Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.42, No.1. July 2023

http://jaet.journals.ekb.eg

Design and Implementation of Light FidelityCommunication Systems

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Abstract

In recent years, visible light communication (VLC) has grown in prominence to accommodate the ever-increasing demand for data traffic. As global awareness of energy-related issues rises, solar cells with dual functions of energy harvesting and data collection emerge as the preferred choice for photodetectors on the receiver side of the VLC system.

This research looks into the design of a low-cost Light Fidelity (Li Fi) system using a solar panel as a photodetector. The proposed system is capable of simultaneous data transmission and energy harvesting. The generated energy can potentially be used to power a user terminal or at least to prolong its operation time. It also discusses various parameters such as distance, visibility and angle that affect the Li-Fi communication. The modulation and demodulation have been implemented on the software level and algorithms for them are clarified in this paper. The prototype was put to the test by sending a text message via visible light from one PC to another.

Keywords: Visual Light Communication (VLC), Light Fidelity (Li-Fi), Light Emitting Diode (LED), On-Off Keying (OOK).

1. Introduction

One of the most essential daily activities is the transmission of data from one place to another. The existing wireless networks which are responsible for connecting users to the internet turn to be very slow once several devices get into connection together [1]. The increase in the number of devices that gain access to the internet makes enjoying high rates of data as well as connecting to secured network more difficult due to the available fixed bandwidth [2]. Moreover, the usage time of wireless systems is rising annually in an exponential manner, but because of Radio Frequency (RF) resources limitations the capacity is declining. Consequently, suffering from severe communication problems is inevitable.

In order to defeat this obstacle in the future, Harald Haas who is a specialist in optical wireless communications suggested in 2011 an applicable and superb solution via utilizing light in order to transmit data. He illustrated how a Light-Emitting Diodes (LED) bulb supplied with the technology of signal processing is capable of streaming a high-definition video to a computer and he revealed that a one-watt LED light bulb would be sufficient to supply net connectivity to four computers [3].

The name of this new technology is Light–Fidelity (Li-Fi). It is a system of short range wireless communication which is depending on light illumination from LED, and the visible light is utilized as a signal carrier rather than conventional RF carrier as in Wi-Fi [4].

On the other hand, Renewable solar power has been designed to be integrated into regular domestic housing and utility power systems as a result of technological breakthroughs in recent decades. Following developments in photovoltaic (PV) technology, information technology, intelligent management, and power electronics, the efficient transmission and distribution of electricity among large-scale, distributed, solar-powered devices have also been realized. [5]. this is critical in addressing the energy issue as well as environmental damage. They are infiltrating every aspect of our life and hastening the global energy structure's green makeover. Recent advancements in solar cell-based optical wireless communication (OWC) have resulted in significant business prospects for solar cells in fifth-generation (5G) and beyond signal detection networks [6, 7].

The aim of this paper is to design a visible light communication system that is capable of sending and receiving data while harvest energy to

Received:2 July, 2021, Accepted18November, 2021

charge devices. And investigate the trade-off between energy harvesting and wireless communication.

This paper is arranged in five sections. The first section is an introduction and the second section explains a literature review of the VLC system and the third section introduces the hardware and software requirements for the VLC system design and based on that it explains the prototype for implementing the system. The forth section gives the results of the paper. The fifth section highlights a group of conclusions and future work points. A list of the utilized references is provided at theend of the paper.

2. Literature Review

Indoor communication, visible light wireless LAN, underwater VLC, and so on are instances ofVLC, and they have all had notable success [2,8].VLC's transmission rate has increased fromtens of Megabits per second to 500 Megabits per second and then to Gigabits per second in just over ten years [9, 10]. New ideas and innovations arise in a never-ending stream, and VLCis likewise in an active phase of growth, as themode of connection shifts from point to point to several inputs multiple outputs (MIMO)[11]. VLC has a standard application prospect as a complement and expansion of wireless communication in a particular area [12].

VLC technology, based on LEDs and solar cells, is still in its early stages, as most previous research has concentrated on increasing data speeds and transmission distances without taking into account the consequences on VLC channels, such as blockage, mobility, and alignment concerns [13–15]. Exploiting LED and solar cell arrays with complex digital signal processing technologies like orthogonal frequency division multiplexing (OFDM), multiple-input multiple-output (MIMO), and equalization algorithms is a promising solution for improving communication performance and implementing more robust systems. Furthermore, the advancement of semiconductor and photovoltaic technologies is without a doubt the strongest driving force in the race to meet the demands of next-generation applications [16,17].

