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The OICETS mission

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ABSTRACT

The Optical Inter-orbit Communications Engineering Test Satellite (OICETS) was successfully launched on 23th August 2005 and thrown into a circular orbit at the altitude of 610 km. The main mission is to demonstrate the free-space inter satellite laser communications with the cooperation of the Advanced Relay and Technology Mission (ARTEMIS) geostationary satellite developed by the European Space Agency. This paper presents the overview of the OICETS and laser terminal, a history of international cooperation between Japan Aerospace Exploration Agency (JAXA) and ESA and typical results of the inter-orbit laser communication experiment carried out with ARTEMIS.

1. INTRODUCTION

Free-space laser communication system offers many advantages such as high data rate, small sized equipment, low consumption electric power and others. There are, however, many development factors to construct a realistic laser communication system in space. Precise acquisition, tracking, and pointing functions are key issue to establish the laser communication system in space.

Japan Aerospace Exploration Agency (JAXA) developed the Optical Inter-orbit Communication Engineering Test Satellite (OICETS), which has a laser communications terminal called the Laser Utilizing Communications Equipment (LUCE), constructed by NEC TOSHIBA Space Systems, Ltd. The OICETS flight model was well developed and the proto-flight test (PFT) of the satellite finished in January 2001 [1–7]. The satellite was then stored and waited for its launch. The functional test of the entire satellite system was periodically performed every 6 months. The mechanical moving parts in the satellite were turned on every 3 months during this storage period. 2 years after the PFT, the optical pointing and tracking characteristics of LUCE were confirmed again in February 2003 [8].

On 23rd August 2005, OICETS was successfully launched and thrown into a polar sun synchronous

orbit at the altitude of 610 km. OICETS was planned to demonstrate the free-space inter-orbit laser communications with the cooperation of the geostationary satellite, ARTEMIS, developed by the European Space Agency (ESA).^[8] Inter-orbit laser communications between OICETS and ARTEMIS succeeded on 9th December 2005.

2. INTERNATIONAL COOPERATION BETWEEN ESA AND JAXA

JAXA and ESA started discussing the in-orbit optical link experiment between ARTEMIS and OICETS in the framework of international cooperation in 1992 and signed a memorandum of understanding in December, 1994. JAXA and ESA then made a space interface control document and a ground interface document for developing the laser communication terminals. Terminals at Japan and at Europe had been designed and manufactured by each agency based on the documents.

To mitigate the risk facing the program, an optical acquisition, tracking and communications test was planned to confirm the two satellites optical interfaces in September 2003 before the launch of the OICETS satellite with the international cooperation with ESA. For this test, a LUCE engineering model was set up at the ESAs Optical Ground Station (OGS) in Tenerife where it would establish communications with the ARTEMIS. The optical compatibility tests were to verify the end-to-end optical characteristics [9].

We were concerned that some interface might be missing of space and ground system, but the completed laser terminals and ground systems satisfy requirements stated in the interface documents. That can be proved by successful in-orbit experiment results.

3. DEVELOPMENT OF OICETS AND LUCE

JAXA started research activities of the optical inter-orbit communications technologies in 1985 and constructed some research models of the optical communication terminal. JAXA conducted the concept designs and feasibility studies of the experiment satellite named OICETS in 1992. The OICETS

