Design And Implement Of A Visible Light Communication Circuit For Radio Frequency Spectrum Mitigate In Mobile Data Communication

DR. ANUSIUBA Overcomer Ifeanyi Alex
Phone Number: +2348035509616 **E-mail:** oi.anusiuba.unizik.edu.ng
Department of Computer Science, Faculty of Physical Sciences
Nnamdi Azikiwe University Awka

DR. Asogwa Doris Chinedu
Phone Number:+2348067674642 **E-mail:** dc.asogwa@unizik.edu.ng
Department of Computer Science, Faculty of Physical Sciences
Nnamdi Azikiwe University Awka

Onyeizu, MacDonald Ndukaku
Phone Number: +2348032677369 **E-mail:** wikimacd@gmail.com
Department of Computer Science, Faculty of Physical Sciences
Nnamdi Azikiwe University Awka

ABSTRACT

The societal dependence upon wireless systems continues to rise due to mobile data interchange. According to the Federal Communication Commission the current allocation of 38GHz 5G Cellular is to a great extent pointing to the crowding of the radio frequency spectrum especially in Mobile data communication. Therefore this study will grant an opportunity to explore visible light communication as one of the emerging technologies to serve as an alternative to provide solution to these challenges and further prototyped a complete circuit for Mobile Data Transmission using light emitting diodes and or visible light communication. 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. This study appraises the existing literature on Solid State Lighting (SSL), with emphasis on Light Emitting Diodes (LEDs) to ensure that visible light can be used to mitigate frequency spectrum for mobile data transmission. The study focused on the Prototyping of Visible Light Communication complete Circuit for Wireless and particularly for mobile Data Transmission; an analogue circuit that can be integrated with a computer or mobile phone, which can send some form of data

using visible light LEDs from a transmitter, and decoding it with an appropriate photodiode as a receiver. The complete circuit comprising all the three phases of the transmitter, the free space and the receiver was tested with PROTUES 8 Professional software which was designed specifically for simulation of electrical signals and audio data of 3kH to 20kH was sent consistently and precisely over a short distance at a fair speed and the initial goals for the functionality of the new system which is to send audio, at a data rate of at least 10 Mbps was achieved. The study shows that Visible light communication has the prospective to provide high speed mobile data communication with improved energy efficiency and communication security/privacy due to its unique characteristics and advantages. It is therefore to so extent certain that the Visible Light Communication can complement the Radio Frequency (RF) based mobile communication systems in designing high-capacity mobile data networks and can be incorporated as an innovation in the oncoming 5G network Technology. It will be of greater advantage when error control mechanism and Dimming Support is integrated in the subsequent research work.

1.0 Introduction

The exponential boost of mobile data traffic in the last decades has acknowledged the precincts and deficiency of Radio Frequency only mobile communications. Moreover Chvojka *et al.*, (2015), opined that 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. It is clear that several modulation techniques have been proposed in theory to improve the data rate and maximum range of Visible light communication system in solid state lighting; but in practice, the intensity modulation tends to be vulnerable to ambient noise while pulse width modulation flickers the LED at a human eye distressing frequency. Based on the limitations of the past attempts to practically implement a noiseless transmission at a high data rate, this work is determined to designing and implementing a visible light communication circuit for

Radio frequency spectrums mitigate for a mobile data communication in a real time VLC system, which is capable of noiseless data transmission using quasi pulse with modulation.

1.1 Statement of the Problem

According to Zheng and Zhang (2014) 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. In this recent VLC technology, it is obvious that VLC can be adopted as a green technology which helps in the reduction of precarious gaseous emission. 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 and this has created eagerness in the heart of modern researchers to explore it; by utilizing the advantage of fast switching characteristic of the LEDs compared with the conventional lightings. Therefore, modulating the LED light with the data signal makes the LED illumination to have the potential to be used as a communication source owing to the fact that 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. Therefore, it is quite obvious that there will be a geometric increase in 2020 and beyond if we carefully observe the trends to which the growth will occur from 2015 upwards.

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 audio, 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 mobile 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 especially in mobile data transfer 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 phosphorous 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 Radio Frequency-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

1.2 Aim and Objectives

The aim of this work is to design and implement a visible light communication circuit for Radio Frequency Spectrum Mitigate in Mobile data Communication. 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 the complete 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 block, the Free Channel block and the Receiver block which is shown in Figure 1

