Enhancing Underwater Communication through MIMO Technology Utilizing Diverse Modulation Schemes

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Publication Date: 2025/05/08

Abstract:- Visible Light Communication (VLC) using Laser and Multiple-Input Multiple-Output (MIMO) technology has shown great potential for underwater communication due to its high data rates and strong noise immunity. VLC employs visible light for data transmission, while MIMO enhances performance by using multiple transmitting and receiving elements to mitigate multipath fading, thereby improving reliability and throughput. This paper presents a performance analysis of a MIMO-VLC system using Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Minimum Shift Keying (MSK) modulation schemes. The Q-factor and Bit Error Rate (BER) were evaluated across various link ranges, with a focus on a 50 km link. At this distance, Q-factor values were measured at 15.3184 for ASK, 11.5334 for MSK, and 14.2969 for PSK, with respective BER differences. These results demonstrate the relative effectiveness of different modulation techniques for reliable data transmission in underwater environments. The study also includes eye diagrams for each modulation scheme at a 50 km link range, further validating the findings. The comparative analysis emphasizes the advantages of ASK and PSK over MSK in terms of Q-factor performance and highlights the importance of selecting appropriate modulation schemes for optimized underwater communication systems.

***Keywords**: Underwater Communication, MIMO, ASK, PSK.*

How to Cite: Alisha; Chhavi Sharma; Pankaj Kumar Sharma (2025) Enhancing Underwater Communication through MIMO Technology Utilizing Diverse Modulation Schemes. *International Journal of Innovative Science and Research Technology*, 10(4), 2862-2870. https://doi.org/10.38124/IJISRT/25apr2192

I. INTRODUCTION

Visible Light Communication (VLC) using Laser and MIMO (Multiple-Input Multiple-Output) technology is a relatively new technology that has gained interest in recent years due to its potential applications and advantages. The origin of VLC can be traced back to the invention of the Light Emitting Diode (LED), which is widely used in lighting and display applications. Researchers realized that LEDs could also be modulated to transmit data, and this led to the development of VLC as an alternative to radio frequency- based communication systems[1].

The use of laser in VLC was first demonstrated in the 1980s, but it was not until the 2000s that researchers began to investigate the potential of using lasers for high-speed VLC applications. MIMO technology, on the other hand, has been widely used in wireless communication systems for over two decades. Researchers recognized the potential of MIMO technology in VLC, and since then, numerous studies have been conducted to develop MIMO-based VLC systems. In recent years, VLC using laser and MIMO technology has found applications in various fields, including indoor positioning, visible light positioning, underwater communication, and smart city applications. With its high data transmission rates, security, and interference immunity, VLC using laser and MIMO technology is expected to play a significant role in the development of future communication systems. In the early 2000s, underwater communication emerged as a potential application for VLC. Traditional underwater communication systems relied on acoustic waves, which suffered from limited bandwidth and susceptibility to noise and interference. VLC using lasers offered a viable alternative, allowing for higher data rates and greater immunity to underwater noise. MIMO technology further enhanced the performance by mitigating the effects of multipath fading and improving communication reliability in challenging underwater environments. This proposed work presents a performance analysis of a MIMO-VLC system using Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Minimum Shift Keying (MSK) modulation schemes. The proposed work on MIMO-VLC systems for underwater communication is significant due to its potential to achieve high data rates and improved reliability. By employing visible light and MIMO technology, the system mitigates multipath fading and offers strong noise immunity. Evaluating ASK, PSK, and MSK modulation schemes, the

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr2192

study highlights their effectiveness through Q-factor and Bit Error Rate (BER) analysis at various link ranges, particularly a 50 km distance. The results underscore the advantages of ASK and PSK over MSK, providing valuable insights for optimized underwater communication systems, validated by eye diagrams. This research is crucial for advancing underwater exploration, scientific research, and various industrial applications. The remaining paper is organized as follows: section II gives the brief literature review of underwater communication. Basic principle of the proposed work is presented in section III. Simulation setup and simulation parameters details are given in section VI. In section V, simulation results are discussed in detail. Finally, conclusion and future scope is presented in section VI.

II. UNDERWATER COMMUNICATION

Underwater communication (UWC) plays a vital role in numerous fields such as underwater exploration, environmental monitoring, and defense operations. Acoustic wave-based underwater communication (UAC) has traditionally been considered the most effective method for transmitting data over long distances, up to several tens of kilometers. This technique relies on acoustic waves due to their ability to propagate effectively in underwater environments. However, UAC faces significant challenges, including a limited data rate, typically in the kilobits per second range. This limitation arises from a narrow system bandwidth, around the kilohertz range, as the carrier frequency generally ranges from kHz to MHz [1]. Additionally, the propagation speed of acoustic waves is around five orders of magnitude slower than that of radio waves, resulting in a propagation delay of roughly 0.67 seconds per kilometer [2]. The bulky design of acoustic transceivers further raises concerns regarding cost efficiency and energy consumption [3].

