Evaluation of Parts for a Low Temperature Environment on Mars

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Content

ExoMars Programme Overview

- ESA programme carried out in cooperation with Roscosmos and Thales Alenia Space in the role of Prime Contractor
- Two missions are foreseen:
  - 1st mission with launch date in 2016 consisting of an Orbiter plus and Entry, Descent and Landing Demonstrator Module
  - 2nd mission in 2018 featuring a Rover with a drill and instruments dedicated to exobiological and geochemical research
- Goal
  - Investigate environment on Mars, search for signs of life
  - Develop and demonstrate technologies necessary for future exploration missions, e.g. surface mobility with a rover, access to the subsurface, sample acquisition, preparation and analysis of samples
- Tesat-Spacecom GmbH & Co. KG was contracted by Thales Alenia Space as CPPA and has carried out the Evaluation Test Campaign

ExoMars Mission 2018 Scenario and Requirements

- Temperature on Mars: -120°C (night) to +30°C
- Nominal system operation: 218 sols
- Mission Scenario:
  - Certain equipment can not be heated or operated over night due to limited power available.
  - Thus, EEE parts in un-heated equipment in dormant mode will cool down to the low Martian night temperature -120°C
  - During Martian day time, the parts will be within the qualified temperature range
- EEE Parts:
  - Lowest temperature limit for which parts are normally qualified is -65°C
  - Tesat-Spacecom‘s extensive data research and manufacturer survey revealed that only very limited information about parts performance at this low temperature is available
  - Almost no information about long term reliability, especially when exposed to a high number of temperature cycles, is available
- Consequence: Necessity of Low Temperature Evaluation

Procedure for Parts Selection

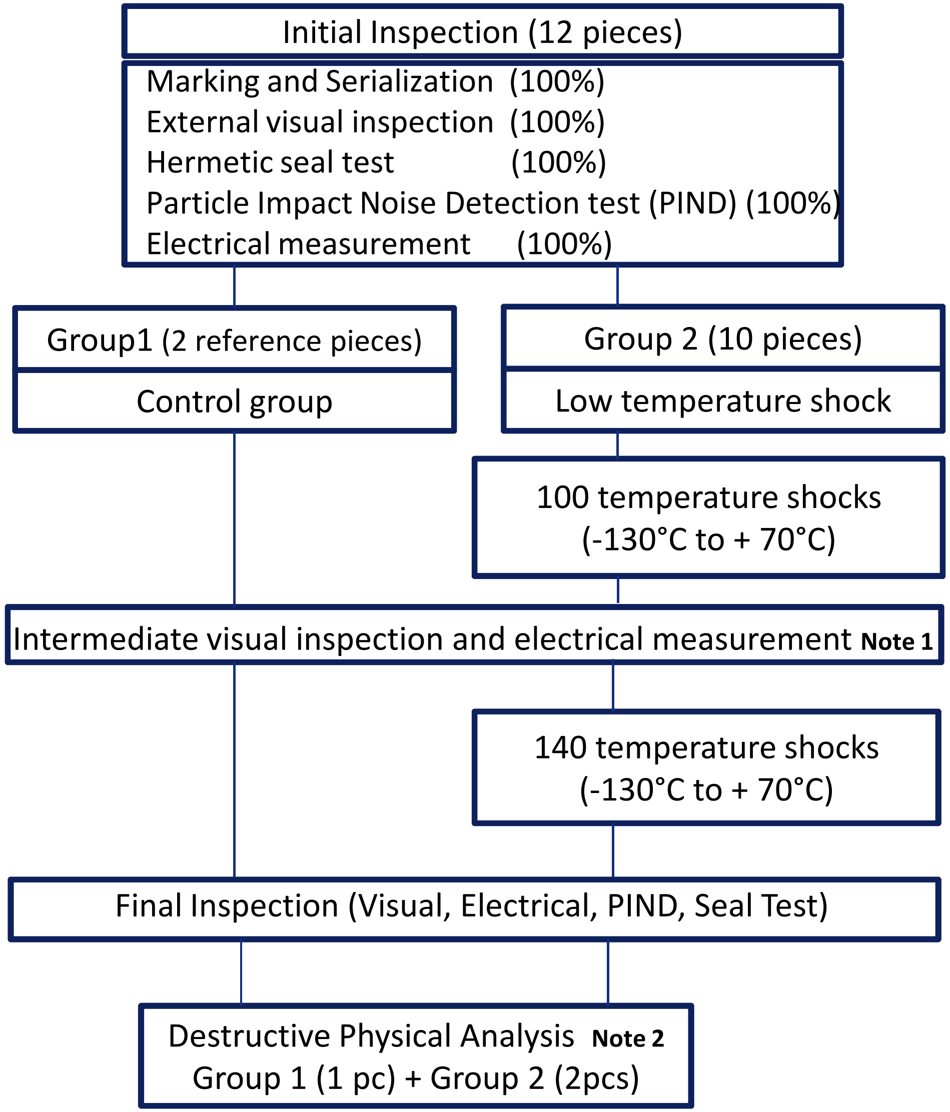
- Parts selection by Tesat considering the following criteria:
    - Package type
    - Assembly method
    - Function
    - Value and style for passive components
    - Technology
    - Construction
- Test candidate to reflect worst case of package and combination of assembly technologies
- Selection of 67 test candidates based on users' parts lists and representative for 245 part types

