EVALUATION OF OPTOELECTRONIC DEVICES AND TECHNOLOGIES FOR SPACE APPLICATIONS

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Outline

- About ALTER
- Photonic Technologies Used in Spacecrafts and Applications.
- Typical Space Requirements.
- COTS Selection Philosophy.
- Photonics Spaceflight Experience (ESA).
- ALTER Experience.
- Conclusions
Evaluation of Optoelectronic Devices and Technologies for Space Applications

About ALTER

- Group encompasses 3 companies (ALTER France, ALTER Italy and ALTER Spain)
  - > 180 employees
- 4 specialised laboratories
- Specialised in Electronic Components
- Mainly focused on High Reliability Engineering, Procurement & Testing
- Most of the services related to high reliability electronic components in only one Company
  - Electronic Components
  - Space & aerospace sectors
  - Electronic components engineering
  - Obsolescence management
  - Quality requirements compliance
  - DPA and technological evaluations
  - Purchasing
  - Incoming inspections and acceptance
  - Special testing
  - Electrical screenings
  - Radiation Verification Testing
  - SEE
  - Optoelectronics testing
  - Storage
  - Logistics
  - Consultancy

- More than 10,000 lots of Hirel components, are processed every year in our laboratories
- More than 25 years of experience in our field of expertise.
  - ALTER has participated virtually in the development of most of the European Satellites.
  - Our presence in the Japanese market goes back over 10 years
- ALTER works with all the Hi Reliability Electronic Components Manufacturers
Photonic Technologies Used in Spacecrafts and Applications

Properties of the Photonic Technologies

• Almost unlimited bandwidth (i.e. 1550nm fibre 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).

Source: Photonic Technologies Used in Spacecrafts and Applications
Advantages of using photonic technologies in spacecrafts

- Reduced noise generation and Electromagnetic immunity are clear advantages in cases where satellite operation works close to the sensors sensitivity bandwidth (i.e. natural Earth microwave emissions).
- Mechanical flexibility and low weight of FO compared with standard hardness are an advantage when articulated systems are used or many meters of cabling are required.
- Mass reduction possibilities in case of using photonic systems may result in important cost reduction during handling and launching of the S/C.
- Huge bandwidth and multiplexing properties makes FO systems is a clear advantage for signal processing, and thermal and structure monitoring applications.
- The use of optical wireless technologies will reduce cost and time in the Assembly and Test (AIT) phase.

Source: Photonic Technologies Used in Spacecrafts and Applications
Photonic Technologies Used in Spacecrafts and Applications

Technology R&D goals in optical telecommunications

• Maintain Europe’s strong position in optical communication applications and technologies.

• Implement/guarantee European independence.

• Develop secure optical communication technologies through atmosphere.

• Develop optical communication technologies for deep space links.

• Reduce cost, mass and volume of optical communication terminals.

Source: Photonic Technologies Used in Spacecrafts and Applications
Photonic Technologies Used in Spacecrafts and Applications

Photonic technologies used in spacecrafts

- fibre optic devices
- Integrated optics
- Microphotonics

Applications

- Photonic communications
- Photonic Signal Processing
- Photonic Sensing
- Speciality applications
Photonic Technologies Used in Spacecrafts and Applications

Optoelectronic technologies for Telecommunication Satellites

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

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

Source: Artemis and SPOT 4 communicating via the SILEX system - Artist's impression. Credits: ESA-J.Huart
Photonic Technologies Used in Spacecrafts and Applications

Payload - Digital Communication Links

Generic Digital Links – Space Fibre
High speed extension to Space Wire Standard 1-10 Gbps

ADC to DSP to ADC
Hybridisation of optical transceivers with functional electronic devices.
Specifications for up to 5THz between ADC and DSP.
– Use of Vertical Cavity Surface Emitting Lasers (VCSELs) at 850nm
– Graded Index Multimode (GIMMM) fibres
– PIN detectors

Source: Photonic Technologies Used in Spacecrafts and Applications
Photonic Technologies Used in Spacecrafts and Applications

Payload - Digital Communication Links

Interboard Interconnects
- High efficiency-High density optical interconnects. Up to 2000 interconnects @ Gbps rate are required for the inter-board in the Next Generation DSP

Interchip Interconnects
- Future direction (90% of the power of an ASIC onboard modern DSPs is consumed in interconnections) – Silicon Photonics

Photonics PCBs
- Based on Photonic waveguides
Payload - Analog Communication Links

Local Oscillator (LO) transmission
- LO harness based on fibre optics.
- Use of Directly Modulated Distributed Feedback (DFB) lasers.

