Design of Indoor Wireless Communication System Using LEDs
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ABSTRACT

An indoor wireless communication system using commercial white LED is presented in this paper. OOK (On-Off Keying) modulation is adopted in the transmitter module. Data transmission is realized based on RS-485 protocol. A DC-balanced coding with error check and correction abilities is applied to avoid blinks and improve the performance of the system. The system can keep $10^{-7}$ error bit rate within 2.5m reach at a rate up to 115200 bps.

Keywords: VLC (Visible Light Communication), On-Off Keying, RS-485

1. INTRODUCTION

RF (Radio Frequency) is the most prevalent technology in wireless communication field at present. However the forthcoming new generation of lighting based on LEDs provides some advantages comparing to fluorescent and incandescent technology, such as: significant energy saving, longer lifetime, etc. LEDs’ short response time is also the prerequisite for communication with visible light. It is sensible that communication with semiconductor lighting could be reckoned as a complementary wireless communication technology of RF\(^1\), and even can replace RF in some high safety demand and RF pollution awareness situations.

The LED could be easily modulated for communication due to its short response time. By quickly switching LED on and off (brighter and dimmer) logical “1” and “0” can be sent out serially\(^2\). Taking a rough comparison between RF and VLC technology, not only is the bandwidth of VLC (Visible Light Communication) 10,000 times higher than the highest frequency used in RF technology, but also by introducing WDM (Wavelength Division Multiplexing), more than 1000 independent data channels can be grouped into the air on a single optical beam which largely widens the bandwidth of VLC\(^3\).

RF technology is more susceptible to interference from other existing channels. However, light waves are obstructed by physical obstacles, and it’s easy to prevent interference from adjacent rooms. Moreover, VLC is much safer in terms of information feasibility by eavesdropping.

RF technology is relatively expensive and difficult to implement\(^4\). Because of VLC occupying no RF spectrum, neither does it need expensive RF band license nor produce RF pollutions. In RF pollution awareness and RF forbidden situations, VLC is a strong candidate for wireless access. Low-cost components that a VLC system requires also make it an economical competitive product.

The origin of VLC can be traced back to the 1970s, but there are not many major breakthroughs until LEDs’ performance improved greatly in the last decade, and LEDs have become the most promising illumination devices

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recently. The concept of indoor optical wireless communication system was first suggested by a team of researchers at Keio University in Japan\textsuperscript{4}. However, the study was mainly focused on the layout of LEDs' lighting\textsuperscript{5,6}, the design and realization of VLC system based on white LEDs was not seen reported much\textsuperscript{2,7}. In this paper, we design a demonstrative indoor simplex broadcast VLC system using off-the-shelf LED lamps for the transmitter module and the PIN detectors for the receiver module. Serial data is transmitted over RS-485 protocol. The performance of the system is evaluated and some experiment results, such as text messages and files transmission are also demonstrated.

2. SYSTEM DESIGN

Typically, a VLC system mainly contains two parts, one is the transmitter module, and the other is the receiver module. Our VLC system appears in the form of point to multi-points which permits data transmission in one direction only. Figure 1 shows the overall VLC system block diagram which has a broadcast topological structure. The receiver occupant may realize information uplink with extra optical devices, and the duplex system is more sophisticated.

![Figure 1. A VLC broadcast system which is typically composed of one or more transmitters and several receivers distributed in a recipient radius.](image)

2.1 Transmitter Module

In the transmitter module, we choose off-the-shelf LED whose type is PAR38 as the light emitting source, and its characteristic I-V curve is shown in Figure 2. This commercial LED lamp is designed to make sure that the power and the color temperature are both safe and comfortable for human eyes. The operating voltage of the LED is 24V DC, and the power rating is 15W. OOK (On-Off Keying) was applied to modulate the LED. The modulation circuit is shown in Figure 3. In order to do this, Q1, Q2 and Q3 are used to switch the LED at a very high speed. As OOK is adopted, the LED’s brightness is totally affected by the duty cycle of the RS-485 signal (average power consumption) which is similar to a PWM brightness control\textsuperscript{8}. Obvious blinks are harmful to human eyes when used for illumination; it would make people feel uncomfortable and dizzy. Therefore, neither continuous “0(1)” nor DC-unbalanced code should be sent in order to eliminate the harmful blinks. Considering this, we do a lot of work to solve the problem through a coding method which will be mentioned later in the coding design section. It’s important to note that the receiver occupant may block the light beam and put the receiver in shadows\textsuperscript{9}, so more than two LED lamps should be modulated simultaneously...
from various directions to cover a larger recipient area. When the receiver loses connection with one transmitter, it will be able to receive data from another transmitter instantaneously.

![Characteristic I-V curve of LED PAR38](image)

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![Modulation circuit](image)

Figure 3. Modulation circuit. Q1, Q2 and Q3 are used to switch the LED at a very high speed in an OOK (On-Off Keying) manner.

2.2 Receiver Module

The receiver module is mainly composed of PIN detectors and signal conditioning devices. Taking optical spectral sensitivity and availability of devices into account, we choose OSRAM SFH203p PIN photodiode as the detector, and its spectral sensitivity and directional characteristic are shown in Figure 4. The visible light wave band which covers from 400nm to 700nm coincides with the detector’s 50% peak responsibility band. The detector has a very short switching time (typically 5ns) which fulfills the demand of the system transmitting rate. Because of the relatively low data rate, the inter-symbolic interference caused by multipath effect is not taken into account10, 11.