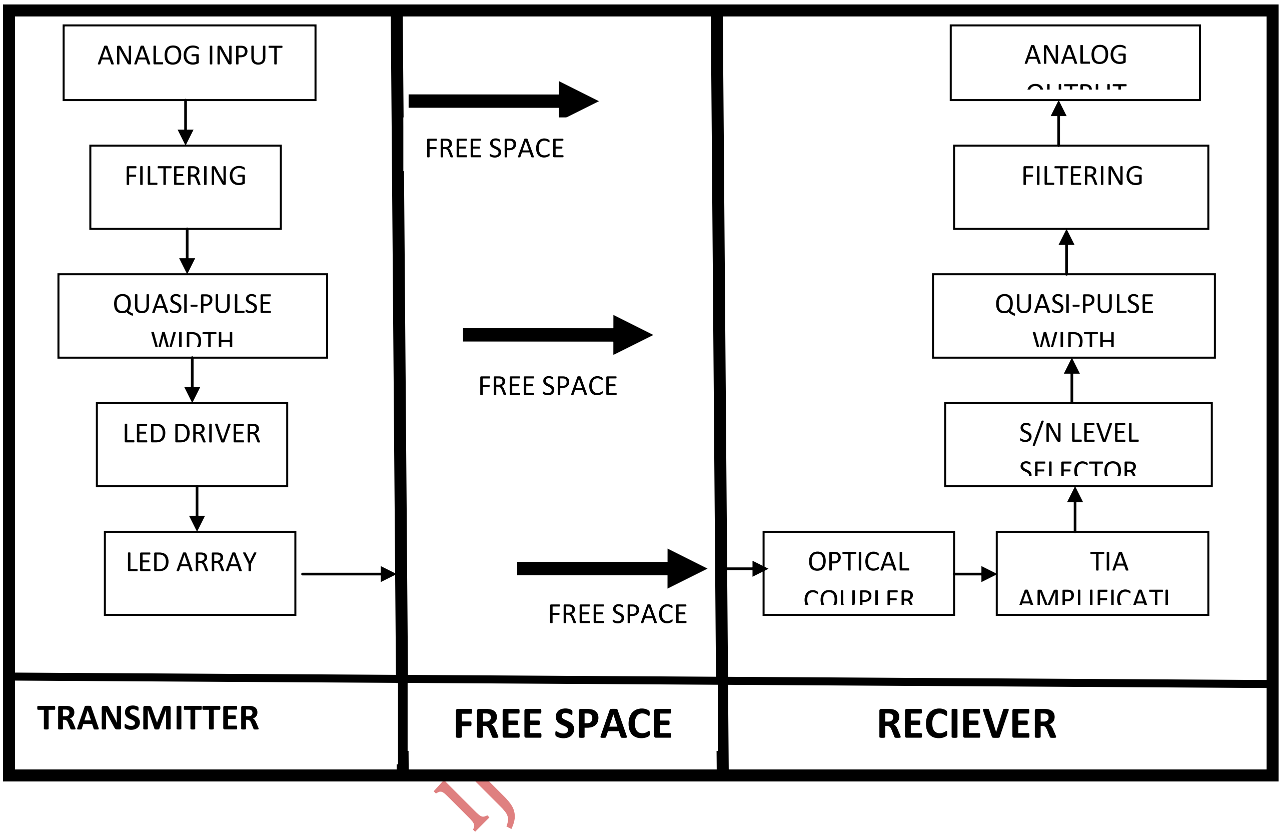


Figure 1: High level model of the new system

2.2 The Block Diagram of Transmitter Circuit of the New System

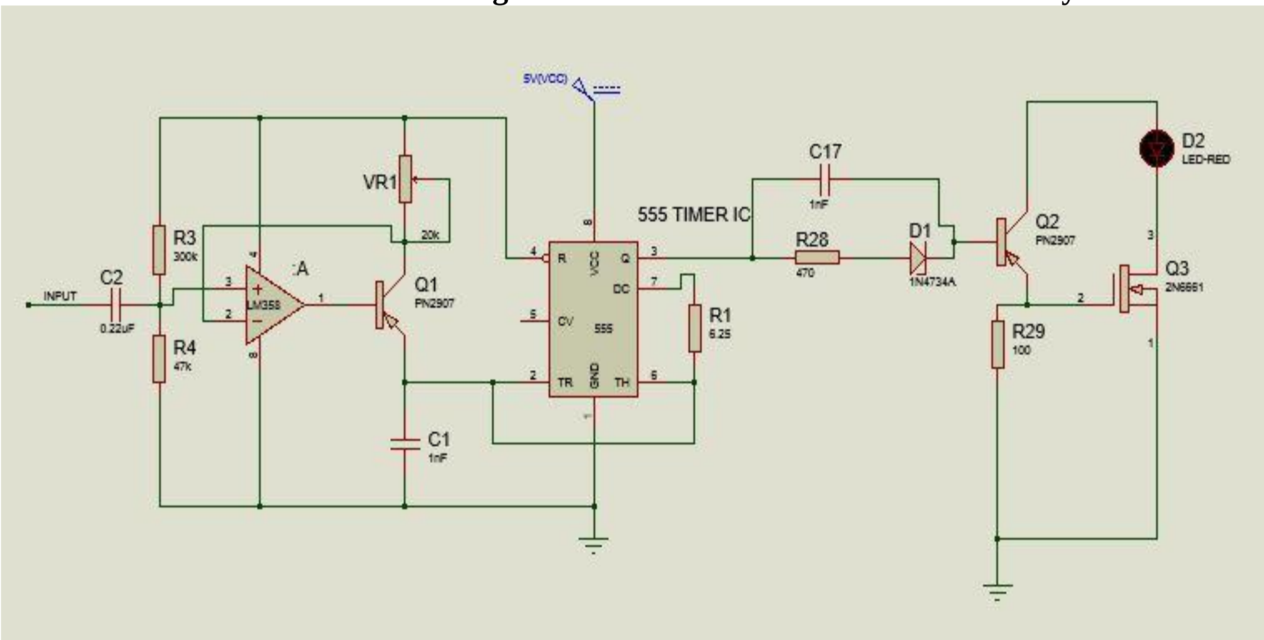


Figure 2: The Block Diagram of Transmitter Circuit of the New System

2.3 Transmitter circuit

VLC transmitter driver circuit is an electro-optical device that uses visible light to transmit data over wireless medium. The transmitter driver circuit is used to drive the current needed to operate an array of LEDs. The input to this circuit is an analog signal from mobile phone, computer or storage device which is small signal. So, the function of this circuit is to modulate the analog signal so as to be transmissible across the free space medium and also amplifies the current of the data signal to be able to operate the LED array. Transmitted data rate is limited by the switching speed of the transmitter LEDs and other components, while the distance between transmitter and receiver is limited by the transmitted power and ambient light sources. Now we are going to illustrate some of the used components in the transmitter circuit.

2.3.1 Input Signal Filter and Amplifier Circuit

The input audio signal is filtered from any DC component using C1. Operational amplifier Lm358 configured as voltage follower buffers the input signal as shown in the circuit of Figure 3

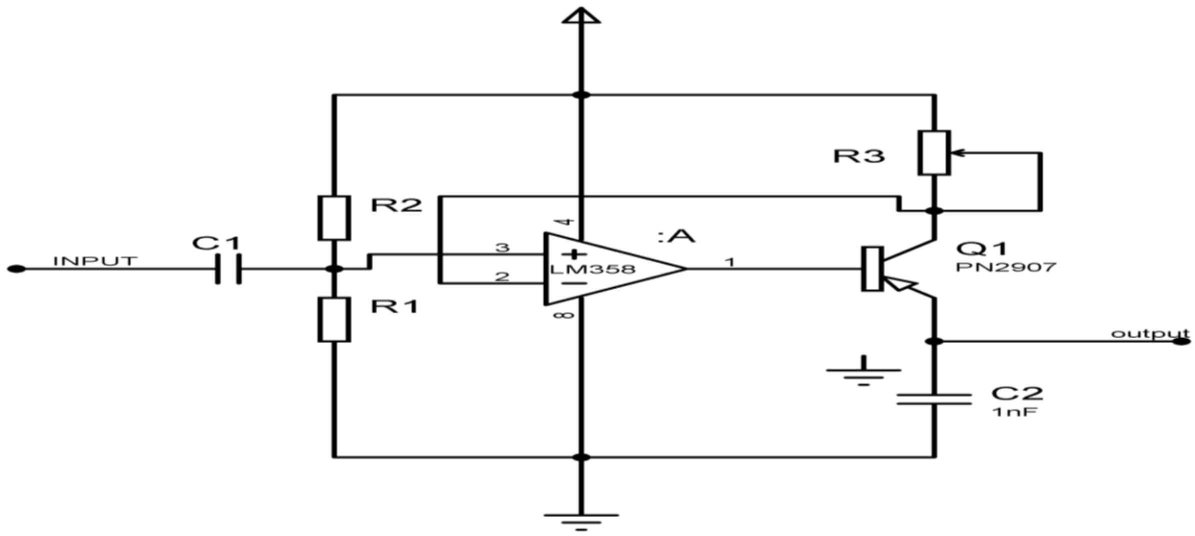


Figure 3 Filter and Amplifier circuit

The output of the opamp biases the amplifying transistor with a voltage determined by R_1 and R_2. The values are obtained using voltage division rule

$$V_{bias} = \frac{R_1 V_s}{R_1 + R_2} \quad (1)$$

Where Vs is the supply voltage and R_1 and R_2 are the resistors

For a transistor bias voltage of 4.3V and supply voltage of 5V, R_1 and R_2 are chosen to be 47K and 300K respectively

2.3.2 Quasi Pulse Width Modulator

Quasi pulse width modulator modulates the low state pulses generated by the pulse generator unlike pulse width modulation which modulates both the high and low state pulses. At power on, the pulse generator generates streams of pulses that serve as a carrier frequency. The stream of pulses is characterized by high state and low state level (1 and 0). The high pulse frequency is also initially set by the pulse generator, however, this frequency/pulse width increase or decrease across the set frequency as the amplitude of the input signal increases or decreases respectively. To determine the low state and the high state frequency, two factors were considered.

