Diversity-Enhanced Fluorescent Fiber Antennas for MIMO VLC Systems

Xingchen Yu[1], Zhihong Zeng[1], Dengke Wang[1], Fengli Yang[1], Cuiwei He[2], and Chen Chen[1,*]
[1]School of Microelectronics and Communication Engineering, Chongqing University, China
[2]School of Information Science, Japan Advanced Institute of Science and Technology, Japan
[*]Email: c.chen@cqu.edu.cn

***Abstract*—In this paper, a multiple-input multiple-output (MIMO) visible light communication (VLC) system employing diversity-enhanced fluorescent fiber antennas (FFAs) is experimentally demonstrated. By introducing spatial and angle diversities in FFAs, the error performance of a 2×2 MIMO VLC system can be significantly improved.**

***Index Terms*—Visible light communication (VLC), multiple-input multiple-output (MIMO), fluorescent fiber antenna (FFA).**

I. Introduction

Visible light communication (VLC) is an emerging technology poised to play a pivotal role in future wireless networks [1]. The performance of VLC depends on the signal-to-noise ratio (SNR) at receiver. To enhance SNR, VLC systems employ optical concentrators at the receiver. However, conventional solutions such as compound parabolic concentrators tend to be bulky, and due to the conservation of étendue, they impose a fundamental trade-off between optical gain and field of view (FOV) [2]. Therefore, VLC systems exhibit high sensitivity to transmitter-receiver misalignment. Recently, fluorescent fiber antenna (FFA) presents a promising alternative. These antennas are designed to capture photons emitted by embedded fluorophores, channeling them efficiently toward the photodiode (PD). This mechanism not only concentrates incident light but also circumvents the constraints of étendue conservation [3]. As a result, FFA has been widely applied in various VLC system [4]-[6].

While single-channel VLC suffers from limited data rates, multiple-input multiple-output (MIMO) techniques have been widely adopted to enhance system capacity in VLC networks [7]. An ideal MIMO VLC receiver has a wide FOV and a high optical gain. Non-imaging MIMO receivers, for instance, offer a wide FOV but suffer from small input apertures, restricting their optical gain [8]. Conversely, imaging MIMO receivers employ lenses to boost optical gain, but this comes at the expense of a reduced FOV [9]. The FOV of imaging MIMO receivers can be increased using an array of PDs [10]. However, this array increases the system complexity and cost. To address these limitations, FFA reveals its potential for MIMO VLC systems. By leveraging fluorescence-based light collection, as these antennas potentially deliver both a wide FOV and high optical gain without the need for complex multi-PD architectures, offering a more efficient and scalable solution [11].

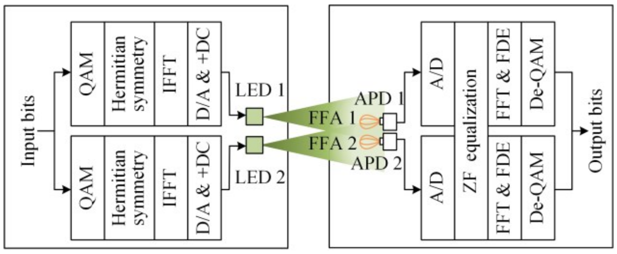

Fig. 1. Schematic diagram of a 2×2 MIMO VLC system using FFAs.

To substantially enhance the performance of MIMO VLC systems using FFAs, in this paper, we introduce and demonstrate FFAs with both spatial and angle diversity for MIMO VLC systems. Experimental results verify the superiority of diversity-enhanced FFAs in a 2×2 MIMO VLC system.

II. Principle

The schematic diagram of a 2×2 MIMO VLC system with orthogonal frequency division multiplexing (OFDM) using FFAs is shown in Fig. 1. At the transmitter side, the input bits are first divided into two streams and each stream is mapped into quadrature amplitude modulation (QAM) symbols. After imposing Hermitian symmetry, inverse fast Fourier transform (IFFT), the obtained digital signal is converted into an analog signal via digital-to-analog (D/A) conversion and a direct current (DC) bias is further added to ensure the non-negativity of the analog signals. The two resultant signals are modulated onto LED 1 and LED 2, respectively. At the receiver side, two FFAs are adopted to collect the MIMO signal and each FFA is connected with an avalanche photodetector (APD) which converts the optical signal into an electrical signal. After analog-to-digital (A/D) conversion, zero-force equalization (ZF) is conducted for MIMO demultiplexing. The equalized signals then perform OFDM demodulation including fast Fourier transform (FFT) and frequency-domain equalization (FDE). Finally, the output bits can be obtained through QAM demapping and bit combining.

As can be seen from Fig. 1, each of the adopted FFAs mainly consists of a few fiber bundles. By including more

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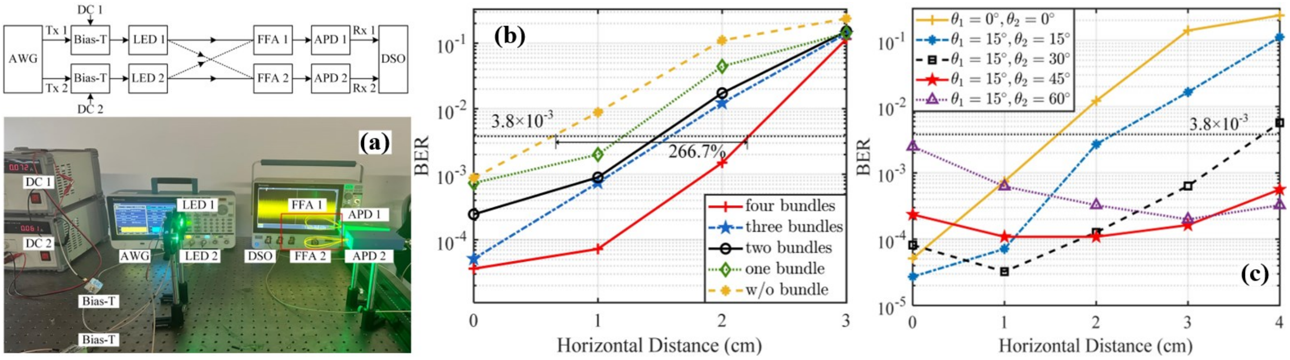

