2 Overview of the Optical Inter-orbit Communications Engineering Test Satellite (OICETS) Project

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The Optical Inter-orbit Communications Engineering Test Satellite (OICETS “KIRARI”) is an experimental technology satellite aiming the orbital demonstration of optical communication with the ESA (European Space Agency) ARTEMIS (Advanced Relay and TEchnology Mission Satellite) geosynchronous satellite. Its main orbit demonstrations are laser acquisition and tracking technology, on-orbit performance degradation of optical devise and system, and future international inter-orbit operation of optical communications technology.

OICETS started the project in 1995, was launched at Baikonur in August 2005, after the ARTEMIS geosynchronous orbit acquisition. OICETS made success of two world first demonstrations in the laser optical communications. One was two-way communication with ESA ARTEMIS in 2005. Another was communication with the NICT ground station in 2006. This paper describes the overview of OICETS project such as development status, key technologies and launch and experimental results.

Keywords
Optical Inter-orbit communication, Low earth orbit satellite - optical ground station, Laser, International inter-orbit operation, International cooperation

1 Introduction

Radio wave communications support various space activities. They are used for example to transmit remote sensing data from an earth observatory satellite, transmit images of distant planets from an exploration satellite, and exchange information between satellites in orbit. As earth observation from space and other space activities become more active, the resolution of observation sensors mounted in earth observatory satellites should be improved and the data volume should increase [1]. However, due to a limitation of the frequencies that can be used for space communications, radio wave interference is becoming a problem. Optical communications using laser beams has therefore attracted attention as a future technology for the efficient transmission of a tremendous amount of observation data. Just like optical fibers for communication networks on the ground, laser beams can be used in space to transmit a large volume of data.

Inter-orbit communication technology, which is used between a low earth orbit satellite, such as an earth observatory satellite or International Space Station (ISS), and data relay satellites (geostationary satellite), are important technologies to support various space activities including the acquisition of observation data from earth observatory satellites or the continual securing of communication lines from the ISS. Optical inter-orbit communication technology using laser beams is a key technology for future data relay satellites as it not only improves the speed and capacity of data transmission drastically but also reduces the size and weight of communication antenna.

In-orbit optical communication technology using laser beams has drawn attention as a future technology. To demonstrate it, the Japan Aerospace Exploration Agency (JAXA) began to develop the Optical Inter-orbit Communications Engineering Test Satellite (OICETS). The satellite was expected to play a role as a test satellite for elementary technologies for the load map of satellite communications and broadcasting.

Figure 1 shows an image of optical inter-orbit communications between the OICETS and ARTEMIS and Fig. 2 that of an optical communications experiment with an optical ground station. The configuration of the OICETS in orbit and its major performance

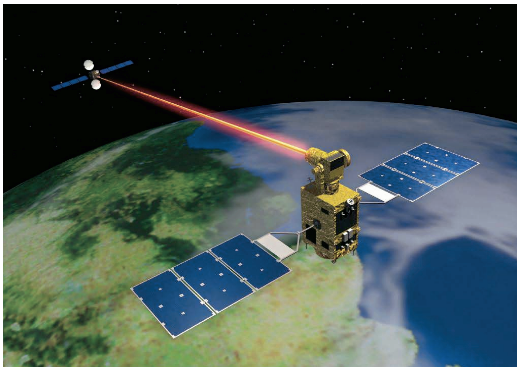


Fig.1 *Image of optical inter-orbit communications experiment between the OICETS and ARTEMIS. (The satellite on the near side is the OICETS)*

