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A Prototype of Visible Light Communication Circuit for Wireless Data Transmission

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ABSTRACT

It is not gainsaying that the societal reliance upon wireless systems continues to rise due to mobile data interchange. According to the Federal Communication Commission a closer look at the current allocation of 38GHz 5G Cellular is desperately pointing to, and suggesting the crowding of the frequency spectrum. Therefore this study explores visible light communication as one of the emerging technologies to help meet up with these challenges and further prototyped a transmitter and a receiver circuit. The visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component. The study focused on the Prototype of Visible Light Communication Circuit for Wireless Data Transmission by designing an analogue circuit that can be integrated with a computer or mobile phone, and then sending some form of data using visible light LEDs from a transmitter, and decoding it with an appropriate photodiode as a receiver. The circuit was tested with PROTUES 8 Professional and audio data of 3kH was sent reliably and accurately over a short distance at a fair speed which ensures that the initial goals for the functionality of this new system which includes being able to send audio, at a data rate of at least 10 Mbps was achieved. The study shows that Visible light communication has the potential to provide high speed data communication with improved energy efficiency and communication security/privacy due to its unique characteristics and advantages. Also, Visible Light Communication can complement the RF-based mobile communication systems in designing high-capacity mobile data networks and can be incorporated in the next generation 5G network. The study therefore recommends error control mechanism and Dimming Support to be integrated in the subsequent studies.

1.0 Introduction

The exponential increase of mobile data traffic in the last two decades has identified the limitations and deficiency of RF-only mobile communications. Visible light communication VLC research has shown that it is capable of achieving very high data rates (nearly 100 Mbps in IEEE 802.15.7 standard and up to multiple Gbps) however lacking practical implementation. Several modulation techniques have been proposed in theory to improve the data rate and maximum range of VLC system. In practice, the intensity modulation tends to be susceptible to ambient noise while pulse width modulation flickers the LED at a human eye disturbing frequency. Based on the limitations of the past attempts to practically implement a noiseless transmission at a high data rate, this work focused on designing and implementing a real time VLC system capable of noiseless data transmission using quasi pulse with modulation.

1.1 Statement of the Problem

According to Zheng and Zhang (2014) it is worthy to note that the recent advancements in Solid State Lighting (SSL) have triggered Research in the domain of Visible Light Communication (VLC) which enables us to use Light Emitting Diodes (LEDs) for illumination as well as low cost, high speed, power efficient and secure data communication. VLC technology is considered to be a green technology which helps in the reduction of hazardous gases emission. The visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as a signal receiving component. Due to the growing commercialization and development of illuminating LEDs; it is said that the illumination LEDs will replace the conventional illumination lightings such as incandescent bulbs and fluorescent lamps since they have the characteristics of long lifetime, mercury free, color mixing, fast switching, etc. By utilizing the advantage of fast switching characteristic of the LEDs compared with the conventional lightings, i.e., modulating the LED light with the data signal, the LED illumination can be used as a communication source. Since the illumination exists everywhere, it is expected that the LED illumination device will act as a lighting device and a communication transmitter simultaneously everywhere in a near future.

According to Chvojka *et al.*, (2015), there is an increasing throughput requirement from the next generation of communication networks (5G), which are expected to be deployed beyond 2020. Network designers face several critical challenges, all of which need to be addressed, such as optimal spectra allocation, high capacity broadband links, power consumption, quality of services (QoS) and mobility. Chvojka, (2014) stated that approximately one exabyte (EB) of data was transferred across the entire global internet in 2000 (0.083 EB/month). In contrast, approximately 30 times more data was carried by the mobile networks per month in 2014, which corresponds to approximately 2.5 EB/month.

Moreover, Zhang *et al.*, (2015), observed that the latest projections from Cisco, predicts that the overall mobile data traffic will reach approximately 24 EB/month by 2020, which is approximately one order of magnitude larger than 2014. This corresponds to a compound annual growth rate (CAGR) of 57% for the 2014-2019 periods. Following the projection, the fit for this data estimates that more than 30 EB/month, will be transmitted beyond 2020. Most of this mobile data traffic (up to 69%) is expected to consist of video and media by the end of 2020.

