High Data Rate Optical Wireless Communication over Wide Range by Using Nonuniform-space Optical Phased Array

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Abstract: We demonstrate a high-data-rate optical wireless communication (OWC) system over wide steering range by using a nonuniform-space optical-phased-array (OPA) chip. More than 70 Gb/s data transmission covering 100° steering range over 10 m is achieved.

1. Introduction

The rapidly developing 5G mobile communication derives myriad data-hungry applications like Internet of Things (IoT), urging the increasing demands for high-data-rate wireless communication [1]. Compared to the spectrum-congested radio frequency (RF) wireless communication, the optical wireless communication (OWC) possesses sufficient license-free optical spectrum ranging from visible to infrared wavelength and thus can provide data transmission at GHz-rate. Moreover, the OWC system is immune to the electromagnetic interference and can ensure high-quality data transmission. Optical wireless transmission over long distance usually requires sufficient emission laser power. Therefore, the infrared OWC with high threshold for human eye safety is suitable to the long-range wireless communication. To build flexible connections among mobile terminals, agile and accurate beam steering is critical in the infrared OWC systems. Recently, silicon-based optical phased arrays (OPAs) gain extensive attention. The OPAs exhibit significant potential in the OWC applications for providing agile, small-divergence and wide-steering-range beam. Previous studies on OPAs are mainly focused on LIDAR applications but few studies have been reported on the OWC systems so far. To date, a 512-channel OPA has been reported to achieve 10 Gb/s NRZ optical wireless data transmission over 50 m [2]. To our knowledge, the highest data rate in the reported works is 32 Gb/s achieved via a 64-channel OPA [3].

In this work, we propose and demonstrate high-data-rate infrared light wireless communication system over wide steering range by using a 128-channel OPA with nonuniform-space antenna [4]. Thanks to the nonuniform distribution of grating antenna, the OPA can provide over 100° field of view (FoV) in the horizontal direction without beam aliasing. In the experiment, we demonstrate 10-m transmission of 50 Gb/s four-level pulse amplitude modulation (PAM4) optical signal over 100° FoV by using the OPA-based OWC system. The bit-error-rate (BER) performance of the system is evaluated, indicating the optical signal can outperform the pre-forward error correction BER threshold at 3.8×10^{-3}. To our best knowledge, the FoV of 100° is the widest range in the reported OPA-based OWC systems. In addition, we manage to achieve 70 Gb/s PAM4 optical signal transmission by using the OWC system. The clear eye diagrams measured at the 0°, 25° and 50° horizontal steering angles reveal the capability of the system to support high-data-rate optical wireless communication.

2. OPA Architecture and Numerical Analysis

An OPA-based OWC system with wide communication coverage range requires the OPA chip to feature wide field of view without beam aliasing. In terms of grating antenna distribution, an OPA can generally be divided into a uniform-space OPA and a nonuniform-space OPA. The uniform-space OPA normally introduces beam aliasing in the FoV, since the antenna pitch hardly attains less than half wavelength restricted by the waveguide crosstalk. The severe channel interference induced by grating lobes could degrade the quality of the OWC system dramatically. In contrast, the nonuniform-space OPAs characterized by sparse distribution of grating antennas can eliminate the beam-aliasing effect in the 180° FoV. To be a specific comparison, we perform a simulation to evaluate the far-field pattern of the uniform-space OPA and the nonuniform-space OPA respectively. The simulation results are illustrated in Fig. 1(a). The normalized polar plot for the far-field patterns of the uniform-space OPA with 4-μm pitch exhibits multiple grating lobes in the FoV. In contrast, the far-field pattern of the nonuniform-space OPA with 29.7-μm average pitch shows only mainlobe in the FoV. The unique far-filed pattern of the nonuniform-space OPA not only