RF communication represents another conventional approach for underwater data transmission. Compared to UAC, RF communication offers advantages such as easier passage through the air-water interface and improved resistance to water turbulence. RF signals also travel significantly faster in seawater than acoustic waves, with speeds over 100 times faster at 10 kHz and more than 2000 times faster at 10 MHz, which helps reduce latency in command transmissions [4]. However, RF waves face considerable attenuation in conductive saltwater, with only extremely low frequencies (30-300 Hz) able to effectively propagate [5]. This attenuation restricts the modulation bandwidth, resulting in a limited data rate of about Mbps over short distances. Additionally, RF communication requires large antennas and high transmission power to counteract signal loss. Studies have shown that RF frequencies in the MHz range can propagate up to 85 meters in seawater but demand significantly higher power levels for effective transmission [6].

To address the limitations of both UAC and RF methods, Underwater Wireless Optical Communication (UWOC) has emerged as a promising alternative. UWOC is capable of achieving exceptionally high data rates, often exceeding Gbps, due to its wide modulation bandwidth ranging from hundreds of MHz to GHz [7]. Moreover, it can support data transmission over several hundred meters [8]. These features make UWOC suitable for real-time applications, as demonstrated by successful real-time underwater video streaming with minimal latency, averaging around 100 milliseconds [9].

III. PRINCIPLE OF MIMO BASED UNDER WATER COMMUNICATION WITH VLC SYSTEM

MIMO technology has demonstrated the advantageous impact on wireless communication within the atmosphere, establishing its potential applicability in Underwater Optical Wireless Communication (UOWC) systems. Particularly in fading channels, the MIMO system exhibits substantial enhancements in channel capacity, leading to a significant increase in transmission rates. Additionally, the implementation of MIMO introduces spatial diversity, resulting in a reduction in Bit Error Rate (BER) during system operation. By combining these advantages, the MIMO technique aims to ensure reliable transmission in the context of underwater wireless communication. The investigation of the fading-free impulse response (FFIR) of the UVLC channel, specifically within a Multiple-Input Multiple-Output (MIMO) UVLC system, has been explored in a recent study documented in [10].

The basic system block diagram of underwater communication is depicted in Fig.1 and MIMO system is shown in Fig.2. The working of a underwater communication system involves the transmission and reception of data using visible light technology. The process begins with an input signal, which is processed by the transmitter to prepare it for optical transmission. The modulated signal is sent to a laser diode, where the electrical signal is converted into an optical signal in the form of a focused laser beam. This laser beam propagates through the underwater channel, where it may experience scattering and absorption. At the receiving end, a PIN photodiode detects the incoming optical signal and converts it back into an electrical signal. The receiver then processes this signal to recover the original data. In a MIMO system, multiple laser diodes and photodiodes can be employed on both the transmitting and receiving ends to enhance data throughput, improve signal quality, and mitigate multipath fading, thereby increasing the capacity and reliability of underwater communication systems.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr2192

