3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Optical Beam Stabilizer for Free-Space Optical Communication Systems

Abdelmoula Bekkali, Hideo Fujita, Michikazu Hattori and Yuichiro Hara
TOYO Electric Corporation, R&D Center, Japan
E-mail: bekkali_a@toyo-elec.co.jp

Abstract

In this paper, we introduce the concept of a novel optical beam stabilizer (OBS) control for laser beam pointing and tracking. The long-term outdoor evaluation of our newly developed FSO transceiver implementing this OBS control is also presented.

1 Introduction

The ever increasing demand for higher data rate transmission has led to innovative and more advanced technologies for communication systems with the ultimate goal to fulfill the requirements of the B5G/6G networks in terms of high capacity and mobility, connection density, energy efficiency, and low latency [1]. Nonetheless, the congestion of the existing radio frequency (RF) spectrum and its limited bandwidth are expected to be the major limiting factors due to the massive growth of the future wireless systems. To circumvent these issues, Free-space optical communication (FSO) systems have been recognized as a promising wireless interconnecting solution for cost-effective and high-capacity communication networks. They combine the advantages of high transmission capacity enabled by optical device technologies and the ease of deployment and mobility of wireless links. Moreover, the FSO link is interference and license-free, which makes the system very attractive for the emerging heterogeneous wireless networks [2]. Despite its potential advantages, the FSO link has several inherent challenges that should be addressed carefully to achieve stable and reliable communication. These challenges include absorption and scattering loss and atmospheric turbulence. Furthermore, the FSO link is restricted to strict line-of-sight alignment, which requires advanced optical alignment and beam tracking techniques.

This paper presents the concept of our proposed optical beam stabilizer (OBS) for beam alignment and tracking inside the FSO transceiver. Unlike the existing FSO system based on 2-axis fast-steering mirror (FSM) technology [3], we propose to utilize "movable lenses" and low-cost 3-axis voice-coil motors (VCMs) actuators that are currently implemented in smartphones to ensure auto-focus (AF) and optical image stabilization (OIS) functionalities. The miniaturized VCM actuators have been customized and optimized for our newly designed transceiver to expand its field-of-view (FOV) and reduce the impact of the random beam angle-of-arrival (AOA) fluctuations induced by the atmospheric turbulence and pointing errors, as well as maintain an efficient direct coupling.

2 Optical Beam Stabilizer Concept

The majority of the FSO systems incorporate the FSM technology which consists in moving the mirror for beam steering and alignment [3]. As an alternative to the FSM technology, we propose a novel approach, i.e., OBS technology, based on moving the lenses located on the optical path [4]. The OBS concept is similar to the AF and OIS features widely used in the modern smartphones to compensate for the image quality degradation and blurring induced by the natural hand jitter and camera motion. To enable OBS, the 3-axis VCM actuator is used due to its low cost, low power consumption, quick response, and small size.

The VCM actuator is a direct-drive motor that can achieve high precision position servo control. It mainly operates according to the principle of electromagnetic induction such that when the electricity passes through a coil, it produces a magnetic field that reacts with a permanent magnet to either repel or attract the coil. In general, the VCM actuator consists of two main modules. The first module is fixed and includes two magnets, known as yoke and base, while the second module is moving and has the lens with holder attached using coils. Thus, based on the Lorentz-Force principle, the lens can be moved by a directly proportional distance to the current applied to the coil.

Figure 1 illustrates a typical transfer curve, the image, and the size of our used VCM actuator. The VCM can move linearly to reach the maximum stroke by varying the driving current. Hence, by maintaining the VCM displacement at the linear region, we can easily control the movement of the lenses to the desired position. The VCM actuator is also well known for its hysteresis tolerance and higher upward and downward displacement resolution.

In the following, we describe in detail the operation of the 3-axis VCM lens for increasing the fiber coupling efficiency and compensating for the beam deviation. As shown in Figure 2, the beam size can be controlled by simply moving

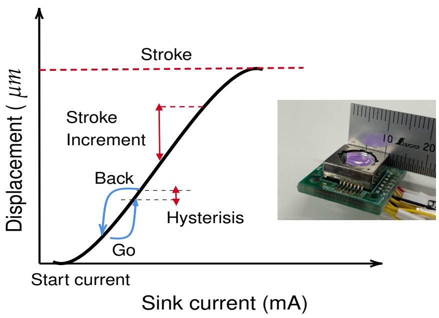


Figure 1. VCM actuator transfer curve.

