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Light Emitting Diode Simulation using MATLAB for Visible Light Communication

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Abstract

This work focuses on Visible Light Communication (VLC), which designs and optimizes LED-based communication systems utilizing MATLAB simulations and light-emitting diodes (LEDs) circuit. Designing LED and photodiode circuits with components such as current-limiting resistors is the first step in this study. Then, LED brightness variations are used to encode digital information by combining ASK and PSK modulation. In evaluating the designed VLC system performance, signal of the designed photodiode circuit has been compared to the input signal of the designed LED circuit. Referring to PSK modulation signal as input signal of the VLC system, it requires setting signal parameters of the amplitude and frequency, while for ASK modulation only includes adjusting the duration of the signal. Due to these modulation schemes and as an effective 2-bit and 4-bit data transfer, the study examines modulation situations focusing on amplitude, frequency, and signal statistics changes. The results reveal that intentional modifications to signal characteristics maximize data transport, demonstrating the circuits' flexibility to accommodate varying data sizes and modulation techniques.

1. Introduction

The advancements in LED technology have opened new opportunities for environmental lighting. The numerous benefits of LEDs compared to traditional incandescent sources, including reduced energy consumption, extended lifespan, increased physical robustness, compact size, and fast switching, have led to their widespread adoption in various applications. LEDs have become omnipresent, being used in various applications such as electronic board advertising, traffic signals, camera flashes, automotive headlamps, and general lighting. The swift switching capabilities of LEDs have not only transformed conventional lighting but have also accelerated its usage in state-of-the-art communications equipment. Visible Light Communication (VLC) is a prominent example in which the visible light spectrum and the infrastructure of white LEDs come together. VLC has several unique advantages from ecological and human health perspectives; and the optical range is free from regulation [1]. VLC operates inside the optical wireless communication domain, utilising the wavelength range of 380 to 750 manometers, which corresponds to a frequency range of 430 to 790 terahertz. VLC's property makes it an attractive option to Radio Frequency (RF) communication by circumventing bandwidth limits. Switching properties of LEDs in the visible spectrum are considered as the most important constraint that has a rapid capability to be switched on and off because of which it makes it possible to analyse data through impression on the human eye with their radiated power and optical intensity [2]. This work has two main objectives: to explore the potential of VLC (Visible Light Communication) and to utilise MATLAB for controlling the brightness of LEDs (Light Emitting Diodes). The work seeks to obtain valuable information about the impacts of manipulating LED brightness via amplitude modulation, altering colour using colour shift keying, and adjusting phase through phase shift keying. This comprehensive investigation examines the interaction between visible light and data transmission, providing a nuanced comprehension of the prospective uses and developments in VLC technology.

2. Methodology

2.1 Circuit Design in MATLAB Simulink

The circuit in Fig. 1 features 1-ohm resistors to protect the LED and photodiode from excessive current. The LED operating at a voltage range of 1.6 to 2.4 volts, serving as the primary light source for encoding ASK and PSK signals through controlled voltage adjustments. The photodiode, with a current specification of 50mA and 2 volts voltage converts emitted light into an electrical current proportional to intensity. In this VLC system circuitry, signal flow starts with ASK or PSK signal creation, conveyed to a controlled voltage source modulating LED brightness. Both the signal is being tested using 1 Hz frequency to get an immediate confirmation of the data transmission. The power supply gain block ensures sufficient power for modulated light emission. The modulated wave controls the LED circuit and the resulting signal, which mimics the modulated waveform, powers the LEDs [3]. The LED encodes the signal into light with varying intensity. The photodiode strategically converts emitted light into an electrical current, quantified by a voltage sensor. The photodiode is used to receive the optical signal that is transmitted by LEDs [4]. A scope visually presents the photodiode's voltage signal, offering a comprehensive platform for data visualization and analysis, concluding the VLC system's signal flow.

