HYBRID DISPERSION COMPENSATION MODULE DEVELOPMENT USING OPTISYSTEM FOR ADVANCED OPTICAL COMMUNICATION

By

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THESIS COMPLETION CERTIFICATE

This is to certify that the thesis entitled **"Hybrid Dispersion Compensation Module Development using Optisystem for Advanced Optical Communication"** by **Ashwani Kumar (500043354),** in Partial completion of the requirements for the award of the Degree of **Doctor of Philosophy** (School of Computer Science) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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Ashwani Kumar

DECLARATION

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text".

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Communication involves propagation of signals through air to convey information. Wireless technologies for communication provide an effective way to transport signals and pulses for progressively and speedier voice, video etc. All things considered, light has been another long-lasting type of communication and optical fiber communication has progressed at a pace equivalent to or surpassing the development of wireless communication. In optical fiber communication, infrastructure is circulated starting with one correspondences area then onto the next. Fiber-optic links must be introduced starting with one point then onto the next to empower optical communications. The effectiveness of optical fiber link mainly depends upon the type and the quality of cables used. Since they can be worsen and wear out with respect to time so their maintenance and care is must. Generally speed of the light slows down while propagating in the outer space, especially, when they passes through glass and plastic fibers in optical cables. Optical fiber communication systems normally don't have the advantage of a straight way and should regularly twist around corners through a city or in a place of business for the path of their signals. Likewise with light reflecting off around the corners of walls, each twist in the link diminishes the speed of the light proliferating through that link. Also the latency of an optical fiber communication system is longer than that of fixed wireless communication. Apart from these disadvantages, optical fiber communication is mostly preferred in comparison to fixed wireless communication. This is because of the most prominent factor of measuring the effectiveness of signal transmission i.e. bandwidth. Optical links are fit for supporting relatively unlimited bandwidth, which means Gb/s information rates. Whereas in wireless communication, since they are sending signals through free space as opposed to through an optical fiber or other limited medium, works inside the fixed portions of frequency spectrum. Therefore, the restricted transmission capacity of any wireless system will likewise confine the amount of data that can be exchanged between locations at any one time. Optical fiber provides a bandwidth of about 10THz or more.

When optical signals are transmitted over the optical links, different wavelength components of the signals will generally experience different propagation time due to the fact that the transport medium has different effective refractive indices for different wavelengths. In the recent years, with the rapid growth internet business needs, people urgently need more capacity and network

systems. So the demand for the transmission capacity and bandwidth are becoming more and more challenging to the carriers and service suppliers. Under this situation, optical fiber is becoming the most favorable delivering media and laying more and more important role in information industry, with its huge bandwidth and excellent transmission performance. Therefore, it is necessary to investigate the transmission characteristics of optical fiber. The main goal of any communication system is to increase the transmission distance. Loss and dispersion are the major factors that affect the fiber optic communication system. The EDFA (Erbium doped fiber amplifier) is the gigantic change that happened in the optical fiber communication systems; the loss is no longer major factor to restrict the fiber optic transmission. Since EDFA works in 1550 nm wave band, the average single mode fiber (SMF) dispersion value in this wave band is very big, about 15-20ps/(nm.km). So, it is easy to see that the dispersion become the major factor that restricts the long-distance fiber optic system. There are different techniques available for the dispersion compensation. But the most popular are dispersion compensating fiber (DCF), Fiber Bragg grating (FBG) and electronic dispersion compensation (EDC).

Further, it is clear from the literature survey that various specialists have examined these techniques in their own ways to compensate the dispersion. The problem of dispersion in optical fiber, the impact of various Parameters and the compensation techniques to be undertaken. Based on their examinations different results were produced. These results are for the most part in view of investigations for a small distances, and low bit rate, which don't coordinate for higher bit rate and larger distance. The models based on different compensation techniques for 120Km distance at a bit rate of 100Gbps using single mode fiber has been designed. It is accordingly, more hypothetical and trial studies are required to consolidate the real stream conditions for dispersion compensation.

Dispersion has impact on both performance and reliability of an optical fiber. Bit rate and length of fiber are the main causes of dispersion. The change in bit rate and length of optical fiber can enhance the dispersion losses. The present investigation was carried out for dispersion compensation using different techniques.

Keeping this in view, the present study is carried out with respect to the following objectives;

- To assess the existing dispersion compensation techniques used in Optical fiber communication system and find out their effect on dispersion reduction.

- To select the most significant type of Grating by performing the analysis over the grating types in the existing dispersion compensation based optical communication systems.
- Propose a hybrid approach with best FBG technique with the filtration process and EDC (electronic dispersion compensator) based system for achieving the upgraded model to achieve high data rate.
- Evaluate and Compare the proposed model with the existing model's performance using Optisystem simulation tool.

Dispersion compensation in optical fiber communication system is necessary to overcome the non-linear and other signal degradation factors. In this work, dispersion has been compensated at 100 Gbps rate over a transmitting distance of 120Km. A simulation model was designed using Optisystem 7.0, a simulation software, to investigate the effect of the different dispersion compensation techniques.

In the initial part, dispersion compensation using DCF as dispersion compensator has been simulated and its results has been analyzed at three different configurations of Pre, Post and symmetrical at input power ranging from 1-10dBm. It has been found that Post configuration of DCF exhibited the maximum Q-Factor and least BER in comparison to other configurations. Next experiment has been done using another mostly used dispersion compensation technique of IDCFBG in three schemes of Pre, Post and Symmetrical. Post configuration of IDCFBG has been found to be the best among others with a highest Q-Factor and lowest BER. All the simulations have been considered at input power ranging from 1-10dBm.

Another experiment accomplished the simulations using uniform fiber Bragg grating (UFBG) at input powers ranging from 1-10dBm. During analysis it has been found that increase in input power increases the Q-Factor for all the three schemes of Pre, Post and Mix compensation. Hence, after analyzing all the factors, Post compensation of UFBG at input power 10dBm found to exhibit best results with a maximum of Q-Factor and minimum BER, when compared with the remaining techniques. Finally in third objective, this post compensation technique of UFBG along with EDC is modeled as Hybrid Dispersion compensation. This hybrid model has been executed at input powers from 1-10dBm. Q-Factor, BER, received power and eye height of this hybrid technique has been compared with all the best configurations of DCF, IDCFBG and UFBG i.e. Pre DCF, Post IDCFBG and Post UFBG. After analyzing the results, it is clear that the Hybrid model has maximum Q-Factor and least BER. This, the conclusion shows the hybrid technique to be the best for dispersion compensation at 100Gbps over 120Km distance among other existing compensation techniques.

Since the Optical fiber communication is well known due to its high bit rate transmission but due to unawareness about the Dispersion, it doesn't perform well as it can, particularly due to the variations in the distance and bit rate. There can be huge data loss, if such types of problems are not targeted first. In this research work different dispersion compensation techniques has been utilized to improve the performance of Optical fiber communication by mitigating the Dispersion, considering all the objectives as discussed earlier.

LIST OF SYMBOLS

a_1	Normalized post cursor value of pulse response
c	Speed of light in vacuum
$d(n)$	Transmitted binary data
D_1	Dispersion coefficients of SMF
D_2	Dispersion coefficients of DCF
D_f	Dispersion coefficient of optical fiber channel
D_g	Grating dispersion
D_{DCF}	Dispersion of DCF
D_{SMF}	Dispersion of SMF
h_1	First tap weight of DFE
k_1	Tap weight of first FFE
L_1	Lengths of SMF
L_2	Lengths of DCF
L_f	Propagating distance of the signal before compensation of dispersion
L_g	Length of FBG
L_{DCF}	Length of DCF
L_{SMF}	Length of SMF
n	Index of refraction of the medium
$\bar{n}$	Average mode index
n_1	Refractive index of the core
n_2	Refractive index of the cladding
n_{eff}	Refractive index of uniform fiber Bragg grating

$y(n)$	Recovered signal from DFE
$y^{\wedge}(n-1)$	Previously detected signal
θ_c	Critical angle
π	Pie
$\Delta\lambda$	Grating bandwidth
λ_B	Bragg wavelength
Λ	Grating period

LIST OF ABBREVIATIONS

APD	Avalanche Photodiode
ATM	Asynchronous Transfer Mode
BER	Bit-Error-Rate
CD	Chromatic Dispersion
CDMA	Code Division Multiple Access
CFBG	Chirped Fiber Bragg Grating
CSRZ	Carrier Suppressed Return to Zero
DCF	Dispersion-Compensating Fiber
DCM	Dispersion-Compensating Module
DFE	Decision Feedback Equalizer
DMD	Differential Modal Delay
DPSK	Differential Phase Shift Keying
DRZ	Duo binary Return to Zero
DSF	Dispersion Shifted Fiber
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EAM	Electro Absorption Modulator
EDC	Electronic Dispersion Compensation
EDFA	Erbium-Doped Fiber Amplifier
EO	Electro-Optical
ER	Extinction Ratio
FBG	Fiber Bragg Grating
FBGDCM	Fiber Bragg Grating Dispersion Compensating Module
FDM	Frequency Division Multiplexing
FFE	Feed Forward Equalizer
FWM	Four Wave Mixing
Gbps	Giga Bits Per Second
GDR	Group Delay Ripple
GUI	Graphical User Interface
GVD	Group Velocity Dispersion
IF	Intermediate Frequency
IL	Insertion Loss
IR	Infra-Red
ISI	Inter Symbol Interference
LASER	Light Amplification by Stimulated Emission of Radiation
LAN	Local Area Network
LED	Light Emission Diode
LTI	Linear Time-invariant
MAN	Metropolitan Area Network
MC-CFBG	Multi-channel chirped Fiber Bragg grating
MDRZ	Modified duo Binary Return to Zero

MMF	Multi-mode Fibers
MUX	Multiplexer
MZM	Mach-Zehnder Modulator
NRZ	Non-return to Zero
NZ-DSF	Non-Zero Dispersion-Shifted Fiber
OADM	Optical add/drop multiplexers
OE	Opto-Electronic
OFC	Optical Fiber Communication
PMD	Polarization Mode Dispersion
Q-Factor	Quality factor
RF	Radio Frequency
ROF	Radio Over Fiber
RZ	Return to Zero
SDH	Synchronous Digital Hierarchy
SMF	Single-Mode Fiber
SONET	Synchronous Optical Network
SSFBG	Sampled Fiber Bragg Grating
SSMF	Standard Single-Mode Fiber
STM	Synchronous Transport Module
TDM	Time Division Multiplexing
TIR	Total Internal Reflection
TV	Television
UFBG	Uniform Fiber Bragg Grating
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

CHAPTER-1
INTRODUCTION

1.1 CHAPTER OVERVIEW

Because of the swift development in the use of web business, high capacity networks are becoming more necessary and essential to fulfill the requirements of the people. Hence, fulfilling this demand of high capacity and more bandwidth is becoming a challenge for the service providers. Thus, in comparison to other transmission mediums fiber optic has become the appreciative channeling medium with its excellent features of more transmission capacity and bandwidth. Fiber optic is getting more attention in transmission of the signals and other information over longer distances.

The major objective of any communication medium is to enhance the channeling distance of information carrying signal. This requirement can be accomplished by using optical fiber as communication medium. Like other communication mediums, optical fiber also has some problems that are encountered while transmitting the signals over longer range. Dispersion, losses, attenuation and other fiber non linearity are the prime factors that influences and degrades the optical signal during transmission.

Out of all the signal degradation factors, dispersion is the most influential factor which restrains the channeling distance of any signal by widening the pulses travelling through the fiber. Thus, distinct dispersion compensation techniques are required in order to ensure the better transmission. This chapter explains the whole concept of use of optical fiber for transmitting signals along with their advantages and disadvantages. The concept of dispersion along with dispersion compensation methods like DCF, FBG, UFBG, EDC and digital filters are also explained in detail.

1.2 INTRODUCTION

Information exchange is an imperative segment of day to day routine. Consistently, distinctive kinds of Communication facilities are utilized by users, for example, Audio, video, pictures, and other sort of communication. Due to the increasing requirement of those facilities, requests for vast transmission limit or bandwidth also additionally increases. While considering the ultimate goal of satisfying the expanding interest for higher information rate and bigger transfer speed, optical communication came into existence. Adding glass fiber gives a gigantic channeling capacity change when compared with transmission lines through copper and electrical wires. Therefore transmission through optical fiber innovation will continue to exist the significant communication innovation for a long time to come [1, 4].

Optical fiber has been utilized by all major network technologies as a medium for transmission, for example, FDDI, SONET, ATM and SDH because of its tremendous transfer speed and least corruption of signal. Its utilization is done by numerous media communications organizations to transmit phone signals, Internet correspondence, and digital TV signals. Along with these lines, it is important to examine the channeling attributes of fiber. Fundamental objective of any particular communication framework is to expand the channeling distance. Signal losses and scattering are central point that influences fiber optics framework. Erbium doped fiber amplifier is the immense revolution that has been occurred in fiber optics frameworks over the years; Signal losses are never again the main consideration to restrain the fiber optic communication.

Due to the working of EDFA in 1550 nm wave band, the normal single mode fiber (SMF) has extremely high value of dispersion in this band, around 15-20ps/(nm.km). At the point of transmitting optical pulses over the optical connections, diverse wavelength elements of the pulses will encounters different propagation time because of the reason that the carrying medium has diverse effective refractive indices for diverse wavelengths and reaches at receiver at different intervals of time causing pulse broadening or in short dispersion. In this way, it is clear from the above discussion that dispersion or scattering turn into the central point which limits the long-distance in fiber optic link. Before going in detail about dispersion, firstly I am going to explain about Optical system [5]-[7].

1.3 STRUCTURE OF AN OPTICAL COMMUNICATION SYSTEM

An advanced fiber optics communication linkages relies basically on 4 segments: optical fiber, optical transmitter, optical recipient and the optical amplifier. Communication utilizing fiber optics includes the essential steps given below: Producing optical signal utilizing a transmitter, handing-off the signal along the optical fiber, guaranteeing that signal does not turn out to be excessively twisted or powerless, then getting the optical signal and changing it to an electrical pulse. Optical fiber communication frameworks comprises of an optical transmitter to change over an electrical signal to an optical signal for transmission through the fiber, a link containing a few groups of optical fibers, optical enhancers to enhance the energy of the optical signal, and an optical recipient to reconvert the received optical signal back to the initially transmitted electrical flag [8]. Elementary optical fiber communication system is shown in Fig.1.1.

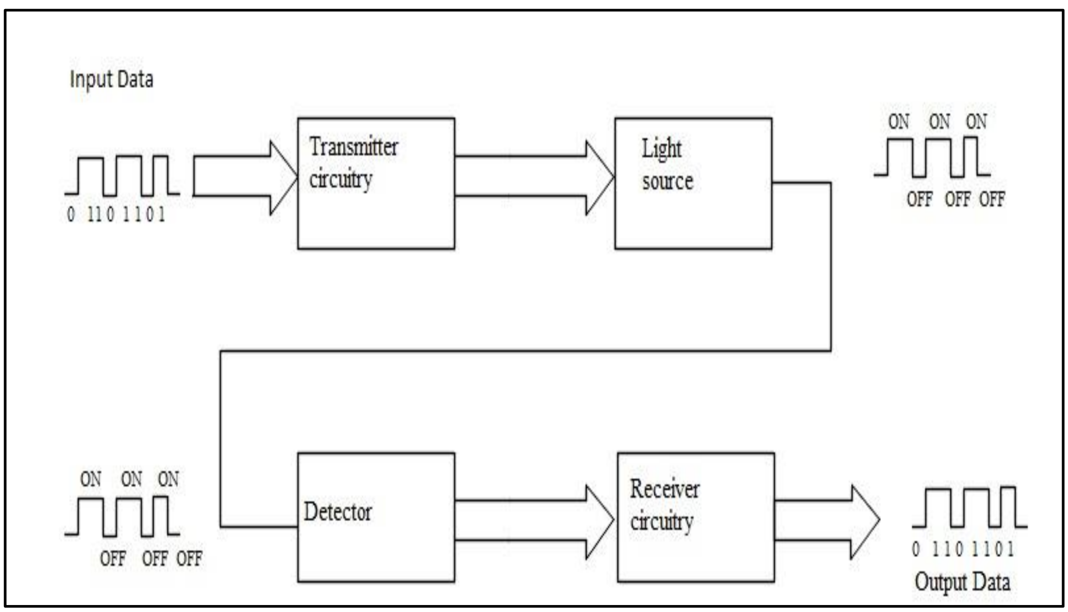


Fig.1.1: Elementary optic fiber communication systems

In optical communication system, the optical transmitter is utilized to produce optical signal and modulate the weak data with that signal, the optical recipient accepts the transmitted signal and transforms it into the original data, here the optical fiber is used as a transmission medium of light, and the optical amplifier is used to enhance the distance. The whole setup is shown in Fig.1.2.

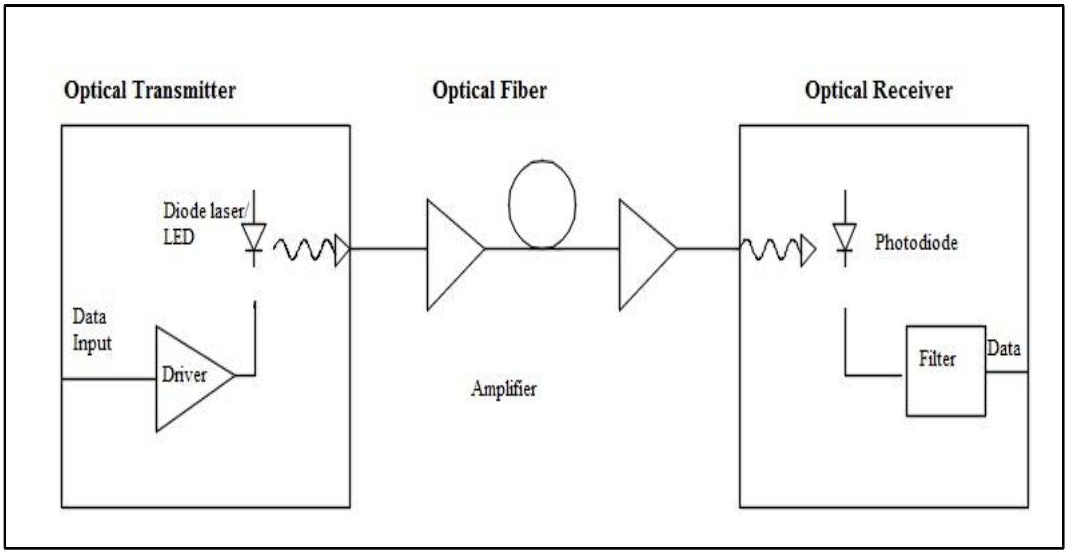


Fig.1.2: Optical link system

1.3.1 Optical fiber

Optical fiber comprises of a fine chamber of glass center, through which light travels. Center is encompassed by another layer of glass, named cladding, and that is wrapped by thin plastic coat. Center or core has a somewhat higher refractive index than the cladding glass. Structure of optical fiber is shown in Fig.1.3 whereas the concept of critical angle in Fig.1.4. The proportion of refractive index of center and cladding characterizes the critical angle Θ_c shown in eqn. (1.1) given below:-

$$\sin \Theta_c = \frac{n_2}{n_1} \tag{1.1}$$

Where n_1, = refractive index of the core

n_2 = refractive index of the cladding

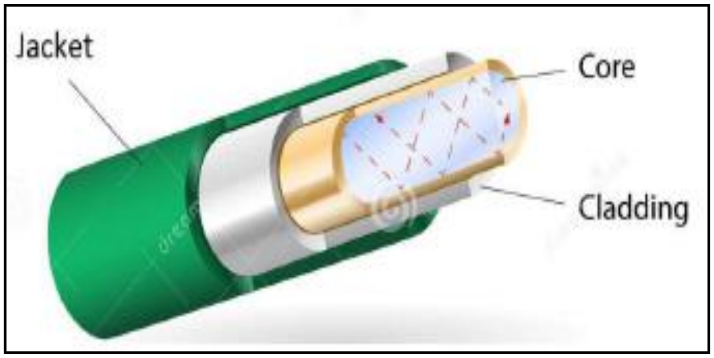


Fig.1.3: Optical fiber structure

What influences optical fiber to work is TIR (total internal reflection). When a beam of optical signal travels from the center –cladding border at an edge bigger than ϴc, beam is totally bounce back to the center. In this manner flag can be guided inside optical fiber [10]-[12].

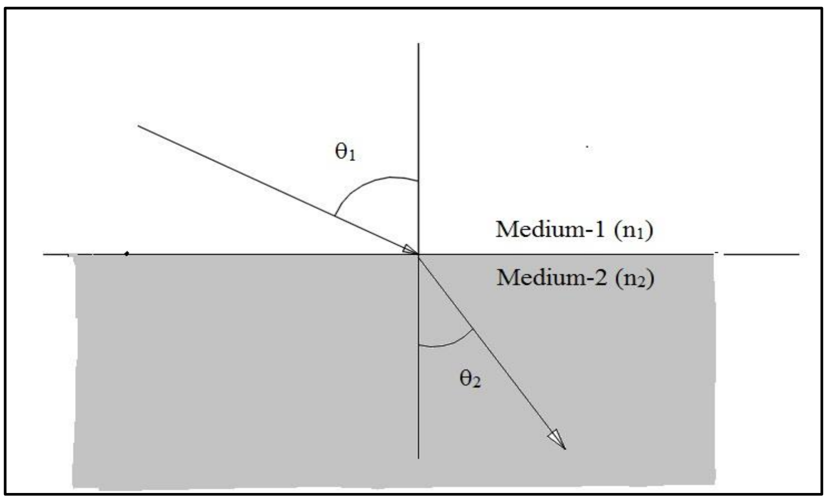


Fig.1.4: Critical angle.

- **Advantages of optical fibers**

- Optical fibers are less in weight and smaller in size.
- Transmitted signal consumes very small power θ
- Signal Losses are quite low (typically not more than 0.3 dB/km).

- Larger Bandwidth.
- Optical fibers can carry huge data.
- Optical fibers are immune to nuclear electromagnetic pulses and electromagnetic interference also.
- These are very safe to use near high-voltage equipment because they have high value of electrical resistance.
- There cannot be any crosstalk between different optical cables.

➢ **Demerits of optical fibers in comparison with wires**

- Huge expenditure is required.
- High cost optical transmitters and recipients are must for faithful communication.

1.3.2 Classification of optical fiber

There are two categories of Optical fibers, frequently mentioned as single mode fiber and multimode fiber.

1.3.2.1 Single-mode fiber

For a given wavelength, Single mode fibers are optical fibers intended to carry only single mode/polarization direction. The core and cladding diameters are typically between 8 and 125 µm, respectively [13]. For single-mode fiber, a smaller core influences and limit the light engenders in one mode or one way just down the fiber shown in Fig. 1.5.

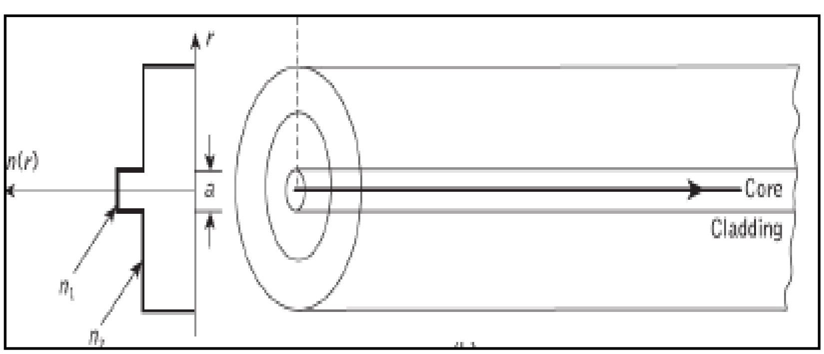


Fig.1.5: Single mode fiber

1.3.2.2 Multi-mode fiber

Multi-mode fiber permits various ways, termed as modes, for propagation of light through them. It utilizes an expensive number of frequencies (or modes). Multi-mode fiber center is bigger in comparison to single-mode fiber (normally 50 or 62 µm). Multimode fiber is generally determined for Local area networks and wide area networks. It likewise also relies on the wavelength utilized. Multimode fiber is shown in Fig.1.6. At long wavelength, even "multimode" fiber can engender just a solitary or single mode. At short wavelengths, a few methods of signal may spread in a "solitary mode" fiber. Thus, single-mode fiber have alleged knee wavelength. Underneath the knee wavelength, a solitary mode fiber turns into a multimode [14].

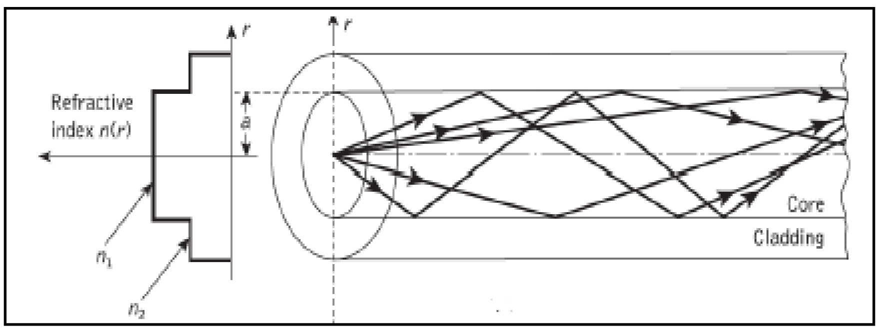


Fig.1.6: Multi-mode fiber

1.3.3 Optical sources

In optical communication field, an optical source is utilized to produce an optical carrier frequency. Modulating signal is modulated along with carrier signal. This region looks at essential light sources used as a part of optical transmission. Two fundamental sources of light are utilized in fiber optics: lasers and light emitting diodes (LED).

1.3.3.1 Light emitting diode (LED):

A Light emitting diode (LED) is basically a P-N junction semiconductor diode that transmits light when a current is connected through the gadget. Basic part of LED is the chip made up of semiconductor. Chip is partitioned into 2 sections and isolated by a limit termed as junction. The P- side is overwhelmed by holes and the N- side is commanded by electrons. The boundary wall behaves as a potential barrier to restrict charge carrier movement. Electrons move over intersection into the P- side. Distance between the bands i.e. gap between bands decides the required potential for the electron to lift up to the conduction band from the valence band. When the electron in the conduction band merges with holes in the valence band, it emits energy which is equivalent to the energy of band gap. This energy is emitted in the form of photons [2, 3]. Fig.1.7 is determining the structure of LED.

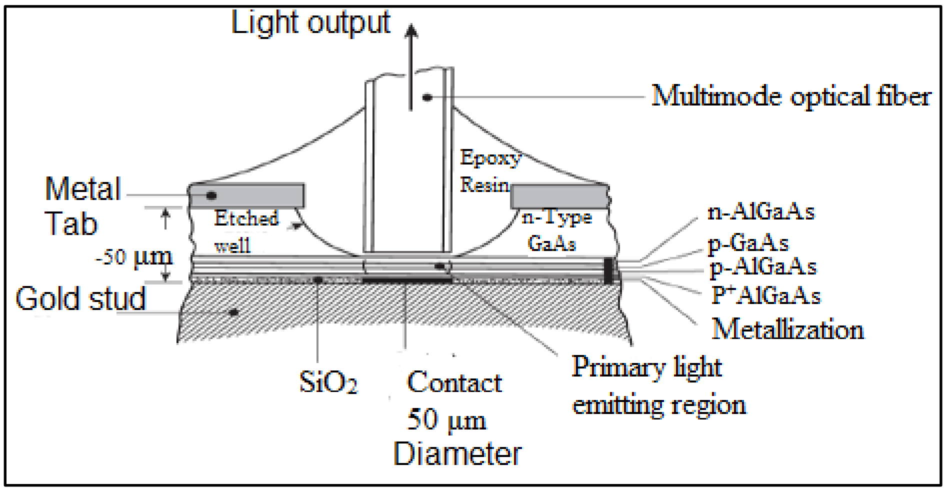


Fig.1.7: LED structure

1.3.3.2 Laser diode

LASER is abbreviated as "Light Amplification by Stimulated Emission of Radiation". Lasers made up of semiconductors are fundamentally the same as edge Light Emitting Diodes in structure. These are also p-n junction semiconductor diodes which can changes over the electrical signal provided to junction into optical rays. In both laser diodes and LEDs, wavelength of the yield radiation relies upon the energy gap in between the p-n junction. Nonetheless, the light signal yielded from a laser diode is exceedingly consistent and able to travel to a larger distance, while the light output signal from a LED is non-coherent and it can't be able to travel to a larger distance [9, 15]. Laser structure is defined in Fig.1.8 showing all the layers in detail.

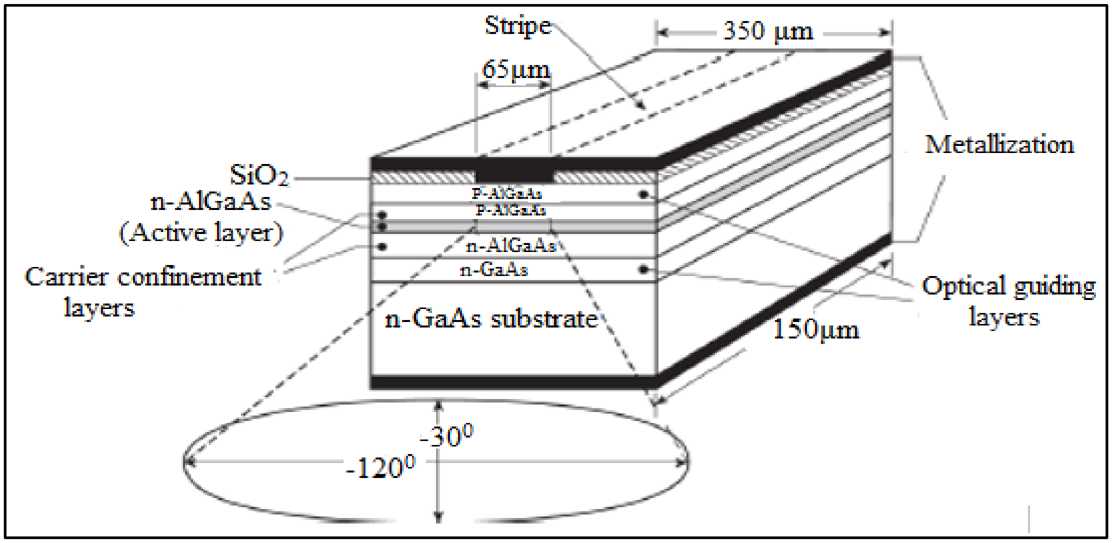


Fig.1.8: LASER structure

a) LEDs Vs Lasers

Merits of LEDs against Laser:

- LEDs are very simple in design hence the cost is quite low.
- Due to less sensitive to temperature change, LEDs are more reliable.
- As LEDs require simplest circuitry hence they have better linearity.
- Power consumption is very less.
- LEDs have wide emission area.

b) Laser Vs LEDs

The advantages of Lasers over LEDs include:

- Laser is a highly efficient device
- Wavelength range is quite high.
- Its small emission area is very much suitable for fiber core dimension.
- Laser provides very high output power.
- It generates extremely directional and coherent light which is desired for optical transmission.
- Laser is compact in size.

1.3.4 Optical amplifier

To enhance the strength of weak optical signals, an optical amplifier is used. Due to which the signals can be travel to a longer distance. Without the necessity of converting the light signal to electrical form, light signals can be directly amplified.

1.3.4.1 Erbium doped fiber amplifiers (EDFAs)

An Erbium-Doped Fiber Amplifier is designed to boost the optical signal. To achieve the desired amplification, the core of the optical fiber is doped with a trivalent erbium ion to change its characteristics. Hence EDFA comprises an optical fiber having smaller length which is added with an impurity known as erbium. Normally at infrared wavelength, when information fetching laser rays crosses the optical fiber, outer energy is provided. It is called a pumping process. In this process, usually the atoms are excited in the doped region of fiber by external pumping, which causes the huge increment in the intensity of laser rays travelling through it. The rays pass through the EDFA maintains their real features. The only difference is in terms of intensity of rays, which is higher than the rays at the input of EDFA. Fig.1.9 elaborate this approach. In case of optical fiber system the major drawback is the lack of transparent material for optical fiber. Either IR rays or visible light are greatly suppressed by the material of the fiber. Hence there is a huge requirement of repeater stations within every 100 km [16, 18]. Generally, repeater station works in three steps:

1) It converts optical signal into electrical signal

2) Then it amplifies the converted electrical signal.

3) Finally, it converts back the electrical signal into optical.

Such kinds of repeater stations, generally restrict the signal bandwidth. Hence, such repeaters are not that much efficient to regenerate the signal. Moreover, they contain very complex steps like conversions for their working. Hence, to remove such complexities EDFAs with wave division multiplexing technique are used. WDM technology enhances the bandwidth of the signal as compare to repeater stations.

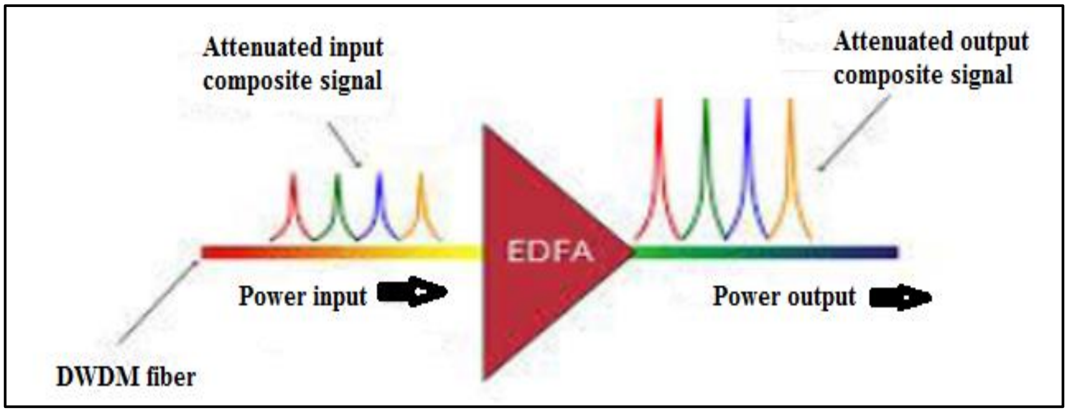


Fig.1.9: EDFA

1.3.5 Receiver

It performs in an opposite manner to that of transmitter. It receives the optical signal and convert it back into electrical one. It also convert the electrical signal into desired real form like audio, video or in terms of data [19]-[21]. Avalanche photo detectors and pin photo detectors are majorly used to detect the optical signal and to convert it into electrical form.

1.3.5.1 PIN photo detector

In case of optical communication system, mostly used detectors works on the bases of ionization.

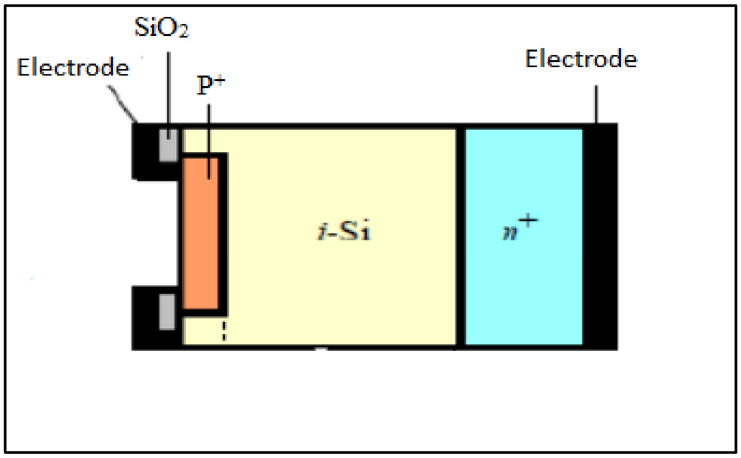


Fig.1.10: PIN photo detector

It means that when a powerful photon hits active area of semiconductor, it quickly transfers towards contact from where it is taken out of detector in amplified form as elaborated by Fig.1.10. Smaller amount of stray capacitances can survive in photo detector at higher frequencies typically, in terms of GHz, which indicates about the smaller size of detector [22, 23, 25]. Pin photodiode is shown in Fig.1.10.

1.3.5.2 Avalanche photo detector

The APD works in reverse biasing mode. During reverse biased mode, it generates powerful area near barrier. As hole- electron pairs are generated by the photons, so these pair travels across the barrier. Due to the powerful area near barrier, excited electrons generate more electron-hole pairs. Hence avalanche (or multiplication) process occurs, and actual current is produced by photons [27, 28].

1.4 THE DETERIORATION OF SIGNAL IN FIBER

Number of aspects are there causing signal deterioration, when optical rays proceeds inside fiber core. There are very rare chances to receive the signal across receiver, if the link length is longer. This is because of attenuation and dispersion of light wave travelling down the optical fiber. The attenuation effect decreases the signal power whereas the shape of the pulse is distorted by dispersion as light wave propagates inside fiber. Attenuation in a signal is caused by three fundamental procedures in an optical fiber. Their names are absorption, scattering and imperfection [33]-[35].

1.4.1 Dispersion

Distortion is caused in analog and digital signal transmission by a phenomenon called dispersion. Because of the dispersion in the fiber, pulses becomes broader as they travels through the fiber. As the pulses becomes broader, they starts interfering with the neighboring pulses and becomes almost identical at the output. This effect is known as inter symbol interference which is shown in Fig.1.11 and Fig.1.12. The travelling speed inside the optical fiber is specified by amount of dispersion.

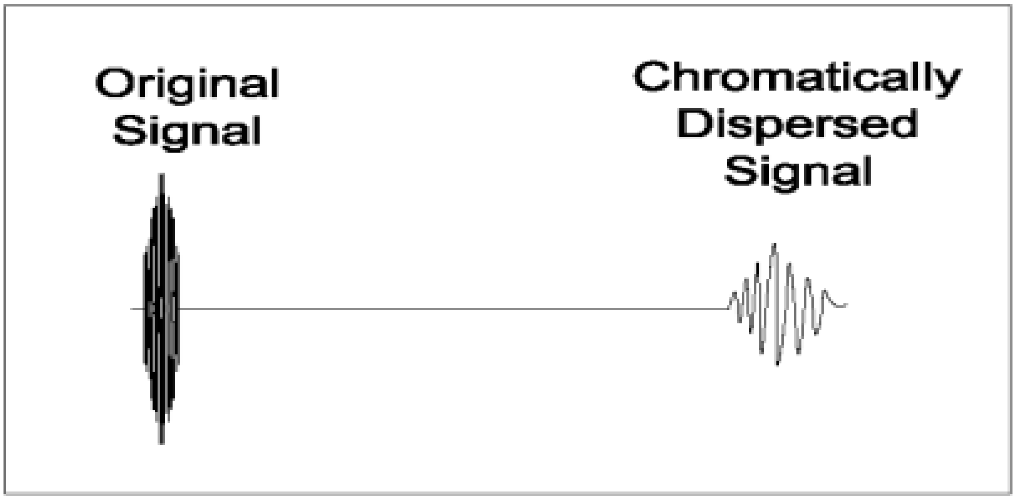


Fig.1.11: Chromatic dispersion.

Due to the difference in refractive index profile of optical fiber, the pulses with distinct wavelengths entering inside it propagates at distinct velocities. These pulses expands as propagates inside the optical fiber and continue spreading throughout along the length of the fiber. This expansion of pulse width is termed as dispersion. This dispersion causes moderate growth in the width and decrease in the power of pulse. [38, 39].

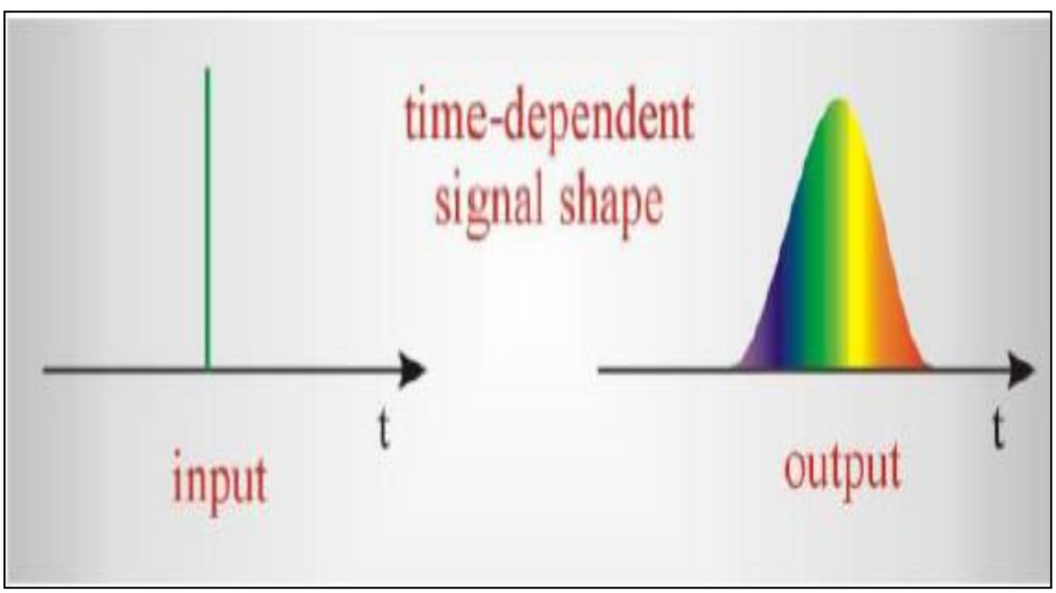


Fig.1.12: Principle of dispersion

The data carrying capacity at greater transmission speeds is restricted by dispersion. Due to the dispersion there is a reduction in essential bandwidth. Similarly, it enhances bit error rate (BER) which in turn enhancing ISI. Hence for the removal of inter symbol interference or broadening in the pulse width, compensation of dispersion is the main need. Intramodal dispersion or chromatic dispersion generally decreases the execution of the SMF (single mode fiber). It generally happens because of the fact that the refractive index of the glass based upon the wavelength of rays, and rays don't have the zero-width coming from transmitter. There as one more problem in optical fiber communication, i.e. PMD (Polarization mode dispersion). PMD also causes dispersion in the received signals. Whenever signal enters inside the fiber, it divided into two orthogonal modes, which are perpendicular on each other. Each mode travels faster than the other. Hence received at different intervals of time causes pulse broadening or birefringence [40]-[42].

1.4.2 Types of dispersion

There are three types of conversions basically defined as follows:-

- Intermodal Dispersion
- Polarization Dispersion
- Intramodal or Chromatic Dispersion

1.4.2.1 Intermodal dispersion

Intermodal dispersion mostly occurs in multimode fibers. The reason behind the occurrence of intermodal dispersion is that when the beam of light passing from multimode fiber then the light gets dispersed and travels through various propagation angles shown in Fig.1.13. Hence this is known as critical mode. Similarly if the beam of light travels equal to the fiber it is known as fundamental mode. Fig.1.13 shows the beam of light travelling parallel to the fiber and also shows the beam that travels through various modes [43, 44]. The beam which travels through various modes reaches to the output at different times.

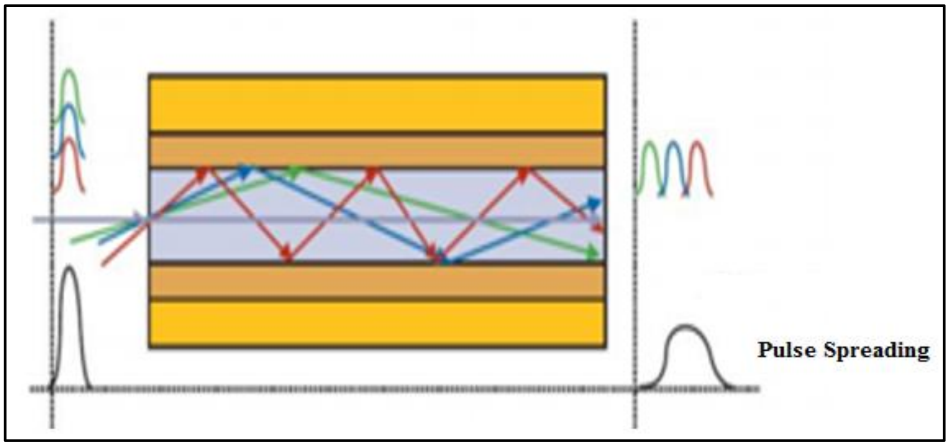


Fig.1.13: Intermodal dispersion in multimode fiber

Hence it leads to the scattered output and finally dispersion occurs to the signals at receiver or output end.

1.4.2.2 Polarization mode dispersion

PMD is an additional type of dispersion which takes place in fiber optic network of WDM. The following Fig. 1.14 describes the concept of polarization mode dispersion. The polarization mode dispersion takes place when two linear polarized waves takes place in fiber optic cable and these waves or signals mutually propagates at perpendicular plane.

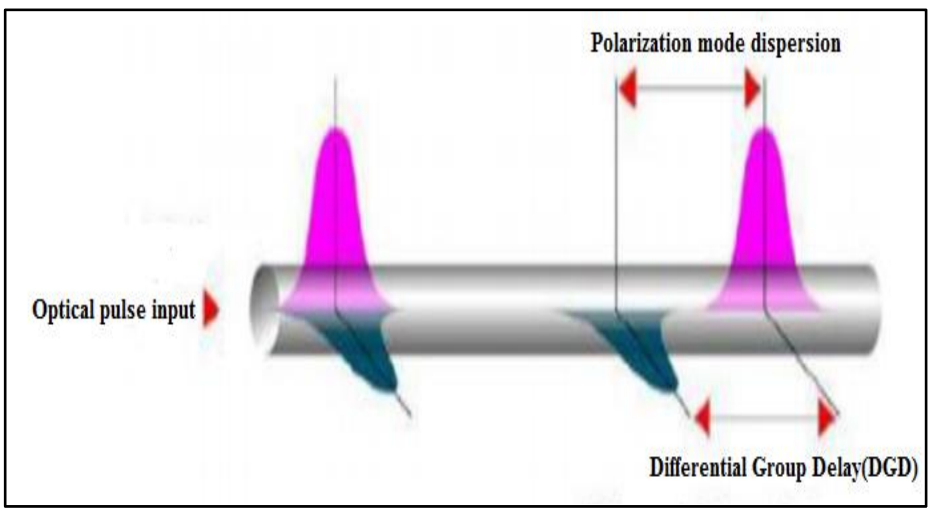


Fig.1.14: Polarization mode dispersion

But the perpendicular planes are not same because of asymmetry in fiber cable, splicing process, refractive index and this cause polarization dispersion [45]-[47].

1.4.2.3 Intramodal dispersion or chromatic dispersion

It is a dispersion which can occur in single mode fiber optic network and multimode fiber network as well whereas the intermodal dispersion takes place in multimode fiber network only. The intra-modal dispersion leads to the scattering of the signals. The signals are scattered because the signals that carries the information contains multiple wavelength. This process gives rise to group velocity dispersion [49]. The difference between intermodal dispersion and intramodal dispersion is that the intermodal dispersion takes place in SMF i.e. Single Mode Fiber only whereas the intramodal dispersion can occur in SMF and Multimode fiber also. The other difference is that the intermodal dispersion occurs when the signals passes from multimode fiber along with the various propagation angles whereas the reason of intramodal dispersion is that the signals pass from fiber optic carries multiple wavelengths and it leads to the occurrence of group velocity dispersion. Chromatic dispersion is shown in Fig.1.15 given below:-

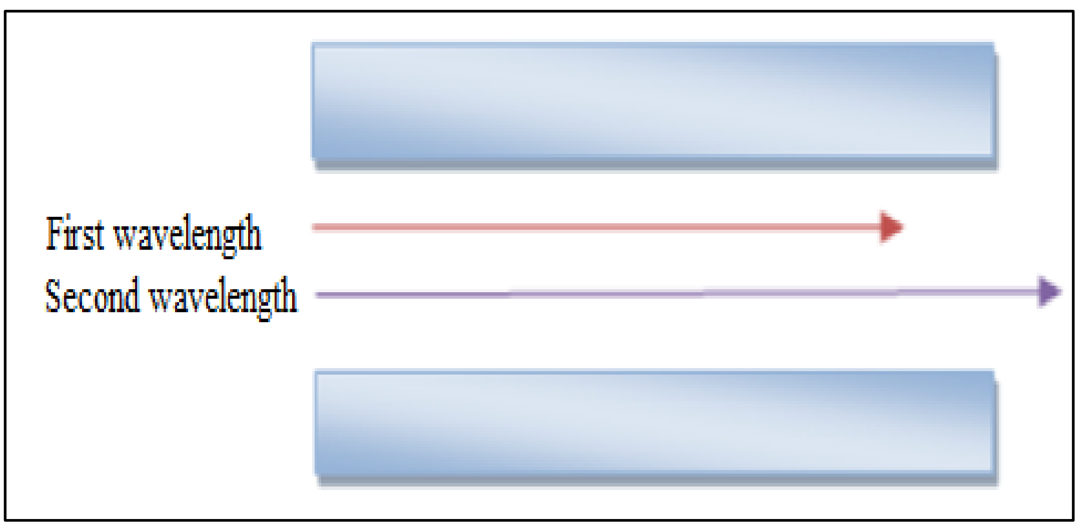


Fig.1.15: Chromatic dispersion

Chromatic dispersion is caused by 2 kinds of dispersion named as, dispersion by material & and dispersion by waveguide. These both types of dispersion are explained below in detail.

a) Material dispersion

Rays travelling in the vacuum propagates at the speed of c = 3×108 m/s whereas in another means, rays propagate slowly described by $v = c/\text{n}$, here n = refractive index of material. For the stuff utilized in the making of fiber, refractive index increases along with wave length of the ray propagating within the optical fiber. Therefore, a different wavelength (or say color) of light travels at different speed within optical fiber [50]. The word "dispersion" generally explain the facts of wavelength dependent speed of travelling signal, when the speed alteration is occurred due to different characteristics of the stuff. This out-turn is termed as material dispersion. The problem of dispersion caused by material may be elaborated by taking into consideration circumstances described in Fig.1.16.

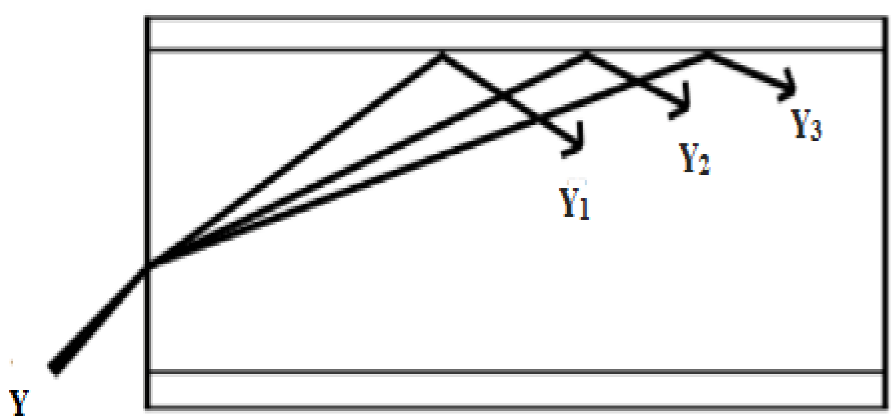


Fig.1.16: Material dispersion

b) Waveguide dispersion

Dispersion caused by waveguide is different kind of dispersion and is termed as waveguide dispersion, which is generally disregarded in the applications of fiber with multimode. When the light source emits its rays inside the optical fiber, only the 80% of light ray enters inside the fiber core, rest got coupled into the cladding. As we knows that there is a huge difference in the refractive index of the core and cladding of fiber, hence rays propagates at dissimilar speeds. Moreover, in case of lower refractive indexes, rays propagates at higher speed as compare to the stuff having higher refractive index. Due to the lower refractive index of the cladding ray propagates with more speed as compare to core, which causes dispersion. The drawing of optical fiber decides the quantity of dispersion [53, 54]. Dispersion due to waveguide is caused by radius of the core, difference between the core and cladding refractive indexes and refractive index profile design. In SMF, at specific wavelength, the dispersion due to waveguide may be attentively planned to reduce the dispersion caused by material.

1.4.3 Dispersion compensation techniques

For dispersion compensation, different methods can be utilized. Following techniques are one of those techniques: -

- FBG (Fiber Bragg Grating)
- DCF(Dispersion Compensating Fiber)
- EDC(Electronic Dispersion Compensation)

1.4.3.1 FBG (Fiber bragg grating)

FBG is a technique used for dispersion removal in Wavelength Division Multiplexing. The shared bragg reflector that reflects a specific pulse or wavelength is used in this technique. The fiber bragg grating may be used to refined optical signal which blocks the specific wavelength. The refractive index varies with respect to the propagating medium. The working of FBG relies on the principle of Fresnel reflection. The principle of Fresnel reflection describes that the beam of light that is passing through the media can reflect at the junction. Refractive index value can vary at a specific area. The whole of the rays reflected back, during the time of refraction. These reflected optical rays are grouped into a single large reflection corresponding to a particular wavelength. This particular wavelength indicates the value of grating period equal to the half of the input light wavelength [55, 56]. This situation or point leads to the bragg condition on the wavelength and the wavelength will be considered as bragg wavelength. The eqn. (1.2) is used for bragg wavelength as shown below:-

$$\lambda_B \equiv 2\bar{n} \tag{1.2}$$

The value of bragg wavelength will change according to the grating length. Hence at the point where the bragg situation is fulfilled, frequency component is reflected over that point.

