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# Utilizing 64-QAM for Enhanced Data Transmission in Underwater Optical Communication System

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***Abstract:** Underwater acoustic channels are affecting by many factors like time varying multipath propagation, Doppler spread, and salinity, which can greatly limit the quality of data rate and transmission distance. Underwater optical communication represents a crucial technology that supporting higher data rate, secure links and low latency. In his paper the use of 64-Quadrature Amplitude Modulation (64-QAM) in underwater optical communication systems is investigated. The system is designed to offer higher data rate than those of acoustic communication system. The proposed design achieve data rate of 10 Gbps over a challenging transmission distance of 50 km. In our study, a simulation technique is used to evaluate the performance of the proposed design in the underwater conditions, focusing on factors such as Bit Error Rate (BER), constellation diagram and Quality factor (Q-factor). The achieved BER is of about $10^{-10}$ with a minimum signal to noise ratio (SNR) of about 30dB. This paper provides valuable results for the design of next-generation underwater communication systems for applications such as pollution monitoring, oil control and oceanography research.*

***Keywords:** Optical Communication, BER, SNR, Simulation Technique*

## I. INTRODUCTION

With the growing demand for high-speed data rate, acoustic underwater communication systems are faces significant limitations in bandwidth, capacity and data rate [1]. Due to these limitations make it challenging to transmit high data rate in real time. As a result, there is an urgent need to investigate alternative communication methods that can offer higher data rates and enhanced efficiency [2].

Underwater optical communication technology is a promising solution, having many technical benefits compared to acoustic systems. By using light source in the visible to near-infrared spectrum, it can support high data rates reaching several Gbps [3].

However, the underwater environment is a challenging channel because of the water is highly absorbs light signal and the second problem is light scattering due to water particles and biological organisms, which can limit the transmission distance and efficiency [4]. In order to increase the capacity under the same bandwidth, (QAM) are being considered. QAM is a sophisticated modulation method that allows amplitude and phase of two independent message signals to be transmitted on the same carrier frequency [5]. The transmitter can change the amplitude of the signal in addition to the phase. The amplitude / phase combinations are called symbols. These features makes QAM provides many advantages including high data rate, high noise immunity and reduced errors [6].

This paper presents a detailed evaluation of underwater optical communication system utilizing 64-QAM modulation. The nonlinear effects are analyzed in terms of constellation diagram, (BER), Q-factor, and threshold value [7]. A 64-QAM modulation is chosen due to its providing a good balance between data rate, complexity and reliability. The selected order is 64 because high order QAM offers higher data rates which is preferred in applications need to transmit large amount of data quickly [8].

## II. OPTICAL WIRELESS COMMUNICATION

Optical wireless communication (OWC) is a viable solution for highspeed communication with high performance [9]. It uses carrier in the visible and near-IR band to carry a message. These systems use light-emitting diodes (LEDs), laser diode (LD), Fabry-Perot (FP) lasers and distributed feedback (DFB) lasers as an optical source to transmit message through modulation process in which the light intensity, frequency and phase are adjusted [10].

In the last decades, OWC in underwater environments has emerged as a vital field in marine researches. It gains attention due to its crucial advantages because it can support high data rates making it suitable in video streaming and sensor data transmission [11]. The optical signal can be directed and focused rather than acoustic communication systems. This reduces the power consumption due to scattering effect [12].

In addition, due to high bandwidth of optical signal as compared to RF signals, simultaneous communication channels are established [13]. However, there are challenges to OWC in underwater communication systems. The optical signal can be absorbed and scattered in water especially at longer wavelengths [14]. So, light in the blue-green spectrum can propagate long distances with relatively low losses. As well as, it is required to provide a clear line of sight between the transmitter and receiver, limiting their applications where obstacles may block the path in underwater life [15]. Factors including water temperature, water quality, movement (waves) and pressure fluctuations can greatly affect the performance of optical signal quality and transmission distance [16].

Furthermore, using robust modulation techniques are essential to handle the changing of underwater

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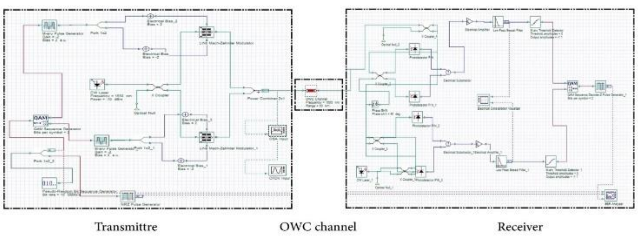
settings and to enhance the performance and reliability of the system [17]. In order to adapt the rapidly changing settings, many modulation techniques can be used including On-Off Keying (OOK), Pulse-Position Modulation (PPM), Orthogonal Frequency Division Multiplexing (OFDM) and QAM. Factors including data rate, capacity and efficient bandwidth are limiting the choice of modulation technique [18].