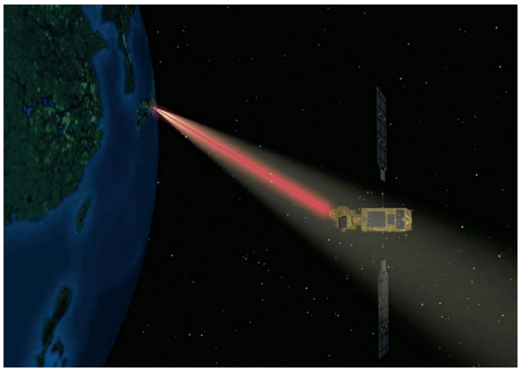
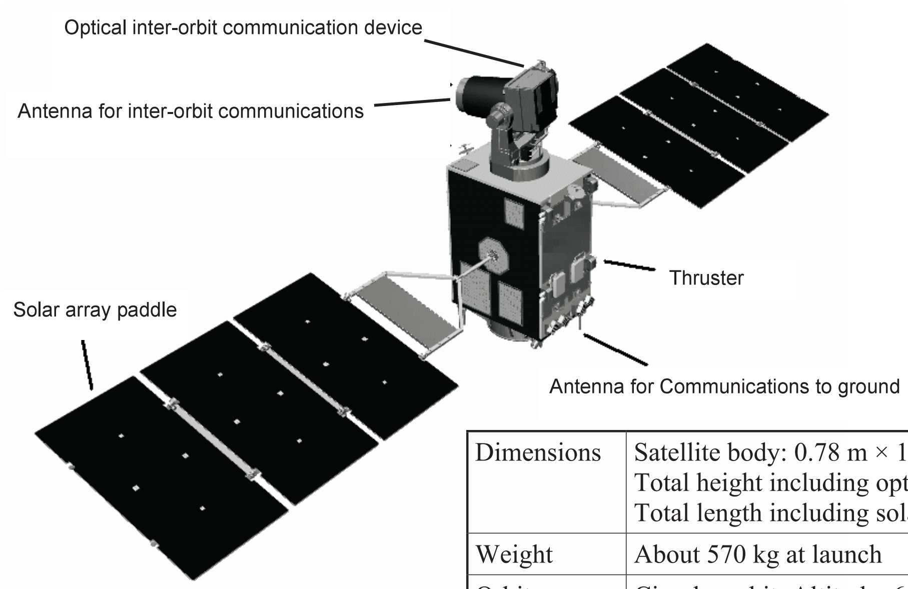


Fig.2 *Image of optical communications experiment made with an optical ground station of the National Institute of Information and Communications Technology (NICT)*



Dimensions	Satellite body: 0.78 m × 1.1 m × 1.5 m (height) Total height including optical antenna: 2.93 m Total length including solar array paddle: 9.36 m
Weight	About 570 kg at launch
Orbit	Circular orbit: Altitude: 610-550 km Orbital inclination: About 98°
Designed life	1 year

Fig.3 *Configuration and major performance of the OICETS on orbit*

details are presented in Fig. 3.

2 Development history

In an administrative meeting between Japan and ESA in 1992, discussions started for a joint experiment of optical communications. Optical inter-orbit communications were expected to be used for data relay satellites and hence mutual operability was important (because the space agencies could share the communication service by making a common communication method). In this situation, actual in-orbit demonstration of the technology in a practical situation was required and international collaboration was needed to conduct the project in a limited schedule and utilize costs efficiently.

Technological coordination began in 1993 using ESA's geostationary satellite ARTEMIS. In December 1994, the commissioner of ESA and the president of the National Space Development Agency of Japan (currently JAXA) exchanged a MOU with each other about optical inter-orbit communications experiments, which was the start of the joint experiment project to be conducted through international cooperation.

JAXA began the development of the OICETS in 1995 and the detailed technological coordination with ESA. Although international technological coordination was difficult, JAXA learned a lot from Europe which had advanced experience. The ARTEMIS was launched in July 2001 but it turned out that the deployment of the geostationary satellite to orbit was significantly delayed due to trouble with the launch vehicle. Since it was necessary to see whether the ARTEMIS could be made geostationary, the Space Activities Commission decided in August 2001 to postpone the launch of the OICETS.

However it turned out that, after ESA worked hard, the ARTEMIS was able to be put into the geostationary orbit in the beginning of 2003. Then, JAXA made a proposal to the Space Activities Commission for launching the OICETS in 2005, considering the fact that the optical communication device in the ARTEMIS would end its design life in 5 years (in July 2006). The Commission checked if the initial significance and purpose were still maintained in the project and discussed the validity of the project including the launch vehicle. As a result it was appreciated once again that the initial significance of the demonstration of optical inter-orbit communications in space was still valid, that early demonstrations of optical communications in space were still important for future technologies of Japan, and that the techniques could be applied to high-precision ranging and other technologies. On the other hand, the discussion on the launch vehicle was continued in order to select the most appropriate launch method with an aim to launching the OICETS in 2005. Through