The eqn. (1.3) is used for grating dispersion given below:-

$$D_g = \frac{2\bar{n}}{C(\Delta\lambda)} \quad \dots \tag{1.3}$$

In equation (1.3),$\bar{n}$ is used for defining the average mode index; $\Delta\lambda$ indicates grating bandwidth; c stands for light velocity.

a) Working principle of FBG

FBG behaves as a reflector, which reflects or selects a particular frequency or wavelength. Due to the strong laser emission of rays coupling to a fiber with the addition of germanium doping, FBGs comes into existence. Afterwards, different ways were carried out for the fixing of gratings inside fiber, out of which extensive kinds of pulsed laser and continuous lasers were utilized in visible & UV fields. Due to the selectivity of the grating, particular wavelength got reflected and propagated inside optical fiber as per the bragg wavelength [57, 58]. Working principle of fiber bragg grating is elaborated in Fig. 1.17. In this Fig.1.17, three wavelengths are taken. These wavelengths are then passed through fiber bragg grating. Out of those, only wavelength λ_2 is reflected and remaining wavelengths are passed through the grating.

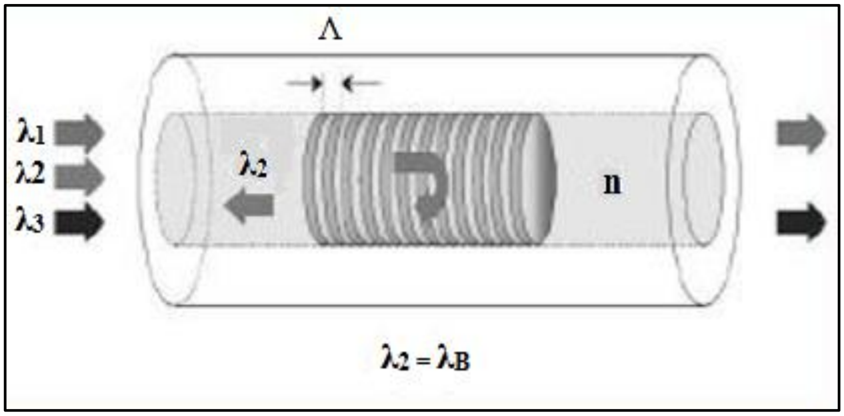


Fig.1.17: Principle operation of FBG

b) Advantage

Less insertion losses is the biggest merit of FBG. The typical value of the insertion losses for 120 km is about from 3 to 4 dB, which is again dependent on the kind. Moreover, the FBGDCM has many advantages like it contains fixed value of the insertion losses against distance, whereas in DCF-DCM these losses increases with the distance. There is one more problem which is to be taken into account, i.e. Residual dispersion. As we know that the gratings are chosen by the approximation method which is very flexible, the chirp features can freely be opted as per fiber parameters. Moreover DCF introduces nonlinear effects at least optical signal power, whereas the FBG-DCM does not, even at high signal power. The main target is to reduce the dispersion due to the fact that with the enhancement in the bandwidth, dispersion also grow high.

1.4.3.2 Dispersion compensating fiber (DCF)

DCF is dispersion compensating fiber. It is used as a technique for updating the installed links which are created by using single mode fiber. DCF supports the negative dispersion value ranging from -70 to -90 ps/nm/km. It is required for compensating the amount of positive dispersion of fiber. The performance of WDM decreases because of group velocity dispersion in the network. The smaller size of the DCF is suitable for mostly cases because it supports low ILs value, Less PMDs value, less optical nonlinearities & large value of CD (Chromatic Dispersion) coefficient. The value of net dispersion should be zero when there is a negative DCF after a positive SMF [60, 61]. The eqn. (1.4) shows the required condition given below:-

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \quad (1.4)$$

In eqn. (1.4), the variable D defines the dispersion and the variable L defines the Length of each fiber. The principle of operation of DCF is elaborated in Fig.1.18 given below:-

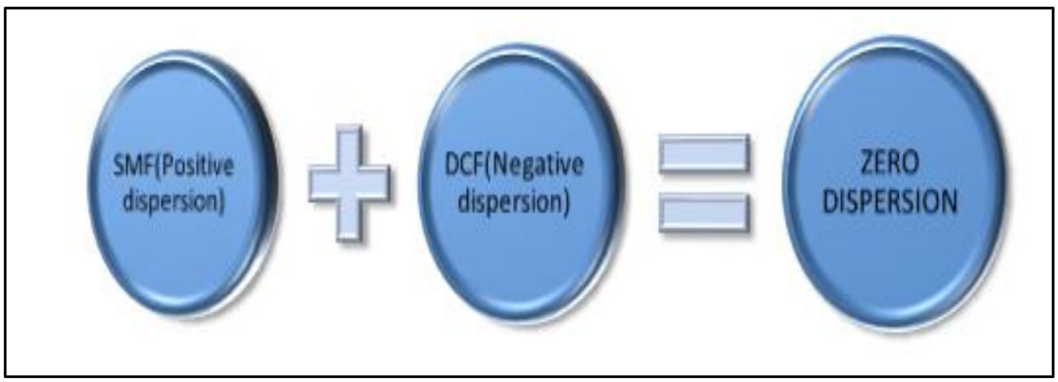


Fig.1.18: Dispersion compensating fiber principle.

a) Advantages

DCF may be effortlessly prepared & is extremely reliable. It gives regular compensation against a variety of light wavelengths. In DCF section, the value of insertion losses should be less, should have least PMD and least light signal non-linearity. Above all of these, it should be blessed with the enough CD coefficients in the reduction of DCF section size.

b) DCF Vs FBG

- DCF allows longer distances compared to FBG.

- DCF causes more bending losses, greater insertion losses & is quite costly.
- DCF has non-linear results whereas FBG has linear results.
- DCF has more bandwidth.

There are so many dissimilarities between FBG and DCF, which are given below in Table- 1 .1 given below:-

Table 1.1: Difference between DCF and FBG

Sr. No.	Characteristics	DCF	FBG
1	Construction	Complex	Simple
2	Fiber Length	17-20 km	10-15 cm
3	Dispersion	16 ps/km/nm	17 ps/km/nm
4	Banding Losses	0.4-0.6 dB/km	0.14dB/km
5	Insertion Losses	High	Low
6	Reflection ratio	99.99%	10-95%
7	Construction	Complex	Simple
8	Attenuation	0.8dB/km	0.2dB/km
9	Non-Linear Effects	Some Limitations	No
10	Overall cost of System	High	Low

1.4.3.3 EDC (Electronic dispersion compensation)

Electronic equalization methods are utilized in this technique. As the signal is directly detected by receiver, successive deformation in the optical realm, for example CDs, are converted into non-successive deformation at the end of optical-to electrical transformation. This is because of the fact that the topic of non-successive nullification and non-successive channel modeling is carried out [65, 66]. To do so, two equalizers namely FFE (Feed forward equalizer) & DFE (Decision feedback equalizers) circuits are utilized. Due to the slow digital-to-analog conversion, communication speed is also slow using Electronic Dispersion Compensation. FFE is shown in Fig.1.19 whereas Fig.1.20 is showing Single stage decision feedback equalizer. Since conversion from optical to electrical pulses is a

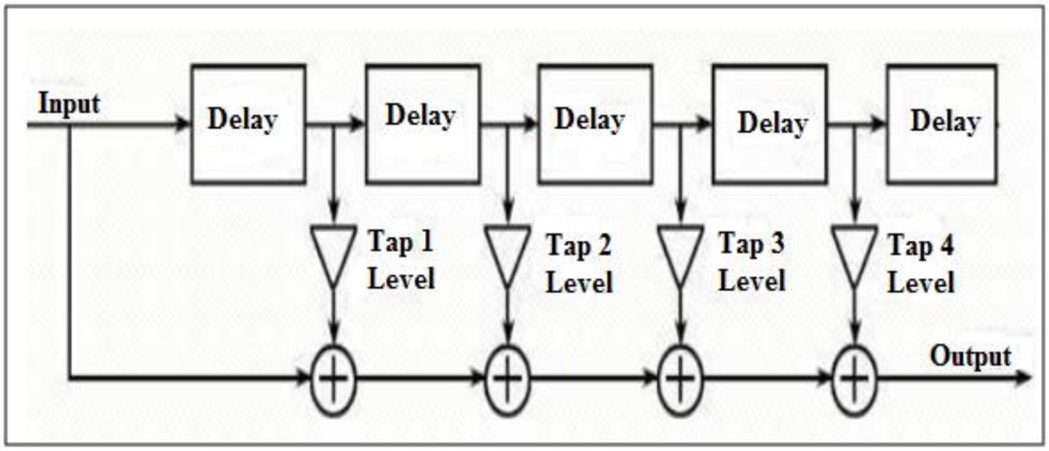


Fig.1.19: Feed forward equalizer

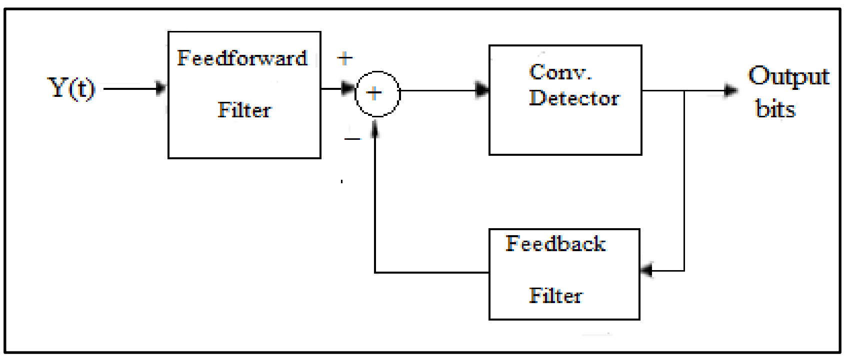


Fig.1.20: Single stage decision feedback equalizer

requirement in current optical fiber communications systems, it is not difficult to imagine that additional functions could be implemented in the electrical domain. One such function could be an electronic equalizer, which can be included in the recipient side. An electronic equalizer can be used to extend the minimum distance between repeaters or allow the bit rate of a distortion limited fiber communications channel to be increased [69, 70]. Electronic equalization can consist of RF filtering, Digital Signal Processing (DSP) and mixed-signal functions. Equalization is widely used in telephone systems, wireless receivers, and magnetic recording. Magnetic recording has among the most complex implementation. Long sequences of weights are used in feedback loops to create vectors that carefully track the magnetic head to drive response and compensate for low speed effects such as temperature and wear and tear. However, with the exception of simple single stage linear equalizers, equalization is a relatively new concept to fiber-optic communications [71]-[73]. An electronic equalizer is most advantageous when analog functions and digital functions are adaptively tuned and programmed to fit a specific link. If custom tuning can be avoided, then no specialty manufacturing would be required for any given link and dispersion compensation could be achieved at a significantly lower cost than optical solutions. Moreover, with an effective adaptive tuning algorithm, an electronic equalizer could be used to correct both CD and PMD, which would be a notable advantage. In this section, linear and nonlinear electronic equalization concepts will be reviewed. Linear equalization supports the highest bit rates, but nonlinear techniques benefit from architectures that can recover incoming data even when the received eye is fully closed by taking into account unique pattern dependencies at the output, has been divided two types [74,75].

a) Linear electronic compensation technique

A linear equalizer is a form of a filter that provides emphasis to certain elements in a spectrum while attenuating others. It is of interest in a variety of applications for the adjustment of corresponding amplitudes of the frequency elements in a wave or perhaps complete removal of few frequency elements [76, 77].

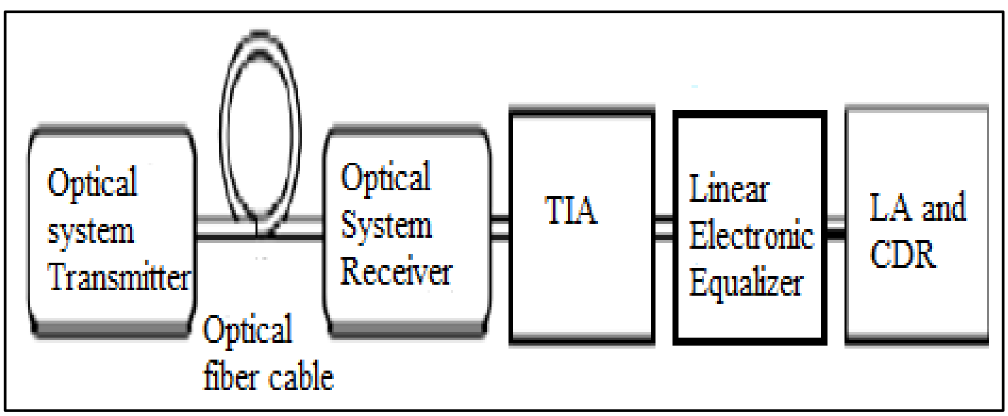


Fig.1.21: Linear electronic equalizer

LTI (Linear time invariant) systems are generally used to adjust the structure of the range of frequency and are termed as frequency- selective filters, but in certain applications such filters are referred to as linear equalizers as shown in Fig.1.21.

b) Nonlinear electronic compensation techniques

When distortion takes place in an optical fiber link because of the successive & non-successive design, a successive equalizer design across receiver may not be proficient to entirely rectify the linkage. Linear equalizers will also not be able to predict or compensate PMD. A purely nonlinear equalizer, or an analog equalizer with nonlinear features, may be able to extend link lengths or data rate beyond what can be compensated with a linear equalizer [79]. An electronic equalizer can acquire a nonlinear response if mixed-signal and digital circuit operations are used. A nonlinear equalizer can make use of A to D converters, D to A converters, and more velocity digital memories to extend performance beyond that of linear equalizers, but this comes at the cost of added complexity namely a larger die size, a slower clock rate, and higher power consumption. Fig.1.22 is showing a nonlinear electronic equalizer.

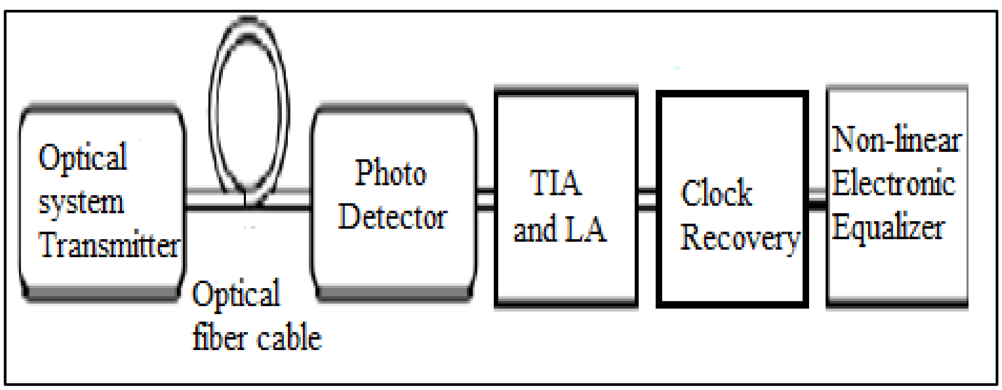


Fig.1.22: Nonlinear electronic equalizer

With higher complexity, the most severe implication is that the fiber's maximum data rate may be limited by the clock rates in the equalizer circuitry and/or response times through feedback loops. This is possibly because, until recently, nonlinear equalization has not been seriously considered for fiber optic applications [80]. But the aggressive advances that have been seen in integrated circuit technologies have made nonlinear equalization a viable solution. In addition to considering the highest possible bit rates achievable in a fiber-optic system when evaluating equalization techniques, one needs to consider also the transmission distance (which exacerbates signal distortion).

1.5 MOTIVATION/NEED FOR THE RESEARCH

As there is a huge requirement of Digital transmission system having features like larger bandwidth and cheaper in cost, hence optical fiber communication system with 100Gbps is best suited to satisfy above requirements. It has all the desired features like it supports higher data rates with high speed, huge bandwidth & less losses. CD (Chromatic Dispersion) is the major problem which reduces the best outcomes of such a feature loaded optical communication system. These deleterious results of CD (Chromatic Dispersion) and other problems should be eliminated to get desired communication for desired distance.

The material used for the preparation of transparent optical fiber is either plastic or silica. It is extremely thin just like hairs. It is also very flexible. In comparison with other wired media like copper wire, twisted pair cable or coaxial cable, optical fibers can transmit light signal to a larger distance with greater data rates. Optical fibers are mostly preferred above other wired media due to the low losses. As the other wired media made-up of metals or more prone to EM interference, whereas optical fibers are not. In case of optical cable, it has a core which transparent and is covered by cladding with smaller value of refractive index. Total internal reflection is a phenomenon responsible for keeping light inside the core. This phenomenon makes optical fiber to behave just like waveguide. Optical fibers supporting different travelling modes are known as MMF (Multi-mode fibers) whereas the optical fibers supporting only one path termed as SMF (Single-mode fibers).

Pulse broadening is the major problem in single mode fiber, which is caused by either PMD or CD. As the refractive index profile of the material changes, it effects the wavelengths of light signal. As a result, Chromatic dispersion will appear. Due to the changes in the refractive index profile of the optical fiber, light pulse having dissimilar wavelengths propagates at dissimilar velocities inside optical fiber to result into occurrence of pulse broadening across receiver. Chromatic dispersion doesn't affect at 1310 nm window due to the reason that, fiber attenuation is sufficient to reduce the distance for communication. But above this window i.e. 1550-nm window and 100 Gbps data rate, Chromatic dispersion is more problematic as compare to the fiber attenuation. Because of the deficiency in the design of optical fiber, light ray got divided into two orthogonal modes having the different velocity and received at different times, causing Polarization mode dispersion. Where, in case of multi-mode fibers, light pulse propagates through dissimilar modes at dissimilar velocities.

When the signal added across the receiver, it causes pulse broadening across the receiver and as a result intersymbol interference occurs. The major reason for this ISI is DMD i.e. differential modal delay, which is the result of delay in the propagation time through dissimilar modes. As compare to multi-mode fiber, differential modal delay is mainly responsible for reduction in bandwidth. Hence, single-mode fiber may have larger bandwidth. Due to this reason, for a long distance communication, single-mode fibers are on top priority. It is very complicated for the engineers dealing in communication to create WDM system, because of the GVD (Group Velocity Dispersion), another name of CD. ISI is the result of pulse broadening i.e. overlapping of neighboring pulses, which is caused by CD due to the increment in the fiber length.

The CD is also inversely proportional to the FWM (Four Wave Mixing) that means FWM is highest when CD is lowest. The pulse broadening has direct relation with the fiber length, which means if the fiber length will increases, it will also increase the pulse broadening. As the light pulse becomes broader in width due to dispersion in communication link, it results in the degradation of the signal quality. Dispersion occurs due to the limitations in the optical fiber. SMFs mostly suffers with the CD and MMF with PMD. Due to intense broadening, neighboring bits will overlap on each other and it will be extremely difficult to separate these overlapped bits. As a result, bit error rate will increase. To receive good quality signal at far distance, it is extremely compulsory to remove dispersion first.

In case of optical communication, as the bit rate increases, dispersion also increases. Up till less than 2.5 Gbps, the amount of dispersion is tolerable but beyond that it starts affecting the received signal. The acceptable limits of CD are reduced by a factor of 16 when bit rates increases from 2.5Gbps to 10Gbps, and so on. So, it is clear from the above discussion that it is extremely important to address the problem of dispersion first to avoid the pulse broadening and for high quality of received signal.

1.6 OBJECTIVES

- To assess the existing dispersion compensation techniques used in Optical fiber communication system and find out their effect on dispersion reduction.
- To select the most significant type of Grating by performing the analysis over the grating types in the existing dispersion compensation based optical communication systems.
- Propose a hybrid approach with best FBG technique with the filtration process and EDC (electronic dispersion compensator) based system for achieving the upgraded model to achieve high data rate.
- Evaluate and Compare the proposed model with the existing model's performance.

1.7 RESEARCH METHODOLOGY: Fig.1.23 is showing flow graph of research methodology.

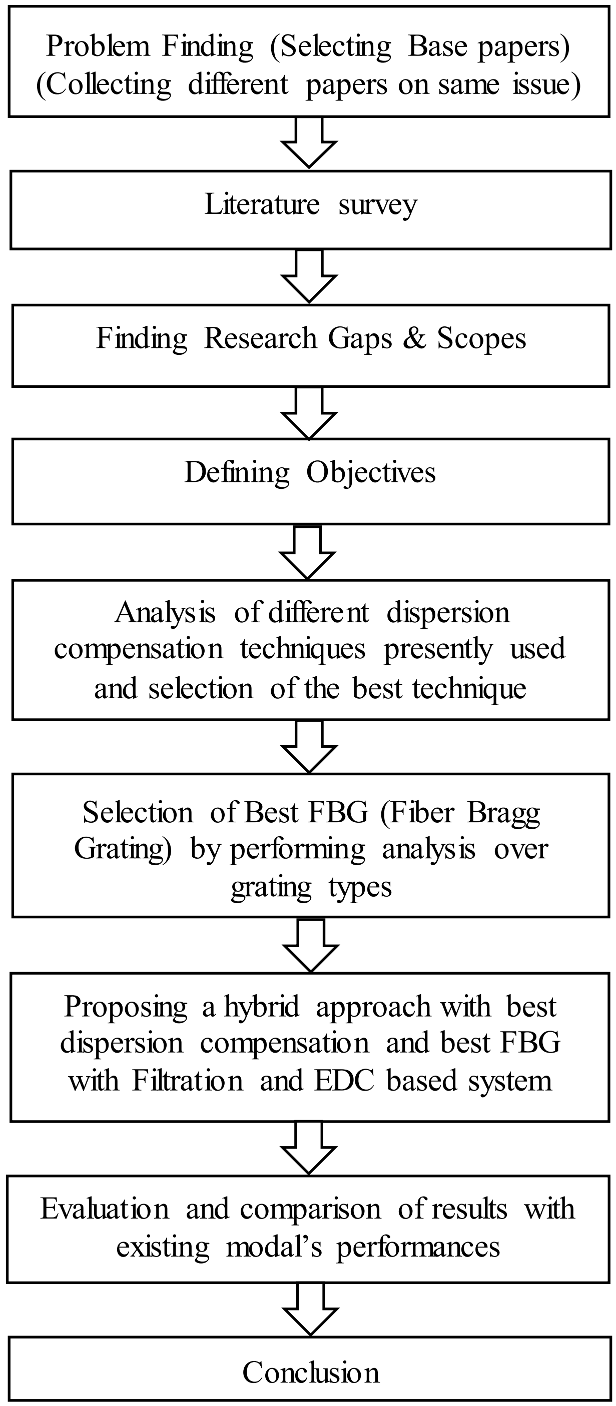


Fig.1.23: Research Methodology Flow Graph

- **Problem finding**: The initial phase in the process is to distinguish an issue or identify a problem for research. The problem might be something the field recognizes as an issue, some learning or data that is required for betterment, or the craving to recreate broadly. Here optical fiber communication has been chosen as a research field, and then accordingly found out some problems in OFC and collected some base papers.

- **Survey the literature:** Since the issue has been distinguished, the specialist must take in more about the point under scrutiny or the problem under investigation should be learned in detail. To accomplish this, the detailed survey of the literature must be done by the researcher about the issue. This step provides foundational knowledge about the problem area. The survey of literature instructs the researcher about what have been done previously, how these investigations were led, and the conclusions in the issue.

- **Finding research gaps and scopes**: Commonly the underlying issue distinguished in the initial step of the procedure is too huge or expansive in scope. In stage 3 of the procedure, the researcher clears up the issue and limits the extent of the examination. This must be done after the literature has been evaluated. Moreover, through the study of literature, the learning increased the scientist in clearing up the concept and narrowing the research area.

- **Defining objectives:** In the 3rd step, researcher will be able to find the gaps, which can be utilized in defining the objectives. Objectives in the research are basically the gaps or the work which is not done previously. Objectives are the main part of research. Without objectives, the research is meaningless. Hence to find out the research objectives, it very much important to study huge literature and then to find out research gaps. After studying and analyzing the literature survey, objectives are defined which includes the topics of research and also the other scopes in that research field.

- **Presently used techniques comparison:** After defining the objectives, in my first objectives I have made the comparative analysis of presently used dispersion compensation techniques as per my simulation parameters. After simulation and result comparison, the best method for dispersion compensation is selected. Here I have used DCF and FBG for dispersion compensation as per my simulation parameters. Out of which FBG provides better results as compare to DCF.

- **Selection of best FBG:** In the previous step FBG gave better results than DCF, so the next step is to find out the best FBG out of different types, which is again my second objective. So in this step, I have made the result comparison of IDCFBG and UFBG, out of which UFBG performed better than IDCFBG as per the required parameters.

- **Proposing hybrid model:** In this step, I have suggested a hybrid model, which combines UFBG & Electronic Dispersion Compensation (EDC). After designing Hybrid model using required parameters i.e. 100Gbps data rate for a distance of 120 km simulation has performed. All the achieved results have been tabulated.

- **Comparison and conclusion:** The achieved results of Hybrid model in the last step are compared with the results of all the techniques used in previous steps. On the basis of comparison, final conclusion has been made. It shows that the Hybrid model performs better than any other technique for dispersion compensation.

1.8 CHAPTER SCHEME

This section covers the research carried out in the form of different chapters. The thesis includes five chapters defining the overall work done during research. Chapter-1 of the thesis is defining the introduction of the topic over which research has been done. Introduction section initially includes the concept of dispersion and types of dispersion in detail. Subsection of this section explains the distinct types of available dispersion compensation methods along with their advantages, disadvantages and applications.

Chapter-2 is all about the literature survey of different techniques and different researches done on the problem of chromatic dispersion. This section is divided into various subsections. Subsections include various review papers on chromatic dispersion problem, Dispersion compensation by using FBG and Compensation of dispersion utilizing DCF. Various comparison papers of DCF and FBG and papers which have used dispersion compensation modules are contained in this section. Literature survey of research papers based on EDC is also covered in this section.

Chapter-3 includes the details of the software used for research work explained in this thesis. Optisystem 7.0 is explained along with its components library and applications in the fiber optics communication system. Techniques used for compensation of chromatic dispersion in our research work are also taken into account and demonstrated in detail. DCF, FBG, UFBG and EDC are illustrated and rationalized in much better manner.

Chapter-4 covers the major four objectives of the research. First objective reviews the existing techniques for compensation of dispersion in fiber optics and find out their impact on limiting the dispersion. Second objective includes selection of most effective grating by comparing the results of all the existing dispersion compensation techniques. A Hybrid approach resulting from combination of best grating technique and EDC is introduced in third objective. Fourth and final objective compares the proposed Hybrid model with the existing techniques of dispersion compensation. These all simulations have been done by using Optisystem 7.0. Software.

Chapter-5 carries the conclusion of research done on chromatic dispersion problem in fiber optics communication system. A section of this chapter also explains the other scopes of this research in the future.

1.9 CHAPTER SUMMARY

Optical fiber is the most efficient and effective communication medium for the transmission of signals in comparison to others. They provide long distance coverage with more bandwidth and lesser amount of attenuation EDFA is used to lessen and mitigate the effect of attenuation on the transmitted message signal. The impact of other signal degrading elements such as CD, PMD, fiber non-linearity can also be reduced by using different dispersion compensation methods like DCF (Dispersion compensating fiber), FBG (Fiber Bragg Grating) & EDC (Electronic dispersion compensation). Out of above mentioned methods, EDC performs in a better way to reduce dispersion at any bit rate.

CHAPTER-2
LITERATURE SURVEY

2.1 GENERAL

To compensate the chromatic dispersion, distinct dispersion compensation techniques are available and have been used previously by different authors. Research has been done using DCF, FBG and EDC for reparation of signal transmitted over optical fiber. Literature survey is the initial and the most important step to start any research as it provides the complete description of the work done previously on our research topic. Literature surveys of distinct researches in this field of optical fiber communication are provided. Initially this chapter explains the various review papers on dispersion compensation techniques. Previously done work using DCF, FBG and EDC are also explained. Dispersion compensation modules and comparison papers of different methods is also shown in literature survey.

2.2 REVIEW PAPERS ON DISPERSION COMPENSATION TECHNIQUES

A. N. Pilipetskii et al. [1] showed the influence of dispersion compensation on the execution of the system in the presence of the nonlinearities. They showed that compensation of dispersion in any nonlinear system have major impact on the pulse widening and, on the signal variance. This has been demonstrated by utilizing a wavelength division multiplexed test bed of 4970Km for 8 channels. They showed that pulse broadening can be minimized by choosing appropriate dispersion compensation technique rather than signal variance. James F. Brennan [2] provided an update and review on the components of dispersion reduction produced due to chirped FBG.

The author gave a brief outline of FBG in this paper and afterwards concentrated on the development and focused on challenges occurred during fabrication of chirped FBG into dispersion compensating module and how imperfections in gratings caused and affect their characteristics. Their conclusions showed that numerous specialized hindrances that have kept chirped FBGs to be utilized just like dispersion compensator in fiber optic communication has been reduced. M. Sumetsky et al [3] provided an overview on FBG which performed batter for the removal of dispersion in many applications. Fabrication methods of fiber Bragg grating were discussed along with the importance of chirped fiber Bragg grating in compensation of dispersion. Examination of the scope of FBG parameters empowered by current manufacture strategies has been done and in addition the connection in the middle of precision of Fiber Bragg Grating specifications & execution of compensators depending upon FBG has been done. Group delay ripple (GDR) theory created by the apodised FBG has also been discussed by the authors. The author reviewed the correction techniques for GDR so as to improve the quality of FBG and possibly empowers predictable creation of compensators based on FBG and dispersion compensators with tunable features. Analysis concluded that CFBG provided an option of dispersion tuning which was not possible with dispersion compensating fibers (DCF's). The presence of this option was of significance for WDM and OTDM systems which has been restricted by GDR. The work in this paper showed that there exists an approach to diminish GDR. It has been illustrated, both hypothetically and tentatively, that generally low frequency segments of noise present in parameters of CFBG appeared in the range of spectrum. For high data rates, iterative correction lower down the effect of GDR.

S. Devra et al. [4] did their research on dispersion compensation methods. In this paper the authors provided different dispersion compensation techniques and their advantages and disadvantages over other compensation techniques. Basically, the focus was on three mains chromatic dispersion compensation techniques- DCF (Dispersion compensating fibers), EDC (Electronic dispersion compensation) and FBG (Fiber Bragg grating). The other type of compensation using digital filters has also been introduced. The least complex was DCF embedded along the optical fiber with negative dispersion however it provided more insertion losses. Next was EDC utilizing decision feedback and decision feed forward equalizers. It has been shown that EDC provided different compensations for different transmission distances that are 1600ps/nm for a distance of 80Km at 10Gbps, 2400 and 3200 ps/nm for 120 and 160Km, respectively at 10Gbps. But EDC has a disadvantage of slowing down the communication speed. Finally, the concept of Fiber Bragg grating has been discussed and shown that it was a complex technique. Hence, the authors concluded the digital filters technique to be the best chromatic dispersion compensation technique for wavelength division multiplexed systems over long distance applications. S. Yhu [5] worked on the problem of dispersion in the larger span fiber optic communication systems. The author has showed the presence of two types of dispersion in the optical systems- chromatic and polarization mode dispersion. He has also showed the effects of the bandwidth limiting dispersion on the transmission of signals over long distances. Detailed types of optical fiber with dispersion features have been explained in the paper. He has shown that dispersion of all common types of fibers existed among 4~ 20 ps/nm/km. Without compensation the maximum distance covered at 10Gpbs would be 60~ 300Km whereas at 40Gbps it would be 4~ 18Km.FBG and DCF has been shown as dispersion compensation techniques for chromatic dispersion whereas electric field and light field compensation for polarization mode dispersion.

N.K. Kahlon et al. [6] provided a paper having analysis of the compensation of dispersion in modern fiber optic communication systems. The survey included the detailed concept of the dispersion, its types and also the various solutions for the compensation of dispersion to get the high-speed flow of data over the communication system. The authors have been shown that dispersion can be divided in 3 common types, chromatic dispersion, modal dispersion and PMD. Four most commonly used dispersion compensation schemes has been discussed in detail including DCF (Dispersion Compensating Fibers), FBG (Fiber Bragg Grating), DF (Digital Filters) and EDC (Electronic Dispersion Compensation). The paper has shown that EDC uses the techniques of electronic equalizers for the compensation by converting linear dispersion into nonlinear dispersion and then uses DFE and FFE for removing the dispersion. But speed of transmission has been slowed down by EDC. Further in FBG technique, chirped fiber Bragg grating has been considered more efficient than others due to the smaller insertion losses and minor nonlinear effects. But FBG has a disadvantage of complex structure. Hence, digital filters using the technique of digital signal processing has been studied. All pass filters have been observed the most effective filters for chromatic dispersion compensation among other digital filters like band pass, Gaussian and super Gaussian filters. Finally, this paper described the use of distinct techniques for chromatic dispersion compensation so as to transmit the signal over large distances with low signal degradation. G. Kaur et al. [7] presented an analysis of jobs that have been accomplished by various scholars for CD reduction. The authors have shown the concept of dispersion and its consequences across long distance transmission of signal over optical fiber. This paper reviewed DCF, Optical filters, FBG and EDC as dispersion compensation methods. Pre and post configuration of DCF has been studied and concluded that a maximum of 100 Km transmission has been achieved with DCF for single channel. Next fiber Bragg grating has been studied and concluded that that multi chirped FBG can provide effective compensation than DCF. Further the principle of EDC has also been discussed with FFE and DFE used as electronic equalizers. After analyzing and studying the literature surveys of various researchers, authors concluded that EDC has more effectiveness for dispersion compensation than DCF and FBG. This happened due to the negligible cost of equalizers and their capability to mitigate non-linear dispersion. P.K. Dubey et al. [8] described a review of various published research papers and articles to provide a complete picture of the optical fiber and its merits in communication systems. Distinct types of optical fibers has been discussed and reviewed. This paper also illustrated the various causes and the impact of chromatic dispersion along with different ways to measure its effects. This review paper classified the optical fibers in two types: SI (Step Index) and GI (Graded Index). SI has been further divided into single and multimode fibers. Dispersion shifted fibers, non-zero DSF (Dispersion Shifted Fibers) and dispersion unshifted SMFs have specially been designed for dispersion compensation. Out of them NZDSF has been most commonly used due to its property of eliminating non-linear effects. Three measurement methods for chromatic dispersion has been reviewed- phase shift technique, differential phase shift technique and pulse delay method. Due to more cost, phase shift methods of measurement have not been used for modern applications. Hence, CD-OTDR technique has been considered as an alternative to phase shifts methods due to its cost effectiveness. Further a comparison between phase shift and CD-OTDR methods has also been shown to make it clear that each of the method has its own advantages and dis-advantages.

S. Dev et al. [9] presented a review paper on dispersion reduction due to FBGs and then analyzing it at various lengths of fiber. The simulated system has been investigated at 10Gbps rate with 25Km of SMF and a fiber grating of 5mm length. Various parameters like gain, noise fig., Q-Factor and output power has been evaluated at fiber lengths of 5, 10, 15, 20 and 25 Km. Same parameters has been analyzed at 20Gbps rate with a SMF of 50 Km. Finally comparison of Q- Factors of these two bit rates has been done at 10 and 20 Km of SMF and found that with the increment in transmission rate, Q-Factor started decreasing bit by bit. K. Kaur et al. [10] provided a review paper on the compensation techniques of dispersion in communication system. The authors investigated the various research papers and concluded that by utilizing DCF, FBG, EDC and digital filter techniques, dispersion can be limited up to some extent and hence, the transmission distance can be increased at various data rates. This review paper has provided the detailed concept of DCF, EDC, FBG and digital filters along with their merits and demerits over long distances. In the end, it has been shown that digital filter technique of dispersion compensation has better results than other compensation techniques for high speed long distance transmission. N. Dalal et al. [11] provided different techniques for the management of dispersion in order to achieve high speed long distance communication over optical fibers. Different theories provided by different authors regarding the compensation of dispersion has been discussed and reviewed in this paper. Four compensation techniques i.e. DCF, EDC, FBG and digital filters by utilizing digital signal processing has been studied along with their applications in different types of systems. By making the comparative analysis of all these methods it has been shown that use of digital filters as dispersion compensators has provided a best way to achieve a transmission with lesser non-linear effects or almost negligible non-linear effects. The authors also provided different scopes of work in the field of digital filters. A.B. Dar et al. [12] provided a review of various dispersion compensation techniques. The work in this paper has been focused onto the dispersion and its reduction techniques including DCF, FBGs, optical phase conjugation, virtually imaged phased arrays and photonic crystal fibers. All the researches done using these techniques till now have been discussed in this paper. FFE, MLSE and DFE techniques for the compensation at the receiver (post compensation) has also been discussed along with their pros and cons. It has shown that DCF is most commonly used technique. Also the optical phase conjugation has good response in limiting the dispersion but has sensitivity towards phase modulation techniques. Characterization of FBG has also been done by changing the apodization function and then comparing their group delay and reflection spectrum. It has been found that tanh apodised FBG has better capabilities of dispersion compensation than other FBG's. Thus, the authors concluded that FBG has capacity to reduce the dispersion in a more promising way than other techniques. Garima et al. [13] presented a review paper on the problem of dispersion and how to compensate its effects so as to get a better communication between transmitter and receiver with lesser losses and attenuation. The authors proposed four techniques to mitigate the effects of dispersion i.e. DCF, EDC, FBG and EDFA. All the techniques have been discussed in detail. It has been shown that EDFA overcome the losses that occurred during transmission of the optical signals and for the dispersion compensation, any of the remaining three techniques can be employed. R. Kaur et al. [14] presented a review paper on the issue of dispersion in optical systems by analyzing the various researches in the regarding field. For the maximum bandwidth and minimum degradation of transmitted signal, the communication system requires various compensation techniques along with EDFA. Hence, the authors have discussed two compensation techniques of dispersion i.e. DCF and FBG. The principles of both techniques and their various characteristics like insertion loss, cost, bandwidth has been compared and it has been revealed that FBG exhibited better results than DCF. P. Shukla et al. [15] presented a paper for reviewing fiber Bragg grating as dispersion compensator so as to reduce the degradation of the signal during transmission over long haul optical networks. Literature surveys from different researches and publishes articles has been taken and studied. It has been shown that fiber Bragg grating worked well as dispersion compensator at various rates and transmission lengths.

2.3 LITERATURE SURVEY ON FIBER BRAGG GRATING AS DISPERSION COMPENSATOR

K.O. Hill et al. [16] worked on the chirped fiber Bragg grating that has been provided the compensation for the dispersion in 1549nm window. The fabrication of high grade chirped FBG has been done by using novel double exposure method. These chirped fiber Bragg gratings were developed to be used as dispersion compensators in various applications. The authors apodized the Bragg grating to reduce the ripples occurred in dispersion delay characteristics and to lower the power penalty by using a grating of length 3cm.

D. Garthe et al. [17] demonstrated the use of chirped FBG to compensate chromatic dispersion at 10 and 20Gbps rates, respectively for 80Km and 160Km standard single mode fibers. The authors used adjustable equalizers in which grating was adjustable unlike the earlier used constant value equalizers. Without equalizers the power penalty was 1.7dB for 80Km at a rate of 10Gbps but when equalizers were used the power penalty reduced to 0.2dB. In this case transmission without error was possible if negative chirp was used but in case of fiber length of 160Km non-equalized transmission was next to impossible. When 20Gbps bit rate is considered it is found that transmission without error is possible at 160Km but with power penalty of 5dB. Results concluded that overall compensation has been provided by equalizers up to 160Km for 10Gbps and 80Km for 20Gbps with minimum penalty. R.I. Laming et al. [18] investigated a way to mitigate the effects of dispersion by utilizing 40mm fiber brag grating (tunable) at a rate 10Gbps using step index optical fiber communication link. Compensation of dispersion was done between 103-217 Km because for extended distances it was difficult to find the center wavelength of the grating thereby caused reduction in bandwidth.

B.J. Eggleton et al. [19] investigated the problem of dispersion during transmission and used FBGs for dispersion compensation to mitigate the effects of the dispersion. Initially the transmission distance taken was 72 Km at a rate of 10Gbps of non-dispersion shifted fiber by utilizing a grating of length of 11cm. By embedding the grating, it was observed that no power penalty occurred in transmission at a distance of 72Km. But when no dispersion compensator was used, the power penalty raised to approximately 6dB.These results showed that the grating has been making up for the majority of the dispersion which is responsible for the pulse widening in the optical fiber communication systems. When distance has been increased to 106Km a power penalty of 2dB occurred even with the dispersion compensator. The author outcome has shown out of blue that fiber Bragg grinding in transmission can be utilized to adjust for dispersion. Moreover, designing of the grating, by for instance, utilizing distinctive gratings and by cascading them, would allow the dispersion compensation and specifically the dispersion at higher orders to be remove.

W.H. Loh et al. [20] did their investigation for the compensation of dispersion for a transmission distance of 700Km at a rate of 10Gbps using SMF (single mode fiber). For the compensation of dispersion, 10cm chirped FBG were used along with a duobinary transmitter. They showed that for a transmission of upto100Km no compensation was required but for longer distances up to 400Km, pre-compensation was utilized for the reduction of nonlinear effects. For distances 500Km, 650Km and 700Km, grating was placed closer to the center of the link. They proved that almost penalty free transmission can be achieved for a distance up to 600Km with duobinary transmitter and a single grating element, placed properly. They concluded that 700Km has been the longest achievable distance at 10Gbps with an individual compensating component.

Natalia M. Litchinitser et al. [21] worked-on dispersion compensation during transmission by utilizing fiber Bragg grating (FBG) as dispersion compensator. Their proposed model included a dispersion compensator of apodised chirped fiber Bragg grating. A concept of fig. of merit was introduced to upgrade the parameters of the fiber grating for the compression of the widened pulses. Three examples have been discussed to show the maximum range up to which dispersion compensation can be done using gratings of different lengths. First example included a grating of length 10cm with a reflectivity of $50cm{-}1$. Numerical analysis of first example have been done which showed that their proposed model was precise for a solid grating used for the dispersion compensation for a fiber having length of 100Km.In the second and third example with the same fiber parameters analysis is done but grating reflectivity changed to $100cm{-}1$ and grating length to 20cm.With these gratings maximum distance achieved was 400Km. Thus, the authors finally concluded that by increasing the length of the fiber gratings or by making the gratings stronger, fig. of merit became small and hence, by neglecting the third order dispersion, absolute recompression of signal can be done. They further explained that apodization causes suppression of oscillations which in turn lessen the insertion losses up to some extent at the output of the gratings. These components can be used for WDM applications as they provide improved bandwidth along with enhancement in compression ratio.

A.H. Gnauck et al. [22] demonstrated a model of wavelength division multiplexed system with 8 channels at distinct data rates of 10Gbps and 20Gbps, respectively. That model was illustrated for the distances of 480 and 315Km SMF, respectively by utilizing chirped fiber Bragg grating having bandwidth of 6.5nm for compensation of dispersion. Initially for 20 Gbps four spans of length 80Km each has been interrogated and a quality factor of 21dB bit error rate of $1.5 \times 10{-}29$ were examined. Similarly, for a rate of 10Gbps and 480Km distance, six gratings with six amplified spans of 80Km each has been used and the outcomes included a quality factor of 21.5dB & bit error rate of 1×10^{-32}.When analyzed the authors came to a conclusion that for 8×20 Gbps system with 315Km length, four gratings in cascade provided better results but with small polarization. For 8×10 Gbps with 480Km fiber length WDM system, six gratings in cascade gave nearly perfect performance. L.D. Garrett et al. [23] described the 16-channel wavelength division multiplexed signal transmission at a rate of 10Gbps over a single mode fiber of 840Km.This has been showed by compensating the dispersion using eleven gratings of the chirped fiber Bragg gratings.50GHz spacing has been provided between sixteen channels. Each of the gratings has been provided with a dispersion value of -1330 ps/nm/km for the compensation of the SMF of 80Km but one grating has been provided with an extra dispersion slope compensation equal to -35ps/nm. Ten spans of 80Km and an additional 40Km SMF were used thus making overall transmission distance equal to 840Km.They concluded that signal to noise ratio for the middle channels was 25-26dB (for channels 2-15) whereas it was 22dB for channels having longest and shortest wavelengths. Q-Factor has been analyzed and found to be more than 17.75dB for total channels with BER equivalent to 6×10^{-15}.Even in case of worst performance Q-Factor was more than 16.9dB and BER equivalent to 1.3×10^{-12}.

Isabelle Riant et al. [24] used CFBG for the compensation of CD in WDM systems at 10Gbps rate. The authors made a dispersion compensator for analyzing the dispersion at 10Gbps in multispan fiber. Two techniques were presented for fabrication of dispersion compensating gratings. They concluded that by using DCG's in cascaded form dispersion compensation can be done up to some hundred kilometers. The work in this paper showed dispersion compensation for four channels at 80Km and for two channels at 400Km. L.D. Garrett et al. [25] did their research on the compensation of dispersion over a bandwidth of 18nm by utilizing chirped fiber Bragg grating in a module. Their analysis has been done for 375 Km distance over a rate of 10Gbps in WDM system having 32 channels. The authors used two distinct modules for dispersion compensation in which first one contained two gratings connected in series and other contained a single grating. Division of 32 channels were done into a group of three included 8 wavelengths of spacing=100GHz (blue band), 15 wavelengths of spacing 50GHz (lower red band) and 9 wavelengths of spacing 100GHz (upper red band). The outcomes showed Q-Factor from 18.35dB to 21.4dB with BER from 7×10^{-17} to 4×10^{-32} (for channel-1 to channel-9). In blue band and red band (upper) the mean value of quality factor came as 19.8dB whereas for red band (lower) it was 20.2dB. Hence, the authors concluded successful transmission at 375Km by utilizing modules in two distinct bands of wavelength.

B.J. Eggleton et al. [26] provided a design for a device that was able for the management of the dispersion of time division multiplexed system at 160Gbps.A dispersion compensator was made which was tunable and this has been done due to the use of chirped FBG with the power penalty of the system lower than 1.3dB. They analyzed the behavior of tunable dispersion compensator by placing it after a generator which produced dispersion and the calculated the compensation of dispersion in terms of power penalty. L. Zhu et al. [27] proposed a new specially sampled fiber Bragg grating (SSFBG) for the removal of dispersion in fiber optic communication. Substitution has been done of dispersion compensating fiber with sampled fiber Bragg grating over a distance of 1000Km at 10Gbps rate. The effects of dispersion compensation of SSFBG were also compared with the chirped fiber Bragg grating. Two compensation schemes of pre and post compensation has been demonstrated by the authors. SSFBG was used in each of the ten sections in both pre and post compensation. The authors concluded that pre-compensation was better in performance as compared to post compensation using SSFB but with very small difference. They showed that dispersion was linear so the location of SSFBG has negligible effect on the overall working outcomes of design. Another analysis included substituting SSFBG by CFBG in post compensation scheme and found that CFBG has superior performance than SSFBG. Finally, the authors came to a conclusion that both CFBG and SSFBG have almost same effect on dispersion.

L. Pei et al. [28] worked on dispersion compensation in a long-haul system of transmission distance 3100Km with fiber Bragg grating. By upgrading the process used for the fabrication of CFBG the authors fabricated a chirped FBGs which have been able to reduce dispersion successfully for a 13-channel system for a distance of 3100Km at a rate 10Gbps. The BER of the system was found to be less than 10−4. At the transmission, three distinct codes i.e. NRZ (Non-return to zero), RZ(Return to zero) & CSRZ(Carrier Suppressed Return to zero) were analyzed & it was found that the best alternative for transmission was CSRZ with a power penalty of only 2.5dB unlike RZ having power penalty of 6dB for one channel. K. Kashyap et al. [29] demonstrated the compensation of dispersion for 10Gbps rate by utilizing FBG as dispersion compensation method at distinct lengths of fiber. The authors showed how the Q-Factor changed because of increase fiber length with and without fiber Bragg grating. The simulations have been done by varying the length of fiber i.e. at 1Km, 10Km, 25Km, 50Km, 75Km and 100Km and then the quality factors of these lengths have been analyzed with and without fiber Bragg grating. It has been noticed that as the lengths of the fiber raised the corresponding Q-Factor started decreasing without FBG. When FBG was used along with the optical fiber, the Q-Factor showed an increasing graph with the increase in fiber length. Thus the authors have been concluded that FBG eliminated dispersion up to some extent but was not capable of completing diminishing the dispersion from the long distance optical fiber communication. R. Udayakumar et al. [30] explained the concept of CD in fiber optic communication systems and used FBGs dispersion compensation & OPC(Optical Phase Conjugation) methods for compensation of dispersion. The linear chirp coefficient and the grating period of the fiber Bragg grating has been varied to analyze the BER at the receiver end by analyzing eye diagrams. Initially BER has been analyzed without using grating (FBG) and then with grating (FBG). It was found that bit error rate without the utilization of grating was equal to 1.0288 c10 and when fiber Bragg grating was used it become1.4545 c−12. Hence, the author finally concluded that FBG can limit dispersion effectively by decreasing BER of the system. M. Singh et al. [31] investigated the behavior of the optical fiber system with FBG used as dispersion compensation technique for the reparation of chromatic dispersion. The simulations have been carried by utilizing a fiber of length 100 Km for a data rate of 2.5Gbps. The simulation results have been calculated at various modulation formats of RZ and NRZ with a variation in the input power of signal. The signal power has been varied from -5dBm to 18dBm for return to zero & non-return to zero formats across transmitter section. With return to zero (RZ), the maximum achieved Q-Factor was 54.5192 at power = 6dBm with BER equals to 0 whereas for non-return to zero (NRZ), the maximum value of Q-Factor achieved was 31.4792 with a BER of $5.82c{-}218$. Hence, final result recommended the use of RZ modulation technique instead of NRZ format of modulation for a better transmission over optical fiber communication systems. A.Z. Rashed et al. [32] investigated a model for the improvement of the capacity of radio over fiber systems (ROF) by utilizing sixteen channels at a rate of 40Gbps launched over a SMF of length equal to 100 Km. FBG has been used for the dispersion compensation in the proposed system. Simulations have been done at different modulation formats like RZ, NRZ and MDRZ (Modified Duo Binary Return to zero) along with variation in fiber length (10-100Km) and input power (-10 to 8dBm). By observing the Q-Factor at different combinations it has been revealed that RZ (Return to zero) & MDRZ (Modified Duo Binary Return to zero) has fine performance to be used for long distance transmission of the signals. NRZ exhibited a smaller Q-Factor thereby making it suitable only for communication at shorter distances.

2.4 LITERATURE SURVEY ON DISPERSION COMPENSATING FIBER (DCF) AS DISPERSION COMPENSATOR

R.J. Nuyts et al. [33] explored experimentally the performance analysis of a transmission system operating at 10Gbps using the dispersion compensating fibers (DCF) as dispersion compensation method. The layout of the system has been consisted of a standard mode fiber of 360Km along with an optical regenerator with DCF found each 120Km distance. A DFB laser with a non-return to zero modulator has been used as transmitter. They concluded their results in the terms of eye position method instead of the eye-opening penalty which provided eye margin more accurately than the standard EOP method. Their results have showed that the overall dispersion in a system must be positive to some extent to incorporate the SPM impact. They further showed that the after dispersion compensation the eye margin at 360Km is 48.5% for 10^{-15} BER as compared to eye margin without compensation (33.3% for 10^{-15} BER). L. Nielsen et al. [34] worked on the dispersion compensating fibers (DCF). Their research included three distinct types of DCF. The first DCF provided better fig. of merit whereas second one was upgraded for dispersion compensation of non-shifted fibers. Finally, the third DCF has been optimized for the non-zero fibers for their dispersion slope compensation. The authors also showed and compared two distinct methods for the measurement of effective area and found that it was higher by a factor of 5 as compared to that of non-shifted standard optical fibers. Their research also examined the DCF cabling out of the blue and the outcomes looked extremely promising, opening the likelihood for another sort of use of DCF.