 Functions of a Transparent Analog Telecom Repeater that can be performed by photonic technologies (in blue)
Photonic Technologies Used in Spacecrafts and 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

Source: Photonic Technologies Used in Spacecrafts and Applications
Photonic Technologies Used in Spacecrafts and 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

Source: Photonic Technologies Used in Spacecrafts and Applications
Photonic Technologies Used in Spacecrafts and Applications

Photonic Sensing

Chemical and electric propulsion systems (temperature measurement points)

- fibre Optic Sensors (fibre Bragg Gratings), surface mounted or embedded.

Fibre optic gyroscopes

- laser diodes
- low noise photo-detector
- Lithium Niobate phase modulator,
- Erbium doped fibre,
- Bragg grating,
- sagnac fibre loop and isolator
Photonic Technologies Used in Spacecrafts and 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.
Photonic Technologies Used in Spacecrafts and Applications

Other applications

Earth observation and science

- Far infrared laser diodes and detectors
- Highly uniform and multicolour large area IR focal plane arrays operating in long wavelength (LWIR)
- IR Detectors operating up to 15 µm
- Long wavelength detectors (up to 15 µm for meteorology, up to 18 µm for atmospheric chemistry and astronomy)
- Vis, NIR, SWIR and MWIR detectors operating at high temperature
- Spectrometers: SWIR (short wave band infrared) array detectors for future needs
- CMOS Read Out Integrated Circuits (ROIC)
- p-type CCDs
- APS/CMOS CCDs for imaging device used in space.

Source: Photonic Technologies Used in Spacecrafts and Applications
**Typical Space Requirements**
(applicable to optoelectronic COTS)

- Reliability: 15 years of operation in space.
- Resistance to radiation environment: resistance to 100 Krad(Si) and protons fluence of $2\times10^9$ protons $65\text{MeV/cm}^2$.
- Operating temperature range: $-40^\circ\text{C}$ to $+85^\circ\text{C}$.
- Operation in vacuum.
- Resistance to thermal cycles.
- Resistance to vibration and mechanical shock.
COTS Selection Philosophy

1. Identification of potential suppliers for a given technology/device type.
2. Comparative assessment of potential suitability to survive space environment:
   - Analysis of the available technology/reliability data.
   - Construction analysis.
   - Environmental test.
     - Radiation, thermal vacuum, vibration.
   - Reliability test.
3. The supplier commitment to support the space business
4. Space qualification (if possible)
### Photonics Spaceflight Experience (ESA)

<table>
<thead>
<tr>
<th>Mission</th>
<th>Photonic application</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTEMIS</td>
<td>Deliver laser pump power for the SILEX ISL beacon beam</td>
<td>In space since 2001</td>
<td>Successful, (contamination of optics ?)</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>Single Mode fibre for the MIRAS instrument</td>
<td>In space since 2002</td>
<td></td>
</tr>
<tr>
<td>SMART-I</td>
<td>Deliver reflected light from Moon’s surface to on board Spectrometer</td>
<td>In space since 2002</td>
<td>Successful</td>
</tr>
<tr>
<td>NANOSAT-1</td>
<td>Spanish technology demo carrying Optical Wireless</td>
<td>In Space since 2004</td>
<td>Continuous successful operation</td>
</tr>
<tr>
<td>SMOS</td>
<td>Data link distributing the clock signal and connecting antennas with the control and correlator unit</td>
<td>To be launched in 2009</td>
<td>Some qualification issues have arisen but can be addressed</td>
</tr>
</tbody>
</table>

Source: [eesa](http://eesa)
## Photonics Spaceflight Experience (ESA)

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<thead>
<tr>
<th>Mission</th>
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<th>Status</th>
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</tr>
</thead>
<tbody>
<tr>
<td>PROBA-II</td>
<td>fibre optic sensors for the propulsion subsystem</td>
<td>To be launched in 2009</td>
<td>Proceeds nominally</td>
</tr>
<tr>
<td>ATV</td>
<td>Deliver the laser beam in both directions between the optical scanning head and the</td>
<td>First ATV mission in 2008</td>
<td>Problems in harnessing during AIT – addressed – successful mission</td>
</tr>
<tr>
<td></td>
<td>electronic control unit of the Randevous &amp; Docking proximity sensor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERRASAR-X</td>
<td>German EO Satellite. Optical modulator by LITEF Single Mode Polarization maintaining</td>
<td>In space since 2007</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fibres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOTON-14</td>
<td>Optical wireless communications</td>
<td>In space since 2007</td>
<td>Successful</td>
</tr>
</tbody>
</table>