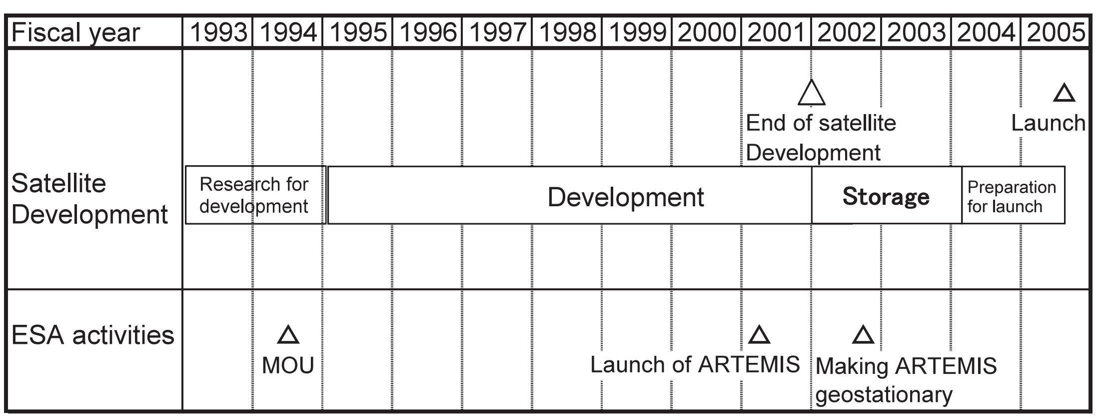


Fig.4 *OICETS development schedule (from start of development to launch)*

the discussions on the selection of the launch vehicle, it was found that the first stage of the J-I rocket could not be used due to an accident with the H-IIA rocket No. 6, and H-IIA rocket could not be used as it was to be used to launch another satellite, M-V rocket could not be used due to a launch environment problem, and GX rocket could not be used as it was still under development. In this difficult situation, the possibility of using a foreign rocket was examined as the second best way. In these discussions, the actual flight record and reliability of the rocket launching, the compatibility of the schedule, and delivery problems of the satellite were taken into account. As a consequence, a plan for launching the satellite with the Russia-Ukraine Dnepr rocket from the Baikonur Cosmodrome in 2005 was proposed in December 2004 to the Space Activities Commission, which then approved the proposal. Figure 4 shows the development schedule of the OICETS from the start of development to the launch.

3 Demonstration experiment in orbit

Compared to radio wave communication systems, optical communication systems have the following advantages:

(1) High antenna gain increases data transmission rate, reduces transmission power, and softens requirements for receivers.

(2) The size, weight and power consumption of communication devices can be reduced.

(3) The attitude is highly stable due to low attitude disturbances from the operation of small optical antenna.

(4) EMI (electromagnetic interference) can be reduced.

(5) The systems are highly resistant to interference and interception of communications and advantageous in terms of communication confidentiality.

Figure 5 compares actual radio wave communications satellites and optical inter-orbit communications satellites.

To take advantage of optical inter-orbit communications, there are some technical problems to be solved. The maximum distance between a geostationary satellite and a low earth orbit satellite is 40,000 km. For satellites that are far away from each other to transmit and receive laser beams to a precision of several micro radians, high-precision optical devices and technology for their accurate control are necessary. We demonstrated with the OICETS the key element technologies, checked performance degradation in the space environment, and obtained data for practical use.

