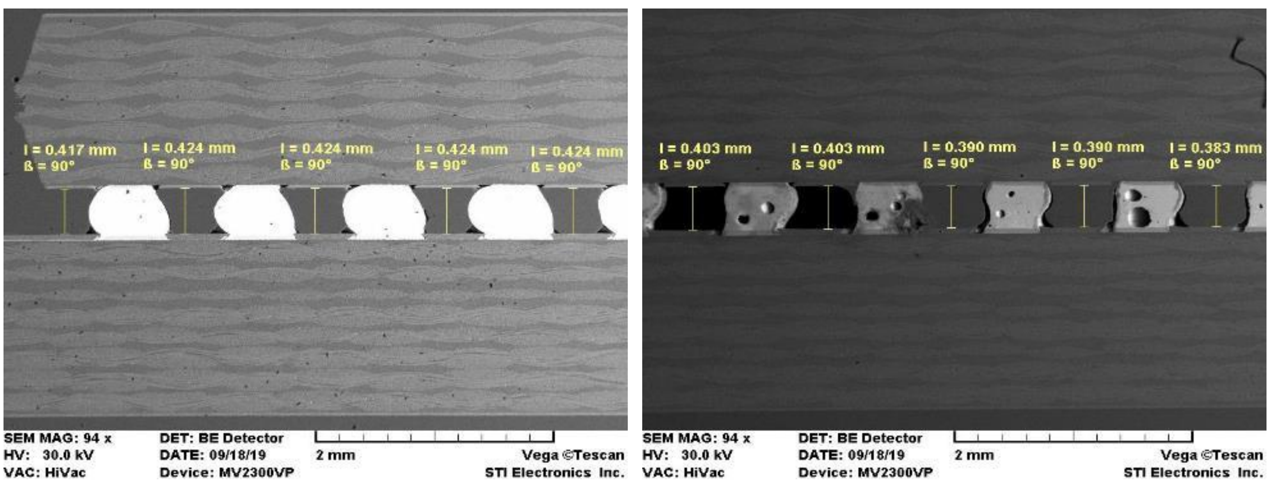



**Figure 5. Standoffs – Topline BGA (left), Magnalytix Laminate BGA (right)**

Figure 5 shows a comparison between the Topline FBGA with a standoff of 0.423 mm (16.7 mils) and the Magnalytix laminate dummy BGA (from Round 1) with a standoff of 0.394 mm (15.5 mils). The Topline standoff was consistent between Round 1 testing and Round 2.

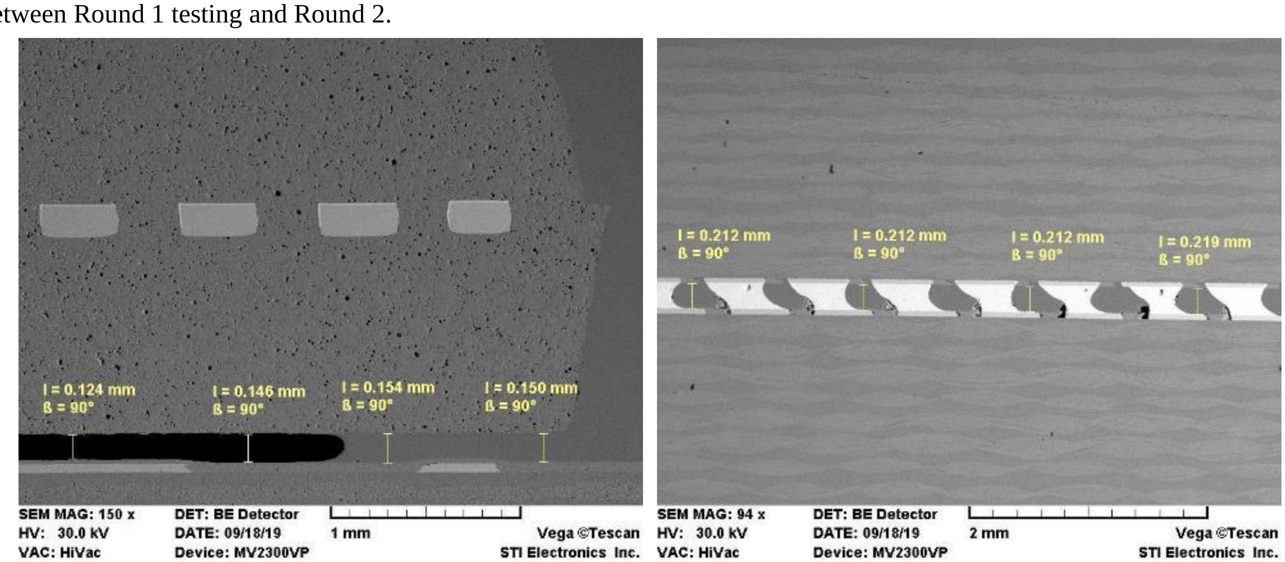



**Figure 6. Standoffs – Search QFP80 Topline (left), Magnalytix Laminate QFP80 (right)**

Figure 6 shows a comparison between the Search QFP80 mechanical dummy with a standoff of 0.144 mm (5.7 mils) and the Magnalytix laminate dummy QFP80 with a standoff of 0.214 mm (8.4 mils) (Round 2).

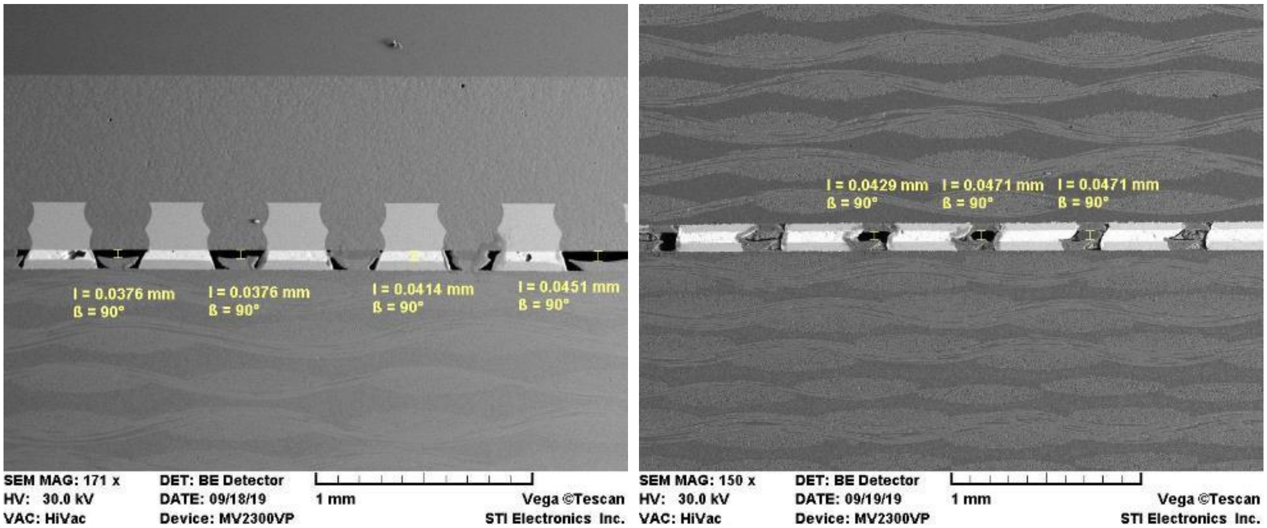



**Figure 7. Standoffs – Topline QFN48 (left), Magnalytix Laminate QFN48 (right)**

Figure 7 shows a comparison between the Topline QFN48 mechanical dummy with a standoff of 0.0404 mm (1.6 mils) and the Magnalytix laminate QFN48 with a standoff of 0.0457 mm (1.8 mils) (Round 2).

**Experimental Design**

Run 1 of the test program was designed to be a screening experiment. Ten of the four-up panels of test cards were fabricated by a Collins Aerospace qualified board fabricator. The following shows the use of the panels.

- Panel 1: Used for setup for manufacturing
- Panel 2: No components - Used for ion chromatography validation
  - Two cards tested for initial cleanliness using ion chromatography
  - Two cards segmented out to serve as an unprocessed controls for SIR testing
- Panels 3-5: Test cards manufactured with the standard Collins Aerospace tin-lead process, using the mechanical dummies in Quadrants 1-3, cleaned with the standard Collins Aerospace in-line saponified cleaning process. The expected yield was 12 test cards.
  - Seven test cards (with no electrical shorts) for SIR testing
  - Three test cards (can have shorts) for ion chromatography testing per IPC method 2.3.28
  - Two manufactured assemblies retained as spares for possible rework simulations
- Panels 6-8: Test cards manufactured with the standard Collins Aerospace tin-lead process, using the laminate dummies in Quadrants 1-3, cleaned with the standard Collins Aerospace in-line saponified cleaning process. The expected yield was 12 test cards.
  - Seven test cards (with no electrical shorts) for SIR testing
  - Three test cards (can have shorts) for ion chromatography testing per IPC method 2.3.28
  - Two manufactured assemblies as spares for possible rework simulations
- Panels 9-10: Reserved for future use

While ion chromatography was performed as part of this experiment, the IC data will not be presented in this paper but will be the focus of a follow-on paper.

Seven IPC-B-52 Rev B test assemblies, which had been previously manufactured using the same standard Collins Aerospace tin-lead process, were taken from inventory for testing. The assemblies were included to give a direct comparison between the Magnalytix test cards and the same B-52 test patterns.

**Assembly Processes**

All test processing was done in the Collins Aerospace Coralville Iowa Common Process Center using qualified manufacturing processes.

- The solder paste used for these test cards was a qualified J-STD-004 ROL0 low residue (no-clean) tin-lead solder paste.
- The solder paste was applied using a 0.005 inch (5 mil) thick stainless steel stencil which had been precleaned.
- Solder paste deposits were examined using a Koh-Young instrument prior to component placement.
- All components were machine placed using Universal pick and place equipment. All components had been previously loaded into tape and reel format. It was observed that the laminate dummies did not place as easily as the mechanical dummies.
- After component placement, the test assemblies were reflowed in a Heller oven using the tin-lead reflow profile shown in Figure 8. This is a fairly common reflow profile for tin-lead solders.

