Unlocking the Potential of Li-Fi for Next-Generation Wireless Communication

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Abstract: ***Light fidelity, or Li-Fi, is a wireless communication technology that enables secure line of sight communications, efficient connectivity in RF hostile environments, ultra-high transmission data rates, dense and reliable networks for smart cities and nations. Optics and photonics have been important research areas for next-generation communication systems, with Li-Fi being one of them. Although wi-fi is excellent for general wireless coverage, Li-Fi technology is superior for high-speed data transfer in confined areas and data transfer without radio frequency interference. In comparison to Wi-fi, it allows you to connect a lot more devices and transfer data at a much faster rate. Li-Fi offers high efficiency and also a much-secured network system. In this paper, we explored the distribution of power density using Li-Fi technology, a simulation model is described. This paper presents a mathematical analysis of the simulation model to study the variation of power density with a change in height or change in angle between transmitter and receiver. We also tried to optimize the parameters for the best performance of the Trans receiver system. Along with mathematical simulation, we have also shown the data transmission through text and audio using the Proteus Design tool. We could successfully transmit and receive text signals with multiple inputs and multiple outputs (MIMO). We have also presented a prototype for successful audio transmission using Li-Fi technology.***

Keywords: Light fidelity, Optics, Photonics, Power density, Wireless communication

1. Introduction

Digital communication today has revealed an unexpected growth in terms of data transfer rate, noise immune long-distance communication in a cost-effective manner. The major communication technologies rely on the radio frequency spectrum and 4G bands and are at their upsurge at utilization level. The rapid growth in the number of users and the amount of data transferred has led the researchers to explore unconventional methods of communication. Optical communication, which has much greater bandwidth, has been an interesting domain in this respect. At both the academic and industrial levels, there is a lot of research being done on the commercialization of optical or visible light communication systems. Light fidelity, or "Li-Fi" for short, is a more advanced subset of optical communication. It is a fundamental 5G technology [1]. It is not a replacement for or equivalent to wireless fidelity (Wi-Fi), but rather a strategy for developing a future communication method. Li-Fi is a wireless communication technology using visible light. Visible spectrum ranging from 380 nm to 780 nm wavelength, corresponds to the frequency ranging from 385THz to 789 THz [2]. This technology was introduced by German physicist Harald Hass in the year 2011. Visible Light Communication (VLC) is a point-to-point data communication technique [3]. However; Li-FI is bi-directional multiuser communication. Visible Light Communication can be used to complement current RF systems as Li-Fi can give safer networks and faster speeds [4]. The basis for Li-Fi is that it uses light-emitting diodes (LEDs) to convert an electrical signal to optical power. The advantage of using LED is that it is used for communication as well as illumination, hence, creating a completely networked wireless system. At the receiver end photodiodes are connected to convert the received optical power to an electrical signal. Li-Fi allows a device to connect to the internet without using a wire [5]. Figure 1 depicts the working principle of Li-Fi technology in a basic concept block diagram. It comprises a transceiver and the transmission of the medium as light. A Li-Fi system mainly cosists of two parts:Transmitter and receiver. The input signal at the transmitter section is sent through LED as data string of 1's and 0's (ON & OFF). At the receiver end, a photodiode is used to receive the optical signal from LED and after processing through microcontroller gives the corresponding output electrical signal. As shown in block diagram (Figure 1), both transreciver works as transmitter as well as receiver, this fundamental principle is referred to as duplex communication [6]. Light is used to communicate data in the Li-Fi and VLC systems. The difference between Li-Fi and VLC is that VLC uses unidirectional, low-data-rate point-to-point light communication. Li-Fi is a completely networked, bidirectional, and high-speed wireless communication technology. According to reports, Li-Fi is a combination of Wi-Fi and VLC. The serial communication based prototype implementation is alreasy present in the literature. In this paper, we have presented a Li-Fi system with its implementation for bidirectional data transfer for text and audio data types using MIMO (multiple-input multiple-output). The proposed design implements the parallel communication using Li-Fi approach. This will increase the data rate speed and capacity to manyfolds. We also presented the optimization results for an environment consisting of an LED data source and a photodiode receiver.

