Keynote II. Quality Challenges and Risk Mitigation for Passive Components in Harsh Environments

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ABSTRACT

In the procurement and qualification of passive components for use in harsh environments, quality assurance remains a central challenge, especially when dealing with COTS (Commercial-Off-The-Shelf) parts. This presentation compiles multiple real-world case studies encountered during various projects, highlighting recurring issues such as pure tin finishes, solder joint cracks, poor adhesion in gold plating, and compatibility mismatches with assembly methods. We discuss the methods used for detection, including DPA, SEM, and outgassing/solderability assessments, and evaluate the procedural and regulatory responses, including the interpretation of standards. A particular focus is given to proposed improvements in inspection protocols and communication practices with both suppliers and clients to ensure robust qualification pathways and risk management, especially under time-constrained or mission-critical conditions.

INTRODUCTION

Passive electronic components—resistors, capacitors, inductors, and connectors—play critical roles in systems exposed to extreme conditions, such as aerospace, military, and industrial applications. In these harsh environments, temperatures, pressures, and mechanical vibrations levels frequently exceed those encountered in commercial settings. As a result, component failures can lead to mission-critical malfunctions, costly rework, or even loss of life. Ensuring the reliability of passive components under such conditions is therefore paramount, driving the need for rigorous procurement and qualification processes, even when using Commercial-Off-The-Shelf (COTS) parts.

Over the past two decades, industry and space agencies have developed standards—such as ECSS-Q-ST-70-02C for outgassing, ESCC-21001 for dielectrical tests, and MIL-STD-202 for environmental assessments—to guide qualification. Academic literature and technical reports highlight success stories of bespoke designs and hermetically sealed components, but COTS qualification remains less documented, often relying on case-by-case deviations or waivers. The growing trend toward cost and schedule pressures has further incentivized the use of COTS, despite the associated quality risks.

Despite the availability of standards, several gaps persist. First, regulatory documents often lack detailed guidance on interpreting test deviations for COTS finishes, such as pure tin plating. Second, suppliers and primes may employ inconsistent inspection criteria, leading to non-conformances detected late in the assembly flow. Third, communication workflows between quality engineers, design teams, and suppliers are seldom standardized, causing delays when addressing risk mitigation measures.

This paper aims to fill these gaps by analyzing multiple real-world case studies encountered at ALTER Technology TÜV Nord. We focus on recurring quality challenges—pure tin finishes, solder-joint cracking, poor gold-plating adhesion, and assembly mismatches—and document detection methods (e.g., DPA, SEM, outgassing, solderability), interpretation of regulatory requirements, and procedural responses. Finally, we propose an integrated inspection and communication protocol designed to streamline the qualification of passive COTS components under time- and mission-critical constraints.

MATERIALS AND METHODS

Component Selection and Procurement

Passive components were selected based on their intended use profiles: operating temperature ranges up to –55 °C to +125 °C, and exposure to vacuum or high-humidity environments. Procurement followed the internal sourcing protocol at ALTER Technology, which includes supplier screening for certification (ISO 9001, ESCC Qualified) and initial review of material composition and finish data sheets. Whenever possible, type-derived and family-approvals were leveraged to reduce lead time; otherwise, tailored procurement orders were issued with explicit finish and substrate requirements.

Inspection and Characterization Techniques

Four principal inspection methods were applied:

- **Outgassing**: Per ECSS-Q-ST-70-02C, material outgassing was measured using a quartz crystal microbalance system. Components exceeding the Total Mass Loss (TML) or Collected Volatile Condensable Materials (CVCM) limits triggered cleaning or alternative sourcing.
- **Solderability**: Evaluations adhered to ISO 9454-1. Dip-and-look tests at 245 °C assessed wetting angle and percent coverage. Failures prompted surface activation procedures or solderability-enhancement coatings.
- **Decapsulation and Particle Analysis (DPA)**: Components were chemically decapsulated following ESCC-21001 protocols, and internal die surfaces were inspected under an optical microscope for contaminants or delamination.
- **Scanning Electron Microscopy (SEM)**: Plating thickness and morphology (e.g., tin whiskers, gold adhesion) were examined at magnifications up to 5,000×. Energy-dispersive X-ray spectroscopy (EDS) provided elemental mapping to confirm plating composition.

CASE STUDIES AND RESULTS CASE STUDIES AND RESULTS

Case 1: Peeling in D-Sub Contacts

Problem Description

During procurement of D*MA Series D-Sub connectors with removable crimp contacts, visual inspection and microsectioning revealed cracks and peeling of the gold and nickel plating on the contacts.

The issue was detected during incoming inspection after crimping and confirmed by ESA investigation as part of a major project requiring imminent vibration testing.

The defects represented non-compliance with ECSS standards, risking both electrical performance and long-term reliability.

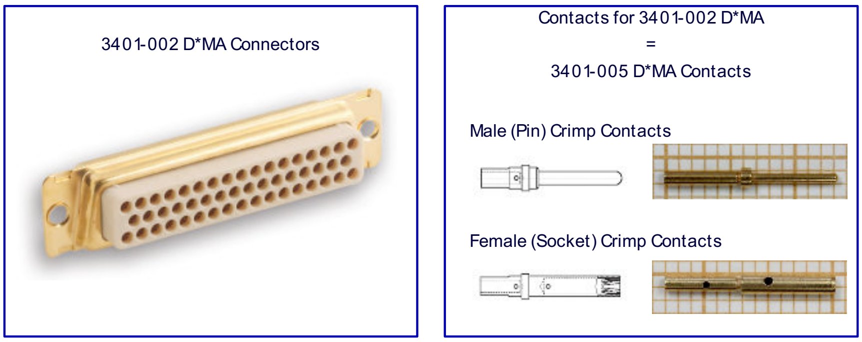

Figure 1 D-SUB CONNECTORS WITH REMOVABLE CRIMP CONTACTS

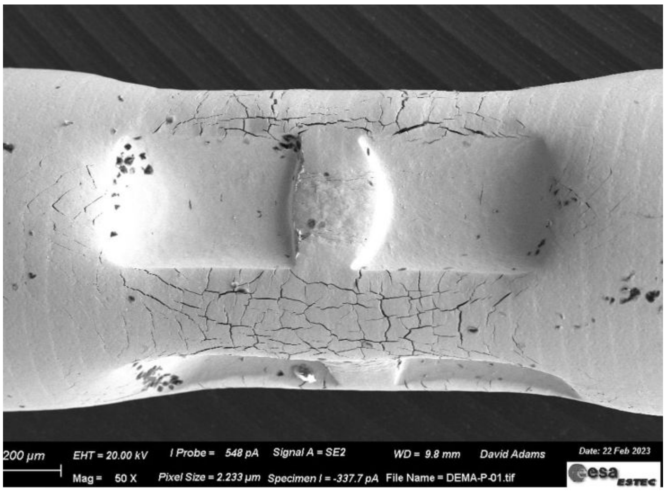

Figure 2 C/N 340100508B Cracks in crimping area (Credits: ESA)