Low Temperature Evaluation Test Flow

- Thermal Shock is considered as confidence indicator for capability of EEE parts to survive large temperature changes
- Storage condition is applied
- In analogy to ESCC flow and agreed with ESA and Thales
- Sample size 12 pieces: 10 pieces in test group, 2 reference sample (in exceptional cases less parts)
- Total number of shocks: 240 (100 shocks + 140 shocks)

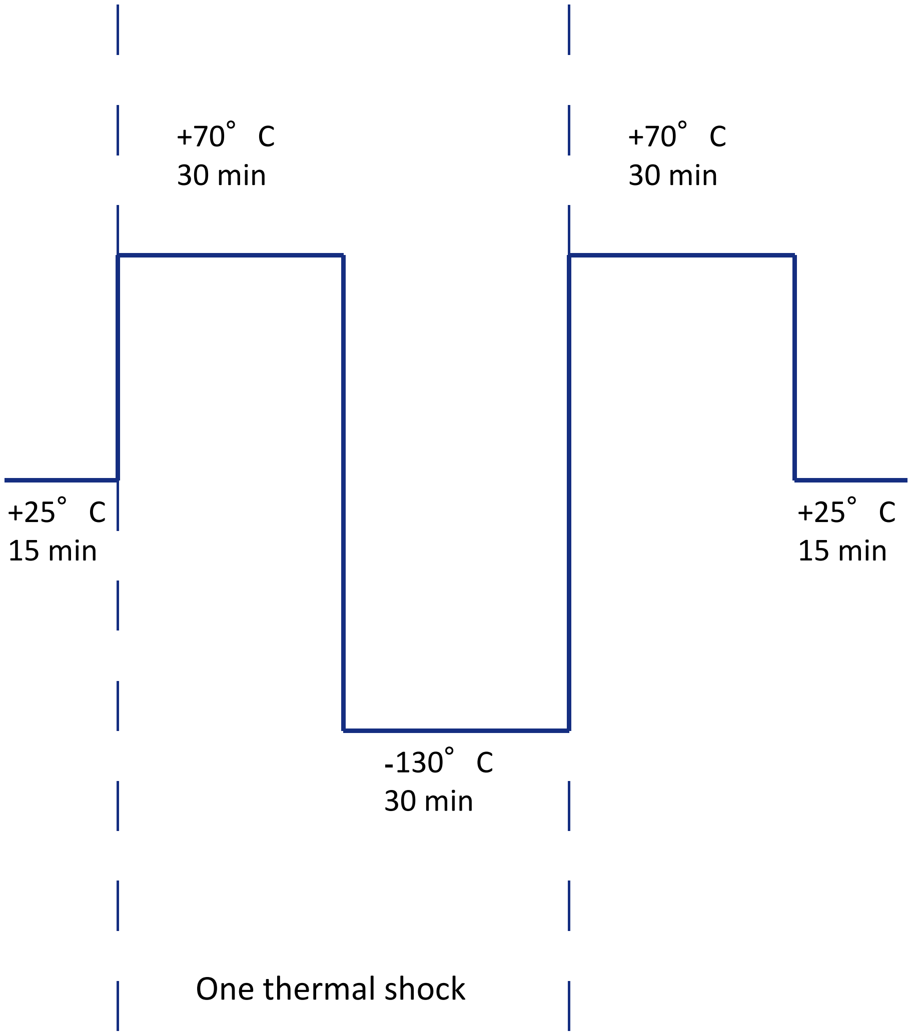
- Note 1: Removal of part from test group in case of failure, continuing with Failure Analysis
- Note 2: Only failed parts or parts showing significant drifts were submitted to DPA (Exception: DPA on FPGA, oscillators, optocouplers)