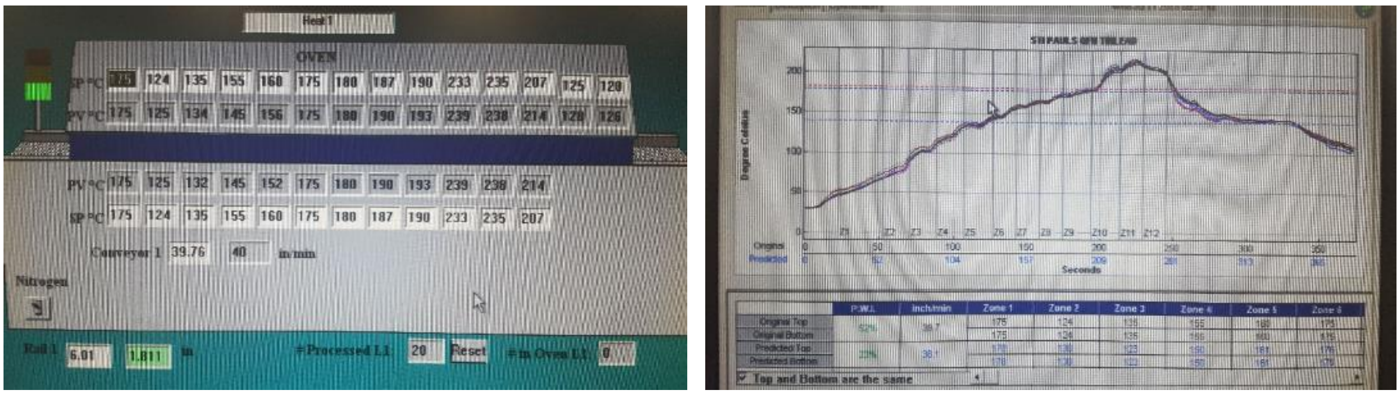



**Figure 8. Tin-Lead Reflow Profile**

- Test cards were tested for electrical shorts prior to aqueous cleaning using a digital multimeter.
- Following reflow, all test cards were run through an Electrovert Aquastorm 200 in-line aqueous cleaner using Kyzen Aquanox 4625A saponifier. The cleaning parameters were kept the same as for all production hardware.
- Following cleaning, all test boards were placed into clean polyethylene cleanroom bags and sealed until ready for testing.
- Individual test cards were removed from the panel using a Dewalt scroll saw outfitted with jewelers' blades. All surfaces were wiped down with isopropanol between segmenting activities. Individual test cards were again checked for electrical shorts prior to testing. All cards were blown clean of dust using clean ionized air. All boards were handled with nitrile-gloved hands.
- Pictures of the manufactured test cards are shown in Figure 9.

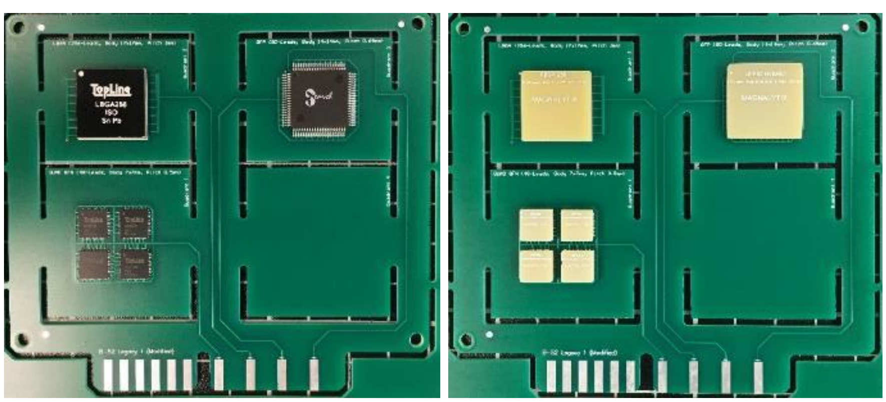



**Figure 9. MD Card (left), LD Card (right)**

**SIR Test Procedure – Round 1**

The Magnalytix SIR test system is shown in Figure 10. The system consists of a programmable switching matrix, a programmable power supply, a programmable electrometer, shielded cabling, a test fixture, and custom software.

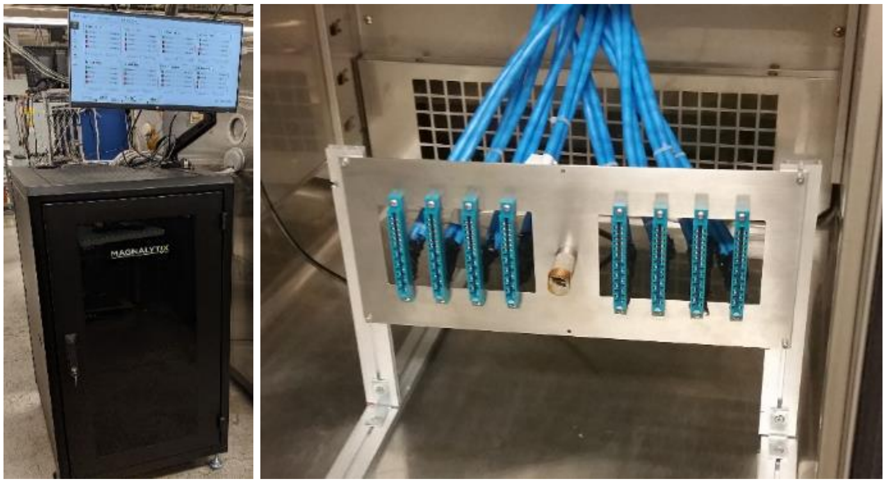



**Figure 10. Magnalytix SIR Test System**

Prior to SIR testing, the fixture and system were validated using test cards with known value resistors, encased in resin. The test fixture is shown in Figure 10. These cards have resistors of 1E6 ohms (1 megohm), 1E7 ohms (10 megohms), 1E8 ohms (100 megohms), and 1E9 ohms (1000 megohms). These cards were measured frequently over a 48 hour period at ambient conditions and all test channels showed consistent values at the expected levels. This fixture can hold eight test cards at one time. The testing was split into two test runs (A and B):

- Run A: (1) unprocessed control; (3) mechanical dummy cards; and (4) laminate dummy cards
- Run B: (1) unprocessed control; (4) mechanical dummy cards; and (3) laminate dummy cards

Collins Aerospace has a similar system based on a Gen3 Systems Ltd. AutoSIR256, automated high resistance data logger. This system was used to SIR test the IPC-B-52 assemblies. This system was similarly validated using test cards with known 1E11 ohm test cards. This system and fixture can test 16 IPC-B-52 test assemblies at one time. All seven processed B-52 test boards were tested in one run.

For both systems, the test cards were inserted into the edge card connectors inside an Espec programmable temperature-humidity chamber. The chamber door was closed and the chamber allowed to come to 25°C / 50% relative humidity (RH). Initial resistance measurements were made using the following parameters:

- 3 measurement sets, 15 minutes apart
- 10 volts DC measurement voltage
- 10 volts DC bias voltage (voltage applied between measurement sets)

After the initial measurement sets were completed, the chamber was ramped to a 40°C / 90% RH condition over the course of 15 minutes. Measurements were taken every 20 minutes, using the parameters listed above, for a period of 168 hours (7 days). After the final measurement set, the chamber was returned to 25°C / 50% RH conditions and a final set of ambient measurements were taken, as done with the initial measurements, one hour after the chamber returned to the 25°C / 50% RH conditions. This is the SIR test protocol set forth in IPC-9202.

The IPC-B-52 test assemblies were tested in the same manner as the Magnalytix boards.

The test data from all tests were imported into Microsoft Excel spreadsheets for graphing and into Minitab for statistical analysis.

Following SIR testing, the test cards were removed from the humidity chamber, photodocumented, and analyzed for residues using ion chromatography (reported separately).

## SIR Test Results – Round 1

This kind of testing generates huge amounts of raw data, making it a challenge to accurately outline the SIR performance or make comparisons between test groups. It is a common industry practice to show SIR data graphically, as shown in Figure 11. The Y-axis in each chart is the base-10 logarithm of the measured resistance (commonly called LogOhms), 6.0 = $1x10^6$ ohms = 1 megohm, 8.0 = $10^8$ ohms = 100 megohms, etc. The X-axis for each chart is the number of measurement sets at the 40°C / 90% relative humidity (RH) test conditions. The X-axis represents seven days of test exposure.

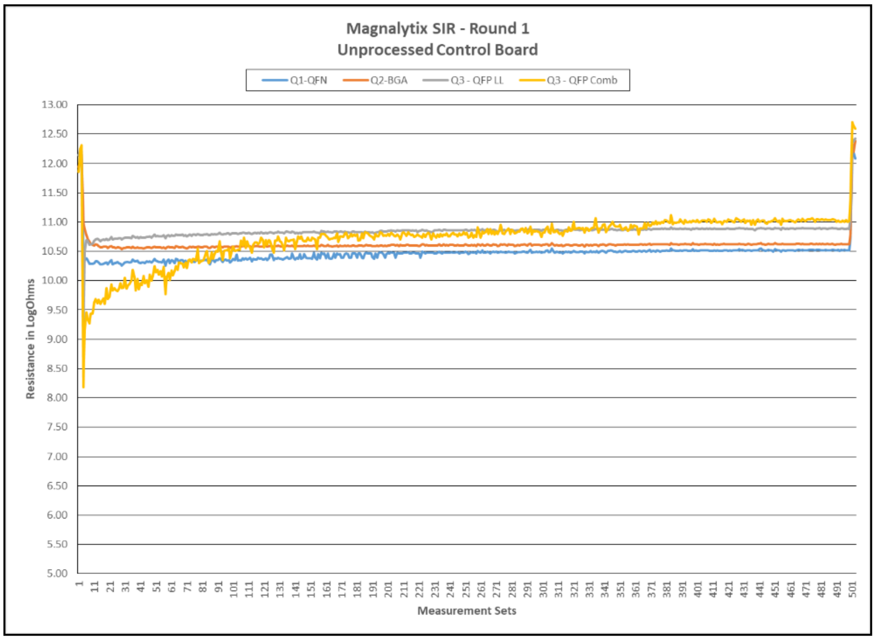



**Figure 11. Example SIR Chart**

Figure 11 shows the SIR levels for the unprocessed control card (no components, no processing) for the first SIR test run (Run A). Overall, the observed SIR levels were desirably high (above 10 LogOhms) indicating that the bare boards were adequately clean to begin with. An unprocessed control card was included with each SIR test run.

## What is a "Good" SIR Number?

When viewing SIR data, a common question asked is "what is a good or acceptable number"? That is a difficult question to answer as there is no "universal" number determined to divide acceptable from unacceptable performance, and since SIR test data is also dependent on the geometry of the test electrodes, the data will vary by test pattern. Consider the chart shown in Figure 12, taken from previous research [2].