## III. SIMULATION SET-UP

The proposed design is simulated using Opti System software aims to evaluate the 64-QAM underwater communication system [19]. In transmitter, 64-QAM modulator is effectively encodes the input digital bit stream by adjusting both the amplitude and phase [20]. The optical carrier signal is generated by a Continuous Wave (CW) laser that operates at 1550nm [21]. A laser output is connected to a two dual-drive Li-Nb Mach-Zehnder Modulator (MZM), which modulate the intensity of laser according to the digital bit stream modulated by the 64-QAM modulator [22]. After that, the modulated signal is transmitted through underwater channel, which has specific values for attention and scattering parameters [23]. The OWC channel is specified for different transmission distance which is 10, 20, 30, 40, 50, and 60 km. The simulation results show best results over a transmission distance of 50km, as discussed in the next section. However factors like temperature changes and the presence of biological organisms are not taken into the account in the simulation.

In the receiver, an array of photodetectors (PIN) is used to improve the sensitivity and extend the reception zone. It converts the incoming optical signal back into an electrical signal. A CW laser is used in the receiver side to facilitate effective mixing with the incoming modulated signal for reliable detection. After photodetection process, the detected signal is processed by an M-ary threshold detector. It analyzes both the amplitude/phase and makes decisions according to a predefined threshold levels to estimate the nearest symbol based on the received signal.

In the final stage, a QAM demodulator is maps the detected symbols into a bit stream according to the output from M-ary threshold detector. This optimized design allows for efficient and robust QAM signal. Figure 1 shows the simulation model of 64-QAM underwater optical communication system.

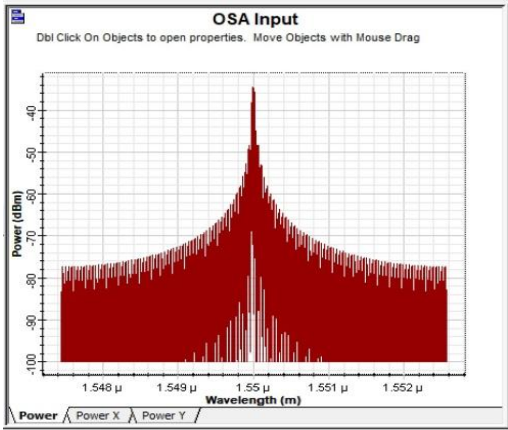



**[Fig.1: A Simulation Model of 64-QAM Underwater Optical Communication System]**

## IV. RESULTS AND DISCUSSIONS

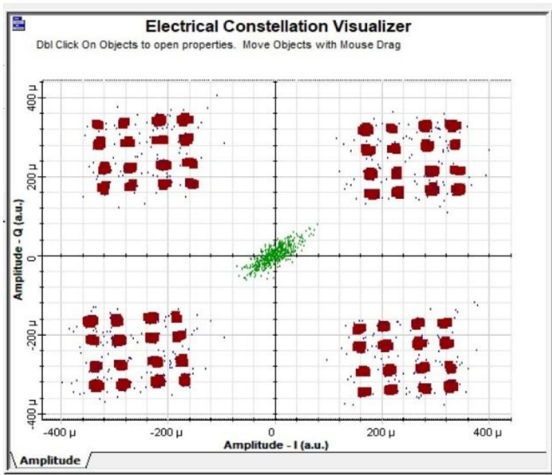
In this section, the results obtained from the proposed model are presented. The analysis examines several performance parameters including the Optical Spectrum Analyzer (OSA) of modulated signal, constellation diagram, BER, Q-factor, and threshold value.

Figure 2 illustrates the performance of modulated optical signal before transmission through the OWC. It shows the relation between wavelength and power of the modulated signal. The signal shows a clear waveform utilizing the characteristics of 64-QAM. The OSA signal is necessary because it represents the base point for efficient data transmission.




**[Fig.2: The Quality of Modulated Signal in OSA]**

Figure 3 shows a two-dimensional graph for 64-QAM which is called a constellation diagram. It is used to analyze the interference of symbols in the presence of noise during transmission. The points are arranged in a 64 point grid, showing the performance of encoding several bits per symbol. The dispersion of points from their ideal positions represents noise which causes degradation in signal quality. This noise highlights the challenges in real underwater environment.