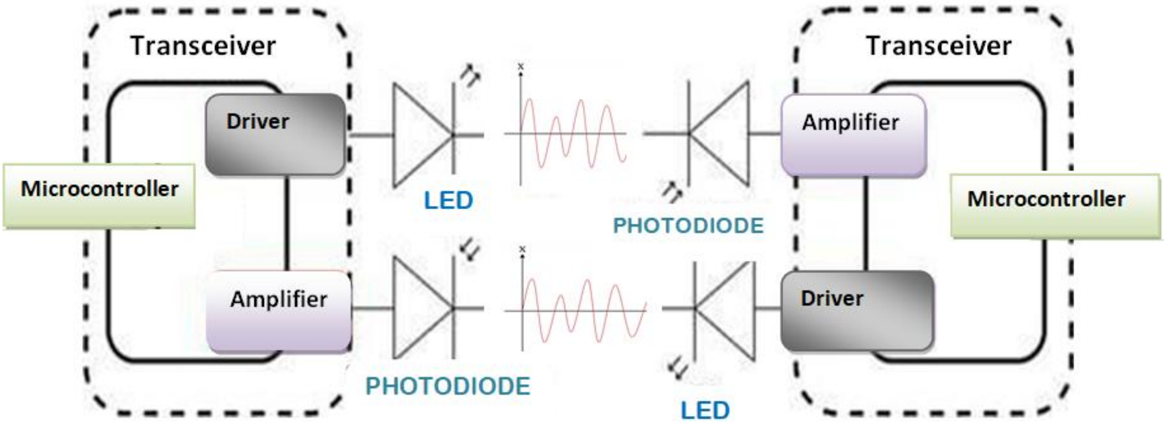


Figure 1: Basic Li-Fi Transceiver system

A mathematical model for Li-Fi Trans-receiver

In order to obtain the optimized values of parameters such as height at which LED is placed and angle between transmitter (LED) and receiver (photodiode) mathematical modeling is done using MATLAB simulation software. Figure 2 shows the suggested white LED lighting set-up to calculate the characterization. The center of the roof was fitted with a white LED. 4 pieces of LEDs were tightly packed to improve the lighting of the room (Metropolis et al., 1953). The room dimensions are 5m x 5m x 3m and the distance between LEDs is shown in Figure 2.

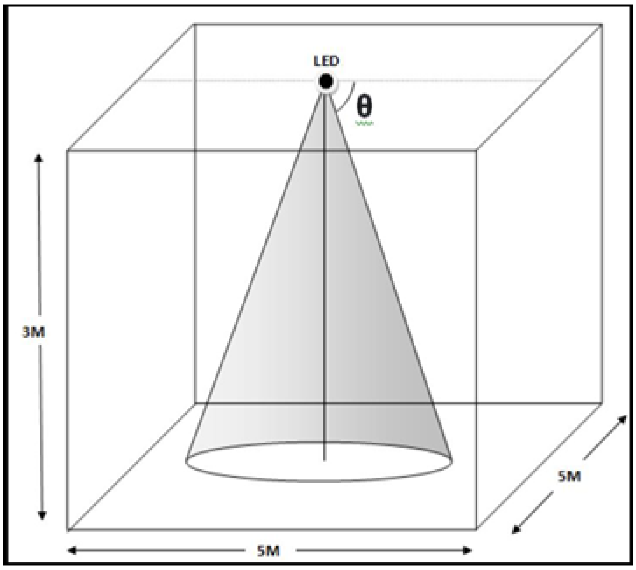


Figure 2: Model design considered in this work for simulation

Table 1: Parameters used for Mathematical Model

Room	Size	5m x 5 m x 3m
Transmitter	LED location	2.5 m,2.5m,3m
	Transmitted power	7 W
	Intensity	21.4 lx - 1401 lx
Receiver	Rx. active area	25 m^2
	Half Angle Field of View (FOV)	60 °

