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Performance Analysis of OWC System based (S-2-S) Connection with Different Modulation Encoding

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Abstract: High data speeds are possible with Optical Wireless Communication (OWC) since it is free, wide-bandwidth, and low-cost. Inter-satellite optical communication is a breakthrough technique that aims to establish communication among satellites. However, broadcasting aiming mistakes causes turbulences in an inter-satellite link. This paper proposed a performance analysis for OWC system. Such investigation were based on using the modulation format of NRZ and RZ and using Photo Detector (PD) with type of PIN and APD. Also, varying the transmission distance was included with investigation. Results obtained indicate that using NRZ achieve much better results for the entire distances investigated than using RZ. Also, under the utilization of NRZ the transmitter and receiver aperture diameters have a greater reliability to be varied in size as compared situations of using the RZ. This study provide a brief observation about the most important parameters related with OWC.

Keywords: *Optical Wireless Communication (OWC), parameters, observation, utilization, transmission*

1. Introduction

In 1962, a mechanism for secure communications between a satellite and a submarine was described. A lot has happened in the last 40 years in terms of inter-satellite optical wireless communication (ISOWC) between governments, companies and individuals [1,2]. It uses microwave technology to communicate with ground stations and geosynchronous satellites. Satellite-to-ground communications will continue to be microwave, but satellite-to-satellite communication will be optical. The device employs infrared laser light to send optical signals across space. A signal is sent across free space instead of an optical connection capable of sending data, sound, or video. As the space is regarded to be vacuum, IsOWC can be utilized to connect two satellites in the same orbit or in separate orbits. The ability to transfer high-speed data over thousands of kilometers using a modest payload is an advantage of optical links over radio frequency lines [2,3]. The mass and cost of the satellite will be reduced by lowering the payload size. Aspects of wavelength are also used in OWC. A laser's beam width can be narrower than an RF system's beam width due to the RF's longer wavelength. Determining if the connected satellites are aligned and have line of sight is critical to the OWC connectivity. However, environmental effects including absorption, scattering, and shimmering influence the transmission of such transmissions. In all three cases, the transmitted energy is reduced, reducing reliability and bit error rates. Satellites orbit the planet in one of three ways. Low Earth Orbit satellites have an orbital height of about 1000 km (LEO) [4]. Circular LEOs are common. In 2–4 hours, LEO satellites will orbit the earth. With this orbit, multiple satellites can be launched into space to accomplish a single mission, as seen below. Medium Earth Orbit (MEO)/Intermediate Circular Orbit (ICO) satellite orbits have an average height of 5000 km to 25,000 km (ICO). Contrary to popular belief, MEO is not limited to circular orbits [5,6]. Geographically, the satellite is in an equatorial circular orbit of 35,786 km altitude and 24 h period. GEO communications are covered by three satellites stationed 120 degrees apart above the equator [7]. It is estimated that there are currently 6124 satellites in orbit [8]. Parallel to this, OWC technology has evolved over the year. Laser communication can now transport data at up to several Gbps across thousands of kilometers. Thus, Inter-Satellite Optical Wireless Communication (ISOC) is developed [9].

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2. Related Work

Several works were proposed for handling the satellite to satellite communication. For instance, in [10], author proposed a performance analysis for a OWC system with respect to use different types of modulation format (RZ and NRZ). The data rate and distance included were 3 Gbps and 1700 km. Also, the transmitter power was 15 dBm. Results obtained with respect to QF and BER showed that using NRZ achieved higher impact of results with increasing about 3 dBm in QF and e-15 in BER. However, this study perform investigation with respect to lower data rate value and distance and it need to be further analyzed by increasing these values.