**[Fig.3: The Constellation Diagram of 64-QAM with Noise]**

Figure 4 illustrates a plot of a logarithm of the BER over time. The curve shows an improvement in the transmission quality as time progresses. It illustrates a decrease in error rate indicating a very low probability of error.

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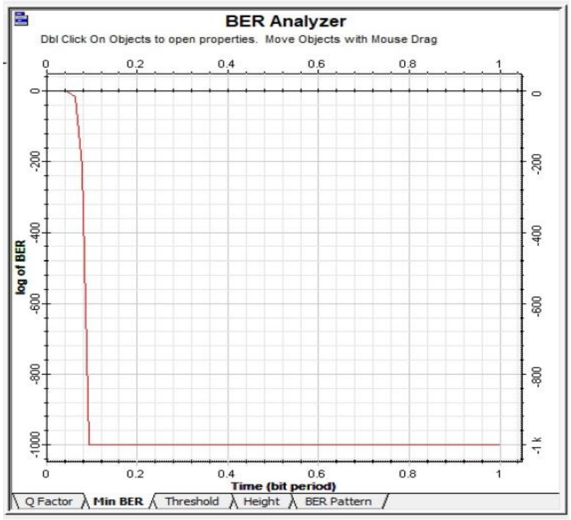
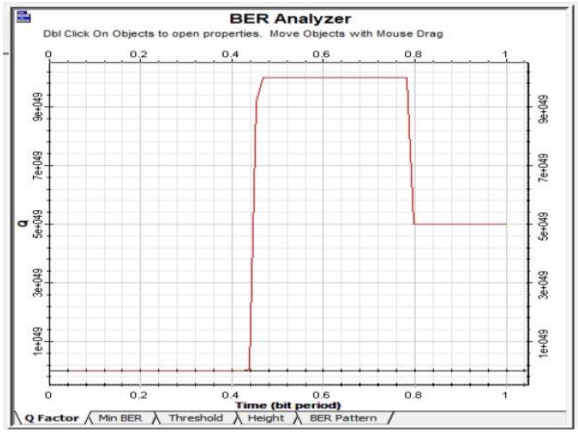


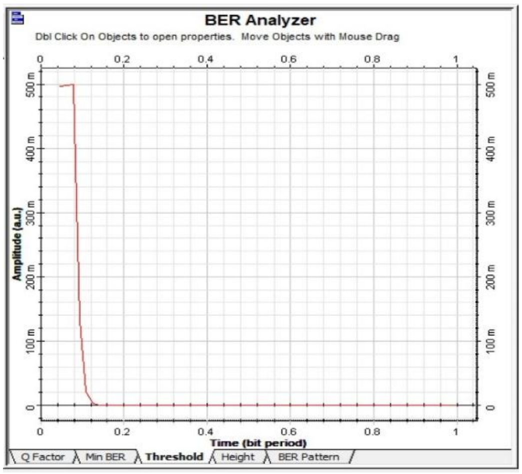

**[Fig.4: The log of BER Versus Time]**

Figure 5 represents the Q-factor as a function of time, reflecting the ability of recognizing different symbols in the presence of noise. The figure provides additional understanding about the quality of received signal. A stable and high Q-factor indicates good signal quality and maintaining acceptable error rates.




**[Fig.5: The Q-Factor Vs Time for 50km OWC Length]**

Figure 6 shows the threshold values used in detection process over the time. The threshold values present the dynamic change over time indicating a system that can respond to fluctuating underwater channel conditions.




**[Fig.6: Threshold Vs time for 50 km OWC Length]**

To conclude the analysis, the representation of the constellation diagram, BER, Q-factor, and threshold values over time gives valuable understanding to some parameters that evaluate the proposed design. A suggestion for the future work is search for improvement of adaptive algorithms for threshold adjustment and investigation of more advanced error correction techniques in order to enhance the performance under varied conditions.

## V. CONCLUSION

In this paper, 64-QAM modulation system for underwater optical communication is designed. The analysis demonstrated that the proposed system offers higher rate than those of acoustic communication system reaching to 10 Gbps over a transmission distance of 50km. The performance of the system is evaluated through a series of simulations done using optisystem software. Factors including constellation diagram, BER and Q-factor are analyzed. The effectiveness of 64-QAM scheme is highlighted by a constellation diagram set within a grid. The results show a well-designed system and efficient signal encoding. It indicates that the design with a proper optimization can maintain reliable communication over moderate distances.

## DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is **contributed** solely.

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