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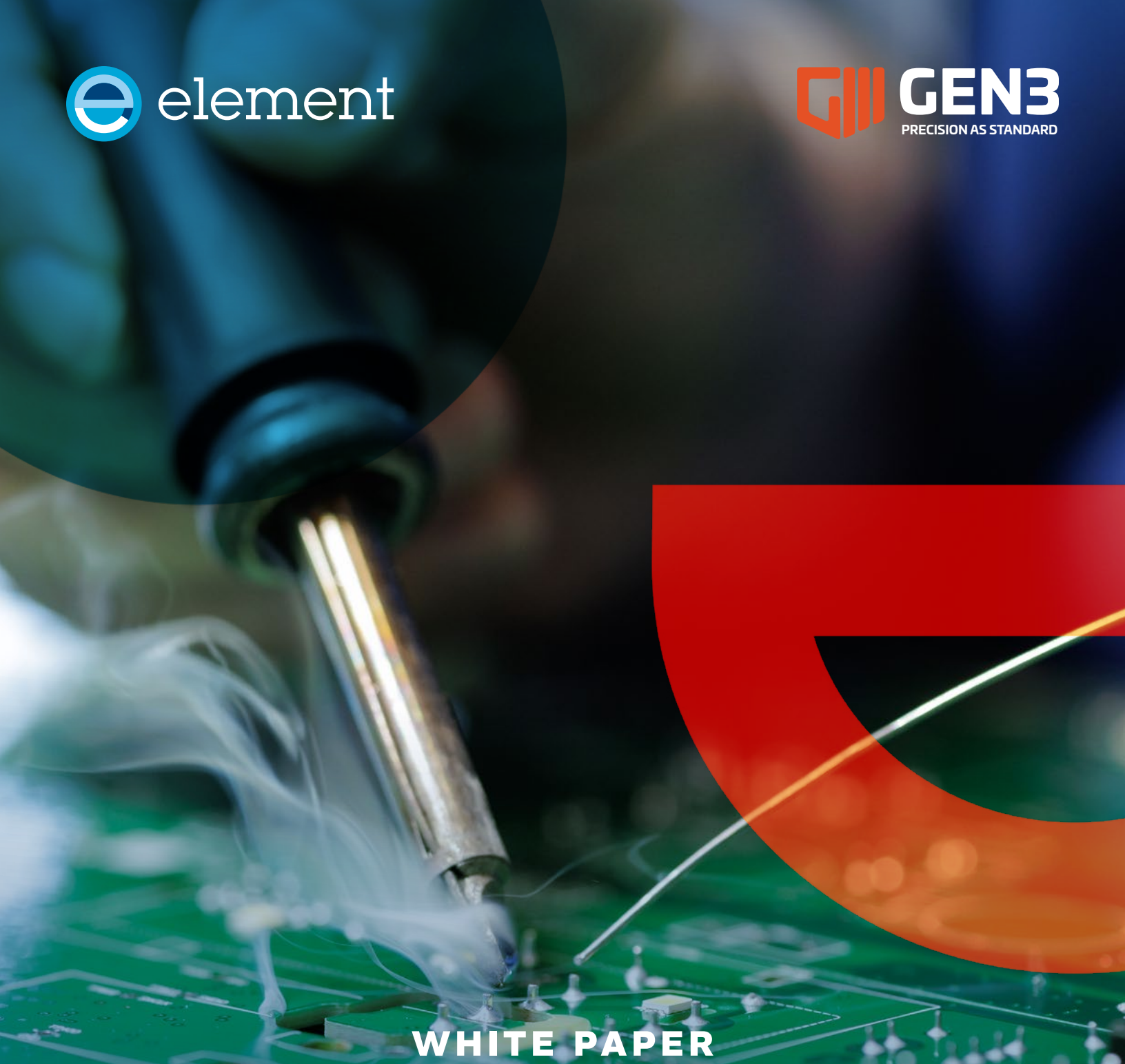

WHITE PAPER

Surface Insulation Resistance (SIR) and Conductive Anodic Filament (CAF) Testing

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EXECUTIVE SUMMARY

As Printed Circuit Boards (PCBs) continue to shrink and conductor spacing tightens, the risk of failure mechanisms driven by surface residues and moisture increases significantly. Element's Surface Insulation Resistance (SIR) testing—also known as Temperature Humidity Bias (THB) testing—provides detailed insight into how your PCB performs under these challenging conditions.

