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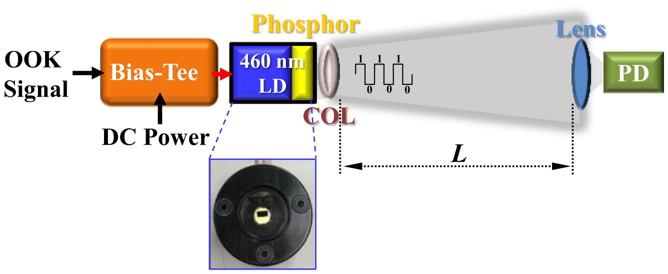
Chien-Hung Yeh
Chi-Wai Chow
Liang-Yu Wei



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1250 Mbit/s OOK Wireless White-Light VLC Transmission Based on Phosphor Laser Diode

Chien-Hung Yeh,[1] **Chi-Wai Chow**,[2] **and Liang-Yu Wei**[2]

[1]Department of Photonics, Feng Chia University, Taichung 40724, Taiwan
[2]Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

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Abstract: In this work, for the first time, we demonstrate a 1250 Mbit/s ON–OFF keying white-light visible light communication (VLC) transmission in a free space transmission length of 1 m by utilizing a yellow-phosphor laser diode (LD). Here, the blue optical filter, which is used to enhance the data rate by removing the yellow color component, is not required to. Besides, the wireless transmission lengths, illuminations, and modulation traffic rates of the proposed LD-based VLC system are analyzed and discussed.

Index Terms: Visible light communication (VLC), free space optical communication (FSO), laser diode (LD), phosphor.

1. Introduction

Recently, the white-light light-emitting-diodes (LEDs) are dominate in the illumination market as promising light sources due to the benefits of lower power consumption and longer lifetime [1]. Furthermore, employing white-light LED for the applications of visible light communication (VLC) and indoor/outdoor illuminance simultaneously has gained considerable attention [2]. The VLC technology can offer many advantages for wireless access, such as cost-effectiveness, high network security, license-free and no electromagnetic interference (EMI) etc. To achieve higher VLC data rate, using laser diode (LD) transmitter (Tx), which has a higher power conversion efficiency, has been proposed and demonstrated [3]–[5]. Moreover, several high-speed LD-based VLC transmission systems have been demonstrated. For example, Watson *et al.* proposed a 2.5 Gbit/s on-off keying (OOK) VLC transmission by using 422 nm GaN LD [6]; Lee *et al.* demonstrated a 4 Gbit/s OOK transmission with distance of 0.15 m by utilizing 450 nm GaN LD [7]; Yeh *et al.* investigated a 10.6 Gbit/s orthogonal frequency division multiplexing (OFDM) VLC traffic by employing 682 nm vertical-cavity surface-emitting laser (VCSEL) [8]. However, the demonstrations reported can only provide the VLC communication but not white-light illuminance. Hence, to deliver the VLC access and white-light illumination simultaneously, utilizing the phosphor-based blue LD and tricolor R/G/B LDs have been proposed [9]–[12]. However, the proposed technique either required separable three R/G/B LDs or has limited the VLC transmission lengths of less than 1 m. In addition, to enhance

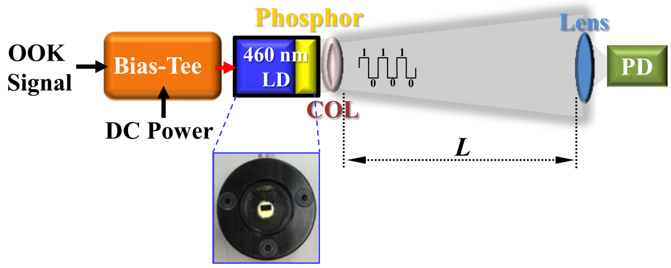

Fig. 1. Experimental setup of proposed phosphor LD based white-light VLC transmission.

the traffic rate of phosphor-based VLC, a blue optical filter could be utilized at the receiver (Rx) side usually [1], [13].

In this paper, for the first time we propose and demonstrate a 1250 Mbit/s white-light phosphor-LD VLC and illumination system to provide the practical indoor transmission length. The white-light LD, which composed of 460 nm LD and yellow-phosphor diffuser, can be utilized in the experiment to provide the data rates of 1250 and 1062.5 Mbit/s OOK after a free-space transmission distances of 100 and 150 cm, respectively. Here, no blue optical filter is used at the Rx side to improve the modulation rate of VLC system. Moreover, the wireless transmission lengths, illuminations and modulation data rates of proposed LD VLC system are analyzed and discussed.

