Design And Simulation Of QPSK Modulator For Optic Inter Satellite Communication

A Penchala Bindushree, Nataraju A. B., Vijesh T V, Laxmiprasad A S

Abstract— We have proposed a digitally implemented QPSK system for Free-Space Optics (FSO) systems for future satellite missions. We have used a Laser source of 1550nm wavelength and data rate of 2.5Gbps.The system consists of a modulating and a demodulating block and an advantage of filters added to improve the performance and optimize errors like noise. The best suited modulator for FSO is Mach-Zehnder modulator which is tuned for high performance. The LiNB03 demodulator demodulates the signal which in turn passed to a filter to attenuate the demodulated output and then through an amplifier to increase the signal strength. Digital approach for implementation of QPSK Modulation is attempted here and compared with existing systems. Simulation and characterization is done to freeze design parameters. The system mainly concentrates on parameter like performance, security, minimum size and cost saving which will be the future of satellite communications.

Index Terms— FSO, ISL, BER, Q factor, Quadrature Phase Shift Keying (OQPSK), Differential Phase Shift Keying (DPSK), Optisystem 12

1 Introduction

In the communication world, optical satellite communication is one of the major areas that remain to be comprehensively researched [1].Optic Inter satellite links (OISL) provides an attractive alternate to microwave systems for both military and commercial applications. The advantage of optic ISL is it includes higher band width, smaller antenna size and lower power requirements. It is important in optical satellite communication to dissipate minimum power and to obtain minimum BER. This aim can be achieved by very small transmitter divergence angles to assure maximum received power. Such design reduces the price of the mission and increases the reliability of the system [4]. The overall system performance of a communication link is easily quantified by three important parameters: transmitter power, receiver sensitivity, and propagation losses. This receiver sensitivity is the amount of optical power needed to maintain the signal to noise ratio required to achieve a desired quantity of service In satellite communication, modulation is necessary to transfer the information between satellite and the earth. Free-space optical (FSO) communications is a concept that has been there for many years. Today's market is primarily ISLs for space-based optical communications.

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Free Space Optics (FSO) is a new communication technology that uses the light propagating in free space to transmit data between two points and although there are several companies currently producing systems for ground based commercial use, deep space optical communications remains a controversial topic [1]. Radio has had such a strong hold on space communications that the huge infrastructure surrounding it makes it hard for a new technology to break into the field. Many opponents will say that radio works fine, so why change it. And this is a large reason why a lot of the free space optical communication technology currently coming to fruition has been around only in the form of ideas and on paper for close to 30years. FSO is particularly applicable to inter-satellite communications as it is relatively interference free, travels for longer ranges and offers better connections than RF signals. Lasers provide high bandwidth communication links between satellites, lenses, mirrors, deep-space probes, and orbiting telescopes using lasers. These connections allow for fast communication between transmitters and receivers [2]. Some space-based FSO communication links operate reliably millions of miles apart. ISLs can send and receive data that are exponentially larger than RF signals can provide, while using less power. There has been a new spark of interest from the NASA Mars program, which has been a major driving force in the push for deep space optical communication [8]. FSO system uses a laser beam as a wireless connectivity between transmitter and receiver, freespace as propagation medium for carrying information. The performance of the system is greatly influenced by the propagation medium. Thus, the selection of modulation technique is a vital role in the design process of the system. The most common modulation scheme used in satellite communication is BPSK. In this work, QPSK and DPSK systems have been compared. The system is modelled using Optisystem 12 software from Optiwave. This project illustrates that QPSK can give better results. Below are a quick summary of the bullets points as why QPSK is superior.

A. QPSK requires half the bandwidth of PSK and hence is quite effective in optical communication.

B. It is used to double the data rate compared to a BPSK system.

C. QPSK's BER performance in AWGN and Rayleigh fading channels is shown to be superior to that of all PSKs.

D. Application of QPSK would lead to a 95% increase of system capacity compared to PSK. It is concluded that the power and spectrally efficient QPSK make it an excellent candidate for future high-capacity communication system networks **Error! Reference source not found.**.

2 SYSTEM ARCHITECTURE

The basic architecture used to model ISL system is shown in Figure 1. This gives an overview of proposed optical ISL system. Then, the selection of suitable optical wavelength which is used for deep space links. Then we revise the ISL link performance and freeze the system parameters focusing on transmitted bit rate between LEO satellites at bit error rate (BER) ranged from 10^{-6} to10^{-9} employing APD detector and QPSK modulation at desired wavelength maximizing the quality of the system as well.