In [18] triple-cation perovskite solar cells were optimized for VLC by varying the thickness of the active layer. Under white LED illumination (incident power, 0.9 mW/cm2), the PCE varied in the range of 18%–21% for devices in therange of thickness of 170–640 nm of the active layer in the solar cell. While using a red laser diode (LD) with an output power of 50 mW, a maximum data rate of 56 Mb/s was achieved by using the OFDM scheme over a 40-cm air channel.

In [19] a custom-designed a-Si thin-film solar cell-based receiver, called AquaE-lite, successfully received OFDM signals at data rates of 1 Mb/s and 908.2 kb/s over a 20-m long-distance air channel and a 2.4-m turbid outdoor pool water channel, respectively, under bright background light, but the PCE achieved was approximately 4.8%.

3. Design of VLC Systems

The requirements and steps engaged in the system prototypedesign will be explained in this section, algorithms utilized for the application ofcoding technique and modulation. In section (3.1), we introduce the hardware requirements of the transmitter and receiver. In section (3.2), we discuss the corresponding software.

3.1The Hardware

The transmitter and the receiver are the two parts which make up the system of VLC. The system's block diagram is revealed in Figure1. The system of VLC primarily comprised of:

- PC in the transmitter which used to send the information data.
- Modulator.
- LED driver circuit: consists of two transistors in Darlington pair.
- High power LED
- Polycrystalline photocell.
- Bandpass filter.
- Amplifier.
- Charging circuit.
- Demodulator.
- PC in the receiver which used to view the received data.

Each block is explained in details in the following section.

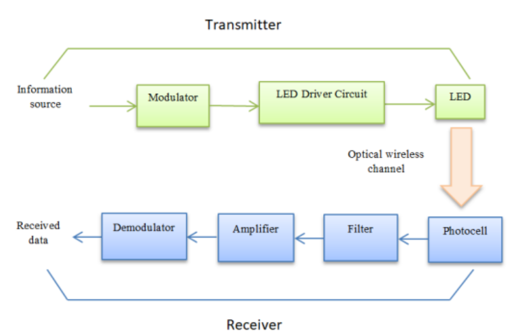

Figure 1: VLC system block diagram

3.1.1 The Transmitter

The primary objective of the transmitter is to send the text data represented in a digital signal via converting it into visible light.

The text data is sent from the PC at the transmitter to the Arduino via the universal asynchronous receiver transmitter (UART) protocol. The Arduino converts the data to an array of bits and sends it to LED. The LED driver circuit which is connected to the Arduino board comprises two transistors in a Darlington pair for rapid LED switching [20]. For this objective, a LED is utilized due to its linearity between the intensity of light and current. LED provides the benefits of low power consumption, green environmental protection, and small size, reliable and stable unlike other sources of light [21]. Furthermore, LED is featured for having high modulation bandwidth, high sensitivity, and good modulation performance [22]. The technology of VLC uses the high-speed switch characteristic of LED for the transmission of information [23-25]; figure 2 shows the schematic of the transmission circuit. We used here a high power LED to achieve large distance between transmitter and receiver. The main characteristics of LED according to the manufacturer are:

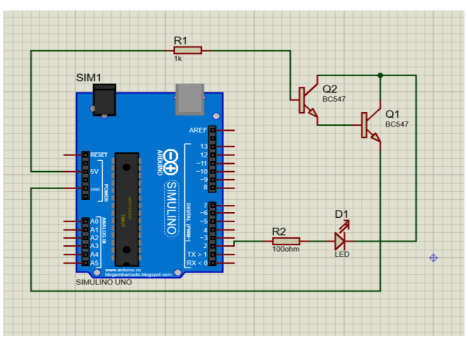

Figure 2: The transmitter circuit

- Color temperature: Warm White 3000-3200K / white 6000-6500K.
- Forward current: 700MA.
- Luminous flux: White 180-200LM (lumens).
- Forward voltage: 3.3 - 3.6V.
- Reverse voltage: 5V.
- Power: 3W.
- Viewing angle: 180°.

