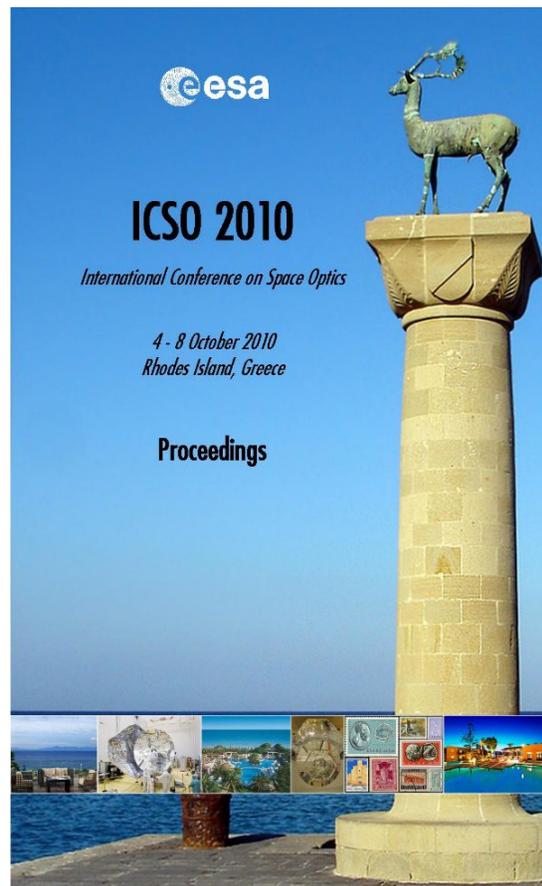


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## *Optoelectronic devices product assurance guideline for space application*

*A. Bensoussan, M. Vanzi*



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## OPTOELECTRONIC DEVICES PRODUCT ASSURANCE GUIDELINE FOR SPACE APPLICATION.

A. Bensoussan<sup>1</sup>, Prof. M. Vanzi<sup>2</sup>.

<sup>1</sup>*Thales Alenia Space,  
26 avenue J.F. Champollion – PO BOX 33787, 31037 Toulouse Cedex 1, France  
phone +33 34353637  
email: alain.bensoussan@thalesaleniaspace.com*

<sup>2</sup>*University of Cagliari - DIEE  
Piazza d'Armi 09123 Cagliari ITALY  
phone +39 070 6755775  
mobile +39 3204373029  
email : vanzi@diee.unica.it*

### I - INTRODUCTION

New opportunities are emerging for the implementation of hardware sub-systems based on OptoElectronic Devices (OED) for space application. Since the end of this decade the main players for space systems namely designers and users including Industries, Agencies, Manufacturers and Laboratories are strongly demanding of adequate strategies to qualify and validate new optoelectronics products and sub-systems [1]. The long term space application mission will require to address either inter-satellite link (free space communication, positioning systems, tracking) or intra-satellite connectivity/flexibility/reconfigurability or high volume of data transfer between equipment installed into payload.

To prepare this challenge and to consolidate the potentiality of these type of products and systems, we need to build up and to elaborate standardized qualification and procurement methodologies dedicated to Space needs.

It is now mandatory to draw specific Quality Standard approaches for such products dealing with a wide range of expertises from integrated electronics, optoelectronics, thermal and power management to reliability models and methodologies : the well established quality standard by an “a posteriori” proof (i.e. lot test sequence as for example group B, C and D for MIL Standards) must be well balanced and modified by some “a priori” quality requirements related to the important topics as Quality by Design, Industrialization processes, Quality by Manufacturing and Testing, and Reliability by Design.

In order to enhance their competitiveness within the broadband communications market, the next generation of multi-beam satellite systems for multiple interactive services will probably need to operate with more and more flexibility. The key breakthrough related to the increase of flexibility is to design optoelectronic based equipment for high reliability space application as the biggest coming challenge.

The corresponding enabling technologies to support this major progress must be introduced in conjunction with the definition and the revision of existing Standards for Space application. Starting from on ground well known standards, as for example the well established BELLCORE-TELCORDIA standard, the Space harsh environment must be taken into consideration as inputs to optimize the test conditions rules and to provide us with best practice for high reliability application.

