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Integration of Photodiode as a Data Receiver in Visible Light Communication Circuit

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Abstract— *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, implementing and integration of photodiode as a data receiver for a real time VLC system capable of noiseless data transmission using quasi pulse with modulation. The design adopted Beagle-Bone-Black (BBB) as development platform while prototype modeling methodology was adopted for VLC implementation and the circuit was tested with PROTUES 8 Professional and data 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, text or pictures over a distance of approximately 10 meter at a data rate of at least 10 Mbps was achieved using Photodiode as Data Receiver.*

Keywords— *Beagle-Bone-Black (BBB), quasi pulse-width modulation (QPWM), Photodiode, PROTUES 8, quasi pulse-width modulation (QPWM), Visible light communication (VLC), Oscilloscope.*

I. STATEMENT OF THE PROBLEM

According to Chvojka *et al.*, (2015) as societal reliance upon wireless systems continues to rise, there is need for wireless technology to develop to meet this demand. Phones, printers, laptops, and global positioning systems are all devices that employ certain forms of wireless communication to send information to another location. However, the availability of this current form of data transmission is becoming limited. The Federal Communications Commission (FCC) regulates many wireless applications including radio, television, wire, satellite, and cable. Each application is given a frequency band in which it is allowed to operate to allow efficient use of the available frequency spectrum; it is quite evident that this spectrum is very crowded and at the same time, there is a huge growth in demand in the limited radio frequency spectrum. Zhang et al., (2015) suggested the need to more easy and free method of data transfer is needed and the better alternative could be to integrate photodiode, which makes data transfer faster in a light form through the use of photodiode that is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode. Zhang et al., (2015)

Furthermore, Bangerter (2014) opined that around 2% of all carbon-dioxide emissions worldwide are produced by communication technologies; this will increase significantly with the aforementioned increasing mobile data traffic demand. Moreover, approximately 57% of overall wireless network energy consumption is dissipated in radio access nodes and light emitting diodes will help to reduce this hazard since it is environmental friendly.

According to Zheng and Zhang (2014), VLC systems have more flexibility and integrity than other communication systems in many regards. Since the medium for transmission in VLC systems is visible light and not RF waves that can penetrate walls, the issue of security is inherently solved because light cannot leave the room thereby containing data and information in one location. There is no way to retrieve and access the information unless a user is in a direct path of the light being used to transmit the data and with an appropriate photodiode. In addition, LEDs are highly efficient and becoming more durable, adding to the integrity of these systems. (Zhou and Campbell 2014)

II. AIM AND OBJECTIVES OF THE STUDY

The aim of this work is to design, implement and integrate a photodiode in Visible Light Communication Circuit (VLC)for wireless data transmission and ensuring that the transmitted data are received with appropriate Photodiode through a free space medium.

The objectives of this work are:

1. To design and implement an analog circuit that will be capable of sending data using visible Light Emitting Diodes (LEDs.) through a free space channel with photodiode serving as the Receiver component.
2. To design the functional circuit of VLC system with photodiode as a receiver in virtual platform using PROTUES 8, professional circuitry software.

III. METHODOLOGY ADOPTED

The design adopted Beagle-Bone-Black (BBB) as development platform while prototype modeling methodology was adopted for VLC implementation and the circuit was tested with PROTUES 8. 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.

IV. HIGH LEVEL MODEL OF THE NEW SYSTEM

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 1.0

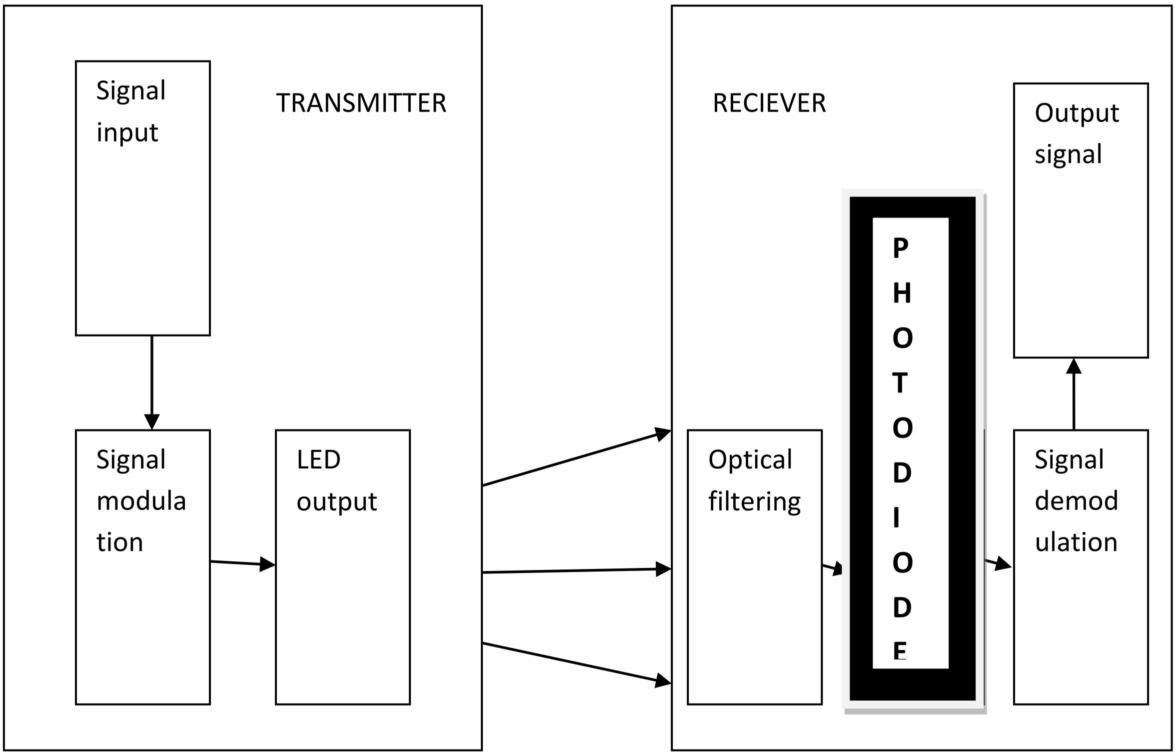


Figure1.0: High level model of the new system

V. DECOMPOSITIONAND COHESION OF THE HIGH LEVEL MODEL

This work comprises the receiver section highlighting the photodiode as the receiver component, the transmission section and the free space as show in Figure 1.1.

