Invited Paper

Research and development activities on space laser communications in NICT

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ABSTRACT

The R&D activities and current status in NICT on space laser communications are reported, where it is shown the goal and scenario originating from the satellite-ground laser communication demonstrations with ETS-VI since 1994 for two decades. The experiences obtained in the demonstrations have been inherited to the experiments with OICETS in 2006. The experiments using the satellite are on going in 2008. Among these demonstrations, a laser terminal with combination of key technologies was experimentally produced. For the next space laser communication system, we have started the next version development technologies, on which trial manufactures are currently in progress. They have been (and will be) implemented and tested at the ground station.

Keywords: laser communications, satellite-ground, digital coherent receiver, transportable optical ground station

1. INTRODUCTION

Recently, research and development activities in the field of laser communications have attracted much attention. Inter-satellite, satellite-plane and satellite-ground communications have been successfully demonstrated, respectively [1-9]. Concerning the satellite-ground laser communications, NICT was one of the parties of the satellite-ground laser communication trials. In the trials, we measured atmospheric influence on propagating light and performed bi-directional communications with the data rate of 2Mbps for transmission and 50Mbps for reception.

When a communication system is designed, a suitable communication scheme is selected according to the requirement. The arbitrary choice causes a demand for additional means if mutual connection of communication systems employing different schemes is required. We consider the preparation for the situation is important even in the field of the space laser communications. Therefore, as one of the approaches for that, we plan to develop a receiver in which the acceptable communication scheme is programmable [10].

The fast steering mirror is one of the important functions for efficient coupling of the received light into a single mode fiber. We made the trial production and estimated the operation characteristics. This fast steering mirror will be placed in front of the input port of our receiver.

When high data rate links between space and ground are required, the laser communication is most promising candidate. But it is pointed out that the optical link is easily blocked by clouds and the probability of link establishment is insufficient for the practical use. However the combination of the site diversity scheme with the terrestrial networks will contribute to overcome the problems and improve the probability to form the laser communication channels. The site diversity scheme increases the probability of link establishment with plural ground stations distributed in wide area so that at least one of the stations has a clear sky even though other stations have thick clouds in the overhead area. Ideally, if a lot of ground stations are put over large area enough, the probability to obtain at least one station with fine weather becomes close to unity. Another approach is to use a few ground stations transportable instead of building many ground stations fixed. Therefore we decided to fabricate a transportable ground station and plan to move toward areas where satellites can be seen directly from the ground. We aim to show that a combination of the weather forecast and a transportable ground station can be much for the fixed several ground stations with respect to the site diversity.

In our current activities, an optical receiver, a fast steering mirror and an optical ground station are in course of manufacture. The optical receiver is a kind of coherent detector and consists of an optical part and an electrical part. The

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optical part receives the signal beam and mixes it with a local beam. The electrical part provides a function for signal processing in which the algorithm can be modified flexibly so that the receiver is adaptable to various communication schemes. The optical ground station is designed to be decomposed and transportable. The fast steering mirror has a role to stably couple the received light into a single mode fiber that is the input port of the receiver. We plan to use the transportable optical ground station as a node of terrestrial network connecting to space as well as regarding the ground station as our test bench for equipment being developed.

In this report, we show the current status of activities with a scenario. We describe the optical receiver and the fast steering mirror of test productions, and show our optical ground facility used for satellite-ground trials and a small ground station currently in course of manufacture.

2. SCENARIO OF ACTIVITIES

The inter-satellite communications of GEO-LEO and LEO-LEO links, and the satellite-ground links from GEO and LEO were already demonstrated, respectively. The combination of those links with GEO-GEO and deep space links will put forward a point-to-point system to a network system. Besides, one of the interesting applications is a free-space laser communications on the moon or planets as well as the terrestrial optical channels. The high data rate channels by laser communication technologies will support various applications such as the sharing and exchanging of electro-magnetic environment around areas of human activities.

Figure 1 shows a flow of our activities. Starting with the experiences of the ETS-VI experiments, the preparative studies for a next optical terminal have been followed with the NeLS terminal development and the OICETS demonstrations. The dotted line indicates the current period where the coherent detection and transportable optical ground station are included. The quantum cryptography is a new challenging research. With those activities we aim to contribute for enhancement of space qualified technologies with respect to the inter-satellite, the satellite-ground and the long-distance communications with large capacity and absolute security.

