Optical Communications for Very High Throughput Satellites

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Abstract: In this paper, the potential of Photonic Integrated Circuits for very high throughput satellites is discussed. Summary of the undertaken approach, current development status and challenges related to the space environment are provided. © 2021 The Author(s)

1. Introduction

The large increase in the global internet traffic over the past several decades resulted in optical communications systems becoming essential for meeting the data-rate needs. Terrestrial systems, such as long-haul fiber networks, managed to keep up with the demand and continuously increased channel capacity through developing novel and more sophisticated solutions. Photonic Integrated Circuits (PICs) are one of the key employed technologies that allowed for high-performance while reducing power consumption and system footprint. Given that further miniaturization and integration of additional functionalities is required for increasing bandwidth demands (e.g. 5/6G networks), PICs are expected to remain an active area of interest and play an important role in future systems [1].

Over the past decade, satellites became another application area for optical communications technologies that has been rapidly growing. It has a great potential to complement the existing terrestrial networks in order to provide global broadband access. While densely populated areas are well-served through optical fiber connections, satellite systems can be used to cover rural or more remote areas. Worldwide coverage can be achieved withthe means of, for example, a constellation of smaller satellites in the low-earth-orbit (LEO) or a few satellites in the geostationary orbit (GEO). Both scenarios can greatly benefit from not only the increased bandwidth, but also improvements in cost, size, weight and power (C-SWaP) offered by optical communications and PICs.

2. Very high throughput satellite communications

Currently vast majority of satellite communications are performed using the radiofrequency (RF) technology. This is the case for both feeder-links connecting the satellite to the ground network as well as for user-links providing connectivity for the end-users. Recently launched GEO satellites providing internet access and video broadcasting, such as Viasat 3, offer throughput up to 1 Tb/s using Ka-band. Similarly, LEO constellations used for mobile satellite services and broadband services with speeds of tens of Mb/s are based on Ku- and Ka-bands [2].

However, RF spectrum may not suffice to pursue the vision of global coverage with high data throughput, thus becoming a bottleneck in the future systems. A solution that is increasingly explored is using optical frequencies that offer much larger unregulated bandwidth. Intersatellite links employing free-space optical communications (FSOC) are already operational on different orbit types. The GEO-LEO connectivity in the European Data Relay System (EDRS) is achieved via 1.8 Gbit/s optical channels [3] and since the beginning of this year new Starlink LEO satellites are also equipped with laser terminals for intersatellite links, to communicate with one another [4].

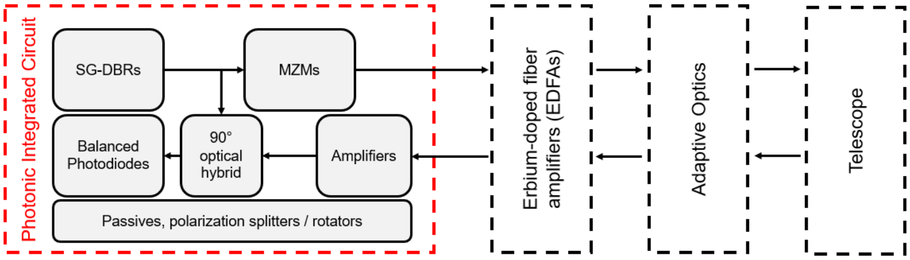

Fig. 1. Block diagram of satellite/ground station laser terminal highlighting potential PIC subsystem.

3. Photonic Integrated Circuits for satellite communication

The currently demonstrated laser communication systems are built using discrete optical components, meaning that those systems are still relatively large and heavy. Since satellite platforms are limited in terms of sub-system size, weight and power consumption, miniaturization of components benefits the entire system. Reduced footprint of the optical transceiver leads to overall satellite size decrease or more space to fit additional devices. PICs can be used to combine multiple functionalities currently provided by discrete components on a single die, thus improving the overall C-SWaP of the on-board laser terminal.

Indium phosphide (InP) is a mature PIC platform that has been developed and thoroughly tested over the years for terrestrial networks. It enables monolithic integration of all key building blocks needed for advanced high-speed transceivers as depicted in Fig. 1. This includes not only active devices (e.g. lasers, semiconductor optical amplifiers (SOAs) or modulators), but also passive components such as waveguides, couplers and filters [5]. Furthermore, InP is optimized for the telecommunication C- and L-bands, which are also suitable wavelength regions for satellite communication. While reliability and technology readiness of InP are critical factors, there is still a number of uncertainties related to the space environment that need to be addressed.

One of the key additional challenges faced by satellite-borne devices, but not in the terrestrial communications systems, is the impact of radiation on the system performance. Space radiation is a broad phenomenon that has multiple sources that impact semiconductor components in different ways and its levels vary on the orbit profile. These range from single-event effects (SEE) to total-ionizing dose damage (TID) and displacement damage (DD) caused by a combination of galactic cosmic rays, high-energy solar flares and particles trapped by the Earth's magnetosphere [6]. Even though the impact of radiation on various photonic components varies depending on its source, it is important to identify any potential device vulnerabilities and the underlying physical processes [7]. Knowledge of component reliability can provide useful information on which standard integrated devices can be selected for a given mission. Furthermore, understanding the degradation mechanisms behind specific PIC components can lead to improvement of their robustness through rad-hardening by their redesign.

4. Development approach and status

DLR is investigating the potential of PICs for space applications by taking advantage of the maturity of InP foundries that enable easy access to high performance platform. A 25 Gb/s transceiver chip operating in the C-band is designed to demonstrate feasibility of high-speed integrated photonics as well as gain better understanding of environmental impact on its performance. The required functionality of the current design is based on a combination of standard and customized integrated photonic devices. Existing reports on the space environment impact on various component performances are accounted for. For example, sampled-grating Distributed Bragg Reflector (SG-DBR) lasers are selected as sources due to their narrow linewidths and wavelength tunability. The latter is of particular importance as it offers a possibility to counter the wavelength shift resulting from radiation [8]. Other key selected functional blocks are Mach-Zehnder modulators (MZMs), balanced PIN photodiodes, multi-mode interferometers (MMIs) and directional couplers for 90° optical hybrid, as well as polarization splitters and rotators.

The fabricated prototypes will undergo selected space qualification testing in order to assess impact of radiation, temperature and vibrations. Based on the results not only the limits of selected photonic components will be established, but also the developed device models will be assessed and improved. The obtained knowledge will be then used to develop further PIC transceiver chips that can undergo full space qualification procedure.

Additionally, the transceiver performance as a system will be tested using a DLR testbed emulating the transmission channel of a bidirectional link between a satellite and an optical ground station. This 10.5 km free-space link represents worst-case turbulence conditions [2] and has allowed for investigation of various optical communications systems such as wavelength division multiplexing (WDM), coherent reception or adaptive optics.

5. Conclusions

Optical technologies are an area of great interest for the next generations of satellite communications. The key advantage offered by optical communications, and PICs in particular, is much higher throughput while reducing the C-SWaP of the spacecraft. In this paper, development approach and current status of the PIC design, component selection and planned space environment testing is presented.

References

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