Table 1 lists the different parameters required for simulation [3]. The receiver was viewed at 120°, with a half-power semi-angle at 60°. The 4 pieces of 2,4 w LEDs produced about 358 lumens, generating total optical power of about 7W and the transmitted power of the LEDs. The received and transmitted power are related by the equation:

$$P_{rx} = H(0).P_{tx} \quad (1)$$

Where further H(0) is the luminous intensity received power on physical area A at distance d between receiver and transmitter.

$$H(0) = \frac{(m+1)A}{2\pi^2 d^2} \cos m_{(\emptyset)} \cos(\theta) \quad (2)$$

where Φ, Θ angles are defined by the angle of incidence and angle of field of view at the receiver (greater than critical angle required) respectively. Using above equations and above mentioned parameters, mathematical simulation using MATLAB has been done. It is to be noteworthy to mention that all the simulation calculations are based on Lambertian radiation pattern distribution. This is valid for all the optical sources, particularly for LED sources used for Li-Fi technology.

1.1. Text Transmission using Li-Fi system

Li-Fi is based on the basic principle of data communication that if the LED is ON then a digital ‘1’ is transmitted in case the LED is OFF then a digital ‘0’ is transmitted. The LEDs are switched ON and OFF very quickly depending upon the data which need to be transmitted. Further, to increase the transmission capacity of the transceiver system which open gateways for transferring high data rates, MIMO technique is used. In this, numbers of LEDs are connected in parallel at the input. We have to just vary the rate at which the LED’s flicker based on the data to be encoded [4]. Further at the receiver end for multiple output number of photo-detectors are connected. Such advancement promises any theoretical speed of 10Gbps which means that one can download an entire high-definition film in just 30 seconds. A simple adaptive method is proposed for multiple-input-multiple-output (MIMO) visible light communication (VLC) to increase energy efficiency. Based on channel conditions, the desired spectral efficiency, and a target error rate, at each location, the MIMO technique with a smaller input energy requirement is chosen, and thus the energy consumption is reduced. Such an adaptive method can be significantly beneficial in applications such as Internet-of-things (IoT) where energy consumption is a critical factor.

The transfer of data by Li-Fi is given in this work is based on the concept of parallel data communication or MIMO. We are using MIMO as a technology that does not cause multipath fading of the intensity modulation (IM) and that LEDs are extremely directional [5]. This will contribute novel algorithms for networked, multiuser Li-Fi systems. There are various network topologies but in this emerging technology, the network spectrum is increasing and better efficiency is obtained. Figure 3b, shows aurdino microcontroller used and the circuit diagram for the trans-receiver system [6].

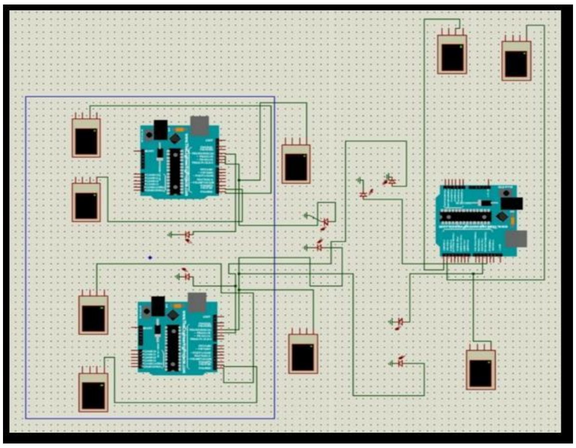


Figure 3: Circuit diagram for Trans receiver system

A prototype of the transmitter-receiver system using an Arduino microcontroller is made and virtual terminals for data visualization have been designed. Data transmission was performed using Arduino's parallel communication pins and a binary code was loade [7]. After a valid serial signal has been received, the I/O port and serial port are initialized in the simulation, and data is sent using the Li-Fi principle. In the circuit for parallel transmission of data, serial receiver R_X (digital pin 10) and T_X (digital pin 11) of all the three Arduino's are mutually interconnected. In this prototype, we have been successfully able to send a text with multiple inputs and multiple-output (MIMO). Figure 4 below shows the successful real-time transmission of text data string using the designed circuit. It shows data is transmitted from one to T_x pin of Arduino and is received at different virtual terminals of the other two Arduino. We have been able to send Multiple T_x signals and received them respectively using the above circuit.

