1 Introduction

WAKANA Hiromitsu

When the data resolution of the observation of the earth environment by satellite is improved and the data transmission volume is increased, a high-speed, high-capacity communication link will be needed to transmit the data to the earth. Earth observation satellite and space stations moving in low earth orbits transmit data to the earth via a geostationary satellite called a data relay satellite, or transmit data directly to a ground station. In the former case, an inter-orbit communication technology is necessary for communication between the orbiters and the geostationary satellite. For a transmission link, either radio waves or laser beams can be used. Laser communication is advantageous from the viewpoints of compactness of communication devices, high speed, high capacity, interference immunity, and confidentiality, although it has difficulties in areas such as high-precision tracking and pointing technologies. On the other hand, in the latter case, ground-to-satellite optical communications have transmission problems due to the atmosphere, etc. Japan has performed research on ground-to-satellite optical communications since the 1980s. In 1994, the laser communication equipment developed by the Communications Research Laboratory (currently NICT) was mounted on Engineering Test Satellite Ⅵ (ETS-Ⅵ) of the National Space Development Agency of Japan (currently JAXA) and succeeded as the world’s first optical communications experiment between the ground and a satellite.

This special issue describes the development and demonstration experiment of the Optical Inter-orbit Communications Engineering Test Satellite (OICETS “Kirari”), which was an achievement of subsequent research and development for optical satellite communication technologies. With Kirari, JAXA succeeded in the world’s first inter-orbit communications experiment and NICT and JAXA succeeded in joint experiments of ground-to-satellite optical communications.

For this OICETS, JAXA started a technical survey in 1993 using the geostationary satellite ARTEMIS, which was developed by the European Space Agency (ESA), as a partner satellite for optical inter-orbit communications experiments, and began formal development in 1995. After overcoming many problems, including a delay in making ARTEMIS stationary and change from the planned launch of the OICETS with the J-Ⅰ rocket from Tanegashima to the launch with the Dnepr rocket from the Baikonur Cosmodome, OICETS was finally launched on August 24, 2005 (to a sun synchronous orbit with an orbital altitude of 610 km and an orbital inclination of 97.8°). On December 9, 2005, it succeeded with the world’s first bidirectional optical inter-orbit communication with the ARTEMIS, and the communications experiment continued for about a year with no particular problems. Then in March 2006, optical communications experiments were conducted between an optical ground station and OICETS. They were the world’s first successful ground-to-orbiter optical communications experiments. These optical communications experiments continued as second-stage experiments with the participation of NICT and other foreign space institutes. After making many achievements in these optical satellite communications experiments, OICETS stopped its operations on September 24, 2009.

This special issue mostly describes the

second-stage experiments made between the NICT optical ground station and the OICETS, although the description of the optical inter-orbit communications experiments between the OICETS and the ARTEMIS is given in Sections **2** and **3** by JAXA staff who actually conducted these experiments. Section **2** shows an overview of the JAXA project, including the development history of the OICETS and its in-orbit demonstrations. In Section **3**, **3-1** describes an overview of the development and launch, and **3-2** gives a system summary of the optical inter-orbit communications experiments between the OICETS and the ARTEMIS and the results of the in-orbit demonstration experiments. Then **3-3** introduces the optical compatibility test performed in September 2003 between laser utilizing communications equipment (LUCE) on the ground and the ARTEMIS in orbit, before the launch of the OICETS.

Section **4** summarizes the technologies and results of experiments related to the NICT optical ground station. **4-1** gives an overview of the optical ground station facilities (in Koganei City, Tokyo) with the 1.5-m optical telescope used for ground-to-satellite experiments, and shows the orbit accuracy of the communications experiments. **4-2** gives an overview of the laser communications system of the optical ground station and reports on the joint experiments of phases 1-3 conducted in 2006 by NICT and JAXA, and phase 4 performed in 2008 and 2009. In **4-3**, fiber coupling efficiency measurements using a fine tracking and pointing system are compared with simulation results, on the basis of the ground-to-satellite optical communications experiments. **4-4** is devoted to a discussion on the results of experiments and the design of coded data transmissions, which are made in the OICETS repeater mode using LDPC (Low-Density Parity Check) code for error-correction. **4-5** describes the development of a ground-to-satellite fading simulator that simulates laser propagation links using the atmospheric fluctuation data measured in the OICETS experiments. **4-6** reports the results of an analysis of the polarization degree and Stokes parameter of laser beams on the ground-to-space atmospheric propagation links. It is expected that these can be applied to quantum cryptography in the future.

Section **5** introduces an international joint experiment (called GOLCE), which was reconducted in 2008 using the OICETS and optical ground stations. The German Aerospace Center (DLR), European Space Agency (ESA), and Jet Propulsion Laboratory of the National Aeronautics and Space Administration (JPL/NASA) joined GOLCE from other countries. **5-1** describes an overview of GOLCE and that of the international workshop that was held to share research results. **5-2** compares and analyzes the optical propagation characteristics in each region's environment, on the basis of the experimental data that was obtained with the OICETS and various optical ground stations used in GOLCE. **5-3** and **5-4** report the results of experiments obtained from the foreign research institutes that joined GOLCE. **5-3** reports the results of an analysis of the scintillation obtained in the down-link experiments conducted by DLR. **5-4** reports the results of the preceding experiment obtained by JPL and the results of the experiments conducted four times in various atmospheric conditions. It is reported that effective data was obtained for the proof of the link model and the future establishment of ground-to-space optical communications.

The last Section **6** (**6-1**) shows an overview of optical communications experiments where the OICETS was not used. For example, bidirectional optical communications experiments with ETS-Ⅵ launched in 1994, optical communications experiments with the ARTEMIS of ESA and its optical ground station (Tenerife Island), optical communications experiments with the ARTEMIS and French low-earth-orbit satellite SPOT4, and experiments with American satellites NFIRE launched in 2007 and the DLR satellite TerraSAR-X (both are low earth orbit satellites) are introduced.

As introduced above, this special issue

covers various topics from the development of the Optical Inter-orbit Communications Engineering Test Satellite OICETS to the results of experiments. The optical communication technology capable of realizing high-speed, high-capacity communications in space would be an important core technology for future human space development and activities. I think that this project played an important role in the science and technology of optical communications. The success of this project was due to the constant efforts of the people who were involved in this project. I hope that this special issue would contribute to future space developments as much as possible.

***WAKANA Hiromitsu**, Dr. Sci.*

Distinguished Researcher, Wireless Network Research Institute

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