Currently, several alternatives to radio frequency communications exist. For example, there are cognitive radio, which utilizes radios programmed to adapt to surroundings by constantly analyzing the frequency spectrum to determine how the surrounding spectrum is currently being utilized, and laser communication systems, which transmits data through free space by shooting a laser with wavelengths close to the infrared spectrum to a receiver.

Given that one major issue in wireless communication is the crowded frequency spectrum, many engineers spend their time and effort focusing on determining solutions for this issue. Since there is limited access to the frequency spectrum, these engineers are focusing on options that could optimize the spectrum. By optimizing the frequency spectrum's usage, it would be possible to provide all end users a portion of the spectrum. As the current trend continues, devices that normally would not be able to wirelessly communicate, such as lamps or temperature sensors, will be connected to some type of wireless network. This will increase the number of end users and further crowd the frequency spectrum. (Zhang *et al.*, 2015).

According to Abu-alhiga and Haas (2009) Visible Light Communication (VLC) based on white Light Emitting Diodes (LEDs) is promising for realizing ubiquitous wireless networks, since LEDs would be used for both illumination and wireless transmission simultaneously. There are two common approaches to produce white light illumination by using LEDs. One involves blue colored LEDs with wide-band phosphors that produce the form white light. The alternative option is by means of the RGB solution which is more preferable than phosphorous-based white LED to improve the data rate, since in the latter case, the slow response of the phosphors limit the modulation bandwidth whereas the power efficiency is reduced if combined with blue filter in order to reject the phosphorescent components. red, green and blue (RGB) LEDs

Conclusively we can deduce that the exponential increase of mobile data traffic in the last two decades has identified the limitations and deficiency of RF-only mobile communications. Visible light communication VLC research has shown that it is capable of achieving very high data rates (nearly 100 Mbps in IEEE 802.15.7 standard and up to multiple Gbps) however lacking practical implementation. Several modulation techniques have been proposed in theory to improve the data rate and maximum range of VLC system. In practice, the intensity modulation tends to be susceptible to ambient noise while pulse width modulation flickers the LED at a human eye disturbing frequency. Based on the limitations of the past attempts to practically implement a noiseless transmission at a high data rate, this work focused on designing and implementing a real time VLC system capable of noiseless data transmission using quasi pulse with modulation.

1.2 Aim and Objectives

The aim of this work is to Prototype a Visible Light Communication Circuit for Wireless Data Transmission. The objectives were the design of a functional circuit of VLC system in virtual platform using professional circuitry software; validate the input-output performance of both the transmitter and the receiver circuitry by simulation; implement and test the virtual circuitry for maximum bandwidth.

2.0 Methodology

The prototype modeling methodology was adopted for VLC implementation. Quasi pulse width modulation and demodulation technique adopted for data encoding and decoding. LED and photodiode for data transmission and reception across a free space channel. Fresnel lens and optical filter for channel signal amplification and ambient noise suppression. Analog filters and amplifiers for system noise suppression and signal amplification. Proteus 8 professional and oscilloscope for simulation and testing.

2.1 The High Level Model

The High Level Model of the New System can be viewed in three stages which includes the Transmitter stage, the Free Channel stage and the Receiver Stage which is shown in Figure 1