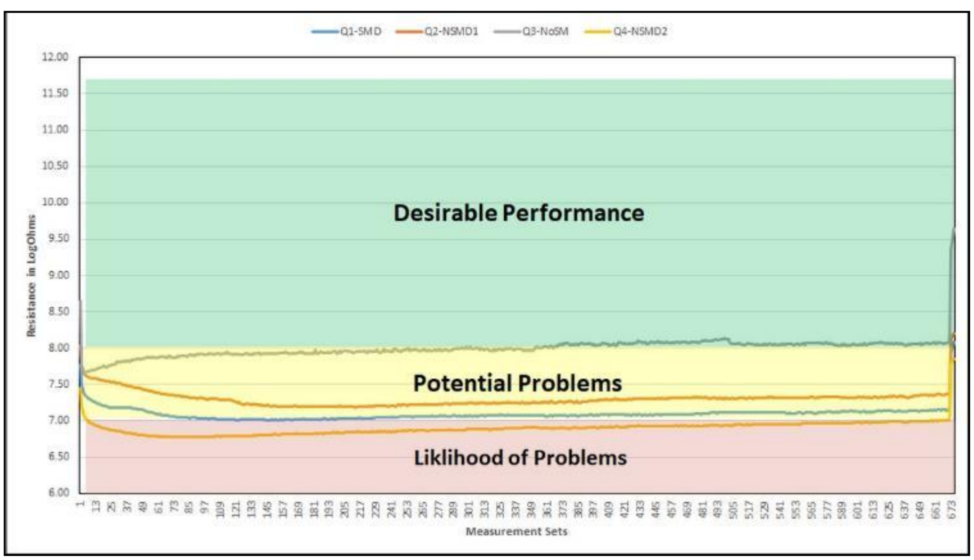



**Figure 12. Evaluating SIR Levels**

Figure 12 is based on experience with the IPC-B-52 test assembly, which has 14 different SIR test patterns of varying configuration. IPC-9202 calls out a minimum SIR value (at 40/90 conditions) of 100 megohms (8.0 LogOhms) for all test patterns, regardless of test pattern configuration. For some applications, observed resistance levels in the 7-8 LogOhm range may be acceptable, but the risk of electrochemical failures increases as the overall SIR levels decrease. The author's experiences are that resistance values below 7.0 LogOhms represent a higher risk of electrochemical failure mechanisms. Since the goal of the research was to examine the SIR performance of alternate component configurations, the structure of Figure 12 is used for viewing the generated SIR test data.

**BGA Comparisons**

Figure 13 shows the SIR performance of the seven BGA test patterns from the IPC-B-52 test boards, which used the mechanical dummies (MD), over the course of the seven-day exposure to 40°C/90% RH conditions.

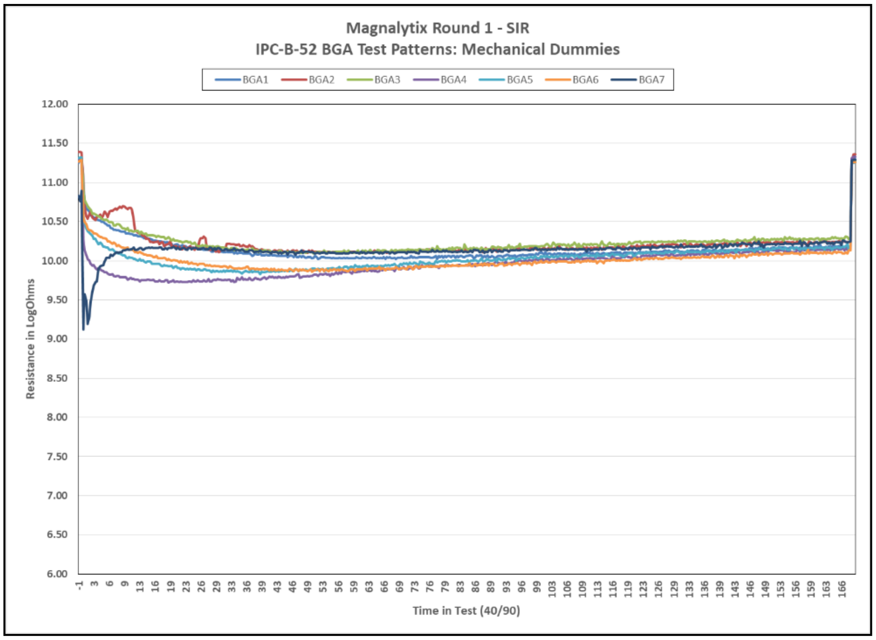



**Figure 13. B-52 BGA Test Pattern SIR**

For the data shown in Figure 13, the most variability is observed in the first 24 hours of testing, which is not unusual for SIR test data. During this time, the residues are coming to an equilibrium condition as moisture from the surrounding air is absorbed by flux residues or other process residues. The data showed relatively consistent performance for the seven test patterns after 24 hours. Overall, the SIR levels were above 9 LogOhms (1 gigohm), which was desirable.

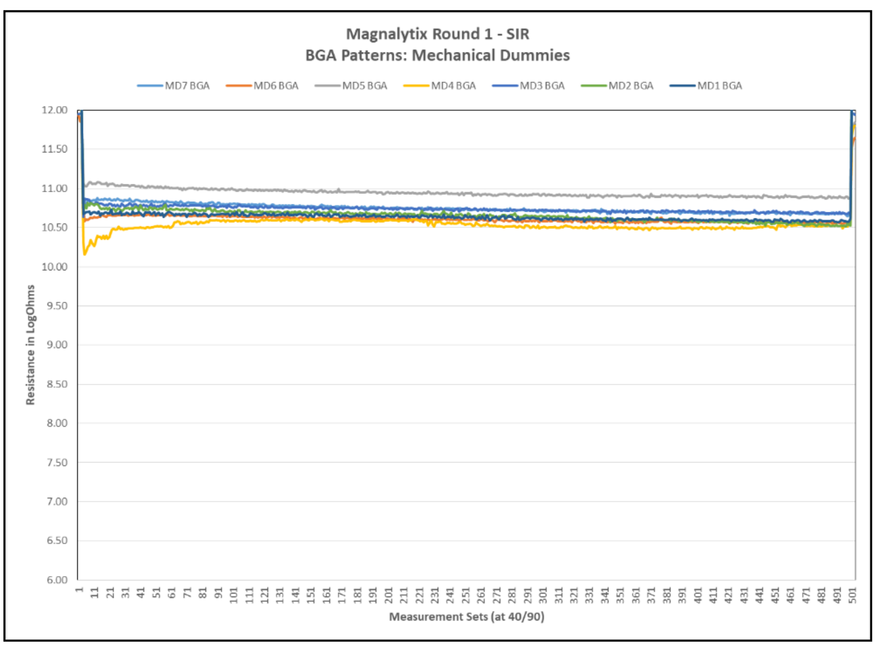



**Figure 14. B-52 Legacy Card – BGA MD SIR**

The data in Figure 14 shows the BGA test pattern translated to the Magnalytix B52 Legacy Card, manufactured with mechanical dummies. IPC-9202 does not differentiate by a supplier for mechanical dummies, so the SIR performance should be the same as for the B52 board, which also used mechanical dummies, though from a different supplier. Overall, the SIR levels were above 10 LogOhms (10 gigohms) and were comparable to those observed for the B52 BGA test patterns.

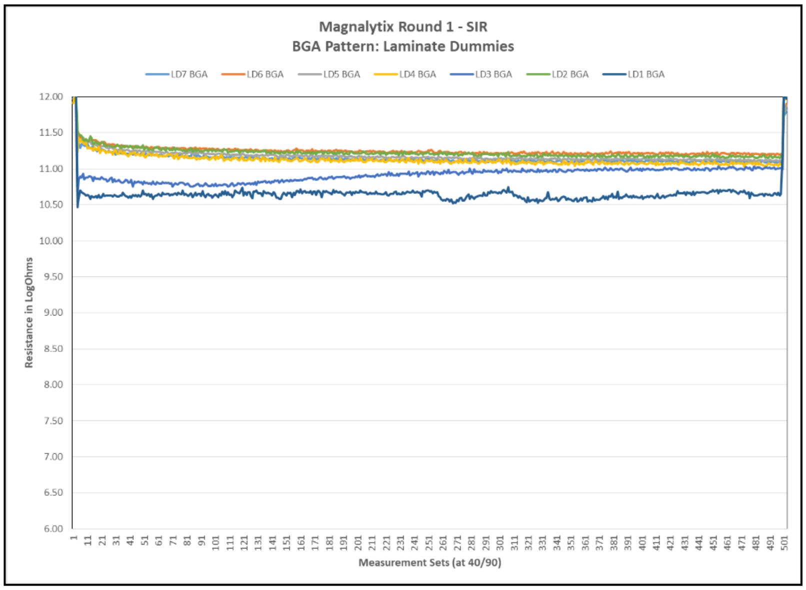



**Figure 15. B-52 Legacy Card – BGA LD SIR**

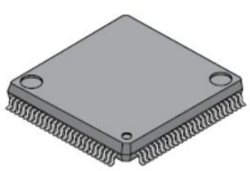
The data in Figure 15 shows the BGA test pattern translated to the Magnalytix B52 Legacy Card, manufactured with laminate dummies. While the observed SIR performance was slightly more variable than that noted for the mechanical dummies, the overall SIR levels were above 10 LogOhms (10 gigohms) and were comparable to those observed for the IPC-B-52 BGA test patterns.

**Conclusions for BGA Test Patterns**

Laminate dummies (LD) give comparable and consistent performance to mechanical dummies (MD) for the BGA test pattern, with both configurations running slightly higher than 10.5 log ohms. It may be concluded that laminate-based dummies are an acceptable substitute for the true mechanical dummies for the BGA testing.

**QFP80 Lead-Lead Comparisons**

Figure 16 shows the SIR performance of the seven QFP Lead-Lead test patterns for the IPC-B-52 assembly, which used the mechanical dummies (MD), over the course of the seven-day exposure to 40°C/90% RH conditions. One of the QFP patterns showed a dramatic difference from the rest, but the remaining six samples showed good agreement.



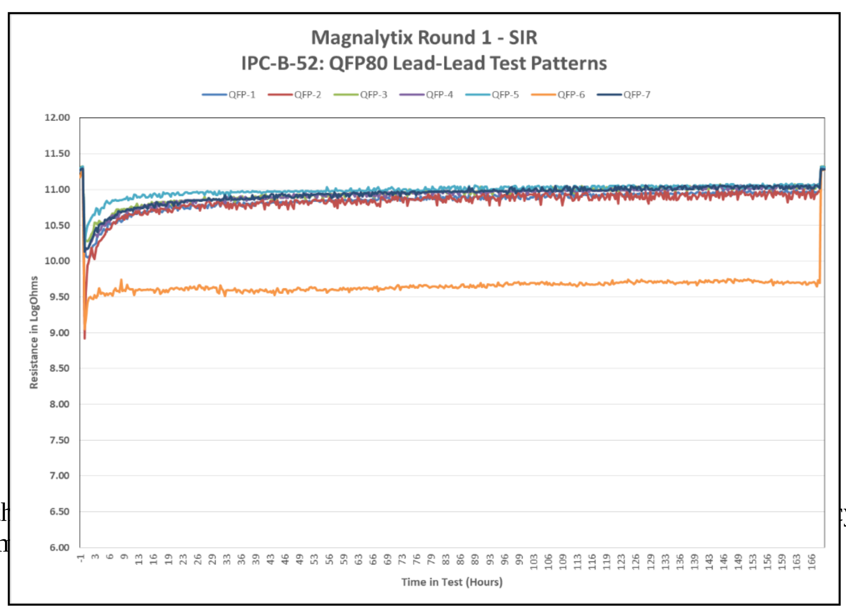



**Figure 16. B52 QFP L-L Patterns**

Figure 17 shows the results for th … y Card, and manufactured with mechanical dum … Of the three data lines showing lower SIR levels, two were from SIR Run A and one from Run B, so it is unlikely that the lower SIR values observed were due to the test chamber.