a. The Input Stage

The signal to be transmitted is sourced from a memory unit which may be either from the mobile phone, computer or any other memory unit in form of a text, image, audio or video file. But in this work we are considering audio transmission via mobile phone through the visible light communication channel and the free space. The audio signal has a sinusoidal waveform characterized by amplitude and frequency. Ideally, audio frequency ranges from 20Hz to 20 KHz, but practically, audio signal may contain other unwanted frequencies as a result of input noise. This unwanted noise may interfere with the transmission via the channel.

b. The Filter Stage

In other to handle the unwanted frequencies which will act as noise we need to filter off the noise. Therefore the input audio signal is taken to the filter block for noise removal. The filter stage utilizes Band-Pass filter specially designed to accept certain frequencies and discriminate other frequencies below and above the cutoff frequency. At this level, the filtered signal is thus ready for modulation.

c. The Modulation Stage

Modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted. Modulation here simply means manipulating or adjusting the characteristic (properties) of the carrier signal so as to match the characteristics (properties) of the input signal. As earlier stated, the characteristics of the audio input signal are the amplitude and frequency.

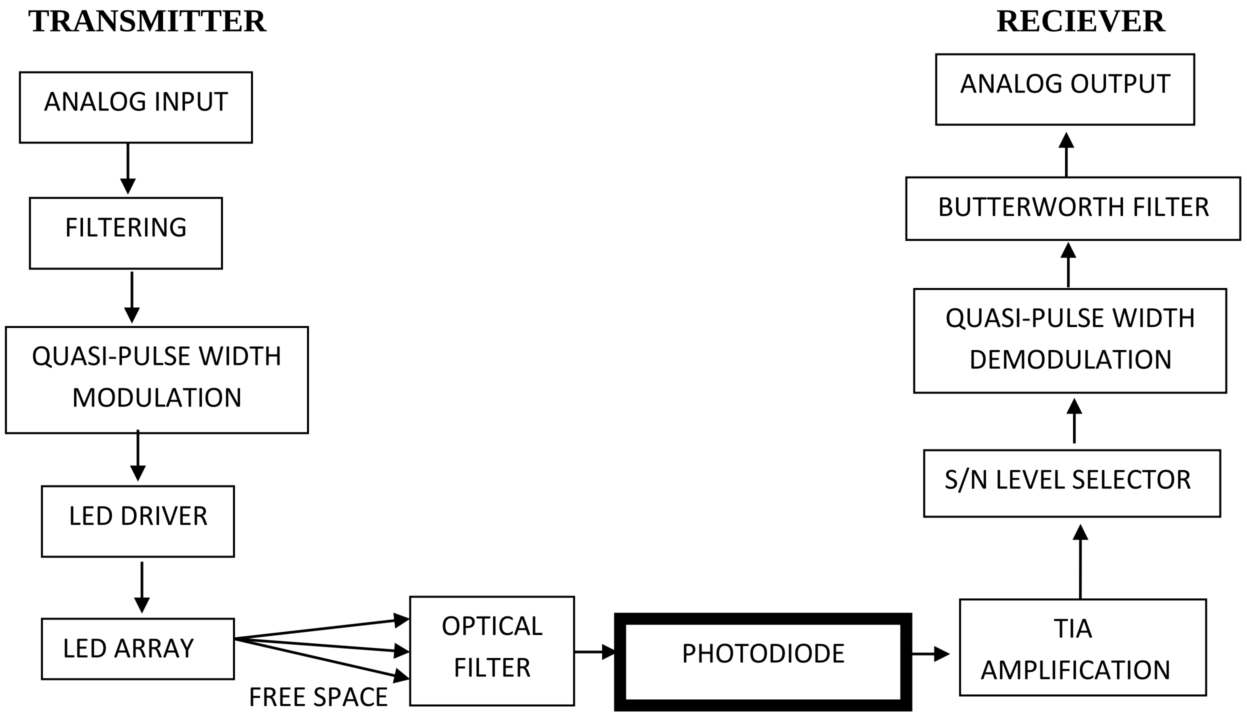


Figure 1.1: Block diagram model of the proposed VLC system

We therefore need to use a particular modulation technique that will perform the expected work therefore quasi pulse-width modulation (QPWM) is adopted as demonstrated in Figure 4.2, which is aimed at continuously adjusting the frequency and the pulse width of the carrier signal to correspond to the frequency and the amplitude of the input signal respectively. The quasi pulse width modulator is centered on an oscillator IC known as 555 Timer. Initially, the 555 timer generates digital pulses of 10 MHz which is utilized as the carrier signal. This signal on its own carries no audio signal and it is thus said to be un-modulated, but its serves as the conveyor or the transporter of the input audio signal. The audio signal from the filter block contains a sinusoidal waveform with varying frequency and amplitude corresponding to the pitch and the loudness of the audio respectively. The signal therefore goes into the input of 555 timer.

