High speed optical feeder link communication system onboard ETS-9 using a new screening process for space photonics

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Abstract

The National Institute of Information and Communications Technology (NICT) is currently preparing a 10 Gbps-class optical feederlink demonstration between a geostationary-orbit (GEO) satellite and ground. The satellite payload is called High Speed Communication with Advanced Laser Instrument (HICALI) and is planned to be mounted on the Engineering Test Satellite-9 (ETS-9) which will be launched in 2023 [1]. Current status of the development of the HICALI payload including the novel screening process for the space photonics will be presented. Also, the optical ground station design will be shown and discussed with preliminary test results.

1. Introduction

Satellite laser communications, especially the optical feeder link possibilities between ground and geostationary (GEO) satellites, are gaining popularity because of the low size, weight and power consumption together with much higher possible data rates compared to radio-frequency-based solutions (Fig. 1). The GEO-to-Ground link, however, has a number of specific challenges that have to be addressed.

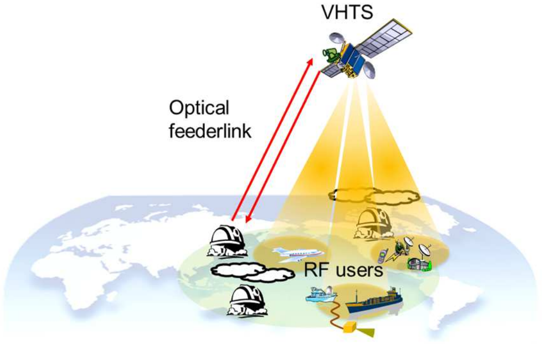

Figure 1. Geostationary VHTS example with RF users and an optical feederlink.

2. GEO-to-Ground Link Challenges

The link budget design is critical for a telecommunication link. In the case of GEO-to-Ground links the link distance is over 35000km which leads to very high link losses. In order to design a high data-rate link, a trade-off between size/weight of the system, state-of-the-art components, etc. is necessary. For example, the aperture size directly influences the link budget through the transmitting and receiving antenna gains, and the path loss. While intuitively bigger size is better, there are a few issues for both satellite and ground sides. For example, bigger aperture would require bigger Gimbal system for coarse tracking. Also, it would mean narrow beam divergence, which poses stiff requirements for the pointing accuracy. Otherwise, although we keep higher level of power within the narrow beam, due to the big pointing errors we will have significant losses due to tracking error. The above considerations pose system limitations for the satellite side due to space/weight limitations and state-of-the-art components. In the ground segment these limitations are more relaxed, but as explained below, the atmospheric propagation in the downlink leads to wavefront aberrations which also can limit the aperture size since the bigger the aperture is the more aberrated wavefront we have. If no Adaptive Optics is implemented, the aberrated wavefront leads to inability to efficiently concentrate the received light in the photo detector and size dimensions are a trade-off between bigger size advantages (bigger Rx antenna gain, Aperture averaging effect) and disadvantages (concentrating inefficiency due to wavefront aberrations).

Due to the wind the atmosphere consists of multiple areas with slightly different refraction index mainly due to temperature differences. When the optical beam propagates through it, each area acts as a small lens, which affects the beam wavefront. [2]. Thus, spatial and time fluctuations in the beam irradiance are observed. In the downlink, the laser beam propagates mainly through media with no air where main effect is diffraction, and its wavefront gets significantly distorted in the final 20 km atmosphere layer. Example is shown in Fig. 2, left side. Because of the big receiving aperture in the order of tens of centimeters, it is generally much bigger than the Fried parameter [2], being used to quantify the rms wavefront aberrations and this is the main obstacle for efficient light concentration in a small-size receiver. Most efficient wavefront correction technique is the AO system, in which the phase aberrations are measured using a wavefront sensor and corrected with a deformable mirror [3].

3. HICALI Payload

The characteristics of HICALI are listed in Table I. Following the discussion in Section 2, the HICALI aperture was chosen to be big enough to allow small divergence angle in the downlink, enough received power in the uplink and to keep the total payload mass low.

TABLE I
HICALI PAYLOAD CHARACTERISTICS

Parameter	Characteristics
Transmit power	34 dBm
Tx diameter	0.15 m
Wavelength	Downlink: 1540 nm Uplink: 1560 nm 1530 nm (Beacon)
Polarization	Downlink: LHCP Uplink: RHCP
Modulation	Downlink: NRZ-DPSK Uplink: RZ-DPSK
Received power	-44 dBm
Pointing angle range	± 10 °
Mass	80 kg
Power	340 W