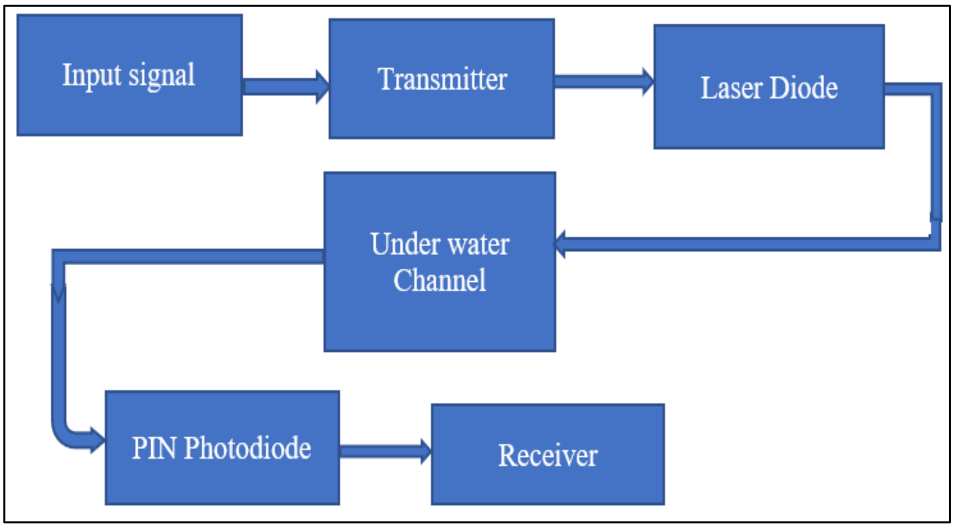

Fig.1 Block Diagram of Underwater Optical Wireless Communication

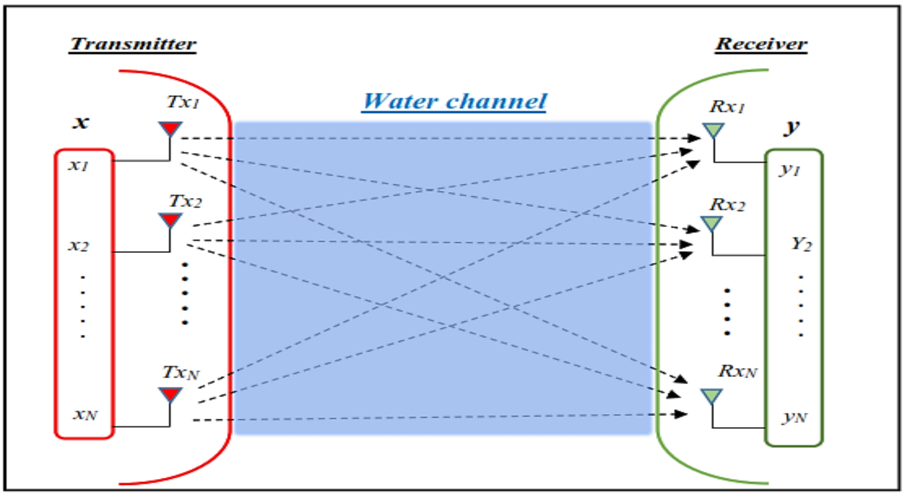

Fig.2 System Model of MIMO

IV. SIMULATION SETUP

The simulation is conducted utilizing the OptiSystem Simulation Software, a tool designed for the analysis and simulation of optical communication systems. OptiSystem facilitates the modeling of a diverse array of optical components and devices, providing the capability to simulate and optimize intricate optical systems. The proposed work involves three distinct simulation setups. The initial setup employs amplitude shift keying (ASK), followed by phase shift keying (PSK) in the second setup, and minimum shift keying (MSK) in the third setup. The table 1 shows the parameters used in the simulation setups. Each simulation setup consists of three main segments: the transmitter, channel, and receiver. In the transmitter section, components such as the PRBS (Pseudorandom Binary Sequence) generator, laser, and modulation techniques (ASK/PSK/MSK) are employed. The channel section utilizes the multiple-input and multiple-output technique as depicted in Fig.3. At the receiving end, the setup includes a PIN photodetector, low-pass Bessel filter, and a Bit Error Rate (BER) analyzer. This configuration enables the analysis of results in the form of an eye diagram for the Bit Error Rate and a Q-Factor graph.

Table 1. Simulation Parameters

Parameters	Values
Bit Rate	40 Gbps
Wavelength	520 nm
Transmitter	Laser diode with 20dBm power
Receiver	Pin photo diode with dark current 5 nA
Channel	Tuboid water
Distance	50 km
Turbulence model	Gamma- Gamma
Modulation	ASK, PSK, MSK