The 555 timer chops or slices the signal at a high speed of 10 million slices in one second (10 MHz). This process of chopping or slicing the incoming signal is known as Sampling and the rate at which the slicing takes place is known as Sampling Frequency. After each sampling, the 555 timer measures the sampled signal and increases or decreases the pulse width of the carrier signal to correspond to the measured value of the sampled signal. The process of measuring the sample signal is known as Quantization and the complete process of adjusting the pulse width of the carrier signal by the input signal is referred to as Quasi Pulse Width Modulation.

d. The LED Driver Stage

The work done at this stage is simply to amplify the modulated signal. LED driver is an electrical device which regulates the power to aLED or a string (or strings) of LEDs. ALED driver responds to the changing needs of the LED, or LED circuit, by providing a constant quantity of power to the LED as its electrical properties change with temperature. The modulated signal from the Quasi Pulse Width Modulator is amplified by the led driver to the level required to power the LED (light emitting diode). The amplification is done using NPN transistor.

e. The LED Array Stage

LED arrays are assemblies of LED packages or dies that can be built using several methods. Each method hinges on the manner and extent to which the chips themselves are packaged by the LED semiconductor manufacturer. It is quite obvious that following the amplified modulated signal that the light emitting diode (LED) is now powered to switch ON and OFF depending on the state which is either low or high, where the LOW is referred to as OFF and the HIGH is referred to as ON. This Low or High state is dependent on the incoming signal because the switching is performed at high frequency of 10 MHz. At this stage the light that is produced from the light emitting diode (LED) appears to be steadily lighted in human eye.

f. The Free Space Stage

Free-space is an optical communication technology that uses light propagating in free space to wirelessly transmit data for telecommunications or computer networking. "Free space" means air, outer space, vacuum, or something similar. Therefore the light rays from the light emitting diode (LED) are propagated through a free space channel where it is distributed in the entire room via direct and diffused rays.

g. The Optical Filter Stage

The optical filter stage consists of the Fresnel lens and the light filter. A Fresnel lens is a type of compact lensthat can capture more oblique light from a light source at all angle, thus allowing the light from a light source to be visible over greater angle. Therefore the direct and diffused rays get to the receiver through an optical concentrator known as Fresnel Lens. Fresnel lens is designed in such a way as to focus all the rays in the room to the lens focal point and hence allow for maximum mobility of the transmitter and or the 4.3 receiver; An optical filter is a device that selectively transmits light of different wavelengths, usually implemented as a glass plane or plastic device in the optical path, which are either dyed in the bulk or have interference coatings. Therefore the Optical filter here will accept only one color and reject other colors when placed after the Fresnel lens. The true color of the light emitting diode (LED) employed in the design is blue and thus blue optical filter is used and every other color is rejected.

i. The Photodiode Stage

A photodiode is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Therefore the amplified signal is connected to thelight emitting diode (LED). The photodiode placed at the focal point of the Fresnel lens picks up the filtered light and converts it to its equivalent electrical signal.It is quite obvious that the photodiode signal however at this stage will be very minute depending on the relative distance between the transmitter and the receiver, and needs to be amplified.

j. The Amplifier Stage

A Trans-impedance amplifier (TIA) is a current-to-voltage converter, most often implemented using an operational amplifier. The TIA can be used to amplify the current output of Geiger–Müller tubes, photomultiplier tubes, accelerometers, photo detectors and other types of sensors to a usable voltage. Current-to-voltage converters are used with sensors that have a current response that is more linear than the voltage response. This is the case with photodiodes, where it is common for the current response to have better than 1% linearity over a wide range of light input. The Trans-impedance amplifier presents a low impedance to the photodiode and isolates it from the output voltage of the operational amplifier. In its simplest form a Trans-impedanceamplifier has just a large-valued feedback resistor, R_f. The gain of the amplifier is set by this resistor and has a value of $-R_f$ (because the amplifier is in an inverting configuration). There are several different configurations of Trans-impedance amplifiers, each suited to a particular application. The one factor they all have in common is the requirement to convert the low-level current of a sensor to a voltage. The gain, bandwidth, as well as current and voltage offsets, change with different types of sensors, requiring different configurations of Trans-impedance amplifiers. Therefore the Trans-impedance amplifier is used to amplify the signal up to 1 million times. The amplified signal may contain undesired signal from other blue light sources

k. The Tuned Filter Stage

The Tuned Filter Stage is necessary because the desired signal is pulsating at a known frequency of 10MHz, and the undesired signal is steady or if pulsating cannot probably be at 10MHz, a tuned filter is adopted which allows only the signal pulsating at 10MHz and discriminate other frequencies. At this point, the signal is free from external noises but the signal level increases as the receiver gets closer to the transmitter, and decreases as the receiver gets farther from the transmitter.

l. The Signal to Noise Selector Stage

To solve the problem, we use signal to noise selector to trim the signal to a fixed threshold level. The signal to noise selector monitors the incoming signal to detect whether the signal is going low or high. If the signal is going high, it ignores the signal level and project it to a fixed high level but if the signal is going low, it demotes it to a fixed low level A closer observation at this stage will show that the output at this stage is a replica (exact copy) of the output signal of the modulator stage in the transmitter section.

m. The Demodulation Stage

To retrieve the original signal, the signal is demodulated using 555 timer to perform the reverse functions of quasi pulse width modulation. Firstly, the 555 timer increases or decreases the amplitude of the signal depending on the pulse width of the input signal. Then the last stage will be the introduction of the Butterworth Filter.

n. The Butterworth Filter Stage

The Butterworth filter removes the carrier signal of 100MHz. The final output signal is the replica of the original audio file. The file can be stored in a memory unit or can be streamed instantaneously.

VI. DEVELOPMENT PLATFORM

During the project a Beagle Bone Black (BBB) was used as development platform. It is a small, inexpensive and relatively powerful single board computer. The BBB is a single-board computer, which means it can run a variety of Linux distributions, such as Debian and Ubuntu. That means the project can use the functionality already present in the operating system, such as the network stack and TCP/IP protocol suite. Furthermore, the operating system makes it easy to run several execution threads in parallel. These reasons should make development easy, and is the reason why BBC was chosen over a micro controller. The board is used in this work to interface the VLC system to computer system.