1. The maximum bandwidth
2. The power limit of LED

Since the maximum bandwidth is specified as 100mbps, the low state frequency is set to 10MHz. A duty cycle of 10% ensures maximum efficiency in powering the led. Hence the high state frequency is set to 1MHz. In this design, TLCS55 IC is chosen for pulse generator for the following reasons:

1. Low power consumption as low as 100uV at 5volt
2. Maximum operation frequency of 200MHZ,
3. Operating Temperature of 20 degree Centigrade.
4. Operating Voltage of 3V to 16V.

The IC operates in three stable mode, Mono-stable, Astable and Bistable mode. For pulse generation, the IC is configure as Astable Multivibrator as shown in Figure 4

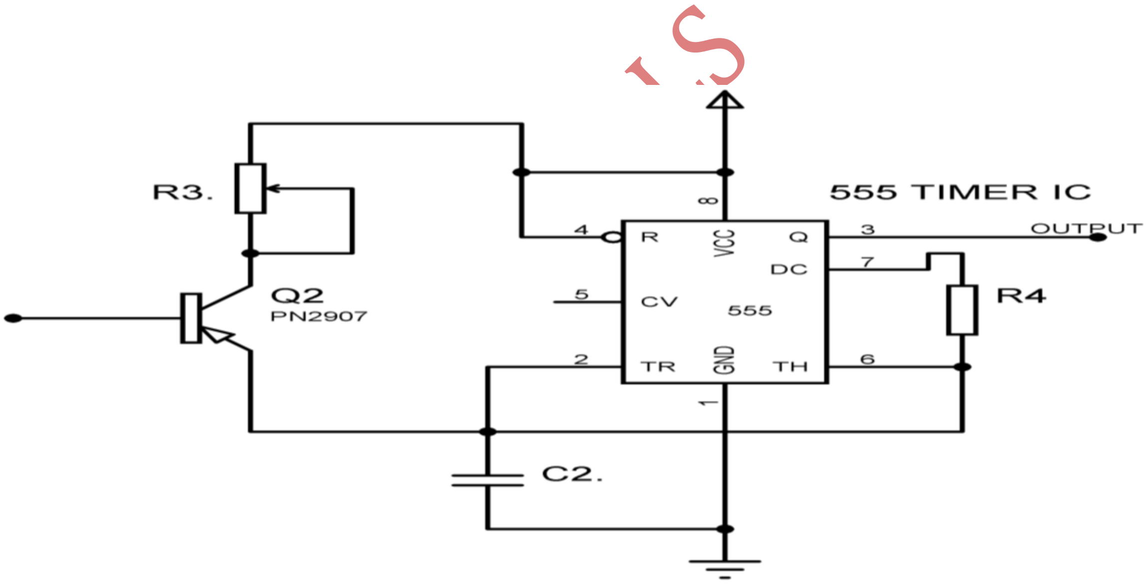


Figure 4 555 Oscillator Circuit

The input signal modulation is centred on NE555 IC configured as voltage controlled oscillator. The discharging and charging time of capacitor C2 correspond to the width of the output pulses (low and high pulses respectively). The discharge frequency is set to be the constant carrier frequency determined by R_4 and C2. The value of R and C is obtained from the datasheet as in the equation below

$$f_c = f_d = \frac{1.42}{RC} \qquad 2$$

Where $f_c \ and f_d$ are the charging frequency and discharging frequency respectively.

For 10MHz carrier frequency, 1nF capacitor C2 and resistor R_4 of 140 ohms are used obtained from eqn 2

The input signal modulates the charging frequency and must be initially set to a preset frequency. The charging frequency is determined by the resistor R_3 and the transistor's R_{ce}. The value of R_3 is obtained from eqn 2. A resistor R_3 value of 1.5kilo ohms is used and adjusted for a stable preset frequency of 1MHz. A change in the input voltage changes the charging frequency and also the output low pulse width.

2.3.3. LED Driver Circuit

The driver circuit amplifies the modulated output signal to the level that can power the LED array. When a voltage is applied to the gate of the transistor, it generates an electrical field which lowers the internal resistance to increase the current from drain to source. Due to the high input resistance, the MOSFET can handle high currents with almost no current on the gate. This makes it possible for NE555 output signal to handle the MOSFET for switching the LED array. The MOSFET used is an N-channel named IRLR3715ZPBF. It is a switching power transistor and was chosen for the capability of switching high current. With a capability of switching 49 A at a gate voltage of 10 V at 25°, the transistor makes no limit for further development with more LEDs as shown in Figure 5

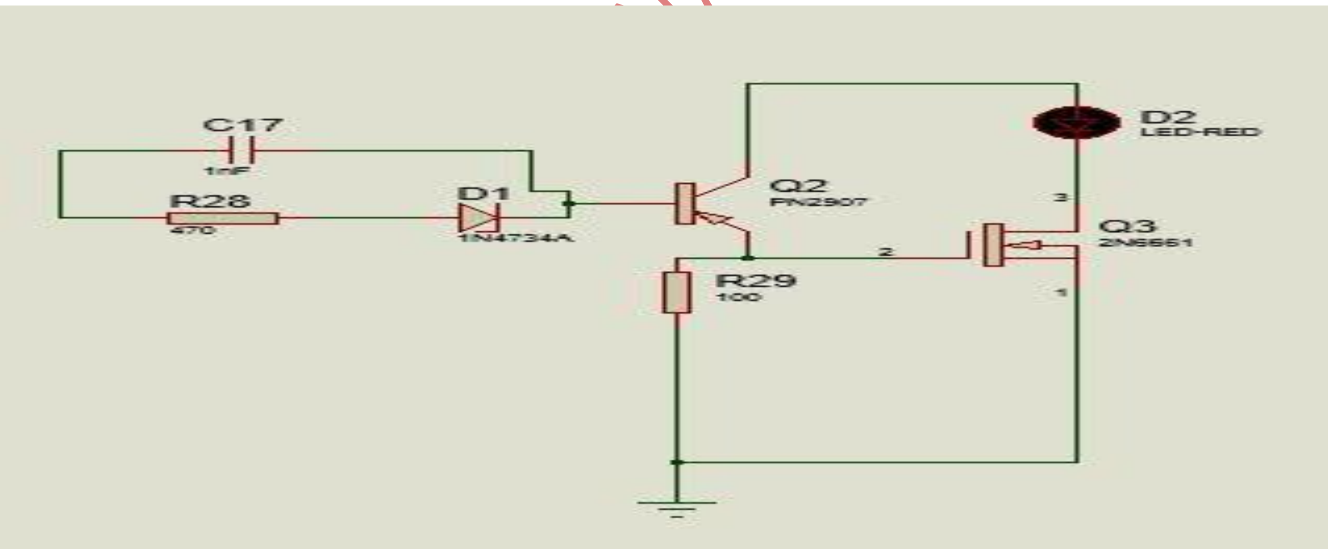


Figure 5 LED Driver Circuit

2.3.4. LED Arrays

An LED is a semiconductor that produces light. When electrons enter the semiconductor they bond with holes in the substrate and energy is released in the form of photons. There are several variables that need to be considered when choosing an LED and these variables have to be weighed against each other; the maximum intensity of the LED affects the rise time. A low intensity makes it possible to have a short rise time and increasing the intensity increases the rise time. The more intensity a LED generates the more power it needs and the more heat it produces. The NE555 IC has a maximum voltage output of 5 V, maximum current output of 1mA and can send a square wave with the maximum frequency of 10MHz. To meet these criteria the CREE MCE4WT-A2-0000-000HE7 was chosen. This is a white LED with an intensity of 240lm.The LED has a forward voltage from 3.1 V to 3.9V. The LED has its peak wavelength at 450 nm and 610 nm. Manufacturers of LEDs do not specify switching characteristics in their datasheets and therefore the diodes had to be tested in order to check its function with the frequencies that were used. The chosen LED was tested and can perform well at frequencies over 10MHz.

