Free-space Laser Communications for Small Moving Platforms (Invited Paper)

Alberto Carrasco-Casado
Space Communication Systems Laboratory
National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei, Tokyo, Japan 184-8795
alberto@nict.go.jp

Abstract: The Japanese National Institute of Information and Communications Technology (NICT) is currently working towards the development of a series of miniaturized space laser-communication terminals with the aim to meet the requirements of a variety of different platforms, from drones to satellites, and to be applied in a variety of different scenarios, from fixed to moving platforms, operating in a wide range of distances and conditions, and without the need of extensive customization. This paper describes NICT's current efforts in this topic, and it introduces the prototypes that are being developed for the verification tests, which will happen in 2022.
OCIS codes: (060.2605) Free-space optical communication

1. Introduction

Space laser communication (lasercom) has the potential to provide the massive bandwidth of optical fibers, enhancing the communication capabilities of moving platforms. This technology has already become mature enough, after been demonstrated repeatedly during the last few years [1]. The Japanese National Institute of Information and Communications Technology (NICT) has been a pioneer, carrying out some of the most significant demonstrations over the last three decades. In 1994, NICT carried out the first space-to-ground downlinks using the GEO satellite ETS-VI [2]. Ten years later, NICT participated in the first LEO-to-ground demonstration using the JAXA's LEO satellite OICETS in 2006 [3]. Another ten years later, NICT mounted the first lasercom terminal onboard a microsatellite to perform LEO-ground laser communications and quantum key distribution (QKD) experiments using the LEO satellite SOCRATES in 2014 [4].

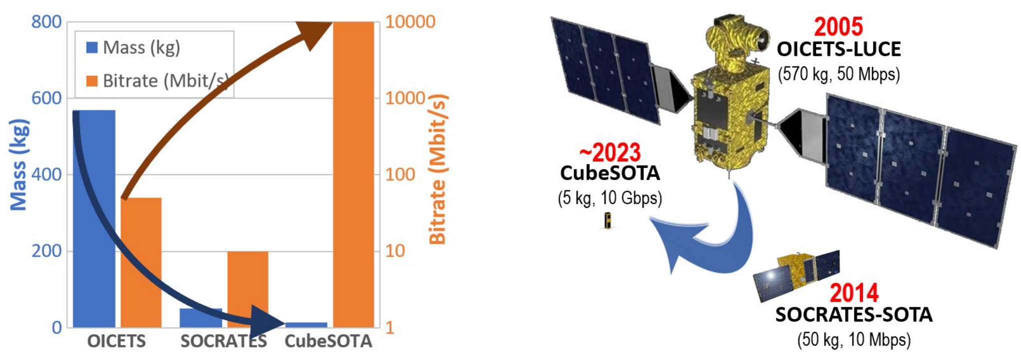


Fig. 1. Evolution of NICT's lasercom terminals onboard LEO satellites.

For the sake of comparison, considering only the LEO satellites with NICT's lasercom terminals, which share an scenario with similar requirements, Fig. 1 (left) shows how the mass (satellite + terminal) and bitrate have evolved over the last two decades, as well as their relative-size comparison (Fig. 1, right). In less than 20 years, it is observed that a reduction of the mass in two orders of magnitude, and an increase of the datarate in three orders of magnitude (potentially, four) has been experienced as the result of this evolution. The last step that has been considered in this evolution is CubeSOTA [5], which was the origin of the lasercom-terminals series which are presented in this paper. Specifically, the CubeSOTA version which is shown in the figure is the non-gimballed type (designed for CubeSats [6]) of the ST terminal, which will be presented below.

2. Miniaturized lasercom-terminals series

Free-space laser communication is expected to play a key role to cope with the demanding bandwidth requirements of 5G (and beyond) networks to support an increasing number of wireless terminals disseminated throughout the world and generating an unprecedented amount of data. For this purpose, practical and versatile lasercom systems will be necessary to be developed and deployed in real scenarios as soon as possible. NICT intends to meet this requirement by developing a series of terminals that can fit a variety of platforms and scenarios to fulfill the requirements of different use cases. Fig. 2 shows several of these use cases, where NICT is currently planning to demonstrate these terminals.