VII. FINAL DESIGN

The final design is the complete Circuit diagram of the proposed system shown in the Figure 1.2 showing the Transmitter stage, the Free space stage with the Receiver stage and the appropriate photodiode

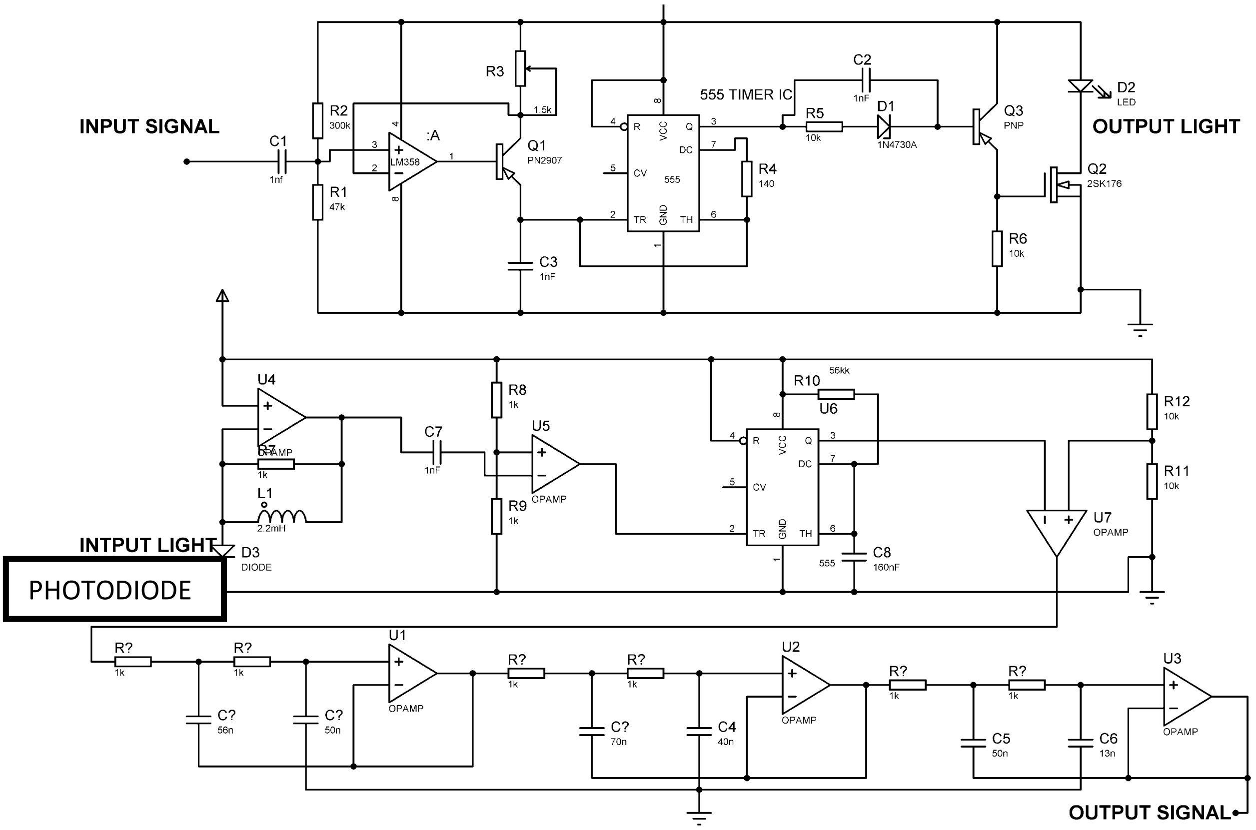


Figure 1.2: The complete circuit diagram of the proposed VLC system with Photodiode

VIII. 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. 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.

To further 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 oscilloscope is shown in Figure 1.3.

The output signal of each stage is shown in Figure 1.4, Figure 1.5 and in Figure 1.6

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 Trans-impedance amplified and filtered signal (d) is the replica and amplified version of the photodiode signal**.**