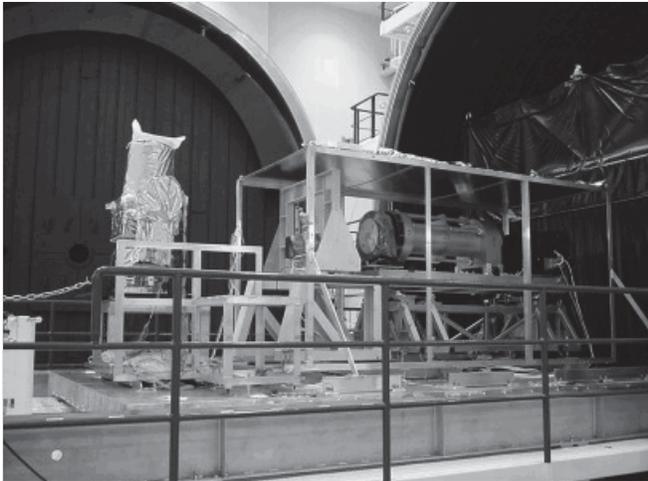


Fig. 1. LUCE FM (left) in the 6m space chamber

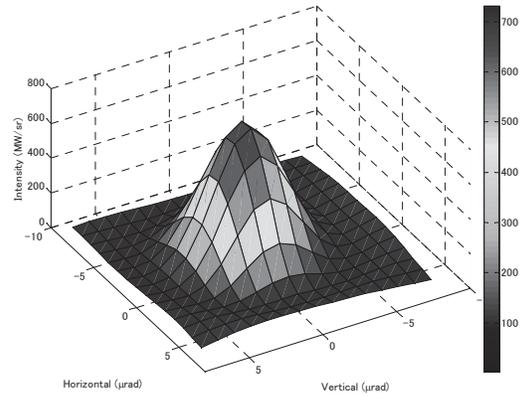


Fig. 2. Far field pattern of the LUCE FM.

program started to perform on-orbit experiment in 1993. A preliminary design of the OICETS system, including the LUCE, was completed in 1994. After the design review, the LUCE Engineering Model (EM) was assembled followed by performing tests listed below:

- Electrical performance test with a Target Terminal Simulator (TTS),
- Optical performance test with a Ground Optical Assistance for LUCE (GOAL) and the TTS,
- Sinusoidal vibration test,
- Thermal vacuum test with the GOAL,
- Electrical magnetic compatibility test.

Additionally, a structural and thermal model of the optical antenna was manufactured in order to evaluate structural and thermal robustness of optical antenna made by glass and glass ceramics. After these EM tests, the critical design of LUCE was finished and a LUCE

Flight Model (FM) was manufactured. We performed the similar tests to EM tests, and then series of the tests included the OICETS satellite system test named PFT were completed in 2001.

It is important for an optical equipment to measure the characteristics of vacuum and thermal conditions. The LUCE EM and FM were tested in a 6m-diameter space chamber at the Tsukuba space centre. The GOAL was installed in the space chamber, and it measured on-axis intensity, far field pattern, thermal drift of laser pointing angle, and others. The figure 1 shows an overview of the space chamber and the LUCE FM. The figure 2 shows the far field pattern on the LUCE FM emitting beam measured by the GOAL in the case of 80mW averaged laser diode output power. It was measured in a vacuum and predicted thermal conditions.

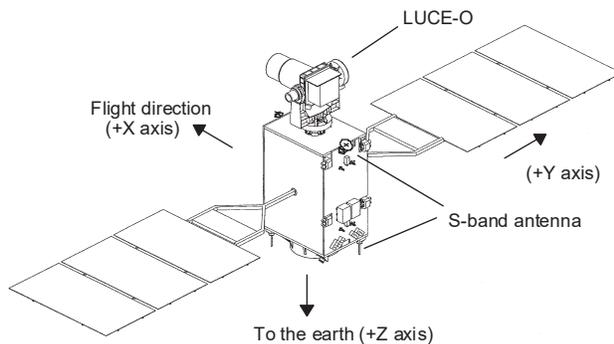


Fig. 3. In-orbit satellite configuration of OICETS

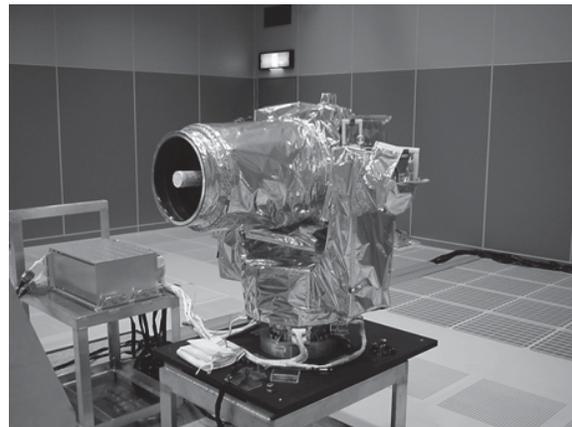


Fig. 4. Overview of the LUCE

4. OUTLINES OF OICETS AND LUCE

The OICETS is a relatively small satellite with a mass of approximately 570 kg. When the solar paddles are fully extended on orbit, the satellite is about 9.4m in width. It was launched by a Dnepr launch vehicle from the Baikonur Cosmodrome in the Republic of Kazakhstan. The OICETS orbit for the experiment is circular with a height of about 610 km and an inclination of 97.8 degrees. The satellite is operated by three axis stabilized attitude control, and its Z-axis (yaw axis) points toward the earth. The OICETS satellite system consists of bus subsystems and mission payloads.