2. Experiment and Results

Fig. 1 presents the experimental setup of proposed white-light laser-based VLC transmission system. In the Tx site, the white-light laser, which is composed of a blue light generated by the 460 nm LD and the yellow phosphor diffuser, with 1 GHz bandwidth is used as the VLC source. The photograph of phosphor-based white-light LD with package is also displayed in Fig. 1. The LD is a commercially available device and the threshold voltage is ∼1 V. Besides, the LD is cool white and has a color temperature of ∼5000 K while the operated voltage is 4.1 V. Here, the modulated VLC data and operated bias voltage can be combined via a bias-tee (BT) circuit launching into 460 nm laser, as shown in Fig. 1. Besides, a proper collimator (COL) is applied in front of phosphor laser for focusing. After transmitting through different free space transmission lengths, the white VLC signal can be received by a 1.25 GHz PIN-based photodiode (PD) via a focusing lens. As shown in Fig. 1, no blue optical filter is employed in the Rx side to enhance the traffic rate of proposed phosphor-LD VLC. In the measurement, the bias voltage of LD is 4.1 V and the diameter of focusing lens is 21 mm.

Fig. 2 presents the measured optical spectrum of phosphor-based white-light LD which is operated at 4.1 V at the back-to-back (B2B) status. Besides, the insert of Fig. 2 is the observed white-light illuminance after passing through a free space transmission of 215 cm, showing the optical beam is white in colour and is suitable for illumination. The detected illuminance at the Rx would determine the signal performance of VLC traffic under different free space transmission lengths. Fig. 3 shows the measured illuminance and corresponding optical beam diameters of white-light laser under the free space transmission lengths from 100 to 215 cm. While the free space transmission length is 100, 150 and 215 cm, respectively, the observed corresponding illuminance and beam diameter are 754, 545, and 305 Lux and 9, 12 and 18 cm. As shown in Fig. 3, by increasing of free space transmission length gradually, the obtained illuminance would decrease and the beam diameter would increase.

To evaluate the proposed VLC system performance based on the white-light laser, the on-off keying (OOK) modulation signal with a pseudo random binary sequence (PRBS) of $2^{23}-1$ is applied to laser for direct modulation. Besides, depending on the different detected power of VLC signal, we can apply the optimal data rate on the laser for VLC traffic. Hence, Fig. 4(a) presents the

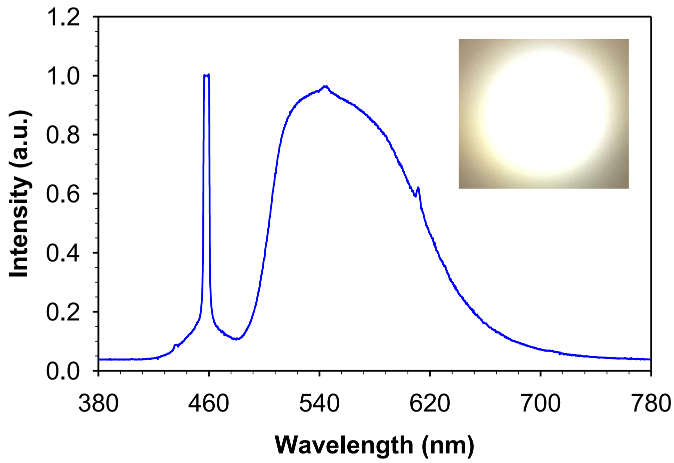

Fig. 2. Measured optical spectrum of phosphor-based white-light LD. Insert is the observed white-light illuminance through a free space transmission of 215 cm.

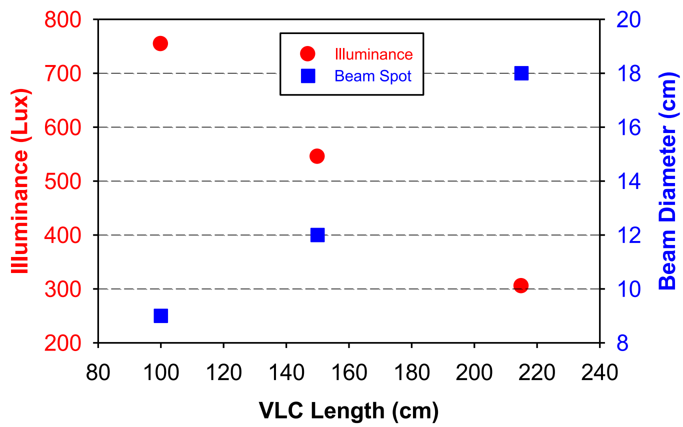

Fig. 3. Measured illuminance and corresponding beam spot of white-light LD under the free space transmission length of 100 to 215 cm.