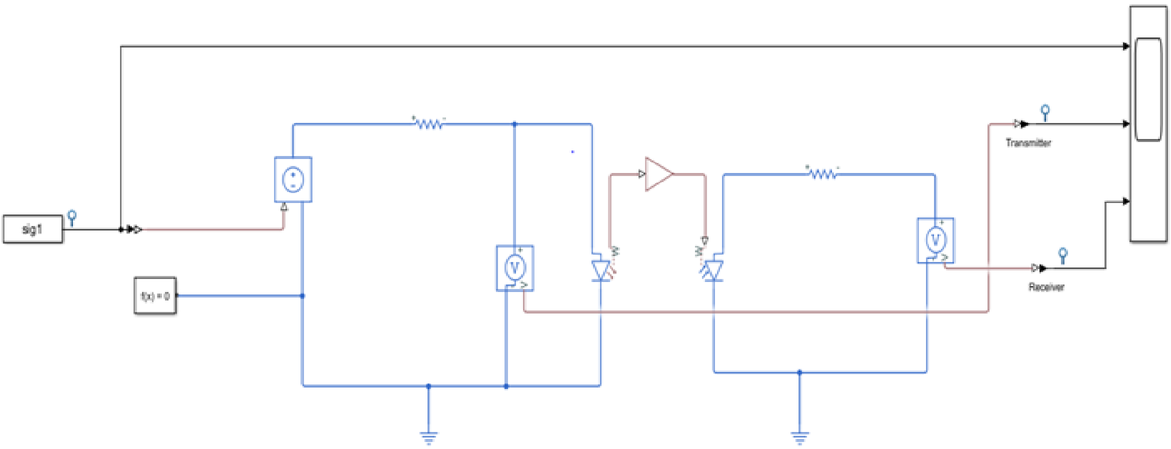

Fig. 1 *VLC system Diagram utilizing LED and Photodiode Circuit*

2.2 Amplitude Shift Keying Signal

Fig. 2 shows ASK signal generation flowchart where it begins with initializing values for the critical parameters of the-ASK signal, which include carrier frequency, pulse frequency, bit count, bit duration, and total signal time. It then produces a high-frequency carrier signal higher than the data frequency, which is necessary for ASK modulation. Based on this flowchart, after the carrier signal is generated, the binary message signal can be generated by altering the carrier signal's temporal dimension and using alternating amplitude levels to represent binary data. The total signal length is then determined by adding padding bits. The ASK signal is produced at the end of the flowchart by multiplying the carrier and binary message signals. This produces a modulated signal ready for transmission, with amplitude changes signifying encoded binary data that will be retrieved and communicated in the future.