M.Y. Hamza et al. [35] studied the problem of dispersion reduction in the existence of non-linearity in fiber optic communication numerically by taking the Gaussian pulse into account. For their study, they considered two spans of 80Km each and explored the ideal choice for compensation of dispersion in the existence of losses and group delay ripple. The authors used DCF as dispersion compensator by varying the position of DCF throughout the optical fiber. Four setups have been considered by altering length of dispersion compensating fibers (DCF) & then exploring the domain of dispersion maps, keeping the overall compensation fixed at 100%.The launch power was varied from 3 to 10dBm. In the first setup of the model, DCF were used at two positions one at mid span and other at the output. In the second setup it was at input and mid span whereas in the third setup DCF was kept across the output as well as input. The final setup placed DCF at input, mid span and output. The authors concluded that smaller value of $L2$ (pulse degradation) corresponded to better system performance. Hence, the pulse degradation for four setups are 15.10, 21.53, 19.18 and 34.93 respectively. The work in this paper demonstrated the significance of dispersion maps within the sight of the non-linearity in order to limit the dispersion in communication system. Bo-ning Hu et al. [36] gave a detailed study on dispersion present in fiber optic communication systems & impact of dispersion on transmission of the signals in the communication systems. An eight channel 40Gbps WDM system has been studied for analyzing the dispersion over a distance of 160Km SMF (Single Mode Fiber). DCF have been used for the compensation of dispersion in three distinct schemes (pre, post & mix compensation) depending upon the place of the Dispersion compensated fiber in the design. The frequency of the laser used was varied from 192.6 to 194.01 THz. For analyzing the results, input power was varied from 3 to 14 dB and it was found that at input power equal to 9dB, the Q-Factor was having maximum value and after that it started decreasing gradually. When the three configurations were compared, it was observed that mix compensation provided better performance than other two configurations. B. Patnaik et al. [37] demonstrated a model for the ultra-high capacity dense wavelength division systems (DWDM) system using DCF. The proposed model provided a capacity of 1.28 Tbps over 64 channels having bit rate of 20Gbps by utilizing some different formats of modulation with narrow bandwidth. Three modulation schemes i.e. duobinary return to zero (DRZ), CSRZ and MDR were used and then compared to get the best scheme among them. It was found that with the channel spacing = 200GHz MDRZ modulation scheme exhibited maximum covered distance of 200 Km at 20Gbps rate and also a Q-Factor of 14.42. BER obtained with MDRZ = $1.5 \times 10-47$. MDRZ modulation scheme has been utilized for 3 distinctive connections i.e. pre, post & symmetrical. After analyzing three configurations for quality factor & bit error rate, it was found that symmetrical compensation was superior then other schemes. Another setup included a channel spacing of 50 and 100 GHz along with the Gaussian band pass filters in which a distance of 950 and 500Km was covered, respectively. In that case, Q-Factor obtained equal to 7.25 with a BER = $1.5 \times 10-13$. Hence, the authors concluded a trade-off between these two factors i.e. distance covered and spacing between channels. Rajani et al. [38] worked on the investigation of dispersion reduction by utilizing DCF technique in three distinct schemes of pre, post & symmetrical compensation. Outcomes of these configurations were then compared at distinct power levels and by using distinctive modulation schemes. They did their investigation at a rates of 10 and 15Gbps using two setups. In first case, length of the optical cable was kept constant while varying the power of EDFA. Outcomes have been compared using bit error rate and quality factor by utilizing distinct formats for modulation that are Non-return to zero, Return to Zero & Return to zero super Gaussian format at 10 & 15Gbps respectively. It has been observed that when Q-Factor was analyzed, symmetrical compensation scheme using NRZ modulation scheme exhibited the best performance than other schemes at 10Gbps but for RZ & RZ super Gaussian format, post compensation performed better than the remaining two for a power level up to 12dB. At 15Gbps rate, different results have been analyzed including the symmetric compensation scheme best for RZ and NRZ formats and post compensation scheme for RZ super Gaussian format for a power level of up to 14dB of EDFA (Erbium Doped Fiber Amplifier). When evaluation of BER has been done, it was found that for a bit rate of 10Gbps, symmetrical configuration of DCF has least BER = 10−40 with NRZ modulation scheme when power of EDFA was 8dBm.In the second setups both the fiber length as well as EDFA power was varied and then comparison as per quality factor & bit error rate has been done. Thus, the author finally concluded that all the three configurations of dispersion compensating fibers (DCF) has better performance up to a power level of 12dBm of EDFA. Increase in the power levels of EDFA (12-18dBm) further increased the bit error rates (BER) for different modulation schemes for the transmission rates of 10 and 15Gbps.

A. Sangeetha et al. [39] worked on the analysis of the dispersion in coherent orthogonal frequency division multiplexed systems at a rate of 100Gbps. The authors used quadrature amplitude modulation scheme with Q-channel and I-channel modulated by utilizing two MZ modulators, one for the each. DCF technique has been used for dispersion compensation. Without DCF, the longest length achieved was 18Km at 100Gbps but when DCF of 24Km was used in pre-compensation scheme, the fiber length increased to 61Km (DCF=24 Km and SMF= 37Km). In post compensation a maximum length of 59Km (DCF= 24Km and SMF= 35Km) has been achieved. A BER of 10^{-5} and 10^{-4} have been observed for pre and post compensation for both I and Q channels, respectively. Hence, the authors concluded this technique a good alternative to other techniques at an expense of small increase in BER.

S. Kumar et al. [40] did their research in analyzing the performance of system with DCF as dispersion compensation method along with FBG as dispersion compensator. Here, author proposed a using bit rate of 40Gbps for the transmission distance of 100Km. Three compensations configurations of DCF have been validated that are pre, post & symmetrical with input power varied from 5 to 10dBm. Initially the results of three configurations have been compared on the bases of quality factor and bit error rate & it was concluded that post compensation exhibited highest quality factor & lesser bit error rate than others at an input power of 5dBm. The authors also simulated the model for different values of dispersion in FBG compensators and input power. In it, Q-Factor of the post compensation has highest value at 5dBm power level and afterwards started decreasing gradually. Thus, the researchers finally concluded the post compensation scheme to be the best among others at 100Gbps in WDM systems. G.H. Patel et. [41] al investigated a WDM system using pre, post and mix configurations of DCF at 40Gbps rate utilizing NRZ format for modulation. WDM system consisted of four channels at 10Gbps rate thus making overall rate of the system equal to 40Gbps. Pre-compensation configuration used a SMF of 60Km along with a DCF of 12 Km whereas a SMF of 50Km with DCF of 10Km has been used for the post compensation method. Thus the simulations parameters consisted of 24Km of DCF with 120Km of SMF. Conclusions have been made as per the BER and quality factor. Pre-compensation gave a Q-factor = 4.8720 and BER = 4.08×10^{-7} whereas post compensation provided a Q-Factor = 4.9843 with BER =2.32×10^{-7}. Q-Factor = 5.0224 and BER = 1.91×10^{-7} has been provided by mix compensation. Thus the author made a comparison among three configurations and concluded that mix compensation has superior performance than other two schemes at 10Gbps rate for four channels. A.V. Patel et al. [42] performed a comparative analysis of dispersion compensation at 40Gbps rate over a long transmission distance of 4000Km in the existence of Kerr non linearity. Comparison has been done by utilizing three different modulation schemes that are MDRZ (Modified duobinary Return to Zero), CSRZ (Carrier Suppressed Return to Zero), DPSK (Differential Phase Shift Keying). DCF was used as dispersion compensation technique in three configurations of pre-configuration, post- configuration and symmetrical configuration for these three formats for modulation. Single mode fiber with length of 50Km along with DCF of 10km with N spans (10, 20, 30, 40, 50, 60, 70 and 80) have been used for the simulations at distinct input powers ranging from -20 to 20dBm. Analysis has been done and it was found that DPSK yielded better performance than other schemes at input power of 0dBm in symmetrical compensation configuration with a Q-Factor equals to 5.58 and BER in orders of 10−14. M. Sharma et al. [43] did the analysis of chromatic dispersion problem in wavelength division multiplexed systems (WDM). The simulations have been performed by using DCF as dispersion compensation technique in three configurations, which are pre- configuration, post- configuration and symmetrical configuration. SMF of 80Km with a dispersion compensated fiber of 24Km has been used for the simulations. Initially DCF has been used in pre-compensation scheme and it provided a Q-Factor of 17.8956 along with minimum BER of 3.77955 c−072. After that the analysis of post compensation DCF has been done which yielded the highest Q-Factor equals to 17.50 and least BER equals to 4.19689 c−069. Finally, symmetrical compensation scheme has been analyzed and found that it exhibited a Q-Factor of 12.0591 and BER = 6.28605 c−034. Hence, the conclusion showed the pre compensation scheme of DCF to be the best scheme among others because of highest quality factor, least bit error rate & improved S/N. V. Senthamizhselvan et al. [44] investigated the performance of DWDM systems in the presence of the dispersion at various modulation formats, distinct input powers and for different no. of channels. The whole setup included a SMF of 100 Km along with dispersion compensating fibers (DCF) as dispersion compensation scheme at a rate of 10Gbps. Initial calculations included a 20 channel WDM system at 7dBm input power for return to zero and non-return to zero formats for modulation. The simulation has been done by using DCF of length of 20 Km. The outcomes showed a Q-Factor and BER of 4.6268 and 1.70442 $c-006$, respectively when NRZ modulation format has been used at power level equal to 7dBm whereas at the same input power with RZ modulation a Q-Factor and BER of 8.78378 and 7.50674 $c-019$ have been shown respectively. Hence, RZ modulation scheme has been considered better than NRZ at this input power and transmission rate. Further the authors simulated the same model for 12 channel WDM system with 3dBm input power and found a maximum Q-Factor of 7.41189 along with minimum BER of 5.96652 $c-014$. Model has also been simulated for 16 channels with an input power of 5dBm with a quality factor of 8.06647 and BER of 3.4751 $c-016$. After analyzing the proposed model at distinct input powers, RZ modulation technique has been found superior than NRZ technique at 10Gbps rate for 12, 16 and 20 channel WDM systems. R. Arya et al. [45] demonstrated a model for the simulation of 16 channel dense wavelength division multiplexed system (DWDM) by utilizing two distinct formats for modulation of CSRZ (Carrier Suppressed Return to Zero) and DRZ (Duobinary Return to Zero). The experimental setup has been consisted of standard single mode fiber (SSMF) of 50 Km and DCF of 10Km with total spans equals to 24 at a data rate of 10Gbps. Dispersion compensation has been done by using DCF in two different configurations of pre-compensation and post compensation. Post compensation configuration with CSRZ modulation format provided a Q-Factor of 10.5093 whereas with the DRZ modulation technique it was equal to 7.75883 over a distance of 1200 Km. Simulations has also been performed at input power equal to 5mW with pre-compensation scheme. At the same distance of 1200 Km, the pre-compensation with CSRZ modulation format provided a Q-Factor of 9.2243 while it was equal to 6.73939 for DRZ modulation format. Hence, the conclusion showed the performance of CSRZ modulation format better when compared with DRZ on the bases of quality factor & a communication length has been improved to 1200Km for 16 × 10Gbps DWDM system. M. Kaur et al. [46] investigated a model for the compensation of dispersion using dispersion compensating fiber (DCF) as dispersion compensator at 20Gbps rate over the fiber. Optisystem 7.0 has been utilized for the simulation of the proposed model. DCF has been used in pre- configuration, post- configuration & symmetrical configurations to get the results. The outcomes have been analyzed as per eye height, threshold value, bit error rate & quality factor. The experimental setup has been consisted of SMF of 150Km length and a DCF of 30 KM thus making the overall length of the transmission fiber equals to 180Km. After analyzing the results, the values of Q-Factor and BER of these three configurations have been compared. Pre compensation of DCF exhibited a Q-factor of 10.8464 with BER equals to 7.79899 $c-028$ while post compensation has values equal to 9.89048 and 1.6453$c-023$, respectively. Symmetrical compensation was having a minimum BER of 3.04743$c-044$ with a Q-Factor of 13.8771. Thus, the comparison results showed the outcomes of symmetrical configuration much superior as compare to pre- configuration & post- configuration of DCF. M. Yadav et al. [47] discovered a model for evaluating the performance and behavior of the optical system with wavelength division multiplexed channels (WDM) at 40Gbps transmission rate. This paper compensated the dispersion by using dispersion compensating fibers (DCF) in pre-compensation, post-compensation & symmetrical compensation. Initially the comparison of quality factor & bit error rate of pre- compensation, post-compensation, symmetrical compensation has been done at different values of laser frequencies i.e. 193.0, 193.2, 193.4, 193.6 and 193.8 THz. After evaluating it has been found that increase in frequency from 193.0 to 193.4 THz caused a significant increase in Q-factor and it became highest for frequency equals to 193.4 THz with post compensation exhibiting maximum quality factor. After this frequency, the performance of the system started degrading. Hence, the conclusion has shown the performance of post compensation of DCF one step ahead in comparison with other configurations at a frequency of 193.4 THz.

R. Rout et al. explained the role of various dispersion compensation techniques in enhancing the optical communication systems. DCF, FBG & EDC methods have been discussed in detail with their merits and demerits. The observations have been taken by employing DCF in pre, post and mix configurations with varying transmission power from 0 to 20dBm at 40Gbps. The resulting outcomes have been analyzed in terms of both bit error rate & quality factor. It can be seen that when input power expanded around 9dB, Q-Factor incremented. At the point it reached to 16dB, it became maximum. Further increment in input power diminished the Q-Factor bit by bit. Same results have been observed with BER. Thus, the final conclusion included better performance of mix configuration of DCF as it can mitigate the non-linear effects of dispersion better than pre and post compensation. R. Kaur et al. [49] used dispersion compensation technique of DCF in three distinct configurations of pre, post and symmetrical at 40Gbps with NRZ format for modulation. The whole setup included eight channels with input power varied from 9-10dB. Chirped fiber Bragg grating has also been studied with grating length equals to 6mm. Fiber parameters included a SMF of 120 Km along with DCF of 24 Km. Q-Factors of all these three schemes have been evaluated at different frequencies of 192.3, 192.5 and 193.7 THz and it was found that among all the schemes, post compensation exhibited better Q-Factor at all frequencies. The authors also concluded that as per the rise in chirp parameter the input power of pulse has also been increased. M. Singh et al. [50] analyze the performance of a system operating at 10Gbps rate with DCF of 20Km and SMF of 150 Km. Uniform grating of FBG of length 2mm has been considered for dispersion compensation. DCF has been used in three configurations i.e. pre- configuration, post-configuration & symmetric configuration along with fiber Bragg grating. Initially the results have been observed at varying length of single mode fiber with constant power. Symmetric compensation has been analyzed at a constant power of 17dB whereas both pre and post analyzed at 0 dB. It was found that symmetric compensation has highest Q-Factor than others. Another analysis has been done by varying input power at a constant fiber length and got the same results. Similar results occurred when graph of input power has been plotted against min. BER. Hence, the authors came to a conclusion that symmetric compensation has better performance than pre and post compensation of DCF.

S. Khatoon et al. [51] demonstrated a model for WDM system with 32 channels at 10, 20 and 40 Gbps rate. The channel spacing of 100 GHz has been used at frequencies from 191-194.1 THz with return to zero (RZ) modulation format. Post and symmetrical compensation of DCF has been utilized to compensate the dispersion in Wave division multiplexed model. The experimental setup consisted of SMF of 80 Km along with DCF of 16 Km. Final conclusion has been made by evaluating the results of the two schemes as per quality factor & bit error rate. It has been seen that in post configuration of DCF, results of quality factor & bit error rate are worthy at 10 & 20Gbps data rates however at 40Gbps the results are not acceptable. Same analysis has been done using post compensation of DCF and it has been found that the results with symmetrical DCF configuration, gives nearly higher Q Factor and better BER even at 40Gbps. Simulations at various frequencies have also been evaluated and it has been observed that the BER obtained with Symmetrical DCF scheme is satisfactory at 10Gbps, 20Gbps and 40Gbps. From the acquired outcomes, it has been concluded that the symmetrical DCF configuration performs superior to post DCF method in WDM system of 32 channels.

2.5 LITERATURE SURVEY OF COMPARISON OF FIBER BRAGG GRATING (FBG) AND DISPERSION COMPENSATING FIBERS (DCF) AS DISPERSION COMPENSATORS

H.S. Fews et al. [52] performed their simulations by comparing two different techniques for the dispersion reduction for long haul DWDM (Dense Wavelength Division Multiplexed) model. Their analysis included a contrast between dispersion compensating fibers and fiber Bragg grating for a DWDM system with 40 channels and 10Gbps transmission rate over a distance of 525Km using single mode fiber (SMF). Three different layouts has been provided for the comparison that are distributed mid stage, single stage and lumped mid stage compensation. In distributed compensation both FBG and DCF provided almost same results. When FBG was introduced into the spans it provided better insertion loss and noise fig. with low intensity as compared to the DCF. It has been showed that power penalty has expanded due to the incorporation of FBG before the optical spans. To overcome this FBG was lumped into the amplifiers in mid stage which further produced tradeoff among the cost, power and amplifier performance. This configuration provided a reduction of about 4dB in transmitted power when compared with DCF and it was done only with a penalty of 0.5dB. Thus the authors concluded that FBG has better performance when compared with DCF in applications involving short transmission distances. G. Gnanagurunathan et al. [53] simulated a model comparing the two dispersion compensation techniques DCF and FBG in a long wavelength division multiplexed system. Their proposed model consisted of 4 channels over a distance of 600Km.These two techniques were compared initially by varying the load and then by varying modulation schemes in order to determine whether change in load and modulation format has been endured by dispersion compensators and on the off chance that yes, which of these two compensators can support the change better. The results were analyzed by comparing them as per quality factor, eye diagram & bit error rate. When dispersion compensated fiber & fiber Bragg grating dispersion compensators have been compared it was found that FBG surpassed DCF models as BER of FBG was smaller than DCF. Loads have been varied from 2.5 to 40Gbps for DCF and FBG dispersion compensators and it was found that with the increase in bit rates, the pulses got significantly nearer and hence increased the vulnerability towards dispersion. At this condition FBG was more robust than DCF as it deteriorates much lesser than DCF. Another analysis has been done by operating FBG and DCF with non-return to zero & return to zero formats for modulation and it was observed that FBG has been performed well than DCF with both the modulation formats. Thus, the study concluded that FBG was far better than DCF at the same bit rates over a particular distance of 600Km regardless of the modulation format used.

W. Liu et al. [54] demonstrated a model for the transmission of the optical signals for a distance of 2500Km at a rate of 10Gbps with FBG utilized as dispersion removal component. The authors used four distinctive schemes of FBG for dispersion compensation that are pre-configuration, post-configuration & two types of symmetrical configuration. In one type of symmetrical configuration FBG were placed at the input and output whereas in another type FBG were placed in the mid span. Four schemes of FBG have been compared by taking three input powers into account that are 4dBm, 6dBm and 8dBm. It was found that at all input powers, post compensation scheme of FBG has superior performance than other schemes and also the performance of pre-compensation was worst at this rate. Another analyzing has been done by comparing the output pulse with the input pulse at powers equal to 6 and 14dBm, respectively. It was observed that as the input power increased it caused increase in no-linear effects and hence, pulse broadening. The work in this paper also included the comparison of post compensation of DCF with the post compensation of FBG at different input powers and concluded that FBG has superior performance than DCF. The authors also showed that at input power equal to 7dBm, post compensation of FBG has maximum Q-Factor. K. Khairi et al. [55] investigated the behavior of pre-configuration & post- configuration techniques of dispersion compensation by utilizing chirped fiber Bragg grating. They did their experimental simulation by utilizing SSMF (Standard Single Mode Fiber) using bit rate of 10Gbps by using NRZ format for modulation. Transmission distance of 100Km was used for the experimental analysis. Multi-channel chirped fiber Bragg grating has been compared with the mostly used DCF technique and it was found that MC-CFBG have more advantages than DCF including lower amount of non-linearity. When both the schemes of MC-CFBG were evaluated at different input powers it has been shown that pre-compensation of MC-CFBG has better results than post compensation as it provided a power penalty of only 1dB. Hence, the authors finally concluded MC-CFBG as a favorable and economical technique for compensation of chromatic dispersion. V. Bobrovs [56] compared FBG and DCF techniques for the chromatic dispersion compensation in a network of wavelength division multiplexed systems. This experiment was done for a model with 16 channel WDM system. It has been shown that CD (Chromatic Dispersion) is the biggest reason behind the low outcomes of fiber optic cable during transmission over longer distances. Pre and post compensation configurations of FBG and DCF have been compared in order to find the best compensation scheme. Initially 57 Km distance was taken without any dispersion compensation. When DCF of 7Km was used in pre-compensation scheme it causes increment in the communication length from 57 to 68 Km and but when DCF of 2 km was used in post compensation scheme the distance has been increased only by 3Km i.e. from 57 to 60 Km. same analysis has been done with FBG as dispersion compensator. It has been observed that FBG in pre-compensation scheme increased the distance from 57 to 72 Km and but in case of post- configuration, the distance increased was of only 9 Km i.e. from 57 to 66 Km. Thus, by analyzing all the results of DCF and FBG, the authors concluded FBG to be more prominent for dispersion compensation than DCF in DWDM systems.

S. Anand et al. [57] performed the compensation of dispersion in optical communication system by utilizing FBG along EDFA. FBG with post configuration has been used. Here every channel transmitted at a rate of 40Gbps in a 4-channel wave division multiplexed model, which has been proposed for the simulations. The frequency of the laser varied from 192.1 to 194.4 THz with the SMF and DCF length equals to 100Km. The authors have also shown the various parameters like dispersion, power, S/N at various frequencies before & after multiplexing. NRZ format for modulation has been used for analyzing results of the proposed model. Simulation results have shown the Q-Factor and BER equals to 13.8681 and 3.06393 c−044, respectively. The authors concluded that this configuration has a lower value of Q-Factor than IDCFBG and post DCF. At a frequency of 193.1, 193.3 and 193.4THz noise and dispersion value decreased which further increased the signal to noise ratio whereas at frequency equal to 193.2THz, dispersion increased which further caused decrease in SNR ratio. G. Singh et al. [58] designed a model for simulation of eight channel WDM system over 120Km distance, in which every channel was using a bit rate of 15Gbps thus, making the overall rate of the system equals to 120Gbps. The system was modeled by utilizing two techniques of dispersion reduction which are, DCF & FBG. DCF has been used in pre- configuration, post- configuration & mix-configurations whereas only pre & post configurations of FBG have been utilized. The simulations have been done and the outcomes were compared as per quality factor & bit error rate. After analyzing the eye structures, it was fond that there was a significant difference in the Q-Factors of these five configurations. With pre-compensation of DCF, Q-Factor and BER was equal to 12.8 and 2.077 $c-38$, respectively whereas for post compensation, it was 15.5 and 6.192 $c-055$, respectively. In mix compensation of DCF, the observed Q- Factor and BER was 15.9 and 1.263 $c-057$, respectively. Further, FBG in pre-compensation provided a maximum Q-Factor of 16.0 along with BER equal to 2.328 $c-058$. Also, with post compensation, the result included a BER of 2.478 $c060$ with Q-Factor equals to 16.3. Hence, the authors concluded that post compensation of FBG has better performance than the corresponding schemes of DCF and FBG for 8× 15 Gbps WDM system. M. Tosson et al. [59] presented and evaluated the results for the compensation of dispersion by utilizing two methods- DCF and FBG over 150Km of length of cable at a rate of 40Gbps for a dense WDM of 8 channels. Simulation parameters included a NDSF (Non-dispersion Shifted Fibers) & NZDSF (Non-zero Dispersion Shifted Fibers) of length 150Km each along with DCF of 10Km. With DCF, NDSF and NZDSF have shown a maximum Q-Factor of 7.1408 and 9.34726, respectively for channel-8. Same analysis has been done with FBG and found a maximum Q-Factor of 9.72884 and 15.9645 for NDSF and NZDSF, respectively. After comparing the readings of quality factor & bit error rate of DCF & FBG, it was observed that FBG have shown results far better than DCF with both types of fiber cables. However, the authors concluded that it has been practically impossible in case of DWDM systems. This happened because insertion of FBG at each channel after de multiplexer resulted into increased cost. Hence, the authors finally reached to a conclusion of using DCF for removing chromatic dispersion in DWDM systems.

Gopika P et al. [60] demonstrated a model for improving the complete outcomes of a model by using dispersion compensated fiber & fiber Bragg grating as dispersion compensating schemes. 120Km of SMF with 24Km of DCF has been taken into account for the simulation of eight channel 15Gbps WDM systems. Initially the analysis has been done by utilizing dispersion compensated fiber in pre-configuration, post- configuration & symmetrical configuration & then utilizing fiber Bragg grating in pre and post configurations. By varying the input power from 0 to 9dB, it has been observed that Q-Factor lowered down with increment in input power. When the DCF schemes have been compared, symmetrical compensation provided a higher Q-Factor of 15.9 than others. Same comparison has been done with pre and post of FBG showing post-compensation better than pre with a Q-Factor of 16.3. This paper has shown a comparison between DCF and FBG and found that post compensation of FBG has a very high Q-Factor and least BER of 16.3 and $2.478 \times c{-}060$, respectively. V. Dilendorfs et al. [61] evaluated the effectiveness of DCF and FBG as dispersion removal method for single channel & multiple channel systems. All the simulations has been done at 10Gbps. Two frequencies of 193.1 and 195.9 THz has been used for single channel analysis while multiple channel analysis has been done at 193.1-193.8 and 195.9- 196.6 THz. At a frequency of 193.1THz in single channel, the maximum length of the fiber covered was estimated to 156.3Km with pre-compensation of DCF. With 195.9THz the maximum length covered was of 162.9 Km with pre + post DCF configuration. Same analysis has been done with multiple channels and it has been shown that maximum fiber link length was supported with FBG (150.5 Km utilizing 193.1-193.8 THz and 168.3 Km using 195.9 – 196.6 THz). Thus, the researchers decided to use DCF for single channels and FBG for WDM systems. V. Joshi et al. [62] analyzed the performance of the system by putting forward DCF and linear chirped FBG for the dispersion removal in the fiber optic systems. Behavior of the system has been evaluated and analyzed in terms of eye diagram, bit error rate, & quality factor. Pre- configuration, post- configuration & symmetrical configuration of both DCF and FBG has been modeled. Three types of comparison have been provided in which firstly all the six schemes have been compared in terms of both bit error rate, & quality factor at distinct distances of optical fiber. Secondly, comparison of these two factors at various input powers and then at different bit rates (2.5, 5, 10, 20, 30 and 40Gbps) has been done. After the complete analysis of the system, it has been observed that FBG has superior performance when compared with DCF. Also, symmetrical configuration of FBG exhibited highest Q-Factor and least BER which is the required condition for the reduction of dispersion in transmission model.

G. Singh et al. [63] has demonstrated a model for the removal of CD in long distance transmission model by using two different techniques of compensation. The whole setup consisted of eight channels of 10Gbps rate at varying SMF lengths of 10, 50 and 100Km. Firstly the simulations have been done by using DCF as dispersion compensator. It has been found that for the lengths of 10, 50 and 100Km the corresponding Q-Factors have values equal to 8.10, 8.06 and 2.57, respectively. Secondly, the analysis has been done by using FBG. It has been found that for lengths of 10, 50 and 100 Km, the Q- Factors were 11.40, 9.90 and 4.12, respectively. The authors concluded that FBG has better performance than DCF for 8 × 10 Gbps WDM systems as per quality factor & bit error rate. But FBG has a disadvantage of more cost than DCF as eight FBG has to be used at receiver for eight channels. Hence, it has been shown that both techniques are efficient in their own way and can be used depending on the requirement of the users. K. Jadav et al. [64] compared the simulation results of two methods of dispersion compensation- DCF and FBG at a rate of 10Gbps for 10 and 50 Km of SMF. Input power has been kept constant at 5dBm. At 10Km, Q- Factor of DCF has been observed equal to 277.282 with BER = 0 and whereas for FBG, the corresponding values came out to be 47.49 and 0, respectively. Similar analysis has been done at 50 Km and it has been found that DCF has higher Q- Factor than FBG. So, in conclusion DCF has a output better than DCF at 10Gbps rate for both the distances.

2.6 LITERATURE SURVEY OF DISPERSION COMPENSATION MODULES AS DISPERSION COMPENSATOR

W. Chen et al. [65] fabricated a dispersion compensation module for optical transmission of signal at a rate of 40Gbps in wavelength division multiplexed system. Initially DCF's were made by plasma chemical vapor deposition method and then they have been used for the fabrication of DCM's with more sophisticated characteristics then DCF like less insertion loss, lower amount of non-linearity and lesser dispersion. DCF along with pigtail fibers at the two finishes of DCF made dispersion compensating modules for dispersion compensation. The work in this paper showed the successful transmission of 48 channel 40Gbps system with the fabricated dispersion compensation modules. The authors finally concluded that DCM's have better function of slope compensation and dispersion compensation within a wavelength scope of 1525- 1625 nm. T. Xie et al. [66] provided a model to compensate dispersion for 40Gbps system at distinctive lengths varied from 50 to 200Km of single mode fiber (SMF). Dispersion compensation banks (combination of IDCFBG (Ideal dispersion compensating grating), FBG (Fiber Bragg grating) & Gaussian optical filter) have been utilized for compensation of dispersion in the proposed model. The simulations has been done by varying the power from 5-20dBm. Initially the dispersion has been observed at 50, 100 and 200Km of SMF and found that at 200Km the effect of dispersion was more prominent than at other distances. To compensate the dispersion, signal at 200Km distance has been passed through DCB at different power levels of 5, 10 and 20dBm. As input power equal to 5dBm, the observed quality factor and BER equals to 3.46637 and 0.000142324, respectively. Similarly, at input power equal to 10dBm, highest Q-Factor achieved was 3.4541 and minimum BER = 0.000171007. At input power 20dBm, 3.4326 and 0.000198058 were the achieved Q-Factor and BER, respectively. Hence, the authors concluded that the increased in input power caused a significant rise in BER & decrease in Q-Factor of the overall system. S.K. Gill et al. [67] evaluated the performance of a WDM system with 32 channels over different distances of 120 and 80 Km, respectively. Dispersion compensation units consisted of both DCF and FBG have been utilized. The proposed model evaluated the dispersion at different rates of 10, 20 and 40Gbps using RZ and NRZ formats for modulation. Simulation results for different combinations have been showed to determine the highest Q-Factor. At a bit rate of 10Gbps and 80Km of SMF, the corresponding value of Q-Factor and BER was 53.9142 and 0, respectively. At the same rate with 120Km of SMF, the Q-Factor was 36.093 with BER equal to $9.91086c-286$. Further with 20Gbps rate and 80Km of SMF, Q-factor was equal to 56.9276 and BER = 0. With 120Km of SMF, Q-Factor and BER were 24.2101 and $5.57302c-130$. These results were analyzed for RZ modulation format. Similarly, NRZ modulation scheme has also been analyzed for different combinations. Hence, after the complete analysis of Q-Factors and BER, the authors declared RZ modulation scheme more effective and efficient than NRZ for DWDM systems. R. Rao et al. [68] designed a structure for the compensation of dispersion by utilizing DCF and FBG techniques. For enhancing the transmission capacity of the system, DCF with FBG has been used in the proposed model for simulations. All the simulations in three configurations of pre, post and symmetrical has been performed at 10Gbps rate for eight channels in WDM system. A comparative analysis among three schemes has shown that symmetrical compensation has better Q-Factor with least BER. Q- Factor of 36.3051 with BER of $5.56636c-287$ has been achieved by symmetrical configuration.

2.7 LITERATURE SURVEY USING ALL PASS FILTER AS DISPERSION COMPENSATOR

S. Devra et al. [69] proposed a method for compensation of dispersion using all pass filters in WDM systems having multiple channels. Their research showed that all pass filters can be considered for effective transmission in WDM systems as compared to other compensation techniques like Fiber bragg grating, dispersion compensating fibers and electronic dispersion compensation. This happened because the phase response of all pass filters has periodic properties. Implementation and designing of all pass filters have been discussed. The authors concluded that a WDM system having rate 10Gbps and free spectral range of 50GHz with a BER = 10^{-9} can be realized with a properly designed all paper filters. S. Devra et al. [70] demonstrated a model for the dispersion compensation by utilizing raised cosine filters. In this article the authors made comparison of all types of dispersion reduction techniques with the raised cosine filter technique for the compensation of intersymbol interference (ISI). The author compared the outcomes of the all pass filter and raised cosine filter design and found that it exhibited the similar kinds of outcomes just like all pass filters but with a little problem & lesser cost. Hence, the author concluded the raised cosine filters to be better and easily reliable than all pass filters.

2.8 LITERATURE SURVEY USING ELECTRONIC DISPERSION COMPENSATION (EDC) AS DISPERSION COMPENSATOR

Dr. P. Venugopal et al. [71] proposed a new technique of electronic equalization for the removal of CD in fiber optic communication design. The authors also demonstrated how effective the electronic equalizers when compared with optical equalizers (DCF and FBG) in terms of cost. The whole setup included MZ modulator, EDFA, Gaussian filter, photo detector, electrical filter, electrical limiter and then electronic equalizers. The work in this paper included the evaluation of bit error rates initially at different fiber lengths of 130,140,150 and 160 Km and then at different bit rates of 1 and 10Gbps, resp. It has also been seen that with the rise in length of the fiber, power of the receiver showed a gradual decrease. When BER was varied in accordance with the received power at different rates it was found that the model was upgraded for a rate of 10Gbps. BER with and without equalizers has also been shown. Dispersion compensation with electronic equalizers has shown a BER between 10^{-3} and 10^{-5} in comparison to optical equalizers after the transmission distance of 100 Km. The research has shown that without the use of inline amplifiers, 160Km transmission distance with 10Gbps rate can be achieved with electronic equalizers. Thus, the authors concluded to use electronic equalizers instead of the adaptive decision feedback equalizers for the transmission. M. Singh

[72] provided a concept of monitoring and suppressing the chromatic dispersion in optical fiber links. The author investigated the technique of adaptive equalization to lessen the effect of inter symbol interference which is a major hindrance in transmission of signals at longer distance with higher bit rates. The whole setup consisted a fiber of 50Km with equalizer having leakage factor = 1, four forward taps and step size of 0.003 at a rate of 2.5Gbps. Improvement in the performance of the system has been observed from the outcomes before equalization and after equalization. By evaluating the parameters, it has been seen that Q-Factor before equalization was 64.037 which rose to a value of 102.843 after equalization. Thus, the author concluded that by the manipulation of different parameters, it is possible to repair the distorted signal even at higher bit rates.

2.9 LITERATURE SURVEY COMPARISON TABLES OF VARIOUS DISPERSION COMPENSATION TECHNIQUES

Table 2.1: Literature survey on fiber bragg grating as dispersion compensator

S.No.	Author's Name	No. of Channel	Bit Rate(in Gbps)	Transmitting distance (in Km)	Q-Factor (dB)	BER
1	A.H. Gnauck et al.[22]	8	10 and 20	480 and 315	21.5 and 21	1×10^{-32} and 1.5×10^{-29}
2	L.D. Garrett et al. [23]	16	10	840	17.75	6×10^{-15}
3	L.D. Garrett et al. [25]	32	10	375	18.35 to 21.4	7×10^{-17} to 4×10^{-32}
4	L. Pei et al. [28]	13	10	3100	----	Less than 10^{-4}
5	K. Kashyap et al. [29]	1	10	1,10,25,50,75 and 100	45,30, 22,16,15 and 10	---
6	M. Singh et al. [31]	1	2.5	100	54.5192 dB	0

Table 2.1 is showing the list of authors, worked on dispersion compensation by using fiber bragg grating with different bit rates and different transmission distances. Authors have used different no. of channels. Hence, accordingly they

have got different values of quality factors and BER. Table 2.2 is showing the list of authors, worked on dispersion compensation by using DCF with different bit

Table 2.2:- Literature survey on dispersion compensating fiber as dispersion compensator

S. No.	Author's Name	No. of Channel	Bit Rate (in Gbps)	Input Power (dBm)	Transmitting distance (in Km)	Best Config.	Q-Factor	BER
1	R.J. Nuyts et al.,[33]	1	10	-5 to +5	480	-----	------	10^{-15}
2	Bo-ning Hu et al. [36]	8	40	5 to 12	160	Mix	31	10^{-12}
3	B. Patnaik et al. [37]	64	20	3	200	Symm.	14	1.5×10^{-47}
4	A. Sangeetha et al. [39]	1	100	3	61	Pre	-----	10^{-5}
5	S. Kumar et al.[40]	1	40	5 to 10	100	Post	12	0
6	G.H. Patel et al. [41]	4	10	0	144	Mix	5.0224	1.91×10^{-7}
7	A.V. Patel et al. [42]	1	40	-20 to 20	4000	Symm.	5.58	10^{-14}
8	V. Senthamizhselvan et al. [44]	12,16 and 20	10	3, 5and 7	120	-----	7.41189 , 8.06647 and 8.78378	$5.96652\ e^{-014}$, $3.4751\ e^{-016}$ and $7.50674\ e^{-019}$
9	R. Arya et al. [45]	16	10	5mW	1200	Post	10.5093	-----
10	M. Kaur et al. [46]	1	20	5	180	Symm.	13.8771	$3.04743e^{-044}$
11	M. Yadav et al. [47]	1	40	0	50	Post	3.0433	6.30161 e^{-0-240}
12	R. Kaur et al. [49]	8	40	9 to 10	144	Symm.	11.6514	6.62201e-029
13	M. Singh et al. [50]	8	10	0 and 17	170	Symm.	36.3051	5.56636 e^{-0287}
14	S. Khatoon et al. [51]	32	10,20 and 40	0	96	Symm.	More than 7 for 40Gbps	Less than 10^{-9} for 40Gbps

Table 2.3:- Literature survey on Comparison of FBG & DCF					
S.No.	**Author's Name**	**No. of Channels**	**Bit rate(in Gbps)**	**Transmitting distance (in Km)**	**Best Technique**
1	H.S. Fews et al.[52]	40	10	525	FBG
2	G. Gnanagurunathan et al. [53]	4	2.5 and 40	600	FBG
3	W. Liu et al. [54]	1	10	2500	Post configuration of FBG
4	K. Khairi et al. [55]	1	10	100	MC-CFBG
5	V. Bobrovs [56]	16	10	57	Pre configuration of FBG
6	G. Singh et al. [58]	8	15	120	Post configuration of FBG
7	M. Tosson et al. [59]	8	40	150	FBG
8	Gopika P et al. [60]	8	15	144	Post configuration of FBG
9	V. Joshi et al. [62]	1	2.5,5,10,20,30 and 40	5,10,15,20,25 and 30	Symm. Configuration of FBG
10	G. Singh et al. [63]	8	10	10,50 and 100	FBG
11	K. Jadav et al. [64]	1	10	10 and 50	DCF

rates and different transmission distances. Again, authors have used different no. of channels & configurations. Hence, accordingly they have got different values of quality factors, BER and best configuration. Table 2.3 is showing the list of authors, worked on the dispersion compensation by using fiber bragg grating and DCF with different bit rates and different transmission distances and made comparison between both of these techniques. Hence, accordingly they got best techniques depending upon the parameters they used.

Table 2.4:- Literature survey on Dispersion Compensation Modules as Dispersion Compensator

S. No.	Author's Name	No. of Channel	Input power (dBm)	Bit rate (Gbps)	Transmitting distance (in Km)	Best config.	Max. Q-Factor	Min. BER
1	T. Xie et al. [66]	1	5,10 and 20	40	50, 100 and 200	----	3.46, 3.45 and 3.43	0.0001423 , 0.0001710 and 0.00019805
2	S.K. Gill et al. [67]	32	10	10,20 and 40	80 and 120	----	53.91 , 36.09 ,56.92, 24.21	0, $9.91086e^{-2}$,0, $5.57302e^{-1}$
3	R. Rao et al. [68]	8	-5 to 20	10	170	Sym m.	36.3051	$5.56636e^{-2}$

Table 2.4 is showing the list of authors, worked on dispersion compensation by using Dispersion compensation module with different bit rates, different transmission distances and at different input power. Authors have also used different no. of channels. Hence, accordingly they have got different values of quality factors and BER. In table 2.5, there is a list of authors using EDC for dispersion compensation.

Table 2.5:- Literature survey using Electronic Dispersion Compensation (EDC) as Dispersion Compensator					
S.No.	**Author's Name**	**Bit Rate(in Gbps)**	**Transmitting Distance(in Km)**	**Q-Factor**	**BER**
1	Dr. P. Venugopal et al. [71]	1 and 10	130,140, 150 and 160	-----	10^{-3} and 10^{-5}
2	M. Singh [72]	2.5	50	102.843	------

2.10 SUMMARY

Literature survey of different dispersion compensation schemes has been provided in order to know how much work has been done using a particular method of dispersion compensation. Simulations have been done using DCF and FBG at a bit rates of 10, 20 and 40Gbps either using SMF or WDM systems. Similarly, EDC has been used at 2.5 Gbps and in some researches it has been used at 10 Gbps. By analyzing all the researches done in fiber optics field for dispersion compensation, it has been found that electronic dispersion compensation (EDC) is the best suited method for eliminating chromatic dispersion so far. This thesis contained work mainly focusing on using all available techniques for dispersion compensation.

CHAPTER-3

MODELLING AND SIMULATION

3.1 CHAPTER OVERVIEW

The work in this thesis is based on the compensation of chromatic dispersion. In order to implement the model for compensating dispersion present in communication system, software named Optisystem 7.0. is used. This software consists of various distinct tools including various modulation formats, distinct modulators, attenuators, amplifiers, filters, compensation techniques (DCF, FBG, EDC) etc. Components of Optisystem 7.0 along with their applications are explained in detail. Dispersion in the communication system results into a major loss of light pulse travelling from transmitter end to recipient end. These losses, in turn, decays the level of signal and information content is lost. Hence, to recover that lost information, dispersion compensation methods are used. Distinct techniques available for reparation of chromatic dispersion includes DCF, FBG and EDC. These are the existing techniques for alleviating the effect of chromatic dispersion. All these methodologies have their own merits and demerits based on their applications in fiber optics.

3.2 OPTISYSTEM 7.0 SIMULATOR

It is an extensive software based on empowering users to perform various processes including planning, testing, and simulating optical links in the channeling layer of present day light systems. This software is based on the practical modeling of fiber optics communication. Components, net list, layout of optical components and all the graphics are controlled by extensive graphical user interface. Optisystem allows virtually automating any kind of optical link in the physical layer.

And then analyzing the wide spectrum of these networks from long distance networks, metropolitan areas and also from local area networks. A comprehensive library of .osd files is inbuilt in optisystem which provides various templates for the designing of projects and also for demonstration and learning intentions. By adding user components, the capabilities of optisystem can be extended and can be consistently relate to immense variety of tools.

3.2.1 Optisystem - Main features

- Component Library: Hundreds of elements has been handled by the component library of optisystem. All of them are then carefully approved to get outcomes that are approximate to real life implementation.
- User-defined components: New components can be created by user based on user-defined libraries and subsystems or use co-simulation with a third party tool such as Simulink or MATLAB.
- Representation of mixed signal: Mixed signal arrangement for the electrical and optical signals present in the library which includes components are handled by optisystem.
- Performance and Quality: It computes parameters like Q- Factor and BER in order to determine the performance of the system.
- Measured components: The Component Library of Optisystem authorize the users to undertake the parameters which can be measurable from real gadgets in the future. It incorporates with measurement and test apparatus from distinct traders.
- Data monitors: Any element port can be selected by the user and it can save the data. The saved data can be monitored at the simulation. Another merit involves attaching a random no. of visualizers to monitor at similar port.
- Multiple layouts: Quick and efficient modification and creation of the designs are allowed to the users. The users can also make various designs using the similar project file.

- Parameter sweeps and optimizations: With the recapitulated changes in the parameters simulations can also be replicated. The user can combine multiple frameworks sweeps and multiple optimizations.
- Report page: A completely personalized report page makes the user able to unveil any kind of frameworks and outcomes present in particular design. Those outcomes obtained from the reports are well assembled into moveable and resizable spread-sheets, graphs (2D and 3D), text etc.
- Material's bills: A table including the cost analysis of system that has been designed and arranged is also provided by the Optisystem.

3.2.2 Optisystem applications

Optisystem has an outspread scope of applications which includes:

- All system components can be stimulated.
- SONET/SDH ring outline.
- Approximating the bit error rate and penalties of system with distinct recipient models.
- CATV or TDM/WDM/CDM network design.
- Transmitter, channel, amplifier, and receiver outline.
- FTTx based on Passive Optical Networks.
- Dispersion map design.
- FSO systems. ROF systems.
- Link budget calculations and Amplified system BER.

3.2.3 Optical system components

A transmitter, channel and receiver are the fundamental elements of any basic optical communication system are shown in Fig.3.1.

- Optical transmitter function includes converting electrical pulse into optical pulse, and then launching that developed optical pulse into optic fiber.
- Communication channel acts as a transporter to transport the optical pulse from transmitter section to recipient section without deteriorating it.

➢ The major function optical receiver performs is to convert the optical pulse obtained at the yield back into the initial electrical pulse.

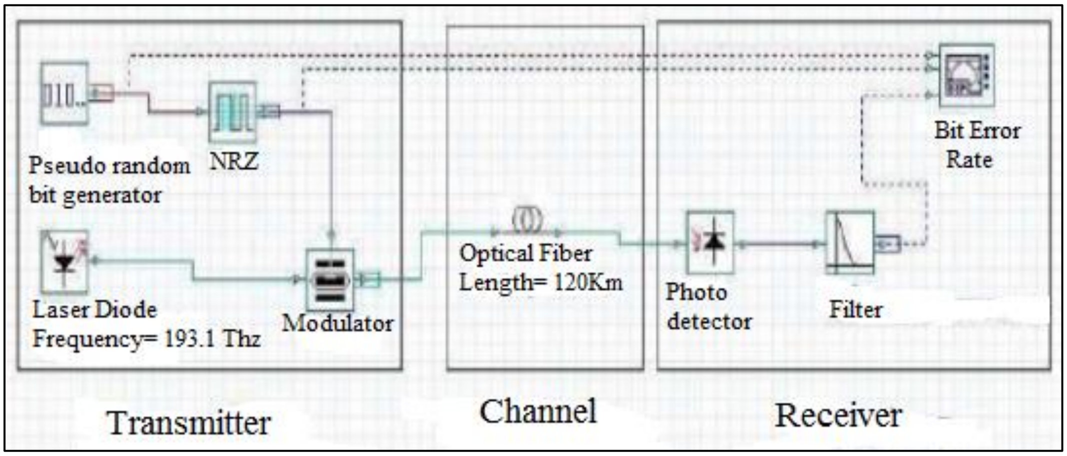


Fig.3.1: General components of Optisystem

A description of the key elements in the optisystem platform is given below:-

➢ **PRBS:** It generates PRBS according to the required distinct operation modes. Designing of bit sequence is done to roughly estimate the features of random information. Data and information signals are also disorganize by using PRBS with reference to bit rates. It also disorder input information signal in respect of bit rate.

➢ **Non return to zero pulse generator:** Light data pulses get regulated with signal from optical source and make 2 sorts of pulses that are Return to zero and non-return to zero. In case of Return to zero pattern, the signal which represents bit 1 is generally smaller than bit slot, and before the end of bit duration, its amplitude returns to zero. In case of Non return to zero pattern, optical signal stays on throughout the whole bit slot and the amplitude never becomes zero between 2 or more consecutive 1's bits. When bit pattern is concerned, pulse width of non-return to zero (NRZ) changes whereas it is alike in RZ format. In fiber communication using RZ pattern helps in designing high-potential light wave systems. Microwave carrier frequencies are 1 GHz while optical carrier frequencies are 200 THz. The information carrying potential of optic communication systems are increased to a point of up to 10,000, due to the use of high frequencies (carrier) for light wave systems. Non return to zero signal generator offers a merit of managing bandwidth. The characteristic of returning signals to zero between bits is the main reason behind this advantage.

- **Mach-Zehnder modulator:** The amplitude at the output or the phase of the light passing through the gadget is generally controlled by optical modulators. Waveguide-based modulators are utilized in optical applications in order to reduce the area of device and driving voltage.

- **Optical fiber:** It is a crystalline and flexible fiber made up of extruded plastic and glass. It can behave as a waveguide to impart light between ends of optical fiber. Field of applied science and engineering related with application and design of optical fiber is called fiber optics. Optical fibers commonly consists of a crystalline core surrounded by a cladding having smaller refractive index. Total internal reflection is a phenomenon responsible for keeping the core inside the fiber. This makes fiber to behave like a waveguide. Numerous transverse modes are supported by fibers termed as multi-mode fibers. It can be utilized as means for computer networking and telecommunication due to its malleable nature and capability of bundling as cables. This fiber is particularly powerful for communications at long distances, because in it light wave travels down the fiber with small attenuation when compared with electrical cables. This makes longer distances be capable to crossed using few regenerators.

- **EDFA's:** EDFA's have received a lot of recognition because of their traits of having more gains, lesser noise levels, bandwidths and more efficiencies. Optical boosting of signal is compulsory to master the loss in fiber and to boost signals before their reception at receiver by Photo detector.

- **Continues laser diode (CW):** A continuous laser beam is emitted by continuous laser with a controlled heat at output. Most of the times these are used with metals. Two types of lasers are there either pulsed or continuous.

3.2.4 Eye diagram

Eye diagram is also referred as eye pattern. It carries lots of information about the quality of incoming pulse and state of channel, which is useful for the detection of digital input. Also, more details of the performance of any system can be gathered from the display of eye pattern.

Significance

1) It is generally used for the visual examination of Inter symbol interference.

2) It can also be used for accuracy of timing extraction.

3) For noise immunity

Inter symbol interference (ISI) is not a noise, it is caused by non-ideal channels which are not distortion less over the entire signal bandwidth. Eye diagrams can be visualized by using CRO. In CRO, there are two axis or inputs i.e. vertical and horizontal. The output of receiver is provided to the vertical input and on horizontal input the rate of signal will be triggered as shown in the diagram below in Fig.3.2.

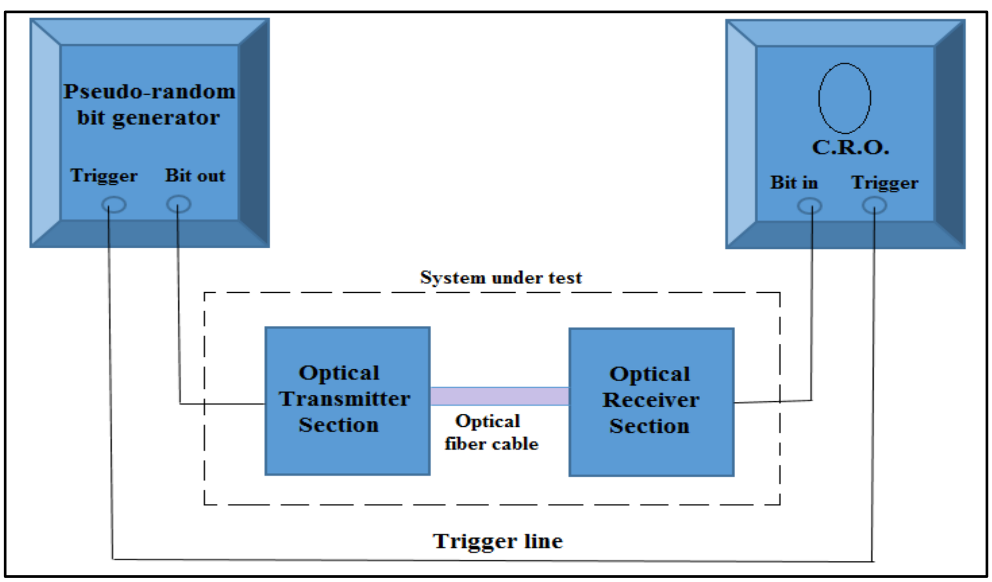


Fig.3.2: Eye diagram setup

To understand the eye design, consider the improved attracting indicated Fig.3.3. The accompanying data with respect to the timing jitter, distortion in amplitude and system rise time can be as follows:

- Sampling of the recipient signal can be done without any fallacy due to intrusion from neighboring pulses (termed as intersymbol interference) during the time interim defined by width of eye opening.
- The perfect time of sampling the recipient waveform is when eye height gap is greatest. Height becomes smaller and smaller as the amplitude distorts in the original information signal. The concept of distortion degree can be determined by the vertical space between the peak of eye opening and topmost level of signal. The more is the closing of eyes, the more it will become burdensome to discriminate between 0s and 1s in the original signal.
- The perfect time to test the available waveform is the point at which status of the eye opening is biggest. This stature is decreased because of distortion in amplitude of the information signal. The perpendicular separation between the highest point of eye opening and the greatest signal level provides a level of error. The greater the level of shutting the eyes, the more troublesome it is to recognize 0s and 1s present in the signal.
- Noise margin can be demonstrated by the stature of the eye opening at the predefined sampling time.
- The incline of the eye- design sides decides the affectability of system to timing blunders. Likelihood of timing blunders increments as the slant turns out to be more even (horizontal).
- Pulse distortion in the optical fiber and receiver noise results in “Timing jitter”.
- Non-linearity of the channel exchange attributes will make an inequality in eye design. On the off chance that a simply arbitrary information stream is gone through an absolutely linear system, all the eye openings will be indistinguishable and balanced.