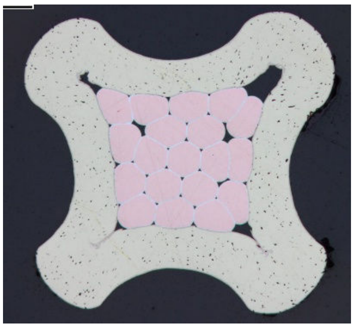

Figure 3 Cross section in crimping area (Credits: ESA)

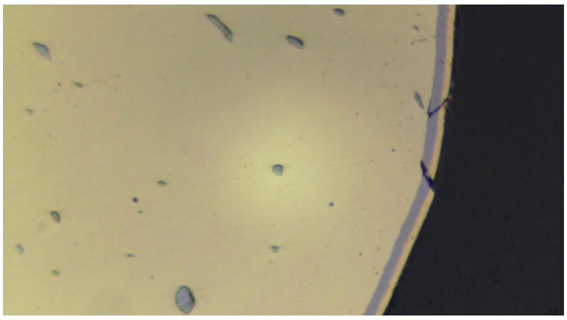

Figure 4 High magnification view of the cross section where the cracks are evident and going through underlayer

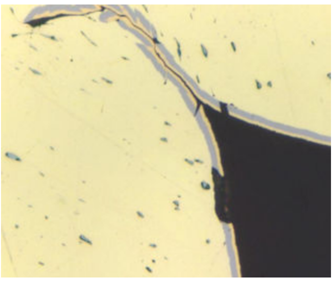

Figure 5 Detachment visible (Credits: ESA)

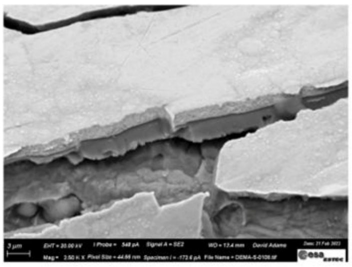

Figure 6 Detachment visible on the SEM (Credits: ESA)

Passive Component Involved

Type: D*MA Series D-Sub Connectors (removable crimp contacts)

Application: High-reliability interconnects for space and harsh environment missions

Relevant Specs: ECSS-Q-ST-70-26 Crimping of high-reliability electrical connections

Resolution Development and Technical Analysis

Visual inspection and Microsection analysis confirmed the presence of cracks and areas where the nickel underlayer detached from the base material.

SEM imaging revealed excessive phosphorous content (~12.5%) in the nickel layer, making it too hard and unsuitable for deformed or crimped contacts.

The **cause** of those cracks in the gold and nickel are due to a **Nickel plating with excessive Phosphorous content**. Nickel with high Phosphorous content is hard and not suitable for parts that are deformed. Therefore, there is a major action to be taken to the manufacturer in order to modify the plating parameters. The phosphorous content of the nickel has been measured around 12.5%, which is indeed *is compliant* with applicable specifications.

Cracks and plating detachment are considered as a major non compliances with the ECSS.

ECSS-Q-ST-70-26C Rev.1
15 March 2017

5.5.4.2 Post-crimp inspection (performed by quality assurance)

3. The crimp barrel has no unintentional sharp edges, peeled metal, burrs, cracked platings or cuts after crimping;

As the crimped barrels of the contacts had peeled metad and cracked platings effectively the crimped contacts are reject per ECSS

This manufacturer Sub D-contacts are ESCC qualified for decades. Sub D-contacts had Cooper underplating until 2019. In 2019 C&K changed Cooper by Nickel underplating. In 2020 ESCC qualified with cracks in barrel following manufacturer justification. Cracks were validated as cosmetic for environmental, high temp, corrosion and resistance.

But in addition, there is contamination risk due to gold plating pealing.

The other ESCC qualified manufacturer use also Nickel underplating and no longer copper for Sub-D contacts.

Lessons Learned and Recommendations
Strict control of plating processes and continuous monitoring of chemical composition is essential for high-reliability applications.

Collaboration and transparency between the user, supplier, and certification bodies accelerates problem resolution.

Proactive identification and communication of non-compliances enables timely mitigation and reduces risk to critical schedules.

Always have contingency plans (alternative sources or technical mitigations) in place for key components.

Documentation and sharing of such cases help prevent similar failures in future projects and improve industry standards.

And the main one, all users that follow ECSS-Q-ST-70-26C **avoid the risk of contamination working per the "standard".** The shrink must cover all the barrel.

ECSS-Q-ST-70-26C Rev.1 Corrigendum 1 is a requirement to put shrink tubes after crimping.
Paragraph 5.2.4 Contact barrel and single wire crimping

f. On D-sub contacts, a transparent shrink fit insulation sleeve shall be applied over the rear of the contact and the wire insulation both to cover the insulation clearance and to prevent any risk of a short circuit.

NOTE Examples of crimping parameters are given in Table A-1. An example of a typical contact barrel and an example of single wire crimping is shown in Figure 5-2.

ECSS-Q-ST-70-26C Rev.1
15 March 2017

Figure 5-2: Example of a typical connector barrel and single wire crimping

Case 2 Loss of Electrical Contact in SMD Inductor

Problem Description

In the frame of a major space mission, ALTER procured several passive components for a high-reliability RF hybrid. Among them was the SMD inductor size 0603, which was identified by the customer as the potential source of an intermittent loss of RF capability. The issue arose during final integration and testing of the hybrid, where intermittent failures suggested unstable electrical contact.

