



# Audio SIMO system based on visible light communication using cavity LEDs

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## Abstract

The necessity for access to a high data rate has been the motivation behind expanding new technologies. The increasing of wireless devices has caused the radio wave spectrum to become congested. Additionally, radio waves cannot be used in EMI-vulnerable places. Hence, the interest in visible light communication (VLC) offers real alternatives to radio-based communications. This paper focuses on the use of visible light as a data communication medium and introduces a designed audio SIMO (Single-Input-Multi-Output) data transmission system from point to multipoint to demonstrate the functionality of the VLC system in audio transmission through modulated LEDs light. The system is made up of the transmitting unit and multi-receiving units. The transmitting unit consists of three stages: audio in, preamplifier, and white LEDs array that transmits the data using the ON-OFF keying (OOK) modulation technique to all receivers. On the other hand, the receiving unit consists of three receivers that have different photodetectors aspects with fixed distances separation between them. The line of sight (LOS) communication between transmitter and receivers for the purpose to transfer audio data has been employed. Based on the LOS link, simulation and experimental analysis have been done in multiple semi-angles for studying the output performance of receivers and the characteristics of the white LEDs such as luminous intensity and received power at 20,45 and 70 semi-angle at half-power through MATLAB® software.

**Keywords** Optical Wireless Communication (OWC) · Visible Light Communication (VLC) · Li-Fi · Data communication · Audio signals transfer · Light Emitting Diode (LED)

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# 1 Introduction

Recently, there has been an increased demand for wireless electronic communication. This wireless data communication is allotted on low frequency (below 10 GHz). Because of increased demand, the provided spectrum has become insufficient. Though the wireless communication industry had considered using a radio-frequency spectrum above 10 GHz, there was a significant drawback. For higher frequencies ( $f$ ), the path loss ( $L$ ) increases. Also, the free and undisturbed propagation of high frequencies is difficult in a very terrestrial kind of communication, where wireless data transmission has been achieved through radio frequency (RF) spectrum in the range of 3 kHz to 300GHz [9]. But wireless communication uses radio frequency including problems like path loss, energy loss, and interference. So a new source for transmitting the data is required. Optical wireless communication (OWC), which offers practically limitless bandwidth and includes infrared (IR), visible light (VL), and ultraviolet (UV) that can be used for communications purposes and offers unique opportunities, is one possible alternative complementary technology that may address and overcome these problems. OWC technology will operate in an unregulated spectrum, requiring no licensing, and providing a low-cost option for a variety of applications. [12]. Visible light which is a source of electromagnetic energy can be used as an alternative to RF communication. In comparison to the RF spectrum, the visible light spectrum is 10,000 times larger. It uses light emitted from LEDs as an optical carrier which LED can be switched off and on faster than it can be perceived [7, 8]. Visible Light Communication (VLC) operates in the visible bands of (780 nm) 400 THz and (375 nm) 800 THz, as indicated in Fig. 1. VLC is one of the most promising new wireless communication technologies for the next generation. That uses light as a carrier for data transmission and illumination [14, 17]. It uses fast pulses of light to transmit information wirelessly. It's possible to appreciate illumination and data transfer simultaneously through Light Emitting Diodes (LEDs) are the most popular lighting equipment days. Without the use of an additional communication system, both internal lighting and data transfer can be accomplished. [5].

Nowadays, energy conservation and emission reduction are significant challenges that social development must be faced. Among these challenges, is Light Emitting Diode(LED) (as a strategic emerging green light source in the field of lighting. In actual lighting applications, since the power of signal LED lamp bead is difficult to meet the requirements, almost all lighting equipment use multiple LED combinations to form an array to meet the illumination brightness, access to a VLC system that provides higher signal powers and ensures a high level of security where light cannot go through opaque objects confers a security aspect to VLC [15]. From the fast development of LED on its material, VLC

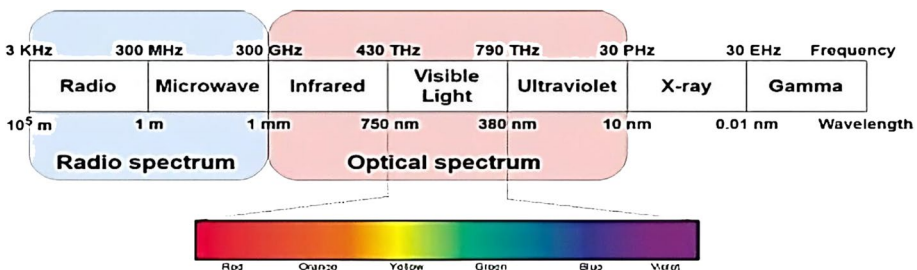


Fig. 1 Electromagnetic spectrum

has adopted remarkably with impressive progress in the field of communications [11]. Unlike communication technology using Radio Frequency (RF), has overcome some issues on limited bandwidth, security, and power consumption [3, 12]. For these challenges, this paper uses such technology.

