Grenze International Journal of Engineering and Technology, June Issue

Simulation of Optical Homodyne Coherent Receiver for Inter-Satellite Links

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***Abstract*— Coherent communication is one of the most favored technique for optical satellite communications as it offers data rates which are high and lesser Bit Error Rates (BER) along with the highest receiver sensitivity and full signal recovery, but with a carrier recovery system at the receiver. The Costas loop is a most popular phase locked loop used in almost all coherent receivers where the carrier synchronization is an important aspect. This paper has a mathematical approach to the design of Costas loop for each modulation scheme considering the bitrate of 2.5Gbps and the optical source. The theoretical approach as well as simulations both are discussed. Simulations are carried out in using Opti system software tool and the results such as the eye diagram and the constellation diagram are discussed.**

***Index Terms*— Homodyne receiver, QPSK modulation, BPSK modulation, Inter-satellite links.**

I. INTRODUCTION

Satellites are launched into space for voice, video, and data communication purposes. A satellite may reside in any one of the several orbits namely Low Earth orbit (LEO), Medium Earth Orbit (MEO), Highly Elliptical Orbit (HEO) and Geo- Synchronous Orbit (GEO). Mainly satellites are placed in LEO and GEO. Instead of relaying data from one satellite to another through earth relay station, a direct communication link between two satellites can be established [1]. This is called as Inter-Satellite Link (ISL). There are two types of links called as the Radio Frequency (RF) communication link and Optical link which are widely used in ISL communications.

Hence the Optical Inter-Satellite Link (OISL) technology aimed with utilizing small size antennas with less power consumption which helps in longer distance interference free transmission over great distances results in high data rates and it is the best replacement for microwave systems [2]. Light is used for communication between two points in Free Space Optical (FSO) communication [3]. For free space communication laser beam is used to carry the data between transmitter and receiver satellite wirelessly which provides higher bandwidth and faster communication. Figure 1 shows the FSO system where satellite A is transmitter and satellite B is the receiver. In the proposed OISL system continuous wave lasers are used as FSO channel carrier which is further modulated with binary phase shift Key (BPSK) using 2.5Gbps serial digital bit stream. Mach-Zehnder Modulator (MZM) with external electro-optic modulation scheme used to accomplish this system. An optical amplifier is used to further amplify the signal generated and transmitted over free space through optical antenna. Acquisition and Tracking system is required at both transmitter

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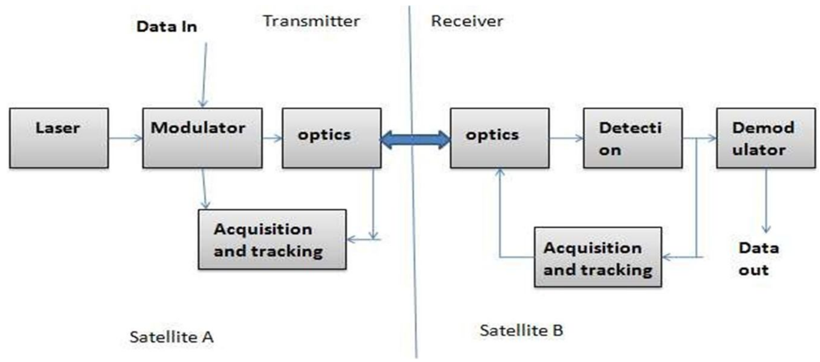

Figure 1. Optical Intersatellite links block Diagram

and receiver to maintain line of sight communication. There will be loss of optical path with respect to laser wavelength and distance between two end points. The process is overturned on the receiver side in order to get original data [4].

