Li-Fi: A Comparison Among Its Implementation Techniques

Waqad Hashmi, M Asif Arif, Sarmad Shams, Sarwar Wasi, Shahzad Nasim

Abstract: In past few years, Light-Fidelity (Li-Fi) also called Visible Light Communication (VLC) has emerged as a promising technology in the field of wireless communication. It has enabled the engineering community to envision a reliable solution to current bandwidth restrictions and open a new horizon for large capacity wireless communication. In such communication system, an optical sensor or receiver translates the data which is in the form of luminous modulation flux into an electrical signal. The receiver plays an important role in data translation. In general, the Li-Fi receivers either utilize a photovoltaic module or it based on PIN photodiode. The objective of this paper is to present a comprehensive study for implementing the visible light communication system using both photovoltaic cell and PIN diode. The paper discusses the hardware modules and implementation of VLC system. In addition, the paper also provides a comparison by using an experimental setup between the photovoltaic cell and PIN diode to receive wireless data

Index Terms: Li-Fi, visible light communication, photovoltaic cell, PIN Photodiode, Wireless Communication Using Li-Fi, Indoor Li-Fi.

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1 Introduction

With the widespread use of wireless communication around the globe, the bandwidth requirement for radio communication is under strain [1]. In addition, the procurement of new channels for communication is a cumbersome process. Barry and his team [2, 3] comes with the idea of indoor communication with infrared LEDs. But, its practical implementation was not possible until Nakamura and colleagues have developed the first blue LED [4, 5]. This development has opened a new door of wireless communication for the engineers, and practical work has started to replace radio communication with optical wireless communication in some areas of application [6,18]. These areas include optical wireless communication in sensitive environments (hospitals, oil refineries), communication in large buildings and offices for high data rate where each user has an allocated cell of his/her own (also known as the attocell concept), underwater wireless communication, in ad hoc networks for communication between vehicles, in wireless communication in underground tunnels and in military installations for secure networking [7, 8]. In contrast, The performance of LiFi is claimed to be more better than the WiFi and is 1000 times faster so, the Wifi technology could be replaced by this new technology [9, 10]. LiFi utilizes visible light, the nature of its transmitters and receivers is fundamentally different from antennas used in radio communication. Therefore, LiFi transceivers pose different challenges and require unique solutions [1, 14]. To handle these problems two different techniques are used, PIN photo diode and photovoltaic cells [11]. PIN photodiodes are widely used in optical fibre communication systems and have an established reputation for their accuracy and cost [15]. In addition, it is commonly prefer for indoor communication purpose [12]. On the other hand, a photovoltaic cell is a source of renewable energy poised to change the outlook of the energy requirements of the future [13]. The objective of this paper is to present and discuss an off-the-shelf approach for hardware implementation of a VLC for indoor LiFi. Also, two separate receiving devices photovoltaic cell and PIN photodiodes are reviewed on its own merits and scrutinized in detail. This paper will discuss the uses of both these devices and compare their results.

The rest of the paper is organized as follows; Section 2 will discuss the system model of LiFi system. Section 3 presents the hardware details of LiFi System. Section 4 will present the main results that show the comparative analysis of photovoltaic cell and PIN diode as a LiFi detector. Finally, section 5 will give the conclusion.

2 System Model

This section discusses the LiFi system model and its components. The LiFi system block diagram is shown in figure 1. The software used for transmitting and receiving the data from the application layer is based on MATLAB, while the software used for sending e-mail is developed on Python. The GUI is designed in MATLAB which provide the connectivity with the Python and use to transmit and received the data from the PC. The LiFi transceivers are connected to the PCs using USB port. The LiFi transmitter and receiver are discussed next.