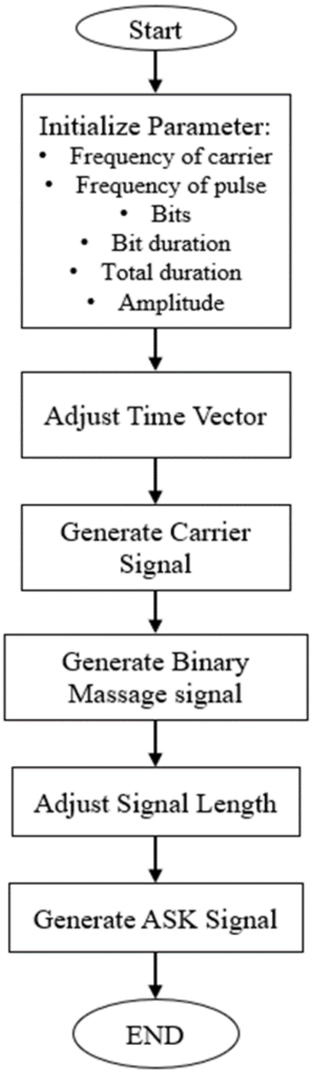

Fig. 2 *ASK Signal Generation Flowchart*

2.3 Phase Shift Keying Signal

The process of PSK modulation signal generation in this study is as shown in the flowchart of Fig. 3. The flowchart specifies important signal parameters such as bit rate, symbol rate, and the chosen PSK modulation. Next, it generates PSK data, which converts binary streams into symbols that can be modulated. Subsequently, the carrier signal, typically a sinusoidal wave can be adjusted its' amplitude and frequency by the data signal. The PSK modulation process, as illustrated in the flowchart, can emphasize the phase alignment of the carrier signal with the PSK data symbols. Information is encoded via discrete phase changes. To ensure discrete encoding, separate PSK modulation signals are generated for each data stream. The last step in this PSK signal generation system is to combine these modulated subcarriers into a composite signal prepared for transmission. This allows for effective and simultaneous data transfer.

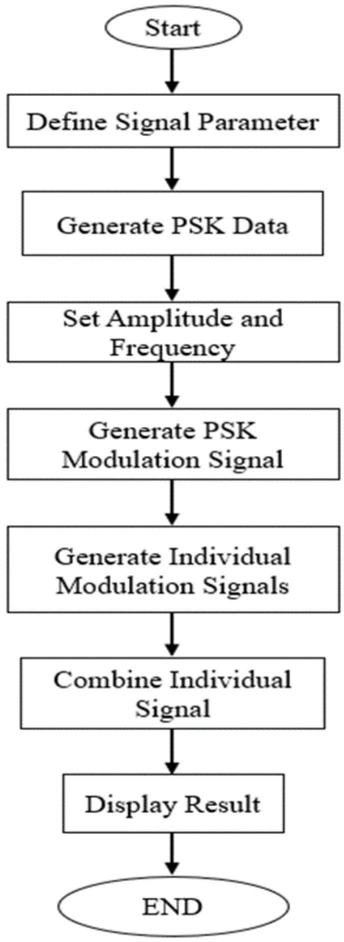

Fig. 3 *PSK Signal Generation Flowchart*

3. Results and Discussion

3.1 2-bit Amplitude Shift Keying Data Signal

The characteristics of the ASK signal in the designed VLC circuit system of this study intended for transferring 2-bit data over 10 seconds are shown in Table 1 both before and after transmission of the modulation signal. The waveform's timing and precision hold up during transmission, even when its amplitude significantly decreases. Path loss, high-frequency noise, and possible differences in LED and photodiode efficiency are the reasons for the amplitude drop. Strategic actions like modifying the transmission distance, boosting LED power, putting circuit protection in place, filtering mechanisms, and enhancing LED and photodiode characteristics are advised to improve this VLC transmission system. Differences in amplitude and signal statistics between an ASK transmitter and receiver point to possible problems with signal intensity, attenuation, or interference that need to be fixed for better signal transmission system performance. Fig. 4 shows the 2-bit ASK signal received by the designed photodiode circuitry in this study, which is clearly able to distinguish between the signal of '0's and '1's.

