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# Design 0f a Light Fidelity (Li-fi) Prototype

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## Abstract

Li-fi is a promising technology in today's communication system. It may bring up the many benefits over other communication technologies. Since light is the main source to provide data, and this is available everywhere around, it may compete with other technologies that use radio communication. This technology is completely a new way of communication. Therefore, it is important to study firstly the literature review of this new and emergent technology. Besides, a prototype is designed corresponding to this Li-fi technology. In this prototype, a Li-fi communication system has been established using ASK modulation technique, and Data transmission and reception is performed by sending bits '1' and '0' using LED (Light-emitting diode).

## 1. Introduction

Now a days there are internet users all around, one can surf the web using wireless internet anywhere in the street, park, vehicles, home, office, stealing it from the next door, or competing for bandwidth at a conference, resulting the slow speeds as numerous devices are tapped in a network [1]. As the more users are increased, the more radio frequency spectrum fails to fulfil the internet needs [2]. Consequently, a serious problem may be occurred due to the shortage of Radio frequency (RF) resources [3]. Since the need for data is increasing gradually concerning the radio spectrum, hence, it is important to think of an alternative solution that can easily fulfill the necessities of data.

To solve this issue, Harald Hass, a German physicist, proposed a new technology called Light Fidelity (Li-fi) [4]. Professor Harald Haas at the University of Edinburgh pursued his research in the field in 2004, gave his presentation of the Li-Fi prototype at the TED Global conference in Edinburgh on 12th July in 2011. His demonstration showed the transmission of a video of blooming flowers using a table lamp with an LED bulb. During the projection, Professor Harald Haas temporarily blocked the light from the lamp that was truly the source of incoming data. At TED Global, a data rate of around 10Mbps had been demonstrated by Haas that is likely to better UK broadband connection. Haas achieved 123Mbps after a couple of months [1].

Li-fi, a short-range wireless communication system is latest example of revolutionary technology that moves toward the higher frequency spectrum in the field of indoor wireless communication systems [5]. Li-fi is based on VLC (visible light communication) technology, VLC is an optical wireless communication, carries data by modulating light in the visible spectrum, combines illumination and communication [6]. Li-fi communication system is generally designed by using white LED, cheaper transmitter, and receiver in a VLC system. In Li-fi technology the modulation in LEDs is so fast that human-level observation fails to determine any change in the state of Light [7]. Li-fi can play a vital role to meet the needs of data whereas the illumination of Light Emitting Diode (LED) can be used to transmit the data. As the number of devices are increasing according to the demand of the people, radio spectrum is not sufficient comparing to the rapid growth of user, therefore, the visible light spectrum can allow all the devices due to its well capacity. On the contrary, radio waves can cause signal distortion due to RF interference, but light rays are completely free from harmful radiofrequency radiation since Li-Fi transmits data through light waves on the electromagnetic spectrum. Li-Fi technology introduces us to connect to the internet by light from lamps, streetlights, or LED televisions. Moreover, Li-fi implementation is cheaper, faster, and safer than Wi-fi.

This technology does not require any router. It is only required to point out the mobile or tablets towards the light bulb and easily surf the web. This technology is a remarkable discovery over the recent technology such as Wi-fi. Li-fi is better than Wi-fi, it multiplies the speed and bandwidth of Wi-Fi, 3G, and 4G. For instance, in the case of Li-fi, it carries a band frequency of 200,000 GHz whereas Wi-Fi, a maximum of 5 GHz, therefore Li-fi is 100 times faster and transmits more information per second [6], [8]. Li-fi communication system not only transmits data but also points out the position between the devices [7], [8]. The light communication system can transmit data over visible light, ultraviolet and infrared spectrums. Although, UV and Infrared have drawbacks. UV generally affects the health i.e., cause of chronic eye damage, skin damage, immune system suppression and so on. Infrared wave also causes eye damage at high power, infrared frequencies get blocked by objects (e.g., walls, doors). Due to the above disadvantages, only LED lamps currently are used to transmit visible light.

## 2. Literature Review

In references [1] and [7], they presented about the concepts of Li-fi technology, Li-Fi is typically implemented using white LED light bulbs. These devices are normally used for illumination by applying a constant current through the LED. However, by fast and subtle variations of the current, the optical output can be made to vary at extremely high speeds. Unseen by the human eyes, this variation is used to carry high-speed data [1]. Li-fi device is composed of the LED lamp and the photodetector, whereas the LED lamp act as media transmission and the photodetector act as the receiver of transmitted data. A lamp driver is required to operate the LED properly. The signal that comes from the photodetector is usually conducted by amplification and processing [7].

Following, in references [5], [9], [10], they presented about the construction of Li-fi technology, in a Li-Fi system, transmission is done by using a white LED and the utilization of the silicon photodiode forms receiving element. LEDs can be switched on and off for the generation of digital strings of different combination of 1s and 0s. It is possible to encode the data in the light by varying the flickering rate of the LED in order to produce a new data stream. The LEDs can be used as a sender or source, by modulating the LED light with the data signal. The LED output appears constant to the human eye by virtue of the fast-flickering rate of the LED [9].