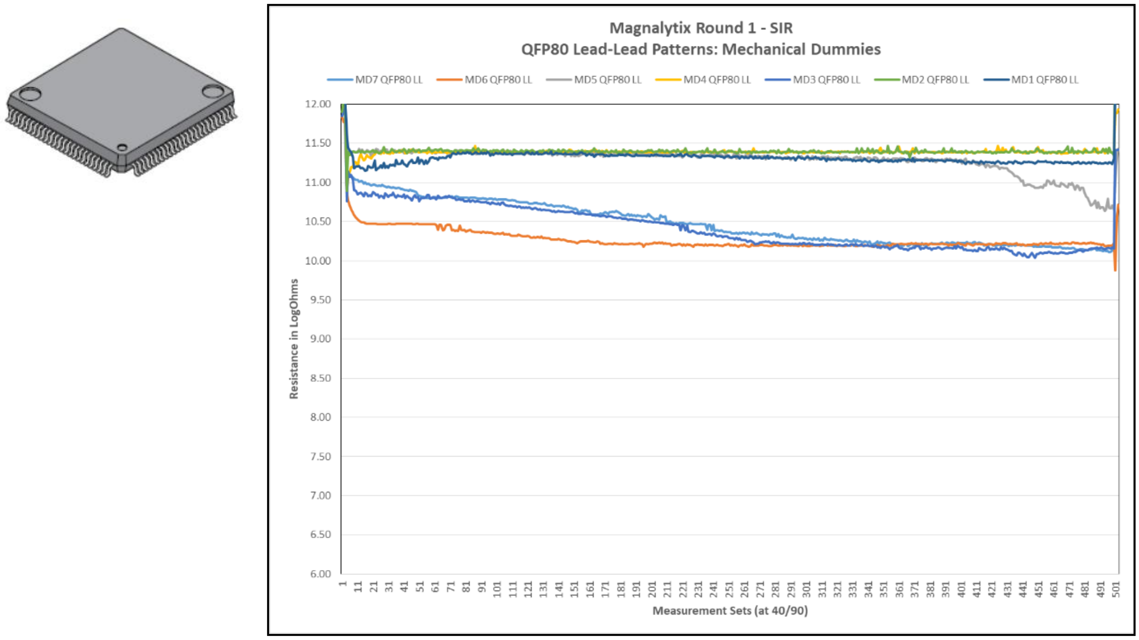



**Figure 17. B52 Legacy Card – QFP80 LL MD SIR**

Figure 18 shows the SIR results for the laminate QFP80 component. Insulation resistance was 4-6 decades lower than the mechanical dummy. The data finds that the laminate OFP80 dummy is not a good match to the mechanical OFP80 dummy. The mechanical dummy is constructed with leads extending from the component body. The laminate dummy is constructed with lands stencil printed lands under the body of the component. The SIR finds that the laminate dummy is significantly harder to clean than the mechanical dummy. The component acts more like a QFN with the tight pitch between the lands bridging and trapping flux residues under the bottom termination.

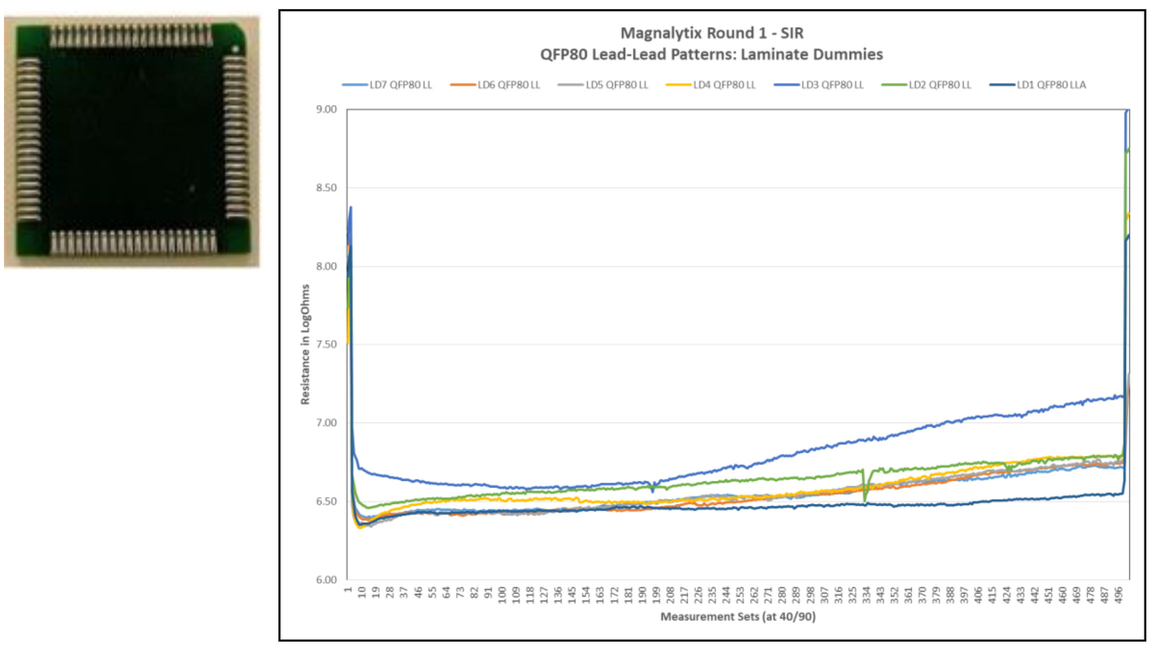



**Figure 18. B52 Legacy Card – QFP80 LL LD SIR**

## QFP80 SIR Comb Comparisons

Figure 19 shows the SIR performance of the seven QFP80 comb test patterns, which used the mechanical dummies (MD), over the course of the seven-day exposure to 40°C/90% RH conditions.

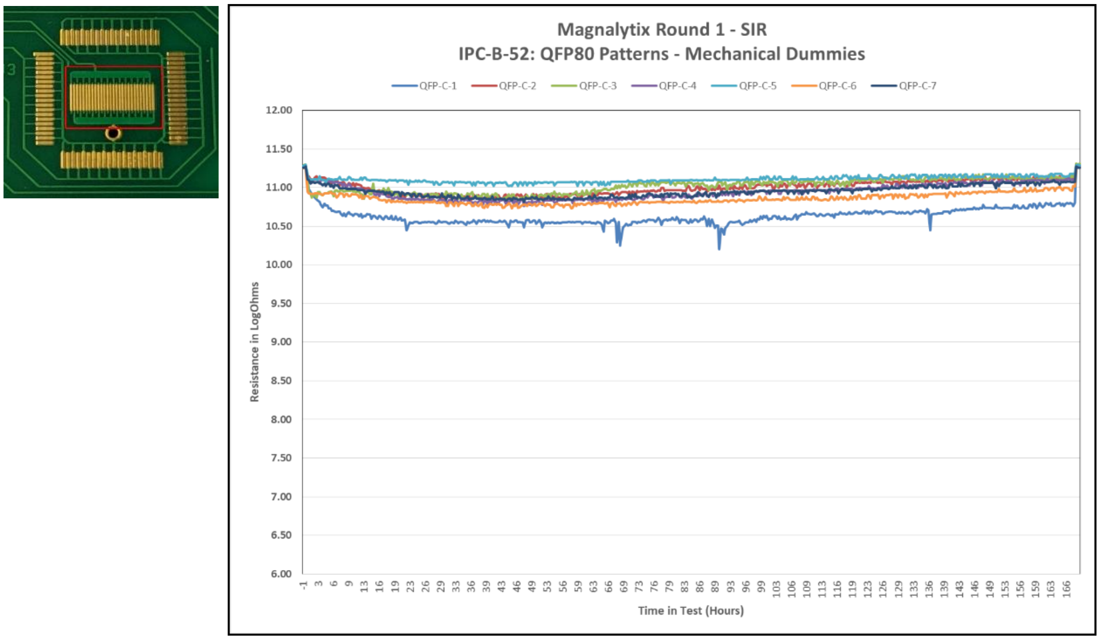



**Figure 19. IPC-B-52: QFP80 Comb – Mech Dummies**

## Comparison QFP80 Combs

The SIR insulation resistance of the SIR Comb patterns located under the body of the component on the mechanical dummies ranged from 11-12 LogOhms.

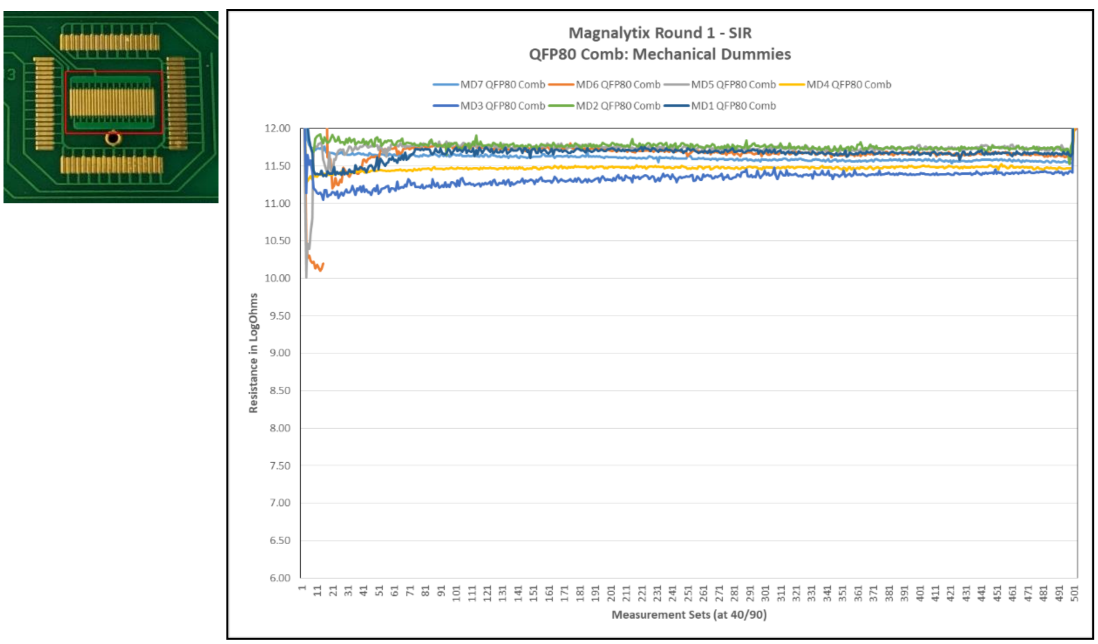



**Figure 20. QFP80 Comb - Mechanical Dummies**

The SIR insulation resistance of the SIR Comb patterns under the component on the laminate dummies ranged from 10-11.5 LogOhms. Some of the SIR combs were a decade lower. The laminate dummy data indicates that this component is harder to rinse, which could be the reason for the lower insulation resistance values.