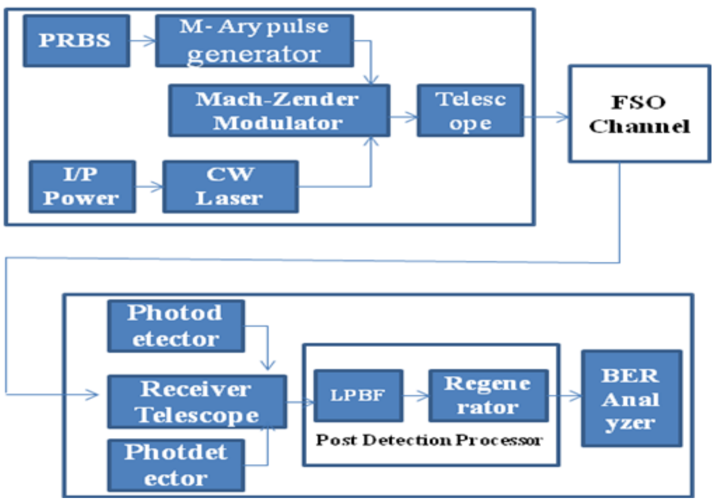

Figure 2: ISL System

Modulation technique is one of the most significant processes in ISL system where the RF electrical signal is applied to modulate the optical carrier. Optical modulation methods can be categorized into two main groups: direct modulation and external modulation. Direct modulation, a simple technique, directly modulates the amplitude of the laser beam but suffers from a laser-frequency chirp effect that degrades severely the performance of the system. However, this can be eliminated by using the external-modulation scheme that is used to modulate the phase of the optical carrier. No doubt such systems are capable of meeting the future requirements of High speed high data transfer services. The optical system of ISL is consisting of two transceivers communicating by means of emitting and receiving optical signals. The proposed ISL uses continuous wave (CW) lasers in free space channel as a signal carrier as well a wireless connectivity between transmitter and receiver as in Figure 3. Using this FSO channel is considered as a key technology for realizing an ultrahigh speed and long-haul communication system. CW laser is modulated by a phase modulator using 2.5 Gps non-return to zero (NRZ) data to generate the desired signal. The generated signal is emitted using an optical antenna and is sent over FSO bearing some losses. The optical path loss depends on the laser wavelength and distance between transmitter and receiver platforms. At the receiver, the process is reversed and optical signal is converted into a bit stream. These bit streams modulated using Non Return to Zero (NRZ) modulation because it is superlative scheme for obtaining maximum coverage distance of the link .It becomes extremely difficult to modulate the laser directly; therefore Mach Zehnder (MZ) modulator used as an external and alternative optical modulator as shown in Figure 4. External modulators are either integrated with Mach-Zehnder interferometers or electro absorption modulator. The MZM remains the proven technology for high speed optical systems [12]. A Mach-Zehnder modulator consists of a beam splitter that divides the laser light into two paths, one of which has a phase modulator. The two beams are then recombined. At the output changing the electric field on the phase modulating path will determine whether the two beams interfere constructively or destructively, and thereby control the intensity or amplitude of the exiting light [13]. Main objective of this research is to design and simulate the QPSK modulation scheme to achieve data rate of 2.5 Gbps at a wavelength of 1550 nm using external modulation in free space optics using Optisystem 12 software. This design is about components that will be used in this system including the specific parameters of each component, how it works and the function of the system. This proposes an alternative approach for delivering high frequency signals using intersatellite link between satellites.

