

477 Mbit/s visible light transmission based on OOK-NRZ modulation using a single commercially available visible LED and a practical LED driver with a pre-emphasis circuit

Nobuhiro Fujimoto and Hikari Mochizuki

Kinki University, 1 Takaya-Umenobe, Higashi-Hiroshima, Hiroshima 739-2116, Japan
fujimoto@hiro.kindai.ac.jp

Abstract: We have first confirmed the maximum bit rate of 477 Mbit/s OOK-NRZ-based transmission using a single commercially available visible LED and a low-cost PIN-PD by adopting a practical LED driver with a simple pre-emphasis circuit.

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1. Introduction

The white light emitting diodes (LEDs) have been dramatically developed in their performance. Now, they have high bright output, high power efficiency, and a long lifetime. Therefore, they will eventually replace incandescent or fluorescent lights in offices, homes, cars, and traffic lights. And it is expected that packaged LED market will experience tremendous growth between 2012 and 2018. According to these backgrounds, visible light communication (VLC) system [1] using white LEDs is one of promising infrastructure for Ubiquitous Network. In the network, they are used for both illumination and wireless data transmission.

There are many approaches to realize high-speed VLC system. A 100 or 125 Mbit/s on-off-keying (OOK)-NRZ-based transmission experiment [2] was demonstrated in VLC link with a phosphorescent white LED and a low-cost PIN photo diode (PD). Deploying an avalanche photodiode (APD) in place of the PIN-PD doubled the rate to 230 Mbit/s [3]. However, these experiments required filtering the low-speed phosphorescent component to increase the bandwidth of the VLC system. And recently, quadrature-amplitude-modulation (QAM) on discrete multitone (DMT) was used to modulate a phosphorescent white LED and a 513 Mbit/s transmission were performed [4]. However, DMT requires complex circuitries. An aggregate rate of 1.25 Gbit/s wavelength division multiplexing (WDM) experiment was performed on DMT modulation of an RGB-type white LED with expensive optical RGB filters [5]. The assigned transmission rates to LED chips were about 376 Mbit/s, 439 Mbit/s and 430 Mbit/s for the red, green and blue LED chip [5], respectively. In this case, its circuit configuration becomes complicate because three drive circuits, three suitable dichroic filters, three expensive APDs, three receiver circuitries, and complicate DMT codec are required. And we have reported a 614 Mbit/s Duobinary transmission using a single commercially available visible LED [6]. However, Duobinary technique requires a precoder at the transmitter and a decoder at the receiver. Then, the configuration of the system with Duobinary technique also becomes complicate. Consequently, the maximum operating speed of a single visible LED on OOK-NRZ-based modulation is 125 Mbit/s by a PIN-PD and 230 Mbit/s by an APD, on Duobinary modulation is 614 Mbit/s, and on DMT modulation is 513 Mbit/s. And above all approaches adopted a bias T in order to combine a bias current with a data current and its combined current was supplied to the white LED. Its configuration is not practical.

In this paper, we demonstrate for the first time the maximum transmission speed of 477 Mbit/s for the simplest OOK-NRZ-based modulation using a single commercially available red LED and a low-cost PIN-PD by adopting a proposed practical LED driver with a simple pre-emphasis circuit. And we have also confirmed 456 Mbit/s error-free operation of our proposed simple and low-cost high-speed VLC system that requires a single LED drive circuit with a single RGB-type white LED and one optical receiver with a low-cost PIN-PD and no optical filter.

2. Proposed practical LED driver with a pre-emphasis circuit

In generally, a drive circuit, such as a conventional LD drive circuit, was specially designed to optimize for characteristics of an optical source. For example, a conventional LD driver circuit consists of many specific circuits such as an ECL input buffer, an LD driver, and a bias supplier. On the contrary, the LEDs have no threshold current. Therefore, a bias supplier and typical temperature control circuit are not required. However, there have not yet been any proposal of a practical LED driver circuit that could supply a large forward current and realize high-speed modulation.

