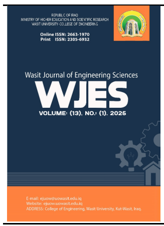

Wasit Journal of Engineering Sciences
Journal homepage: https://ejuow.uowasit.edu.iq
Vol. 13 No. 1 March 2025, pp.1-13
https://doi.org/10.31185/ejuow.Vol13.Iss1.607

ISSN 2305-6932
Original Research

Blue Laser Underwater Optical Visible Light Communication Using Recursive OFDM

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ABSTRACT

Water covers more than 75% of the earth's surface in the form of the ocean. The ocean investigation is far-fetched because the underwater environment has distinct phenomenal activities. The expansion of human activities inside underwater environments includes environmental monitoring, offshore field exploration, tactical surveillance, scientific data collection, and port security. This led to increased demand for underwater applications used in communication systems. Therefore, the researcher develops many methods for underwater VLC Visible Light Communications. The new technology of blue laser is a type of VLC that has benefits in the application of underwater communications. This research article investigated the benefits of underwater blue laser communication with recursive OFDM for different water types and discovered the effects of baud rate, bit error rate, and latency which affected several subcarriers of the recursive OFDM that have same characteristics but different water environments. The design uses a Xilinx Kintex-7 FPGA evaluation board with high-speed analog daughter card ADC/DAC. It is connected to the terminal blue laser diode as a source of transmitting and receiving signals. Different experiments are done to find the result and discuss the characteristics of blue lasers in underwater communication for various water environments.

Keywords: Underwater wireless communication, Recursive OFDM, Laser Diode, Optical VLC

1. Introduction

In the 21st century, with the rapid development of the globe's marine economy, an increasing number of underwater operations have been conducted [1]. Thus, effective marine communication is urgently needed to facilitate personnel and goods transportation, marine environment monitoring, and oil resources exploitation, more specifically, as a potential technology for a promising underwater communication system. Optical visible light communication technology in the underwater medium such as underwater-visible light communication especially blue laser technology has attracted more attention in recent years because the blue laser can pass the water medium with low attenuation [2]. The optical visible light can carry a larger information capacity, while the OFDM technology is outstanding in resisting multiple path interference and precisely demodulating the information. OFDM technology consumes more power due to complex digital signal processing (DSP), which generates orthogonal between subcarriers. Therefore, to recover these issues using recursive OFDM this technology has a lower complex DSP and low power consumption with high data transmission. This attempt, greatly benefits, especially for the UWOC system design in the complex and crowded water medium environment [3]. This paper aims to investigate a blue laser optical visible light communication system used for underwater communications affected by different water-type environments used as a channel of underwater communications. A novel recursive OFDM signal generation scheme able to combine the differential DC bias modulation and adaptive digital pre-emphasis technologies is proposed in this study, aiming at effectively mitigating the interference from constant signals on the receiver through the pre-processing of the transmitted electric signal flowing into the blue-voltage-laser current driver [4]. In this paper the recursive OFDM system performance for the sake of the system block diagram simplicity and bandwidth modulation. The system uses MATLAB program which cooperated with device hardware parameters uses Kintex-7 FPGA with a high-speed analogue daughter card for design recursive OFDM combined with high-power VLC using a blue laser diode for transmission data to fit the experimental system used in this paper for easy commercial use. The performance of the investigated scheme is tested by BER, Latency, and Bit rate for different environments underwater channels by using a blue laser as a source of communications. Finally, the experimental results is analyzed and tested data for different water environmental types such as clear tab water (clear water), bubble water, coastal ocean, and turbid water and discover the technology can efficiently for underwater vehicle communication using the laser transmitter and photodiode receiver for the total system.

2. Related Work.

Underwater optical communication systems have become necessary to expanding a scientific and defense research in maritime and offshore industries [5]. Historically, the use of acoustic, passive acoustics, low-frequency acoustics, radio, high-frequency radio, and low-frequency radio has been employed for underwater communication. In the last decade, ultrasonic systems with underwater acoustics, are not affected by light absorption and are effective at low depths [6]. The acoustic system is slow, has limited range, offers low bit rates, and has low noise immunity. Due to these limitations and various issues, it is suggested that ambient light communication, visible light communication, and blue laser communications [7]. In an operational military ship, the exchange of information and control orders is paramount but limited underwater. The underwater communication channel is usually noisy, energy-efficient at long range, and has limited bandwidth [8]. New optoelectronics and quantum magnetics developments have made underwater laser communication a feasible option. Various visible light and optical communication methods show increased reliability, high data transfer rates, and low power consumption [9][10]. Blue or ultraviolet laser light has better transmission capability in pure seawater compared to other visible spectrum lights. Therefore, blue-green laser light or ultraviolet transmission lines have a competitive edge over pure seawater and lower attenuation in water. Soft communication and visible light in blue water and seawater have become an important focus in recent research projects on water disclosure systems [11]. Efforts have been made to improve these systems, including the multiband recursive OFDM modulation technique. During the literature review, we examined a variety of optical communication types such as blue laser LED, and recursive OFDM, for underwater communication [12]. Recursive OFDM division techniques have been found to significantly improve because have low power consumption when compared with traditional OFDM [13]. Our study proposes improving the OFDM technique with a recursive OFDM network approach where the underlying system consists of blue laser and visible light. This feature makes this work more reliable for deep underwater communication. In this study, we used visible radiation with laser sources and blue lasers. This could have spectral specifications of 400 to 490 nm [14]. The trailing and processing circuits of a laser transceiver can be expanded with photonic networks [15].