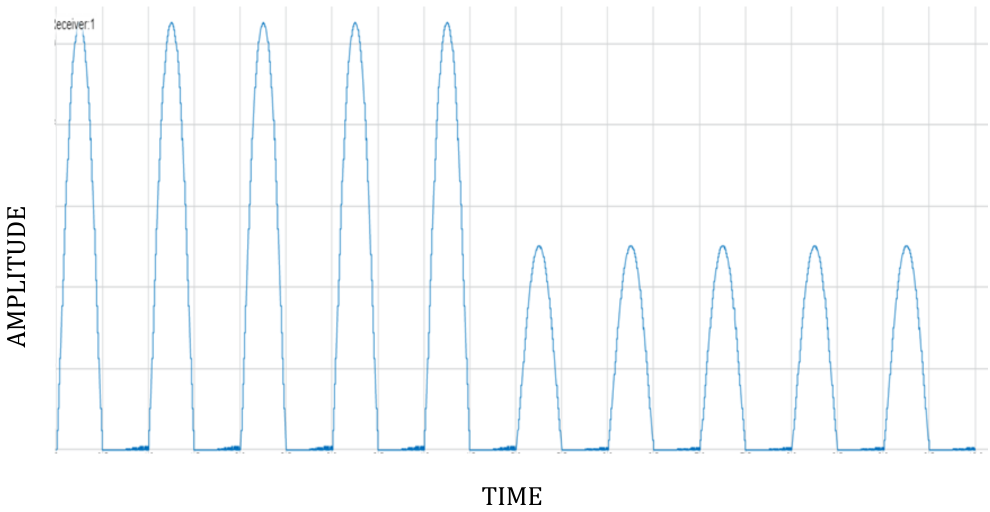

Fig. 4 *2-bit ASK Signal After Transmission*

Table 1 *ASK Before and After Transmitting 2-bit Data*

	ASK Transmitter	ASK Receiver
Amplitude	3.25V	1.042V
Frequency	1.000 Hz	1.000 Hz
Signal Statistic		
Max	8.663V	1.051V
Min	-8.999V	0V
Peak to Peak	17.660V	1.051V

3.2 4-bit Amplitude Shift Keying Data Signal

The features of ASK signal before and after VLC system transmission using the designed LED and photodiode circuit intended for 4-bit data transmission are shown in Table 2. Upon closer inspection, a slight waveform distortion in the received signal is seen as shown in Fig. 5, suggesting that the system may be non-linear or have clipped. Furthermore, there is more noise in the received signal, which could indicate interference from nearby lights or electrical disturbances. Thankfully, there is acceptable time coordination between the transmitted and received signals. On the other hand, amplitude and frequency parameters differ significantly between the ASK transmitter and receiver. The frequency difference is significant, with the transmitter's amplitude being 3.782V and the receiver being noticeably lower at 1.041V. To improve signal quality in the ASK system, more research is required to minimize distortions and reduce noise. Signal statistics further highlight the difficulties in maintaining amplitude and frequency between the transmitted and received signals.

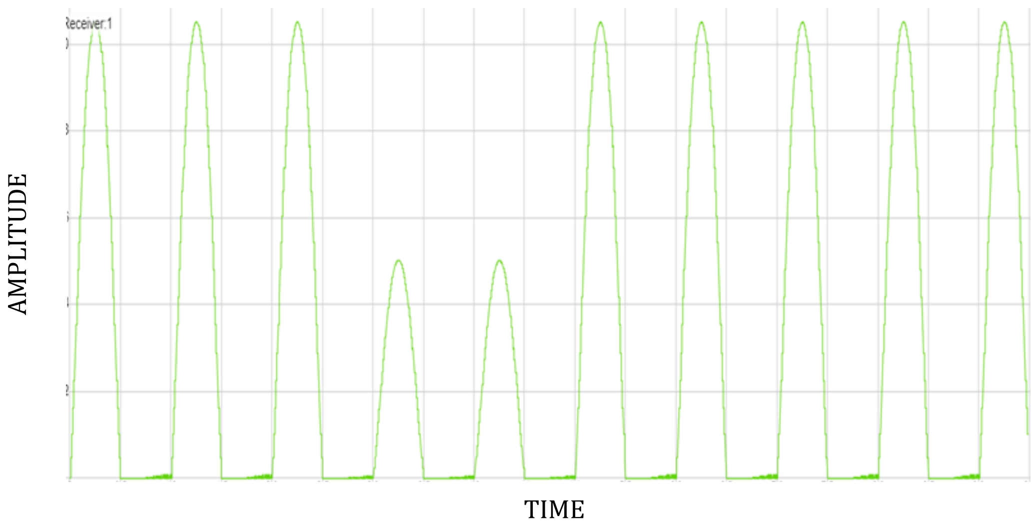

Fig. 5 *4-bit ASK Signal After Transmission*

Table 2 *ASK Before and After Transmitting 4-bit Data*

	ASK Transmitter	ASK Receiver
Amplitude	3.782V	1.041V
Frequency	1.000 Hz	777.778 mHz
Signal Statistic		
Max	8.663V	1.051V
Min	-8.999V	0V
Peak to Peak	8.660V	1.051V

