Executive Summary Report

PROJECT: RELIABILITY OF NON-HERMETIC OPTICAL TRANSCEIVERS

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1 INTRODUCTION AND PROJECT OVERVIEW

Historically, space missions relied on hermetically sealed components for reliability. However, there's a shift toward using commercial, non-hermetic optical transceivers, which enable high-speed, multi-gigabit data communication. These transceivers offer advantages over traditional copper RF systems, such as reduced mass and size, elimination of interference, and no need for heavy RF shielding. Despite their potential, non-hermetic devices carry higher risks for space applications.

The European Space Agency (ESA) previously attempted to develop a hermetic optical transceiver, but this did not yield a flight-ready model. This development highlighted that manufacturing and qualifying sealed optical transceivers is challenging, expensive, and time-consuming. While hermetic packaging is recommended for reliability, ESA is now exploring commercially available non-hermetic transceivers to evaluate their performance in clean room and space environments, aiming to demonstrate their reliability and reduce costs.

This study is focused on the reliability testing of non-hermetic packaging susceptible to moisture ingress.

The key concepts conforming to the criteria for this study are the following:

- **Commercial parts**: So, to focus the analysis on existing parts on the market and not considering new developments
- **Non- Hermetic reliability test** so to define the proposed test campaign on those environmental factors that may affect parts performance degradation due to lack of hermeticity
- Maximise use of **European Suppliers** as main selection factors of potential candidates in the frame of European Independence on this technology

Following an exhaustive state-of-the-art review of the existing devices, the following three different part types were selected, purchased and tested:

- **Device 1**: 25Gbps Rugged SCFF optical transceiver (1TRx) @850nm, from Amphenol (PN TRX25S000LCS1A10).
- **Device 2**: 12x25 Gbps Leap OBT 12 channel Transmit & 12 channel Receive @850nm, from Amphenol (PN 10124588-410).
- **Device 3**: 4-Channel 10Gbps Optical Transceiver 4 channel Transmit & 4 channel Receive @850nm Multi-mode, from Apitech (PN 16009).

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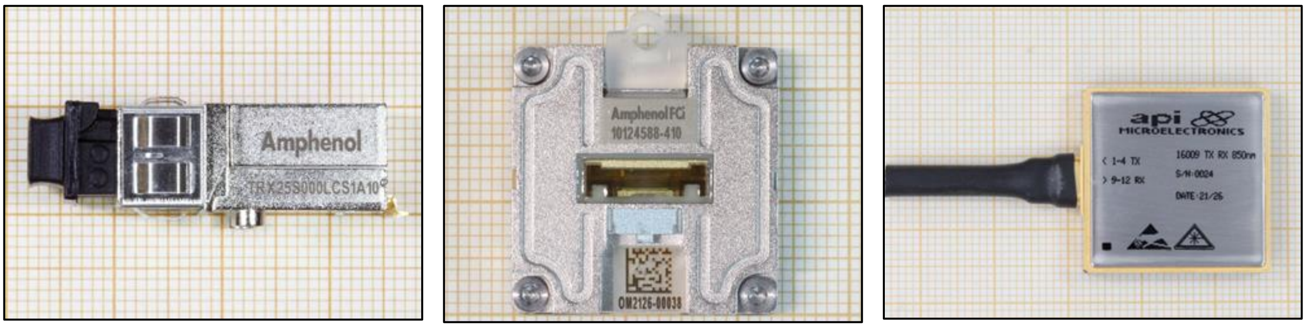

Figure 1. Photographs of the three devices: device 1 (left), device 2 (center), and device 3 (right).

The rationale of the proposed tests is based on the ISROS Optical Transceivers Guidelines. These main tests are:

- Life test to verify the overall reliability of the samples at maximum operating temperature conditions.
- Mechanical, Thermal and humidity tests to verify if the lack of hermeticity may influence the reliability of the samples.

The main aim of this evaluation is to prove that the three optical transceiver's part types can support extreme conditions of stress as the ones that take place in outer space so that they can be used in applications related to the space field.

The results show that these three transceivers are affected differently for each of the subgroups of tests performed.

2 OBJECTIVES

The main objective of the project is to assess the reliability of non-hermetic optical transceivers through rigorous testing, identify potential failures and provide recommendations for improving their design and manufacture.