2.1. Blue Laser Technology

Blue laser refers to a laser with a blue light wavelength, it is an important part of visible light communication. The reason why blue laser has this name is because a wavelength is mainly concentrated in the blue light part with a wavelength range of about 400 to 490 nm [16]. Due to the characteristics of smaller laser wavelength and higher frequency, the current production efficiency of blue laser has not been effectively improved, so the energy utilization efficiency of the entire blue-violet laser is not high [17][18]. From the aspect of optical communication, the global population-oriented optical cable reaches all corners of the world, so there is a need for Fiber-Optic communication with underwater vehicles. Underwater optical communication is a new type of data communication method that is applied to underwater communication systems. It transmits Recursive OFDM signals in the form of different wavelengths of light [19]. The use of high-efficiency blue lasers in underwater optical communication has the following advantages: the range and penetration of optical communication performed in a medium are directly related to the operating wavelength of the communication system. To communicate in water, it is a requirement to use blue lasers instead of visible light [20]. The research on optical communication in underwater shows that the loss caused by absorption and scattering is mainly caused by the operating band of the light wave, especially in the visible light area from 400 nm to 490 nm [21]. The absorption band of water can be reduced by using a 450 nm blue laser instead of wide-spectrum visible light, which helps reduce the loss caused by underwater transmission and improves communication performance. In the development of laser technology, the low-cost blue laser development technology has matured. In various underwater vehicles, blue laser technology has begun to be applied and has been widely used in sea surface vehicles. [22][23]. The analysis of the four fundamental properties of a blue laser that are driving its development will be presented. Blue lasers operate in the wavelength range between 400 nm and 490 nm [24]. Their fundamental properties are that they are very efficient in the transfer of power from the electric to the light field due to the small electron energy difference and the smaller fractional amount of photon energy that is in the form of heat. For a beam of 405 nm light, this is for solar cells a detailed analysis has shown that solar cells designed for 405 nm light are highly resistant to changes in irradiance, and operation at solar concentrations of 5 to 50 is feasible [25]. Blue lasers currently have the lowest cost per delivered lumen of any other light source. Several other qualities of blue lasers may impact communication advantages, such as single frequency propagation and other illumination characteristics, but are outside the present scope [26]. The evolution of the blue laser has involved many of the world's largest and most successful companies. These industry dynamics underline that blue lasers are a very exciting technology investment that offers unexplored opportunities for substantially improving the performance of many products [27]. In particular, these suggest Recursive OFDM with blue laser has a great potential for the development of novel and extraordinarily low power consumption long-range underwater communication systems. [28]..

2.2. Recursive OFDM

Recursive Orthogonal Frequency Division Multiplexing (R-OFDM) is an advanced version of Orthogonal Frequency Division Multiplexing (OFDM) with low power consumption and lower complexity, which has crucial applications in optical and wireless communication systems, especially for underwater communication systems [29][30]. In the last few decades, research has been directed to study the efficiency of optical wired and wireless communication systems that demand ultrahigh data rates [31]. It is pertinent to mention that the performance analysis of the R-OFDM system is done under the Recursive IFFT/FFT [32]. This recursive channel deals with uncorrelated noise in the time direction and correlated noise in the spatial direction. In addition to these properties, the frequency hops that are chosen in the design of the recursive IFFT/FFT contribute to an even distribution of subcarrier energy, thus restricting sidelobes created due to the multipath effect, combating inter-symbol interference (ISI). Underwater optical wireless communication is a topic of interest, and many researchers have provided simulation results of optical wireless communication [33][34]. The performance of a communication architecture is severely affected in a challenging communication channel. OFDM, the core concept of our proposed work, is a robust modulation technique that can be used against multipath propagation [35]. In such scenarios, recursive OFDM improves the performance of the system, and power must be invested [36]. Another approach is to minimize the degradation of the underwater optical wireless channel, which results from blue and green laser lights [37]. The OFDM approach is considered expensive and complex compared to recursive IFFT/FFT in frequency fading channels. Recursive is key to efficient channel equalization, which has considerable applications in underwater wireless communication systems, and R-OFDM is a variation of conventional OFDM to resolve future wireless communication subjects for high data rates. The fundamental purpose of conducting such research work is to enhance spectral efficiency under challenging communication environments. [38]. The key idea of R-OFDM lies in optimizing off-grid multiplexing of information-carrying signals for both reduced error rate and improved latency. The main mathematical insight is conceptually similar to graph colour from combinatorics, yielding latency reduction from increasing the channel freedom gained with each successive recursion. The R-OFDM concept consists of encoding and multiplexing the data into individual channels, resulting in sub-channels with ever-decreasing bandwidth in each recursive step. We have shown theoretical examples for optimal usage, as well as practically relevant numerical investigations. Applications of R-OFDM Outside of Underwater Communications: Recursive schemes in cooperative MIMO communication are continuously engineered and researched. Recursive bit allocation and shaper gains for high-speed OOK and NRZ signal transmission are investigated to reduce differential mode delay; top unfilled multiplexing showed research potential. Applications of ROFDM in Underwater Communications: OFDM is a multi-carrier modulation protocol and is used as an underwater vehicle communication paradigm. Due to the delay spread and low transmission speed, all communication signals are affected seriously. Compared to orthogonal frequency division multiplexing and optical frequency comb communications, the results show that the recursive structure can significantly reduce the required data rate to achieve the same throughput while providing reliable data transfer over the underwater channel. Thus, the recursive structure achieves a powerful underwater vehicle robust communication system. In summary, R-OFDM provides a robust solution for the underwater vehicle communication problem. The brightness of the visible light laser diodes was 100 mW when developing the R-OFDM, and the noticeable benefit regarding the suppression of the noise floor is that it is possible to have a higher dynamic in the signal modulation in the LD [39].