Fig. 2. (a) Experimental setup, and BER vs. horizontal distance for (b) different number of fiber bundles in FFA and (c) different FFA rotation angles.

fiber bundles in each FFA naturally introduces spatial diversity to the FFA and hence increases its optical gain. Moreover, considering the channel correlation in MIMO VLC, rotating the angle of each FFA can introduce angle diversity to reduce channel correlation and hence improve the overall performance of MIMO VLC systems.

III. Experimental Setup and Results

The experimental setup of a 2×2 MIMO VLC system using FFAs is depicted in Fig. 2(a), where the transmitted signals are generated offline. Then, the digital signals are uploaded into an arbitrary waveform generator (AWG). Subsequently, the AWG output signals with respect to two LEDs are all combined with DC voltages of 2.5 V via two bias tees (Bias-Ts). The resultant signals are used to drive LED 1 and LED 2, respectively. At the receiver side, two FFAs made of Kuraray O-2 fluorescent fibers are adopted to collect the signal. Each FFA is connected with an APD. Finally, the detected electrical analog signals are captured by an oscilloscope (DSO) and the digitized signals are further processed offline. The IFFT/FFT size is 512 and the constellation is 4QAM for both channels. The total data rate of the 2×2 MIMO VLC system is 50 Mbps. Moreover, each FFA is constructed from multiple 20-cm fiber bundles. The LEDs and APDs are arranged with inter-element spacings of 8 and 4 cm, respectively, and the vertical distance is 20 cm.

Fig. 2(b) shows the BER versus horizontal distance for different numbers of fiber bundles in FFA, where APD 2 was horizontally displaced while APD 1 is fixed. Both two APDs are vertically oriented without rotation. It can be observed that the BER gradually increases with the increase of horizontal distance. Moreover, the BER is greatly reduced when there are more fiber bundles in each FFA, due to the increase of the harvested spatial diversity gain. Compared with the case without FFA, a distance extension of 266.7% can be obtained when each FFA has four fiber bundles. Fig. 2(c) shows the BER versus horizontal distance for different FFA rotation angles with three fiber bundles in FFA, where θ_1 and θ_2 are the rotation angles of FFA 1 and FFA 2, respectively. As we can see, by rotating each FFA with a proper angle, the overall BER performance can be efficienty improved due to the harvested angle diversity gain.

IV. Conclusions

In this paper, we have experimentally demonstrated diversity-enhanced FFAs for MIMO VLC systems, where spatial and angle diversities are introduced in FFAs to enhance the overall performance of MIMO VLC systems. These insightful findings validate FFAs as an effective solution for robust MIMO VLC implementations, particularly in scenarios requiring both wide coverage and mobility tolerance.

References

[1] N. Chi, et al., “Visible light communication in 6G: Advances, challenges, and prospects,” *IEEE Veh. Technol. Mag.*, vol. 15, no. 4, pp. 93–102, 2020.

[2] J. Kahn and J. Barry, “Wireless infrared communications,” *Proc. of the IEEE*, vol. 85, no. 2, pp. 265–298, 1997.

[3] C. He, et al., “Capillary-based fluorescent antenna for visible light communications,” *Opt. Exp.*, vol. 31, no. 11, pp. 17716–17730, 2023.

[4] M. Faruki, et al, “Fluorescent fiber-based optical antenna for visible light communication applications,” *IEEE Access*, vol. 12, pp. 165582–165590, 2024.

[5] C. He, et al., “Wavelength division multiplexing in visible light communications using fluorescent fiber antennas,” *J. Lightw. Technol.*, vol. 42, no. 10, pp. 3725–3735, 2024.

[6] X. Yu, et al., “Low-crosstalk, filter-free and secure WDM for optical inter-CubeSat communication using fluorescent fiber antennas,” *Opt. Exp.*, vol. 33, no. 12, pp. 26461–26472, 2025.

[7] T. Fath and H. Haas, “Performance comparison of MIMO techniques for optical wireless communications in indoor environments,” *IEEE Trans. Commun.*, vol. 61, no. 2, pp. 733–742, 2013.

[8] A. Burton, et al., “Experimental demonstration of 50-Mb/s visible light communications using 4×4 MIMO,” *IEEE Photon. Technol. Lett.*, vol. 26, no. 9, pp. 945–948, 2014.

[9] K. Dambul, D. O’Brien, and G. Faulkner, “Indoor optical wireless MIMO system with an imaging receiver,” *IEEE Photon. Technol. Lett.*, vol. 23, no. 2, pp. 97–99, 2010.

[10] C. Chen, et al., “Wide-FOV and high-gain imaging angle diversity receiver for indoor SDM-VLC systems,” *IEEE Photon. Technol. Lett.*, vol. 28, no. 19, pp. 2078–2081, 2016.

[11] R. Mulyawan, et al., “MIMO visible light communications using a wide field-of-view fluorescent concentrator,” *IEEE Photon. Technol. Lett.*, vol. 29, no. 3, pp. 306–309, 2017.