3.3 2-bit Phase Shift Keying Data Signal

A significant attenuation in the received signal is depicted in the Fig. 6 data, which shows PSK signal characteristics before and after modulation in the VLC system communication circuit designed in this study. This is confirmed visually and quantitatively by a notable decrease in amplitude from the transmitter's 1.00V to the receiver's 0.84V as can be seen in Table 3. The receiver's frequency of 1.222Hz is 22.2% higher than the transmitter's frequency of 1Hz, indicating a slight frequency shift. The general signal form seems to be retained despite attenuation and frequency shift, suggesting the possibility of successful demodulation. Aligning the receiver's peak-to-peak value with the anticipated attenuation and the requirement for further noise level and phase distortion analysis to conduct a thorough evaluation of signal quality are other factors to consider. Significant variations, particularly in amplitude and frequency, between the PSK Transmitter and Receiver signals are seen in Table 3, indicating possible difficulties in preserving signal characteristics in the PSK system.

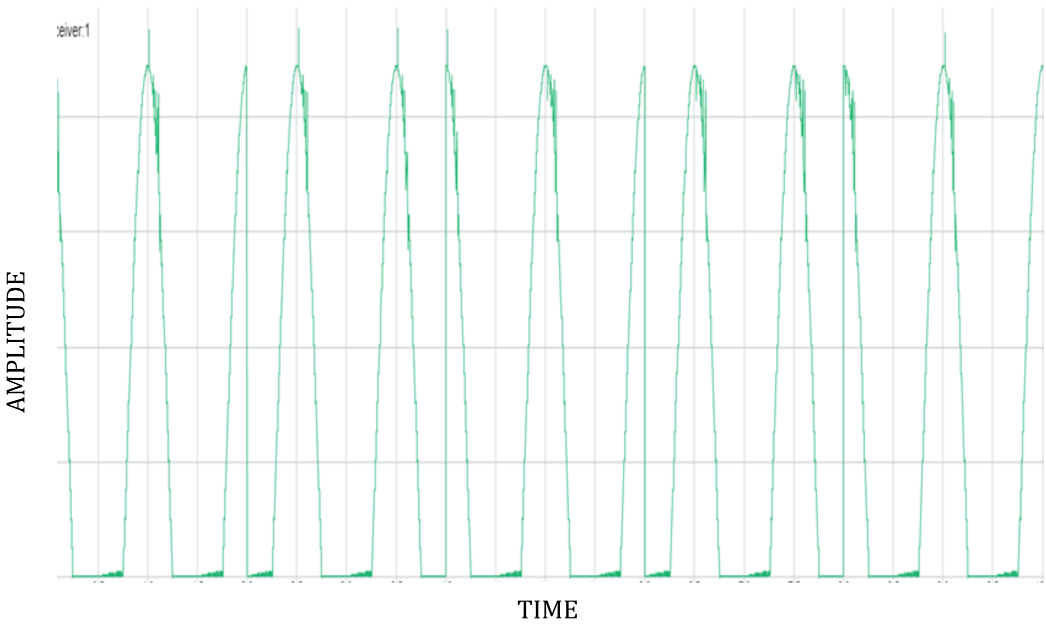

Fig. 6 *2-bit PSK Signal After Transmission*

Table 3 *PSK Before and After Transmitting 2-bit Data*

	PSK Transmitter	PSK Receiver
Amplitude	1.00V	0.84V
Frequency	1 Hz	1.222 Hz
Signal Statistic		
Max	0.999V	0.95V
Min	- 1.000V	0V
Peak to Peak	1.999V	0.96V

