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Photonics used for Space Communication

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Abstract: Photonic technologies have changed the world of communications in the form of fiber optics, integrated optics, electro-optical components, and micro-photonics. They offer some compelling advantages compared with their traditional RF counterparts when considered for use in space applications. Thus, research and development of photonics technologies for space applications in areas of communications, sensing, and signal processing has been a major theme for several years.

The use of photonic technologies for space applications has risen the problem related to the ability of optoelectronic and optic components to withstand the space environment as all optoelectronic and optic components come from terrestrial applications. Thus, the development of photonic technologies for space applications has made the selection and acceptance test criteria of all optoelectronic and optic components that are part of the photonic system imperative.

The paper presents a summary of the experience of Alter Technology Group on the mechanical, thermal, radiation, and endurance testing of several photonics technologies. In addition, the paper describes an assessment related to the reliability of these parts to be used in space applications together with the critical requirements to be considered for associated environmental testing.

INTRODUCTION TO PHOTONICS IN SPACE

The selection and evaluation procedures of COTS optoelectronic components for its use in space application need to be established because no qualified components exist and no standards are available that define the procedures to be applied for optoelectronic devices to be used in space qualifications. The following paragraphs propose a generic procedure for the selection and acceptance test criteria for optoelectronic devices and also include an analysis related to the Specification Performance Requirements and Environment Constraints related to space applications.

Summary results of a large number of parts that have been tested by Alter Technology are also presented to demonstrate the current status of the most promising technologies. Finally, one case example is presented related to optical amplifiers.

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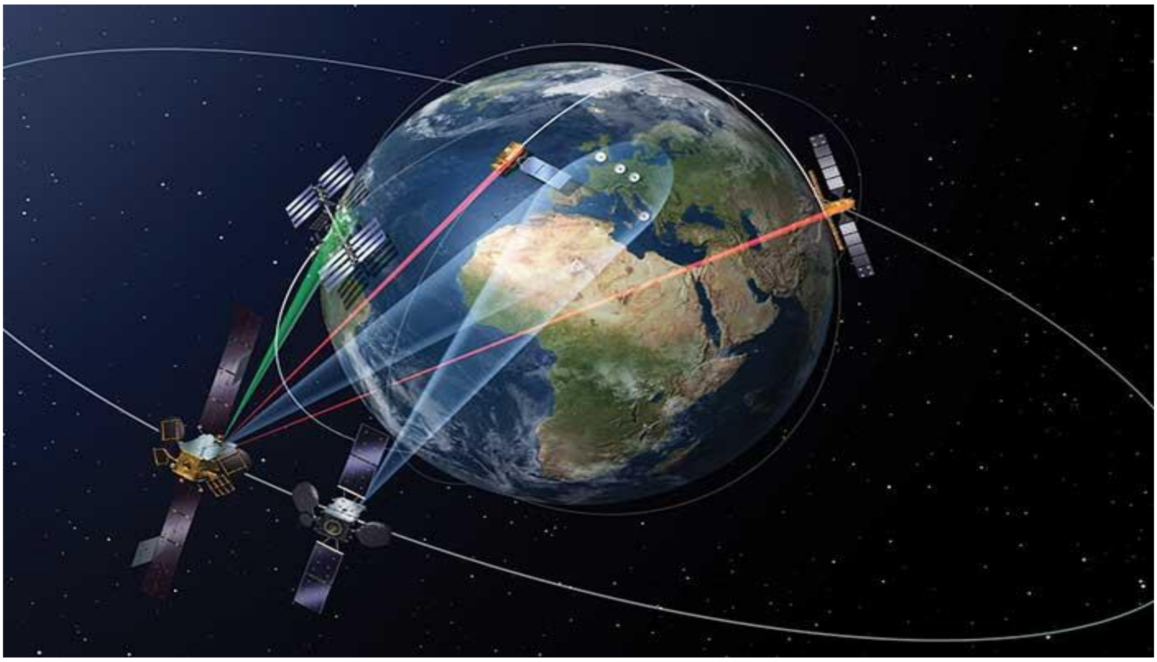