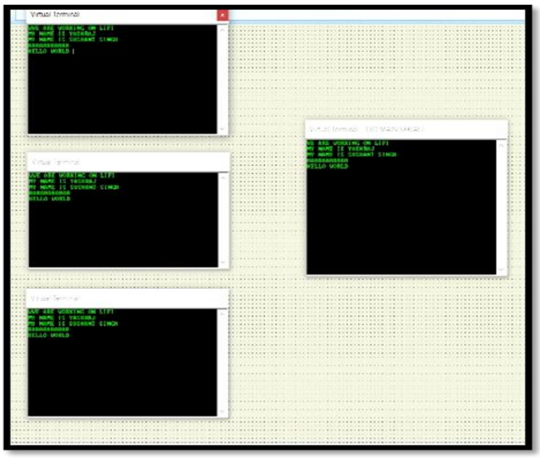


Figure 4: Virtual Aurdino terminals showing text data transfer using Li-Fi system.

Audio Transmission using Li-Fi system

After successful transmission of the text, we could also send the audio signal. Figure 5 illustrates the simulation circuit with the successful input to output audio transfer. In the restricted environment, the output obtained has the minimum noise possible. In the process of audio communication through the visible light, on the transmitter side, an audio signal (any music from mobile) is used as the input signal. This signal is fed to the LED. The light signal from the LED varies according to the intensity of an audio signal. At the receiver side, the light photodiode will receive the light signal and correspondingly generate an electrical signal proportional to it. This electrical signal is processed by a low voltage audio power amplifier, which is then fed to a speaker and it produces the audio signal which was at the input of the transmitter side. The input and output of the audio signal transmitted and received is as shown in Figure 6.

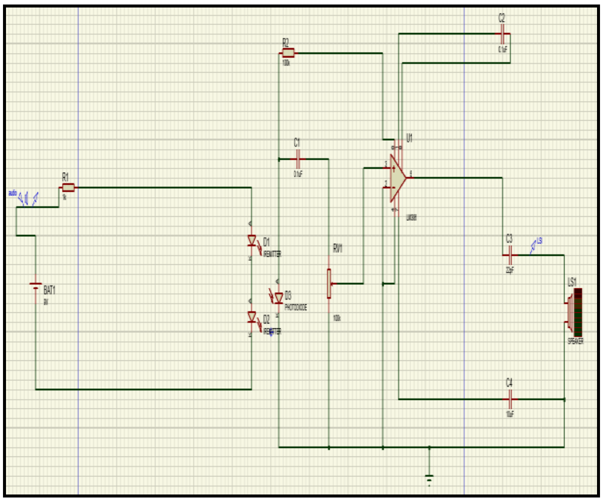
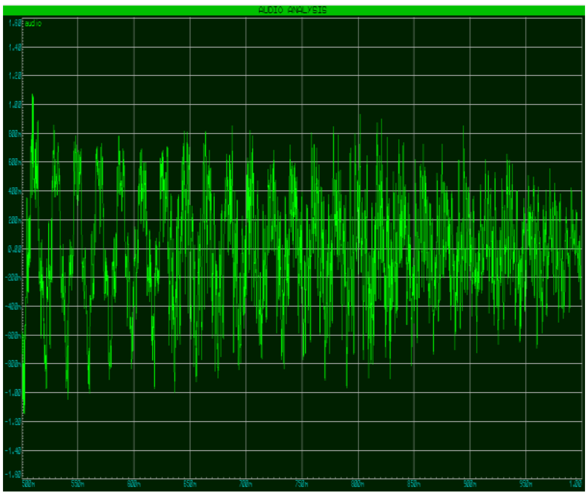