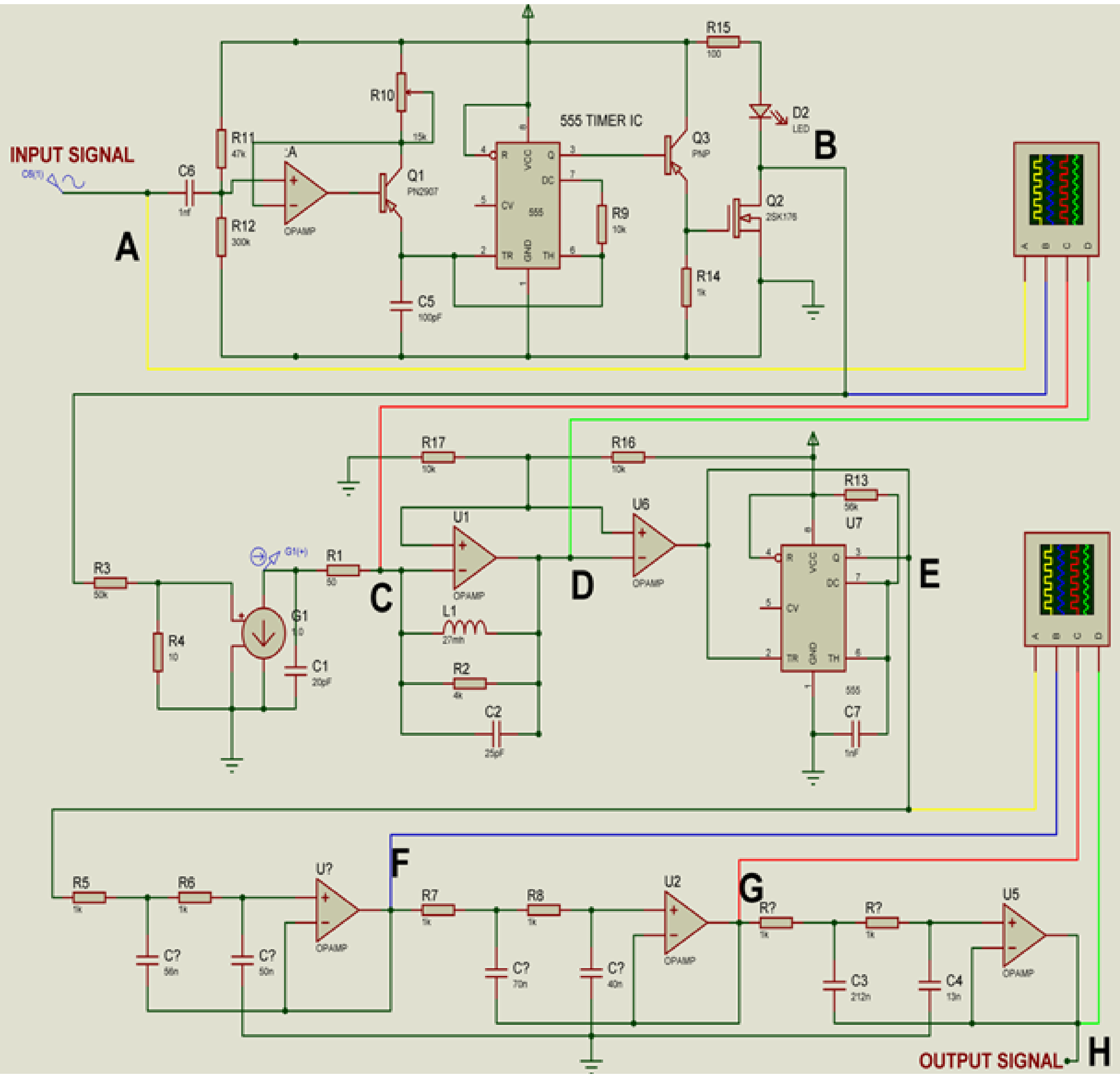


Figure 1.3: The Simulation of the Receiver Circuit

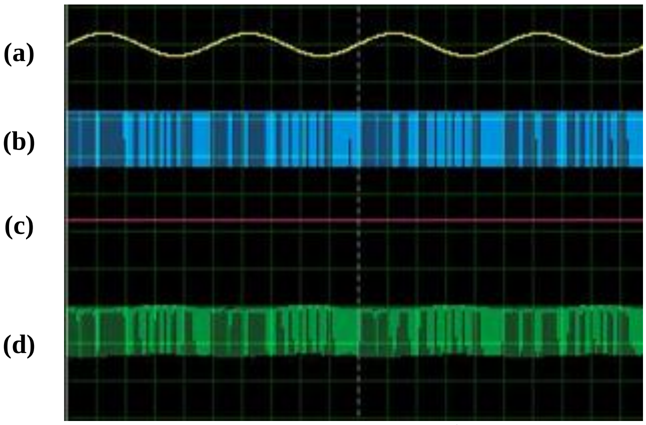
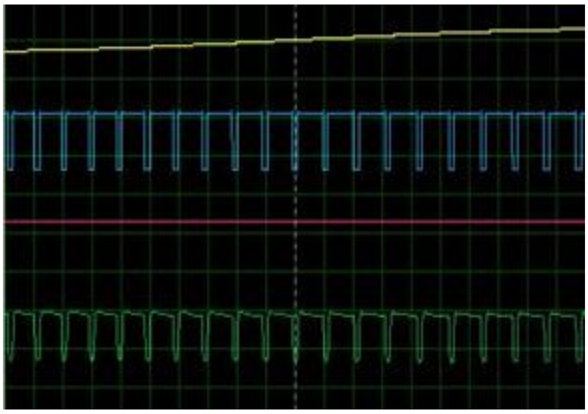


Figure 1.4 The Receiver signal simulation of (a) the original sine wave transmitter input signal, (b) the LED output light signal, (c) the photodiode received signal, (e) the amplified and filtered signal.



The expanded view of the receiver signal simulation.

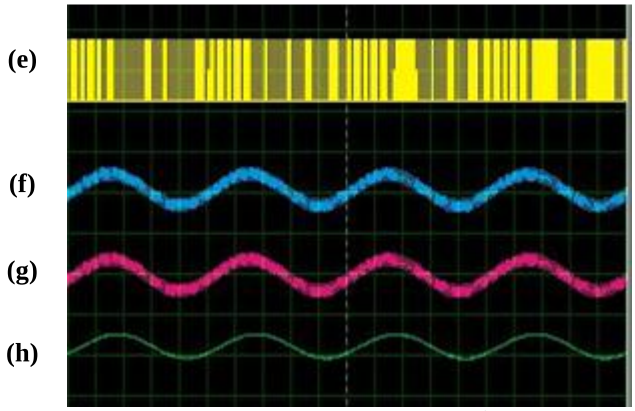
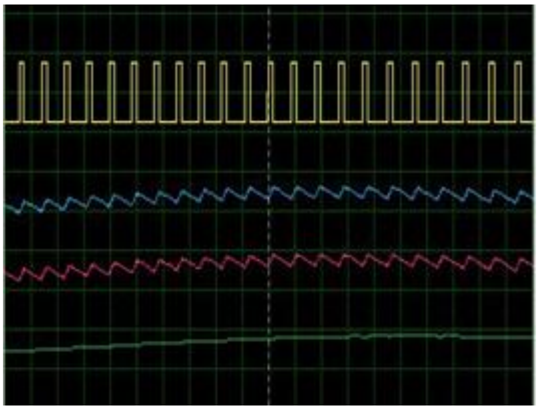


Figure 1.5: The Receiver signal simulation of (e) the QPW demodulated signal, (f) the first stage Butterworth filtered signal, (g) the second stage Butterworth filtered signal, (h) the third stage Butterworth filtered signal also the output signal.



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 quasi pulse-width modulation (QPWM) signal presents a noiseless signal that replicate the original input sine wave signal at the transmitter section.

Figure 1.6 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.