3.1.2 The Receiver

At the receiver side, a band pass filter was employed to remove the background noise. Then a low noise amplifier was used to amplify the amplitudes of the received signals and thus improve the signal-to-noise ratio at the receiver, figure 3 shows the circuit diagram, the input to this circuit is the solar cell output, and its output is connected to an Arduino pin. A polycrystalline solar panel is used to convert the received light into an electrical signal along with harvesting energy to produce the power needed to the receiver circuit.

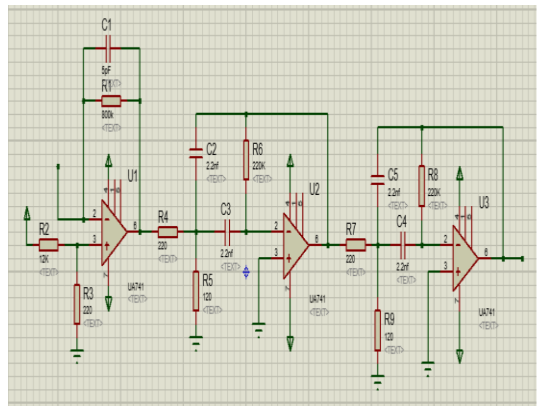

Figure 3: The receiver circuit

Polycrystalline solar cells have high power conversion efficiency (PCE) of around 22.3% [26]. Thin-film solar cells, on the other hand, continue to lag behind due to structural inhomogeneity and light-induced loss of dangling bond density [27]. The PCE of hydrogenated thin-film solar cells remains at 12.69%, as shown in [28].

The main characteristics of solar panel according to the manufacturer are:

- Rating: 2w (12Vdc/165mA).
- Size: 136mm x 110mm.
- Cell type: Poly Crystalline.
- Operating Temp: -20 ~ +60 C.

After converting light to electrical signal it is then demodulated in the Arduino and represented as a text on the receiver PC.

3.1.3 The Circuit Model for synchronous VLC and energy harvesting

The analogous circuit for using the solar cell for simultaneous energy collecting and communication can be modeled as shown in figure 4. The inductor L simulates the inductance of any wire connections to the solar cell, while the capacitor C in parallel with RSH captures the internal capacitance of the solar cell. The solar cell's output has both DC and AC components. A capacitor C0 and an inductor L0 separate the DC component of the electrical signal, which is utilized for energy harvesting, from the AC component, which is used for communication. To acquire the desired bandwidth and signal gain in the receiver system, the DC current is terminated through a load resistor RL, and the AC current is terminated through a resistor RC that is matched to the inductor–resistor-capacitor equivalent circuit of the solar cell [13, 29]. While the capacitor C and inductor L values must be optimized for the solar panel, it has been reported that increasing their values improves their performance in the low-frequency band, which corresponds to the frequency range of OOK modulation.

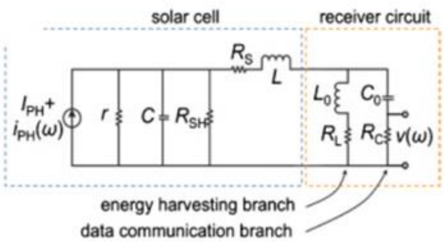

Figure 4: Solar cell model: an equivalent circuit in a configuration for synchronous energy harvesting and data communication.

3.2 The Software

This is a main part of this project and it comprises of:

a) Modulation and demodulation scheme implementation.

b) Packaging of data.

d) Receiver calibration for compensation of ambient light.

The description of algorithms which utilized to clarify the points mentioned above isin sections 3.3 and 3.4.

3.2.1 On Off Keying Modulation

On-off keying (OOK) modulation is the simplest binary modulation scheme that is easy to implement with low-cost off-the-shelf hardware. Also, it is immune to the nonlinearity of LEDs and thus able to improve the performance of the VLC system. However, it has a low spectral efficiency [30,31].OOK in its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero [32]. This scheme of modulation is applied on a software level, in which the Arduino code converts the information data into a bit stream.