Modulation methods are used in VLC systems to incorporate data into the intensity of the light source acting as a transmitter. Modulation techniques are required so as the communication continues to be available even illumination isn't required [10]. As a result, a modulation technique could enable dimmable illumination. The knowledge contained in the message signal is represented by variations in light intensity. Figure 2 shows the modulation methods that use VLC technology.

ON-OFF Keying (OOK) modulation is used to transmit information in this paper due to its simplicity and low implementation costs as well as the fact that it allows the transmitter to rest during the transmission of a “zero,” saving power.

VLC includes any use of the visible light region of the electromagnetic spectrum to transmit data. In his TED Global Talk, professor Harald Haas the chair of mobile communications at the University of Edinburgh proposed an alternative to Wi-Fi and developed a new technology called Li-Fi. Li-Fi is a data transfer technique that uses visible light rather than the usual radio communication Wi-Fi [10]. It transmits data using LEDs that vary in intensity faster than the human eye can follow, employing a visible light spectrum that is rarely used.

Li-Fi relies on a light by using white LED light bulbs. Typically, lighting is provided by these devices utilizing a steady current. Nevertheless, tiny but quick changes in the current can change the optical quality at incredibly fast rates. The Li-Fi wireless communication system makes use of the optical current principle. Figure 3 shows the working principle

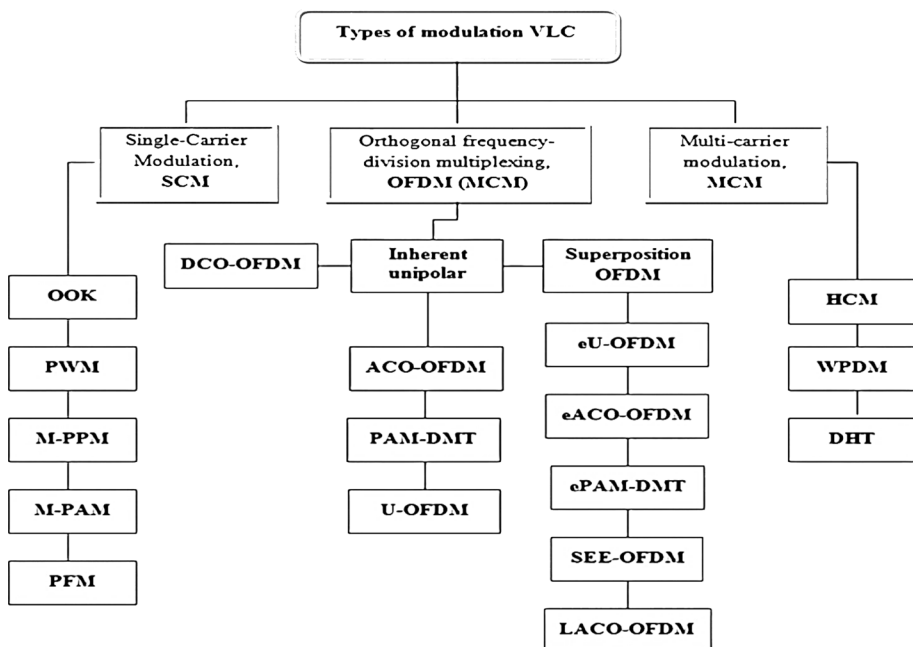
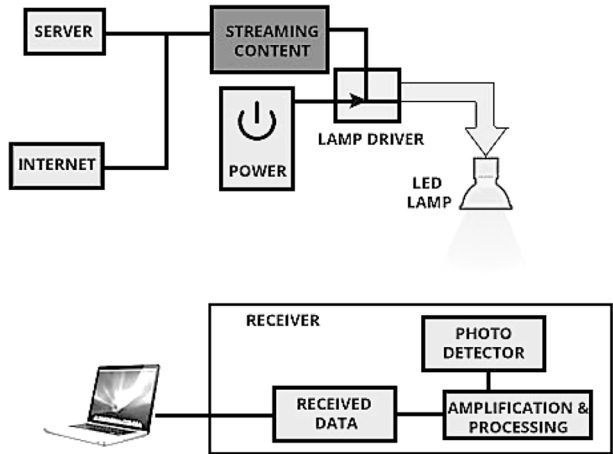


Fig. 2 Modulation schemes in VLC [7]

Fig. 3 Principle of Li-Fi



of the Li-Fi, the input data usually in binary is fed to the Lamp driver and it will directly modulate and drive the LED Lamp source. Then LED Lamp will flicker between ON-OFF at a speed of LEDs less than  $1 \mu s$  which is not perceived by the human eye according to the input data. This discreet ON-OFF activity allows data to be sent using binary coding. When an LED is turned on, it is binary “1”, and when it is turned off, it is binary “0”. By altering the rate at which LEDs turn on and off to provide a varied set of 1 s and 0 s, it is possible to encrypt data in light [18].