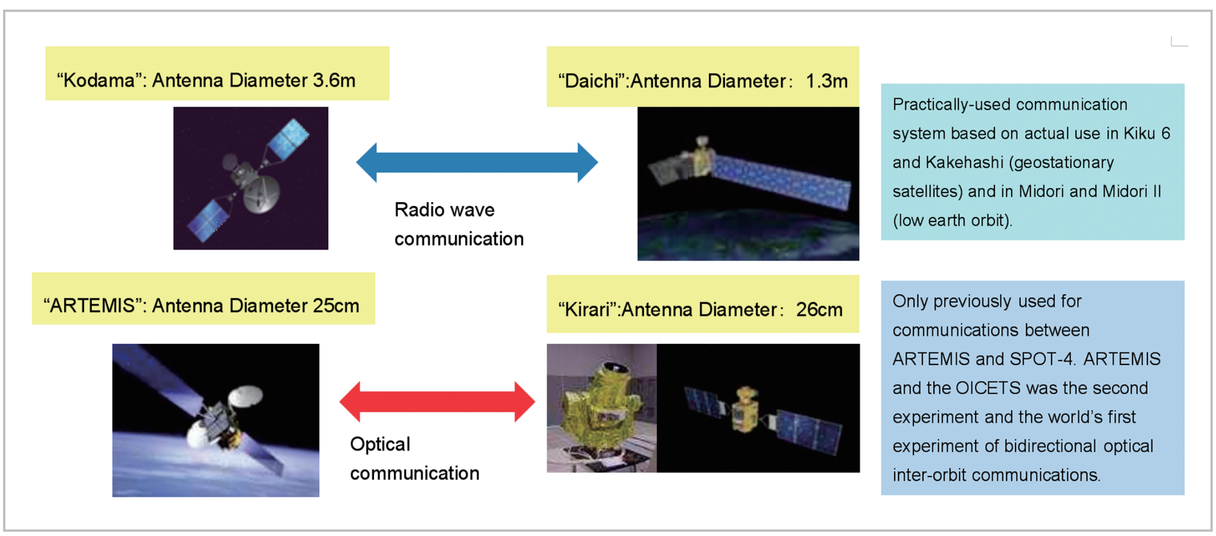


Fig.5 *Comparison of radio wave communications and optical communications*

The major items of the in-orbit experiments are shown below:

(1) Fine tracking and pointing experiments
- Bidirectional optical inter-orbit communications are performed and their major key element technologies are demonstrated.

(2) Optical inter-orbit communications experiments
- Optical inter-orbit communications experiments are performed many times to obtain statistical data for practical use.

(3) Evaluation experiments for optical devices
- Degradation characteristics of major optical devices are examined in space environment.

(4) Satellite micro vibration measurement experiments
- Micro vibration of the satellite is measured to evaluate its influence on optical inter-orbit communications

(5) Optical ground station experiments (Additional experiments after launch)
- Experiments of optical communications between the OICETS and ground stations are conducted.

4 Launch

As mentioned in Section **2**, the launch vehicle was changed from the J-I rocket at Tanegashima to the Dnepr rocket at the Baikonur Cosmodrome. Although there were a number of problems to be solved such as technological problems, satellite delivery problems, and problems of working in an unfamiliar launch site, not only those who were involved in the development of the satellite but also those who were involved in the ground system collaboratively worked on the hardware changes of the satellite, adjustment with the launch vehicle, and redevelopment of a tracking system and experiment system for a short period of time. About two months before the launch, the satellite was delivered to the Baikonur Cosmodrome in Kazakhstan and preparation work for the launch began. It was the first time for Japan to launch a JAXA satellite from the Baikonur Cosmodrome. It was also the first time using the Dnepr rocket. We therefore made prior surveys and checking of the rocket and launch site. Since not only people but also check-out equipment were restricted to enter the Baikonur Cosmodrome,

Fig.6 Group picture after launch

necessary preparatory work was conducted as much as possible. These were very difficult but we were able to get over the highest barriers through the effort and enthusiasm of the people involved.

On August 24, 2005, the OICETS was launched. It was deployed to orbit as scheduled and operated according to plan after separating from the launch vehicle. The successful launch of the satellite was a moment when the one-year effort was rewarded [2]. Figure 6 shows a commemorative group picture after the launch.

5 In-orbit experiments

The OICETS was put into the orbit at an altitude of 610 km and an orbital inclination 97.8°. After the OICETS was separated from the launch vehicle, the operations, such as deployment of the solar array paddles, were conducted as scheduled and critical operations were finished on August 25. The operational check (initial functional check) of the bus equipment and mission equipment of the satellite in orbit were carried out for about three months. The optical inter-orbit communication equipment was calibrated and the automatic tracking and pointing function was checked using the star Sirius. On December 9, 2005, the world's first experiment of bidirectional optical inter-orbit communications with the ARTEMIS was performed successfully during the initial functional check. It had been about 10 years since the start of development of the OICETS, and we finally succeeded in the demonstration of optical inter-orbit communications using laser beams, which had seemed impossible at the start of development. Then the project entered a stationary stage, where bidirectional optical inter-orbit communications experiments between the OICETS and the ARTEMIS were conducted for the planned mission period of about a year. Since optical inter-orbit communications between the OICETS and the ARTEMIS could be performed with no particular problems, additional experiments of optical communications between the OICETS and an NICT optical ground station were conducted in March 2006. Although it was expected to be quite difficult for the specifications of the satellite, the optical communication between the low earth orbit satellite and the ground station was successfully performed for the first time in the world by utilizing ingenious techniques for the operation and by taking advantage of the satellite's own capability. After the public release of the success of optical communications with the optical ground station, we received proposals for joint experiments from various space agencies. In June 2006, we also succeeded in optical communications with a transportable optical ground station from the German Aerospace Center (DLR). From October 2006, the project entered the second stage of using the satellite. In this stage, degradation data was successively collected to evaluate the life of the bus equipment (wheel, etc.) and optical communication equipment. In March 2008, the ex-post evaluation of the Space Activities Commission indicated that the OICETS project "performed as expected." The satellite operation was supposed to be terminated after the ex-post evaluation. However, since strong requests for optical communications experiments between the OICETS and optical ground stations were received from the NICT and foreign space agencies, additional experiments were performed in addition to the second stage.

