LOW TEMPERATURE EVALUATION OF EEE PARTS ON EXOMARS ADE ROVER 14TH SYMPOSIUM ON ADVANCED SPACE TECHNOLOGIES IN ROBOTICS AND AUTOMATION

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ABSTRACT

The special feature of the Martian surface is the extreme low temperature that may be reached along the Martian night, down to -113ºC. Exomars rover mission includes an ADE (Actuator Drive Electronics) equipment dedicated to house control electronics of rover motors and mechanisms. The ADE is located externally to the thermal controlled area and therefore it will be submitted to the inclemency of the extreme Martian environment.

Low temperature evaluation campaigns were performed at EEE (Electrical, Electronic and Electromechanical) component level to validate the behaviour of the electronic parts under extreme temperature and the effects of thermal fatigue produced by the alternation of high and low temperature exposure.

1. INTRODUCTION

The 2020 mission of the ExoMars programme will deliver a European rover and a Russian surface platform to the surface of Mars. The ExoMars rover will travel across the Martian surface to search for signs of life. It will collect samples with a drill and analyse them with next-generation instruments. It will be the first mission to combine the capability to move across the surface and to study Mars at depth. ExoMars is a mission led by the European Space Agency in collaboration with Roscosmos. Airbus Defence & Space UK is the Rover Module Prime Contractor, Thales Alenia Space in Italy is the Mission Prime.

The rover will carry a payload capable to detect bio-signatures in the depth of Mars surface. To accomplish this ambitious mission a mobility system for the rover will be required in order to conduct the scientific experiments along different location of the Martian surface.

The rover provides key mission capabilities: surface mobility, subsurface drilling and automatic sample collection, processing, and distribution to instruments. It hosts a suite of analytical instruments dedicated to exobiology and geochemistry research: this is the Pasteur payload.

The rover includes an ADE (Actuator Drive Electronics) equipment, which provides power and signal for the three Bogie ElectroMechanical Assemblies (BEMA), the deployable mast (DMA) including its pan and tilt mechanism and the solar array hinges.

The Actuator Drive Electronics (ADE) plays a major role in the movement of the rover as its main task is the driving of the motional actuators on board. ADE is also in charge of handling a number of hold-down release mechanisms and the management of other sensors and actuators so as to keep under control the thermal behaviour of the motors.

One of the main challenges of the ADE development is driven by the accommodation place of the unit within the rover. The ADE is located externally to the thermal controlled area and therefore it will be submitted to the inclemency of the extreme Martian weather. The placement of the ADE has been selected in order to optimize the overall mass of the rover and to allow optimum access to the actuators; however this need generates a set of critical issues related to the environment that the ADE shall sustain.

2. EEE EXOMARS REQUIREMENTS

The Exomars mission has specific constraints that are originating from the environmental and planetary protection requirements. In this way, extended evaluation of components, materials and processes have been carried out to validate the thermal and radiation robustness and as well as to commit with the sterilisation requirement.

Accordingly, the design of the ADE electronic system has been conditioned with the constrains imposed by the environmental conditions.

2.1. Radiation

During the 9-month dormant cruise phase and the at least 6 month Martian land operational the space radiation environment can cause serious effects on spacecraft equipment. In terms of electronics, accumulated damage from electron and proton exposure

will limit system endurance.
Energetic particle radiation sources from the natural environment and related possible detrimental effects are considered. They include the Solar Energetic Particles (cosmic ions and protons) and the secondary radiation generated by interaction of the aforementioned primary radiation with the spacecraft materials or with the components at the surface of the planet Mars, and are directly or indirectly (after radiation transport through the spacecraft material layers) cause of a variety of physical effects. Transient effects from individual high-energy protons or cosmic rays can disrupt system operation, perhaps irreversibly.
These physical effects in sensitive components are expressed by parameters as Total Dose, Displacement Damage and SEE.