Initial data reviews were inconclusive. A more detailed failure analysis was triggered due to the criticality of the mission and the hybrid's sensitivity to even minor electrical deviations.

Passive Component Involved
Type: SMD Inductor
Quality level: Class S
Application: RF hybrid assemblies in a GEO satellite
Mounting Method: Conductive silver epoxy over gold pads

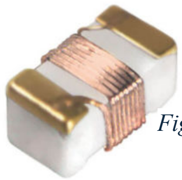

Figure 7

Resolution Development and Technical Analysis
A comprehensive investigation was conducted, starting with die shear testing in accordance with MIL-STD-883, Method 2019.7. The test confirmed robust mechanical attachment (shear strength well above the limit 500 g), ruling out handling or bonding failures.

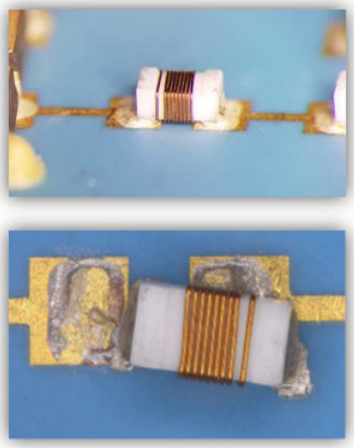

Figure 8 Before and after Die Shear test

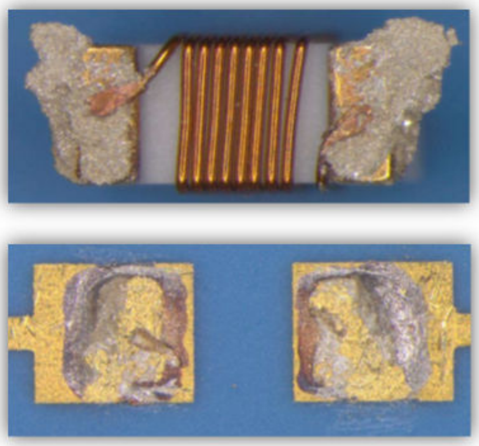

Figure 9 Views after Die Shear test. Silver Epoxy is observed

Further analysis via Scanning Electron Microscopy (SEM) revealed that the enamel coating of the coil wire was not fully removed and remained trapped within the joint. This residual enamel acted as a dielectric barrier, preventing a consistent electrical connection between the wire and the pad, especially under RF operation.

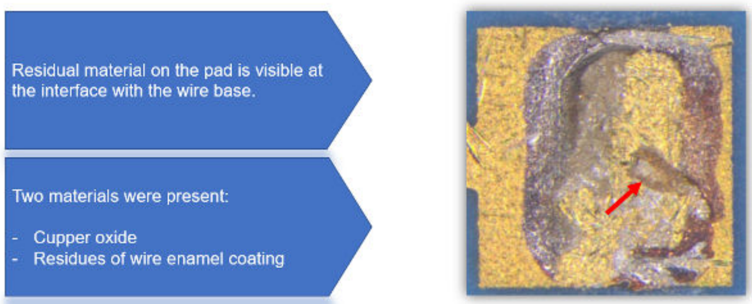

Figure 10

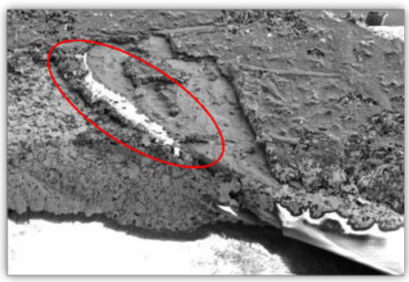

Figure 11 SEM picture of the coil contact / wire

Additional visual inspections across other inductor types from the same manufacturer revealed similar issues: oxidation, bent terminals, and partial enamel retention on the wires. It became clear that the assembly method—conductive epoxy over gold pads—was incompatible with the hybrid design, which relied on the assumption that the enamel coating would be effectively removed during the soldering process.

Reference [1]

Discussion and Outcome

The failure was rooted in a mismatch between component construction and the epoxy-based assembly process, not in a manufacturing defect.

The manufacturer confirmed that soldering with SnPb was the intended attachment method, and that epoxy-based processes may not reliably remove enamel from wire terminations. They recommended soldering or a full compatibility assessment prior to epoxy use.

Lessons Learned and Recommendations

- For wire-wound components, enamel removal must be guaranteed by the assembly method. Conductive epoxy may be insufficient unless enamel is stripped beforehand.
- Clear communication of assembly constraints is essential at the procurement stage, particularly for non-standard mounting techniques.
- Manufacturer datasheets and process recommendations should be reviewed in detail when selecting components for sensitive RF applications.
- Consideration of component structure, termination materials, and assembly chemistry is crucial to ensuring long-term electrical integrity.

This case highlights the need for system-level thinking in procurement—understanding not just the part, but its integration context.

Case 3: Set-up Conditions Discussion about Mechanical Shock Test on High-Density PCB Connectors

Problem Description

During the mechanical shock qualification of high-density rectangular PCB connectors used in modular power supply assemblies, one out of three test samples exhibited a critical failure. A socket pin on the female connector cracked following shock exposure along the X-axis. The anomaly was identified during post-test external visual inspection (EVI) and triggered a temporary suspension of the qualification flow for all units of the same lot, which were intended for flight use.

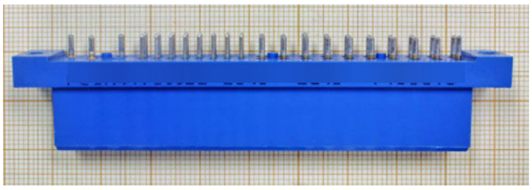

Figure 12 Side view of connector

Reference [2]

This type of connector had previously passed similar qualification sequences, suggesting the failure was not inherent to the product design, but rather linked to the mechanical setup of the test itself.

Component Involved

- **Type**: High-density rectangular board-to-board connector
- **Application**: Modular systems in space-grade power electronics
- Relevant Standards:
    - EEE-INST-002 (Inspection and Testing of EEE Components)
    - MIL-DTL-24308 (Shock Test Procedures)
    - ATN Test Plan (internal reference: ATN-SC-1020)

Test Execution and Failure Details

Shock tests were performed on three orthogonal axes using a closed-loop control system with tri-axial accelerometer feedback. During testing on the X-axis, one female connector sample developed a visible crack in one of its socket pins. No anomalies were observed in the remaining units or on the other axes.

