A New Approach to Process Qualification – SIR Testing + Functional Components

Mike Bixenman
Magnalytix, LLC
TN, USA
mbixenman@magnalytix.com

Terry Munson
Foresite Inc.
IN, USA

ABSTRACT

Process Qualification requires key elements: boards from your supplier, mixed technology assembly, functional components from approved vendors, and SIR test patterns on the same PCBA. This is the next step in assessing the materials and processes interacting during the multiple soldering/cleaning operations. This test vehicle is designed to assess the residues from solder paste from the reflow, laser soldering, and wave solder / selective solder, as well as thermal chemical effects on specific component packages and circuit performance, compared to SIR measurements.

What does this mean? SIR testing is the traditional assessment of the residues from the solder paste and wave solder processes but doesn't include the PCB cleanliness or component cleanliness, nor does the SIR assess the over-fluxing or rework/brush cleaning effects. With this new approach, we have designed a series of sensitive functional effects next to SIR patterns on one eight-layer board.

The experiment will build test vehicles with soldering materials susceptible to electrical leakage and electrochemical failures. The test vehicles will be tested using a test instrument designed to power and record the outputs of functional and dummy components.

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

INTRODUCTION

Flux and process residues from all process steps are collected on the active circuit traces, pad-to-pad, via-to-pad, and hole-to-hole spacing.[1] Component pitches have reduced while board density has increased. Electrochemical failures (parasitic leakage and dendrite formation) are point-specific.

As trace gaps and component geometries decrease, electrical performance must be validated using electrical test methods. Testing the assembly under accelerated test conditions using high temperature, high humidity, and electrical bias enables the assembler and design authority to understand product reliability by speeding up possible faults. The electrical properties are evaluated during testing to determine product reliability under severe conditions. As the test voltage and pitch of the test pattern are reduced, surface insulation resistance (SIR) values drop.

Climatic conditions (temperature and humidity) directly impact an electronic device's functioning, lifetime, and overall reliability.[2] High humidity dissolves ionic contaminants by increasing leakage currents (metal oxide alignment) on the surface of printed circuit boards, which reduces surface insulation resistance. The threshold relative humidity for the SIR failures in the circuitry is greatly affected by the type and amount of ionic contamination present on the printed circuit board assemblies (PCBAs).[3] The functional/SIR test board adds the second dimension of testing live components when exposed to harsh climatic conditions.

PURPOSE OF THE RESEARCH

This research aims to assess the IPC failure limit of 1e8 ohms of resistance by comparing these SIR patterns to functionally sensitive circuits. It will also determine whether a clean, bare board dummy component represents the residue effects on live functional circuits. The custom test board uses sensitive circuits such as battery circuits, RF and antenna uplink, LED and clock circuits comprising multiple components, and circuit performance to assess and qualify the process.

FUNCTIONAL / SIR TEST VEHICLE

The test board is designed with functional, CAF and SIR test circuits monitored under power. The test assembly is a tool to understand the material effects under SIR conditions using different component structures. The test board is designed to test the interactive effects of the collective residues from multiple soldering steps, whether No-Clean or Cleaning, on functional circuits and their interactivity in typical operation conditions. This shows why a short in one area will cause a failure at a separate part of the circuit with just a few ohms of leakage on sensitive circuits that may or may not recover. SIR misses the effect of circuit sensitivity on functional performance, and this test vehicle is the first step to creating this understanding.

The front side of the test board design in Figure 3 contains the following components.

- SIR components

- 8-pin SIR header
- BGA, inner and out balls
- 2 (0805) resistors to SIR pad
- 6 CAF via pairs and plane test

- Functional components
  - Solder continuity BGA.
  - Coin cell battery.
  - RF Wireless circuit and antenna
  - Real-time clock
  - Temperature Monitor
  - Humidity Monitor
  - Switch/LED
  - Cap leakage current (whiskers)

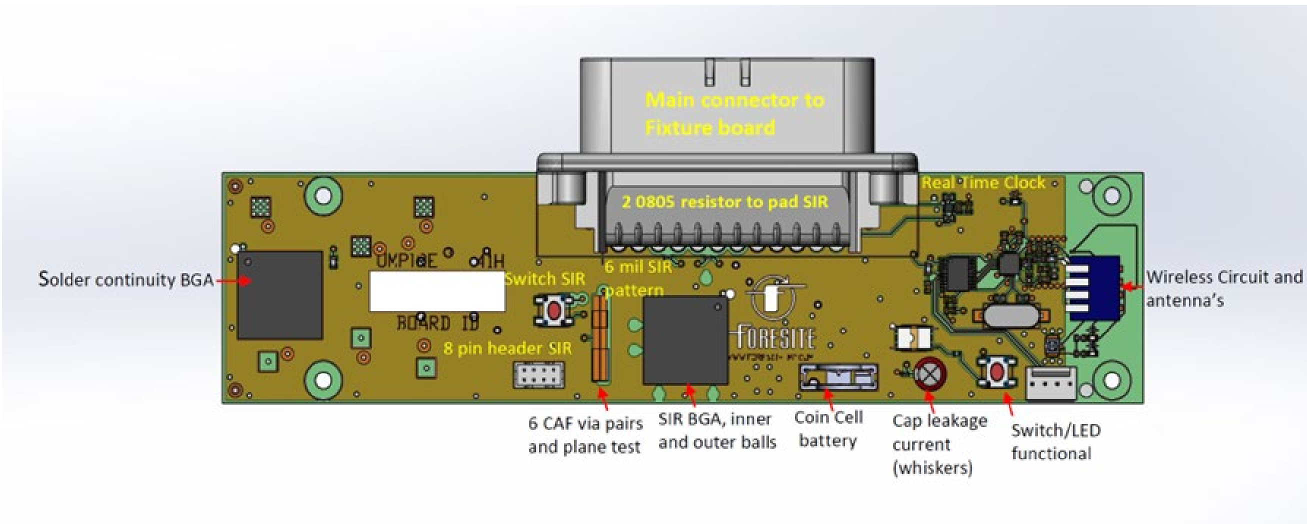


Figure 1: Front side of the Functional / SIR Test Board

The back side of the board design in Figure 4 contains the following components.

- SIR Components
  - 2 (0805) resistors to SIR pad
  - PQFP SIR over leads and Comb pattern under part
  - 3 raised QFNs
  - 3 standard QFNs
- Functional Component
  - High Impedance Circuit
  - Core Voltage Circuit Monitoring