The OICETS finally ended its operations on September 24, 2009 after the additional experiments of communications with all of the foreign optical ground stations.

The experiment results of the OICETS in orbit are described in "**3-2** Optical Inter-orbit Communication Experiment between OICETS and ARTEMIS".

Major operations of the satellite and a summary of the experiments after launch are shown in Fig. 7 [3].

6 Conclusions

The launch of the OICETS was considerably delayed due to the change of schedule of

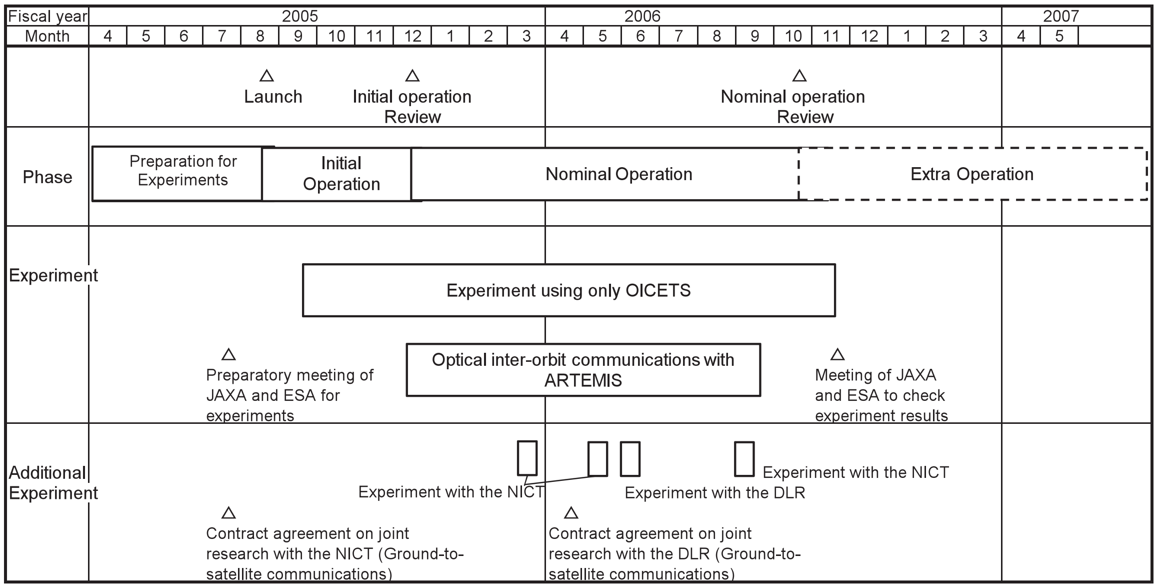


Fig.7 *Summary of in-orbit experiments of the OICETS*

the ARTEMIS and the change of the launch vehicle. However, we succeeded in the world's first bidirectional optical inter-orbit communications experiments owing to the efforts and enthusiasm of the people involved. We also succeeded in optical communications between a low earth orbit satellite and an optical ground station. We could thus achieve significantly greater results than expected in the initial plan for in-orbit experiments. Also in the second stage of using the satellite, we contributed, with the efforts of the NICT, to optical communications experiments with the optical ground stations of foreign space agencies. I hope that the results of the optical communications experiments will greatly contribute to future space development and that Japan can maintain a leading position in optical communications in space.

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