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr2192

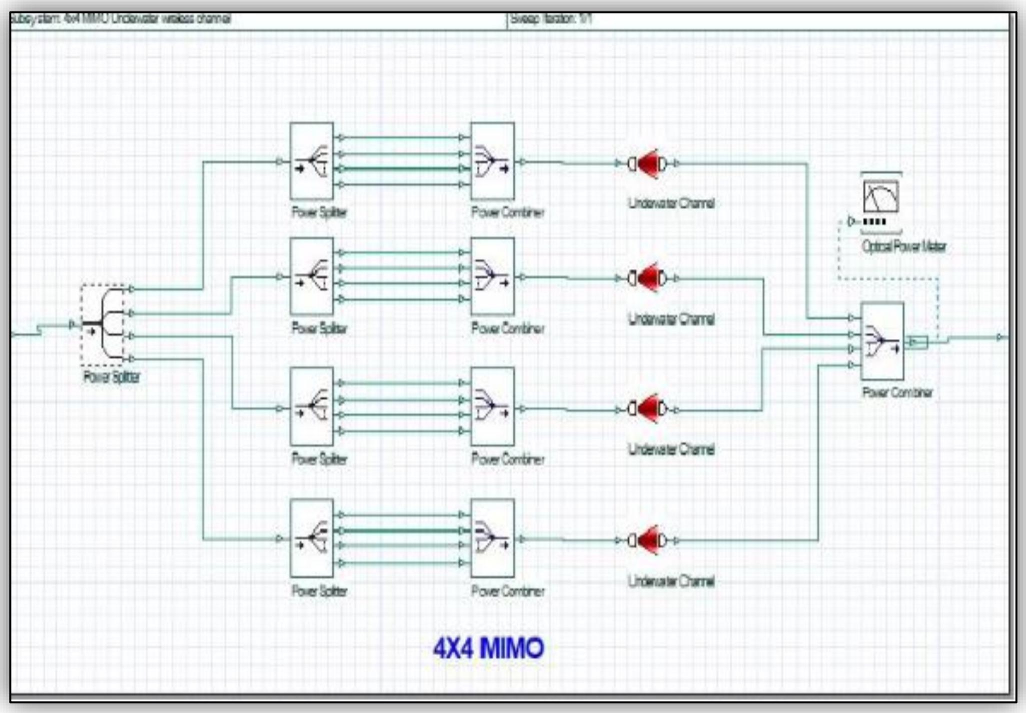

Fig.3 4x4 MIMO System for Under Water Communication

V. V RESULTS AND DISCUSSION

This section evaluates the performance of the underwater communication system with three different modulation techniques. The values of Q-factor and BER is been observed at different link ranges i.e. from 10 km to 100 km as depicted in Fig.4. Fig. 5, 6 and 7 shows the Q-factor curve at a link range of 50 km for ASK, MSK and PSK modulation respectively. The Q-factor value at a link range of 50 km is about 15.3184 for ASK, 11.5334 for MSK, and 14.2969 for PSK technique. The difference between the Q-factor value when using ASK and PSK modulation is very less as compared to that of MSK technique