Using GEN3 AutoSIR2+™ platform, real-world environmental stresses are accurately replicated to reveal potential reliability threats such as Conductive Anodic Filament (CAF) formation and Electrochemical Migration (ECM). This testing approach helps manufacturers validate the impact of their processes on surface insulation resistance and ensure long-term PCB reliability.

INTRODUCTION

Surface Insulation Resistance (SIR) testing and Conductive Anodic Filament (CAF) testing—also known as Temperature-Humidity Bias (THB) testing—are critical methods used to evaluate whether a printed circuit board (PCB) is susceptible to failure under elevated temperature and humidity conditions.

In these tests, an industry-standardized test vehicle undergoes the whole manufacturing process. Any residual contamination on the board can trigger electrochemical reactions, leading to corrosion, ionic migration, and dendritic growth. These mechanisms reduce the insulation resistance between conductors and, in severe cases, can create complete electrical shorts.

WHY TEST PRINTED CIRCUIT BOARDS (PCBS)

The Risk Landscape for Modern Electronics

As electronic design advances, PCB architectures are increasingly characterized by finer line widths, tighter spacing, higher layer counts, and more complex materials. While these advances enable higher performance and smaller form factors, they also increase sensitivity to contamination, moisture, and bias-driven electrochemical activity.

SIR and CAF testing provide early insight into whether a PCB design, material selection, or manufacturing process introduces latent reliability risks that may not be detectable through visual inspection or basic electrical testing.

Key Reasons for PCB Testing

PCB testing through SIR and CAF methods is performed to:

- Validate soldering, flux selection, and cleaning processes
- Assess the impact of residues and ionic contamination
- Confirm material compatibility in multilayer constructions
- Identify susceptibility to electrochemical migration (ECM) and CAF growth
- Reduce field failures, warranty claims, and costly redesigns
- Support qualification, supplier validation, and process change approvals

These tests are particularly valuable during new product introduction (NPI), process changes, supplier transitions, or when addressing unexplained field reliability failures.

APPLICATIONS FOR SIR AND CAF TESTING

SIR and CAF testing are widely used across industries where environmental exposure and long-term reliability are critical.

Typical Applications Include:

- **Aerospace and Defense:** Avionics, flight control electronics, mission-critical systems
- **Automotive and EV:** Power electronics, ADAS systems, battery management systems
- **Industrial Electronics:** Controls, automation, sensors, and power conversion
- **Medical Devices:** Implantable electronics, diagnostic equipment, patient monitoring
- **Consumer and Commercial Electronics:** High-density assemblies operating in variable environments
- **Data Centers and AI Systems**

These tests are commonly applied during:

- Product qualification and design validation
- Manufacturing process development and optimization
- Failure analysis and root cause investigations
- Ongoing quality and reliability assurance programs

PASS / FAIL CRITERIA AND DATA INTERPRETATION

Surface Insulation Resistance (SIR) Criteria

Pass/fail criteria for SIR testing are typically defined by applicable industry standards, customer specifications, or internal reliability requirements. Common expectations include:

- Minimum insulation resistance thresholds maintained throughout exposure
- Stable or increasing resistance values over time
- No evidence of sudden resistance drops indicative of ionic migration or dendritic growth

Standards such as IPC-TM-650 Method 2.6.3.7 often specify resistance limits (e.g., $\geq 10^8$ or $\geq 10^9$ ohms), depending on test conditions and application requirements.