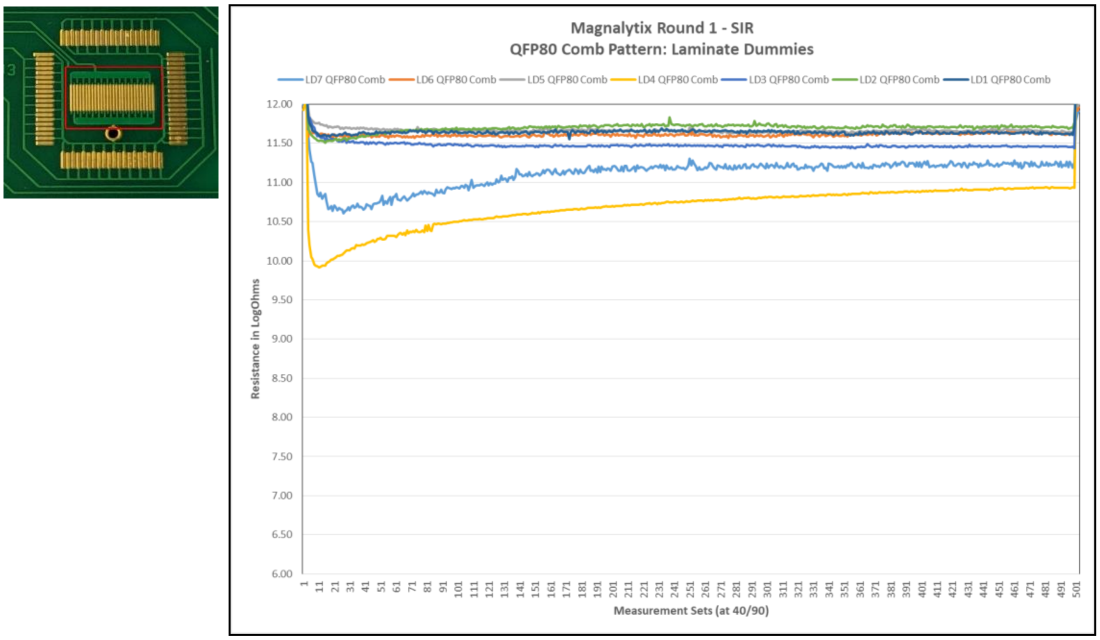



**Figure 21: QFP80 Comb - Laminate Dummies**

## Conclusions for QFP80 Test Patterns

The QFP 80 comb pattern showed good correlation with the true mechanical dummy (MD) averaging 11.5 log ohms vs the laminate dummy (LD) averaging 5 out of 7 readings at 11.5 and 2 readings out of 7 averaging 11 log ohms. The LD was slightly more difficult to clean under for the comb pattern than the true mechanical dummy. The real disconnect ( lack of correlation) came on the lead to lead SIR value between the true mechanical QFP 80 dummy component – 11 log ohms vs. the LD QFP 80 - 6.8 log ohms where the results were drastically different. This is believed to be caused by the z axis height of the LD having a ceiling over the leads whereby the true mechanical part does not have anything above the leads, thus the part is significantly more difficult to clean as evidenced by the SIR results. This study found a weak link in the design of QFP parts due to its lead configuration being non-obstructed when out gassing or in cleaning applications. Phase 2 looks at increasing the z axis height from 4 mils to 8 mils for resolving this design difference between true mechanical dummy QFP 80 vs the LD QFP80. The idea was to create laminate dummy components that replicate their true mechanical dummy counterparts. The research team is considering design changes for the laminate dummies that render cleaning results comparable to the mechanical dummies. These design options will be presented in a follow-on research paper.

## Comparison of QFN Patterns

The IPC-B-52 test assembly does not have a QFN test pattern, so a direct correlation to a B52 board is not possible. A comparison of the QFN mechanical dummy to the QFN laminate dummy is presented in Figure 22. There were higher levels of variation across the test boards assembled with the mechanical QFN dummies. The laminate dummies were more consistent across the test boards.

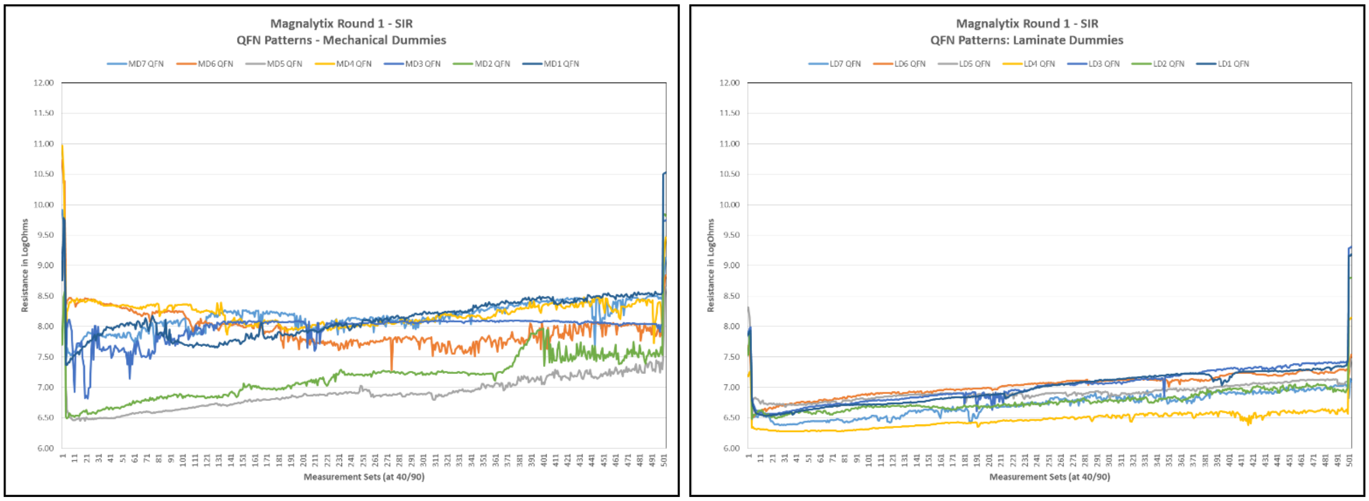



**Figure 22. Comparison of MD and LD QFNs**

**Conclusions for QFN48 Test Patterns**

The true mechanical QFN component was close with the SIR laminate dummy component being more difficult to clean than its true mechanical dummy part by 1 decade – i.e. (The average between LD QFN was 7 log ohms vs True Mechanical Dummy QFN was 8 log ohms). QFN 48 results were close with the LD part being more challenging to clean than their true mechanical counterpart with a one decade drop lower than the actual part. This is not a bad thing because it shows worst-case and ensures a greater understanding of the cleaning process which gives a higher design margin in the process.

**Round 1 Boxplots**

Box and Whisker plots, also called Boxplots, are useful graphical tools for displaying a data population's level and distribution. An example is shown in Figure 23.

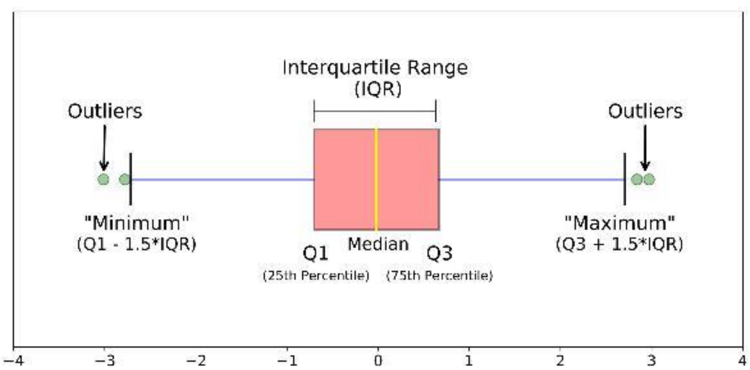



**Figure 23. Boxplot Example**

A useful function of a Boxplot is that two data populations can be compared, and for most situations, statistical difference can be determined from the plots. An example is shown in Figure 24. In the plot on the left, the median line of Box B does not overlap Box A. The two populations are significantly different. In the plot on the right, the two populations do overlap, so the two populations are not significantly different.

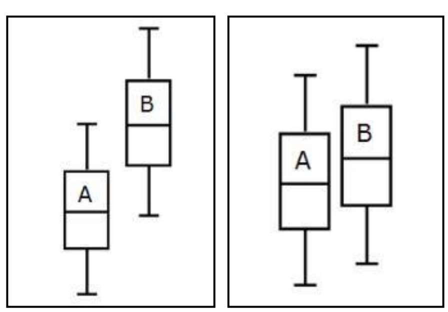



**Figure 24. Boxplots**

As indicated earlier, this kind of SIR testing generates vast volumes of raw data. How then, are two SIR data populations, such as Laminate Dummies (LD) and Mechanical Dummies (MD) to be compared? For this evaluation, the authors chose to examine the SIR levels at four different points in time: 8 hours, 24 hours, 96 hours, and 160 hours of exposure to the 40°C/90% relative humidity test conditions. However, the amount of data at precisely 8 hours (for example) was not extensive. To give a greater sample size for comparison, the two measurement sets prior to the target time, and the two measurement sets after the target time (5 measurement sets total), were grouped together for analysis. An example boxplot of comparison data for 8 hours of exposure is shown in Figure 25. As with the SIR charts, the vertical axis is in LogOhms.