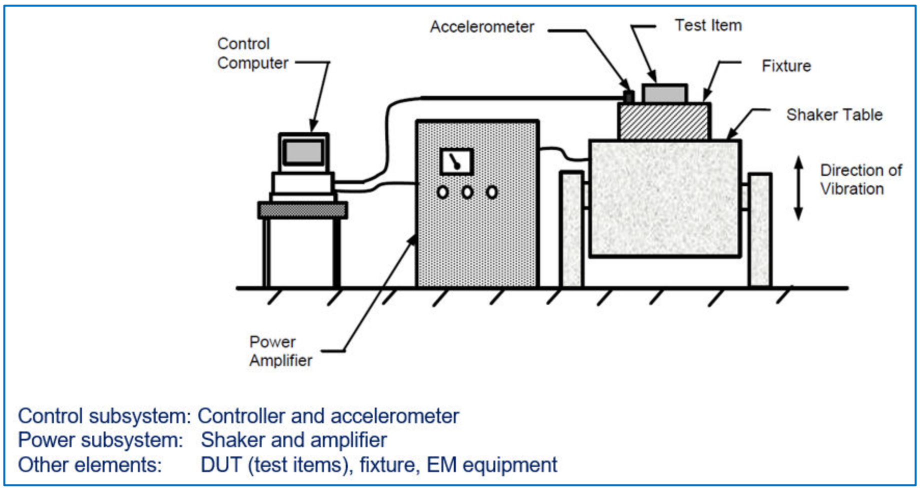

Figure 13 Mechanical Shock Test. General schematics

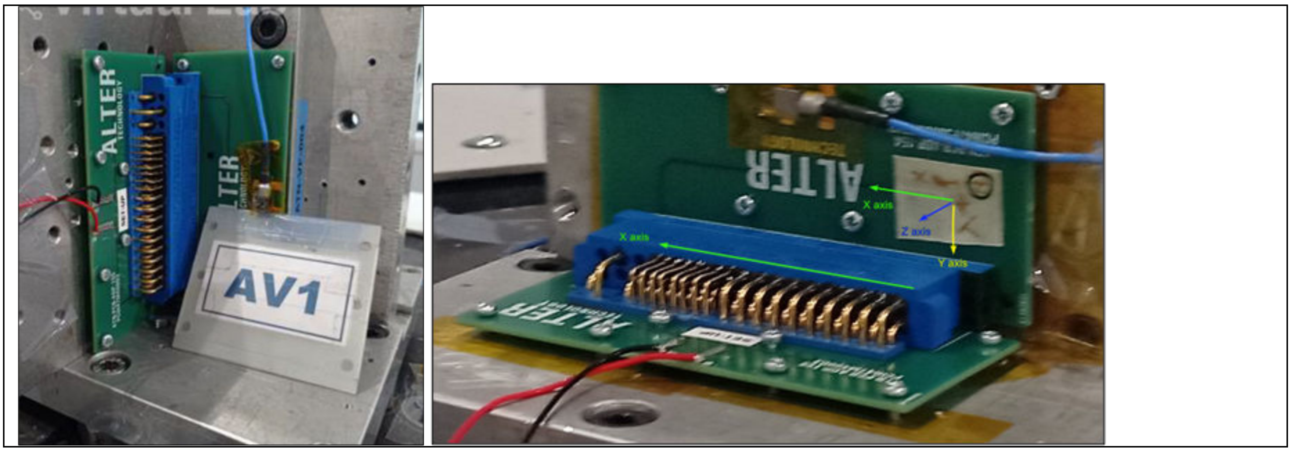

Figure 14 Mechanical Shock. Control Strategy. Example X Axis

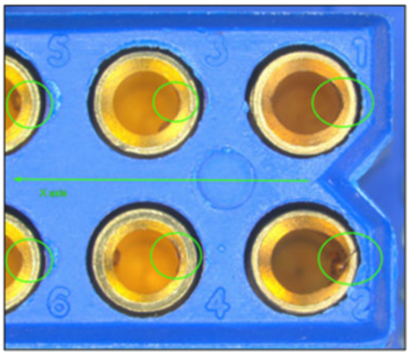

Figure 15 External Visual Inspection (EVI) after Mechanical Shock test

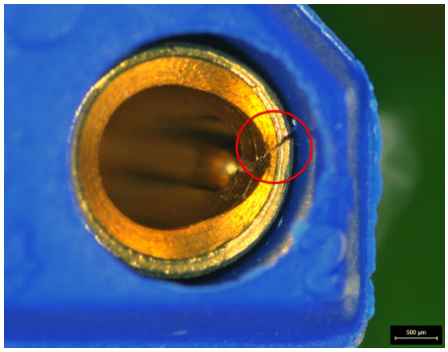

Figure 16 EVI after Mechanical Shock test: Female Connector with socket pin #2 cracked

The presence of only a single failure in a small sample group, combined with prior positive results on similar components, indicated the need to review the test fixture and mechanical interface conditions.

Root Cause Analysis and Fixture Redesign

An internal investigation was launched, focusing on the mechanical aspects of the setup:

1. Initial Observations
   - The test fixture allowed relative movement between the PCB and support walls due to tolerance gaps.
   - Oversized mounting holes introduced instability and unintended flex during shock application.
   - The PCB was partially elevated from the base, lacking uniform support and increasing mechanical stress concentration.
2. Fixture Improvements
   - A redesigned test fixture was developed using a single rigid module to eliminate structural asymmetries.
   - Additional mechanical fixation was introduced with the use of screws and toothed washers.
   - Mounting holes were adjusted to ensure precise alignment without inducing stress during assembly.
   - The base was modified to provide complete and stable support under shock loads.
3. Retesting
   - A new set of three connectors underwent the same shock test sequence using the improved setup.
   - All samples passed the test, and no cracking or mechanical deformation was observed.

