ANALYSIS OF FSO SIGNAL TRANSMISSION USING DENSE WAVELENGTH DIVISION MULTIPLEXING METHOD

DISSERTATION-II

Submitted in partial fulfilment of the

Requirement for the award of the degree

Of

MASTER OF TECHNOLOGY

IN

Wireless Communication

By

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Under the Esteemed Guidance of

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MAY 2017

PAC FORM

TOPIC APPROVAL PERFORMA

TOPIC APPROVAL PERFORMA

School of Electronics and Electrical Engineering

Program : P175::M.Tech. (Electronics and Communication Engineering) [Full Time]

COURSE CODE : ECE521 REGULAR/BACKLOG : Regular GROUP NUMBER : EEERGD0021

Supervisor Name : Rajan Miglani UID : 16957 Designation : Assistant Professor

Qualification : ____________ Research Experience : ____________

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SPECIALIZATION AREA : Communications systems Supervisor Signature: ____________

PROPOSED TOPIC : Analysis of FSO signal transmission using DWDM method

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Final Topic Approved by PAC: Analysis of FSO signal transmission using DWDM method

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4/27/2017 12:18:46 PM

CERTIFICATE

This is to certify that the pre-dissertation titled **Analysis Of FSO signal transmission using DWDM method** that is being submitted by **Ifat Rasheed** in partial fulfilment of the requirements for the award of **Master Of Technology Degree(Wireless Communication)**, is a record of bonafide work done under my guidance. The content of this report, in full or in parts, have neither taken from any other source nor have been submitted to any other Institute or university for award of any degree or diploma and the same is certified.

Mr. RAJAN MIGLANI
ASSISTANT PROFESSOR
(LOVELY PROFESSIONAL UNIVERSITY)

Objective of the Thesis is satisfactory /unsatisfactory

Examiner I **Examiner II**

ACKNOWLEDGEMENT

I would like to thank **LOVELY PROFESSIONAL UNIVERSITY** for giving me opportunity to use their resource and work in such a challenging environment. I am grateful to the individuals whom contributed their valuable time towards my thesis.

I wish to express my sincere and heart full gratitude to my guide **MR. RAJAN MIGLANI** Assistant professor, who guides me to take up this thesis in sync with global trends in scientific approach.

I would also like to extend my gratitude to my friends and family who always encouraged and supported me in this thesis work.

Last but not least, I would like to thank all the staff members of department of Electrical and Electronics engineering who have been very patient and co-operative with us.

IFAT RASHEED

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DECLARATION

I, **Ifat Rasheed,** student of **Master of Technology(Wireless Communication)** under Department of ELECTRONICS ENGINEERING of Lovely Professional University, Punjab, hereby declare that all the information furnished in this dissertation-II report is based on my own intensive research and is genuine.

This dissertation-II, to the best of my knowledge, does not contain any part of my work which has been submitted for the award of my degree without proper citation.

Date:

IFAT RASHEED

Registration No. 11502286

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LIST OF ABBREVATIONS

DWDM	Dense Wavelength Division Multiplexing
WDM	Wavelength Division Multiplexing
FSO	Free Space Optics
LED	Light Emitting Diode
BER	Bit Error Rate
Q factor	Quality factor
PRBSG	Pseudo Random Bit Sequence Generator
SNR	Signal To Noise Ratio

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ABSTRACT

During the last few years, the demand of high speed internet traffic and multimedia services has been increasing tremendously. This increased demand stimulated the use of high capacity networks which focus on enhancing the transmission capacity and coverage area. Free space optics (FSO) being a medium of high bandwidth with maximum data rates is a promising technology for providing maximum transmission rate with minimum errors. The transmission rates provided by FSO are very higher than transmission rates possible by RF technology. To support multiple users and make FSO a reliable commercial technique ,various channels are multiplexed using Dense Wavelength Division Multiplexing technique. In this paper, different DWDM systems varying in terms of number of channels are designed and the effect of increase in number of channels with respect to increase in FSO length is observed. The DWDM system showing best performance than the other systems is evaluated for further investigations.

The main objective is to vary the system parameters like number of channels, attenuation, FSO range, type of modulation etc and observe the effect on performance evaluating parameters such as BER .The effect of increase in number of users with respect to increase in FSO length is investigated. The work includes the use of Compensation techniques (Pre- ,Post & symmetric) and hybrid amplifiers like EDFA, SOA in FSO based DWDM system to increase the range of FSO. Also , the effect of varying channel spacing between the channels with the variation in FSO length is carried out

It was observed that while analyzing the effect of increase in number of channels ,30 channel system performs best followed by 40,50 & 60 channel setups.The pre, post and symmetric compensation techniques for NRZ link using dispersion compensated fiber(DCF) for 30 channel setup are analysed and a comparative analysis between systems employing different compensation techniques is made. The simulation results indicate that the post-compensation scheme having a minimum BER value of 10^-63 at 1 km FSO length is superior followed by pre compensation, symmetric compensation and uncompensated models with minimum BER values as 10^-57,10^-18 & 10^-29 respectively at 1 km, the use of compensation techniques increased FSO range from 2km to 5km.

CHAPTER 1
INTRODUCTION

1.1 Free Space Optical Communication

In the present era where communication has bought a revolution, high speed networks are highly required which thus focus on increasing the transmission capacity and coverage area. Free space optical communication is one of the most promising technology for providing transmission rates that are very higher than transmission rates possible by RF technology[1]. Free space optical communication (FSO) has a combined properties of wireless and optical fiber and is called as optical wireless communication or laser com (laser communication).FSO is an optical communication technique in which line of sight is used to meet the demand of high bandwidth over short distances[2].An optical modulated data is transmitted by FSO using a visible or IR band of frequencies which are unlicensed part of the spectrum and hence there is no need to pay any charges to the government agencies .This property of FSO system makes it cost efficient technique.

Besides the combined properties of fiber optics and wireless in FSO, the difference lis in the transmission medium. FSO uses air/space as a transmission medium while fiber optics uses glass fiber as a transmission medium[1]. Therefore, the light pulses instead of transmitting through glass of fiber are transmitted through atmosphere.

Free space optical communication is cost efficient, flexible, simple and have easy installation. Since the transmission medium used in FSO is atmosphere, hence, digging of earth for fiber laying is not required ,this results in both the time and cost efficient nature of FSO technique.

The use of Atmosphere as a transmission medium in FSO limits its performance due to the atmospheric turbulences that limit this technique to short range distances. The atmospheric turbulences include rain, dust, fog, snow, smoke and scintillations. These atmospheric turbulences deteriorate the performance of FSO link. To remove these shortcomings, some techniques have been introduced. These techniques include diversity, aperture averaging and the use of optical amplifiers for amplification of signal[2].

Optical amplifiers can be deployed for optical amplification of signals and these optical amplifiers include Raman, SOA, or EDFA (Erbium dopped fiber amplifier). EDFA is the most commonly used optical amplifier and due to its high gain and bandwidth it is used for multiple wavelength amplification or in other words it can be deployed in WDM networks easily.

The increase in the number of channels and reducing the spacing between the channels results in the increase in the capacity of the system and hence the increased demand of broader bandwidth is met. This fact led to the introduction of wavelength division multiplexing (WDM) technique in FSO communication. Therefore the increased demand of broader bandwidth is achieved by using WDM based FSO communication [3].

1.1.2 Working

Free space optical communication uses two transrecievers at both the ends for providing full duplex communication. The network traffic is first converted into the pulses of invisible light representing binary 1's and 0's. Infra red waves are generated by LED and Laser diodes at a transmitter side that act as a carrier for data transmission.

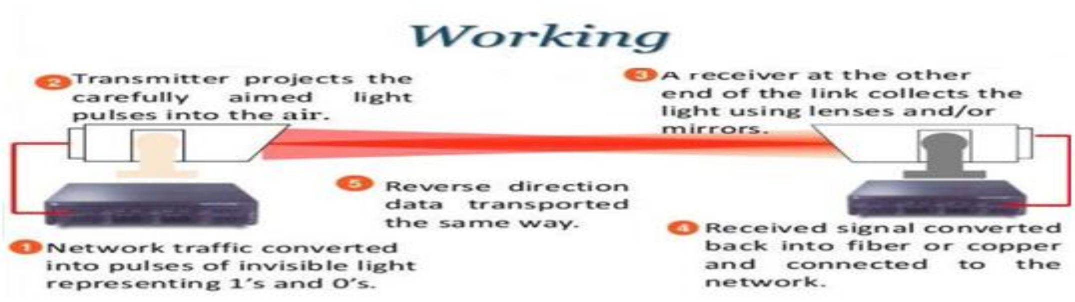


Fig 1.1.FSO Overview

1.1.3 Block diagram of FSO

The block diagram of FSO is shown in figure 1.2

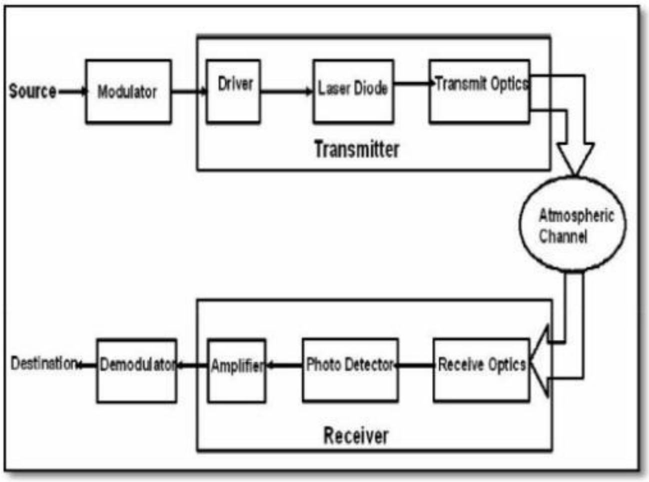


Fig 1.2 Block diagram of a terrestrial FSO system [3]

The components of block diagram of FSO communication system are explained as follows:

(i) Transmitter:

The transmitter is primarily concerned with the modulation of the source data. The modulation is done by using optical signal as a carrier and intensity modulation is the most common type of modulation used. Intensity modulation refers to the modulation of source data where irradiance of optical signal is used as a carrier wave. This modulation can be performed either directly by an external modulator (like symmetric Mechzender interferometer) or by directly changing driving current of optical source in response to the transmitter information[3].

(ii) Atmospheric channel:

An atmospheric channel is composed of gases, aerosols and suspended tiny particles. Some atmospheric turbulence includes rain, dust, fog, snow and scintillations.

(iii) Receiver: Receiver retrieves the source data from incident optical field. The components of receiver are receiver telescope, optical band pass filter, and photo detector and decision circuit / post demodulation process.

1.1.4 Advantages of FSO:

(i) FSO technique does not require any RF license from any of the agencies, as the signal is optically modulated.

(ii) There is no interference of the signal by the radio frequencies ,hence, fewer disruption to the information flow.

(iii) Digging of streets and no expensive rooftop installation is needed.

(iv) No security upgrades are required as there is a line of sight based communication.

(v) The data rates provided by FSO channels is very high as compared to that of the RF links and it operates on the frequency range of up to 3THZ.

1.1.5 Applications of FSO:

FSO links are used in a number of fields. Some of the applications are described below:

(i) Outdoor wireless access: FSO do not require any license from any agency, hence, it can be used for communication by wireless service providers.

(ii) Last mile access: To dig the streets for fiber laying in the last mile is very costly, FSO can be implemented in the last mile along with other networks.

(iii) Enterprise connectivity: FSO being an easily installing technique is used for interconnecting LAN segments to enable communication between two buildings etc.

(iv) Fiber backup: In case of a failure transmission through a fiber link, FSO can be used in providing a backup link.

(V) **Military access:** FSO being a secure and undetectable technique can connect large areas safely with minimum planning.

1.2 Multiplexing In Optical Networks

Multiplexing is a technique of combining multiple message signals into a single composite signal for transmission over a shared medium. To transmit several signals over the same medium, and separate these signals easily at the receiver end, the signals must be kept apart so as to avoid the interference between the signals.

Due to the higher bandwidth of optical fibres, the high speed data and video applications prefer to get transmitted through such a medium .There are several types of multiplexing and the two most commonly used are Wavelength division multiplexing and Time division multiplexing.

Since digital signal transmission is best supported by optical fibre, electronic parallel to serial converters like Agilent G-link or cypress Hotlink are used for the time division multiplexing of many low rate digital information. Many low speed data signals are merged into a composite high rate channel for transmission and is then regenerated at the receiver end.

Wavelength division multiplexing is a technique of transmitting multiple wavelengths on a single optical fibre. Multiple wavelengths of light like different colours propagate through a single optical fibre without interfering each other [5]. Such Devices that perform the optical combining at the transmitter side and the optical separation at the receiver side are called as WDMs.

1.2.1 Need Of Multiplexing

Since the bandwidth of communication media is very large and it has been observed that most of the devices involved in the communication of individual data signals utilize medium data rate. As a result, whole capacity of data link is not utilised. Hence, when the bandwidth of communication media is much higher than the single data signals that are to be transmitted via medium, medium can be shared by the multiple transmitting signals so as to make effective utilisation of available channel capacity. Multiplexing also results in cost reduction, simplification of driver electronics and direct interface with the microprocessors [6].

1.2.2 Types Of Multiplexing

The property of higher bandwidth of optical fibre makes it a preferred medium for the propagation of high speed data and video applications. Different types of multiplexing are needed to make use of this bandwidth [6]. The most common forms of multiplexing are Wavelength division multiplexing and Time division multiplexing.

1.2.2.1 Time Division Multiple Access

Time division multiplexing is a type of multiplexing in which the data is transmitted and received over a common individual channel by the use of synchronised switches on both the ends of transmission medium, as a result of which the transmitted signals appear on a medium in an alternating manner only a fraction of time. Time division multiplexing is mainly used for digital signals, but analog signals can also be multiplexed by using time division multiplexing in a way that multiple data signals are transmitted such that they appear as sub–channels simultaneously in a single communication channel, but physically take turns on the channel. The Time domain is divided into various repeated time slots having fixed length, and one time slot per sub-channel. During time slot 1, a data signal of sub-channel 1 is transmitted, during time slot 2, a data signal of sub-channel 3 is transmitted etc. One time slot per sub-channel a synchronisation channel and sometimes error correction channel before the synchronisation constitute one TDM frame channel.

Time division multiplexing is a technique of accessing a channel for shared medium networks. Different users are allowed to share a common frequency channel by dividing the signal into several time slots [7]. The users transmit the data successively, each utilising its assigned time slot .This results in the sharing of common communication medium by the multiple users making use of only the part of medium capacity.

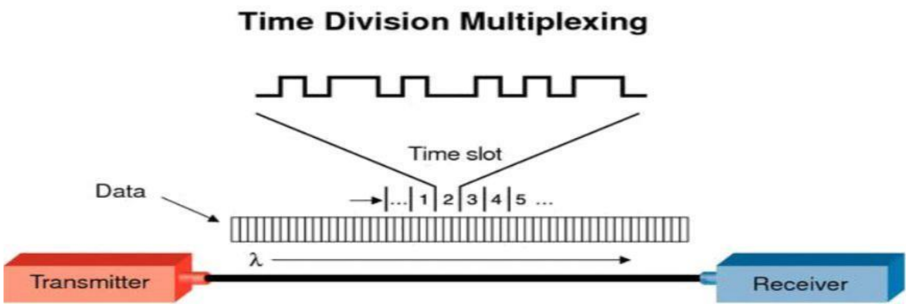


Fig 1.3 Time division multiplexing [8]

1.2.2.2 Wavelength Division Multiplexing

In order to meet the increasing demand of large amounts of bandwidth, the capacity of optical fibres was found to be insufficient by the services like high internet traffic (video conferencing and streaming audio) and multimedia services. Time division multiplexing has been used to increase the capacity but due to some of its drawbacks like allowing multiplexing only up to 10 Gb/s lead to the introduction of wavelength division multiplexing in the field of telecommunication. Wavelength Division Multiplexing is one of the most promising technology that can utilise the available bandwidth of the fibre.

Wavelength Division Multiplexing is associated with the division of optical transmission spectrum into several number of non-overlapping wavelength bands, such that each wavelength supports an individual communication channel operating at highest electronic speed[9]. Therefore, the huge bandwidth can be utilised by the different wavelengths that exist simultaneously on a single optical fibre.

Wavelength Division Multiplexing is a method of multiplexing various optical carrier signals having different operating wavelengths (like different colours of laser light).This technique results in bidirectional communication over a single optical fibre and also result in the multiplication of capacity.

A wavelength division multiplexing system consists of a multiplexer at the transmitter side that combines the multiple signals from the multiple users and a demultiplexer at the receiver side that seperates the signals at the receiver end.

Most of the WDM systems are used in single mode fibres having a core diameter of 9µm. However, some forms operate in multimode fibres having a core diameter of 50µm or 62.5µm[10].

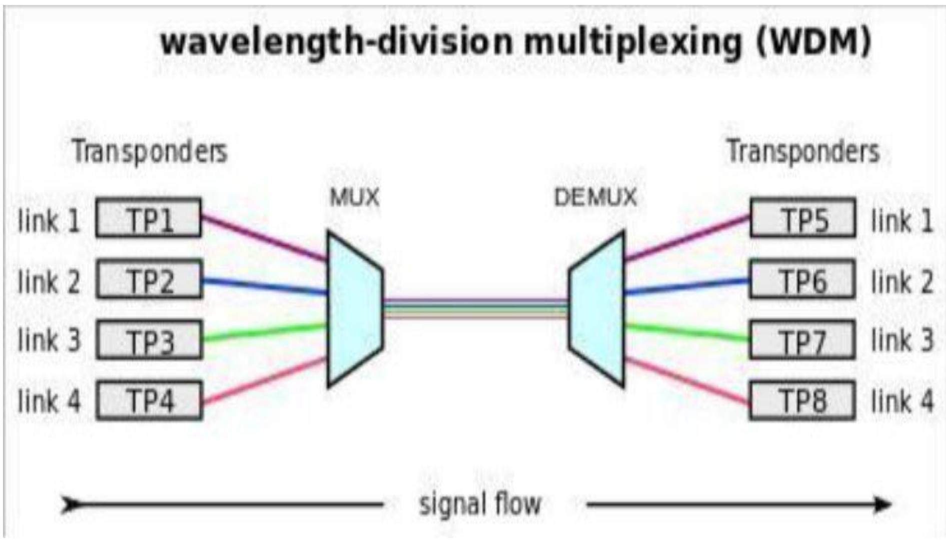


Fig 1.4 Wavelength Division Multiplexing [11]

1.3 Types Of WDM

Depending on the channel spacing, WDM systems are classified in the following classes:

(a) Simple WDM: This kind of WDM is made by using very simple and less costly components and this principle is being used by a number of applications from a number of years.

(b) Dense WDM: This type of WDM has channel spacing less than 1 nm, Hence, it refers to the close spacing of channels.

(c) Coarse WDM: This type of WDM has channel spacing of more than 5nm, hence, the number of channels is lesser than in dense wavelength division multiplexing (DWDM) and greater than in standard wavelength division multiplexing (WDM).

1.4. Development Of DWDM Technology:

The concept of Wave Division Multiplexing in optical fiber communication was introduced in the late 1980's where two broadly spaced wavelengths in the regions of 1310 nm & 1550 nm (or 850 nm & 1310 nm) were used, this is sometimes known as wide band WDM[3]. The second generation of WDM called as Narrow Band WDM was introduced in early 1990's,which supported two to eight channels having a channel spacing of about 400 GHZ in the 1550 nm window. After that, Dense Wavelength Division Multiplexing (DWDM) evolved in the mid-1990's, supporting 16 to 40 channels having channel spacing from 100 to 200 GHZ. However , in the late 1990's, the advancements in DWDM led to the support of 64 to 160 parallel channels having dense packing at 50 or even 25 GHZ intervals[12].

