Optical Inter-satellite Communication Technology for High-Speed, Large-Capacity Data Communications

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Abstract

NEC Corporation is building a network based on optical inter-satellite communication technology to achieve inter-satellite data communications with a higher speed and larger capacity than the present. It will improve the ability to transmit data immediately from satellite observations for use in various fields. As a first step, NEC has developed an optical communications equipment that is onboard the optical data relay satellites launched by the Japan Aerospace Exploration Agency (JAXA). The equipment was launched on November 29, 2020 and succeeded in establishing an optical link with an optical ground station approximately 40,000 km away. NEC is also planning an in-orbit testing of optical inter-satellite communication with an optical communication system onboard an earth observation satellite. The onboard service operation will be started after the in-orbit testing.

Keywords

Optical inter-satellite communication system, optical acquisition and tracking, optical transponder, optical data relay satellite, earth observation satellite

1. Introduction

Optical inter-satellite communication has been attracting worldwide attention because of the growing need for larger capacity and higher speed transmissions of observation data thanks to the recent improvements in the performance of Earth observation satellites and because of its features such as not needing the frequency coordination and the ease in which confidentiality is ensured compared to radio frequency (RF) communication. Also in Japan, since the first success of space optical communication experiment in 1994, research and development (R&D) continues in this area even now in 2021. NEC has cultivated its optical inter-satellite communication technology through the development of optical communication systems such as the optical inter-orbit communications engineering test satellite (OICETS) called Kirari launched by the Japan Aerospace Exploration Agency (JAXA) and the optical communication systems such as small optical transponder (SOTA) of the National Institute of Communications and Technology (NICT).

This paper introduces a future space system based on optical inter-satellite communication as well as the features and technologies of the laser communication terminal for satellites developed for JAXA's optical data relay and earth observation satellites.

2. Future Space Systems Using Optical Inter-satellite Communications

NEC aims to improve the ability to transmit data imme-

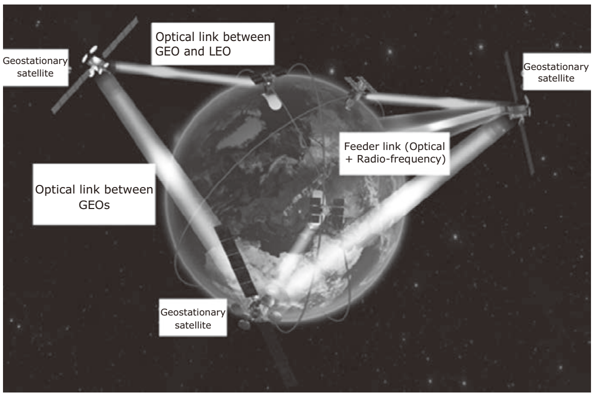

Fig. 1 Image of optical inter-satellite communications.

diately from satellite observations, which is becoming increasingly large in volume, so that it can then be applied to various fields. To achieve this goal, a data relay system that enables faster inter-satellite communications with a higher capacity and increased coverage for data transmission is necessary (**Fig. 1**). NEC's goal is to build an optical communication network system that uses our optical inter-satellite communication technology.

3. Features of Optical Inter-satellite Communications

Traditional inter-satellite communication uses radio frequencies (RF). With this method of communication, however, interference has to be avoided, so it has various limitations. Also, it is hard to achieve high-speed communication due to limited bandwidth.

Compared to RF communications, high-speed, high-capacity optical inter-satellite communications can be achieved because of its high frequency carrier waves and large bandwidth. Another important feature is that it is not affected by radio interference. Also, optical antennas can be smaller and lighter than RF antennas, because their short wavelengths provide high energy and high gain even with a small antenna diameter. The weight reduction of a satellite is a great advantage because launch costs are then greatly reduced.