The following paper is organized in three main chapters. The first chapter will describe how the space application are evolving using such optoelectronics based equipments. Interests and perspectives will be highlighted in order to categorize main questions and needs to be solved to help the emergence of best practice. The second chapter will detail the main quality assurance theatre to be elaborated, the quality rules for the achievement and the demonstration of the high reliability Optoelectronic based equipment. Design constraints and evolution of existing test methods will be presented. The last chapter will present the Optoelectronic Product Assurance Guideline project as a worldwide contribution between actors in this industry.

### II - SPACE INDUSTRY APPLICATION INTERESTS AND PERSPECTIVES.

Optoelectronics applications may play a major role in space exploration and scientific missions as well as in Earth observation and remote sensing satellites. The novelty is that the communication satellite industry has recently confirmed potential applications for optics, microwave photonics and optoelectronics in the communication payloads. Optoelectronics and microwave photonics bring unusual but attractive and performing solutions for implementing communication payload functions and to create new functions. In mid term, there are several functions where optical technologies could apply: optical serial gigabit connections, LO distribution

with photonic [2], RF frequency-conversion, microwave photonics repeaters, wireless telemetry and command systems.

Optical gigabit serial links allow high data rate connections between the VLSI Integrated Circuits and between the Printed Circuit Boards (PCB) of large digital processing units of communication payloads (OBP-On-Board Processing) or remote sensing satellites (mass memories, image compressors). The interconnections between PCB are becoming a limiting factor to the progression of miniaturization and processing speed in digital electronic units. Serial gigabit optical link is able to increase the bandwidth and reduce the number of connections between ASIC, PCB or units.

In LO distribution with photonic RF frequency-conversion application and the photonic RF frequency mixing for both up- and down-conversion of microwave signals can be achieved optically by means of electro-optical modulators (EOM). The sinusoidal transfer function of Mach-Zehnder modulators make them attractive as mixer products.

One concern is the limited efficiency of the frequency-conversion process (i.e. conversion gain/loss). This latter critically depends on the modulator performance, and in particular on RF driving power and optical loss. Such electro-optical mixers feature specific attributes; they are intrinsically broadband and could support multiple frequency-conversions when fed with several optical LO's with wavelength-division-multiplexing (WDM). Thus, it is required that the optical modulator operates with similar performance in a certain wavelength range.

Microwave photonics repeaters of telecommunication satellite is a mid-term expected application of optoelectronics. Telecommunication microwave signals can be processed by photonics technologies. Optic fibers can advantageously replace the coaxial harness in communication payloads. MOEMS (Micro-Opto-Electro-Mechanical System) will significantly enhance the routing capability of payloads. Frequency reference distribution network by optical fibers is also a promising application of microwave photonics.

A new class of analogue repeater based on microwave photonics was proposed in the frame of the SAT'N LIGHT ESA project, for supporting broadband, transparent, and flexible cross-connection of hundreds of radio-frequency (RF) channels in such future payloads with multiple antenna beams. A simplified architecture of such a payload is shown in Figure 1.

It is based on conventional microwave low-noise receive and high-power transmit sections, and incorporates optical technologies in between to distribute microwave local oscillators (LO), perform frequency down-conversion, and achieve channel routing. All the LO's are transferred on optical carriers and delivered to modulator-based electro-optical mixers. Such a flexible repeater is expected to exceed the capabilities of microwave implementations; at identical system functionality and scale, it may bring drastic mass savings, and above all, could grow up to larger connectivity (10's of beams) and cross-connect a large number of channels. Other benefits arise from transparency to RF frequency bands, full RF isolation and suppression of EMC/EMI issues. Generally speaking, the main advantages are lightweight and very low loss of optical fibers compared to copper wires, very large bandwidth, galvanic isolation and full electromagnetic compatibility (EMC/EMI), new functions routing function like WDM (Wavelength Division Multiplexing).

Wireless infrared links are attractive solution to build the onboard telemetry and command system for the next generation of satellite. This technology allows addressing remote sensors inside or outside the satellite and built up wireless sensor network to monitor the satellite and its payload in orbit as well as on ground during the assembly, integration and test (AIT) phase. The expected benefits are the reduction of the wire harness, the development of "plug and play" integration, shorter development schedule...