II. System Model

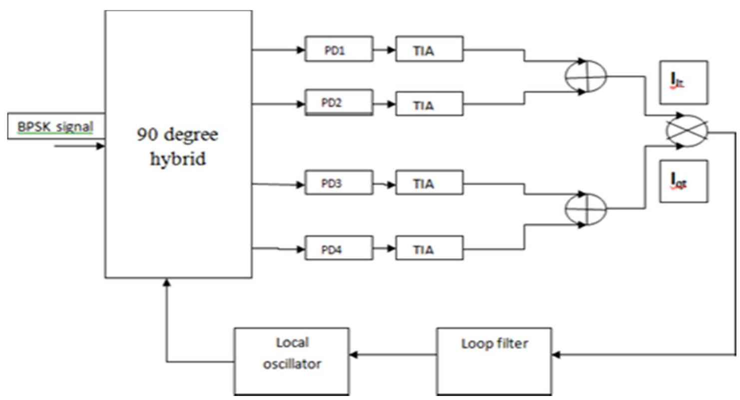

Figure.2 Costas loop for BPSK receiver

The proposed Costas based Optical Coherent BPSK receiver is shown in Figure 2. The received BPSK modulated signal and the Local oscillator laser signal is given to a 90^0 optical hybrid. The four output signals from hybrid differ by 90^0 and are phase interfered signals of the both inputs. The signals from the hybrid are given to two balanced receivers each consisting of four photodiodes for differential detection. The electric currents obtained from the in phase and quadrature phase channels are given to Trans-Impedance Amplifiers (TIA) which converts electric current signals to electric voltage signals [5]. The signals from both channels are then carried through Low Pass Filters (LPF) to reject high frequency components and multiplied. The phase difference between the received optical modulated signal and the local oscillator laser signal is given to a loop filter and the corresponding error voltage generated. The error voltage is used to control a tunable laser local oscillator which acts as a Voltage Controlled Oscillator (VCO). Let the power of the BPSK modulated signal be P_s and that of the local oscillator be P_{lo}. The electric fields associated with them be E_s and E_{lo}. Let wc be the carrier frequency with a phase of ϕ_c and the frequency of the local oscillator be w_{lo} with a phase of ϕ_{lo}. The electric field of the modulated signal and the local oscillator is given by:

$$E_s = sqrt(\frac{P_s}{4})\cos(w_c t + \phi_c) \text{ ...[1]}$$

$$E_{lo} = sqrt(\frac{P_{lo}}{4})\cos(w_{lo} t + \phi_{lo}) \text{ ...[2]}$$

Then the photodetectors current is given as I1 ,I2,I3 and I4 respectively generated by all the four photodetectors. The R is the responsivity of the photodetector [6].

$$I1 = RP1$$

$$I1 = R(E_S + E_{lo})^2 \text{ ....[3]}$$

$$I2 = R[\frac{P_s}{4} + \frac{P_{lo}}{4} \frac{sqrt(P_s P_{lo})}{4} \cos(\Delta wt + \Delta\phi)...[4]$$

$$I3 = R[\frac{P_s}{4} + \frac{P_{lo}}{4} \frac{sqrt(P_s P_{lo})}{4} \sin(\Delta wt + \Delta\phi)...[5]$$

$$I4 = R[\frac{P_S}{4} + \frac{P_{lo}}{4} - \frac{sqrt(P_S P_{lo})}{4} \sin(\Delta wt + \Delta\phi) \text{ ....[6]}$$

$$I_{it} = I1 - I2$$

$$I_{qt} = I3 - I4$$

$$I_m = I_{it} \times I_{qt} \text{ .... [7]}$$

$$I_m = \frac{R^2}{8} \quad sqrt(P_S P_{lo}) \sin(2(\Delta wt + \Delta\phi))\text{......[8]}$$

The equation 8 shows the input current signal given to the loop filter of the Costas loop. The beauty of the Costas loop is seen significantly as it is sine of two times of phase deviation. present subtracts the currents coming from photodiodes and the resulting current is given to the multiplier. The multiplier multiples the in phase current and the quadrature phase currents as shown in equation 8 and the resulting current is given as the input to the loop filter given by equation 8.

The figure 3 illustrates the Costas loop for QPSK receiver. The Optical QPSK receiver is shown in the figure 3 which is same as that of the BPSK receiver with some minor changes. The similar calculation is carried out at photodetector 2. At the photodetector 3 and 4 the local oscillator phase is shifted by 90 degrees and it becomes sine term which then is taken for the calculation of the I3 and I4[7, 15].