Additionally, in [11] authors proposed an analysis for OWC system based on the utilization of channel diversity based techniques with different set of channels up to 16 channel. These results analyzed based on using optisystem software version 7. The data rate obtained was 40 Gbps and distance estimated was 5000 km. Meanwhile, the wavelength set to 1550 nm with a very small line width equal to 0.01 MHz. Also, the antenna diameter was 25 cm. Results of WG and BER obtained showed that 2 channel system were3.16 dB, and 0.007 respectively. While, for 4 channel model it was 5.60 dBm and 9.62. And for 6 channel system they were 7.42 dBm and 3.95 e-14 respectively. Finally, 16 channel system showed the best results obtained for QF and BER, which were 9.4 dBm and e-20 respectively. This work showed an interesting results. However, increasing member of channel would resulted in raising he implementation costs and even though the system uses a lower input power of 15 dBm. As a result, such matte should be keep in considerations.

In the same context, author in [12] proposed a 16 channel OWC system for satilate communication. The distance investigated was 1000 km with NRZ modulation format, AMI and Diobinary encoding based methods. Results obtained indicate that using the last method has achieved the optimum results in term of the studied parameter of QF and BER. Especially, with respect to the higher impact to point of error parameter up to 3 microrad and a power of 20 dBm. However, QF and BER results for the optimum selection of modulation method were 9.96 dBm and 1.02e-23 which may be less than normal and needs to be further improved via the investigation of variation for different related parameters. Keeping in mind, the small distance of 1000 km used in the proposed system which needs to be further improved.

Recently, authors in [13] proposed a transceiver system based on OWC communication and used both the LED and LASER source for input power generator and data rate of 10 Gbps and 40 Gbps. The distance studied were up to 5000 km. Analyzing results were based on both cases of RZ and NRZ schemes for encoding. Based on the observation found it concluded that using LASER is much better than using the LED and using the RZ type showed higher reliable results as compared to NRZ with improvement of less than 1 dBm for different investigated distances. However, this study didn’t consider that variation of different parameters related with the OWC components.

Furthermore, in [14] a 16 channel OWC system was proposed via using the DWDM technique. The system could achieve a data rate of 160 Gbps with NRZ modulation format and power of 30 dBm. The distance included with investigation were in range of (2000-7000) km. Optical Amplifier (OA) has been used in the proposed system before the OWC block to improve the transmitted signal. Results obtained showed that the OA utilization could improve the QF results by 1 dBm with respect to 7000 km of distance for transmission and BER improved by e-3. However, the authors didn’t consider the utilization of other modulation formats to improve the overall performance of the proposed system .

Finally, in [15] a coding scheme based advanced modulation for OWC system has been designed and investigated. Results analyzed based on QF and BER variation between the schemes of NRZ, RZ and On-Off Keying (OOK) modulation types and indicate that using the last method achieve the best results in which the QF increased by 13% and BER by 28 %. The distance analyzed was only 500 km, which needs to be further improved and increased especially when handling such type of communication.

3. Simulation Setup

The setup carried out for the proposed simulation performed via optisystem software. The transmitter side consist of PRBS component with data rate of 10 Gbps and handled with both cases of NRZ and RZ modulation schemes as seen in Figure 1 and 2 respectively. The aim of using these modulation in first class is t convert the binary data into electrical signal in the two proposed forms. Then the signal outputted would be considered as an input for the MZ modulator, which is used to combine electrical signal with optical signal generated from the CW laser source. The frequency set for the CW laser was 850 nm and the power selected was 30 dBm. The outputted signal from the MZ modulator would be send over OWC component with the specification listed in Table 1. The distance investigated ranged between 1000-5000 km. For the receiver part, it include the utilization of PIN and APD types of photo detector in demonstrate the impact of each type in achieving best results. The aim of using photo detector is to convert optical signal to electrical. Then the signal would enter to filter for shaping the required waves and finally BER analyzer tool is used for finding the required results based on the QF, BER and Eye Diagram (ED) parameters.