3. Method.

3.1. Integration of Blue Laser, Visible Light, and Recursive OFDM for Underwater Vehicle Communication

Blue laser technology has recently been applied to optical underwater communication for terrestrial and underwater vehicle mediums. Especially, wireless data transmission has a wide range of applications in the aquatic environment as a potential underwater communication platform like acoustic waves [40]. Blue laser communication aims to enhance the performance of existing visible light for underwater vehicle systems using advanced technologies available in terrestrial communication networks. The visible light communication systems have grown into a leading candidate for the underwater wireless communication medium [41]. The recursive OFDM scheme proposed underwater communication cable network has a more comprehensive data rate, robust connection, and improved information efficiency [42]. A complete analysis has shown that Recursive OFDM provides an efficient environment for underwater vehicle applications that can resist severe repetitive channel impulse noise and enhance transmitted signal efficiency. In underwater vehicle applications, wireless networking focuses on efficient modelling and accurate transmission through signals. Generally, available optical communication and radio frequency signal processing provide a wireless signal for underwater vehicles. Blue laser and visible light communication can take advantage of both explicit and visible light technologies to develop data models for underwater communication. Blue laser technology is a newer and developing technology in today's scientific world and offers a far larger bandwidth that can be effectively achieved by parasitic information channels with visible light. The recursive orthogonal frequency division multiplexing uses an infrastructure exploration of blue laser systems to provide more robust data signals underwater and efficient power consumption. The processing of an optical wireless link is improving based on underwater vehicle communication. The research on underwater communication has already developed using advanced technologies with lower DSP complexity and efficient power consumption such as Recursive OFDM integrated with blue laser.

3.2. System Architecture

To tackle the need for full-dimension underwater vehicle communication, an integrated system design that combines blue laser, visible light, and recursive-OFDM signal generation with lower DSP complexity modulation is introduced as shown in Figure (1). The transmitter uses a blue laser diode to transmit data through an underwater channel to communicate between the vehicle and the control unit. The receiver side uses a photodiode for receiving blue laser recursive OFDM data and demodulation to recover the original signal. All the connections are by using optical cables and optical connectors which are water resistant.

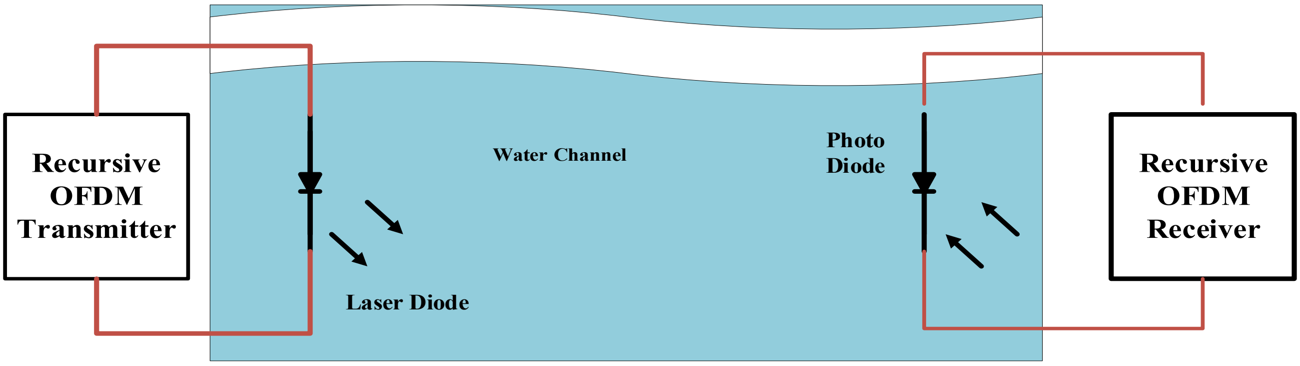

Figure 1. Main diagram of Recursive OFDM by Laser Diode

The system architecture, combining the blue laser as a visible light source located at the two ends of a 200-meter-long underwater channel, is presented concerning the receiver and transmitter uses the recursive OFDM architecture as shown in Figure (2). The main structure of the experiment uses the interface between MATLAB and FPGA Xilinx Kintex-7 evaluation board with AMD Xilinx system generator.