Li-Fi based LED lamp consists of four components which are listed below[5], [10], :

a) Bulb
b) RF power amplifier circuit (PA)
c) Printed circuit board (PCB)
d) Enclosure

In Li-fi technology, LED lamp consists of an aluminum jacket known as enclosure which composed of all the elements. A bulb acts as a source of light that is fitted with enclosure. The PCB is functioned for the management of lamp as well as controls the electric signal. To generate the radio frequencies guided into electric field about to bulb, the RF power amplifier is required shown in fig.2.1.

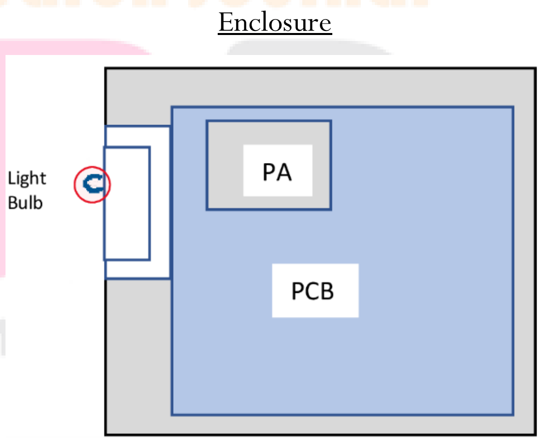


*Fig 2.1: A simple construction of a Li-fi system*

The Li-Fi emitter's heart is the bulb sub-assembly. It's built up of a sealed bulb that's encased in dielectric material. This concept outperforms traditional light sources that use degradable electrodes in the bulb. The dielectric substance is useful in two ways. The RF energy transmitted by the PA (Power allocation) travels through it as a waveguide. It also serves as an electric field concentrator, concentrating energy within the bulb. The electric field's energy rapidly warms the material in the bulb to a plasma state, which emits high-intensity, full-spectrum light [5].

As far as working Principles of Li-Fi is concerned, they presented regarding the transceiver in coherence with the operation of Li-fi in their paper [7], [9], [11], The transceiver consists of LED to transmit the light and photodiode to receive the light. Transceiver act as a transmitter and a receiver at the same time (fig.2.2). To strengthen the power of the received light, an amplifier is required to be embedded. For modulation and demodulation, a modem is used. A signal that comes from the photodiode is analogue followed by converting into digital in the modem. For transmission, LED sends the analogue signal which converts from the digital signal in the modem. For successful flickering which functions LED for data transmission, transmitting digital '1' turn the LED on and LED is off if digital '0' is sent [7], [9], [11].

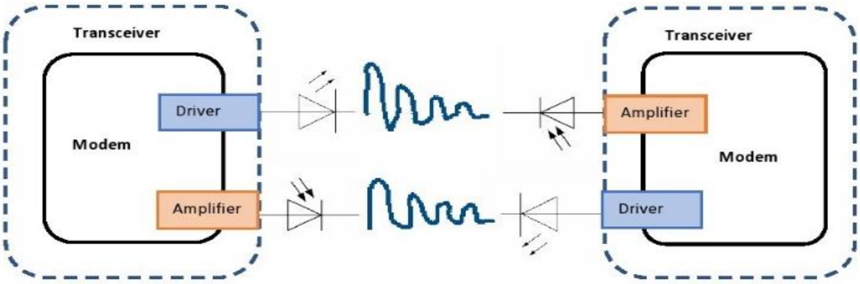


*Fig. 2.2: Transceiver Li-fi based on VLC*

In this project, a prototype of data transmission is designed through LED flickering. While data transmits '1' LED turns on and LED is off if '0' is sent.

In the same vein, in reference 1, they presented the operating principal model of Li-fi technology. In fig.2.3, Web connection is made by the switch and LED lamps, which are all connected to the lamp driver through the optical fiber cable. The signal is received by the photodetector and performs operations. A detector is also connected to PCs, Laptops, or LAN ports. The digital data is converted into light form, which is done by microchip, it occurs while the "ON" state of the LED. After receiving the light signal the Light detector converts it again into the original digital form [1].