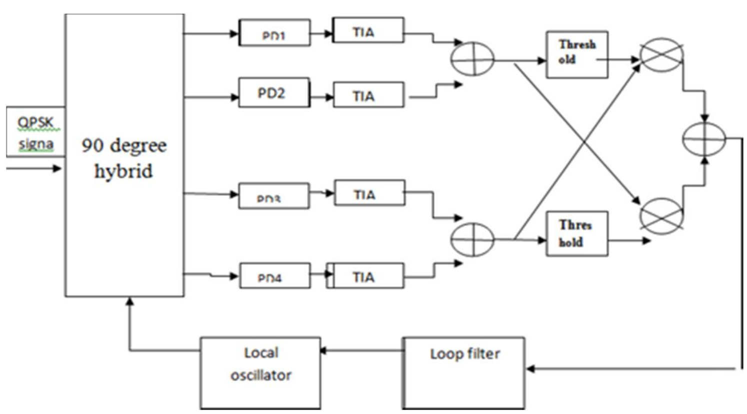

Figure 3: Costas loop for QPSK receiver

Let the power of the QPSK modulated signal be P_s and that of the local oscillator be $P_{lo.}$ The electric fields associated with them be E_s and $E_{lo.}$ Let wc be the carrier frequency with a phase of ϕ_c and the frequency of the local oscillator be w_{lo} with a phase of $\phi_{lo.}$ The electric field of the modulated signal and the local oscillator is given by:

$$E_S = Isqrt\,(\frac{P_S}{4})\sin(w_C t + \phi_C). + Qsqr\,t(\frac{P_S}{4})\cos(w_C t + \phi_C)...[9]$$

$$E_{lo} = sqrt\,(\frac{P_{lo}}{4})\cos(w_{lo}t + \phi_{lo}). \ldots\ldots[10]$$

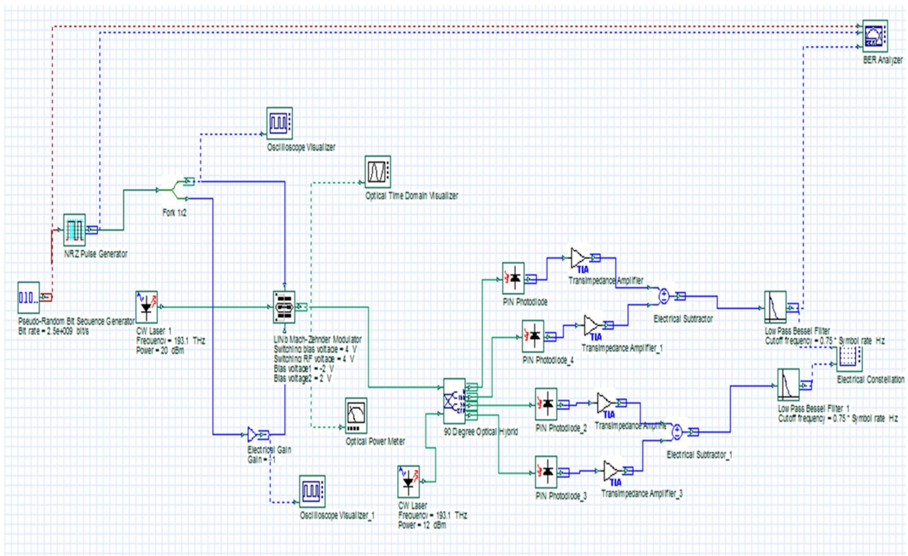

Figure 4: Simulation model in Opti system of BPSK Tx and Receiver

Here I and Q are the message signals belonging to {+1,-1}. Then the photodetectors current is given as I1,I2,I3 and I4

respectively generated by all the four photodetectors[8][9]. The R is the responsivity of the photodetector from Figure 4.

$$I1 = RP1$$

$$I1 = R(E_s + E_{lo})^2 \ldots\ldots\ldots\ldots\ [11]$$

$$I2 = R[\frac{P_s}{4} - \frac{P_{lo}}{8} - Q\,\frac{sqrt(P_s P_{lo})}{4}\sin(S\ {}_{3]} L_{3]}. + I\,\frac{sqrt(P_s P_{lo})}{4}\cos(S - L)\ldots\ldots \qquad [12]$$

