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# The approach to realize a higher speed, more compact and longer-lasting operational optical space communications system

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*Abstract* — **The requirements of optical space communication technology mean smaller onboard communication terminals must be developed and operated to satisfy future data transmission needs in the 2020s and beyond. JAXA has developed the "KIRARI OICETS" (Optical Inter-orbit Communication Engineering Test Satellite) and established acquisition, pointing and tracking techniques on orbit. The optical communication terminal "LUCE" on "KIRARI" is large (150 kg) and has a low data rate (50 Mbps) compared to the practical requirement imposed, hence our wish to achieve a more high speed, compact and long-lasting optical communication terminal. We describe our recent activity to achieve a new-generation optical communication terminal by applying excellent ground optical communication technologies and new devices.**

*Keywords — Optical Space Communication, faster, more compact and longer-lasting*

## I. INTRODUCTION

Since optical space communication technologies for satellites will achieve more compact onboard communication terminals than RF technologies, optical space communication technologies must be developed and operated to meet future data transmission needs accordingly, in the 2020s and beyond. JAXA developed and tested the "KIRARI"[1] in orbit from 2005 to 2009 and established a counter-satellite acquisition technique with micro-radian precision as well as pointing and tracking techniques. Since the "LUCE" optical communication terminal on "KIRARI" uses a GaAs (Gallium Arsenide)-based laser diode (LD) and intensity modulation and direct detection (IM/DD) technology, it is too large (150 kg) and its data rate (50 Mbps) too low to meet future demands; hence the need for a higher speed, more compact and longer-lasting optical communication terminal as our research target. A communication data rate exceeding 2 Gbps will be required for Earth observation satellites (EOSs) in the near future via inter-satellite links, which may increase beyond 10 Gbps in around 2030. A communication data rate of 10 Gbps will also be required for satellite-to-ground direct links. NASA and ESA have been developing Gbps-order optical inter-satellite communication systems via different approaches. NASA has been developing a 1550 nm-wavelength optical communication terminal with a DD-DPSK (Direct detection, Differential phase shift keying) modulation method [2], while the ESA has developed a 1064 nm-wavelength optical communication terminal with a Homodyne BPSK (Binary Phase Shift Keying) modulation method[3]. Based on our analysis, however, wavelength is not the key parameter for optical space communication technologies during the research phase, except for high-power amplifiers on transmitters. Accordingly, we describe our research activity for new-generation optical space communication technologies applying excellent ground optical communication technologies and new devices applicable for both 1064 and 1550 nm.

## II. RESEARCH COMPONENTS

### A. *Our research target*

The term "optical space communication" includes diverse forms of communication; inter-satellite (space-to-space) links, satellite-to-ground and satellite-to-airplane. The primary aim of optical space communication is to relay data for EOS in LEO (Low-Earth Orbit), particularly for high-resolution observation missions, and other users. Present high-resolution EOS sensors and those in the near future create image data of around 1 or multiple Gbps in size after data compression.

Conversely, data transmission from a data relay and tracking satellite (DRTS) in Geostationary Earth Orbit (GEO) to Earth stations is also a relevant topic. Since a high link operation rate is required, even in a cloudy country like Japan, we chose a Ka-band communication system in a GEO satellite-to-ground link, rather than an optical communication system. Accordingly, optical space communication technology operating at several Gbps and for space-to-space links will be researched as the 1st step and then connected to the Ka-band link on GEO. The optical data relay scenario from a LEO satellite to a ground station via a GEO satellite is discussed in section III.

### *B. Discussion and selection of research components*

We initially introduce selected research components and Fig. 1 shows a rough block diagram of our future optical communication terminal. Since we have experience of “KIRARI”, passive optics (optical antenna (telescope) and internal optics) and 2-axis gimbal do not require component-level research. A high-power and radiation-proof new transmitter component and a rapid and highly sensitive receiver component must be realized for Gbps-order optical space communication, as the Gbps-order communication rate is 20 times or more higher than that of “KIRARI”. Such components will also allow a more compact optical communication terminal than “KIRARI” to be achieved.