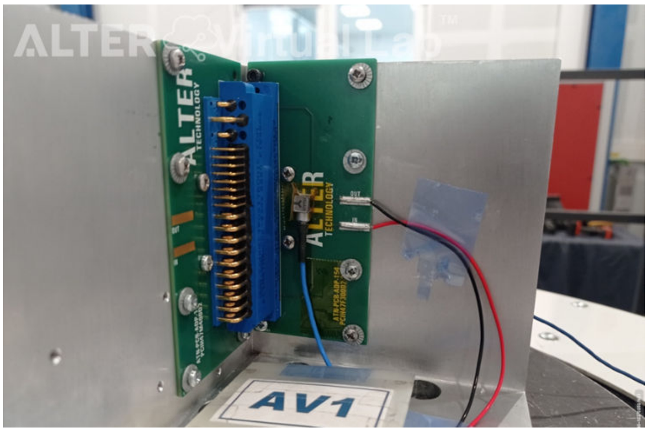

Figure 17 Enhanced fixture and set up

Test Planning and Qualification Considerations

Because the new test samples had not undergone the full qualification flow (e.g., thermal cycling, solderability), their results were not formally admissible as a direct substitute for the original data. Instead, both the original and the additional results were recorded, with a clear explanation that the failure was attributed to test setup and not to component quality.

Two options were considered:

- **Option 1**: Continue qualification, documenting the anomaly and the corrected fixture design.
- **Option 2**: Restart the full qualification sequence using the new fixture.

Following review, **Option 1** was implemented, acknowledging the improved setup as sufficient to support component reliability.

Lessons Learned and Recommendations

- The design and mechanical integrity of test fixtures are critical to the validity of shock test results.
- Minor setup issues—such as loose tolerances, unsupported PCB sections, or asymmetrical force distribution—can result in non-representative failures.
- Qualification strategies should incorporate flexibility for setup validation, especially when mechanical loads are involved.
- Component failures must be analyzed in conjunction with test environment and setup conditions to avoid incorrect rejection.
- Collaboration between mechanical and electronic engineering teams ensures that test designs reflect real-world mounting and structural constraints.

This case demonstrates the importance of comprehensive mechanical validation during environmental testing. Failures linked to setup must be identified and mitigated early to preserve schedule, maintain technical credibility, and ensure the reliability of flight hardware.

Case 4: Interaction between Outgassing Test and Solderability Test

Problem Description

During the qualification of PCB connectors intended for flight units, a critical issue was identified in the sequence of environmental and material tests. Devices subjected to the solderability test showed non-compliant results during subsequent outgassing testing, as per ECSS-Q-ST-70-02C. The affected components—reference p/n 2007042-3 initially underwent standard solderability assessments using SnPb dip and flux processes. These steps, however, appeared to leave marginal flux residues, which triggered failures during the subsequent outgassing characterization.

This scenario raised concerns over the compatibility of test sequences involving chemical flux exposure followed by outgassing measurements.

For the case of Connectors like next examples from TE Connectivity, they are showing a geometry with different locations that will be in direct contact with the flux bath before dipping parts into the Sn/Pb bath.

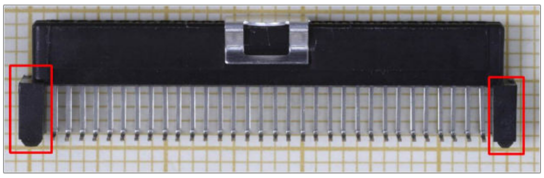

Figure 18

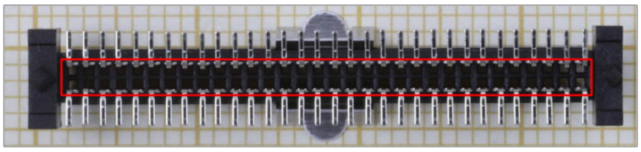

Figure 19

This means that shell and internal areas could keep flux residues. Cleaning process by IPA application could be not enough as to remove flux residues from some internal areas of Connectors with this kind of geometry.

Component Involved

- **Type**: PCB connector (through-hole mount, multipin)
- **Part Number**: 2007042-3
- **Application**: High-reliability interconnects in space systems
- Applicable Specs:
    - ECSS-Q-ST-70-02C (Outgassing Test)
    - MIL-STD-883 / 2022 (Solderability and Wetting Evaluation)
    - ECSS-Q-ST-60-13C (Commercial EEE Components)

Test Execution and Failure Details

The solderability test included preheating, flux application, and immersion in a SnPb bath at standard conditions.

Cleaning was performed using isopropyl alcohol (IPA) as per internal guidelines.

When the same units were later subjected to the outgassing test (TML/RML/CVCM analysis using quartz crystal microbalance), non-compliant values were recorded:

- First test sample (post-solderability):
    - RML: 1.141% (limit: <1.00%)
    - CVCM: 0.115% (limit: <0.10%)
      → *Failed*
- Second sample from same lot (no solderability exposure):
    - RML: 0.868%
    - CVCM: 0.004%
      → *Passed*

The failed result was linked not to intrinsic material properties, but to residual flux trapped in internal connector geometries that was not fully removed by standard cleaning. This flux likely volatilized during bake-out, skewing the outgassing values beyond acceptable thresholds.

Resolution and Internal Guidelines

A specific internal recommendation (IRN) was issued to address the sequencing conflict between solderability and outgassing tests. The following corrective actions were introduced:

1. Sample Splitting
   - Outgassing samples must be separate from those used for solderability and marking permanence tests.
2. Advance Quotation Disclaimer
   - New quotations must include a note warning of the risk of false outgassing failures when solderability is performed beforehand.
3. Dedicated Cleaning Measures
   - For cases where test separation is not feasible, additional cleaning methods are applied prior to outgassing, including:
     - Ultrasound cleaning
     - Dry ice blasting
     - Targeted spray solvents
4. Test Planning Adjustments
   - Screening and qualification flows were updated to ensure that flight units designated for outgassing are preserved from prior exposure to flux-based tests.

Lessons Learned and Recommendations

- **Test sequence matters**: Chemical contamination from solderability processes can bias mass loss readings during outgassing.
- **Cleaning alone may be insufficient**: Standard IPA procedures may not reach inner cavities in complex components.
- **Sample traceability and control are critical**: Dedicated tracking of which units undergo which tests is mandatory to avoid mixed results.
- **Transparency with customers**: Risks must be communicated at quotation stage when sample quantities are limited and multi-purpose usage is expected.
- **Adaptation of standards**: ECSS-Q-ST-60C and internal procedures now provide greater flexibility to manage known risks from COTS parts and real-life test constraints.