Where S= $w_c t + \phi_c$ and L= $w_{lo}t + \phi_{lo}$. Similarly, the current I2 is calculated given by:

$$I3 = R[\frac{P_s}{4} - \frac{P_{lo}}{8} + Q\,\frac{sqrt(P_s P_{lo})}{4}\sin(S - L) - I\,\frac{sqrt(P_s P_{lo})}{4}\cos(S - L)\ldots[13]$$

The photocurrents I3 and I4 are calculated but the local oscillator phase changes by 90 degrees thein the equations below signal for Elo,cos becomes sine and hence I3 and I4 are:

$$I4 = R[\frac{P_s}{4} + \frac{P_{lo}}{8} + Q\,\frac{sqrt(P_s P_{lo})}{4}\cos(S - L). + I\,\frac{sqrt(P_s P_{lo})}{4}\sin(S - L)\ldots.[14]$$

These currents after passing through the transimpedance amplifiers gets subtracted and we get the in phase and thequadrature phase component currents.

$$I_{it} = I1 - I2$$
$$I_{qt} = I3 - I4$$

The error signal generated is given by:

E(t)= I_{it} L_i- I_{qt} L_q......... [15]

where L_i and L_q are the outputs from the decision threshold block which are the demodulated symbols I and Q.

III. Results

The input to the MZM is the is the Laser source emitting at 193.1THz of frequency and the two electrical inputs are the NRZ bit streams [10]. The CW laser used here has line width of 1Mhz and also the frequency of 193.1Thz (1550nm).as shown in the Figure 7 below.

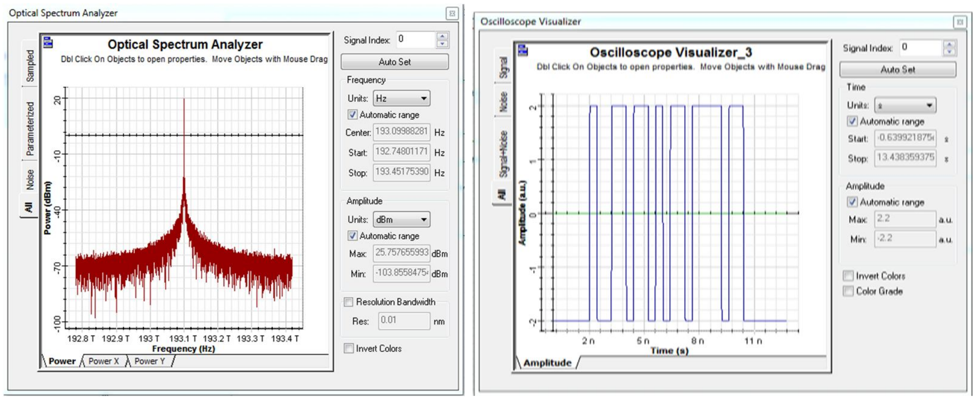

Figure 5 & 6: Input Electrical Signal and Spectrum of CW laser

The MZM being Electro optic modulator modulates the laser power with the phase changes from 0 to 180 degrees as shown in the Figure 8.

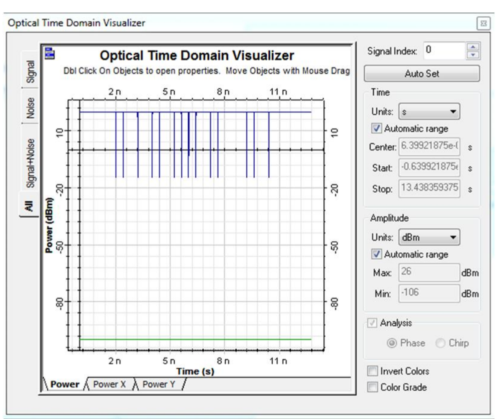

Figure 7: Power at the output of MZM modulator

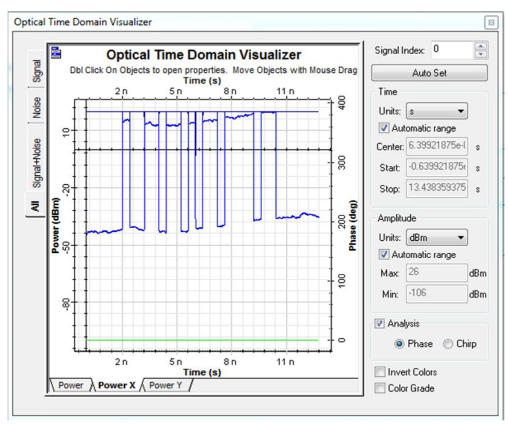

Figure 8: Phase variation in Output signal of MZM

The eye diagram after the BPSK demodulation by the optical Costas receiver is shown in the Figure 10 below. The constellation diagram is also shown where the distance between the two message points can observed.