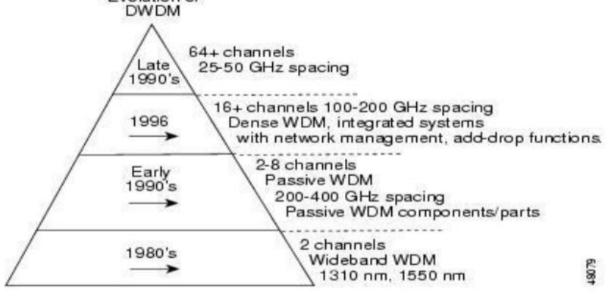


Fig 1.5 Development in DWDM technology[12]

CHAPTER 2

LITERATURE REVIEW

For completion of my thesis, following research articles were referred and followed primarily;

1) SOORAJ PARKASH, ANURAG SHARMA, HARSUKHPREET SINGH & HARJIT PAL SINGH,(2016), This research article is about the demonstration of a DWDM based FSO communication system working on 8 channels with channel spacing of 0.8 nm and each channel having a data rate of 5 GB/s such that the overall data rate of a system is 40 GB/s . The range of FSO link is 4km. The study also concludes that bit error rate increases sharply when the range of FSO is increased beyond 4km[2].

2)SIMRANJIT SINGH & R.S.KALER,(2014), This paper presents the design of novel flat-gain amplifier using a hybrid combination of Er-Yb co-doped amplifier (EYDWA) and a semiconductor optical amplifier (SOA) for 100*10-Gb/s dense wavelength division multiplexed system at 0.2 nm interval as a result of which a flat gain of >14 dB is obtained across the effective bandwidth with a gain variation of 0.75 db without using any gain clamping techniques. This proposed hybrid amplifier reduce the gain of DRA-EDFA HOA from approximately 2.01 to 1.15 dB efficiently. Hence, resulted in improved performance in terms of cost, gain flatness etc [13].

3)XIAOJIE GUO & CHESTER SHU,(2014), In this paper ,backward Raman pump has been used to reduce the cross gain modulation for multi wavelength amplification in a fiber optical amplifier (FOPA) and a comparison is made between the performances of two wavelength amplifications of FOPA's with and without Raman pump under the condition of identical unsaturated gains. This resulted in the reduction of cross gain modulation of one channel due to the presence of other WDM channel having high input power as compared to the conventional FOPA having identical unsaturated gain. Hence,a power penalty of 6.3 dB is obtained for a 10-Gb/s RZ-OOK signal at a BER of 10^{-8} [14].

4)MAHMOUD JAZAYERIFAR, STEFAN WARM,ROBERT ELSCHNER, DIMITAR KROUSHKOV et al (2013), The authors have derived the analytical expressions for the performance of long-haul DWDM communication system employing in-line phase sensitive fiber optic parametric amplifiers(FOPA).The errors due to transmission fibers and FOPA’s are considered and the model is then verified using simulations. The performance of FOPA is compared with EDFA and it is observed that the broad band long haul DWDM transmission system based on FOPA’s could be feasible[15].

5) HARDEEP SINGH & SUKHWINDER SINGH (2014), This paper investigates the performance of hybrid amplifiers- RAMAN-EDFA ,RAMAN-SOA,EDFA-SOA in WDM systems having 120 channels, with each channel having data rate of 10 Gb/s and reduced channel spacing of 50 GHZ. The performance has been compared by varying the different parameters like fiber length, Q factor, BER etc and it is observed that RAMAN-EDFA is the best alternative to RAMAN-SOA & EDFA-SOA in high capacity WDM system with reduced channel spacing[16].

6) XIAOJIE GUO & CHESTER SHU,(2015), The authors investigated both theoretically and experimentally the reduction of four wave mixing crosstalk in multi-wavelength amplification in backward pumped Raman assisted fiber optical parametric amplifier (FOPA).A suppression of more than 7 dB in FWM crosstalk initiated from both degenerate –FWM and non degenerate –FWM has been obtained. The authors also described the effects of signal channel number and the powers of the parametric pump and the Raman pump on the FWM crosstalk[17].

7) SIMRANJIT & R.S.KALER, (2013), This paper provides the demonstration of an efficient gain-flattened L-band optical amplifier using a hybrid configuration of distributed Raman amplifier(DRA) and an erbium-doped fiber amplifier (EDFA) for 160*10 Gb/s dense wavelength division multiplexed system at 25-GHZ interval. A flat gain of >10dB is obtained with an input signal power of 3 mW across the frequency range from 187 to 190.975 THZ having a gain variation of <4.5 dB without the use of any gain flattening technique [18].

8) THOMAS TOROUNIDIS,(2003),This paper demonstrates experimentally the performance of fiber optical parametric amplifier(FOPA) in WDM applications for the first time. The authors investigate both 3 * 10 GB/s and a commercial 7*2.5 Gb/s WDM system with the parametric amplifier. This paper also presents the performance in terms of power penalty and gain versus input-output signal power [19].

9) M.F.C STEPHENS,(2015),The authors of this paper demonstrate experimentally a Raman Assisted Fiber Optical Parametric Amplifier(RA-FOPA) having 20 dB net gain using WDM signals .They also reported amplification of 10*58 Gb/s 100 GHZ-spaced QPSK signals and showed that the gain improvement of upto 5 dB can be obtained for the RA-FOPA by properly tuning parametric pump and compared with the combined individual contribution from the parametric and Raman pumps. Also, RA-FOPA is compared with a conventional FOPA having same gain and it was observed that the four wave mixing crosstalk is suppressed upto 5.8±0.4 dB using RA-FOPA[20].

10) E.CIARAMELLA,Y.ARIMOTO,G.CONTESTABILE,M.PRESI,A.D ERRICO,V.GUARINO & M.MATSUMOTO ,(2009), This paper provides the highest transmission rate of 32*40 Gbps that is four times greater than the results obtained in the previous studies. The system is also upgraded to its highest capacity of 1.28 Terabit/s which was the highest capacity obtained than the capacity obtained in the previous results[21].

11) VISHAL SHARMA,GURIMANDEEP KAUR, (2013), The authors of this paper analysed the architecture of multipath fading resistant fading communication system using OFDM multicarrier scheme along with OTSB (optical tandem side band) and OSSB (optical single side band) schemes. This system provided a great flexibility in the atmospheric turbulences like fog, haze etc that affect the performance of FSO communication system and hence resulted in increase in the transmission rate. The study also reveals that due to the large immunity against fading, the performance of OSSB is better than OTSB at high data rates[22].

12) SOORAJPARKASH, ANURAG SHARMA,MANOJ KUMAR & HARSUKHPREET SINGH,(2015) , In this paper, a WDM-PON(wavelength division multiplexing- passive optical network) based FTTH (fiber to the home) is designed aiming to offer the high data rates (GB/S) to the residential subscribers and the data rate transmission was upgraded to 20*32 GB/S(640 GB/S).Also, The appreciable values of bit error rate are obtained[23].

13) G.NYKOLAK,P.F.SZAJOWSKI,A.CASHION,H.M.PRESBY, G.E.TOURAGEE & J.J.AUBORN, The authors of this paper obtained the data rate of 40Gb/s over a free space optical link of 4.4 km in a DWDM based FSO communication system. The designed system works on 16 separate channels having 200Ghz of channel spacing between them[24].

14) JASVIR SINGH,PUSHPA GILAWAT &BALKRISHNA SHAH,(2014), In this paper, a WDM based FSO communication system is developed. The system supports 32 channels ,each having a data rate of 40 Gbps over a range of 1km of FSO link using NRZ and RZ line coding. The results also showed that NRZ performs better than RZ line coding technique[25].

15) AMNINDER KAUR,SUKHBIR SINGH & RAJEEV THAKUR,(2014), This paper includes review of free space optics. In this paper, the authors have discussed FSO and its need, improvements that can be made in FSO technique and the use of FSO technology in DWDM systems. The various parameters that limit the performance of FSO system like atmospheric turbulences including scintillation losses, fog attenuation etc have also been discussed[26].

16) POOJA KUMARI & RAJEEV THAKUR,(2013), The authors in this paper proposed the use of hybrid amplifiers in FSO system. FSO technique has been discussed in detail . Different types of hybrid amplifiers, their features and comparison are discussed . It has been observed that the Raman –EDFA[27] .

17) S.GUIZANI, A. CHERITI, M. RAZZAK, Y. BOUSLIMANI & H.HAMAM,(2005), The authors in this paper incorporated a post-compensation technique to optically compensate the chromatic dispersion in fiber. A temporal effect is used by a fiber having a range beyond 40G/bits[28].

18) RAJANI, RAJU PAL & VISHAL SHARMA, (2012), In this paper, various compensation techniques including pre-compensation, post- compensation and symmetric compensation are used by using standard mode fiber and dispersion compensated fiber and a comparative analysis between these compensation techniques is made at data rate of 10/15 Gbps at different modulation formats and different optical power levels. It was observed that post and symmetric compensated systems showed better results[29].

19) MOHAMMAD ALI KHALIGHI,MURAT UYSAL,(2014), In this paper, a detailed theoretical information about FSO channel models and transmitter/receiver structure have been discussed by the authors. The limitations of FSO system and algorithmic level system designs have been discussed to overcome these limitations[30].

20) ALLA ABBAS KHADIR, BAYDAA F.DHAHIR & XIQUAN FU,(2014), In this paper, the simulation of various systems using different techniques by optisystem program is discussed. The main aim of authors is to make the use of optisystem clear to the ones who are not aware of it. Various simulation models like DWDM system, DCF system , DBM system have been designed and simulated by the author using optisystem program[31].

21) ANKITA SHIVHARE, ANKITA MOWAR &SONI CHIGLANI,(2015),In this paper, the authors demonstrated the behaviour of optical wireless communication system by varying the aperture of FSO link. The simulation results indicate that the variations in FSO aperture result in improving distance of FSO[32].

22) VISHAL SHARMA,MINI LUMBA & GURMANDEEP KAUR,(2014),In this paper, authors have demonstrated CDMA-FSO coherent detection system with 10 Gbps data rate and reasonable SNR under the effect of atmospheric turbulences like rain, snow etc[33].

(23) SHAO HAO WANG, LIXIN XU,P.K.A.WAI & HWA YAW TAM,(2011), In this paper, the authors investigated the gain of Raman assisted fiber optical amplifier. Also, a normalised phase-matched model is proposed to achieve the performance of peak value of gain of RA-FOPAs that operate in low magnitude region [34].

(24) R.S.KALER,AJAY K SHARMA & T.S.KAMAL,(2002), The authors in this paper have demonstrated the compensation schemes (pre-,post-,symmetric) in a system with 10Gbps data rate &NRZ modulation by using single mode fiber & dispersion compensated fiber to achieve transmission at high data rates. It is observed that symmetric compensation is superior followed by post-,& pre compensation schemes [35].

(25)MANPREET KAUR,HIMALI SARANGAL,(2015),In this paper compensation techniques are used to investigate 40 Gbps WDM system by using dispersion compensated fiber. Also, comparative analysis is made at the receiving side with respect to variation in different parameters[36]

(26) MANPREET KAUR,HIMALI SARANGAL,(2015), In this paper, authors have compensated the dispersion of a fiber by using dispersion compensated fiber at 20 Gbps. Three compensation schemes(pre- ,post- & symmetric-) have been used and a comparative analysis between these schemes is made[37].

CHAPTER 3

RATIONALE & SCOPE OF THE STUDY

3.1 Rationale :

- FSO communication is the promising technology for providing maximum data rates with minimum errors.
- In the past years, the use of optical fibers proved to be a very costly technique. FSO, on the other hand do not require any spectrum fees, henceforth, a cost efficient technique.
- DWDM allows multiplexing of signals that can provide data rates upto 100 Gbps. Therefore, transmission at maximum data rates is possible.
- DWDM leads to interference and losses due to many reasons like less channel spacing etc
- Compensation schemes are proposed to combat the losses that occur due to minimum channel spacing or that are incurred in the atmospheric channel. Pre-, Post and symmetric compensation schemes are used to deliver the data at reasonable BER values.

3.2 SCOPE OF THE STUDY:

- Free space optical links are highly affected by atmospheric degrading effects like rain, snow , fog, turbulence etc which reduces the effective line of sight link length.
- DWDM allows multiple users to provide a high data rate communication and if the same is used with FSO, then optical signal can reach the end user.
- Tuning of hybrid optical amplifiers to support FSO signal .
- To design FSO-DWDM system which can deliver reasonable performance over long distances.
- To design FSO-DWDM system to operate with higher number of multiplexed users to ensure higher bandwidth and capacity utilization.
- To investigate the performance of FSO-DWDM link for reduced channel spacing.
- To investigate the effect of pre-,post-, and symmetric compensation techniques in improving the link reliability.

CHAPTER 4

OBJECTIVES OF THE STUDY

- To investigate the performance of FSO link using DWDM technique .
- To evaluate and design suitable FSO-DWDM link using compensation techniques to enhance link reliability.
- To evaluate performance of FSO-DWDM link for reduced channel spacing using different optical modulation techniques.
- To optimise FSO-DWDM link so that desired link characteristics can be maintained for data rates higher than 10Gbps.
- To design FSO-DWDM link that can support multiple users in excess of 30 in number for decreased values of channel spacing.

CHAPTER 5

RESEARCH METHODOLOGY

This chapter describes the methodology and the approaches that were followed to complete this research work. The whole research work revolves round the simulation software-Optisystem(version 7.0).The primary aspect of the methodology includes the process of simulation. The main aim of simulation is to design different DWDM systems with FSO transmission link varying in number of channels and to apply the use of hybrid amplifiers and compensation techniques for increasing the transmission distance. The number of channels are varied as 30, 40, 50 and 60 and the transmission distance is varied from 1 km to 5 km. The system with 30 channels showed better performance followed by 40, 50 and 60 channel systems and this 30 channel system is considered for further study. The compensation techniques used are pre-compensation, post-compensation and symmetric compensation. A Hybrid combination of EDFA and SOA amplifiers are also used in a DWDM system and the performance of system is evaluated. The study also includes the variation of various parameters including attenuation, channel spacing, data rates, modulation format with respect to the change in FSO length and observing the effect on performance of the system.

The dissertation was completed in the following stages:

5.1 Dispersion Compensation Techniques:

5.1.1 Design of different FSO based DWDM systems varying in number of channels without use of any compensation technique-Uncompensated simulation model:

A simple 30 channel DWDM system was designed by simulating a DWDM transmitter with DWDM receiver using FSO channel as a transmission medium. The system was redesigned and upgraded for 40, 50 and 60 channels also. The simulation was done using optisystem (version 7). The performance of these systems is evaluated with respect to change in FSO length and It was observed that the 30 channel system showed better performance followed by 40, 50 and 60 channel systems. Henceforth, 30 channel system is considered for further study.

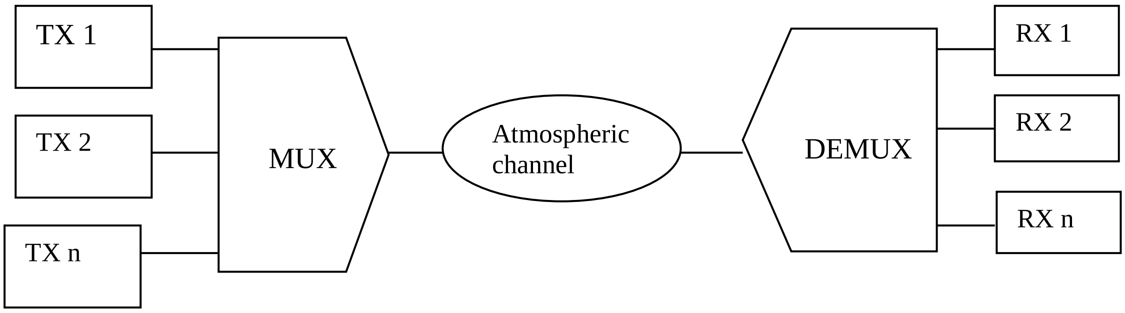


Fig 5.1.1 Uncompensated DWDM system with FSO channel

5.1.2 Design of a 30 channel FSO based DWDM system incorporating Pre-compensation technique :

A 30 channel DWDM system was designed in which FSO link was introduced as a communication medium and a dispersion compensated fiber (DCF) was deployed before FSO link to remove the losses that occur due to dispersion. A negative dispersion optical fiber is termed as Dispersion Compensated Fiber. The design of a Dispersion Compensated Fiber involves upgrading a standard mode fiber (SMF) by taking its dispersion value as negative so that an ordinary fiber can get its positive dispersion value compensated.

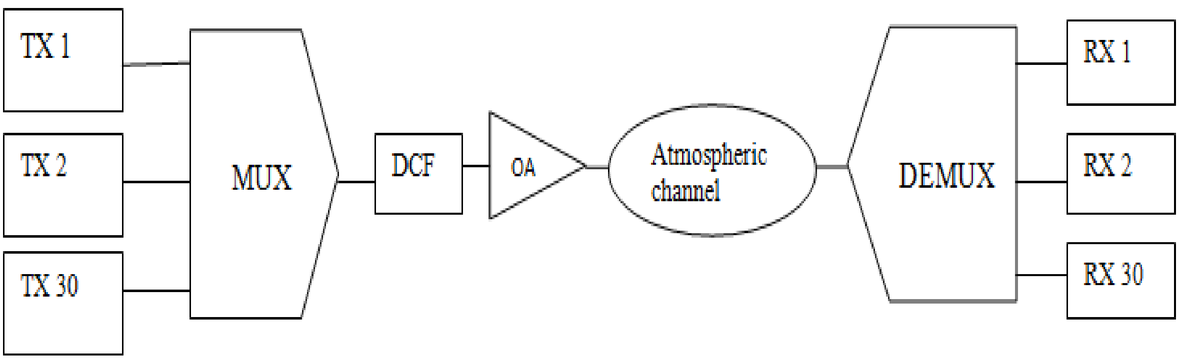


Fig 5.1.2 Pre- compensated DWDM system with FSO channel where OA is Optical amplifier & DCF is dispersion compensated fiber

5.1.3 Design of a 30 Channel FSO Based DWDM system incorporating a Post-compensation technique:

A 30 channel DWDM system was designed by incorporating a dispersion compensated fiber after the FSO channel. The role of using dispersion compensated fiber is to compensate the positive value of dispersion of an ordinary fiber by setting its dispersion as a negative value. The FSO length is varied from 1 km to 5 km and the effect on the performance of the system is evaluated in terms of performance evaluating parameter called as Bit Error Rate (BER).Post- compensation technique when employed in FSO based DWDM system showed better performance than the other compensation techniques.

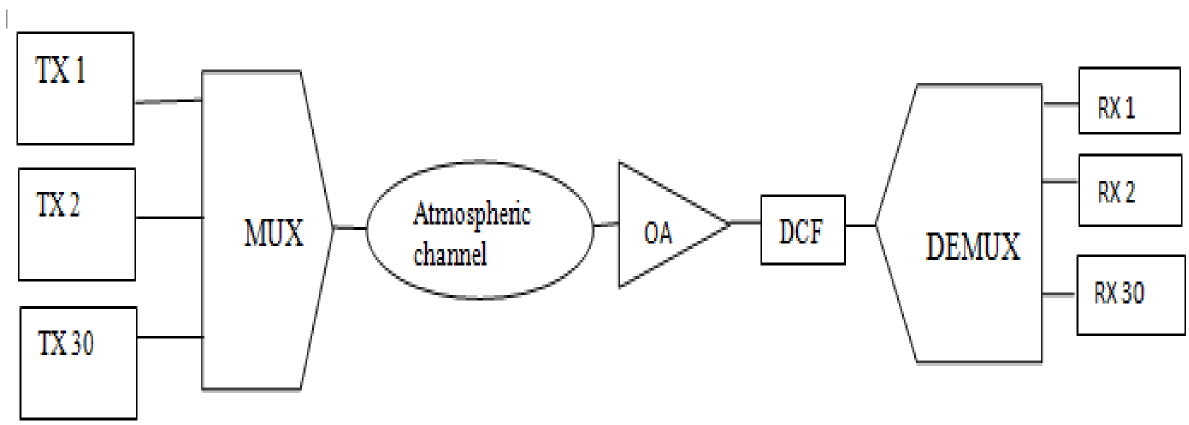


Fig 5.1.3 Post- compensated DWDM system with FSO channel where OA is Optical amplifier & DCF is dispersion compensated fiber.

5.1.4 Design of a 30 Channel FSO Based DWDM system incorporating a Symmetric-compensation technique:

A 30 channel DWDM system is designed in which FSO link is taken as a transmission medium and pre-post compensation technique (symmetric compensation) is applied in the system. A dispersion compensated fiber is incorporated before the FSO channel and after the FSO channel to compensate the positive dispersion values and the performance of the system is evaluated in terms of BER values.