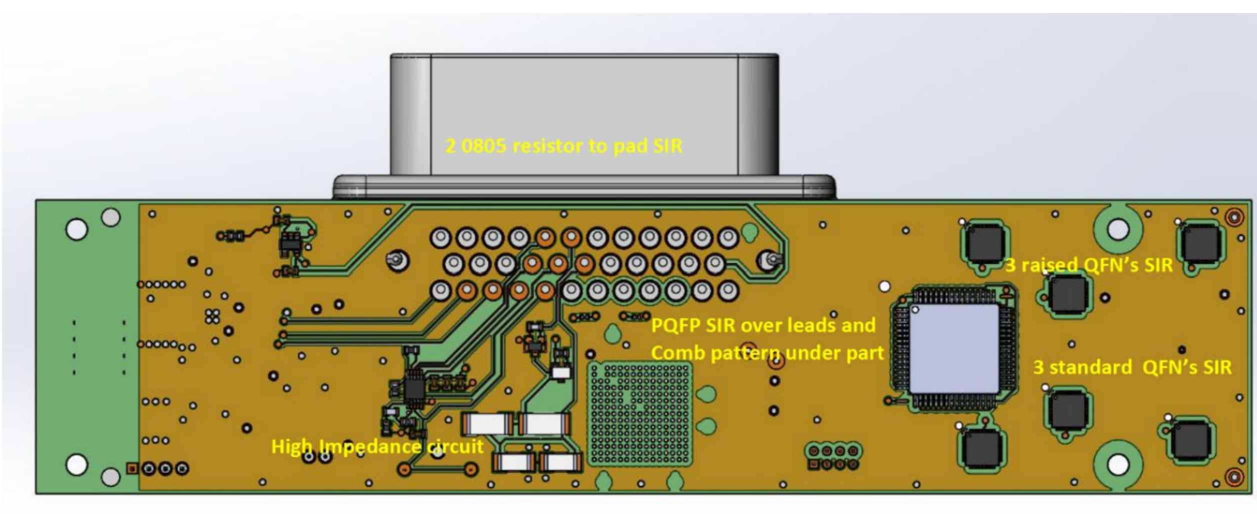


Figure 2: Back side of the Functional / SIR Test Board

The identifier/location assigned to each component during testing is a crucial reference point for determining the circuit board's X, Y, and Z (Front/Back) coordinates. These coordinates are used to precisely locate and display an image of the circuit board, facilitating visual inspection and analysis of individual components within the context of the entire board.

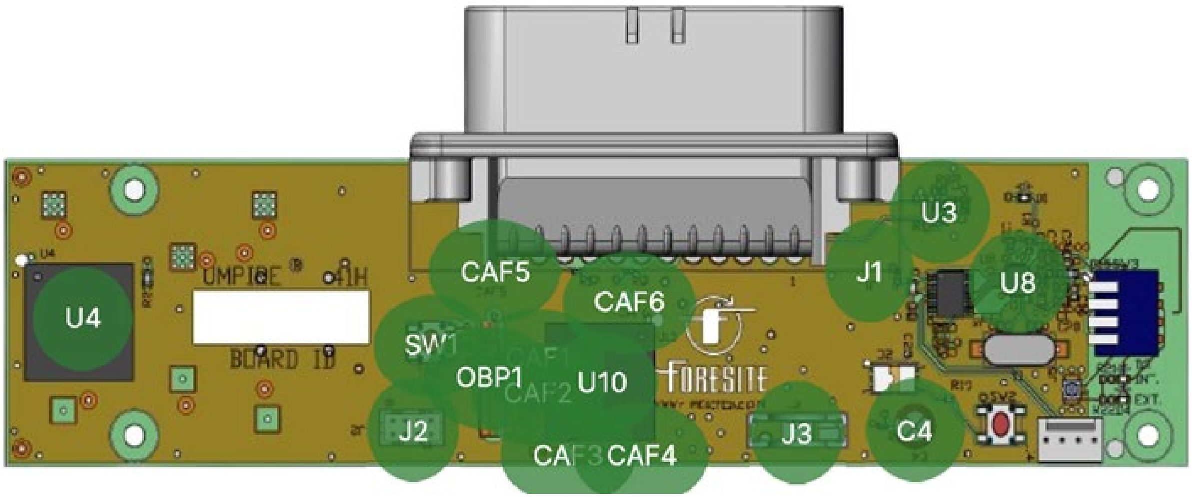


Figure 3: Component Locations on the Top Side of the Test Board

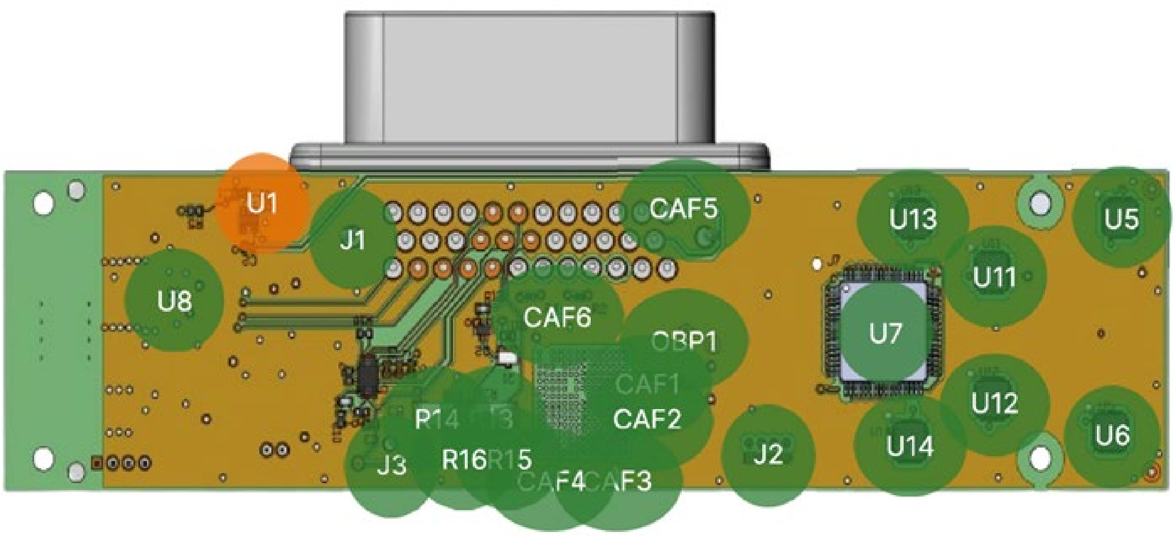


Figure 4: Components on the Back Side of the Test Board

Pass/Fail Criteria

1. Binary: Detects a simple pass/fail outcome. It's typically used when there is a clear yes/no, on/off, or true/false condition to evaluate.
2. Range: Checks whether a numerical value falls within a specified range or interval. Once the minimum and maximum value is established, the status is determined based on whether the actual value falls within the range.
3. Maximum: A maximum allowable value for a numerical parameter is established. If the actual value exceeds this maximum, it triggers a specific status.
4. Minimum: A minimum required value for a numerical parameter is established. If the actual value is below this minimum, it results in a particular status.

Table 1: Numerical Outputs – Pass/Fail Set Points

Component	Location	Minimum	Maximum	Unit	Criteria	Warning
Battery Voltage	J3	1.3	3.6	V	Standard	5%
250µF Capacitor Leakage Current	C4	0	35	mA	Standard	5%
High Current	R13 – R16	200	230	mA	Standard	5%
3.3 V Rail	U1	3.135	3.465	V	Standard	5%
Temperature				°C	Custom	5%
Humidity				%	Custom	5%
Main Connector SIR	J1	100 megΩ		Ω	Standard	5%
BGA Outer SIR	U10	100 megΩ		Ω	Standard	5%
BGA Inner SIR	U10	100 megΩ		Ω	Standard	5%
Switch SIR	SW1	100 megΩ		Ω	Standard	5%
Comb SIR	U7	100 megΩ		Ω	Standard	5%
8-pin connector SIR	J2	100 megΩ		Ω	Standard	5%
Probe SIR	OBP1	100 megΩ		Ω	Standard	5%
QFN1 SIR	U5, U11, U12	100 megΩ		Ω	Standard	5%
QFN2 SIR	U6, U13, U14	100 megΩ		Ω	Standard	5%
PQFP SIR	U72	100 megΩ		Ω	Standard	5%
CAF Via Resistance	CAF1	100 megΩ		Ω	Standard	5%
BGA Solder Joint			500	Ω	Standard	5%

TEST INSTRUMENT

The test instrument consists of:

- Fixture Board – Contains the A-D circuits, control processor, and wireless and USB communication interfaces.
- Coupon Board – the test board contains 20 functional, CAF, and SIR test circuits monitored under power.
- Enclosure – Holds 6 Fixture Boards, power supply, and wiring.
- Control: User Interface to capture, monitor, and process the data into desired outputs.

