Reliability issues of photonic components for space applications

Demetrio López
February 21st 2017
1. Short introduction to ALTER TECHNOLOGY
2. Photonic parts for Space Applications.
3. Parts selection rules regarding photonic parts
4. Case studies
5. ATN experience in photonics for space applications
ALTER TECHNOLOGY, A TÜV NORD COMPANY
OBJECTIVE

To become a single solution provider for all parts selection, design, procurement, testing and validation activities.

- Requirements Definition
- Parts selection

- Procurement
- Design
- Packaging

- Test bench development
- Reliability Testing
- Failure Analysis
SPACE CUSTOMERS & PARTNERS
Photonics parts for space application

Why?

- Almost unlimited bandwidth (i.e. 1550nm fiber can go to several THz.)
- Reduced propagation losses at spacecraft level (due to short communication distances).
- Supports any modulation or coding format
- Immunity against electromagnetic interferences,
- Optimum mechanical properties (light weight, mechanically flexible, reduced volume, resistant against corrosion of contamination).
Photonics Technologies in Space applications

Telecommunication Satellites

- **Payload**
  - Digital Communication Links
  - Analogue Communication Links
  - Optical Switching
  - Signal Processing
  - Microphotonics

- **Spacecraft Platform**
  - Optical Wireless Low rate Links
  - Sensors
  - Pyrotechnic

[Image: Artemis and SPOT 4 communicating via the SILEX system - Artist's impression. Credits:ESA-J.Huart]
Photonics Technologies in Space applications

**Photonic Signal Processing**

**Local Oscillator (LO) generation**
- Lasers modulated up to 10GHz
- Electro-optical modulators for high bit-rate ground transmission (up to 40GHz)
- Use of Directly Modulated Distributed Feedback (DFB) lasers

**Down Conversion**
- Electro-photonic mixers (i.e. Mach-Zehnder intensity modulator)

**Switching**
- Photonic switch based on Micro-Opto-Electromechanical Systems (MOEMS)
- Hybrid electro-optical digital transparent processors that include ultra-fast tuneable lasers and wavelength selectors

**Beam forming**
- Microphotonic technologies for Beam Forming Networks functionality.
Photonics Technologies in Space applications

**Photonic sensing**

**Structures (thermal control)**
- fibre Optic Sensors (fibre Bragg Gratings), surface mounted or embedded.
- Optical Add Drop Multiplexers (OADM).

**Antenna reflectors (thermo-mechanical deformations)**
- fibre Optic Sensors (fibre Bragg Gratings), embedded.

**Direct radiating antenna**
- fibre Optic Sensors (fibre Bragg Gratings),
- tuneable lasers

**Fibre optic gyroscopes**
- laser diodes
- low noise photo-detector
- Lithium Niobate phase modulator,
- Erbium doped fibre,
- Bragg grating,
- sagnac fibre loop and isolator
Photonics Technologies in Space applications

Other applications

- **Optical Wireless communications**
  - IR LEDs
  - IR Photo-detectors

- **Opto-pyrotechnics**

- **LIDARS**
  - IR detector (1.55 to ~4 μm)

- **Formation flight**
  - High power lasers

- **S/C visual inspection**
  - Imaging systems

- **Quantum cryptography**
  - Laser at different wavelengths
  - Micro-optics
  - Optical Amplifiers

Wireless Optics in a S/C mock up using battery-powered IR diffused transmitters attached to electronic temperature sensors.
### ESA QUALIFIED PARTS LIST

**Last edition: January 2017**


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<table>
<thead>
<tr>
<th>Sub-Section</th>
<th>Page No.</th>
<th>Cert.</th>
<th>Type Designation</th>
<th>Manufacturer</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Currently there are no qualified sources of Optoelectronics</td>
<td></td>
</tr>
</tbody>
</table>
## Parts Selection for Space Applications

**Step by step approach for optoelectronics parts**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Specification performance requirements</td>
</tr>
<tr>
<td>02</td>
<td>Definition of environmental constrains</td>
</tr>
<tr>
<td>03</td>
<td>Survey of available commercial candidates</td>
</tr>
<tr>
<td>04</td>
<td>Parts Engineering</td>
</tr>
<tr>
<td>05</td>
<td>Parts Procurement</td>
</tr>
<tr>
<td>06</td>
<td>New Packaging (As needed)</td>
</tr>
<tr>
<td>07</td>
<td>Pre-evaluation test</td>
</tr>
<tr>
<td>08</td>
<td>Screening</td>
</tr>
<tr>
<td>09</td>
<td>Evaluation</td>
</tr>
<tr>
<td>10</td>
<td>LOT readiness</td>
</tr>
</tbody>
</table>
3769 line items procured for FM