3 SYSTEM PERFORMANCE

Performance of a system can be evaluated in many ways such as by analyzing the BER and Q-factor. BER can be said to be the ratio of the number of bit errors detected in the receiver and the total no. of bits transmitted. Bit error happens when the receiver results in incorrect decisions due to the presence of noise on a digital signal [15][16]. Meanwhile, Quality factor, Q, describes the sharpness of the system's response and is a measurement of the signal quality. Q factor is proportional to the systems signal to noise ratio. In optical communication, the BER is typically too small to measure hence Q-factor is more suitable to be used [14]. The relationship between Q-factor and BER can be given as $BER= 1/2 erfc (Q/\sqrt{2}) \approx 1/\sqrt{2\pi}Q exp(-Q^2/2)$ [17] The attenuation, A, for ISL and satellite to earth link is calculated using the equation, $A = L2 (\lambda/DT)^2/DR^2 TRTT (1-LP)$ Where λ is the wavelength, L is the distance between the transmitter and receiver, DR is the optical receiver antenna diameter, TR and TT are the transmission factor for the transmitter and the receiver respectively, LP is the pointing loss, DT is the diameter of the optical transmitter antenna According to Pfennigbauer [18] following values are considered D=DT=DR, LP = .2, TR=TT=0.8, λ=1550nm.Thus the propagation attenuation, A, for ISL is given as $A=4.69*10^{-22}L^2/D^4$

4 SIMULATION USING OPTISYSTEM 12

The proposed FSO system consists of a transmitter, freespace channel, a receiver and a few numbers of visualisers as shown in Figure 2 .It is designed, simulated and optimized using Optisystem 12 software. The transmitter consists of a Pseudo Random Bit Sequence (PRBS) generator and an optical QPSK transmitter.

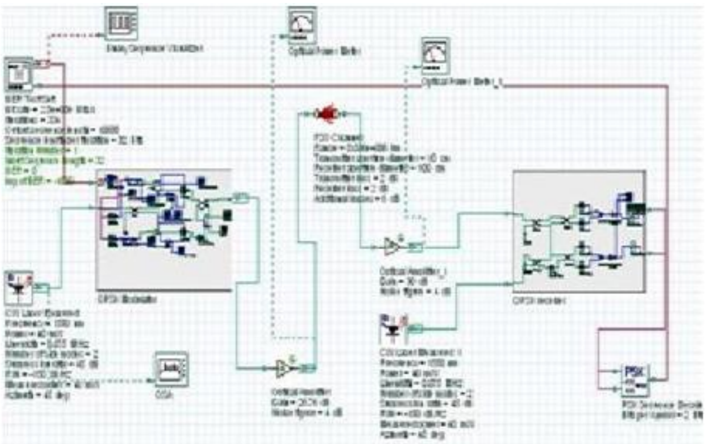

Figure 2: ISL system using OPTISYSTEM

Free-space path loss is taken into account in the simulation. Receiver consists of an Optical QPSK receiver followed by an amplifier, low-pass filter, M-ary threshold detector and a PSK decoder. The PSK decoder is used here, for reproducing 0s and 1s from the received signal. Visualisers are used to find the Q-value, Bit Error Rate (BER) pattern, signal constellation diagram, the transmitted and received signal in time and frequency domain. For the proposed setup, the considered parameters are given in Table 1.

Table 1: Simulation parameters

Parameter	*Value*
Wavelength	1550nm
Bit rate	2.5 Gbps
Targeted BER	10^{-9}
Link distance	36,000 km (GEO - GND)
Sequence length	128
Samples per bit	64
Modulation	QPSK
Optical QPSK transmitter power	5 dBm, 3 dBm
Optical QPSK transmitter Frequency	193.1 THz
Line width of optical QPSK transmitter	0.1 MHz
Attenuation of free space	25 dB/km, 200 dB/km
Transmitter aperture diameter	5 cm for Diffused link(DL), 15 cm for Line of sight(LOS)
Receiver aperture diameter	20 cm for DL, 15 cm for LOS

