A novel color division multiplexing system for visible-light transmission using a white LED comprised of R, G, B chips

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R, G, B 3色チップからなる白色LEDを用いる可視光通信用

新色分割多重システム

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A simple and low-cost color division multiplexing system using a white LED and a commercially available logic IC for visible-light transmission are proposed to enable Ubiquitous Network. The proposed multiplexing system using a simple compensation circuit for a low-speed white LED enables over a 50 Mb/s operation. Experimental results show that the proposed system can play a key role in visible-light transmission.

keywords: white LED, multiplexing, logic IC

1. Introduction

The visible-light communication system [1] using white LEDs is one of promising infrastructure for Ubiquitous Network. In the network, these white LEDs are used for both illumination and wireless data transmission. The white LEDs [2] 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. There are many proposal in visible-light communication [1],[3]. However, few transmission characteristics in visible-light communication using white LEDs have been experimentally confirmed. In this paper, I have proposed a simple and low-cost color division multiplexing transmission system using a white LED comprised of the three primary color (red, green, and blue) chips. Furthermore, I have proposed a simple and high-speed circuit configuration using a commercially available logic IC as a LED driver. Finally, I have performed basic CDM transmission experiments which...
show that the proposed system can play an important role in the visible-light transmission.

2. White LEDs

The white LED is required to realize simultaneous illumination and communication for visible-light communication [1]. There are two types of white LEDs. One is a fluorescence type white LED using a blue LED chip and a phosphor [2]. When the blue LED chip is driven by electric current, the blue light is emitted from the chip. The phosphor is excited by the blue emission and emits yellow fluorescence. The mixture of the blue and yellow lights results in a white light. The other is a three chip type white LED comprised of the three primary colors, such as red, green, and blue [3]. In this type LED, three LED chips emit each color simultaneously. The mixture of the each color is also results in a white light.

3. Modulation characteristics of white LEDs

I have performed experiments to investigate modulation characteristics of these white LEDs. In the experiments, the commercially available logic IC (74LS06) is adopted as a drive circuit to simplify its circuit configuration as shown in Fig. 1.

![Proposed simple LED drive circuit](image)

A small signal frequency characteristic of the fluorescence type white LED (UW3804X) has been investigated as shown in Fig. 2. The low 3-dB down frequency of less than 500 kHz was obtained. The operation of the fluorescence type white LED is limited to low frequency owing to the phosphor responsibility of the LED.

![Frequency response of fluorescence type white LED](image)

On the contrary, the same frequency characteristics of the three chip type white LED [4] are shown in Fig. 3 (a), (b), (c ). There are no limitation of the phosphor responsibility in the operation of the three chip type white LED. Moreover, the chip mount enables high-speed operation. Therefore, higher 3-dB down frequencies of 12.6 MHz, 4.6 MHz, and 10.2 MHz were conformed for the Red chip, the Green chip, and the Blue chip, respectively. These 3-dB down frequencies may be due to the difference between the compound ratio of the semiconductor material of these chips.
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However, in order to transmit full-motion video signal (DVD) in the optical network, more than 5.4 MHz 3-dB down frequency is required. Therefore, a simple R-C combination circuit was adopted between these chips and the logic IC as shown in Fig. 4 to compensate the frequency response of these chips for full-motion video signal transmission.

Fig. 3 (a) Frequency response of red chip of three color white LED

Fig. 3 (b) Frequency response of green chip of three color white LED

Fig. 3 (c) Frequency response of blue chip of three color white LED

The schematic diagram of the drive current characteristic for the LED with the compensation circuit is shown in Fig. 5. The beginning frequency of the peaking, \( f_1 \) is given by

\[
f_1 = \frac{1}{2\pi CR_1} \quad (2.1)
\]

Here, \( f_1 \) is the 3-dB down frequency without the compensation circuit.

The end frequency of the peaking, \( f_h \) is given by

\[
f_h = \frac{1}{2\pi C(R_1R_2/(R_1+R_2))} \quad (2.2)
\]

According to the above equations, a capacitance \( C \), a resister \( R_1 \), and a resister \( R_2 \) are calculated from the 3-dB down frequency of each chips without the compensation circuit. For example, improved frequency characteristic and improved the 3-dB down frequency of the red chip with the compensation circuit are shown in Fig. 6 and all 3-dB down frequencies are summarized in Table 1. It was confirmed that the red chip had the highest speed of 21.4 MHz and the green chip had the lowest speed of 8.9 MHz which can transmit video signal.
fluorescence type white LED as shown in Fig. 7(a). This is the simplest configuration. However as previously mentioned, its operation speed is limited to low frequency owing to the phosphor responsibility of the LED. The other system adopts a three primary colors type LED as shown in Fig. 7(b). This LED can enable color division multiplexing (CDM) to enhance its transmission capacity. On the other words, CDM is equal to wavelength division multiplexing (WDM) which is adopted in the trunk and access line transmission for the public optical network in the world. In this system, three wavelength filters, three photo diodes, three receiver electric circuits, and a 3 to 1 multiplexing circuit are required for the receiver side. Therefore, its configuration is very complicate.

I have proposed a reduced CDM configuration using the white LED [4] comprised of three primary color chips. The proposed system configuration is shown in Fig. 8. In the optical transmitter, three LED drive circuits and digital processing for the demultiplexing circuit are not inevitable to enable both illumination and communication. The configuration of the proposed receiver is drastically simplified. Since time division multiplexing is performed in the free-space, the 3 to 1
A novel color division multiplexing system for visible-light transmission using a white LED comprised of R, G, B chips is not needed. And no expensive color filter is also needed. Consequently, the optical receiver in this system is the same of the simplest configuration for the fluorescence type white LED as shown in Fig. 7(a). However, the same operating speed of the input data to the 1 to 3 demultiplexing circuit is required for each chip. Then, in this configuration, the pulse width of the input data is required for the optical output of the three chips as shown in Fig. 8.

Fig. 8 Proposed color division multiplexing system

5. Fundamental experiments

I have performed fundamental experiments to confirm the possibility of the proposed system. Drive currents of the LED chips are fixed to the recommended currents of the LED chips. I adopted a very cheap commercially available logic IC, 74LS06 as a LED driver. This line driver IC is also suitable for the LED drive which requires both large modulation current and large built-in voltage. And I also adopted GM5WA06270A as a white chip LED [4] which has been produced for backlight illumination of liquid crystal display, S5973 as a photo diode for visible-light detection, OPA355 as a preamplifier, and LT1016 as a limiter amplifier for stable decision. I have confirmed stable CDM error-free operation from several Mb/s to 60 Mb/s as shown in Fig. 9. The transmission distance between the LED and the PD where the bit error rate is less than $10^{-6}$ becomes short according to the increasing of the transmission speed. By proposed compensation, each chip operating speed of the LED is improved over 50 Mb/s which is speed limit of adopted TTL logic IC, 74LS06. An ECL or a high-speed CMOS logic IC will be required for higher operating speed of the system and enough distance between the LED and the PD.

6. Conclusions

A simple and low-cost CDM system using a commercially available logic IC and a three primary color white LED for visible-light transmission have been proposed and experimentally confirmed 60 Mb/s stable operation. The proposed system and this LED can play a key role in visible-light transmission.

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References

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