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Collaboration of ranging and optical communication mission RISESAT

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Abstract *A 50kg-class micro satellite RISESAT has various missions for space research: a laser communication terminal called VSOTA, a 5m GSD multi-spectral high-resolution telescope called HPT, a corner cube retro reflector, and so on. In this paper, collaborate experiment plan of VSOTA, HPT, CCR and ground SLR stations for satellite attitude determination is introduced.*

Introduction

Small satellites are expected to reduce the cost and period required for satellite development. In Japan, "Hodoyoshi" small satellite project has been proceeded to employ the advantage of small satellites efficiently[1]. The word "Hodoyoshi" means "reasonable reliable" in Japanese. This concept tries to find out an appropriate design point which yields "high reliability per cost". Five small satellites have been developing in this project. The second satellite, RISESAT (Rapid International Scientific Experiment Satellite), has missions for space research proposed by several countries. Development of RISESAT is led by Tohoku University in collaboration with Hokkaido Univ., Kyoto Univ., and other organizations and companies[2][3]. In Table 1, specifications of RISESAT are shown.

Table 1 Specifications of RISESAT.

Size and Weight	Attitude Control
Size W 500 x D 500 x H 500 [mm]	Method 3-axis stabilization
Weight less than 55 kg	Poiniting Accuracy
Orbit	< 0.1 [deg] (requirement, 3σ)
	< 0.04 [deg] (objective, 3σ)
Type Sun Synchronous	Poiniting Stability < 6 [arcsec/s]
Altitude 500 - 900 [km]	Sensors Star Sensor, FOG, Magnetometer, GPS Receiver, Sun Sensors
Inclination approx. 98 [deg]	Actuators Reaction Wheels, Magnetic Torquers

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. Optical communication unit of RISESAT, Very Small Optical Transmitter for Component Validation (VSOTA), has been developed by National Institute of Information and Communications Technology (NICT) [4]. Using VSOTA, RISESAT aims to demonstrate satellite-to-ground laser communication by means of accurate attitude control of the satellite body, i.e. the direction of the laser beams fixed to the satellite structure, with an attitude control accuracy of down to 0.04 deg (3σ). The desired maximum bitrate for this mission is 1 [Mbps]. This is the first step toward the establishment of future optical communication infrastructures.

In addition to various scientific instruments, RISESAT carries a 5 [m] GSD multi-spectral high-precision Cassegrain telescope called HPT. It is planned that the HPT is utilized to determine the direction of the pilot signal sent from the ground station, which can be fed back to the attitude control system for achieving higher control accuracy.

In this paper, concept of optical communication experiment is described. Moreover, collaborated experiment plan for evaluating attitude controll accuracy by use of the combination Laser transmitter on the ground and HPT is also shown.

Optical Communication Experiment using VSOTA

VSOTA is a dual-band (980 [nm] / 1550 [nm]) laser signal transmitter without gimbal mechanism or internal fine pointing mechanism[4]. 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" shown in Fig. 1. Specification of VSOTA are summarized in Table 2. Fig. 2 illustrates mission instruments on RISESAT including VSOTA-COL, an optical collimator. VSOTA-E is the electric part which consists of the transmitter laser diode control unit. These two units are connected to each other via a pair of optical fibre. Four types of ground station will be used in this experiment: (1) 1.5 [m] telescope at Koganei, (2) 35 [cm] telescope at Kashima, (3) 1.0 [m] telescope at Koganei, Kashima, and Okinawa, and (4) portable telescope that aperture is about 20[cm] [5].

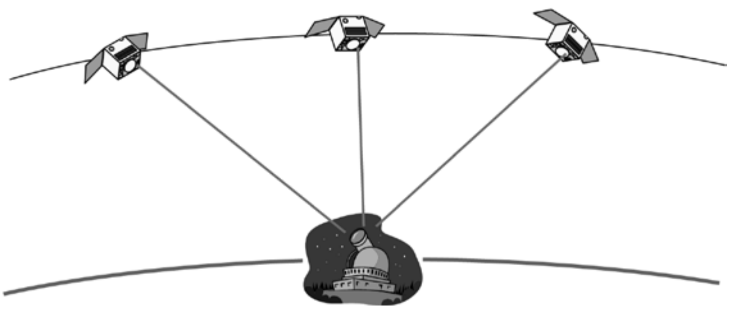

Fig. 1 Target Pointing Mode of RISESAT.

VSOTA is capable of transmit a NRZ waveform on/off keying signal with a maximum 1 [Mbps], however, due to the limitation in pointing direction accuracy, output power, and ground equipment, the maximum downlink rate of VSOTA is estimated to be up to a couple of 100 [kbps] or less. VSOTA can transmit PN pattern signal for BER evaluation, as well as the real scientific data obtained by scientific instruments. Dual-band (980 / 1550 [nm]) laser signal transmitter with a power 270 and 40 [mW] respectively at modulation allows us to monitor difference of atmospheric effect simultaneously.

Table 2 Specifications of VSOTA.

