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# *Dual wavelength optical coherent receiver front end for inter-satellite communication*

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***Abstract***— **This paper presents the new concept of 1.06um/1.55um dual wavelength optical coherent receiver frontend which can obtain optical phase error signals in PSK communication data as well as spatial tracking error without any extra tracking sensor, leading to downsizing of optical inter-satellite communication terminals. This new receiver frontend consists an optical 90 deg hybrid mixer with free space optical components, segmental photo detectors and RF electronics, to realize not only balanced detection of both in-phase and quadrature components but also heterodyne detection of tip/ tilt error signals.**

***Keywords—Optical Inter Satellite Communication; Coherent Receiver; Optical 90 Degree Hybrid; Acquisition Pointing Tracking; Quadrant Detector***

## I. Introduction

Since satellites in low earth orbit (LEO) on which equipped such high resolution sensors has short connecting times to ground station, the huge amount of mission data needed to be transferred via a satellite in geostationary orbit (GEO) to a designated ground station with the data-rate of a few Gbps or more [1]. For such inter-satellite link, an optical coherent communication has an excellent potential because of its better sensitivity, its less vulnerability to stray or background light and attainable recovery both intensity and phase information [2-4]. About spatial acquisition and tracking in the free space optical communication terminals, it was needed to share received optical power including communication data with spatial tracking sensors leading to systematic losses. It is also imperative to establish interoperability between the different inter-satellite optical communications systems. This paper presents the new concept of 1064 nm/1550 nm dual wavelength optical coherent receiver frontend which can obtain optical phase error signals in PSK communication data as well as spatial tracking error without any extra tracking sensor, leading to downsizing of optical inter-satellite communication terminals. This new receiver frontend consists an optical 90 deg hybrid mixer with free space optical components, segmental photo detectors and RF electronics, to realize not only balanced detection of both in-phase and quadrature components but also heterodyne detection of tip/ tilt error signals.

## II. Configuration

### *A. Conventional system configurarion*

Figure 1 shows the block diagram of our conventional receiver front end with an optical antenna unit. A communication laser beam with circular polarization is received with a telescope, then converted to linear polarization by quarter wave plate (QWP) transferred to receiving path via a polarization beam splitter (PBS). Tracking errors of the receiving beam is detected with a fine tracking sensor and then minimized by fine pointing mechanism (FPM) to be fed back . After minimizing tracking errors the communication beam transferred to an optical homodyne receiver with an optical phase locked loop (OPLL). The optical homodyne receiver consists of a local oscillator laser (LO-laser), an optical 90 degree hybrid, two balanced receivers, a Costas loop circuit. Optical 90 degree hybrid combined received light and LO-laser in-phase signals at I1, I2 port and quadrature components at Q1, Q2 port. Two balanced photo diodes product in-phase data by subtracting I1 to I2, as well as quatrature data by Q1-Q2. A costas loop circuit detects carrier phase difference as a base band error signal from BPSK-modulated in-phase and quadrature signals, and to feedback to LO-laser. Note that it needs not only very accurate alignment between fine tracking sensor and balanced photo diodes but also constant optical power to fine tracking sensor leading to power penalty for communication power budget.

### *B. New optical coherent receiver front end*

Figure 2 shows our new concept of optical coherent receiver frontend. A fine tracking sensor is built in optical coherent receiver after an optical 90 degree hybrid. This configuration leads no systematic loss due to optical power splitter in communication path. In order to detect the tracking errors we newly developed two types of segmented photo diodes and settled on the back focal plane with different azimuth angles. To accept dual wavelength optical input, both

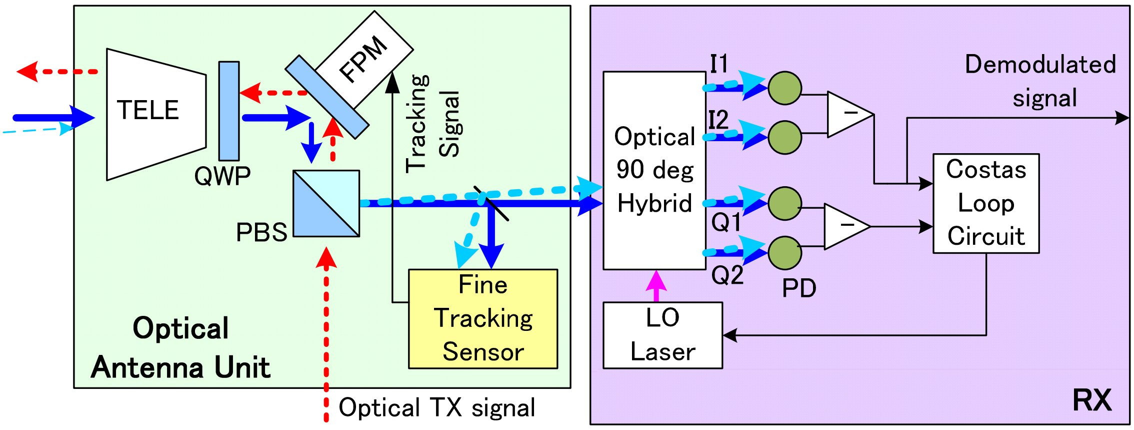


Fig.1 The block diagram of our conventional receiver front end with an optical antenna unit