The satellite bus system consists of communications and data handling systems, a power unit, a solar array paddle system, an attitude and orbit control subsystem, a structure, and a thermal control subsystem. The major characteristics of the OICETS are summarized in Table 1 and in-orbit satellite configuration is shown in Fig. 3.

Table 1. Major characteristics of OICETS

ITEM	VALUE
Launch Date	23rd Aug. 2005
Launch site	Baikonur Cosmodrome in the Republic of Kazakhstan.
Eccentricity	0
Attitude control	Three-axis stabilized
Size	9.4 m × 1.8m × 3.1 m
Orbit inclination	97.8 deg
Weight	570 kg

LUCE can be divided into two parts, the optical and electrical parts. The optical part involves a telescope mounted on two axes gimbals attached to the anti-earth side of the satellite. The electrical part provides functions to control the acquisition, tracking and pointing mechanisms as well as the communication electronics. Fig. 4 shows overview of the LUCE optical part and electrical part. The optical antenna shown in Fig. 4 has the diameter of 26 cm and is categorized into a center-feed Cassegrain mirror-type telescope.

LUCE's communications system employs the Intensity Modulation and Direct Detection (IM-DD) technique which switches the transmit laser source directly by the data stream On-Off Keying (OOK). LUCE utilizes the semi-conductor Laser Diode (LD) as a transmission

device and the Avalanche Photo Diode (APD) as detection device. The forward link uses 2 Pulse Position Modulation (2PPM) format at 2.048 M bits/sec, while the return link uses NRZ format at 49.3724 Mbits/sec.

5. IN-ORBIT EXPERIMENT WITH ARTEMIS

5.1 Over view of the experiment result

The experiment between ARTEMIS and OICETS started in December 5, 2005. After starting an experiment, the experiment was successfully completed more than 20 times. Results of acquisition, tracking, pointing and two-way communications satisfied us and it showed that the optical inter-orbit communication was eligible for operational use. The experiment objectives were not only to perform laser communication but also to perform interoperability between JAXA and ESA space network operation systems. Operation planning schedule, both satellite orbit data, real-time monitoring data of the ground equipment at REDU and both satellite real-time telemetry data were exchanged automatically and surely between the ESA's operation and scheduling system at REDU station and the JAXA's system at Tsukuba space centre.

5.2 Acquisition, Tracking and Pointing Performance

In order to establish inter-orbit laser communications successfully, it is important to design the acquisition procedures for two laser terminals. In our experiments, ARTEMIS (GEO terminal) has a beacon beam, but OICETS (LEO terminal) does not. Therefore, the following acquisition procedures are needed.

- Both terminals point to each other by applying open-loop control based on on-board orbital models,
- ARTEMIS scans an uncertain area with the beacon beam whose divergence is much wider than its communication beam's,
- Upon reception and detection of the beacon beam from ARTEMIS, OICETS immediately transmits its communication beam toward the ARTEMIS,
- Upon reception and detection of the communication beam from OICETS, ARTEMIS stops scanning the beacon beam and transmits a communication beam to OICETS, After that, the beacon beam is turned off,

