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Modeling of Inter-satellite Optical Wireless Communication (IsOWC) System

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Abstract
Free space optical communication provides a very important method for the satellites orbiting around the earth to communicate with each other. Inter-satellite optical wireless communication systems (IsOWC) are one of the important applications of FSO/WSO technology that will be expanding in space in the near future. These systems provide a high bandwidth, small size, light weight, low power and low cost to present microwave satellite systems. In this paper, optical inter-satellite link (ISL) is modeled using opti-system software between two satellites separated by a distance of 1700 km at data rate 3Gbps at varying modulation formats.

***Keywords**: Free space optical communication, Inter-satellite optical wireless communication (IsOWC), Inter-satellite link (ISL).*

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1. Introduction

The application of laser technology to communications, particularly space communications, was envisioned in the very early days of laser development around 1962, described a method for secure communications between a satellite and a submarine. In the 40 years since, government agencies, companies, universities, and individuals in many countries have made tremendous technical progress in optical space communication, i.e. inter-satellite optical wireless communication. The present satellite communications system uses microwave technology for space-to-ground and geosynchronous satellite to low earth orbiting vehicles. In the future system, the satellite to ground links would remain in the microwave regime but satellite-to-satellite communication will be governed by optical wireless links. The technology uses laser light of infrared wavelengths to transmit optical signals between two points via free space. This requires devices similar to those used for the transmission through fiber-optic cable, except that the signal is transmitted through free space and not via optical cable capable of transmitting data, voice or video. IsOWC can be used to connect one satellite to another, whether the satellite is in the same orbit or in different orbits and the data can be sent at speed of light without much delay and with minimum attenuation since the space is considered to be vacuum. The advantages of using optical link over radio frequency (RF) links is the ability to send high speed data to a distance of thousands of kilometers using small size payload . By reducing the size of the payload, the mass and the cost of the satellite will also be decreased. Another reason of using OWC is due to wavelength. RF wavelength is much longer compared to lasers hence; the beam width that can be achieved using lasers is narrower than that of the RF system. Due to this reason, OWC link results in lower loss compared to RF but it requires a highly accurate tracking system to make sure that the connecting satellites are aligned and have line of sight. However, the transmission of such transmissions is affected in different ways by the environment processes such as absorption, scattering and shimmering. All three conditions attenuate the transmitted energy, affecting reliability and the bit error levels. Satellites revolve around earth at their own orbit and there are three commonly used orbits for satellites. Satellite orbits with orbital height of approximately 1000 km or less are known as Low Earth Orbit (LEO). LEOs tend to be in general circular in shape. LEO satellites take from 2 to 4 h to rotate around earth. This orbit is commonly used for multi-satellite constellations where several satellites are launched up to space to perform a single mission. Satellite orbits with orbital heights of typically in the range of 5000 km to about 25,000 km are known as Medium Earth Orbit (MEO)/Intermediate Circular Orbit (ICO). MEO and ICO are often used synonymously, but MEO classification is not restricted to circular orbits. In Geosynchronous Earth Orbit (GEO) the satellite is in equatorial circular orbit with an altitude of 35,786 km and orbital period of 24 h. Three satellites in GEO placed 120◦ apart over equator cover most of the world for communications purposes [3]. At present there are 6124 satellites orbiting earth and this number increases year by year [4]. At the same time the optical wireless communication (OWC) technology has grown and advanced throughout the year. Laser communication is now able to send information at data rates up to several Gbps and at distance of thousands of kilometers apart. This has open up the idea to adapt optical wireless communication technology into space technology; hence inter-satellite optical wireless communication is developed. In this work, we have presented the simulation investigation of inter-satellite optical wireless communication systems at high transmission rate of 3Gbps over a space distance of 1700 km and there is comparison between modulations formats i.e. NRZ and RZ.