Simulations of optical QPSK coherent homodyne receiver:

The input bits are being generated by the pseudo random bit sequence generator which is NRZ coded and then is given to two MZM modulators using a fork. The optical input to the MZM modulators is the same 193.1Thz source laser which has power of 20dBm is given to both MZM modulators by splitting the power by two[11]. The receiver for the detection for QPSK signal remains the same with slight changes in the Coastas loop shown in figure 12.

The optical QPSK receiver consists of two MZM modulators and the phase shifter of 90 degrees for the modulation. The subsystem consists of two MZM modulators same used for the BPSK modulation. The input to the MZM modulators is the NRZ pulse generators [12]. The data rate given to them was 2.5Gbps each. For the subsystem 2 there is phase shifter of 90 degrees is present which helps in achieving the 90-degree phase shift for quadrature phase modulation.

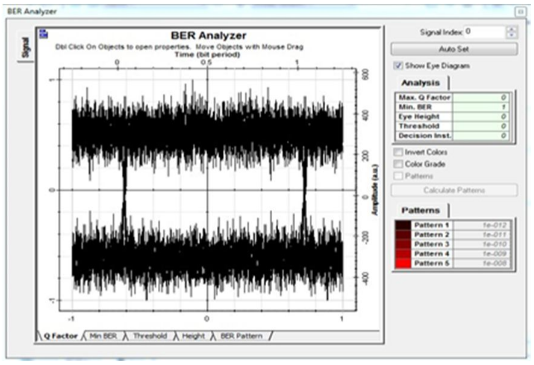

Figure 9: Eye Diagram of BPSK demodulated signal

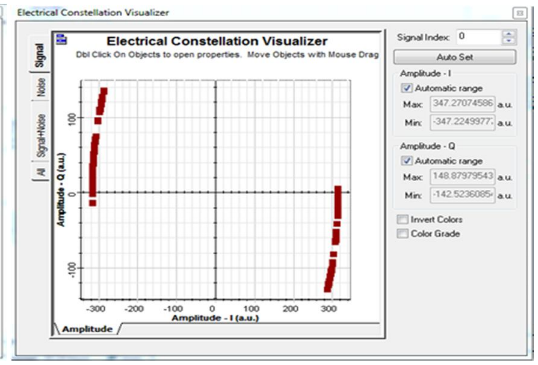

Figure 10: Electrical constellation of the BPSK demodulated signal

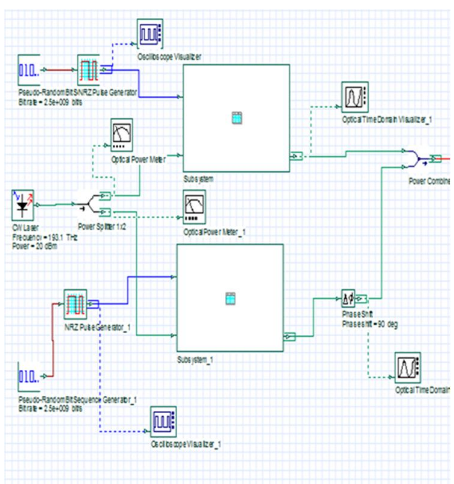