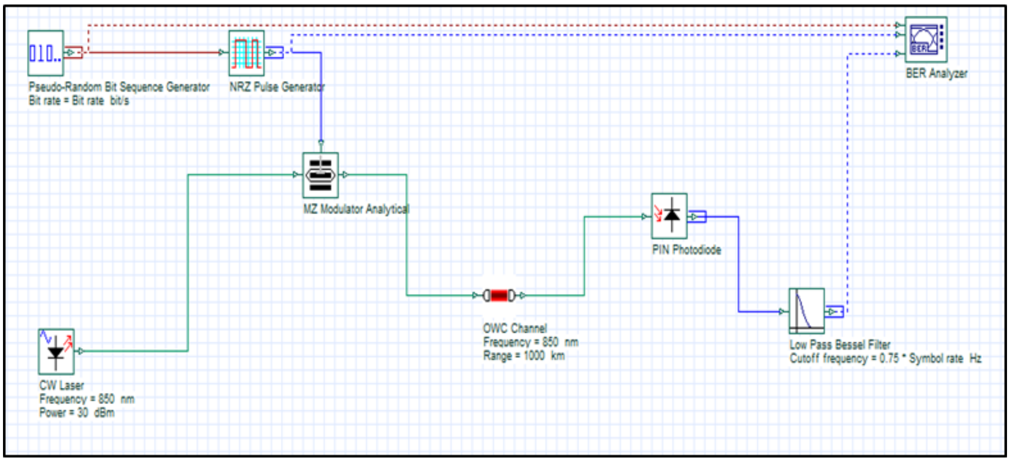


Fig. 1: Proposed system with NRZ modulation

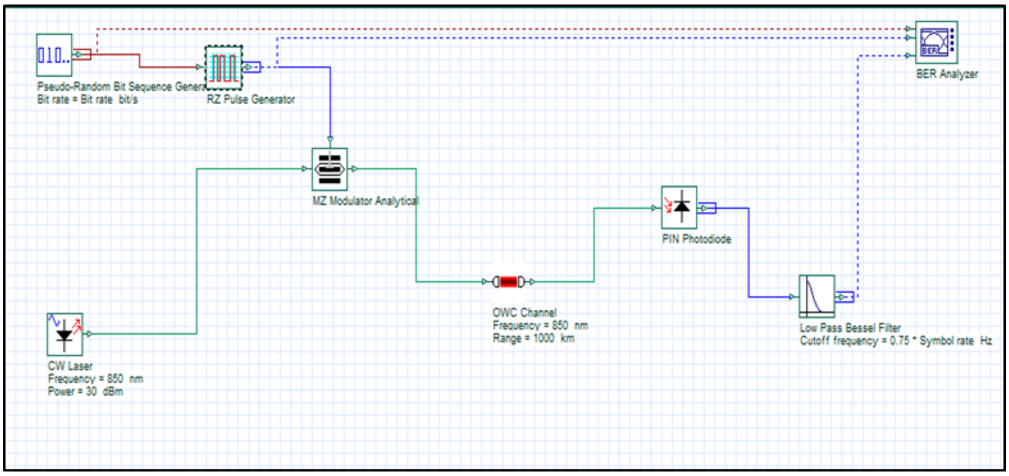


Fig. 2: Proposed system with RZ modulation

Table 1: the parameters used form the OWC channel

parameter	**value**	**unit**
Frequency	850	nm
Range	varied	km
Free space path loss	yes	
Geometrical gain	yes	
Transmitter aperture diameter	15	cm
Receiver aperture diameter	15	cm
Transmitter telescope gain	0	dB
Receiver telescope gain	0	dB
Transmitter optics efficiency	0.8	
Receiver optics efficiency	0.8	
Transmitter pointing error angle	1.1	urad
Receiver pointing error angle	1.1	urad
Attenuation	0	dB/km
Additional losses	5	dB
Propagation delay	0	ps/km

4. Results and discussion

The results of the investigation would be classified into two cases which will be demonstrated as below

A- Case 1 investigation

In the first investigation case, the Antenna aperture diameter for both the transmitter and receiver would be investigated in different values for diameter. This scenario will include three portions. In the first it would set the transmitter diameter varied (5,10,15 and 20) cm while the receiver diameter is fixed to 5 cm. Second scenario is vice versa for the first and the last scenario include variation of both diameters for transmitter and receiver as a per of sets (10,10), (15,15) and (20,20). The three scenarios would be studied with respect to both the APD and PIN types of PD and with both modulation format of NRZ and RZ. These results would be listed li Tables 1,2,3 and 4. It's worth to mention that the distance in this investigation is considered fixed and equal to 1000 km and power equal to 30 dBm.