The LEDs have many characteristics to be considered in the design of a LED driver. In specially, it is very important for a LED driver to supply a large and high-speed signal current for illumination and high-speed data

transmission. We have proposed a simple and practical LED driver as shown in Fig.1. A current mode logic (CML) circuit is a typical configuration for high-speed modulation. A high-power visible LED requires a large drive current for illumination. However, a large switching current degrades the high-speed response of a CML circuit. In our proposed circuit, to avoid this degradation, the CML circuit makes a high-speed voltage data V_0 having large amplitude given by the equation of a small switching current I_d times R_0 . And this voltage data is fed into the next emitter follower circuit. The LED and the resistor R_1 work as a load of the emitter follower circuit. By adopting this configuration, it is very easy to control and adjust the driving condition of the LED. Selecting the combination of the supply voltage V_e and the resistor R_1 can fix the average forward current. And the amplitude of the data V_0 fixes the high-speed modulation current of the LED. We investigated the optimum driving condition of the LED from the viewpoint of the maximum operation speed. Consequently, we found out the optimum average forward current of 200 mA and data amplitude of 2 Vp-p. Furthermore, this driver can easily improve the frequency response of the LED by adding a simple CR network to R_1 in parallel as shown in Fig.1. For example, the frequency response of the LED is improved from the frequency given by $1/(2\pi C(R_1+R_2))$ in the case of Fig.1.

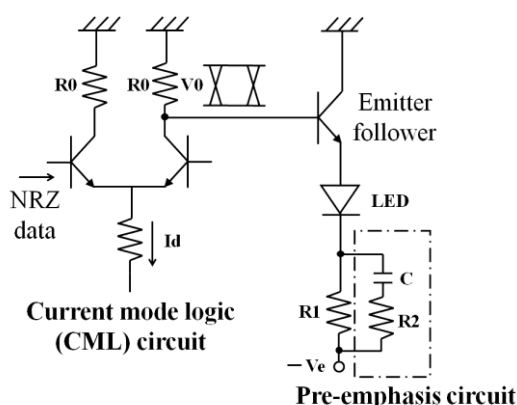


Fig. 1. Proposed LED driver with a pre-emphasis circuit

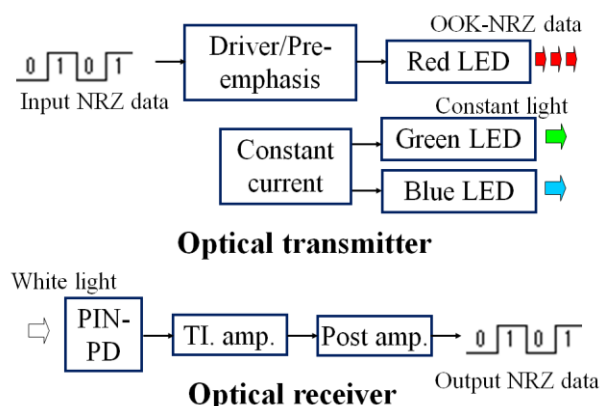


Fig. 2. Proposed visible light communication system

3. Proposed visible light communication system

Two kinds of white LEDs are used for VLC system. A phosphorescent white LED has the illumination and data transmission functions. On the other hand, a RGB-type white LED has the possibility for wavelength division multiplexing (WDM) in VLC system [5]. Furthermore, its operating speed is higher than that of the phosphorescent white LED, because the RGB-type LED has no low-speed phosphor layer. However, three-color LED chips should be modulated to realize white color for illumination and three drive circuits were required in conventional proposed VLC configurations.

Therefore, we have proposed a simple and low-cost VLC system based on OOK-NRZ modulation with a single RGB-type white LED as shown in Fig. 2. In this system, one-color LED chip is modulated for data transmission and illumination and constant currents are supplied to the rest two-color LED chips for illumination. This system requires one LED drive circuit and one low-cost PIN-PD optical receiver circuit for data transmission. No expensive RGB color filters are also required. As a consequence, these simple configurations enable low-cost and high-speed VLC system. In this system, the receiver sensitivity degradation by the constant background noise due to the non-modulation color LED chips happens, and its affection results in the degradation of the transmission distance. However, it could be easily recovered by using several LED modules in parallel.

4. NRZ transmission experiments

We have performed the transmission experiments to confirm the possibility of the proposed LED driver and the proposed VLC system using only commercially available devices. The optical source is a commercially available high-power RGB-type white LED (Avago ASMT-MT00-00001) which is comprised of 625 nm, 527 nm and 470 nm LED chips. The LED driver consists of discrete GHz-Transistors (Sanyo, MCH4021). In the optical receiver, a Si PIN-PD (Hamamatsu photonics, S10784) for visible light detection and a high-speed operational amplifier (TI, OPA847) as a transimpedance (TI) and post amplifier are adopted.