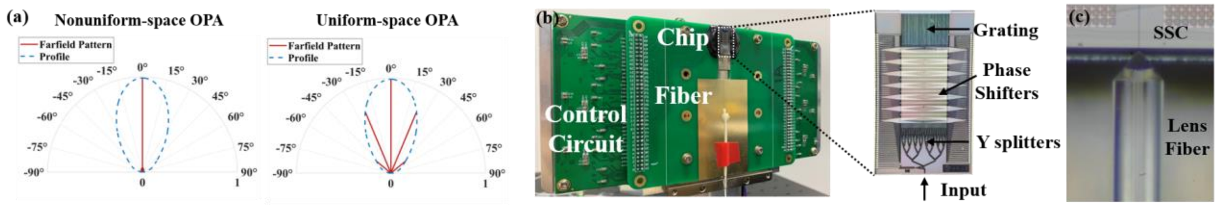

Fig. 1. (a) The simulation results on normalized polar plots for far-field patterns of a nonuniform-space 128-channel OPA (left) compared by that of a uniform-space 128-channel OPA (right). (b) a 128-channel nonuniform-space OPA chip embedded in peripheral control circuit. The inset is an optical microscope image of the OPA chip. (c) An optical microscope image for a lens fiber coupled to the OPA chip through a spot size converter (SSC).

offers wide-range FoV to secure the point-to-point optical wireless communication, but also potentially reduces channel crosstalk in the multi-targets OWC system.

In this work, we have demonstrated 10-m transmission of 50 Gb/s PAM4 optical signal over 100° in free space via an OWC system embedded by a 128-channel nonuniform-space OPA chip [4]. The OPA chip is fabricated based on Silicon-Silicon Nitride platform. It consists of 128 parallel grating antennas at nonuniform spacings to form a 12 mm2 emission aperture. Thanks to the large aperture, the divergence angle of the mainbeam can be as small as 0.021° × 0.029°. In particular, the fishbone-type dual-level grating enables the OPA chip to provide 100° FoV. Fig. 1(b) is a picture for a 128-channel nonuniform-space OPA chip embedded in peripheral control circuit. The inset is an optical microscope image of the OPA chip. The average antenna pitch of the nonuniform-space OPA is 29.7 μm. Fig. 1(c) is an optical microscope image for a lens fiber coupled to the OPA chip. The optical signal from the lens fiber is coupled into the OPA chip though a spot size converter (SSC).

3. Experiment Results and Discussion

Fig. 2 shows the experimental setup for an optical wireless communication system embedded by a nonuniform-space OPA chip. In the transmitter part, a CW laser centered at 1550 nm is directed into Mach-Zehnder modulator (MZM) with 20 GHz bandwidth. The MZM is biased at 2.2 V and driven by the pseudorandom bit sequence (PRBS) signal with 2^{15}-1. The PRBS signal in PAM4 format is synthesized from a pattern generator embedded in a bit error ratio tester (BERT). Subsequently, the PAM4 optical signal is boosted by an erbium-doped fiber amplifier (EDFA) prior to directing to the OPA chip. A polarization controller (PC) is insert to align the polarization state of optical signal to the OPA chip. The PAM4 optical signal is emitted directionally to a receiver at 10 m away via the nonuniform-space OPA chip. In the receiver part, the transmitted optical signal is collected by a fiber collimator and then is amplified to 4 dBm by a back-end EDFA. The amplified PAM4 optical signal is detected by a fiber-coupled photodetector (PD) with 50-GHz bandwidth followed by a RF amplifier. Finally, the BER performance of the received PAM4 signal is analyzed by the BERT.

Fig. 2. Experimental setup of an OPA-embedded optical wireless communication system for the PAM4 optical signal transmission over 10 m.