3.0 The Free Space Channel

The VLC channel is a free space consisting of natural and artificial ambient light noise sources such as sunlight, incandescent and fluorescent lamps. These ambient noises if not filtered, degrade the performance of the VLC system. The modulated light signal propagates through the channel in line of sight (LOS) mode and non line of sight (NLOS) mode. NLOS signals get to the receiver optics through reflections from wall and objects and in the room.

4.0 The Block Diagram of Transmitter and Reciever Circuit For Radio Frequency Spectrum/New 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

4.1 The Receiver circuit

As explained in the block diagram after transmitting the signal with the transmitter signal, a receiver needs to capture the signal, the main two crucial points about the receiver is the maximum data rate that could be handled, and the other point is the distance in which the receiver can operate at and also ambient light tolerance. And there comes the tradeoff between the distances versus the data rate. A lot of experiments have been done to test both distance and the data rate

4.2 Optical Coupler

Optical coupler consists of converging Fresnel lens that focuses the incident light from all angles to the photodiode and blue optical filter that reject light of various colors and allow a blue light to pass. The characteristic of Fresnel lens facilitate the convergence of any light signal in the room unto the photodiode.

The true color of the LED light adopted in the transmitter is blue in nature and thus permeate through the blue filter.

4.3 Photodiodes

Photodiode are considered a device that converts light into electrical charges. Photodiodes can produce voltage output as well as current output. However, using it as voltage output (photovoltaic mode) produce nonlinear response and a very restricted bandwidth. This later problem can be overawed by using the photodiode as an output current (photoconductive mode) then transforming it using current to voltage op-amp circuit. This allows the circuit to operate at a very high frequency.

Our system is operating at Visible light spectrum (400nm-700nm). So spectrum sensitivity of the photodiode must support the visible light spectrum. Another important parameter in the photodiodes is called Dark Current, which is an existing current in the absence of light. This current arises when the photodiode is operated in photoconductive mode. Dark current is generated due to saturation current of the semiconductor junction. This is a serious problem as it shortens the distance which the system can operate at, and this noise also has a frequency gain which needs to be filtered in order to retrieve the signal. Response time is also considered for the photodiode, the generation of current inside the photodiode under the effect of electric field moving the electron-holes released when photon is absorbed by semiconducting. The resistance and the capacitance which exist in the photodiode affects the response time by time constant ţ=RC. Noise equivalent power (NEP) is about the minimum detectable power. A low NEP is an indication to compare different photodiodes. A small NEP is a good indication for a better noise resistance. The requirements of the photodiode in VLC systems are a quick response time, a spectral sensitivity in the visible spectrum and a large radiant sensitive area. The size of the radiant sensitive area is crucial and therefore the photodiode used was a VISHAYBPW21R. It has suitable wavelength peak sensitivity at 565 nm. The spectral bandwidth is from 420 nm to 675 nm and gives a perfect range for the intended application. It has a linear light intensity to current ratio and the radiant sensitive area is 7.5 mm^2, which was larger than most photodiodes found. It has a rise and fall time of 3 µs each, which provides a switching frequency of 166MHz. This was enough since it is above the capabilities of the rest of the hardware and software.

4.4 Trans-impedance Amplification

The operational amplifier opa643 is configured as trans-impedance amplifier which converts the input photodiode current signal to amplified voltage signal. A higher feedback resistance results to higher amplification, however, the goal of this stage is to selectively amplify the pulsating modulated signal and rejects the DC ambient signal, thus tuned trans-impedance amplification is adopted.

An inductor will pass DC unaffected but will exhibit a resistance effect or reactance to AC signals. This reactance circuit is exactly what is needed to help extract the small modulated AC light signal from the large DC component caused by unmodulated ambient light. DC signals from ambient light will yield a low current to voltage conversion while high frequency AC signals will experience a high current to voltage conversion. Such techniques are used throughout radio receiver circuits to process weak signals. The TIA circuit is shown in Figure 6

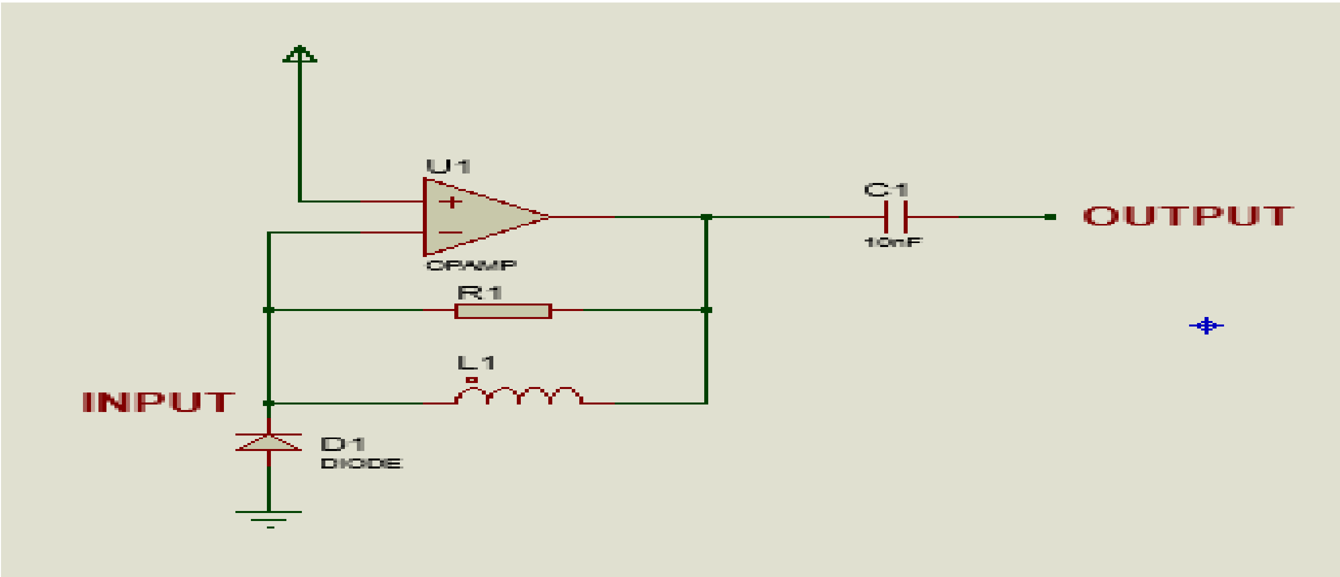


Figure 6 The Transimpedance amplifier circuit

The value of the feedback reactance is carefully chosen so that the effective reactance of the inductor and the resistor is in resonance with the pulsating frequency of the desired signal. The value of the resistance and the inductance is obtained from the published standard resonance Table. The corresponding resistance and inductance of 1MHz frequency is given as 14k ohms and 2.2mH respectively. The combined reactance of the resistor R_1 and inductor L1 is given as

$$R_{eff} = \frac{2\pi f L \, * R}{2\pi f L \, + R} \qquad 3$$

Thus, the effective reactance is calculated as 6912 ohms using the formula above.