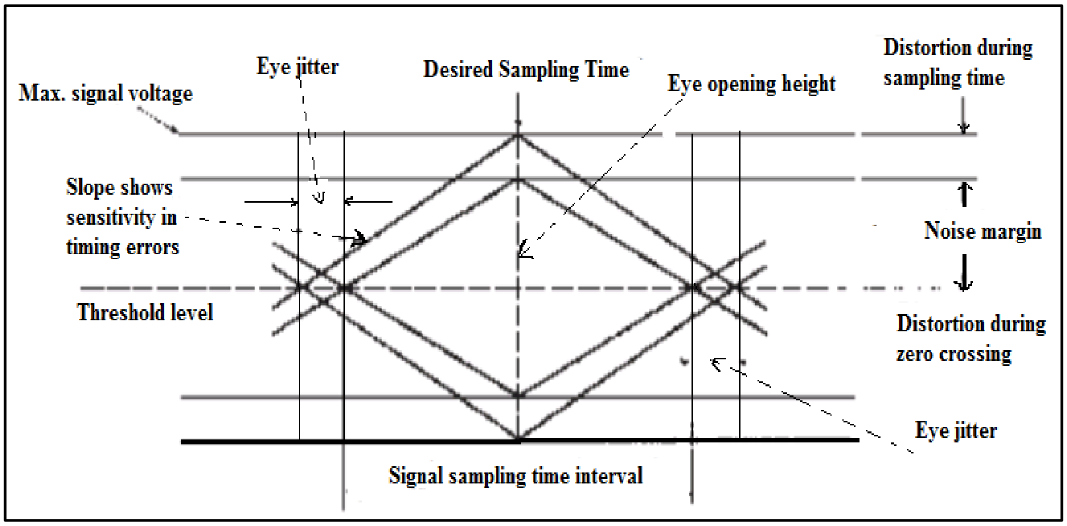


Fig.3.3: Simple eye diagram with performance parameters

For the eye diagram, following aspects are important:

1. The distinction between one-bits and zero-bits is indicated by the value of contrast in signal level which is the measure of the vertical eye opening. The greater the distinction, more easy it is to segregate in between 1s and 0s. Obviously, this is influenced altogether by noise.

2. The jitter exhibit in the signal is demonstrated by the horizontal eye opening. The more extensive the eye opening in the horizontal direction is, the less issue we are probably going to have with jitter.

3. The width of the bunch of signals at the zero-intersection point is likewise a decent measure of jitter in any signal.

4. The larger size of eye opening indicates best sign of signal "goodness". The bigger it is the simpler it will be to identify the signal and the lower will be the mistake rate. At the point when the eye is about shut it will be extremely troublesome or difficult to get important information from the signal.

3.3 DISPERSION COMPENSATION TECHNIQUES

Various Methodologies are there that can be employed for dispersion compensation, some of them are given below:

- Dispersion Compensating Fiber

- Fiber Bragg Grating
- UFBG (Uniform Fiber Bragg Grating)
- EDC (Electronic Dispersion Compensation)

3.3.1 Dispersion compensating fiber

The idea of using DCF was initially suggested in 1980's. DCF has various advantages due to which it is considered to be one of the finest methodology to remunerate dispersion. SMF always exhibits positive value of dispersion coefficient. Thus, to counteract this positive dispersion coefficient a reverse value is required that is negative dispersion so that overall dispersion becomes zero. This work is accomplished by utilizing dispersion compensating fiber along with SMF in communication system as DCF has negative dispersion coefficient. DCF is stable as its components are not straightforwardly distressed by change in temperature & bandwidth. Using DCF as dispersion compensator is the most efficient and effective technique in WDM and DWDM networks also. The eqn. (3.1) shows the required condition for making overall accumulated dispersion to be zero.

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \quad (3.1)$$

Where, D_{SMF} = Dispersion of single mode fiber

D_{DCF} = Dispersion of Dispersion Compensating Fiber

L_{SMF} = Length of single mode fiber

L_{DCF} = Length of Dispersion Compensating Fiber

a) **Configurations:** DCF supports three configurations as follows:

   - Pre-compensation: It refers to a situation when the DCF of dispersion is placed before standard fiber so that the positive dispersion of standard fiber can be compensated shown in Fig.3.4.

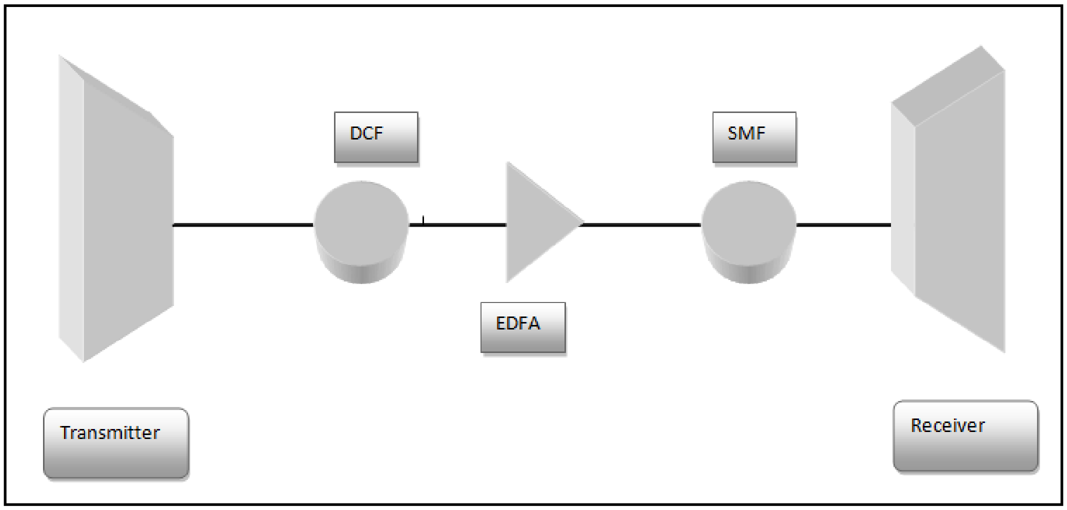


Fig.3.4: Pre-compensation in DCF

- Post-compensation: It refers to a situation when the DCF of dispersion is arranged after standard SMF fiber so that the positive dispersion of standard SMF fiber can be compensated shown in Fig.3.5.

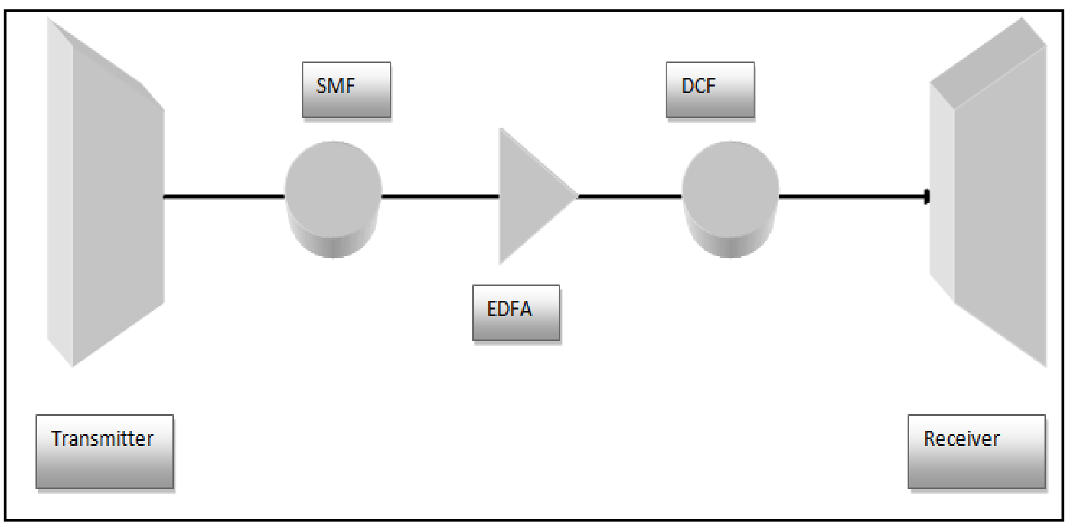


Fig.3.5: Post compensation in DCF

- Mix compensation: It refers to a situation when the DCF of dispersion is placed before and after standard fiber so that the positive dispersion of standard fiber can be compensated shown in Fig.3.6.

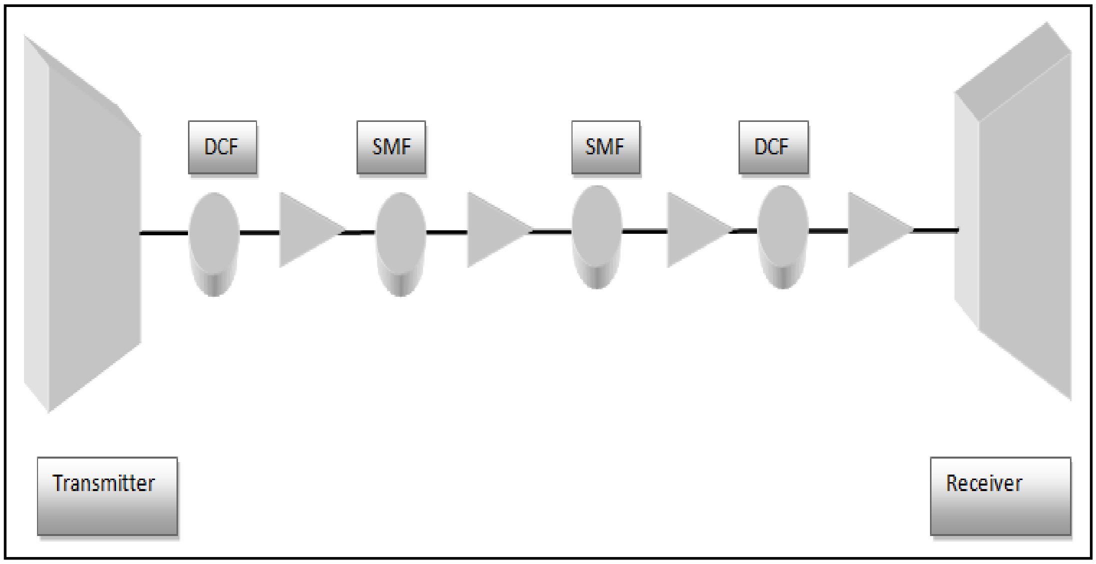


Fig.3.6: Mix compensation in DCF

b) Advantages

- Highly reliable.
- Acts as dispersion compensator for compensation of chromatic dispersion present in optical signal travelling down the fiber.
- Small insertion loss.
- Small polarization mode dispersion.

c) DCF & FBG comparison

- Construction of DCF is complex than FBG.
- DCF has low insertion loss and system cost in comparison to FBG.
- DCF exhibits a dispersion of approximate 16ps/nm whereas FBG exhibits a dispersion value of 17ps/nm.
- Wider bandwidth bands are available in DCF.

3.3.2 Fiber bragg grating (FBG)

A new device is formed because of the repeated changes in the refractive index of core along its length, normally mentioned as grating in optical fiber. Gratings having short period are known as Bragg gratings. These Bragg gratings permits particular wavelength of any signal to travel in straight direction while propagating through the optical fiber but also acts like a reflector to reflect all other wavelengths. It is the primary principle behind the working of fiber Bragg grating. FBGs are made by uncovering the core of SMF to a repeated pattern of UV light. By varying refractive index profile of fiber bragg grating, it can be divided into chirped fiber bragg grating and uniform fiber bragg grating. If grating period alters along the grating length then it is known as chirped fiber bragg grating. At the point when light spreads down such a grating, distinct wavelengths elements introduced in incident pulse will get returned at distinct locations. This will prompt distinct wavelength parts having distinct time delays to come back to the information end. By utilizing a properly chirped FBG, one can surely adjust for the differential delay of distinct wavelengths gathered while spreading through a fiber link. Another type of grating is called uniform fiber bragg grating in which refractive index period remains constant throughout the length of the grating. The eqn. (3.2) is used for bragg wavelength as shown below.

$$\lambda_B \equiv 2\bar{n} \tag{3.2}$$

The value of Bragg wavelength will change according to the grating length. Hence at the point where Bragg condition is fulfilled the frequency component is reflected over that point. The eqn. (3.3) is used for grating dispersion given below.

$$D_g = \frac{2\bar{n}}{C\,(\Delta\lambda)} \quad \ldots \tag{3.3}$$

Where, $\bar{n}$ = average mode index$\Delta\lambda$, indicates grating bandwidth

c = light speed.

Basic working principle of fiber bragg grating is described in the form of diagram in Fig.3.7.

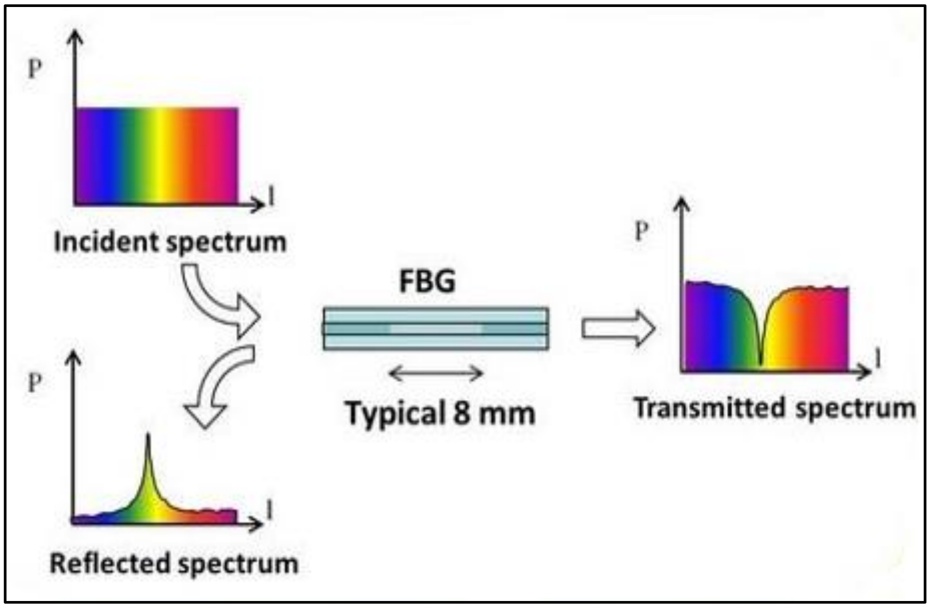


Fig.3.7: Basic Principle of FBG

a) Configurations: Basically, there are two configurations of FBG as follows:

- Pre-Compensation: It defines the situation when the FBG is arranged at the starting of optical link and before amplifier. Following Fig.3.8 describes the concept of pre-compensation.

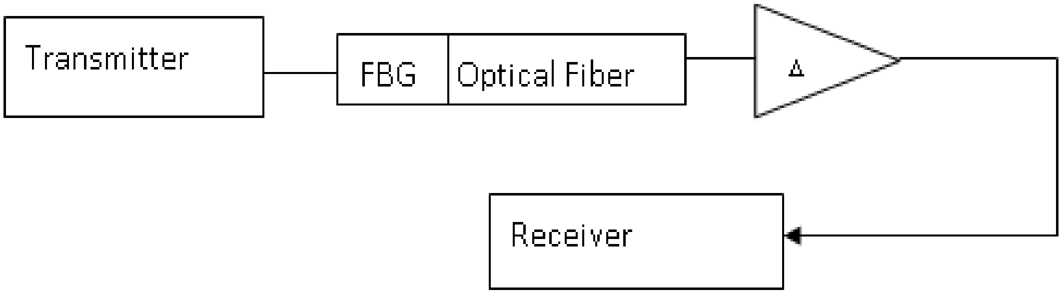


Fig 3.8: Pre-compensation in FBG

- Post Compensation: It defines the situation when FBG s placed at the end of optical link. Fig.3.9 describes the post compensation.

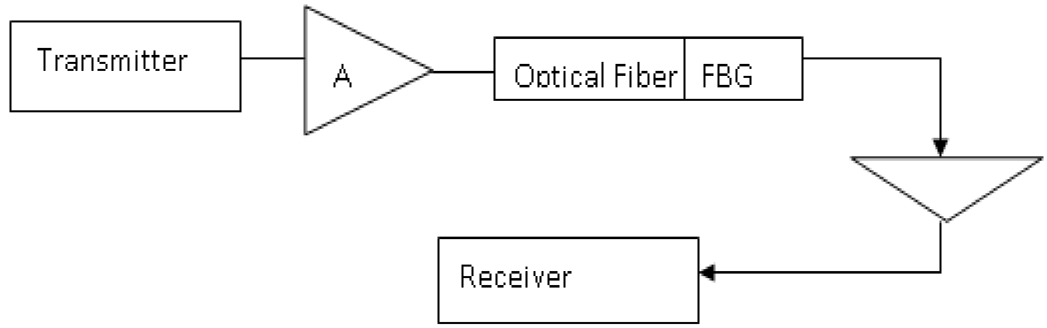


Fig.3.9: Post compensation in FBG

b) Applications

- In communication systems.
- As a dispersion compensator for dispersion compensation in fiber optics.
- In Fiber lasers.
- In Fiber amplifiers.
- In Fiber Filters.
- Fiber Sensors.

3.3.3 Uniform fiber bragg grating (UFBG)

Using distinct ways of generating fringes have a notable effect on the attributes of the originated grating, especially temperature response & its capacity to with stand the raised temperature. Hence, distinct types of fiber bragg gratings are available. Out of them uniform fiber bragg grating is the most efficient and effective technique for the compensation of chromatic dispersion available nowadays.

A device that periodically updates the intensity or phase of the reflected wave transmitted through it is called uniform fiber bragg grating. The meaning of word uniform means that period of grating and refractive index profile remains constant throughout grating length. If the wavelength of propagating pulse equals to bragg resonance wavelength then the propagating wave is reflected otherwise transmitted. Fig.3.10 is showing the structure of UFBG system. This figure also shows the spectral response of input pulse, transmitted pulse and then of the pulse reflected by the uniform fiber bragg grating.

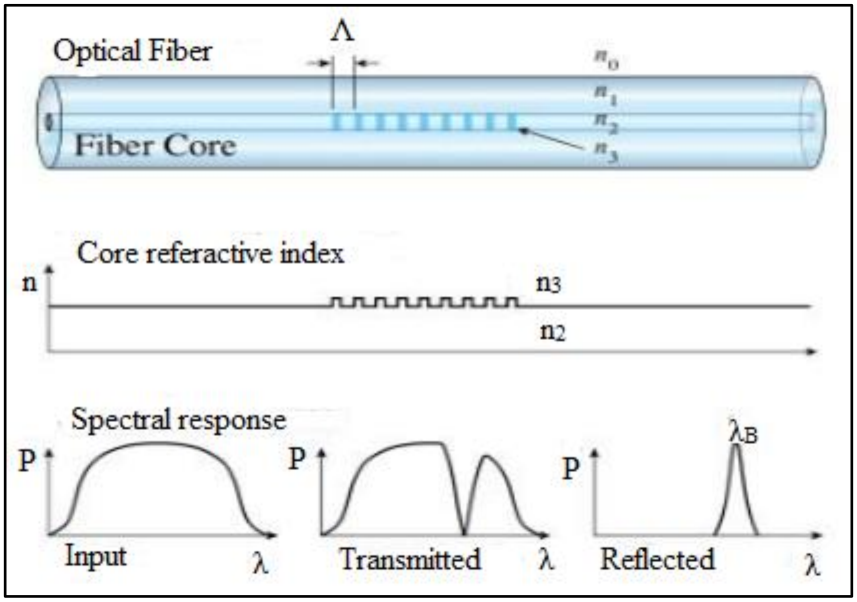


Fig.3.10: Structure of UFBG system

In case of uniform fiber bragg grating, dispersion coefficient is given in eqn. (3.4) as given below:-

$$D_g = -\frac{n_{eff}^2}{2\pi c^2 \lambda^2} \Big/ \left({}^{2\pi}/_{\lambda} - {}^{2\pi}/_{\lambda_B} \right)^3 \tag{3.4}$$

Where, n_{eff} = Refractive index of uniform fiber bragg grating

λ_B = wavelength of FBG

λ = wavelength of wave travelling in UFBG

c = light velocity in vacuum

After the analysis of eqn. (3.4), it is found that the value of D_g is negative and very high when $\lambda > \lambda_B$ whereas it is positive when $\lambda < \lambda_B$. This conclusion is very useful for compensation of dispersion present in the wave travelling through the optical fiber. In order to get the maximum efficiency of dispersion compensation D_g should be according to the eqn. (3.5).

$$D_f L_f + D_g L_g = 0 \quad (3.5)$$

Where, D_f = Dispersion coefficient of optical fiber channel

L_f = Propagating distance of the signal before compensation of dispersion

L_g = Length of FBG

This eqn. (3.5) describes that if dispersion of fiber bragg grating is larger than dispersion of the channel then the accumulated dispersion in long transmission distance can be compensated by using short FBG.

3.3.4 Electronic dispersion compensation (EDC)

Electronic dispersion compensation makes use of electronic equalizers for their operation. Because of the undeviating recognition at the recipient, linear malformations in the optical estate, e.g. dispersion, are converted into nonlinear malformations after conversion from optical to electrical. It is because of this logic that the hypothesis of nonlinear channel modeling and nonlinear cancellation is executed. Hence, feed forward equalizer and decision feedback equalizers structures are used for fulfilling this purpose. Electronic dispersion compensator de-escalate the communication speed because it decreases digital to analog conversion. FFE is shown in Fig.3.11 whereas Fig.3.12 is showing decision feedback equalizer $a_1 z^{-1}$.

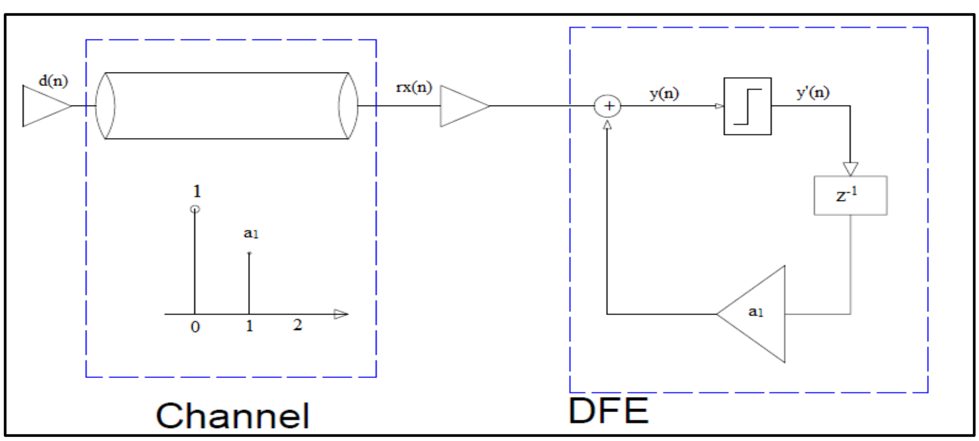


Fig.3.11: Feed forward equalizer

The common ways to decrease the impact of inter symbol interference (ISI) are either by using decision feedback equalizers at receiver section or by using feed forward equalizers at transmitter section. DFE works as a nonlinear equalizer and furthermore retrieves the received input data by subtracting the inter symbol interference obtained from the previously detected data whereas feed forward equalizers used at transmitter section, pre-distorts the optical signal in such a way that it can be retrieved at the receiver end with appropriate pulse shape.

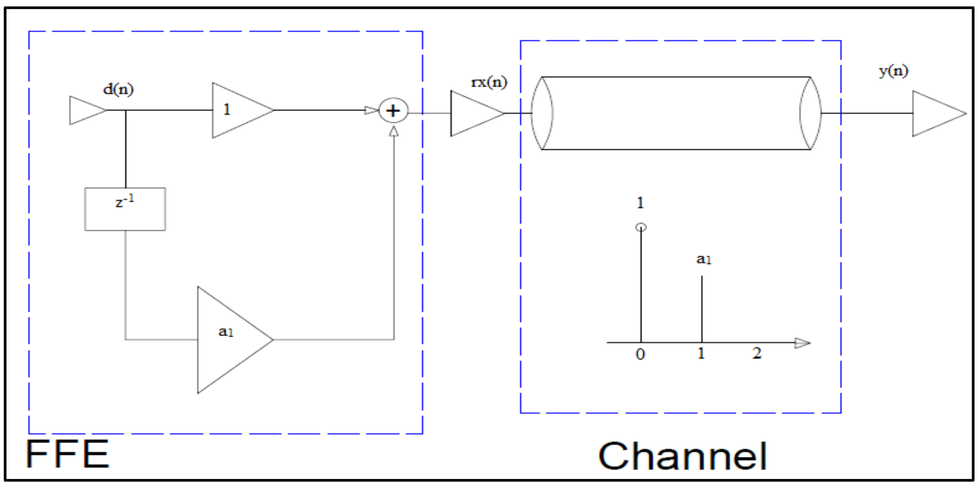


Fig.3.12: Decision feedback equalizer

Sampling of input signals is done at discrete time by the equalizers. The impact of ISI is characterized by theses discrete time samples. Input signal to the decision feedback equalizer is described in eqn. (3.6) as follows:-

$$rx(n) = d(n) + a_1 d(n-1) \quad (3.6)$$

Where, $d(n)$ denotes the transmitted binary data.

a_1 Denotes normalized post cursor value of pulse response.

Hence, the culminated equation of decision feedback equalizer is illustrated in eqn. (3.7).

$$y(n) = rx(n) - h_1 y^{\wedge}(n-1)$$
$$= d(n) + a_1 d(n-1) - h_{1.} y^{\wedge}(n-1)$$
$$= d(n) \quad (3.7)$$

Where, $y(n)$ = Recovered signal from DFE.

h_1 = First tap weight of DFE.

$y^{\wedge}(n-1)$ = Previously detected signal and its value equals to 1 if $y(n-1) \geq 0$ otherwise -1.

In order to cancel the first inter symbol interference, value of $h1$ is set equal to $a1$. In that case, the signal recovered from DFE is same as the transmitted binary data. Similarly, the signal obtained at the output of feed forward equalizer is described in eqn. (3.8) as follows:-

$$tx(n) = d(n) - k_1 d(n-1) \quad (3.8)$$

Where, $d(n)$ denotes the transmitted binary data.

k_1 denotes the tap weight of first FFE.

The culminating equation after crossing the optical channel is given in eqn. (3.9) shown below:-

$$y(n) = tx(n) + a_1 . tx(n-1)$$
$$= d(n) - k_1 d(n-1) + a_1 d(n-1) - k_1 a_1 d(n-2)$$
$$= d(n) - (a_1)^2 . d(n-2) \quad (3.9)$$

Where, $y(n)$ = Recovered signal form FFE.

Even though the value of $k1$ is set equal to $a1$ to cancel out the effect of ISI, the signal recovered form FFE is not exactly same as the transmitted binary data. FFE is a linear equalizer and due to that reason previously transmitted binary data also undergoes from ISI. Thus, the first tap FFE voids the first inter symbol interference on the channel but the accumulation of errors arises on the channel. Since conversion from optical to electrical pulses is a requirement in current optical fiber communications systems, it is not difficult to imagine that additional functions could be implemented in the electrical domain. One such function could be an electronic equalizer, which can be included on the recipient side of channel. An electronic equalizer can be used to extend the minimum distance between repeaters or allow the bit rate of a distortion limited fiber communications channel to be increased. Electronic equalization can consist of RF filtering, Digital Signal Processing (DSP) and mixed-signal functions. Equalization is widely used in telephone systems, wireless receivers, and magnetic recording. With the exception of simple single-stage linear equalizers, equalization is a relatively new concept to fiber- optic communications. An electronic equalizer is most advantageous when analog functions and digital functions are adaptively tuned and programmed to fit a specific link. If custom tuning can be avoided, then no specialty manufacturing would be required for any given link and dispersion compensation could be achieved at a significantly lower cost than optical solutions. Moreover, with an effective adaptive tuning algorithm, an electronic equalizer could be used to correct for both CD and PMD which would be a notable advantage.

3.3.4.1 Types of equalizers

a) Linear electronic compensation technique

A linear equalizer is a form of a filter that provides emphasis to certain elements in a spectrum while attenuating others. The basic structure is shown in Fig.3.13.

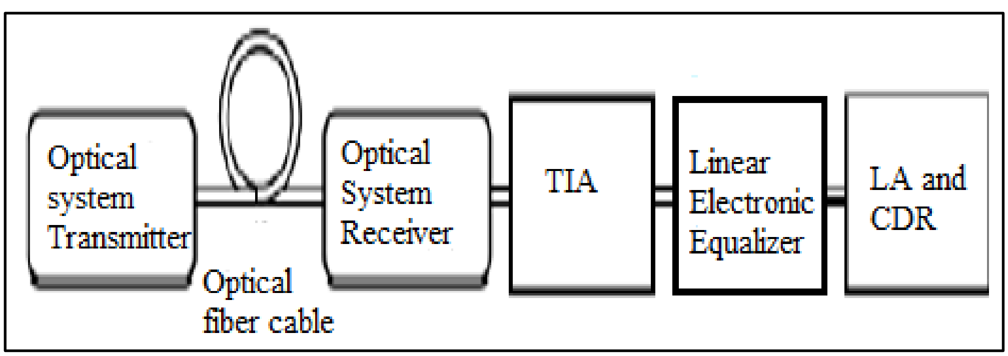


Fig.3.13: Linear electronic equalizer

It is of interest in a variety of applications to change the relative amplitudes of the frequency components in a pulse or perhaps mitigates some of the frequency elements completely. Linear time-invariant systems that turns shape of spectrum are commonly termed as frequency- selective filters, but in certain applications such filters are referred to as linear equalizers.

b) Nonlinear electronic compensation techniques

When distortion takes place in an optical fiber link because of linear and non- linear mechanisms, a linear equalizer circuit at the recipient may not be able to completely remunerate the optical link. Linear equalizers will also not be able to predict or compensate PMD. A purely nonlinear equalizer, or an analog equalizer with nonlinear features, may be able to extend link lengths or data rate beyond what can be compensated with a linear equalizer. An electronic equalizer can acquire a nonlinear response if mixed signal and/or digital circuit operations are used. A nonlinear equalizer can make use of analog-digital converters, digital-analog converters, and high velocity digital memories to extend performance beyond that of linear equalizers, but this comes at the cost of added complexity namely a larger die size, a slower clock rate, and higher power consumption. With higher complexity, the most severe implication is that the fiber's maximum data rate may be limited by the clock rates in the equalizer circuitry and/or response times through feedback loops.

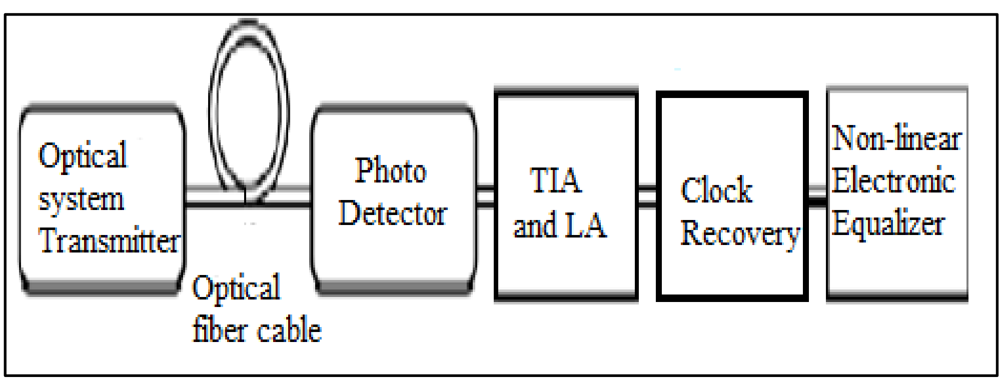


Fig.3.14: Nonlinear electronic equalizer

This is possibly why, until recently, nonlinear equalization has not been seriously considered for fiber-optic applications. But the aggressive advances that have been seen in integrated circuit technologies have made nonlinear equalization a viable solution. In addition to considering the highest possible bit rates achievable in a fiber-optic system, when evaluating equalization techniques, one needs to consider also the transmission distance (which exacerbates signal distortion). A nonlinear electronic equalizer is shown in Fig.3.14.

3.4 SUMMARY

Modelling and simulation of dispersion compensation models can be done by using different software. Among them, Optisystem 7.0 has been used. The major component of optisystem involves transmitter, channel and receiver. Simulation results of any model can be viewed in terms of eye diagram. It shows the amount of intersymbol interference (ISI) present in any propagated signal and also responsible for checking the noise immunity. The more the eye opening, smaller is the error rate. Further, Major compensation techniques of dispersion are DCF, FBG, UFBG and EDC. All these methods have their merits and demerits. EDC has two types of equalizers- linear and nonlinear electronic equalizers. The most commonly used equalizers are linear feed forward equalizers and decision feedback equalizer.

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The work in this thesis is focused on compensating chromatic dispersion by utilizing the available methods of DCF, IDCFBG, UFBG and EDC. Four objectives are defined and fulfilled. First objective initially uses DCF as dispersion compensator and analyze its performance with respect to Q-factor and BER. Similar analysis is done using IDCFBG and UFBG as separate techniques. All the simulations are done using DCF, IDCFBG and UFBG in three configurations of pre, post and mix. Second objective compares the DCF, IDCFBG and UFBG with respect to BER and Q- Factor to determine the best existing methods of dispersion compensation. Third and final objective of the thesis proposed a hybrid model of best existing compensation method with EDC. Results of all these simulations are analyzed and discussed to get the chromatic dispersion technique with superior performance than others.

4.2 OBJECTIVE-1: To assess the existing dispersion compensation techniques used in Optical fiber communication system and find out their effect on dispersion reduction .In order to attain maximum capacity information transmission rate at longer distances, optical fiber should be updated in a way to compensate for the losses and deterioration caused by dispersion. For this, different compensation techniques are used like DCF, IDCFBG and UFBG.

4.2.1. Dispersion compensated fiber:

The idea of utilizing DCF was first suggested in 1980. Since the elements of DCF are more stable and not effectively influenced by the temperature so it gives wide bandwidth. DCF is the best technique to manage compensation and upgrade already installed fiber links. In SMF second and third order positive dispersion is available while DCF have negative dispersion value. So by inserting DCF, normal dispersion winds up plainly zero as appeared in Fig.4.1. In request to get a high estimation of negative dispersion, doping of core of compensating fiber ought to be as high when contrasted with other conventional fibers. Earlier Dispersion Shifted Fibers are utilized to remunerate dispersion at 1. 55micrometer wavelength, for example, cross phase mixing & four wave mixing are more at this wavelength. That is the reason DCF is utilized. Given eqn. (4.1) satisfies the condition of dispersion compensation.

$$D_1L_1 + D_2L_2 = 0 \tag{4.1}$$

Where

D_1D_2 are the dispersion coefficients of SMF and DCF, respectively

L_1L_2 are the lengths of SMF and DCF, respectively.

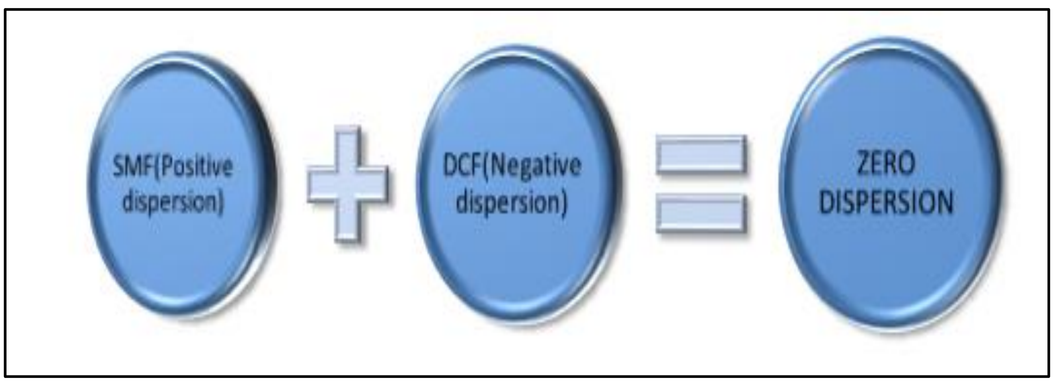


Fig.4.1: DCF

It is executed in three ways i.e. pre, post and symmetric. Here Optisystem 7.0 is used for the simulation of above mentioned model. Table-4.1 is showing simulation parameters utilized in the simulation model whereas simulation parameters of single mode fiber are shown in Table-4.2.

Table 4.1: Simulation Parameters		
Sr. No.	**Parameter**	**Value**
1	Bit Rate(Gbps)	100
2	Sample Rate(THz)	6.4
3	Frequency(THz)	193.1
4	Power(mW)	1
5	Extinction Ratio	30
6	Gain (dB)	20
7	Noise(dB)	2

Table 4.2: Fiber Parameters		
Sr. No.	**Parameter**	**Value**
1	Length of Fiber(Km)	120
2	Reference wavelength(nm)	1550
3	Length of DCF(km)	24
4	Attenuation(db/km)	0.3
5	Differential slope (ps/$nm2/km$)	0.21
6	Dispersion(ps/nm/km)	-80

4.2.2 Simulation Models

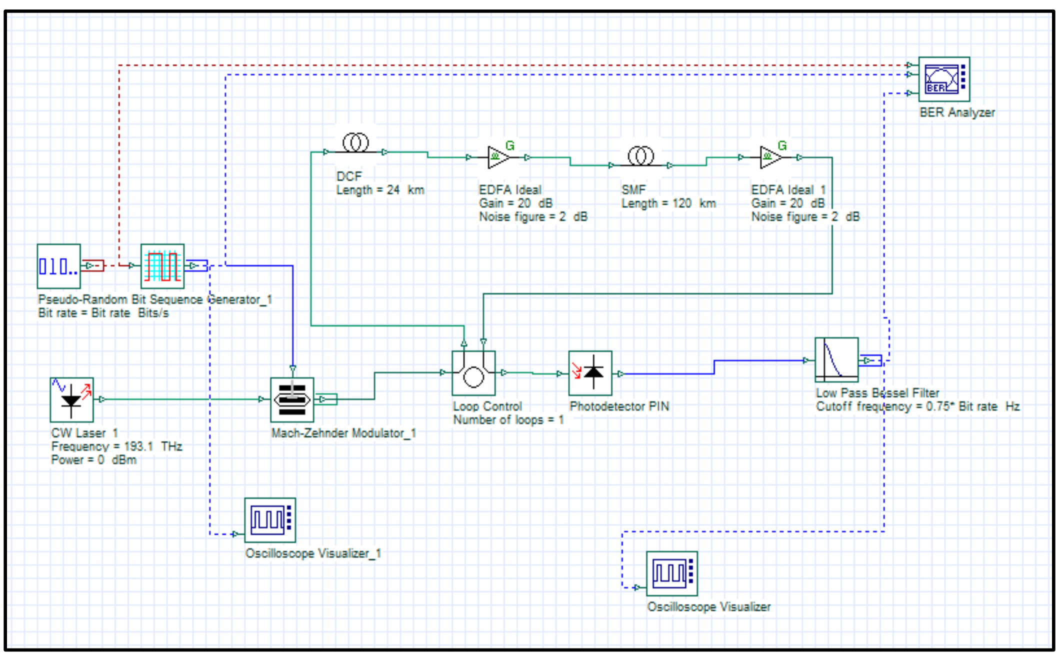


Fig.4.2: Compensation using pre scheme of DCF

Different results have been achieved by connecting the DCF in different configurations like pre compensation, post compensation and symmetric compensation and the simulation models for the respective configurations are displayed in Fig. 4.2, 4.3 & 4.4, respectively.

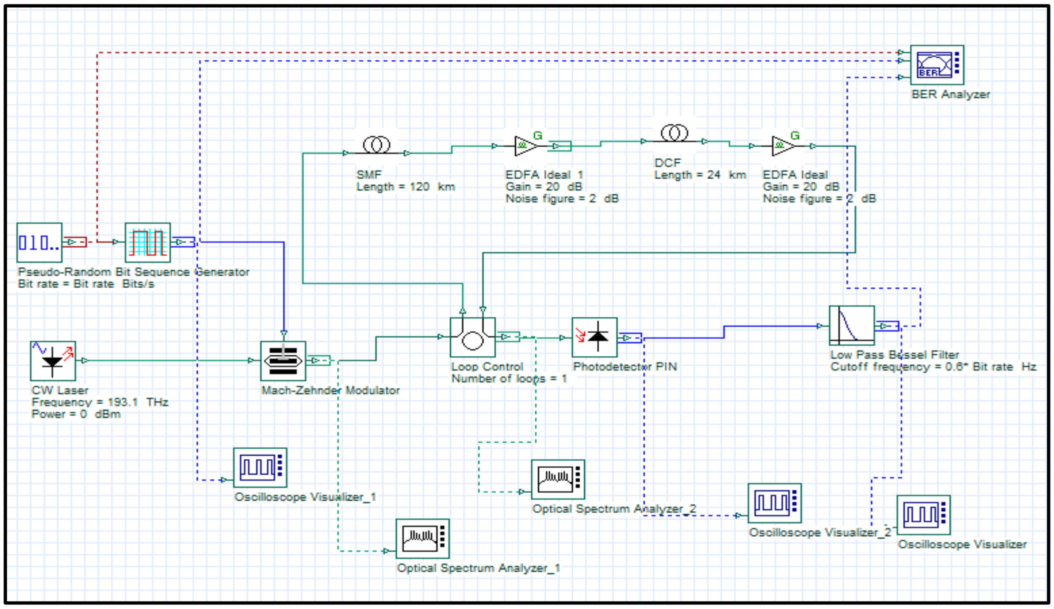


Fig.4.3: Compensation using post scheme of DCF

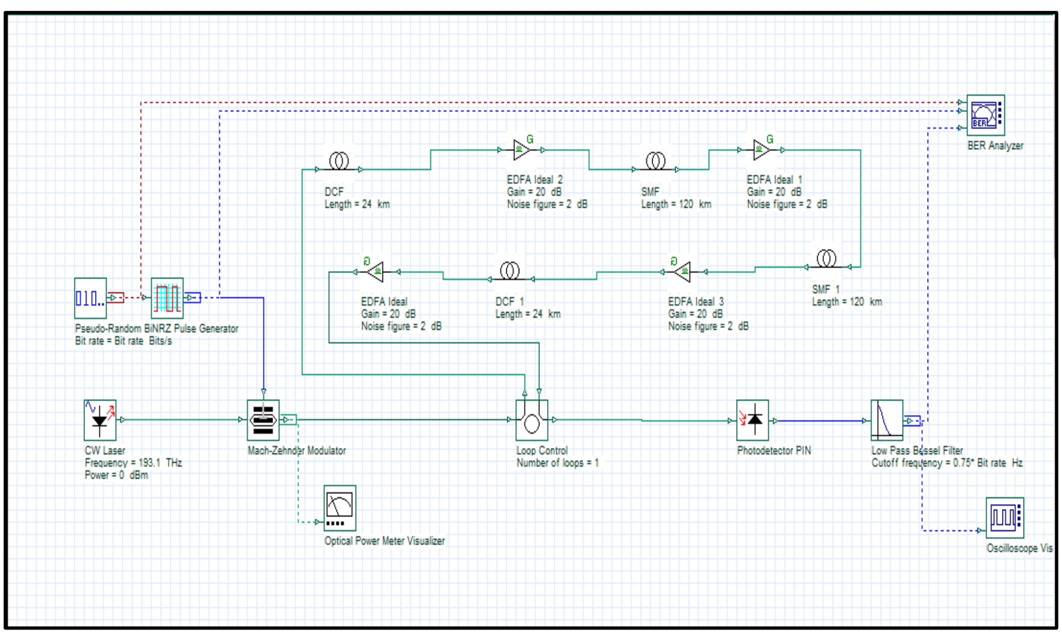


Fig.4.4: Compensation using symmetrical scheme of DCF

4.2.3 Comparative results of different configurations

4.2.3.1 Pre-compensation results: Table-4.3 is showing the outcomes of pre-configuration of DCF at input powers form 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible It is clear from readings that as input power (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increases and corresponding value of BER decreases.

Table 4.3: Results for Pre-Compensation of DCF at inputs 1-10dbm

Iterations	Q-factor	BER	Eye Height	Power (dbm)
1	6.28	1.52E-10	0.000174	-42.3
2	6.95783	1.65E-12	0.000239155	-40.511
3	7.63629	1.08E-14	0.000321066	-38.649
4	8.29053	5.49E-17	0.000424823	-36.739
5	8.9069	2.57E-19	0.00055543	-34.795
6	9.42722	2.08E-21	0.000718801	-32.832
7	9.76613	7.79E-23	0.000920044	-30.855
8	9.89721	2.12E-23	0.00116854	-28.869
9	9.64992	2.42E-22	0.00145903	-26.877
10	9.16792	2.35E-20	0.00180107	-24.887

a) Eye diagrams at different input power (1-10dBm) in pre-compensation:

Fig.4.5 to 4.14 are showing the eye diagrams of DCF at input power from 1-10dBm in pre-configuration. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as input power (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increases and corresponding value of BER decreases. These changes can be clearly seen in eye diagrams.

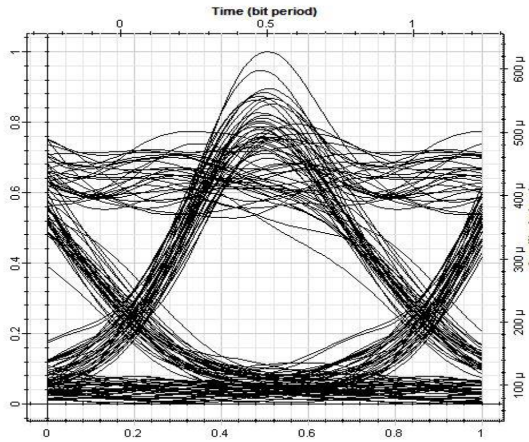


Fig.4.5: At input power 1 dBm

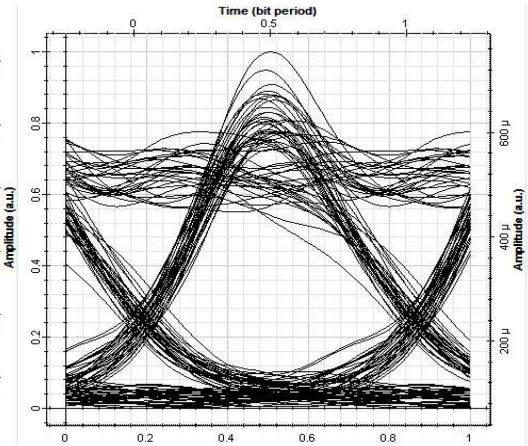


Fig.4.6: At input power 2 dBm

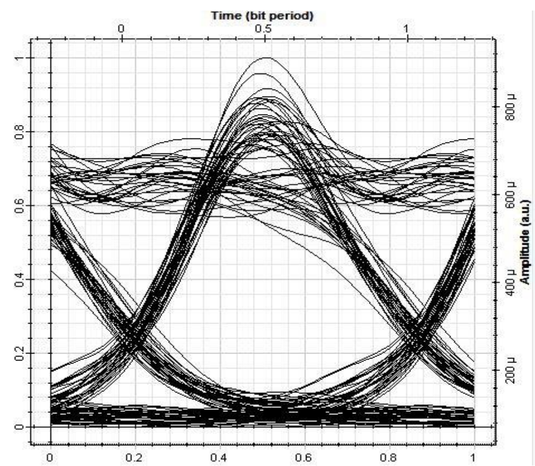


Fig.4.7: At input power 3 dBm

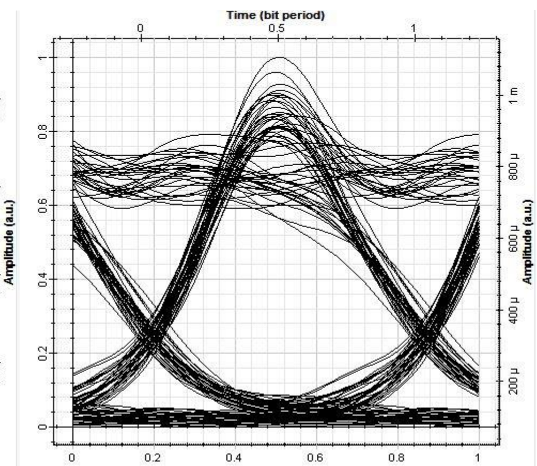


Fig.4.8: At input power 4 dBm

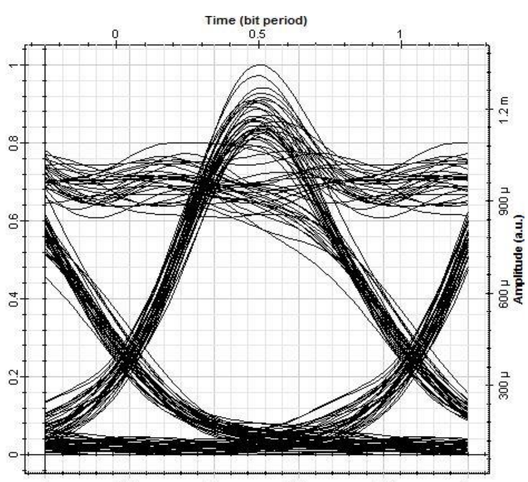


Fig.4.9: At input power 5 dBm

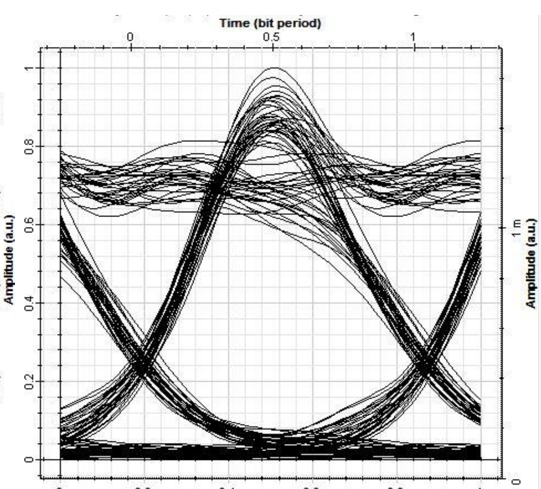


Fig.4.10: At input power 6 dBm

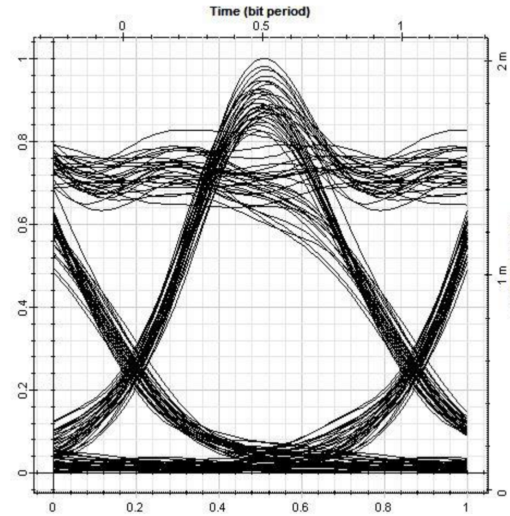


Fig.4.11: At input power 7 dBm

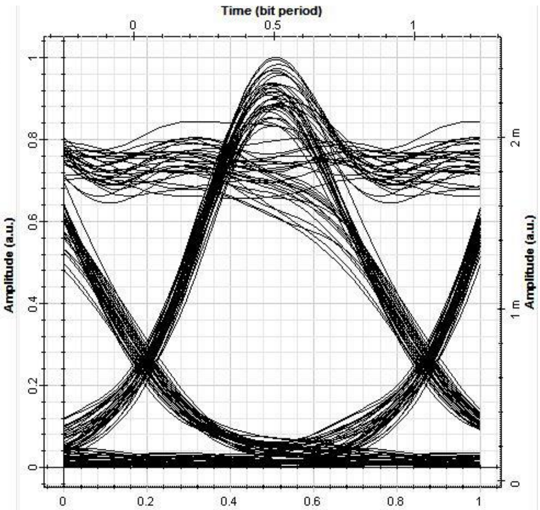


Fig.4.12: At input power 8 dBm

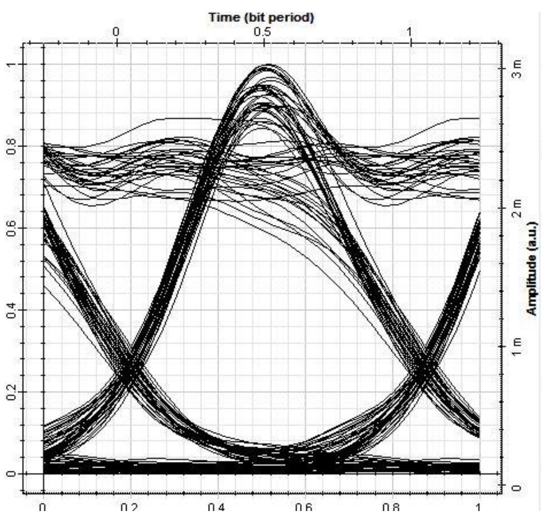


Fig.4.13: At input power 9 dBm

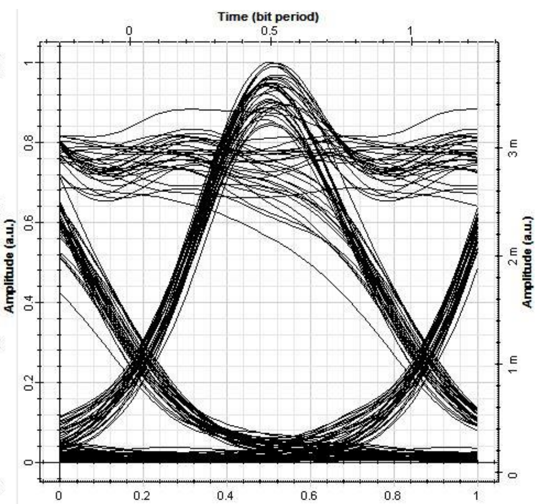


Fig.4.14: At input power 10 dBm

4.2.3.2 Post-compensation results: Table-4.4 is showing the outcomes of post configuration of DCF at input powers from 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as input power (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increases and corresponding value of BER decreases. The tabulated form of DCF in post compensation demonstrated the values of Q-factor, BER, eye height and power when input power is varying from 1-10dBm.