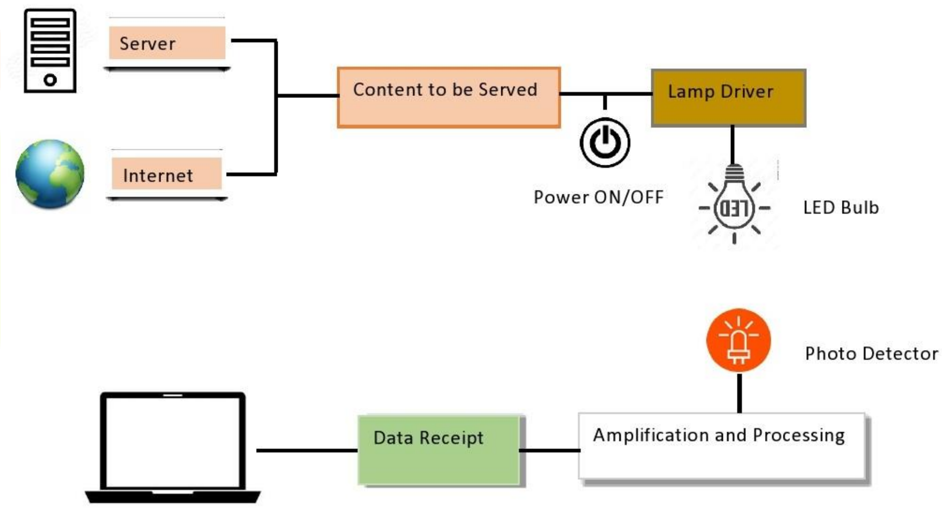


*Fig. 2.3: How Does the Li-Fi Technology Work*

As far as Li-fi service is concerned, they presented it in reference 7, Li-fi provides services to communication technology such as the transceiver fitted lamp act as media transmission as well as lighting the room. This similar medium i.e., light can be used for Li-fi and VLC as data communication. VLC is a unidirectional, point-to-point light communication at low data rates. On the contrary, Li-fi technology is fully networked, bi-directional, and high-speed wireless communication [7].

## 3. Equipment

For Modulation techniques, there are components utilized i.e., PCB board, analog multiplexer (DG408) (in fig.3.1), op-amps (IC 741), resistors, potentiometers, LED's, a photodiode (SFH203), diode, capacitor, and jumper wires. Electronic equipment- oscilloscope, signal generators, power suppliers, probes, and cables are needed.

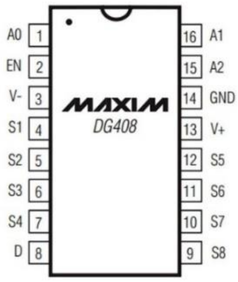


*Fig 3.1: Pin diagram of IC (DG408)*

Table 3.1: Pin description of IC (DG408)

| PIN NO. | SYMBOL | NAME AND FUNCTION |
|---|---|---|
| 8 | D | Common Output |
| 2 | EN | Enabled Input |
| 13 | V+ | Supply Voltage |
| 14 | GND | Ground |
| 1,16,15 | A0, A1, A2 | Binary Control Input |
| 4,5,6,7,12,11,10,9 | S1-S8 | Individual i/o |
| 3 | $V^{-}$ | Negative supply voltage |

For data transmission, it is required to be equipped with a PCB board, two Arduino UNO, two LED, and a light dependent resistor (LDR).

## 4. Methodology

In this methodology part, it would be focused on the method of prototype designing. It's included software and hardware which are developed based on the prototype design. Refer to fig.4.1, both hardware, and software are required to build up the prototype. Firstly, prototypes are designed in the hardware section followed by testing and troubleshooting. In the next step, it has been checked whether the prototype works or not. If the above testing is successful, this would be forwarded to the following step. Otherwise, it is required to repeat the previous step previous due to failing to work. Besides, In the software section, Arduino IDE is used for the programming. After testing the program, it has been observed whether the programming success or not, if successful, then it would proceed to the next step. On the contrary, if failed, it is needed to repeat the work on programming. After both hardware and software development, the next step is to combine the hardware and software. Following, the above process is tested, resulting in a final prototype because of successful testing. On the other hand, this would go back to the earlier step to fix it. Eventually, after the final prototype is built up, this entire procedure is ended.