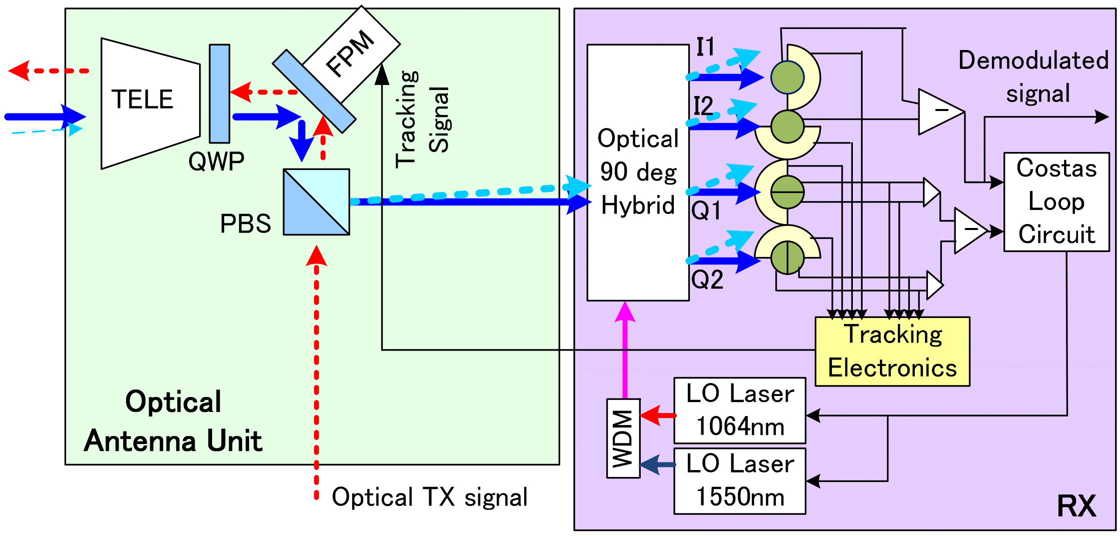


Fig.2 The block diagram of our new concept of optical coherent receiver frontend.

1550 nm and 1064 nm LO lasers are combined with a wavelength division multiplexing (WDM) coupler applied to optical 90 degree hybrid.

Optical 90 degree hybrid

An optical 90 degree hybrid is a device to obtain optical interference signals between received light and a LO-laser. Recently in the terrestrial optical network optical 90 degree hybrid also used to a receiver front end of digital coherent receiver [2]. In the terrestrial fiber network, some optical wave guiding technologies such a planar light wave circuit has been adopted to reduce the volume in the integrated package [5]. This type of optical 90 degree hybrid is good for optical fiber network because of minimizing amount of optical coupling, however, it needs more precise alignment than free space optical coupling. In order to detect tracking error we adopted the free-space components which contains a quarter wave plate (QWP), a 3 dB beam splitter, and two polarization beam splitters (PBS). Note that the tracking error is conserved in the optical 90 degree hybrid because of optical reflection and refraction in the propagation path. Figure 3 shows the outer view of the optical 90 degree hybrid for wavelength of 1064 nm which all optical components were adhered on the low expansion glass substrate.

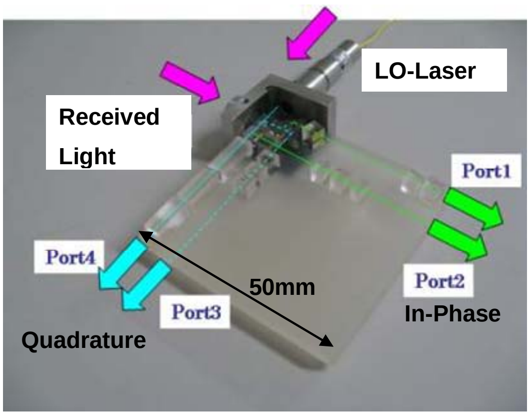


Fig.3 Outer view of the optical 90 degree hybrid

In order to share a same optical 90 degree hybrid for both wavelength of 1550 nm and 1064 nm, designing wavelength was chose at 1300 nm. The power penalties were estimated as 0.9 dB, 3.5 dB for wavelength of 1550 nm, 1064 nm respectively.