3.4 4-bit Phase Shift Keying Data Signal

Fig. 7 shows 4-bit PSK signal after transmission. A VLC system circuit's signal statistics analysis in this study shows apparent post-modulation alterations using an LED transmitter and a photodiode receiver as given in Table 4. As the maximum value rises, LED based signal modulation for information transmission causes the signal to become stronger. A shift from 1.00V to 0.00V for the minimum value is consistent with the modulation strategy. The post-modulation peak-to-peak value drop indicates changes in frequency and amplitude that are directly related to the modulation method. The higher Root Mean Square (RMS) value suggests variations in signal strength, which illustrates how modulation dynamically affects the overall VLC signal properties—reduced peaks and valleys in the receiver signal during the PSK transmission analysis point to a decrease in signal intensity during transmission. Despite this, the signal stays around zero, indicating little background noise and ideal demodulation circumstances. Differences in amplitude and frequency preservation between the PSK transmitter and receiver highlight the difficulties in preserving signal characteristics in the PSK system.

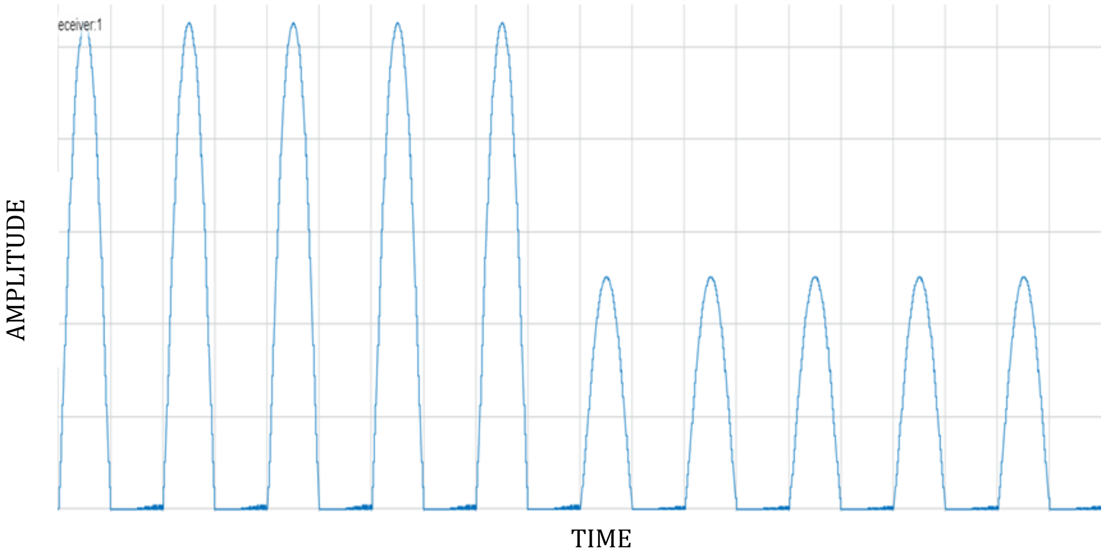

Fig. 7 *4-bit PSK signal after transmission*

Table 4 *PSK before and after transmitting 4-bit data*

	PSK Transmitter	PSK Receiver
Amplitude	3.25V	1.042V
Frequency	1.000 Hz	1.000 Hz
Signal Statistic		
Max	8.663V	1.051V
Min	-8.999V	0V
Peak to Peak	17.660V	1.051V

4. Conclusion

By the end of this study, the VLC circuit had been designed successfully using MATLAB Simulink to analyze the ability of the VLC system to transmit data in true light. A basic VLC system consists of a light source, free space, and a light detector. Generally, light-emitting diodes (LEDs) are the light sources and photodiodes (PDs) are the light detectors [5]. Completing the VLC circuit design, where the LED acts as a transmitter and the photodiode acts as a receiver. The visible light communication system has been simulated with an amplified shift keying signal (ASK) and phase shift keying signal (PSK) using the MATLAB Simulink software. Finally, the simulation result has been analysed and is able to show the visible light communication system performance on the output signal received by the communication system. The visible light communication circuit using MATLAB with LED and photodiode with 2 different signals and 2 different data types has shown the evolution of wireless communication's better performance and effectiveness.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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