

Optical Communication Experiment Using Very Small Optical Transponder Component on a Small Satellite RISESAT

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Abstract

The development of satellite-to-ground optical communications instrument onboard the small satellite RISESAT was discussed. Since there is no gimbal on the component, it is necessary to change the attitude of the satellite in order to direct the laser beam toward the ground station. The plan of optical communication experiment and the methods to evaluate the laser beam width and the accuracy of beam pointing were also shown.

1. Introduction

Small satellites are expected to reduce the cost and period required for satellite development. In Japan, "Hodoyoshi" project has been developed since 2010 to employ these advantages of small satellites efficiently^[1]. The word "Hodoyoshi" means "reasonable reliable" in Japanese. "Hodoyoshi" concept tries to find out an appropriate design point which yields "high reliability per cost". Hodoyoshi project are developed by the University of Tokyo in collaboration with other universities and organizations.

Five small satellites have been developing in this project within the period of 2010-2013^[1]. The first satellite "Hodoyoshi-1", which will be launched in 2012, aims at 5 [m] ground sampling distance in remote sensing. The second satellite, Hodoyoshi-2, has missions for space research proposed by several countries and selected. This Hodoyoshi-2 satellite is also called RISESAT: Rapid International Scientific Experiment Satellite^{[2][3]}. The third to fifth satellites will be operated in constellation to create and try a new satellite business.

One of the purposes of RISESAT is satellite-to-ground optical communication experiment. The advantages of optical communication systems compared to radio frequency communications are wider bandwidth, larger capacity, lower power consumption, more compact equipment, and protection against interference. Therefore, optical communication is suitable system for micro/nano satellites. Optical communication unit of RISESAT has been developed by National Institute of Information and Communications Technology (NICT).

In this paper, development concept of the optical communications mission aboard the RISESAT satellite are proposed. Section 2 describes the outline of RISESAT. Onboard optical communication instruments are shown in Section 3. Concept of optical communication experiment is summarized in Section 4. Link analysis between RISESAT and a ground station is shown in Section 5. In Section 6, methods to evaluate the beam width and the accuracy of beam pointing are discussed.

2. Hodoyoshi-2 : "RISESAT"

The second satellite in the Hodoyoshi project, has missions for space research proposed by several countries and selected^{[2][3]}. It will be launched in 2013. Development of RISESAT is led by Tohoku University in collaboration with Hokkaido Univ., Kyoto Univ., and other organizations and companies. In table 2.1, specifications of RISESAT are shown. Size of the main bus is about 50 x 50 x 50 [cm]. Its mass is about 50 [kg].

RISESAT carries sciences missions such as High Precision Telescope (HPT) for both astronomical and Earth observation, particle counter, ocean observation 3-axis Dosimeter for radiation environment monitoring, Micro Magnetic Field Sensor, Meteor Detection Sensor, and Ocean Observation Camera^[3]. RISESAT also carries 8 engineering mission: (1) high performance attitude control, (2) Panel development mechanism, (3) Thin film Deployment, (4) Micro Monitoring Camera, (5) High Speed Downlink in X-band, (6) New robust and redundant main computer, (7) Store and forward demonstration, and (8) Optical Communication^[3]. Optical communication experiment using RISESAT will be a first step toward the future optical communication mission such as data transfer from micro/nano satellites in lower orbit to a mid/large sized satellite in geostationary orbit.

3. VSOTA: Very Small Optical Transponder

In 1994, NICT successfully performed first bi-directional laser communications using laser communication equipment aboard the ETS-VI satellite in the geosynchronous orbit^[4]. First bi-directional laser communications demonstration between two satellites (OICETS and ARTEMIS)

was successfully conducted in 2005[4]. Ground-to-satellite laser communication experiments between the optical ground station located in Koganei City and OICETS was conducted since March 2006[5].

Taking advantage of these experiences, NICT initiated R&D activities of Small Optical TrAnSponder (SOTA) for micro-satellites in the frame of the Space Optical Communication Research Advanced Technology Satellite (SOCRATES) project[6]. However, due to the mass limit, SOTA cannot be carried in RISESAT. Therefore, we have decided to build a new, simple, and light equipment which is suitable for RISESAT. We call this new equipment as VSOTA (Very Small Optical Transmitter for component validation). VSOTA's basic structure of Laser Collimator and LD driver are the same as SOTA. In other words,

Table. 2.1 Specifications of RISESAT.