In receiving section, the photodetector will detect the modulated light signal and convert it into an electrical signal. This signal is further amplified and processed for intended applications. During processing, the signal will again be converted into binary levels for use.

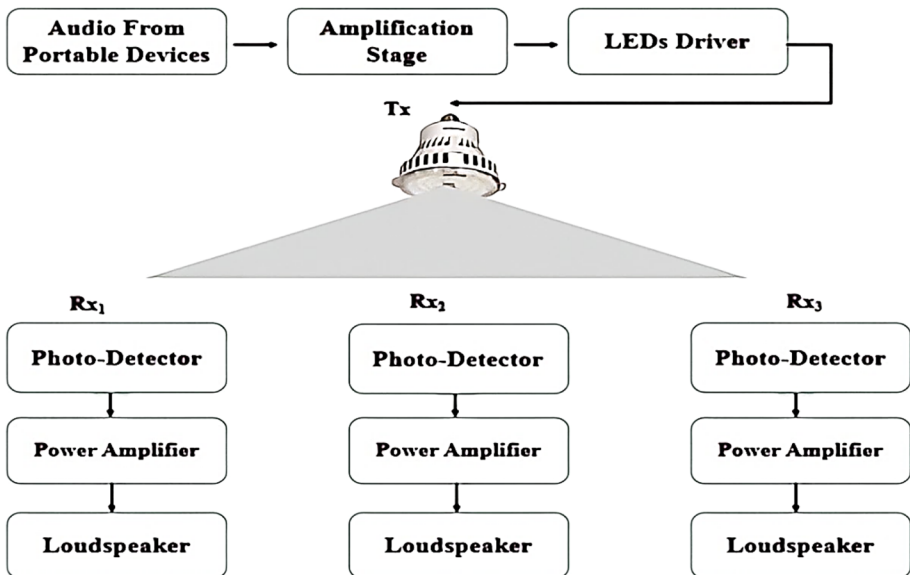


Fig. 4 Proposed SIMO VLC system diagram

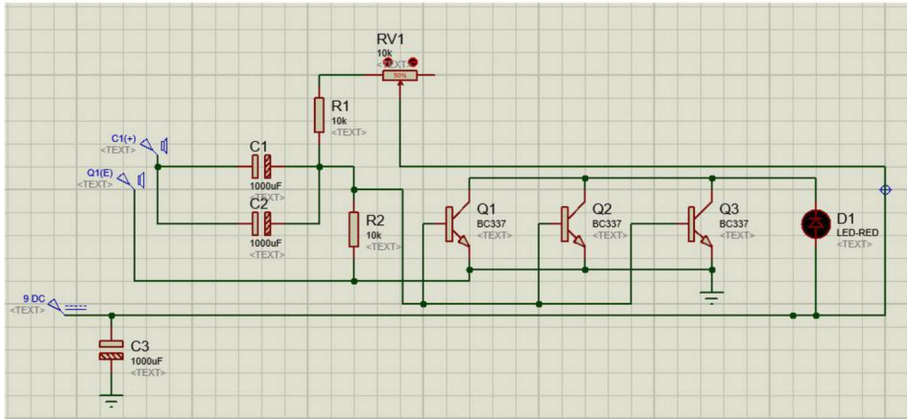


Fig. 5 VLC transmitter circuit

Li-Fi will be regarded as superior to Wi-Fi [1]. Li-Fi is perfect for providing high-density wireless data coverage in congested regions while also reducing radio interference. Li-Fi includes a lot of advantages and characteristics compared to Wi-Fi such as larger spectrum availability, safety, high efficiency, more security, and high data rates [8, 14].

In this work, we designed and enhanced the VLC system based on LEDs to keep on the power consumption and take advantage of environmental infrastructure and costs.