Source: [ESA](http://www.esa.int)
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<tr>
<th>Mission</th>
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<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS- NODE-2</td>
<td>Communications links</td>
<td>In space since 2007</td>
<td>Central procurement by Boeing</td>
</tr>
<tr>
<td>ISS- COLUMBUS</td>
<td>Communication links (Data, video, audio links up to 125 Mbps)</td>
<td>In space since 2008</td>
<td>Central procurement by Boeing</td>
</tr>
<tr>
<td>ISS -CUPOLA</td>
<td>Audio signal links</td>
<td>To be launched in 2010</td>
<td>Central procurement by Boeing</td>
</tr>
<tr>
<td>ISS - NODE-3</td>
<td>Communications links</td>
<td>To be launched in 2010</td>
<td>Central procurement by Boeing</td>
</tr>
</tbody>
</table>
Photonics Spaceflight Experience (ESA)

<table>
<thead>
<tr>
<th>Mission</th>
<th>Photonic application</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPERT</td>
<td>Sensors</td>
<td>To be launched in 2010</td>
<td></td>
</tr>
<tr>
<td>ALPHA-SAT</td>
<td>MEMS switch and Parallel fibre Optic Digital Links in the TDP-8 demonstrator</td>
<td>To be launched in 2012</td>
<td></td>
</tr>
<tr>
<td>EXOMARS</td>
<td>Power delivery from and to a Spectrometer on board a Mars Lander</td>
<td>To be launched in 2015</td>
<td></td>
</tr>
</tbody>
</table>
# ALTER Experience

## Space Evaluation of Photonic Devices

<table>
<thead>
<tr>
<th>Project</th>
<th>Devices under evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOS Satellite – MOHA (Mira Optical Harness) Qualification of optical components</td>
<td>FO laser diode, FO detector, Optical fibre, FO splitters</td>
</tr>
<tr>
<td>OWLS (Optical Wireless Link Systems for intra-satellite communications.)</td>
<td>IR LEDs, IR Photodiodes</td>
</tr>
<tr>
<td>Multigigahertz Optical Modulators of very low RF driving power (Testing of selected Optical modulators)</td>
<td>Optical modulators 1550nm</td>
</tr>
<tr>
<td>High Efficiency Optical Amplifiers for FO on board applications. (Testing of selected optical amplifiers; project management).</td>
<td>Optical amplifiers 1550nm</td>
</tr>
</tbody>
</table>
## ALTER Experience

**Space Evaluation of Photonic Devices**

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>POE (Programmable optoelectronic adaptative element) Design &amp; Qualification of POE elements for space application</td>
<td>Liquid crystal</td>
</tr>
<tr>
<td>FOD (SpaceFibre) Development of an EM model of a high speed optic transceiver for use onboard telecom satellites</td>
<td>Optical transceiver 10 Gbits (1550 nm)</td>
</tr>
<tr>
<td>PHT (Photonic Transceiver for Secure Space Applications) Design &amp; Qualification of PHT element</td>
<td>Pump Lasers (450nm) FO lasers (840nm) Beam splitters Optical amplifiers NL crystals</td>
</tr>
<tr>
<td>ELECTRO-PHOTONIC ADC</td>
<td>Optical modulators</td>
</tr>
</tbody>
</table>
# ALTER Experience

## Space Evaluation of Photonic Devices

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</tr>
</thead>
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<tr>
<td>SWIR (Short wave-band Infra red laser diodes)</td>
<td>Short wave Infra red laser diodes</td>
</tr>
<tr>
<td>(Other)</td>
<td>Photodiodes InGaAs 800-1600 nm</td>
</tr>
<tr>
<td>(Other)</td>
<td>LED IR 770</td>
</tr>
<tr>
<td>(Other)</td>
<td>LED Red, green &amp; blue</td>
</tr>
</tbody>
</table>
## ALTER Experience
### Test Results Summary