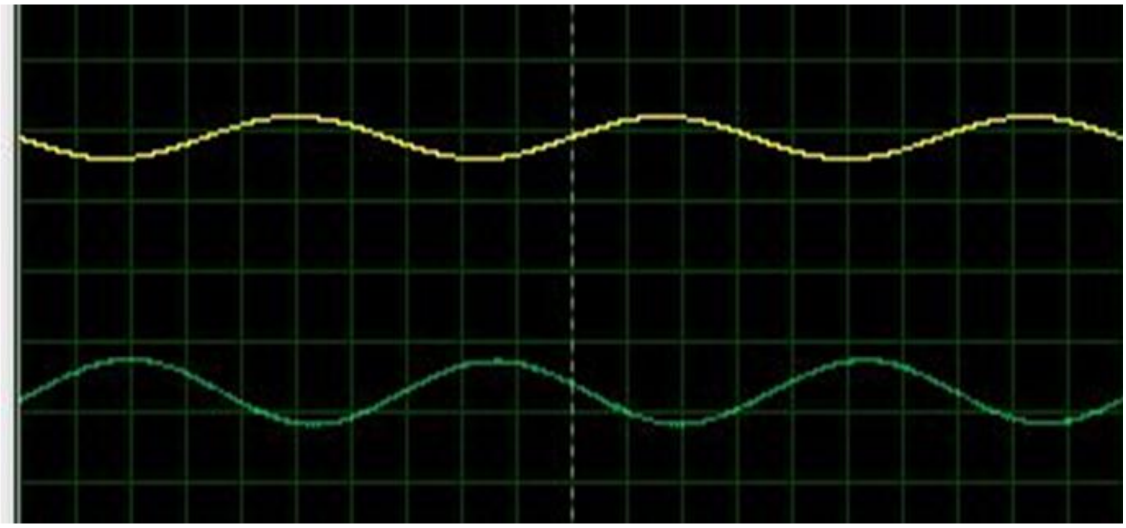


Figure 1.6: The Simulated Transmitter Input Signal and Receiver Output Signal.

IX. HARDWARE IMPLEMENTATION AND RESULTS

This section will describe our hardware development and test results, as well as what was actually achieved with our implementation. Firstly, we will discuss our results from the analog circuitry of the transmitter and receiver. The transmitter was slowly distanced from the receiver to determine the maximum transmission distance. By displaying the received signal on an oscilloscope, it was possible to determine when the transmitter had no effect on received signal.

Hardware of transmitter driver circuit is tested initially on a breadboard and then implemented on a strip-board. To test the circuit capability the function generator is used to generate a square wave used as input signal. In addition, oscilloscope is used to view the output voltage signal across the LED. Figure 2.1 and Figure 2.2 shows the implementation of the circuit on breadboard