Another application as Optical Inter-Satellite Links (OISL) permits to connect two neighbouring satellites inside a constellation [3] or two distant satellites on different orbits [4]. Furthermore, successful experiments have demonstrated the feasibility of free-space optical communication between a satellite and a ground station [5]. Several technologies are candidates: 800/860nm, 980nm, 1064nm and the popular 1310/1550 nm technology.

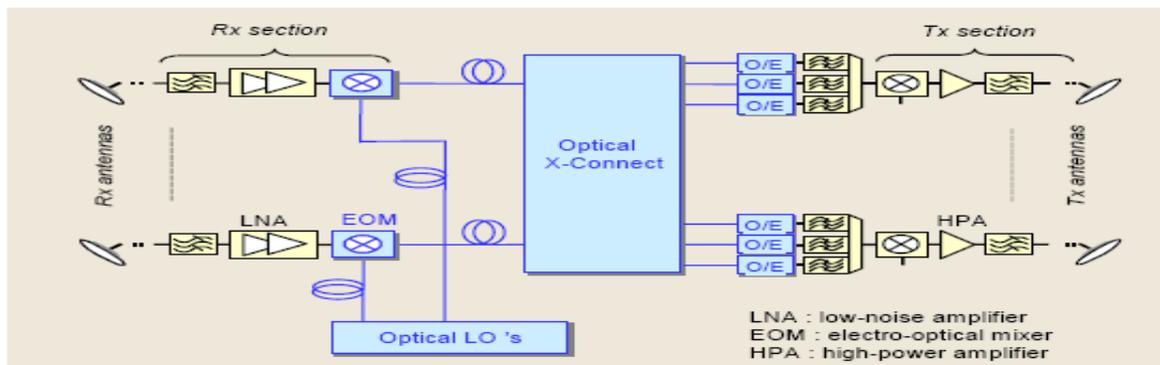


Fig. 1 : Flexible telecom repeater with microwave photonic cross-connect

A last range of application of optoelectronics in space is mentioned into the roadmap presented by CNES during ISROS 2009 [6]:

- thematic roadmaps in Astrophysics and Astronomy, Climate, Environment and Atmosphere monitoring, Earth observation, Cartography, Security, Ocean observation and Maritime monitoring.
- Instruments roadmaps for Imagers, Radiometers, Polarimeters, Microbolometers, Interferometers and spectrometers,
- Technical roadmaps for UV sensors, Visible and Infrared sensors, Video Chains, CCD, CMOS image sensors and optoelectronic parts (quantum detectors, IR avalanche photodiodes HgCdTe and InSb detectors)

### III - QUALITY ASSURANCE OF OPTOELECTRONIC BASED EQUIPMENTS UNDER SPACE ENVIRONMENT.

Quality Standards and Quality procedures for EEE parts are existing applicable documents for Optoelectronics components. They define the baseline criteria for selection, screening, qualification, and derating of optoelectronic parts for use on equipment operating on space program. But in some extent they are not enough deeply defined to cover all quality and reliability aspects of such components. For example, the derating rules to be applied to guarantee high reliability application must be extended to optical parameters. How to define output optical power in order to be safe with respect to the mirror COD failure mechanism ? What could be the screening process (burn-in conditions) for active or passive optical components ?

Optoelectronic components are very complex product constituted either by some single element in a simple package (as per example an active laser diode or a photo-detector) or a complex hybrid module which may be considered as a mini-system on a package. The quality approach must be adapted to this variety of product and their complexity. MIL-STD-883 and ESA ESCC and ECSS standards are quality documents to be collected and synthesized in order to build an adequate optoelectronic Quality Assurance methodology. A summary of this collection of test methods taking into consideration MIL, ESA and TELCORDIA requirements have been already presented in table 1 of reference [1]. Four categories of MIL-STD test methods area have been depicted including Mechanical, Environmental, Characterization and Endurance testing. Advantages and drawbacks, implementation ability and effectiveness have been considered.