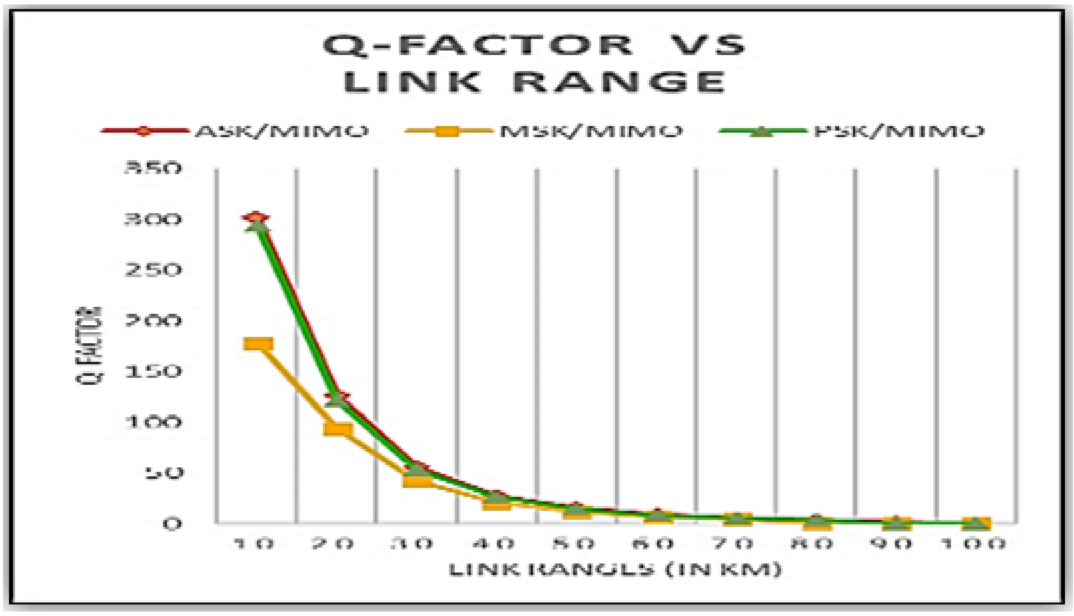

Fig.4 Q factor Variation for Different Modulation Schemes

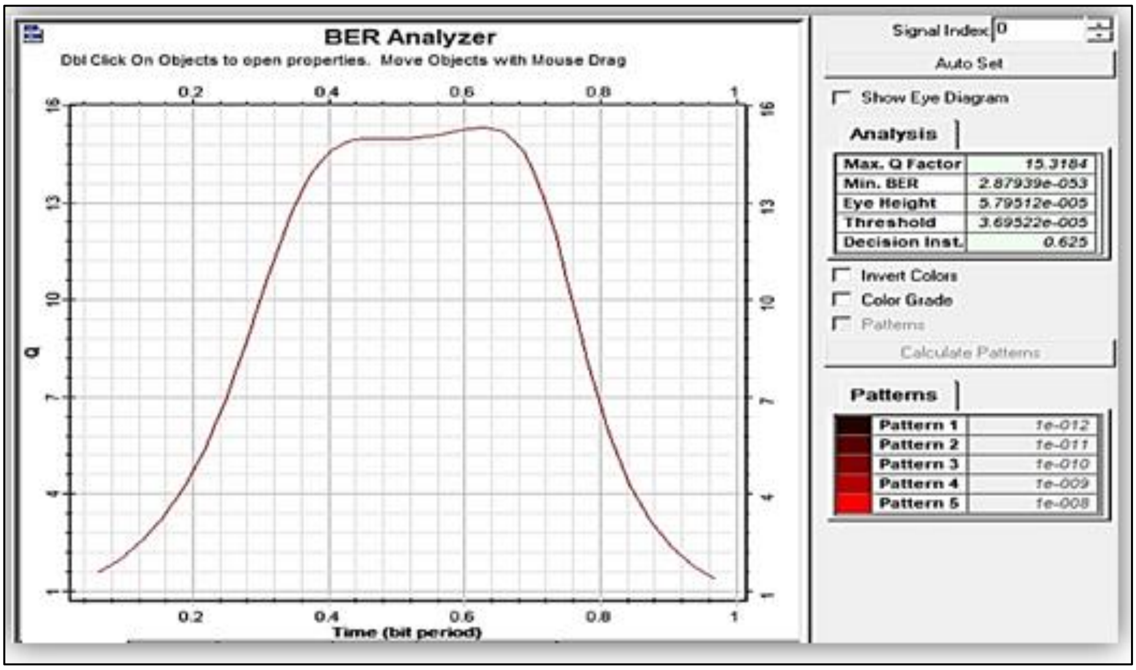

Fig.5. Q-Factor curve (link range=50km, Modulation=ASK)

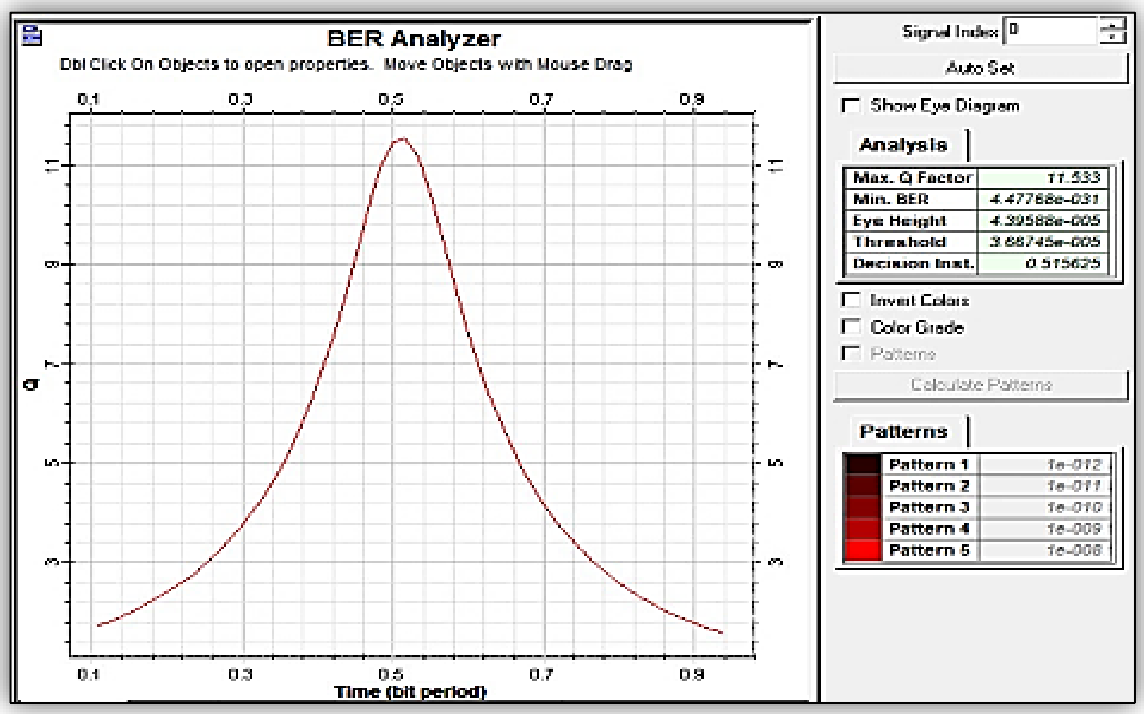

Fig.6. Q-Factor curve (link range=50km, Modulation=MSK)

