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PHOTONICS IN SPACE COMMUNICATION

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ABSTRACT

Photonics is the physical science and application of light generation, detection, and manipulation through emission, transmission, modulation, signal processing, switching, amplification and sensing. Though covering all light's technical applications over the whole spectrum, most photonic applications are in the range of visible and near-infrared light. Photonics could potentially be a key technology in the emerging market of laser space communications, with unique performance characteristics. Photonics is expected to play a key role in space applications as optics and fibre-optics penetrates into satellite payloads and photonic components and subsystems become integral functional parts of telecommunication, on-board signal distribution and/or remote sensing instrumentation. Photonic Integrated Circuit based optical devices are dominating the terrestrial domain in medical facilities, data centers and civil infrastructures. The Space instrument science increasingly uses optics and photonics for Earth observation and astronomical exploration with operational requirements in extreme environments.

Keywords*—Photonics, Signal processing, fiber-optics, Laser*

1. INTRODUCTION

Photonics is rapidly transforming into an enabling space technology with potential to cross-fertilize multiple markets in the space domain. Among them: navigation, remote sensing and telecommunications, as well as ground-breaking scientific and planetary exploration missions. Because of advantages related to bandwidth, mass, power consumption, beam size and immunity to electromagnetic interference, photonic subsystems are now being considered in navigation satellite systems, Earth observation satellites, low Earth orbit (LEO) constellations and within telecom satellite payloads. Token examples of functionalities being demonstrated in the laboratory and in space include stable laser sources, high-speed transmitters, highly sensitive receivers, on-board optical processing systems and optical clock distribution. A key milestone in the robustness of photonics was the 2009 deployment of 1.55-μm fused fibre couplers on a mission-critical payload onboard the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) satellite. The nominal lifetime of the satellite was three years (including a six-month commissioning phase). Other light sources include single photon sources, fluorescent lamps, cathode ray tubes (CRTs), and plasma screens. Laser communications between satellites or from satellite-to-ground can enable high-speed connectivity with reduced spacecraft resources in terms of mass, real estate and power. Space-based laser systems rely on 1064- or 1550-nm wavelength windows for establishing high-capacity networks from satellites on the low Earth or geostationary orbits.

This allows for piggybacking proven terrestrial photonic technologies and, where required, exploiting wavelength division multiplexed technology for increasing the aggregate channel capacities. Fig 1.1 shows a laser communication terminal (LCT) is the space equivalent of a transponder in line-side equipment of terrestrial networks

2. METHODOLOGY

The recent improvement in satellites and the development of micro- and nano-satellites, it is now easier than ever to send experimental devices to orbit the Earth. Many examples of laser photonic devices and missions that have successfully studied our planet evolution from space have been reported, although the most common example is the space-based LIDAR, which sends laser pulses to the target surface and analyzes the reflected signal. The observer effect is a well-known physics phenomenon that states that observation of an experiment can alters some of its parameters, so remote, non-interfering characterization techniques can provide better objective information. In the same way, observing the Earth from space can provide better perspective, additional information, and a more global vision to study our planet.

Early Space-Based laser Altimeters:

The first space-based lidar instrument was a laser ranger developed by the Un ited States 011 the Apollo 15 mission in 1971 using a flash lump pumped ruby laser 3t3.75 pulses per minute. The Apollo 15, 16, and 17 missions combined, made a few thousand measurements of the lunar surface around the equator. With the advent of diode pumped lasers in the late 1980s, the lifetime, efficiency, resolution and the mass of lasers and space lidar all improved dramatically. A laser altimeter (also called light detection and ranging or laser image detection and ranging (LIDAR)) transmits laser pulses (energy in the order of several tens of mJ per pulse) toward planetary surfaces with a typical pulse rate of 10–30 Hz. The instrument measures the round-trip time of the light pulse between emission and the returned surface reflection to determine the distance of the spacecraft with respect to the surface. A laser altimeter operates in a very similar way to radar technology, which uses RF pulses instead of light pulses. The laser pulses are produced, for example, with a neodymium-doped yttrium aluminum garnet (Nd:YAG), which is optically pumped with laser pumping diodes. Active or passive Q-switching is used to produce the controlled laser pulses. The laser pulse emission is in the IR for a Nd:YAG (mainly 1064 nm), but with different YAG doping emission in UV, visible, or near IR that can be produced. A laser has a very narrow beam, emitted via a transmitter optic, which introduces a designed beam divergence, which allows the mapping of surface features with much higher spatial resolution compared to radar. The first space-based lidar that used a diode pumped Nd:Y AG laser was Mars Orbiter Laser Altimeter (MOlA) developed at the National Aeronautic and Sp3ce Administration (NASA) Goddard Space Flight Center (GSFC) on the Mars Observer mission in 1992. Unfortunately. the spacecraft developed a problem and did not reach the Mars orbit. A smaller laser ranger with similar laser and detector developed by the Naval Research lab new on the Clementine mission \0 the Moon in 1994 and provided a global topographic map of the entire lunar surface at a few hundred-meter platform.