This case underscores the need for careful planning and coordination in multi-step environmental qualification programs, especially when dealing with commercial parts in high-reliability applications.

Case 5: Lessons Learned on Detection of Kemet Chip Ceramic Capacitors Failures

Problem Description

Multiple failures were reported during the qualification of chip ceramic capacitors procured for a space program, following solderability and DPA (Destructive Physical Analysis) tests. The affected components—industrial-grade capacitors with part numbers 1515B392K202EM and 1825B392K202EM—exhibited internal cracking in the ceramic dielectric, revealed during cross-section analysis.

Initial analysis by the manufacturer attributed the damage to electrical overstress during factory testing. However, ALTER's investigation demonstrated that the cracks likely occurred during laboratory handling, more specifically between external visual inspection and the solderability test. This conclusion was supported by evidence of fluorescent resin inside the cracks, which confirmed that damage was present before encapsulation and not a polishing artifact.

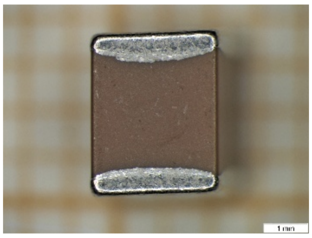

Figure 20 1515B392K202EM, EVI side 1

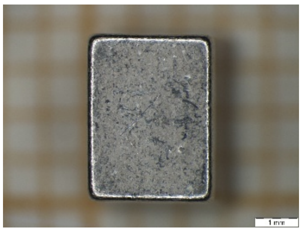

Figure 21 1515B392K202EM, EVI side 2

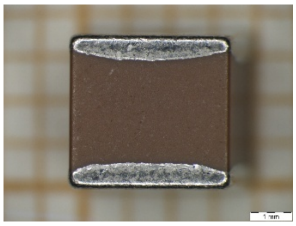

Figure 22 1515B392K202EM, EVI side 3

Figure 23 Cross Section general view

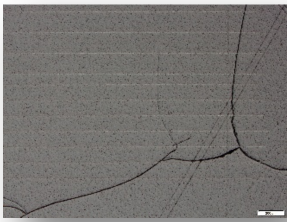

Figure 24 Cross Section detail of several cracks affecting active part

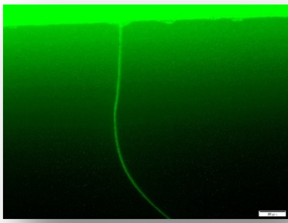

Figure 25 Cross Section. Thanks to fluorescence it is confirmed that the crack was before cross section.

Components Involved

- **Type**: Chip Ceramic Capacitors (Industrial Grade)
- **Part Numbers**: 1515B392K202EM and 1825B392K202EM
- **Application**: Power regulation and filtering in space-grade electronics
- **Standards Referenced**: MIL-STD-202G Method 208 (Solderability), DPA protocols per ESCC and internal ATN specifications

Investigation and Root Cause Analysis

1. **Failure Repetition in Replacement Lot**
   A replacement lot using a different case size (1825) but the same electrical characteristics failed in the same way after the solderability test, with identical crack morphology in the dielectric.
2. **Non-Destructive Analysis (SAM)**
   Scanning Acoustic Microscopy (SAM) was performed prior to cross-sectioning, revealing delamination-like features consistent with internal cracking.

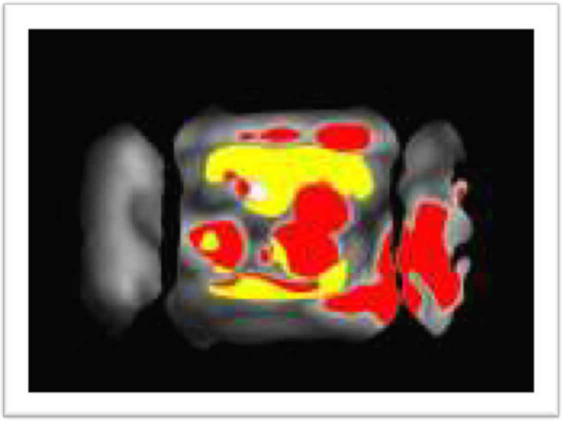

Figure 26 Delaminations observed in SAM before cross section

3. **Visual Correlation**
   Post-solderability inspection images showed subtle lines and fractures on the ceramic surface, not present before the test. This suggested that test conditions—not factory defects—were the trigger for the failure.
4. **Mismatch with Datasheet Conditions**
   A detailed review of the datasheet revealed that these industrial-grade capacitors require a specific preconditioning sequence before undergoing solderability testing, per the manufacturer's recommendation. This step was initially overlooked.
5. **Repetition with Correct Preconditioning**
   A new DPA was conducted on three additional samples following the recommended preconditioning. No cracks or defects were found in either visual, SAM, or cross-section analysis. The final conclusion validated that the original solderability method caused the failures.

Lessons Learned and Recommendations

- Always review manufacturer datasheets thoroughly when procuring industrial-grade components for high-reliability applications.
- Solderability test conditions must be tailored to the specific construction and material properties of the part; generic application of MIL-STD methods may be insufficient or damaging.
- Preconditioning steps—such as controlled heating or aging—must be applied when specified by the manufacturer.
- SAM inspection is a powerful non-destructive tool that can detect internal defects early in the analysis flow.
- Collaboration between quality assurance and materials lab teams is essential to distinguish between manufacturing defects and test-induced artifacts.

This case highlights how procedural gaps in test planning—even when following standard methods—can lead to false failure attribution. Adapting qualification processes to component-specific requirements is essential for avoiding unnecessary rejections and preserving the integrity of procurement decisions.

Case 6: Reliability Issues in Coil Assemblies Using Copper Wires < 63 µm in Diameter

Problem Description

During the integration of flight hardware for a Class 1 Satellite project, one chip-type inductor failed during post-assembly electrical testing, exhibiting an open circuit. The failure was found on one of six devices of the same lot, which were mounted onto a flight electronics board and subjected to a standard Vapor Phase soldering process (approx. 220 °C). The device used ultra-thin copper wire—specifically 32 µm in diameter—for the internal winding.