The test sequence proposed within this project is focused on testing the non-hermeticity of the selected packages. It is, therefore, important to know the possible related humidity failure modes. The following is a list of the possible causes of failures of non-hermetic optical transceivers:

- Shorting or corrosion due to water vapor and subsequent condensation
- Possible oxide depletion of the laser diode facets due to ambient gases.
- Corrosion and/or optical surface contamination due to reactions between volatile gases or surface migration of non-volatile species; typical sources include:
  - Trapped hydrogen in metalized packages due to insufficient annealing.
  - Oxygen, carbon dioxide, hydrogen, and water vapor from incomplete epoxy curing or outgassing.
  - Non-volatile residues, particularly dimethyl siloxane, from materials processing, subcomponent packaging material, cleaning methods, and numerous other sources
- Shorting due to electro-chemical migration, arising from anions on the surface (from handling or insufficient cleaning) combined with water vapor and electrical bias.

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It must be mentioned that the lack of hermeticity does not necessarily mean a cavity filled with ambient gases. Most of the non-hermetic optical transceivers are expected to have no cavities and therefore to have a compact design with no air gaps. A destructive constructional analysis (CA) is proposed at the beginning of the project. In case of degradation during any test step, the final DPAs of the samples submitted to that test will be compared with the Constructional Analysis samples.

3 WORKFLOW

The three device types have undergone the workflow presented in the test flow described in Figure 2.

The manufacturer's evaluation kits were used for characterization purposes. Also, those evaluation kits were the baseline design for the development of specific test boards to carry out all biased tests. In particular, life test was done in active configuration with the optical transceiver in operation at maximum operating temperature. A board with the corresponding sockets was developed for this purpose. They were all customized for each part type.

There is not an ESA standard related to Optical Transceivers. Most of the test proposed were based on the ISROS_GL_002_V01 document titled "Reliability assurance guideline for digital optical transmitter, receiver and transceiver modules" was used as a reference for the testing of this project.

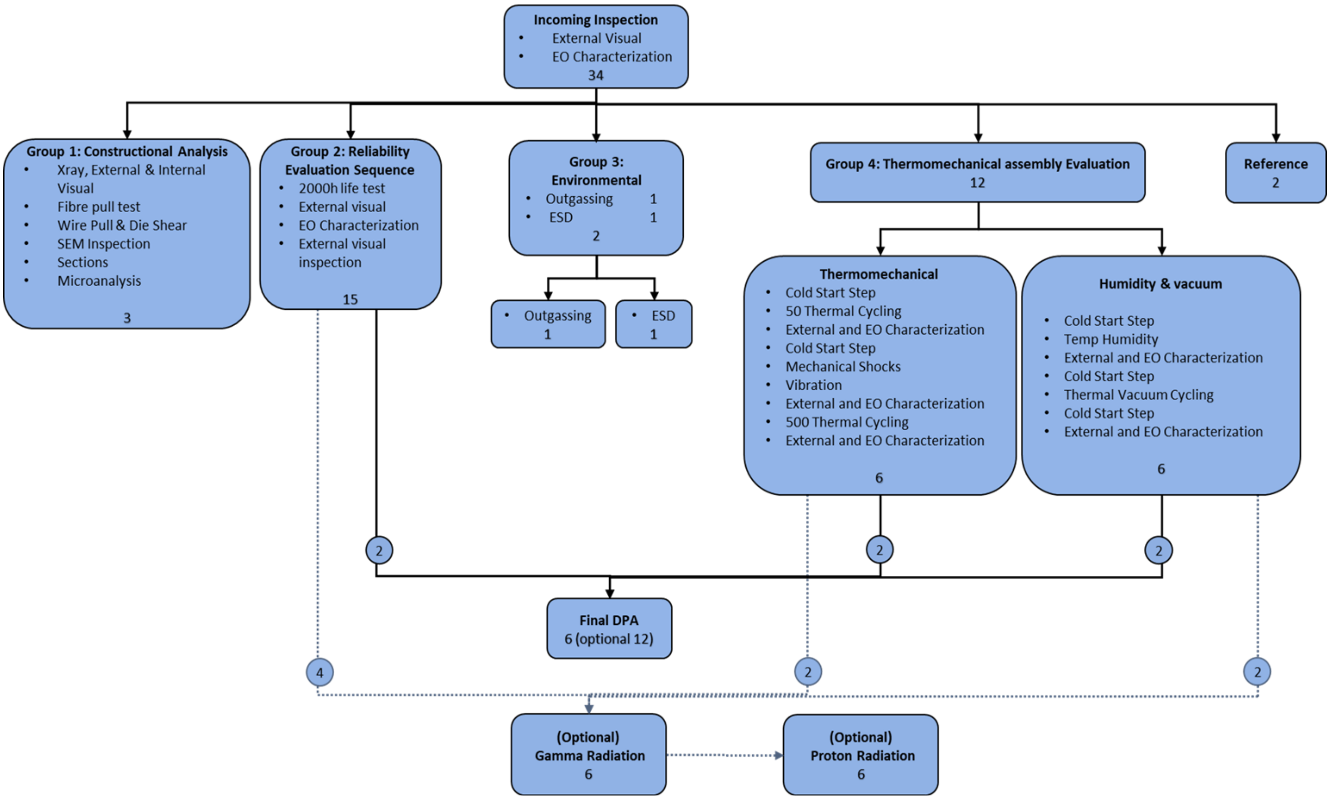

Figure 2. Workflow of the testing activities.