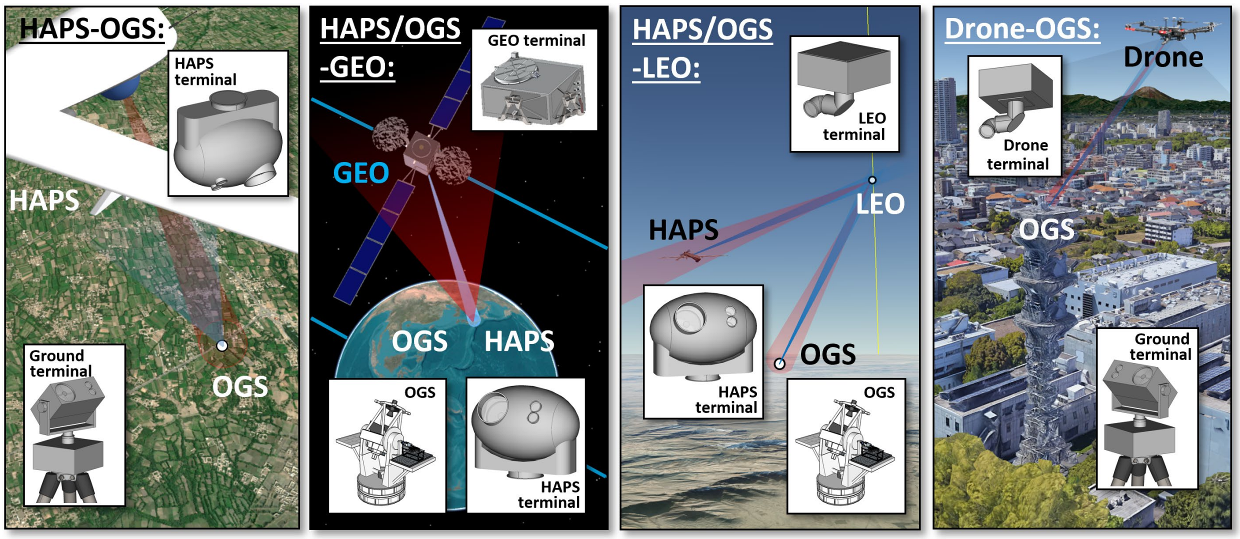
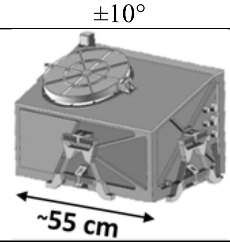


Fig. 2. Use-case examples of NICT's lasercom terminals in a variety of different scenarios and platforms.

Table 1 shows all the lasercom terminals that are currently being developed by NICT. The first one is HICALI [7], which development was already completed, and it is currently under qualification and test, prior to be integrated and embarked in the GEO satellite ETS-IX [8], to be launched in 2023. HICALI was designed specifically for a very well-defined scenario, i.e., bidirectional 10-Gbit/s links between ground and GEO orbit. The other two terminals are called Full Transceiver (FX) and Simple Transmitter (ST). Unlike HICALI, these terminals were not designed for a specific scenario or platform, but with the goal to make them as versatile as possible. The maximum distance range, which is defined in the table, refers to the worst-case scenarios in which the terminals can work, but they are designed to adapt their operation to support other use cases with shorter distances as well.

Table 1. Optical-head assemblies (OHA) of NICT's space laser-communication terminals.

	HICALI terminal	**FX terminal**	**ST terminal**
Maximum distance range	GEO-ground (2 ways)	LEO-GEO (1 way), LEO-LEO (2 ways)	LEO-ground (1 way) HAPS-ground (2 ways)
Aperture size	15 cm	9 cm	3 cm
Mass (OHA)	~80 kg	~6 kg	~3 kg
Data rate (max)	10 Gbps	2 optional modems: 10 Gbps & 100 Gbps	
Spectral band	C-band		
Direction discr.	Polarization + wavelength	Wavelength (tx side polarization compatible)	
Field of regard	±10°	±90°	±90°
Image (OHA)			

The FX terminal, as its name indicates, was designed to meet the requirements of high-speed bidirectional communications at long distances. Bidirectional communications can be supported up to several thousands of kilometers in a LEO-LEO scenario such as LEO constellations. However, it can also support one-way communications up to GEO to support users such as LEO observation satellites that needs to transmit data to a GEO relay with very-high availability. This specific application was the original use case of the CubeSOTA concept, which was conceived to work together with ETS9-HICALI [9]. The key component of the FX terminal, which enables it for high-speed bidirectional long-range communications is the 9-cm miniaturized telescope that allows collimating a very-narrow beam to cover long distances with small geometrical losses, as well as providing enough receiving gain to close the link at high speed.

The ST terminal is a further-miniaturized version of the FX terminal with a very-compact gimbal design and a small aperture, enough to collimate a laser beam to support LEO-ground downlinks, which was the original concept for this terminal. In the ST terminal, the smaller aperture allows to significantly miniaturize the gimbal thanks to implementing a smaller aperture at the cost of the smaller receiving gain, which sacrifices the bidirectional operation at moderate distances such as LEO-ground. However, one-way communication can meet the requirement of many LEO satellites, which needs to downlink data to the ground at high speed, but not so much to receive data in the satellite. The ST terminal can support bidirectional communications too when the distance is shorter, such as LEO-LEO in dense satellite constellations, or HAPS-ground scenarios, because the internal optical configuration is equivalent to the FX terminal, including the receiving part.

