Solar panel receiver characterisation for indoor visible light communication system

AM Zaiton¹, HR Muhammad¹ and F Jasman²

¹Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka.
²Institute of Nano Optoelectronics Research and Technology (INOR), Universiti Sains Malaysia.

zaiton@utem.edu.my

Abstract. Visible light communication (VLC), where light is used for illumination and communication simultaneously is considered as one of the enabling technology for the fifth-generation (5G) communication standards. Recently energy harvesting capabilities is proposed to be integrated into VLC system by employing a solar panel as the photodetector instead of using the commonly used photodiode. In this paper, an experiment is conducted to analyse the performance of two types of photodetector at the receiver namely a photodiode and a solar panel. First, the transmitter and receiver circuits are built for both unmodulated scheme and modulated scheme using On-off keying (OOK). The performance of unmodulated scheme is included for comparison purposes. It is shown that the transmission distance obtained by using photodiode is better than the solar panel.

1. Introduction

Optical wireless communications (OWC) is seen as the potential technology for high-speed wireless communication that can alleviate the congestion in the RF spectrum. This technology is a form of optical communication in which unguided visible, infrared (IR), or ultraviolet (UV) light is used to carry information. In addition to the high speed that it offers, it has several other advantages such as large amount of unregulated bandwidth, no interference with electronic equipment and high security [1].

One of the subsets of OWC is visible light communication (VLC) where the visible spectrum (350 nm-700 nm) is used for short-range communication such as for indoor environment. In VLC, light is simultaneously used for communications and illumination [2]. This is done by modulating the visible light at a very fast speed which is undetectable by human eye. Typically, light-emitting diodes (LEDs) are used at the transmitter as the existing illumination infrastructure is shifting towards LED-based lamps. This shift is motivated by the advances in solid-state lighting which produces LEDs that are more efficient and economical compared to traditional light such as fluorescent lamp. For example, the lifetime of LED lamps is estimated to be around 50 000 hours whereas the lifetime of incandescent lamp is only around 15 000 hours only [1].

Recently, the concept of energy harvesting which is popular in RF communications is proposed to be embedded in VLC systems. This integration where the same VLC system has the capabilities of illumination, communication and energy harvesting is expected to enable and accelerate the advancement of Internet-of-Things (IoT) applications and technologies. It is first proposed in [3]
where an experiment is conducted to investigate the feasibility of using a solar panel as the photodetector and energy harvesting device. It is shown that energy harvesting can be done simultaneously with communication without degrading the communication performance. The generated energy from the solar panel can be used as a power supply for the photodetector itself or even other devices. Recently, a bandwidth of 24.5 MHz is demonstrated for GaAs photovoltaic (PV) cells which enable a data rate of 0.5 Gbps [4].

Thus, with the promising results shown earlier, this paper aims to investigate the use of solar panel as the receiver in VLC system. The research study the performance comparison of three different receivers, using (a) 570 nm PIN photodiode, (b) 1 V solar panel, and (c) 5.5 V solar panel. The performance was compared based on power, transmission distance and field-of-view (FOV) of the receiver, under two measurement conditions: (1) controlled environment (in the dark), and (2) normal room environment (with the presence of ambient light). Section II reviews the various devices that are used as the optical sources and receivers highlighting their advantages and disadvantages. Section III presents the circuit design for transmitter and receiver circuit. Section IV discusses the results and analysis of the experiment conducted and section V concludes the work.

2. Background

2.1 Optical Sources

The most commonly used light sources for OWC are LEDs and laser diodes (LDs). For indoor VLC systems, LEDs are preferred compared to LDs due to safety factor, cost and simplicity [2]. However, the modulation bandwidth of an LED can only reach up to several MHz. Thus, various techniques have been investigated in order to improve the modulation bandwidth. At the device level, works on increasing the bandwidth of the device are by developing LEDs with dimension of less than 100µm (‘µLEDs’) where a bandwidth of several hundred of MHz can be achieved [5].

In parallel with the extensive works at the device level, various techniques at the system level have been employed to improve the data rates of the VLC communication system which includes spectrally efficient modulations and coding, advance signal processing and multiplexing techniques [6]. For example, in [7] a data rate of 15.73 Gbps is achieved in VLC systems utilizing the off-the-shelf LEDs employing wave division multiplexing (WDM) with forward error coding. In addition to that, orthogonal frequency division multiplexing (OFDM) with adaptive bit loading is also utilized to improve the spectral efficiency of each LED.