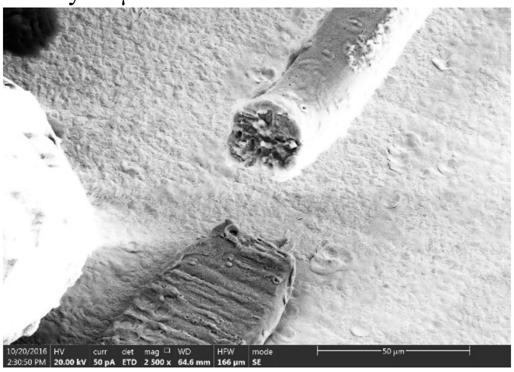

Figure 27 SEM view if broken wire causing open circuit

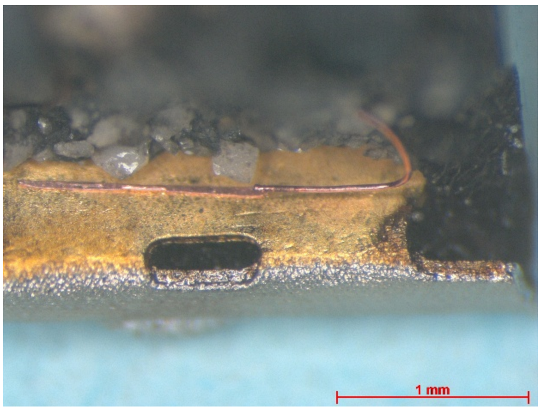

Figure 28

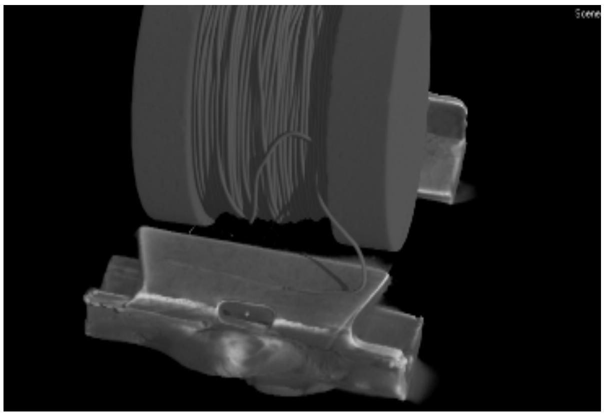

Figure 29

Notably, qualification models assembled manually had not shown this failure, which prompted a detailed failure analysis to determine the effect of production processes on the mechanical reliability of thin-wire components.

Component Involved

- **Type**: Surface-mounted chip inductor (molded body)
- **Inductance**: 1 mH, 10% tolerance
- **Internal Construction**: Copper wire diameter: 32 µm
- **Mounting Process**: Vapor Phase reflow
- **Applicable Specs**: ESCC 3201/008 series (20K), Internal IRN-001

Investigation and Root Cause Analysis

Failure analysis confirmed that the wire fracture occurred precisely at the junction between the winding and the lead frame. The wire was broken in such a way that contact could be temporarily restored by physically pressing the wire down with a micro-probe, demonstrating that the open circuit existed prior to decapsulation.

Key findings included:

- **Mechanical Stress Sensitivity**: The ultra-fine wire (32 µm) was vulnerable to damage during welding and thermal excursions. Crimping force during the weld operation likely exceeded safe mechanical tolerances.
- **Incomplete Inspection Practice**: The visual inspection applied by the supplier was limited to top-side evaluation. Lateral crushing at the junction was not observable from that perspective and thus went undetected.
- **Process Induced Stress**: A degolding process, performed prior to reflow soldering, may have induced thermal shock, aggravating stress on the wire-lead connection.
- **Electrical Test Gaps**: During qualification at ESCC Class C level, certain electrical tests (e.g. Chart F3) were omitted, missing early signs of mechanical weakness.

Corrective Actions and Recommendations

- **Mandatory Precap Inspection for Thin Wire Components**
  For all inductors using copper wires with diameter < 63 µm, Precap Inspection shall be performed on 100% of the batch to evaluate:
  - **Vertical crushing**: must not exceed 50% of the wire's original diameter.
  - **Horizontal spreading**: must not exceed 25% of the wire diameter.
- **Enhanced Visual Criteria**
  Precap and IVI should include side-view inspection specifically focused on the lead-frame/wire junction.
- **Assembly Adaptation Based on Wire Size**
  Soldering, degolding, and handling procedures must be specifically qualified for ultra-thin wire windings to prevent overstress.
- **Reinforcement of Qualification Flow**
  Inclusion of intermediate electrical continuity tests is recommended, especially when using parts with fragile internal geometry.
- **Procurement Planning**
- For future procurements, PADs and test plans must define construction-specific risks and integrate manufacturer-specific inspection criteria (e.g., junction compression rules) into the evaluation.

Lessons Learned

- Components with internal wires < 63 µm require special process control at all stages—from procurement to final assembly.
- Standard inspection and soldering processes may be inadequate without adaptation to the mechanical limitations of the component design.
- Visual inspection must be multidirectional, especially for miniature components with critical internal terminations.
- Explicit coordination between QA, laboratory, and design teams is essential to align process capability with part design.

This case emphasizes how mechanical stress on thin wire junctions, when undetected, can lead to critical latent failures in high-reliability assemblies. Preventive inspection strategies and custom handling instructions are key to ensuring long-term performance in space-class electronics.

Case 6: Cracks in Solder Joints of Electromagnetic Latching Relays (Metal Can, Hermetic)

Problem Description
During the Precap Internal Visual Inspection (IVI) of a batch of electromagnetic latching relays (metal can, hermetically sealed), a significant anomaly was detected. More than 80% of the units showed cracks in the solder joints between the relay header pins and the internal connections. The anomaly was found across several lots intended for different end users, and was initially detected during precap of a lot of 173 relays.

The non-compliance was classified as critical under ESCC Basic Specification No. 2043600, section 4.4.d, which explicitly disallows solder joints with visible cracks.