The Total Ionising Dose (TID) is related to ionisation effects of radiation inducing degradation of electronic components and materials. The components have been selected to withstand 10 Krad(Si).
The Displacement Damage (also TNID, Total Non Ionising Dose)) is related to non-ionisation effects of radiation inducing bulk damages into materials and degradation of sensitive electronic components like CCDs, optocouplers and sensors; photovoltaic cells used to convert solar power into electric power suffer degradation of this kind, too.
The Single Event Effects are described as function of Particle Fluxes or Fluences spectra versus Energy or Linear Energy Transfer (LET), and of device cross sections and physical properties, inducing transient or permanent consequences into sensitive analogical and digital devices No functional failure shall be produced for heavy ions or solar particles having energies lower than $60 MeVcm^2/mg$.

2.2. Dry heat microbial reduction

Exomars Rover must guarantee the compliance, in addition to all typical requirements for a normal space program, with the Martian environment requirements and Planetary Protection rules. Planetary Protection rules are defined on the Outer Space Treaty of 1967 where article IX says: “States parties shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extra-terrestrial matter and, when necessary, adopt appropriate measures for this purpose”.
ADE will be placed on Exomars Rover which will run over Martial surface, then, sterilization shall be done to avoid bioburden (like bacteria) contamination.
The ADE shall be sterilised using Dry Heat Microbial Reduction (DHMR) to achieve previous requirement with the following parameters:

- 110ºC during 27 hours in cleanroom Class ISO8 conditions (45-65% humidity, overpressure higher than 0,5 mm H_2O)

Materials, processes and EEE parts have been selected to survive without degradation to Dry Heat Microbial Reduction (DHMR).
All EEE parts used in ADE have been selected to guarantee maximum storage temperature equal or higher than 125ºC.

2.3. Low Temperature

Maximum Mars temperature during the day is about +10ºC, but the special feature of the Martian surface is the extreme low temperature that may be reached along the Martian night, down to -113ºC in the worst case environment.
During the night, the ADE equipment remains switched off. A dedicated warm up electronics to heat the unit have been implemented to allow the system be operative at 12pm. Warm up circuit will be operating until a minimum temperature of -45ºC is guaranteed for any point of ADE printed circuit boards.
In Space applications, for the majority of hirel EEE parts, the standard operating range is -55ºC/+125ºC and standard storage temperature range is -65ºC/+150ºC.
The nominal mission life for the ExoMars rover is foreseen to be 218 sols (Martian days - 1sol=24,6 hours).
Of all EEE Exomars requirements, the most critical issue is the evaluation of the components and processes to cope with this thermal environment.

2.4. Warm up circuit

The only components that have to operate at low temperature are PT1000 Rosemount thermistors, BeO H1206 State of the Art resistors and Hypertac MHD and C&K MDM microminiature connectors. These components are part of warm up circuit in charge of heating ADE equipment [4].
The PT1000 thermistor is designed to measure surface temperatures in the range of -269ºC to +400ºC, but BeO H1206 resistors and connectors must be validate to operate at low temperature.
Thermal analysis showed -99ºC for initial temperature for warm up components in the worst case environment.
Thermal uprating plans have been edited by Thales Alenia Space in Spain to characterize H1206 BeO resistors and connectors at low temperature in operation.

3. LOW TEMPERATURE EVALUATION PLAN FOR EEE.

3.1. Background and heritage

This is not the first mission with constrains at low temperature. Some papers and documents had taken into account to write Low Temperature Evaluation Plan for

Exomars ADE.
Thales Alenia Space in Spain evaluated some parts at low temperature in the frame of Herschel-Planck Cryogenic equipment surviving 80 thermal cycles -258ºC (15ºK) to 23ºC (296ºK) (i.e. dT=285ºC).
TESAT performed evaluation of parts reliability after thermal cycling below rated temperature [1] and these results were used to select initial parts for Exomars ADE equipment.
The initial selection of parts tried to avoid critical parts in terms of construction as LCC and SMD0.5 packages, nano connectors, moulded parts, COTS (commercial of the shelf), PEMs (plastic encapsulated microcircuits) and devices based in silicone and epoxies.
According to Reference [1] failures in optocouplers after low temperature evaluation were explained by the silicone light pipe, which should exhibit a deformation point in the range -70ºC to -120ºC, below which the elastic modulus rises till power of ten, stressing wire bonding by contraction and dilatation (and die attach too). For that reason optocouplers with no silicone inside has been selected for Exomars ADE. One of them has been manufacturer by Isolink without silicone inside to avoid failures after low temperature thermal cycles.

