Qualification & Reliability of Photonic Devices System Perspective

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Introduction

- This talk concentrates on photonics devices of a system that JPL is in the process of qualifying.
- Unlike electronics parts, standard guidelines for qualification and screening of photonics parts for space application do not exist.
- JPL had to develop process for qualify and screening of these photonics parts.
- The system is a metrology system capable of measuring displacement with nms accuracy.
- This talk focuses only on the photonics part of the system.
A Laser Metrology System is a “yardstick,” with “nm-marks” provided by the interference fringes of the laser beam. Changes in the distance $d$ between the Beam Launcher (BL) and the Corner Cube (target) are measured as phase shifts between input and output beams. It uses heterodyne techniques to measure phase. “Count fringes” corresponds to the changes in $d$.

It can be used for alignment and wavefront control of the future NASA segmented telescope such as Luvior or HabEx.
Type of Photonics Devices

- Two type of photonics devices
  - Passive
    - Buy COTS and put them through environmental requirements
    - 6 thermal cycles
    - Radiation
  - Active
    - Screening and lot qualification using Telcordia and Mil-STD combine
Passive Devices (1/2)

- Waveguide
  - Custom made interferometers integrated photonics on a silicon chip (~14x14x0.7 mm)
  - Perform full Qualification on 3 units
    - Performance (PER, II, thermal sensitivity)
    - Dynamic test
    - Radiation (100 Krad)

- Screening other devices after qualification
  - Performance
  - Thermal cycle
Passive Devices (2/2)

- Splitters/coupler 1x2 and 2x8
  - Planar Lightwave Circuits (PLC)
  - Screening
    - Performance (PER, IL, uniformity)
    - Thermal cycle

- Fiber optics
  - Single mode (SM)
  - Polarization maintain fiber (PM)
  - Polarizing fiber (PZ)
  - There are plentiful data on most fibers
  - Perform lot qualification
Qualification Process for Passive Devices

- Different process used for passive devices
  - Different performance parameters and different reliability parameters

Interferometer:

- Performance Test → Measure All Thruputs & Pointing
- Random Vibration Test → Measure All Thruputs & Pointing
- Pyro-shock Test
- Measure All Thruputs & Pointing
- Non-Op Thermal Atosphere Test
- Measure All Thruputs & Pointing
- Radiation Test
- Measure All Thruputs

Splitters & Fibers:

- Measure All Thruputs, insertion loss, PER
- Non-Op Thermal Atmosphere Test
- Measure All Thruputs & Pointing
- Radiation Test
- Measure All Thruputs, insertion loss, PER
Active Devices - Laser

- Laser - 1.5 um external grating semiconductor laser with narrow linewidth
  - COTS laser, with screening and lot qualification
  - Guidelines developed at JPL for screening and qualification
  - 21 lasers were used for lot qualifications
Qualification Process for Laser

- JPL developed qualification process using Mil-STD and Telcordia

### Qualification Steps for Laser

<table>
<thead>
<tr>
<th>Qualification Step Number</th>
<th>Test</th>
<th>Method</th>
<th>Conditions</th>
<th>Quantity Accept (Failure No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgroup 1</td>
<td>Environmental Stress Tests</td>
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<tr>
<td>1</td>
<td>Performance Tests</td>
<td>Per Table VII</td>
<td>Tests 1-12 of Table VII</td>
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<tr>
<td>2</td>
<td>Mechanical Shock</td>
<td>TM 2002</td>
<td>Condition A, 200 Hz to 2000 Hz</td>
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<td>3</td>
<td>Performance Tests</td>
<td>Per Table VII</td>
<td>Tests 1-8 of Table VII</td>
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<td>4</td>
<td>Vibration</td>
<td>TM 2006</td>
<td>Condition A, 200 Hz to 2000 Hz</td>
<td></td>
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<td>5</td>
<td>Performance Tests</td>
<td>Per Table VII</td>
<td>Tests 1-8 of Table VII</td>
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<td>6</td>
<td>Thermal Shock</td>
<td>TM 1011</td>
<td>Condition A, 0°C to 100°C, 20 cycles</td>
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<td>7</td>
<td>Seal</td>
<td>TM 1014</td>
<td>Method compatible with sealed module</td>
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</tr>
<tr>
<td>8</td>
<td>Performance Tests</td>
<td>Per Table VII</td>
<td>Tests 1-8 of Table VII</td>
<td></td>
</tr>
</tbody>
</table>

| Subgroup 2 | Package Tests |
| 1 | Solderability | TM 2003 | Steam aging not required |
| 2 | Metal Package Integrity | TM 2004 | RIN defined to 100 VDC, 100 A maximum |
| 3 | Lead Integrity | TM 2004 | - B2 lead fatigue |

| Subgroup 3 | Accelerated Aging |
| 1 | Accelerated Module Life Test via Temperature Cycling | Table 5-1 in Telcordia GR-468 | -40°C to 85°C Continuous Temperature Cycling tests (Subgroup 1, step 12) using devices that have completed Subgroup 1 testing to accumulate a total of 500 cycles. |
| 2 | Performance Tests | Per Table VII test 1-12 | Perform Tests 1-8 at the end of every additional 100 cycles, and Tests 1-12 at the end of 500 cycles. |
| 3 | Accelerated Aging Tests via High Temperature Storage Test | Table 5-1 in Telcordia GR-468 | -85°C Continuous High Temperature Storage Test (Subgroup 1, step 8) using devices that have completed Subgroup 1 testing to accumulate a total of 5000 hrs. |
| 4 | Performance Tests | Per Table VII test 1-12 | Perform Tests 1-8 at the end of every additional 1000 hrs and Tests 1-12 after the 5000 hrs. |
Active Devices - AOM

- Acousto-Optic Modulator (AOM) - provide frequency shift (modulation) to the laser light
- Custom made, with screening and lot qualification
- Guidelines developed at JPL for screening and qualification
- 10 AOMs were used for lot qualification
Qualification Process for AOM

- JPL developed qualification process using Mil-STD and Telcordia
In closing

- Photonics market is a growing market, in some estimate it is expected to be over $900 billions by 2024.
- Space application is a portion of this growth with its unique need and requirement.
- More photonics parts are being used or considered for space application due to its benefit, small mass, small size and low power.
- Need to develop guidelines and methodology on how to qualify photonics devices for space application.
- Need to have a good understand of failure modes of photonics devices.
- Goddard has done some great work in this area, and ESA has been also working on this area as well.
Strategy for Qualification

- General strategy - Test according to Mil-STD and Telcordia
- Standard tests are generally not suited for the photonics devices
- Some considerations and constrains
  - Cost reduction
    - Smaller number of devices per test groups
    - Reduction in the characterization parameters at each steps
  - Small procurement volume
    - Not very attractive for COTS manufacturers
  - Reliability and failure data
    - Development of photonic devices are moving fast and not enough time to have complete reliability and failure data for FM
  - Challenge of space environments, vacuum, hermeticity, radiation, temperature range
Recommendations

- Establish a collaboration with other NASA centers, universities, industries and other institutions
- Prioritize parts that are being considered for near term missions
- Develop methodology for evaluation and space qualification of the photonics devices
- Develop guideline on how to bring photonic devices from TRL1 to TRL6
Thank You