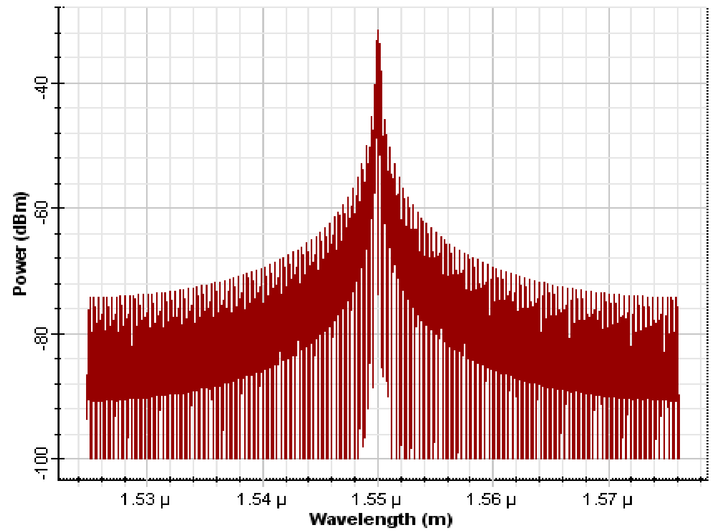

Figure 5: Input optical spectrum of 2.5 Gbps FSO system

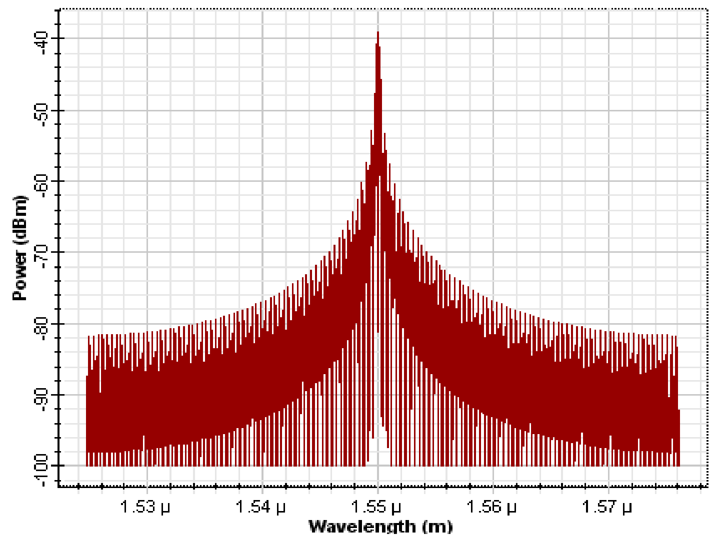

Figure 6: Output optical spectrum of 2.5 Gbps FSO system

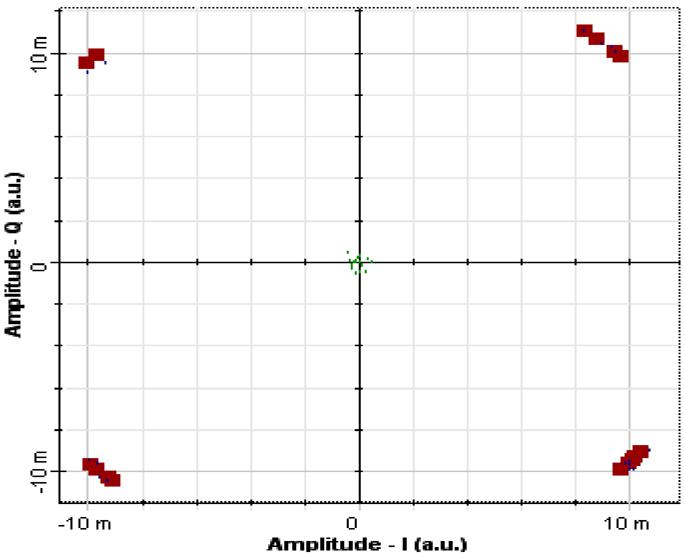

Figure 5: Signal constellation diagram at receiver of 2.5 Gbps

The Mach Zehnder Modulator has three ports: the first port is for electrical modulation type, the second is the CW laser input and the third port is the outlet of output optical signal. The extinction ratio is set to 20 dB to characterize the division power ratio of the upper path to lower path. The output optical signal is shown in Fig.4. It is clear from the figure that there is symmetry around 193.1 THz. The output power is measured by using the optical power meter before and after the FSO channel; P_{out} (Before) = -10 dBm and P_{out} (After) = -40, the power loss is due to the insertion loss of the circulator. FSO link distance of 36000 km with an attenuation loss of 25dB/km is used. The signal also undergoes many atmospheric losses, transmitter losses, receiver losses and additional losses. The optical signal is then received by photodetector PD operating at 193.1 THz frequency to convert it back to electrical form, the received signal after photo detection is illustrated in Figure 5. It is clear that there is a power loss and signal distortion due to the conversion process, the signal power decreases to -42.775 dBm. To recover the message signal; a low pass Bessel filter (BPF) is used with central frequency of 2 GHz and 0.8 GHz bandwidth. For this setup, Figure 3 shows the input spectrum of the optical signal transmitted at 2.5 Gbps, which is about -10 dBm. As the signal travels through the free space of 36000km, the signal power decreases to -42 dBm approximately as shown in Figure 4. Signal constellation diagram shown in Figure 5 of the receiver, which is as expected for QPSK modulation scheme.