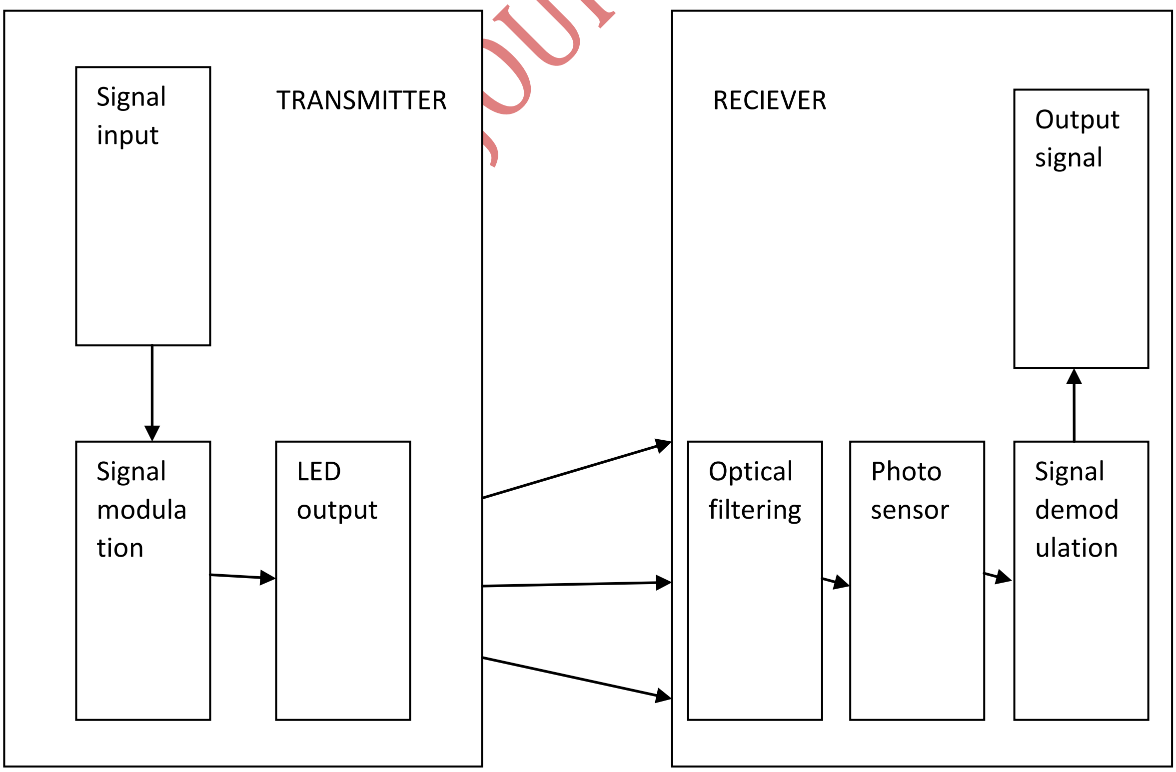

Figure 1: High level model of the new system

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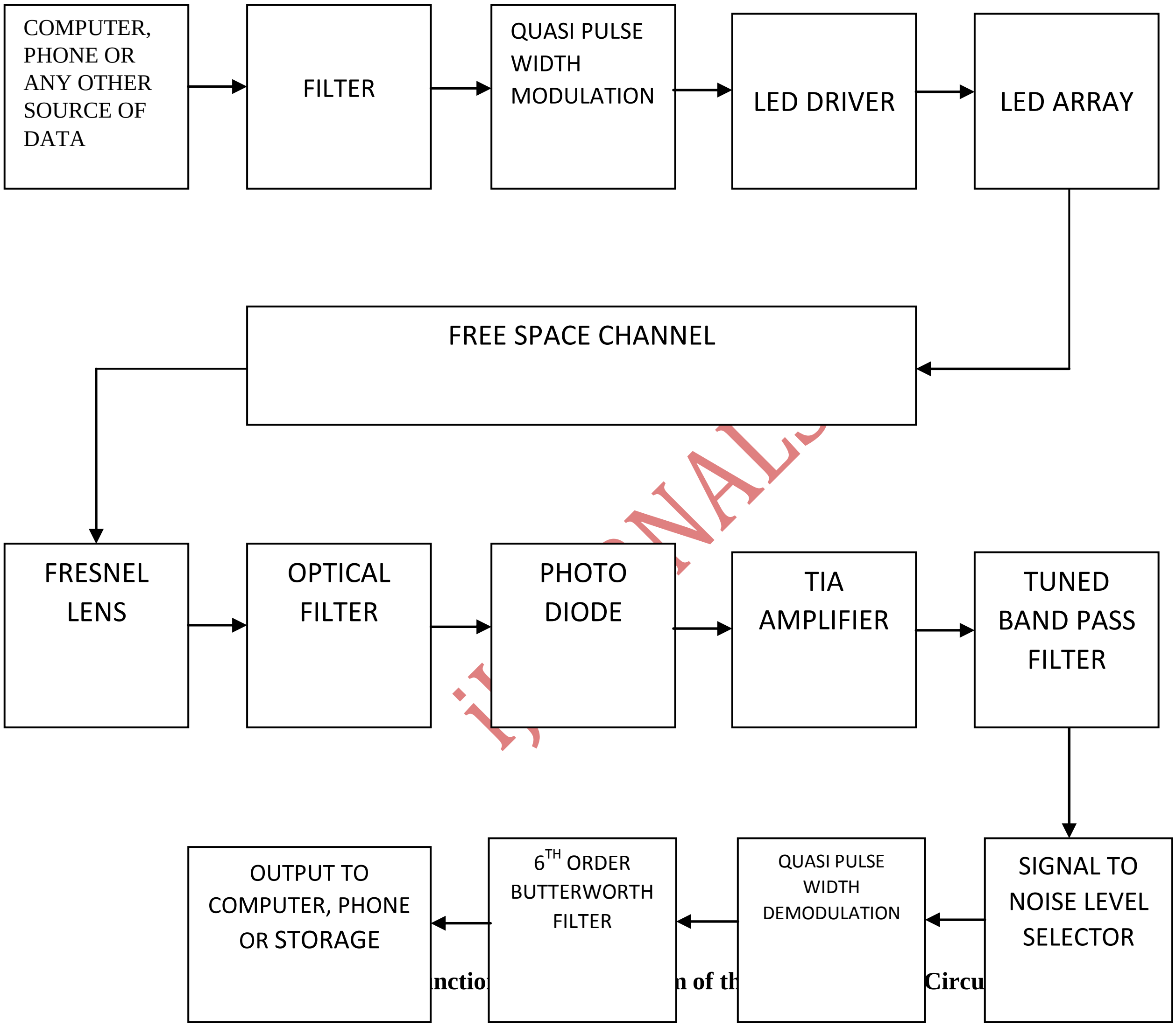
2.2 Functional Block Diagram