Figure 5: Circuit diagram for audio trans-receiver using Li-Fi(Simulated on Proteus)



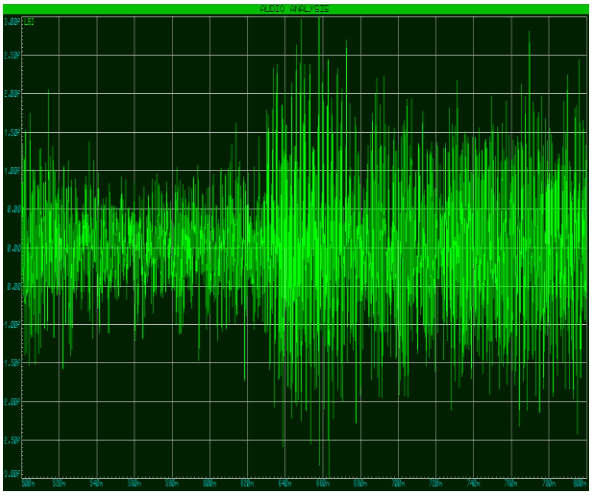


Figure 6 (a) & 6 (b): Input and Output waveform for audio trans-receiver for the above circuit

It is observed that the output waveform received is prone to noise and shows fluctuations and disturbances. Hence, to improve the received signal quality, we modified the trans-receiver circuit as shown in Fig. 7. The operational amplifier is replaced by Darlington pair to utilize the benefit of low current operability conditions by Arduino. Darlington pair is a suitable choice for interfacing any high current load like (bright LED source) with microcontroller boards.

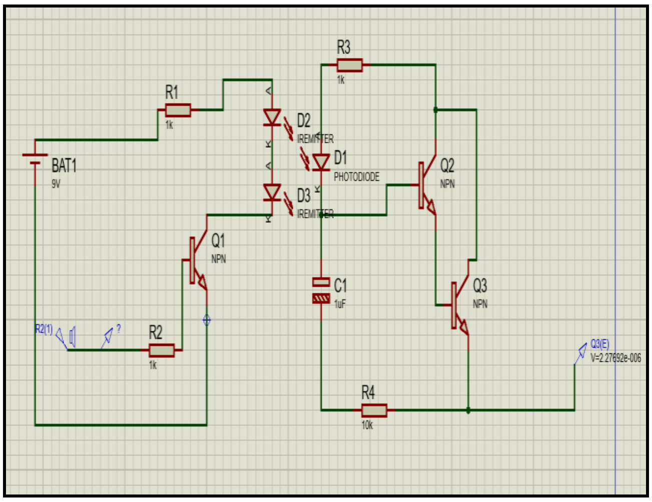
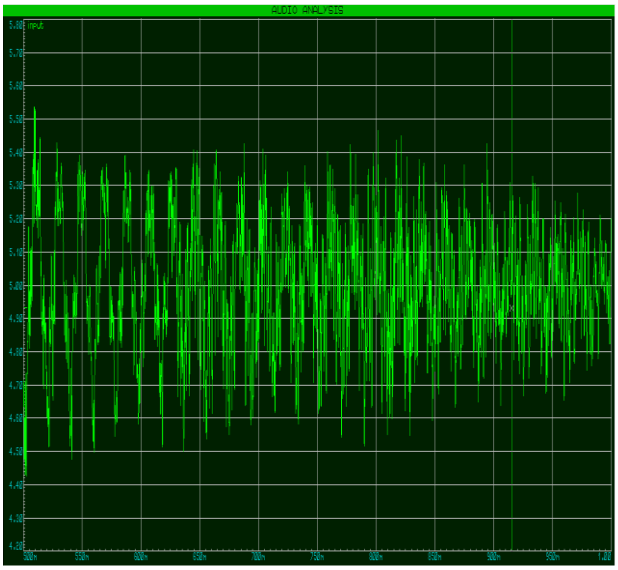
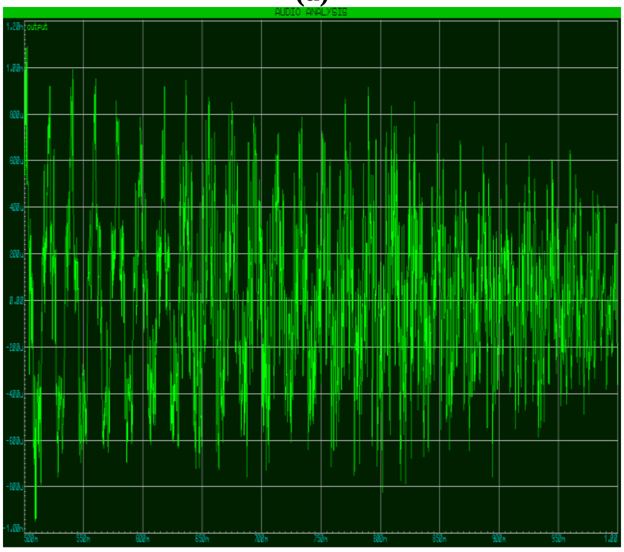