All these standards may rise to some confusion when we try to use and select them for space application. To build a general Standard for such a type of optoelectronic products is an important task to organize. The final standard documents issues are under the responsibility ESA PSWG (Policy Standard Working Group) management and the task is attributed to the ESA Photonic Working group. Generic specifications proposed by ESA on hybrid microcircuits (including microwave IC) or MIL and TELCORDIA standards are proposing us some orientation on how to select and consider the best test flow sequence. Definitions of these standards are strongly related to the level of integration: indeed, considering a single laser diode chip or a more complex module with transmit and receive paths is not simple. Integrated optoelectronic modules refer to hybrid modules that contain significant amounts of electronic circuitry within the module package. Element evaluation approach as required by MIL-PRF-38534 must be completed by defining some important aspect as reliability by design for example (derating rules). To access to the individual parameters of active emitter component elements (e.g., L-I curves or V-I curves) is often limited by the module's electronic circuitry.

The methodology proposed for the Qualification of such integrated optoelectronic modules must include four separate stages as Optical Qualification test sequence, Electronics Qualification, Packaging Qualification and Module Qualification test sequences. A number of procedures and test methods are available but the approach must be defined and standardized for two reasons. First, the Space constraints and environment induce specific testing sequences to be implemented. Secondly, common practices are not completely identified within the community of users and manufacturers of optoelectronic devices. Although process qualification may be the starting phase to certify a given fabrication process and to qualify device family, it must be recognized that optoelectronic technologies are constantly evolving. This technology and product evolution is complex too because of the large change of fabrication procedures between manufacturers. To build a methodology to qualify optoelectronic products is not an easy route and we must consider the whole complexity of such processes at the union of several expertise domain including electrical, optical, thermal, mechanical disciplines, with basic physics of metallurgy, physics of radiation, reliability, physics of failure, etc ... The figure 2 is a tentative to describe the various levels of qualification and expertise needed in the frame of a Quality Management System (QMS) implemented both at manufacturer's and at end-user's premises. In one hand, for the Manufacturer's quality assurance and responsibilities, OEDs are defined by their intrinsic performances and reliability limits well characterized by in house design, industrialization and manufacturing programs. On the other hand, the end user's quality assurance and responsibilities are product and application oriented: consequently they must drive application related stresses and qualification programs. The proposed

recommended qualification methodology as drawn in figure 2 and highlights the five common levels of qualification and reliability test programs we may have to conduct in a generic approach involving competences from both actors.

The number of options in the different practices currently employed by manufacturers and suppliers make it virtually impossible for a satellite service provider or other customer of equipment containing such devices to establish a meaningful baseline for performance. Consequently, before building such a new methodology, it is anticipated that this list of test procedures will provide a focus for discussions within the industry and offer a starting point for industry standards-setting organizations.

The initiative of a collaborative work started in the frame of ISROS support has been offered to consolidate with Industries and Manufacturers a recognized methodology and shared background experience on best test methods to be implemented for Space Application.