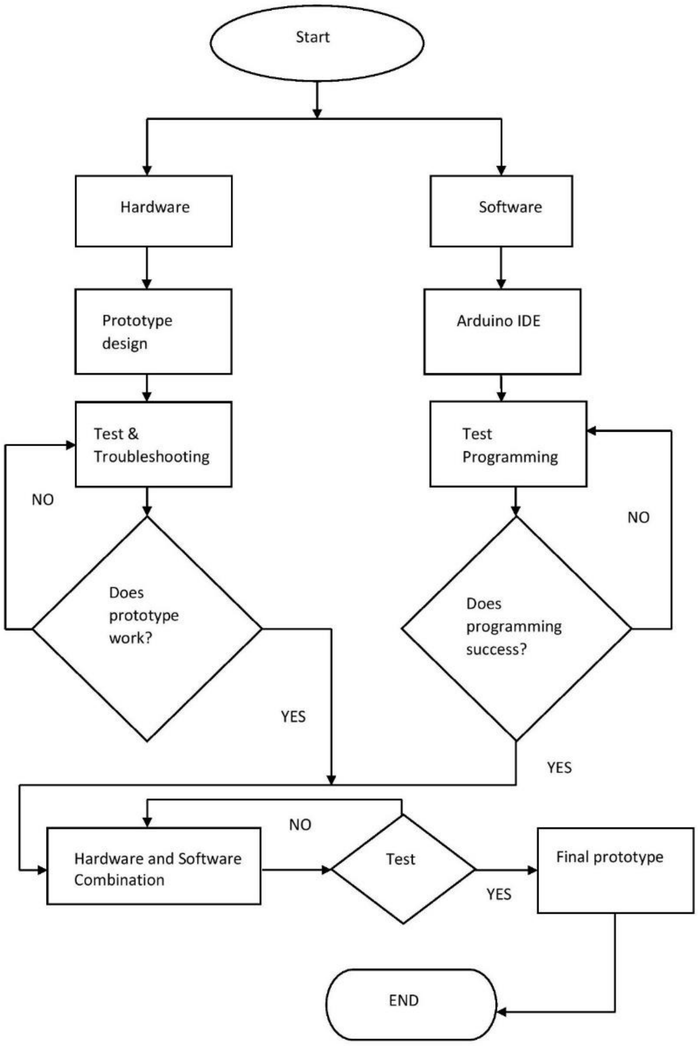


*Fig 4.1: Flow chart of the project's procedure*

An idea for Li-fi system establishment has been depicted briefly in the following block diagram. The digital input data is given to the modulator followed by forming modulated waveform, henceforth modulated signal is amplified to run the LEDs with respect to the photodiode in the receiver section. At the demodulator, the original signal has been retrieved as demodulated waveform, an amplifier is used as a comparator to obtain the final digital output data in fig.4.2.

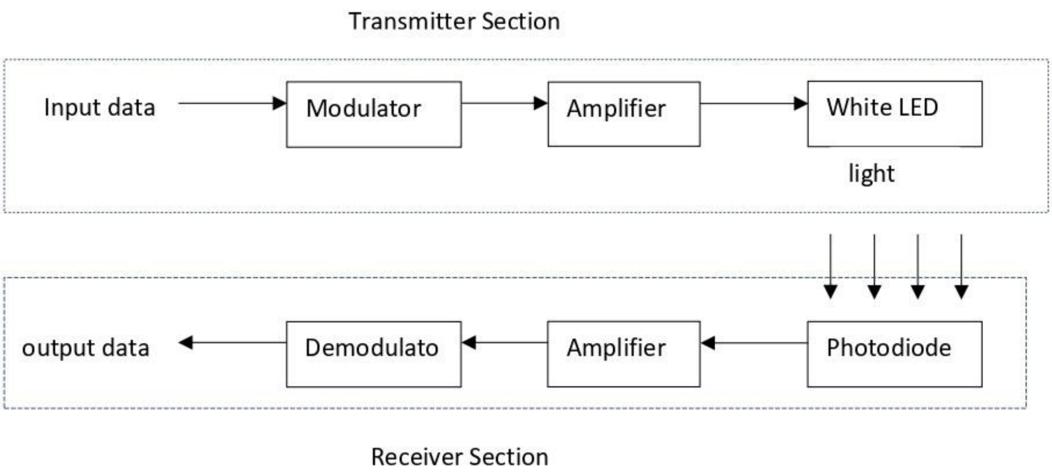


*Fig 4.2: Block diagram of Li-fi system*

## Design and Implementation of a Li-fi System

To design and implement of a Li-fi system, the transmission and reception are done using ASK (Amplitude Shift Keying) modulation and demodulation techniques. The experimental setup for this task is discussed in several sections in fig.4. 3.