Terrestrial optical fiber networks have been dominating technology for decades and have proven their reliability providing a wide spectrum of connectivity from long-haul links to fiber-to-the-home end user links. It is reasonable to consider using the available terrestrial devices for satellite laser communications, which will allow direct adoption of laser sources, amplifiers, receivers, wavelength-division multiplexing technologies, etc. with no cost in terms of development. Space-qualified components have a high cost due to the specific requirements and development costs. Furthermore, current state-of-the-art would allow up to several Gbps communication. Instead, our approach is to use commercial-off-the-shelf (COTS) parts for terrestrial network and to improve their reliability through the screening test process newly established by the space agencies, allowing their reliable implementation in space [4]. The electronic, electric and electromechanical (EEE) parts for space applications are already described in "Certified Parts" by the Japan Aerospace Exploration Agency (JAXA) (e.g JERG-0-052A, [5]), in "Qualified Parts List (QPL)" by the European Space Agency (ESA) and in "NASA Parts Selection List (NPSL)" by National Aeronautics and Space Administration (NASA). Also, screening test procedures for some COTS parts are already established by the above agencies. There are a few prerequisites regarding these parts, however. For example, the stated COTS parts are high-reliability components (e.g. automotive, industrial grade, but not consumer grade). Also, manufacturer confirmation regarding the used materials is necessary to confirm there are no prohibited materials used. The quality assurance level is defined as described in [5], based on the mission duration (e.g. Class III : Lowest assurance and highest risk (mission duration : less than one year)).

4. Optical Ground Station

The main optical ground station for the experiments is located in an urban area in Tokyo, Japan. A 40-centimeter aperture of the available 1-meter telescope is to be used (Fig. 2).

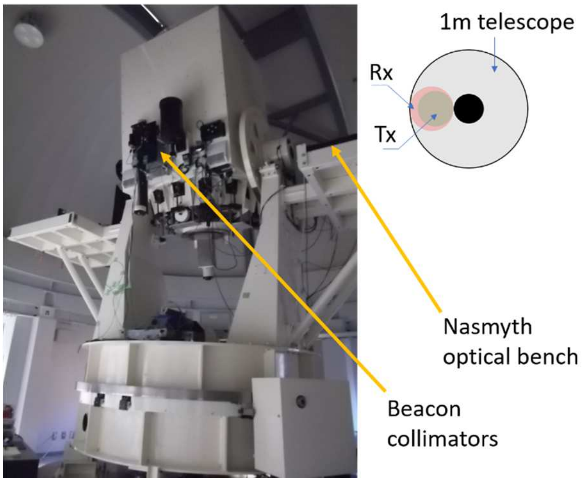

Figure 2. NICT OGS with 1-meter telescope.

The optical bench is located at the nasmyth table and its structure is shown in Fig. 3. First, the bench is adjusted to the telescope beam size using a beam reducer. Both uplink and downlink paths use the same fine-pointing mirror and the uplink chain has additional fine-pointing mirror to compensate the uplink point-ahead angle. Single-mode fiber coupling is available in both paths. To compensate the wavefront errors, adaptive optical system with separate deformable mirrors for receiving and transmitting chain are used.

One main issue in the proposed solution remains to be the optical isolation between the strong transmit signal in the order of Watts, and the small received signal, especially in the Quadrant sensor being used for the tracking system. The required isolation is in the order of 90-100dB. To be able to achieve that a number of techniques were implemented. First, all common surfaces were tilted and masks have been inserted to assure that the back reflections will not reach the receiving side. Furthermore, as also shown in Table I, the receiving and transmitting polarizations are different, which allows further optical isolation using polarization beam splitter and polarizer. Finally, optical filters are implemented.

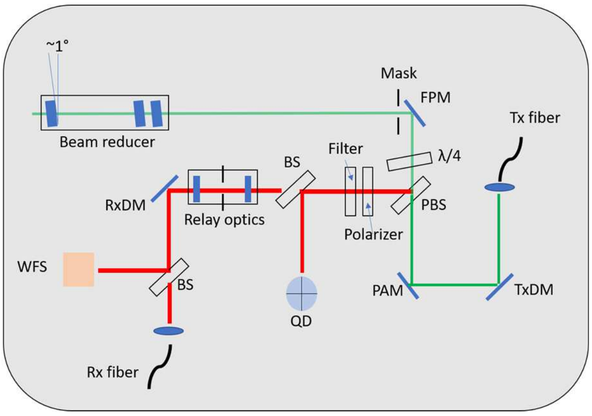

Figure 3. NICT Optical bench solution.

Preliminary experiments were conducted with the optical bench using light from Venus (Fig. 4). The results show that the measured pointing error was in the order of 1.33 µrad (3σ) on the x-axis, and 2.2 µrad (3σ) on the y-axis. It is important to note that due to the low light we had to remove the bandpass filters and the provided results are based not on a single wavelength but a wide spectrum of wavelengths. Furthermore, the spot at the QD sensor that Venus forms is quite different from the expected one from a satellite. These factors are assumed to lead to higher values for the error, compared to the ones, expected during the actual experiments.

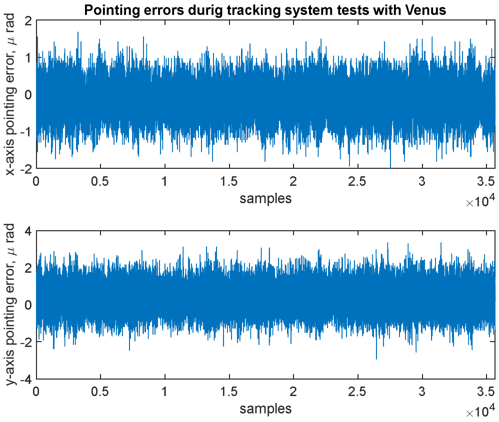

Figure 4. Pointing error in the OGS tracking system.

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