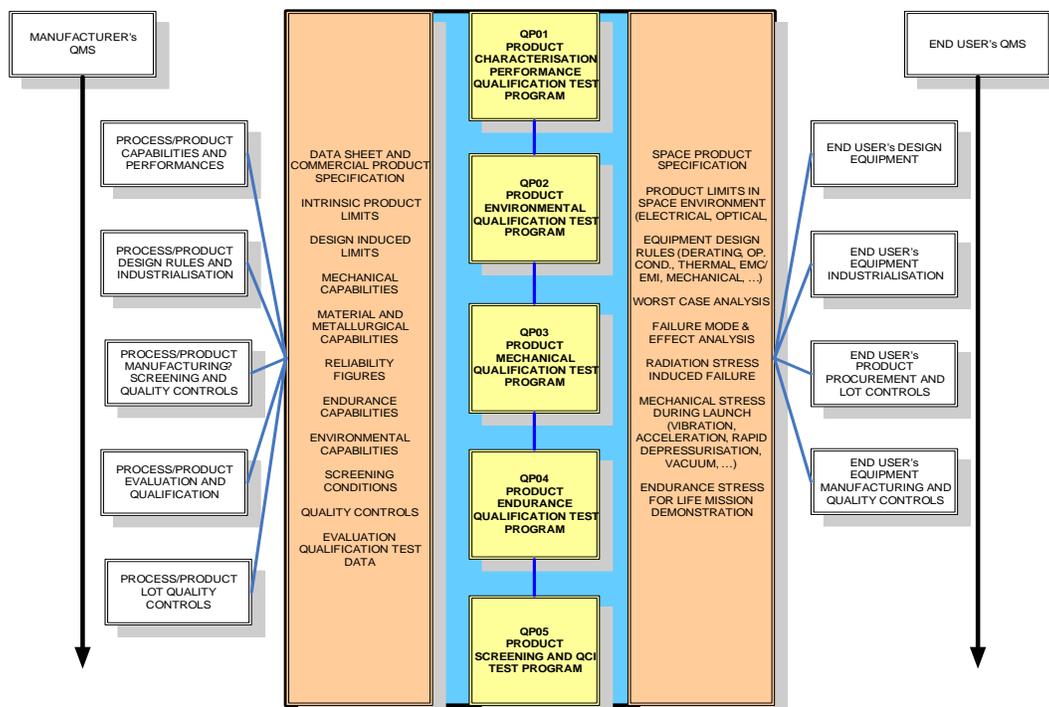


Figure 2: Qualification methodology proposed for development of high reliability optoelectronic products

#### IV - OPTOELECTRONIC PRODUCT ASSURANCE GUIDELINE.

Representatives of Space Agencies, Industries, Manufacturers and Research Laboratories claim to define a document to synthesize a common quality assurance procedure related to optoelectronic devices and collect the quality rules for an usage for Hi-Rel space application. It was noted a strong need of a Product Assurance guideline to synthesize the best practices and recommendations to design, test, industrialize, use, quality control, screen and qualify optoelectronic products for end-use in Space Application. This document will not substitute to the official Quality Standard under definition at ESA but rather will provide inputs to help to built such documents.

The ISROS Association (International Society on Reliability of Optoelectronics for Space), takes the initiative to edit a guideline document in feedback to the first symposium ISROS held in Cagliari (Sardigna, Italy) in May, 11th-15th, 2009. This guideline is foreseen to be the beacon of the Association to synthesize the knowledge in the domain of Optoelectronic products and based systems used for Space Application in order to disseminate the best practices in the fields.

The guide will be a reference for understanding the various aspects of optoelectronic devices behaviours under Space Application constraints. There are special emphases on the reliability aspects of Optoelectronic devices. Semiconductor material properties and device structures along with the final products (Emitters, Receivers, Optoelectronic functions, passive Optoelectronic functions) used in harsh space environment and the possible failure mechanisms are addressed in detail. The handbook will present in details optoelectronic device designs, packaging, tests, industrializations, application uses, quality controls, screening sequences, qualification procedures and test methods, environment effects (Radiation, vacuum, thermal, mechanical, long term and end

of life, ...) and will provide the reader with the means of developing suitable qualification plans and demonstrate high reliability equipment achievement using optoelectronic products.

The organization of the guideline is established through six grand chapters dealing with the following topics:

Grand chapter 1 : ***Solid State physics for optoelectronics*** will detail state of the art physics and properties, products and processes implemented for on-ground optoelectronics systems (communication, medical, data handling and metrology, automotive, ...). Basic physics principles are listed, presented and summarized with corresponding literature references. Physics and Properties of semiconductors and heterostructures, optical structure principles (waveguide, facet, bragg reflectors, ...), Physics and modelling (Maxwell, stimulated emission, Thermal models, Quantum Physics, ...) will be developed with respect to properties of III-V materials used, design structures, active device descriptions (emitters, receivers, imagers, bolometer, ...), Optoelectronic functions, optical passive functions.

Grand Chapter 2 : ***Space environment constraints*** deals with the harsh environment existing in space. Starting from the description (radiation, vacuum thermal), effects induced implemented to reproduce similar stresses and ending by equipment production controls (Pre-development phase and industrialisation, built-in for testability and reliability), Quality assurance and quality controls (In-process, screening, testing, inspections, ...), test and repair, non-conformance process.

Grand Chapter 3 : ***Optoelectronic devices - technologies, main performances and reliability***. This chapter is dedicated to components and related characterization techniques (electrical, optical, CW or pulsed). How to define their performances and limits, maximum rating and derating. Test methods (reproducibility, sensitivity, precision, accuracy, lot characterization, statistics, test equipments specifications,...).