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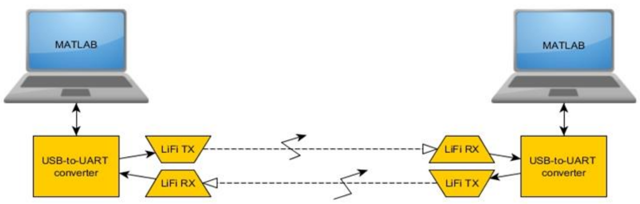


Figure 1: *Block diagram of the overall system*

2.1 Transmitter

The LiFi transmitter is based on four fundamental components which are microcontroller, amplifier, LED driver and power LED as shown in figure 2. The microcontroller used to receive serial data from the PC and do the encryption. After that, an amplifier used to amplify the incoming signal such that it can easily drive the MOSFET based Power LED driver circuit.

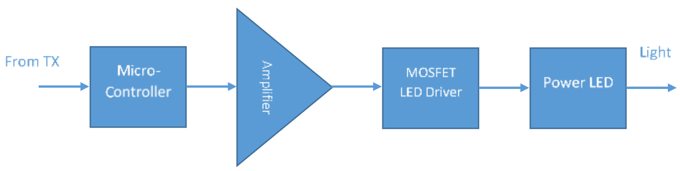


Figure 2: *Transmitter Block Diagram*

Finally, power LED is used to transmit the visible light signal at a typical beam angle of 120˚ and luminosity of 1000 lm at 1000 mA current.

2.2 Receiver

The LiFi receiver is also based on four fundamental components which are receiving sensor, amplifier, highpass filter and a microcontroller as shown in figure 3. Furthermore explanation of the receiver is as follows.

- The first part is the receiving sensor (either solar cell or PIN photodiode), which converts the oncoming light signals into electrical signals.
- The second part is an amplifier, which amplifies the incoming signal from the sensor.
- A High Pass Filter, which primarily blocks DC light from the environment.
- A Microcontroller (PIC12F1840), which decodes the incoming signal, and send the decoded information to the Controller using UART.

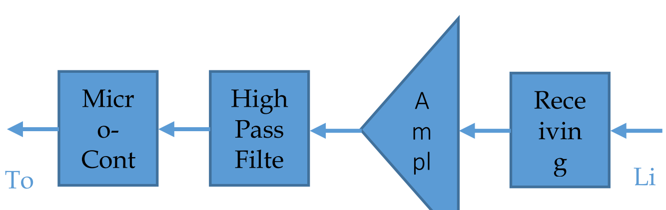


Figure 3: *Receiver Block Diagram*

2.2.3 Functionality of the microcontroller in the receiver

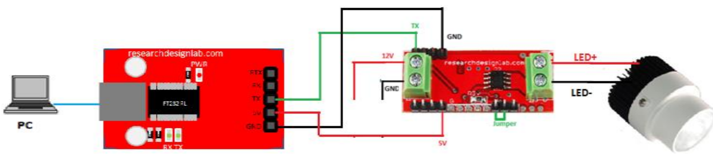
- The Microcontroller is used to convert the amplified and filtered signals from the previous stages into meaningful digital values between 0-1023.
- It follows all of the prerequisite steps of A/D conversion, including "sampling", "Quantization" and "Digitization"(interpreting the received signals (between 0-1023) in terms of binary signals.).
- The PIC12F1840 has a 10-bit A/D converter, thus 2^10=1024, and 1023 is the maximum discrete value that can be received after the Quantization phase of the conversion.
- The given microcontroller has 8 clock modes, and the project utilizes the INTOSC (Internal Oscillator) mode. This is due to the fact that the internal oscillator of the device is quite reliable, and also eliminated the need to add an external clock source which will only add to the power consumption and the physical size of the Transmitters/Receivers.
- The range of the INTOSC is from 31 kHz to 32 MHz. This project utilizes the 1 MHz internal clock source. This is achieved by setting the FOSC bits (2:0 in the Configuration Words to set the source to INTOSC. FOSC bits should be set to "100" in order to achieve this) and SCS bits (1:0 in the OSCON register. This value should be "00").
- The controller utilizes the High Frequency Internal Oscillator (HFINTOSC) in order to attain a frequency of 1 MHz. This is achieved by setting the value "00001011" in the OSCCON register. In other words, the IRCF bits should be set to "1011".