Table 1: QF and BER results for diameter variation in TX and RX with NRZ modulation and PIN type of PD

parameter	variation of transmitter aperture diameter in cm			
	5	10	15	20
QF	x	x	x	x
BER	x	x	x	x

parameter	variation of receiver aperture diameter in cm			
	5	10	15	20
QF	x	x	x	3.34355
BER	x	x	x	0.000412888

parameter	variation of transmitter and receiver aperture diameter in cm			
	(5,5)	10,10	15,15	20,20
QF	x	4.81181	15.6519	27.1022
BER	x	7.47E-07	1.61E-55	4.61E-162

Table 2: QF and BER results for diameter variation in TX and RX with RZ modulation and PIN type of PD

parameter	variation of transmitter aperture diameter in cm			
	5	10	15	20
QF	x	x	x	x
BER	x	x	x	x

parameter	variation of receiver aperture diameter in cm			
	5	10	15	20
QF	x	x	x	3.34355
BER	x	x	x	0.000412888

parameter	variation of transmitter and receiver aperture diameter in cm			
	(5,5)	10,10	15,15	20,20
QF	x	3.99355	12.9089	22.2968
BER	x	3.25E-05	2.00E-38	1.97E-110

Table 3: QF and BER results for diameter variation in TX and RX with NRZ modulation and APD type of PD

parameter	variation of transmitter aperture diameter in cm			
	5	10	15	20
QF	x	4.09102	6.9472	9.1831
BER	x	2.12E-05	1.84E-12	2.05E-20

parameter	variation of receiver aperture diameter in cm			
	5	10	15	20
QF	x	3.95899	6.91702	9.39293
BER	x	3.73E-05	2.27E-12	2.86E-21

parameter	variation of transmitter and receiver aperture diameter in cm			
	(5,5)	10,10	15,15	20,20
QF	x	12.8191	32.47	47.3011
BER	x	6.27E-38	1.29E-231	0

Table 4: QF and BER results for diameter variation in TX and RX with RZ modulation and APD type of PD

parameter	variation of transmitter aperture diameter in cm			
	5	10	15	20
QF	x	3.24933	5.95376	7.40717
BER	x	0.000575167	1.29E-09	6.34E-14

parameter	variation of receiver aperture diameter in cm			
	5	10	15	20
QF	x	3.28943	5.83653	7.13515
BER	x	0.000498178	2.63E-09	4.74E-13

parameter	variation of transmitter and receiver aperture diameter in cm			
	(5,5)	10,10	15,15	20,20
QF	x	10.0977	27.6558	39.1943
BER	x	2.74E-24	1.11E-168	0

10 cm. Additionally, the NRZ based modulation method showed higher results as compared to RZ based method.

The observations from tables 3 and 4 shows that the utilization of APD type of PD and for both NRZ and RZ. For NRZ, the variation of Transmitter or receiver diameter in each time and keep the other fixed at 5 cm showed interesting results, where the effectiveness of such case is validate only for diameters of 15 cm and above.

The observation about first case from tables 1 and 2 indicate that for the case of PIN PD the use of RZ and NRZ has fails to achieve successful transmission for the portions of changing transmitter diameter and fixing the receiver and vice versa. Meanwhile, for the portion of varying the two diameters with same values it shows interesting results especially with diameter values above diameters and NRZ showed much higher results as compared to RZ.