The Mars Orbiter Laser Altimeter (MOLA) was launched in 1996 aboard the Mars Global Surveyor mission and conducted a multiyear mapping mission of the red planet beginning in early 1999 (Smith et al., 2001). An earlier version of the MOLA instrument had been on the Mars Observer mission that never reached orbit. The Ice, Cloud, and Land Elevation Satellite (ICESat) was launched into the Earth's orbit in January 2003 and carried the Geoscience Laser Altimeter System (GLAS), with a primary mission to measure changes in the Earth's ice sheet elevation over time (Schutz et al., 2005; Zwally et al., 2002). Although radar altimeter data have been used to measure ice sheets for some time (e.g., Zwally and Brenner, 2001), the accuracy of the radar measurement over the ice is much worse than over the ocean, because ice sheet elevation changes so much over the footprint of the radar pulse. A small laser ranger developed by the Johns Hopkins University Applied Physics laboratory on board the Near-Earth Asteroid Rendezvous (NEAR) mission, launched in 1994, successfully measured the topography and shape of the near Earth asteroid 433 Eros. A second MOlA was but by NASA GSFC and launched in 1997 on board Mars Global Surveyor (MGS). MOlA was both a laser ranger and a laser radiometer. It measured not only the laser pulse time-o f-night but also the pulse width and energy, which were 10 correct the range walk caused by the signal amplitude variation, to infer the surface slope from the laser pulse broadening. and 10 estimate the surface reflectance to the laser light. MOlt\ 011-board science algorithm tracked the ground surface returns and dynamically adjusted the receiver detection threshold and range gate to keep the instrument at the highest receiver sensitivity

3. SPECIFIC REQUIREMENTS

ELECTRO- OPTICAL REQUIREMENTS: The first step in the parts selection process is the exact definition of the electro-optical performance required for the application. This implies the clear identification of:

1. Key parameters.
2. Acceptable limits to the range of variation of these parameters during the mission, taken into account:

Operating temperature range. Environmental conditions (radiation). Expected mission lifetime.

The key parameters have to be selected in such a way that they allow a wide margin of potential commercial candidates at the time that the performance of the mission is not jeopardized. Some aspects will require the maximum possible flexibility. To make that flexibility possible it is necessary that the selection process is initiated at the first steps of the design, to reduce as much as possible the design related constrictions.

QUALITY REQUIREMENTS: Quality requirements are determined by the type of mission and application; nevertheless, it is strongly recommended to apply the quality requirements established in ECSS-Q-60A. These quality requirements have to be followed to the maximum extent as possible in terms of:

1. Procurement policy
2. Screening
3. Package and assembly quality and testing
4. Acceptance test criteria

RELIABILITY REQUIREMENTS: Reliability is one of the main concerns when using commercial components in space applications. This asseveration does not mean that the commercial components are not reliable enough for their application in space, but its real reliability has to be verified. This verification can be performed by means either of the analysis of the reliability data provided by the manufacturer (if available) or by testing, in order to warranty a minimum of 10 years (typical value) of operation in space environment.

ENVIRONMENTAL CONSTRAINS: The environmental constraints imposed by the space missions are mainly driven by the conditions stress during launching and by the operation in free space. The following elements constitute the main constrains compared with the majority of the commercial applications [18]:

1. Operating temperature range
2. Thermal variations
3. Vibration
4. Accelerations
5. Vacuum

6. Harsh Radiation Environment

OPERATING TEMPERATURE RANGE: Typical operating temperature range warranted by the manufacturer for commercial parts goes from 0 to 40 º, while space application requires in general parameters and functional stability in the range from -55 to +125ºC (although some specific missions / applications may require ranges from -185ºC to +300ºC). The selected parts need to remain functional and parametrically stables in the specified temperature range.

