Pulse Position Modulation characterization for indoor visible light communication system

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Abstract. Visible light communication (VLC) systems which employ visible light for communication is one of a promising technology for 5G due to its high bandwidth, efficient power consumption and higher security. In VLC, typically LEDs are used as a light source for transmitting information and providing illumination simultaneously. The intensity of the light is modulated at a very fast speed which is undetectable by human eyes. This paper explores the performance of two types of single-carrier modulation schemes suitable for VLC, namely OOK and PPM based on power, path-loss and data rates. The performance of unmodulated signal is also included for comparison purposes. The maximum distance achievable for each modulation schemes are recorded. It is shown that PPM has a superior performance compared to OOK in terms of the transmission distance and path loss, while OOK was excellent choice for highest data rates.

1. Introduction
The rapid advancement of solid-state technologies has stimulated the revolution in visible LEDs for illumination. Nowadays, the traditional light sources such as incandescent and fluorescent lamp are being switched to LEDs, which have several advantages. LEDs have longer lifetime of 50,000 hours, minimum generated heat, low power consumption, high brightness, better reliability, small in size and environmentally friendly, compared to other wireless competitors [1]. This trend has created a unique opportunity to use the LEDs as a data transmission device as LEDs have a high modulation bandwidth (up to 100's of MHz) [2]-[3]. This technology where light served as lighting and data transmission is known as visible light communication (VLC). Historically, this idea was introduced by a group of researchers from Keio University [4]. To standardize the technology, Visible Light Communication Consortium (VLCC) was established in 2003 by Nakagawa laboratories with collaborations with CASIO, NEC and TOSHIBA in Japan [5]. VLC is suitable for short-range applications such as indoor environment since the path loss is very high. It is also preferable in places where electromagnetic interference is avoided. Some application examples include high-speed data communication via lighting infrastructures in offices, hospitals, aeroplane cabins and vehicle-to-vehicle communication.
This paper compares the performance of two low-level modulations schemes namely (1) On-Off Keying (OOK) and (2) Pulse Position Modulation (PPM), along with the unmodulated scheme for comparison purposes. Section 2 provides the background of VLC system which includes the concept of IM/DD, modulation schemes and a brief overview of transmitters and receivers. Section 3 describes the circuit design used in the experiment. Section 4 presents the results and discussions and Section 5 concludes the paper.

2. Background
The implementation of VLC is based on Intensity Modulation/ Direct Detection (IM/DD) where the light source intensity is modulated with the signal and direct detection-based photodetector is used to recover the signal. Basic block diagram representing the IM/DD concept is shown in Figure 1. The light to be transmitted is modulated by the drive current. This modulated light propagates through the channel such as an indoor environment. At the receiver, the modulated light will be detected and current recovered to get the original data [6].

![Figure 1. The concept of IM/DD [6].](image)

Two major challenges for VLC data transmission are flickering improvement and dimming sustainability in order to provide optimum data rates. Flickering results from fluctuation in modulated light intensity should be minimized to an optimal fluctuation number, based on the rules that maximum flickering time period (MFTP) should be less than 5 to escape any unsafe impacts [7]. Thus, the modulation process in VLC is not able to initiate any unnoticeable change in power intensity.

2.1. Modulation
In principle, VLC can use various modulation schemes, either single-carrier or multi-carrier modulation. Single-carrier modulation highlights OOK, PPM, pulse width modulation (PWM), M-ary pulse position modulation (M-PPM), variable On-Off Keying (VOOK) and (2) Pulse Position Modulation (PPM) and variable pulse amplitude position modulation (VPAPM).

OOK is widely used due to its simplicity and feasible implementation. A bit one is represented by an optical pulse and bit zero is represented by the absence of an optical pulse. In this paper, the OOK modulation used refers to Non-Return to Zero (NRZ) OOK. The review of the OOK modulation has been discussed in [8]-[9] with 3.5 kbps at transmission distance between 20 – 45 cm.

Another low-level modulation considered is PPM, in which the information is represented by the position of the pulses within fixed time frames. Even though the power efficiency of both schemes is the same, PPM has a low bandwidth efficiency and a more complex system. Figure 2 shows the waveform comparison between OOK and PPM.
Research on other advanced modulations scheme that utilizes several variations of PPM are also proposed such as multilevel PPM (MPPM) and Differential PPM (DPPM), as well as carrier-less amplitude and phase modulation (CAP), optical spatial modulation (OSM) and colour shift keying (CSK) are also ongoing. In order to improve the bandwidth efficiency [7]-[12].

2.2. Transmitter

Typically off-the-shelves LEDs are preferred as a light source as it is more economical and generally considered eye-safe. Most of the white LEDs are either Phosphor-based LEDs or red, green blue (RGB) LEDs. The modulation bandwidth of LEDs based on phosphor are limited to 10s of MHz only due to the fact that phosphor has a slow response [7]. A higher modulation bandwidth can be achieved using RGB LEDs. However, it is more complex and costly [8]. Recently, LD is proposed to be used as the light sources for VLC as LDs can provide higher optical power output and larger modulation bandwidth [9]. However using LDs as the light source is still under study due to few challenges in terms of health and safety issues, cost as well as complexity [1].