The functional block diagram of the proposed system is shown in Figure 2. The transmitter side consists of the source of the signal, quasi-pulse width modulator and an analog circuit which incorporates the LEDs. The receiver side is similar to the transmitting side, containing an analog circuit which incorporates the photo-detectors, opto-coupler and quasi-pulse width demodulator.



2.3 The complete circuit diagram of the proposed VLC system

The final design is the complete Circuit diagram of the proposed system shown in the Figure 6 showing the Transmitter stage, the Free space stage with the Receiver stage and the appropriate photodiode

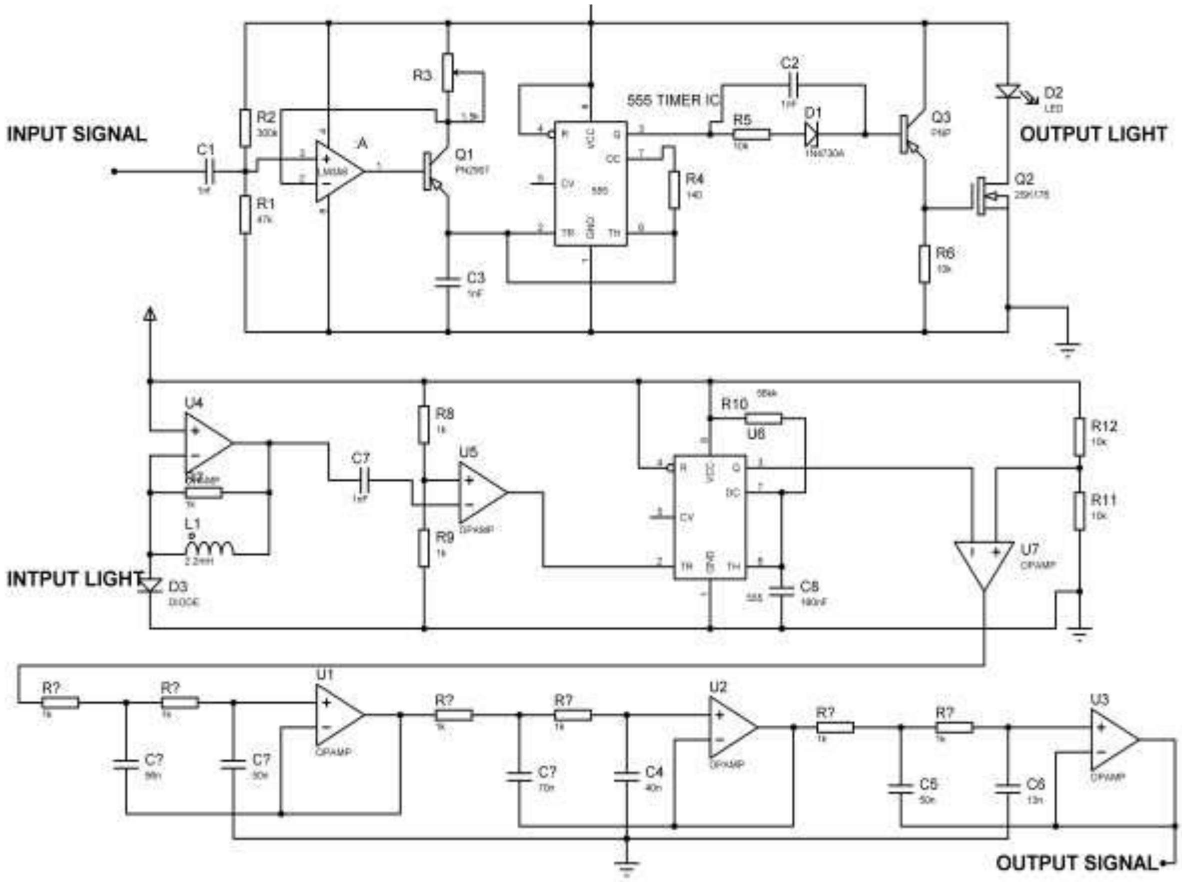


Figure 6: The complete circuit diagram of the proposed VLC system

2.4 Design Verification

Tests were conducted to verify the design and see if the right properties were achieved. These initial tests were mainly done using PROTEUS software. Sending sine waves through the systems made it easy to look at different parts of the circuit and see how the signal propagates through each block. The final design verification was done using an oscilloscope, function generator and the complete system; transmitter section, receiver section, and the results were documented at each section. To verify the functionality of the circuit design, we introduce sine wave signal (representing audio signal) into the transmitter input stage and observe the signal at each block and or section. The circuit design and simulation is performed with PROTEUS 8 PROFESSIONAL software with inbuilt digital oscilloscope.