Radiation tests are of great interest for any space related use; however, the ITT clearly does not consider this to be studied during the project. The possibility of doing radiation tests was not completely discarded,

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but in any case, considered as optional testing that might be considered after the completion of the ITT related test sequence.

4 KEY FINDINGS

The primary objective of this evaluation is to assess the performance of these three non-hermetical optical transceiver types under various stress conditions relevant for space applications. Below is an analysis of the behaviour of each device type across the different tests:

Life Test Subgroup

The life test is crucial for evaluating reliability, assessing device operation over the entire mission lifespan. Both SCFF and OBT transceivers exhibited strong resilience during this test, with no performance failures noted. In contrast, API transceivers displayed performance deviations, with two samples failing the E/O measurements for the BER parameter after 240 and 500 hours, respectively. It should be noted that samples exhibited parametric failure. Further investigation is needed to determine if this reflects a genuine reliability concern.

Environmental Subgroup

This subgroup encompasses outgassing and ESD tests, both critical in aerospace applications due to the potential impact of outgassed products on optical sensors and electronic components. The SCFF and OBT units passed these tests, though SCFF exhibited a reduction in the eye diagram post-ESD, remaining functional. API, on the other hand, failed the outgassing test due to its inclusion of a fiber pigtail, which in their commercial versions are generally unsuitable for space applications. It is recommended that API consider eliminating the pigtail or incorporating space-grade fibers for such uses.

Thermomechanical Assembly Evaluation

- **Vibration and Shock**: The outcomes varied by device. One SCFF sample failed post-vibration, while OBT samples were unaffected. API exhibited BER parameter failures prior to vibration tests. Analysis of the failures could not be related to the effects of the mechanical tests.
- **Extended Thermal Cycling Test**: API showed an increase in samples with detectable BER values, though all remained under the limit. OBT devices withstood the test successfully. SCFF experienced electrical performance deterioration after 100 cycles, with moisture traces observed.
- **Humidity Test**: SCFF and OBT both had failed samples, and while moisture traces were noted, they weren't conclusively linked to electrical failures. API passed the test successfully.
- **Thermal Vacuum Test**: API had ongoing BER values below the maximum limit throughout testing but not failure. OBT experienced a single failure post-cycling. SCFF successfully passed the tests with no major issues.

Constructional Analysis and DPA

The test protocol included an initial constructional analysis and subsequent DPA after stress tests, facilitating an in-depth examination of the samples' internal structures and degradation. API devices featured simpler constructions with fewer components, while Amphenol devices (SCFF and OBT) were more complex, utilizing PCB technology without sealed cases.

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The constructional analysis revealed a void in a SCFF solder joint that could affect reliability, although this was not noted in any DPA tests. A lack of die attach was identified in the DPA, posing a reliability risk. Other defects observed, such as cracks in die attach and ceramic capacitors, could be linked due to degradation from previous environmental and mechanical testing.

For OBT, constructional analyses only showed cracks in the ceramic of one capacitor, a defect not linked to the failures and presumably linked to the capacitor itself and not the tests.

API devices presented various constructional defects, including lack of die attach, wire pull test failures, and excess material used in optical fiber fixation, along with inadequate separation between die and die attach, likely arising from testing conditions and construction issues.

5 CONCLUSIONS

The findings indicate that the transceivers react differently to the specific test subgroups, making them more robust or weaker against different test conditions. Anyhow, all of them are identified as good candidates to be qualified for a possible space application.

Device 1

Samples showed good electro-optical performance since the beginning of the tests, meeting the manufacturer's specifications. According to the results obtained, reliability of the device shows no concern at the nominal operating conditions at maximum operating temperature. Moreover, no outgassing issue was identified.

The internal construction of the device was also expected to show no major issues after the constructional analysis results. Even if the device construction is quite complex (based on PCB and flexPCB), only a void at the solder joint of a capacitor was found. However, the expectations could not be achieved during the final DPA, where the inspected samples showed fabrication issues on several samples such as lack of die attach. Other defects (wire pull or die shear) are not necessarily fabrication issues. It should be noted that these are COTS components that are not subjected to space requirement inspections. It would be advisable for Amphenol to review the manufacturing processes in order to avoid these fabrication defects.