## 2 System design

### 2.1 Audio SIMO (Single Input Multi Output) system based on visible light communication

As shown in Fig. 4, analog communication by light is illustrated. The prototype shown here is designed to transmit audio signals by light and receive it via three receivers that are

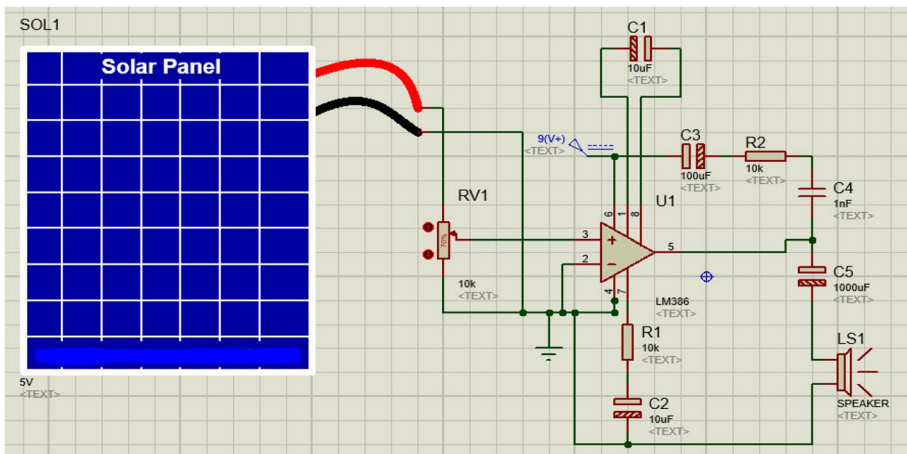


Fig. 6 VLC receiver circuit

**Table 1** Characteristics of used solar panels

Solar Panel	Input Voltage [volt]	Field of View [FOV]
R <sub>X1</sub>	5.5–12	Narrow
R <sub>X2</sub>	5.5–12	Wide
R <sub>X3</sub>	5.5–12	Narrow

located between 1.70 and 2 m away from the transmitter. Because LEDs are semiconductor devices, they are ideal for handling digital data without causing any distortions. This trait makes LEDs incredibly easy to configure for the appropriate purpose because they will copy and transmit the input content exactly as it was in the source.

According to the audio signal, the transmitter is designed to adjust the brightness of the LEDs. Our eyes are accustomed to seeing a static illumination of white LEDs because the brightness variations brought on by the audio stream are so small that they are hardly noticeable to the human eye [2].

The receivers are made up of three photodetectors (PDs). In VLC systems, the core element of a receiver is a photodetector (PD). This component converts the received optical signals into electrical signals, that is, the optical power into electrical current. It is known that the main parameters associated with the receiver include physical area of photodetector, the receiver's field of view (FOV), responsiveness of a detector, and so on. Generally speaking, the receiver will utilize the assembly technique to suppress stray light noise, while allowing the optimal detection of the desirable optical signals [16].

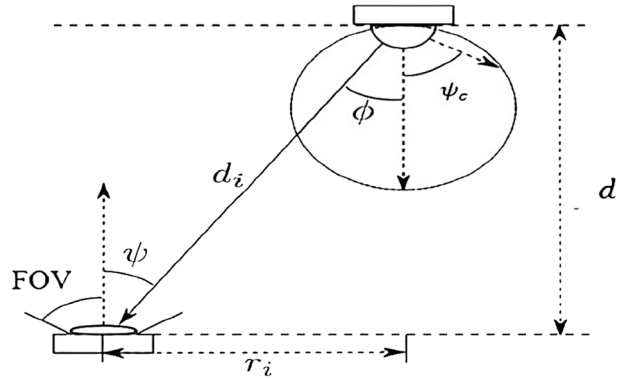
### 2.1.1 VLC transmitter

The transmitter circuit consists of three stages as shown in Fig. 4 which are audio in, preamplifier, and White LEDs array. The main concept of the study was to combine the communication and illumination purposes. Using the light to transmit information was the main purpose of the system. The audio input in this study came from mobile devices (cell phones, tablets, or laptops) or from a microphone. The process includes the amplification of the audio input signal, modulation of the information through a power LED and transmitting the information wirelessly. Driving the LED using on-off-keying (OOK) Modulation. When the LED is set on, it sends a digital 1; otherwise, it sends a digital 0. To drive the white LED array, the preamplifier comprises three transistors (BC337) linked in parallel. Each transistor base contains a voltage divider that provides the required bias for each transistor. Capacitors at the base of each transistor in the input stage prevent DC signals that could decrease output quality. Variable resistance is used to control the audio volume. White LEDs are used as a transmitter. LEDs produce variation in light due to audio signals. This light is emitted in open space to be received by the photodetector. A simulation schematic was made using the Proteus application to test the circuit diagram as shown in Fig. 5.