2.2.4 Analog to Digital Conversion

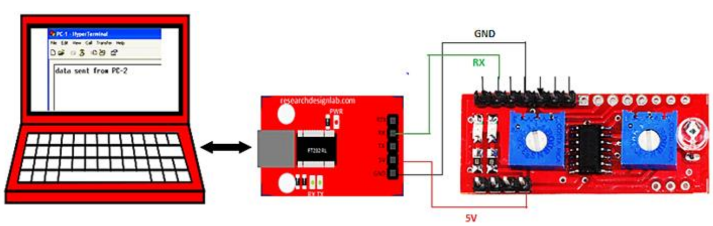
- We shall first select the desired I/O pin and configure it to work as an analog pin. This is done by setting the TRIS and ANSEL bits of the corresponding pin.
- The reference voltage for the A/D conversion is set to be Vdd. This is done by setting the desired values in the ADPREF and ADCON1 Special Function Registers.
- The conversion clock is set by again setting the required values in the ADCS bits of the ADCON1 register. Now, as the Time required to successfully complete a 10-bit conversion is Fosc/X * 11.5 (where "X" is the value determined by setting the appropriate bits in the ADCS bits)
- The conversion clock is set by again setting the required values in the ADCS bits of the ADCON1 register. Now, as the Time required to successfully complete a 10-bit conversion is Fosc/X * 11.5 (where "X" is the value determined by setting the appropriate bits in the ADCS bits).
- Thus, we shall set the value "000" in the ADCS bits of the ADCON1 register. This is due to the fact that at this value, X=2. Thus, our entire conversion takes place in 2 uSec * 11.5 = 23 uSec. Since our receiving elements and other circuit components have a limited frequency range, we shall stick to this configuration. In addition, this is also the fastest possible configuration for the ADC in the 1 MHz internal clock range.
- The 10 bit values are then stored in the ADRESH and ADRESL registers. After reading the bits, a conditional statement determines whether the analog value should be interpreted and transferred as a digital "0" or "1", to the serial port of the computer.

3 HARDWARE COMPONENTS FOR LIFI SYSTEM

This section discusses the hardware components used for the implementation of this project. LiFi NANO V2 module is used for the transmitting and receiving the LiFi signals. The photovoltaic cell and PIN diode are used for receiving the LiFi signals. On the transmission side, PIC microcontroller (PIC12F1840) is responsible for taking the data from the USB-to-UART converter as digital input, and then drive the IRF 8736 MOSFET using a digital output. On the receiver side, PIC microcontroller is responsible for receiving the data from the differential amplifier which is designed using LM324, converting the analog input to a digital value (between 0 to 1024), then deciding if the received value is either a digital 0 or digital 1, and then transferring the corresponding digital bit to the USB-to-UART converter as an output. High power LED array is used for transmitting the light signal. The transmitter and receiver circuits are shown in Figure 4.



(a) Transmitter Circuit



(b) Receiver Circuit

Figure 4: *The transmitter and receiver circuits of LiFi System*

4 MAINRESULTS

This section discusses the main results obtained using the indoor implementation of LiFi system. In general, the LiFi receiver either utilize a photovoltaic module or it based on PIN photodiode. This section presents a comprehensive study for implementing the visible light communication system using both photovoltaic cell and PIN diode.

4.1 ANALYSIS OF PHOTOVOLTAIC CELL IN INDOOR LI-FI

A medium power small size (3.37in x 2.125 in) photovoltaic cell is used in this context. The photovoltaic cell has a maximum voltage of 5V with typical voltages of 4.5V and maximum current 100 mA [17]. Initially, a square wave of different frequencies was sent through the transmitter to check the general receptivity of the photovoltaic cell. Figure 4a shows the transmitted waveform at 100 Hz which is received by the photovoltaic cell without any distortion as shown in figure 4b. However, as the bandwidth of the transmitted signal increases the signal starts getting distorted which shows a small range of photovoltaic cell and thus is not able to successfully detect the pulses of light above a small range of frequencies. Thus, the baud rate at which serial communication could successfully be achieved using this panel is limited to 2.4 Kbps bauds. The maximum efficiency of the photovoltaic cell can be obtained using Equation 1.

$$\eta_{max} = \frac{P_{max}}{E \times A} \times 100 \qquad (1)$$

where $P_{max} = V_{max} \times I$ is the maximum output power of the photovoltaic cell, E is the incident radiation flux (W/m2) and A is the area of the photovoltaic cell (m^2). For the photovoltaic cell of maximum 5V, 100mA, area of 0.0047m2and the solar irradiance of 1000W/m2, the efficiency of the photovoltaic cell can be calculated as 10.65%.