Also the amplification factor of the amplifier is given in as

$$\alpha = \frac{R_{feedback}}{R_{in}} \quad 4$$

Where R_{in} Is the input resistance of the photodiode taken from the photodiode datasheet as 650 ohms. Thus the amplification results to 1000.

4.5 Signal to Noise Level Selector

Once the signal has been sufficiently amplified and filtered, it often needs to be separated completely from any background noise. Since we used quasi pulse width modulation techniques to transmit the information, the most efficient method to separate the signal from noise is with the use of a voltage comparator. The comparator can produce an output signal that is thousands of times higher in amplitude than the input signal. As an example, a properly designed comparator circuit can produce a 5 volt peak to peak TTL logic output signal from an input of only a few millivolts.

But to insure that the comparator can faithfully extract the signal of interest, the signal must be greater in amplitude than any noise by a sizeable margin of about 10db. The comparator output would change state (toggle) only when a signal is present and will not be affected by noise. A signal discriminator circuit is shown in Figure 7

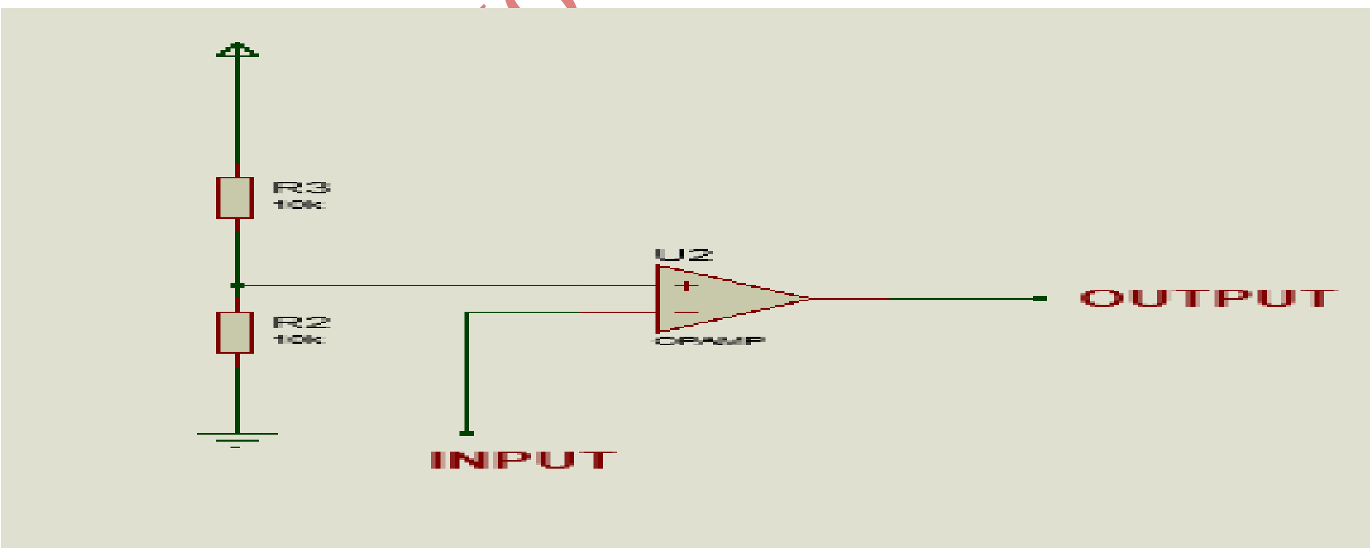


Figure 7 Signal Discriminator Circuit

The circuit is designed so a positive input pulse needs to exceed a threshold voltage before the comparator produces a negative output pulse. The input threshold is set by R_2 and R_3 using voltage division rule given as

$$V_{out} = \frac{R_2 V_{in}}{R_3 + R_2} \qquad 5$$

Chosen a 2.5volts output threshold and supply voltage of 5V, the value of R_3 and R_2 are equally chosen as 10k ohm. The 2.5V output voltage biases the comparator and thus rejects any signal below 2.5V and passes signals above 2.5V.

4.6 Quasi Pulse Width Demodulator

The light pulses being transmitted are frequency modulated to carry the information; the reverse must be done to restore the original information. The pulse frequency must therefore be converted back into the original amplitude changing signal using the reverse of the initial quasi pulse width modulation. The quasi pulse width demodulator circuit is shown in Figure 8

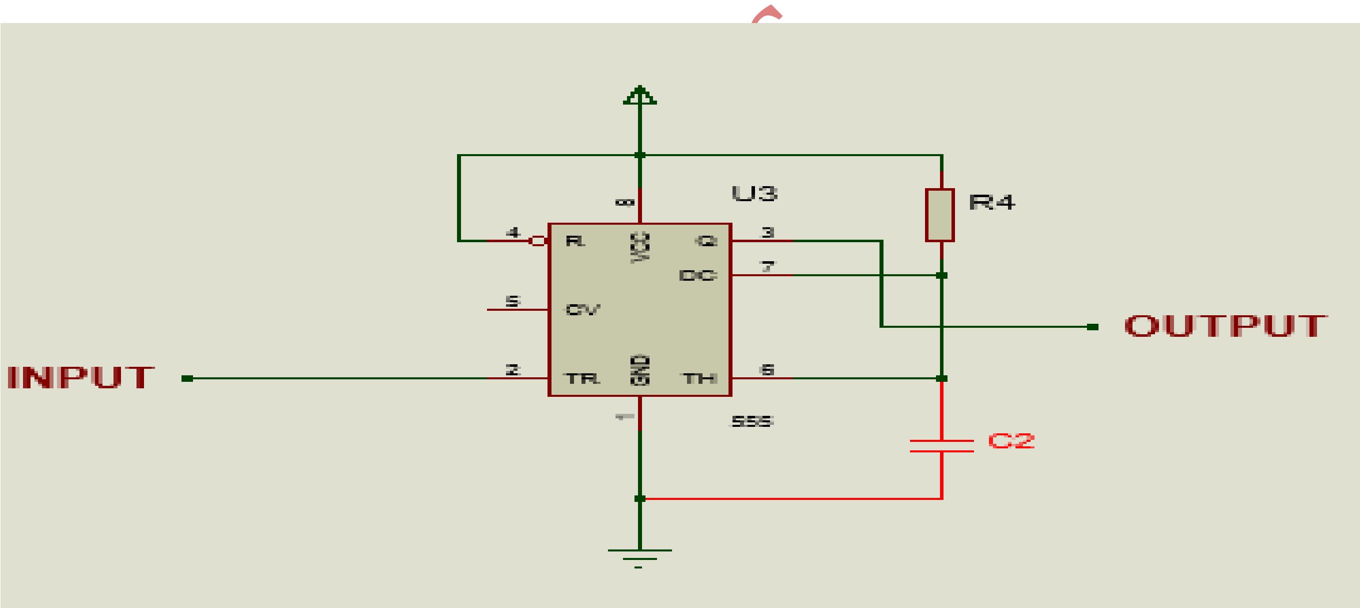


Figure 8 The Quasi Pulse Width Demodulator Circuit

Each pulse from the pulse discriminator circuit is converted into a well defined logic level pulse that lasts for a specific time. As the frequency increases and decreases, the time between the pulses will change. The changing frequency will therefore cause the average voltage level of the signal produced by the converter to change by the same proportion. The 555 timer is set to oscillate at the carrier frequency of 1MHz using R_4 and C4. The incoming signal adjusts the frequency to correspond to the original signal. The value of R_4 and C4 is obtained from the formula given in the equation 4.6

$$t = 1.1RC \qquad (6)$$

$$f = \frac{1}{t} \qquad (7)$$

Thus for oscillating frequency of 1MHz, R_4 and C4 is chosen as 56k ohms and 160nanofarad respectively.