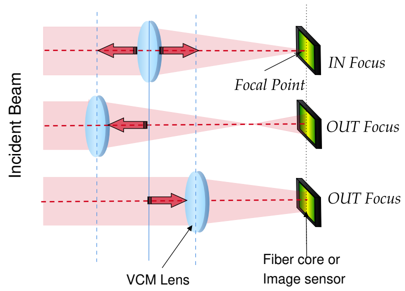


Figure 2. Concept of beam size control and fiber coupling.

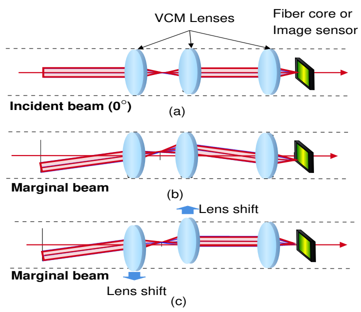


Figure 3. Concept of OBS operation.

the lens along the z-axis (back/forward) direction. Therefore, higher coupling efficiency can be obtained by placing the lens at an optimal position. On the other hand, Figure 3 illustrates the OBS operation. By controlling the VCM actuator along the x-axis (left/right) and the y-axis (up/down) and shifting the VCM lenses to the appropriate location, the received laser beam deflection angle can be efficiently compensated.

3 Performance Evaluation in 200 m Outdoor Environment

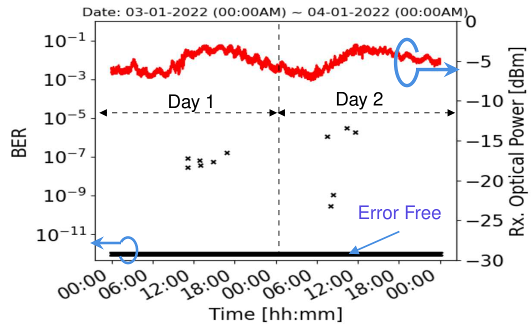
In order to quantify the performance of our OBS control for compensating the turbulence effects, we performed on 48 hours real-time transmission of 10Gbps signal over a reflected 200-m link in a clear day. In our experiment, the Tx. power was +10dBm, and the average reflected-back optical power was about -5dBm. Figure 4(a), depicts the received BER results and its corresponding Rx. optical power. From the figure, only occasional burst errors were recorded around noon and attributed to the changes in the ambient temperature. As can be seen in Fig. 4(b), the OBS control deviation was less than 10% and became higher around noon where the laser beam AoA fluctuation is larger. Since the bandwidth of our commercially used VCM actuator is up to 100 Hz, and the OBS control can not suppress all the rapid beam AoA fluctuations due to the insufficient tracking dynamic range. Indeed, using a larger bandwidth VCM actuator can significantly increase the performance of the OBS and thus the overall FSO system reliability.

4 Conclusion

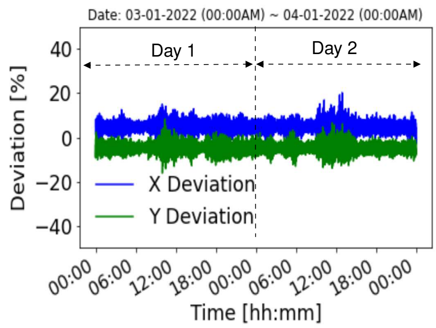
We presented our novel OBS concept for beam pointing and tracking and the long-term outdoor transmission evaluation of an OBS based all-optical FSO transceiver.

5 Acknowledgements

This work is supported in part by "Ultra-high capacity Integrated Terahertz and Optical Wireless communication system for Beyond 5G Networks (CN. 0050105)" the commissioned research of NICT, Japan.



(a)



(b)

Figure 4. (a) Variation of the BER and the corresponding Rx. optical power with time, (b) Control deviation.

References

[1] K. Nishimura *et al.*, "Optical access technology for B5G MFH/MBH," *Optical Fiber Communication Conference (OFC)*, W3J.1, 2019.

[2] C. Ben Naila *et al.*, "Transmission analysis of digital TV signals over a radio-on-FSO channel, " *IEEE Comm. Mag.*, **50**, 8, August 2012, pp. 137–144 .

[3] A. Bekkali *et al.*, "Free-space optical communication systems for B5G/6G networks," *Opto-electronic and Communication Conf. (OECC)*, WA1.1, 2021.

[4] A. Bekkali *et al.*, "Fiber-to-fiber FSO system with advanced VCM controlled laser beam pointing and tracking, " *Optical Fiber Communication Conference (OFC)*, W7E.6, 2021.