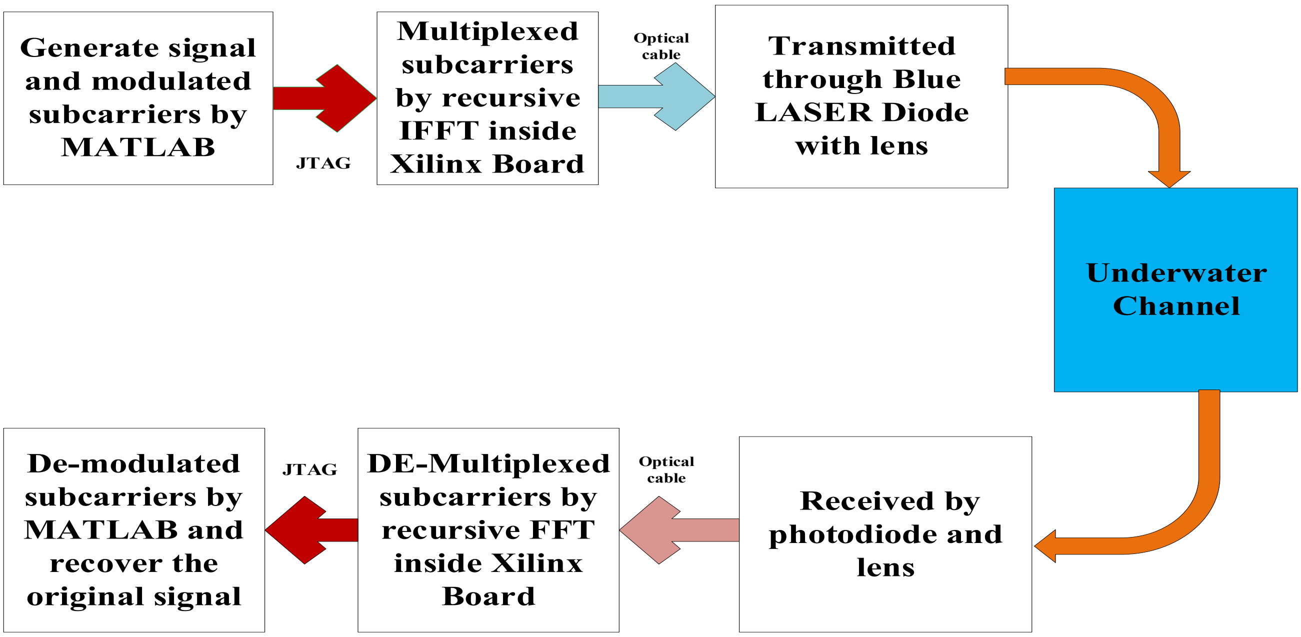

Figure 2. The structure of Recursive OFDM underwater communications

First; the signal is generated and encoded by 16-QAM inside MATLAB and then transferred to the FPGA board which is used to generate a recursive OFDM and convert it to an analog signal through an FMC port-connected DAC/ADC high-speed daughter card. The signal generated is moved to the channel of transmission through a laser diode and lens to increase the distance of transmission through the underwater channel. On the receiver side which an underwater vehicle uses a photodiode with the lens to receive the signal and then demultiplexed inside FPGA finally recovering the original signal in MATLAB the interface between MATLAB and Xilinx board uses a USB JTAG cable. The data was generated from MATLAB Simulink which is encoded by 16QAM but can increase the order of encoding to 32 or 64 QAM. The signal is exported to the AMD Xilinx Kintex-7 evaluation board through a JTAG USB cable between the computer and the Xilinx evaluation board with a high-speed analog daughter card. The processing of the signal through multiplexing the signal happens inside the Kintex-7 FPGA evaluation board and transmits the recursive OFDM through the laser diode with a magnifier lens. The lens is used for signal dispersion through water which makes it easier to receive the signal from the other lens after that photodiode are used as a source of receiving and demodulation to recover the original signal as shown in Figure (3). This figure describes the process of transmission and receiving in detail. The 16 QAM encoded signal is generated by PC using MATLAB (system generator) program and transferred encoded signal to the evaluation board through a USB J-TAG cable which stores the 16 QAM into RAM inside the AMD XILINX Kintex-7 evaluation board. The subcarriers read in parallel format from RAM and transfer to recursive IFFT to generate the orthogonality between subcarriers. Finally, the signal is recursive OFDM and converted to serial then to analogue signal through DAC the analogue signal is transmitted through the laser diode and magnifier lens. The signal passes through the different water environment types such as tab, coastal ocean, bubble, and turbid water. the receiver side a lens used to receive the blue laser light then photodiode the signal received converted to digital through ADC and processing the digital signal from serial to parallel remove the cyclic prefix and stored into AMD XILINX RAM to de orthogonal the recursive OFDM by R-FFT. Finally moved to MATLAB PC to recover the original signal. This experiment was done multi times for different water type and test BER, bit rate, and signal latency between transmitter and receiver.