Size and Weight	
Size	W 500 x D 500 x H 500 [mm]
Weight	less than 55 kg
Orbit	
Type	Sun Synchronous
Altitude	500 - 900 [km]
Inclination	approx. 98 [deg]
Attitude Control	
Method	3-axis stabilization
Pointing Accuracy	< 0.1 [deg] (requirement, 3σ) < 0.04 [deg] (objective, 3σ)
Pointing Stability	< 6 [arcsec/s]
Sensors	Star Sensor, FOG, Magnetometer, GPS Receiver, Sun Sensors
Actuators	Reaction Wheels, Magnetic Torquers
Power Supply	
Solar Cells	2 Deployable Panels and 1 Body Panel
Power Generation	> 100 [W]
Power Consumption	> 50 [W]
Communication	
Command Uplink	UHF 1200 [bps]
HK Downlink	S-band 500 [kbps] (Max)
Mission Data Downlink	X-band 2 [Mbps] (Max)

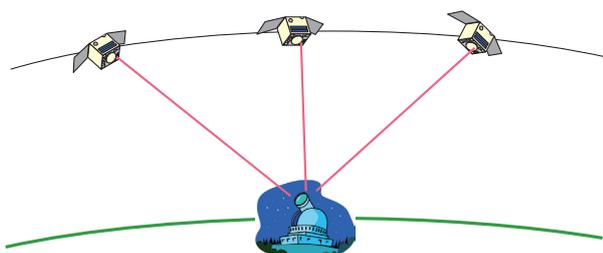


Fig. 3.2 Target Pointing Mode of RISESAT.

VSOTA is a transmit-only system. Moreover, there is not a gimbal for changing the direction of transmitting laser. Therefore, in order to direct the laser beam to the desired direction, i.e. toward the ground station, it is necessary to change the attitude of RISESAT. This mode of attitude control is called as "Target Pointing Mode". In this mode, +z plane in the satellite body fixed frame (the plate whose normal is along with light axis of RISESAT) are maintained toward the ground optical station. Whether the laser beam from RISESAT can be detected by the ground station or not depends on the beam width, accuracy of attitude control, and the accuracy of axis of VSOTA and normal of +z plane.

Specification of VSOTA are summarized in Table 3.1. Values of SOTA is also listed for comparison. VSOTA consists of two parts; i.e. VSOTA-COL and VSOTA-E (Fig. 3.2). VSOTA-COL has two LDs with different wavelength (Table 3.2). There is also an alignment cube on the base plate of VSOTA-COL. Using this alignment cube, direction of light axis of LDs can be measured pre-

Table. 3.1 Specifications of VSOTA and SOTA.

	VSOTA	SOTA
Mass	< 1 kg	6.2 kg
Power consumption	< 10W	40W
Max. Link Range	2000 km	2000 km
Wavelength (TX)	980 nm 1550 nm	980 nm 1550 nm 800 nm
Wavelength (RX)	-	1064 nm
Data Rate	1 - 100 kbps	< 10 Mbps

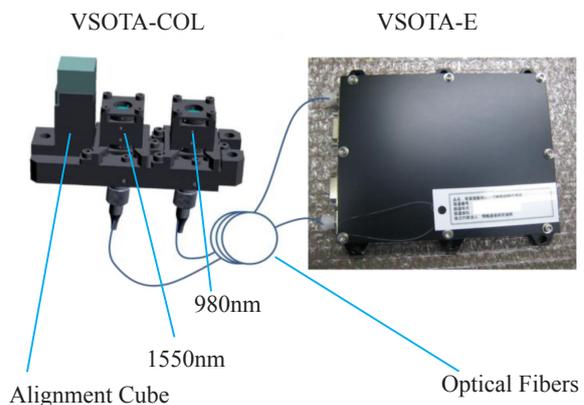


Fig. 3.2 Configuration of VSOTA.

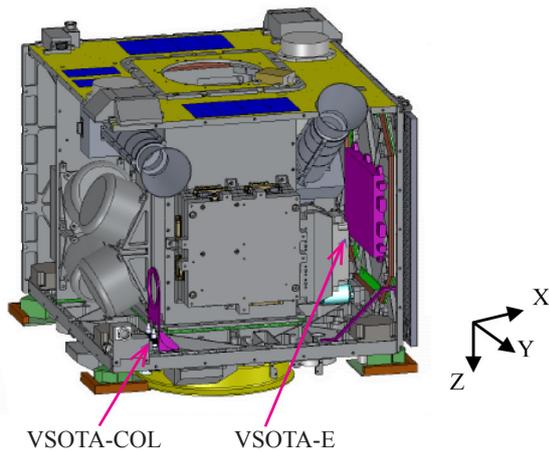


Fig. 3.3 Internal Structure of RISESAT and the position of the optical communication unit.