The spectrum analyzing from optisystem withdrawn for all the four cases as seen in Figures 3,4,5 and 6

Meanwhile, for RZ its effectiveness only for 20 cm diameters. For the portion of varying the two diameters with same values it shows significant results for both parameters of QF and BER for the (10,15 and 20) cm

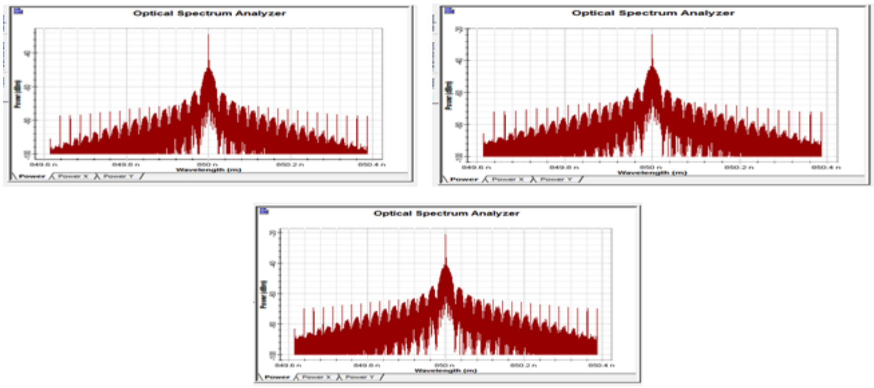


Fig. 3: spectrum analyzer with PIN PD and NRZ modulation for the three set of aperture diameters

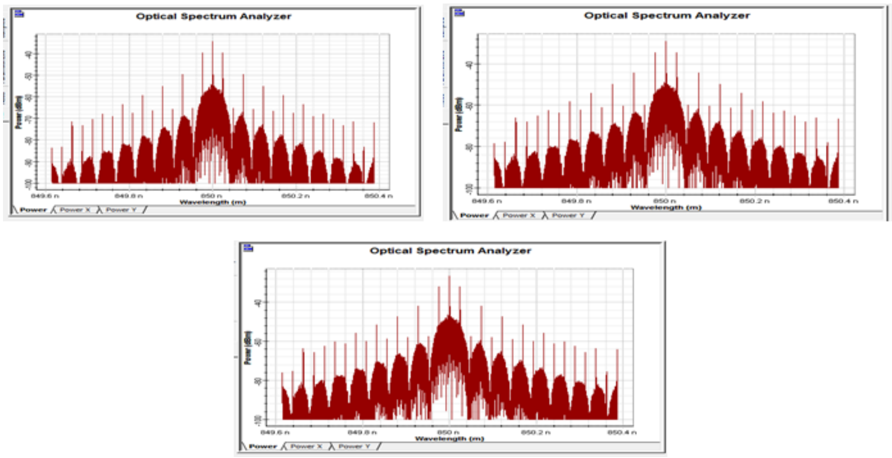


Fig. 4: spectrum analyzer with PIN PD and RZ modulation for the three set of aperture diameters

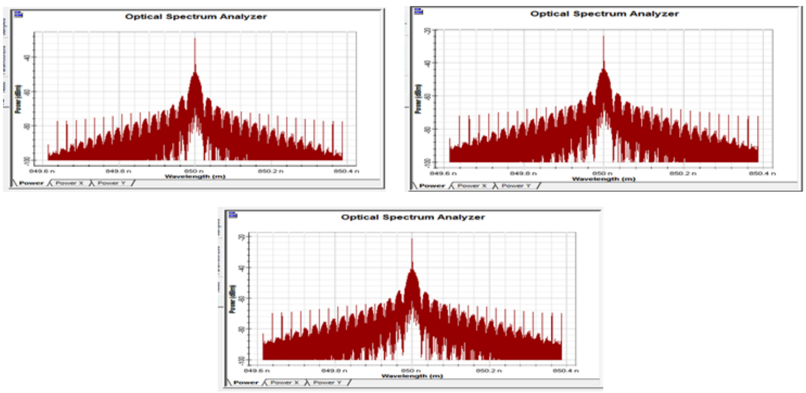


Fig. 5: spectrum analyzer with APD PD and NRZ modulation for the three set of aperture diameters