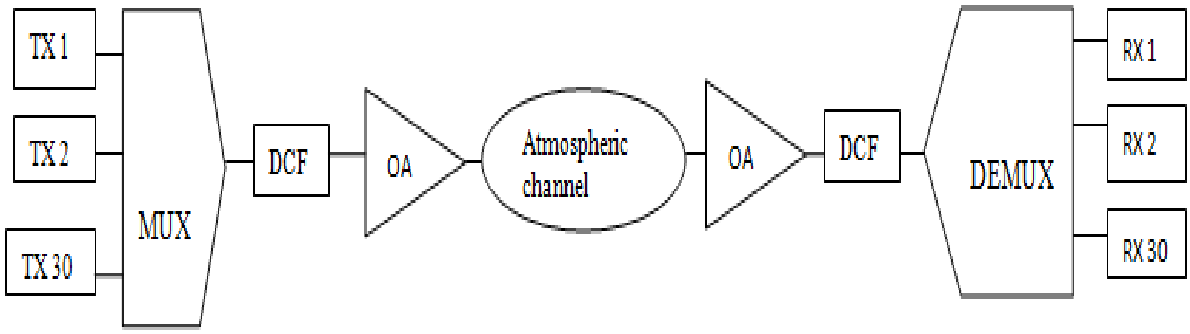


Fig 5.1.4 Symmetric - compensated DWDM system with FSO channel where OA is Optical amplifier & DCF is dispersion compensated fiber.

5.2 Amplification/ Hybrid Amplification:

5.2.1 Design of a 30 channel FSO Based DWDM system using Semiconductor Optical amplifier (SOA):

A 30 channel DWDM system using FSO link as a transmission medium and semiconductor optical amplifier for compensating the losses incurred in the communication channel is designed. Therefore, 30 data streams when combined in a composite signal and send through FSO channel is amplified by using SOA which ensures that the SNR levels are boosted to compensate the losses.

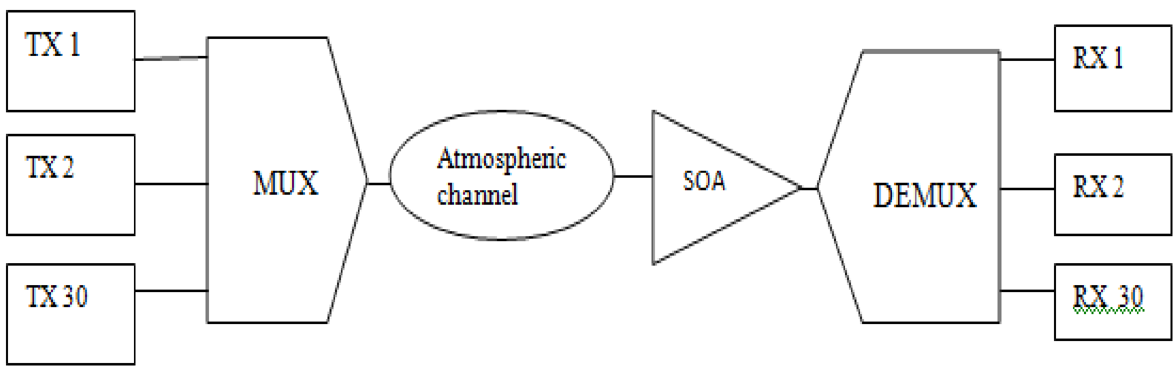


Fig 5.2.1 DWDM system with FSO channel & SOA, where SOA is Semiconductor Optical amplifier

5.2.2 Design of a 30 channel FSO Based DWDM system using Erbium Dopped Fiber Amplifier (EDFA):

A 30 channel DWDM system is designed in which atmospheric channel acts as a transmission medium and Erbium dopped fiber amplifier (EDFA) is incorporated for amplifying the signal obtained after multiplexing various data streams and passed through FSO channel. The role of EDFA is to amplify the signal and compensate the losses incurred by FSO channel. The performance of the system is evaluated in terms of BER value.

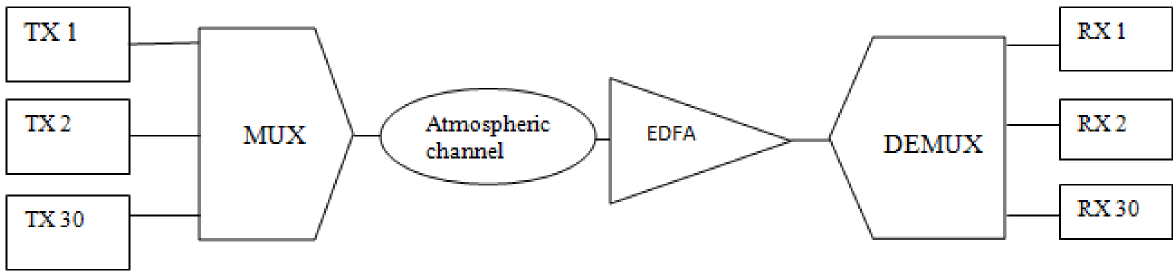


Fig 5.2.2 DWDM system with FSO channel & EDFA, where EDFA is Erbium Dopped Fiber amplifier .

5.2.3 Design of a 30 channel FSO Based DWDM system using hybrid combination of Erbium Dopped Fiber Amplifier & Semiconductor Optical Amplifier (SOA):

A 30 channel DWDM system with FSO link and a hybrid combination of EDFA and SOA amplifiers was designed. The role of using hybrid amplifiers is to amplify the signal and censure that the SNR value is boosted to compensate the losses incurred in FSO channel. The performance of the system is evaluated and a comparative analysis between the systems using SOA, EDFA and hybrid combination respectively is made graphically.

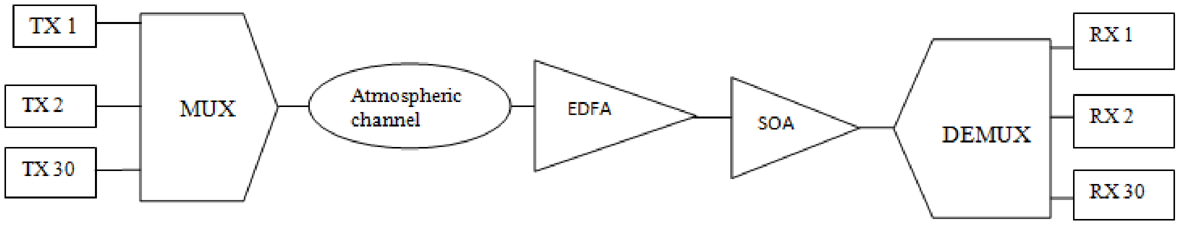


Fig 5.2.3 DWDM system with FSO channel & Hybrid amplifier EDFA+SOA, where EDFA is Erbium Dopped Fiber amplifier & SOA is Semiconductor optical Amplifier.

CHAPTER 6

Results and Discussions

6.1 Simulation Setups

Various setups were designed and validated using optisystem 7.The proposed designs and their results are listed in the following sections:

6.1.1 Design of Different FSO based DWDM systems varying in number of channels:

(1) FSO trans-receiver for 30 channels:

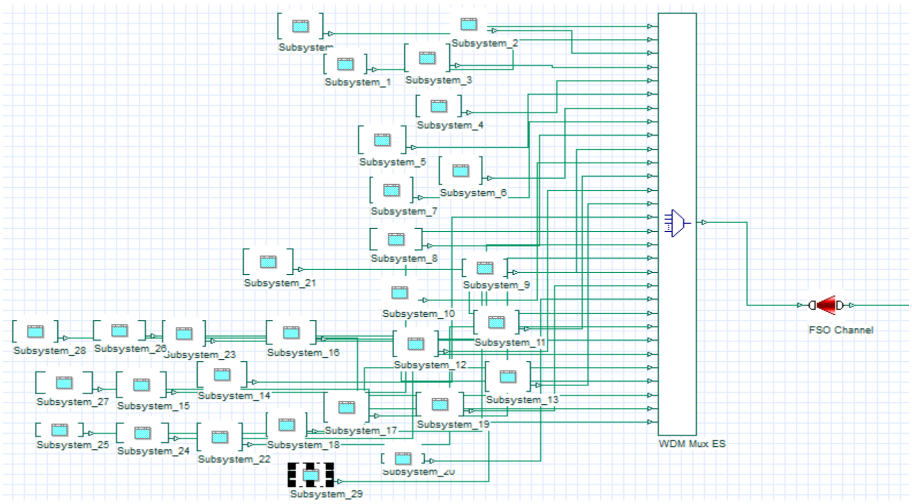


Fig.6.1.1(1) (a) transmitter section

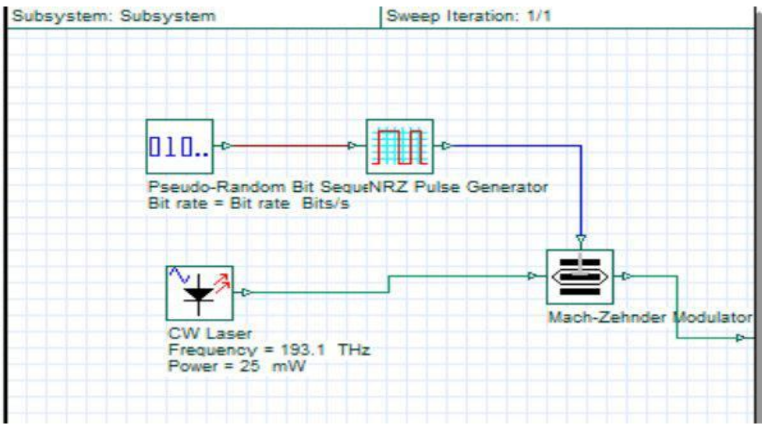


Fig 6.1.1(1) (b) Transmitter Sub-System

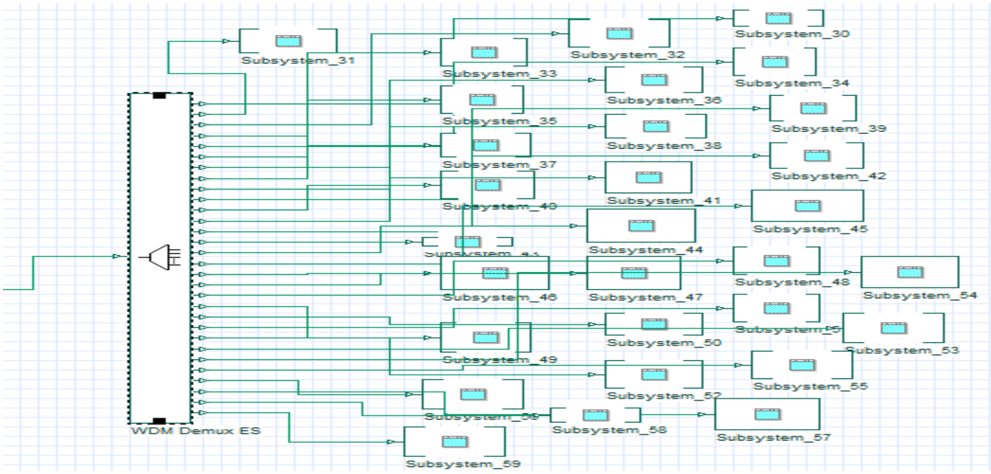


Fig 6.1.1 (1) (c) Receiver section

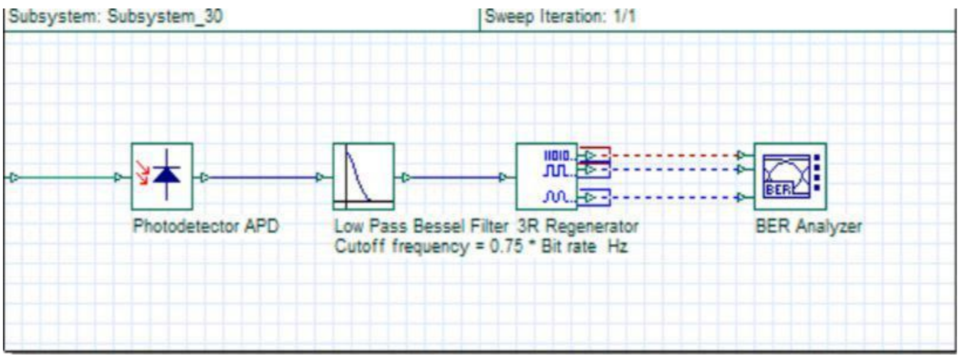


Fig 6.1.1(1) (d) Receiver Sub-System

In above figures, an FSO system was designed for 30 data channels. The individual data channels were simulated at different CW LASER frequencies with a mutual frequency spacing of 0.8nm.The data channels after going through electrical and optical modulation techniques are multiplexed using 30X1 WDM MUX and then the composite optical signal is transmitted through FSO channel. The systems are optimized in layout using transmitter subsystems and receiver subsystems as shown in figures (b) & (d). The intercepted signal at receiver is de-multiplexed using 1X30 WDM De-MUX and then detected back using PIN photo-detectors and electrical filters to retrieve back the original baseband. The system performance is evaluated using spectral analyzers and BER analyzers.

(2) FSO trans-receiver for 40 channels:

The same simulation model of 30 channels was redesigned and upgraded for 40 channels . An FSO system was designed for 40 data channels. The individual data channels were simulated at different CW LASER frequencies with a mutual frequency spacing of 0.8nm.The data channels after going through electrical and optical modulation techniques are multiplexed using 40X1 WDM MUX and then the composite optical signal is transmitted through FSO channel. The systems are optimized in layout using transmitter subsystems and receiver subsystems as shown in figures 7.1.1(1) (b) & (d). The intercepted signal at receiver is de-multiplexed using 1X40 WDM De-MUX and then detected back using PIN photo-detectors and electrical filters to retrieve back the original baseband. The system performance is evaluated using spectral analyzers and BER analyzers.

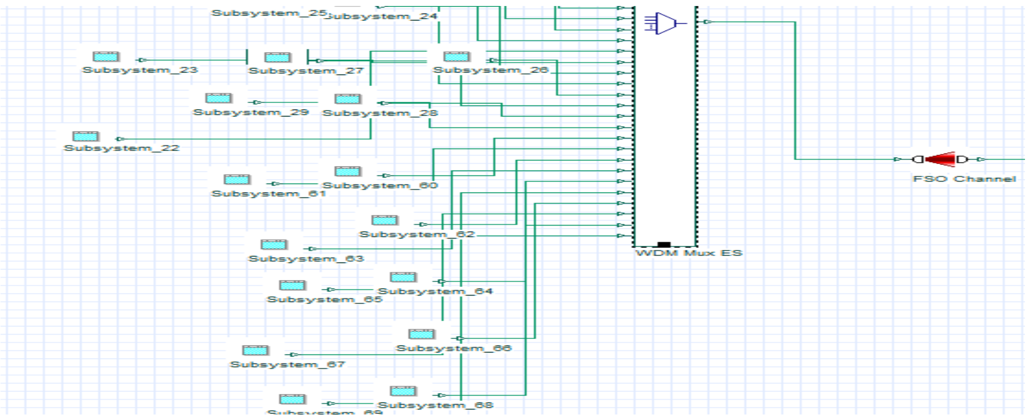


Fig.6.1.1(2) (a) transmitter section front end part

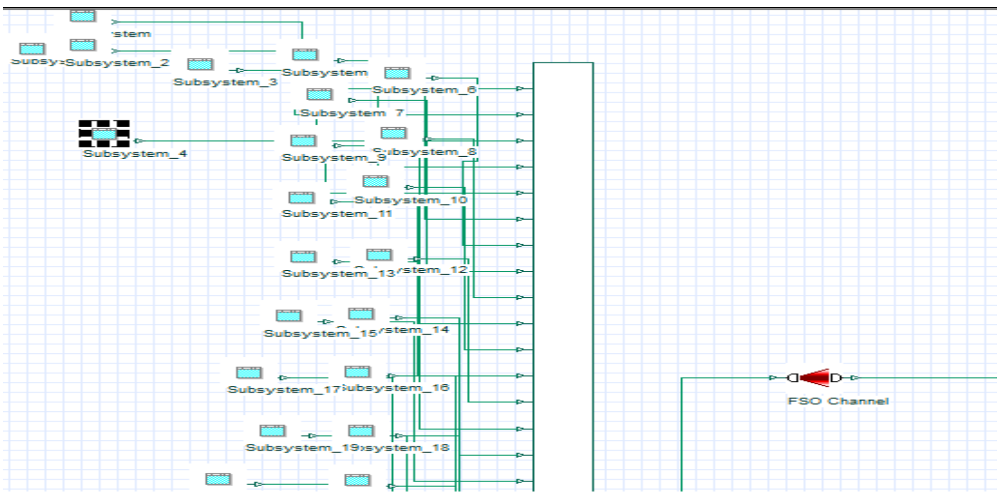


Fig.6.1.1(2) (b) transmitter section back end part

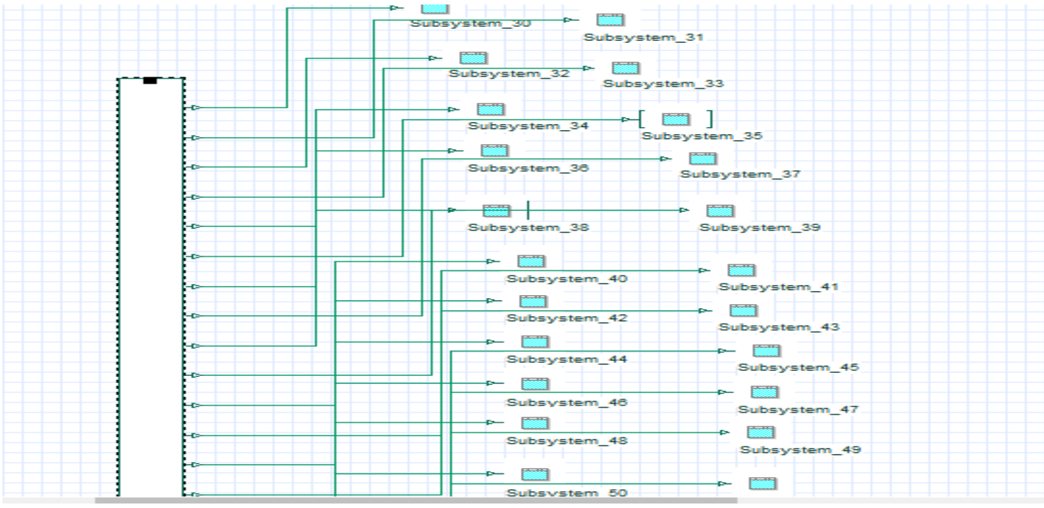


Fig.6.1.1(2) (c) Receiver section front end part

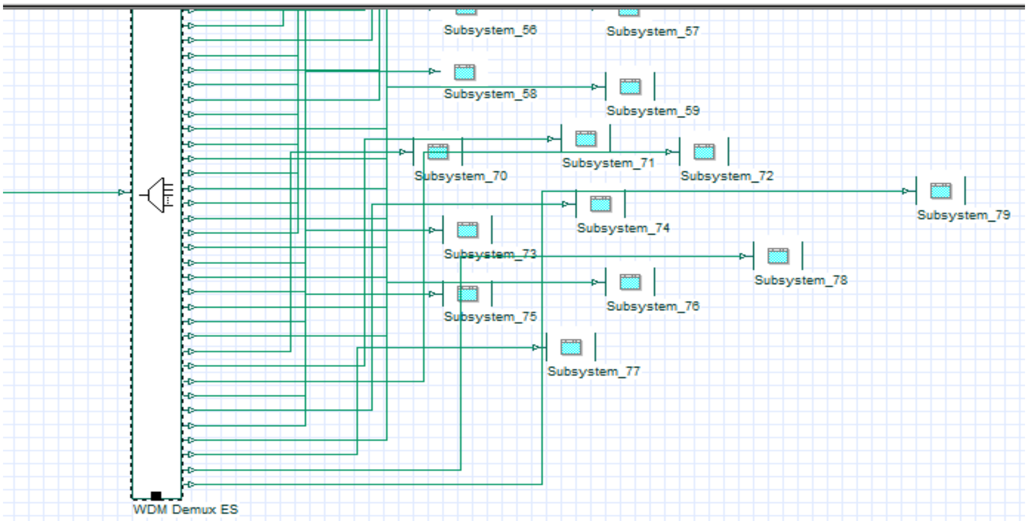


Fig.6.1.1(2) (d) Receiver section back end part

(3) FSO trans-receiver for 50 channels:

The same simulation model of 30 channels was redesigned and upgraded for 50 channels . An FSO system was designed for 40 data channels. The individual data channels were simulated at different CW LASER frequencies with a mutual frequency spacing of 0.8nm.The data channels after going through electrical and optical modulation techniques are multiplexed using 50X1 WDM MUX and then the composite optical signal is transmitted through FSO channel. The systems are optimized in layout using transmitter subsystems and receiver subsystems as shown in figures (b) & (d). The intercepted signal at receiver is de-multiplexed using 1X50 WDM De-MUX and then detected back using PIN photo-detectors and electrical filters to retrieve back the original baseband. The system performance is evaluated using spectral analyzers and BER analyzers.