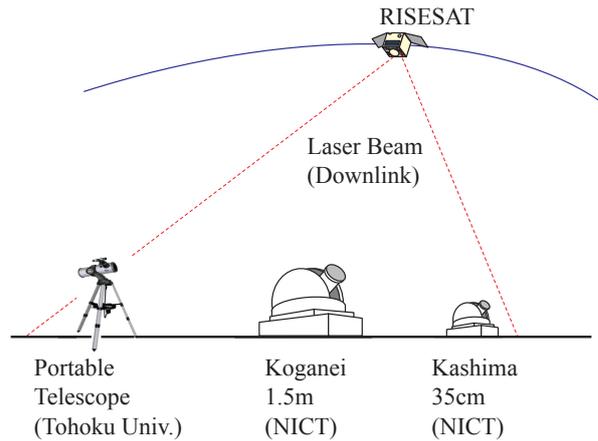


Fig. 4.1 Configuration of satellite-to-ground laser communications experiment using RISESAT.

Table. 3.2 Specifications of Two LDs.

Optical Source	TX1	TX4
Wavelength	980 nm	1550nm
Power (Max)	540 mW	80 mW
Modulation Speed (NRZ, Max)	10 Mbps	10 Mbps
Beam Div.	3.5 mrad	1.3 mrad
Polarization	Arbitrary	Linear



Fig. 4.2 1.5 m Telescope at Koganei, NICT.

cisely. VSOTA-E is the electric part which consists of the transmitter laser diode control unit. Internal structure of RISESAT is shown in Fig. 3.3. VSOTA-COL is attached on the +z plate and VSOTA-E is attached on +x plate. These two units are connected by the optical fibers.

4. Plan of Optical Communications Experiment

In Figure 4.1, concept of optical Communications experiment is shown. Three types of ground station will be used in this experiment: (1) 1.5 [m] telescope at Koganei JAPAN (Figure 4.2), (2) 35 [cm] telescope at Kashima, JAPAN (Figure 4.3), and (3) portable telescope that aperture is about 20[cm]. Telescopes at Koganei (1) & Kashima (2) are operated by NICT. The portable telescope (3) has been developing by Tohoku University.

In the satellite bus of RISESAT, data for Bit Error Rate (BER) Estimation and observation data obtained by other instruments are stored. These data will be used to optical communication experiment. Optical communications



Fig. 4.3 35 cm Telescope at Kashima, NICT.

experiment will be conducted raising difficulty: (1) turn on the power of VSOTA, (2) both LDs' status are OK on telemetry, (3) optical tracking is successful by ground telescope, i.e. light spot of 980 [nm] beam can be detected as a bright spot on the picture taken by the tracking camera, (4) photo diode with DIMM can be recorded both wavelength (especially 1550 [nm]) for atmospheric turbulence research, (5) transmit PN code to evaluate BER at any transmitting rate, (6) transmit mission data such as the position of the satellite obtained by the onboard GPS receiver.

5 Link Analysis

The analysis for optical communication links estimated between RISESAT and ground stations was performed[7]. Apertures of the telescopes at ground stations were assumed to be, 1.5 [m], 35 [cm], and 20 [cm]. Receiver at ground station consists of Avalanche Photo Diode (APD) or Photo Diode (PD). Specifications of receivers are summarized in Table 5.1. Moreover, we made following assumptions: (1) Altitude of RISESAT is 900 [km]. (2) Loss due to scintillation of atmosphere is 7 [dB]. In Table 5.2, conditions for the link analysis were summarized. Result of link analysis with the link distance of 900 [km] is shown in Table 5.3. This link distance corresponds to the case where the elevation of the RISESAT is about 61[deg].

6. Assessment of the body pointing accuracy

As we mentioned before, collimator of VSOTA has two LDs with different wave lengths. Width of the laser beams are also different. Width of Narrow beam is 1.2 [mrad] (0.07 [deg]). This value is comparable to the attitude control accuracy of RISESAT (0.1 [deg]). Light axis of VSOTA-COL required to be aligned with body fixed coordinate system of RISESAT by order of 0.01 [deg]. Before the launch of RISESAT, the direction of light axis of VSOTA and other science instruments, such as High Precision Telescope will be measured using several alignment mirrors (or cubes). This values will be important parameters for "target pointing mode" of RISESAT attitude control. However, due to the vibration or thermal distortion, axis of onboard instruments may shift during or after the launch. Therefore, it is important to prepare the methods of evaluating the attitude of RISESAT on orbit and the direction of laser beam.