Table 4.4: Results for Post Compensation of DCF at inputs 1-10dbm				
Iterations	**Q factor**	**BER**	**Eye Height**	**Power (dbm)**
1	6.8305	1.04E-12	0.000186	-42.5
2	7.46805	3.91E-14	0.00025	-40.647
3	8.11492	2.40E-16	0.0003316	-38.74
4	8.80386	6.56E-19	0.0004352	-36.8
5	9.33	5.20E-21	0.0005621	-34.85
6	9.8	5.31E-23	0.000722	-32.88
7	10.11	2.42E-24	0.000917	-30.9
8	10.14	1.73E-24	0.00115	-28.92
9	9.84	3.46E-23	0.00142	-26.93
10	9.2	1.69E-20	0.00173	-24.954

a) Eye diagrams at different input power (1-10dBm) in post-compensation:

Fig.4.15 to 4.24 are showing the eye diagrams of DCF at input power from 1-10dBm in post configuration. Eye diagram is also referred as eye pattern. It carries lots of information about the quality of incoming pulse and state of channel, which is useful for the detection of digital input. Also, more details of the performance of any system can be gathered from the display of eye pattern.

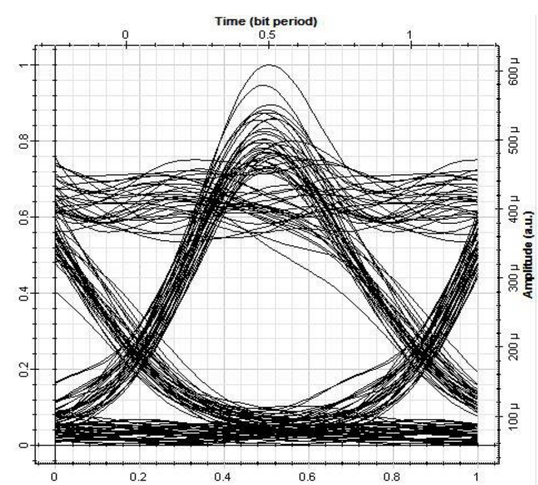


Fig.4.15: At input power 1 dBm

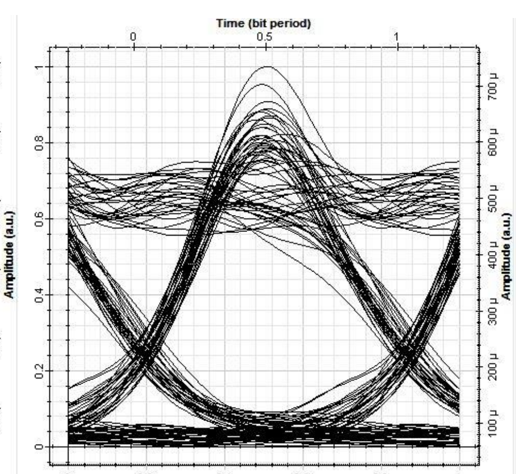


Fig.4.16: At input power 2 dBm

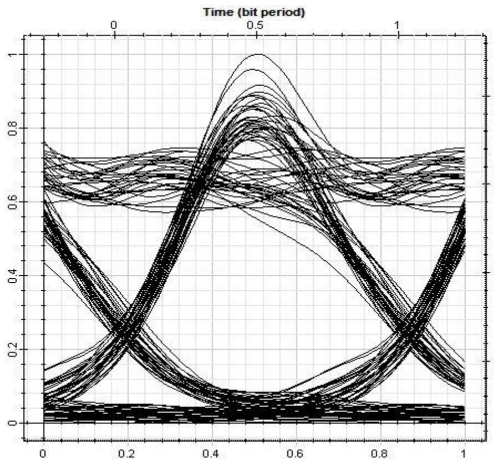


Fig.4.17: At input power 3 dBm

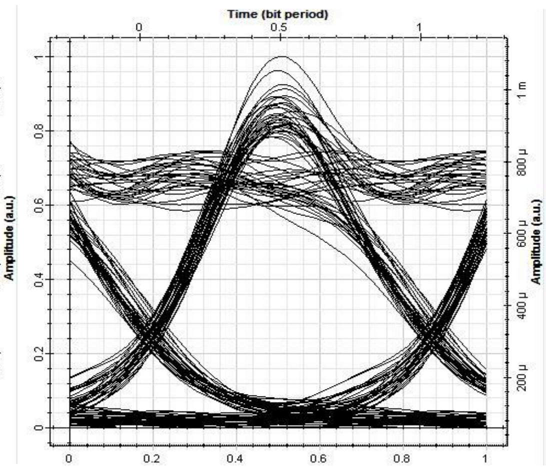


Fig.4.18: At input power 4 dBm

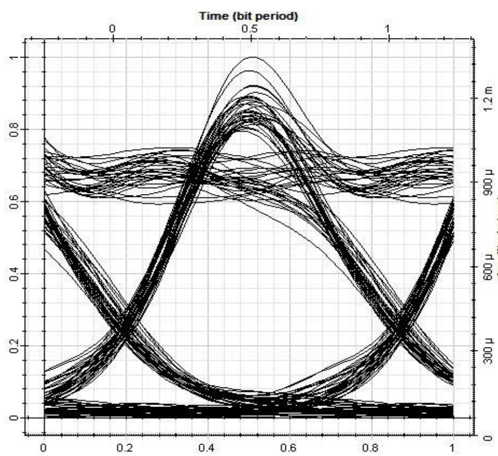


Fig.4.19: At input power 5 dBm

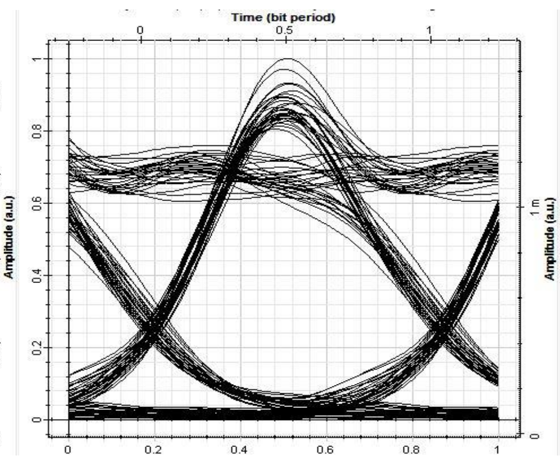


Fig.4.20: At input power 6 dBm

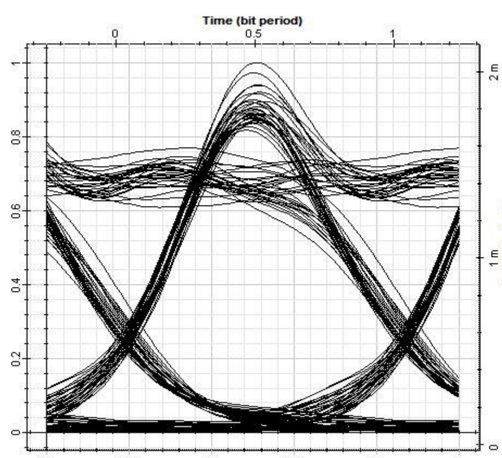


Fig.4.21: At input power 7 dBm

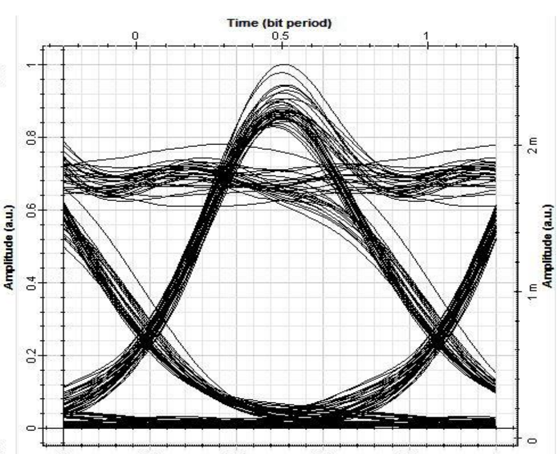


Fig.4.22 At input power 8 dBm

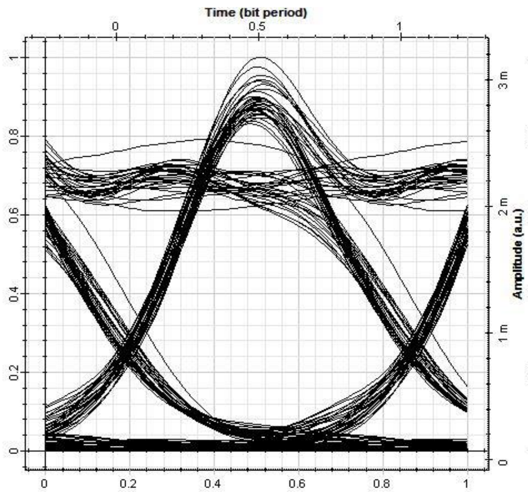


Fig.4.23 At input power 9 dBm

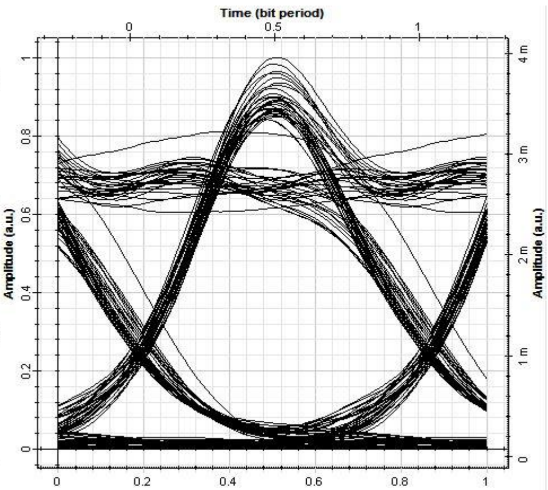


Fig.4.24: At input power 10 dBm

4.2.3.3 Symmetrical compensation results: Table-4.5 is showing the outcomes of symmetrical configuration of DCF at input powers from 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level (input) rises from 1-10dBm, value of Q-factor is also somewhat increases and corresponding value of BER decreases.

Table 4.5: Results for Symmetrical Compensation of DCF at inputs 1-10dbm				
Iterations	**Q factor**	**BER**	**Eye Height**	**Power (dbm)**
1	3.1	8.86E-04	3.20E-06	-48.89
2	3.62	1.30E-04	2.71E-05	-48.19
3	4.22	1.07E-05	4.41E-05	-47.26
4	4.9	4.19E-07	7.39E-05	-46.11
5	5.61	8.72E-09	1.10E-04	-44.74
6	6.37	7.93E-11	1.57E-04	-43.18
7	7.1	5.23E-13	2.10E-04	-41.5
8	7.8	2.69E-15	2.80E-04	-39.7
9	8.36	2.74E-17	3.70E-04	-37.84
10	8.69	1.49E-18	4.70E-04	-35.94

a) Eye diagrams at different input power (1-10dBm) in symmetrical compensation: Fig.4.25 to 4.34 are showing the eye diagrams of DCF at input power from 1-10dBm in post configuration.

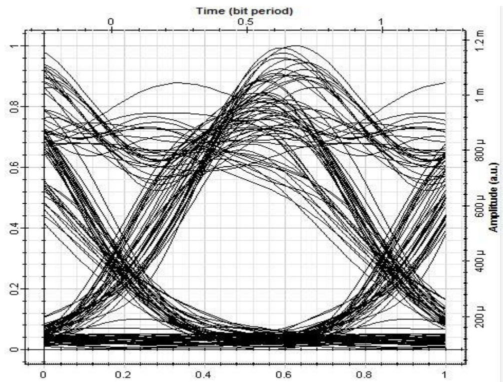


Fig.4.25: At input power 1 dBm

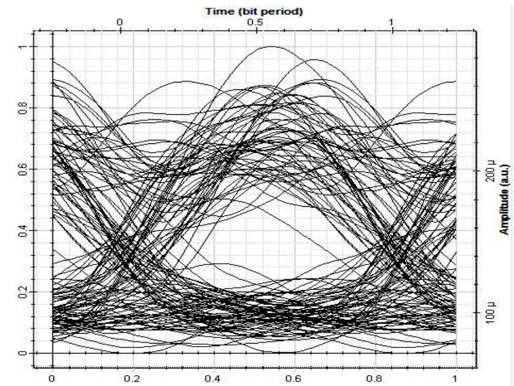


Fig.4.26: At input power 2 dBm

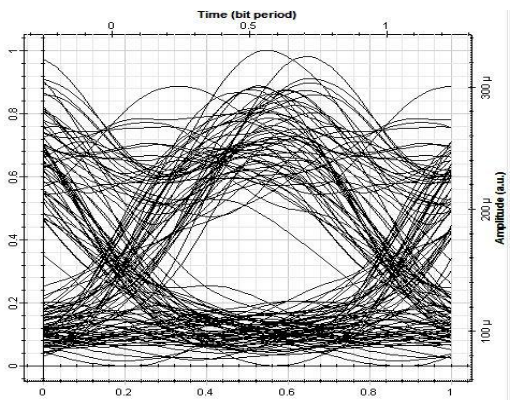


Fig.4.27: At input power 3 dBm

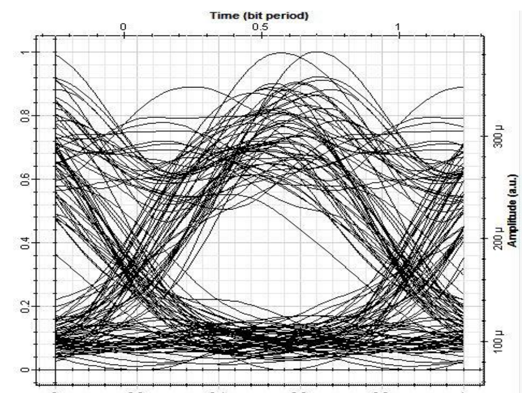


Fig.4.28: At input power 4 dBm

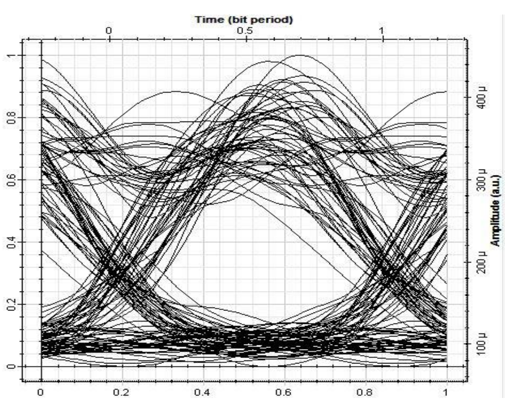


Fig.4.29: At input power 5 dBm

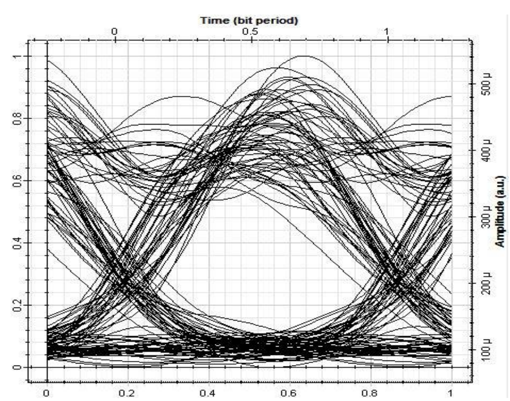


Fig.4.30: At input power 6 dBm

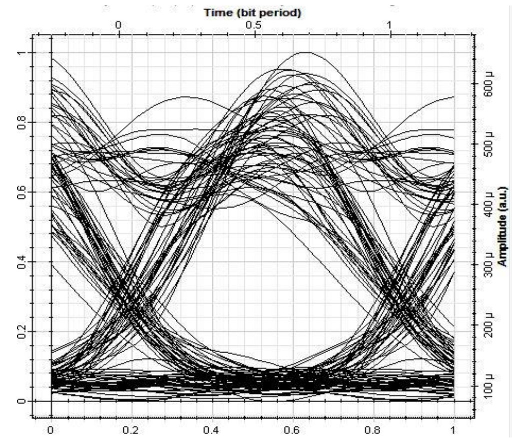


Fig.4.31: At input power 7 dBm

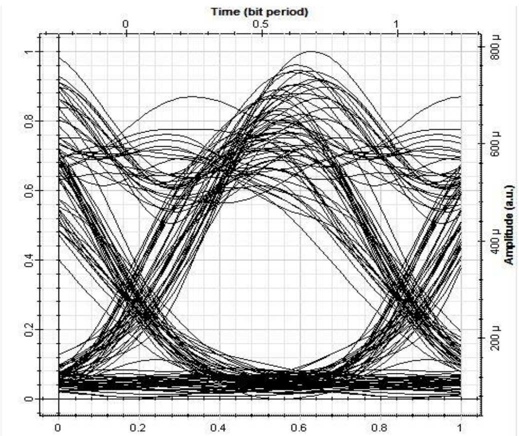


Fig.4.32: At input power 8 dBm

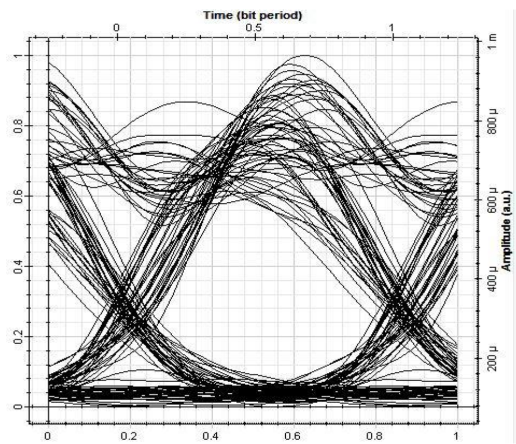


Fig.4.33: At input power 9 dBm

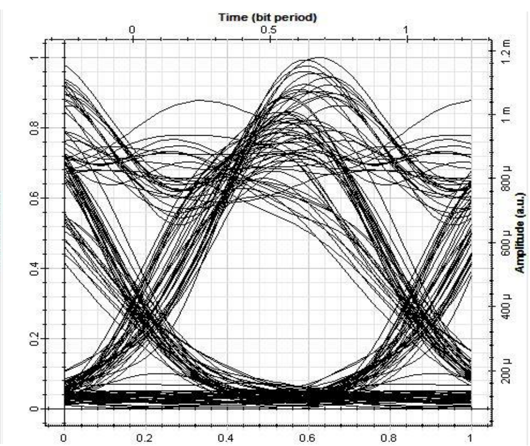


Fig.4.34: At input power 10 dBm

4.2.4 Graphical representation of change in various parameters w.r.t. input power (1-10dBm) in different configurations:-

Fig. 4.35 is showing the graph of Q-Factor with reference to variation in power level (input) whereas change of BER with change in input power is shown in Fig. 4.36. Fig.4.37 is showing graph for eye height and Fig.4.38 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for DCF in three configurations. It is clear from the graphical representation of Q-factor vs. input power that post-configuration showing maximum results. Similarly, in the graphical representation of input power vs. BER, eye height, and received power, post-configuration performs better and provides better results as compare to other configurations.

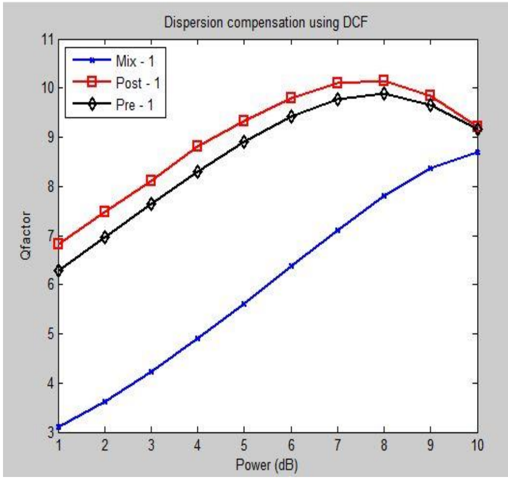


Fig.4.35: Input Power Vs Q- Factor

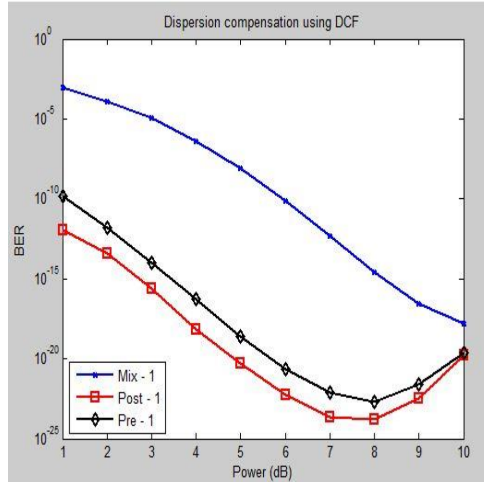


Fig.4.36: Power Vs BER

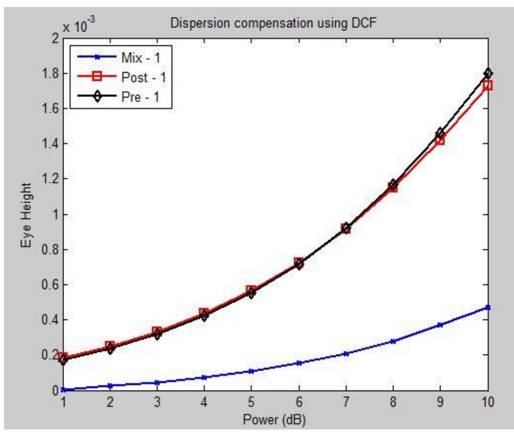


Fig.4.37: Power Vs Eye Height

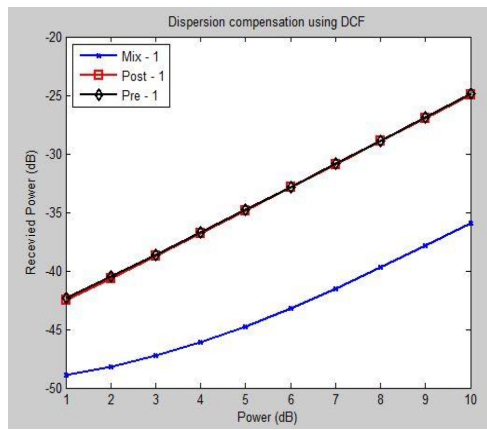


Fig.4.38: Input Power Vs Received Power

4.3 IDEAL DISPERSION COMPENSATED FIBER BRAGG GRATING (IDCFBG)

The concept of FBG was initially presented in 1980 and has been utilized as a part of a few applications and broadly inquired about. FBG is a kind of Bragg reflector developed in a small fragment of optical fiber that returns specific wavelengths of light and transmits all others. This is accomplished by forming an intermittent variety in the refractive profile of fiber core, which creates reflection for a particular wavelength. In this manner FBG can be utilized as an inline optical channel to hinder particular wavelengths, or as a wavelength- particular reflector. FBG can be utilized as a MUX & DEMUX gadget in wavelength division multiplexed frameworks for taking out a particular signal with a specific wavelength from number of signals. Fig. 4.39 is showing the principle of fiber Bragg grating.

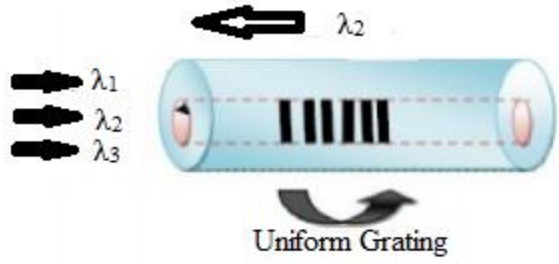


Fig.4.39: Fiber Bragg Grating Principle.

The light which enter into the grating, depends upon the wavelength of light got reflected by grating. More distance will be travelled by the signal having larger wavelength in grating before getting reflected. On the other hand less distance will be travelled by the signal having small wavelength in the grating before getting reflected. Hence the pulse which is spread by CD in a single mode fiber got reduced by travelling through FBG. The reflected wavelength λ_b otherwise called as Bragg wavelength and is given by the relationship shown in eqn. (4.2) below:-

$$\lambda_b = 2n\Lambda \quad (4.2)$$

Where, n *is* effective refractive index of the grating in the fiber core

Λ is grating period

Next eqn. (4.3) is showing the main wavelength which is also known as Bragg Wavelength, got reflected from the grating is presented by:-

$$\lambda_b = 2n_{eff}\,\Lambda \quad (4.3)$$

The primary target of the suggested framework was to dissect the execution of FBG as a remunerator of dispersion in single channel optic fiber model. In the framework composed, the 100 Gb/s NRZ signal was propelled onto 120 Km utilized SMF and PRBS produces the sequence of random bits. Mach-Zehnder modulator was utilized to tweak the optical source and frequency jointly. At the receiver end, photodetector is used to detect and then convert the optical signal back into the electrical signal. For the removal of noise acquired during propagation inside optical fiber, low pass filter is used. Further for the analysis of quality factor and bit error rate, BER analyzer is used. BER analyzer shows the eye pattern for the received pulse. The more the opening of eye, the lesser will be the dispersion. It also shows the amount of intersymbol interference in the received signal. The most repeatedly employed, FBG scheme is inspected in this analysis. Three methodologies naming pre, post and intermix of both i.e. mix compensation of dispersion reimbursement with IDCFBG are suggested. By employing all the above mentioned methodologies, a single channel system has been designed by using Optisystem (a simulation software for optical systems). Table-4.6 is showing simulation parameters employed in the simulation model whereas the simulation parameters of single mode fiber are shown in Table-4.7.

Table 4.6: Simulation Parameters

Sr. No.	Parameter	Value
1	Bit Rate (Gbps)	100
2	Sample Rate (THz)	6.4
3	Frequency (THz)	193.1
4	Power(mW)	1
5	Extinction Ratio(dB)	30
6	Gain(dB)	20
7	Noise(dB)	2
8	Bandwidth (THz)	1
9	Dispersion FBG (ps/nm)	-2028

Table 4.7: Fiber Parameters		
Sr. No.	**Parameter**	**Value**
1	Length of Fiber (Km)	120
2	Dispersion(ps/nm/km)	17
3	Attenuation(db/km)	0.2
4	Differential group delay(ps/km)	3
5	Differential slope (ps/$nm2/km$)	0.008

4.3.1 Simulation models

Different outcomes have been achieved by connecting the FBG in different configurations like pre-compensation, post compensation and mix compensation & the simulation models for the respective configurations are shown in Fig. 4.40, 4.41 and 4.42, respectively. The acquired outcomes, such as Eye height, BER, Eye diagram and Q factor are stated and immensely examined.

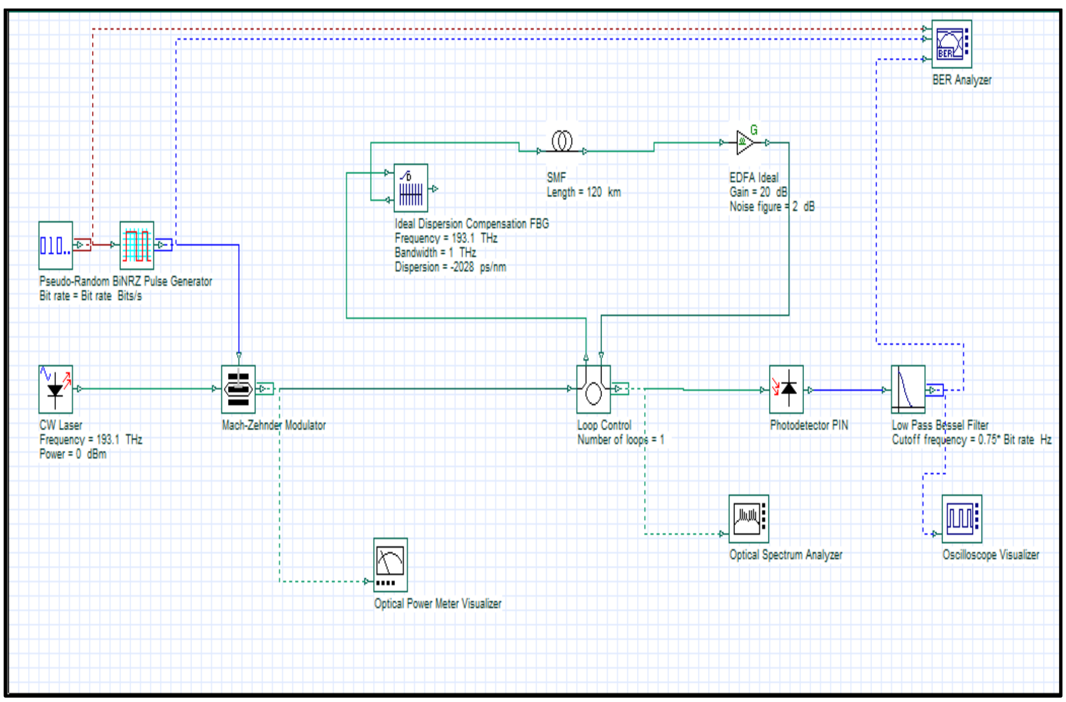


Fig.4.40: Compensation using pre scheme of IDCFBG model

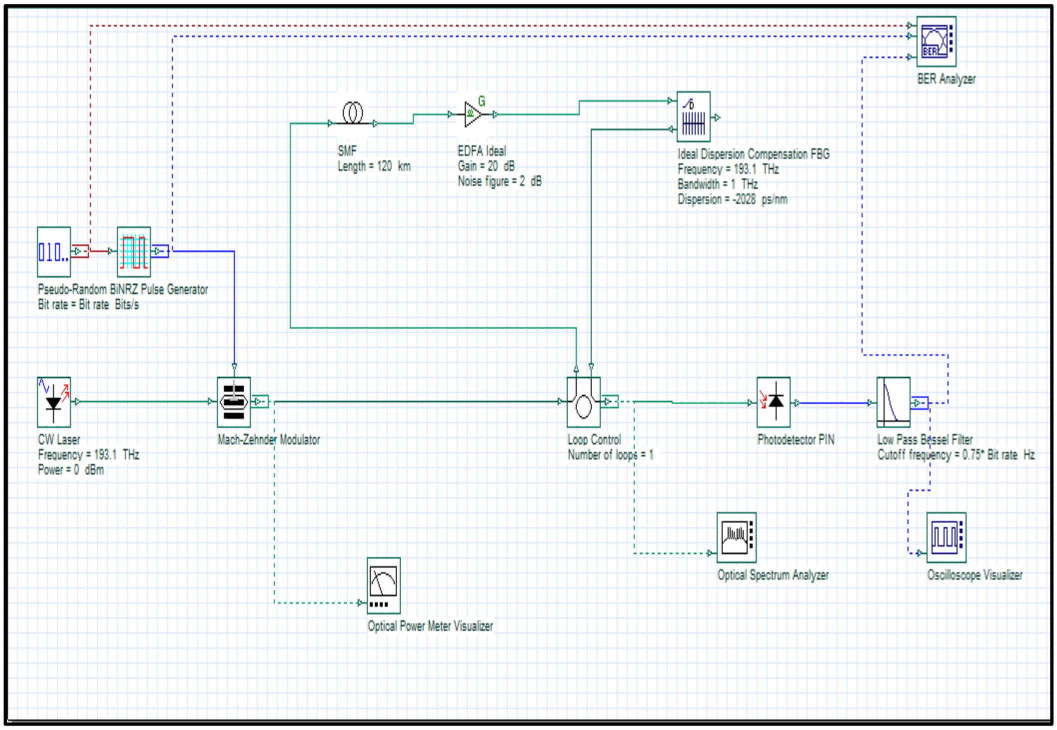


Fig.4.41: Compensation using post scheme of IDCFBG model

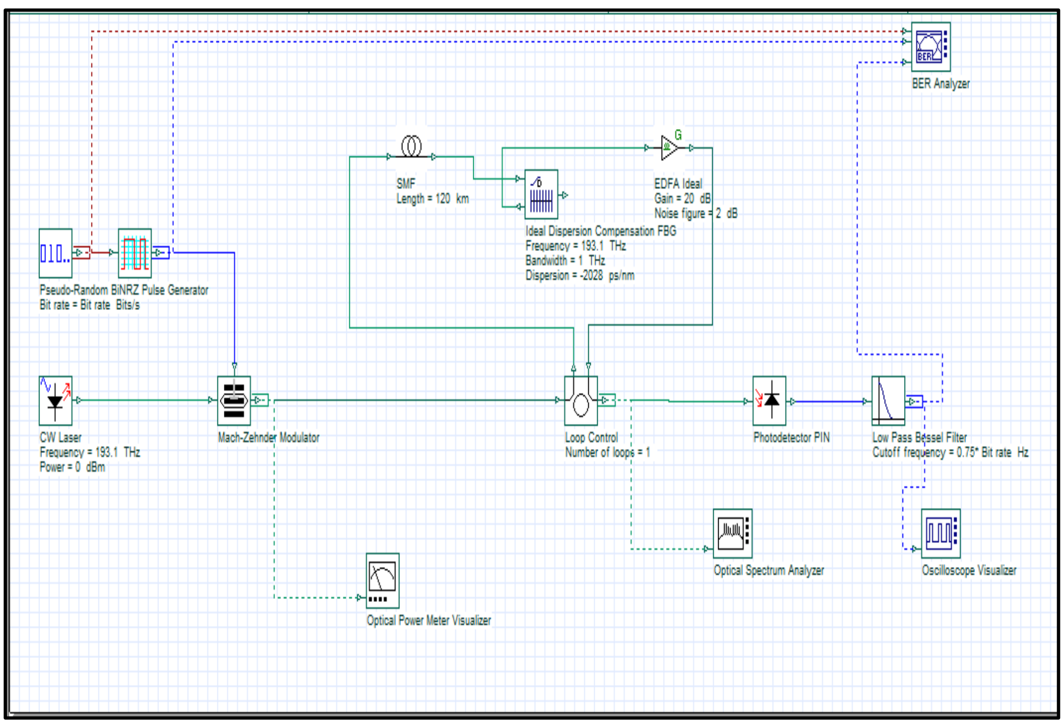


Fig.4.42: Compensation using mix scheme of IDCFBG model

4.3.2 Comparative results of different configurations

4.3.2.1 Pre-compensation results: Table-4.8 is showing the outcomes of pre-configuration of IDCFBG at input powers from 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level (input) rises from 1-10dBm, value of Q-factor is also somewhat increasing and corresponding value of BER decreases.

Table 4.8: Results for Pre-Compensation IDCFBG at inputs 1-10dbm

Iterations	Q factor	BER	Eye Height	Power (dbm)
1	5.6126	9.56E-09	0.000207	-39.25
2	6.0295	7.97E-10	0.00028	-37.509
3	6.44271	5.74E-11	0.000374	-35.67
4	6.80368	5.02E-12	0.000492	-33.788
5	7.13709	4.72E-13	0.000642	-31.86
6	7.4555	4.46E-14	0.000833	-29.905
7	7.69731	6.93E-15	0.001071	-27.93
8	7.84282	2.20E-15	0.001366	-25.95
9	7.86216	1.88E-15	0.001783	-23.96
10	7.67143	8.50E-15	0.00214	-21.96

a) Eye Diagrams at different input power (1-10dBm) in Pre-Compensation:

Fig.4.43 to 4.52 are showing the eye diagrams of IDCFBG at input power from 1-10dBm in pre-configuration. Eye diagram is also referred as eye pattern. It carries lots of information about the quality of incoming pulse and state of channel, which is useful for the detection of digital input. Also, more details of the performance of any system can be gathered from the display of eye pattern. It is generally used for the visual examination of Inter symbol interference. It can be used for accuracy of timing extraction. It also provides noise immunity.

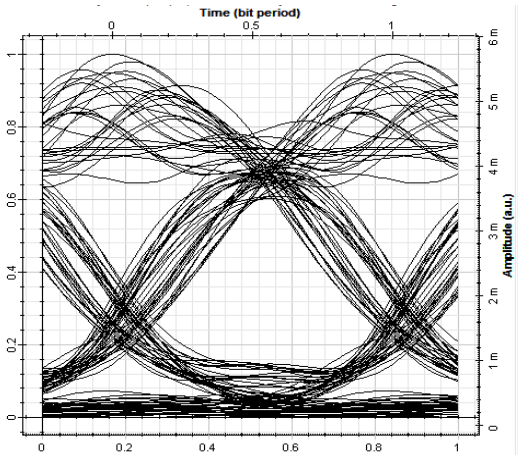


Fig.4.43: At input power 1 dBm

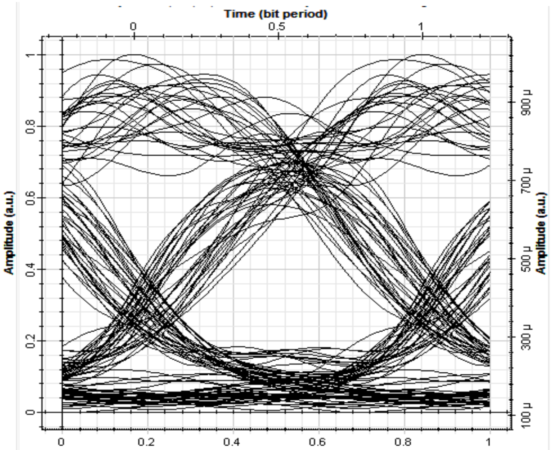


Fig.4.44: At input power 2 dBm

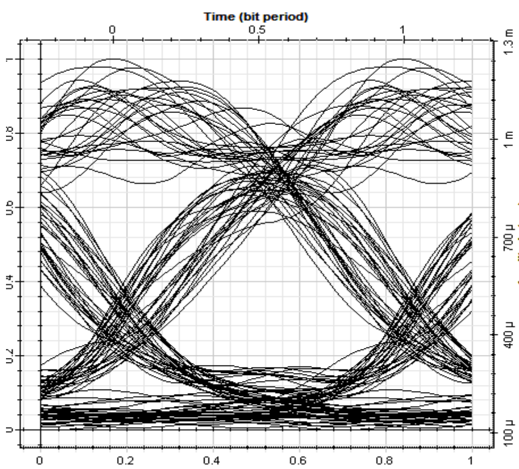


Fig.4.45 At input power 3 dBm

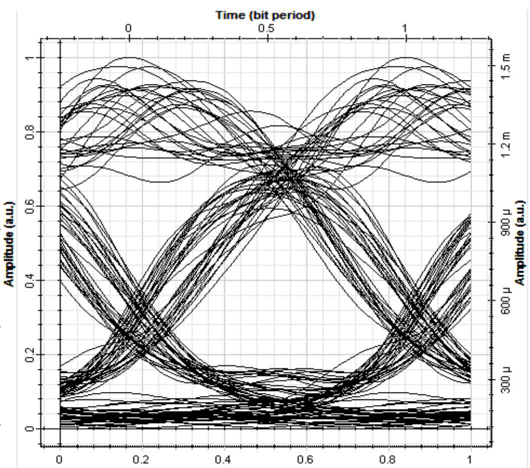


Fig.4.46 At input power 4 dBm

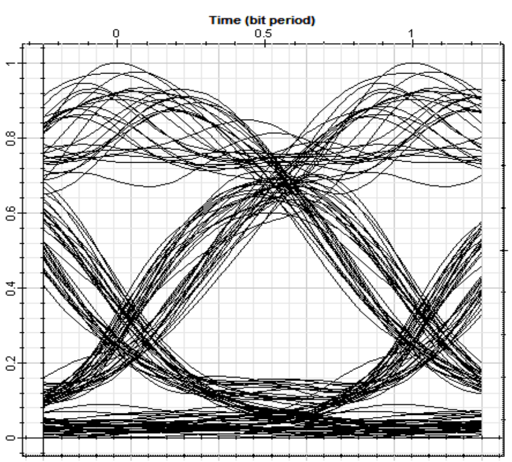


Fig.4.47: At input power 5 dBm

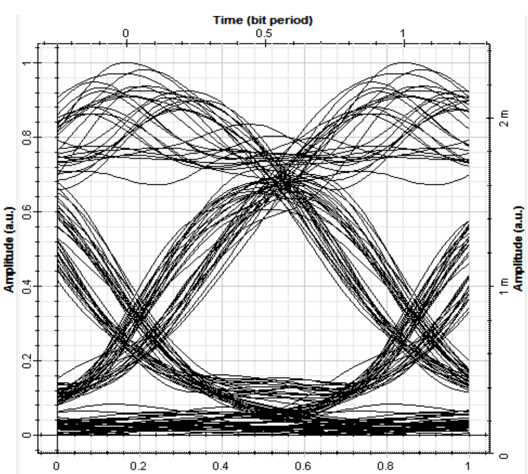


Fig.4.48: At input power 6 dBm

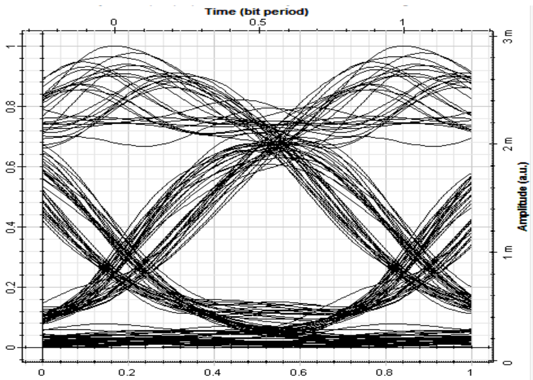


Fig.4.49: At input power 7 dBm

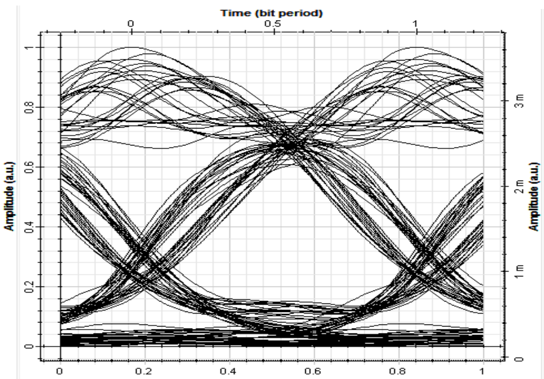


Fig.4.50: At input power 8 dBm

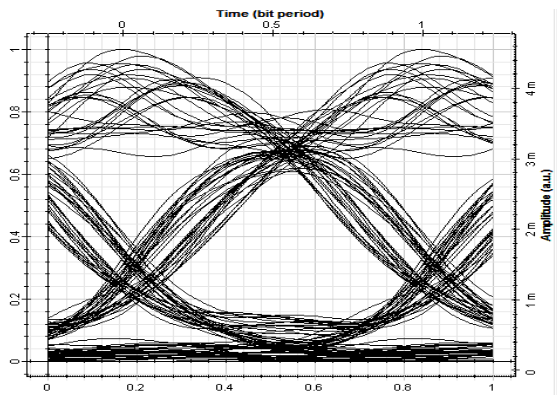


Fig.4.51: At input power 9 dBm

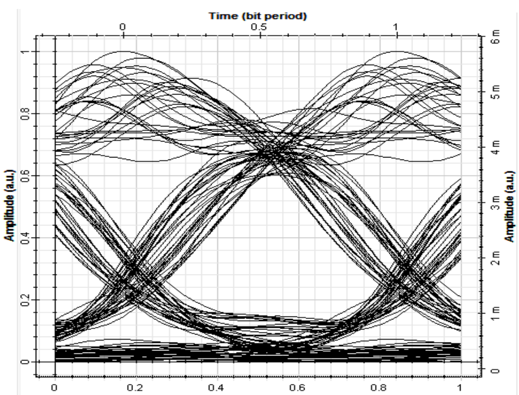


Fig.4.52: At input power 10 dBm

Table 4.9: Results for Post Compensation IDCFBG at inputs 1-10dbm

Iterations	Q factor	BER	Eye Height	Power (dbm)
1	6.2989	1.48E-10	0.000226	-39.957
2	6.81376	4.73E-12	0.000304	-37.969
3	7.31658	1.27E-13	0.000404	-35.978
4	7.87031	1.77E-15	0.000534	-33.983
5	8.37922	2.66E-17	0.0007	-31.988
6	8.94922	1.78E-19	0.000915	-29.98
7	9.43164	2.01E-21	0.001186	-27.99
8	9.86961	2.18E-23	0.00153	-25.99
9	10.1927	1.06E-24	0.001962	-23.99
10	10.2168	8.32E-25	0.002486	-21.99

4.3.2.2 Post-compensation results: Table-4.9 is showing the outcomes of post configuration of IDCFBG at input powers from 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level of input (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increasing and corresponding value of BER decreases.

a) Eye diagrams at different input power (1-10dBm) in post compensation:

Fig.4.53 to 4.62 are showing the eye diagrams of IDCFBG at input power from 1-10dBm in post configuration.

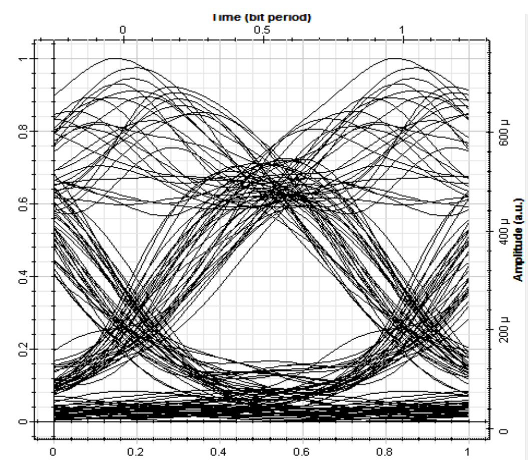


Fig.4.53: At input power 1 dBm

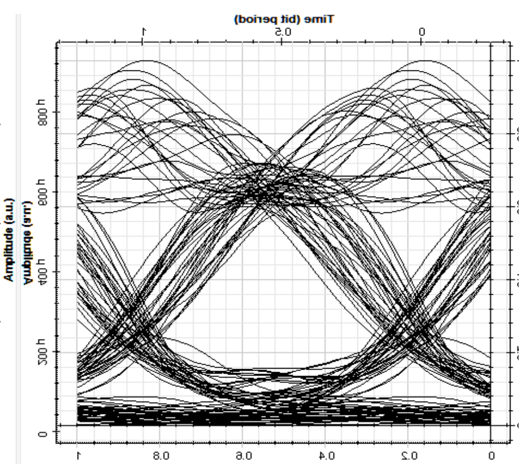


Fig.4.54: At input power 2 dBm

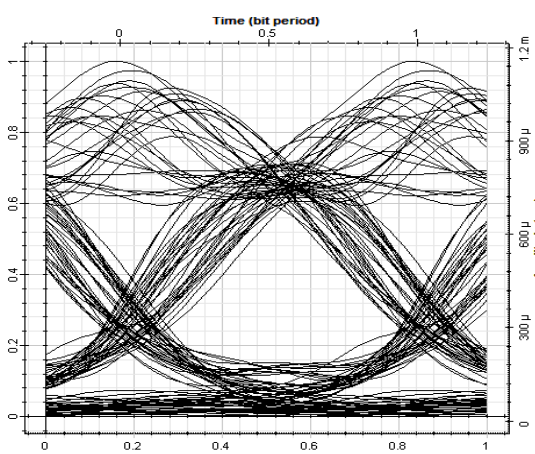


Fig.4.55: At input power 3 dBm

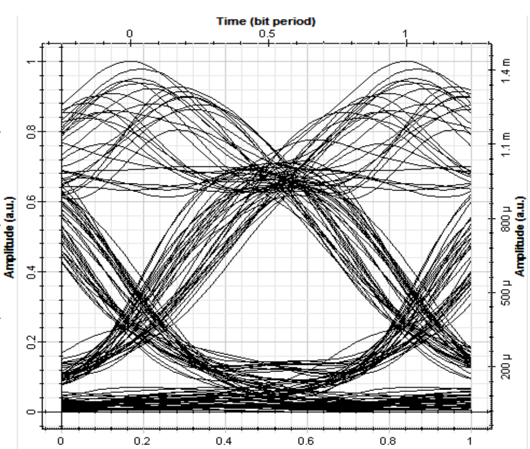


Fig.4.56: At input power 4 dBm

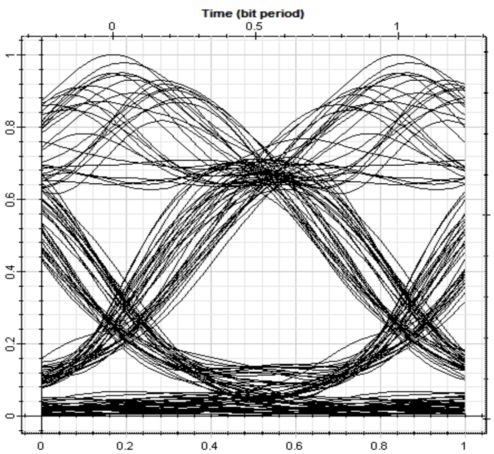


Fig.4.57: At input power 5 dBm

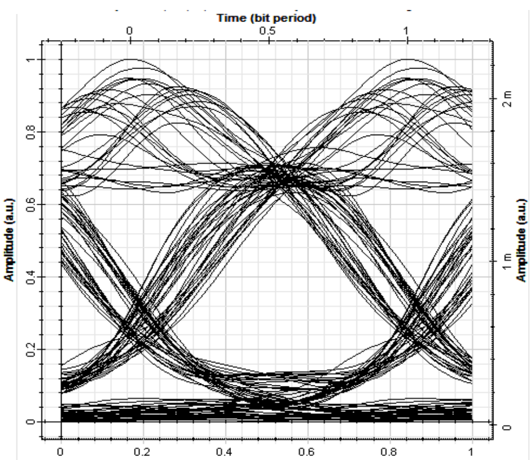


Fig.4.58: At input power 6 dBm

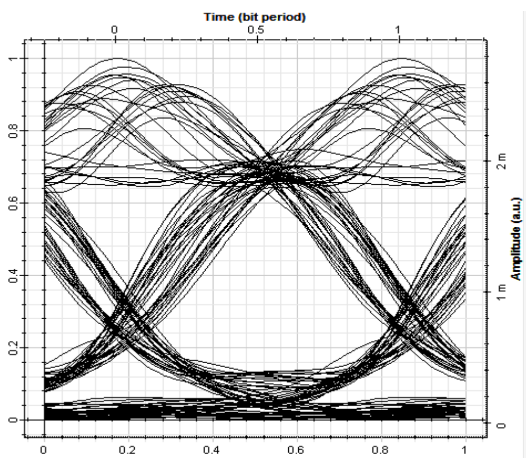


Fig.4.59: At input power 7 dBm

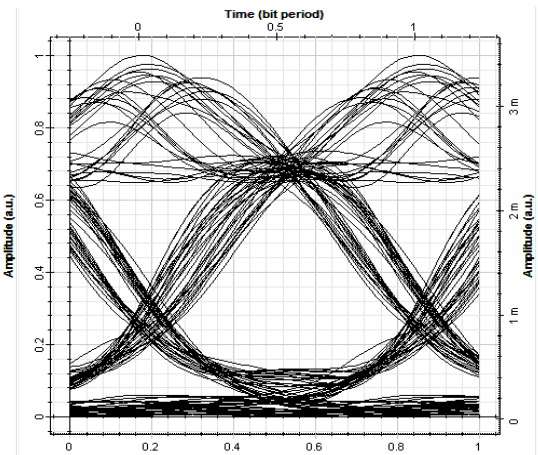


Fig.4.60: At input power 8 dBm

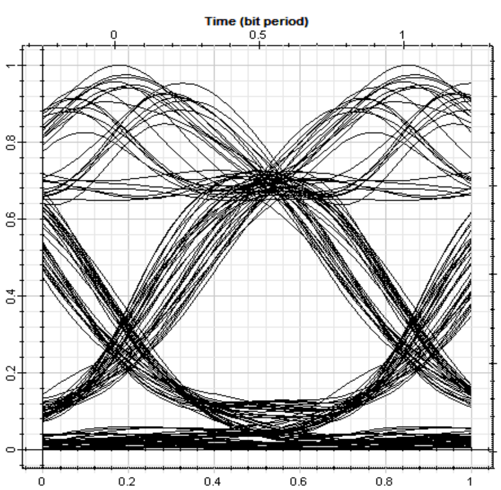


Fig.4.61: At input power 9 dBm

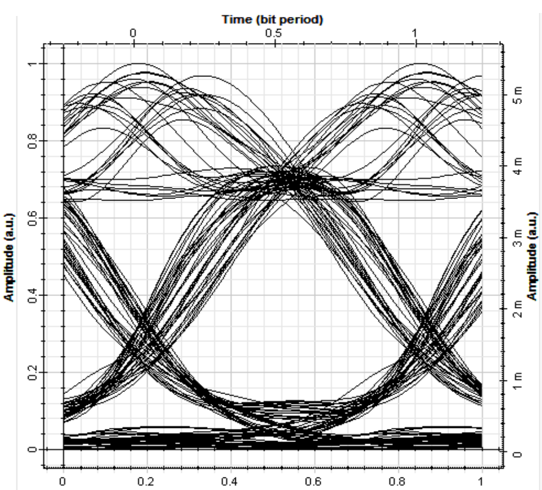


Fig.4.62: At input power 10 dBm

4.3.2.3 Mix-compensation results: Table-4.10 is showing the outcomes of mix configuration of IDCFBG at input powers form 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level of input (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increasing and corresponding value of BER decreases.