**Table 2** Characteristics of loudspeakers

Speaker at R <sub>X1</sub>	4 Ω – 3 W
Speaker at R <sub>X2</sub>	8 Ω – 5 W
Speaker at R <sub>X3</sub>	4 Ω – 3 W

Fig. 7 System model of LOS link



### 2.1.2 VLC receiver

In the receiving side there are three receiver circuits. Each receiver circuit consists of three stages: solar panel, power amplifier, and loudspeaker. A solar panel is used as a photodetector element that receives the analog signal emitted by the LED and generates an electric pulse according to the light incident on the solar cell. As the intensity of light of the power light emitting diode varies according to the intensity of the input signal, the electrical signal that the solar cell will produce at the receiver will also vary according to the intensity of light being captured. The weak electrical signal produced by the solar cell will now passed to the amplifier circuit for further amplification before feeding it to the loudspeaker that will produce the desirable audio signal. There will also a volume controller on the receiver side so that the receiver can control and can adjust the desired loudness of the received audio signal. A simulation schematic was made using the Proteus application to test the circuit diagram as shown in Fig. 6.

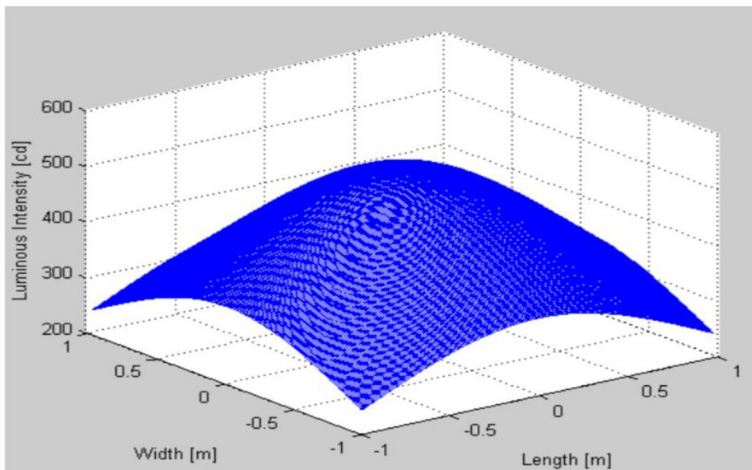


Fig. 8 The distribution of luminous intensity

**Table 3** MATLAB® parameters

Semi angle of half power	20,45 and 70 [deg]
center luminous intensity	0.3 [cd]
number of LEDs array	50 (5 × 10)
Field of View	50 [deg]

### 2.1.3 Solar panel

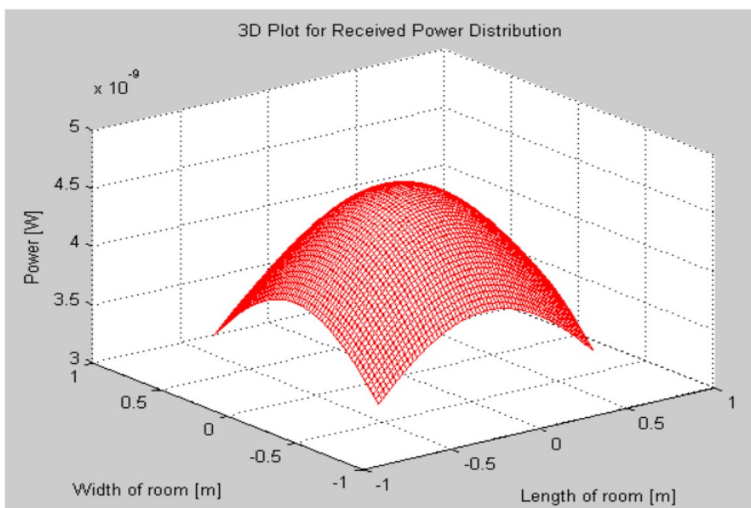
In the receiving section, the solar panel was used as a broadband receiver. The audio data will be fed from the LED driver to LEDs, which will further pass the data in the digitised form to the solar cells. Solar cells are self-sufficient in the sense that they will capture energy as well as transmit data. Moreover, the system also consists of three solar cells, whose characteristics are shown in Table 1.

### 2.1.4 Power amplifier (LM386)

The LM386 is a low voltage amplifier that can be used in a variety of applications. It can drive loads from 4  $\Omega$  to 32  $\Omega$ . The audio amplifier amplifies the low-power audio input signal to the high-power audio signal. Internally, the gain is adjusted to 20 to keep the exterior part count minimal, but by connecting pins one and eight with an exterior capacitor, the gain may be increased to any value between 20 and 200.