3.2.2 Manchester Encoding

Manchester encoding is the technique of coding used in several communication systems combined with OOK [33]. In this method, "0" is encoded into the "01" sequence and "1" into the "10" sequence. In VLC systems, this has the advantage of avoiding LED flicker. A long sequence of succeeded 0s followed by a long sequence of 1s will be recognized as irritating LED flickers even at high frequencies. Manchester encoding resolves this by continuously transmitting an equal number of ones and zeroes [34]. How the bits are encoded is shown in figure 5 below, in the figure, each bit is transmitted in a form of transition from low to high state encoded as "1" and the transition from high to the low state is a "0".

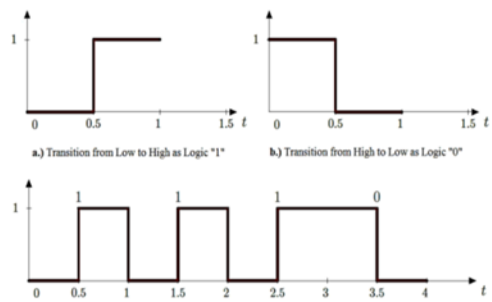

Figure 5: Shows the encoding of bits using Manchester coding

3.2.3 Manchester Decoding

Manchester decoding is defined as the part in which major problems originate and it must be handled carefully. Synchronization is the most essential and complicated aspect of Manchester decoding, i.e. adjusting the receiver to be capable of detecting the point of transition or the edge coming from the circuit of demodulation. Atmel Corporation’s documentation explains Manchester's decoding and encoding procedure clearly [35].

3.3 The Transmission Algorism

Figure 6 shows the flow chart representing the algorithm of transmitting the data process.

The following steps explain this operation on the software level:

1. First, we set the midpoint of each pulse to equal data rate/2.
2. Determine the ID so the receiver can recognize the transmitter.
3. The text data is represented as an array, each element in it is 8-bit.
4. The array is sent to the microcontroller via the UART protocol.

5. The transmitter ID which is an 8-bit decimal value is sent to the receiver to be checked by the receiver's microcontroller.

The frame is then transmitted using LED, which is turned OFF for half (T) and ON for the other half to represent binary '1'.

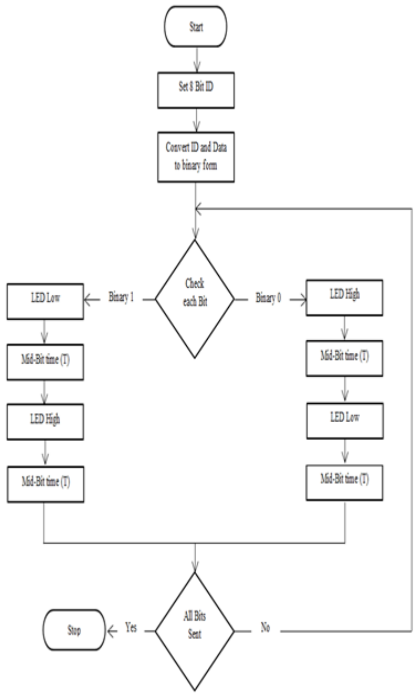

Figure 6: The flow chart of the transmission algorithm

3.4 The Reception Algorism

Figure 8 demonstrates the flow chart of the operation algorithm of the receiver, and the following steps explain the operation algorithm of the receiver on software level:

1. When the receiver is turned on, a threshold value is calculated to distinguish between the logic '0' and logic '1'.
2. The receiver is likewise calibrated in accordance to the ambient light via setting this value of threshold.
3. The transmitter sends an ID that is first conformed to the receiver's ID in order to ensure that the data being received is from the proper transmitter. If the ID of both Transmitter and Receiver match, then only additional signal reception is the data bits.
4. Each letter sent is 1 byte; it is read from MSB to LSB via bringing into comparison the value of sensor with the value of threshold.
5. These received data is then converted back from a binary form to a text.

The sensor of photodiode captures one initial reading and saves it to establish a threshold value, subsequently this initial reading is brought into comparison with multiple subsequent readings till the difference between the concurrent readings and initial reading is sufficiently high. The value of threshold is then calculated by taking the average of both initial reading and current value is calculated giving the value of threshold. The receiver can distinguish between Logic 1 and Logic 0 with the aid of this threshold value.