- Qualified: 86.26%
- Not Qualified: 13.74%

### Parts Selection rules for Space applications

**Case Study: SOLAR ORBITER**

<table>
<thead>
<tr>
<th>STATISTIC</th>
<th>ES CC</th>
<th>MIL</th>
<th>NOT QUALIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPACITORS</td>
<td>391</td>
<td>197</td>
<td>83</td>
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<tr>
<td>CONNECTORS</td>
<td>123</td>
<td>2</td>
<td>123</td>
</tr>
<tr>
<td>DIODES</td>
<td>76</td>
<td>131</td>
<td>9</td>
</tr>
<tr>
<td>FUSES</td>
<td>1</td>
<td></td>
<td>9</td>
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<tr>
<td>HYBRIDS</td>
<td>50</td>
<td>16</td>
<td>57</td>
</tr>
<tr>
<td>INDUCTORS</td>
<td>39</td>
<td>358</td>
<td>88</td>
</tr>
<tr>
<td>MICROCIRCUITS</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>OPTO ELECTRONICS</td>
<td>3</td>
<td></td>
<td>29</td>
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<tr>
<td>PIEZO-ELECTRIC DEVICES</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RELAYS</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RESISTORS</td>
<td>859</td>
<td>796</td>
<td>21</td>
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<tr>
<td>SWITCHES</td>
<td>12</td>
<td>2</td>
<td>19</td>
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<tr>
<td>THERMISTORS</td>
<td>107</td>
<td>70</td>
<td>21</td>
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<tr>
<td>TRANSFORMER</td>
<td>11</td>
<td>28</td>
<td>28</td>
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<tr>
<td>TRANSISTORS</td>
<td>1676</td>
<td>1575</td>
<td>518</td>
</tr>
<tr>
<td>Total</td>
<td>1676</td>
<td>1575</td>
<td>518</td>
</tr>
</tbody>
</table>
Parts Selection rules for Space applications
Case Study: SOLAR ORBITER

EVALUATION & SCREENING FLOW

INCOMING (100%)

SERIALIZATION

PRE-EVALUATION (34 +2 ctrl)

- Electrical @ 5T (10 samples)
- Finish material analysis (5 samples)
- TID (12 samples)
- DDEF (12 samples)

Screening

EVALUATION (35 samples +3Ctrl)

- Electrical @ high and low T
- CA + retinning evaluation (5 samples)
- Humidity life (10 samples)
- Temperature cycles (10 samples)
- Life test (10 samples)
- DPA (3 samples)
Parts Selection rules for Space applications
Case Study: SOLAR ORBITER

SCREENING (100%)
- Retinning
- X-Ray
- Temperature cycling
- Electrical @ RT
- Burn-in
- Electrical @ RT, HT and LT
- PDA calculation
- External Visual Inspection

EVALUATION and SCREENING FLOW

- Flow based on ECSS-Q-ST-60-13
- PIND and Hermeticity were N/A in most of the cases (the components were plastic encapsulated)
- Vibration and shock in evaluation demanded at assembly level (due to exotic packages and assembly techniques)
- Outgassing was also part of evaluation when the plastic compound figure was unknown
- Whenever no Single wafer lot was assured then TID and Life test sampling was increased by 40%
Parts Selection rules for Space applications
Case Study: SOLAR ORBITER

Case of OZ150: after 1 thermal cycling among 85°C to -40°C, 49 out of 72 samples failed "structurally".

WRONG DATA in DATA SHEET

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Working Reverse Voltage (Vrwm)</th>
<th>Average Rectified Current (kA)</th>
<th>Reverse Current @ Vrwm (A)</th>
<th>Forward Voltage (Vf)</th>
<th>1 Cycle Surge Current (amps)</th>
<th>Repetitive Surge Current (amps)</th>
<th>Reverse Recovery Time (ms)</th>
<th>Thermal Impedance (Ohm)</th>
<th>Junction Cap. @ 50VDC @ 1kHz (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OZ150SG</td>
<td>15000</td>
<td>0.30</td>
<td>0.15</td>
<td>1.0</td>
<td>25</td>
<td>0.30</td>
<td>10</td>
<td>2.00</td>
<td>3000</td>
</tr>
</tbody>
</table>


Manufacturer replied that they were told about similar failure by one other user and they had recently updated the data sheet with a tighter temperature range (-40 °C to +70°C) and with the warning that this part should not see thermal cycling.