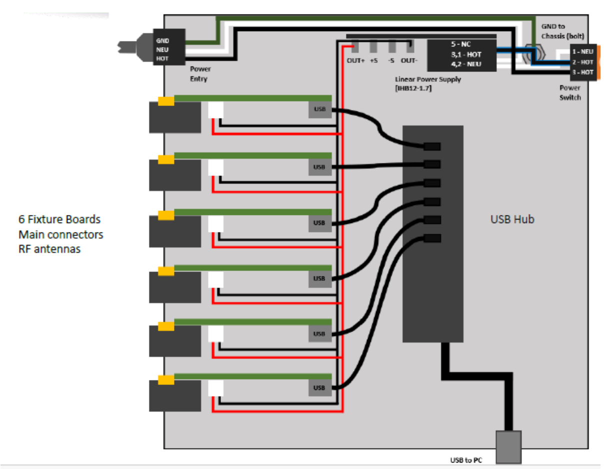


Figure 4: Test System Schematic

EXPERIMENTAL PLAN

Water-soluble and No-Clean solder pastes were used to assemble test boards. The test boards were cleaned using an aqueous inline cleaning machine with an aqueous cleaning agent at a 15% concentration in DI water. The test boards were washed at different conveyor belt speeds.

The boards were tested for one week using the following conditions:

- Temperature: 40°C
- Relative Humidity: 90%
- Bias: 5 Volts
- Measurements: Once every second
- Duration: 168-Hours

The Functional and SIR data were tabulated and will be reported in this paper.

Table 2: Test Board Experimental Plan

Test Board	Solder Paste	Cleaning Agent	Cleaning Machine	Belt Speed
U2	WS	DI water	Inline	0.5 fpm
U4	WS	DI water	Inline	1.0 fpm
U6	WS	DI water	Inline	1.5 fpm
U8	WS	DI water	Inline	2.0 fpm
U10	NC	Eng. Aq.	Inline	0.5 fpm
U15	NC	Eng. Aq.	Inline	2,0 fpm

DATA FINDINGS

The first set of data points reported are SIR circuits, followed by the functional circuits that failed during the testing period.

Temperature – Humidity Circuit.

The Functional temperature and humidity circuit accurately monitored these conditions over the testing period. Figure 5 is a chart showing that once the chamber reached stability, the temperature and humidity did not vary from the set points during the 168-hour testing.

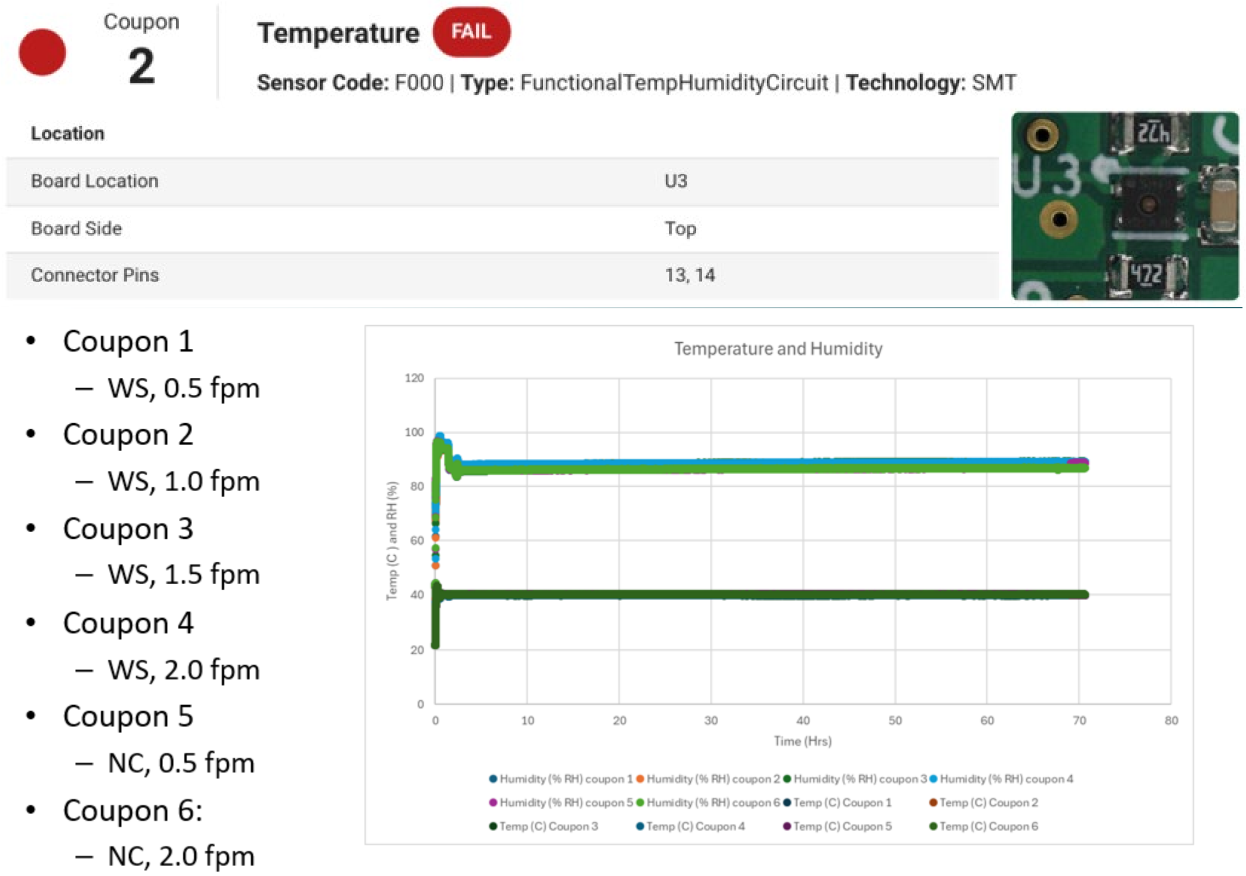


Figure 5: Temperature and Humidity Over the Testing Period – Fail at the Start of the Testing Period

SIR Circuits

SIR channels were designed to measure surface insulation resistance at specific areas on the test board. The resistance of the test measurement will drop when there is an active residue. Measurements that spike down result from a leakage current, most notably due to metal migration (dendritic growth). The data findings for SIR channels are reported below.

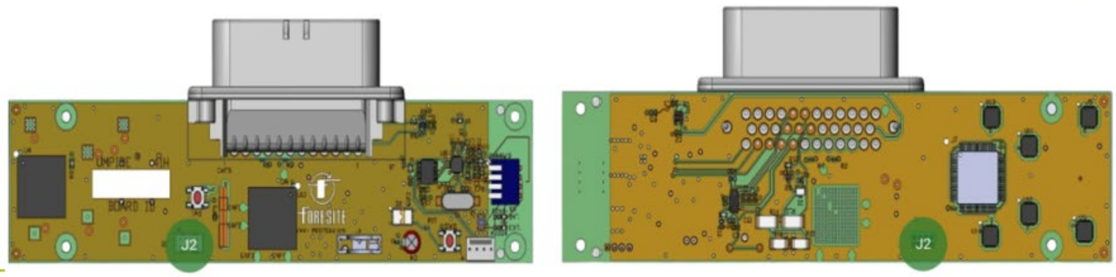
The **8-pin connector** passed SIR for all test conditions.