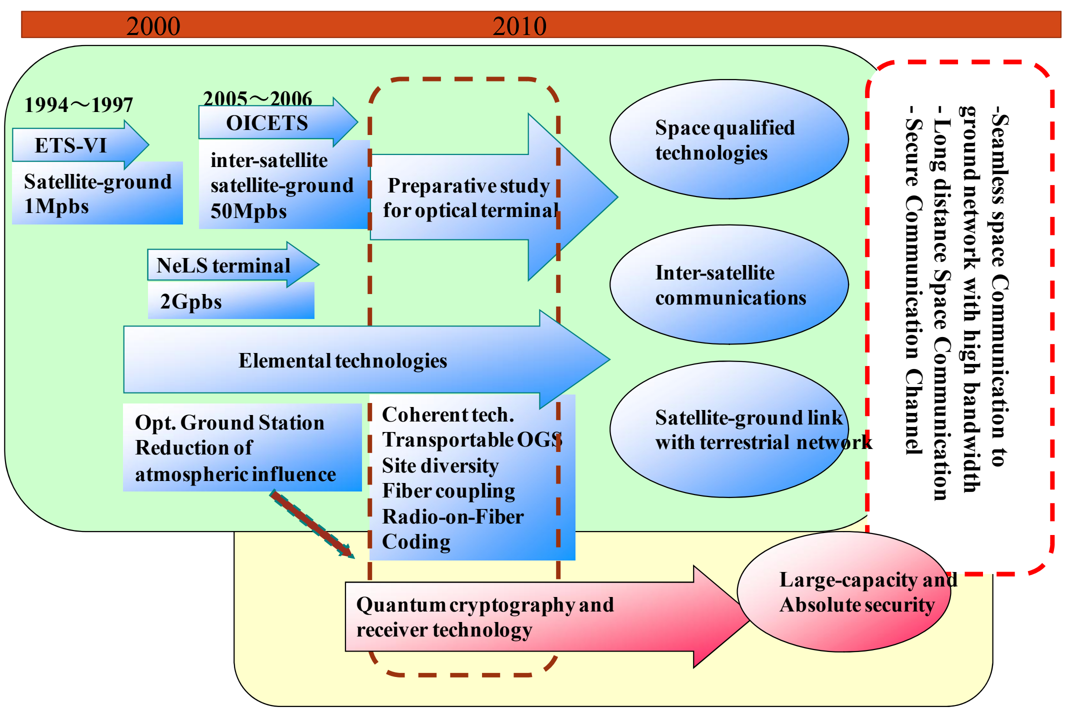
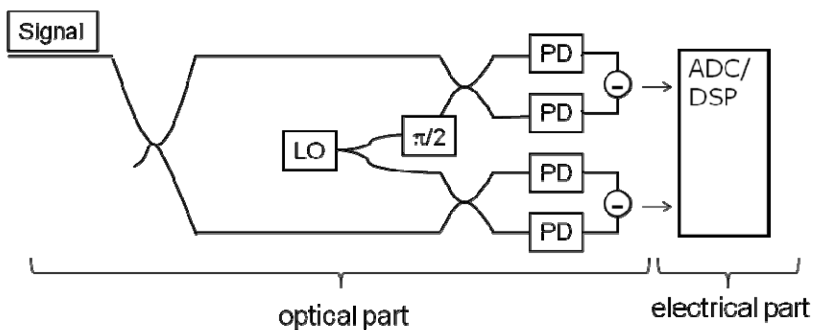


Fig. 1 Scenario of activities

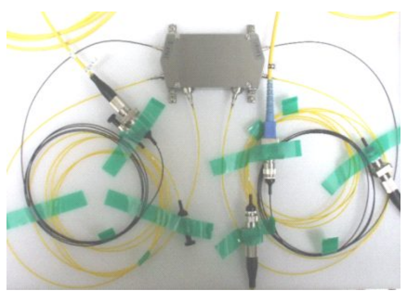
3. OPTICAL RECEIVER

Figure 2(a) indicates a schematic diagram of the optical receiver which consists of the optical part and electric part [10]. Photos of the optical part and the electric part are given in the figure 2(b) and 2(c), respectively. As shown in the figure

2(b), the optical part is a kind of 90-degrees optical hybrid circuits and is accompanied with 6 optical fibers. One corresponds to the input port of signal, one is a port to take in a light from a local oscillator and the rest 4 ports are the output ports connected to photo detectors (PD) as described in the figure 2(a). In the optical part, the received signal light is divided in two and mixed with a light of the local oscillator. A 90 degrees shift is given to the phase of light propagating in one side arm. One of the features of the receiver is that the local source is in free-running. Discrepancy between the signal frequency and the local frequency is compensated by signal processing algorithms. The electric part consists of 2 ADCs with 8 bits. The outputs from the ADCs are processed by a FPGA. Since the function of the electric part is programmable, the receiver can be adaptable to various communication schemes. The function was verified and published in Ref. [10], where the data rate is 2.5Gpbs in BPSK modulation and offset phase error compensation was observed. Even when a communication system employs a scheme of intensity modulation, this optical receiver is adaptable because of the flexibility in the signal processing. Thus this optical receiver contributes to mutual connection of communication systems with different modulation schemes.