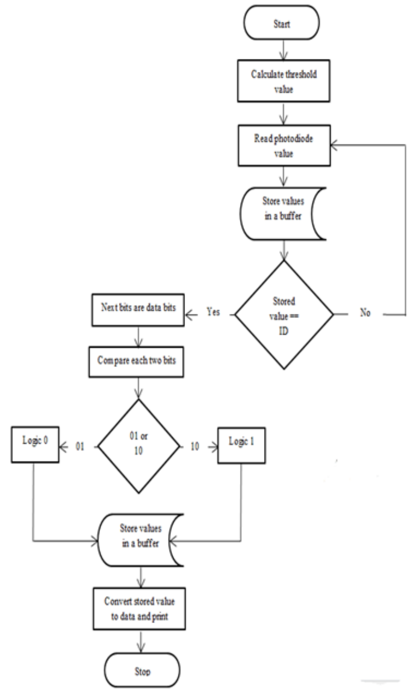

Figure 7: The flow chart of the reception algorithm

4. Results and Discussions

This section discusses and presents the results of operating the VLC system. Figure 8 shows the experimental setup of the system. The system is put to the test at distances up to 1 meter.

Figure 8: the experimental setup of the system.

The data transferred at a speed of 100 Kbps. The use of filter circuit at the receiver minimized the effect of ambient light noise. The use of a high power LED in the transmitter and an amplifier circuit in the receiver availed in reaching longer distance between transmitter and receiver. However, with increasing distance, more than 1 meter,the noise and delay also increased. This is due to the lowering of intensity at the surface of solar cell by increasing the distance as shown in Figure 9. The variation in the angle of incidence light from the LED also shows that as the angle of incidence raises, the signal strength decreases as shown in Figure 10, and subsequently signal tends to get noisy.

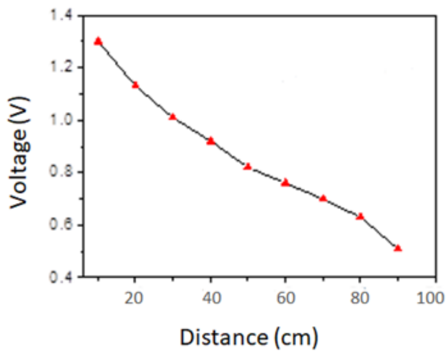

Figure 9: Voltage across the solar panel output vs. distance between the solar panel and LED.

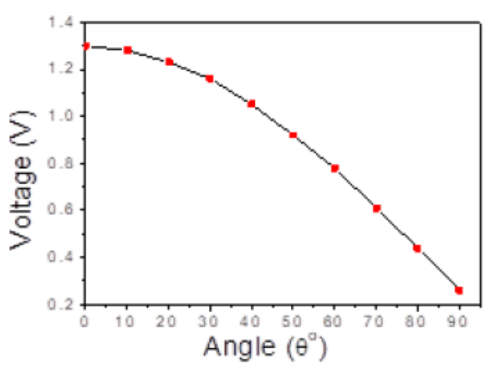

Figure 10: Voltage across solar panel vs. the angle between the surface and incident ray from LED.

Compared with organic and a-Si thin-film solar cells employed in the prior work [18, 19], the polycrystalline solar cells with the superiority in PCE show excellent performance in VLC.

As there is a trade-off between energy harvesting and wireless communication [36], despite that the data rates that could be achieved using OOK lower than that of OFDM, in utilizing system for duel usage it has better performance.

Even though that White-light lasers proved to be good candidates of white-light LEDs to implement simultaneous long-distance lighting and high-speed VLC in the future [16,37], they still cannot be used for wide range of applications because of their power limitations, high cost and smaller bandwidth compared to LEDs [38].

5. Conclusion

In closing, a VLC link has been demonstrated applying a high-power LED as a signal transmitter and a polycrystalline solar cell as a receiver. The polycrystalline cell was chosen because of its excellent power conversion efficiency. Such a receiver operates without an external bias and can concurrently communicate data and harvest power. The solar cell's output power was 0.43 mW. The OOK modulation with Manchester encoding was used to test the VLC link; the data rate of this modulation approach is suitable for the dual operation of the receiver circuit. The load resistor in the energy-harvesting circuit branch can have a significant impact on the VLC link's data rates. At a data rate of 100kbps, the system was tested at various distances between transmitter and receiver, with the maximum distance reached being 1 m. The signal strength on a solar cell is also affected by the angle of the LED's incident ray and the surface.

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