More relevant deviations were observed in the thermomechanical evaluation subgroup where two failures were identified (one in vibration test and another during thermal cycling), and specially, on the humidity subgroup where three of the six parts tested failed. The observed failures are all functional but not the same in all cases. Unfortunately, the root cause of the failures could not be identified and linked to the actual tests, meaning that no conclusion can be extracted about the relation of the non-hermeticity of the sample and the observed failures.

Device 2

According to the detailed summary, it is observed that this device shows good internal construction, with the only defect found in a capacitor. This defect was also observed in a sample inspected during the final DPA. The placement of the crack and the fact that the crack was detected during the reference constructional analysis, leads to the hypothesis of an issue related to the component itself and not the applied stress. It should be noted that this is a COTS device.

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Endurance test has been successfully completed, meaning that reliability of the device should not be a concern. At completion of the endurance test, the characterization of the samples at low and high temperatures showed slight performance deviations with respect to that achieved at room temperature which are still within the limits. The device has also shown to be robust against thermomechanical tests after mechanical shock, vibration test and extended thermal cycling. It showed also robustness in terms of outgassing and ESD sensitivity.

Possible weak points of the device may be found in the humidity and vacuum subgroups, where one sample failed in each of the tests. However, the root cause of the failure was not identified, and no confirmed correlation has been reported between the failure and the test.

In general, regardless of the detected failures, OBT has been found to be very robust to the tests and conditions subjected with an electro-optical performance that has been very stable and repetitive in all the test campaign. In terms of performance, it should be also mentioned that it is the most complex device with 12 transmit/receive channels and requires an overall power consumption that is much higher than the other two tested devices.

Device 3

This device has been particularly sensitive since the beginning of the test flow. In fact, before starting the evaluation, the repeatability and stability of these parts in electrical measurement was studied using different setup configurations. The parts showed random BER errors (below the maximum limit) from the initial incoming inspection and later on during the testing. Several hypotheses have been considered as the cause although none of them has been fully confirmed:

- This part type has a pigtail, and it was observed that failing samples were sensitive to the position and movement of the fibre attached to the sample.
- The resin used to fix the fibers is not uniformly distributed and repetitive in all samples.
- Throughout the test flow, the number of channels and samples with BER errors has increased, which may be due to both the tests themselves but also to the increased handling of the parts.

Based on the gathered experience, the pigtail may be one weakness of this device. On the one hand, it has been identified as the possible root cause of the random BER errors. On the other hand, the pigtail is the reason for the outgassing failure. Hence, it would be advisable for the manufacturer to offer the product without fiber pigtail or when planned to be used for space, to offer the option to incorporate space grade fibers.

Differences have been observed in the construction between the samples, although they could not be correlated to the different shipments or batches. For example, the material used to fix the fibers to the sample does not present the same quantity or distribution in all samples. The non-homogeneity of the construction of the samples is a risk that may jeopardize the outcome of the whole test campaign.

As discussed in the previous paragraphs, several failures have been detected throughout the evaluation of this part type. It can be seen that in many subgroups there are failures present. Most of the failures are parametric failures in the BER parameter. The only functional failures were found after ESD test, and the one caused by the crack in the optical fiber which was due to mishandling.

Nevertheless, this part type shows greater robustness to the humidity and vacuum tests. All samples passed successfully humidity tests, and the failure detected after vacuum test was really caused by mishandling. This may be clearly caused by the construction of the device itself which makes also feasible a hermetic version (in fact available from the manufacturer with a different part number).

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6 FUTURE WORK AND RECOMMENDATIONS

The tests conducted during the campaign did not reveal the root cause of the failures. As a result, we cannot confirm whether the applied stress conditions—such as temperature, thermal cycling, humidity, and life tests—were responsible for the observed issues. Further investigation is necessary, either by analyzing the actual samples or through additional testing. One approach could involve step stress tests to better assess the devices' limitations.

Radiation testing is crucial for space applications; however, the present ITT did not consider this to be studied during the project. It would be essential to extend the testing activities to include radiation hardness assurance at the assembly or subcomponent level to ensure the transceivers can be effectively used in space.

Given the insights gained, there is potential to enhance the testing program with new activities. These could involve designing tests with different bias conditions or testing newly commercialized transceivers.

Additionally, careful attention is needed during the procurement process to guarantee sample homogeneity. Transceivers involve complex assembly and may require reworking, making it more challenging to maintain consistency compared to simpler electronic components. Testing non-homogeneous samples could compromise the validity of the results.

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