Mass	< 1 kg	Wavelength (TX)	980 nm 1550 nm
Power consumption	< 10W	Data Rate	1 - 100 kbps
Max. Link Range	2000 km		

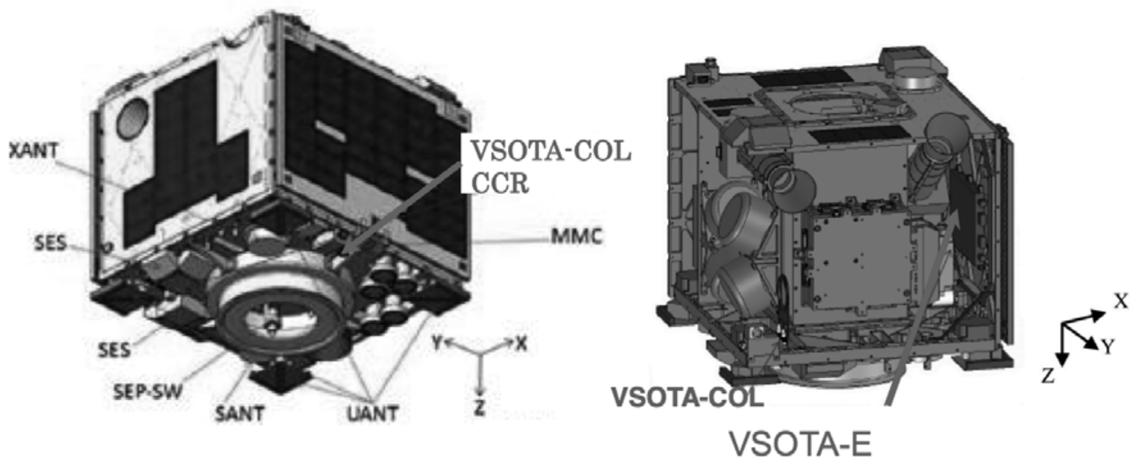

Fig. 2 Mechanical configuration of RISESAT.

Table 3 Specifications of CCR onboard RISESAT.

Parameters	Value
CCR clear aperture diameter	28 mm
CCR Reflectivity	0.8
Refractive index of CCR fused silica	1.45
Dihedral Angle offset	1.4 arcsec
Incident angle of CCR	neary 0 deg

RISESAT also carries a Corner Cube Retro reflector (CCR) developed by NICT of which optical axis is aligned to the same as of VSOTA and of HPT. The specifications of CCR are also shown in Table 3. 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, orbit of

RISESAT can be determined more precisely. The precise orbit leads to more accurate ephemeris which can be used for optical communications.

Collaborated Experiment Plan using HPT and ground station

HPT was designed as a science instrumentfor both Earth and astronomical observations. Diameter of main mirror is 100 [mm] and focal length is about 1000 [mm]. HPT is equipped with two Liquid Crystal Tunable Filters (LCTF) in continuous wavelengths of which step size is as small as 1 [nm]. Each LCTF is combined with a CCD matrix image sensor with pixel resolution of 5 [m] at an altitude of 700 [km].

In order to evaluate performance of body pointing, we have a plan to use the combination of HPT and the laser transmitter of NICT ground station. From the NICT's 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. 3, the concept of this experiment is shown.

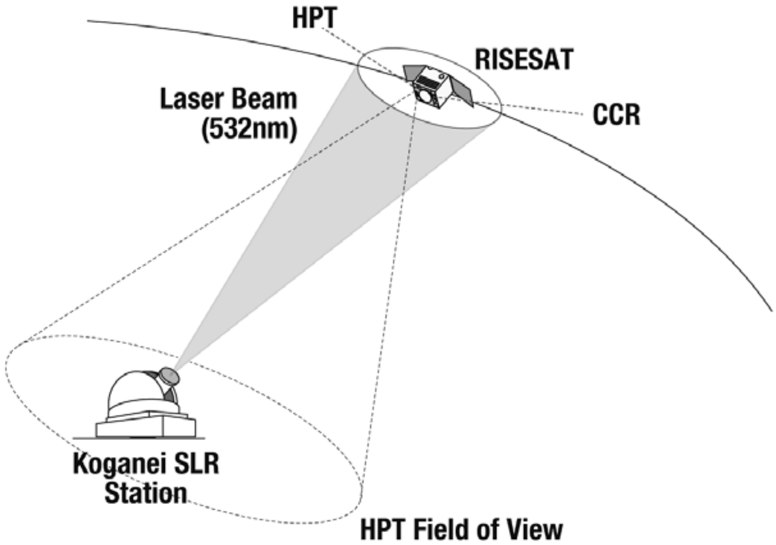

Fig. 3 Configuration of assessment of body pointing accuracy using a pilot laser during experiment.

In the Earth observation mode, RISESAT will conduct either nadir pointing or target pointing modes. In case of target pointing mode, HPT is able to take a selected spectral images of the target area FOV of 3.3 x 2.5 [km]. In this FOV, wavelength different from ones for the optical communication experiment, as a guide beam from optical ground station, optical image focal plane should be recorded above background noise moving around due to the attitude control variation in target pointing mode. Moreover, the position of pilot laser in FOV can be used by Attitude Control Unit (ACU) through recognizing brightest spot in CCD coordinates using FPGA logic and software in μ-RTU.