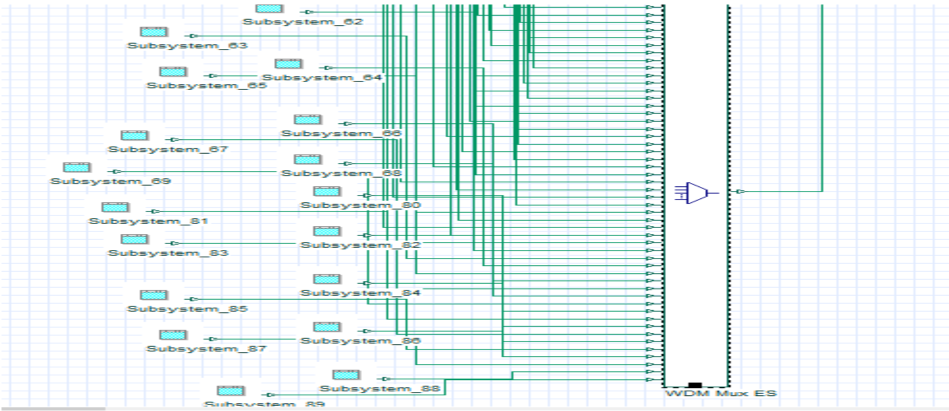


Fig.6.1.1(3) (a) transmitter section front end part

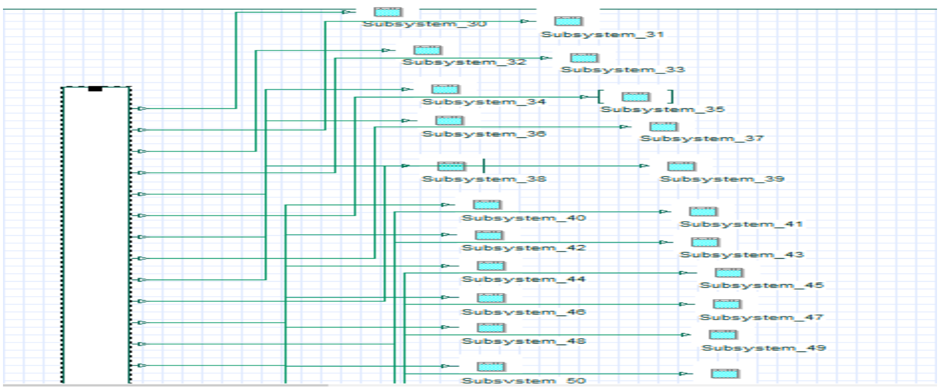


Fig.6.1.1(3) (b) Transmitter section back end part

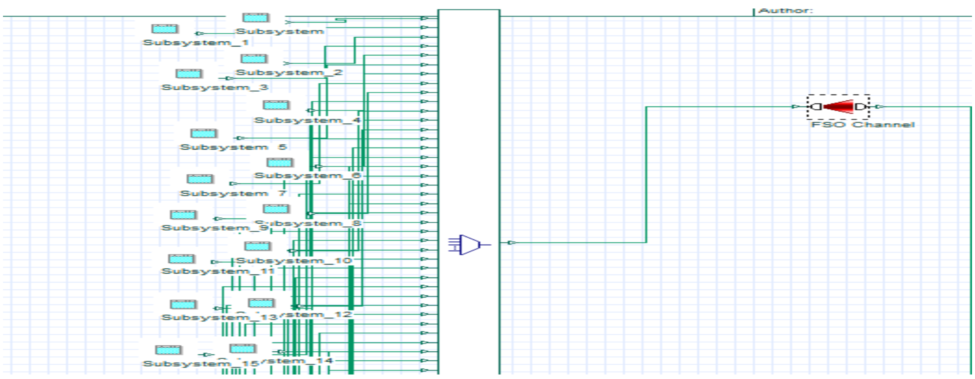


Fig.6.1.1(3) (c) Receiver section front end part

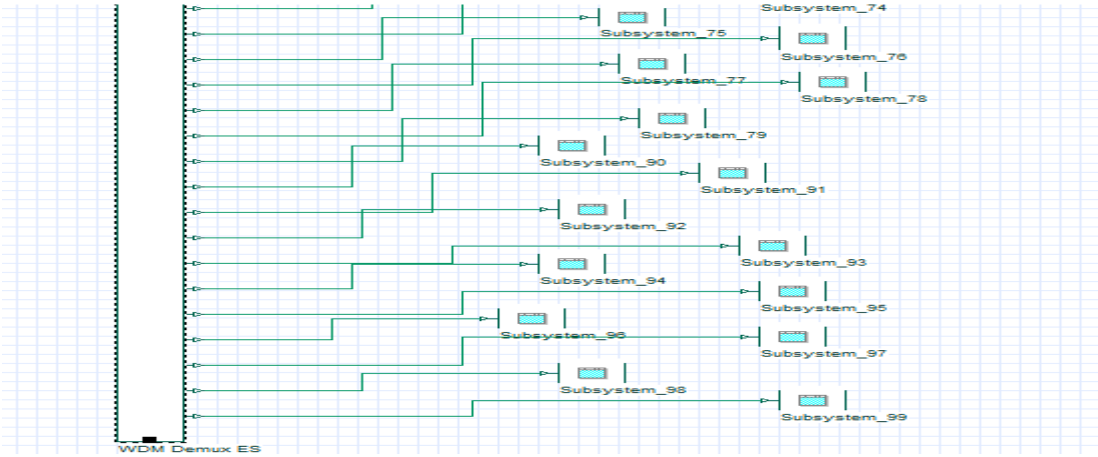


Fig.6.1.1(3) (d) Receiver section back end part

(4) FSO trans-receiver for 60 channels:

The same simulation model of 30 channels was redesigned and upgraded for 60 channels . An FSO system was designed for 40 data channels. The individual data channels were simulated at different CW LASER frequencies with a mutual frequency spacing of 0.8nm.The data channels after going through electrical and optical modulation techniques are multiplexed using 60X1 WDM MUX and then the composite optical signal is transmitted through FSO channel. The systems are optimized in layout using transmitter subsystems and receiver subsystems as shown in figures (b) & (d). The intercepted signal at receiver is de-multiplexed using 1X60 WDM De-MUX and then detected back using PIN photo-detectors and electrical filters to retrieve back the original baseband. The system performance is evaluated using spectral analyzers and BER analyzers.

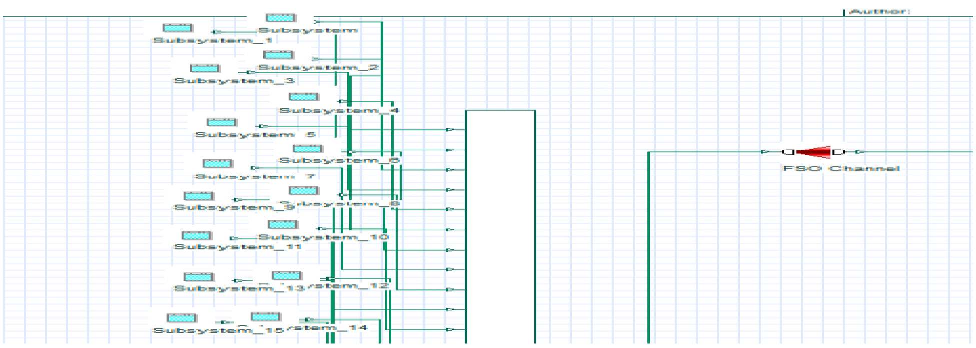


Fig.6.1.1(4) (a) transmitter section front end part

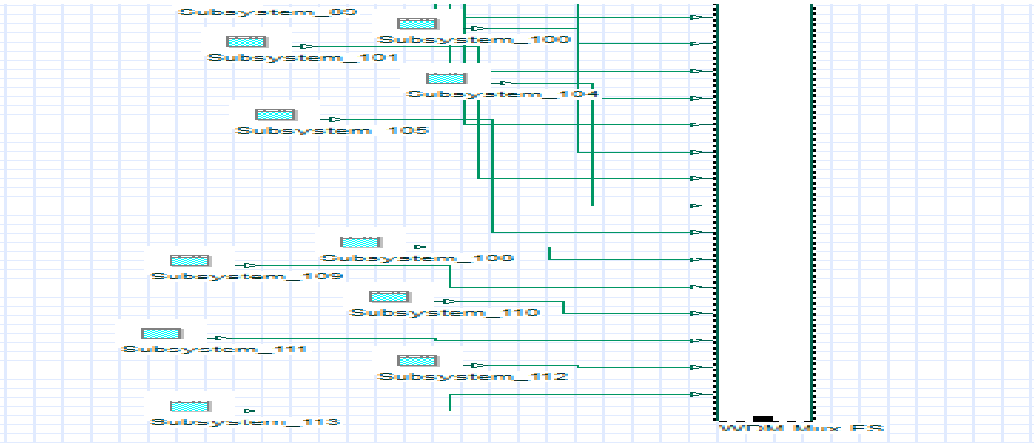


Fig.6.1.1(4) (b) transmitter section back end part

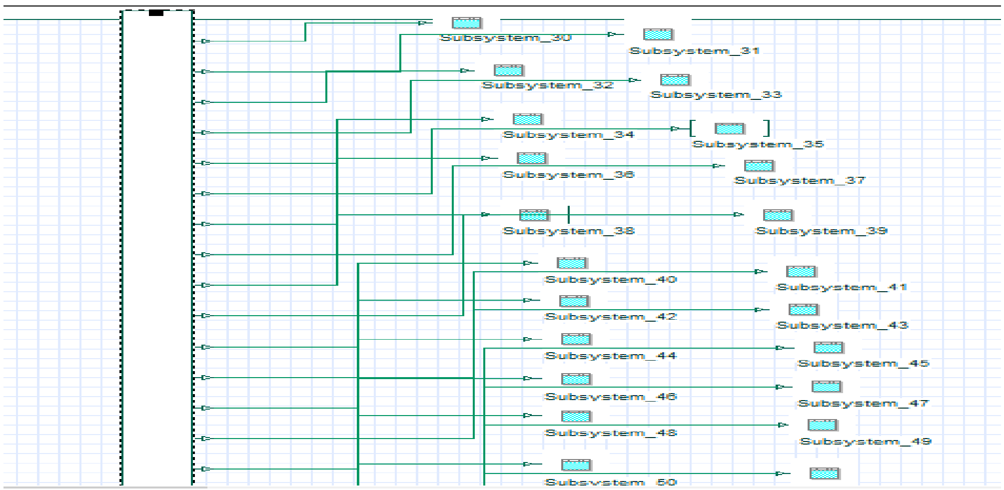


Fig.6.1.1(4) (c) Receiver section front end part

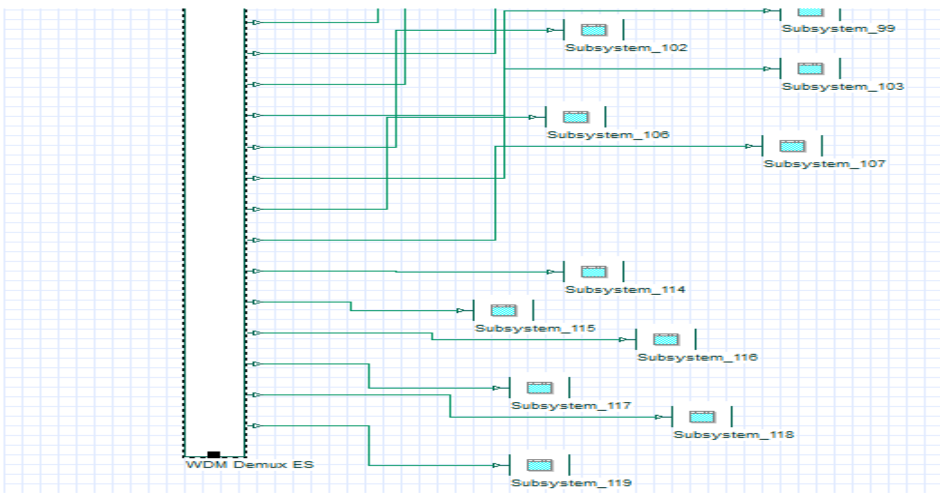


Fig.6.1.1(4) (d) Receiver section back end part

6.1.2 Design of 30 channel FSO based DWDM systems using different compensation techniques:

(1) Pre-Compensated Simulation Model:

Fig 6.1.2(1) (a) &(b) show the setup for 30 channel FSO system incorporating Pre-compensation technique. Here the 30 data streams after forming the composite optical signal is pre-compensated before its transmission through FSO channel. This ensures the SNR levels are pre-boosted to compensate the losses that are likely to be incurred in FSO channel. The transmitter subsystem and receiver subsystem are shown in fig. 7.1.1(1)(a) &(b).The pre-compensation is carried by using a dispersion compensated fiber and optical amplifier just before the FSO channel. The dispersion compensated fiber is obtained by taking the dispersion value of an ordinary fiber as negative such that the positive dispersion s compensated. The system showed considerable improvements in performance evaluating parameters such as BER, Q-Factor, Eye Height and threshold values compared to uncompensated setups. The performance of pre-compensated setup is also better than symmetric compensated model.

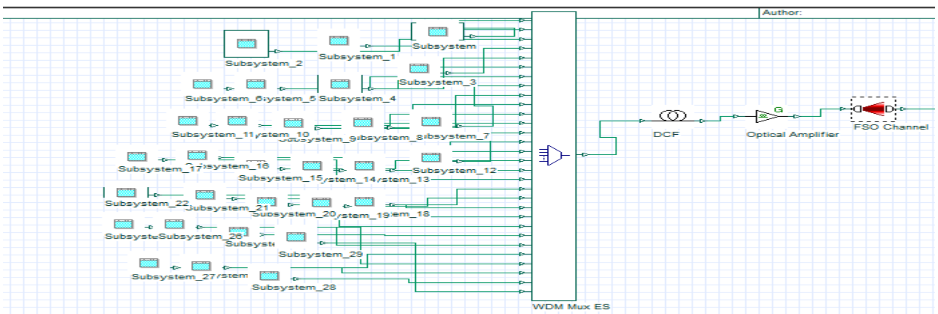


Fig.6.1.2 (1) (a) Pre-compensated Transmitter part

Fig.6.1.2 (1) (b) Pre-compensated Receiver part

(2) Post-Compensated Simulation Model:

In the setup shown in Fig6.1.2(2)(a) &(b), an FSO system for 30 data channels was designed which incorporates a dispersion compensation mechanism using dispersion compensated fiber and optical amplifier placed after FSO transmission link. The transmitter subsystem and receiver subsystem are shown in fig. 7.1.1(1)(a) &(b). In this setup the losses incurred by transmission through FSO channel are compensated by dispersion compensated fiber (DCF)and the use of optical amplifier ensures the boosting of signal obtained after compensating losses by dispersion compensated fiber. The system performance showed considerable improvements in the performance evaluating parameters in comparison to the other compensation schemes. When compared to the other compensation schemes and the uncompensated model, post-compensation is superior and showed the better results than others. The comparison is made graphically where it becomes clear that the BER values obtained in the post compensation scheme are lower than the other relative techniques, Henceforth ,the performance is better.

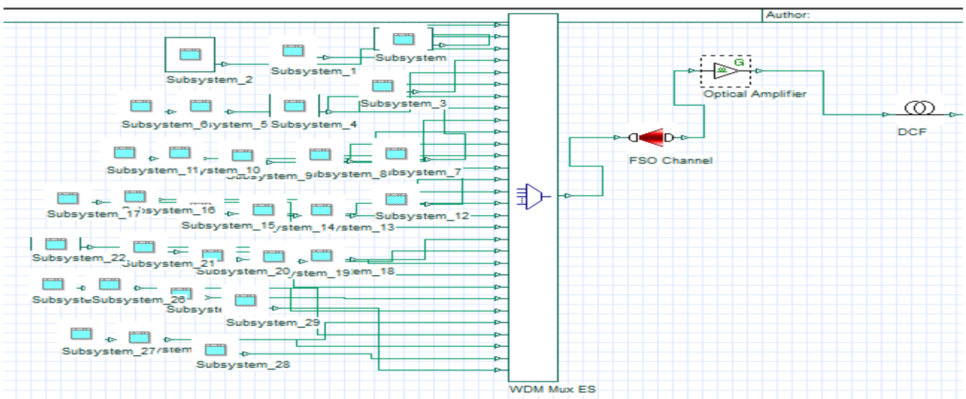


Fig.6.1.2 (2) (a) Post-compensated Transmitter part

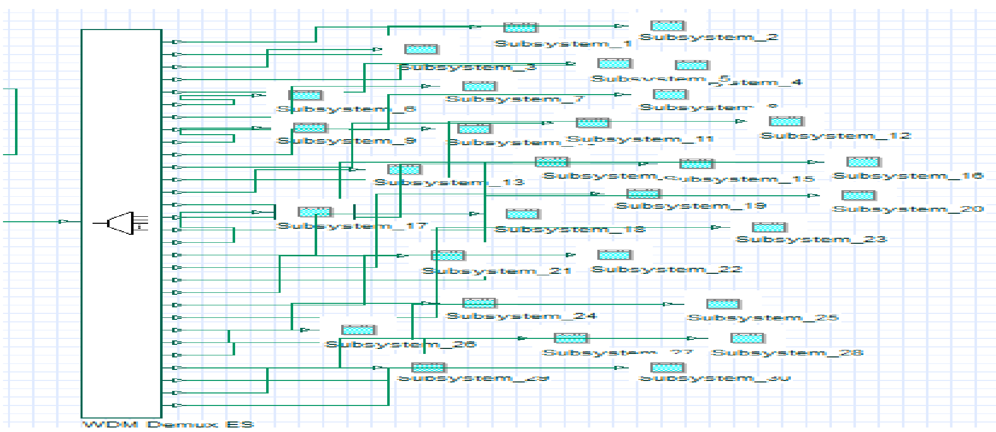


Fig.6.1.2 (2) (b) Post-compensated Receiver part

(3) Symmetric-Compensated Simulation Model:

In Fig. 6.1.2(2), an FSO based DWDM system is designed using a symmetric compensation scheme. This simulation model merges the pre-compensation and post-compensation techniques in a single model termed as symmetric compensated model and the scheme is called as symmetric compensation scheme. A combination of dispersion compensated fiber and optical amplifier are incorporated before and after the FSO channel to compensate the looses and boost SNR values. When compared with other compensation schemes, Symmetric compensation scheme shows almost a linear performance. However, the performance is better than the uncompensated simulation model.