### 2.1.5 Loudspeaker

Speakers are used to convert the electrical or analog signal to the aural form. The audio receiver is the message output sent by the transmitter. The system consists of three loudspeakers, whose characteristics are shown in Table 2.

**Fig. 9** Received power with 20 semi-angle at half power



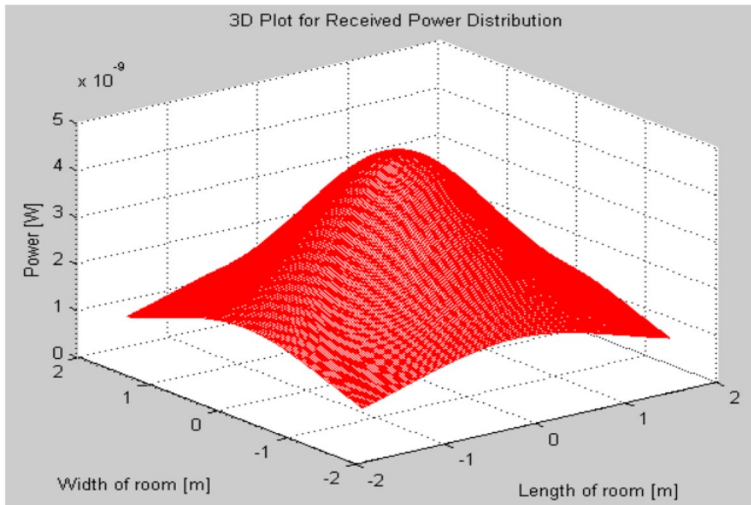


Fig. 10 Received power with 45 semi-angle at half power

### 3 Modeling of optical channel

The geometrical system model of the proposed system configuration is shown in Fig. 7. We consider the LOS condition for illumination as well as communication.

The Lambertian emission describes how the light intensity emitted from a source is proportional to the angle of emission with respect to the surface normal. It's easy to calculate the intensity of light in an optical link is given by Eq. (1) [4, 17].

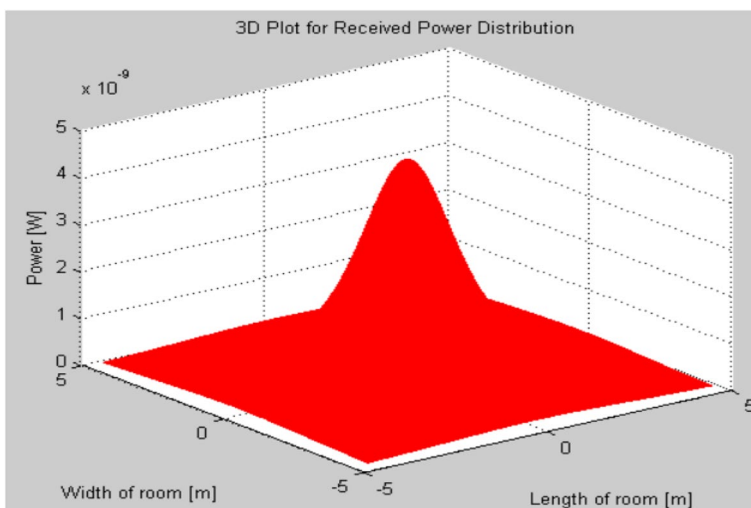


Fig. 11 Received power with 70 semi-angle at half power

**Fig. 12** Practical transmitter circuit



$$I(\phi) = I(0)\cos^m(\phi) \quad (1)$$

where  $I(0)$  denotes the group LEDs' center luminous intensity,  $\phi$  is the irradiance angle, and the Lambertian emission order is  $m$  and is determined by the LEDs' half-illumination semi-angle  $\psi_c$  as given by Eq. (2) [4, 6].

$$m = \frac{\ln 2}{\ln(\cos \psi_c)} \quad (2)$$

The horizontal illuminance  $E_{hor}$  is given by Eq. (3):

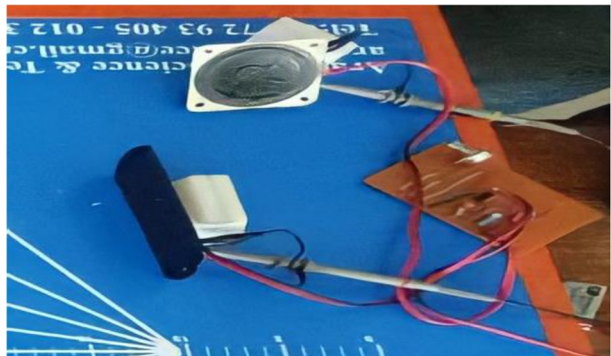
$$E_{hor} = \frac{I(0)\cos^m(\phi)}{D^2} \cos(\psi) \quad (3)$$

where  $D$  denotes the distance between both the transmitter and receiver,  $\psi$  is the incidence angle. The LEDs system's illuminance distribution, the model of the LOS link is shown in Fig. 8, and a LED source, transmission channel, and optical receiver are all included [13].