Figure 7: Improved circuit diagram for audio trans-receiver using Darlington pair



(a)



(b)

Figure 8 (a) & (b): Input and Output waveform for audio trans-receiver using modified circuit

2. Results & Discussion

Optimization of parameters using mathematical Model

We have successfully modeled, measured, and simulated the received power distribution for a white LED using a luminous intensity meter using the model shown in Fig 2. Using this, we have been able to investigate the measured values. From the investigation, we found a practical way of analyzing the characteristics of a LED suitable for optical wireless communication. For simulation, distribution of illuminance of LED is considered as Lambertian radiation pattern and modeling has been done to determine the received power density using MATLAB simulator. It can be seen from Figure 9, that the peak power density decreases as the height increases (distance between LED and photodetector increases).

The beam divergence has also been calculated using MATLAB. Beam divergence usually refers to a circular cross-section. The variation of received power density with respect to angle variation is plotted using MATLAB simulator as shown in Fig. 10. It can be seen that the curve starts expanding at first to reach every corner of the room. Further, the curve starts compressing with the low power density and focuses on the small base area of the room. This observance is clear since the light expands across the room. As the radius of cone considered is decreased, the useful power is obtained which is further decoded to get the original data.As the curve spreads out, the received power is noisy and hence unsuitable for decoding.

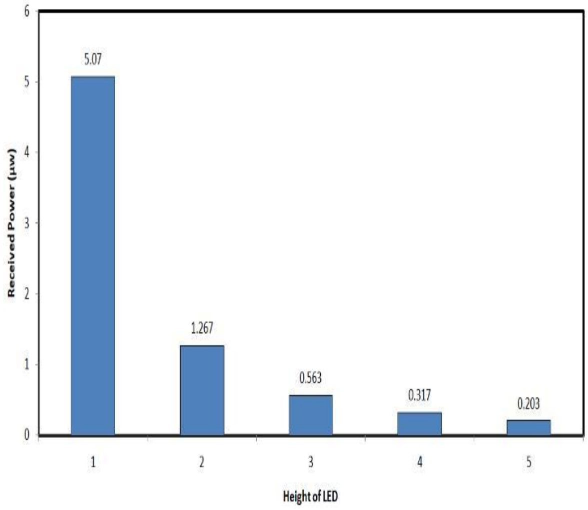


Figure 9: Plot for received power against varying height as depicted from Fig. 2

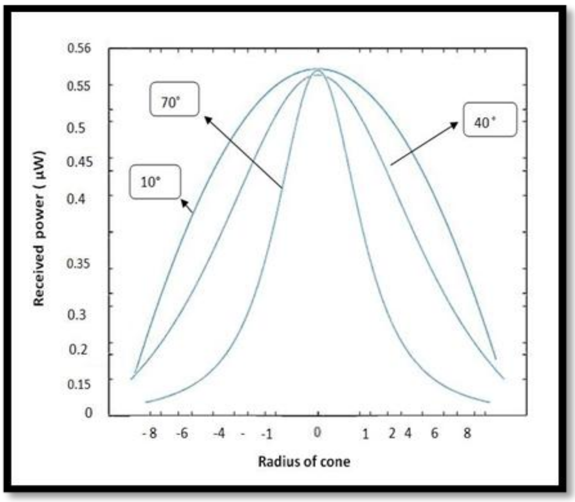


Figure 10 : Plot for received power against varying angle as depicted from Fig. 2