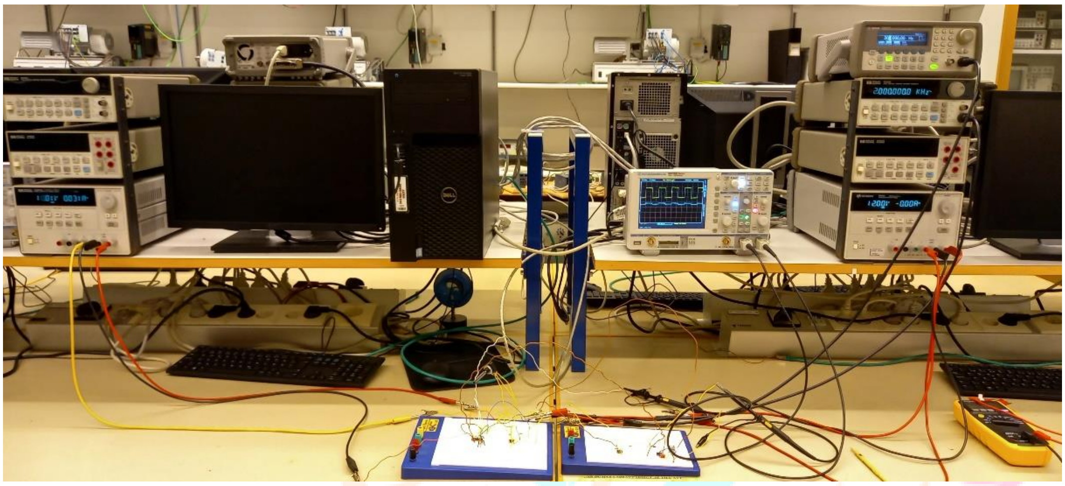

*Fig 4.3: Design and implementation of Li-fi system*

For an ASK modulation technique in Li-fi technology, an analog multiplexer has been operated by using a message signal (square wave), which has been applied at pin 1 on the IC (fig.4.4). This digital signal carries out logic data input 0 and 1, this signal is applied with the frequency of 200Hz. Another generated sine wave with a high frequency of 1kHz, is considered as a carrier signal, which is applied at pin 5 on the multiplexer (fig.4.4). After the power supply, the ASK modulated wave at pin 8 has been investigated. Comparing the modulated wave to the digital bit sequence, it is apparent, that when the digital signal assigns bit 0, the outcome on the modulated wave is zero amplitude, when the signal provides 1 bit, it shows on the scope is amplitudes of the carrier signal.

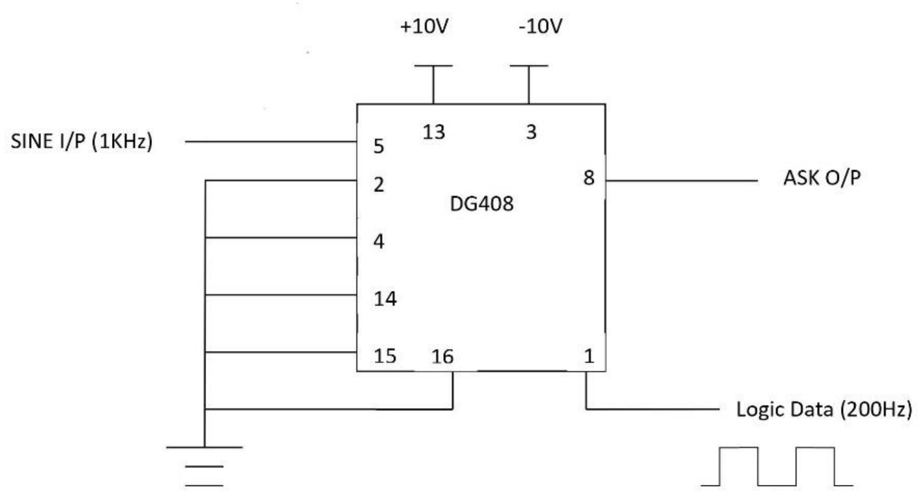


*Fig 4.4: Block Diagram of IC*

The ASK modulated signal is then fed into the non-inverting input of an op-amp (741 IC), which results amplified modulated signal. An amplified modulated output is then used as the input to drive the LEDs. An op-amp (741 IC) has been used in order to drive the LEDs. With respect to LEDs, a photodiode is used. This has been designed using another op-amp (741 IC).

**Voltage Amplifier**

Since the ASK output is low to operate LED, therefore an amplifier is required to amplify the voltage to drive LED. The voltage amplifier is designed using an op-amp IC 741 in the non-inverting configuration. For the non-inverting amplifier, two 10k resistors are required, in which one resistor is connected to pin no. 2 at the op-amp and to the ground, and the other resistor is connected to the ground and to pin-6, which acts as a feedback resistor, $R_f$. Positive and negative power supplies are given to pin no.7 and 4 respectively. The amplified output is obtained at pin no.6.

**LED**

The amplified output is then applied to a cool white LED. A resistor is connected in series with the LED and a potentiometer is used at the non-inverting terminal to switch the LED on.

**Photodiode Amplifier**

A Photodiode (SFH203) is chosen with respect to the LED. Subsequently, an amplifier is designed by using a feedback resistor.

**ASK Demodulator**

An envelope detector and a low pass filter are required to get the ASK demodulated wave. An envelope detector is an electronic circuit that utilizes high frequency as input and gives an envelope of an original message signal as output. It comprises a diode that acts as a rectifier and a resistor and capacitor in series as a filter, followed by a non-inverting amplifier that acts as a comparator, and an input signal with reference voltage is applied to this comparator. A 10k potentiometer is used to provide the reference voltage at inverting pin. Eventually, the ASK demodulated wave is achieved.

The envelope detector setup (shown in fig.4.6) is used in the demodulator section. The ASK modulated signal is applied to the detector circuit where the input signal is rectified by the diode as a rectifier. The combination of resistor and capacitor as LPF makes the signal filtered. The output from the LPF is then passed the comparator (using Op-amp). Finally, the demodulated output has been obtained in accordance with the reference voltage, which has been provided by the potentiometer.