Generic Evaluation Test Plan EXM-MS-EVA-TES-001



Low Temperature Evaluation – Temperature Shock

- Temperature extremes are
  – 130°C (0/–10°C) and
  +70°C (0/+10°C)
- Dwell time 30 minutes at each temperature extreme
- Temperature gradient: 40K/min (±10K/min)
  Temperature change in 5min (± 1min)
- Parts neither mounted nor biased



Test Equipment – Temperature Shock Test Chamber

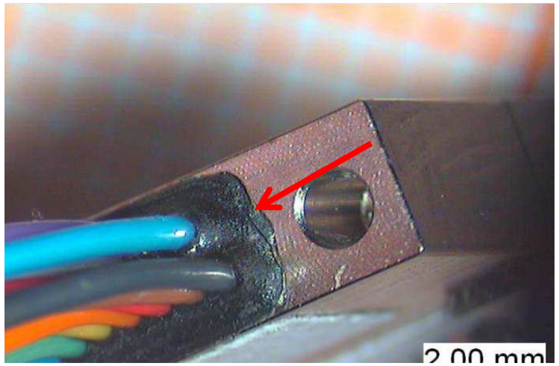
- Customized Low Temperature Test Chamber manufactured by Vötsch
- The chamber consists of a power-coated box with electrolytically galvanized steel panel, with an interior made of high-grade steel with a capacity of 150l
- 4 homogenously distributed slide grids
- Independently operating temperature sensors
- Cooled down by liquid nitrogen
- Designed for temperature extremes -140°C to +90°C
- Software for monitoring and recording the temperature and gradient

Overview of Test Candidates and Test Results after 240 Shocks

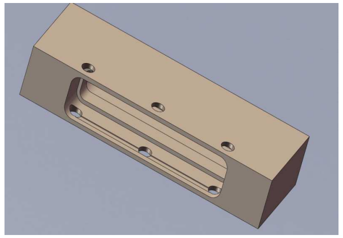
Part Family	Number of Part Types (Total: 67)	Total number of tested parts (pieces)	Critical Failure	Acceptable Finding
Capacitors	14	130	-	-
Connectors	4	20	5	-
Oscillators	4	13	1	-
Diodes	2	20	-	1
Inductors	6	30	30	-
Microcircuits	11	74	-	-
Relays	2	15	-	-
Resistors	16	160	-	-
Transistors	3	20	-	2
Optocouplers	5	50	7	-

- 91,4% of the parts submitted to the temperature shocks have successfully passed the Final Inspection