Table 4.10: Results for Mix Compensation of IDCFBG at inputs 1dbm to 10dbm				
Iterations	**Q factor**	**BER**	**Eye Height**	**Power (dbm)**
1	5.642	8.03E-09	0.00020816	-39.259
2	6.08952	5.47E-10	0.000283	-37.513
3	6.55263	2.76E-11	0.00038	-35.682
4	7.03329	9.93E-13	0.0005058	-33.793
5	7.50209	3.11E-14	0.000666	-31.865
6	8.00555	5.92E-16	0.000875	-29.91
7	8.51057	8.64E-18	0.0011424	-27.94
8	9.01882	9.50E-20	0.00148	-25.959
9	9.51562	9.03E-22	0.00192371	-23.97
10	9.8168	4.77E-23	0.00246	-21.979

a) Eye diagrams at different input power (1-10dBm) in mix compensation:

Fig.4.63 to 4.72 are showing the eye diagrams of IDCFBG at input power from 1-10dBm in mix configuration. Eye diagram is also referred as eye pattern. It carries lots of information about the quality of incoming pulse and state of channel, which is useful for the detection of digital input. Also, more details of the performance of any system can be gathered from the display of eye pattern. It is generally used for the visual examination of Inter symbol interference. It can be used for accuracy of timing extraction. It also provides noise immunity.

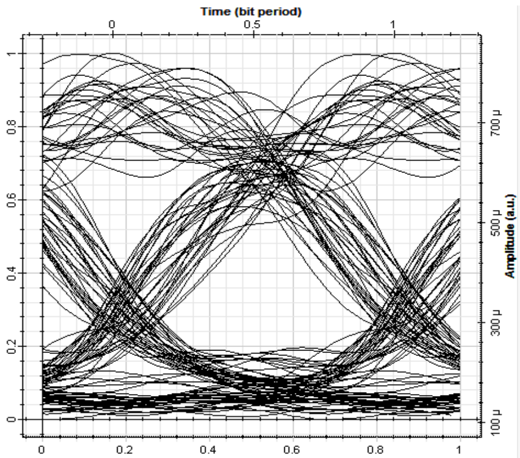


Fig.4.63: At input power 1 dBm

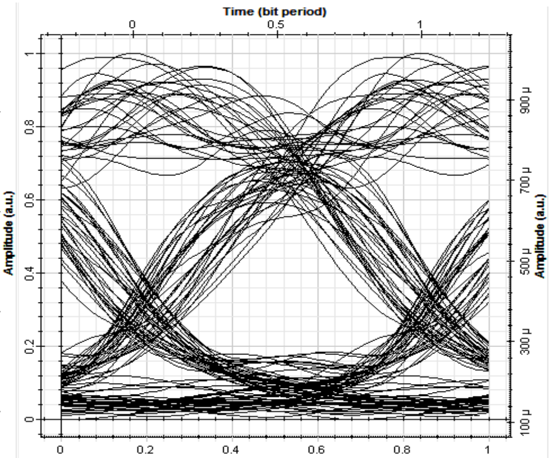


Fig.4.64: At input power 2 dBm

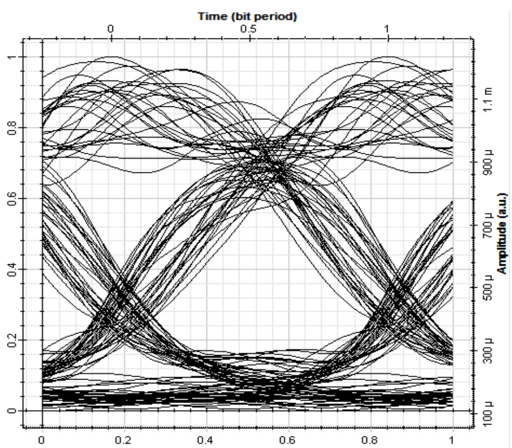


Fig.4.65: At input power 3 dBm

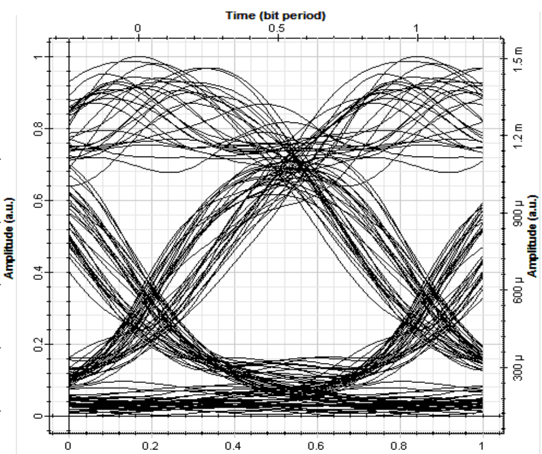


Fig.4.66: At input power 4 dBm

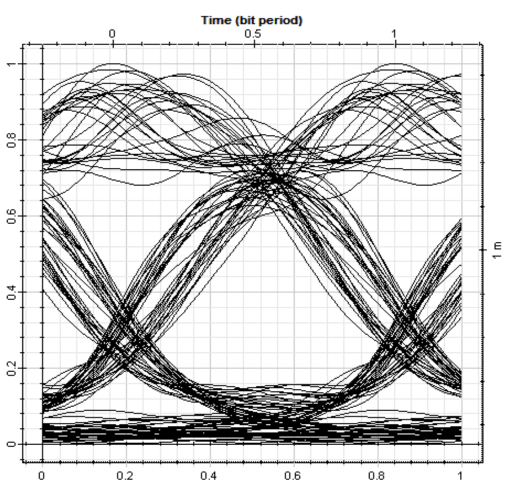


Fig.4.67: At input power 5 dBm

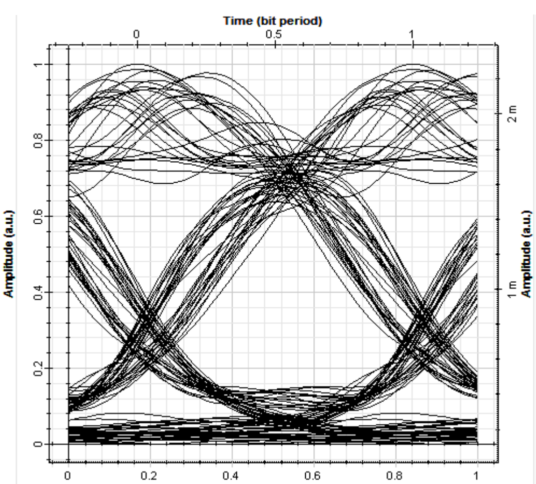


Fig.4.68: At input power 6 dBm

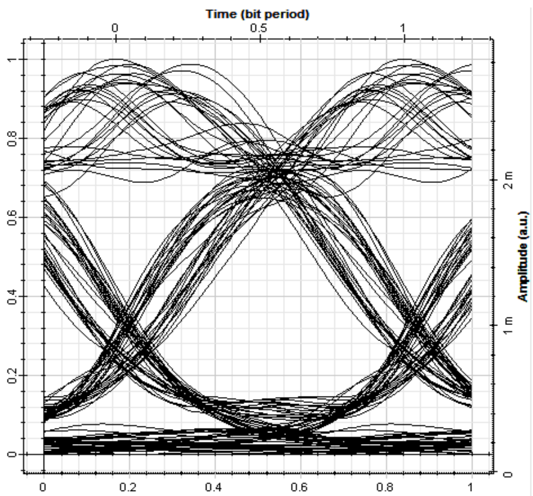


Fig.4.69: At input power 7 dBm

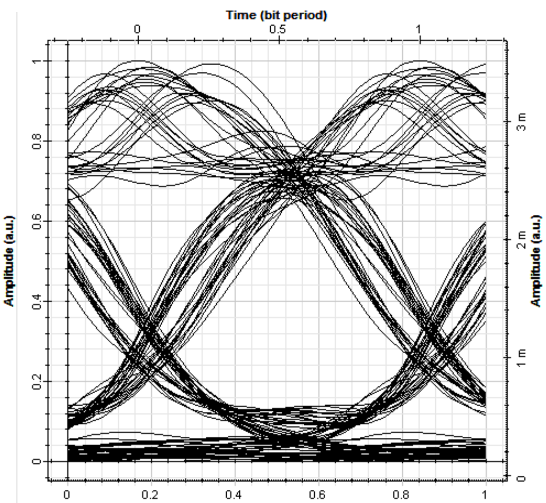


Fig.4.70: At input power 8 dBm

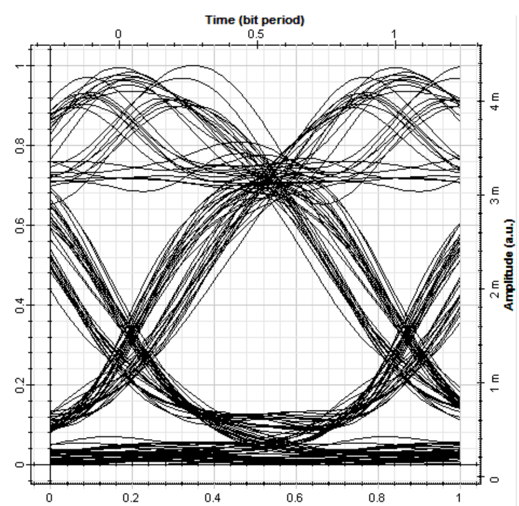


Fig.4.71: At input power 9 dBm

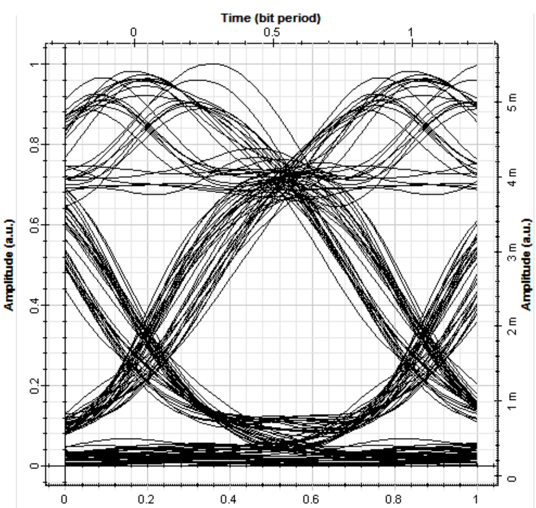


Fig.4.72: At input power 10 dBm

4.3.3 Graphical representation of change in various parameters w.r.t. input power (1-10dBm) in different configurations: - Fig. 4.73 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig.4.74. Fig.4.75 is showing graph for eye height and Fig.4.76 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for IDCFBG in three configurations. It is clear from the graphical representation of Q-factor vs. input power, input power vs. BER, eye height, and received power, post-configuration performs better and provides better results as compare to other configurations.

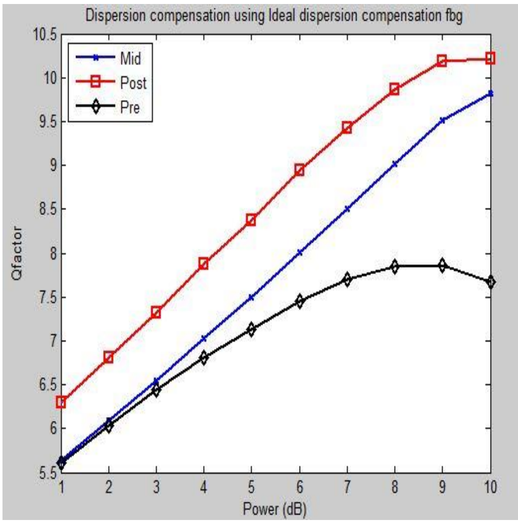


Fig.4.73: Input Power Vs Q- Factor

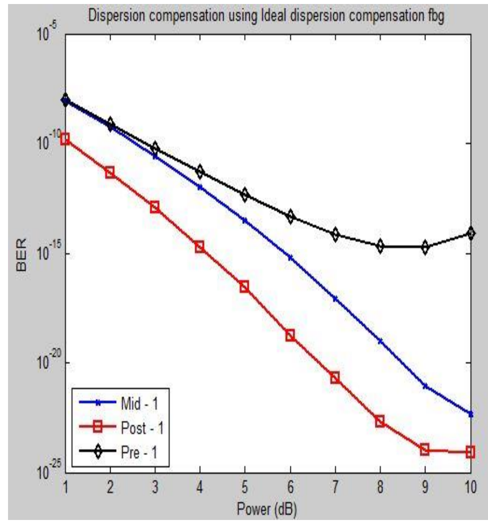


Fig.4.74: Power Vs BER

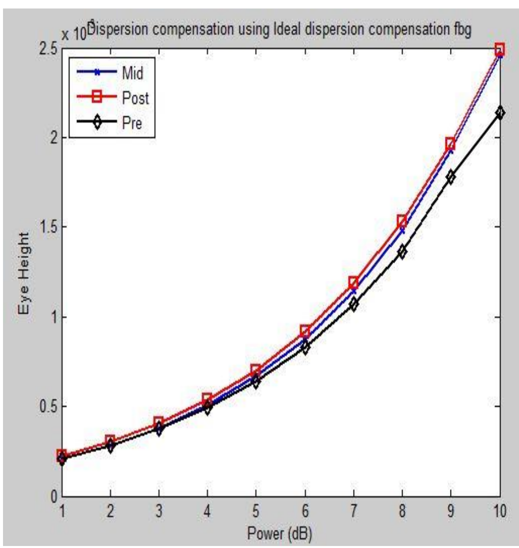


Fig.4.75: Power Vs Eye Height

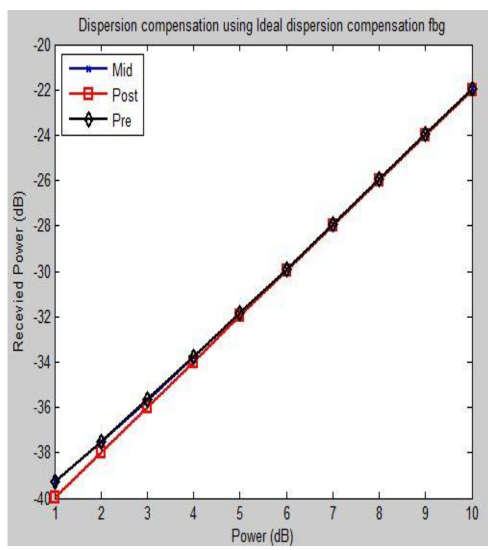


Fig.4.76: Input Power Vs Received Power

4.4 UFBG (UNIFORM FIBER BRAGG GRATING)

Most of the optical fibers are uniform in nature along their respective lengths. In an Uncomplicated optical fiber, there is a periodic variation of the refractive index of core over their lengths, as displayed in Fig. 4.77.

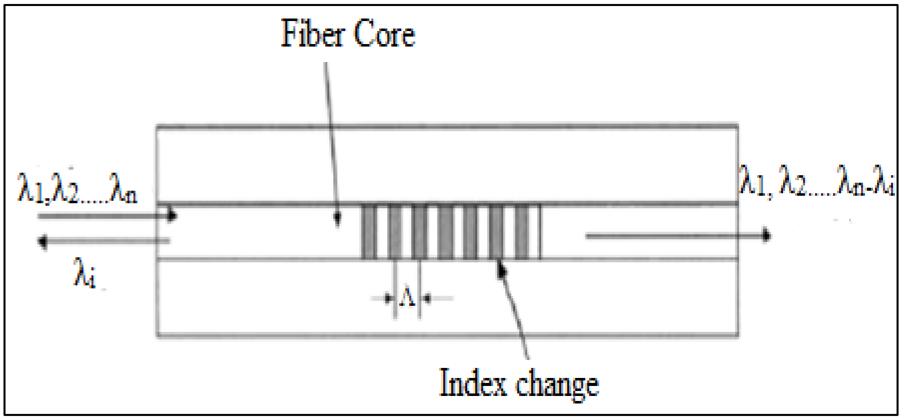


Fig.4.77: Schematic representation of UFBG

Fiber Bragg grating and transmission of light

FBG & transmission of light are displayed in Fig. 4.78. Modulation of refractive index of core is done with period of Λ. A light having wider spectrum is when launches into one of the two ends of the FBG, the fragment of light having wavelength matching with Bragg's wavelength will be returned back to the input boundary, with a feature of passing remaining light to the other boundary. This reflection phenomenon is described in Fig. 4.79 given below:-

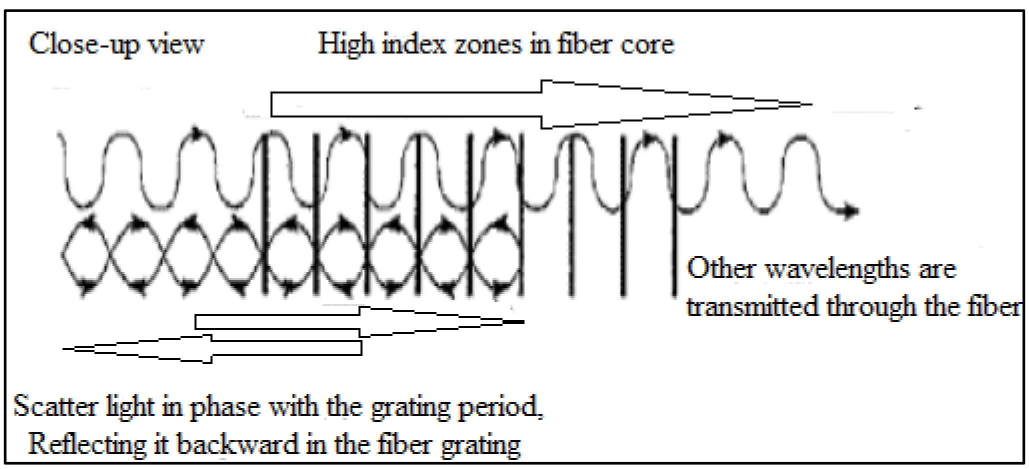


Fig.4.78: Reflection phenomenon of UFBG

It is necessary to have the knowledge of term "Uniform Fiber Bragg grating". A gadget which involves the periodic modification of the intensity and phase of any wave transmitted or reflected through it is termed as grating. If the condition of wavelength equivalent to Bragg's wavelength, λ_{Bragg} is fulfilled then the travelling wave will be reflected else the wave will be transmitted. The term uniform signifies that period of grating, Λ & change in refractive index, δn. Both are constant over the entire span of grating. This eqn. (4.4) is correlating grating spatial periodicity & Bragg resonance wavelength and hence, indicated below:-

$$\lambda_{Bragg} = 2n_{eff}\,\Lambda \tag{4.4}$$

Where n_{eff} is effective mode index

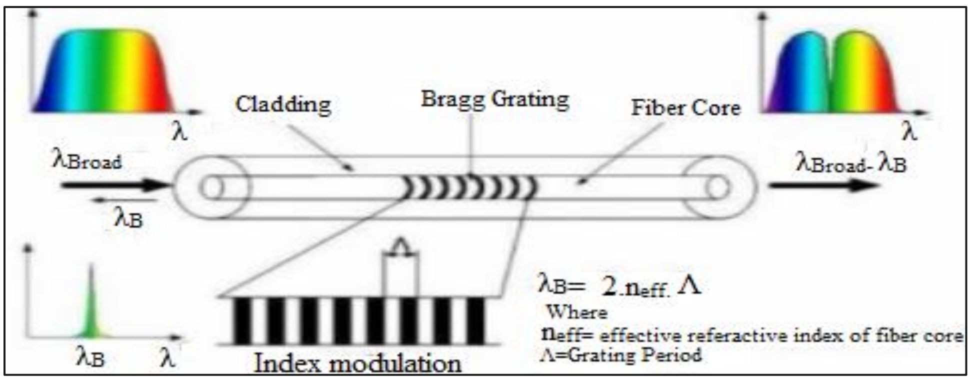


Fig.4.79: Uniform Fiber Bragg Grating

Table-4.11 is showing the simulation parameters of uniform fiber bragg grating whereas simulation parameters used in the simulation model are shown in Table-4.12.

Table 4.11: UFBG Parameters		
Sr. No.	**Parameter**	**Value**
1	Length of Fiber	120 Km
2	Noise Threshold	-100 dB
3	Reflectivity	0.99
4	Sample Rate	500 GHz

Table 4.12: Simulation Parameters		
Sr. No.	**Parameter**	**Value**
1	Bit Rate(Gbps)	100
2	Bandwidth(THz)	1
3	Extinction Ratio(dB)	30
4	Sample Rate(THz)	6.4
5	Power(dBm)	1-10
6	Gain(dB)	20
7	Noise(dB)	2
8	Frequency(THz)	193.1

This technique concentrates on the simulation of the Uniform Fiber Bragg Grating in 3 distinct designs i.e. Pre, Post & Mix Compensation and the simulation models for the respective configurations are shown in Fig.4.80, 4.81 and 4.82, respectively. Inevitably, the outcomes are looked at as far as the Q-factor and BER to decide the best design among the three.

4.4.1 Simulation models

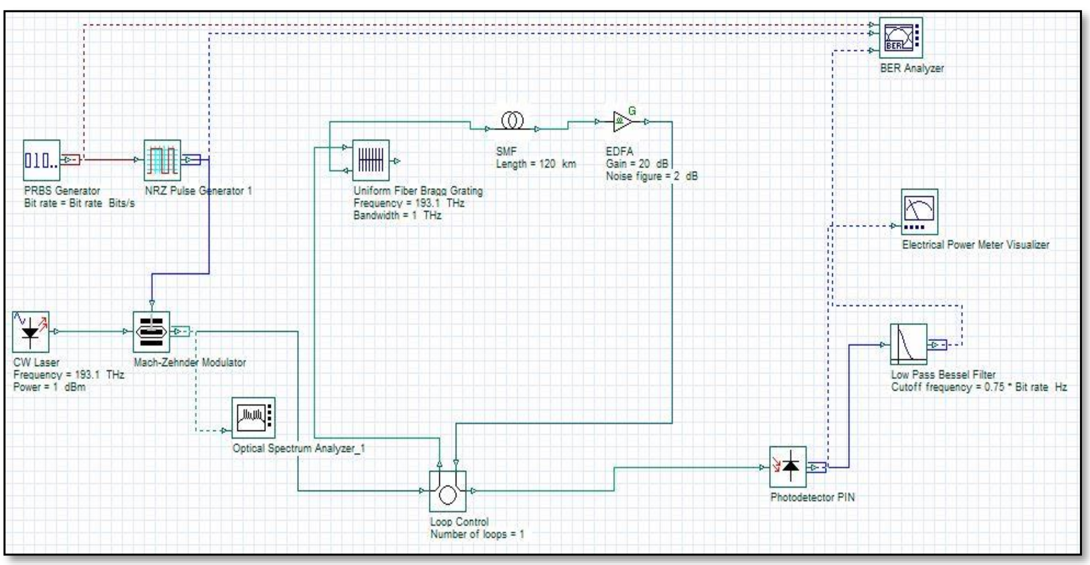


Fig.4.80: Compensation using pre scheme of UFBG model

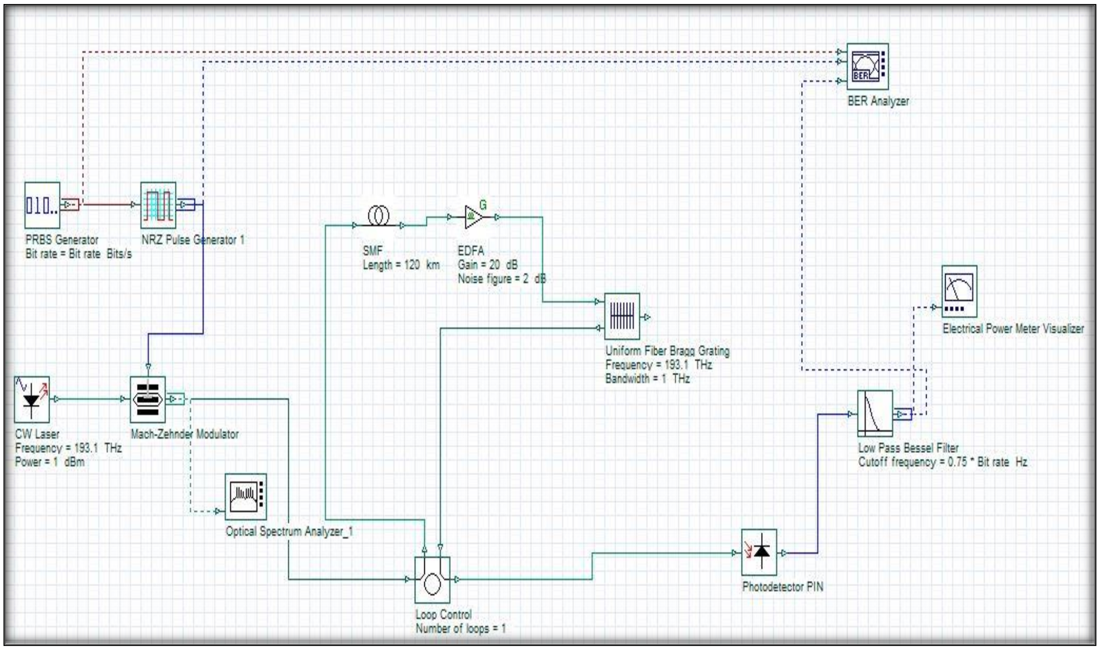


Fig.4.81: Compensation using post scheme of UFBG model

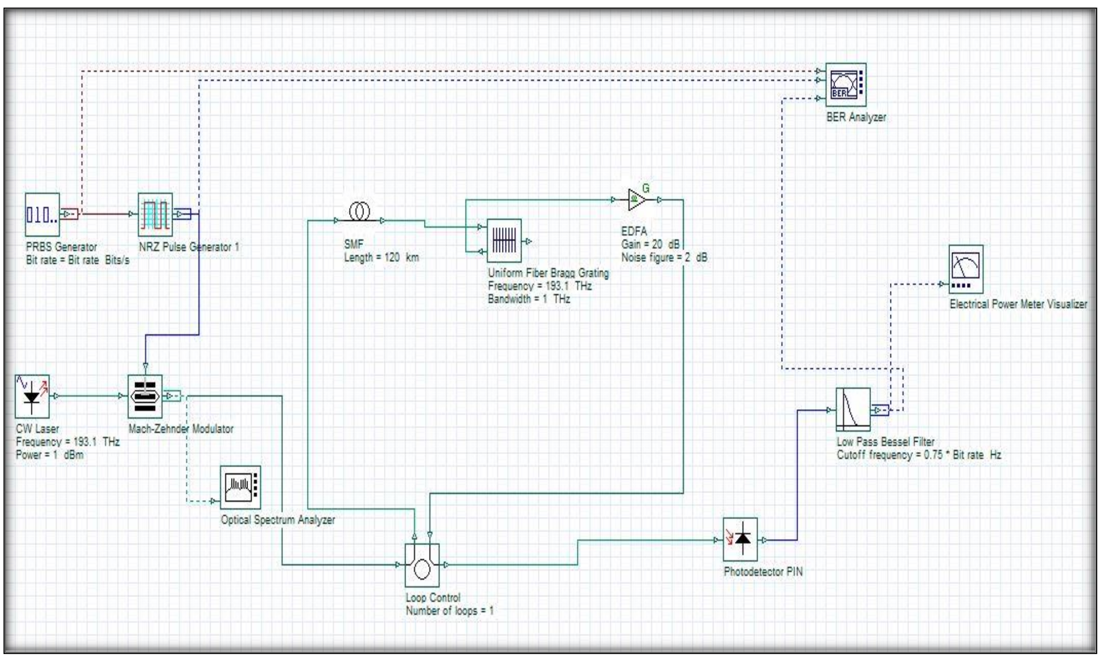


Fig.4.82: Compensation using mix scheme of UFBG model

4.4.2 Comparative results of different configurations

4.4.2.1 Pre-compensation results: Table-4.13 is showing the outcomes of pre-configuration of UFBG at input powers form 1-10dBm.

Table 4.13: Results for Pre-Compensation of UFBG at inputs 1-10dbm					
Input Power	Max Q-factor	Min BER	Eye Height	Threshold	Received Power (dBm)
1	7.86135	1.78E-12	0.000301	0.000291	1.26E-07
2	9.13437	3.02E-20	0.000412	0.000319	1.89E-07
3	10.5549	2.18E-26	0.000555	0.000354	2.90E-07
4	12.1228	3.56E-34	0.000737	0.000398	4.49E-07
5	13.8473	5.75E-44	0.000969	0.000441	7.01E-07
6	15.7283	4.15E-56	0.001263	0.000504	1.10E-06
7	17.7594	6.10E-71	0.001637	0.000561	1.74E-06
8	19.9478	6.47E-89	0.002112	0.00065	2.74E-06
9	22.2657	3.25E-11	0.002714	0.000763	4.33E-06
10	24.7116	3.18E-13	0.003477	0.000838	6.86E-06

It is clear from readings that as power level of input (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increasing and corresponding value of BER decreases.

a) Eye diagrams at different input power (1-10dBm) in pre-compensation:

Fig.4.83 to 4.92 are showing the eye diagrams of UFBG at input power from 1-10dBm in pre configuration.

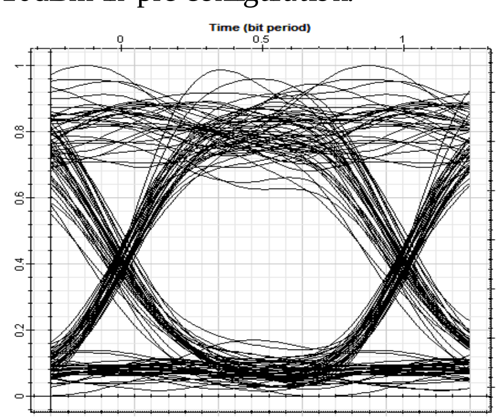


Fig.4.83: At input power 1 dBm

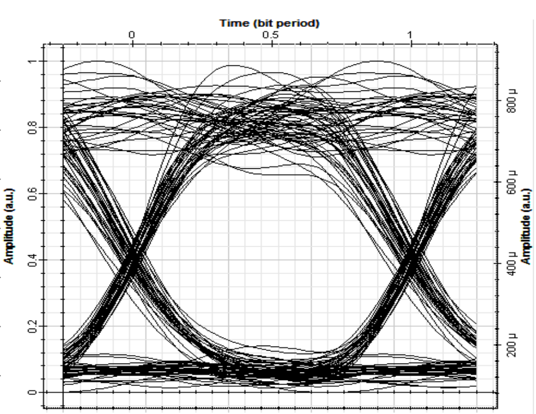


Fig.4.84: At input power 2 dBm

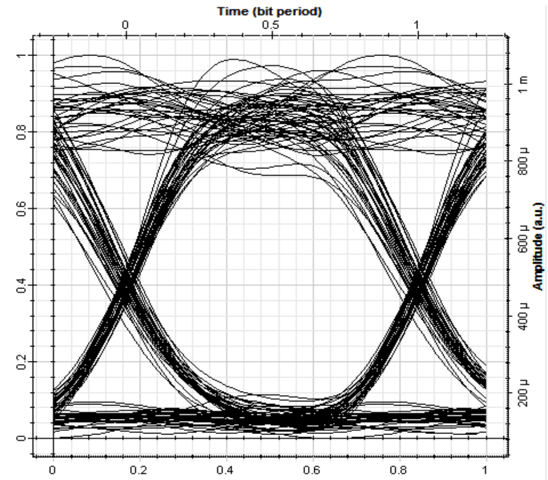


Fig.4.85: At input power 3 dBm

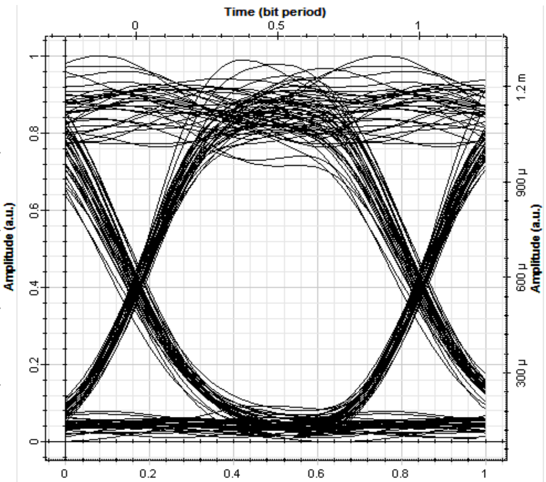


Fig.4.86: At input power 4 dBm

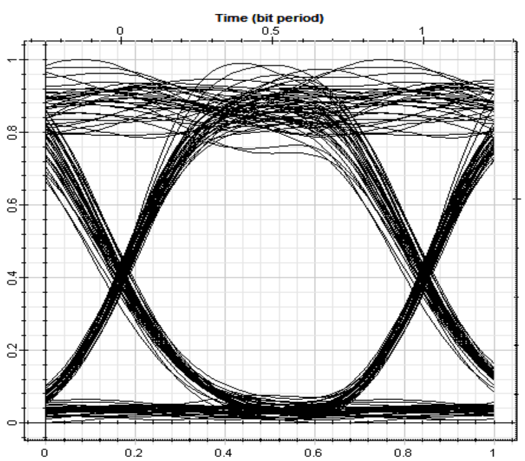


Fig.4.87: At input power 5 dBm

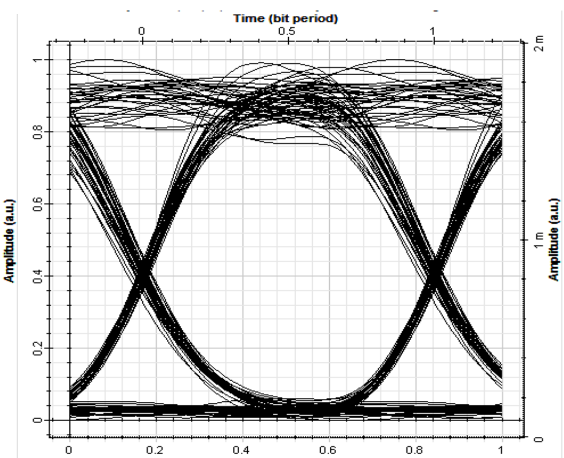


Fig.4.88: At input power 6 dBm

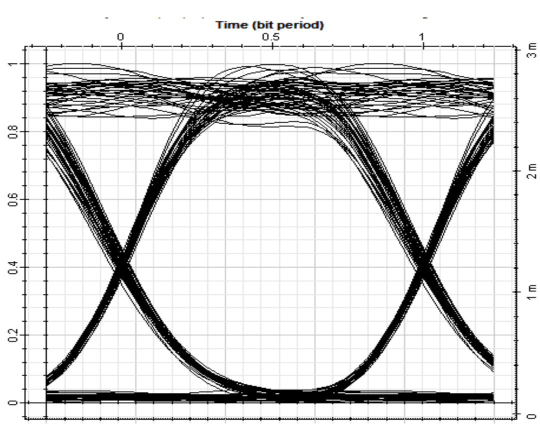


Fig.4.89: At input power 7 dBm

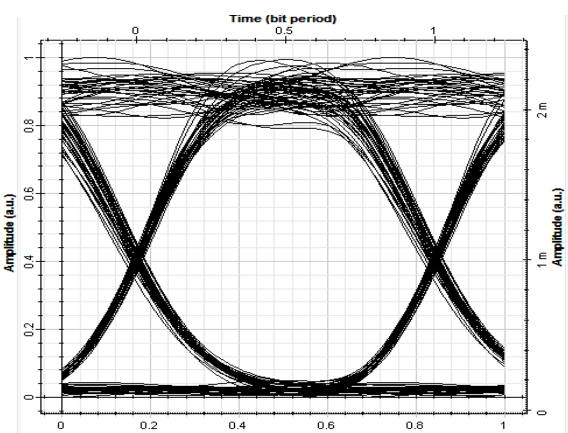


Fig.4.90: At input power 8 dBm

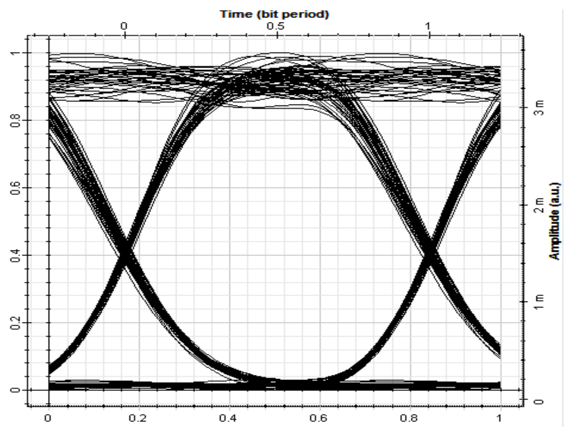


Fig.4.91: At input power 9 dBm

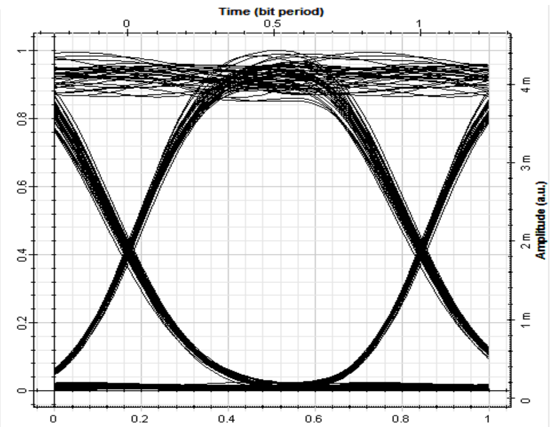


Fig.4.92: At input power 10 dBm

4.4.2.2 Post-compensation results: Table-4.14 is showing the outcomes of post configuration of UFBG at input powers form 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level of input (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increasing and corresponding value of BER decreases.

Table 4.14: Results for Post Compensation of UFBG at inputs 1-10dbm

Input Power	Max Q-factor	Min BER	Eye Height	Threshold	Received Power(dBm)
1	10.5753	1.56E-26	0.00036	0.0001132	1.09E-07
2	11.913	4.04E-33	0.0004752	0.0001343	1.73E-07
3	13.369	3.55E-41	0.0006205	0.0001531	2.73E-07
4	14.9508	5.97E-51	0.0008056	0.00018449	4.32E-07
5	16.663	9.12E-63	0.00104	0.0002099	6.85E-07
6	18.512	6.11E-77	0.00133935	0.00023831	1.09E-06
7	20.5079	6.61E-94	0.001718	0.0002698	1.72E-06
8	22.6786	2.55E-11	0.002197	0.0002909	2.72E-06
9	25.028	1.04E-13	0.002805	0.00033431	4.31E-06
10	27.54	1.95E-16	0.00357	0.0003932	6.84E-06

a) Eye diagrams at different input power (1-10dBm) in post-compensation:

Fig.4.93 to 4.102 are showing the eye diagrams of UFBG at input power from 1-10dBm in post configuration.

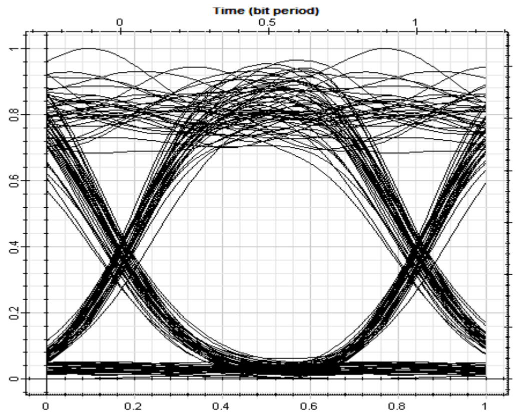


Fig.4.93: At input power 1 dBm

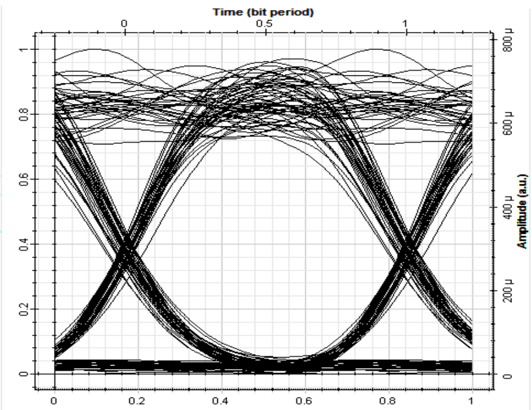


Fig.4.94: At input power 2 dBm

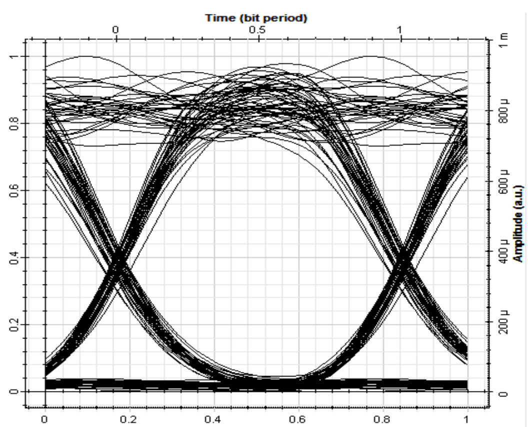


Fig.4.95: At input power 3 dBm

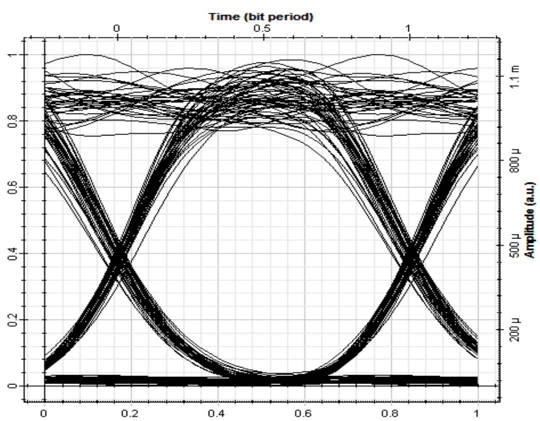


Fig.4.96: At input power 4 dBm

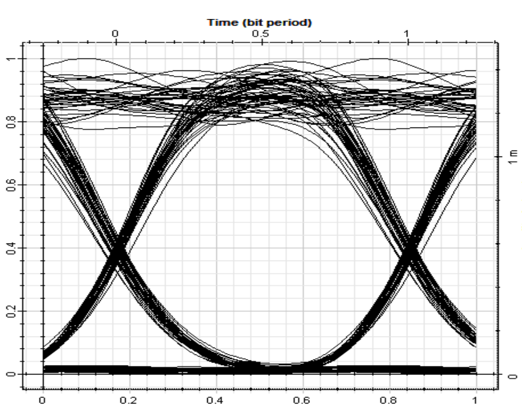


Fig.4.97: At input power 5 dBm

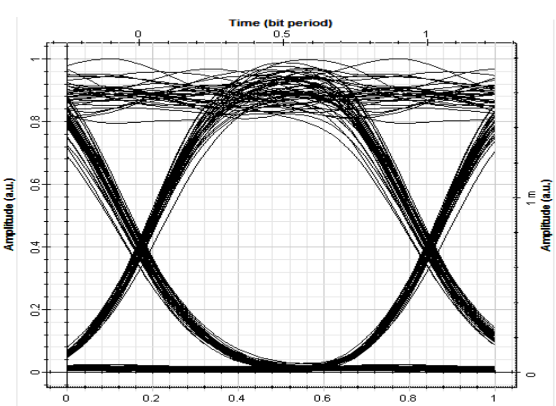


Fig.4.98: At input power 6 dBm

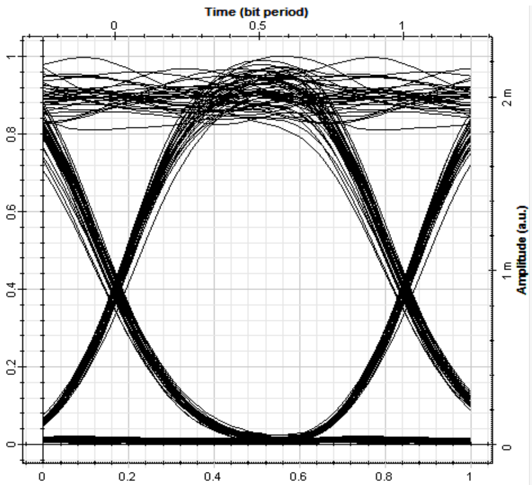


Fig.4.99: At input power 7 dBm

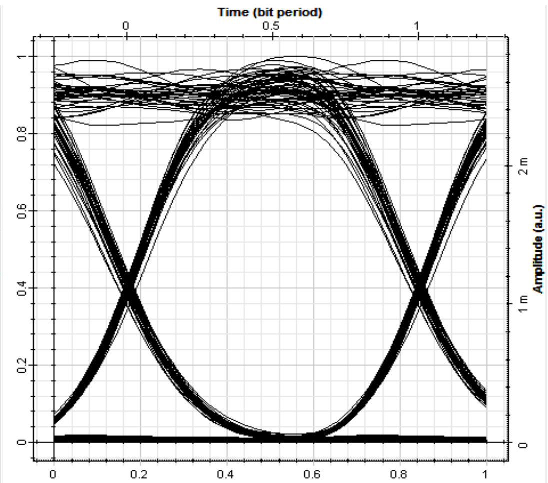


Fig.4.100: At input power 8 dBm

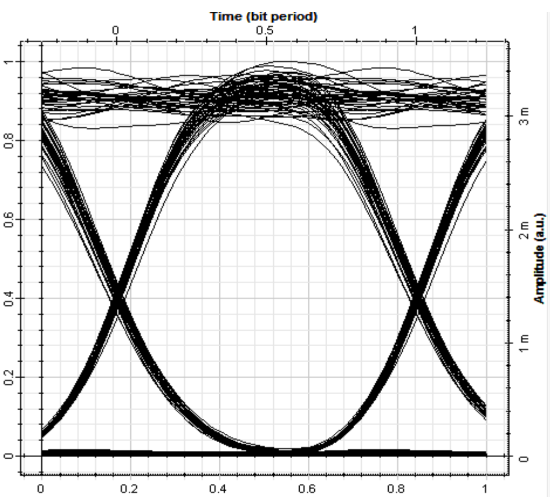


Fig.4.101: At input power 9 dBm

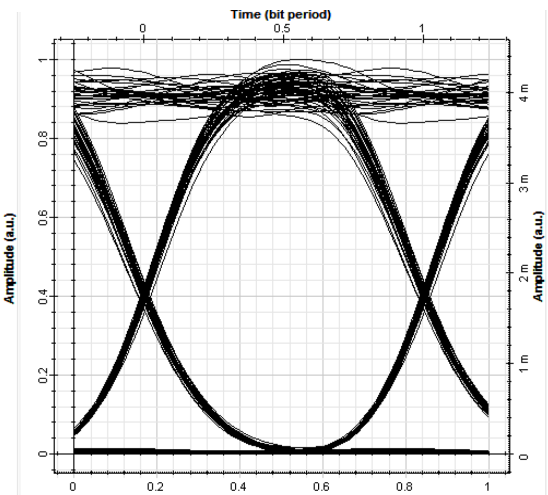


Fig.4.102: At input power 10 dBm

4.4.2.3 Mix-compensation results:-Table-4.15 is showing the outcomes of pre configuration of UFBG at input powers form 1-10dBm. For faithful communication, the value of Q- factor should be as high as possible and the value of BER should be as low as possible. It is clear from readings that as power level of input (Iterations) rises from 1 to 10dBm, value of Q-factor is also somewhat increasing and corresponding value of bit error rate decreases. Here, there is also an increase in the eye height and significant increase in the received power. These all are the required conditions for faithful communication.

Table 4.15: Results for mix compensation of UFBG at inputs 1- 10dbm					
Input Power	**Max Q-factor**	**Min BER**	**Eye Height**	**Threshold**	**Received Power(dBm)**
1	7.86036	1.79E-15	0.000301	0.000291	1.75E-07
2	9.13275	3.07E-20	0.000413	0.000319	2.52E-07
3	10.5523	2.24E-26	0.000555	0.000354	3.72E-07
4	12.1191	3.72E-34	0.000737	0.000397	5.58E-07
5	13.8391	6.43E-44	0.000969	0.000441	8.49E-07
6	15.7154	5.08E-56	0.001263	0.000502	1.30E-06
7	17.7315	1.02E-70	0.001638	0.000581	2.02E-06
8	19.8949	1.86E-88	0.002112	0.000644	3.15E-06
9	22.1653	3.02E-10	0.002715	0.000752	4.93E-06
10	24.5084	4.73E-13	0.003477	0.000819	7.75E-06

a) Eye diagrams at different input power (1-10dBm) in mix-compensation:

Fig.4.103 to 4.112 are showing the eye diagrams of UFBG at input power from 1-10dBm in mix configuration. Eye diagram is also referred as eye pattern. It carries lots of information about the quality of incoming pulse and state of channel, which is useful for the detection of digital input. Also, more details of the performance of any system can be gathered from the display of eye pattern.