In the optical transmitter, the pre-emphasis circuit improves the 3 dB down bandwidth of the optical transmitter from 6.2 MHz to 91 MHz. Moreover, the 3 dB down total bandwidth of the VLC system is improved over 160 MHz

by using the peaking characteristics of the operational amplifier in the optical receiver.

The measured bit error rate (BER) characteristics for the distance between LED and PD are shown in Fig. 3 (a) and (b). In these experiments, input/output electrical NRZ data is the nine-stage pseudorandom noise sequence. In the first experiment, only Red LED is modulated and Green and Blue LEDs are OFF state. In this configuration, the OOK-NRZ operating speed limit of the Red LED is measured. We have first confirmed the maximum bit rate of a 477 Mbit/s error-free operation with a bit-error ratio of less than 10^{-9} at the distance of 40 cm between the LED and the PD on simple OOK-NRZ modulation. It is also confirmed that lower bit rate of 100 Mbit/s and 400 Mbit/s can expand the error-free distance as shown in Fig.3 (a) owing to the improvement of the required power to keep the bit-error rate of less than 10^{-9} . In the second experiment, only Red LED is modulated for data transmission and illumination, and the rest two color LEDs are ON state for illumination. This configuration is the proposed VLC system as shown in Fig. 2. According to the prediction, both the maximum operating speed and the error-free distance between the LED and the PD are degraded. Owing to the increase of the background noise from two non-modulation LED chips, the signal to noise ratio of the optical receiver deteriorates. As a result, the transmission distance shortened and the maximum operating speed was suffered from the temperature increase of the RGB LED by its increase of the power consumption when all three LED chips are ON state. However, it is confirmed that these degradation are small as shown in Fig. 3 (a) and (b). The operating speed of 456 Mbit/s as the simple OOK-NRZ based VLC system is also the world record.

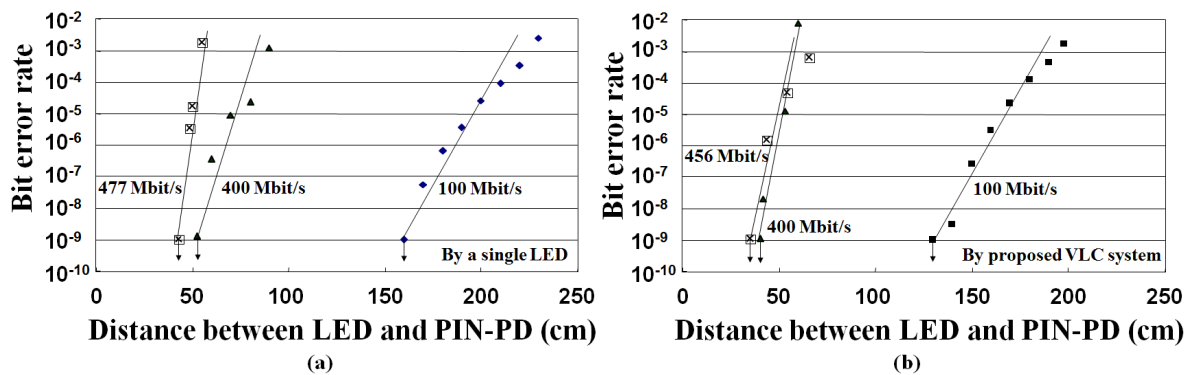


Fig. 3. Bit error rate characteristics of OOK-NRZ transmission experiments. (a) Using a single visible LED, (b) Adopting a proposed visible light communication system

Conclusions

In this paper, we have first confirmed the maximum transmission speed of 477 Mbit/s on simple OOK-NRZ based modulation of the commercially available visible LED by using a proposed practical LED driver with a simple pre-emphasis circuit and a low-cost PIN-PD. It has also been confirmed error-free operation of the proposed high-speed VLC system by using the RGB-type white LED at a speed of 456 Mbit/s NRZ transmission. These experimental results show that our proposed system is suitable for simple, low-cost, and high-speed VLC system.

5. References

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