Conductive Anodic Filament (CAF) Criteria

CAF testing focuses on detecting the formation of conductive paths within the PCB laminate structure. Failure indicators may include:

- Progressive reduction in insulation resistance between vias or conductors
- Electrical shorting or unstable resistance behavior
- Post-test destructive analysis confirming CAF growth

The final pass/fail determination may include an electrical data review combined with microsectioning or analytical confirmation, depending on program requirements.

Trend Analysis and Early Warning Value

Beyond simple pass/fail results, SIR and CAF testing provide valuable trend data. Gradual resistance degradation, intermittent behavior, or bias-dependent responses can reveal emerging risks long before catastrophic failure occurs, allowing corrective actions to be taken early.

ELEMENT'S TESTING PROCESS

Element's comprehensive approach to SIR testing includes controlled exposure to temperature and humidity, real-time evaluation of electrical attributes, and accelerated environmental testing. We help select and implement the most appropriate methodology based on your product and intended use, ensuring thorough validation of assembly processes, soldering fluxes, cleaning processes, and surface insulation resistance.

Using current industry standards, such as IPC-TM-650 Method 2.6.3.7, Surface Insulation Resistance (SIR), and 2.6.25, Conductive Anodic Filament (CAF) Resistance, test vehicles are either hand-soldered or placed in a GEN3 edge connector rack, allowing bias and measurement voltages to be applied continuously.

The test vehicles are then placed in a clean, calibrated temperature-humidity chamber. The temperature is first ramped to the specified set point, followed by humidity ramping after thermal stabilization to reduce condensation risk.

During exposure, a bias voltage is continuously applied, and periodic measurements are recorded and graphed to monitor resistance behavior throughout the test.

EQUIPMENT USED FOR SIR AND CAF TESTING

Environmental Chamber

Any commercially available temperature- and humidity-chamber can be used. Key features include:

- Temperature ranges from 35°C to 90°C
- Humidity capability up to 95% RH
- Access ports for bias and measurement wiring
- Continuous temperature and humidity recording

High Resistance Meter / Power Supply

- Bias voltage capability typically from 5 VDC to 100 VDC or higher
- Continuous bias application
- Measurement capability up to 10^{12} Ω or greater
- Automated measurement intervals (often ≥20 minutes)

Automatic Switching System (AutoSIR)

In place of standalone instruments, an automatic switching system is often used. The GEN3 AutoSIR2+™ provides integrated bias application, automated measurements, and real-time monitoring.

The AutoSIR2+™ is the world's best-selling SIR tester, offering:

- Measurement ranges from 10^{6} Ω to 10^{14} Ω
- 64, 128, or 256 channel configurations
- Multi-bias capability (up to three voltages simultaneously)
- Measurement intervals as short as one minute
- Parallel testing to maximize throughput
- Real-time trend analysis and data visualization

ELEMENT FACILITIES THAT PROVIDE SIR AND CAF SERVICES

Element Anaheim, CA, and Baltimore, MD—formerly Microtek/Preferred and Trace Labs—bring more than 30 years of experience supporting OEMs and manufacturers with advanced circuit board testing.