Optical inter-satellite communications use a very narrow beam, which needs high accuracy pointing, acquisition and tracking technology for communication links. This feature makes it more advantageous than RF communications for security reasons (**Fig. 2**). On the other hand, optical inter-satellite communications must cover very long distances, so the use of very narrow beams makes it extremely difficult to provide enough irradiance to shine the laser beam to the other satellite. Also, to deliver the light to the other satellite, it is necessary to have a high-power optical amplifier that can operate stably even in the vacuum environment of space and can detect weak light from the other satellite.

Considering these issues, optical inter-satellite communications must support ultra-long-haul communications. Section 4 introduces the technologies developed by NEC under the guidance of JAXA.

4. Overview of Optical Inter-satellite Communication Technology

4.1 Optical acquisition and tracking technology

In optical communications in space, the laser beam plays two roles: as a means of establishing a link and as a carrier wave for communications. Optical acquisition and tracking technology is necessary to establish this link.

Information on the locations of the two communicating satellites can be predicted to a certain degree using orbit calculations, but the information obtained is not accurate enough and may be affected by thermal distortions and micro vibration in the spatial environment. As a result, it is essential to have a technology that allows both parties to scan the transmitted laser beam and, at the same time, receive, locate, and track the laser beam from the partner satellites.

In the optical capture operation, the laser beam is first scanned in the expected direction of the communication partner satellite. The partner satellite detects that laser beam with its own optical acquisition sensor to determine the exact position of the other satellite and emits a laser beam in that direction. As a result of both satellites performing these operations, the satellite will eventually track the laser beams from the other satellite and continue to shine the laser beams.

NEC has developed an algorithm for the acquisition and tracking of the communication partner satellite with certainty in a short period of time. This algorithm uses multiple scan shapes depending on the sequence and narrows the scan area for each scan to improve the accuracy. **Fig. 3** shows an image of a spiral scan between a satellite in geostationary orbit (GEO) and one in low earth orbit (LEO). This spiral scan, one of the possible

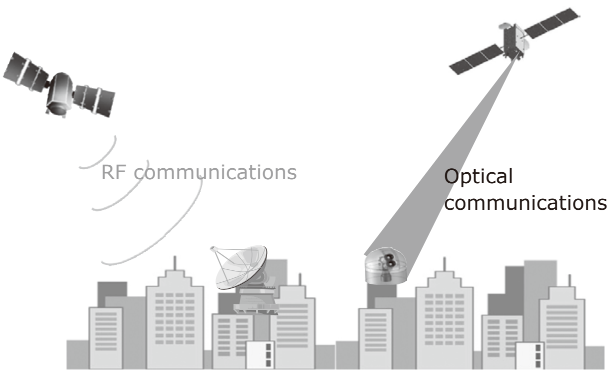

Fig. 2 Difference in beams.

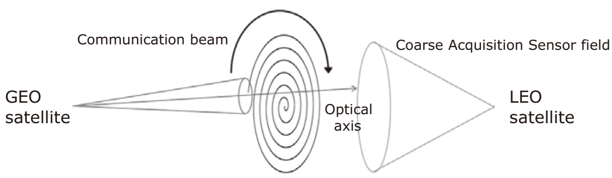

Fig. 3 Image of spiral scan.

scan shapes, is capable of scanning a wide acquisition area at high speeds. Other scan shapes include the raster scan and the random scan. Each of them has its own characteristics depending on the sequence.

4.2 Optical transponders with amplifiers and modems

The distance between a geostationary satellite and an earth observation satellite is 40,000 km. The signal light is attenuated by beam diffusion during long-distance propagation and the Doppler frequency shift is generated by the relative position change between satellites. To secure the communication quality required with such a weak, unstable signal light, NEC has reinforced the already proven 1.5 μm band optical fiber communication technology for the space environment. The configuration of the optical transponder is shown in **Fig. 4**.

The main feature of the transmitter section is the high-power optical amplifier (amp). It uses an erbium doped fiber amplifier (EDFA) similar to those used in fiber-optic communications, but is implemented in a complicated manner to ensure high power characteristic and long-term reliability in the high vacuum environment where waste heat is ineffective. It also calculates the magnitude of the Doppler frequency shift in real time based on the orbit information and feeds it back to the transmitting light source.