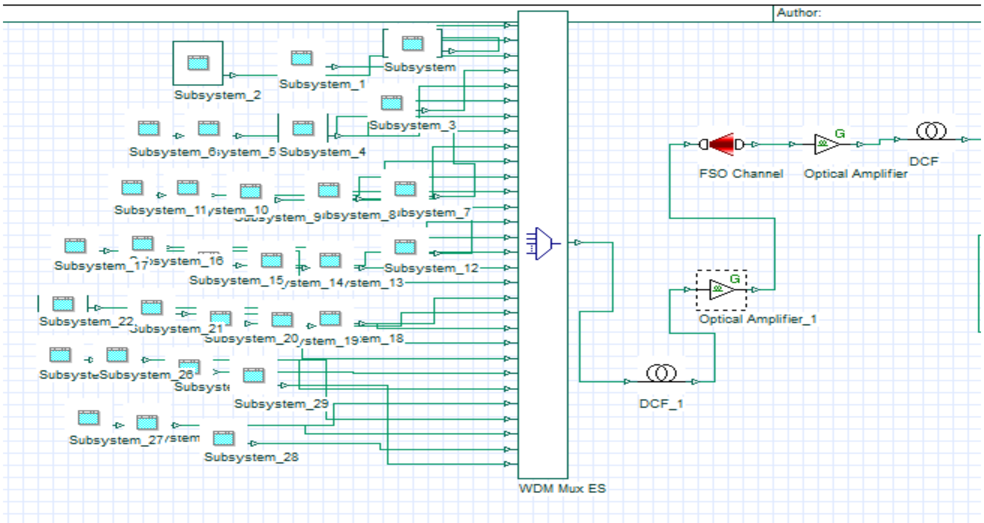


Fig. 6.1.2 (3) (a) Symmetric-compensated Transmitter part

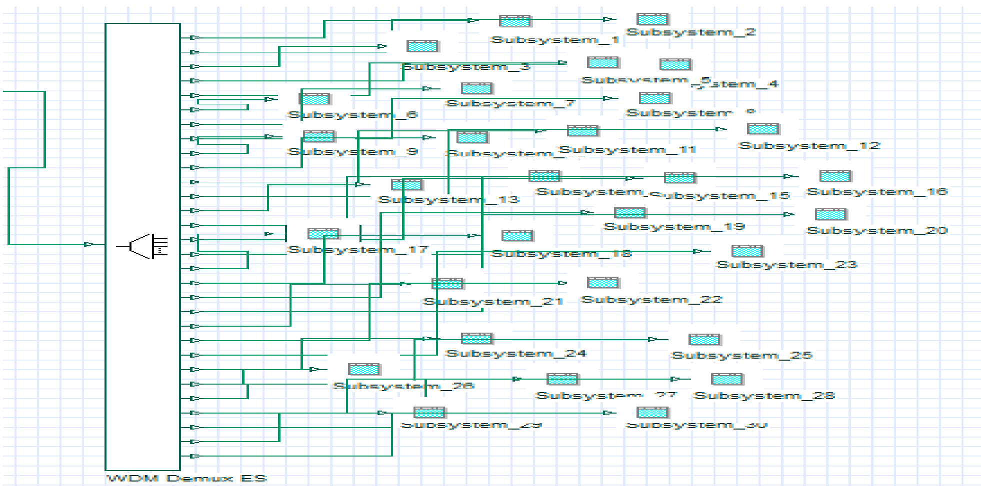


Fig .6.1.2 (3) (b) Symmetric-compensated Receiver part

6.1.3 Design of 30 channel FSO based DWDM systems using different Amplifiers:

(1) Using Erbium Dopped Fiber Amplifier (EDFA):

Figure 6.1.13(1) shows a design of a DWDM system using FSO channel as a transmission medium. 30 data streams are multiplexed in a composite signal which is passed through the transmission medium. An Erbium Dopped Fiber Amplifier (EDFA) is incorporated after the FSO channel to amplify the signal so as to reduce the losses .The performance of the system is evaluated in terms of BER value and is analysed graphically.

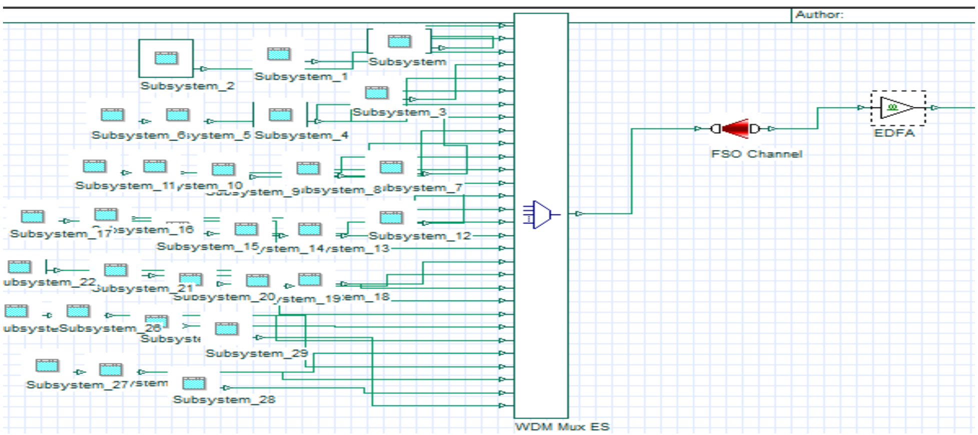


Fig.6.1.3 (1) (a) Transmitter part of FSO based DWDM system using EDFA

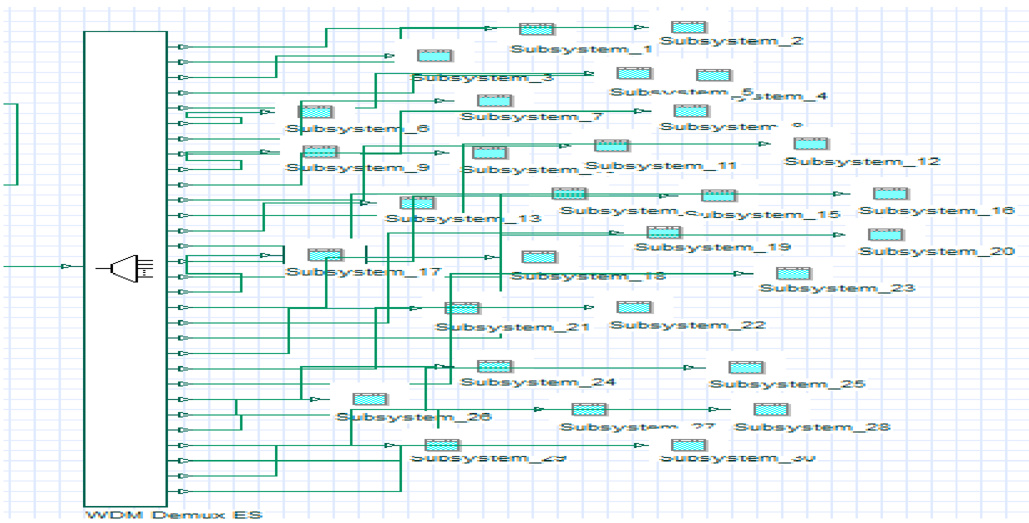


Fig.6.1.3 (1) (b) Receiver part of FSO based DWDM system using EDFA

(2) Using Semiconductor Optical Amplifier (SOA):

An FSO based DWDM system is designed and simulated and semiconductor optical amplifier (SOA) is incorporated in the setup after the atmospheric channel. 30 signals varying in their wavelengths are combined in a single composite signal and passed through an atmospheric channel. Since the multiplexed signal comes across a number of losses in an atmospheric channel, therefore, an Erbium Dopped Fiber Amplifier is incorporated after FSO channel to reduce these losses. The system showed considerable improvements in performance evaluating parameters such as BER, Q-Factor, Eye Height and threshold values compared to unamplified setups.

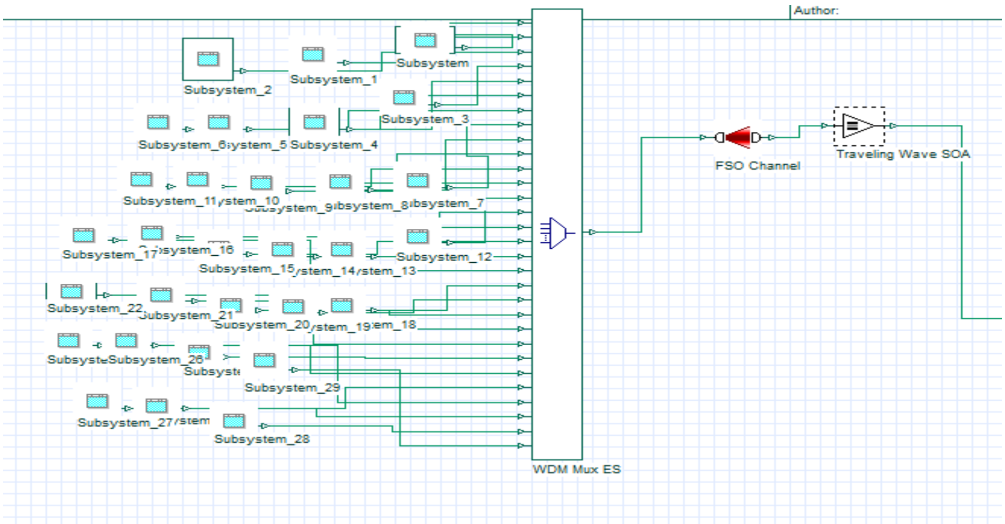


Fig.6.1.3 (2) (a) Transmitter part of FSO based DWDM system using SOA

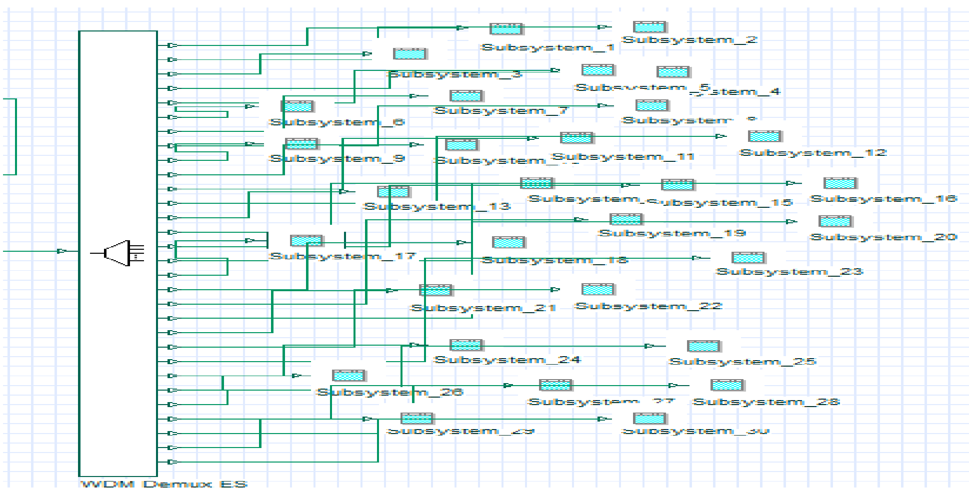


Fig.6.1.3 (2) (b) Receiver part of FSO based DWDM system using SOA

(3) Using Hybrid combination of Erbium Dopped Fiber Amplifier (EDFA) Semiconductor Optical Amplifier (SOA):

In figure 7.1.3(3), an FSO system for 30 data channels was designed which incorporates an amplification mechanism using hybrid combination of optical amplifiers placed after FSO transmission link. In this setup the losses incurred by transmission through FSO channel are compensated by Hybrid amplification setup including semiconductor optical amplifier and an EDFA. The system performance showed considerable improvements in the performance evaluating parameters in comparison to the ones using SOA or EDFA.

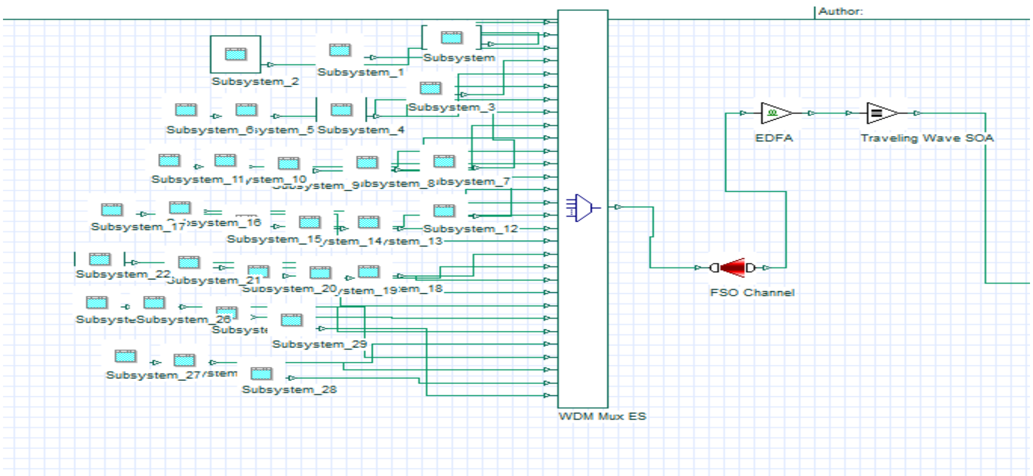


Fig.6.1.3 (3) (a) Transmitter part of FSO based DWDM system using EDFA and SOA

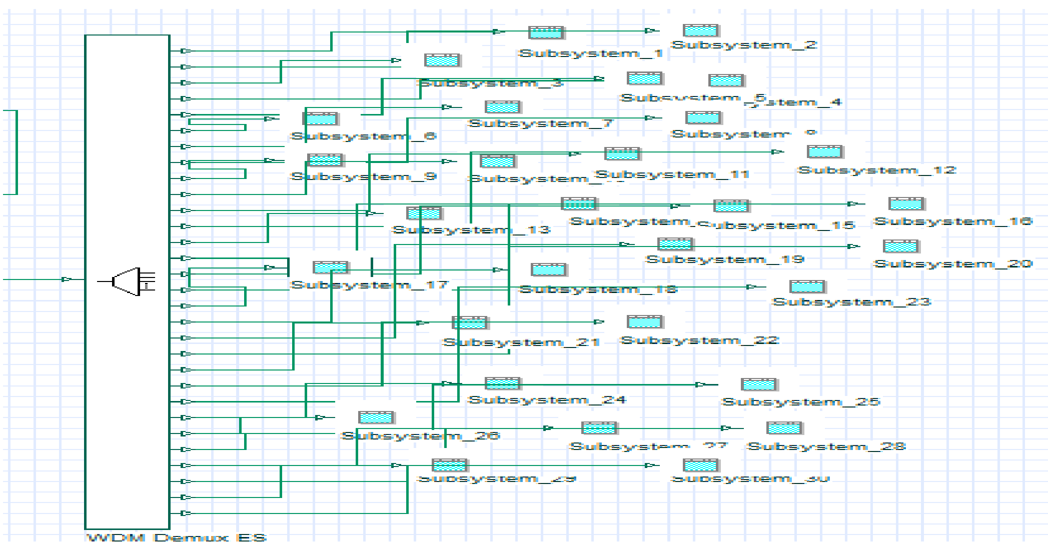


Fig.7.1.3 (3) (b) Receiver part of FSO based DWDM system using EDFA & SOA

6.2 Simulation Results

The designed setups were simulated and evaluated multiple times for various performance evaluating parameters. The extracted results are listed in the form of Analyzer outputs, Time Domain analyzers, BER analyzers and power meters. The outputs extracted from various proposed setups are listed here

a) Analyzer Outputs:

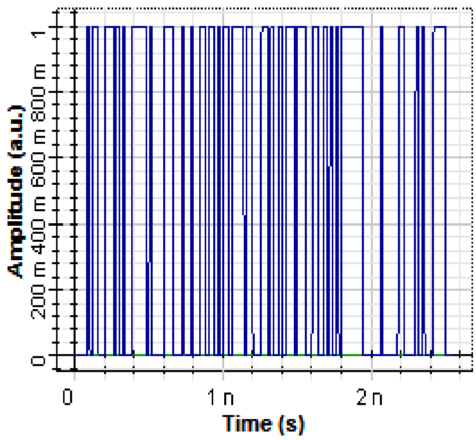


Fig 7.2 (a) Tx1 for 30 Channel FSO

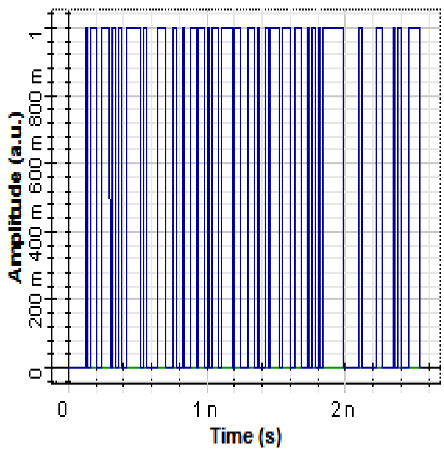
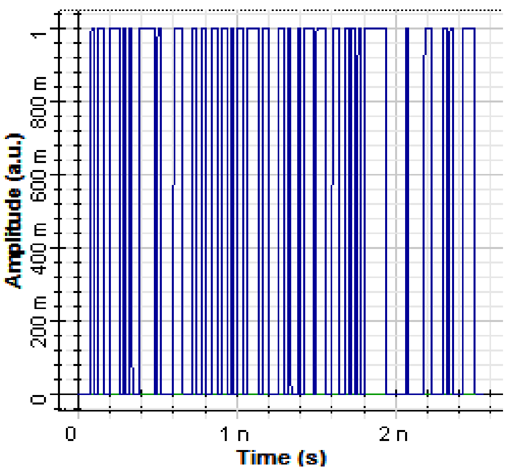
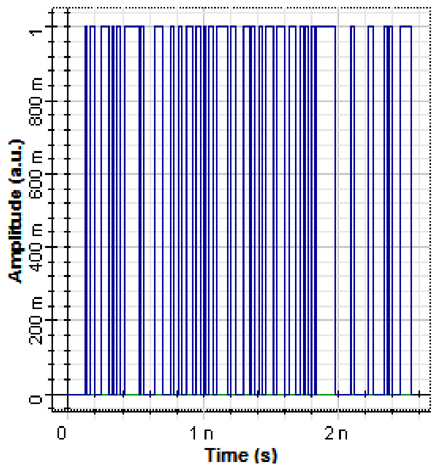