Figure 11: The optical QPSK transmitter

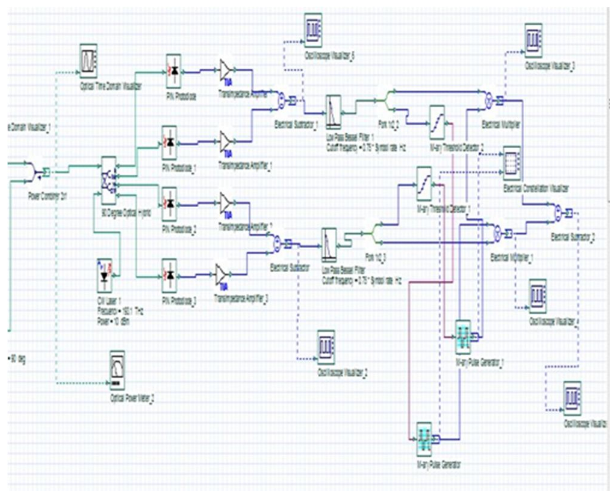

Figure 12: The optical QPSK receiver

The receiver has the 90-degree hybrid and four photodetectors and the transimpedance amplifiers. The responsivity of the photodetectors is 1A/W. A threshold detector is also used in in phase and quadrature phase arm which gives out a M- ary signal. The M-ary signal can further be changed to electrical signal by M-ary pulse generator [13].

Input bit sequence generated by pseudo random bit sequence generator is given to NRZ pulse generator. The data rate is 2. 5GHz.The modulated optical signals of in phase and the quadrature phase arms having power of 16.989dBm.

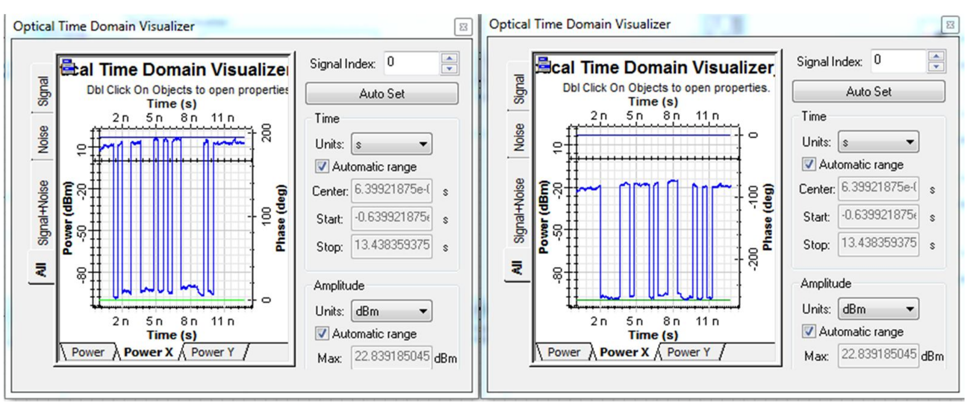

Figure 13: The modulated optical signals of in phase and the quadrature phase arms

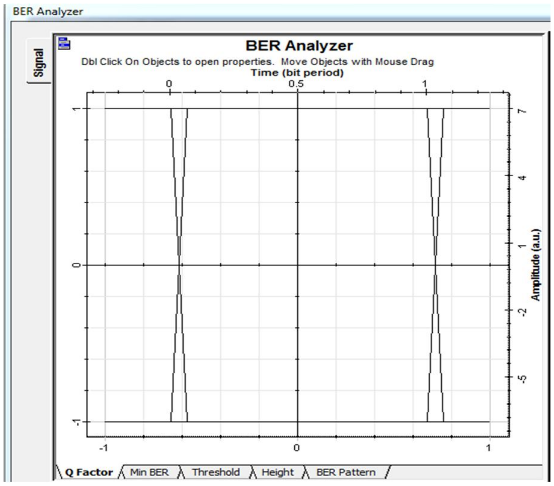

Figure 14:The Eye Diagram of optical QPSKdemodulated signal

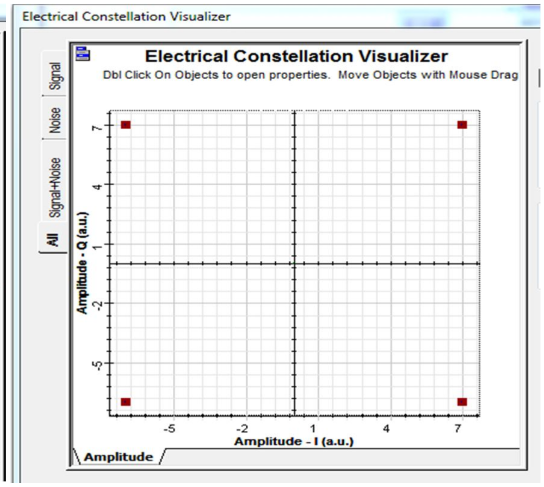

Figure 15: The constellation diagram of Optical QPSK

The constellation diagram for the QPSK modulation is plotted in the Figure 15 which shows that there is minimal noise. The four message symbols (00,01,10,11) represented by digits are plotted in the constellation diagram [14].