Figure 1 Photonics in space

INTRODUCTION TO PHOTON

The photon is a type of elementary particle, the quantum of the electromagnetic field including electromagnetic radiation such as light and radio waves, and the force carrier for the electromagnetic force (even when static via virtual particles). The invariant mass of the photon is zero it always moves at the speed of light within a vacuum.
Like all elementary particles, photons are currently best explained by quantum mechanics and exhibit wave-particle duality, exhibiting properties of both waves and particles. For example, a single photon may be refracted by a lens and exhibit wave interference with itself, and it can behave as a particle with a definite and finite measurable position or momentum, though not both at the same time as per Heisenberg's uncertainty principle. The photon's wave and quantum qualities are two observable aspects of a single phenomenon they cannot be described by any mechanical model as a representation of this dual property of light that assumes certain points on the wavefront to be the seat of the energy are not possible. The quanta in a light wave are not spatially localized.
The modern concept of the photon was developed gradually by Albert Einstein in the early 20th century to explain experimental observations that did not fit the classical wave model of light. The benefit of the photon model is that it accounts for the frequency dependence of light's energy, and explains the ability of matter and electromagnetic radiation to be in thermal equilibrium. The photon model accounts for anomalous observations, including the properties of black-body radiation, that others (notably Max Planck) had tried to explain using semiclassical models. In that model, light is described by Maxwell's equations, but material objects emit and absorb light in quantized amounts (i.e., they change energy only by certain particular discrete amounts). Although these semiclassical models contributed to the development of quantum mechanics, many further experiments beginning with the phenomenon of Compton scattering of single photons by electrons, validated Einstein's hypothesis that light itself is quantized. In December 1926, American physical chemist Gilbert N. Lewis coined the widely adopted name "photon" for these particles in a letter to Nature. After Arthur H. Compton won the Nobel Prize in 1927 for his scattering studies, most scientists accepted that light quanta have an independent existence, and the term "photon" was accepted.

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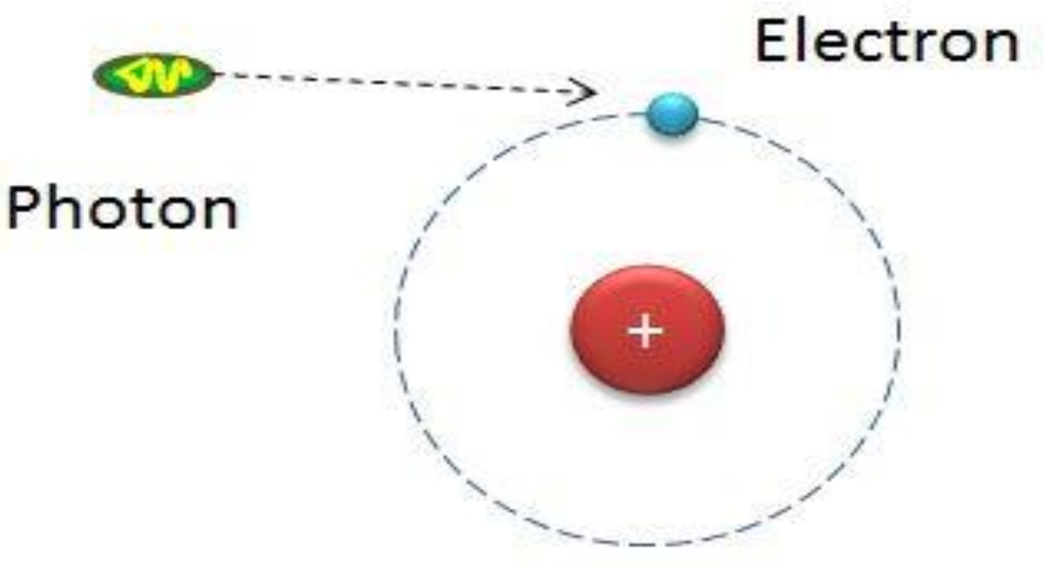

Figure 2 Photon

Physical Properties
A photon is massless, has no electric charge, and is a stable particle. A photon has two possible polarization states. In the momentum representation of the photon, which is preferred in quantum field theory, a photon is described by its wave vector, which determines its wavelength λ and its direction of propagation. A photon's wave vector may not be zero and can be represented either as a spatial 3-vector or as a (relativistic) four-vector; in the latter case, it belongs to the light cone (pictured). Different signs of the four-vector denote different circular polarizations, but in the 3-vector representation one should account for the polarization state separately; it is a spin quantum number. In both cases the space of possible wave vectors is three-dimensional.
The photon is the gauge boson for electromagnetism, and therefore all other quantum numbers of the photon (such as lepton number, baryon number, and flavor quantum numbers) are zero. Also, the photon does not obey the Pauli exclusion principle but instead obeys Bose-Einstein statistics.

WHAT IS PHOTONICS?

Classical Optics
Photonics is closely related to optics. Classical optics long preceded the discovery that light is quantized, when Albert Einstein famously explained the photoelectric effect in 1905. Optics tools include the refracting lens, the reflecting mirror, and various optical components and instruments developed throughout the 15th to 19th centuries. Key tenets of classical optics, such as the Huygens Principle, developed in the 17th century, Maxwell's Equations, and the wave equations, developed in the 19th, do not depend on the quantum properties of light.
Modern Optics
Photonics is related to quantum optics, optomechanics, electro-optics, optoelectronics, and quantum electronics. However, each area has slightly different connotations by scientific and government communities and in the marketplace. Quantum optics often connotes fundamental research, whereas photonics is used to connote applied research and development.
The term photonics more specifically connotes:
· The particle properties of light,
· The potential of creating signal processing device technologies using photons,
· The practical application of optics, and
· An analogy to electronics.
The term optoelectronics connotes devices or circuits that comprise both electrical and optical functions, i.e., a thin-film semiconductor device. The term electro-optics came into earlier use and specifically encompasses nonlinear electrical-

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optical interactions applied, e.g., as bulk crystal modulators such as the Pockels cell, but also includes advanced imaging sensors.