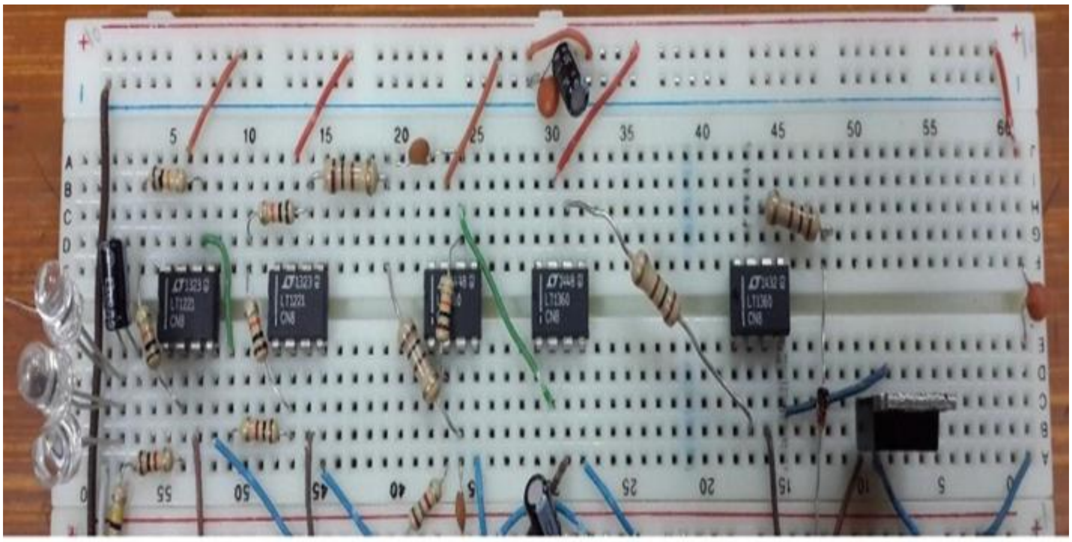


Figure 2.1: The implementation of the circuit on breadboard

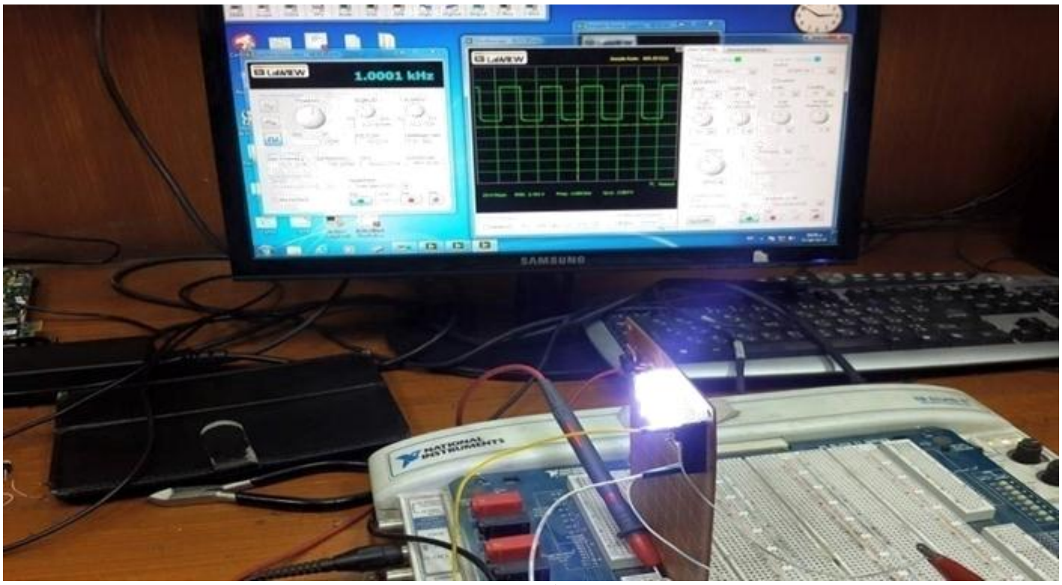


Figure 2.2: Analog Circuitry of the Photodiode Receiver

X. SYSTEM HARDWARE RESULTS

To test that the receiver functioned properly, a LED was connected to the amplifier's output. In this test, two photodiodes were tested; the SFH203P and the SFH229. The first experiment performed was to test if the receiver can recognize a change in light from the receiver. To do this, a manual switch was used to turn the transmitters' LEDs on and off. While this occurred, the LED on the receiver was observed to determine if a change in its status occurred. Once the receiver's LED was switched on by manually turning the transmitter on, the function generator was added to the transmitter to supply a square wave. Initially, the square wave's frequency was set to 10MHz to determine that the LEDs were in fact constantly turning on and off. Again in a dark room, the receiver's LED flickered. Once it was determined that the receiver could recognize the transmitter, the distance between the two systems was increased until the receiver was no longer able to recognize the transmitter. The maximum distance for transmission was measured to be 10m. Through experimentation, it was observed that the receiver recognized the transmitter better when the photodiodes were pointed directly to the transmitter's LEDs. This is due to the photodiode's low angle of visibility. However increasing the transmitter's power increases the coverage area. The two photodiodes that were tested, the SFH229 and the SFH203P, have a half angle lamination detection of ±17: and ±75: respectively. While both photodiodes have similar specifications, the SFH203P functioned better due to its higher half angle. Because of this, the SFH203P photodiode was used when collecting measurements. When the room was lighted, the added light would cause the photodiode to emit a constant current, which resulted in a DC threshold voltage at the amplifier's output. After determining that the receiver could recognize the transmitter, the amplifier's output was measured using an oscilloscope. Initially, the transmitter was set to transmit a square wave with a frequency of 10Hz.

The receiver was able to recreate the square wave that the transmitter sent. However, even after the amplification from the amplifier, the distance from high to low was only 80 mV. Also, the signal contained some noise, but not enough to cause the square wave signal to become indistinguishable. To get a more accurate square wave output, it was decided to replace the 1 MΩ Resistor with a 5.1 MΩ resistor.

The receiver's output continued to contain some noise, but the square wave was still distinguishable. Because of a higher resistor, the amplifier contained a higher gain, thus increasing the square wave's amplitude. The square wave's amplitude was measured to be 960 mV, which is much higher than the 80 mV amplitude from before.After the square wave was found, the distance between the transmitter and receiver was increased until the square wave was no longer distinguishable. The amount of noise present would make it difficult for the receiver to determine the appropriate ones and zeros. The distance measured is very close to the distance goal of 2m we set for the prototype. One way to fix the change would be to increase the number of LEDs at the transmitter. Since we did not have enough LEDs at the time, but had many photodiodes, photodiodes were placed in parallel at the receiver end. On top of adding more photodiodes, the amount of gain was adjusted from the amplifier to determine the best design. The first adjustment we made was using two SFH203P photodiodes along with a 505 kΩ resistor.

The receiver's output had smaller amplitude than before, which was expected because the gain was reduced. On top of that, there was much more noise when an extra photodiode was used. The resistor was changed to a 3.24 MΩ resistor, but the output had more noise than the initial test. Its amplitude was also smaller, about 100 mV. Because of this, we decided to use the 5.1 MΩ Resistor with only one photodiode. After determining which circuit configuration functioned better, the frequency at the transmitter was increased. When the frequency was increased to 3.2 kHz, the receiver's output contained some ringing. While some ringing was present, it was not enough to keep the square wave from being distinguishable. The frequency was increased more until the square wave could not be seen at the output.

The maximum transmission bit rate achieved in the hardware circuit is 10Mb/s. Limitation on transmission bit rate has many reasons related to hardware.LT1221CN8 is used in this circuit after the photodiode directly as an amplifier then another LT1360CNis used as a cascaded amplifier to give a gain of 52db. The signal is modulated by the noise found in the photodiode.Then the signal is filtered using Butterworth filter as low pass filter to remove this noise with the high frequency component and gain with 13db with -3db point of 10MHz in this circuit design and the final output signal is as shown in Figure 2.3

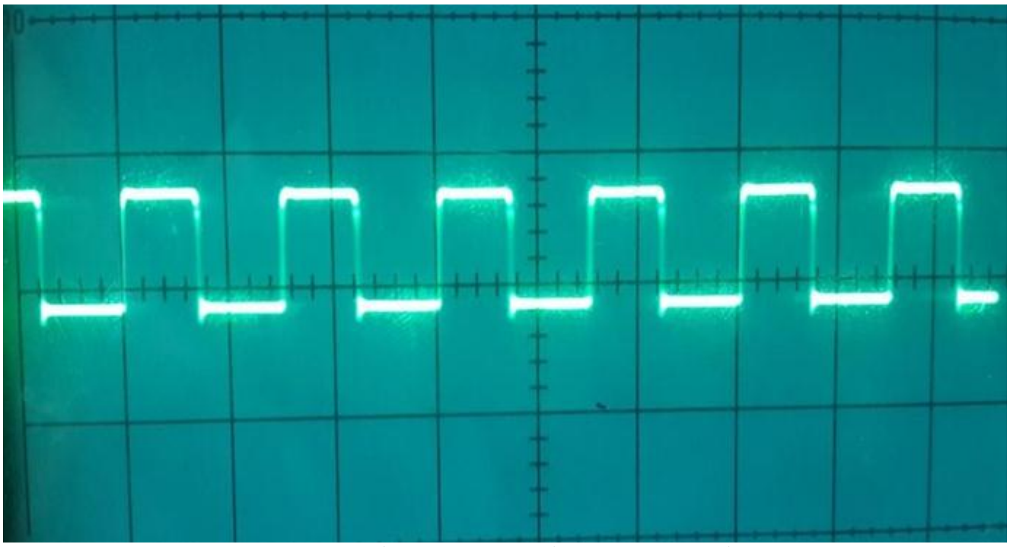


Figure 2.3: The final output signal after the Butterworth filter.