IV. CONCLUSION

In this paper, constellation diagram and the eye diagram for the BPSK and QPSK modulation are obtained with less noise considerations. The mathematical approach is realized in Opti-system. A laser of 1550nm is usedas an optical carrier. Different operating modes of MZMmodulator is studied and to achieve the BPSK modulation in Mach Zehnder modulator it has to be biased at the null point. The mathematical analysis of both the receivers is carried out. Out of two modulation schemes QPSK offers better BER performance compared BPSK.

Further work can be carried out for phase noise removal is using a DSP processor. This is another approach where Mth power loop algorithm can be applied for coarse compensation and Viterbi algorithm can be applied for fine compensation.

REFERENCES

[1] D. L. Begley, "Selected papers on free-space laser communications," Society of Photo Optical, vol.30,1991.

[2] D. A. Shehova, "Teaching pll fundamentals usingMATLAB and Simulink," Annual Journal of Electronics,2014.

[3] Jaz M, Ghassemlooy Z, Ansari S and Adebanjo O, "Experimental investigation of the performance of different modulation techniques under controlled FSO turbulence channel," International Symposium Telecommunications,2010.

[4] Vishal Sharma and Naresh Kumar, "Improved Analysis of 2.5 Gbps optical inter-satellite link(ISL) in Inter-satellite Optical Wireless Communication (IsOWC) system," Optics communications, pp 99-102, 2013.

[5] Abdallah Ahmad Shatnawi and Mohd Nazri Mohd Warip, "Challenges to Inter-Satellite Communication System: A review," International Journal ofComputer Applications, vol.148,no 6, August 2016.

[6] Asma Zaki M, Heba A Fayed, "The Influence of Varying the Optical Wavelength on ISL PerformanceRecognizing High Bit Rates," IOSR-JECE, vol.9, issue 1, pp 64-70, 2014.

[7] Semjon Schaefer, Mark Gregory, Werner Rosenkranz, "Numerical investigation of a free-space optical coherent communication system based on optical phase-locked loop techniques for high speed Inter-Satellite data transmission," IEEE Photonics Networks, pp 1-6, May 2015.

[8] Toshiyuki Ando, Eisuke Haraguchi, " Coherent homodyne receiver with a compensator of Doppler shifts for inter orbit optical communication, " Proceedings Of SPIE, vol.7, June 2011.

[9] Amrinder Kaur, Sanjeev Dewra, "Comparative Analysis of Different Modulation Techniques in Coherent Optical Communication System," IJIRCCE, vol.3,Issue 8,August 2015.

[10] Robert Lange, Berry Smutny, "BPSK Laser Communication Terminals to be verified in Space," IEEE Military Communications Conference, May 2004.

[11] G. Li and P. Yu, "Optical intensity modulators for digital and analog applications," Journal of Lightwave Technology, vol.21, no.9, 2003.

[12] Semjon Schaefer, Werner Rosenkranz, Mark Gregory, "Comparison of Homodyne and Intradyne Detection for Higher-order Modulation Schemes in Optical Inter-satellite Communication Systems," IEEE International Conference on Space Optical Systems and Applications(ICSOS), pp 1-5, 2015.
[13] Yuejang Song, Xuping Zhang,"Investigation of Costas Loop Synchronization Effect on BER Performance of Space Uplink Optical Communication System with BPSK Scheme," IEEE Photonics Journal, vol.7, August 2015.
[14] Hyun-Chul Park, Mingzhi Lu,"40Gbit/s coherent optical receiver using a Costas loop," Optics Express, vol.20, December 2012.
[15] Semjon Schaefer, Werner Rosenkranz, "Costas Loop Based Carrier Recovery in Optical Coherent Intersatellite Communications Systems," IEEE 7th International Congress on Ultra-Modern Telecommuncations (ICUMT), September 2015.