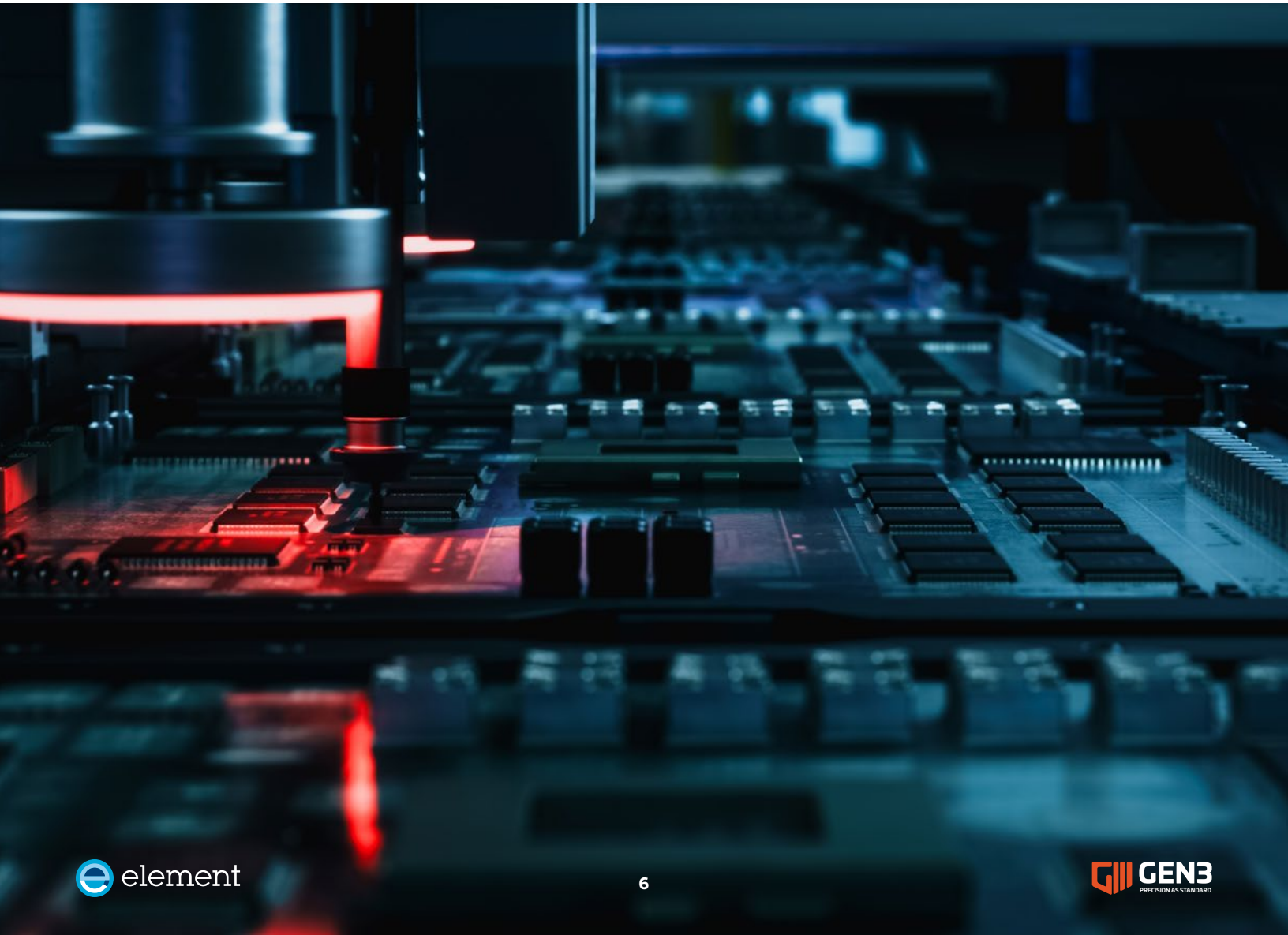
GEN3 has supplied AutoSIR™ instrumentation to Element facilities across the United States for more than 25 years, enabling consistent, high-quality SIR and CAF testing programs.

ABOUT GEN3

With over 30 years of experience, GEN3 supports electronics manufacturers in navigating evolving reliability and compliance challenges through advanced test instrumentation and technical expertise.

ABOUT ELEMENT MATERIALS TECHNOLOGY

Element Materials Technology is a trusted, lab-based testing partner for organizations operating in the world's most highly regulated sectors. We deliver certainty through rigorous testing, inspection, and certification expertise—supporting product performance, safety, and compliance when failure is not an option.



CONCLUSION

As electronics continue to miniaturize and operating environments become more demanding, the risk of electrochemical failure mechanisms increases. Through advanced SIR and CAF testing, Element Materials Technology and GEN3 help manufacturers identify vulnerabilities early, validate processes, and ensure long-term PCB reliability.

Together, Element and GEN3 empower the electronics industry with the data, insight, and confidence required to deliver high-reliability products that meet today's most demanding performance and quality expectations.

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