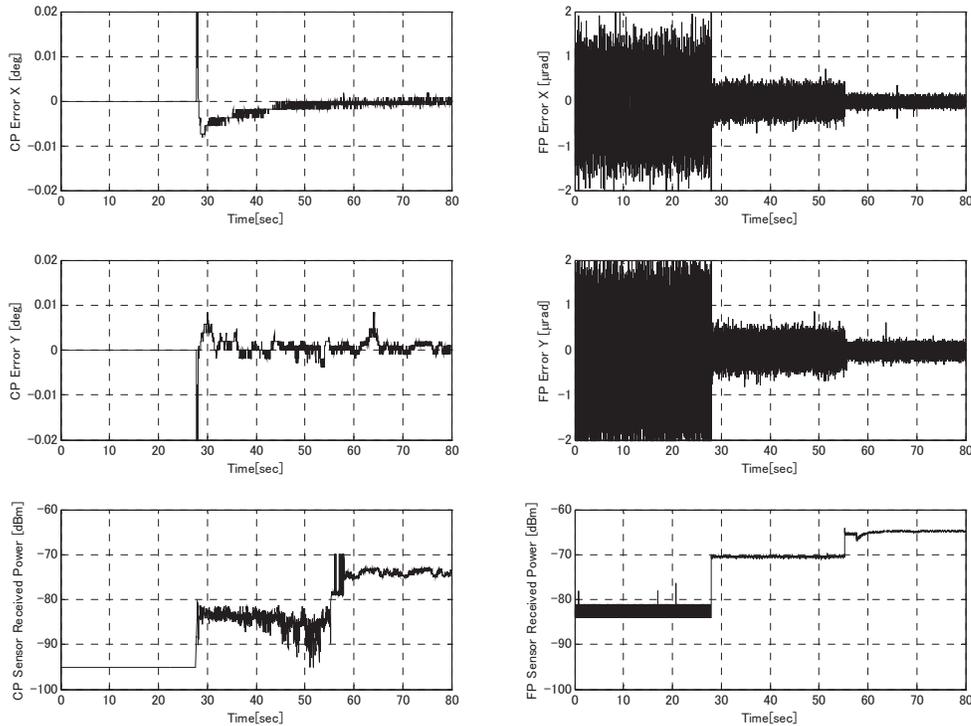


Fig. 5. Acquisition and tracking sequence.

- to initiate inter-orbit link, each satellite continuously transmits the communication beam toward the other to enable the counter satellite to improve its pointing accuracy.

Figure 5 shows the results of the experiment which was performed on February 9, 2006. the LUCE coarse pointing sensor error of X, Y axis, coarse pointing sensor received power, fine pointing sensor error of X, Y axis and coarse pointing sensor received power are shown in Fig. 4 respectively. The figure indicates that both coarse pointing and fine pointing mechanisms worked cooperatively and fulfilled their roles for accurate tracking. Although the fine pointing sensor had limited field of view, there was no failure to catch the beams. There was a sharp increase in the received power of both sensors after the initial acquisition. This indicates that ARTEMIS started to transmit the communication beam. The fine pointing sensor error X and Y are improved after the communication beam was received. Over all acquisition sequence of both terminals was about 33 seconds.

Figure 6 shows the coarse pointing error of the initial acquisition phase. This figure tells us that the LUCE sustains to track the beacon beam and it maintains a

tracking error of less than the field of view of the coarse point sensor of 0.2 degrees.

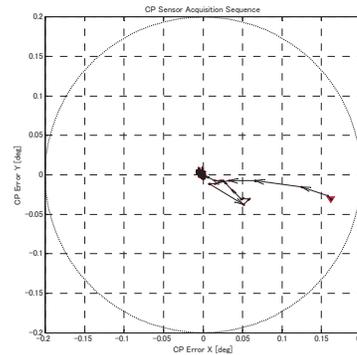


Fig. 6. Coarse pointing error of the initial acquisition.

5.3 Calibration of Pointing Bias

The calibration of the calibration is performed in order to correct a pointing bias of LUCE. Methods of the experiment is as follows:

- a. ARTEMIS and OICETS established the optical communications link.

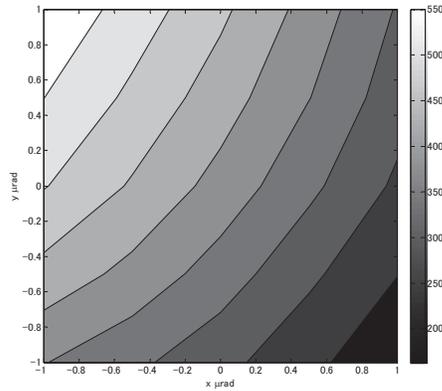


Fig. 7. Far-field pattern of the LUCE on 9 December 2005.

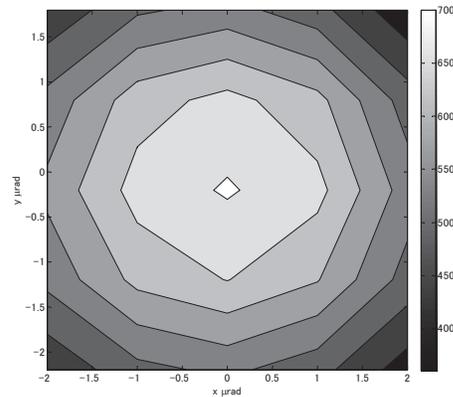


Fig. 8. Far-field pattern of the LUCE on 26 January 2006.