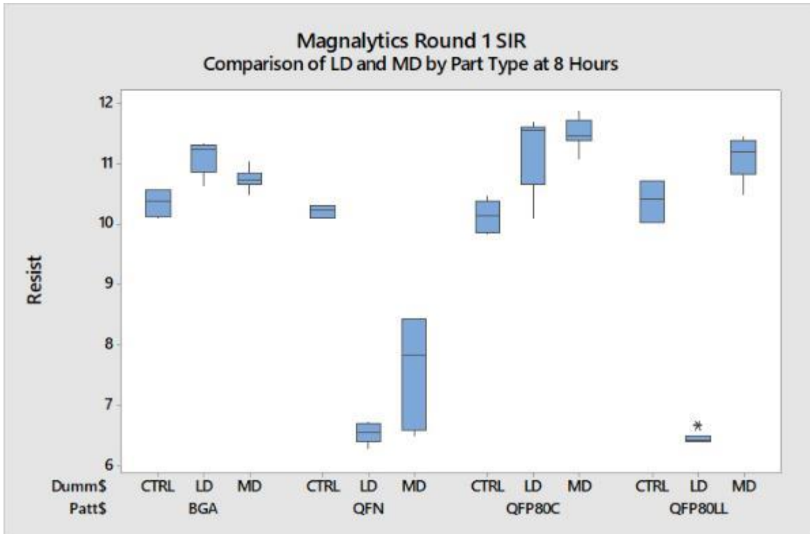



**Figure 25. Magnalytx SIR Boxplot Example**

A summary of the Box Plots finds that the FBGA has a strong correlation between the mechanical and laminate dummies. The QFN laminate dummy has an approximate decade lower insulation resistance as compared to the mechanical dummy. The QFP SIR Comb is slightly lower for the laminate dummy. The land to land comparison for the QFP 80 mechanical to laminate dummies is significantly different.

Figure 26 Box Plots show the insulation resistance as various points during the 168 hour SIR test.

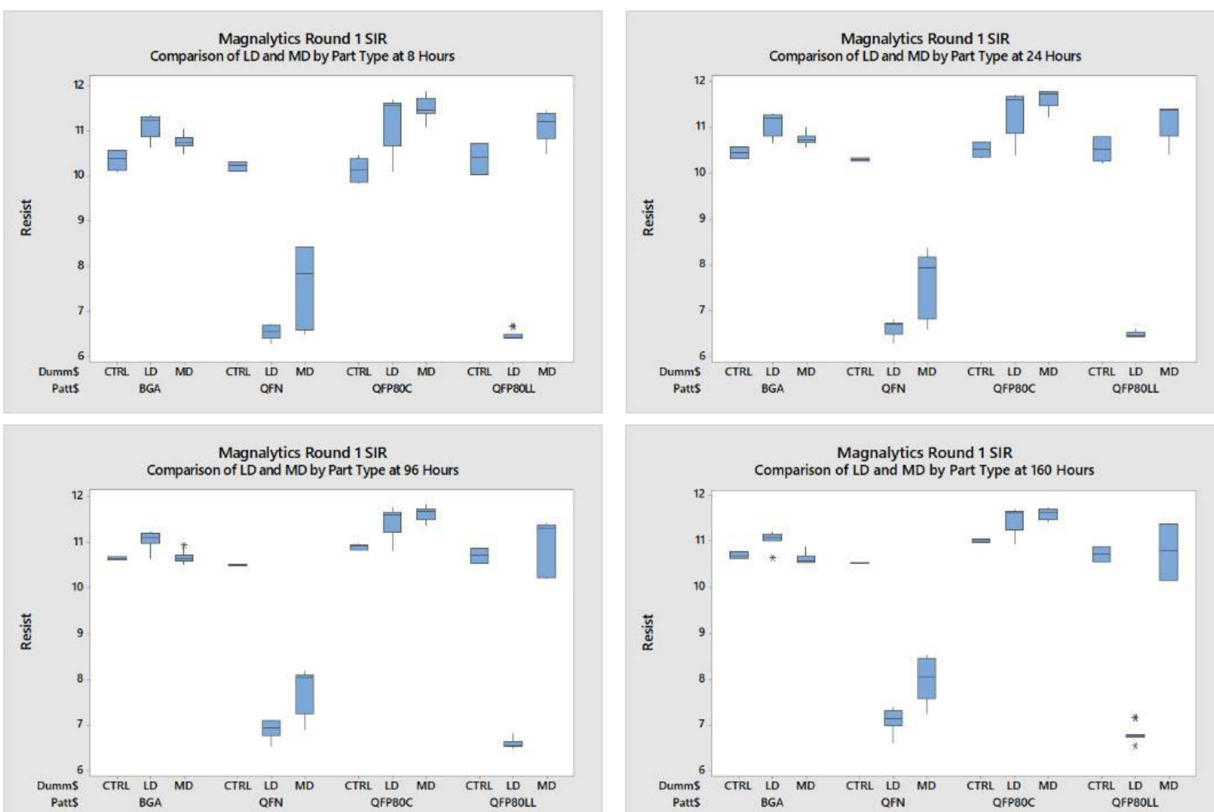



**Figure 26. Round 1 SIR Boxplots Comparing Data Groups Over Time**

Figure 26 shows that the insulation resistance values at 8 hours, 24 hours, 96 hours and 160 hours are not significantly different.

**Observations on the Boxplots – Round 1**

- FBGAs show a tight correlation between the IPC-B-52, the Magnalytix B52 MDs, and the Magnalytix B52 LDs
- QFP80 SIR comb patterns show a similar close correlation between the three data groups
- QFP80 SIR land to land test patterns show no correlation between the three data groups
- QFN48 shows a close correlation between the three data groups

**Inferences from the Data Findings for Round 1**

The most significant inference finds the effectiveness of temperature-humidity-bias testing at determining the variations in cleaning different component designs. The positive outcome is the ability to show that different components types exhibit different cleaning properties.

The data indicates that the chemical make-up of the flux residue is different as a function of standoff and solder joint/thermal lug patterns located under the component's bottom termination. Lower standoffs in combination with more soldered patterns increase the level of flux residue located under the bottom termination. There are three plausible reasons: (1) more solder points result in more flux contamination at the lands and under the bottom termination; (2) during reflow, flux that does not have a path to vent (i.e., outgas), can prevent full decomposition of solvents, activators, and functional additives formulated into the solder paste; and (3) blocking of flux outgassing channels results in residues accumulating under the bottom termination, which can result in pockets of contamination that are both ionic and active.

Temperature-Humidity-Bias SIR testing accelerates electrochemical migration

- Temperature: At 40°C, the rosin-resin oxygen barrier designed to encapsulate metal oxides and other active constituents, starts to expand and soften.
- Humidity: Mono-layers of moisture start to hydrogen bond with ionic contaminations mobilized within the flux residue. Dependent on the activity of the ionic contaminants present in the residue, this electrolyte mobilizes metal oxides present at the soldered area and within the residue.
- Bias: The positively charged metal ion is attracted to the negative pole. Leakage currents in the form of dendrites start to plate out at the cathode. These leakage currents drop insulation resistance. When the dendrite migrates from the cathode to the anode, a dead short results. During SIR testing, shorts will hit the floor (6 LogOhms). Many times these shorts will shatter, resulting in ionic movement or upward and downward spikes on that specific SIR channel.

A stable SIR channel indicates that there is minimal ionic contamination present at the channel being analyzed. This results in higher insulation resistance and less upward and downward spikes during the test period.

Applying this logic to the dummy components researched in this study, the following inferences can be made.

1. A dummy component that has a higher standoff height results in
   a. Lower levels of contamination (flux residue)
   b. Constituents in the flux residue function as designed
      i. Forms a benign residue
      ii. Activators, Solvents and Functional Additives outgas as designed
2. A dummy component that has a lower standoff height results in
   a. Higher levels of contamination (flux residue)
   b. Constituents in the flux residue does not function as designed
      i. Residue is active and pliable
      ii. With increases in temperature and humidity, ionic residues are mobilized
      iii. The contamination increases the potential for leakage currents, which reduce insulation resistance
3. FBGA mechanical dummy
   a. Standoff height was 0.424mm (16.7 mils)
   b. Flux will properly vent (outgas)
   c. Cleaning fluids can easily wet, dissolve and create a flow channel
   d. Part is easily cleaned resulting in high insulation resistance values
4. FBGA laminate dummy
   a. Standoff height was 0.403mm (15.9 mils)
   b. Flux will properly vent (outgas)
   c. Cleaning fluids can easily wet, dissolve and create a flow channel
   d. Part is easily cleaned resulting in high insulation resistance values

5. QFP80 Mechanical Dummy
    a. Leads extending from the component body on all four sides
    b. Standoff height was 0.146mm (5.7 mils)
    c. The exposed solder joint allows cleaning fluids to wet and clean the lands
    d. Part is easily cleaned resulting in high insulation resistance values
6. QFP80 Laminate Dummy
    a. Leads stencil printed on lands plated around the perimeter of the bottom side of the component
    b. Standoff height was 0.214 (8.4 mils)
    c. The pitch between lands is 0.65mm (25mils)
    d. The land dimension was 0.45 mm (17.5 mils) by 1.8 mm (71 mils)
    e. During reflow, the flux residue bridges the lands. This flux bridge blocks flow channels.
    f. The flux can be more active due to the tight pitch and bridging between lands
    g. This data indicates that this component is more challenging to clean
    h. The laminate design is significantly different from the mechanical design
    i. Component acts like a QFN in respect to cleaning
7. QFN-48 Mechanical Dummy
    a. 48 signal pins around the perimeter of the component
    b. Thermal lug is an open copper design with one thermal via at the center of the ground lug
    c. Standoff height is roughly 0.0414mm (1.6 mil)
    d. During reflow, the flux residue bridges the lands and streets between the signal pin and thermal lug
    e. QFN components are extremely hard to clean. Typically requires longer cleaning time and higher wash pressures that deflect to move the cleaning fluid under the component
    f. The mechanical dummy showed a high degree of variability across the eight boards.
    g. There was a high degree of ionic movement during the SIR test
    h. The insulation resistance was roughly a decade higher than the laminate dummy
8. QFN-48 Laminate Dummy
    a. 48 signal pins around the perimeter of the component
    b. Thermal lug is an open copper design with one thermal via at the center of the ground lug
    c. Standoff height is roughly 0.0424 (1.7 mils)
    d. During reflow, the flux residue bridges the lands and streets between the signal pin and thermal lug
    e. QFN components are extremely hard to clean. Typically requires longer cleaning time and higher wash pressures that deflect to move the cleaning fluid under the component
    f. The laminate dummy showed a low degree of variability across the eight boards.
    g. The insulation resistance was roughly a decade lower than the laminate dummy

**Round 2 Changes**

For Round 2 testing, the standoff height on the laminate QFP80 was increased from 4 mils to 8 mils. This was expected to help address the cleaning issue and improve the flux outgassing characteristics, compared to the MD QFP80.

**SIR Test Procedure – Round 2**

The Round 2 test samples were tested by Collins Aerospace using the same parameters as described earlier in Round 1. Four B52 Legacy 1 cards with laminate dummies (LD) and four B52 Legacy 1 cards with mechanical dummies were tested. There were no unprocessed controls in the Round 2 SIR testing.

Each SIR test board was first tested for the presence of electrical shorts. The device shown in Figure 27 was used to detect solder shorts across the individual SIR test patterns. This device detected bridges between the signal pin and corresponding current return path. If a short was detected, the test board was not reworked. The test board is replace by a known good test board. The shorted board was set aside for ion chromatography testing.