5 RESULTS AND DISCUSSIONS

The analysis of the link performance corresponding to the

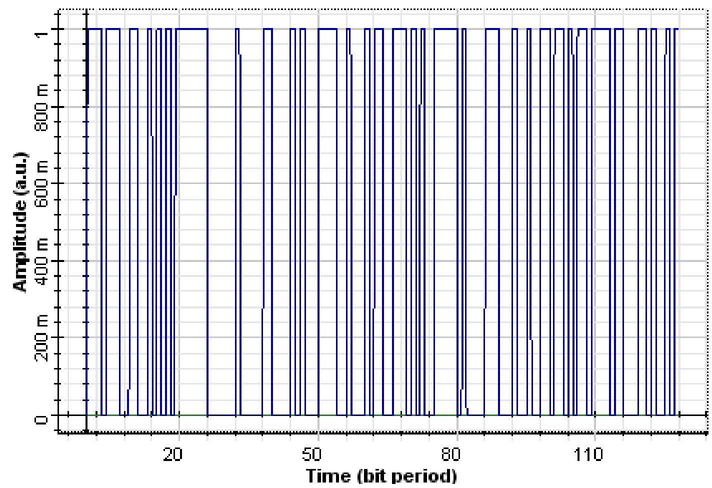

Figure 6: Input electrical signal of 2.5Gbps FSO systemwavelength selection is obtained by simulated link using optisystem Ver.12. We simulate an end to end QPSK modulation system for free-space optical communication.

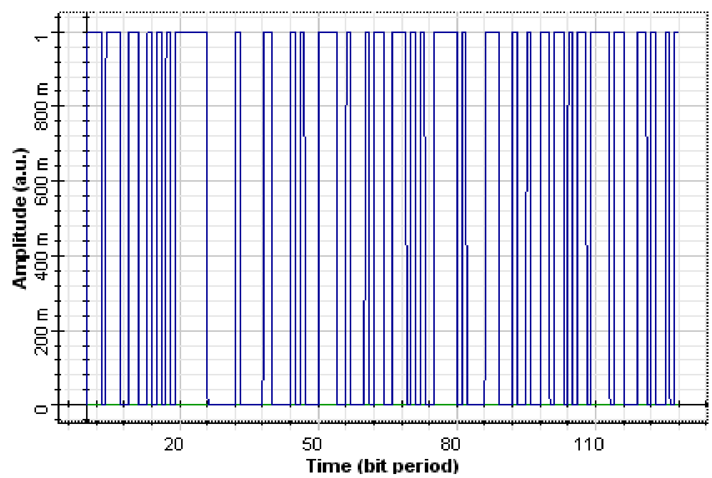

Figure 7: Output electrical signal of 2.5 Gbps FSO system

Now, we will make a detailed comparison between DPSK and QPSK. BER and Q factor curves for both DPSK modulation and QPSK modulation techniques is shown in the following graphs. In general; a minimum acceptable BER rate is about 10^{-12}. Referring to the figure 6& 7; it is clear that system performance is affected by the power variation. The eye diagrams of QPSK and DPSK are shown in figure 8 & 9 respectively. QPSK performs better than DPSK since its BER curves go down the BER curves of the DPSK.