On the receiving side, the low-noise characteristics over a wide temperature range, a digital signal processor with accurate demodulation even when it is buried in noise light, and error correction codes are noteworthy features in the responder section. By applying the best of optical fiber communication technology to these components, high-speed signal transmission of 1.8 Gbps has been achieved.

The resistance to vibration/shocking, vacuum/high-temperature environments, and radiation that is necessary for the communications system we helped develop as part of the equipment onboard the satellite was confirmed through long hours of stringent testing.

The development of optical communication equipment for use onboard the satellites requires a wide variety of technologies. This project moved forward thanks to collaboration between two divisions: the Ground Communications System division that possesses the technology for 1.5 μm optical fiber communications and the Space Systems division that possesses the technology for adapting to the space environment and ensuring reliability.

5. Beginning of Onboard Service of Optical Inter-satellite Communications

Under the guidance of JAXA, NEC has developed three sets of laser communication terminal, including one for a geostationary satellite and two for earth observation satellites. Among them, the system for geostationary satellite was installed in the optical data relay satellite launched in November 2020. The system succeeded in establishing an optical communications link between the satellite and an optical ground station located approximately 40,000 km away. This achievement is the first step toward the onboard service of an optical inter-satellite communication system in Japan.

Fig. 5 shows the configuration of the developed laser communication terminal.

NEC's laser communication terminal employ the 1.5 μm band wavelength, which is widely used in underwater cables and LANs and also has excellent parts availability. The inter-satellite transfer rate of 1.8 Gbps is at the world's top level and more than seven times faster than conventional radio wave communications.

In the near future, we plan to demonstrate and practically use optical inter-satellite communications between

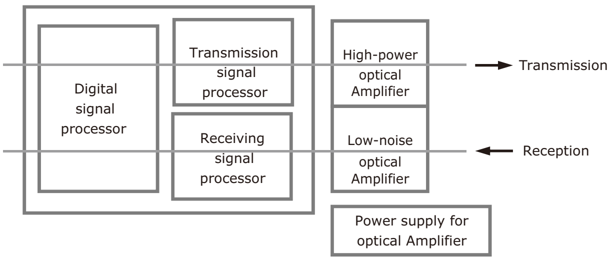

Fig. 4 Configuration of optical transponder.

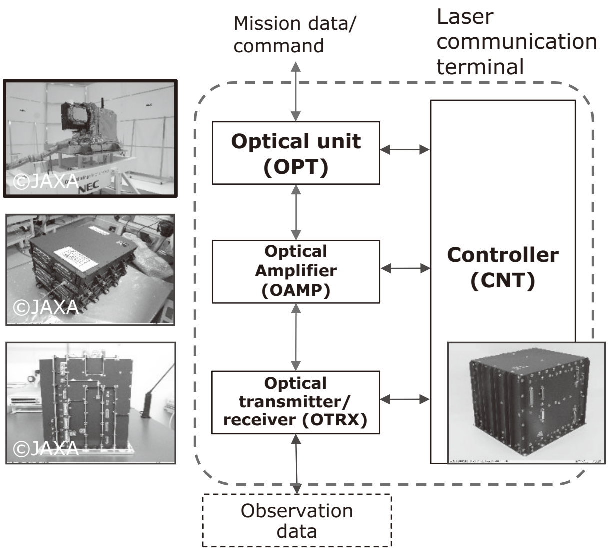

Fig. 5 Configuration of optical communication system.

the optical communications equipment onboard the advanced land observing satellites ALOS-3 and ALOS-4, which will be launched in FY2021 or later. Also, NEC is developing next-generation optical communication technologies to support the sophistication of optical communication networks, such as multiple access, and to achieve smaller, lighter and faster transmission rates.

6. Conclusion

This paper has presented NEC's approach toward optical inter-satellite communications and related technologies, In the future, NEC will continue to develop and demonstrate the technology, with the aim of contributing to society.

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The details about this paper can be seen at the following.

Related URL:

NEC develops laser communications terminals for JAXA's Laser Utilizing Communication System, "LUCAS"
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