Fig. 3(a) shows the measured BER curves of the proposed OPA-based OWC system for the 50Gb/s PAM4 optical signal after 10 m transmission. The performance of data transmission at five different steering angles in horizontal direction of 0° ±25° and ±50° are measured respectively, covering the whole FoV of the OWC system. Noted that the input power is referred to the amplified optical power prior to the OPA chip. In the case of the OPA chip steered at 0°, 25 dBm input power is needed to achieve less than 3.5×10^{-5} BER. The relatively high input power is necessary to support complex signal modulation format and accurate discrimination of the PAM4 signal. To achieve the BER of 3.5×10^{-5}, the required input powers are around 27 dBm at ±25°and 28.5 dBm at ±50° respectively. The all measured BER performance are well below the pre-FEC BER threshold of 3.8×10^{-3}. As shown in Fig. 3(a), a slightly better BER performance at the -50° horizontal angle than that at the 50° horizontal angle can be observed. It can be attributed to the asymmetric emission profile caused by the off-center etched waveguide grating [5]. Hence, the quality degraded mainlobe affects the BER performance. As the OPA is steered to the edge of the FoV, the divergence angle and power loss of the mainlobe both increase simultaneously. Large divergence infers to a large beam size after propagating certain distance in free space, leading to a low receiving efficiency. The mainlobe quality can be improved by expanding the emission profile. The chain waveguide grating may be a potential solution to provide a broader emission profile [5]. To our best knowledge, over 100° steering angle is the widest cover range in the reported OPA-based OWC systems. Accordingly, Fig.3(b) shows the eye diagrams for 50 Gb/s PAM4 optical signal after 10 m transmission as the OPA chip is steered at 0°, 25° and 50°, respectively. The optical eye diagrams are obtained by a 65-GHz bandwidth sampling scope. The eye diagram at 50° becomes a little unclear due to the decline quality of the mainlobe. Moreover, we manage to demonstrate free space transmission of 70 Gb/s PAM4 optical signal over 10 m. The clear eye diagrams of the transmitted PAM4 optical signal as the OPA steered at 0°, 25° and 50° are measured respectively, as shown in Fig.3 (c). The BER performance for the 70 Gb/s PAM4 signal transmission can be further studied as the experimental equipment is updated. The clear eye diagrams verify the capability of the proposed OWC system for high data rate transmission of complex optical signal format.

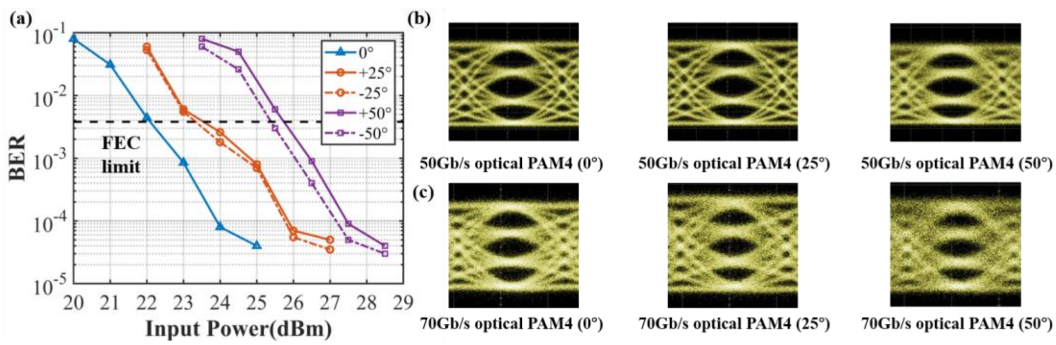

Fig.3. (a) The plot for measured BER of 50 Gb/s PAM4 optical signal after 10-m transmission in the case of the OPA chip steered at 0°, ±25° and ±50°, respectively. (b) the measured eye diagrams of 50 Gb/s PAM4 optical signal after 10-m transmission as the OPA steered at 0°, 25° and 50°, respectively. (c) the corresponding eye diagrams for 70 Gb/s PAM4 optical signal after 10-m transmission.

4. Conclusion

In conclusion, we have demonstrated a high data rate optical wireless communication over wide coverage range by using a nonuniform-space OPA chip. The OPA-based OWC system exhibits over 100° FoV and 0.021°×0.029° beam divergence angle. Up to 70 Gb/s PAM4 data transmission over a distance of 10 m is achieved. Our work paves the way to the high-data-rate and wide-range optical wireless communications and potentially fuel up the vehicle-to-vehicle (V2V) communication.

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