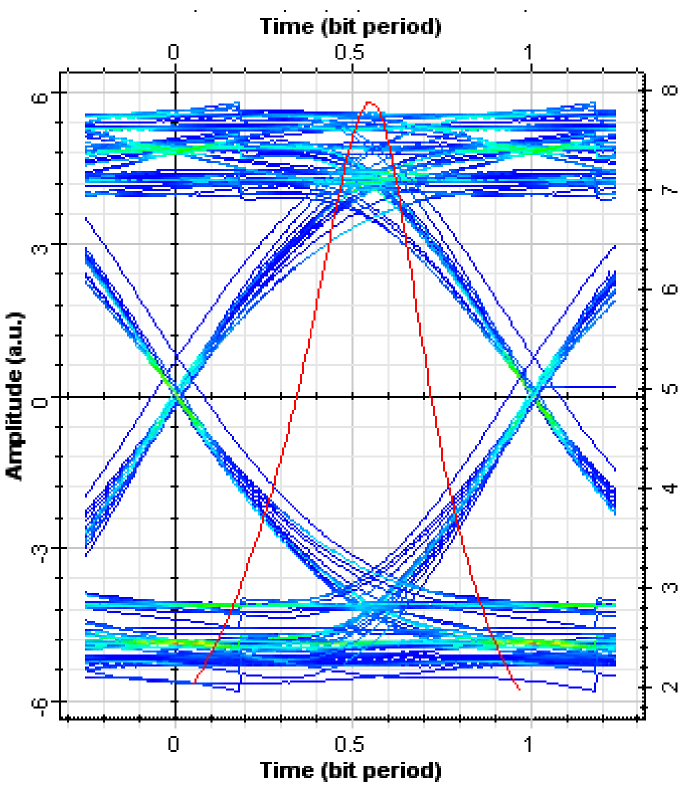

Figure 8: Eye diagram of QPSK System

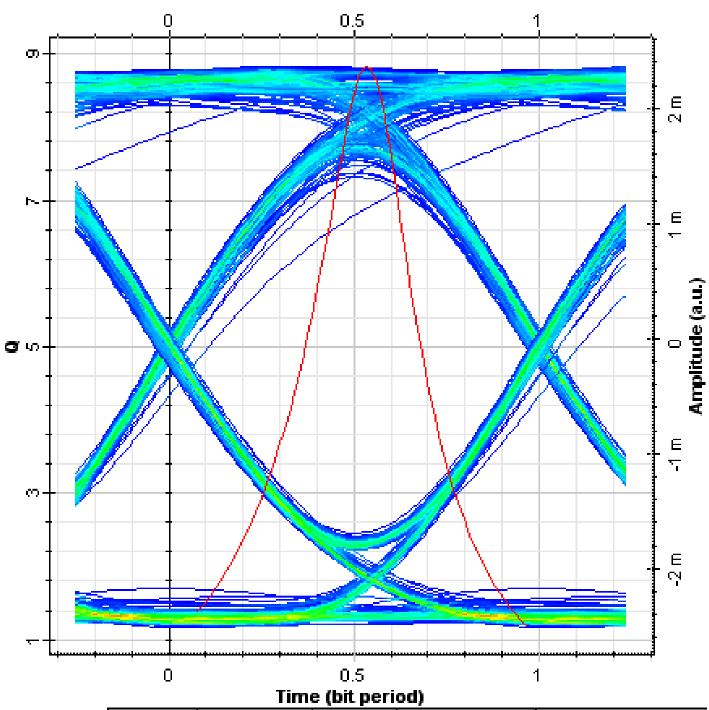

Figure 9: Eye diagram of DPSK System

6 GRAPHICAL RESULTS

Comparing QPSK Modulation with DPSK modulation in terms of BER and Q factor.

a. BER Vs Received Power

From the graph shown in Figure 5 it can be observed that the QPSK (In Blue) has low BER compared to DPSK (In Pink) Since the BER is inversely proportional to Q-factor. Therefore if the system error decreases the BER will thus decrease. So to reduce the BER we must increase the Q-factor.

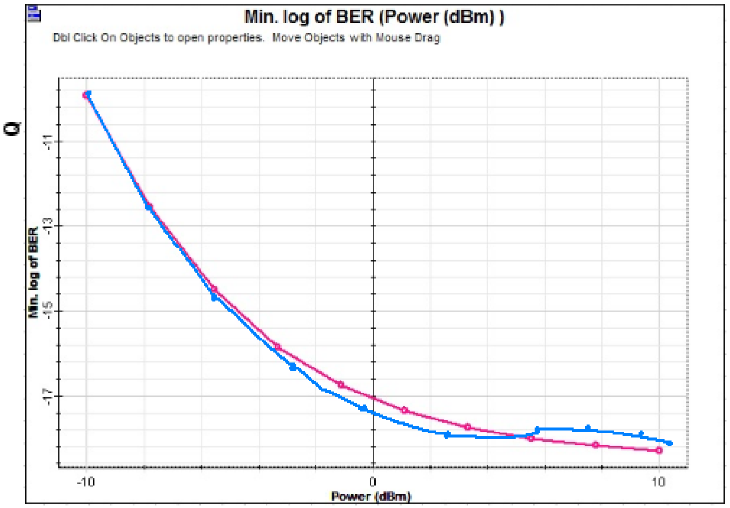

Figure 10: BER Vs Power

b. Q factor Vs Received Power

We know Q- factor is a measurement of the signal quality. For the performance of any system higher value of Q-factor is required. From the graph it shows that QPSK (In Blue) has high Q factor compared to DPSK (In Pink)