Within advanced ground optical fiber communication systems, “digital coherent technology” has been used to achieve Terabit-per-second (Tbps)/fiber order communication. We can apply technologies and many devices to achieve a rapid and highly sensitive onboard receiver as well as applying the classic optical Phase Locked Loop (PLL) technique to achieve a Gbps-order and high sensitivity onboard receiver. Section IV describes our research performed to establish onboard receiver technology.

As ground fiber communications technology uses a 1550-nm band, this wavelength is a candidate for our future system. For this reason and from an eye-safety perspective, NASA has been developing an optical communication terminal [2]. Moreover, since the 1064-nm band laser and amplifier have high (electrical-to-optical) efficiency and have been achieved as an optical space communication system by ESA[3], this wavelength is also a candidate. Since both digital coherent technology and optical PLL will use the InGaAs optical to electrical (O/E) converter as a balanced-receiver with sensitivity within the range 1000 to 1600 nm, we need not decide the wavelength to apply to our future system now.

As for the high-power transmitter, a high-power amplifier (HPA) with polarization maintained and output power exceeding 5 W is required based on our initial analysis. Polarization must also be maintained, since it must be used to separate transmission and received beams in internal optics with high isolation.

## III. Outline of the Optical Data Relay System

An outline of our optical data relay system is described before discussing the optical communication terminal. Fig. 2 shows an under-studying, outline schematic of the data stream of our optical data relay system.

Preconditions for this study are:

1) Ka-band GEO satellite-to-ground link applied, not an optical GEO satellite-to-ground link

2) To apply space-qualified electronics devices only.

In this section, we describe the nature of the digital data processing in a LEO satellite, GEO satellite, and ground station respectively.

The LEO satellite signal processing is performed on a mission data handling subsystem (MDHS), with a data rate of 2 Gbps or less, and including a Forward Error Correction (FEC) code, synchronization code (sync), and so on. MDHS emits a stream form of 2.5 Gbps or less to a Serializer/Deserializer (SerDes)[4] device (transmitter), while an optical modulator on the LEO satellite receives and modulates the bit stream from the SerDes as an optical modulated signal. The optical HPA then amplifies the optical modulated signal, which is transmitted from an optical antenna (see Fig. 3).

The GEO satellite receives the optical signal and delivers it to the 90-degree optical hybrid in front of the receiver (see Fig. 4). A balanced-receiver then converts the optical signal to an electric signal, whereupon it is ADC-digitalized, processing via a demodulation electronics extract 2.5 Gbps bit stream. This bit stream, in turn, is placed into a Ka-band modulator using a SerDes device. This device extracts data at 2 Gbps from the 2.5-Gbps bit stream, then modulates data at 2 Gbps as a Ka-band signal, which is then amplified in a Ka-band HPA, and transmitted to a ground station. There is no digital data processing on GEO in this scenario.

We are investigating a high-order Ka-band modulator up to 2 Gbps to apply the Ka-band downlink as well as the LEO satellite-to-ground link[5].

The ground station receives the 2-Gbps Ka-band signal and demodulates and corrects errors using frame, sync and FEC added at LEO MHDS. This data processing is the same as the present data processing for the Ka-band data relay and the X-band direct transmission subsystem except for the data rate.

## IV. Optical Receiver Technology

In this section, the optical receiver technology we are currently researching is presented.

### *A. Doppler shift compensation*

The unique requirement applicable to LEO-to-GEO space-to-space links rather than other means of optical space communication is Doppler shift compensation. In the data relay between GEO and LEO satellites, the Doppler shift is calculated as follows:

1) +/-5 GHz and 6 MHz/s at a 1550-nm band, and

2) +/-7 GHz and 10 MHz/s at a 1064-nm band.

Both the digital coherent receiver and optical PLL have the same requirement. Our investigation involved using an external cavity-type distributed-feedback LD and controlling the same by drive voltage and its temperature.

The requirements for a local oscillator are as follows (for a 1550-nm band), that not only achieves 2.5-Gbps BPSK but also Mbps-class slow-rate communication for forward links of inter-satellite communication systems.