Coupon **2**

8 Pin Connector SIR PASS

Sensor Code: H005 | **Type:** N/A | **Technology:** PTH

Location	
Board Location	J2
Board Side	Top / Bottom
Connector Pins	20



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

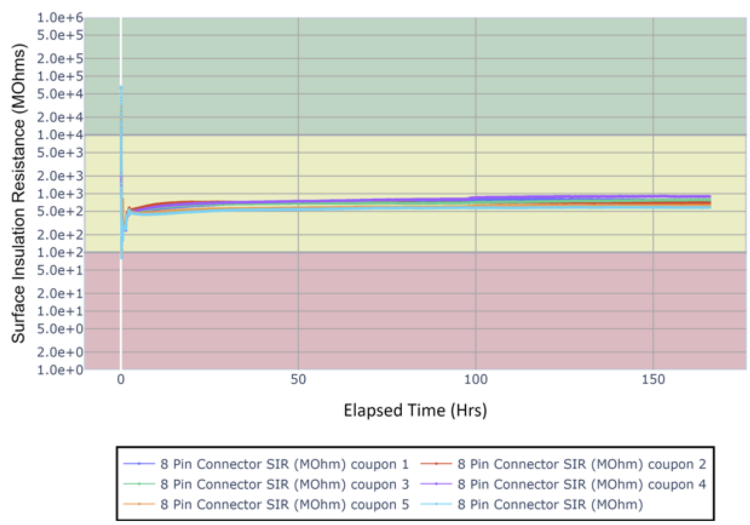


Figure 6: SIR on the 8-Pin Connector

The **Probe** passed SIR except for one leakage current on the WS test board, cleaned at 2 fpm.

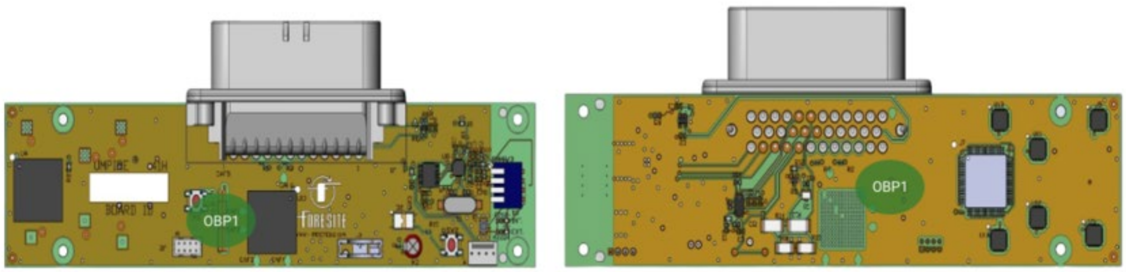
Coupon **2**

Probe SIR PASS

Sensor Code: H006 | **Type:** 50MilGapECM | **Technology:** PCB

Location

Board Location	OBP1
Board Side	Top / Bottom
Connector Pins	31



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

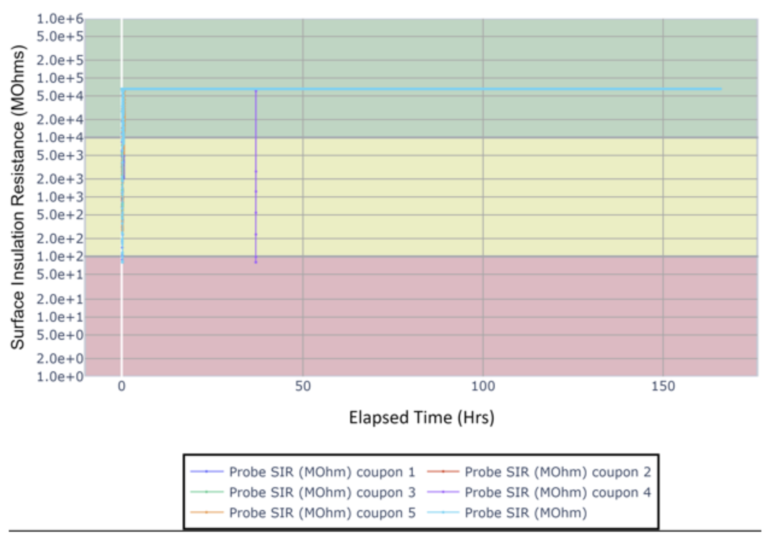


Figure 7: Probe SIR

QFN1 (U13, U11, and U5) had a standoff height between 25-40µms. All test conditions passed SIR. However, insulation resistance was lower on solder pastes cleaned at faster belt speeds.

SIR from Worse to Best

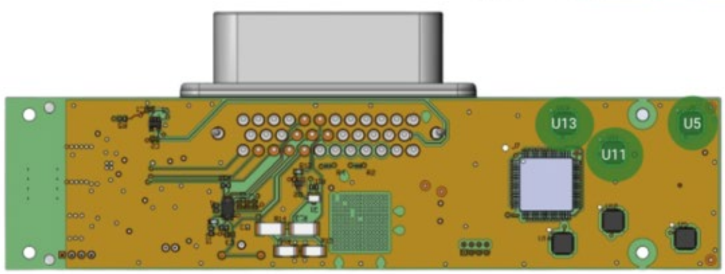
- WS at 1 fpm
- WS at 2 fpm
- WS at 1.5 fpm
- WS at 0.5 fpm
- NC at 2.0 fpm
- NC at 0.5 fpm

Coupon
2

QFN1 SIR PASS

Sensor Code: H007 | **Type:** PQFNSIR | **Technology:** SMT

Location	
Board Location	U5, U11, U13
Board Side	Bottom
Connector Pins	34



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

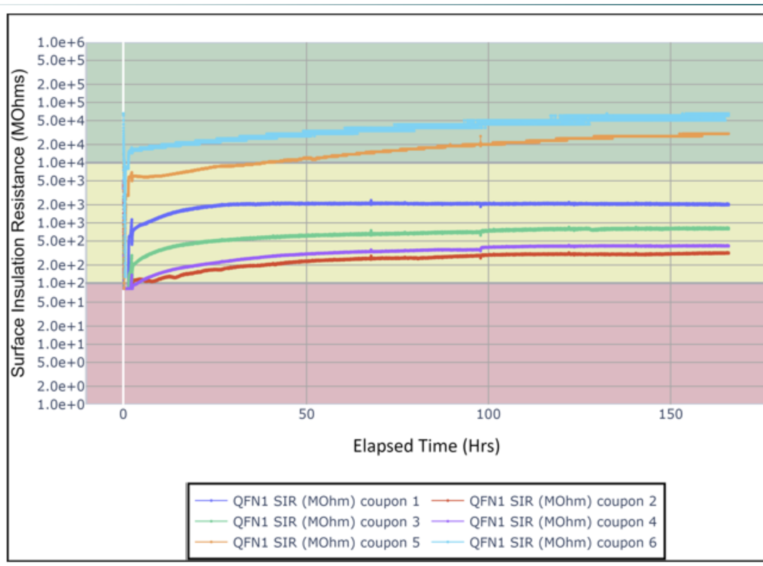


Figure 8: QFN 1 with Lower Standoff

QFN2 (U14, U12, and U6) had posts that increased standoff from 70-90µms. All test conditions passed SIR. However, insulation resistance was lower on solder pastes cleaned at faster belt speeds.