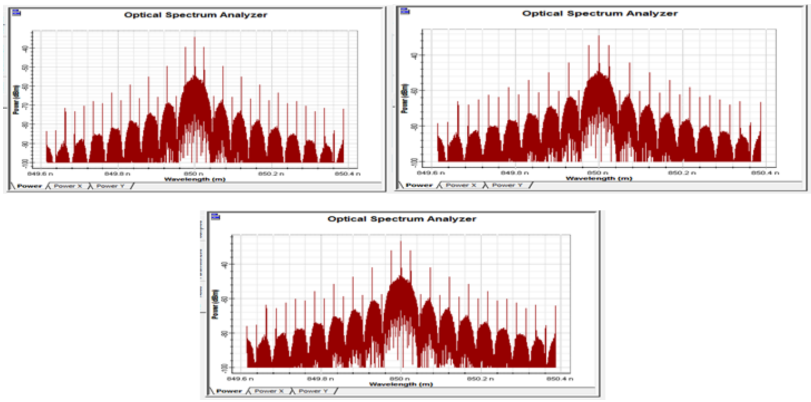


Fig. 6: spectrum analyzer with APD PD and RZ modulation for the three set of aperture diameters

B- Case 2 investigation

In this case, the variation of transmission distance would be varied from (1000-2500) km and the other parameters of transmitter and receiver diameters is fixed at (15,15) cm respectively. This case results listed in Table 5 and 6 for NRZ and RZ format encoding respectively.

Table 5: QF and BER results vs. different distances for APD and PIN type of PD with NRZ modulation

parameter	variation of transmission distance, PD= APD			
	1000 km	1500 km	2000 km	2500 km
QF	31.9704	17.007	10.5555	7.27823
BER	1.28E-224	3.51E-65	2.32E-26	1.66E-13

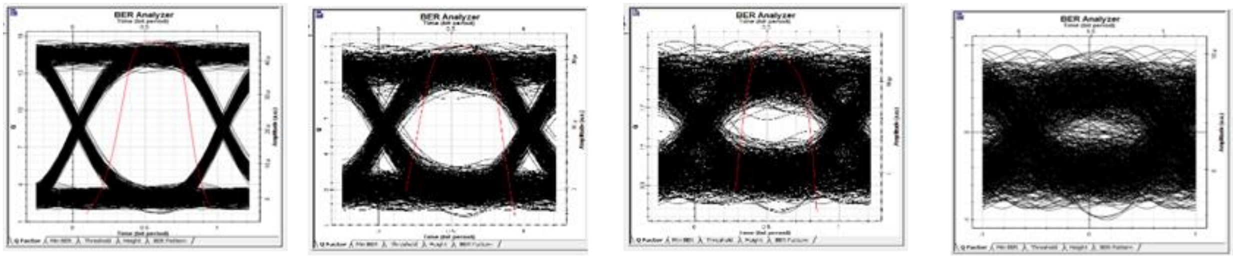
parameter	variation of transmission distance, PD= PIN			
	1000 km	1500 km	2000 km	2500 km
QF	15.6519	7.10341	4.04339	x
BER	1.61E-55	6.07E-13	2.63E-05	x

Table 6: QF and BER results vs. different distances for APD and PIN type of PD with RZ modulation

parameter	variation of transmission distance, PD= APD			
	1000 km	1500 km	2000 km	2500 km
QF	25.8057	14.2222	9.14414	5.92533
BER	3.51E-147	3.20E-46	2.95E-20	1.53E-09

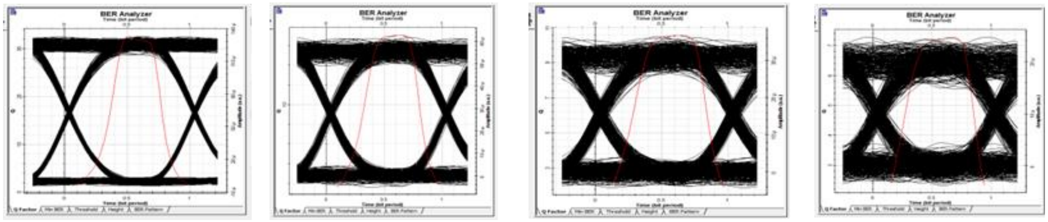
parameter	variation of transmission distance, PD= PIN			
	1000 km	1500 km	2000 km	2500 km
QF	12.9089	5.8799	3.36078	x
BER	2.00E-38	2.05E-09	3.88E-04	x