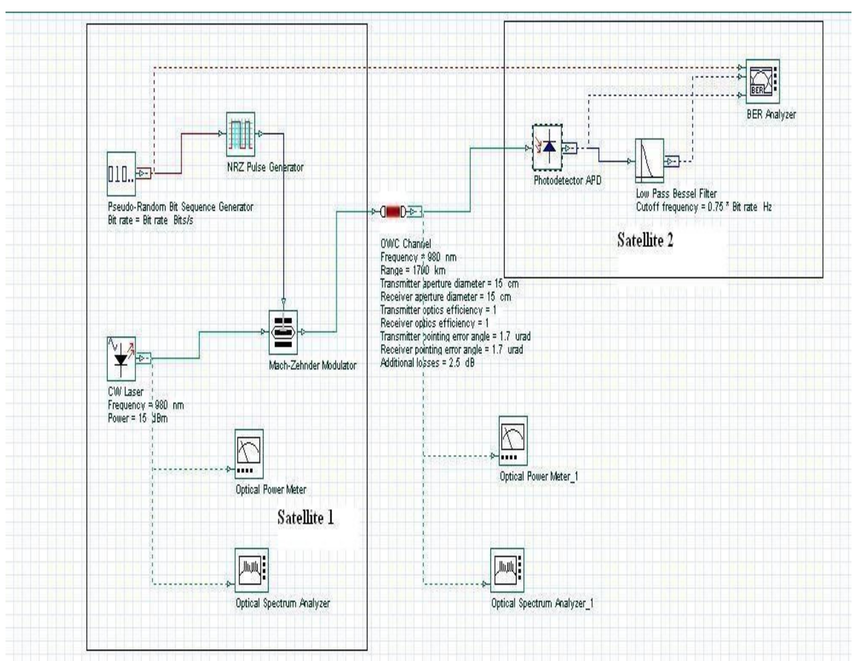

Fig. 1: Optimized IsOWC link using NRZ at wavelength 980 nm

2. System Design

We designed two models of IsOWC link at operating wavelength 980 nm by using different modulation formats i.e. NRZ and RZ. The IsOWC system consists of transmitter, propagation medium and receiver which is shown in fig. 1 where the transmitter is in the first satellite and the receiver is in the second satellite. The free space between the satellites is the propagation medium is the OWC channel that is use to transmit the light signal. Optical wireless communications uses light at near infrared frequency to communicate. The IsOWC system is not much different from free space optics and fiber optic communication where the difference relies in the propagation medium. In the Optisystem software, the OWC channel is modeled between an optical transmitter and optical receiver with 15 cm optical antenna at each end. The transmitter and receiver gains are 0 dB. The transmitter and receiver antennae are also assumed to be ideal. Additional losses are taken 2.5 db. The OWC channel is considered to be outer space where it is assumed to be a vacuum and free from atmospheric attenuation factors and the value of pointing errors taken as 1.7 urad. The aperture diameter of transmitting- and receiving-antenna is taken as 15 cm.