Test Results - Connectors

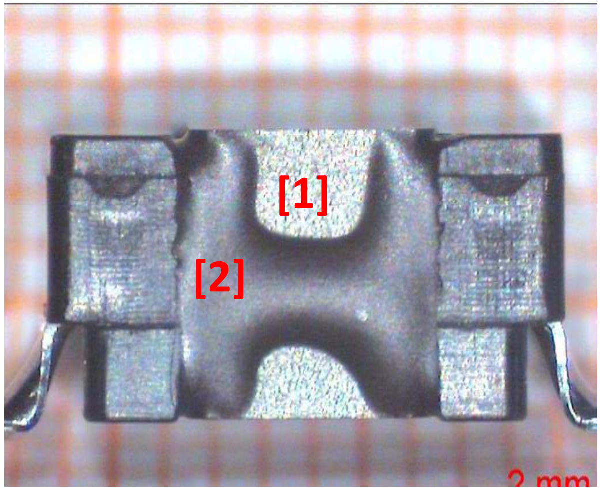


- Test Candidates:
  - 2 Types of Rectangular Nano Connectors per MIL-DTL-32139
  - 2 Types of Rectangular MDM Connectors per ESCC3401/029
- Test and Failure Analysis Results:
  - All parts of one socket Nano connector type show cracks in the potting on the rear side of the connector. Internal visual inspection revealed a shifting in the epoxy.
  - Significant expansions and contractions due to high coefficient of thermal expansion ($\alpha = 148 \times 10^{-6}/K$)
- Conclusion:
  - A shifting or lifted potting could result in a disconnection of the solder contact between the pin and the socket connector and could interrupt the electrical current.
  - Re-design of the housing of the connector to avoid shifting of the potting. The manufacturer proposed an enlarged housing with a slot and with several holes on the side of the shell
  - Three out of the four tested types met the evaluation test requirements.



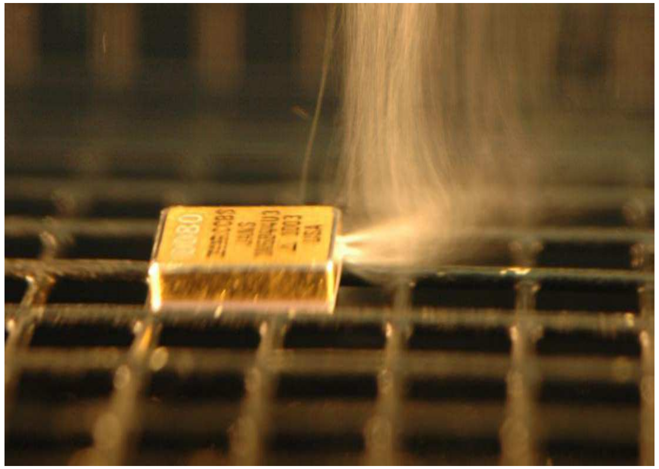
Test Results - Inductors

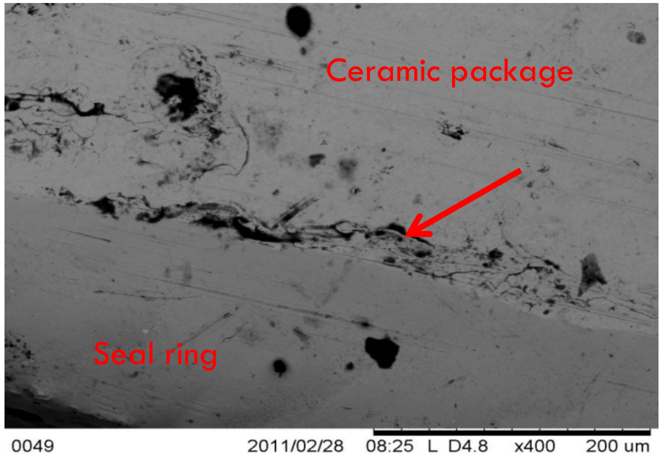
- Test Candidates:
  - Copper winding molded in glass fiber epoxy resin, ferrite [1] halves stuck on the potted sub-assembly and glued together [2]. Six part types evaluated.
- Test Results and Failure Analysis:
  - Deep cracks in the epoxy of all parts after the first 100 temperature shocks, on some samples even cracks in the ferrite
  - Difference in expansion coefficients of epoxy and ferrite results in a shear force between epoxy and ferrite. As a consequence, the epoxy cracks and peels of the ferrite.
  - Temperature shocks induce a weak discoloration
- Conclusion:
  - Redesign with new cyanate ester resin and subsequent evaluation



Test Results – Diodes (1)

- Test Candidates:
  - Silicon diode in SMD B (D-5D) package, Schottky diode in LCC2B, Power Schottky Rectifier in SMD-0.5
- Test Results:
  - The silicon diode in D-5D package in the Schottky diode in LCC2B package showed good performance and met the project's low temperature requirements
  - 1 piece out of 10 tested Schottky Rectifier parts in SMD-0.5 package failed the gross leak testing
- Failure Analysis
  - A crack in the ceramic package near the seal frame was identified by a continuous stream of bubbles during the gross leak testing and verified by SEM