SIR from Worse to Best

- WS at 1.5 fpm
- WS at 1.0 fpm
- WS at 2,0 fpm
- WS at 0.5 fpm
- NC at 2.0 fpm
- NC at 0.5 fpm

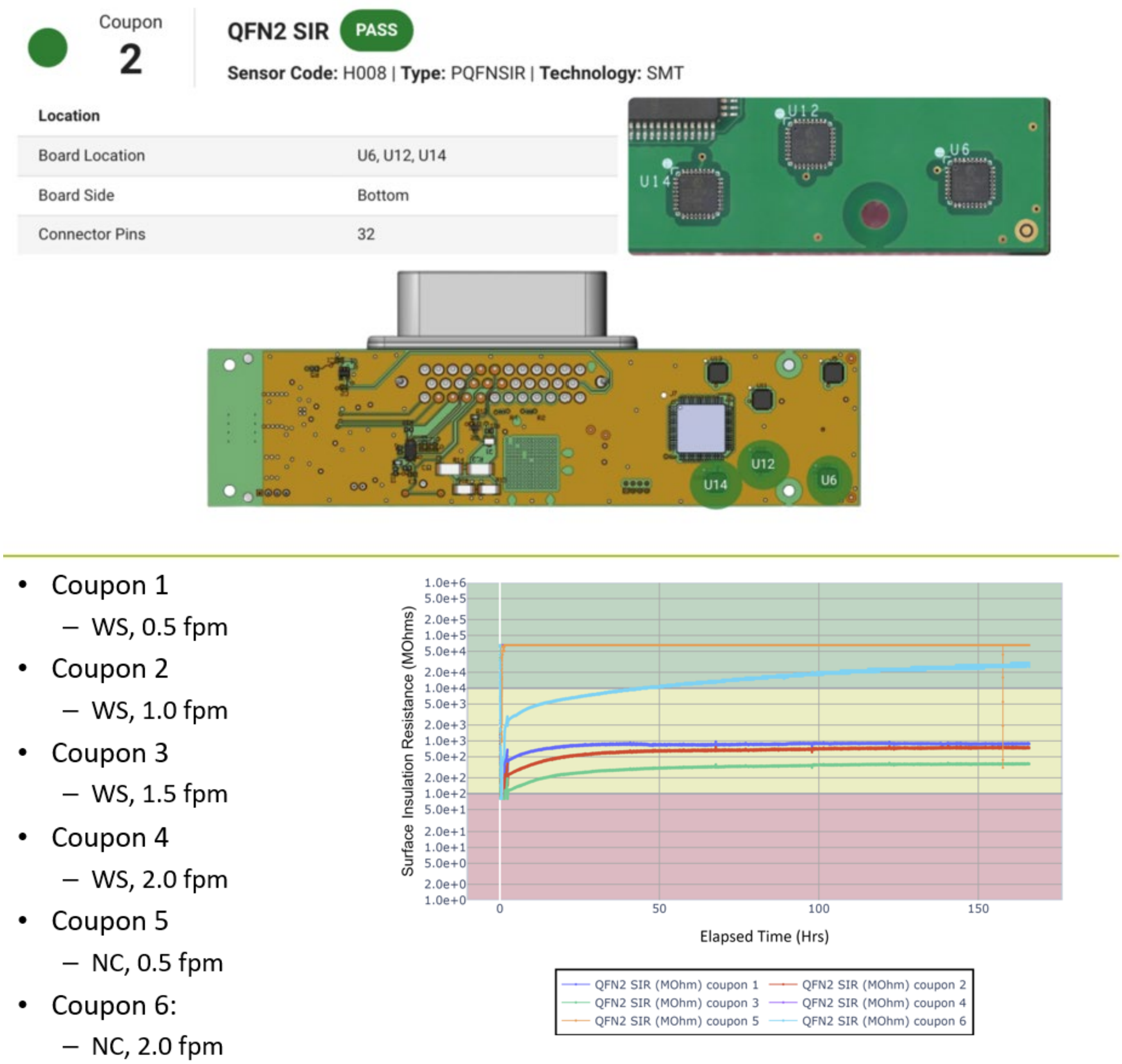
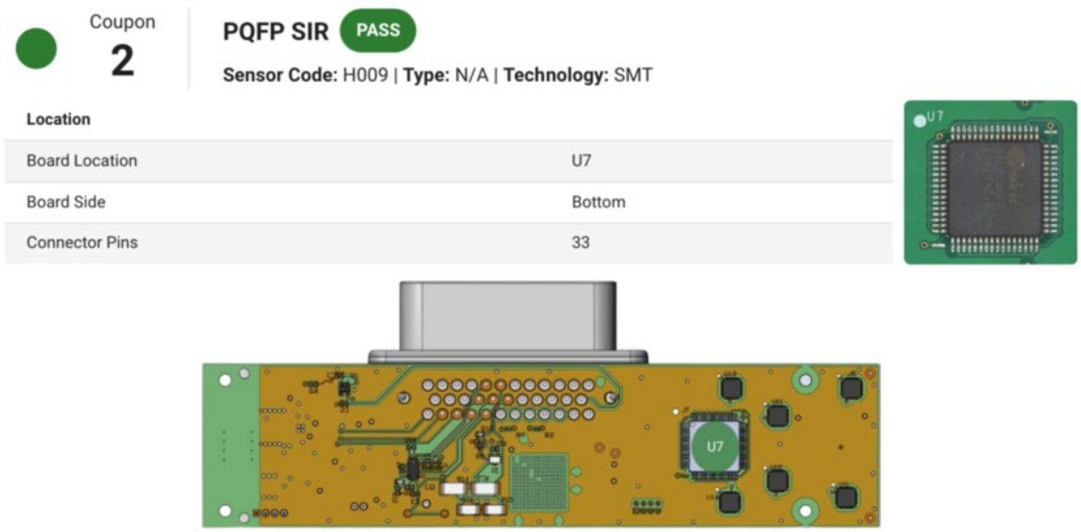


Figure 9: QFN2 with a Higher Standoff

QFP (Quad Flat Pack) SIR passed all test conditions.