VIBRATION: The capability of the optoelectronic components to survive strong vibration conditions during launch is a requirement to be taken into account. Specific requirements need to be defined on a case-by-case mission.

THERMAL CYCLES: Space hardware has to be able to survive extreme temperature cycles produced during operations due to the continuous travelling of the satellite from exposition to solar radiation to shadow during its rotation around the Earth. The mechanical stress produced by these temperature cycles may induce degradation in the mechanical parts of the component.

ACCELERATIONS: Optoelectronic parts should be able to survive hard accelerations during launch, as per the conditions given in the following requirements. Requirements must be defined on a case-by-case basis.

VACCUM: Space operation requires stable performance under vacuum conditions. The main concern related to vacuum conditions operations is related to the risk for certain materials to outgas, with two negative effects: Deposition of out-gassing materials on optical parts and Material degradation due to chemical reaction or de-composition. As a general test requirement, any part must be designed to withstand a depressurization rate of 26 Torr/s from ambient pressure down to 10-10 Torr in free space at full operating conditions.

SPACE RADIATION ENVIRONMENT: Four sources of radiation can be distinguished: Cosmic rays: all kind of ions, but primarily protons (85%) and helium (14%), Radiation belts (Van Allen belts), protons and electrons trapped in the earth's magnetic field, Solar particles (mainly protons), Atmospheric secondary (possible influence on low orbit spacecraft).

4. BLOCK DIAGRAM

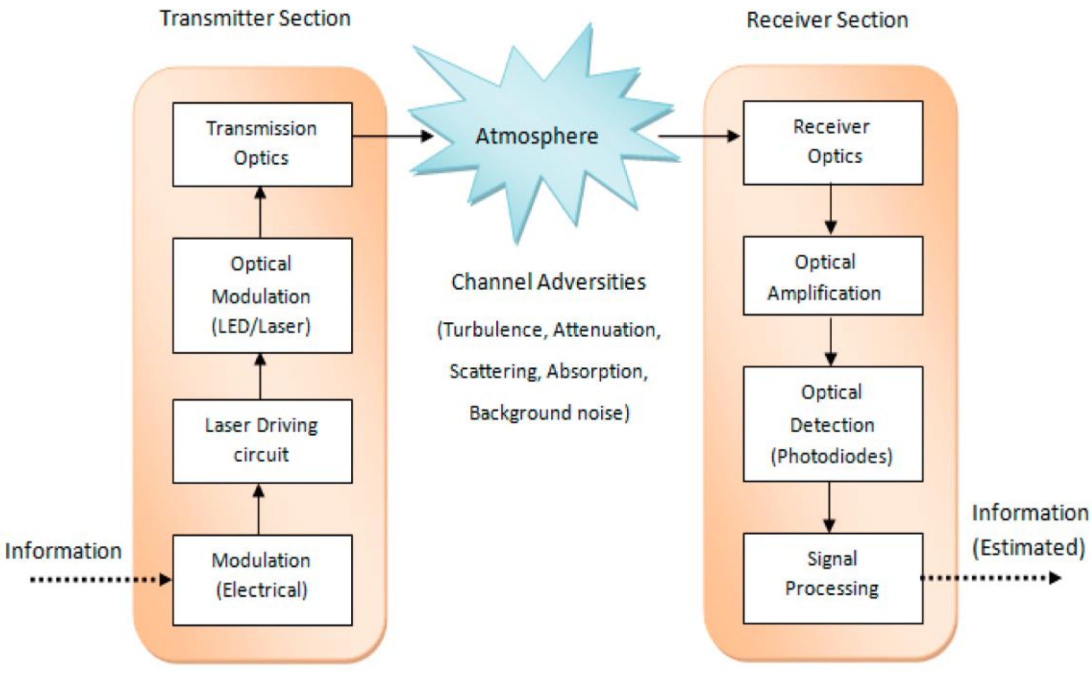

Fig: Block Diagram

5. ADVANTAGES

- Earth Observation: Observing the Earth from space can provide better perspective, additional information, and a more global vision to study the planet.
- Spectroscopy: passive and active spectroscopy are useful in a wide range of scientific and industrial applications, but also in space applications where they have allowed.