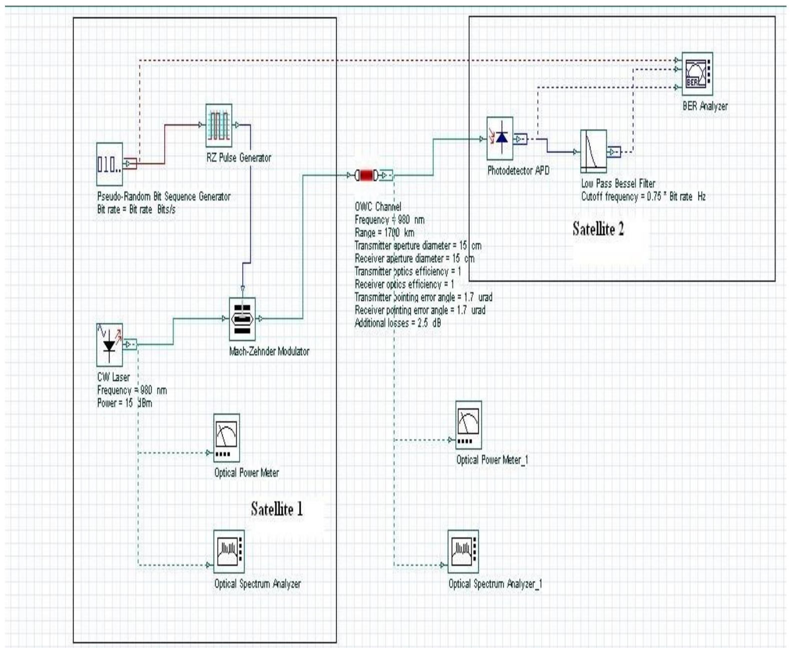

Fig. 2: Optimized IsOWC link using RZ at wavelength 980 nm

IsOWC model using NRZ modulation at 980 nm: In this model we used the modulation format NRZ at 980 nm wavelength. The transmitted power 15 dBm is used. We achieved the IsOWC link with maximum range up to 1700 km at data rate 3Gbps at operating wavelength 980 nm by using NRZ and RZ modulation. The laser used is CW laser. Modulation used for this link is RZ modulation. Here, table 1 shows the simulation parameters.

Table 1: Simulation parameters for link at 980 nm by using NRZ and RZ

Optical efficiency	1

3. Result & Discussion

An inter-satellite optical wireless system is designed with the help of OPTI-SYSTEM simulator consisting of two satellites with a space difference of 1700 km exchanging externally modulated optical data at 3Gbps through free-space medium at operating wavelength of 980nm by using two modulation formats i.e. NRZ and RZ. Table 2 shows the performance analysis of link by using two modulation formats at wavelength of 980nm between two satellites at the distance of 1700 km at data rate 3Gbps.

Table 2: Performance analysis of the optimized link at wavelength of 980nm by using modulation formats

SN	Range (km)	Modulation formats	QFactor	BER
1	1700	NRZ	13.4289	1.6803 e-041
2	1700	RZ	10.095	2.8934 e-025

a) Results for NRZ at 980 nm

Figure 3 shows the eye diagram of link where the distance is 1700 km and the bit rate is 3 Gbps and the wavelength is 980 nm by using modulation NRZ with transmitting power 15 dBm. The Q factor for 980 is 13.4289 and the BER is 10^{-41}.

Parameters	**Values**
Laser	CWL
Wavelength	980 nm
Transmitting power	15 dBm
Link range	1700 km
Data rate	3Gbps
Modulation	NRZ, RZ
Photo detector	APD
Pointing errors	1.7 urad
Additional losses	2.5 db
Aperture diameter of Transmitter and receiver	15 cm

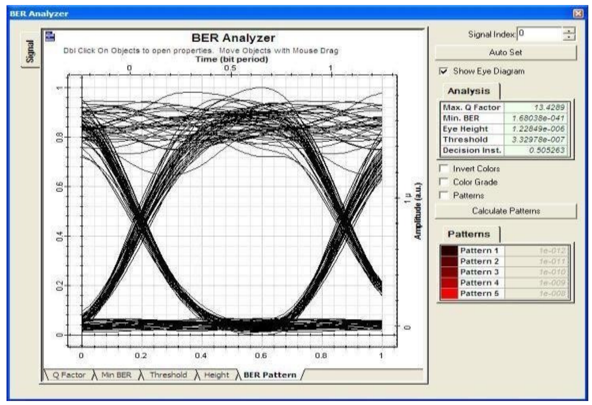

Fig. 3: Eye diagram of OWC inter-satellite system 1700 km apart with transmitting power of 15 dBm at operating wavelength of 980 nm by using NRZ

Figure 4 shows the transmitted optical power spectrum of the optimized link for range 1700 km at operating wavelength 980 nm. Optical power transmitted is $31.623*10^{-3}$ watts calculated by the power meter and this transmitted optical power at operating wavelength 980 nm for RZ is also same. Figure 6 also shows the peak wavelength at 980 nm. The loss of optical power at receiver end can be analyzed by using the

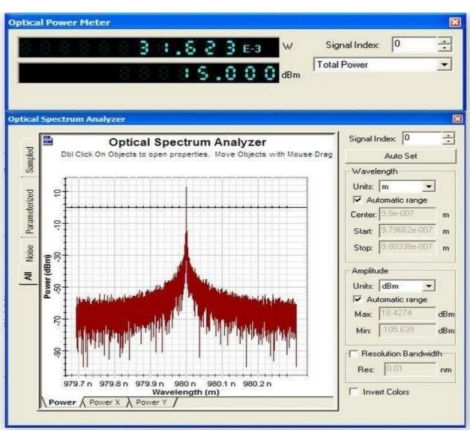

Fig. 4: Transmitted optical power for link range 1700 km at operating wavelength 980 nm.