As an alternative to LEDs, LDs is proposed as the light source in VLC due to its inherent high modulation bandwidth and high coherent source enabling high speed and efficient communication system. LDs also do not suffer from the decrease in efficiency at high current densities as exhibited by LEDs. In [8] a data rate of 100 Gbps has been demonstrated in LD based indoor VLC. However, much work needed in order to assess the implementation of LDs in VLC due to the higher cost and health and safety issues [9].

2.2 Optical Receivers

At the receiver of the VLC system, the widely used photodetectors are based on photodiodes. Typically, photodiodes (PDs) such as p-type-insulator-n-type photodiode (PIN-PD) or avalanche photodiode (APD) are used as the photodetector in VLC systems due to its fast response time, high quantum efficiencies and cheap cost. The APD provides a higher gain compared to PIN-PD at the expense of higher noise [1].

In addition to that, the use of solar panel and image sensors is gaining attention recently. The limitations of both devices are in the low bandwidth that it can support. Amidst that, the solar panel has been proposed to be used at the receiver VLC systems as it is capable of simultaneous energy harvesting and communication. Another advantage of the solar panel is, it does not require an additional power supply and complex circuitry at the receiver (wang2014). Various other advanced
optical receivers such as silicon photo-multipliers (SiPMs), perovskite PD has been proposed and investigated [10][11].

3. Methodology
In this section, the transmitter and receiver circuit used in this study is presented. 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
Two transmitter designs used namely (a) basic unmodulated transmitter, and (b) OOK transmitter. Figure 1 shows the transmitter circuit for OOK modulation with 1 W high brightness LED. OOK is the simplest and widely used modulation scheme for the optical wireless communication system. 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 same transmitter circuit is used for consistency of the transmitted signal.

![Figure 1. OOK transmitter circuit](image1)

3.2 Receiver Circuits
The receiver design used as shown in Figure 2. Receiver design for OOK transmitter is the same except the photodiode is being replaced with solar panel. Two amplification process was done at the receiving end to boost the received signal.

![Figure 2. Receiver circuit](image2)

To evaluate the transmission angle on the receiving end, the transmitter was moved from 0° to 180° in a step of 30° difference, while the receiver is placed at a fixed location, spaced 50cm apart from each other.
4. Result and Discussion

Figure 3 (a) and (b) illustrates the performance comparison between 3 receivers using PIN photodiode, 1V solar panel and 5.5V solar panel, for two transmission conditions namely unmodulated transmission and OOK transmission. The measurement was done in lights OFF condition for controlled environment (represented by dotted lines) and in lights ON condition with the presence of ambient light (represented by solid lines).

The finding shows that the PIN photodiode performed better compared to solar panel 1V and 5.5V in terms of received power, which directly related to transmission distance for both of transmission conditions. The result is the same for either in light ON environment or light OFF environment. It can be concluded that photodiode has a better performance compared to the solar panel for both unmodulated transmission and OOK transmission.

Transmission angle for the photodetector is illustrated as in Figure 4. PIN photodiode is the photodetector with 60° FOV, while the solar panel is considered as a wide FOV receiver. Based on the figure, the PIN photodetector received high optical power compared to solar panel. In the PIN photodiode, the incident optical power of a smaller FOV is concentrated on the area of photodetection. Conclusions made was as wider the FOV of the receiver the more noise being collected from ambient light as background noises, thus affect the measured power received. However, the size of the detection area is also important, as smaller receiver FOV angle frequently leads to blind spots and restricts the transmission performance.

Various bitrate measurements were obtained at different transmission distance, ranges from 3–6 kbps.
Figure 4. Transmission angle for three types of photodetector for (a) unmodulated and (b) OOK transmission

5. Conclusion
The study investigated the performance of three types of photodetector for the optical wireless transmission system, namely PIN photodiode, 1 V solar panel and 5.5 V solar panel, in terms of transmission distance and transmission angle. Smaller FOV optimized the receiver performance. Thus, this concluded that the best photodetector is PIN photodiode. Although solar panel could work and meet the purpose of receiving transmission signal, the performance is still far behind PIN photodiode. The photodiode may have the advantage, as photodiode is mainly designed to detect light, rather than the solar panel that specialist of absorbing heat from the source of light. However, there is ongoing research to improve solar panel, and possible to use as dual purpose for optical detection as well as energy harvesting. Future work will consider the use of optical concentrator and laser diode for better performance.

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