OZ150 rejected for flight replaced by RZ677 (thinned glass version of OZ150) + parylene coating that passed the screening and evaluation.
Additional Challenges

Constellations

Extreme environments:

**JUICE** (JUpiter ICy moons Explorer)

**EUCLID** (Geometry of the dark Universe)

**LISA** (Gravitation waves)
Custom package for space application

Above: Butterfly Package Options
Single & Dual Fibres, Window & RF connections

Fibre Align of High reliability fibre

Dual fibres laser welded in position
**Additional Challenges**

**Space Qualifiable* MiniDIL Module**

Standard Ceramic miniDIL Package: Off the shelf option

Modified Ceramic miniDIL Package: Same footprint in x, y dimensions. Integrating key features of Optocap’s 14 pin butterfly package, such as laser welded fibre alignment. No TEC included.
Additional Challenges

Combined Radiation and Temperature Test

- Combined temperature and radiation
- Low Energy Proton Effects

Jonathan Pellish
One of the
CONCLUSIONS:
CMOS nodes at and below 90nm have been identified as sensitive to low-energy proton direct ionization

Photonic parts in Mars exploration related programmes

Rover Environmental Monitoring Inspection
Arrived to Mars on 6 September 2012

Mars Atmosphere
• Temperature Range (-135°C to +70°C)
• Optical setup characterization:
  - Thermopiles (for non-contact Temp measurement)
  - UV Photodiodes (200nm – 400nm)

Environmental Tests:
• Temp range: -135°C to +105°C
• Radiation neutrons, gamma, protons, etc..
• Life Test to simulate the day-night cycles
  • 600 cycles -130°C to +15°C (Winter cycles)
  • 1410 cycles -105°C to +40°C (Summer cycles)
• Full characterization of UV Photodiodes
  • From -135°C to +105°C with steps of 10°C
  • Linearity
  • Angle of Incidence variation
**Image Sensor Thermal Strap Characterization**

Thermal Vacuum and characterization at liquid nitrogen temp range

- Image sensor dissipation straps
- Vacuum tests from -180°C to more than 200°C.
Additional Challenges

Thermal Vacuum test on Solar Cells

Thermal Vacuum and characterization at liquid nitrogen temp range

- Small Vacuum Chambers for faster thermal vacuum chambers
- Cu sealing for wider temp range
Additional Challenges

- Programmable Optical Element: Tunable Lens

- Lenses are made by generating a lens profile in the switching of the LC
- Most LC lenses work for one polarisation only
- The profile of the lens is tuned by changing the electric field profile
- The focal length can be cast as:

\[ F = \frac{R^2}{2\Delta n L} = \frac{\pi R^2}{\Delta \phi \lambda} \]

- F varies with the wavelength as 1/\(\Delta n\)
Additional Challenges
Photonic Transceiver for Space Applications

ENTANGLEMENT PHOTON SOURCE

L1=Aspheric Lens
L2=Plano-Spherical Lens f=60 mm
L3=Plano-Spherical Lens f=30 mm
L4=Plano-Spherical Lens f=40 mm
UVM= UV Mirror
FM= Flat Mirror

FAINT PULSE SOURCE

EPS tube
Dichroic mirror
Sagnac struc.
Detection
Base plate
# Additional Challenges

## Photonic Transceiver for Space Applications

<table>
<thead>
<tr>
<th>Critical Optical Component</th>
<th>Component Suitability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Diode- Nichia NDV4313</td>
<td>Optimum to be used in the proposed PHT baseline</td>
<td>The maximum wavelength drift of 1 nm only affects the central wavelength of the entangled photons (not defined in the project). The other required optical parameters will not be affected by the drift.</td>
</tr>
<tr>
<td>Non Linear Crystal (PPKTP)</td>
<td>Optimum to be used in the proposed PHT baseline</td>
<td>PPKTP crystal withstood radiation test without affecting its functionality. It did not darken after TID</td>
</tr>
<tr>
<td>99/1 Tap Coupler- FONTCANADA</td>
<td>Optimum to be used in the proposed PHT baseline</td>
<td>There was not noticeable performance degradation. Main e/o parameters remained unaltered</td>
</tr>
<tr>
<td>Polarizing beam splitter</td>
<td>Optimum to be used in the proposed PHT baseline</td>
<td>Test results at 405 nm and 810 nm fulfilled values given by manufacturers in its data sheets.</td>
</tr>
<tr>
<td>Semiconductor Optical Amplifier (SOA)</td>
<td>Optimum to be used in the proposed PHT baseline after including the already defined adaptations</td>
<td>Using optimized electronics and a calibration process which is performed through proximity electronics software, it will guarantee identicalness of the four SOA outputs</td>
</tr>
</tbody>
</table>
| Polarizer                                  | Optimum to be used in the proposed PHT baseline                                         | Polarizer withstood proton irradiation without affecting its functionality.                                                                                                                                
ALTER TECHNOLOGY has gathered a large experience and knowhow in optical and reliability testing on photonics parts covering the full range of different technologies.

Range of optoelectronics and photonics parts:
• Laser & Leds 250 to 5000 nm.
• Receivers modules (180 to 11000 nm).
• Optical Amplifiers & Optical modulators
• Switches and splitters.
• Optocouplers & Photodiodes
• Multimode and monomode Fibers
• Liquid Crystal Devices
• Image Sensors
• Optical Transceivers
Thank you

for your attention

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