3.0 Results

The transmitter and receiver results are simulated and measured on Proteus 8 professional with sinusoidal input signal of 20Hz to 20kHz and a carrier frequency of 100MHz. A significant harmonic distortion introduced by the carrier signal was observed at the demodulated output stage. The harmonic distortion was however insignificant after the 3rd stage of the 6th order butterworth filter. The final output signal was compared with the original input signal with Proteus oscilloscope and the output result was a delayed replica of the original signal without distortion. To test the system performance in real time, we transmitted an audio signal captured through mobile phone and transmitted it through free space at 10Mb/s over a distance of 10m . The audio signals were extracted and streamed and high quality sound was recovered and played.

The input signal is a 3kHz sine wave signal generated with PROTEUS signal generator and the signal across each stage is visualized with PROTEUS virtual digital oscilloscope. The signal output at the input stage, quasi pulse width modulation stage and the LED output stage of the transmitter is shown in Figure 7.

(a)
(b)
(c)

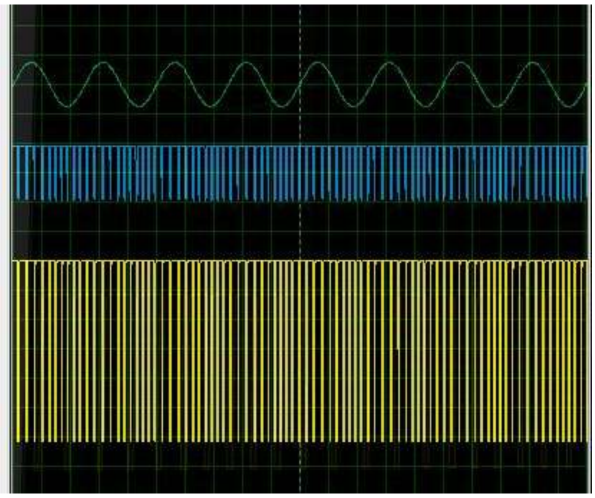
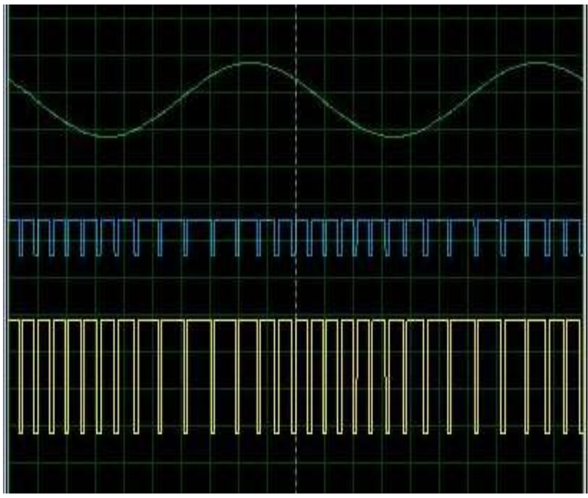