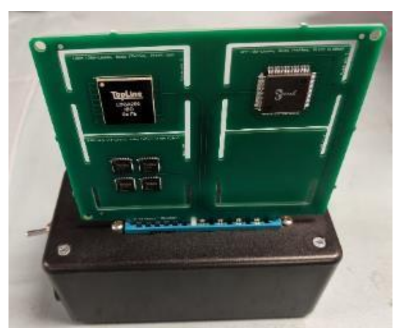


**Figure 27: Short Tester**

**SIR Test Results – Round 2**

The individual SIR plots for the Round 2 data are shown in Appendix A. Figure 28 shows a comparison of the Round 1 and Round 2 SIR testing. In Round 1, the LD standoffs were approximately 4 mils. In Round 2, the LD standoffs were approximately 8 mils. The charts show that there was an improvement in the SIR performance in Round 2, believed to be due to the increase in standoff height, which allowed better cleaning under the LD components. It should be noted that there was a reduced sample size (4) in Round 2 compared to Round 1 (7). Note also that the scales in Figure 28 are expanded compared to other charts in this paper.

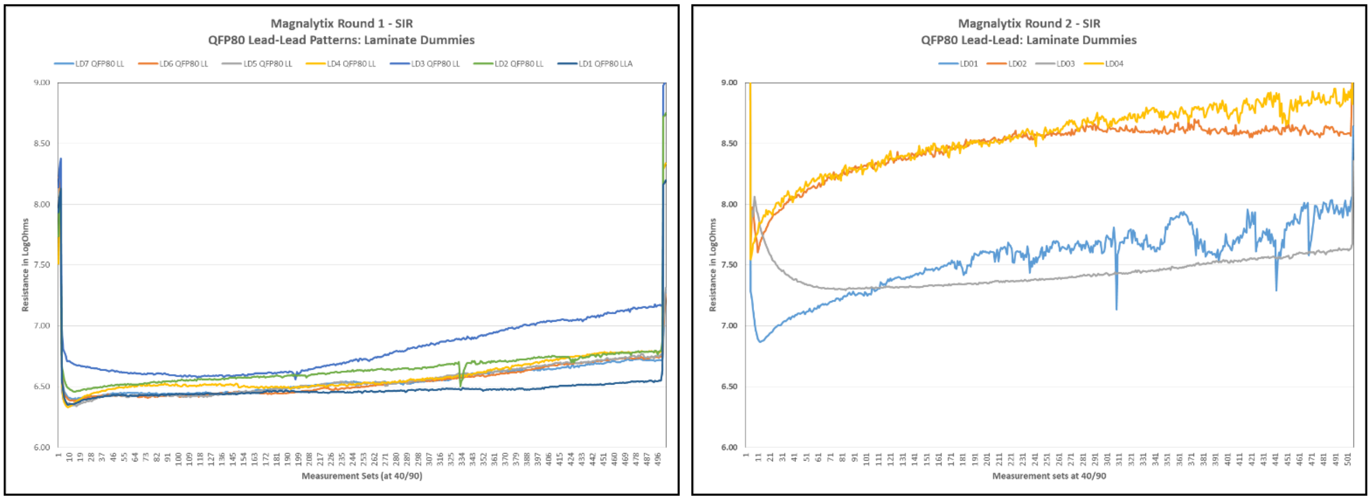



**Figure 28. QFP80 Laminate Dummies – Comparison of Round 1 (Left) and Round 2 (Right)**

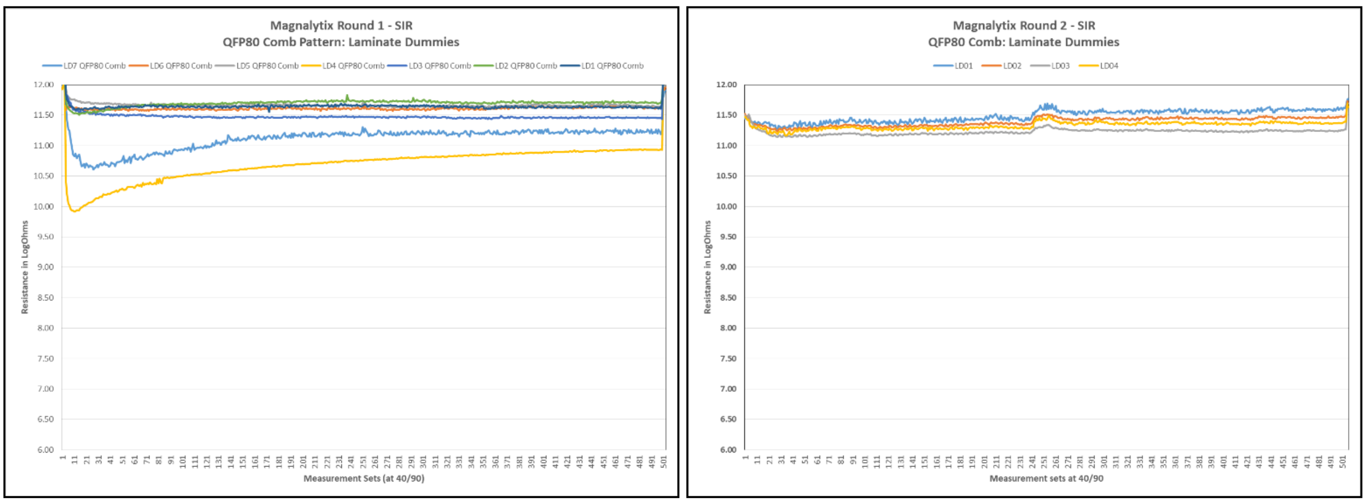



**Figure 29. QFP80 Comb - Laminate Dummies – Comparison of Round 1 (Left) and Round 2 (Right)**

Figure 29 shows a comparison between the comb patterns under the QFP80 component. The increase in standoff height from 4 mils to 8 mils for the QFP80 LD led to higher SIR levels as well as better data consistency. This was not surprising as increasing standoff heights inherently improves the ability to clean and rinse under components.

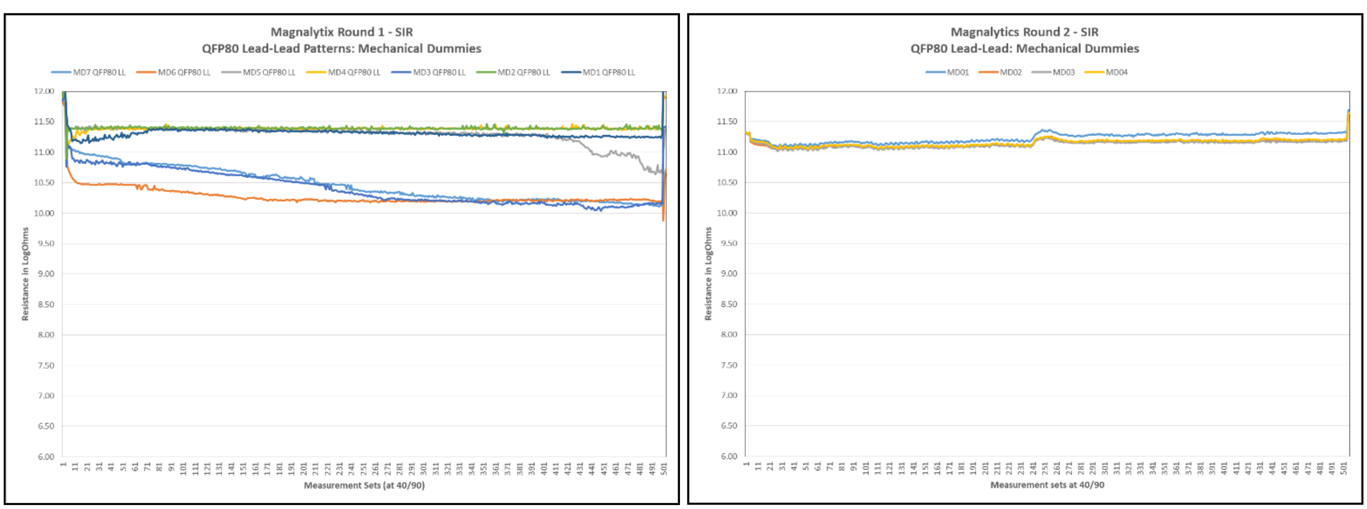



**Figure 30. QFP80 Mechanical Dummies – Comparison of Round 1 (Left) and Round 2 (Right)**

Figure 30 shows a comparison between Round 1 data and Round 2 data for the QFP80 Lead-Lead MD assemblies. The standoff height was the same between the two rounds of testing, but the Round 2 data was much more consistent. This may be due to slight variations in cleaning and rinsing between the two Rounds of processing.