The results using the photovoltaic cell shows that the photovoltaic cell can be used for LiFi applications with limited baud rate. In addition, the poor efficiency of the photovoltaic cell makes it limited to high power in door applications only.

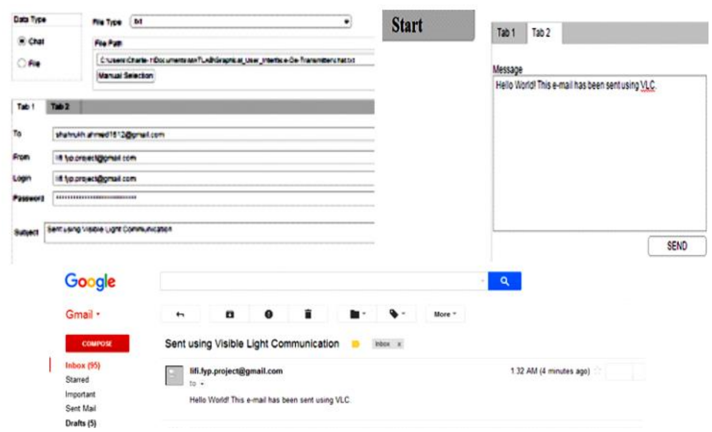


Figure 5: *GUI snapshot for email transmission using PIN diode*

4.2 ANALYSIS OF PIN PHOTODIODE IN INDOOR LI-FI

This part is related to designing and implementing a LiFi system capable of sending and receiving text and e-mail using a PIN photodiode as its receiver. A PIN photodiode is a type of semiconductor diode that contains an intrinsic region in between its positively doped P-region and negatively doped N-region. To detect an optical signal, a photodiode is reverse biased. When a photon strikes the intrinsic material, it energizes an electron such that it jumps from the valence band to the conduction band of its atom. If sufficient numbers of photons strike the material in succession, a current establishes itself in the diode [16]. The performance of a PIN photodiode is measured by its responsivity as shown in equation 2.

$$R = Is / Po \qquad (2)$$

Where “R” is the responsivity of a PIN photodiode which is the amount of electrical output per optical input, “Is” is the average photocurrent and ”Po” is the incident optical power. The pin diode sensor is tested at the baud rate of 38.4 kbps and found efficient for ASCII and email communication. Figure 5 shows the MATLAB based GUI snapshot that is designed to send and receive the email. The designed software can successfully send and receive email over a distance of 2 feet using LiFi. Text files and emails are transmitted at an incredibly fast and efficient manner. This clearly exhibits the reliability of VLC under the right circumstances. In contrast to photovoltaic cell, PIN photodiodes can efficiently receive data at intermediate baud rates. With more efficient transceivers, a very high baud rates can be achieved. However, to achieve communication at a reasonable distance, one must mitigate the factors such as shot noise, thermal noise, inter-symbol interference and bit error ratio.

5 Conclusion

This paper presented the system level discussion and implementation of VLC system. This paper also analyzed and compared the use of photovoltaic cell and PIC diode by using the experimental results. The performed analysis can be deduced that photovoltaic cell provide better NLOS (Non-Line of Sight) reception of signals as compared to PIN photodiodes. Photovoltaic cell with larger efficiency can provide VLC at higher baud rates. PIN photodiodes have a better tolerance to inter-symbol interference as compared to photovoltaic cell. PIN photodiodes can also operate at a baud rate of 34.8 Kbps as compared to a baud rate of 2.4 Kbps provided by the photovoltaic cell. LiFi is a reliable communication medium to carry out indoor wireless communication, provided that the Bit Error Ratio is low and the noise level from the surroundings is also low.

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