- Using light waves instead of electrical wires for microprocessor communication functions could eliminate the limitations now faced by conventional microprocessors.
- Using light has the potential to be brutally energy efficient.
- Single fiber-optic strand can carry a thousand different wavelengths of light at the same time, allowing for multiple communications to be carried simultaneously in a small space and eliminating cross talk.
- Almost limitless bandwidth and propagation to longer distances.

6. APPLICATIONS

- Telecommunication: optical down-converter to microwave, and optical fiber communications.
- Medical applications: laser surgery, poor eyesight correction, tattoo removal and surgical endoscopy.
- Manufacturing processes in industries: involves the use of laser in welding, cutting, drilling, and many surface modification techniques.
- Building and construction: smart structures, laser range finding, and laser levelling.
- Space exploration and aviation: including astronomical telescopes.

7. CONCLUSION

Very few optical components are qualified for space applications. This means that optics are necessary most of the times. A cost-effective approach for selection and acceptance criteria of these has been presented in this topic**.** Detailed construction analysis, endurance, radiation and environmental test performed before the complete qualification flow can be very useful for increasing the reliability of the devices and reducing both the price of the selection and project qualification. It is recommended to do this prior to any project qualification activity. Specific test setup conditions must be considered when working with photonics parts to ensure test bench is suitable to provide electro-optical characteristics while parts are being submitted to environmental test in operating conditions.

REFERNCES

[1] Zeiler, M.; Detraz, S.; Olantera, L.; Pezzullo, G.; El Nasr-Storey, S.S.; Sigaud, C.; Soos, C.; Troska, J.; Vasey, F. Design of Si-photonic structures to evaluate their radiation hardness dependence on design parameters. J. Instrum. 2016.

[2] Tzintzarov, G.N.; Ildefonso, A.; Goley, P.S.; Frounchi, M.; Nergui, D.; Rao, S.G.; Teng, J.; Campbell, J.; Khachatrian, A.; Buchner, S.P.; et al. Electronic-to-Photonic Single-Event Transient Propagation in a Segmented Mach-Zehnder Modulator in a Si/SiGe Integrated Photonics Platform. IEEE Trans. Nucl. Sci. 2020, 67, 260–267.

[3] George N. Tzintzarov, Sunil G. Rao and John D. Cressler, Integrated Silicon Photonics for Enabling Next-Generation Space Systems, Photonics, Issue No. 8, 2021, pp.no 1-20.

[4] Boynton, N.; Gehl, M.; Dallo, C.; Pomerene, A.; Starbuck, A.; Hood, D.; Dodd, P.; Swanson, S.; Trotter, D.; DeRose, C.; et al. Gamma radiation effects on passive silicon photonic waveguides using phase sensitive methods. Optics Express 2020, 28, 35192–35201.

[5] Goley, P.S.; Fleetwood, Z.E.; Cressler, J.D.; Member, S.; Fleetwood, Z.E.; Member, S.; Cressler, J.D. Potential Limitations on Integrated Silicon Photonic Waveguides Operating in a Heavy Ion Environment. IEEE Trans. Nucl. Sci. 2018, 65, 141–148.

[6] Goley, P.S.; Cressler, J.D. Silicon-Based Electronic-Photonic Integrated Circuits: Resiliency in the Space Environment. In Proceedings of the 2019 GOMAC-Tech—Government Microcircuit Applications and Critical Technology Conference, Albuquerque, NM, USA, March 25–28. 2019; pp. 223–227.

[7] Tzintzarov, G.N.; Ildefonso, A.; Teng, J.W.; Frounchi, M.; Djikeng, A.; Iyengar, P.; Goley, P.S.; Khachatrian, A.; Hales, J.; Bahr, R.; et al. Optical Single-Event Transients Induced in Integrated Silicon-Photonic Waveguides by Two-Photon Absorption. IEEE Trans. Nucl. Sci. 2021, 1–8.

[8] Ildefonso, A.; Fleetwood, Z.E.; Tzintzarov, G.N.; Hales, J.M.; Nergui, D.; Frounchi, M.; Khachatrian, A.; Buchner, S.P.; McMorrow, D.; Warner, J.H.; et al. Optimizing Optical Parameters to Facilitate Correlation of Laser-and Heavy-Ion-Induced Single-Event Transients in SiGe HBTs. IEEE Trans. Nucl. Sci. 2019, 66, 359–367.