Light Source

Light sources used in photonics are usually far more sophisticated than light bulbs. Photonics commonly uses semiconductor light sources like light-emitting diodes (LEDs), super luminescent diodes, and lasers. Other light sources include single-photon sources, fluorescent lamps, cathode ray tubes (CRTs), and plasma screens. Note that while CRTs, plasma screens, and organic light-emitting diode displays generate their light, liquid crystal displays (LCDs) like TFT screens require a backlight of either cold cathode fluorescent lamps or, more often today, LEDs.

The characteristic of research on semiconductor light sources is the frequent use of III-V semiconductors instead of the classical semiconductors like silicon and germanium. This is due to the special properties of III-V semiconductors that allow for the implementation of light-emitting devices. Examples of material systems used are gallium arsenide (GaAs) and aluminium gallium arsenide (AlGaAs) or other compound semiconductors. They are also used in conjunction with silicon to produce hybrid silicon lasers.

Transmission Media

Light can be transmitted through any transparent medium. Glass fiber or plastic optical fiber can be used to guide the light along a desired path. In optical communications, optical fibers allow for transmission distances of more than 100 km without amplification depending on the bit rate and modulation format used for transmission. A very advanced research topic within photonics is the investigation and fabrication of special structures and "materials" with engineered optical properties. These include photonic crystals, photonic crystal fibers, and metamaterials.

Photonics In Space

Photonics is the physical science of light (photon) 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. The term photonics developed as an outgrowth of the first practical semiconductor light emitters invented in the early 1960s and optical fibers developed in the 1970s.

The word 'photonics' is derived from the Greek word "phos" meaning light (which has the genitive case "photos" and in compound words the root "photo-" is used); it appeared in the late 1960s to describe a research field whose goal was to use light to perform functions that traditionally fell within the typical domain of electronics, such as telecommunications, information processing, etc.

Photonics as a field began with the invention of the laser in 1960. Other developments followed: the laser diode in the 1970s, optical fibers for transmitting information, and the erbium-doped fiber amplifier. These inventions formed the basis for the telecommunications revolution of the late 20th century and provided the infrastructure for the Internet.

Photonics In Space (Working)

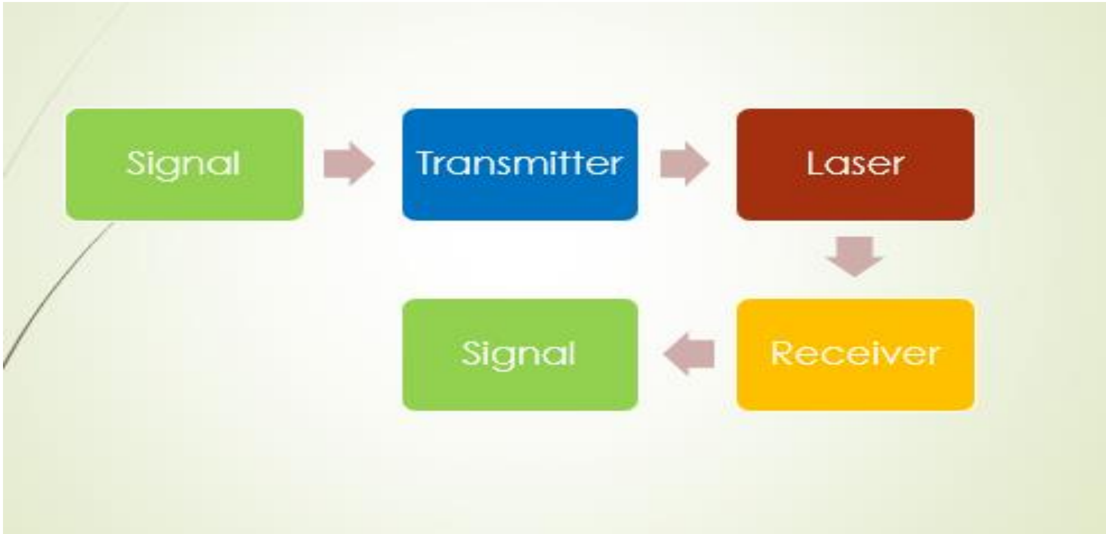

Figure 3 Working of Photonics

Photonics has the potential to transform the space industry and introduce a paradigm shift in the way satellite payloads and communication terminals are designed and built to enhance or enable new navigation, remote sensing, and telecom