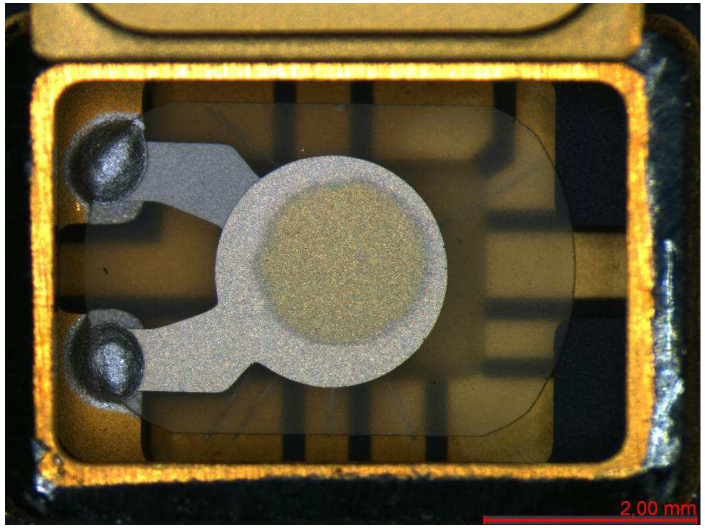


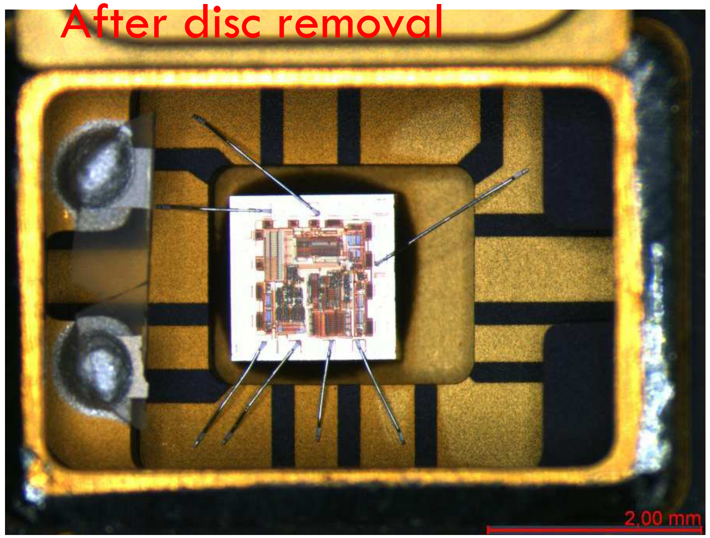
Test Results – Diodes (2)

- Root Cause:
  - Different thermal expansion coefficients
    Housing made of ceramic Al_2O_3: $\alpha_{ceramic} = 6{,}5 - 8{,}9*10^{-6}$ /K
    Kovar Seal ring: $\alpha_{Kovar} = 5{,}2*10^{-6}$ /K
    Silicon die is soldered with Pb/In/Ag to the copper-tungsten pad of the package:
    $\alpha_{AgCu} = 16 - 17*10^{-6}$ /K
    $\alpha_{SnPb} = 24{,}5*10^{-6}$ /K
- Conclusion
  - An insufficient isolation between two electric voltages can cause an inadvertent voltage flashover which generates an arc
  - Due to cracks in the ceramic package, the isolating effect was no longer guaranteed.
  - The risk of arcing due to leakage packages originates only at high voltages (>150V)
  - Schottky diodes are available in SMD-0.5 only up to 150V and are released for use in the low temperature application with operating voltages up to 150V (even though cracks in the packages were revealed)

Test Results – Oscillators (1)

- Test Candidates:
  - 3 Types - 2 Crystal based hybrid oscillator in SMD package whereas the crystal disc is fixed with a conductive silver epoxy (of epoxy type A or T) and crystal based hybrid oscillator in J-lead SMD package
- Test Results:
  - All 3 types passed the visual inspection, PIND test and Seal test
  - One out of five parts of the oscillator with type A epoxy failed the final electrical measurement