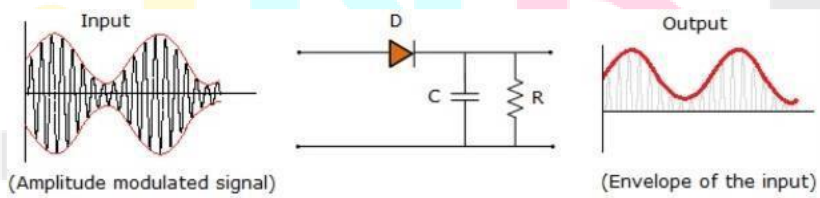


*Fig 4.5: Circuit diagram of an envelope detector*

## 5. Results Analysis and Problems

After such investigation at the modulator section, it can be observed that the values measured 0.623V at the ASK output. The modulated ASK output is then fed to the LED, the measured value at the LED is 2.3V. The following results are analyzed-

**Modulator section**

- ASK output at modulator or input at non-inverting amplifier = 0.623V

- Modulation frequency = 2kHz
- Logic data frequency = 200Hz
- Input to LED from ASK = 2.3V
- Rf = 10k, R1 = 10k
- Estimation of the voltage to operate LED =
- Gain at non-inverting amplifier (experimental) = 3.7
- Gain at non-inverting amplifier (Theoretical)= (1+Rf/R1) = 2
- Gain in dB (experimental) = 20log3.7 = 11.
- Gain in dB (Theoretical) = 20 log2 = 6.02.

**Demodulator Section**

- Frequency of the message signal, fm=200Hz
- Frequency of the message signal, fc = 2kHz
- Reference voltage, Vref = 10V
- The voltage gains of a non-inverting operational amplifier (dB) = 20

At the envelope detector section, the time period, $T_m$ of the message signal must be greater than the time period, $T_L$ of the low pass filter, and $T_L$ must be greater than the time period, $T_c$ of the carrier signal. The following is expressed as-

$1/f_m > R_d C_d > 1/f_c$

5ms> $R_d C_d$>500µs

Let, $R_d C_d = 1ms$

Assume, $R_d$ = 10k

Hence, $C_d = 1/10000 = 0.1\mu F$;

So, Cut-off frequency, $f_{cut} = 1/2\pi RC = 160Hz$

### ASK modulation technique in a li-fi system

A design and implementation of a Li-fi communication system has been demonstrated, besides modulation techniques of this same technology have been studied here in this section.

Since a block diagram has been presented here in this paper in the previous section, as well as the setup has been established and split into multiple sections. Hence, the results have been discussed in several parts. Moreover, the job for this experiment is classified into multiple parts.

Firstly, it comes to the ASK modulation where binary inputs are fed into the modulator followed by multiplying the message signal (binary data) with the carrier signal (sine wave) that has formed the ASK modulated signal shown in fig. 5.1a.

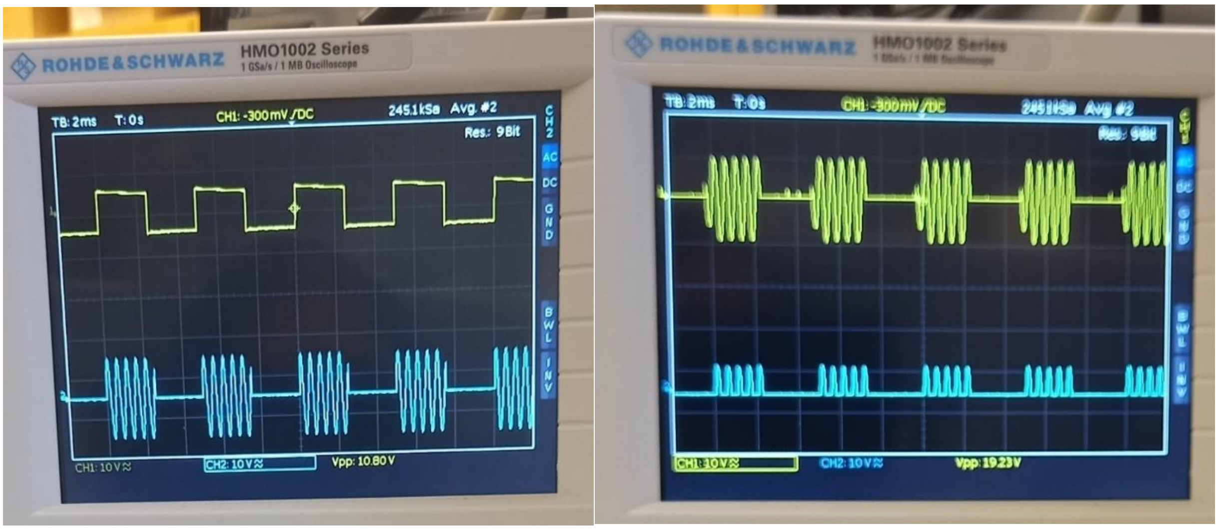


*Fig 5.1: (a) ASK modulated waveform (b) Amplified ASK waveform*

The next level is applying the ASK modulated signal to the voltage amplifier whether this signal can successfully drive out the white LED since LED requires enhanced voltage to be operated. Fig.5.1b shows the amplified signal. It has also been observed the photosensitivity and the effect of the transmission distance with respect to light intensity (lux). The photodiode produces current with respect to light intensity. The light intensity due to modulation changes so rapidly that it could not be followed by the eyes.