2.3. Receiver

VLC receivers convert the received light to current and will be processed further by the receiver system. The main requirement for a good receiver includes high sensitivity, high bandwidth and low complexity. Typically, the common receiver used are PIN photodiodes or avalanche photodiodes (APDs). PIN diodes are widely used due to its low bias voltage requirements. Although APDs have better sensitivity compared to PIN photodiodes, however it requires higher complexity circuits and higher reverse bias voltage requirements [7].

3. Methodology

In this section, the transmitter and receiver circuit design for both OOK and PPM is presented. The measurement was done in two conditions: (1) under a controlled environment (in the dark), and (2) under normal room environment (with the presence of ambient light). Three different types of transmitter circuit used as described below. Although the circuit configuration is different, the same off-the-shelves optical source and PIN photodetector was used throughout this experiment.

3.1. Transmitter circuit

3.1.1. Transmitter circuit for unmodulated transmission. Simple forward bias transmitter circuit as in Figure 3 was used. The input frequency is 1 kHz.

3.1.2. OOK Transmitter. Figure 4 shows the transmitter circuit for OOK modulation. The input frequency is 1 kHz. The 555 timer is used to convert the input sine wave to the square wave, in astable mode. The carrier signal is set at 7.083 kHz in order to avoid the LED from flickering. The carrier signal of 7.083 kHz is computed using the equation given as
3.1.3. PPM Transmitter. Figure 5 shows the transmitter circuit for the PPM modulation scheme. The PPM signal can be generated from Pulse Width Modulation (PWM) waveform which has been modulated according to the input signal waveform.

\[ f = \frac{1.44}{(R_d + 2R_s)C} \]  

(1)

**Figure 3.** Transmitter circuit for the unmodulated scheme.  
**Figure 4.** Transmitter circuit of for the OOK modulation scheme.  
**Figure 5.** Transmitter circuit of the PPM modulation scheme.
3.2. Receiver
Receiver circuit for unmodulated and OOK transmission is as shown in Figure 6, and the receiver for PPM transmission is shown in Figure 7. Two amplification process was done for both circuits.

![Figure 6. Receiver circuit for unmodulated and OOK modulation scheme.](image)

![Figure 7. Receiver circuit for PPM.](image)

4. Results and Discussion
Figure 8 to 10 represented the results from the measurement under two different experimental setting. Clearly, it can be seen that the PPM system manage to achieve the longest transmission distance compared to OOK and unmodulated scheme. With the presence of ambient light, the distance can reach up to 2 m while OOK and unmodulated scheme is limited to 1 m. A similar observation is shown under controlled environment. The attenuation level varies from 0.7 (unmodulated), 6.8 (OOK) and 3.6 (PPM) at 0.1 m, while for 1 m transmission the attenuation level varies from -12.1 (unmodulated), -5.6 (OOK) and 0.3 (PPM).
Figure 8. Output Voltage vs Distance between Transceiver Circuit in Three Different Conditions (Light On)

Figure 9. Output Voltage vs Distance between Transceiver Circuit in Three Different Conditions (Light Off)

Figure 10. Attenuation and output waveform for (a) unmodulated transmission, (b) OOK, and (c) PPM.
Table 1. Overall Achievement for Three Different Conditions

|                | Maximum Distance between the Transceiver Circuit (m) | Data Rate (kbps) |
|----------------|-------------------------------------------------------|------------------|
|                | Light on | Light Off |                                  |                  |
| Simple Unmodulated System | 0.90 | 1.40 | 2.20 ~ 2.30 |                  |
| OOK System     | 1.00 | 1.70 | 15.50 ~ 15.70 |                  |
| PPM System     | 2.00 | 3.20 | 11.00 ~ 13.00 |                  |

Based on the same luminous intensity, data capacity for the three under test circuits are shown in Table 1. The OOK receiver received more data compared to the PPM system. As such, maximum data capacity for OOK was 15.559 kbps compared to PPM which obtained 13.349 kbps. Consequently, the transmission distance is vice-versa. By referring to the output waveforms the transmitted frequency is greater compared to the PPM system. This proved that OOK had high transmitting frequency, thus resulting in higher maximum data capacity that being transferred in 1 second.

5. Conclusion

In this paper, we experimentally compare the performance of two types of modulation schemes OOK and PPM, with the unmodulated transmission. Performance analysis based on single LED, confirms that OOK performed best for shorter distance, while for PPM could possibly be used with limited data rates. The luminous intensity of the single LED also plays an important role in this study. The transmission distance and data rates increase as higher luminous intensity used.

Acknowledgements

The author would like to thank Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka for the facilities used to complete this project. This work was supported by PJP/2018/FKEKK(8A)/S01621 grant.

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