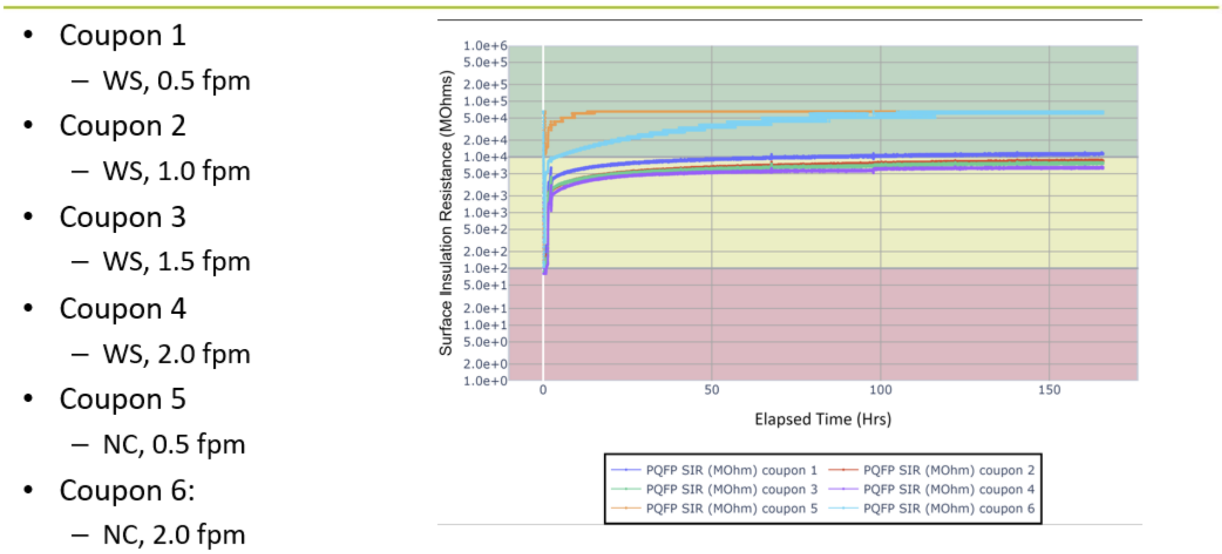


Figure 10: QFP SIR

Main Connector SIR passed all test conditions

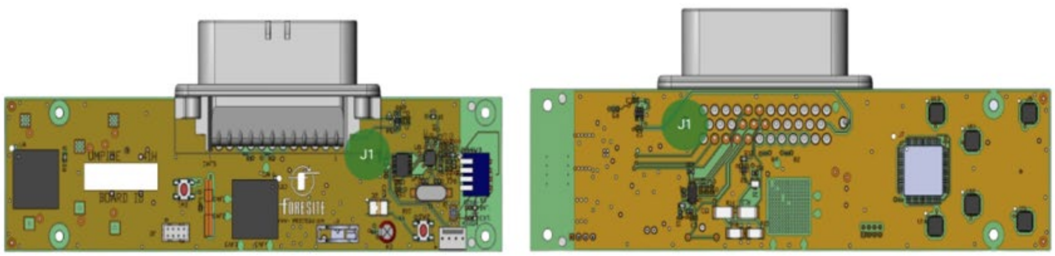
Coupon
2

Main Connector SIR PASS

Sensor Code: H000 | **Type:** MainIOConnector | **Technology:** PTH

Location

Board Location	J1
Board Side	Top / Bottom
Connector Pins	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

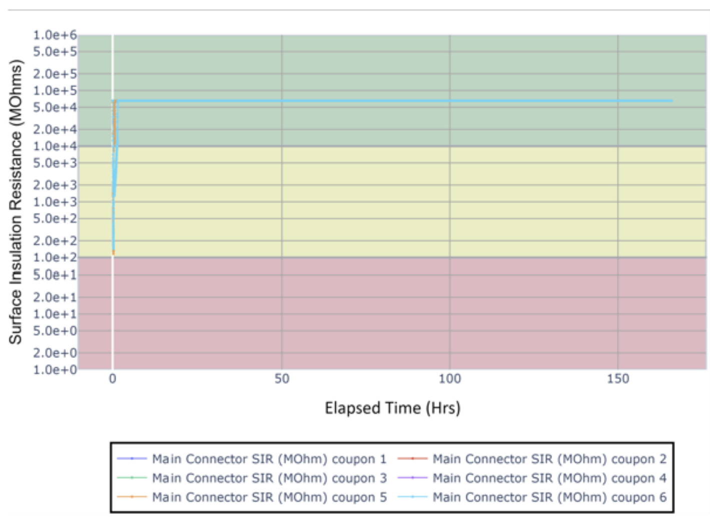
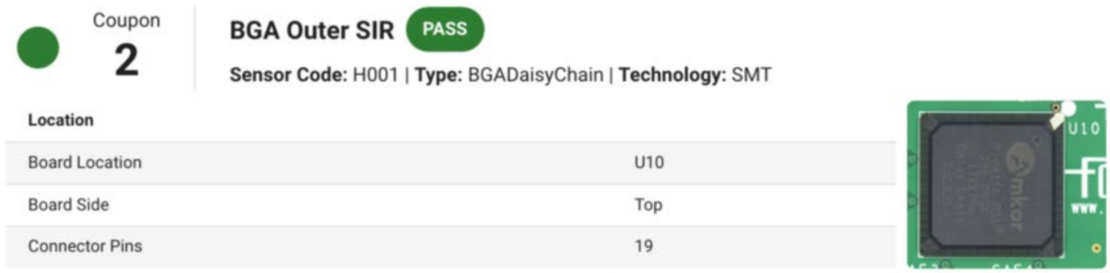
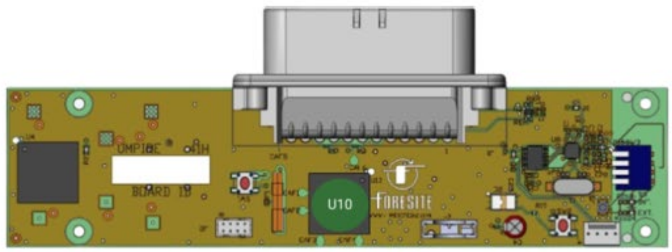


Figure 11: Main Connector SIR

BGA Outer SIR passed all test conditions.





- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

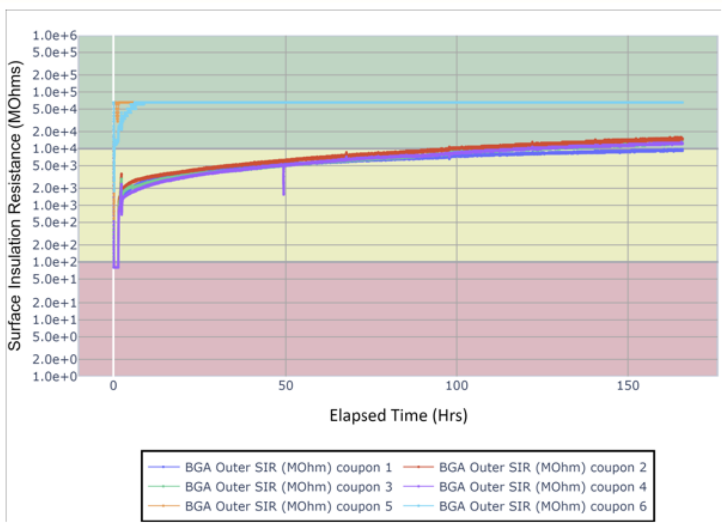


Figure 12: BGA Outer SIR

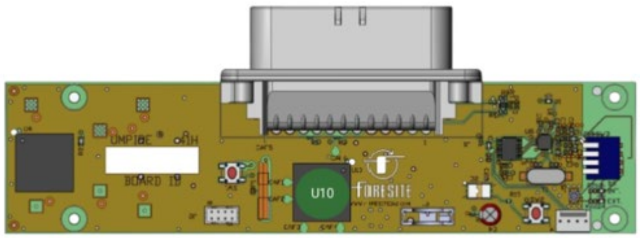
BGA Inner SIR passed all test conditions