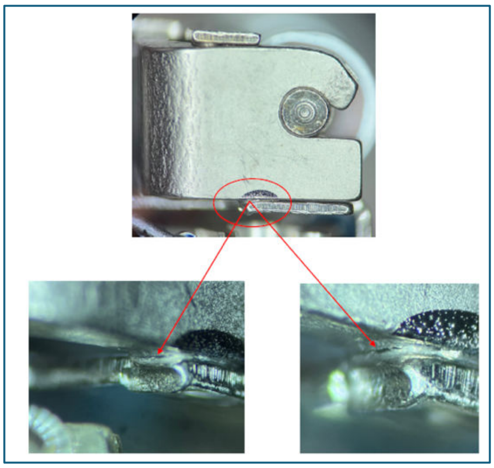

Figure 30 Cracks on solder joint in CSI precap

Component Involved

- **Type**: Electromagnetic latching relays, hermetically sealed, cylindrical metal can
- **Application**: Power switching and telemetry isolation in high-reliability spacecraft
- **Process Stage**: Internal Visual Inspection (IVI)
- **Standard**: ESCC 2043600, ESCC Basic Specification No. 2043600, issue 2, para 4.4.d
  4 DETAILED REQUIREMENTS
  4.4 ELECTRICAL WELDS
  4.4.d Welds with cracks

Root Cause and Manufacturer Analysis
Following the discovery, a technical discussion and root cause analysis were initiated. The manufacturer acknowledged that the anomaly was new and had not been previously reported. Upon investigation, they identified the following causes:

- **Incorrect electrode positioning** during header soldering
- **Excessive energy** applied in a concentrated area during the welding process
- Resulting in localized overheating and mechanical stress → *solder joint cracking*

Further tracing revealed that the problem was present in **seven different production lots**. All exhibited similar cracking phenomena in the solder joints.

Corrective Action and Rework Validation
The manufacturer proposed a rework process using **laser welding** to repair the cracks. To validate the robustness of this rework, a subset of relays underwent **Chart F4-like validation testing**, divided as follows:

- Thermal shock, low-level sine & random vibration, low-level mechanical shock
- High-level sine vibration, high-level mechanical shock
- Mechanical life endurance test

All tests were completed with satisfactory results. The rework method and final product quality were subsequently accepted by the involved agencies.

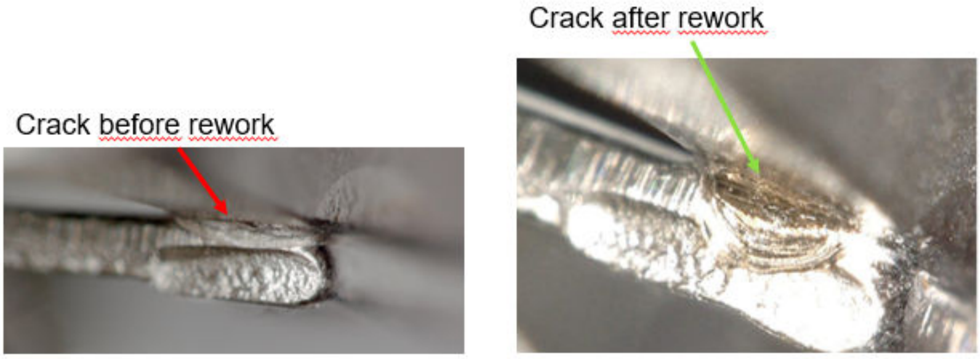

Figure 31 Example of manufacture's reworking of a crack

Lessons Learned and Recommendations

- **Internal Visual inspection must focus on solder joint integrity**, especially in hermetically sealed electromechanical devices where internal stress during sealing can propagate unnoticed.
- When **reworking** cracked solder joints, extensive requalification—including mechanical endurance—is required to ensure flight reliability.
- **Photos and detailed comments** on solder joint condition must be included in DPA reports regardless of whether the units are reworked or not.
- **Internal Visual Inspection criteria must be applied systematically** across relay types, even if the issue was first detected in a specific series.
- Early coordination with the manufacturer is essential to confirm proper tooling setup and parameter control for header soldering operations.

This case emphasizes the importance of proactive inspection and rework validation strategies in electromechanical components where solder joint integrity is critical to mission success.

Conclusions

Common Challenges and Patterns Identified

The case studies presented in this paper reveal a consistent set of challenges faced when qualifying passive components for use in harsh environments. These include:

- Surface finish anomalies such as pure tin usage, gold plating delamination, or inadequate underplating thicknesses, all of which can compromise reliability or process compatibility.
- Solderability issues and incompatibility between components and assembly methods—particularly when epoxy, vapor phase, or degolding processes are involved—leading to latent electrical failures.
- Failures stemming not from the components themselves, but from test setup inconsistencies, inspection blind spots, or misinterpreted standards.
- Gaps in documentation and late communication of critical constraints, which hinder proactive risk identification and mitigation.

In most cases, root causes were traced to a combination of process variability, mismatched assumptions between suppliers and integrators, and regulatory guidance that has not kept pace with real-world COTS adoption and complex assembly flows.

Key Lessons Learned

- **Risk management requires contextual flexibility**: Rigid application of legacy standards without room for judgment can lead to misclassification of recoverable issues.
- **Communication is central**: Early engagement between procurement, quality, test labs, and manufacturers helps surface assumptions and technical constraints before failures occur.

- **Corrective action must be supported by evidence**: Visual documentation, microstructural analysis, and cross-disciplinary collaboration are essential for effective root cause identification and systemic improvement.
- **Knowledge capture and training** are essential to prevent recurrence of similar issues across projects, especially as workforce experience varies and standards evolve.

Recommendations for the Community

- **Engage early and proactively**: Clearly define qualification requirements and process constraints before procurement. Ensure these flow down to all stakeholders.
- **Reinforce inspection frameworks**: Combine traditional visual checks with advanced analysis techniques (e.g., SEM, SAM, microsection) and update inspection criteria based on observed risks.
- **Elevate supplier relationships**: Approach manufacturers not just as vendors but as partners in reliability—share findings, support process improvements, and encourage transparency.
- **Institutionalize feedback loops**: Use NCRs, IRNs, and case reports not only as reactive tools but as inputs for evolving specs, internal guidelines, and industry standards.
- **Maintain agility**: Anticipate that deviations and rework may be necessary. Embed contingency plans and alternate strategies into qualification frameworks, particularly for critical or long lead-time parts.

By synthesizing these lessons, the space and high-reliability electronics community can build a more resilient and adaptive approach to passive component qualification—one grounded in real-world evidence, technical rigor, and collaborative improvement.

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