The ASK modulated signal has been passed to the rectifier, that signal has been represented by the image on the top in fig.5.2a. The envelope of this modulated signal has been viewed as indicated by the below image in the same figure as well.

The output at the low pass filter can be seen in fig.5.2b on channel 2 of the scope.

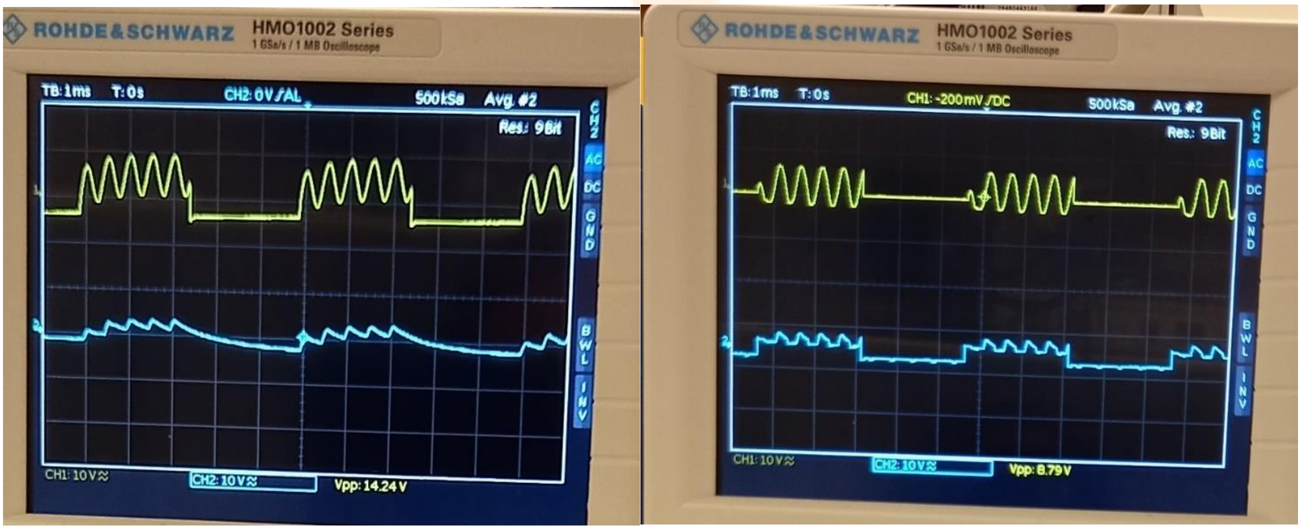


*Fig 5.2: (a) Envelope amplitude of an envelope detector (b)low pass filter output*