Coupon **2**

BGA Inner SIR PASS

Sensor Code: H002 | **Type:** BGADaisyChain | **Technology:** SMT

Location	
Board Location	U10
Board Side	Top
Connector Pins	30



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

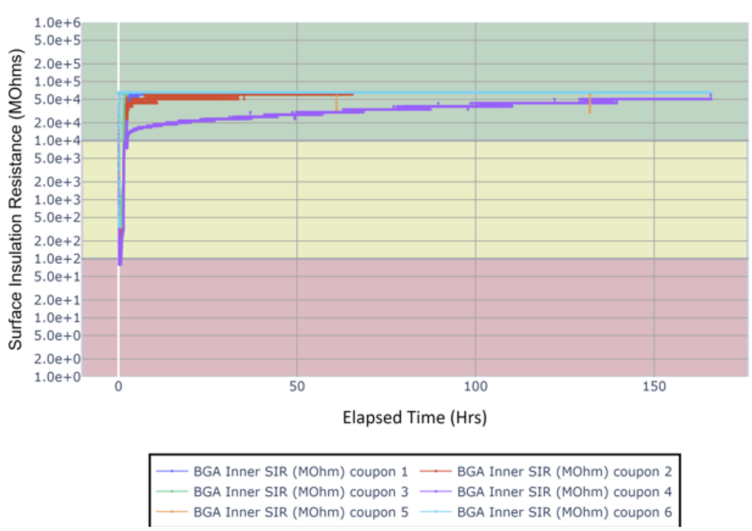


Figure 13: BGA Inner SIR

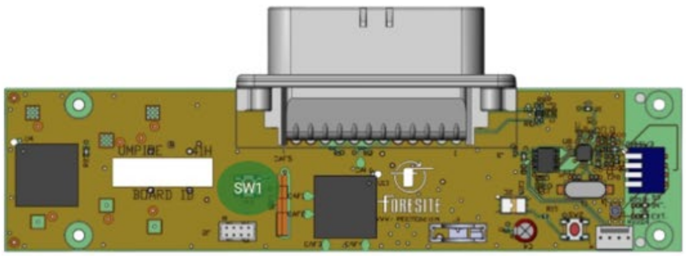
Switch SIR passed all test conditions

Coupon
2

Switch SIR PASS

Sensor Code: H003 | **Type:** N/A | **Technology:** SMT

Location	
Board Location	SW1
Board Side	Top
Connector Pins	21



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

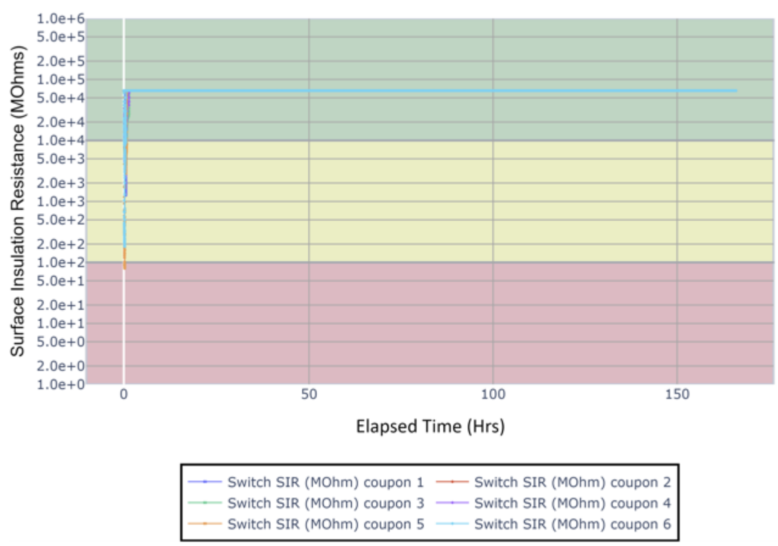


Figure 14: Switch SIR

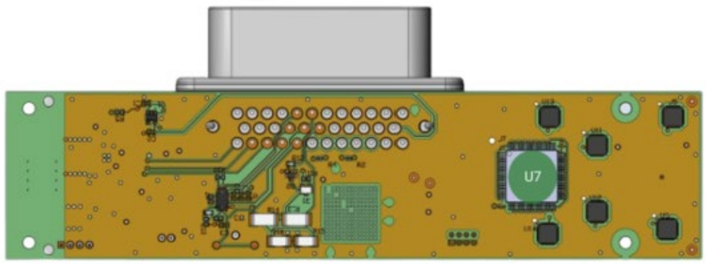
Comb SIR passed all test conditions.

Coupon
2

Comb SIR PASS

Sensor Code: H004 | **Type:** N/A | **Technology:** SMT

Location	
Board Location	U7
Board Side	Bottom
Connector Pins	22



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

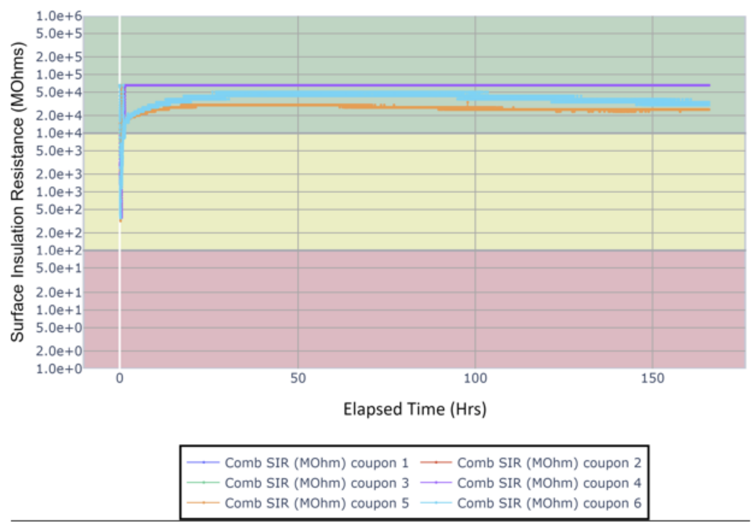


Figure 15: Comb SIR

Functional Circuits that Failed

The battery voltage failed on Coupon #4, soldered with a water-soluble solder paste and cleaned at 2.0 fpm.