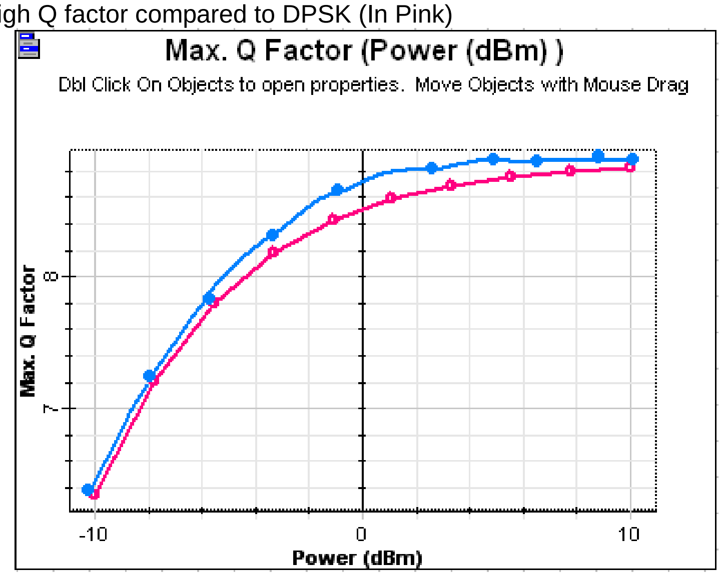

Figure 11: Q factor Vs Power

c. BER Vs Q factor

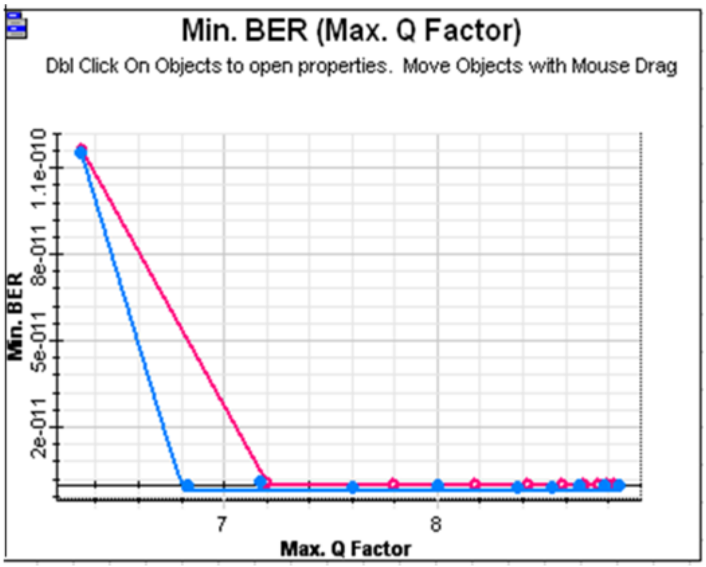

Figure 12: BER Vs Q factor

7 CONCLUSION

In our work, we have proposed free-space optical communication systems employing QPSK modulation for data rate 2.5 Gbps. We have proposed significant comparison with DPSK modulation and every component requirement is presented. QPSK is simulated using the Optisystem 12 software and its various parameters such as Q factor, BER, Eye Diagram, etc were compared for different categories of coding such as QPSK and DPSK Studies shows that in general, we can operate better by using QPSK modulation in high power than DPSK in Free space.

Parameter	QPSK	DPSK	Condition
Max Q Factor	9.25	7.94	DataRate = 2.5Gbps Power = 10mW
Min BER	$1.05*10^{-20}$	$9.45*10^{-16}$	
Eye Height	$4.97788*10^{-005}$	$2.92781*10^{-005}$	

8 FUTURE WORK

It is expected that the future scope of activities described in this report will be taken up along the following lines:

• Hardware implementation of the QPSK modulation scheme as designed in this work

• Parameters like size, weight, power and cost can be optimized in future satellite communication

• Better improved modulation techniques can be used like DQPSK and MPSK coding.

• FSO can be replaced by combination of Hybrid FSO/RF links

• To do the laboratory demonstration of fully functional device unit to overcome the Imperfections.

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