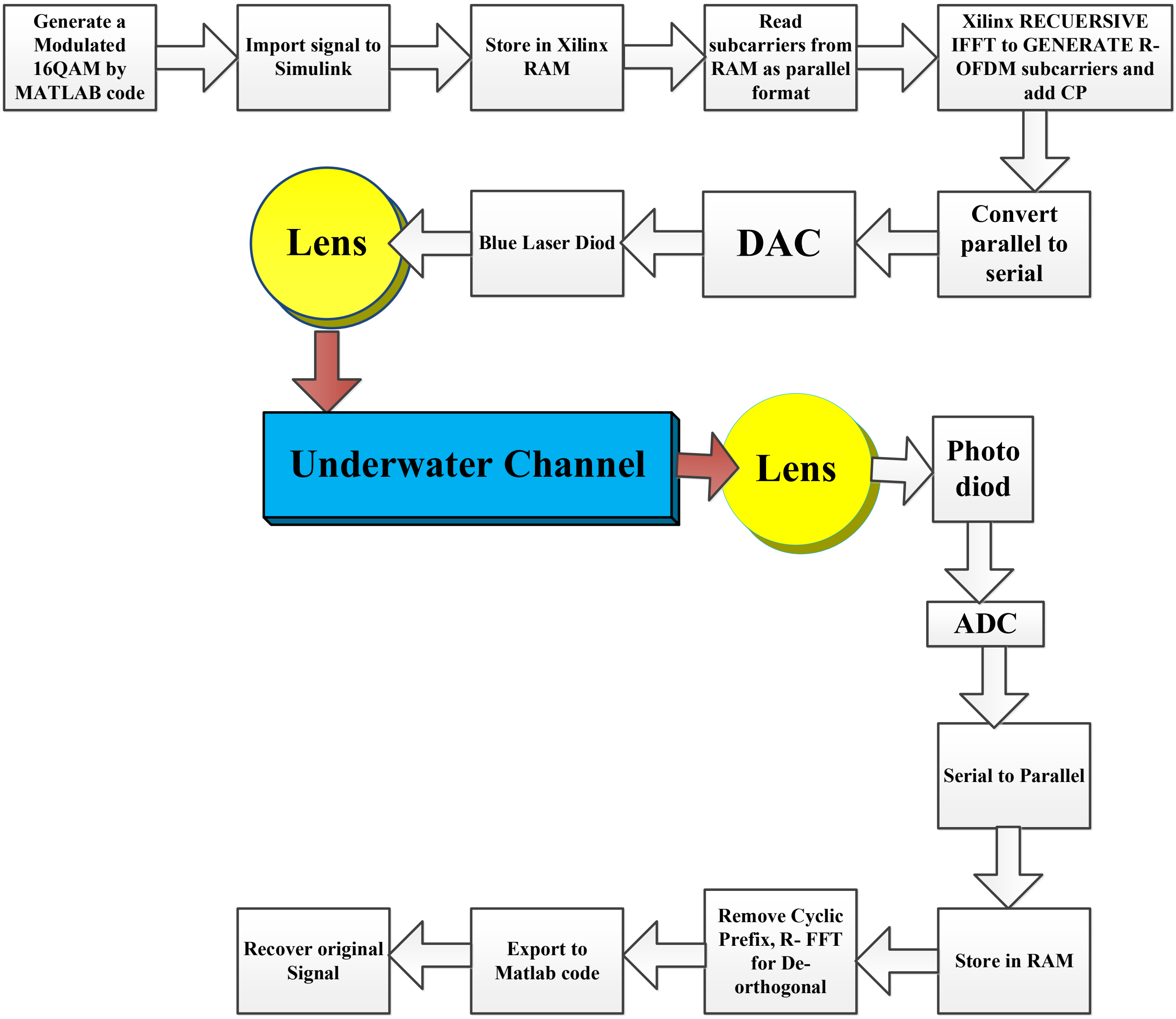

Figure 3. Recursive OFDM by optical laser diode

The data constellation diagram of the generated 16QAM Signal as shown in figure (4) is modulated in the MATLAB system generator to generate a subcarrier that is orthogonal to Recursive OFDM through the AMD XILINX evaluation FPGA board KINTEX-7 which interfaces with MATLAB.

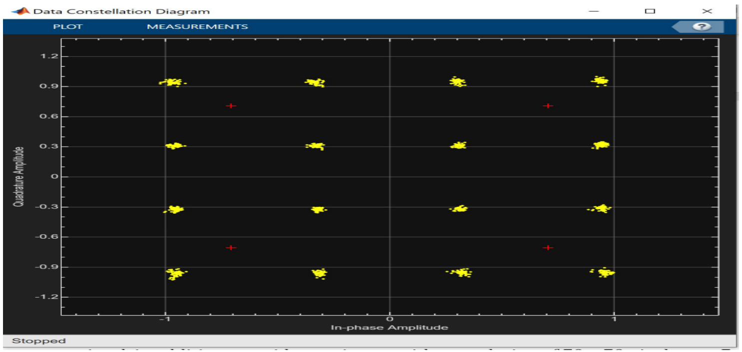

Figure 4. Constellation diagram 16QAM

The blue laser is achieved with proper adjustment of the green laser intensity and the RGB distance from the green laser, and blue used 450nm with a laser-illuminated phosphor in a paint settled into a water tank is used for underwater communication. The blue laser diode as a component is shown in Figure (5) A and with high power and lens as shown in Figure (5) B