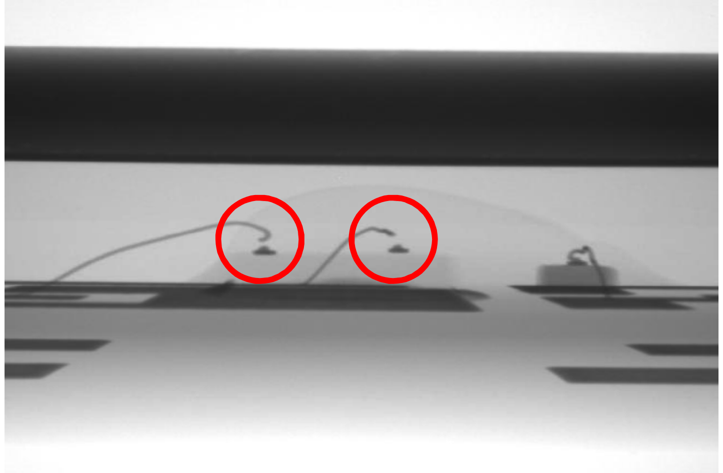


Test Results – Oscillators (2)

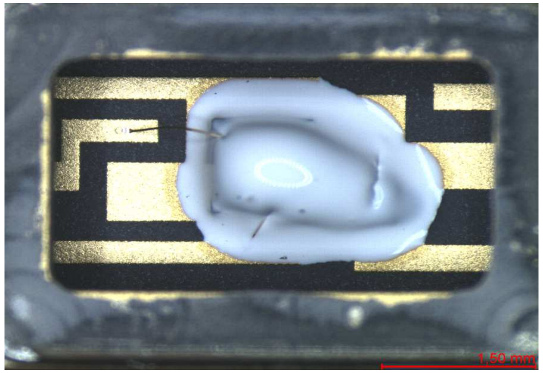
- Failure Analysis
  - The multiple thermal shock exposure resulted in stress settling on the crystal unit and the crystal mounting.
    The thermal stress changed the resistance of the spurious mode to be become dominant in certain temperature range.
  - Type A epoxy has a glass transition temperature of about 103°C
  - High thermal expansion coefficient $\alpha = 55*10^{-6}/K$ (> type T)
  - In glassy state, epoxy type A gets brittle
- Conclusion:
  - Parts that used the epoxy type T are more thermal stress compliant than those parts that used epoxy A.
  - Oscillators with epoxy type A are not recommended for use in equipment exposed to low temperature

Test Results – Optocouplers (1)

- Test Candidates:
  - 5 optocouplers, different packages (LCC6, 6 pin Gullwing package), LED with different wavelengths
  - Optical coupling via a silicone covering the LED and the photo transistor
  - Internal wire bonding with Au bonds with 25 µm or 35 µm diameter
- Test Results
  - All parts passed the external visual inspection, the PIND test and the Seal Test
  - 7 pieces out of 30 tested parts failed the electrical measurement
  - First failures after 100 temperature shocks
  - Failures revealed by DPA: De-bonding of emitter bond balls, broken emitter and basis bond wires, broken LED stitch bonds
  - Failed parts have bonds with 25 µm diameter



X-Ray photograph of the broken emitter and basis bond, crinkled bond wires



Test Results – Optocouplers (2)

- Failure Analysis
  - Glass transition of silicone is about -110°C, curing temperature about 150°C
  - Significant volume contraction of the silicone at low temperature
  - High increase of the modulus of elasticity with decreasing temperature
  - Material is considerably harder below the deformation point and applies stress to the bond
- Conclusion:
  - A thicker wire bond is more robust
  - Material with low deformation point preferable
  - Reduce the silicone light pipe or use a construction without any silicone
  - Recommendation to perform the low temperature evaluation on an optocoupler without silicone

Summary of Test Results & Conclusion

- 91,4% of the tested parts have passed the low temperature evaluation tests
- A good performance has been demonstrated in particular for capacitors, relays, resistors and microcircuits
- The revealed findings are related to
  - Package design: micro-cracks have been found on parts with SMD-0.5 packages, housing of a connector type requires re-design
  - Materials: some epoxy types are not suitable when exposed to low temperature test conditions (e.g. inductors, oscillator)
  - Technology based on use of silicone gel (e.g. optocouplers) is not recommended
- Recommendation to verify suitability of the proposed modifications by evaluation testing after re-design

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Thank you for your attention

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