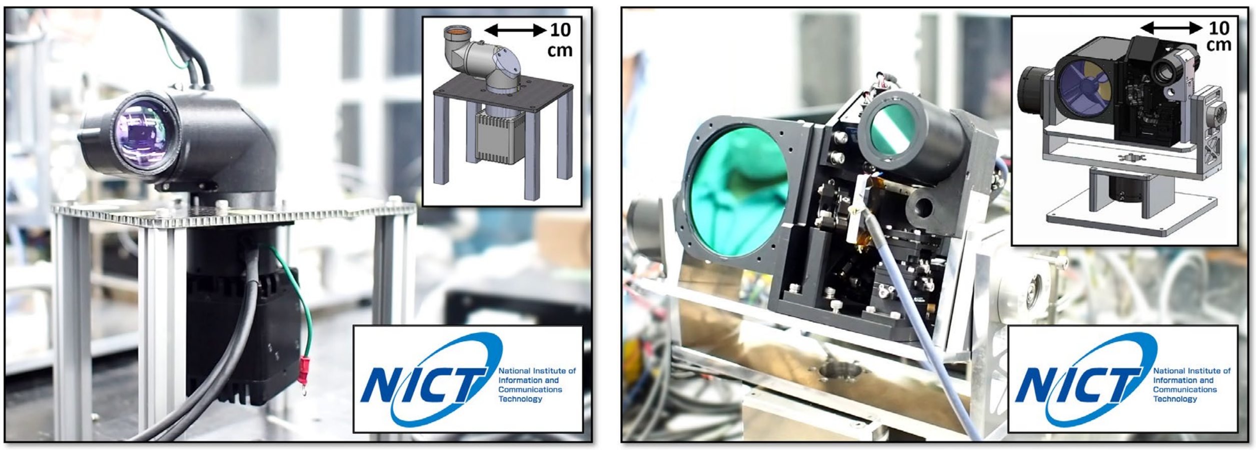


Fig. 3. Early prototypes of ST terminal (left) and FX terminal (right) for preliminary validation.

The classical approach when designing a lasercom terminal is reaching an optimum design for the specific mission or demonstration to be carried out. However, this makes it very difficult to leverage the design for other applications where the conditions may differ. In that case, if the requirements change, then the terminal must be redesigned, or at least customized, which is costly. NICT's strategy is to come up with a design that can be reutilized in different circumstances by the configuration of its components and by its internal adaptive operation. Depending on the scenario and platform, the basic configuration is established by selecting one type or the other, FX or ST. Then, the modem can be selected between a 10-Gbit/s type and a 100-Gbit/s type, to further refine the requirements of the scenario. Moreover, when the basic terminal configuration is fixed for any given platform/scenario, the terminal itself can adapt its performance to the varying conditions of the links by internal adaptive techniques.

3. References

[1] A. Carrasco-Casado, R. Mata-Calvo, Space Optical Links for Communication Networks, in: B. Mukherjee, I. Tomkos, M. Tornatore, P. Winzer, Y. Zhao (Eds.), Springer Handbook of Optical Networks, Springer Handbooks, Springer, Cham, 2020, pp. 1057–1103.

[2] K. Araki et al., Performance evaluation of laser communication equipment onboard the ETS-VI satellite, Proc. SPIE Vol. 2699, Free-Space Laser Communication Technologies VIII, San Jose, United States, 1996, 27 January – 2 February.

[3] M. Toyoshima et al.: Results of Kirari optical communication demonstration experiments with NICT optical ground station (KODEN) aiming for future classical and quantum communications in space, Acta Astronaut. 74, 40 – 49 (2012).

[4] A. Carrasco-Casado et al., LEO-to-ground optical communications using SOTA (Small Optical TrAnsponder) – Payload verification results and experiments on space quantum communications, Acta Astronaut. 139, 377 – 384 (2017).

[5] A. Carrasco-Casado et al., Intersatellite link between CubeSOTA (LEO CubeSat) and ETS9-HICALI (GEO satellite), IEEE International Conference on Space Optical Systems and Applications (ICSOS), Portland, United States, 2019, 14 – 16 October.

[6] A. Carrasco-Casado et al., Optical Communication on CubeSats – Enabling the Next Era in Space Science –, IEEE International Conference on Space Optical Systems and Applications (ICSOS), Okinawa, Japan, 2017, 14 – 16 November.

[7] Y. Munemasa et al., Critical Design Results of Engineering Test Satellite 9 Communications Mission: for High-Speed Laser Communication, "HICALI" mission, IAC-19-F2.2.3, 70th International Astronautical Congress, Washington D.C., United States, 2019, 21 – 25 October.

[8] M. Toyoshima, Hybrid High-Throughput Satellite (HTS) Communication Systems using RF and Light-Wave Communications, 2019 IEEE Indian Conference on Antennas and Propogation (InCAP), Ahmedabad, India, 2019, 19 – 22 December.

[9] A. Carrasco-Casado et al., Development of a miniaturized laser-communication terminal for small satellites, IAC-21-B2.2, 72th International Astronautical Congress, Dubai, United Arab Emirates, 2021, 25 – 29 October.