- line width; less than 10 kHz
- frequency stability; less than 2.5 GHz
- frequency tuning ability; tunable range exceeding +/-5 GHz, frequency tuning speed exceeding 6 MHz/s
- Output power; exceeding 5 mW

- Space-qualified as an electric part

Figs. 3 and 4 show block diagrams of the transmitter and receiver respectively, while the requirements of a seed laser in the transmitter are included in those of a local oscillator in terms of receiver, line width and frequency stability, as shown above. Accordingly, the local oscillator under investigation will also be applied as a transmitter seed laser.

### *B. Digital coherent receiver*

BPSK modulation/demodulation includes planning to apply a future optical space communication system. ESA/DLR developed an LCT (Laser Communication Terminal) on the Alphast and is developing on the EDRS (European Data Relay System) and Sentinel EOSs, which uses a Homodyne BPSK for the LEO-to-GEO data relay[3]. NASA is developing LCRD (Laser Communications Relay Demonstration) applying a DD-DPSK method[2], and the DD-DPSK signal can be demodulated by a BPSK demodulator with electrical differential processing, which means the BPSK rapid demodulator has the potential to achieve interoperable optical space communication hardware, LCT as well as LCDR.

As a candidate BPSK demodulator, we are investigating the “digital coherent receiver” (Fig. 4); key devices for which are a rapid Analog-Digital converter (ADC) and a large high-speed FPGA, to achieve a 5 gigasample-per-second (Gsps) or more analog to digital converter (ADC) for 2.5 Gbps BPSK demodulation based on the Nyquist theorem. Accordingly, we must upgrade commercially available ADC of 5 Gsps or higher, as the space-qualified ADCs available do not meet this requirement [6][7]. Sufficient rapid and large FPGA are there[8] and there is a need to verify its new package. Meanwhile, optical PLL technology has been tested in the laboratory using a 1064-nm-wavelength[9]. There are few issues with the optical PLL of 1550 nm except the controllable local oscillator investigated and mentioned in section IV-A.

## V. CONCLUSION

Following the trial manufacture of the local oscillator, we are planning to achieve 2.5 Gbps BPSK demodulators as TRL (Technical Readiness Level)-4 level components by March 2015.

## VI. ACKNOWLEDGEMENT

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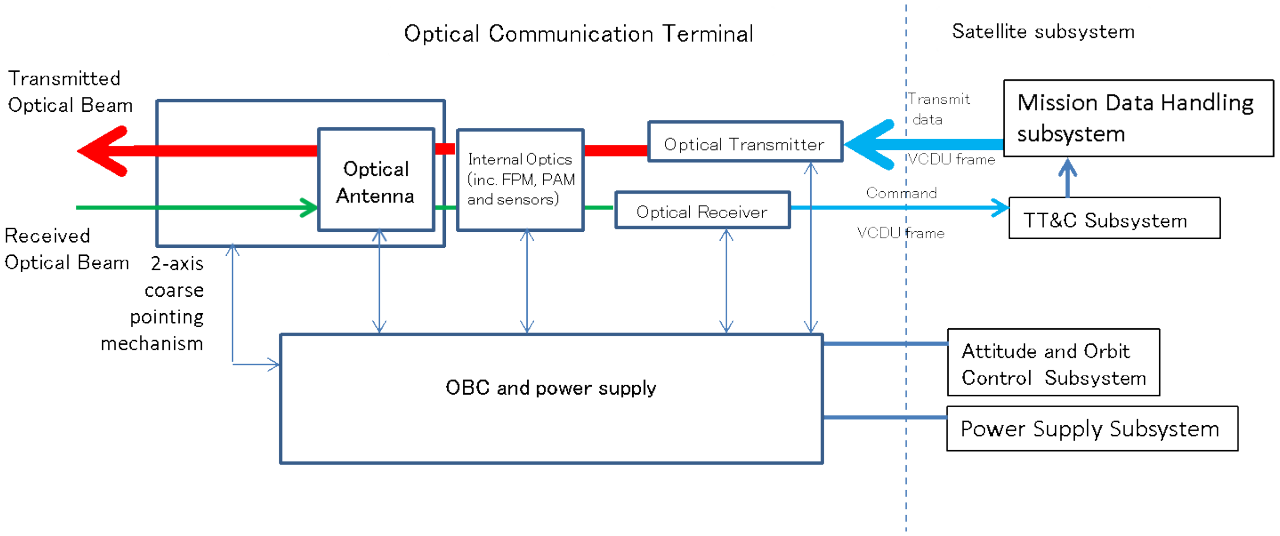