Figure 5. Fig. 5 (A) Blue laser diode (B)High-power Blue laser with lens

physical signal is characterized by displaying wide signal fluctuation with slowly changing intensity dynamic levels, which are related to the channel depth. Signal processing is needed to perform synchronization, phase noise attenuation, and channel identification. The output of the symbol processing is presented in the time and frequency domain, showing clear signal gaps in the time domain, signal spectrum in the frequency domain, and the necessary time slots for the signal frame, signal frequencies, pilots' frequency, and training tones. As an exemplary signal that can be transmitted. Following the recursive OFDM generation algorithm presented the signal is generated separately from the real and imaginary parts of a complex-valued time-domain signal of about 1500 OFDM symbols. This section presents a detailed introduction of the physical layer architecture of the combined VLC capable of facing spatiotemporal fading and adaptive-block challenging channel conditions. Moreover, it details all the dedicated designs and laser diode LED configuration requirements to be kept in consideration in order to guarantee optimal signal integrity of both the communication downlink and uplink. The choice to equip the communication system with a correlation-based and recursively configured OFDM transceiver, and to use glass is explained. In addition, a few downsides of the LED design and VLC-by laser diode used in underwater communication and the physical layer design are discussed.

4. Result and Discussion

The developed system is tested to validate the recursive OFDM-laser communication approach where VLC and UWNC (Underwater Network Communication) are integrated for underwater communication. A commercially available underwater laser diode transports the recursive OFDM signal. Several experiments in different scenarios are conducted along with a set of measurements of some important factors such as bit rate, BER, and latency. The experiment was done with different water types such as bubble, coastal ocean, tab, and turbid water as shown in Figure (6) the experiment used a kintex-7 FPGA evaluation board with a high-speed DAC/ADC daughter card connected to FMC150. The terminal of the daughter card connected a laser diode with a lens as a source of transmission and a photodiode with a lens as a source of receiving information for a recursive OFDM signal. for recursive OFDM signal. The evaluation board contains a processor and RAM, in addition to different port types. One advantage is used to interface MATLAB with this type through the USB JTAG cable and the program called system generator which allows to design the system with low cost and time.