From previous tables it can be seen that for the case of NRZ modulation, APD type showed reliable result in reaching distance of 2500 km, while PIN could only reach distance of 1500 km. For the RZ method based modulation, the effectiveness of using APD as PD was to achieve distance less than 2500 km, while for PIN case the effectiveness reduced to achieve reliable transmission less than 1500 km. It's worth to mention that these observation were based on the minimum threshold for QF parameters which equal to 6 dBm. Eye diagram results obtained from table 5 and 6 were shown in Figures 7 and 8 respectively in order to analyze the impact of NRZ,RZ, PIN and APD parameter variation per different investigated distances.



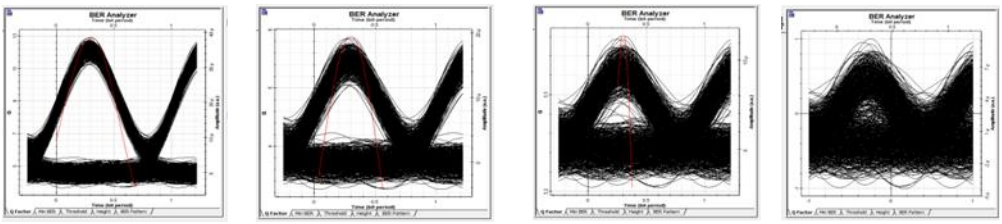
(a) (b) (c) (d)

Fig. 7-a: ED for NRZ case with PIN PD and distances (a) 1000km, (b) 1500 km, (c) 2000 km and (d) 2500 km



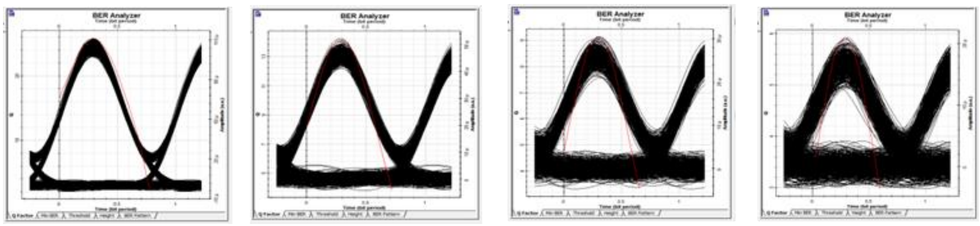
(a) (b) (c) (d)

Fig. 7-b: ED for NRZ case with APD PD and distances (a) 1000 km, (b) 1500 km, (c) 2000 km and (d) 2500 km



(a) (b) (c) (d)

Fig. 8-a: ED for RZ case with PIN PD and distances (a) 1000 km, (b) 1500 km, (c) 2000 km and (d) 2500 km



(a) (b) (c) (d)

Fig. 8-b: ED for RZ case with APD PD and distances (a) 1000 km, (b) 1500 km, (c) 2000 km and (d) 2500 km

5. Conclusion

This work proposed performance analysis for OWC system that utilized the laser source to transmit optical signal. The work investigate several parameters including the transmitter and receiver aperture diameter in cm, the utilization of NRZ and RZ format for modulation and the utilization of PIN or APD PD methods. The analyzed results would be based on the parameters of QF, BER and ED. Results obtained indicate that using NRZ achieve much better results for the entire distances investigated than using RZ. Also, under the utilization of NRZ the transmitter and receiver aperture diameters have a greater reliability to be varied in size as compared situations of using the RZ. This study provide a brief observation about the most important parameters related with OWC.