We have now been preparing three methods for this evaluation. In the first method, portable telescope is set at the place about 1 [km] away from the 1.5 [m] telescope at Koganei. By the simultaneous observations of light from RISESAT using two telescope, we can evaluate the spread

Table. 5.1 Conditions for link analysis.

Power	270 W
Wave Length	980 nm
Beam Divergence (Full Width)	3.3 mrad
Optical Loss (TX)	-2 dB
Satellite Pointing Loss (3σ)	1.7 mrad
Range (1-way)	900 km
Space Loss	-261dB
Optical Loss (RX)	-2 dB
Atmosphere Turbulance Loss	-7 dB
Atmosphere Transmission	-4dB

Table. 5.2 Specifications of receivers at ground station.

Wave Length	980 nm	1550nm
Sensor	APD	PD
NEP [W/Hz ^{1/2}]	0.02E-12	3.0E-14
Sensitivity	13E-12	-
Bandwidth	100 k	100 k
Minimum Noise	-83	-108
Circuit Noise	0	-28
Quantum Efficiency	-3	0
Minimum Sensitivity	-80	-78

Table. 5.3 Results of link analysis. Distance between RISESAT and the ground stations was assumed to be 900 [km].

Aperture of Telescope	1.5 m	35 cm	20 cm	Unit
Receive Gain	134	121	116	dB
Receiving Power	-54.7	-67.3	-72.2	dBm
Margin	24.3	12.7	8	dB

of the laser beam. Concept of this method is shown schematically in Figure 6.1.

Second method uses the combination Laser transmitter of NICT ground station and High Precision Telescope (HPT) onboard the RISESAT. From the Koganei station, laser beam (532[nm]) for Satellite Laser Ranging (SLR) is discharged towards RISESAT. Using HPT, which is attached on the same plane as VSOTA-COL, the laser beam from Koganei can be detected. From the position of light spot in the HPT's field of view, we can estimate the attitude of RISESAT. In Fig. 6.2, the concept of this method is shown.

Third method uses Corner Cube Retroreflector (CCR) attached on +z plane of RISESAT and SLR ground stations. Since field of view of CCR is large (about 15 deg), CCR can be used to detect the satellite when the attitude of RISESAT shifts from the nominal position by over several degrees. Moreover, from the high precision ranging data by SLR, orbit of RISESAT can be determined more precisely[8]. The precise orbit leads to more accurate ephemeris which can be used for optical communications experiment.

7. Summary

The development of optical communications instrument onboard the small satellite RISESAT and the plan of experiment were discussed. Through the experiment, we would like to obtain the "launch pad" for future advanced optical communications, such as bi-directional communication between small satellites in lower orbit and a data link satellite in geosynchronous orbit.

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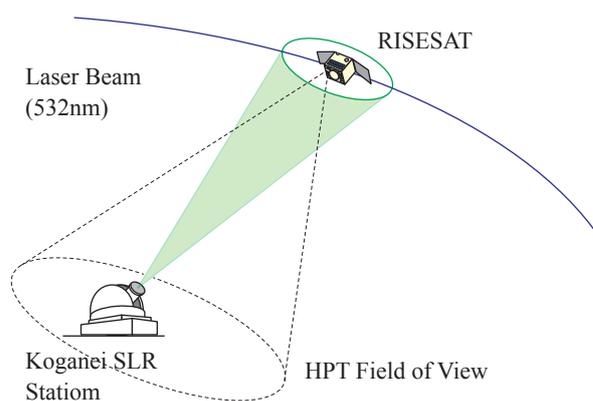


Fig. 6.1 Concept of attitude determination using Satellite Laser Ranging Station and onboard High Precision Telescope (HPT).

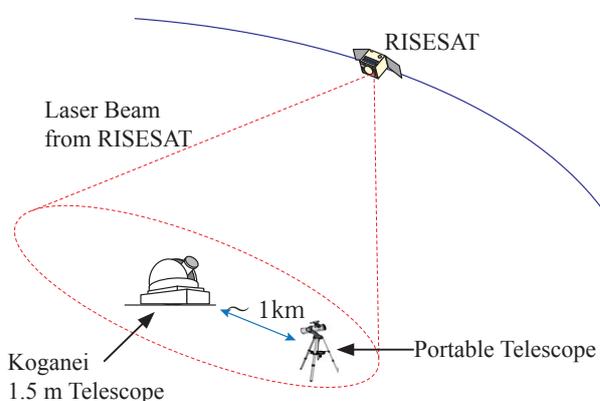


Fig. 6.2 Evaluation of laser beam width using fixed ground station and portable telescope.

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