Figure 7. The Transmitter Signal Simulation of (a) the input signal, (b) the QPW modulated signal and (c) the LED output signal



The Expanded view of Transmitter Signal Simulation

a. The input signal (a) is a sine wave signal that mimics audio signal with varying amplitude.

b. The quasi pulse width modulated signal (b) consists of pulse train of low and high pulses generated by the NE555 IC. The pulse width of the low pulse serve as a carrier frequency set to 10MHz. the pulse width of the high pulse increases as the input signal increases and vice versa as can be seen in Figure 4.19. Thus the input signal modulates the carrier signal

c. The LED output pulses (c) are the amplified replica of the modulated signal amplified by the LED driver circuit. These pulses being connected to LED causes the LED to switch on and off at a very high speed and thus produces light corresponding to the pulses.

To verify the functionality of the receiver circuit, we introduce the LED output signal of the transmitter to the photodiode input of the receiver circuit. In the simulated circuit design, the photodiode is replaced with it equivalent circuit of current source component. The output signal of each receiver stage connected to virtual oscilloscope in PROTEUS 8

The output signal of each stage is shown in Figure 8, Figure 9 and in Figure 10

(a)
(b)
(c)
(d)

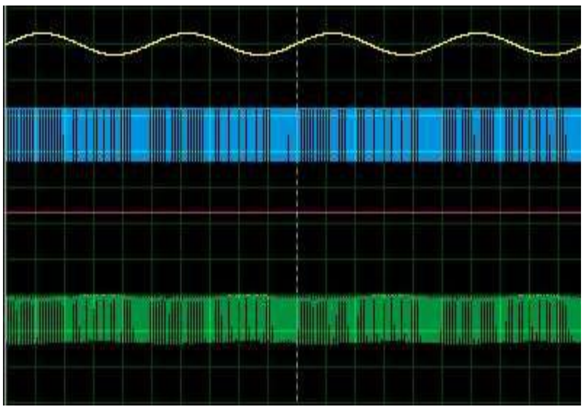
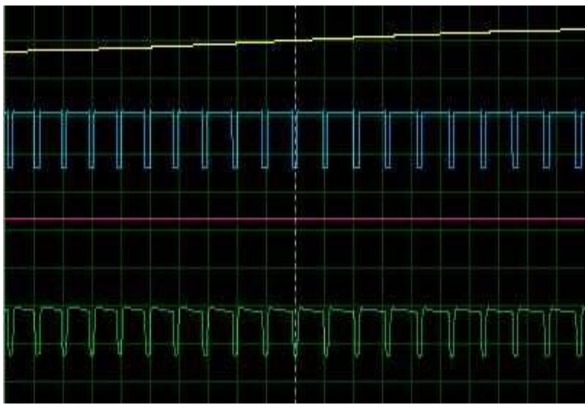


Figure 8 The Receiver signal simulation of (a) the original sine wave transmitter input signal, (b) the LED output light signal, (c) the photodiode received signal, (e) the amplified and filtered signal.



The expanded view of the receiver signal simulation.

1. The signal (a) is the original sine wave signal introduced at the transmitter input stage.
2. The signal (b) presents the LED light output signal in form of light signal.
3. The photodiode receives the LED output signal and replicate the signal (c) (in electrical signal form).
4. The Transimpedance amplified and filtered signal (d) is the replica and amplified version of the photodiode signal.