Number of photons received in HPT is estimated. The parameters assumed in the computation are listed in Table 4. The slant distance to the satellite in this calculation is fixed to 1000 [km]. RISESAT is assumed to be tracked in worst case at the edge of the beam spread in the (1/e^2). Other parameters are based on the current equipment of NICT ground station telescope, Results are shown in Fig. 4. HPT saturation level, photon count (the right side vertical axis) is 1x10^6. If we set divergence 50 [μrad] which is commonly used by SLR for LEO satellite, HPT received photons exceed by more than two orders of magnitude of the saturation even if 1 [μrad] energy used. We need divergence setting equal or larger than 0.3 [mrad] to achieve below the saturation level, decreasing the power of the laser further setting a parameter in a direction to increase the loss of two way CCR reflection link. Under the same conditions as in Fig. 4, pulse energy receiving photoelectron reflected by CCR on RISESAT is shown in Fig. 5. There is less chance of SLR unless squeezed beam divergence in operation dropped energy 1 [μJ] is a condition for which it is not saturated with HPT.

Table 4 Parameters used for estimation of the number of photons.

Parameters	Value
Wavelength of Pilot laser (SLR)	532 nm
Pulse width 1/e2	50 ps
Repetition Rate	20 Hz
Energy per pulse	20 mJ
Transmit optical efficiency	0.6
Atmospheric efficiency (One way)	0.5
Pointing LOSS factor (Efficiency)	0.135
Diameter of Receiving Telescope	1.5 m
Receiving optics efficiency including spectral filter	0.2
Quantum efficiency of SLR receiver	0.2

Summary

We have described the concept of collaborated experiment plan using pilot laser and HPT to evaluate satellite pointing during downlink communication experiment. Number of photons in the CCR reflection echo and photon number of HPT input evaluated. Number of photons received by each instruments is quite different since it is governed by law of two way link (1/R^4), and that of one way link (1/R^2). We may do experiment independently between one-way HPT and CCR using a different energy level of laser setting.

References

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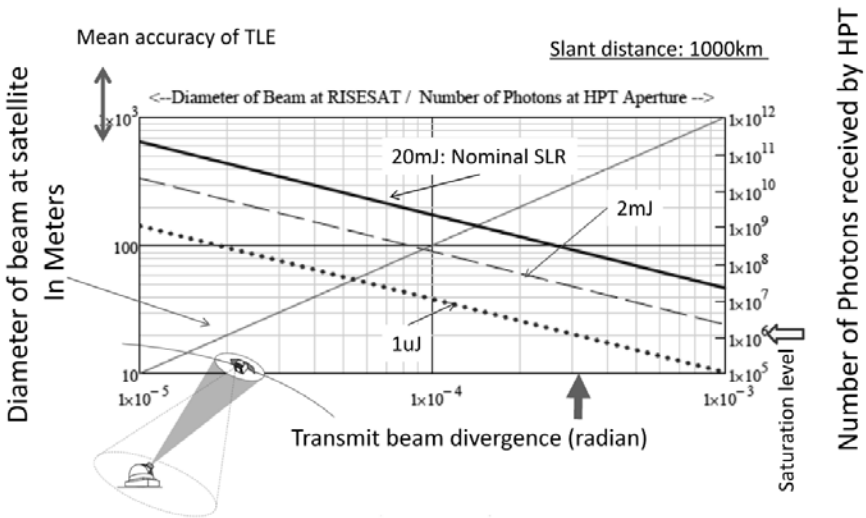

Fig.4 Number of photons received in HPT aperture.

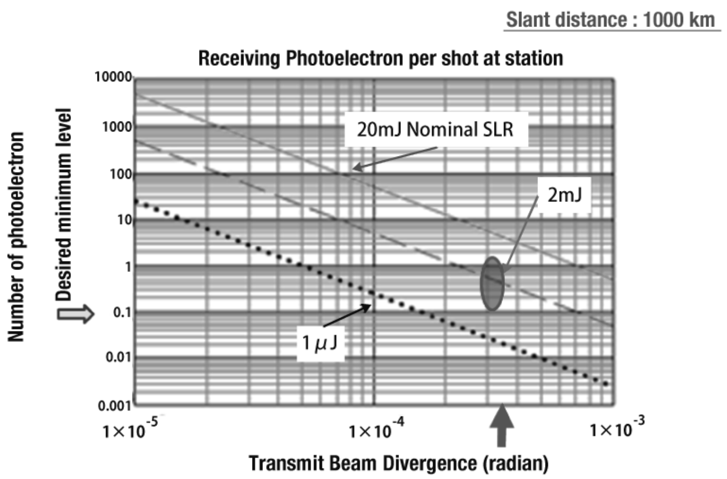

Fig. 5 Receiving photoelectron reflected by CCR on RISESAT