3.7 Butterworth Filter

A 6th order low-pass butter-worth filter is required to discriminate other signals above the cutoff frequency. A butter-worth filter has a maximum flat frequency response below the cutoff frequency and attenuates frequencies above the cutoff frequency. To remove the unwanted carrier frequency from the desired modulation frequency, the output of the converter must be filtered. A 6th order Butterworth filter circuit is shown in Figure 9

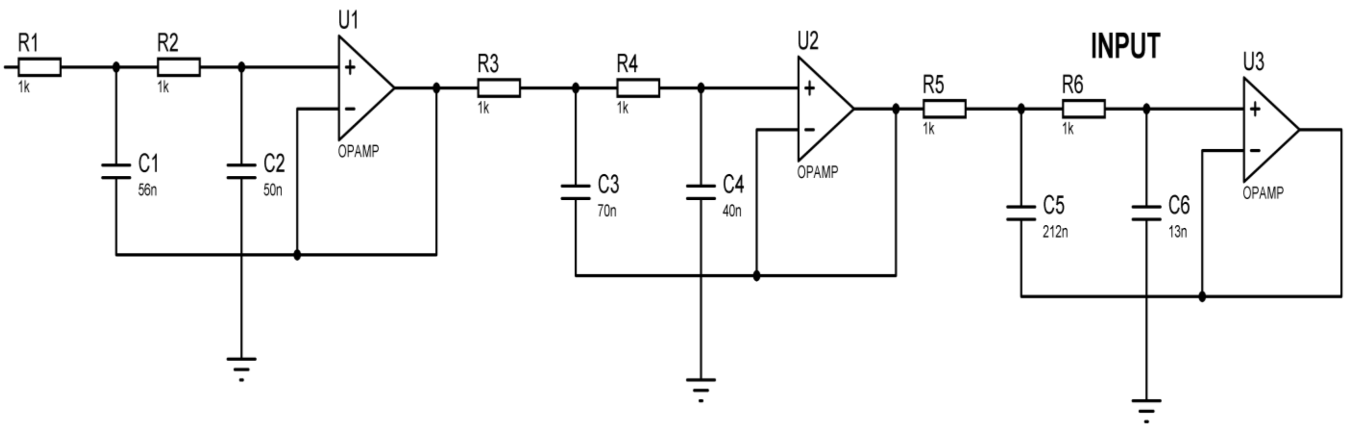


Figure 9: A 6th Order Butterworth Filter Circuit

The circuit uses opa642 integrated circuit from National Semiconductor. The circuit removes the majority of a 1MHz carrier signal, leaving the wanted voice audio frequencies. The filter's cutoff frequency is set at about 3KHz that is the minimum upper frequency needed for voice audio. The 6th order Butterworth filter is realized by cascading 3 second order filter. According to the opamp nodal analysis, the transfer function of the second order low pass filter is represented as;

$$TF = \frac{R_1R_2}{S^2(C_1C_2)+SC_2(R_1+R_2)+R_1R_2} \qquad (8)$$

Normalizing the value of resistors to 1ohm, the characteristic equation becomes;

$$E = S^2 (C1C2) + S (2C2) + 1 \quad 9$$

From the standard pole Table of Butterworth filter, the poles and characteristic equation of 6th order Butterworth filter is given in Table 1. These equations are use to obtain the component values of the 3 cascaded op amps

Table 1: The Poles and Characteristic Equation of 6TH Order Butterworth Filter

Poles	Characteristic equation
-0.966±j0.25	S^2 +1.9S+1 10
-0.707±j0.707	S^2 +1.4S+1 11
-0.259±j0.975	S^2 +0.5S+1 12

Comparing equation 9 and 10,

$$C_1C_2 = 1 \quad 13$$

$$2C_2 = 1.9 \quad 14$$

Thus, C_2 = 0.95F, and C_1 = 1.05F.

$R_1 = R_2 = 1\Omega$

By the implication of normalization in Butterworth poles, the values obtained above poses a cut off frequency of 1Hz. For a specified cut off frequency f, the capacitance value C_f is obtained by the equation that follows. Thus,

$$C_f = \frac{C}{2\pi f R} \quad 15$$

Where R is the resistor value of any choice

$C1 = 0.056\mu F$, $C2 = 0.05\mu F$, $R_1 = R_2 = 1K\Omega$

Comparing eqn 10 and eqn 11,

C1 C3 = 1 16

C2 C4 = 1.4 17

Thus, C4 = 0.7F, and C3 = 1.4F.

For 3 kHz cut off frequency,

$C_3 = 0.074\mu F$, $C_4 = 0.037\mu F$, $R_1 = R_2 = 1k\Omega$

Comparing eqn 9 and 12,

$C_5C_6 = 1$ 18

$2C_6 = 0.5$ 19

Thus, $C_6 = 0.25F$, and $C_5 = 4F$.

For 3 kHz cutoff frequency,

$C_5 = 0.212\mu F$, $C_6 = 0.013\mu F$, $R_1 = R_2 = 1k\Omega$

4.0 The Complete Block Diagram of the Receiver Circuit

The complete Receiver Circuit of the proposed system is show in Figure 10 with 6th order Butterworth filter