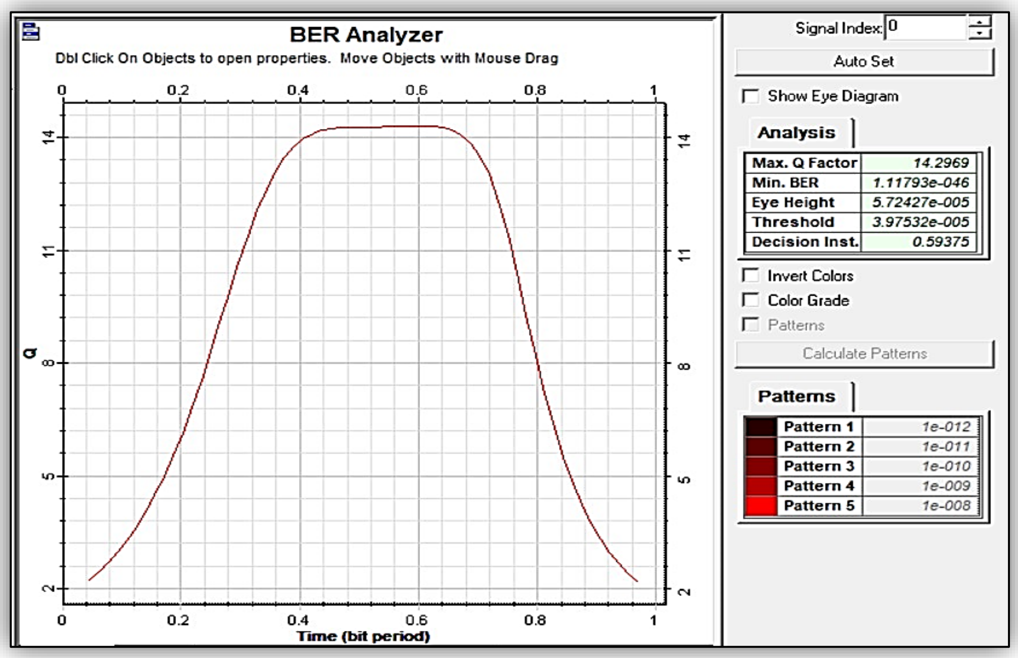

Fig.7 Q-Factor curve (link range=50km, Modulation=PSK)

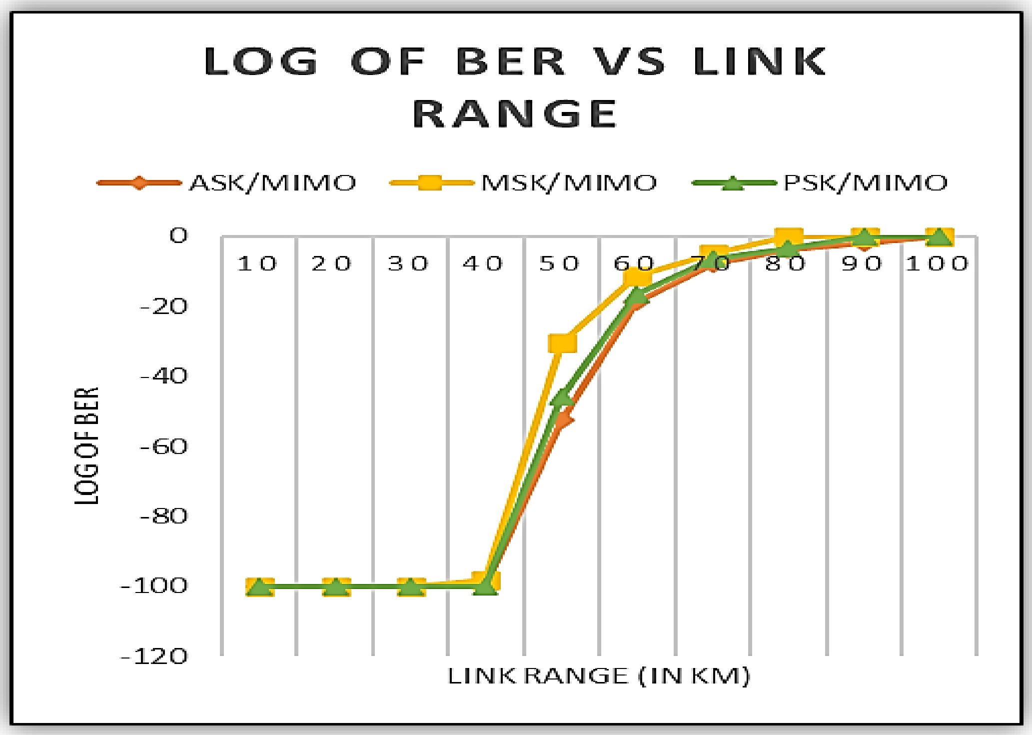

Fig. 8. Log of BER vs Link Range

The log of BER value at a link range of 50 km is -52.54069 for ASK, -30.34894 for MSK and -45.95158 for PSK modulation respectively.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr2192

Figure 9,10 and 11 shows the eye diagram at a link range of 50 km for ASK, MSK and PSK modulation respectively.