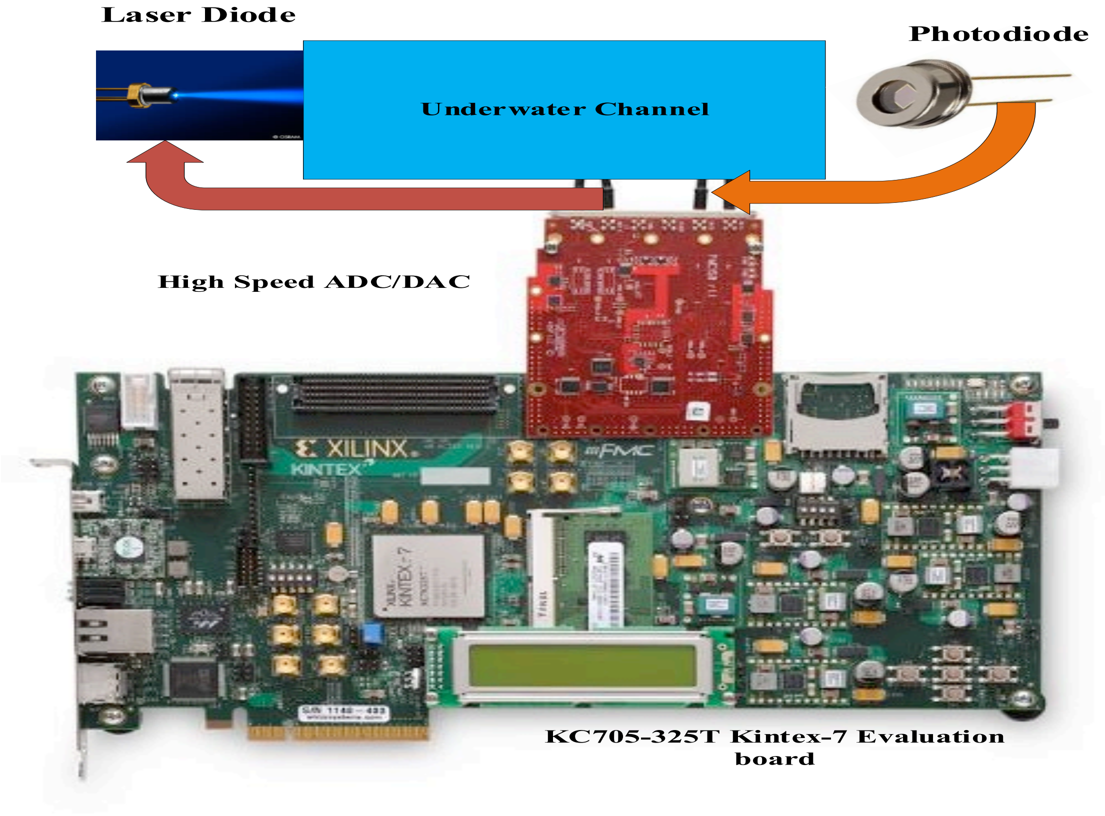

Figure 6. Circuit diagram of the underwater communication by Kintex-7

The results obtained during the experiments show the effect of water type on BER, data rate, and latency when using Recursive OFDM with a blue laser diode. The results show that the communication data rate is affected by water type for different water environments, as shown in Figure (7). This figure shows that the data rate when using a laser diode for Tab water of an underwater channel is low affected by this type of water with different subcarriers. The data rate is highly affected by the bubble and turbid Harbor water because the signal of this water type is scattered by the impurities in the water which is dispersion with the laser light passing through the water. In addition, blue laser beam absorption by water but this type of laser has low absorption when compare with other laser type. This leads to reduced data rate transmission signal in the water environment such as bubble and muddy water. The experiment result shows that clear water has a high data rate when compared with ocean bubble water in addition, turbid water has a lower data rate transmission because the blue laser is affected by the particular inside turbid water which scatters and reflects laser light especially when water is muddy and cloudy. The coastal ocean water is affected blue laser can pass deep through this type of water but is reflected by salt water molecules and marine creatures swim in the coastal ocean water but it stays a good data rate transmission when compared with the other two types.

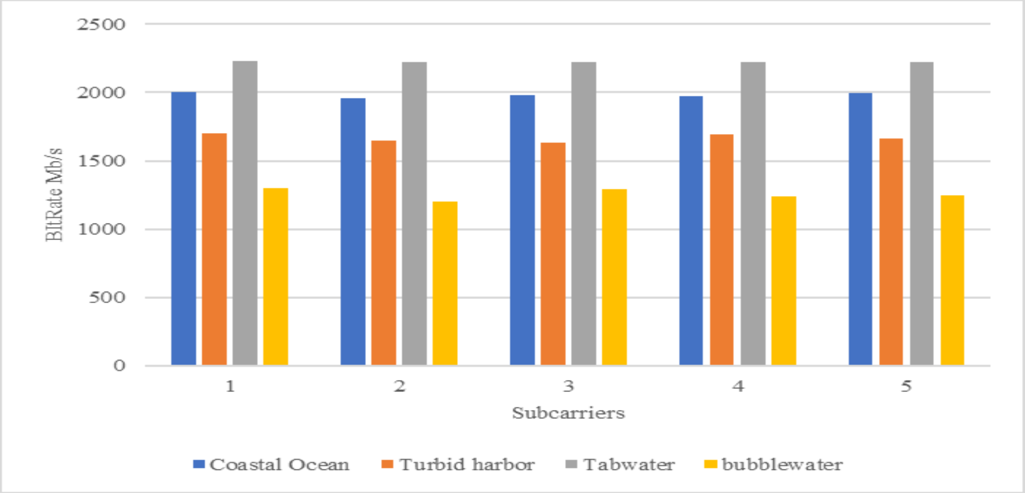

Figure 7. Bit rate with different water types using recursive OFDM with Laser diode

The experiment result analyses BER on various water environments of multi-subcarriers transmitted by recursive OFDM and transports underwater by blue laser, as shown in figure (8). The result shows the comparison of BER with different water environments, showing that the BER is reduced when using tab water as a channel of transmission so that the bit rate is high. Therefore, this type of water is affected by laser light and recursive OFDM signal. The BER increases a little bit in coastal ocean water because the water is not clear and has very few water impurities making a difference between transmission and receiving signal by a low BER rate but when the impurities are increased the BER increases also due to water bubbles and water waving motion, therefore, increased the signal distortion. Finally, the BER increases to double when underwater channels are turbid and bubble water this occurs due to distortion and scattering laser light in this type of water.

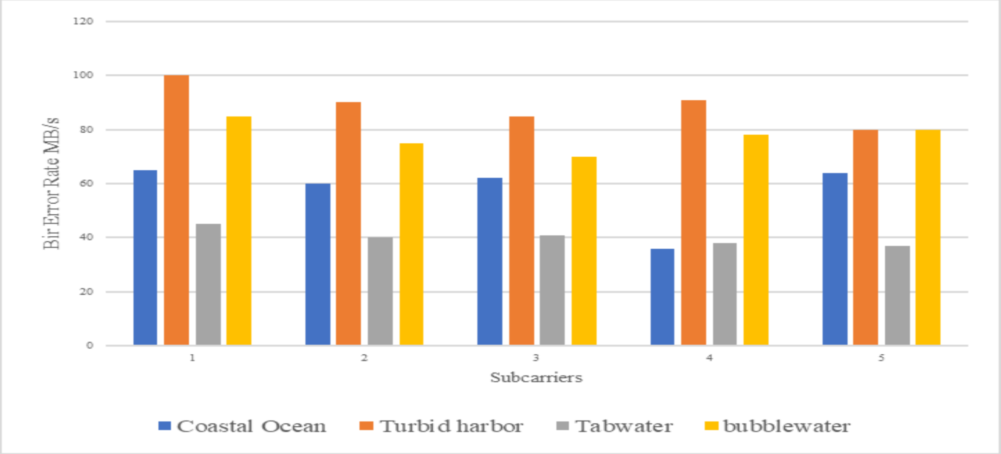

Figure 8. BER with different water types using recursive OFDM with Laser diode

In addition, another experiment is done for the time delay of the signal R-OFDM transport by blue laser using an underwater channel between the transmitter and receiver is analyzed in Figure (9) below. The signal time delay is reduced by clear underwater channels such as tap water due to clearing impurities on it and not scattering the laser beam. However, when compared with turbid water there is a high time delay or latency when the water wave moving increased which means more distribution and the water had more impurities that scattered the blue laser beam then the signal latency increased from clear water.