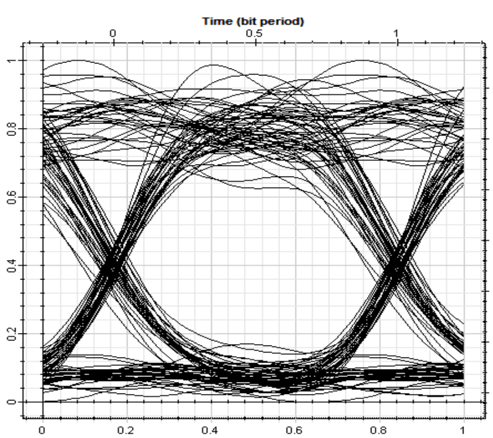


Fig.4.103: At input power 1 dBm

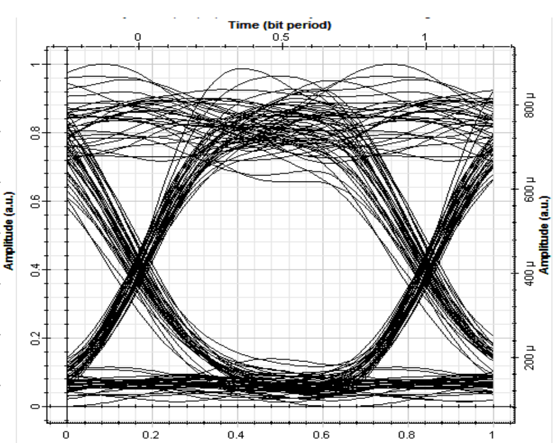


Fig.4.104: At input power 2 dBm

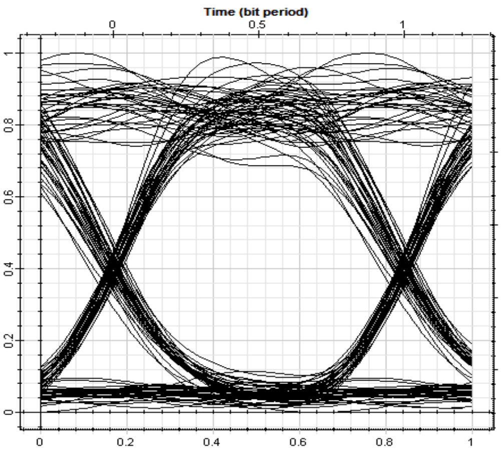


Fig.4.105: At input power 3 dBm

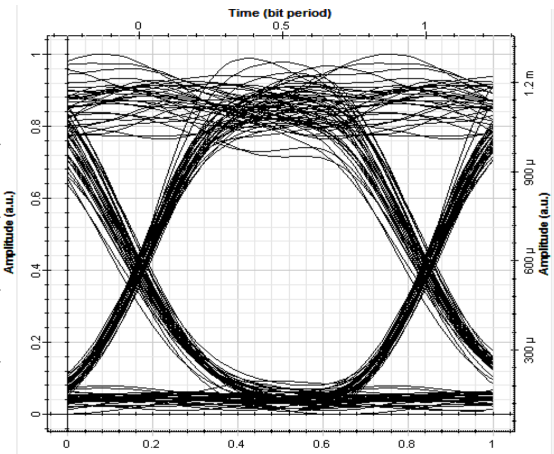


Fig.4.106: At input power 4 dBm

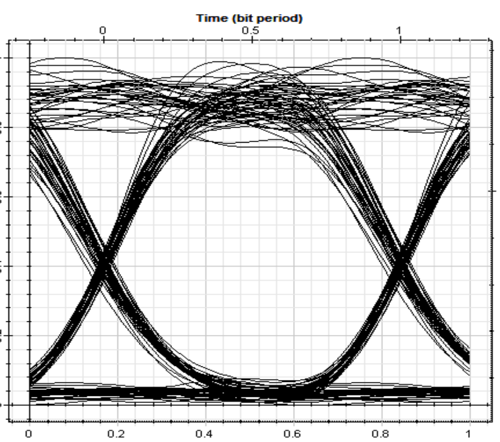


Fig.4.107: At input power 5 dBm

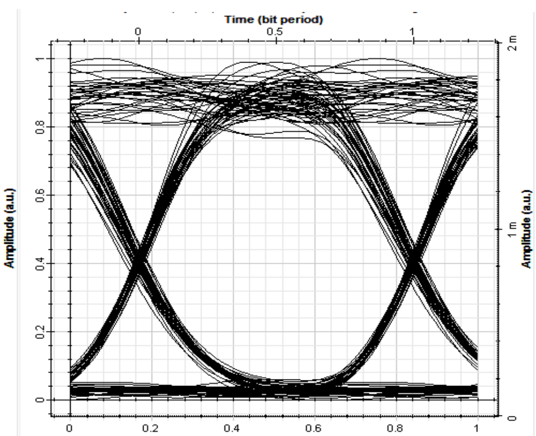


Fig.4.108: At input power 6 dBm

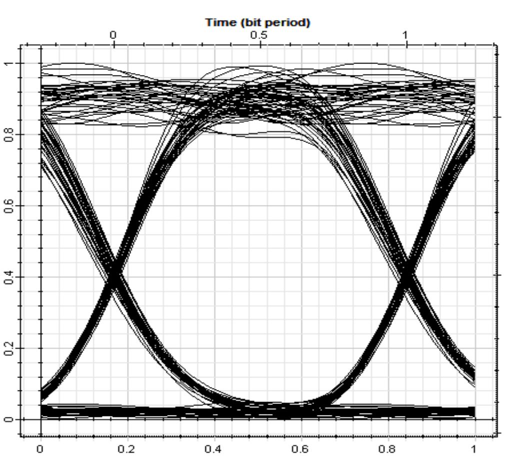


Fig.4.109: At input power 7 dBm

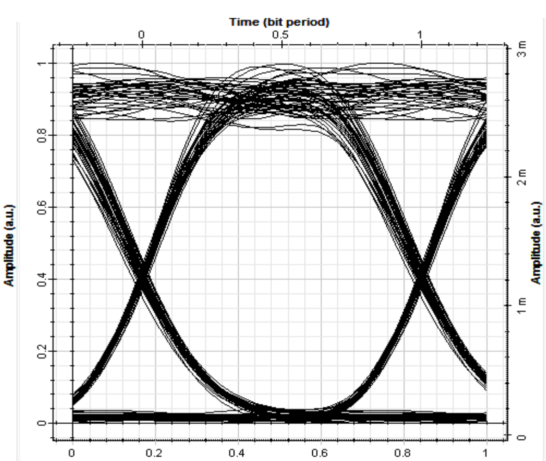


Fig.4.110: At input power 8 dBm

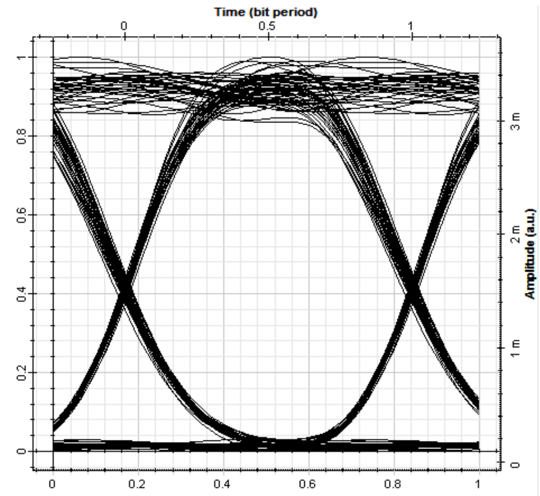


Fig.4.111: At input power 9 dBm

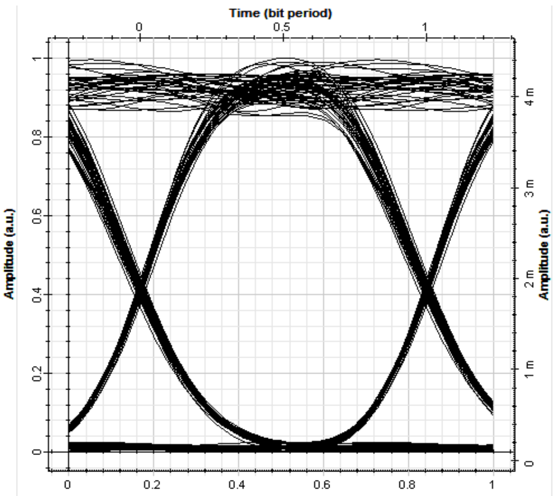


Fig.4.112: At input power 10 dBm

4.4.3 Graphical representation of change in various parameters w.r.t. input power (1-10dBm) in different configurations: Fig. 4.113 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig.4.114. Fig.4.115 is showing graph for eye height and Fig.4.116 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for UFBG in three configurations.

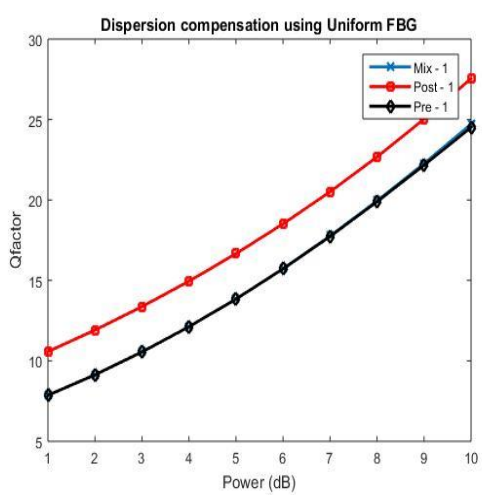


Fig.4.113: Input Power Vs Q- Factor

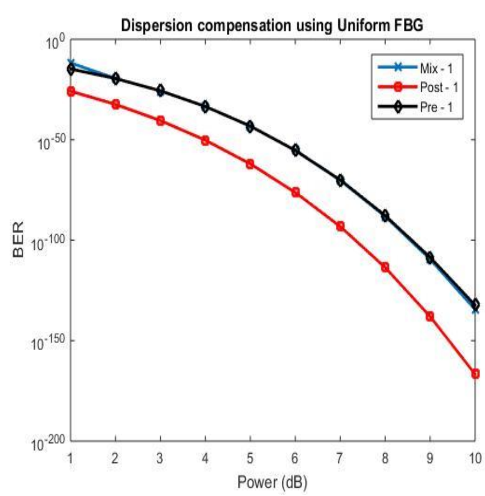


Fig.4.114: Power Vs BER

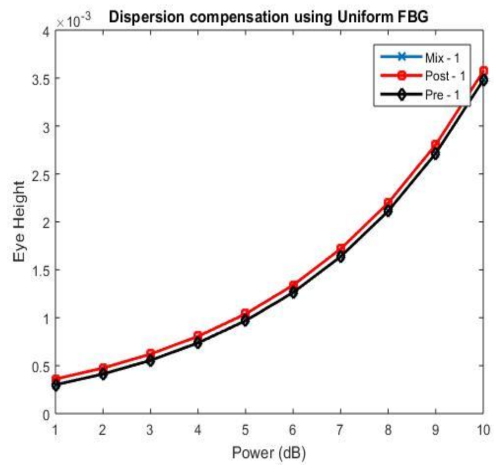


Fig.4.115: Power Vs Eye Height

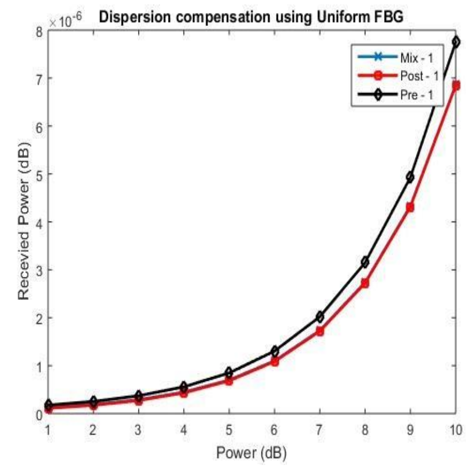


Fig.4.116: Input Power Vs Received Power

4.5 OBJECTIVE-2: To select the most significant type of Grating by performing the analysis over the grating types in the existing dispersion compensation based optical communication systems.

4.5.1 Comparison between DCF, IDCFBG and UFBG in pre-dispersion compensation scheme at 1-10 dBm input power: Table-4.16 is showing comparison of DCF, IDCFBG and UFBG in terms of Q-Factor.

Table 4.16: Pre-compensation (Max. Q factor)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	6.28	5.6126	7.86036
2	6.95783	6.0295	9.13275
3	7.63629	6.44271	10.5523
4	8.29053	6.80368	12.1191
5	8.9069	7.13709	13.8391
6	9.42722	7.4555	15.7154
7	9.76613	7.69731	17.7315
8	9.89721	7.84282	19.8949
9	9.64992	7.86216	22.1653
10	9.16792	7.67143	24.5084

Table 4.17: Pre-compensation (BER)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	1.52E-10	9.5555E-09	1.7896E-15
2	1.65107E-12	7.9658E-10	3.066E-20
3	1.07793E-14	5.7382E-11	2.2378E-26
4	5.48815E-17	5.0244E-12	3.7181E-34
5	2.57404E-19	4.7247E-13	6.4329E-44
6	2.07699E-21	4.4554E-14	5.08E-56
7	7.78861E-23	6.9347E-15	1.015E-70
8	2.1188E-23	2.2008E-15	1.856E-88
9	2.42415E-22	1.88E-15	3.024E-109
10	2.35499E-20	8.4957E-15	4.73E-133

Table-4.17 is showing comparison of DCF, IDCFBG and UFBG in terms of BER in pre-compensation. Table-4.18 is showing comparison of DCF, IDCFBG and UFBG in terms of eye height in pre-compensation.

Table 4.18: Pre-compensation (Eye Height)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	0.000174	0.0002068	0.00030071
2	0.000239155	0.00028011	0.00041252
3	0.000321066	0.00037432	0.0005553
4	0.000424823	0.0004922	0.0007373
5	0.00055543	0.000642	0.00096891
6	0.000718801	0.000833	0.001263
7	0.000920044	0.0010709	0.00163775
8	0.00116854	0.00136614	0.00211245
9	0.00145903	0.0017826	0.00271461
10	0.00180107	0.00214	0.00347716

Table-4.19 is showing comparison of DCF, IDCFBG and UFBG in terms of received power in pre-compensation.

Table 4.19: Pre-compensation (Received Power)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	-42.3	-39.25	-37.561
2	-40.511	-37.509	-35.979
3	-38.649	-35.67	-34.297
4	-36.739	-33.788	-32.534
5	-34.795	-31.86	-30.713
6	-32.832	-29.905	-28.846
7	-30.855	-27.93	-26.944
8	-28.869	-25.95	-25.017
9	-26.877	-23.96	-23.069
10	-24.887	-21.96	-21.106

Fig.4.119 is showing graph for eye height and Fig.4.120 is showing change in received power with respect to change in input power.

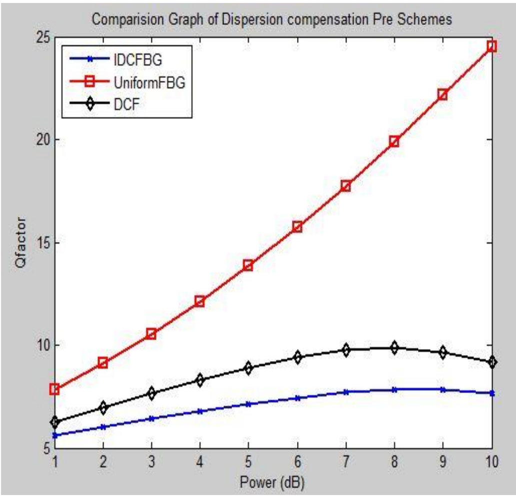


Fig.4.117: Input Power Vs Q- Factor

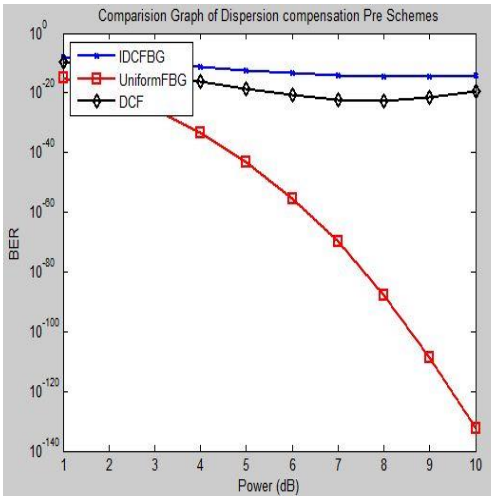


Fig.4.118: Power Vs BER

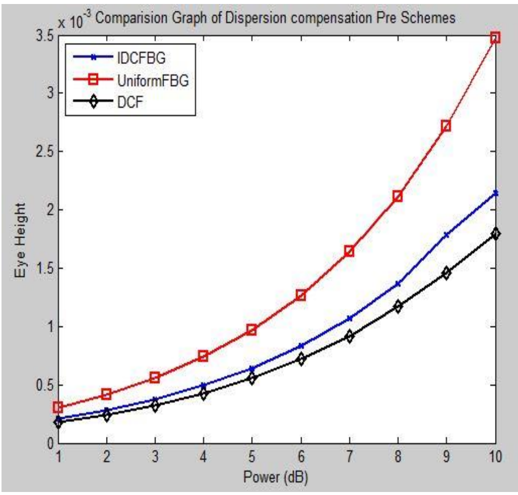


Fig.4.119: Power Vs Eye Height

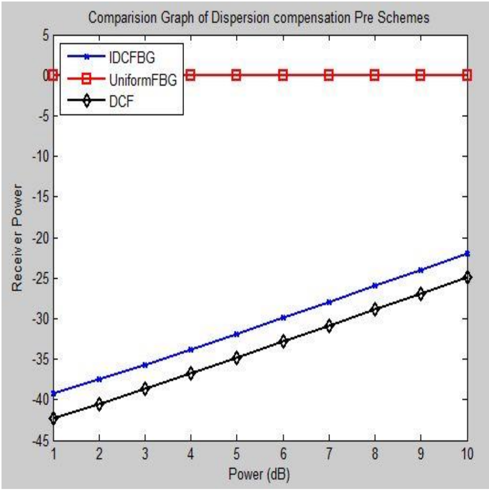


Fig.4.120: Power Vs Received Power

Fig. 4.117 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig. 4.118. All the graphs have been plotted for DCF, IDCFBG and UFBG comparison in pre-configuration. It is clear from the graphs shown above that in every aspect the UFBG is performing better and providing better results than the remaining dispersion compensation techniques i.e. DCF and IDCFBG in pre-configuration.

4.5.2 Comparison between DCF, IDCFBG and UFBG in Post Compensation scheme using 1-10 dBm input power:

Table-4.20 is showing comparison of DCF, IDCFBG and UFBG in terms of Q-Factor in Post Compensation. Table- 4.21 is showing comparison of DCF, IDCFBG and UFBG in terms of Bit error rate (BER) in Post Compensation. Table-4.22 is showing comparison of DCF, IDCFBG and UFBG in terms of Eye height in Post Compensation. Table-4.23 is showing comparison of DCF, IDCFBG and UFBG in terms of received power in Post Compensation.

It is clear from the tables that in every aspect i.e. Q-factor, bit error rate, eye height and received power, UFBG is performing better and providing better results than the remaining dispersion compensation techniques i.e. DCF and IDCFBG in post-configuration.

Table 4.20: Post compensation (Max. Q factor)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	6.8305	6.2989	10.5753
2	7.46805	6.81376	11.913
3	8.11492	7.31658	13.369
4	8.80386	7.87031	14.9508
5	9.33	8.37922	16.663
6	9.8	8.94922	18.512
7	10.11	9.43164	20.5079
8	10.14	9.86961	22.6786
9	9.84	10.1927	25.028
10	9.2	10.2168	27.54

Table 4.21: Post compensation (BER)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	1.035E-12	1.48209E-10	1.56102E-26
2	3.91E-14	4.7295E-12	4.0412E-33
3	2.398E-16	1.27011E-13	3.5465E-41
4	6.56E-19	1.7688E-15	5.967E-51
5	5.2E-21	2.66181E-17	9.121E-63
6	5.31E-23	1.7833E-19	6.1148E-77
7	2.42E-24	2.00538E-21	6.6143E-94
8	1.73E-24	2.17948E-23	2.5457E-114
9	3.46E-23	1.06085E-24	1.0408E-138
10	1.69E-20	8.31665E-25	1.95E-167

Table 4.22: Post compensation (Eye Height)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	0.000186	0.0002255	0.00036
2	0.00025	0.000303981	0.0004752
3	0.0003316	0.0004038	0.0006205
4	0.0004352	0.0005343	0.0008056
5	0.0005621	0.0006996	0.00104
6	0.000722	0.0009152	0.00133935
7	0.000917	0.00118621	0.001718
8	0.00115	0.00152983	0.002197
9	0.00142	0.00196169	0.002805
10	0.00173	0.002486	0.00357

Table 4.23: Post compensation (Received Power)			
Iteration	**DCF**	**IDCFBG**	**UFBG**
1	-42.5	-39.957	-39.619
2	-40.647	-37.969	-37.63
3	-38.74	-35.978	-35.637
4	-36.8	-33.983	-33.642
5	-34.85	-31.988	-31.645
6	-32.88	-29.98	-29.64
7	-30.9	-27.99	-27.649
8	-28.92	-25.99	-25.649
9	-26.93	-23.99	-23.647
10	-24.954	-21.99	-21.646

Fig. 4.121 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig. 4.122. Fig.4.123 is showing graph for eye height and Fig.4.124 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for DCF, IDCFBG and UFBG comparison in post configuration. It is clear from the graphs shown below that in every aspect the UFBG is performing better and providing better results than the remaining dispersion compensation techniques i.e. DCF and IDCFBG in post-configuration.

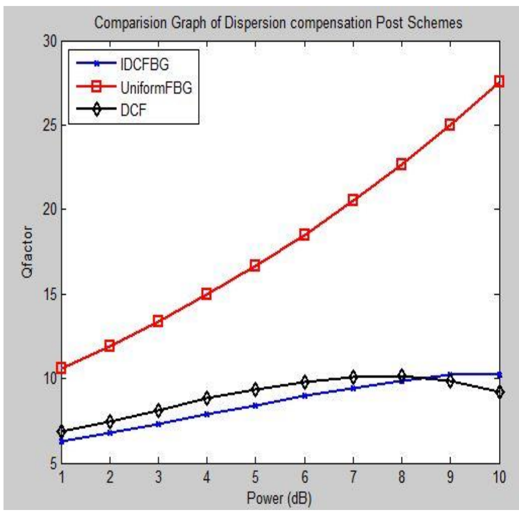


Fig.4.121: Input Power Vs Q- Factor

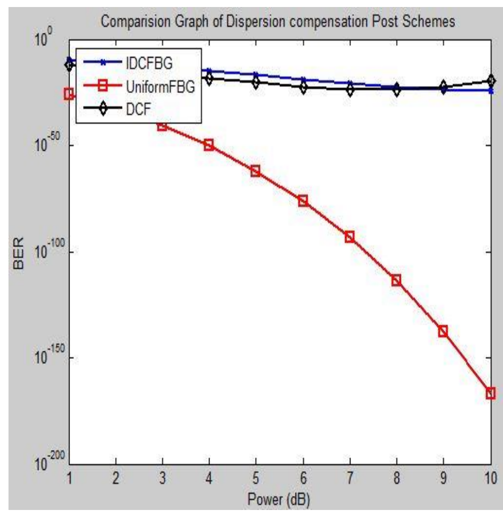


Fig.4.122: Power Vs BER

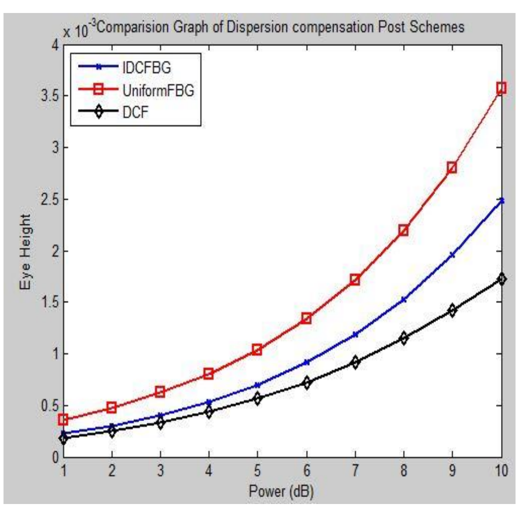


Fig.4.123: Power Vs Eye Height

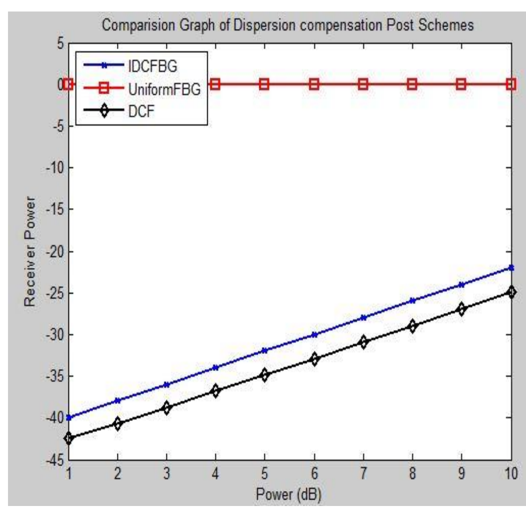


Fig.4.124: Power Vs Received Power

4.5.3 Comparison between DCF, IDCFBG and UFBG in mix-dispersion compensation scheme at 1-10dBm input power: Table-4.24 is showing comparison of DCF, IDCFBG and UFBG in terms of Q-Factor, in mix compensation.

Table 4.24: Mix compensation (Max. Q factor)

Iteration	DCF	IDCFBG	UFBG
1	3.1	5.642	7.86135
2	3.62	6.08952	9.13437
3	4.22	6.55263	10.5549
4	4.9	7.03329	12.1228
5	5.61	7.50209	13.8473
6	6.37	8.00555	15.7283
7	7.1	8.51057	17.7594
8	7.8	9.01882	19.9478
9	8.36	9.51562	22.2657
10	8.69	9.8168	24.7116

Table 4.25: Mix compensation (BER)

Iteration	DCF	IDCFBG	UFBG
1	8.86E-04	8.03E-09	1.78E-12
2	1.30E-04	5.47E-10	3.02E-20
3	1.07E-05	2.76E-11	2.18E-26
4	4.19E-07	9.93E-13	3.56E-34
5	8.72E-09	3.11E-14	5.75E-44
6	7.93E-11	5.92E-16	4.15E-56
7	5.23E-13	8.64E-18	6.10E-71
8	2.69E-15	9.50E-20	6.47E-89
9	2.74E-17	9.03E-22	3.25E-110
10	1.49E-18	4.77E-23	3.18E-135

Table-4.24 and 4.25 is showing comparison of DCF, IDCFBG and UFBG in terms of Q-Factor and BER in mix compensation.

Table 4.26: Mix compensation (Eye Height)

Iteration	DCF	IDCFBG	UFBG
1	3.20E-06	0.000283	0.000412487
2	2.71E-05	0.00038	0.000555242
3	4.41E-05	0.0005058	0.000737193
4	7.39E-05	0.000666	0.000968757
5	1.10E-04	0.000875	0.00126326
6	1.57E-04	0.0011424	0.00163741
7	2.10E-04	0.00148	0.00211202
8	2.80E-04	0.00192371	0.00271419
9	3.70E-04	0.00246	0.00347709
10	4.70E-04	0.000208161	0.000300701

Table 4.27: Mix compensation (Received Power)

Iteration	DCF	IDCFBG	UFBG
1	-48.89	-39.259	-39.003
2	-48.19	-37.513	-37.229
3	-47.26	-35.682	-35.38
4	-46.11	-33.793	-33.478
5	-44.74	-31.865	-31.541
6	-43.18	-29.91	-29.581
7	-41.5	-27.94	-27.606
8	-39.7	-25.959	-25.622
9	-37.84	-23.97	-23.631
10	-35.94	-21.979	-21.635

Table-4.26 and 4.27 is showing comparison of DCF, IDCFBG and UFBG in terms of Eye height and received power in mix compensation.

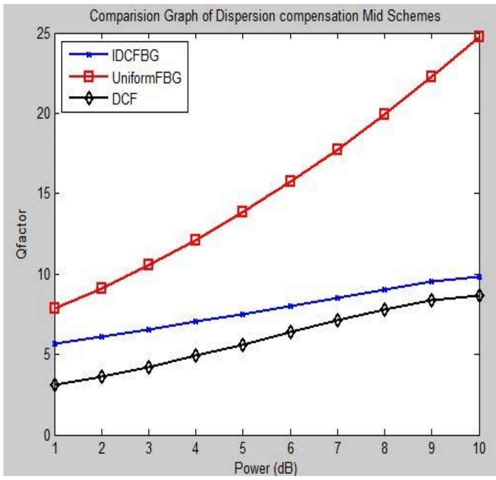


Fig.4.125: Input Power Vs Q- Factor

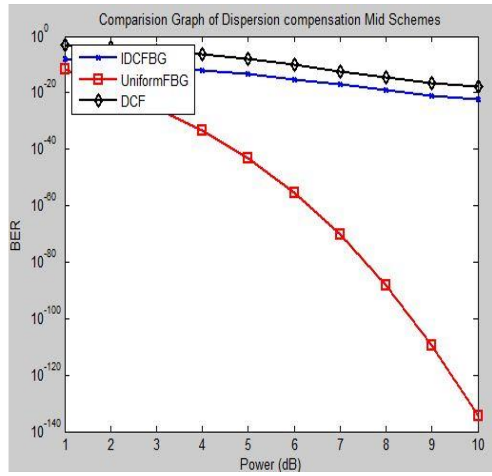


Fig.4.126: Power Vs BER

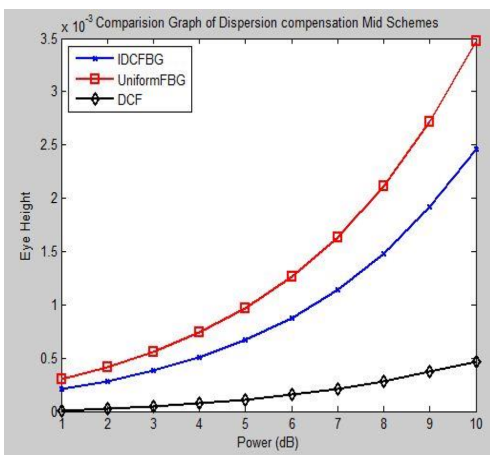


Fig.4.127: Power Vs Eye Height

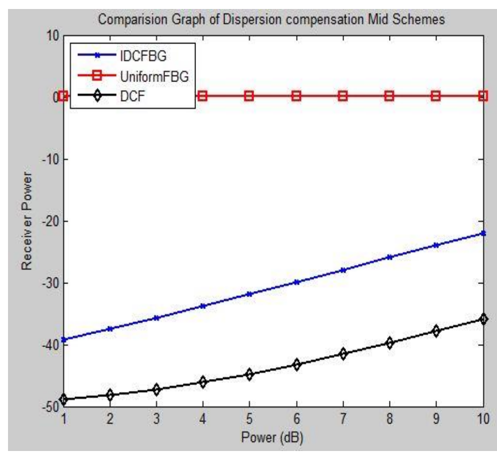


Fig.4.128: Power Vs Received Power

Fig. 4.125 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig. 4.126. Fig.4.127 is showing graph for eye height and Fig.4.128 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for DCF, IDCFBG and UFBG comparison in mix configuration. It is clear from the graphs shown above that in every aspect the UFBG is performing better and providing better results than the remaining dispersion compensation techniques i.e. DCF and IDCFBG in mix-configuration.

4.6 OBJECTIVE-3: Propose a hybrid approach with best FBG technique with the filtration process and EDC (electronic dispersion compensator) based system for achieving the upgraded model to achieve high data rate.

In this objective, a high point capacity model having the transmission rate of 100Gbps using Hybrid dispersion compensation technique is proposed over a distance of 120Km. But due to longer transmission distances, fiber linearity occurs. EDFA can mitigate the effects of these fiber linearity over repeated long-distance transmissions but there are still some factors like dispersion, which restricts the transmission distance. Here, the complete focus is given in the reduction of chromatic dispersion. In objectives DCF, IDCFBG and uniform FBG has been used separately for dispersion compensation and it has been found that uniform FBG has greatest Q-Factor and least BER among them. The technique proposed in this objective for dispersion compensation consists of a hybrid model of uniform FBG with EDC (Electronic dispersion compensation). Eventually results are analyzed for the proposed system at distinct input powers ranging from 1- 10dBm and then on the basis of Q-factor, bit error rate, Eye height & received power. For channeling of high bit rate over longer distance in the existing communication system, this model can provide a significant change.

4.6.1 System configuration of hybrid model

The combination of uniform fiber Bragg grating and electronic dispersion compensation has been proposed as dispersion compensators after single mode fiber and erbium doped fiber amplifier for the transmission of signal through optical fiber. Electronic dispersion compensation comprises of three main blocks- Low pass Gaussian filter, Electronic Limiter and Electronic Equalizer. Fig.4.129 is showing the basic components of electronic dispersion compensation in the form of block diagram.

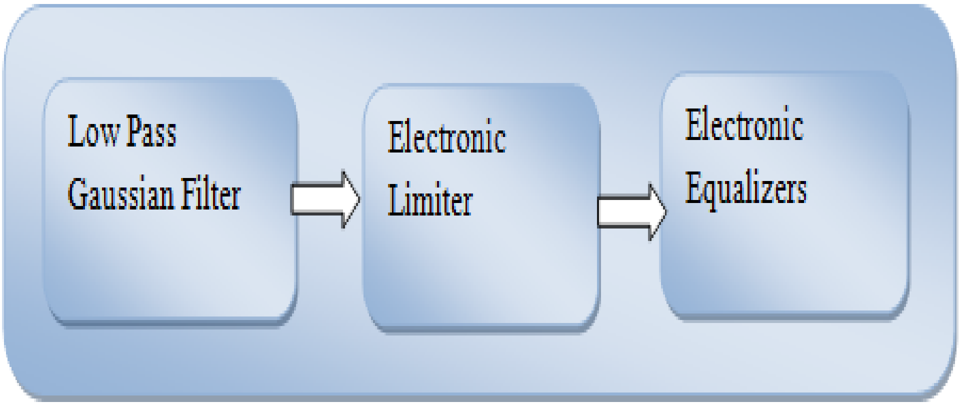


Fig.4.129: Block diagram of EDC

Fig.4.130 is showing the basic block diagram of Hybrid Model both at transmitter and receiver, which includes single mode fiber, Erbium doped fiber, Uniform fiber Bragg grating and Electronic dispersion compensation.

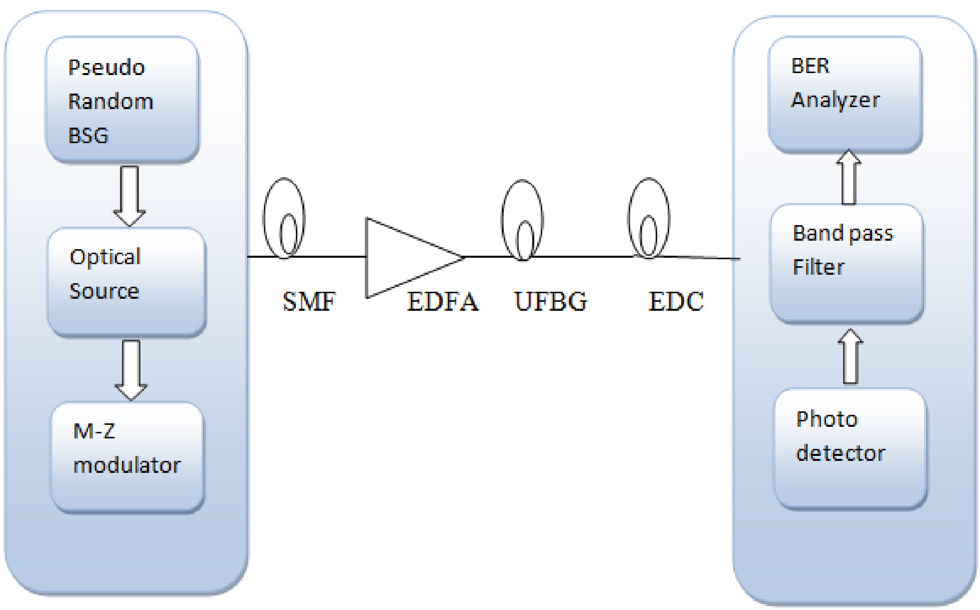


Fig.4.130: Block diagram of hybrid model

Fig.4.131 is showing the simulation setup for the Hybrid model at both the transmitter and the receiver. Table-4.28 is showing the various simulations parameters used in the computational model.

Table 4.28: Simulation parameters		
Components	**Parameters**	**Value/Units**
Uniform FBG	Frequency	193.1 THz
	Bandwidth	1 THz
	Noise Threshold	-100dB
EDC	Bit Rate	100Gbps
	Step Size	0.3
	Minimum Amplitude	0
	Maximum Amplitude	1
SMF	Length	120 Km
	Attenuation	0.2dB/Km
	Dispersion	0.01ps/nm/km

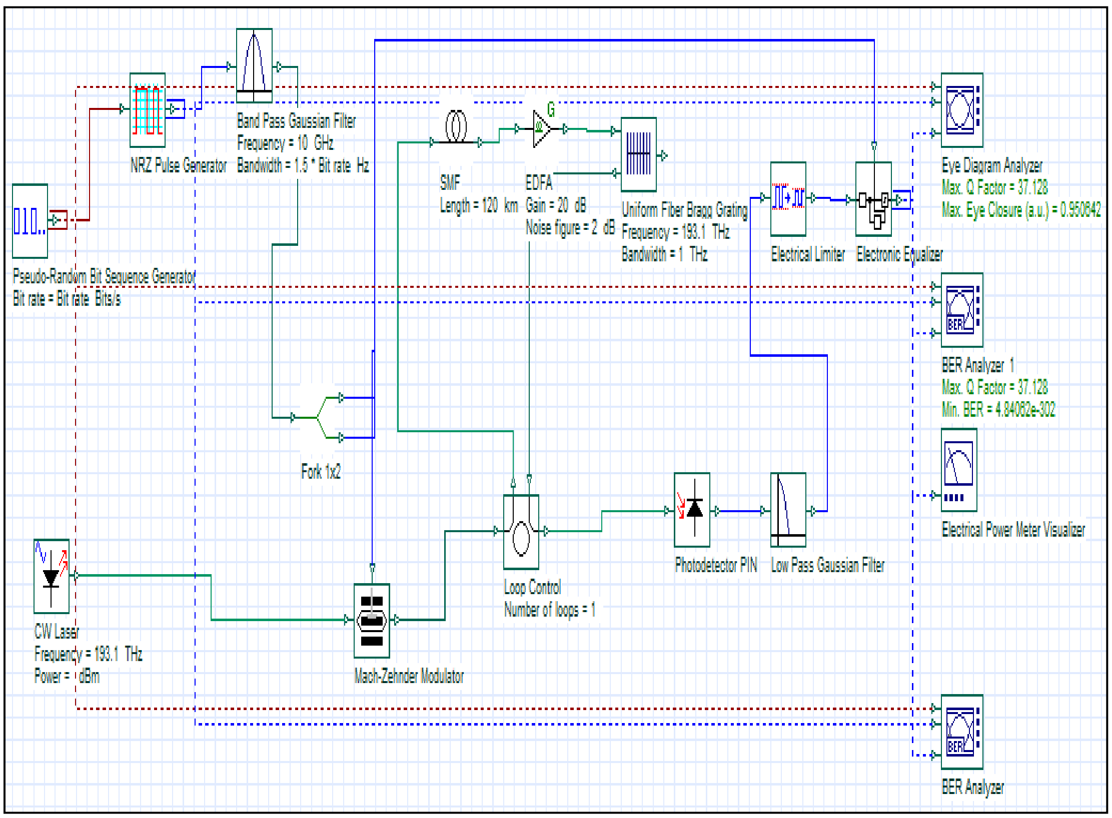


Fig.4.131: Hybrid model simulation setup

4.6.2 Results: Table-4.29 is showing the performance of the Hybrid model at distinct input power ranging from 1dBm to 10dBm. It is clear from readings that as power level of input (Iterations) rises from 1-10dBm, value of Q-factor is also somewhat increases and corresponding value of BER decreases.

Table 4.29: Performance of hybrid model at distinct input power (1-10dbm)

Input Power (dBm)	Max. Q -factor	Min BER	Eye Height	Received Power (dBm)
1	14.48	7.75E-48	0.78	26.494
2	16.69	7.40E-63	0.81	26.488
3	18.84	1.56E-79	0.83	26.481
4	21.01	2.58E-98	0.85	26.472
5	23.22	1.33E-119	0.87	26.463
6	25.51	6.30E-144	0.88	26.457
7	27.96	2.40E-172	0.89	26.45
8	30.64	1.52E-206	0.9	26.444
9	33.66	8.45E-249	0.91	26.438
10	37.12	4.84E-302	0.92	26.434

a) Eye diagrams at different input power (1-10dBm): Fig.4.132 to 4.141 are showing the eye diagrams of Hybrid model at input power from 1-10dBm.

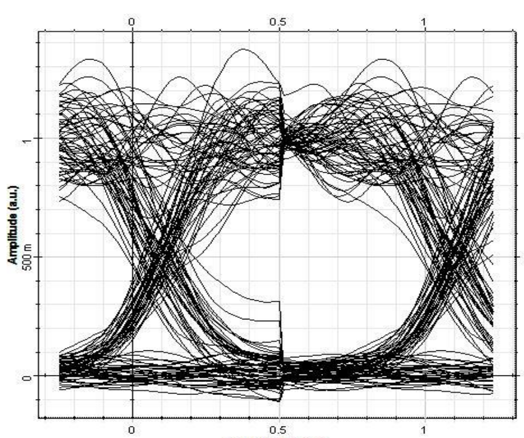


Fig.4.132: At input power 1dBm

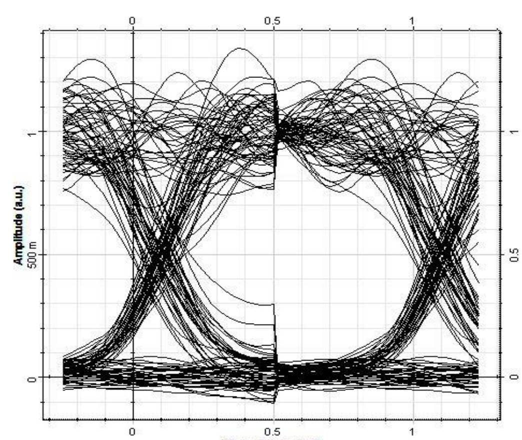


Fig.4.133: At input power 2dBm

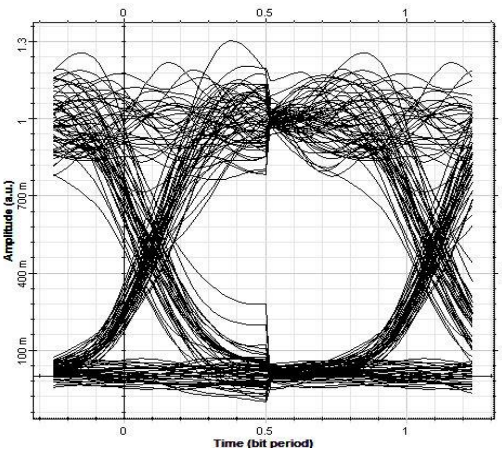


Fig.4.134: At input power 3dBm

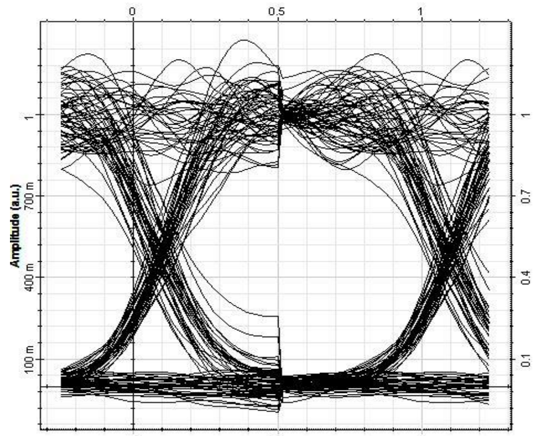


Fig.4.135: At input power 4dBm

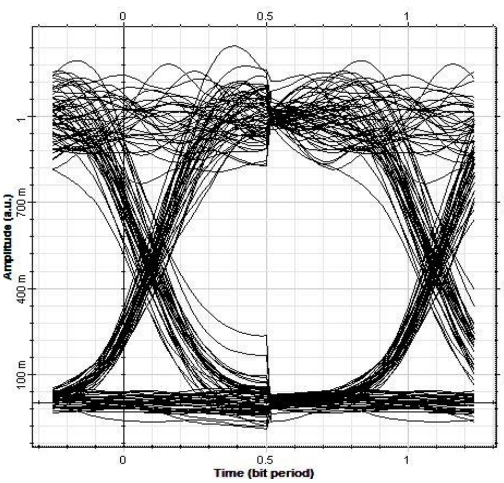


Fig.4.136: At input power 5dBm

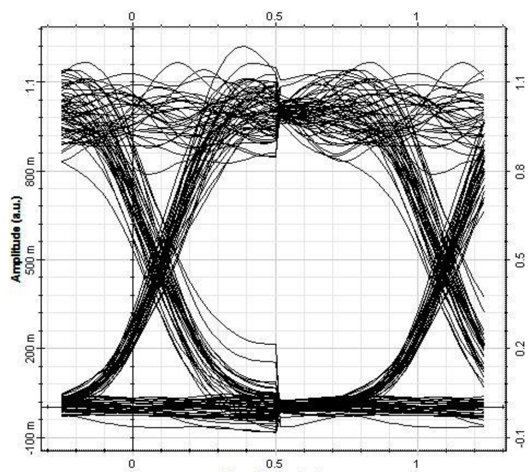


Fig.4.137: At input power 6dBm

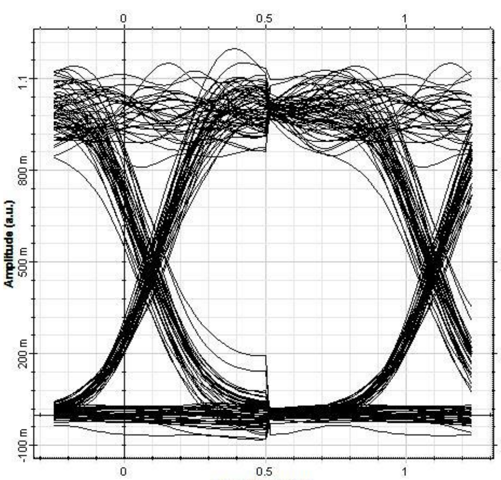


Fig.4.138: At input power 7dBm

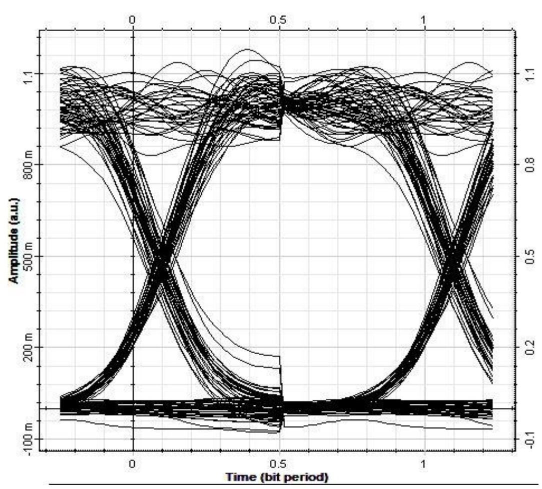


Fig.4.139: At input power 8dBm

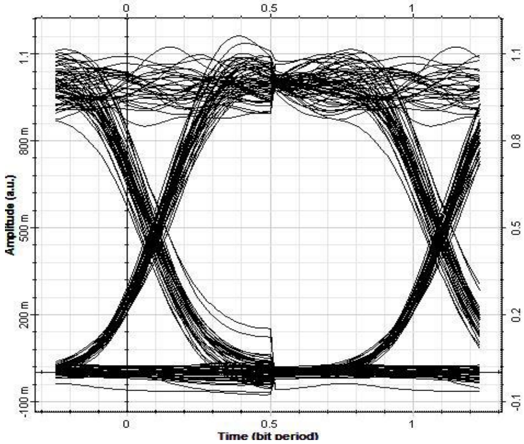


Fig.4.140: At input power 9dBm

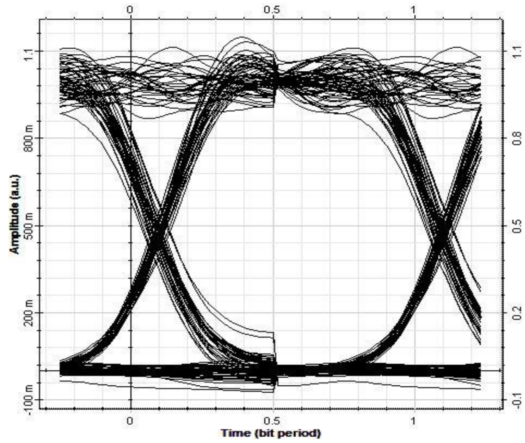


Fig.4.141: At input power 10dBm

4.6.3 Graphical representation of change in various parameters w.r.t. input power (1-10dBm):-

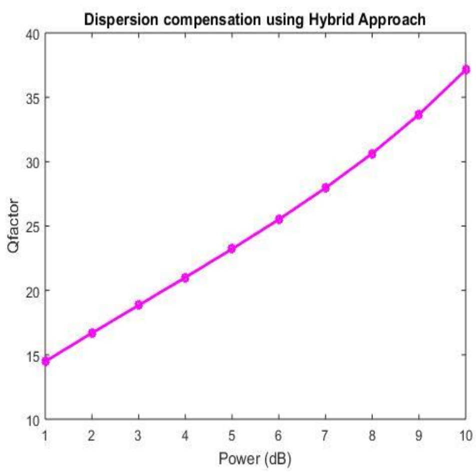


Fig.4.142: Q-Factor Vs Input power

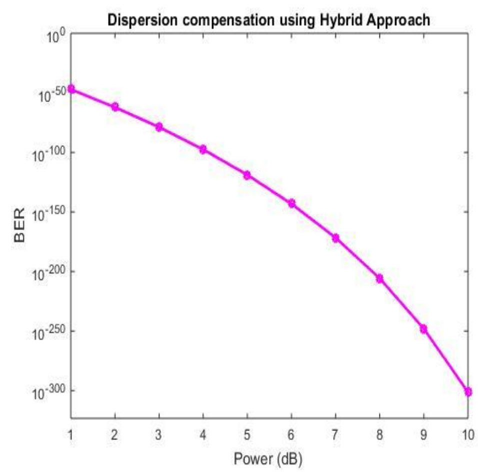


Fig.4.143: Bit Error Rate Vs Input power

Fig.4.142, 4.143, 4.144 and 4.145 are showing the graphs of Q-Factor, BER, received power and eye height with reference to variation in power level of input, respectively. From all figures, it is cleared that Q-Factor is continuously increasing as the input power is increased and hence become maximum at the highest input power (here 10dBm). BER experiences a significant decrease with the increase in the input power and thus making this hybrid model more reliable at higher input power.

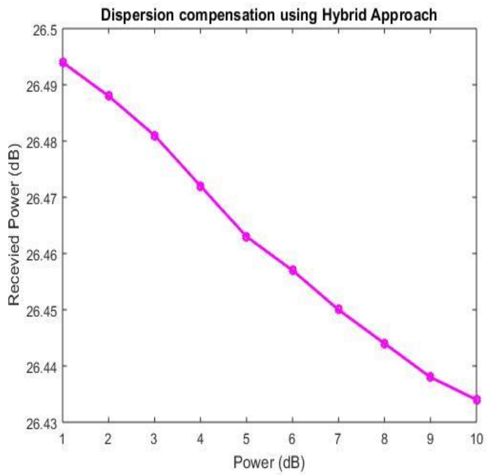


Fig.4.144: Received power Vs Input power

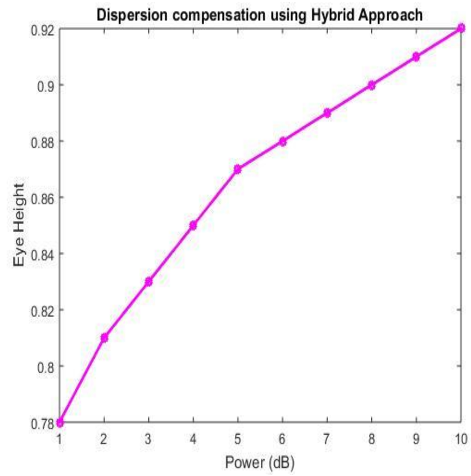


Fig.4.145: Eye Height Vs Input power

4.7 OBJECTIVE-4: Evaluate and Compare the proposed model with the existing model's performance using Optisystem simulation tool.

4.7.1 Comparison of DCF, IDCFBG and UFBG with hybrid model in all dispersion compensation scheme at 1-10dBm input power:

Table 4.30: Pre-compensation (Max. Q factor)

Iteration	DCF	IDCFBG	UFBG	Hybrid
1	6.28	5.6126	7.86036	14.48
2	6.95783	6.0295	9.13275	16.69
3	7.63629	6.44271	10.5523	18.84
4	8.29053	6.80368	12.1191	21.01
5	8.9069	7.13709	13.8391	23.22
6	9.42722	7.4555	15.7154	25.51
7	9.76613	7.69731	17.7315	27.96
8	9.89721	7.84282	19.8949	30.64
9	9.64992	7.86216	22.1653	33.66
10	9.16792	7.67143	24.5084	37.12

Table 4.31: Pre-compensation (BER)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	1.52E-10	9.5555E-09	1.7896E-15	7.75E-48
2	1.65107E-12	7.9658E-10	3.066E-20	7.40E-63
3	1.07793E-14	5.7382E-11	2.2378E-26	1.56E-79
4	5.48815E-17	5.0244E-12	3.7181E-34	2.58E-98
5	2.57404E-19	4.7247E-13	6.4329E-44	1.33E-119
6	2.07699E-21	4.4554E-14	5.08E-56	6.30E-144
7	7.78861E-23	6.9347E-15	1.015E-70	2.40E-172
8	2.1188E-23	2.2008E-15	1.856E-88	1.52E-206
9	2.42415E-22	1.88E-15	3.024E-109	8.45E-249
10	2.35499E-20	8.4957E-15	4.73E-133	4.84E-302

Table 4.32: Pre-compensation (Eye Height)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	0.000174	0.0002068	0.00030071	0.78
2	0.000239155	0.00028011	0.00041252	0.81
3	0.000321066	0.00037432	0.0005553	0.83
4	0.000424823	0.0004922	0.0007373	0.85
5	0.00055543	0.000642	0.00096891	0.87
6	0.000718801	0.000833	0.001263	0.88
7	0.000920044	0.0010709	0.00163775	0.89
8	0.00116854	0.00136614	0.00211245	0.9
9	0.00145903	0.0017826	0.00271461	0.91
10	0.00180107	0.00214	0.00347716	0.92

Table- 4.30, 4.31, 4.32 and 4.33 are showing comparison tables of DCF, IDCFBG and UFBG with Hybrid model in terms of Q- Factor, BER, eye height and received power in pre- configuration. Fig.4.146 is showing the graph of Q- Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig.4.147. Fig.4.148 is showing graph for received power and fig.4.149 is showing change in eye height with reference to variation in power level of input. All graphs have been plotted for the comparison of DCF, IDCFBG and UFBG with Hybrid model in pre-configuration. By evaluating these graphs, it is clear that the hybrid model is performing well as compare to the remaining techniques in pre-configuration scheme.