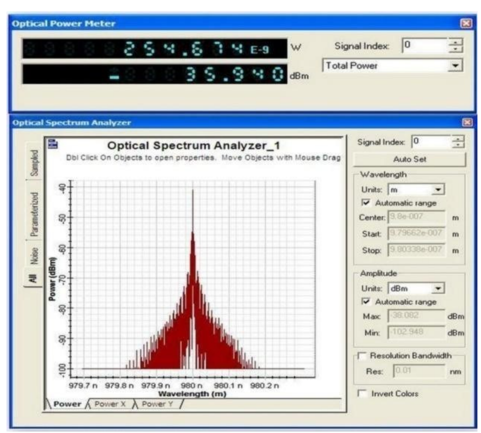

Fig. 5: Received optical power for link range 1700 km at wavelength 980 nm

spectrum analyzer at receiver end. Figure 5 shows received optical power spectrum of the optimized link for range 1700 km at wavelength 980 nm.

b) Results for RZ at 980 nm

Figure 6 shows the eye diagram of link where the distance is 1700 km and the bit rate is 3Gbps and the wavelength is 980 nm by using modulation RZ with transmitting power 15 dBm. Here the Q factor is 10.2975 and the BER is 10^{-25}. However, as we mentioned above the transmitted optical power for range 1700 km at wavelength 980 nm used for RZ have same value as that of 980 nm wavelength used for NRZ. Figure 7 shows the received optical power at wavelength 980 nm having range 1700 km.

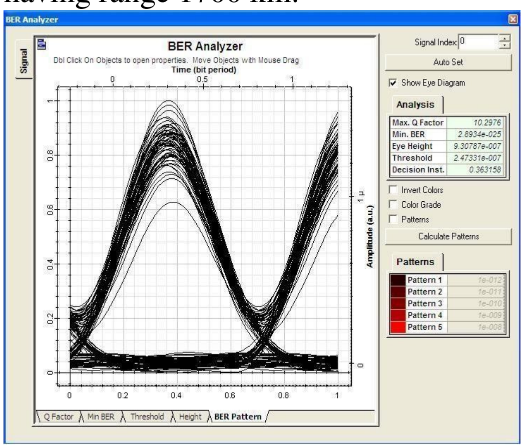

Fig. 6: Eye diagram of OWC inter-satellite system 1700 km apart with transmitting power of 15dBm at operating wavelength of 980 nm by using RZ

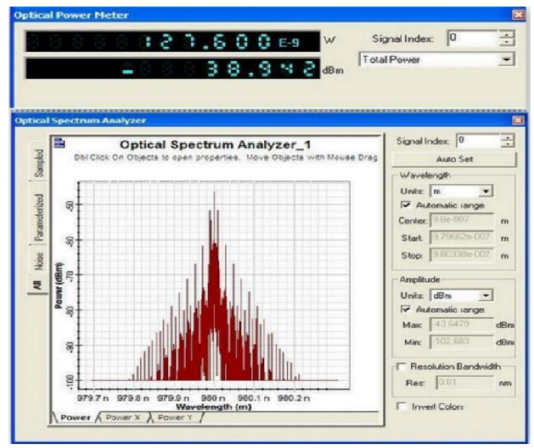

Fig. 7: Received optical power for link range 1700 km at wavelength 980 nm

4. Conclusion

In this work, we have designed an inter-satellite OWC system to establish an inter-satellite link (ISL) of 1700 km between two satellites at data rate of 3Gbps. For the comparison we have used two modulations i.e. NRZ and RZ. The BER for NRZ is 10^{-41} and for RZ is 10^{-25}. It is concluded from our simulated OWC system that the ISL link that NRZ is better than RZ modulation because there is minimum BER in NRZ rather than RZ.

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