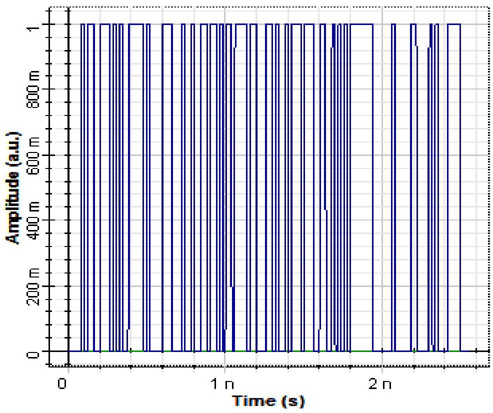
Fig 7.2 (b) Rx1 for 30 channel FSO



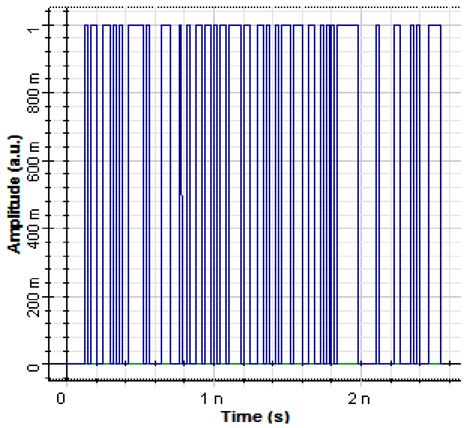
(c) Tx1 for 40 Channel F SO



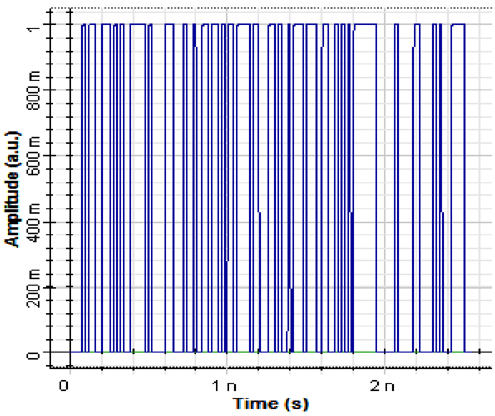
(d) Rx1 for 40 Channel FSO



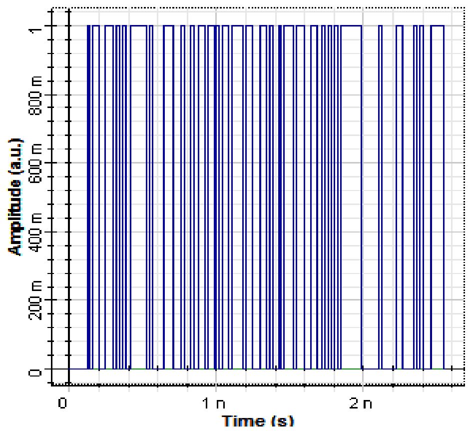
(e) Tx1 for 50 Channel FSO



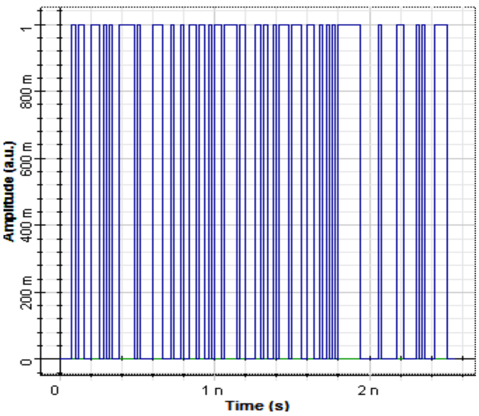
(f) Rx1 for 50 Channel FSO



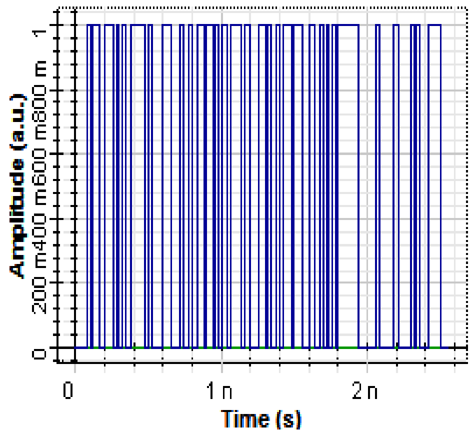
(g) Tx1 for 60 Channel FSO



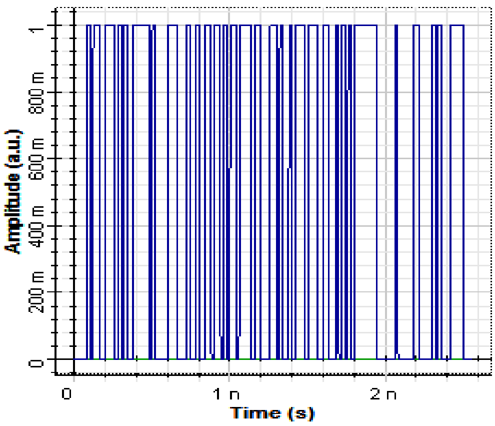
(h) Rx1 for 60 Channel FSO



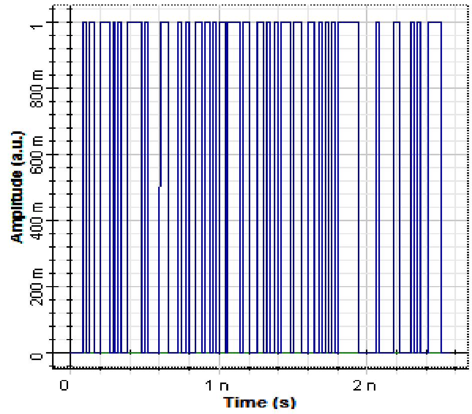
(i) Tx1 for 30Channel pre-compensated FSO



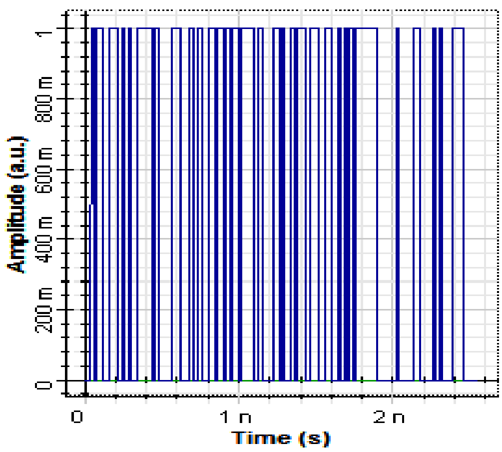
(j) Rx1 for 30Channel pre-compensated FSO



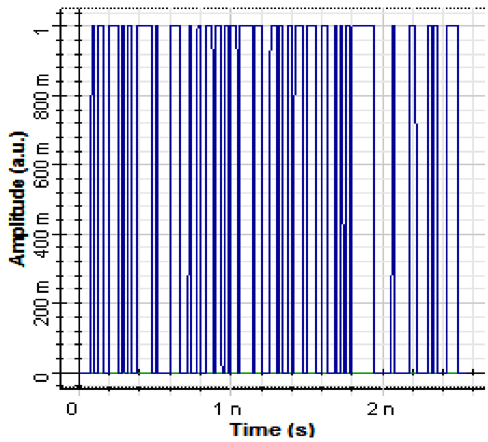
(k) Tx1 for 30Channel post-compensated FSO



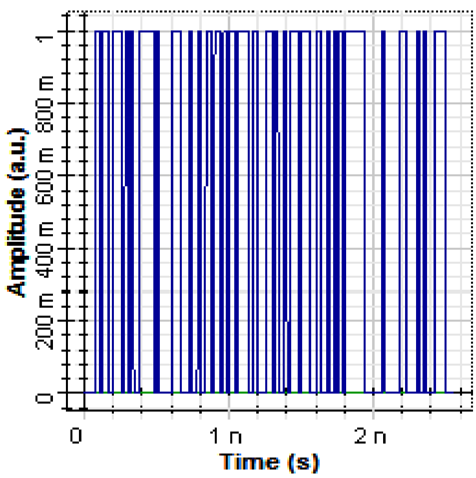
(l) Rx1 for 30Channel post-compensated FSO



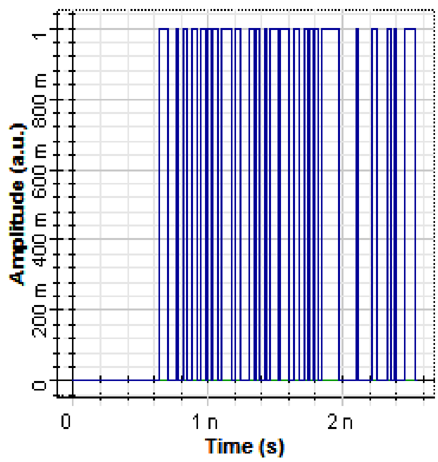
(m) Tx1 for 30Channel sym-compensated FSO



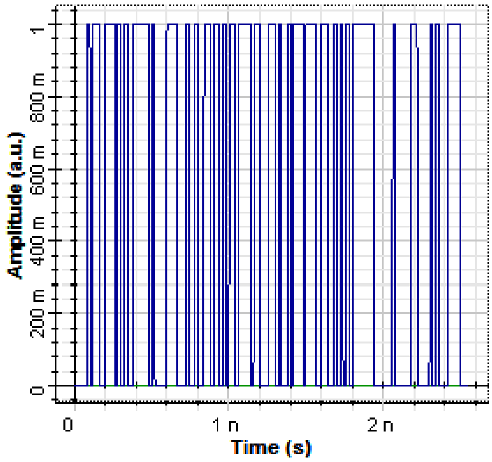
(n) Rx1 for 30Channel sym-compensated FSO



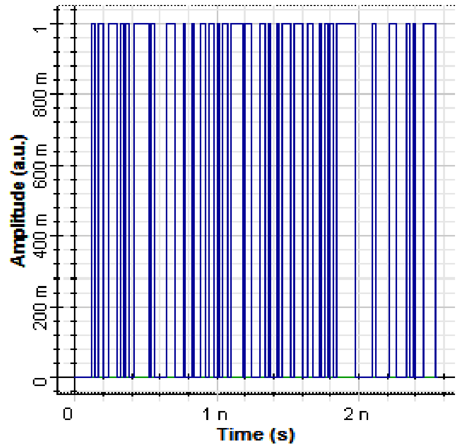
(o) Tx1 for 30Channel FSO using SOA



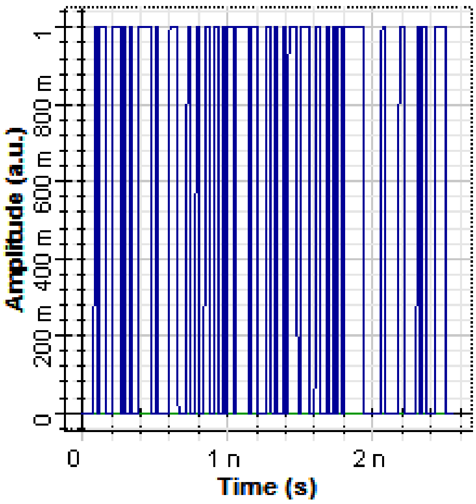
(p) Rx1 for 30Channel FSO using SOA



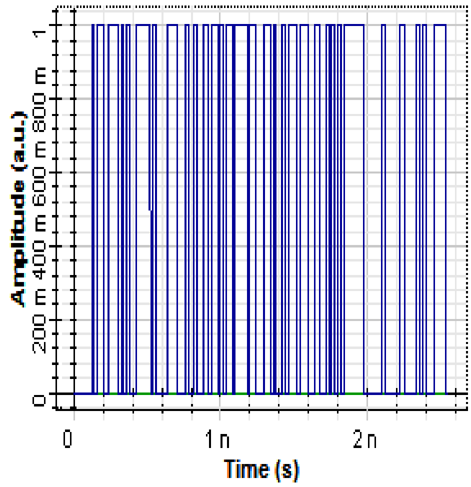
(q) Tx1 for 30Channel FSO using EDFA



(r) Rx1 for 30Channel FSO using EDFA



(s) Tx1 for 30Channel FSO with SOA & EDFA



(t) Rx1 for 30Channel FSO with SOA & EDFA

7.3 Eye Diagrams

Eye diagrams at the reception are a means of depicting how well the transmission has been in terms of error rates and quality factors. Various eye diagrams obtained are shown in below figures,

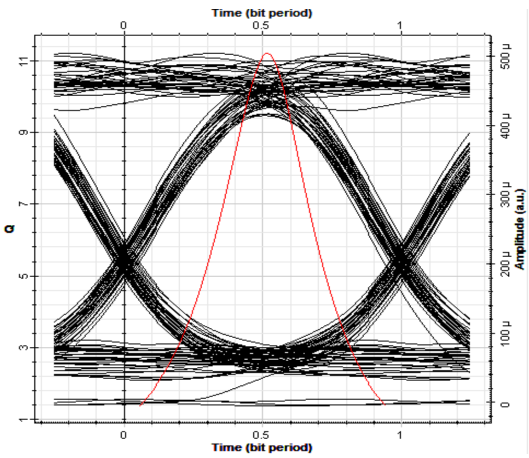
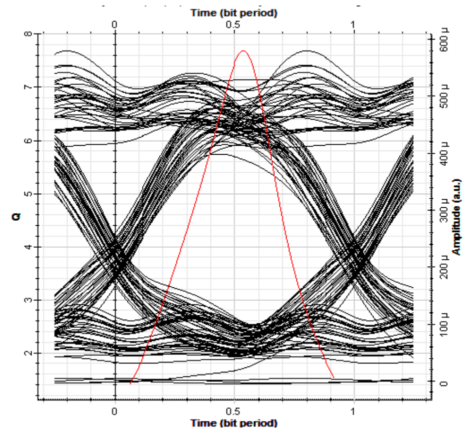
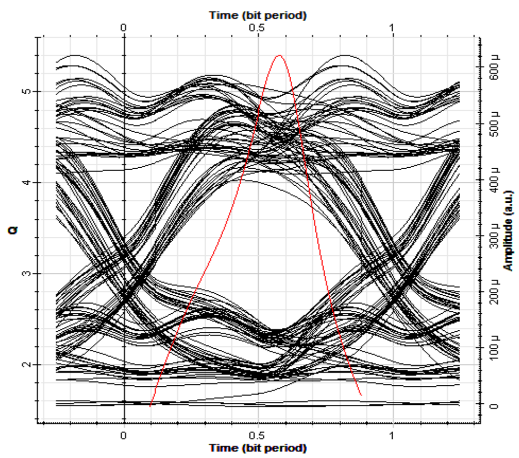


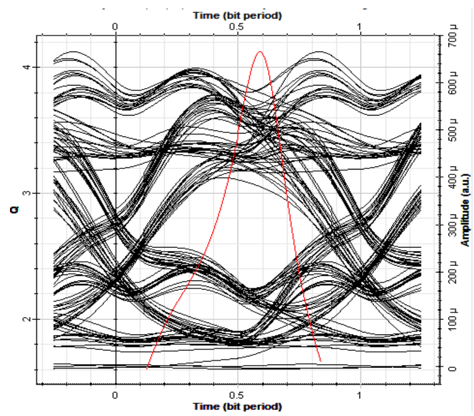
Fig.7.3 (a) 30 channel DWDM with FSO



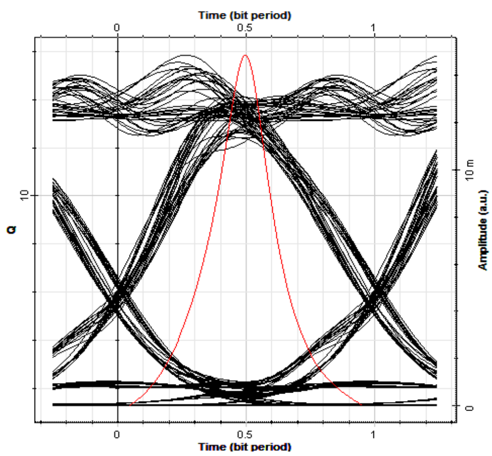
(b) 40 channel DWDM with FSO



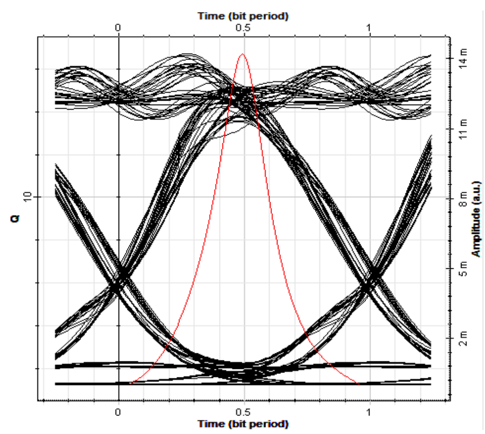
(c) Rx 1 of 50 channel DWDM with FSO



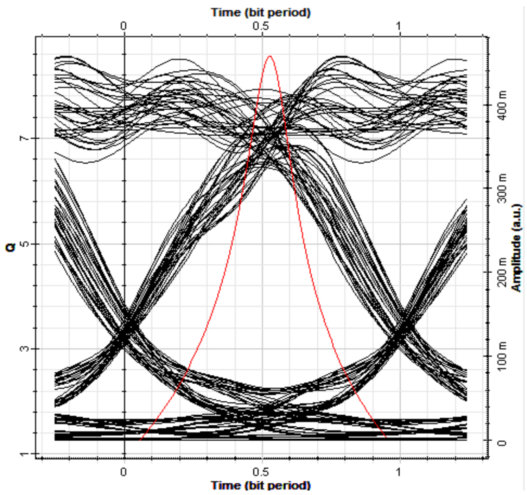
(d) Rx 1 of 60 channel DWDM with FSO



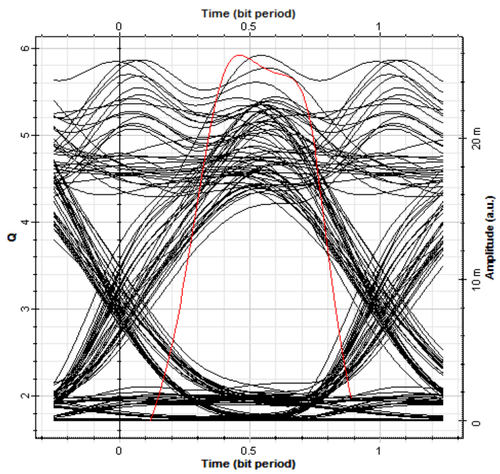
(c) Rx 1 of 30 channel pre-compensated setup



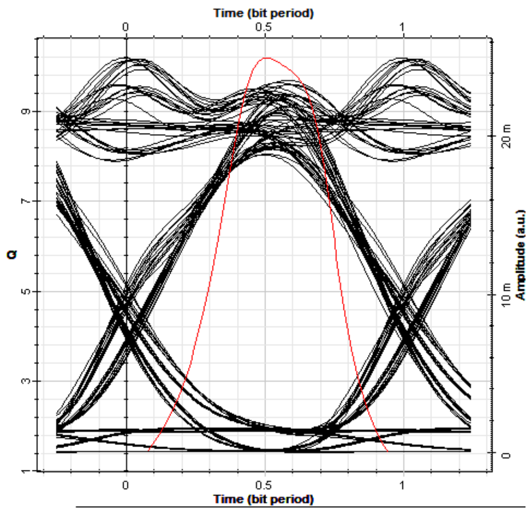
(d) Rx 1 of 30 channel post-compensated setup



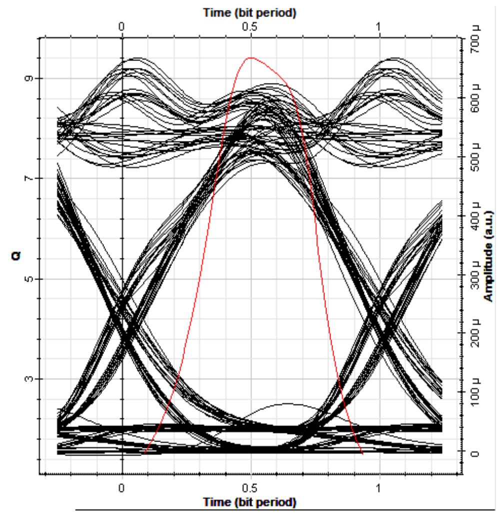
(e) Rx 1 of 30 channel sym-compensated setup



(e) Rx 1 of 30 channel setup using SOA



(g) Rx 1 of 30 channel setup using EDFA SOA



(h) Rx 1 of 30 channel setup using EDFA &

7.4 Simulation Data

The data extracted from various analyzers is tabulated as follows

Table1 Data for uncompensated Setups (varying FSO Length)

Data Rate(Gbps)	Min.BER	Log(Min.BER)
	30 Channel setup	

1	1.76E-29	-28.75412721
2	3.82E-11	-10.41839846
3	1	0
4	1	0
5	1	0
	40 channel setup	
1	7.62E-15	-14.1177761
2	7.45E-09	-8.127721326
3	1	0
4	1	0
5	1	0
	50 channel setup	
1	3.30E-08	-7.481545286
2	2.47E-06	-5.606707399
3	1	0
4	1	0
5	1	0
	60 channel setup	
1	1.86E-05	-4.731050136
2	9.51E-05	-4.021609465
3	1	0
4	1	0
5	1	0

Table2 Data for uncompensated Setups (Varying FSO Attenuation)

FSO Attenuation(dB/km)	Min.BER	Log(Min.BER)
	30 channel system	
1	5.62E-30	-29.25058218
2	1.56E-25	-24.80578547
3	9.01E-18	-17.04537403
4	3.86E-09	-8.413552232

5	0.000568868	-3.244988496
	40 channel system	
1	5.98E-15	-14.223362
2	5.86E-14	-13.23216612
3	1.03E-11	-10.98820972
4	1.03E-07	-6.988154773
5	0.000690223	-3.161010573
	50 channel system	
1	3.13E-08	-7.504158834
2	5.31E-08	-7.274840053
3	2.26E-07	-6.645755145
4	7.98E-06	-5.098023232
5	0.00151322	-2.820097927
	60 channel system	
1	1.86E-05	-4.731050136
2	9.51E-05	-4.021609465
3	1.00E+00	0
4	1	0
5	1	0

Table3 Data for uncompensated Setups (Varying channel spacing)

FSO Length(Km)	Min.BER	Log(Min.BER)
	0.1 THZ	
1	1.11E-23	-22.95322788
2	3.88E-11	-10.41126679
3	0.00209342	-2.679143631
4	1	0
5	1	0
	0.2 THZ	
1	3.03E-205	-204.5185774
2	9.00E-22	-21.04556355
3	0.00217247	-2.663046212