measured corresponding bit error ratio (BER) and VLC data rates under the free space transmission lengths from 100 to 215 cm. As shown in Fig. 4(a), when the illuminance are 754, 545, and 305 Lux respectively, the measured corresponding VLC data rates are 1250, 1062.5 and 125 Mbit/s. Moreover, the corresponding bit error rates (BERs) are also observed at 4.51×10^{-5}, 1.09×10^{-4} and 1.09×10^{-2}, respectively, as seen in Fig. 4(a). The measurement results show that the required illuminance and VLC transmission length need to be larger than 545 Lux and less than 150 cm respectively, to meet with the forward error correction (FEC) limitation at the BER of 3.8×10^{-3}. Even if we decrease the traffic rate to 125 Mbit/s, the corresponding BER still cannot meet the FEC threshold at the free space transmission length of 215 cm, as shown in Fig. 4(a). In this demonstration, by optimizing the analogy-equalization design in our bias-tee circuit [14], the 125 to 1250 Mbit/s OOK VLC traffic can be detected at the PIN-Rx without blue optical filter under different free space transmission lengths. However, as the blue filter will remove most of the yellow color components of the VLC signal, the transmission distance is significantly reduced. Hence, no optical blue filtering is used here.

Then, when the pattern length of OOK modulation signal is changed to $2^{31}-1$, the observed BER performance of proposed phosphor-LD VLC system with various data rate in different wireless transmission lengths is exhibited in Fig. 4(b). The VLC data rates and corresponding BERs of 1250,

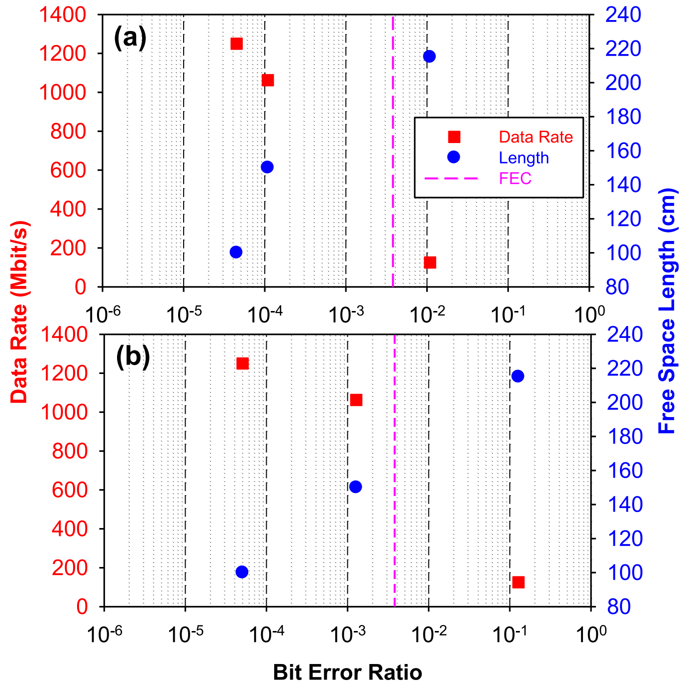

Fig. 4. Measured corresponding BER and VLC data rate under the free space transmission length of 100 to 215 cm, respectively, when the OOK pattern length is (a) $2^{23}-1$ and (b) $2^{31}-1$.

1062.5 and 125 Mbit/s and 5.08×10^{-5}, 1.28×10^{-3} and 1.28×10^{-1} are obtained in the free space lengths of 100, 150 and 215 cm, respectively, as seen in Fig. 4(b). The measured results are similar to that in Fig. 4(a), but with certain pattern-dependent error. This may be due to different responses of the yellow phosphor to different pattern-lengths. To satisfy the FEC threshold, the 1000 Mbit/s white-light LD-based VLC system can be accomplished within the illuminance of 545 Lux. Therefore, as mentioned above, to complete $>$1000 Mbit/s traffic rate of proposed LD VLC system, the free space transmission length must be less than 150 cm for communication and illumination simultaneously.

3. Conclusion

The proposed white-light phosphor-based LD VLC system could achieve 1062.5 to 1250 Mbit/s OOK modulation in the free space transmission length of 100 to 150 cm. Here, the white-light LD, which was consisted of a 460 nm blue LD and yellow-phosphor diffuser, was packaged for illumination and communication simultaneously. In the measurement, there was no blue filter used at the Rx. According to the obtained results, to reach the illuminance of $>$500 Lux in indoor, the corresponding traffic rate of proposed VLC system could be larger than 1000 Mbit/s. Here, only a single phosphor-LD was utilized for VLC demonstration. Moreover, in order to achieve a higher VLC data rate, multiple LDs also could be used in the proposed VLC system.

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