(a) Function diagram



(b) Optical part

(c) Electric part

Figure 2 Optical receiver

4. FAST STEERING MIRROR

The trial production of the fast steering mirror is shown in Fig. 3. The mirror is controlled with two axes by piezoelectric actuators. The response frequency is larger than 2 kHz with the preload of 900N which is determined experimentally. The operation characteristics of the reflection angle were measured with giving the applied voltage on the actuator. The reflection angle is suffered from the hysteresis of the piezoelectric elements and it becomes significant when the stroke of the actuators increase. But in our measurement, the resolution of the reflection angle is estimated as less than 1 μrad if the range of the reflection angle is within 2.7 mrad.

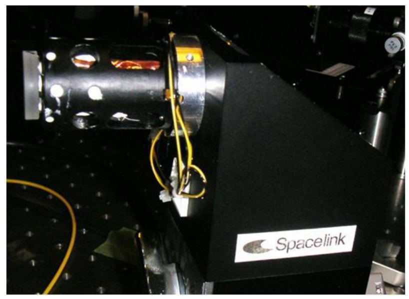


Figure 3 Fast steering mirror.

Table 1. Specification of the fast steering mirror

Items	values
Driver element	piezoelectric actuator
Driving voltage	0-150 V
Preload	900 N
Diameter of mirror	20 mm
Angular range	2.7 mrad
Response	>2 kHz
Weight	94g

5. TRANSPORTABLE OPTICAL GROUND STATION

As the ground facility, we have an optical ground station located in Tokyo Japan which was used in satellite-ground demonstrations. Figure 4 is the photographs of the ground station where the telescope's diameter is 1.5m. The right-hand image expands the telescope inside the dome. To introduce the site diversity scheme into the satellite-ground laser links, we have been developing a small telescope system as shown in the figure 5. The telescope is designed to be decomposed into several parts and transportable. The diameter of the aperture is 0.2m with a reflection type telescope and the height is less than 1.2m. The received light is relayed inside the telescope's pillar to the Coude bench as shown in the figure. This design enables us to use prototype bulk equipment at the foot of the telescope.

The pointing direction of the telescope is driven by three motorized control around the azimuth, the elevation, and tracking axes. We can select the operation to be the usual two-axis control or the three-axis control. The advantage of this three-axis system is found in the decrease of required angular velocity in the azimuth rotation when an object to track is moving in high elevation angle. The figure 6 is a photograph of the three-axis telescope, where three white circles indicate the rotary parts and Table 2 is a specifications.

Figure 4 NICT's optical ground station. The diameter of the telescope aperture is 1.5 m.

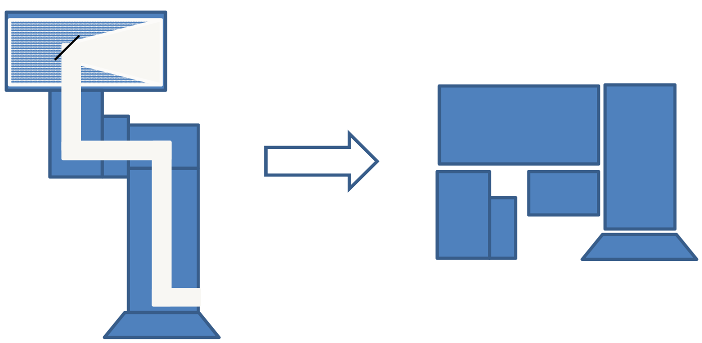


Figure 5 Transportable optical ground station in production.

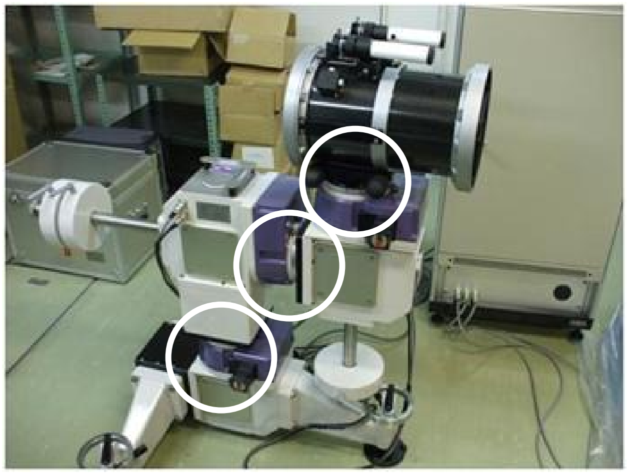


Figure 6. Photograph of the transportable telescope

Table 2. Specification of the telescope

Items	values
Aperture diameter	0.2m
Max. angular velocity	5deg/s
Min. operation angle	0.5asec
Field-of-view	0.5deg

6. CONCLUSIONS

In this report, we have shown the current status of activities, where the optical receiver for mutual connection of communication systems adopting different modulation schemes and a transportable ground station are introduced. The optical receiver's function was verified with 2.5Gbps data rate, the fast steering mirror's operation was confirmed, and the transportable optical ground station is in progress of manufacture.

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