4	1	0
5	1	0
	0.3 THZ	
1	6.21E-170	-169.2068951
2	3.64E-18	-17.43941554
3	0.00425754	-2.370841263
4	1	0
5	1	0
	0.05 THZ	
1	1.93E-08	-7.714667772
2	2.21E-04	-3.655295382
3	0.00280352	-2.552296341
4	1	0
5	1	0
	0.02 THZ	
1	5.71E-08	-7.243166184
2	4.22E-07	-6.374908869
3	8.07E-07	-6.093092563
4	1.35E-06	-5.86963728
5	5.88E-06	-5.230561375

Table4 Data for Compensated Setups(varying FSO length)

FSO Length(Km)	Min.BER	Log(Min.BER)
	Pre-Compensated	
1	8.00E-57	-56.09715546
2	3.09E-55	-54.51015679
3	4.45E-49	-48.351803
4	3.66E-31	-30.43659961
5	4.08E-11	-10.38893447
	Post-Compensated	
1	6.09E-63	-62.21543406
2	5.13E-61	-60.28961181

3	3.99E-53	-52.39903255
4	2.44E-32	-31.61344575
5	4.17E-11	-10.38032348
	Symmetric Compensated	
1	5.65E-18	-17.24782397
2	8.05E-18	-17.09441403
3	5.53E-18	-17.25762684
4	6.70E-18	-17.174097
5	8.63E-18	-17.06402594

Table5 Data for Amplified Setups

FSO Length(Km)	Min.BER	Log(Min.BER)
	Using SOA	
1	2.29E-08	-7.64016
2	4.81E-09	-8.31785
3	2.06E-09	-8.68613
4	1.97E-11	-10.7055
5	3.19E-10	-9.496209
6	3.63E-07	-6.440093
7	5.88E-08	-7.230622
8	1.96E-09	-8.707743
9	4.91E-10	-9.308918
10	1.04E-08	-7.982966
11	2.03E-07	-6.692503
12	1.30E-05	-4.886056
	Using EDFA	
1	1.12E-24	-23.95078
2	2.39E-21	-20.62160
3	1.08E-15	-14.96657
4	4.90E-10	-9.309803
5	1.34E-05	-4.872895
6	4.52E-03	-2.344861
7	1.00E+00	0
8	1.00E+00	0

9	1.00E+00	0
10	1.00E+00	0
11	1.00E+00	0
12	1.00E+00	0
	Using SOA+EDFA	
1	1.47E-06	-5.83268
2	7.33E-09	-8.13489
3	3.68E-08	-7.43415
4	1.19E-08	-7,92445
5	1.77E-09	-8.75202
6	6.93E-11	-10.1592
7	9.01E-14	-13.0452
8	2.08E-17	-16.6819
9	3.61E-20	-19.4424
10	2.42E-21	-20.6161
11	9.53E-21	-20.0209
12	1.89E-17	-16.7235

Table 6 Data for Pre- compensated Setups (Varying Data Rate)

Data Rate(Gbps)	Min.BER	Log(Min.BER)
	10 Gbps	
1	2.00E-65	-64.69940234
2	3.39E-64	-63.46959025
3	6.38E-61	-60.19508199
4	1.83E-51	-50.73669066
5	3.32E-30	-29.47908959
	20Gbps	
1	1.39E-73	-72.85657297
2	5.98E-73	-72.22354944
3	2.18E-68	-67.66207774
4	6.20E-52	-51.20772811

5	4.84E-24	-23.31520938
	40 Gbps	
1	1.34E-64	-63.87202425
2	4.35E-64	-63.36193226
3	1.51E-58	-57.82225001
4	8.98E-39	-38.04654331
5	6.00E-14	-13.2220674
	50 Gbps	
1	8.48E-04	-3.071349177
2	9.04E-04	-3.043935351
3	0.00104213	-2.982078102
4	0.00154961	-2.80977759
5	0.00516721	-2.286743888

Table 7 Data for Post- compensated Setups (Varying Data Rate)

Data Rate(Gbps)	Min.BER	Log(Min.BER)
	10 Gbps	
1	3.64E-74	-73.43847407
2	8.80E-73	-72.05558939
3	1.34E-68	-67.87194016
4	9.41E-57	-56.0264653
5	7.93E-32	-31.10098648
	20Gbps	
1	3.17E-89	-88.49840266
2	2.47E-87	-86.6069568
3	1.74E-79	-78.7586478
4	1.40E-56	-55.85356186
5	2.34E-24	-23.6308324
	40 Gbps	
1	1.19E-78	-77.92501909
2	1.48E-77	-76.83017573
3	9.03E-69	-68.04417184

4	1.78E-42	-41.74918005
5	3.19E-14	-13.49648714
	80 Gbps	
1	7.81E-04	-3.107083244
2	8.32E-04	-3.079760808
3	0.000965268	-3.015352091
4	0.00145471	-2.837223576
5	0.00504419	-2.297208563

Table 8 Data for Symmetric- compensated Setups (Varying Data Rate)

Data Rate(Gbps)	Min.BER	Log(Min.BER)
	10 Gbps	
1	6.62E-66	-65.17911183
2	1.24E-65	-64.90508537
3	4.63E-66	-65.33485258
4	7.73E-66	-65.11204305
5	3.30E-65	-64.48116901
	20Gbps	
1	4.96E-90	-89.30423035
2	3.34E-87	-86.47594288
3	9.61E-88	-87.01749494
4	4.09E-86	-85.38811744
5	3.20E-83	-82.49534839
	40 Gbps	
1	4.59E-40	-39.33793476
2	5.41E-39	-38.26665024
3	1.92E-38	-37.71619013
4	9.28E-38	-37.03251287
5	2.66E-36	-35.5752637
	80 Gbps	
1	2.74E-03	-2.562663324
2	2.72E-03	-2.564945979
3	0.00267567	-2.572567451

4	0.00267321	-2.572966923
5	0.00268876	-2.570447961

Table 9 Data for Uncompensated Setups (Varying Data Rate)

Data Rate(Gbps)	Min.BER	Log(Min.BER)
	10 Gbps	
1	4.56E-53	-52.34077713
2	9.72E-34	-33.01230291
3	2.43E-07	-6.614602882
4	1.00E+00	0
5	1.00E+00	0
	20Gbps	
1	2.25E-53	-52.64704994
2	1.56E-25	-24.80668057
3	1.51E-04	-3.819819626
4	1.00E+00	0
5	1.00E+00	0
	40 Gbps	
1	5.57E-39	-38.25423916
2	3.69E-15	-14.43342111
3	6.07E-03	-2.216708292
4	1.00E+00	0
5	1.00E+00	0
	80 Gbps	
1	2.31E-09	-8.635582221
2	4.23E-06	-5.373860913
3	1	0
4	1	0
5	1	0

Table 10 Data for 30 channel uncompensated Setup (Varying Modulation Format)

FSO Length(Km)	Min.BER	Log(Min.BER)
	RZ Modulation	
1	2.43E-46	-45.61361876
2	5.12E-06	-5.290504468
3	1	0
4	1	0
5	1	0
	NRZ Modulation	
1	1.76E-29	-28.75412721
2	3.82E-11	-10.41839846
3	1	0
4	1	0
5	1	0

6.5 Graphs and Discussions

The performance evaluating parameters extracted from Simulations were graphically analyzed as follows

6.5.1 Varying FSO Length In Different Channels In Setups:

It was observed from the graph shown in figure 6.5.1 that BER (bit error rate) value increases with the increase in FSO length. As the number of channels increase in the system, the performance of the system degrades. The graph further depicts that 30 channel system shows best performance followed by 40,50 and 60 channel systems. Also, the systems perform till 3 km of FSO length while as severe signal distortions were observed after 3 kms of FSO length.

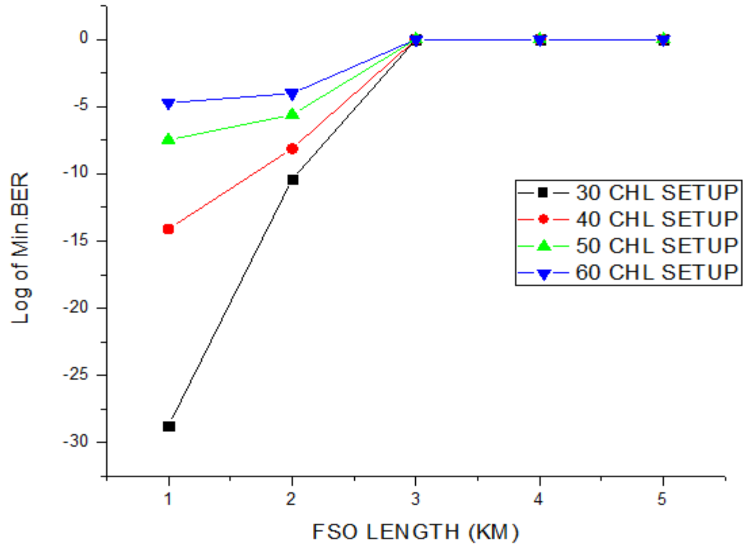


Fig.6.5.1 FSO Length Versus Log Min BER (Uncompensated)

6.5.2 Varying FSO Attenuation In Different Channels Setups:

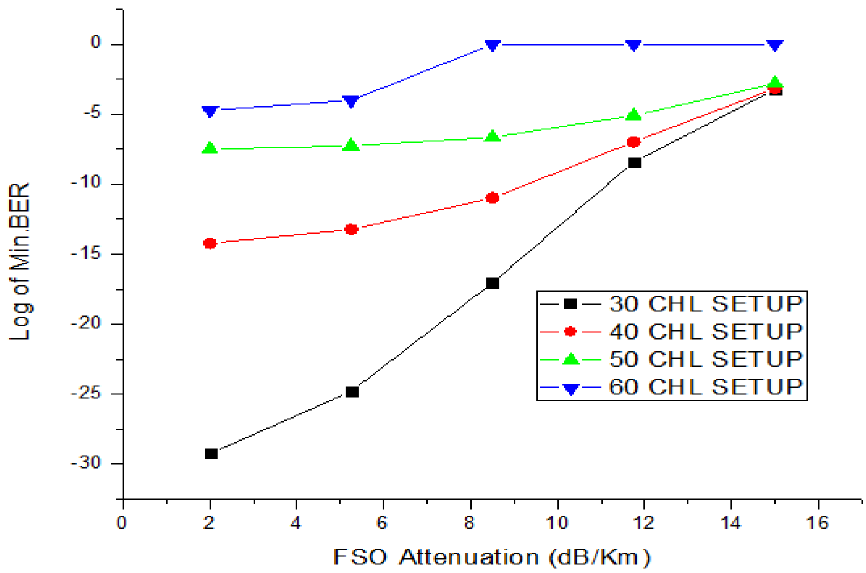


Fig.6.5.2 FSO Attenuation Versus Log Min BER (Uncompensated)

It was observed from the graph shown in Fig.6.5.2 that the BER value goes on increasing with the increase in attenuation of atmospheric channel for each system. The graph further depicts that the 30 channel system having Minimum BER value performs better followed by 40,50 and 60 channel setup. It is also clear from the graph that system performance severely degrades at an attenuation of greater than 10 dB/Km.

6.5.3 Varying Channel Spacing In Different Channel Setups:

The graphs shown in below figures are plotted for different channel systems by varying channel spacing. A graph plotted for 30 channel system predicts that a system performs well at 0.2 channel spacing followed by 0.3 . However the decreased values degrade the performance of the system that may due to the interference caused by closely spaced channels. A 40 channel system works better at 0.1 channel spacing followed by 0.2 & 0.3 respectively. A poor performance is observed at smaller values. A same trend is followed by 50 & 60 channel systems with a slight variation in BER values. The graphs depict that a nominal value of channel spacing should be chosen for transmission as the increased channel spacing result in increased bandwidth utilization and a decreased value results in interference between the channels.

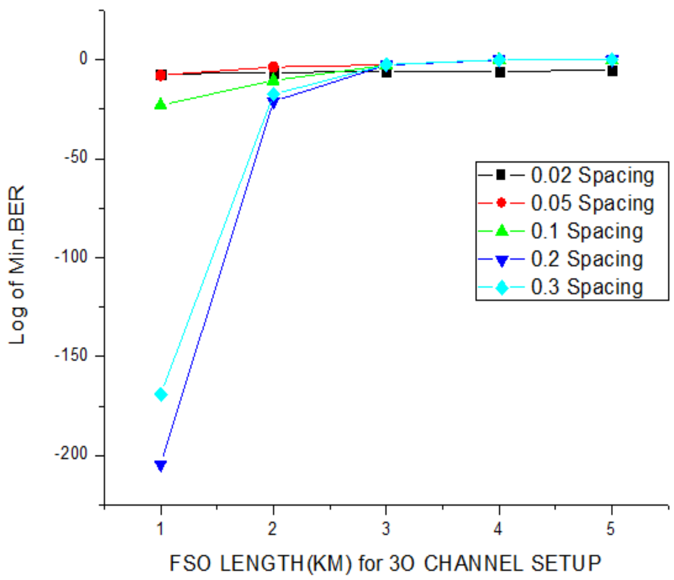


Fig.6.5.3(a) FSO Length Versus Log Min BER (30 channel setup)

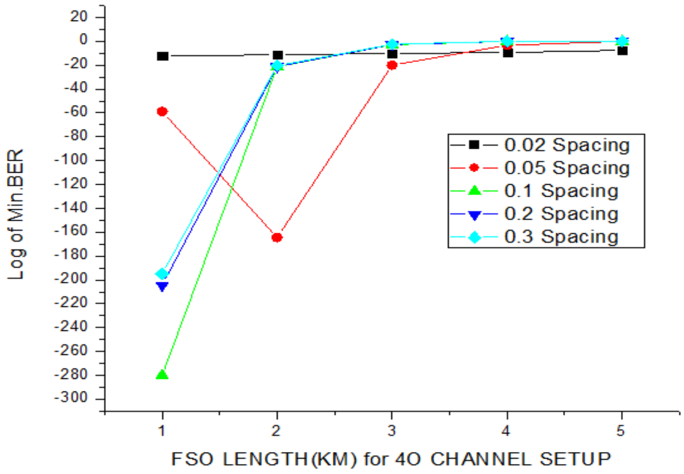


Fig.6.5.3(b) FSO Length Versus Log Min BER (40 channel setup)

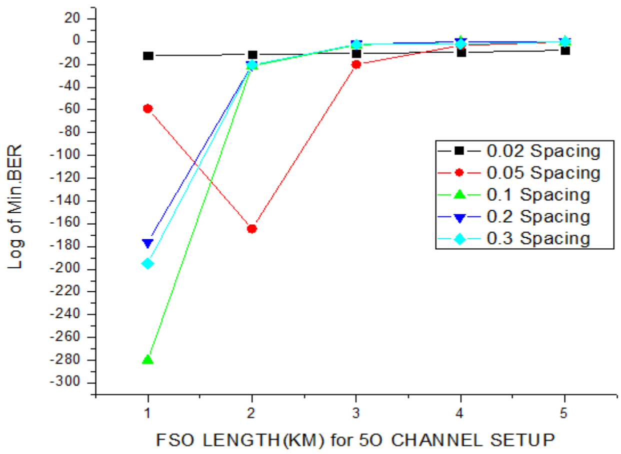


Fig.6.5.3(c) FSO Length Versus Log Min BER (50 channel setup)

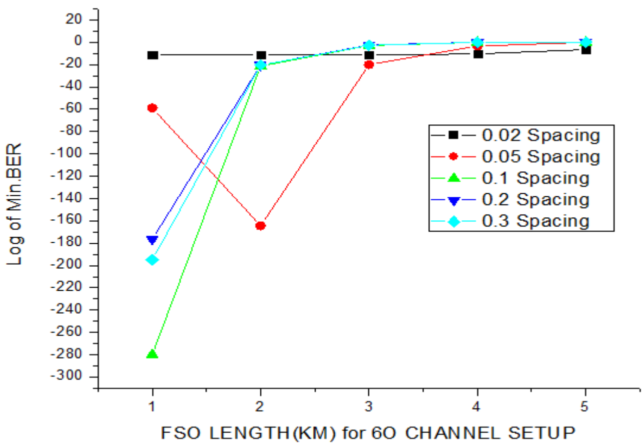


Fig.6.5.3(d) FSO Length Versus Log Min BER (60 channel setup)

6.5.4 Varying Compensation Techniques In 30 channel System:

It was observed from the graph shown in figure 6.5.4 that the increase in FSO length results in an increase in BER value for all the compensation schemes and uncompensated as well. Therefore, the increase in FSO length for different compensation schemes results in the poor performance of the system. The graph also depicts that a 30 channel setup when compensated by post compensation technique shows best performance followed by pre-, symmetric- and uncompensated schemes. However, a symmetric compensation technique shows almost a linear response. Also, an uncompensated technique shows poor performance than other relative techniques.

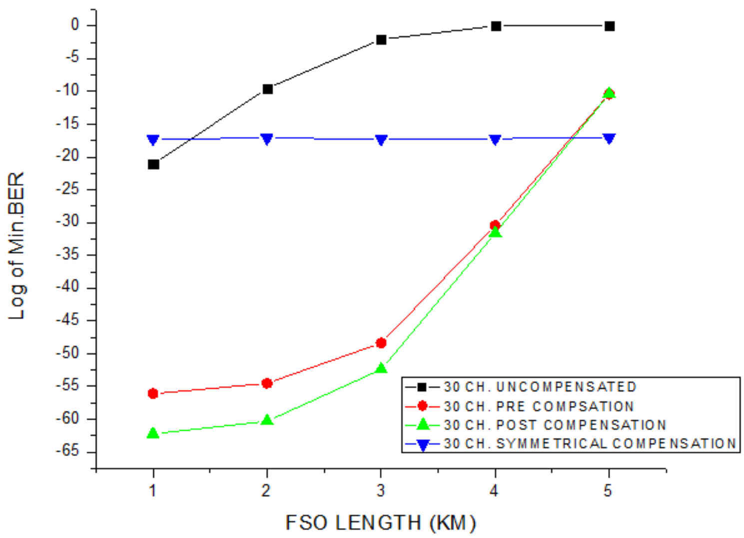


Fig.6.5.4 FSO Length Versus Log Min BER (30 Channel Setup)

6.5.5 Varying Data Rates In different 30 channel compensated models:

The graphs for FSO length against Log Min BER was plotted for different data rates in all compensated setups and uncompensated as well. Two types of graphs were plotted, a particular system at different data rates and different systems at a particular data rate. The data rates are varied as 10 Gbps, 20 Gbps, 40 Gbps & 80 Gbps. For 10 Gbps data rate

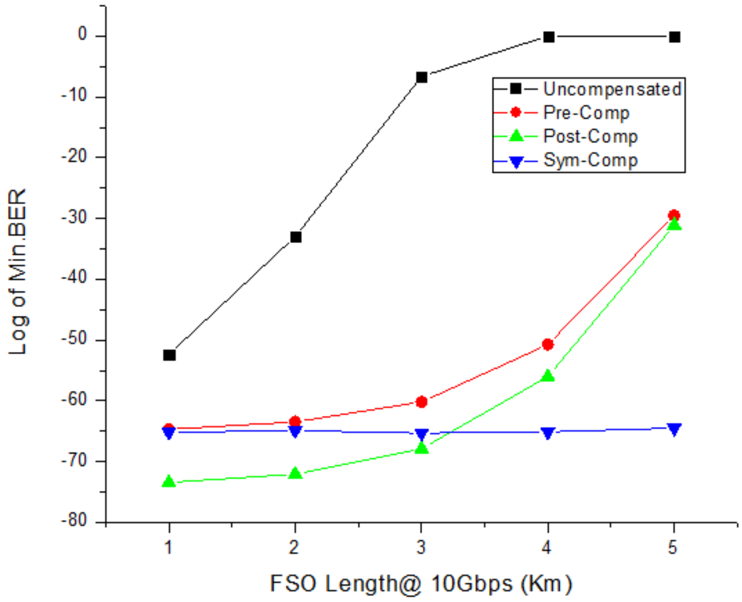


Fig.6.5.5(a) FSO Length Versus Log Min BER (at 10 Gbps)