The output signal from the detector is weak with a lot of background light noises12 and a long free space communication distance only makes the situation worse. Therefore, the signal conditioning circuit becomes the critical part of our VLC system.
Figure 4. Spectral sensitivity and directional characteristics of OSRAM SFH203p PIN detector. Visible light band coincides with 50% peak responsibility band of the PIN detector.

All devices are cascaded in the receiver module. Firstly, a PIN detector is connected with a transimpedance amplifier to convert the current signal into voltage signal. Secondly, a high pass filter with a cut-off frequency of 1000 Hz is applied after to by-pass background light noises and periodical power line noises. Thirdly, the signal is amplified by a main amplifier to appropriate amplitude. Finally, the amplified signal is reshaped into RS-485 standard signal by a tunable voltage level comparator. The output RS-485 signal can be easily read by PC terminals. Figure 5 shows the receive circuit. The evaluation of the system will be shown later in section 4.

Figure 5. Receiver circuit. A transimpedance amplifier, a high pass filter, a main amplifier and a voltage comparator are cascaded.

3. CODING DESIGN

As mentioned earlier, considering human health, safety and aesthetical pleasure, coding is indispensable and must be carefully designed. Firstly, a coding method which is DC-balanced with error check and error correction ability is basically expected. There are several existing coding methods for optical communication field, such as 8B/10B, Manchester, etc. However, if 8B/10B or Manchester coding method were applied, when comes to the data alignment, we would need extra expense to perform decoding from an ASCII stream due to the RS-485’s property frame structure. It would be better to operate upon RS-485 protocol if the coding we re based on ASCII. Secondly, because there is a remarkable difference between the luminance of a modulated LED and the same one’s which is not, the LED needs to be
modulated continuously to hold a stable brightness without blinks. Thirdly, a reasonable redundancy in a coding is also necessary to provide error check and error correction abilities. Finally, according to all these factors, we designed a novel ASCII-based coding method in our demonstrative VLC system.

Codes are divided into valid group and invalid group; both of them are DC-balanced which means the quantity of ‘0’ and ‘1’ are even. The useful information is encoded into valid code group and sent. When no information is being sent, the transmitter module is in idle state, and invalid code group is sent instead. As shown in Figure 6, no vacuum actually exists between valid codes section and invalid codes section, so we manage to make sure that the LED is always under modulation to avoid blinks.

Correspondingly, the receiver has to pick up valid codes from the code stream, and decode them into original data after the error checking and correcting process. The coding redundancy is 50%. Suppose a serial frame pattern of 8 data bits, 1 stop bit, no parity bit were applied for RS-485 protocol, the actual data rate would be 115200×66.7%×0.8 = 61440 bps when the bit rate is 115200 bps, which means the system is practicable at this rate.

4. EXPERIMENTS AND RESULTS

A photograph of our VLC system is shown in Figure 7 (a). Transmitter module and receiver module is shown in Figure 7 (b) and (c) respectively.

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The RS-485’s output waveform of the transmitter, the main amplifier’s output waveform and the voltage level comparator’s output waveform of the receiver are probed with an oscilloscope and shown in Figure 8. The serial signal can be recovered very well at the receiver end when the visible light transmitting distance is within 2.5m at a bit rate of 115200 bps.

Figure 8. Oscilloscope waveforms. (a) Output waveform of the transmitter. (b) Output waveform of the main amplifier. (c) Output waveform of the voltage comparator.

When the LED is modulated, the working current decreases to about 50% of the normal level. The luminance of the LED which is monitored by a luxmeter also shows a 50% falling. The receiver can recover the signal correctly even at a luminance of 17 lux. The recipient angle of the receiver at a distance of 2.5m from the LED lamp is 42°(which is typically the distance from the ceiling to the top surface of a desk), so there is a comparatively large mobility within this area. When more LEDs are modulated simultaneously, the recipient angle can be enlarged, and the performance of the VLC system can be improved to a significant extent (Figure 9). However, there’s a distance threshold, when the transmitting distance exceeds the threshold, the system’s performance deteriorates sharply. The threshold is relevant to the data rate and the LED’s operating power.

Figure 9. Recipient angle of the transmitter. The performance of the system will be improved with more intensive luminance when more LEDs are modulated simultaneously which covers a larger recipient area and directional angle.
In order to demonstrate our VLC system, we have developed a software suite which contains a server and a client on NI’s LabVIEW platform. Texts and files transmission could be accomplished simply by typing some texts and a single clicking on the sending button, or choosing the file to send within a file selection dialog box. The interfaces of our software are shown in Figure 10.

![Interfaces of server and client](image-url)

Figure 10. The interfaces of server and client for texts and files transmission software. The server is shown on the left side, and the client is shown on the right side.

5. CONCLUSION

We have designed and realized an indoor semiconductor illumination and wireless communication system using off-the-shelf LEDs. Data transmission bit rate can be up to 115200 bps with $10^{-7}$ error rate within a transmitting distance of 2.5 m. Until this paper is proposed, a work to raise the bit rate to 460800 bps or higher is pushed on. LEDs illumination is ubiquitous, and VLC based on LEDs has promising perspective for its safety, energy saving, high bandwidth density, etc. However, because most LED lamps for illumination usage emit blue visible light and fluorescent substance is needed in order to emit yellow or white light. When the modulation rate rises, we will meet bottlenecks due to hysteresis caused by the fluorescence substance, inter-symbolic interference effect, etc. Anyway, VLC has provided a new sophisticated indoor networking-access which is often the last few feet to where we live and work. The difficulties we feel troublesome in VLC today, are expected to be overcome in the near future.

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