Table 2 below shows the variation of power density with angle and distance variation. We used Lambert's cosine law for measuring the intensity in our simulations[8.9]. The code was modified to extract the channel transfer function and loss in received power by line-of-sight communication. The concerned noise factors and diffusion variations were taken into account. In order to calculate the optimum point for minima, the differentiation of received power spectrum is performed with respect to the parameters. The variation in both the distance and angle simultaneously was performed to get the best performance as shown in Table 3.

Table 2: Variation of angle and height for received power

Distance (with the angle of 7.5o)	Angle (with a distance of 2.5m)	Received Power with angle (uW)	Received Power with distance (uW)
1 m	10o	0.56	5.07
2 m	30o	0.55	1.26
3 m	40o	0.58	0.56
4 m	50o	0.59	0.32
5 m	60o	0.61	0.20

Table 3: Variation of angle and height simultaneously for received power

Distance (m)	Angle	Received Power (µW)
1 m	20o	5.0
2.5 m	30o	0.8
3.15 m	33.5o	0.52
4 m	70o	0.34
5 m	80o	0.2

From the variation of angle and height, we obtained significant results that for the Li-Fi system at beam divergence of 33.5 degrees and height of LED 3.15m optimized power density is obtained. This implies for the model considered for mathematical simulation, the best performance of the system with the change in height as well as the angle can be obtained at a height of 3.15m and the angle of the trans-receiver should be 33.5°.

Software simulation of Li-Fi system using Proteus

For text transmission, using the Aurdino Transceiver system (Figure 3), we could successfully simulate (using Proteus professional 8.6 Software) and transmit data string as shown in Figure 4. It can be seen that using the above circuit, we could send the text at multiple virtual terminals of Aurdino simultaneously. This results in the implementation of MIMO for data string [10-12]. For Audio transmission, input and output waveforms in Figure 6 and Figure 8, illustrates that there is considerable improvement in terms of the amplitude of the signal received. The received signal for the circuit shown in Figure5, using an op-amp at the output is spread within a range of 5 femto units of amplitude and this is improved to 3 milli units of amplitude range spread with the circuit shown in Figure 7, using Darlington pair instead of an op-amp. The performance of the circuit is improved considerably due to the following important characteristics of the Darlington amplifier. It has extremely high input impedance (several MΩ), extremely low output impedance(few Ω), and extremely high current gain(several thousand) because the overall gain is the product of individual gain [13-15]. Further, the circuit shown in Figure7 gives better quality of audio thereby reducing noise to a greater extent. It was observed that for simulation of the audio signal transmission, a maximum of up to 16MB of data can be sent at a time. However, this limitation can be overcome with hardware design. Also, the amplitude of received power density is still needed to be improved, we are working on using various modulation techniques for the same. This is to mention that the prototype made and successfully implemented, for text transfer is Bi-directional. However, the prototype for audio transfer is not bi-directional.

3. Conclusions

Light fidelity has developed with immense new technologies in continuous exploration. This technology is currently consuming a much lower energy consumption and is highly efficient, and can achieve far higher data rates than conventional SISO channels. Using mathematical simulation techniques (MATLAB), we were also able to optimize the obtained power parameters for a good LiFi system. We have been successfully made a prototype and transmit text string using MIMO through the proteus professional 8.6. Also, the audio transmission was successfully simulated and implemented. we are still working to send video signals through this technology. We are also working on the hardware implementation of the above circuits. The proposed device will be implemented on hardware for real-time transmission of text, audio, and video data in a lab setting in the future. The authors hope to expand the application to include underwater contact and IoT systems.

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