Grand Chapter 4 : ***Optoelectronic Devices development for Space***. In this chapter we detail how the space requirements induce specific application constraints. Standardized and specific test methods sequences must be defined and implemented during procurement steps as well as for evaluation and qualification sequence steps. Consequently, the recommended test flow is defined in order to detect any failure mechanism we want to avoid during flight mission. This information will then be collected in the last Grand Chapter 6 and will help to define a generic product assurance methodology for optoelectronic components for space use.

Grand Chapter 5 : ***Failure mechanisms and failure analysis techniques***. This chapter is related to a collection of failure mechanisms observed in the literature in optoelectronic devices with their associated reliability figures. The domain covered in term of reliability is related to starting materials (III-V, IV and II-VI semiconductors) up to complex active or passive OED's used for space hardware.

Grand Chapter 6 : ***Quality and Product Assurance Standards***. This chapter is intended to propose screening, evaluation and qualification test sequences to be conducted at element level or sub-elements (for example laser bar chip before separation into single laser chip) or up to final OED modules. The high reliability space application specificities are considered from various point of views including equipment design and performance targets (maximum rating and derating limits), environment constraints (vacuum, radiation, mechanical, thermal), test methods for characterization, screening and qualification.

Optoelectronic Systems in Space application requires to initiate mandatory activities which will give enough technical information in order to assess if these products may survive in Space environment. Equipment hardware used in space application are subjected to several type of stresses including :

- ✓ On ground storage before launching : assembly and testing, storage under humidity and salt,
- ✓ During launching : environmental as mechanical vibration and noise, acceleration, rapid depressurization, electrostatic discharge, acceleration and chocks existing on board equipment,
- ✓ In flight : micro-gravity, micro-vibration, radiation, thermal cycling, vacuum, EMC and ESD. material behaviour under radiation environment and lifetime capability,
- ✓ ESD/EOS/EMC constraints and limits ,
- ✓ Mechanical systems under operation,
- ✓ Outgasing limitation and hermetic packaging technologies which may induce long term reliability concerns: as for example influence of ionic contaminant on light emission characteristics and performances.

How to handle the maturity of these technologies for Space use ? How to define industrialisation of these processes to be compatible with the space application? Packaging, testing and screening are some of the key points to be addressed also in this last most important chapter. The guideline community implementation is now started since end of February 2010 and will hopefully issue the first edition of the document within 10 to 12 months from this starting date. Today we have fully implemented the WIKI web site for the community allowing up to 50 people to exchange and communicate on the topics.

A quite large amount of contributors are key people having the willingness to provide their background focussing on the needs of the engineer, the program manager and team, the user and the manufacturer with the emphasis on the common approaches to Optoelectronic reliability and product assurance standards defined and accepted in the industry and the Agencies.

#### V - CONCLUSION.

This paper has presented the concept of the Optoelectronic Product Assurance Guideline in response to comments by various industry and agency representatives lamenting the lack of an industry-accepted method for Optoelectronic Standard (addressing product process description, design, manufacturing, procurement and qualification domains). This concern was proposed to be treated by initiating the Optoelectronic & Reliability Working Group in the spring 2009 after the round table conducted during ISROS symposium.

Some Space industry application were presented to give examples on how the optoelectronic module based could help to change the ring playing game of high reliable space equipments. The breakthrough is starting to be fully demonstrated for Space application. Nevertheless, we must be prepared to introduce such new components in space. A general overview of some existing standards related to space requirements have been summarized. A short description of their requirements were mentioned with comments, advantages and drawbacks, implementation ability and effectiveness. To built a comprehensive Quality and Reliability Assurance program is the most important goal to achieve in the next activities planed for the ORWG in the coming months.

#### *Abbreviations and Acronyms*

COD – Catastrophic Optical Damage  
ECSS – European Cooperation for Space Standardization  
EOM - Electro-Optical modulators  
ESCC – European Space Components Coordination  
LO – Local Oscillators  
MMIC Monolithic Microwave Integrated Circuits  
MOEMS - Micro-Opto-Electro-Mechanical System  
OBP - On-Board Processing  
OED - OptoElectronic Devices  
OISL - Optical Inter-Satellite Links  
PCB - Printed circuit Board  
QMS – Quality management System  
WDM - Wavelength Division Multiplexing

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