Fig. 1 Block diagram of the optical communication terminal

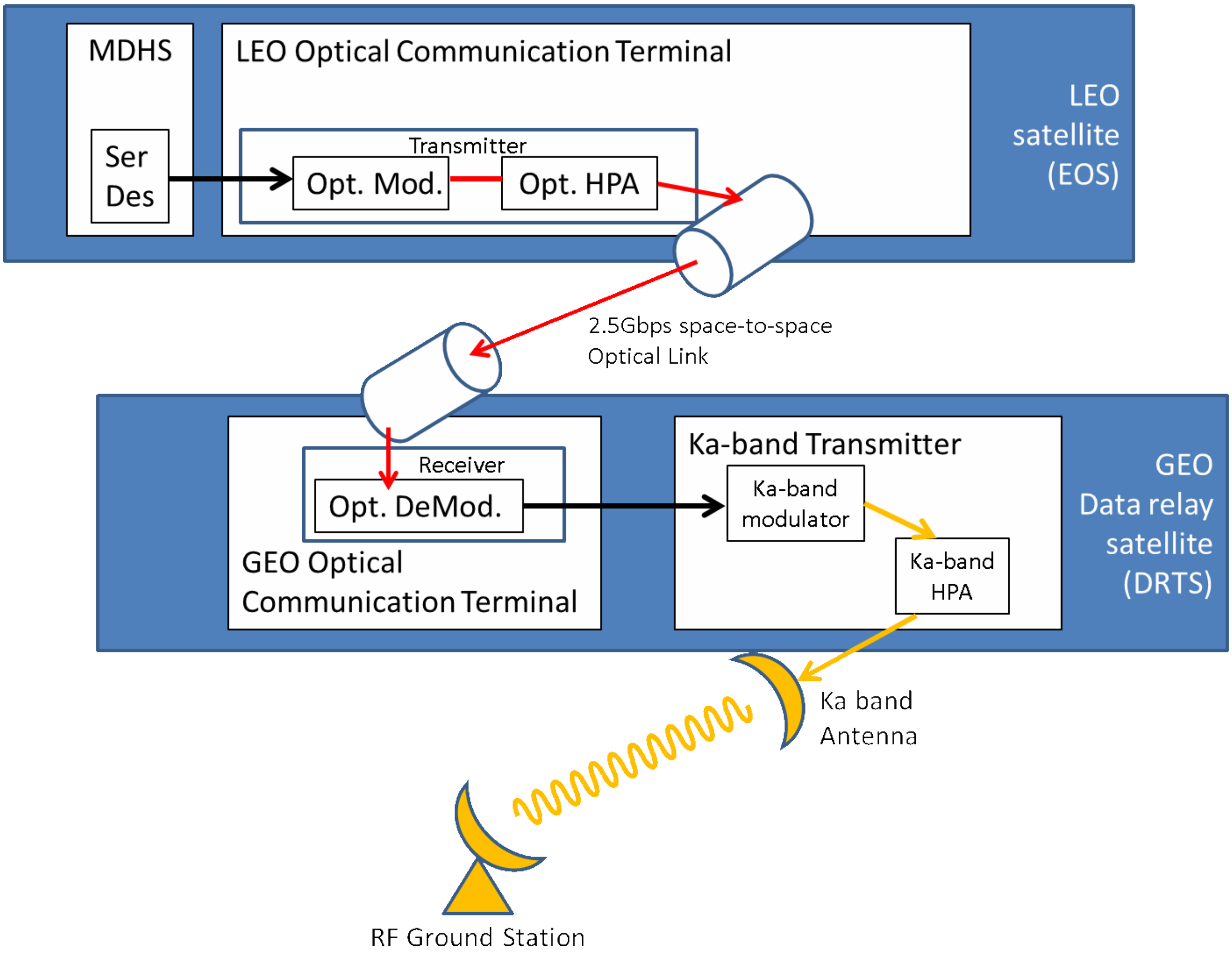

Fig. 2 Data flow from LEO to the ground station