3.2. Policy

In order to guarantee the reliability of the electronic parts to the extreme temperature and the effect of alternate exposure to this extreme range under storage conditions, a comprehensive low temperature evaluation plan was put together by Thales Alenia Space in Spain, with the strong contribution of the customer chain – Airbus, TAS-I and ESA.
Low temperature parts selection and evaluation policy was graded with distinct risk levels was declared, as it can be seen in Table 1.
The following rules were applied in order to ensure the successful development of ADE:

- use only components with very low to middle risk.
- define back-up alternatives for all components with middle or even moderate risks.
- evaluate to low temperature at component level for moderate to middle risk.
- evaluate to low temperature at component level selected parts as well as some back-up alternatives for middle or even moderate risk.

Risk Level #	Risk name	Description of parts falling in this category
0	VERY LOW RISK	Evaluated at LT in reference [3] successfully
1	LOW RISK	Parts very similar to parts covered by reference [3] (same assembly processes & materials)
2	MODERATE RISK	Space Heritage on cryogenic projects requiring LT evaluation.
3	MIDDLE RISK	Similar to Parts of Category 2. Not enough data but expected survivability to LT than to assembly construction
4	HIGH RISK	No data. Assembly/construction risk identified. Poor or non conclusive results in LT evaluation.
5	VERY HIGH RISK	Failed LT evalution

Table 1. General policy for risk analysis

The initial selection of parts tried to avoid critical parts in terms of construction. These EEE parts were discarded and included in risk level 4 and 5.
The only exception were Isabellenhütte SMV shunt resistors and Eurofarad PM94 metallized polyester capacitors considered as critical parts (risk 4) due to plastic moulded construction. They were included in the low temperature evaluation campaign.
EEE parts were submitted to the following thermal cycling profile in a climatic chamber in Alter laboratory.

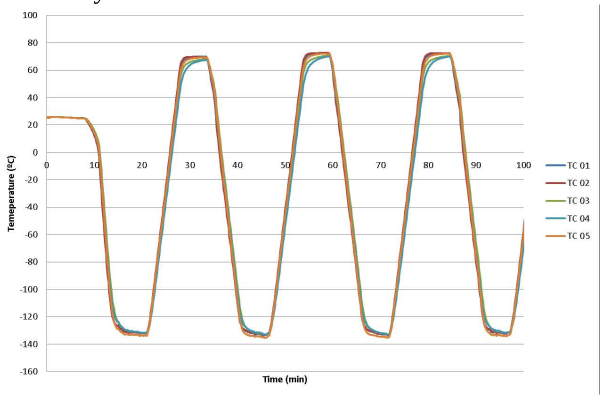

Figure 1. Thermal cycling profile

Thermal cycling profile:

- Number of cycles: 200
- Minimum Temperature: -130ºC (+0ºC, -10ºC)
- Maximum Temperature: +70ºC (-0ºC, +10ºC)
- Dwell time at min & max Temperature: 5 minutes
- Temperature change rate: >40ºC/min
- Continuous temperature monitoring based on at least 5 thermocouples located at different oven

positions.

Low temperature evaluation campaigns were performed at component level including 200 thermal cycles from -130ºC to +70ºC, initial and final electrical measurements at room, external visual inspection and DPA (destructive physical analysis).

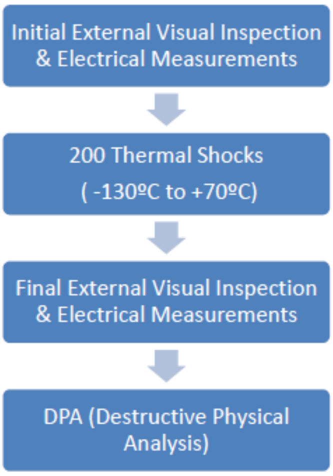

Figure 2. Sequence of test for LT evaluation

The sample size for low temperature evaluation was chosen on a case-by-case basis, taking into account each device and its criticality. Sample sizes ranged from 2 to 10.

The following picture shows the samples placed inside the climatic chamber. The samples were placed on a metal grid. The areas with direct contact to the samples were covered with Kapton, avoiding any direct contact to any metal part of the grid support. The control thermocouple (TC) was placed near the central samples. Additional thermocouples were attached to the metal grid near the samples.