<table>
<thead>
<tr>
<th>Device type</th>
<th>Radiation</th>
<th>Radiation</th>
<th>Thermal</th>
<th>Vibration</th>
<th>Life test</th>
<th>Construc. Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>FO laser 1310 nm</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>FO detector 1310 nm</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Optical fibre</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>FO splitter</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>LEDs 670 nm</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>PIN Photodiodes 400-1000 nm</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Optical modulators (1550 nm)</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Optical amplifiers (1550 nm)</td>
<td>•</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>•</td>
<td>√</td>
</tr>
</tbody>
</table>

- **√** Pass the test
- **•** Fail
- **-** Test not performed
- **√•** Type selection
# ALTER Experience
## Test Results Summary

<table>
<thead>
<tr>
<th>Device type</th>
<th>Radiation Gamma</th>
<th>Radiation Protons</th>
<th>Thermal Vacuum</th>
<th>Vibration</th>
<th>Life test</th>
<th>Construc. Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photodiodes UV 200-400 nm</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Thermopiles IR (up to 20 µm)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>AOM Free space Acousto-optical modulator 1064 nm</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>BAM Laser diode (850nm)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>SLED (820nm)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Liquid Crystal</td>
<td>-</td>
<td>-</td>
<td>On going</td>
<td>-</td>
<td>-</td>
<td>On going</td>
</tr>
<tr>
<td>Optical transceiver 10 Gbits (1550 nm)</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
</tr>
</tbody>
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✓ Pass the test    //    ● Fail    //    - Test not performed    //    ✓ Type selection
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</tr>
</thead>
<tbody>
<tr>
<td>Pump Lasers (450nm)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>On going</td>
<td>✓</td>
</tr>
<tr>
<td>FO lasers (840nm)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Beam splitters</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Optical amplifiers (840nm)</td>
<td>✓</td>
<td>✓</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
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</table>

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<th>Life test</th>
<th>Construc. Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL crystals</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Photodiodes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InGaAs</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>800-1600 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LED IR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>770</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red, green &amp; blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Laser</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2100 nm</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
<td>On going</td>
</tr>
</tbody>
</table>

- ✓ Pass the test
- • Fail
- - Test not performed
- ✓ Type selection
Electro-optical Laboratory Capabilities

Fibre transmission systems:
- Characterization lasers and LEDs 600nm to 12 µm.
- Receivers modules (180 to 2200 nm).
- Optical modulators, switches and splitters.
- Cable Assemblies (FC, SC, AVIM, AVIO, etc..)
- Multimode and monomode fibres.

Diffuse light systems:
- Characterization of LEDs and photodiodes:
  - DC specifications.
  - Spectral characterization (600nm to 12 µm).
  - Power characterization (Integrating sphere).
  - Radiation diagram: Far and near field.
- Optical filter and modulators.
- Mechanical adapter and optical accessors.
- Fibre bare adapters.
- Laser beam splitters.
- Mirrors.
- Lens and Prism.

Testing:
- Electro-Optical parameters.
- Mechanical specifications.
- Thermal vacuum
- Radiation
- Time and spectral response.
- Environmental
- Constructional analysis.
Electro-optical Laboratory Equipment

- Thermal vacuum chamber.
  - Temperature range from -55°C to +125°C
  - Pressure better than 10-5 mbars (up to 10-7 mbars)
  - Dimensions: 30 cm diameter, 15 cm height
- Clean area with laminar flow chamber (class 100).
- Optical table with vibration stability.
- Free ESD area.
- Lasers 1064, 1310 and 1550 with modulating option (up to 20 Gb).
- Integrating sphere (250 – 2500 nm) and detectors.
- Spectrum Analyser (600 – 1750 nm, resolution 20 pm).
- Return loss and OTDR analyser.
- Optical attenuators and splitters.
- Monochromator (180nm – 200nm).
- Translation and rotation positioners.
- Climatic chambers (thermal shock, life, etc...).
- Mechanic test system (Pull, push, torsion test).
Conclusions

• The use of optoelectronic technologies in space applications has shown an important increase in the last years due to the multiple applications and their advantages compared with standard technologies.

• Most of the components required for the different applications are only available at commercial level.

• A complete evaluation of the technology has to be performed in advance in order to select the best components and to reduce the risk of using devices that have not been designed to work in space environmental conditions.

• ATG experience shows that the evaluation of the most critical aspects reveals that not all the commercial devices that are available in the market are suitable for space use.
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