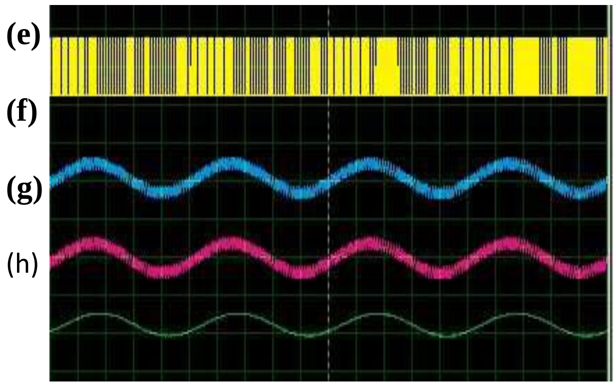
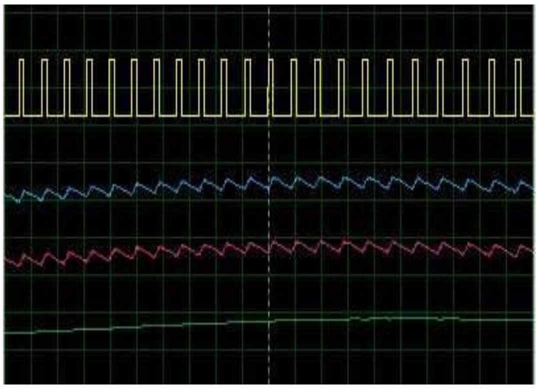


Figure 9: The Receiver signal simulation of (e) the QPW demodulated signal, (f) the first stage Butterworth filtered signal, (g) the second stage Butterworth filtered signal, (h) the third stage Butterworth filtered signal also the output signal.



The expanded view of the Receiver signal simulation.

1. The QPW demodulated signal (e) presents the reversed QPW modulated signal.
2. The first stage Butterworth filtered signal (f) is the output signal filtered from the carrier frequency but still contain some carrier noises.
3. The second stage Butterworth filtered signal (g) contains a cleaner version of the output signal
4. The third stage Butterworth filtered signal presents a noiseless signal that replicate the original input sine wave signal at the transmitter section.

Figure 10 compares the sine wave signal introduced at the transmitter input and the final output signal at the receiver output. The output signal is a delay replica of the input signal. Thus, the communication system is verified. The delay of the output signal is caused by Butterworth filter block and does not present a problem to the system as long as the output signal remains in tandem and in synchrony with the input signal.

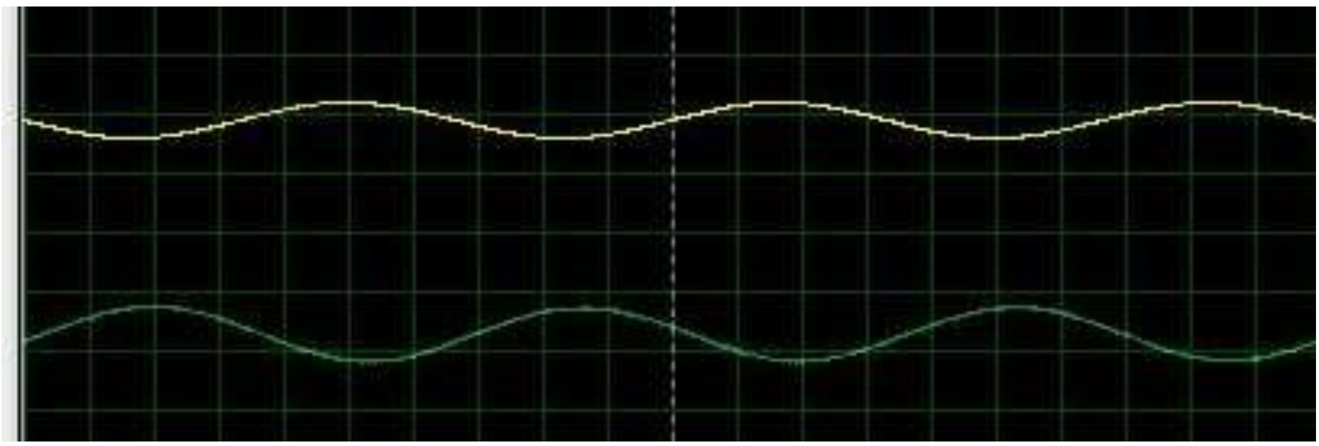


Figure 10: The Simulated Transmitter Input Signal and Receiver Output Signal.

4.0 Conclusion

In this paper, we proposed a real-time VLC design and implementation using LED. System design is illustrated in detail and experimental results are presented. It is shown that transmission of high quality audio with the capacity of transmitting data at 10Mbps bandwidth. Improvements were made by adding focusing Fresnel lens and optical filter between the transmitter and the receiver. Although delay still exist comparing signal before and after transmission, it demonstrates that high quality wireless optical transmission using LED is successful. Future work will concentrate on error control mechanism, dimming control and IP/TCP integration.

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