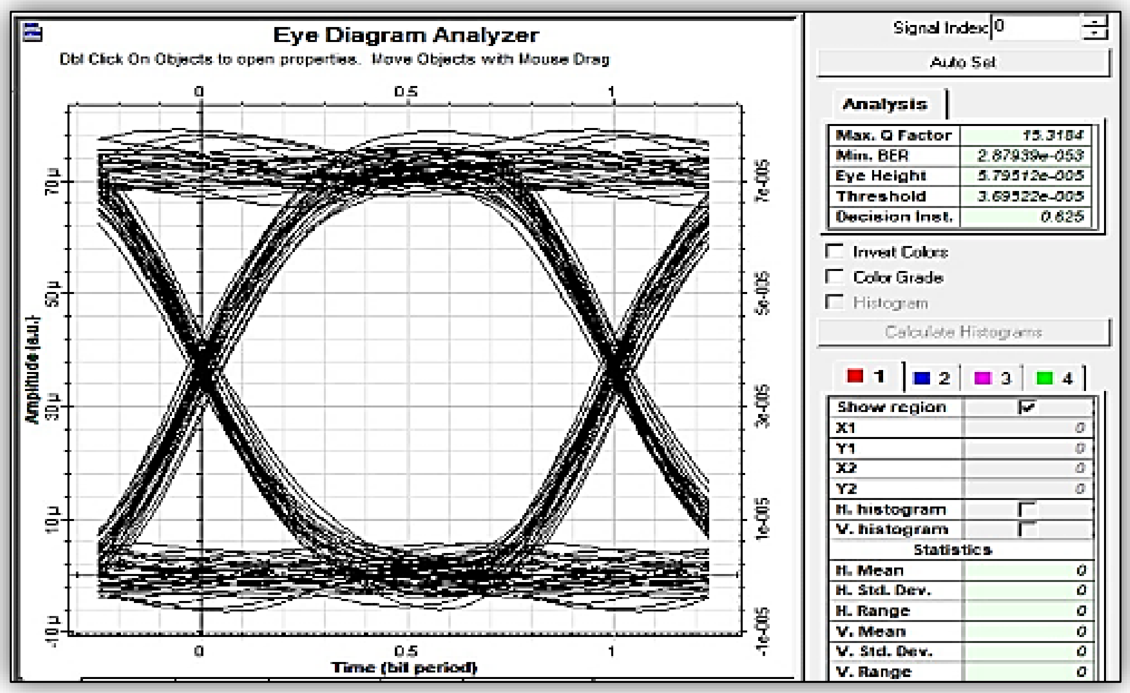

Fig.9 Eye Diagram (link range=50km, Modulation=ASK)