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applications. G&H VP of Space Photonics Efstratios Kehayas's feature – Space Photonics: A Platform Technology for Satellite Systems talks about how.
The use of photonics subsystems for functions such as navigation, remote sensing, and telecoms is gathering pace as the advantages related to bandwidth, mass, power consumption, beam size, and immunity to electromagnetic interference become apparent. The deployment of 1.55 µm fused couplers from G&H onboard the European Space Agency's satellite Soil Moisture and Ocean Salinity (SMOS) satellite in 2009 was a watershed in the history of space photonics as one of the first satellites to use photonics for mission-critical function. The planned lifetime of SMOS was three years and yet after seven years the satellite and its photonic components and sub-assemblies continue to exceed expectations. Satellite-to-satellite or satellite-to-ground laser communications can allow high-speed connectivity whilst using fewer resources compared to conventional systems. Tried and tested terrestrial photonics are exploited, when necessary using wavelength division multiplexing (WDM). The role of the transponder in terrestrial networks is taken up in space by a laser communication terminal (LCT), which is usually responsible for Layer-1 and Layer-2 functionalities. It is composed of a central processor, a transmitter, a receiver, and a pointing and tracking acquisition assembly. Essential components include lasers, electro-optic modulators, amplifiers, and photo-detectors. Photonic components used in space need to be ruggedized compared to their terrestrial counterparts to function after launch and in the presence of radiation present in low earth (LEO) and geostationary orbits.
Photonic components used in space need to be ruggedized compared to their terrestrial counterparts to function after launch and in the presence of radiation present in low earth (LEO) and geostationary orbits. Semiconductor lasers used for transmission, signal generation, and amplification are at the heart of many space photonic assemblies. Not only does their manufacture need to be closely controlled but the compliance and traceability of their components need to be assured.
The European FP7 project HIPPO (High-Power Photonics for Satellite Laser Communications and On-Board Optical Processing), led by G&H has focussed on developing DFB lasers, high-speed detectors, and pump lasers and testing their performance against radiation. G&H also dedicated resources to the development of polarization-maintaining (PM) and non-PM fused couplers and pump combiners suitable for space applications. Integration of HI-REL components and sub-systems, such as amplifiers and transmitters, into an LCT, requires verification through testing according to ESA or NASA standards. Tests include electromagnetic compatibility and thermo-mechanical tests that include shock, vibration, and thermal cycling in a vacuum.
Integration of HI-REL components and sub-systems, such as amplifiers and transmitters, into an LCT, requires verification through testing according to ESA or NASA standards. Tests include electromagnetic compatibility and thermo-mechanical tests that include shock, vibration, and thermal cycling in a vacuum. These tests, and specifically in that sequence, mimic the process of launch and operation in-orbit. Within the frames of two European Space Agency (ESA) qualification programs, G&H followed a test plan to space qualify mid-power booster amplifiers for direct downlinks following ECSS test plans. The unit-level test results were successful and proved that the G&H multi-channel amplifier was ready for an in-orbit demonstration and to move into flight hardware production.
Photonics is coming of age and has indicated proven efficiencies and advantages which can be used to enable the next generation of satellite communication systems. To prove commercially viable, however, cost-efficiencies will need to be found. On this basis, the bandwidth-hungry applications of satellites can be made more viable on the back of the unique performance characteristics photonics offers.

Advantages

- Very quick
- Light travels faster than radio wave.
- It is 10 to 100 times faster than todays Radio Wave Systems .
- High confining optical technology
- It has High Confining Optical Technology.
- Is very stable
- Photonics is Stable Technology
- Well-characterised processing
- The processing of Photonics is well categorized.

Disadvantages:-

- Spurious reflections are more troublesome
- Unwanted signals caused by reflection of surface acoustic waves or bulk waves from substrate edges or electrodes.
- It is more expensive
- It use highly worked machine so it has more Expensive.

- Harder to fix
- It has Complicated Structure so it is difficult to fix.
- Waveguides and fibres are harder to use then wires
- The Light wave and Fibres are difficult to Troubleshoot than wired connection.

CONCLUSION

Few optical components are qualified for space usage. This means that COTS is necessary most of the time. A cost-effective approach acceptance criterion of these COTS has been presented.
– 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 before actual implementation.
– Specific test setup conditions must be considered when working with parts to ensure the test is suitable to provide electro-optical features while parts are being submitted to the environmental test.
– Alter Technology Group has a large experience in EEE parts procurement as well as extensive testing on the most significant photonics technologies for space applications. Reliability data are available for main parts to help in the final selection of the product for the intended application.

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