In the transmission section, an LED is considered to have Lambertian radiant intensity as given by Eq. (4).

$$R_o(\phi) = \left[ \frac{m+1}{2\pi} \right] \cos^m(\phi) \quad (4)$$

**Fig. 13** Practical receiver circuit



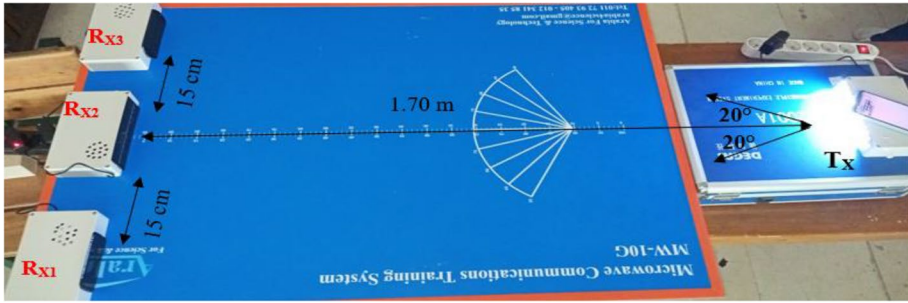


Fig. 14 Sound system prototype with 15 cm separation between receivers

The Lambertian emission order is  $m$ , is associated to  $\psi_c$  and semi-angle of the transmitter (at half power) as given by Eq. (2). The LED’s output power is  $P_{LED}$  and  $\phi, \psi$  are the irradiance and incidence angles. The power transmitted is given by Eq. (5) [4].

$$P_{tx} = P_{LED} \times R_o(\phi) \tag{5}$$

We assume the following physical parameters: The distance between the transmitter and the receivers is 1.70 m, and the distances tested between each receiver are (15, 45, and 60) cm in our system. Simulation parameters are used to be simulated in the MATLAB® software, which is shown in Table 3.

Figure 8 shows the distribution of illuminance intensity with the LEDs’ light. From this figure, the sufficient illuminance is 200.20 to 400 cd. Figures 9, 10, and 11 demonstrate the received power at 20, 45, and 70 semi-angles at half power, respectively, using MATLAB® software where the angle of transmission is a function of the power received. From Fig. 9, the received power at 20 semi-angle at half power is 4 W, which matches with practical measurements. With other semi-angles, 45 and 70, the received powers decrease. It will be obvious that as  $\psi_c$ , increases, the received power in the photodetector decreases. This corresponds to the LOS channel’s characteristic, in which the received power increases as the receiver’s deviation angle from the transmitter approaches 0°.



Fig. 15 Transmitted signal measurements

**Table 4** Measurements of receiving units for 15 cm distance distance between receivers

Receivers	Distance between Receivers	Received Signal Voltage at Solar Panel	Output Voltage of Amplification
R <sub>X1</sub>	15 cm	60 mv	480 mv
R <sub>X2</sub>	15 cm	120 mv	880 mv
R <sub>X3</sub>	15 cm	60 mv	480 mv

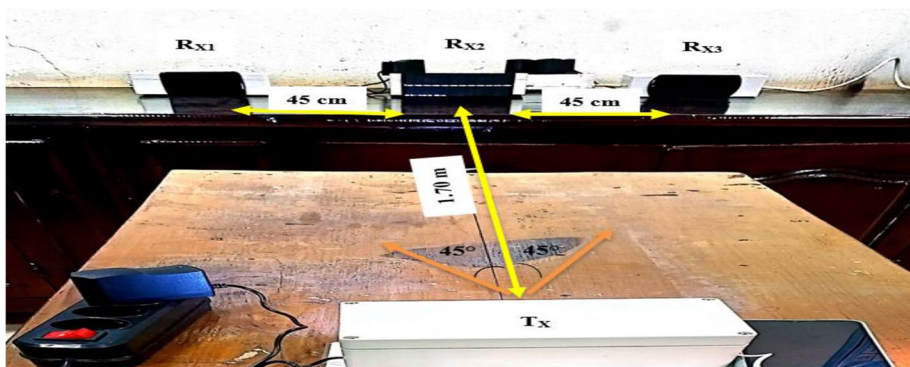
## 4 Practical results

The practical circuits of transmitter and receiver are shown in Figs. 12, 13 respectively.