Figure 3. EEE parts inside the climatic chamber

4. LOW TEMPERATURE EVALUATION RESULTS.

Different families of components were evaluated at low temperature (capacitors, connectors, diodes, fuses, inductors, integrated circuits, relays, resistors, transistors, transformers, optocouplers and hybrids) in 8 campaigns. 95 different types of parts (component families, manufactures, sizes, packages) were tested at LT. A total of 361 samples were evaluated at LT by Thales Alenia Space in Spain.

After 200 thermal cycles, all parts passed the low temperature evaluation except 1N5822US diode and DCDC converter.

1 out of 5 tested pieces of 1N5822US failed after 200 thermal cycles performed. Reverse current was out of specification.

With knowledge of some history of failures due to temperature excursions in some didoes and after the LT evaluation results in the frame of Exomars ADE, Thales Alenia Space in Spain concluded this diode is sensitive to thermal cycling and it was rejected and removed from ADE design.

The DCDC converter hybrid was considered one of the most critical parts in terms of survability at low temperature due to complex internal construction (3 substrates, different die sizes and attach process, heavy magnetic devices, stacking of ceramic capacitors,…). For that reason group A (electrical measurements at room, low and high temperatures -55ºC, +25ºC and +85ºC) were performed before and after thermal cycling.

Three pieces of Date Code (DC) 1448 were subjected to Group A according to MIL-PRF-38534 screening at manufacturer facilities. Two of three parts were successfully tested, but after thermal cycling, one of three units (SN 1418002) passed +25ºC and +85ºC screen, but failed electrical test at -55ºC. Unit was inoperable at any temperature after failure (no signal at the outputs, performance not recovered either at 25ºC or any other temperature).

From the beginning the manufacturer worked together with Thales Alenia Space in Spain to try to find the root cause of failure implementing corrective actions to improve the survivability of the DCDC converter in low temperature thermal cycling.

According to the manufacturer investigations the root case for failing was lifted trace of metallization under one inductor L9.

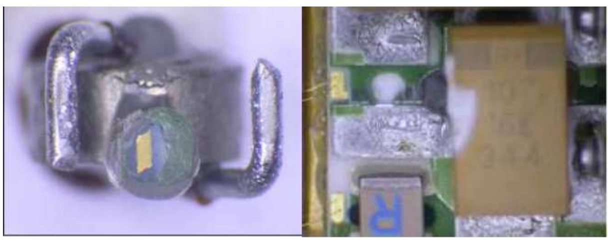

Figure 4. Inductor L9 removed with gold trace damaged

This failure was probably due to the expansion and

contraction of different materials during the thermal cycles and the differences of the CTE (coefficient of thermal expansion) between the substrate and the conformal coating used.
Two different glues are in contact with L9:

1-On the top surface of L9: White Colour epoxy. It used for improving resistance to constant acceleration of the heavy components (magnetics and stacked capacitors), and also for insulation to lid.
2-On the lower surface of L9: Grey colour epoxy to stake L9.

To avoid this problem the grey epoxy was changed to other glue with extremely low Young Modulus, and thus it is highly flexible and has better elongation capability.
Manufacturer delided the parts and performed the rework on
- 2 hybrids that passed 200 cycles.
- 1 virgin hybrid .

3 DCDC converters were reworked and the parts were submitted to full re-screening and group A. The process was satisfactory and the 3 pieces were sent to Alter laboratory to perform again 200 thermal cycles.
After thermal cycling the pieces were returned to manufacturer for electrical measurements at 25ºC, +85ºC and -55ºC. The electrical measurements were satisfactory.
The DPA was performed by Alter on 2 pieces satisfactorily.

5. CONCLUSIONS.

The low temperature thermal cycling evaluation is now completed. Only two types exhibited failures out of 95 types tested. This is explained by a good selection of parts based on initial evaluation campaign performed by TESAT as well as careful review of all published data on very low temperature applications. One type was rejected (glass diode) and the other was modified by manufacturer to make it more robust to the very low temperature constraints of adhesives used for magnetic add-on's. Compiled data can allow us to give a list of preferred types for similar applications.

6. REFERENCES

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