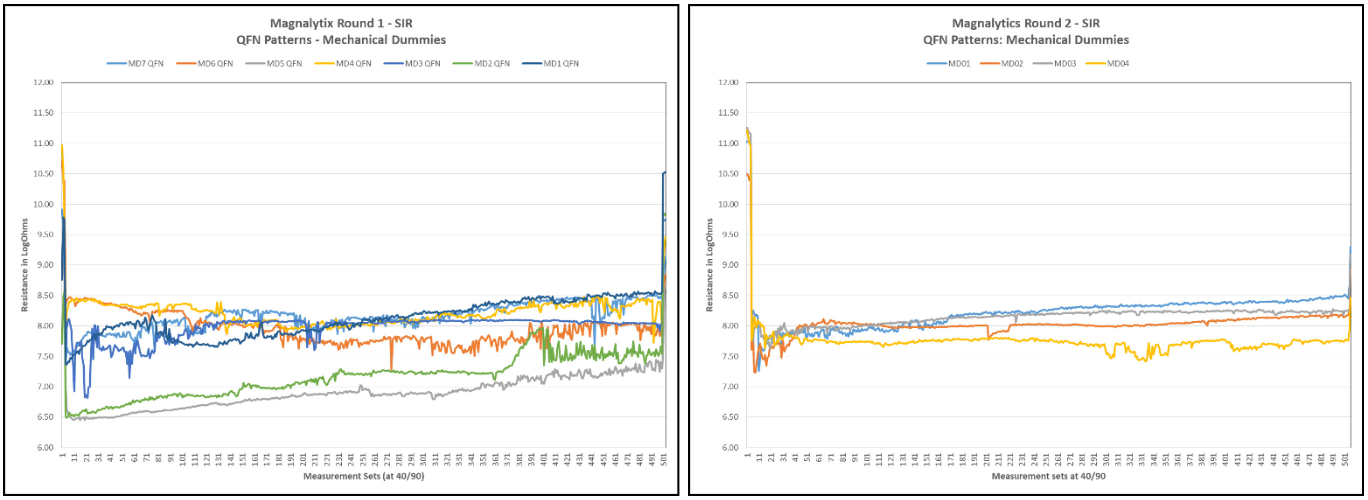



**Figure 31. QFN Mechanical Dummies – Comparison of Round 1 (Left) and Round 2 (Right)**

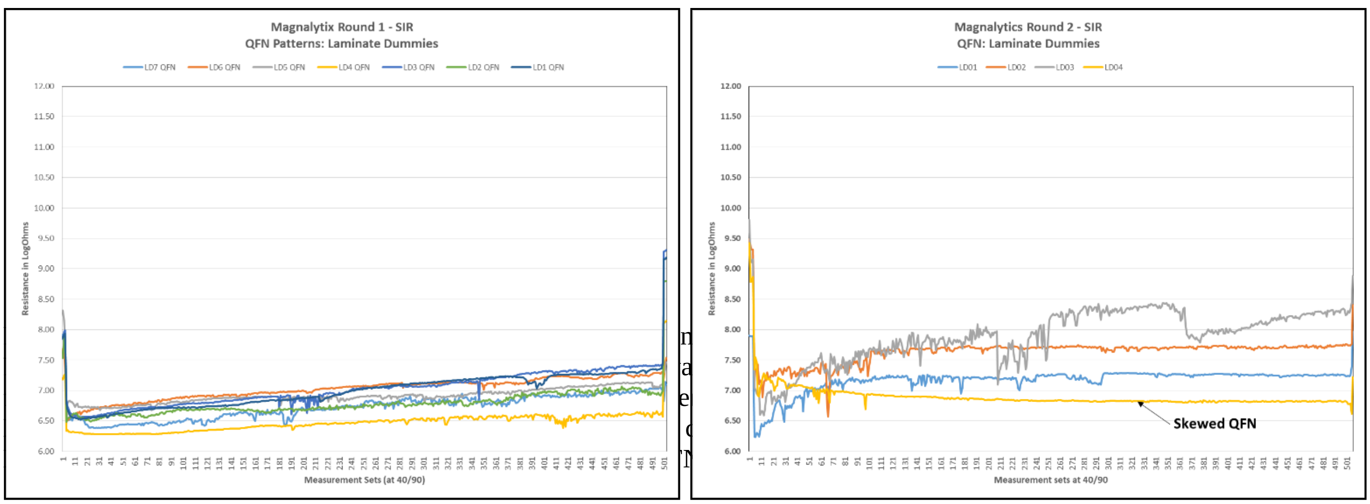



**Figure 32. QFN Laminate Dummies – Comparison of Round 1 (Left) and Round 2 (Right)**

As with the Round 1 data, a convenient way to compare data groups is with boxplots. Figure 33 shows comparisons between Laminate Dummies (LD) and Mechanical Dummies (MD) for each component type at 8, 24, 96, and 160 hours of test exposure at 40°C / 90% relative humidity. As with the Round 1 plots, if the two boxes overlap there is not a statistically significant difference between the two groups.

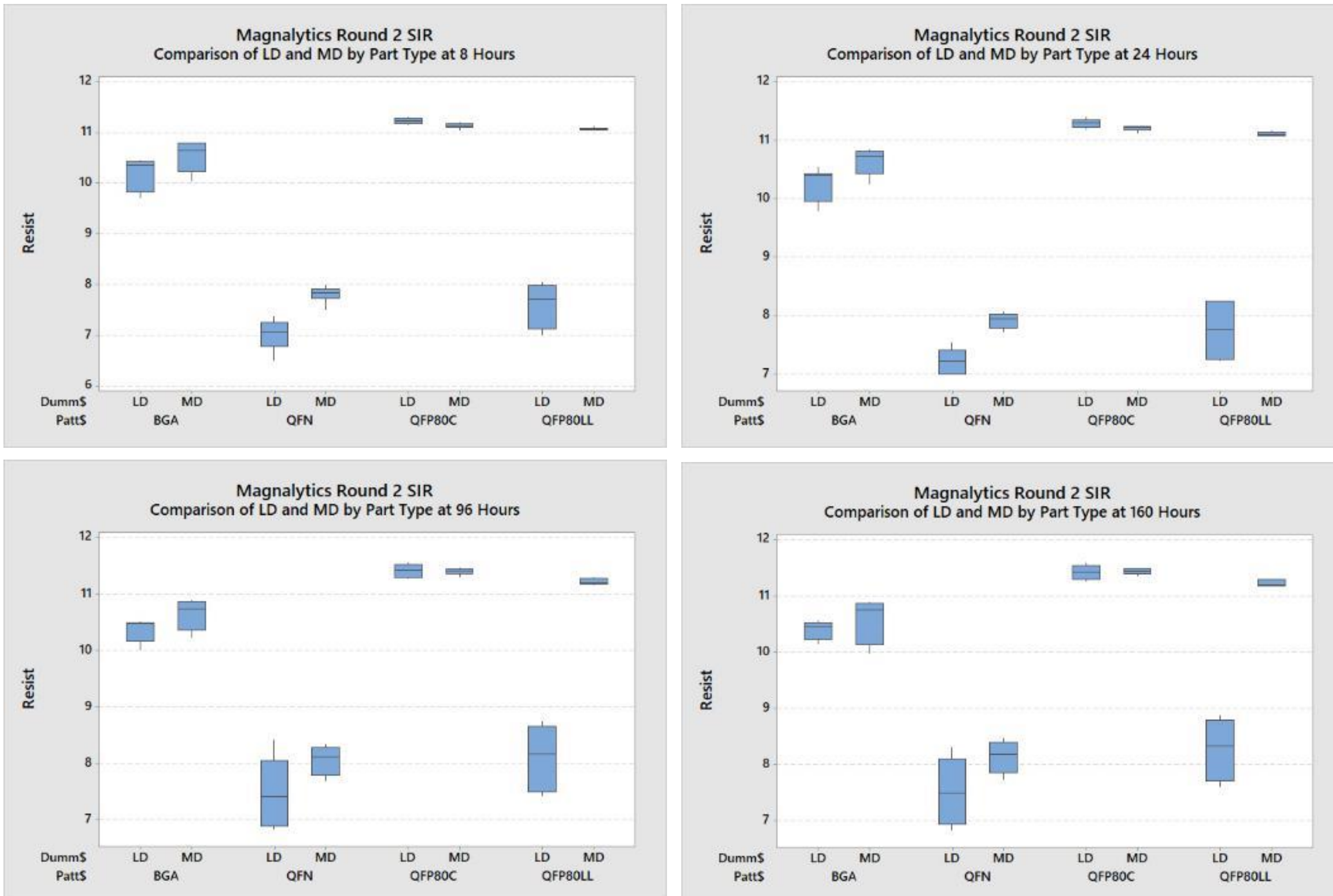



**Figure 33. Boxplots of Round 2 Data Over Time**

**<u>Observations on the Boxplots – Round 2</u>**

- As with Round 1, the FBGA show a tight correlation between the IPC-B-52, the Magnalytix B52 MDs, and the Magnalytix B52 LDs
- As with Round 1, the QFN patterns show a similar close correlation between the three data groups.
- A comparison of the Round 1 and Round 2 data shows that there are still significant differences between the LD and MD components for the QFP80 lead-lead patterns, even with the improved standoff height.
- A comparison of the Round 1 and Round 2 data for the QFP80 comb pattern shows improved SIR levels and better data consistency. It may be concluded that the increase in standoff height from 4 to 8 mils in height led to better cleaning and better rinsability.

**<u>Study Conclusions:</u>**

The four goals for this research were:

1. *Do test cards, all other factors being equal, processed with the laminate dummies (LD) provide the same SIR performance as test cards processed with the mechanical dummies?*

- It may be concluded that the laminate-based dummies provided an acceptable alternative to mechanical dummies for the BGA test patterns, and for the QFN test patterns.
- There were significant differences between the laminate based dummies and the mechanical dummies for the QFP80 test component and test pattern. In Round 1 of the testing, the laminate based dummies had a 4 mil standoff, which led to lower SIR values and more variability. In Round 2 of the testing, the increase of the LD standoff from 4 to 8 mils improved the overall SIR levels, but not enough to rise to the SIR levels observed for the MD components.
    - An additional consideration, to be addressed in subsequent studies, relates to the lead and soldering pad length for the two component configurations. The gull wing configuration of the MD QFP80 parts occupied more solderable surface than the LD QFP80 parts, but the LD QFP80 parts had a larger overall footprint. This may mean that there was a higher amount of flux residues for the MD parts than for the LD parts. How the flux residues behaved during manufacturing may have been a significant contributing factor to the variations observed. Rather than attempting to craft a LD part with the same physical characteristics as an MD part, it may

be wiser to craft the part such that it has the same flux amounts and outgassing characteristics as those displayed by an MD part.

- A correlation can be drawn between the MD and LD components for the QFP80 comb pattern, although the level and variability improved significantly when the LD standoff was increased from 4 mils to 8 mils.

2. *Can the SIR test system distinguish between LD and MD?*

- Yes, as noted above.

3. *Can the laminate dummies serve as a cost-efficient replacement for the mechanical dummies on the IPC-B-52?*

- Overall, laminate-based dummies can serve as cost efficient replacements for mechanical dummies for the BGA test component and the QFN48 test component.
- Additional work must be performed on the laminate-based dummies for the QFP80 component to make them equivalent to the mechanical QFP80 components.
- In many ways, the LD QFP80 components behaved very much like QFNs. The different footprints between the mechanical QFP80 (gull wing leads) and the laminate QFP80 (balled standoffs and larger footprint) led to different cleaning dynamics between the two components.

4. *Can the Magnalytix B-52 Legacy 1 test assembly serve as an acceptable alternative to the IPC-B-52 test assembly?*

- Yes, although it cannot yet be considered a "drop in" replacement for the IPC-B-52 standard test assembly for all test patterns. Additional work must be done on the QFP80 component before such a recommendation could be made to the IPC committees.

Overall, this testing has greatly increased our knowledge of the SIR physics underneath low standoff parts, and how two variables, standoff height and flux volume, impact overall SIR levels and data consistency.

**Future work:**

Additional research is needed to develop laminate dummy components which yield the same cleaning dynamics as that provided by mechanical components with different lead characteristics. Several design options have been identified:

1. Standoff gap
2. Pad Dimensions
3. Surface tension effects of the laminate versus the mechanical dummy

Phase 3 of the research will address the solder flux volume left underneath laminate SIR dummy parts on the QFP80s and QFNs. We believe these to be key variables contributing to the SIR variability noted between LD and MD components. The reduction in lead / pad length on both the LD part and its corresponding test card pad should address the outgassing variable and solder flux residue volume on both the QFP80 and QFN parts.

We would like to better correlate solder flux residue volume and its corresponding outgassing pathway on both the QFP80 and QFN style parts. When we can do so reliably, then laminate based dummies can be designed to approximate a wider array of components, allowing for better SIR characterization of electronics assembly processes.

Additional work, to be presented separately, attempts to correlate SIR performance with ionic residue assays, achieved using methods like ion chromatography. The goal of such research is to better correlate ionic residue species and amounts to overall SIR performance. Standardized test methods for the industry are the ultimate goals.

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