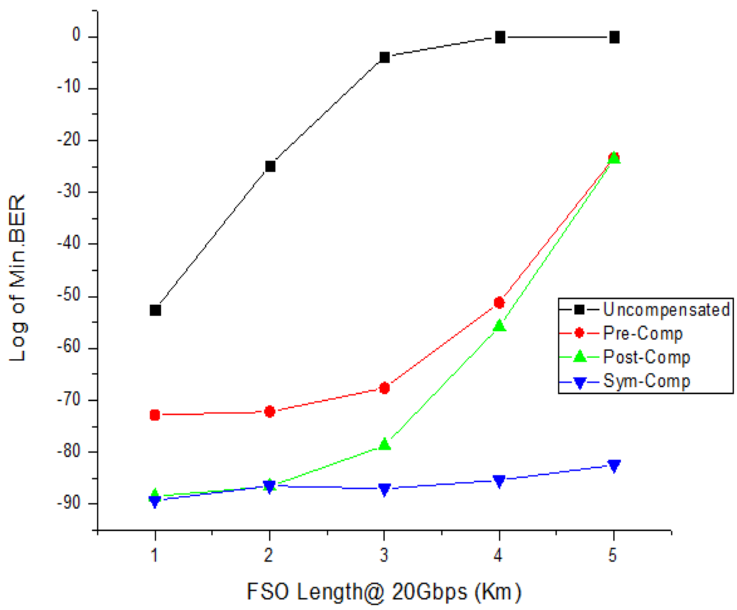


Fig.6.5.5(b) FSO Length Versus Log Min BER (at 20 Gbps)

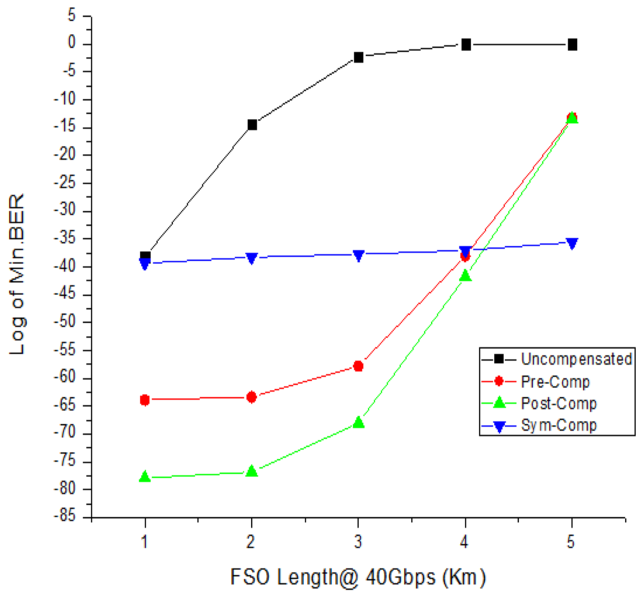


Fig.6.5.5(c) FSO Length Versus Log Min BER (at 40 Gbps)

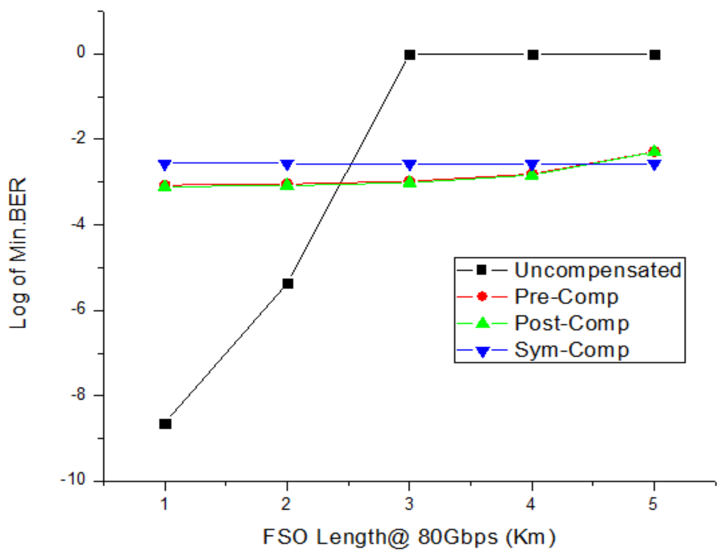


Fig.6.5.5(d) FSO Length Versus Log Min BER (at 80 Gbps)

The observations from graphs are as.

(A)From fig 6.5.5(a), It is observed that at 10 Gbps data rate, post-compensated showing a minimum value of BER & performs better followed by pre-,symmetric & uncompensated models. A symmetric compensated setup shows almost a linear response. Post-, Pre- & symmetric setups show a sharp increase in BER value beyond 3 km of FSO length.

(B)A graph plotted in fig.6.5.5(b) shows that a symmetric model having a minimum value of BER performs better and shows almost a linear response followed by post-, pre-, & uncompensated models at 20 Gbps data rate. Pre-, Post - & uncompensated setups show a sharp increase in BER value beyond 3 Km FSO length.

(C)A graph in fig. 6.5.5(c) indicates that at data rate of 40 Gbps , Post-compensated model performs best followed by pre- symmetric & uncompensated systems. Sharp increase in BER is observed beyond 3 km of FSO length.

(D)A 80 Gbps system is evaluated and the result is shown in fig. 6.5.5(d),The graph indicates that uncompensated model shows a minimum BER value and thus performs better followed by post-, pre- and symmetric setups.

(E)A fig 6.5.5(e) shows that, an uncompensated model performs best at 10 Gbps data rate. The increase in data rate results in performance degradation of the system. At 80 Gbps, the system shows poor performance for greater than 3 km of FSO length.

(F)A graph shown in fig 6.5.5(g) indicates that a pre-compensated model performs better at 20 Gbps for less than 4 km followed by 10 Gbps, 40 Gbps & 80 Gbps. However, beyond 4 km FSO length, 10 Gbps data rate results in better performance of system.

(G)A graph shown in fig 6.5.5(h) indicates that a post-compensated model performs better at 20 Gbps followed by 40 Gbps, 10 Gbps & 80 Gbps data rates. At 80 Gbps data rate, the system shows poor performance.

(H)A symmetric compensated setup is evaluated at different data rates and the result is shown in fig 6.5.5(i),The result shows that a system performs best at 20 Gbps data rate with almost linear response followed by 10 Gbps, 40 Gbps & 80 Gbps data rates.

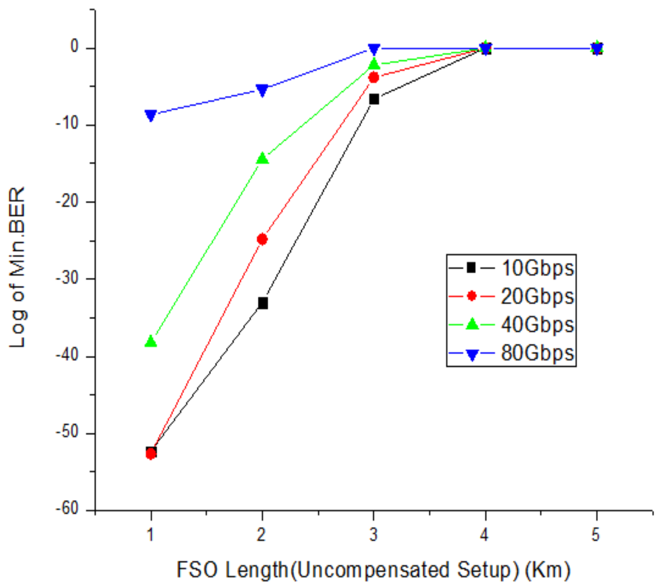


Fig.6.5.5(e) FSO Length Versus Log Min BER (for uncompensated setup)

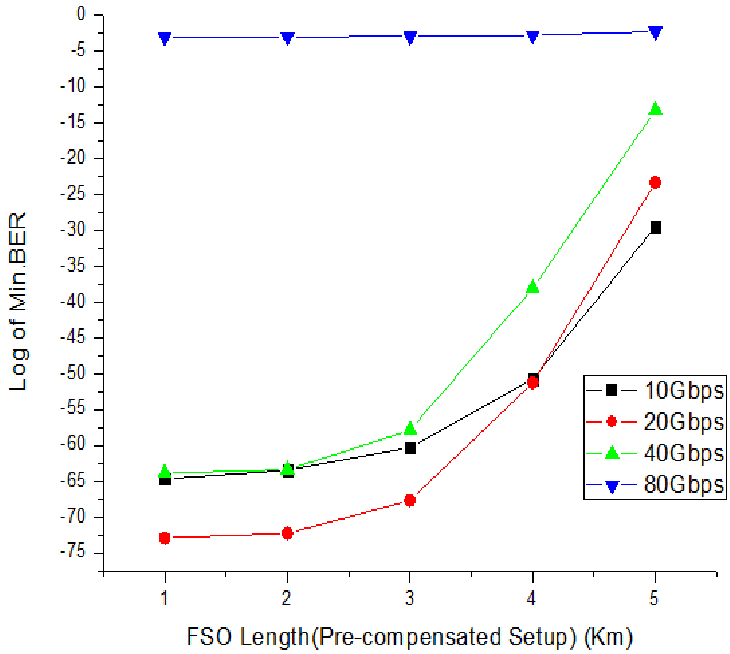


Fig.6.5.5(f) FSO Length Versus Log Min BER (for pre-compensated setup)

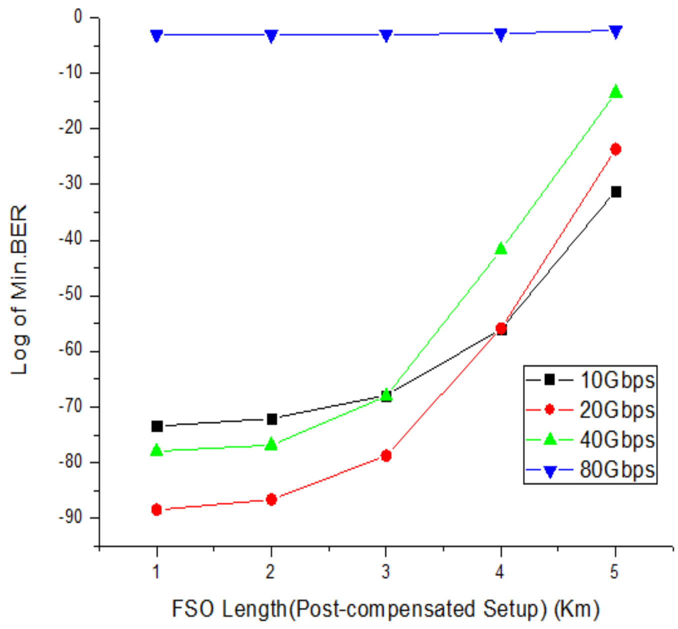


Fig.7.5.5(g) FSO Length Versus Log Min BER (for post-compensated setup)

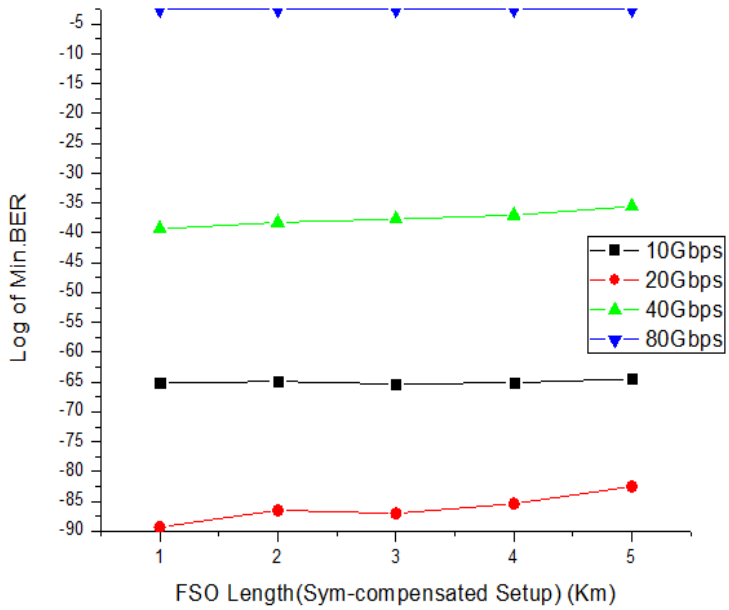


Fig.6.5.5(h) FSO Length Versus Log Min BER (for symmetric-compensated setup)

6.6 Varying amplifiers In 30 channel System:

Various graphs drawn for different channel Spacings are as under:

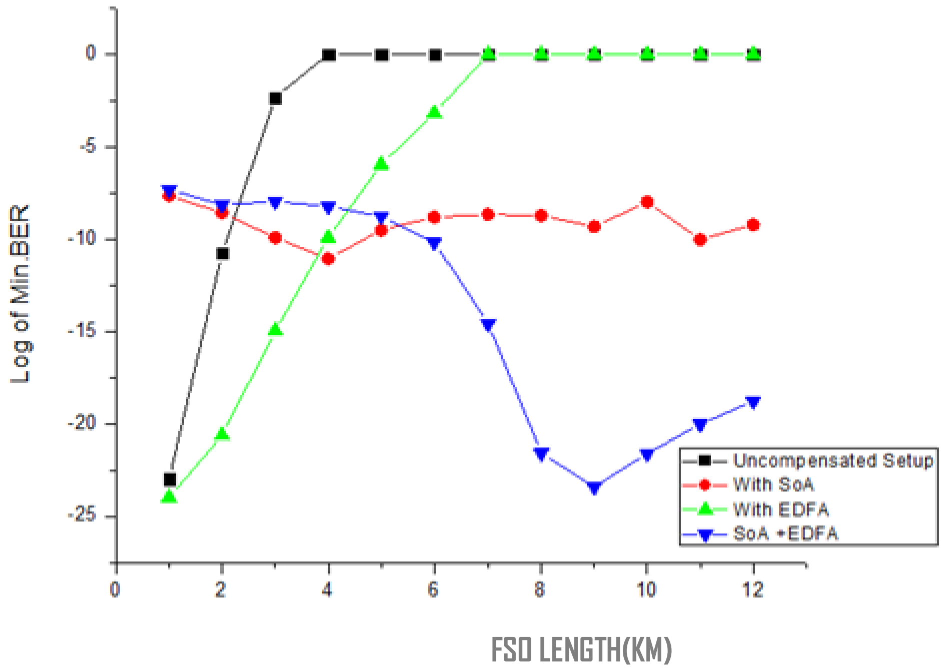


Fig.6.6 FSO Length Versus Log Min BER(30 channel Setup)

A graph of Log of Min.BER against variable FSO length as shown above was plotted for the FSO setup incorporating various Amplification Techniques and the following inferences were drawn from the graph,

(a)The BER values show a general increase with increase in FSO length.

(b)Out of all the propose amplification techniques, the uncompensated setup shows the highest BER values for particular FSO length.

(c)The hybrid amplification technique proved to be best for longer FSO lengths while as for shorter FSO lengths EDFA based amplification technique proved to be more efficient.

(d)The response of SOA based amplification techniques was nearly linear for almost all the FSO lengths.

(e)It was also observed that the maximum supported FSO length was improved by amplification techniques of SOA & hybrid setup from being limited to a maximum of 3 km in case of uncompensated to a maximum of 12 kms in case of proposed amplification techniques.

6.7 Varying Modulation Format In 30 channel System:

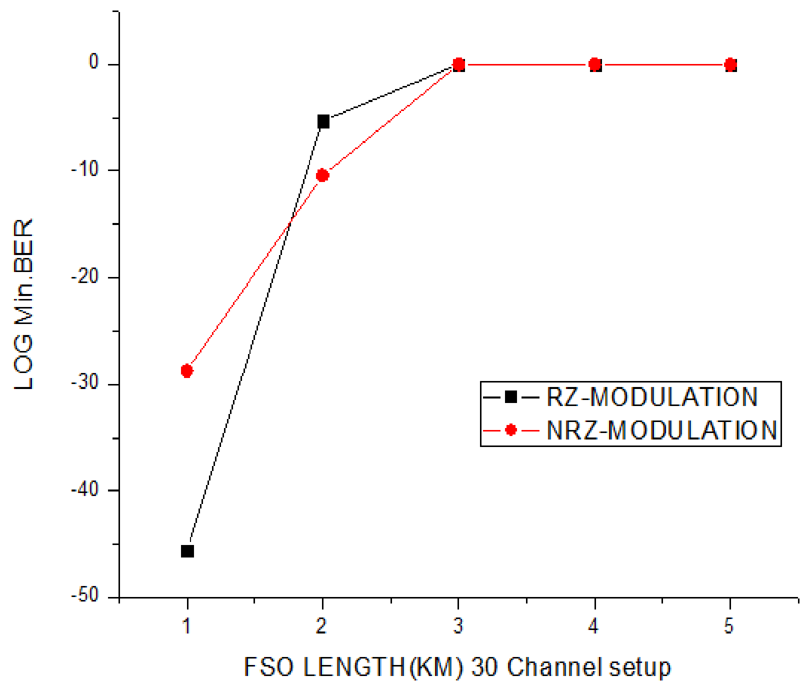


Fig.6.7 FSO Length Versus Log Min BER (Uncompensated 30 channel seup)

From figure 6.7 (f), the graph shows that the increase in FSO length results in increase in BER value for different modulation formats, hence, resulting in poor performance. It is also clear from the graph that BER values for RZ modulation are lower than that of NRZ modulation. Therefore, an optical source when set with RZ modulation shows better results than NRZ modulation.

CONCLUSION

A number of techniques and methods have been proposed and implemented in the past years to increase the number of users in the system and transmit the data to maximum possible range with minimum losses. In this thesis, the features of DWDM technology ,Hybrid amplifiers and FSO are merged in a single system to improve the performance of the system. The work also includes variation of various system parameters like number of channels, attenuation, modulation format, channel spacing and data rates. It is concluded that a nominal value of channel spacing should be selected for transmission as the increased value of channel spacing results in increase in bandwidth utilization and the decreased values result in interference between the channels. Some compensation techniques are also implemented in the system to obtain the better results. While varying number of channels in a system, it is observed that 30 channel system show better results followed by 40,50 and 60 channel setup and the FSO range supported by the systems is less than 3 km. The change in attenuation for different systems proved 30 channel system to perform best followed by 40,50 and 60 channel setup ,however a serious signal distortion is observed for attenuation value greater than 10 dB/km. when the modulation format of optical source in 30 channel system is varied from RZ to NRZ format, the results for RZ modulation are observed to be better than the later. To compensate the losses in the system , compensation techniques are used and the post-compensation technique shows best performance followed by pre-compensation, symmetric-compensation and uncompensated as well. It is observed that a post-compensated setup performs better followed by pre-, symmetric & uncompensated models. The research work also includes incorporation of different amplifiers including hybrid combination in the system to get the better results. The use of SOA & hybrid combination Of EDFA & SOA increases the range of FSO link beyond 4 Kms upto 12 Kms.

FUTURE SCOPE

In this thesis, 30 channel system is considered for carrying out the major part of research. The work can be extended by investigating the other channel systems also. This thesis includes the the use of compensation techniques to reduce the losses resulting from dispersion .In future, work can be extended to limit the effect of geometrical and geographical losses onto the performance of FSO networks. Moreover, modified devices can be suggested/proposed that help in improving overall SNR of system.FSO networks as of now are limited to shorter distances, work can be extended to propose FSO networks for longer distances as well. The work also includes analysis of some amplifiers like SOA, EDFA and hybrid combination of SOA &EDFA, the other amplifiers and their hybrid combinations like Raman-EDFA etc can also be explored in the system. Further, the systems with combinations of more than two amplifiers can also be demonstrated. The effect of varying the other system parameters like channel spacing, data rate, input power can be applied to the proposed system to improve the results.

APPENDIX-I

Proposed workplan with Timeline for Dissertation-II

Week ⇒ Month ⇓	Week 1	week 2	Week 3	Week 4
January	Design different channel setups	Worked on FSO Length	Worked on Attenuation	Worked on Varying Channel spacing
February	Compared channel spacing results	Worked on compensation schemes	Compared different compensation schemes	Using different amplifiers
March	Compared amplifier results	Varying modulation formats	Compared modulation results	Varying data rates
April	Compared data rate results	Result Compilation	Report writing	Report writing

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