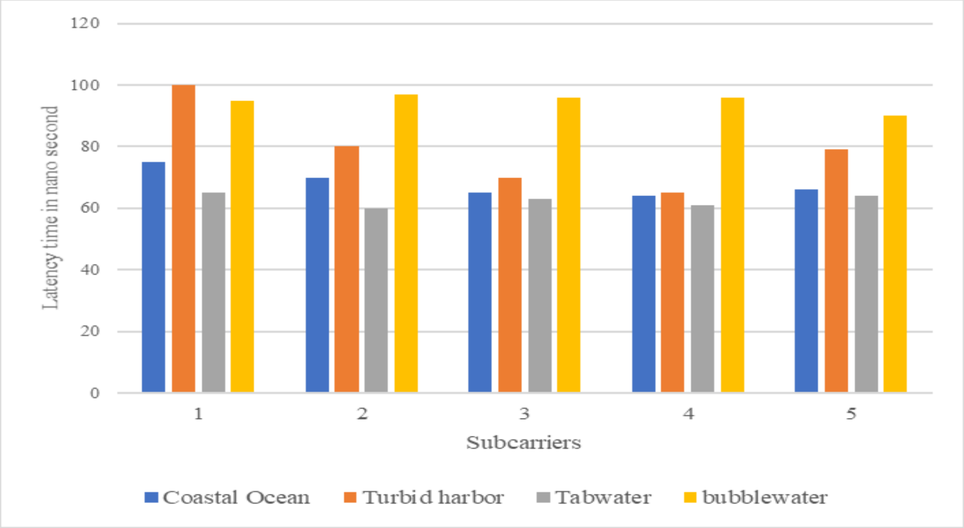

Figure 9. Latency for various underwater channel environments using recursive OFDM with Laser diode

The reported data is the recursive OFDM signal transmitted by a blue laser beam for the deep underwater channel. The formulated data are uploaded to the DAC. The output of the DAC is connected to the base of the transistor (as the Laser diode driver). The diode driver is used as the VLC's 10 Mbit/s optical LED driver. The LED we employ is a 2.4G Wi-Fi visible laser module with a 5V power supply and FC/APC (Fiber Optic Connector/Angled Physical Contact) connector for underwater data transmission. This type of connector is designed for high-vibration environments and minimal back reflection. The laser is an LED mounted on the axis of a free water surface. The divergence of the LED affects its propagation length and power. The light beam is shaped by the optical lens based on experimental requirements and adjusted to fit the fibre optical connector FC/APC. The polarization is at the optimal orientation. The 2 cm laser light beam is sent to the D-tag's optical port. The D-tag is placed at different depths with a 0.5 m distance from the single-axis soft white reflector. In open water, the receiver is installed accordingly, and in the real water case, the device is placed in the same manner underwater for many trials. The humidity or vapors can appear to stick to the flooding sensor/fiber connecting the electronics with the equipment when it is getting close to the water pond, where we might neglect the humidity effect in future testing. The embedded payload is compared with the information produced by the recursive OFDM-based computing system connecting with an optical Laser diode. The real-time payload comparison with transmitted information is performed by the oscilloscope tool.

5. Conclusions

In this study, we accomplished an empirical validation of an underwater optical transmitting system, which integrated blue laser optical visible light technology and recursive OFDM technology with Kintex-7 FPGA for the first time. In this study, we investigate the effect of the various water environment types which is affected on the blue laser transmission data. The investigation includes a study of the effects of BER and Bit rate and signal latency transmitted by the blue laser with recursive OFDM pass through deep underwater channels. The result analyses show that the Clearwater (tap water) had a low effect on blue laser bit rate, BER, and latency which means the best underwater channel for blue laser. The second-best underwater channel for this technology is the coastal ocean it is also clear but has some impurities and Marian life which scatter the laser beam and affect BER, bit rate, and time delay signal. Finally, when increasing the impurities, bubbles, and muddy water the BER increases and reduces the bit rate and increases the time delay because of the recursive OFDM transport by the blue laser which is affected by the factors above scattering the blue laser beam and visible light communication links for underwater vehicle communication. The future work of this research can improve the underwater optical VLC communication system by developing a blue laser optical device to used deeply into underwater channels. In addition, will develop the technology by using recursive NOMA to be compatible with VLUC and compare it with our systems already established in this paper.

Acknowledgments

This project is a part of my research. The deepest gratitude and thanks to Baghdad University/College of Education for pure science/ Ibn Al- Haitham whom I employ.

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