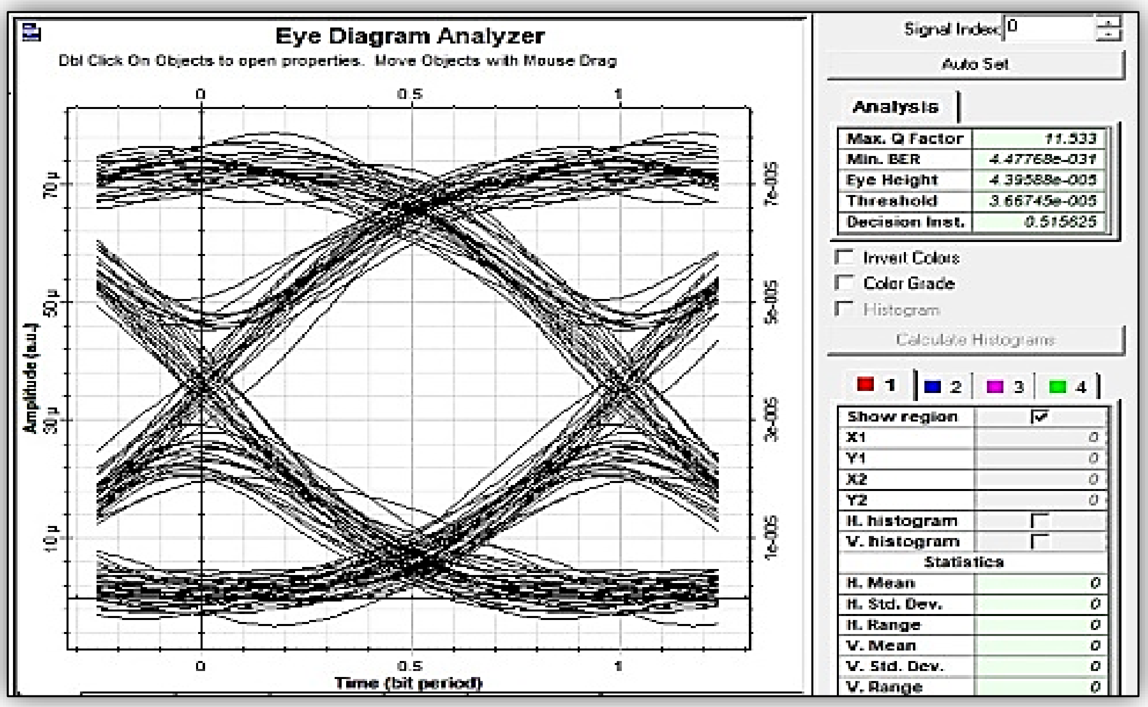

Fig.10. Eye Diagram (link range=50km, Modulation=MSK

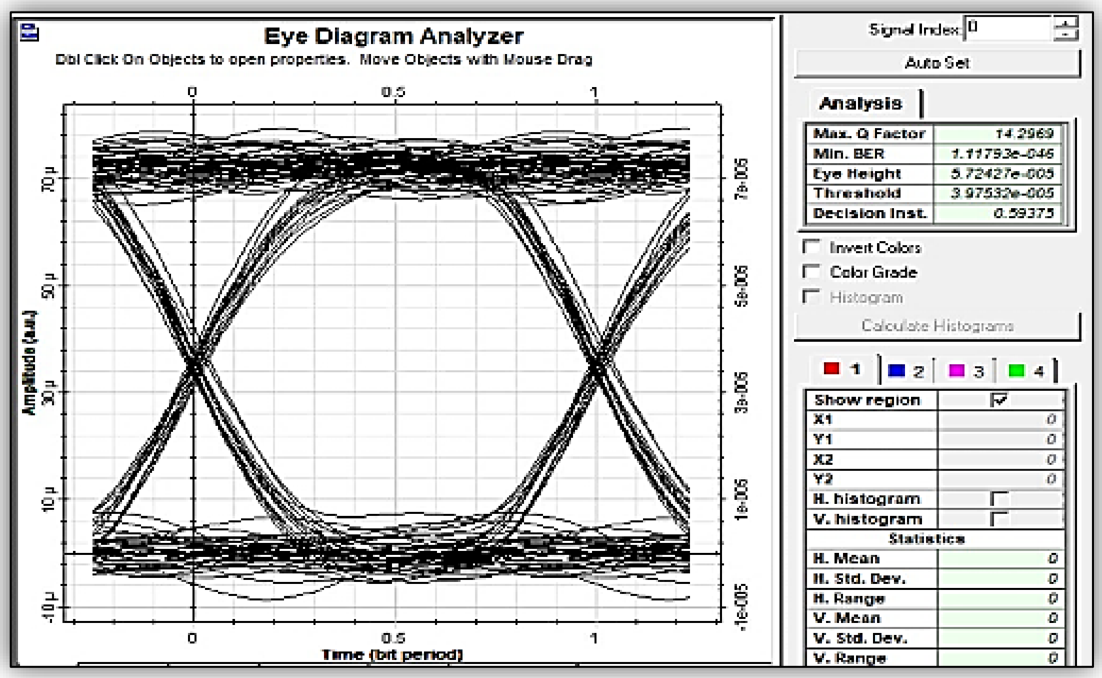

Fig.11 Eye Diagram (link range=50km, Modulation=PSK)

VI. CONCLUSION

Today, underwater communication technology is used in a wide range of applications, including oceanographic research, offshore drilling, and underwater surveillance. The continued development of underwater communication technology is likely to play an essential role in our ability to explore and understand the world's oceans. Underwater communication is a challenging field, with features such as low data rates, high signal attention, and multi-path fading. To address these challenges, advanced techniques such as Multiple- Input Multiple-Output (MIMO) have been developed. MIMO uses multiple antennas to improve the performance of underwater communication systems. Other modulation techniques such as Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Minimum Shift Keying (MSK) have also been used in underwater communication systems. These modulation techniques enable the encoding of data onto light signals, which can be used to transmit information underwater. In conclusion, VLC-based underwater communication, along with advanced techniques such as MIMO and modulation techniques like ASK, PSK, and MSK, has the potential to revolutionize the field of underwater communication. As research and development in this area continue, VLC technology will undoubtedly play a significant role in the future of underwater communication. In the proposed MIMO based underwater communication, it has been observed that by using the amplitude shift keying (ask) the value of Q-factor is 15.3184 at a link range of 50 km and the value of q-factor is above 9.00 at a link range of up to 60 km and from past researches is has been observed that for better communication the q-factor value should be greater than 9.00. Along with that the value of log of BER is minimum at a link range of 50 km i.e. 52.54069 as compared to that of other two modulation techniques. Also, the difference between the results of ASK and PSK techniques is very less. Although for better underwater communication ASK modulation technique is to be preferred and sometimes PSK modulation too can be be used. For the future purpose the use of other modulation techniques like WDM, OFDM etc could be done along with the consideration of water environment.

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