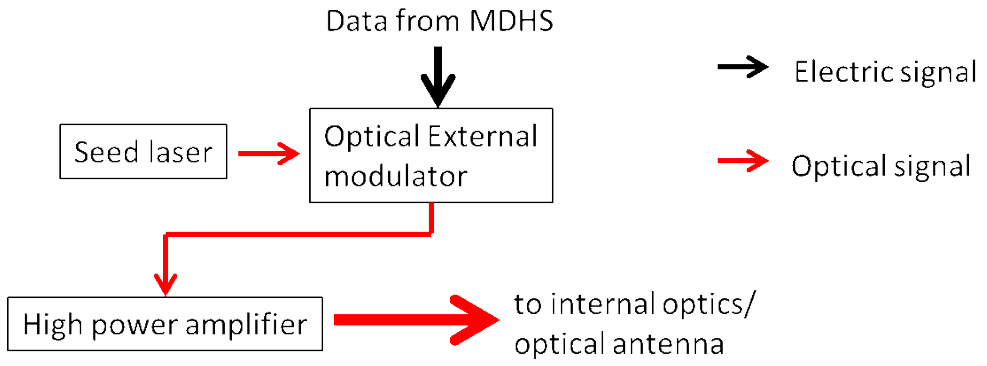

Fig.3 Block diagram of transmitter

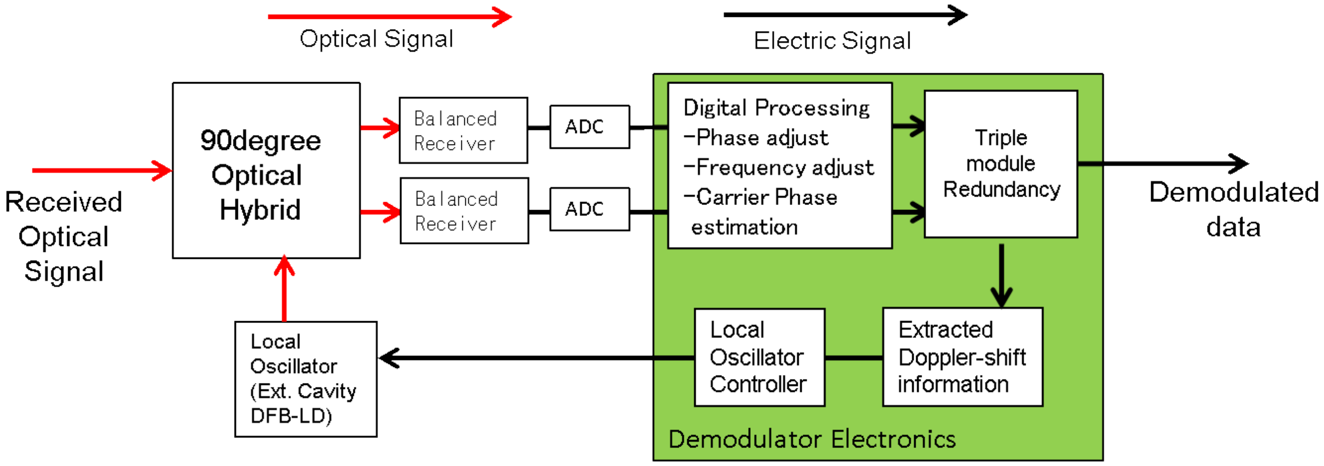

Fig. 4 Block diagram of the Receiver (digital coherent type)