Photo Detectors

In order to detect tracking errors we newly developed two types of segmented photo diodes. The type-one detector has three segments in the active area where the two adjacent areas for communication and fine tracking located in the center, one outer area for detecting in re-acquisition case. Two type-one detectors settled on the back focal plane for port Q1, Q2 of the optical 90 degree hybrid with azimuth angle of 90 degree. The orthogonal tracking errors can be independently detected by subtracting of each photo current of two adjacent photo diodes in the center of the port Q1 (y-direction) or Q2 (x-direction). Note that a quadrature component for the communication is obtained by subtracting Q1 to Q2 signals which gotten by averaging of each photo current of the adjacent photo diodes with rf power combiner. Figure 4 shows two type-one detectors set on a printed circuit board. While the type-two detector has two segments in the active area where a single area for communication and an outer area for detection under re-acquisition. Two type-two detectors mounted on the back focal plane for port I1, I2 of the optical 90 degree hybrid with azimuth angle of 90 degree. In phase signal is obtained by subtraction I1 to I2 in the electrical domain.

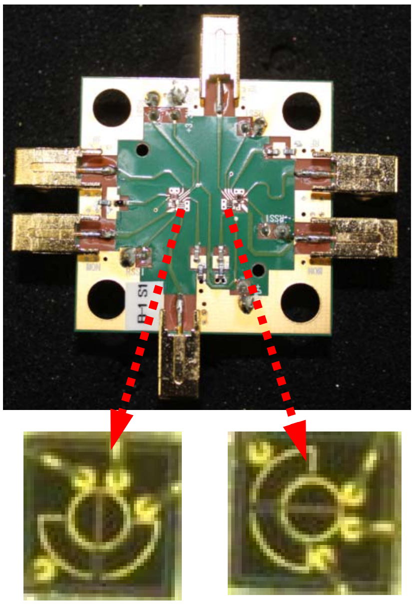

Fig. 4 Two type-one detectors on a printed circuit board

## III. Experimental Results

The rf transfer function of the newly developed photo detector was performed as follows. The single mode 1550 nm linear optical source (EM core 3741A) with a single tone modulation used and connected to a fiber collimator. A collimated beam focused on the segmented photo detector by a focusing lens. Receiving signals are transferred to a vector network analyzer and evaluated S21 characteristics. Figure 5 shows the rf frequency transfer function of inner segmented area in the type-one detector. It was found that nearly flat frequency response with a 3dB cut off frequency of 4 GHz which met our nominal target data rate of 2.5Gbps.

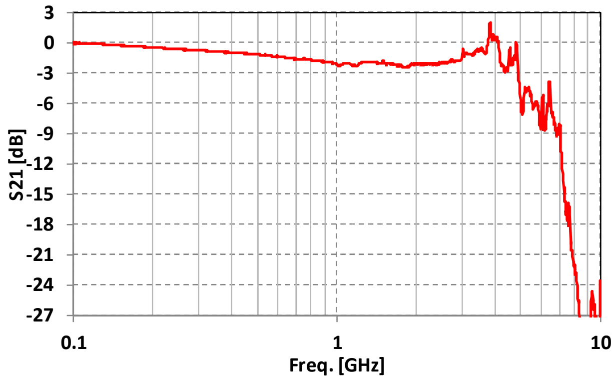


Fig. 5 Rf frequency transfer function of inner segmented area in the type-one detector.

Then the pointing angle of the collimated beam from the linear optical source has been changed by a micro-rotating stage to evaluate characteristics for detection of tracking error with one direction. Two kinds of rf signals from adjacent photodiodes were simultaneously obtained by digital oscilloscope and then subtracted each amplitude of rf signals. Figure 6 shows theoretical curve and measured plots of tracking error signals with respect to the pointing angle. Measured data agreed well with the theoretical curve over a span of the pointing angle between +/- 200 urad.

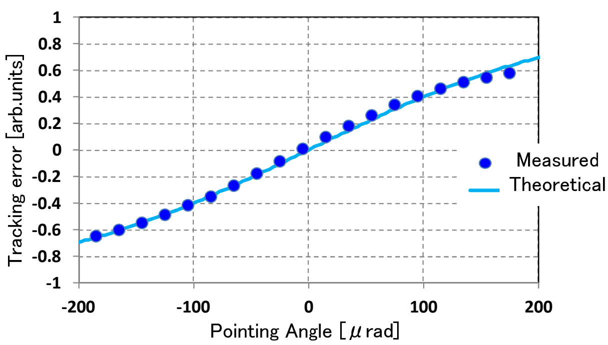


Fig. 6 Tracking error signals with respect to the pointing angle.

# IV. Conclusion

We have proposed the new concept of 1550 nm/1064 nm dual wavelength optical coherent receiver frontend which can obtain optical phase error signals in PSK communication data as well as spatial tracking error without any extra tracking sensor, leading to downsizing of optical inter-satellite communication terminals. We designed the optical 90 degree hybrid for dual wavelength operation whose designing wavelength of 1300 nm. Newly developed segmented-photo diodes have been performed not only enough frequency response up to 4 GHz but also accurate detection of tracking errors over +/- 200 urad.

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