References

[1] Naresh kumar, "Enhanced performance analysis of inter-satellite optical-wireless communication (IsOWC) system", sciencedirect journal, Optik volume 125, 2014, pp 1945-1949.

[2] Vishal Sharma and Naresh Kumar, “Modeling of 2.5 Gbps-inter-satellite optical wireless communications (IsOWC) system”, sciencedirect journal, Optik xxx (2013) xxx-xxx.

[3] Isha Aggarwal, Paras Chawla, Rohan Gupta, “Performance evaluation of inter-satellite free space optical communication system with varied parameters and transreceiver diversity”, ISSN 2231-1297, volume 3, number 7 (2013), pp 847-852.

[4] Aida Hasfiza Hashim, Farah Diana Mahad, Sevia M. Idrus, “Modelling and performance study of inter-satellite optical wireless communication system”, 2010 IEEE.

[5] F. M. Ali, B. J. Hamza, and Y. H. Taher, "Design and evaluation of optical laser diodes LD positioning arrangement and multiple input/multiple output MIMO-OFDM systems," *Periodicals of Engineering and Natural Sciences (PEN),* vol. 8, pp. 1345-1358, 2020.

[6] Z. T. Yaseen and T. Aguili, "Enhanced thresholding-based wavelet noise filtering in optical fiber communications," *Periodicals of Engineering and Natural Sciences (PEN),* vol. 8, pp. 1729-1740, 2020.

[7] S. Alshwani, A. M. Fakhrudeen, M. N. Ismael, A. Al-Dawoodi, and A. Ghazi, "Hermite-gaussian mode in spatial division multiplexing over FSO system under different weather condition based on linear gaussian filter," *International Journal of Mechanical Engineering and Technology,* vol. 10, pp. 1095-1105, 2019.

[8] A. Al-Dawoodi, H. Maraha, S. Alshwani, A. Ghazi, A. M. Fakhrudeen, S. Aljunid, *et al.*, "Investigation of 8 x 5 Gb/s mode division multiplexing-fso system under different weather condition," *Journal of Engineering Science and Technology,* vol. 14, pp. 674-681, 2019.

[9] A. Ghazi, S. Aljunid, A. Noori, S. Z. S. Idrus, C. Rashidi, and A. Al-Dawoodi, "Design & investigation of 10x10 gbit/s MDM over hybrid FSO link under different weather conditions and fiber to the home," *Bulletin of Electrical Engineering and Informatics,* vol. 8, pp. 121-126, 2019.

[10] Kaur, N., & Soni, G. (2015). Performance analysis of inter-satellite optical wireless communication (IsOWC) system by using NRZ and RZ modulation. International Journal of Scientific and Research Publications, 5(1), 125-130.

[11] Sharma, P., & Meena, S. (2018, July). Performance Analysis of Inter-Satellite Optical Wireless Communication (Is-OWC) System by using Channel Diversity Technique. In *2018 International Conference on Inventive Research in Computing Applications (ICIRCA)* (pp. 477-480). IEEE.

[12] Eid, M. M., Houssien, F. M. A. M., Rashed, A. N. Z., & Mohammed, A. E. N. A. (2020). Performance enhancement of transceiver system based inter satellite optical wireless channel (IS-OWC) for ultra long distances. *Journal of Optical Communications*.

[13] Sharma, P., & Meena, S. (2019). Analysis of pointing error at 100 Gbps by using different encoding technique in spatial diversity based inter-satellite optical wireless communication (IS-OWC) system. *International Journal of Engineering Research & Technology (IJERT)*, *7*(9), 1-4.

[14] El-Hageen, H. M., Alatwi, A. M., & Rashed, A. N. Z. (2021). Advanced modulation coding schemes for an optical transceiver systems–based OWC communication channel model. *Bulletin of Electrical Engineering and Informatics*, *10*(2), 767-775.

[15] Ashwani, S. A. A. (2021). Investigation and analysis of inter-satellite-optical wireless communication system based on dense-wavelength-division multiple-access. *Periodicals of Engineering and Natural Sciences (PEN)*, *9*(2), 491-499.