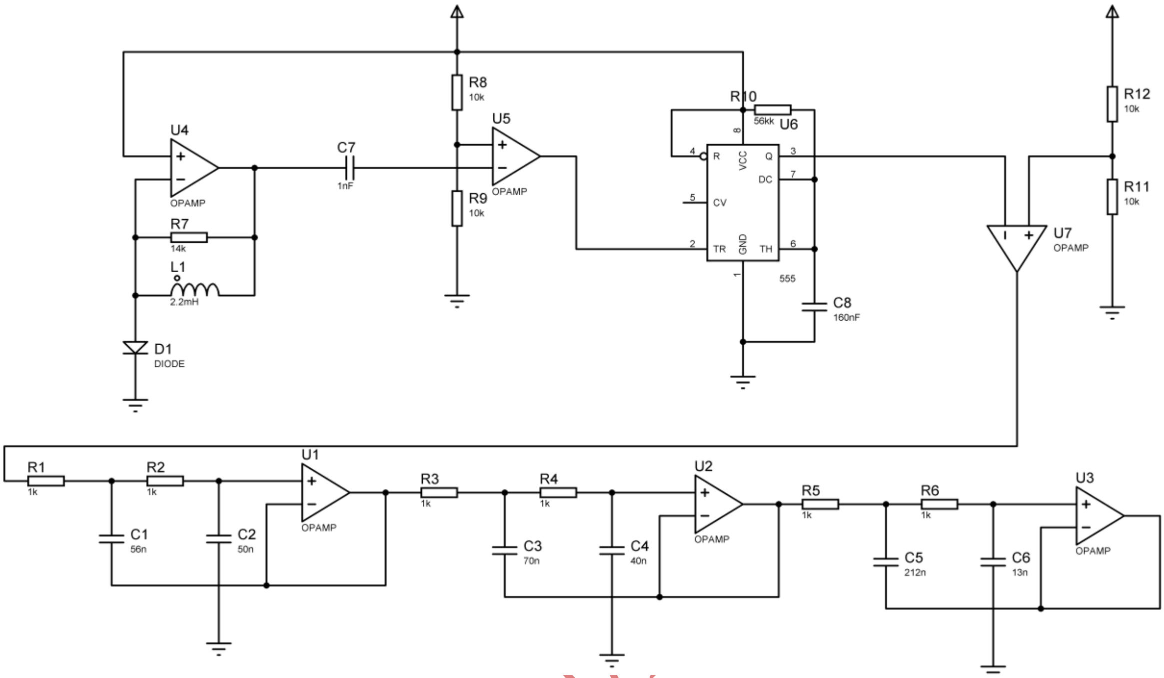


Figure 10: The Complete Block Diagram of the Receiver Circuit

4.1 Final Design

The final design is the complete Circuit diagram of the proposed system shown in the Figure 11 showing the Transmitter stage, the Free space stage with the Receiver stage and the appropriate photodiode

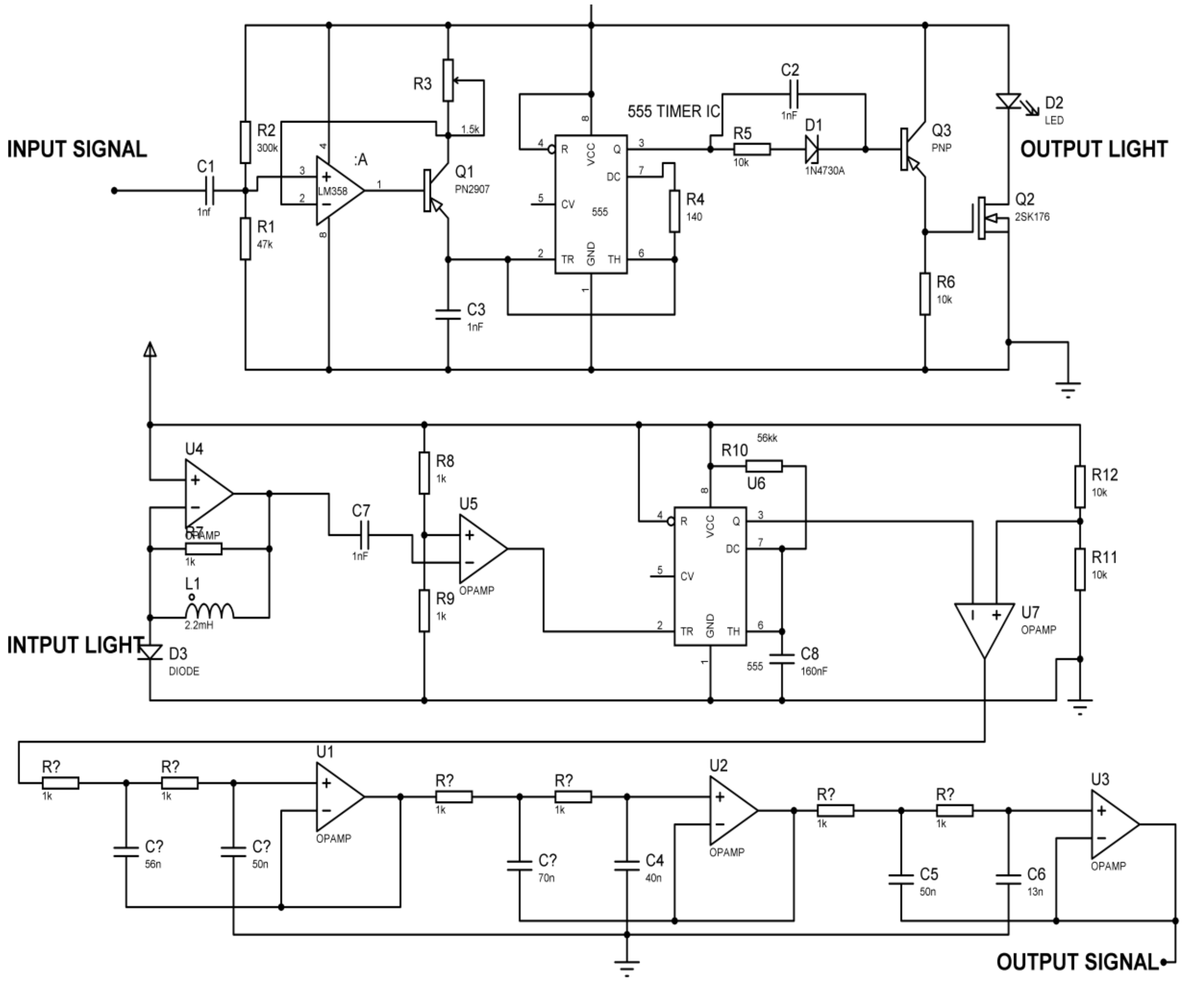


Figure 11: The complete circuit diagram of the New System

4.2 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.

4. 3 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 12.

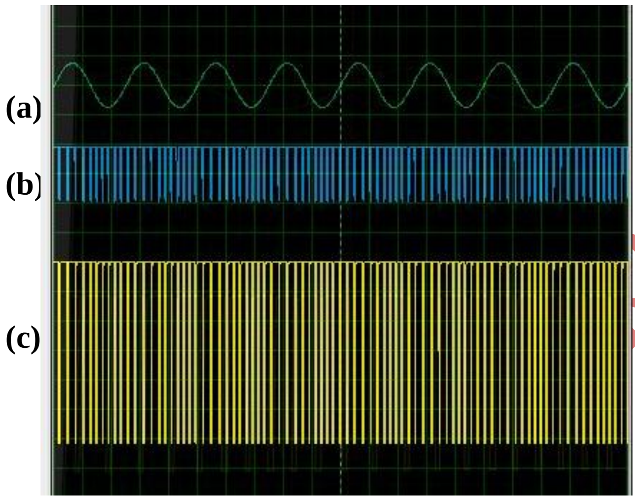
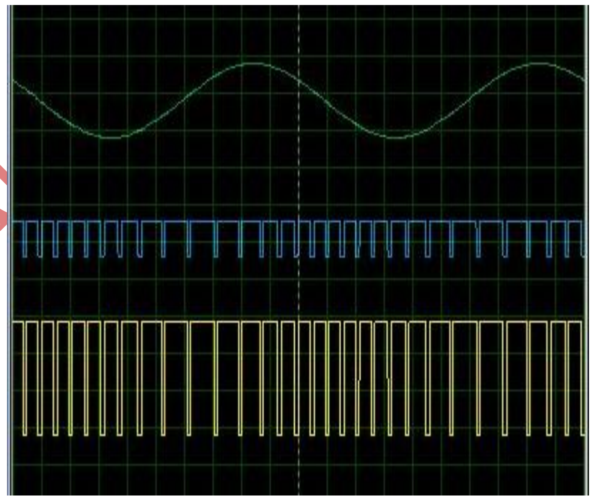