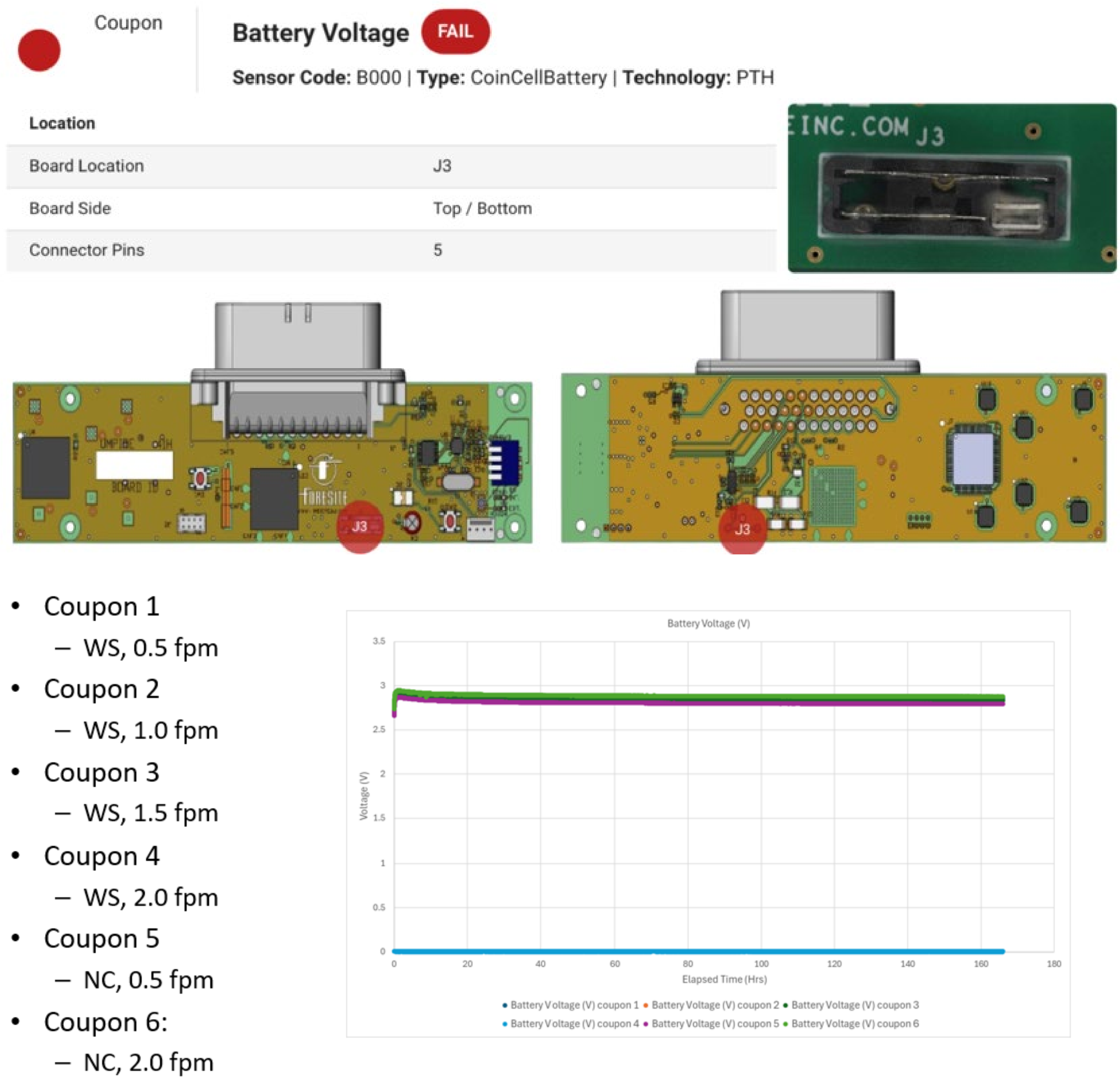


Figure 16: Battery Voltage – Fail

Ionic flux residues dissolved in moisture are conductive. When residue is present, the current will rise as the belt speeds increase. The boards soldered with water-soluble solder paste show higher current levels when the wash time is decreased (higher belt speed), resulting in failures.

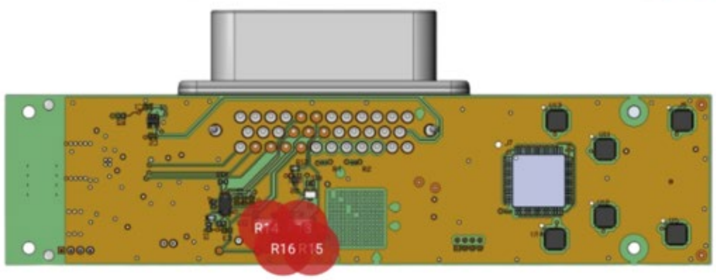
- NC at 0.5 fpm – Pass
- WS at 0.5 fpm – Pass
- WS at 1.0 fpm – Fail
- WS at 1.5 fpm – Fail
- WS at 2.0 fpm – Fail
- NC at 2.0 fpm – Fail

Coupon

High Current FAIL

Sensor Code: D000 | **Type:** N/A | **Technology:** N/A

Location	
Board Location	R13, R14, R15, R16
Board Side	Bottom
Connector Pins	18



- Coupon 1
  - WS, 0.5 fpm
- Coupon 2
  - WS, 1.0 fpm
- Coupon 3
  - WS, 1.5 fpm
- Coupon 4
  - WS, 2.0 fpm
- Coupon 5
  - NC, 0.5 fpm
- Coupon 6:
  - NC, 2.0 fpm

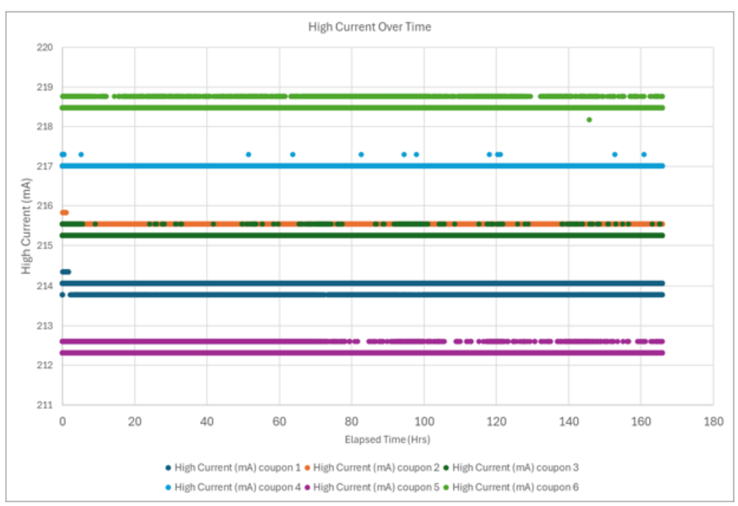


Figure 17: Functional - High Current – Fail

INFERENCES FROM THE DATA FINDINGS

The process conditions for the Water-Soluble and No-Clean solder pastes used to assemble the test board provided insight into the process conditions. The margin of safety varied based on the component type, solder paste, and wash conditions.

The Water Solder and No-Clean solder pastes cleaned at the fastest belt speed showed poorer results. The functional circuits detected higher current levels when partially cleaned flux residue was present. Surface Insulation Resistance was lower in these conditions.

The measurement system functioned properly. The fixture board, cabling, and user interface worked properly.

CONCLUSION

Combining functional and SIR testing enables the design authority to detect parasitic residue effects on sensitive parts of critical circuits while detecting the impact of process residues on SIR circuits. Understanding the material effects under SIR conditions and the interactive effects of the collective of residues from the multiple soldering/cleaning, or soldering and No-Clean operations, on the functional circuits and their interactivity in typical operation conditions provides process data to enable a reliable design. The goal is to show the effect of why a short in one area will crash a separate part of the circuit with just a few ohms of leakage or sensitive circuits that may or may not recover. SIR misses the effect of circuit sensitivity on functional performance. Test instrumentation and test vehicle design are the first steps in creating this understanding.

FOLLOW ON RESEARCH

The Functional / SIR test platform provides the basis for new learning. As with any new idea and system design, you don't know what you don't know until the system is used to test different materials and processes. Multiple experiments are being conducted, and additional research papers will be presented. The ultimate goal is to provide the industry with better tools to develop objective evidence and qualified manufacturing plans.

ACKNOWLEDGEMENTS

The authors want to acknowledge the engineering and software teams who worked to develop and prove the test instrument.

- Zach Papiez, Senior Process Engineer
- Matt Imburgia, Test Engineer
- Bobby Glidwell, Director of Technology
- Jim Gryga, Lead Electrical Engineer
- Steve Middleton, Electrical Engineer
- Paco Solis, Lead Investigator
- Anna Ailworth, User Experience Lead
- Kyle McCarty, Backend Developer

REFERENCES

[1]. Munson, T. (2021). The Forensics of Dendrite Shorting. Foresite Inc., Kokomo, IN.

[2]. Piotrowska, K., Grzelak, M., & Ambat, R. (2019). No-Clean Solder Flux Chemistry and Temperature Effects on Humidity-Related Reliability of Electronics. Journal of Electronic Materials, Vol. 48. No.2, 2019.

[3]. Piotrowska, K., Li, F., & Ambat, R. (2021). Transformation of reflow solder flux residue under humid conditions. Microelectronics Reliability. 123 (2021) 114195.