- b. LUCE changed the beam direction by adding offsets to the point ahead angle. The adding angle sequence followed a spiral pattern.
- c. The received power on ARTEMIS were measured and post-processed in order to recover the LUCE transmitted intensity.
- d. A far-field pattern of the LUCE was processed from the adding angle and the LUCE transmitted intensity.
- e. The bias pointing error was estimated from the far-field pattern.

We carried out nine experiments and succeeded in compensating the pointing bias error. Figure 7 shows a far-field pattern of the LUCE which is the first data measured on 19 December 2005. The bias pointing error was estimated of about 3 micro radians from the experiment results. Figure 8 shows a far-field pattern after the calibration measured on 26 January 2006.

5.4 Communication performance

The optical return link from OICETS to ARTEMIS is modulated with an NRZ format whose data rate is 49.3724 Mbps. LUCE can generate PN code and transmit it to ARTEMIS. These data are downlinked to an ESA's ground station at Redu in Belgium, via a Ka-band radio frequency feeder link of ARTEMIS. The forward link from ARTEMIS to OICETS is modulated to a 2PPM format whose data rate is 2.048 Mbps. The LUCE is equipped with a bit error counter to evaluate the link quality. The forward link data of PN code is also transmitted from the Redu station via the Ka-band feeder link.

In all the experiments, the forward link bit error results measured by the LUCE terminal were zero, these are error free, at the ARTEMIS laser output power condition of 37.5 mW and 60 mW.

Figure 9 shows the bit error count per 1 second data after the acquisition on 9 December 2005. The bit error is around $5.0 \times 10^4 \sim 1.0 \times 10^5$ counts per second. In other words, the bit error rate is around $1 \times 10^{-3} \sim 2 \times 10^{-3}$. When this measurement was carried out, pointing bias calibration was not performed. Figure 10 shows the bit error on 9 February 2006 when the pointing bias calibration was already finished. The bit error are around 0~3 counts per sec and the bit error rate is around $0 \sim 6.0 \times 10^{-8}$. It seems reasonable to suppose that the pointing bias error calibration effects improvement of the bit error rate.

6. CONCLUSION

The experiment result reported in this paper is only a small part of the planned experiment. The inter-orbit experiment with ARTEMIS has been conducted since December 2005. The experiment results show that the optical inter-orbit communication has a quality for operational use.

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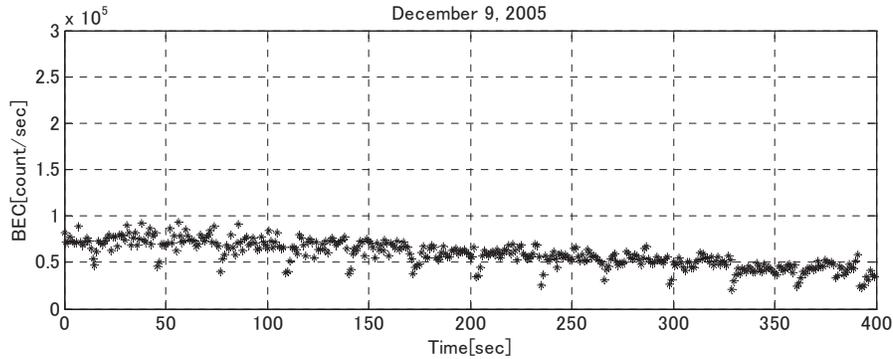


Fig. 9. Return link bit error on 9 December 2005.

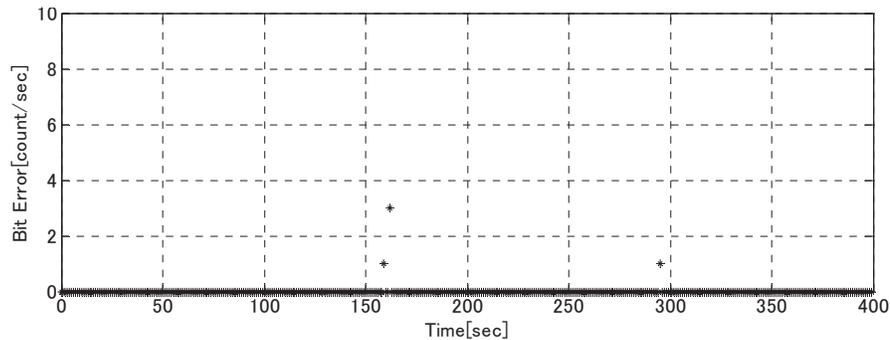


Fig. 10. Return link bit error on 9 February 2006.

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