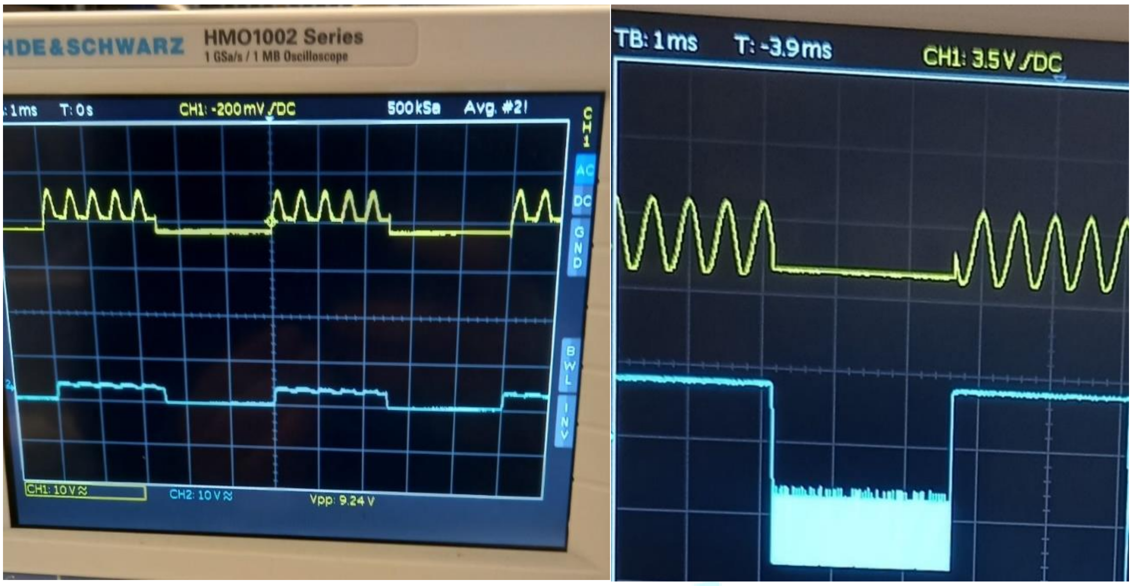


*Fig 5.3: (a) Demodulated signal (non-smooth) (b) Demodulated signal with noise*

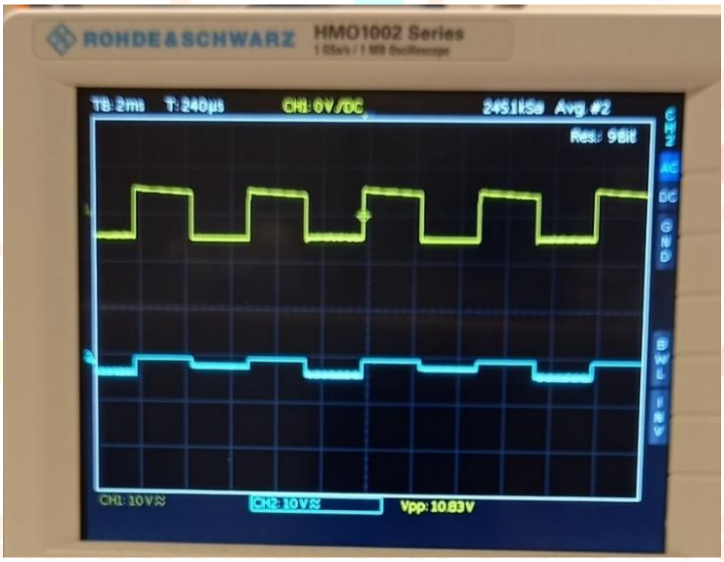


*Fig 5.4: Demodulated signal*

Finally, the envelope detector output is given into the comparator where it compares the voltage with a reference voltage which can be observed from the above figures. The signal is a little bit rough when the envelope amplitude of the envelope detector is greater than the amplitude of the reference voltage it switches to the positive voltage which is shown in fig.5.3a. In fig.5.3b, it can be seen that the output has signaled to noise ratio (SNR), while the envelope amplitude of the envelope detector is smaller than the amplitude of the reference voltage it switches to the negative supply voltage. The last fig. 5.4 shows a quite better-demodulated wave signal.

**Data transmission using li-fi technology**

For the task data transmission using li-fi technology, two pieces of Arduino UNO are utilized. For the transmitter, LED in coherence with push-button via Arduino UNO is utilized. For the receiver, Light-dependent resistor (LDR) is operated as the receiver by Arduino. Data transmission using the li-fi system is performed by transmitting digital data. While data '1' is transmitted LED turns on and turns off for the transmission of '0' in the presence of the receiver. This process is repeatedly operated resulting in LED flickers continuously shown in fig.5.5a and 5.5b.

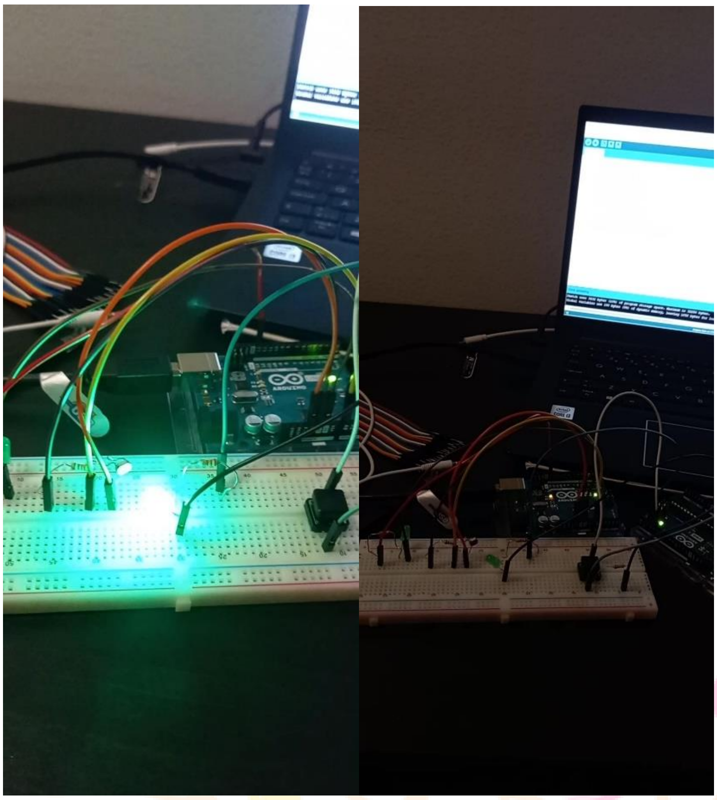

*Fig 5.5: (a) Data transmission by transmitting '1' (b) Data transmission by transmitting '0'*

## 6. Conclusion

Regarding the Li-fi implantation, it has several modulation techniques, whereas the chosen ASK modulation technique has been completed sufficiently. As a result of the above task, the gain is observed at the modulator and demodulator section, for the low pass filter, resistance and capacitance are computed, and cut-off frequency has been found at the demodulator. Data has been transmitted successfully which appears as LED 'ON' and 'OFF'.

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