Figure 12. The Transmitter Signal Simulation of (a) the input signal, (b) the QPW modulated signal and (c) the LED output signal



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 13, Figure 14 and in Figure 15

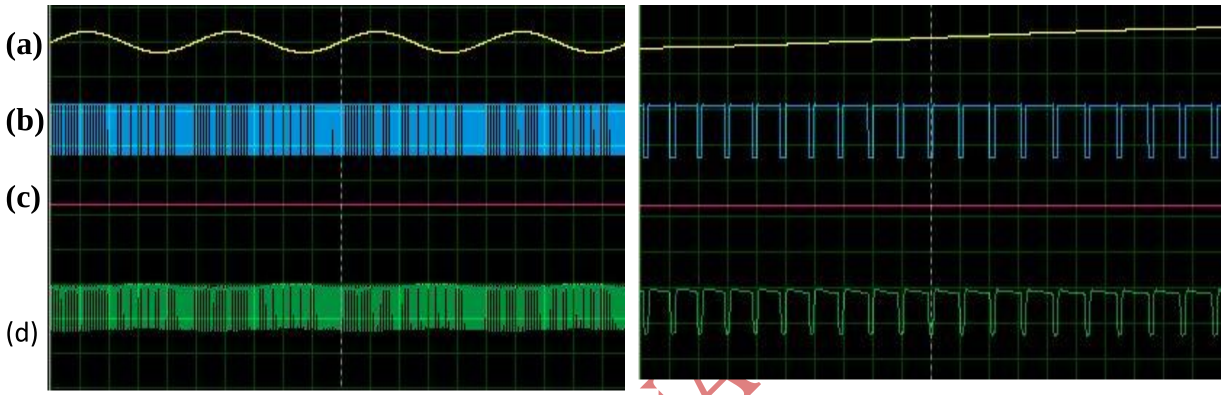


Figure 13 The Receiver signal simulation of (a) the original sine wave transmitter input signal, (b) the LED output light signal, (c) the photodiode received signal, (e) the amplified and filtered signal.

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.

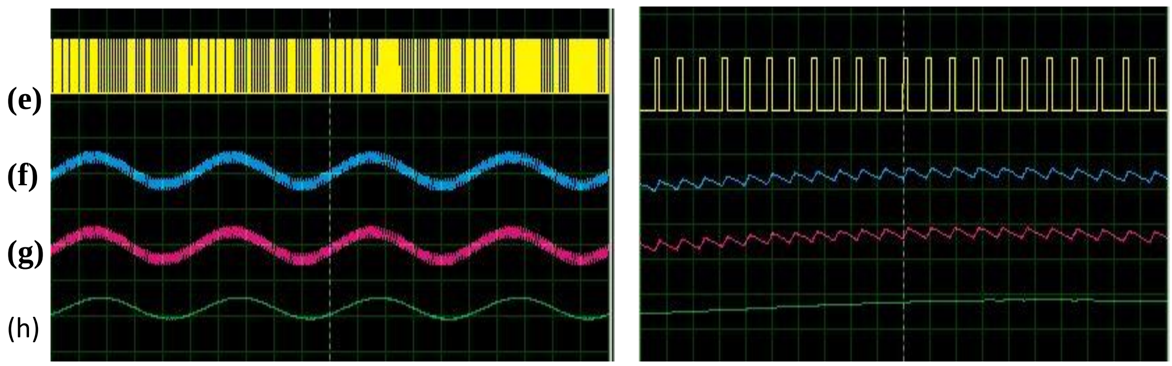


Figure 14: The Receiver signal simulation of (e) the QPW demodulated signal, (f) the first stage Butterworth filtered signal, (g) the second stage Butterworth filtered signal, (h) the third stage Butterworth filtered signal also the output signal.

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 15 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 15: The Simulated Transmitter Input Signal and Receiver Output Signal.

4.4 Performance Evaluation and Validation

Performance evaluation was done by comparing the different characteristics of the existing systems and the new Visible Light Communication (VLC) system with the evaluation of their capabilities. The systems used for evaluation are; Infra-Red, Bluetooth, Wi-Fi, Fiber Optics and the new system Visible Light Communication (VLC). The individual performances of the systems based on some parameters are tabulated in Table 2

Table 2 Evaluation of the Performance of the Existing Communication Technology and VLC Technology

It was clearly observed from the Evaluation of the Performance of the Existing Communication Technology and Visible Light Communication Technology in Table 2 above that the advantages of the new system far outweighs that of the other existing communication technology in the following areas

a) Capacity: Light has 10000 times wider bandwidth than radio waves.

PARAMETERS	COMMUNICATION TECHNOLOGIES				
	VLC	**FIBER OPTICS**	**Wi-Fi**	**BLUETOOTH**	**INFRARED**
IEEE STANDARD	802.15.7	802.3	802.11a/b/g	802.15.1	802.11
SPEED DATA TRANSFER	>1Gbps	>1Gbps	54Mbps	1Mbps	4Mbps
FREQUENCY BANDWITH	100THz	100THz	2.4 – 5GHz	2.4GHz	300GHz-400THz
NETWORK TOPOLOGY	MULTICAST	POINT TO POINT	MULTICAST	PEER TO PEER	PEER TO PEER
NORMAL RANGE	10-100m	1 – 5kM	10 – 100m	10m	1,000(µm)
POWER CONSUMPTION	LOW	HIGH	MEDIUM	HIGH	LOW
COST	LOW	HIGH	HIGH	HIGH	LOW
SECURITY	HIGH	HIGH	MEDIUM	LOW	HIGH
TRANSMITTER/RECIEVER	LED/PHOTODIODE	LASER DIODE/PHOTODIODE	ANTENNA/ANTENNA	ANTENNA/ANTENNA	INFRA RED/PHOTODIODE
CHANNEL	INCOHERENT LIGHT THROUGH FREE SPACE	COHERENT LIGHT THROUGH ENCLOSED FIBER	RADIO WAVES	RADIO WAVES	INCOHERENT INFRA RED

b) Efficiency: Data transmission using VLC is very cheap. LED lights consume less energy and are highly efficient.

c) Availability: Availability is not an issue as light sources are presents everywhere. There are billions of light bulbs worldwide; they just need to be replaced with LEDs for proper transmission of data.

d) Security: Light waves do not penetrate through obstacle. So, they can‘t be intercepted and misused

e) Better and Efficient Power Plants: Radio waves and many other radiation types are bad for sensitive areas like airplane and power plants. But these stations need fast, interconnected data systems to monitor things like demand, grid integrity and (in nuclear plants) core temperature. VLC could offer safe (as no radiation) connectivity for these sensitive locations.

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 3. 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 8 software. 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.

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 below. 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 3 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

5.0 Conclusion

In this paper, we proposed a real-time VLC design and implementation of a visible light communication circuit for radio frequency spectrum mitigate in mobile communication 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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