Finally the performance of the software simulation with PROTEUS 8 PROFESSIONAL software was done to ascertain the generation of data for the input and output signal characteristics variation as shown in Table 2.0. PROTEUS 8 was chosen over MATLAB due to its flexibility in circuit design and net-listing. The model of the input signal shall consist of audio signal characterized by a frequency range of 20Hz to 20 kHz and amplitude of any practical value. We generated a 3kHz signal representing audio signal using PROTEUS 8 inbuilt sine wave generator. The frequency and the amplitude of the signal can be adjusted from the settings of the signal generator. The generated signal is the imitation of real audio signal ready for wireless transmission. The signal is visualized with. PROTEUS 8 oscilloscope connected to the signal generator.

The transmitter circuit consist of electronics ICs, amplifiers, filters, resistors, capacitors, transistors, LEDs, etc. We manually predesigned the circuit on paper and generate the electronics circuit model using PROTEUS 8software. The ideal free space model consists of the transmitted signal mixed with noise signal with a variable range. These parameters are tested in hardware test but due to software limitations, the free space is modeled in PROTEUS 8 by direct connection of the transmitter output to the receiver input via Photodiode.

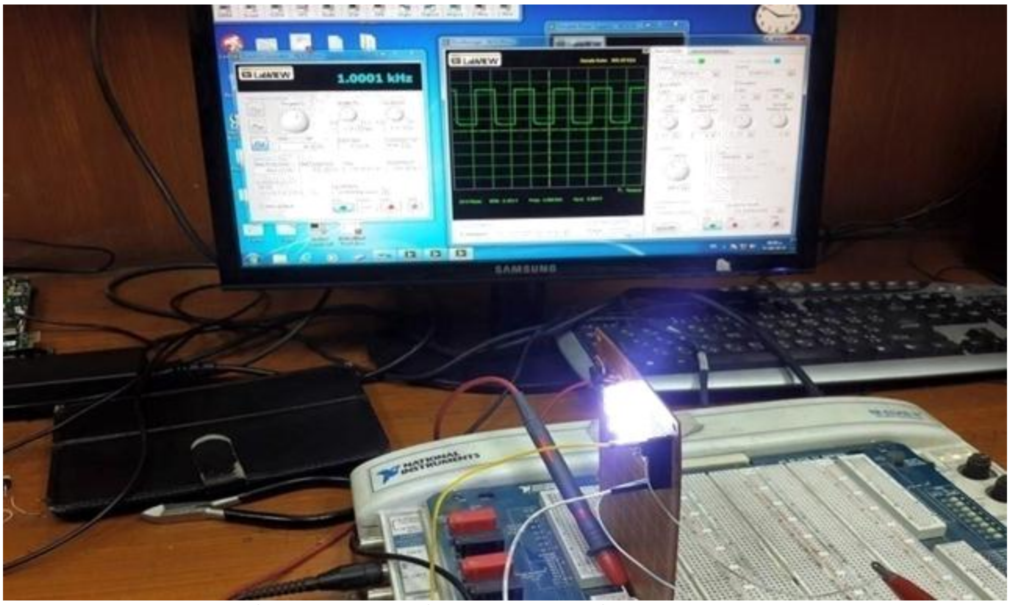


Figure 2.4:The final output signal after the Butterworth filter as shown using Oscilloscope

The transmitter circuitry is modeled using the inbuilt circuit equivalent to the circuit design. The output signal models the input signal which is the real audio model of the original signal. The characteristic of the input and output sine signal as obtained from hardware test and simulation are tabulated in Table 2.0. At all input variation, the output frequency and amplitude remains unchanged. The change in phase of the output signal relative to the input signal is due to delay in system hardware, amplifications and filtering. The signal to noise ratio which determines the quality of the output signal decreases as the input frequency increases. At a maximum audio frequency of 20 kHz, the noise to signal ratio of the output signal still maintain 55dB signal quality which is within our requirement.

Table 2.0 Summary of Input and output signal characteristics variation

Input signal				**Output signal**			
Frequency (Hz)	Amplitude (V)	LED power (W)	Phase shift (degree)	Frequency (Hz)	Amplitude (V)	Phase shift (degree)	Signal to noise ratio (dB)
20	0.01	1	0	20	0.01	20	70
500	0.05	2	10	500	0.05	102	78
1000	0.1	3	20	1000	0.1	100	80
3000	0.2	4	30	3000	0.2	94	92
5000	0.3	5	40	5000	0.3	91	100
7000	0.4	6	50	7000	0.4	80	94
10000	0.5	7	60	10000	0.5	56	90
13000	0.6	8	70	13000	0.6	41	82
15000	0.7	9	80	15000	0.7	32	70
20000	0.8	10	90	20000	0.8	25	55

XI. SUMMARY OF RESULT

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 through free space using PROTEUS 8 professional software at 10Mb/s bandwidth. The audio signals were extracted and streamed andhigh quality sound was recovered.

XII. CONCLUSION

This work has achieved its goal of designing, implementing and integrating a photodiode in Visible Light Communication Circuit (VLC)for wireless data transmission and ensuring that the transmitted data through visible light communication is received with appropriate Photodiode through a free space medium.

More so, Visible Light Communication facilitates the reuse of existing lighting infrastructure for the purpose of communication which means that such systems can be deployed with relatively lesser efforts and at a lower cost. This untapped potential of visible light communication has motivated us to propose the incorporation of visible light communication in the next generation 5G network.

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