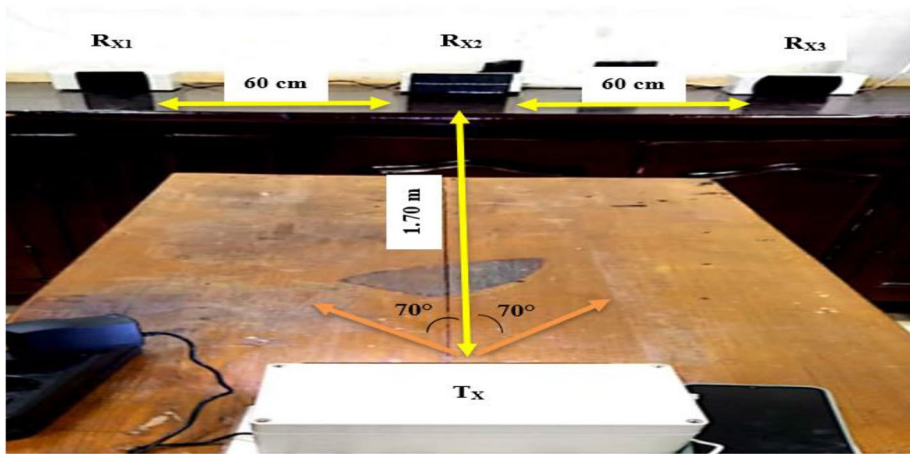
The system is shown in Fig. 14, which demonstrates a sound data transmission system from point to multipoint through LED arrays at various distances and semi-angles in the LOS propagation model. The sound system consists of a transmitting unit and three receiving units. The distance between the transmitter and receivers is 1.70 m, expandable to 2 m, and the distance between each receiver is 15 cm with a semi-angle of 20 degrees. The measurements of a transmitted signal using OOK modulation are shown in Fig. 15 by using a digital oscilloscope device, and the results of receiving units are listed in Table 4.

The system was tested with increments in the distances between receivers to 45, 60 cm, and change semi-angles to 0, 45, and 70 degrees as shown in Figs. 16 and 17. The measurement results of the receiving units are listed in Tables 5 and 6.

The sound system was analysed based on VLC practically by testing the system at multiple semi-angles and distances between receivers. According to the results shown above, the receiving section receives the transmitted signal and amplifies it to the destination output. In our system, three solar panels are used in receivers and the characteristics are shown in Table 2. The better-received signal at receiver 2 with a transmission angle of 0 degrees, which has a wide FOV solar panel and good sound intensity output with speaker's characteristics (8  $\Omega$  – 5 W) but with noticeable noise. The receivers 1 and 3 which have a Narrow FOV solar panel with semi-angle 20, 45, and 70 degrees have less sound intensity and noise with speakers' characteristics (4  $\Omega$  – 3 W) than RX2 in distances (15, 45, and 60 cm) between each receiver. The modulation technique used



**Fig. 16** Sound system prototype with 45 cm separation between receivers



**Fig. 17** Sound system prototype with 60 cm separation between receivers

in our system is OOK modulation, in which a carrier's amplitude varies only in two cases, equal to binary data "0" or "1".

## 5 Conclusion

This paper presents a working prototype for audio transmission using VLC and also discusses the characteristics of VLC. The proposed system was tested at different distances and radiation angles. According to the results, we conclude that the receiver, which has a wide field of view, has an increase in noise, which is obtained from ambient light and subsequently affects the receiving ability. This is in contrast to the receiver, which has a narrow

**Table 5** Measurements of receiving units for 45 cm distance between receivers

Receivers	Distance between Receivers	Received Signal Voltage at Solar Panel	Output Voltage of Amplification
R <sub>X1</sub>	45 cm	40 mv	300 mv
R <sub>X2</sub>		120 mv	880 mv
R <sub>X3</sub>		40 mv	300 mv

field of view (FOV). Therefore, the surface area of the detection area for the photodetector

**Table 6** Measurements of receiving units for 60 cm distance between receivers

Receivers	Distance between Receivers	Received Signal Voltage at Solar Panel	Output Voltage of Amplification
R <sub>X1</sub>	60 cm	21.60 mv	168 mv
R <sub>X2</sub>		120 mv	880 mv
R <sub>X3</sub>		21.60 mv	168 mv

is important because the angle of the lower field of view of the receiver is better where the optical energy of the smaller field of view is focused on the optical detection area.

## 6 Future work

We can build on this work to improve the quality and speed of data transmission using Light-collecting lenses in front of each receiver to collect light sources in a focused point for a photodetector to optimize system output quality.

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**Data availability** Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest regarding the publication of the paper.

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