Table 4.33: Pre compensation (Received Power)

Iteration	DCF	IDCFBG	UFBG	Hybrid
1	-42.3	-39.25	-37.561	26.494
2	-40.511	-37.509	-35.979	26.488
3	-38.649	-35.67	-34.297	26.481
4	-36.739	-33.788	-32.534	26.472
5	-34.795	-31.86	-30.713	26.463
6	-32.832	-29.905	-28.846	26.457
7	-30.855	-27.93	-26.944	26.45
8	-28.869	-25.95	-25.017	26.444
9	-26.877	-23.96	-23.069	26.438
10	-24.887	-21.96	-21.106	26.434

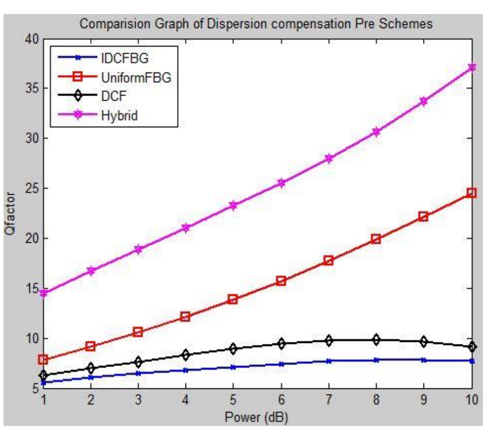


Fig.4.146: Q-Factor Comparison

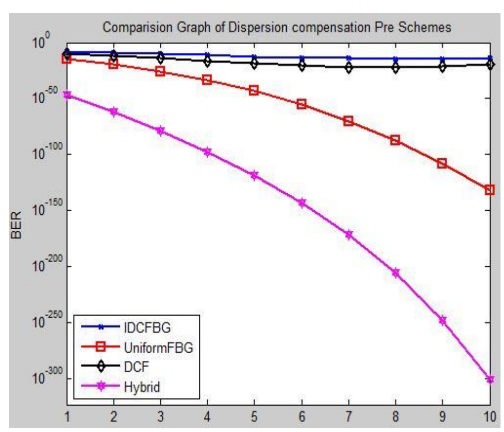


Fig.4.147: BER Comparison

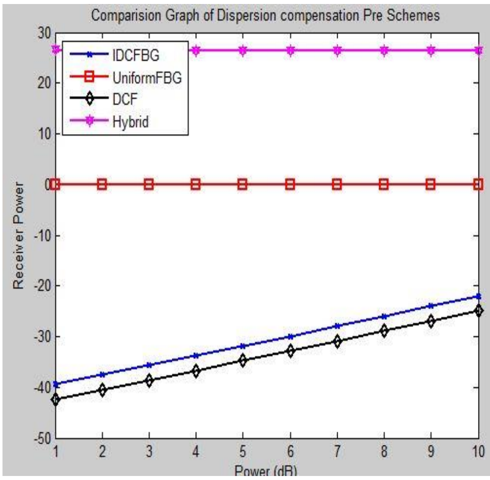


Fig.4.148: Received Power Comparison

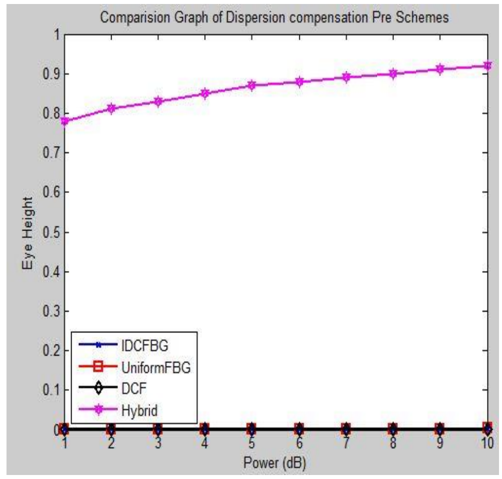


Fig.4.149: Eye Height Comparison

Fig. 4.150 is showing the graph of Q-Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig. 4.151. Fig.4.152 is showing graph for eye height and Fig.4.153 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for the comparison of DCF, IDCFBG and UFBG with Hybrid model in post configuration. By evaluating these graphs, it is clear that the hybrid model is performing well as compare to the remaining techniques in post-configuration scheme.

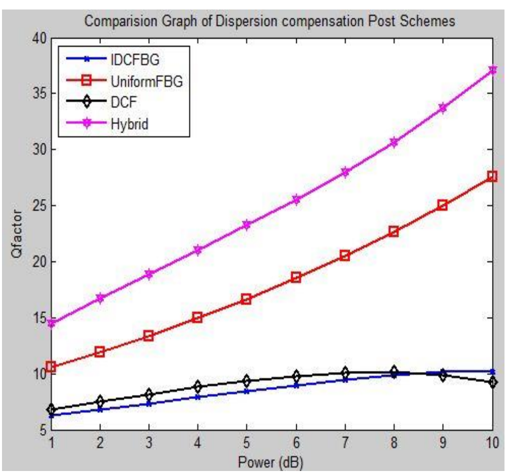


Fig.4.150: Q-Factor Comparison

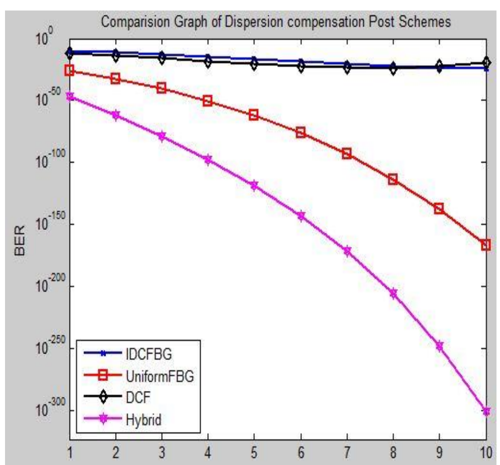


Fig.4.151: BER comparison

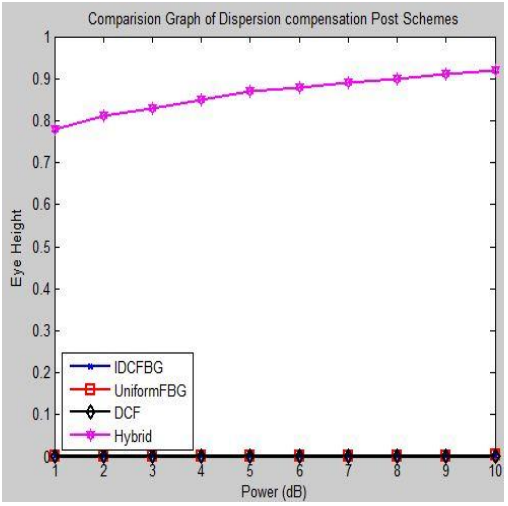


Fig.4.152: Eye Height Comparison

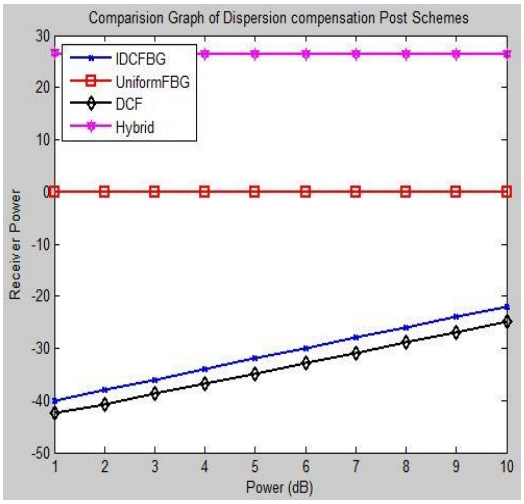


Fig.4.153: Received Power Comparison

Table-4.34, 4.35, 4.36 and 4.37 are showing comparison tables of DCF, IDCFBG and UFBG with Hybrid model in the form of Q-factor, bit error rate, eye height and power received in post configuration. Comparison results has shown that hybrid approach is best among other techniques in post-configuration.

Table 4.34: Post compensation (Max. Q factor)

Iteration	DCF	IDCFBG	UFBG	Hybrid
1	6.8305	6.2989	10.5753	14.48
2	7.46805	6.81376	11.913	16.69
3	8.11492	7.31658	13.369	18.84
4	8.80386	7.87031	14.9508	21.01
5	9.33	8.37922	16.663	23.22
6	9.8	8.94922	18.512	25.51
7	10.11	9.43164	20.5079	27.96
8	10.14	9.86961	22.6786	30.64
9	9.84	10.1927	25.028	33.66
10	9.2	10.2168	27.54	37.12

Table 4.35: Post compensation (BER)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	1.035E-12	1.4820E-10	1.5610E-26	7.75E-48
2	3.91E-14	4.7295E-12	4.0412E-33	7.40E-63
3	2.398E-16	1.2701E-13	3.5465E-41	1.56E-79
4	6.56E-19	1.7688E-15	5.967E-51	2.58E-98
5	5.2E-21	2.6618E-17	9.121E-63	1.33E-119
6	5.31E-23	1.7833E-19	6.1148E-77	6.30E-144
7	2.42E-24	2.0053E-21	6.6143E-94	2.40E-172
8	1.73E-24	2.1794E-23	2.545E-114	1.52E-206
9	3.46E-23	1.0608E-24	1.040E-138	8.45E-249
10	1.69E-20	8.3166E-25	1.95E-167	4.84E-302

Table 4.36: Post compensation (Eye Height)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	0.000186	0.0002255	0.00036	0.78
2	0.00025	0.000303981	0.0004752	0.81
3	0.0003316	0.0004038	0.0006205	0.83
4	0.0004352	0.0005343	0.0008056	0.85
5	0.0005621	0.0006996	0.00104	0.87
6	0.000722	0.0009152	0.00133935	0.88
7	0.000917	0.00118621	0.001718	0.89
8	0.00115	0.00152983	0.002197	0.9
9	0.00142	0.00196169	0.002805	0.91
10	0.00173	0.002486	0.00357	0.92

Table 4.37: Post compensation (Received Power)				
Iteration	DCF	IDCFBG	UFBG	Hybrid
1	-42.5	-39.957	-39.619	26.494
2	-40.647	-37.969	-37.63	26.488
3	-38.74	-35.978	-35.637	26.481
4	-36.8	-33.983	-33.642	26.472
5	-34.85	-31.988	-31.645	26.463
6	-32.88	-29.98	-29.64	26.457
7	-30.9	-27.99	-27.649	26.45
8	-28.92	-25.99	-25.649	26.444
9	-26.93	-23.99	-23.647	26.438
10	-24.954	-21.99	-21.646	26.434

Table 4.38: Mix compensation (Q-Factor)				
Iteration	DCF	IDCFBG	UFBG	Hybrid
1	3.1	5.642	7.86135	14.48
2	3.62	6.08952	9.13437	16.69
3	4.22	6.55263	10.5549	18.84
4	4.9	7.03329	12.1228	21.01
5	5.61	7.50209	13.8473	23.22
6	6.37	8.00555	15.7283	25.51
7	7.1	8.51057	17.7594	27.96
8	7.8	9.01882	19.9478	30.64
9	8.36	9.51562	22.2657	33.66
10	8.69	9.8168	24.7116	37.12

Table 4.39: Mix compensation (BER)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	8.86E-04	8.03E-09	1.78E-12	7.75E-48
2	1.30E-04	5.47E-10	3.02E-20	7.40E-63
3	1.07E-05	2.76E-11	2.18E-26	1.56E-79
4	4.19E-07	9.93E-13	3.56E-34	2.58E-98
5	8.72E-09	3.11E-14	5.75E-44	1.33E-119
6	7.93E-11	5.92E-16	4.15E-56	6.30E-144
7	5.23E-13	8.64E-18	6.10E-71	2.40E-172
8	2.69E-15	9.50E-20	6.47E-89	1.52E-206
9	2.74E-17	9.03E-22	3.25E-110	8.45E-249
10	1.49E-18	4.77E-23	3.18E-135	4.84E-302

Table 4.40: Mix compensation (Eye Height)				
Iteration	**DCF**	**IDCFBG**	**UFBG**	**Hybrid**
1	3.20E-06	0.000208161	0.000300701	0.78
2	2.71E-05	0.000283	0.000412487	0.81
3	4.41E-05	0.00038	0.000555242	0.83
4	7.39E-05	0.0005058	0.000737193	0.85
5	1.10E-04	0.000666	0.000968757	0.87
6	1.57E-04	0.000875	0.00126326	0.88
7	2.10E-04	0.0011424	0.00163741	0.89
8	2.80E-04	0.00148	0.00211202	0.9
9	3.70E-04	0.00192371	0.00271419	0.91
10	4.70E-04	0.00246	0.00347709	0.92

Table 4.41: Mix compensation (Received Power)				
Iteration	DCF	IDCFBG	UFBG	Hybrid
1	-48.89	-39.259	-39.003	26.494
2	-48.19	-37.513	-37.229	26.488
3	-47.26	-35.682	-35.38	26.481
4	-46.11	-33.793	-33.478	26.472
5	-44.74	-31.865	-31.541	26.463
6	-43.18	-29.91	-29.581	26.457
7	-41.5	-27.94	-27.606	26.45
8	-39.7	-25.959	-25.622	26.444
9	-37.84	-23.97	-23.631	26.438
10	-35.94	-21.979	-21.635	26.434

Table-4.38, 4.39, 4.40 and 4.41 are showing comparison tables of DCF, IDCFBG and UFBG with Hybrid model in the form of Quality Factor, Bit error rate, eye height and power received in mix configuration.

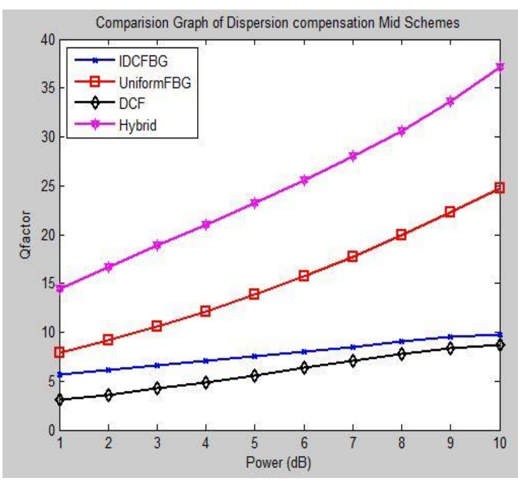


Fig.4.154: Q-Factor Comparison

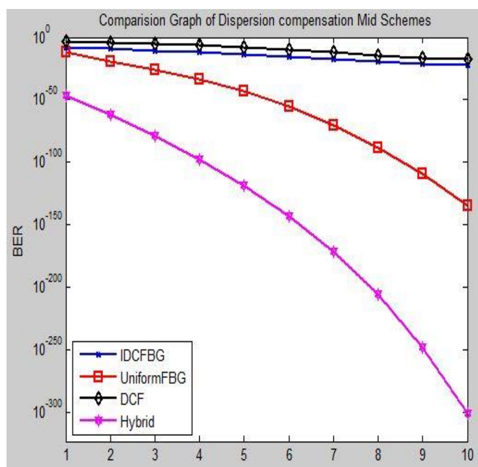


Fig.4.155: BER Comparison

Fig.4.154 is showing the graph of Quality Factor with reference to variation in power level of input whereas change of BER with change in input power is shown in Fig.4.155.

Fig.4.156 is showing graph for eye height and Fig.4.157 is showing change in received power with reference to variation in power level of input. All graphs have been plotted for the comparison of DCF, IDCFBG and UFBG with Hybrid model in mix configuration.

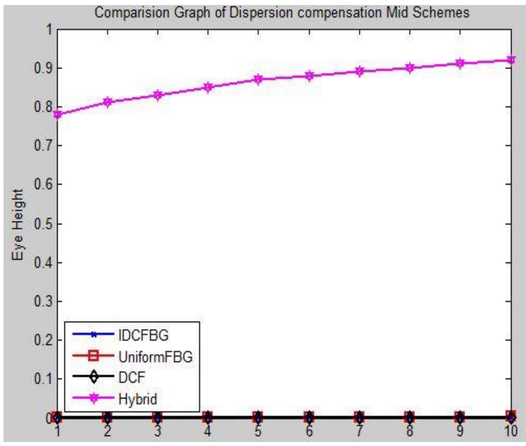


Fig.4.156: Eye Height Comparison

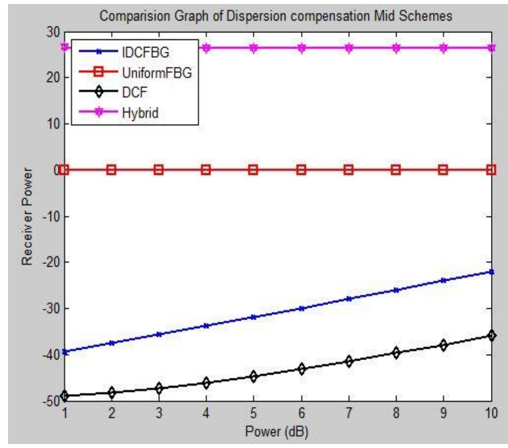


Fig.4.157: Received Power Comparison

4.7.2 Comparison of best existing dispersion compensation techniques with hybrid technique:- Fig. 4.158 is showing the comparison graph of Q-factor of DCF, IDCFBG and UFBG with Hybrid model. Similarly, BER comparison of DCF, IDCFBG and UFBG with Hybrid model is shown in Fig.4.159.

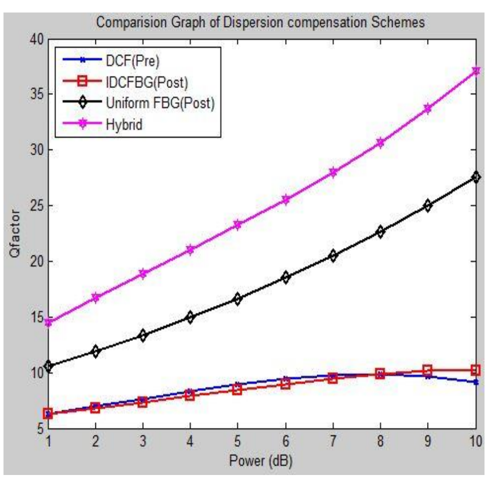


Fig.4.158: Q-Factor Comparison

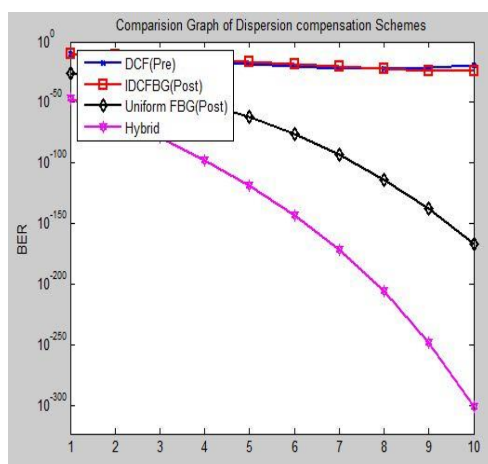
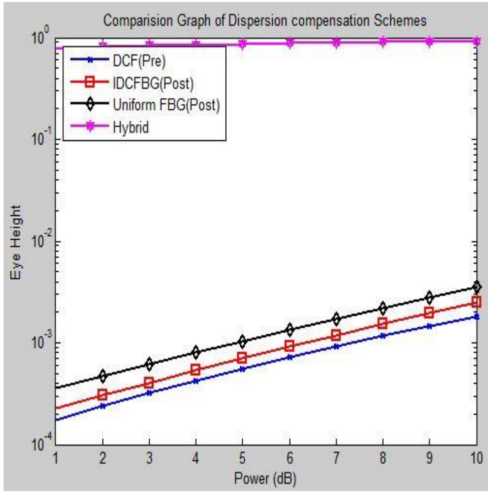


Fig.4.159: BER Comparison



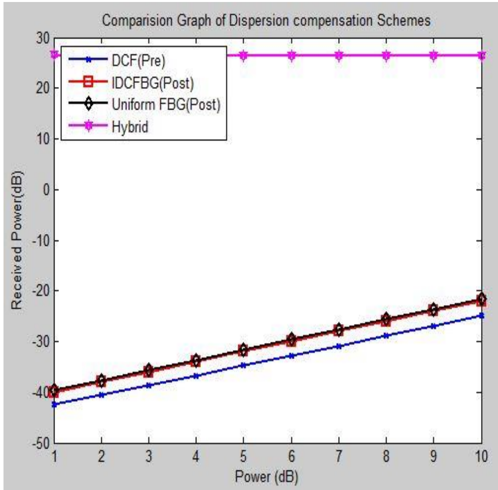


Fig.4.160: Eye Height Comparison   Fig.4.161: Received Power Comparison

Fig.4.160 is explaining the eye height comparison of three schemes with Hybrid approach. It is clear from the graphical representation that eye opening is broader in Hybrid model as compare to the remaining model. Whereas Fig. 4.161 shows received power comparison of three schemes with Hybrid approach. Again, it is clear from the graphs that the received power is more in Hybrid model as compare to the remaining schemes.

The final comparison of best existing configurations of all three techniques i.e. Post configuration of DCF, Post configuration of IDCFBG and Post configuration of UFBG with Hybrid approach is tabulated in Table-4.42.

Table 4.42: Comparison of best existing techniques with Hybrid technique					
Techniques	**Iteration**	**Q-Factor**	**BER**	**Received Power**	**Eye Height**
DCF (Post compensation)	1	6.8305	1.04E-12	-42.5	0.000186
	2	7.46805	3.91E-14	-40.647	0.00025
	3	8.11492	2.40E-16	-38.74	0.0003316
	4	8.80386	6.56E-19	-36.8	0.0004352
	5	9.33	5.20E-21	-34.85	0.0005621
	6	9.8	5.31E-23	-32.88	0.000722
	7	10.11	2.42E-24	-30.9	0.000917
	8	10.14	1.73E-24	-28.92	0.00115
	9	9.84	3.46E-23	-26.93	0.00142
	10	9.2	1.69E-20	-24.954	0.00173
IDCFBG (Post compensation)	1	6.2989	1.48209E-10	-39.957	0.0002255
	2	6.81376	4.7295E-12	-37.969	0.0003039
	3	7.31658	1.27011E-13	-35.978	0.0004038
	4	7.87031	1.7688E-15	-33.983	0.0005343
	5	8.37922	2.66181E-17	-31.988	0.0006996
	6	8.94922	1.7833E-19	-29.98	0.0009152
	7	9.43164	2.00538E-21	-27.99	0.0011862
	8	9.86961	2.17948E-23	-25.99	0.0015298
	9	10.1927	1.06085E-24	-23.99	0.0019616
	10	10.2168	8.31665E-25	-21.99	0.002486
Uniform FBG (Post compensation)	1	10.5753	1.56102E-26	-39.619	0.00036
	2	11.913	4.0412E-33	-37.63	0.0004752
	3	13.369	3.5465E-41	-35.637	0.0006205
	4	14.9508	5.967E-51	-33.642	0.0008056
	5	16.663	9.121E-63	-31.645	0.00104
	6	18.512	6.1148E-77	-29.64	0.0013393
	7	20.5079	6.6143E-94	-27.649	0.001718
	8	22.6786	2.5457E-114	-25.649	0.002197
	9	25.028	1.0408E-138	-23.647	0.002805
	10	27.54	1.95E-167	-21.646	0.00357
Hybrid Model	1	14.48	7.75E-48	26.494	0.78
	2	16.69	7.40E-63	26.488	0.81
	3	18.84	1.56E-79	26.481	0.83
	4	21.01	2.58E-98	26.472	0.85
	5	23.22	1.33E-119	26.463	0.87
	6	25.51	6.30E-144	26.457	0.88
	7	27.96	2.40E-172	26.45	0.89
	8	30.64	1.52E-206	26.444	0.9
	9	33.66	8.45E-249	26.438	0.91
	10	37.12	4.84E-302	26.434	0.92

4.8 SUMMARY

This part of the thesis outlines the results that are achieved after completing the four objectives. Initially DCF is used as dispersion compensator for reparation of chromatic dispersion at bit rate of 100Gbps over 120Km transmission distance. Out of the three configurations of DCF, post configuration exhibited highest value of Q-Factor and least BER at input power of 10dBm. Similar analysis is done by utilizing IDCFBG at different input powers of 1-10dBm. Again post configuration resulted into better scheme in comparison to pre and mix configuration. UFBG is another technique used for chromatic dispersion compensation. After analyzing, it is found that its post scheme is best among others by attaining a highest Quality Factor and least BER at input power 10dBm. Second objective accomplished the comparison performance of all the three techniques i.e. DCF, IDCFBG and UFBG in their respective configurations. Comparison results are analyzed and it is observed that post configuration of UFBG is exhibiting Q -Factor and BER superior than DCF and IDCFBG at same input powers and same rate. Eventually the third objective proposed a hybrid model of UFBG in conjunction with EDC. The outcomes of this hybrid model are analyzed and it came with best results ever when compared with DCF, IDCFBG and UFBG.

CHAPTER-5
CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

Dispersion compensation in optic fiber system is obligatory to overcome non-linear and other signal degradation factors. For the remuneration of the dispersion in optic fiber communication, distinct methods are available. Out of those methods the most commonly used methods are DCF, FBG, Digital filters & EDC using signal processing. All of these dispersion reparation techniques have their own advantages as well as disadvantages. Literature survey of compensation of chromatic dispersion in fiber optics shows the use of these compensation methods at different bit rates. Some of the researches in this field include dispersion compensation either by using single mode fiber (SMF) or by using wavelength division multiplexed (WDM) system. Some simulations have also been carried by using dense wavelength division multiplexed systems (DWDM). In our work, dispersion has been compensated at 100 Gbps rate over a transmitting distance of 120Km by using SMF. The research incorporates use of four distinct techniques for compensation of dispersion by using software Optisystem 7.0. In the initial objective, Dispersion compensating fiber (DCF) is used as dispersion compensator along with SMF to mitigate the consequences of dispersion present in transmitted signal. Simulation models for DCF in pre configuration, post configuration and symmetrical configuration are simulated by using a dispersion compensating fiber (DCF) of length 24 Km along with single mode fiber of length 120Km. The results are analyzed at input power ranging from 1-10dBm. It has been found that Pre configuration of DCF exhibited the Q-Factor and BER of

9.16792 and 2.35E- 20 at input power 10dBm whereas in Post configuration, the values of Q-factor and BER are 9.2 and 1.69E-20, respectively. Similarly, for symmetrical configuration, Q-Factor and BER are equal to 8.69 and 1.49E-18, respectively. Thus, post configuration of DCF achieved better results in comparison to other configurations. Next experiment is done by using another mostly used dispersion compensation methodology of IDCFBG. As like DCF this technique is also implemented in three schemes that are Pre, Post and Symmetrical. All the simulations are carried out at an input power level ranging from 1-10dBm. When the simulation models are simulated, it is observed that the proposed models are exhibiting the maximum value of Q-Factor and minimum value of BER at input power 10dBm only for all the three configurations of IDCFBG. Another analysis reached to an outcome that Post configuration of IDCFBG is the best scheme among others with a highest Q- Factor of 10.2168 and lowest BER of 8.32E- 25. Q-Factor and BER of Pre compensation IDCFBG are 7.67143 and 8.50E-15, respectively whereas for Mix configuration the values are 9.8168 and 4.77E-23. Third objective accomplished the compensation of chromatic dispersion using uniform fiber Bragg grating (UFBG) as dispersion compensator at input powers ranging from 1-10dBm. Different parameters are varied in order to lessen impact of dispersion on the transmitted signal. UFBG is simulated for the three schemes that are Pre configuration, Post configuration and Mix configuration. During analysis it has been found that increase in input power increases the Q-factor for all the 3 mechanisms of Pre, Post and Mix compensation. At input power level of 10 dBm, pre configuration attained a Q-Factor of 24.7116 & BER of 3.18E-13 whereas post configuration of UFBG has values equal to 27.54 and 1.95E-16. Mix configuration also obtained highest Q-Factor of 24.5084 and lowest BER of 4.73E-13. Hence, after analyzing all the factors, Post compensation of UFBG at input power 10dBm found to exhibit best results with a maximum of Q-Factor equals to 27.54 and minimum BER equals to 1.95E-16 when compared with the remaining techniques. Next objective is to find out the best technique among the existing dispersion compensation techniques in optic communication. For achieving this factor, previously used three techniques that are DCF, IDCFBG & UFBG are compared in terms of eye height, Q-Factor, received power & BER. This comparison is done for all the 3 mechanisms of pre, post and mix. Initially, pre configuration of DCF, IDCFBG and UFBG is analyzed by observing the graphs. It is observed that DCF have Q-factor and BER equal to 9.16792 and 2.35499E-20, respectively. Similarly for IDCFBG these values are 7.67143 and 8.4957E-15.Finally, it is concluded that UFBG displays better results than other remaining techniques with a highest Q-factor of 24.5084 and lowest BER of 4.73E-133 in pre-configuration. Another comparison is done by comparing the post configurations of three techniques. Post DCF has values 9.2 and 1.69E-20 of Q-Factor and BER, respectively whereas for post IDCFBG the values are 10.2168 and 8.31665E-25. The conclusion shows that again UFBG is acquiring the desired condition of max. Q-Factor and min. BER equals to 27.54 and 1.95E-167, respectively in post configuration. Same results occur for mix configuration, thereby, making the mix configuration of UFBG superior than mix configuration of DCF and IDCFBG along with Q-factor and BER equals to 24.7116 and 3.18E-135, respectively. Thus, it is concluded that UFBG performs far better than DCF and IDCFBG at 100Gbps over 120Km of single mode fiber, especially in post configuration, thereby, making it optimal technique of dispersion compensation. Finally the last objective proposed a hybrid approach with best FBG technique and EDC (electronic dispersion compensator) based system for establishing an upgraded model to achieve high data rate with least chromatic dispersion. This Uniform fiber Bragg grating (UFBG) dispersion compensation technique in post compensation along with EDC is modeled as Hybrid Dispersion compensation. This Hybrid model is executed in this research only for the first time. This model used electronic equalizer as electronic dispersion compensation. Various parameters of electronic equalizer are varied in accordance to get the desired outcomes. Some of the parameters includes step size of 0.3, leakage factor of 1 and forward tap coefficients equal to 7. LMS algorithm is implemented to upgrade the coefficients of the filter. This hybrid model is executed at input powers from 1- 10dBm. Q-Factor, BER, received power and eye height of this hybrid technique is compared with all the best configurations of DCF, IDCFBG and UFBG i.e. Post DCF, Post IDCFBG and Post UFBG. After analyzing the results, it is clear that the Hybrid model is achieving a maximum Q- Factor of 37.12 and least BER of 4.84E-302 that is more than the Q-factor and bit error rates of all other existing dispersion compensation techniques. Thus, the conclusion shows the hybrid technique to be the best for dispersion compensation at 100Gbps over 120Km distance among other existing compensation techniques.

5.2 SCOPES FOR FUTURE WORK

The future directions for research can be made on optimizing the design parameters which would be carried out to strengthen the work on dispersion compensation for service providers. As we have designed the hybrid model by using EDC and UFBG for dispersion compensation so distinct combinations of dispersion compensation techniques can be combined together to form a new hybrid model for compensation of dispersion. Another scope for future work is to change equalization mechanism in electronic dispersion compensation (EDC) for dispersion compensation.

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APPENDIX-I

Program to Plot the graph showing comparison of Q-factor, BER, Eye height and received power in Pre, Post and mix configuration using IDCFBG technique for dispersion compensation.

```
clc
close all
clear all
MIX1=xlsread('IDCFBGresult.xlsx','mix1');
POST1=xlsread('IDCFBGresult.xlsx','POST1');
PRE1=xlsread('IDCFBGresult.xlsx','pre1');
 %% User 1
 fig.
plot(MIX1(:,2),'x-','linewidth',2)
hold on
plot(POST1(:,2),'rs-','linewidth',2)
hold on
plot(PRE1(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('Mid ','Post ','Pre',2)
title('Dispersion compensation using Ideal dispersion compensation fbg')
 fig.
semilogy(MIX1(:,3),'x-','linewidth',2)
hold on
semilogy(POST1(:,3),'rs-','linewidth',2)
hold on
semilogy(PRE1(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('Mid - 1','Post - 1','Pre - 1',3)
title('Dispersion compensation using Ideal dispersion compensation fbg')
fig.
plot(MIX1(:,4),'x-','linewidth',2)
hold on
plot(POST1(:,4),'rs-','linewidth',2)
hold on
plot(PRE1(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('Mid ','Post ','Pre',2)
title('Dispersion compensation using Ideal dispersion compensation fbg')
 fig.
plot(MIX1(:,7),'x-','linewidth',2)
hold on
plot(POST1(:,7),'rs-','linewidth',2)
hold on
plot(PRE1(:,7),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Received Power (dB)')
legend('Mid ','Post ','Pre',2)
title('Dispersion compensation using Ideal dispersion compensation fbg')
```

APPENDIX-II

Program to Plot the graph showing comparison of Q-factor, BER, Eye height and received power in Pre, Post and symmetrical configuration using DCF technique for dispersion compensation.

```
clc
close all
clear all
dsym=xlsread('ResultExcel.xlsx','SYM');
dPost=xlsread('ResultExcel.xlsx','POST');
dPre=xlsread('ResultExcel.xlsx','PRE');
%% User 1
fig.
plot(dsym(:,2),'x-','linewidth',2)
hold on
plot(dPost(:,2),'rs-','linewidth',2)
hold on
plot(dPre(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using DCF')
fig.
semilogy(dsym(:,3),'x-','linewidth',2)
hold on
semilogy(dPost(:,3),'rs-','linewidth',2)
hold on
semilogy(dPre(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('Mix - 1','Post - 1','Pre - 1',3)
title('Dispersion compensation using DCF')
fig.
plot(dsym(:,4),'x-','linewidth',2)
hold on
plot(dPost(:,4),'rs-','linewidth',2)
hold on
plot(dPre(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using DCF')
fig.
plot(dsym(:,5),'x-','linewidth',2)
hold on
plot(dPost(:,5),'rs-','linewidth',2)
hold on
plot(dPre(:,5),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Received Power (dB)')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using DCF')
```

APPENDIX-III

Program to Plot the graph showing comparison of Q-factor, BER, Eye height and received power in Pre, Post and mix configuration using UFBG technique for dispersion compensation.

```
clc
close all
clear all
uMIX1=xlsread('UniformFBGresult.xlsx','Sheet1');
uPOST1=xlsread('UniformFBGresult.xlsx','Sheet4');
uPRE1=xlsread('UniformFBGresult.xlsx','Sheet7');
%% User 1
fig.
plot(uMIX1(:,2),'x-','linewidth',2)
hold on
plot(uPOST1(:,2),'rs-','linewidth',2)
hold on
plot(uPRE1(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using Uniform FBG')
fig.
semilogy(uMIX1(:,3),'x-','linewidth',2)
hold on
semilogy(uPOST1(:,3),'rs-','linewidth',2)
hold on
semilogy(uPRE1(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('Mix - 1','Post - 1','Pre - 1',3)
title('Dispersion compensation using Uniform FBG')
fig.
plot(uMIX1(:,4),'x-','linewidth',2)
hold on
plot(uPOST1(:,4),'rs-','linewidth',2)
hold on
plot(uPRE1(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using Uniform FBG')
fig.
plot(uMIX1(:,7),'x-','linewidth',2)
hold on
plot(uPOST1(:,7),'rs-','linewidth',2)
hold on
plot(uPRE1(:,7),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Received Power (dB)')
legend('Mix - 1','Post - 1','Pre - 1',2)
title('Dispersion compensation using Uniform FBG')
```

APPENDIX-IV

Program to Plot the graphs showing comparison of Q-factor, BER, Eye height and received power in Pre, Post and mix configuration of IDCFBG, DCF and UFBG techniques to find out best technique with best configuration for dispersion compensation.

```
clc
close all
clear all

MIX1=xlsread('IDCFBGresult.xlsx','mix1');
POST1=xlsread('IDCFBGresult.xlsx','POST1');
PRE1=xlsread('IDCFBGresult.xlsx','pre1');
uMIX1=xlsread('UniformFBGresult.xlsx','Sheet1');
uPOST1=xlsread('UniformFBGresult.xlsx','Sheet4');
uPRE1=xlsread('UniformFBGresult.xlsx','Sheet7');
dsym=xlsread('ResultExcel.xlsx','SYM');
dPost=xlsread('ResultExcel.xlsx','POST');
dPre=xlsread('ResultExcel.xlsx','PRE');

%%
fig.
plot(MIX1(:,2),'x-','linewidth',2)
hold on
plot(uMIX1(:,2),'rs-','linewidth',2)
hold on
plot(dsym(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

fig.
semilogy(MIX1(:,3),'x-','linewidth',2)
hold on
semilogy(uMIX1(:,3),'rs-','linewidth',2)
hold on
semilogy(dsym(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

fig.
plot(MIX1(:,4),'x-','linewidth',2)
hold on
plot(uMIX1(:,4),'rs-','linewidth',2)
hold on
plot(dsym(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
```

```
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

fig.
plot(MIX1(:,7),'x-','linewidth',2)
hold on
plot(uMIX1(:,7),'rs-','linewidth',2)
hold on
plot(dsym(:,5),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Received Power')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

%%

fig.
plot(POST1(:,2),'x-','linewidth',2)
hold on
plot(uPOST1(:,2),'rs-','linewidth',2)
hold on
plot(dPost(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Post Schemes')

fig.
semilogy(POST1(:,3),'x-','linewidth',2)
hold on
semilogy(uPOST1(:,3),'rs-','linewidth',2)
hold on
semilogy(dPost(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Post Schemes')

fig.
plot(POST1(:,4),'x-','linewidth',2)
hold on
plot(uPOST1(:,4),'rs-','linewidth',2)
hold on
plot(dPost(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Post Schemes')

fig.
plot(POST1(:,7),'x-','linewidth',2)
```

```
hold on
plot(uPOST1(:,7),'rs-','linewidth',2)
hold on
plot(dPost(:,5),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Receiver Power')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Post Schemes')

%%

fig.
plot(PRE1(:,2),'x-','linewidth',2)
hold on
plot(uPRE1(:,2),'rs-','linewidth',2)
hold on
plot(dPre(:,2),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Pre Schemes')
fig.
semilogy(PRE1(:,3),'x-','linewidth',2)
hold on
semilogy(uPRE1(:,3),'rs-','linewidth',2)
hold on
semilogy(dPre(:,3),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Pre Schemes')
fig.
plot(PRE1(:,4),'x-','linewidth',2)
hold on
plot(uPRE1(:,4),'rs-','linewidth',2)
hold on
plot(dPre(:,4),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Pre Schemes')
fig.
plot(PRE1(:,7),'x-','linewidth',2)
hold on
plot(uPRE1(:,7),'rs-','linewidth',2)
hold on
plot(dPre(:,5),'kd-','linewidth',2)
xlabel('Power (dB)')
ylabel('Receiver Power')
legend('IDCFBG','UniformFBG','DCF',2)
title('Comparison Graph of Dispersion compensation Pre Schemes')
```

APPENDIX-V

Program to Plot the graph showing Q-factor, BER, Eye height and received power w.r.t. input power using Hybrid technique for dispersion compensation.

```
clc
close all
clear all

%% Proposed Model

Propsd=xlsread('HybirdModelR.xlsx');

fig.
plot(Propsd(:,2),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
title('Dispersion compensation using Hybrid Approach')

fig.
semilogy(Propsd(:,3),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
title('Dispersion compensation using Hybrid Approach')

fig.
plot(Propsd(:,4),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
title('Dispersion compensation using Hybrid Approach')

fig.
plot(Propsd(:,5),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Received Power (dB)')
title('Dispersion compensation using Hybrid Approach')
```

APPENDIX-VI

Program to Plot the graph showing comparison of Q-factor, BER, Eye height and received power in best configuration of IDCFBG, DCF UFBG techniques with Hybrid technique for dispersion compensation.

```
clc
close all
clear all

MIX1=xlsread('IDCFBGresult.xlsx','mix1');
POST1=xlsread('IDCFBGresult.xlsx','POST1');
PRE1=xlsread('IDCFBGresult.xlsx','pre1');
uMIX1=xlsread('UniformFBGresult.xlsx','Sheet1');
uPOST1=xlsread('UniformFBGresult.xlsx','Sheet4');
uPRE1=xlsread('UniformFBGresult.xlsx','Sheet7');
dsym=xlsread('ResultExcel.xlsx','SYM');
dPost=xlsread('ResultExcel.xlsx','POST');
dPre=xlsread('ResultExcel.xlsx','PRE');
Propsd=xlsread('HybirdModelR.xlsx');

%%
fig.
plot(MIX1(:,2),'x-','linewidth',2)
hold on
plot(uMIX1(:,2),'rs-','linewidth',2)
hold on
plot(dsym(:,2),'kd-','linewidth',2)
hold on
plot(Propsd(:,2),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

fig.
semilogy(MIX1(:,3),'x-','linewidth',2)
hold on
semilogy(uMIX1(:,3),'rs-','linewidth',2)
hold on
semilogy(dsym(:,3),'kd-','linewidth',2)
hold on
semilogy(Propsd(:,3),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison Graph of Dispersion compensation Mid Schemes')

fig.
plot(MIX1(:,4),'x-','linewidth',2)
```

```
hold on
plot(uMIX1(:,4),'rs-','linewidth',2)
hold on
plot(dsym(:,4),'kd-','linewidth',2)
hold on
plot(Propsd(:,4),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison Graph of Dispersion compensation Mid Schemes')
fig.
plot(MIX1(:,7),'x-','linewidth',2)
hold on
plot(uMIX1(:,7),'rs-','linewidth',2)
hold on
plot(dsym(:,5),'kd-','linewidth',2)
hold on
plot(Propsd(:,5),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Receiver Power')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison Graph of Dispersion compensation Mid Schemes')

%%

fig.
plot(POST1(:,2),'x-','linewidth',2)
hold on
plot(uPOST1(:,2),'rs-','linewidth',2)
hold on
plot(dPost(:,2),'kd-','linewidth',2)
hold on
plot(Propsd(:,2),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Q-factor')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison Graph of Dispersion compensation Post Schemes')
fig.
semilogy(POST1(:,3),'x-','linewidth',2)
hold on
semilogy(uPOST1(:,3),'rs-','linewidth',2)
hold on
semilogy(dPost(:,3),'kd-','linewidth',2)
hold on
semilogy(Propsd(:,3),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison Graph of Dispersion compensation Post Schemes')

fig.
```

```
plot(POST1(:,4),'x-','linewidth',2)
hold on
plot(uPOST1(:,4),'rs-','linewidth',2)
hold on
plot(dPost(:,4),'kd-','linewidth',2)
hold on
plot(Propsd(:,4),'m-h','linewidth',2)
xlabel('Power  (dB)')
ylabel('Eye  Height')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison  Graph of Dispersion  compensation  Post Schemes')

fig.
plot(POST1(:,7),'x-','linewidth',2)
hold on
plot(uPOST1(:,7),'rs-','linewidth',2)
hold on
plot(dPost(:,5),'kd-','linewidth',2)
hold on
plot(Propsd(:,5),'m-h','linewidth',2)
xlabel('Power  (dB)')
ylabel('Received  Power')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison  Graph of Dispersion  compensation  Post Schemes')

%%

fig.
plot(PRE1(:,2),'x-','linewidth',2)
hold on
plot(uPRE1(:,2),'rs-','linewidth',2)
hold on
plot(dPre(:,2),'kd-','linewidth',2)
hold on
plot(Propsd(:,2),'m-h','linewidth',2)
xlabel('Power  (dB)')
ylabel('Q-actor')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison  Graph of Dispersion  compensation  Pre Schemes')
fig.
semilogy(PRE1(:,3),'x-','linewidth',2)
hold on
semilogy(uPRE1(:,3),'rs-','linewidth',2)
hold on
semilogy(dPre(:,3),'kd-','linewidth',2)
hold on
semilogy(Propsd(:,3),'m-h','linewidth',2)
xlabel('Power  (dB)')
ylabel('BER')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison  Graph of Dispersion  compensation  Pre Schemes')
```

```
fig.
plot(PRE1(:,4),'x-','linewidth',2)
hold on
plot(uPRE1(:,4),'rs-','linewidth',2)
hold on
plot(dPre(:,4),'kd-','linewidth',2)
hold on
plot(Propsd(:,4),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Eye Height')
legend('IDCFBG','UniformFBG','DCF','Hybrid',3)
title('Comparison Graph of Dispersion compensation Pre Schemes')
fig.
plot(PRE1(:,7),'x-','linewidth',2)
hold on
plot(uPRE1(:,7),'rs-','linewidth',2)
hold on
plot(dPre(:,5),'kd-','linewidth',2)
hold on
plot(Propsd(:,5),'m-h','linewidth',2)
xlabel('Power (dB)')
ylabel('Receiver Power')
legend('IDCFBG','UniformFBG','DCF','Hybrid',2)
title('Comparison Graph of Dispersion compensation Pre Schemes')
```

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SIMULATION AND ANALYSIS OF DISPERSION COMPENSATION USING PROPOSED HYBRID MODEL AT 100GBPS OVER 120KM USING SMF

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ABSTRACT

In this paper, a high capacity model of optical fiber communication having the transmission rate of 100Gbps using Hybrid dispersion compensation technique is proposed over a distance of 120Km. But due to longer transmission distances, fiber linearties occur. EDFA can mitigate the effects of these fiber linearties over repeated long distance transmissions but there are still some factors like dispersion, which restricts the transmission distance. In this paper, the complete focus is given in the reduction of chromatic dispersion. In previous papers DCF, IDCFBG and uniform FBG has been used separately for dispersion compensation and it has been found that uniform FBG has greatest Q-Factor and least BER among them. The technique proposed in this paper for dispersion compensation consists of a hybrid model of uniform FBG with EDC (Electronic dispersion compensation). Eventually results are analyzed for the proposed system at distinct input powers ranging from 1-10dBm and it is found that maximum value of Q-Factor and minimum value of BER have been achieved. For transmission of high bit rate over longer distance in the existing communication system, this model can provide a significant change.

Keywords: Dispersion; Single mode fiber (SMF) Q-factor; BER (Bit error rate); CD (Chromatic Dispersion); Uniform Fiber Bragg Grating; Dispersing Compensating Fibers (DCF); Optisystem 7.0

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ANALYZING DISPERSION COMPENSATION USING UFBG AT 100GBPS OVER 120KM USING SINGLE MODE FIBER

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ABSTRACT

The origin of erbium doped fiber amplifiers (EDFA's) is making the transmission in optical fiber communication more irresistible. But already installed standard non dispersion shifted fibers causing the transmission of data at higher rates to be confined by the immense dispersion unless different compensation technologies are utilized. A number of methodologies have been introduced to resolve this issue, for example, DCF (Dispersion Compensating Fiber), FBG (Fiber Bragg Grating), Electronic Equalizers etc. but an approach to decrease the chromatic dispersion by using FBG can altogether intensify the performance of the system. This paper is demonstrating the use of uniform FBG for compensating dispersion at 100Gbps over a SMF of 120Km by using it in distinct schemes and then on the basis of Q-factor and BER, it has been analyzed that Post dispersion compensation is reducing the effects of dispersion at longer distances with high data transmission rates much better than the remaining schemes.

Keywords: Optisystem 7.0; Single mode fiber (SMF) Quality-factor; Bit error rate; Chromatic Dispersion; Uniform Fiber Bragg Grating(UFBG); Inter-symbol interference

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http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&ITyp

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERFORMANCE ANALYSIS OF DISPERSION REPARATION USING DISPERSION COMPENSATION FIBER AT 100 GB/S FOR 120KM USING SINGLE MODE FIBER

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ABSTRACT

Since the data traffic is increasing day by day so there is a need of high capacity long distance optical links.As the data transmission increases over a long distance,signal gets deteriorated.This is because of the pulse widening known as dispersion and it should be compensated for better results.Different compensation techniques are available like FBG, EDC and DCF. Hence, in this paper we have used DCF as dispersion compensator at a bit rate of 100Gbps over a distance of 120km.ThreeDCF schemes i.e. pre,post and symmetric are proposed and investigated at different input power levels (1-10dBm).The results of these three schemes are then compared in terms of quality factor and bit error rate.Post compensation scheme of DCF exhibits low bit error rate and high quality factor.Thus, making it a best technique for dispersion compensation using DCF..

KEYWORDS: Dispersion; Optisystem; Q-factor; Bit error rate (BER); Chromatic Dispersion (CD); Inter Symbol Interference; PMD (Polarization mode dispersion).

I. INTRODUCTION

In the past years there is a brisk growth of internet users around the world.As a result need for high data transmission rates and high bandwidth increases, which is further becoming a tough challenge for service providers. So in order to fulfill these demands optical fiber is becoming more beneficial medium and playing an important role in the transmission of signals with high bandwidth and minimum losses as compared to other earlier used mediums like twisted pair cable, copper cables etc.So it is necessary to explore the transmission characteristics of optical fiber.

In optical fiber communication system,optical signals are transmitted through fiber overa long distance. A signal is made up of different wavelengths and these different wavelength signals have different propagation time because fiber core has different refractive indexes for different wavelengths [1]. The concept of WDM has increased the applications of optical fiber to fulfill the requirements of high data transmission rate with high bandwidth and high channel capacity [2].In WDM all the signals are multiplexed and then send over the fiber. While travelling inside the optical fiber, these signals deteriorate.This deterioration is caused by dispersion and other fiber linearity [3].EDFA is a major change, due to which losses can be avoided to a certain extent, but dispersion is a factor that should be considered during long distance transmission.A fiber loss causes link distance to be limited in optical communication system.Using EDFA in 1550nm wavelength window, increases link distance thus limiting bit error and propagation delay [4].

The major goal of optical communication systemis to achieve long distance transmission with less bit error rate and maximum quality factor.Toachieve this,dispersion should be compensated. Out of different types of dispersion, chromatic dispersion is the most prominent, and can becompensated using different compensation techniques like Dispersion Compensating Fiber(DCF), Fiber Bragg Grating(FBG) and ElectronicEqualizers etc.

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PERFORMANCE ANALYSIS OF DISPERSION COMPENSATION USING IDEAL FIBER BRAGG GRATING IN A 100 GB/S SINGLE CHANNEL OPTICAL SYSTEM

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ABSTRACT

In case of long distance communication, high bit rate and large bandwidth are always the primary requirements. The major limiting factor i.e. Attenuation can be reduced by using optical amplifier. But still one more limiting factor is there, which is known as Dispersion, which degrades the quality of optical communication. Hence,in this present investigation, Fiber-optic scattering or Dispersion and its impact on optical transmission are inspected. The most frequently utilized,Fiber Bragg Grating (FBG) method is examined in this article. Three techniques (pre-compensation, post-compensation and blend of these i.e. mix compensation) of dispersion compensation with IDCFBG at input power ranging from 1-10dBm are proposed.A single channel optical system with the help of simulation software i.e. Optisystem is designed by using the above mentioned techniques. The achieved results, for example, Q factor, BER, eye diagram and Eye height are given and profoundly examined. In this investigation, it has been found that Post-Compensation technique execution is appropriate..

KEYWORDS: Dispersion; Dispersion Compensation; Fiber Bragg Grating; Optisystem7.0; Scattering; Q-factor; Bit error rate (BER); Chromatic Dispersion (CD); Inter Symbol Interference.

I. INTRODUCTION

In past few years, with the quick development in web business, individuals desperately require greater bandwidth and best network. So there is a huge interest for more transmission limit and greater data transfer capacity and it is becoming very difficult for the transporters and administrator to fulfill their requirements [1]. Under these circumstances, with its gigantic data transfer capacity and brilliant transmission execution, optical fiber is turning into the greatest conveying media and becoming increasingly essential part in data industry [2]. The ideal outline and use of optical fiber are imperative to the transmission nature of optical fiber transmission. In this way, it is extremely important to research the transmission attributes of optical fiber. As we know, the major aim of any communication system is to enhance the communication distance. Errors and scattering (Dispersion) are the main problems that influence fiber-optical communication and restrict the distance [3].

Dispersion: Dispersion is characterized as pulse spreading in an optical fiber. As a pulse of light engenders through a fiber, components, for example, core diameter, numerical aperture, refractive index, wavelength, and laser line width make the pulse expand [4]. Dispersion increases along the fiber length. The general impact of Dispersion on the execution of a fiber optic framework is known as Inter Symbol Interference (ISI). Inter symbol interference happens when the pulse spreading caused by dispersion causes overlapping of pulses. Dispersion is of three types: Modal dispersion, Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) [5].

Modal Dispersion: Modal dispersion is characterized as pulse spreading caused when delay occurs between lower order modes and higher order modes. Modal scattering is risky in multimode fiber, causing lower bandwidth as shown in fig-1.

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PERFORMANCE COMPARISON OF VARIOUS DISPERSION-COMPENSATION TECHNIQUES WITH PROPOSED HYBRID MODEL FOR DISPERSION COMPENSATION AT 100GBPS OVER 120KM SINGLE MODE FIBER

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ABSTRACT

This paper includes the comparison of DCF, IDCFBG and UFBG dispersion compensation technique with the hybrid model. The experimentally proved results of Dispersion Compensating fibers, Fiber Bragg grating and unifom fiber Bragg grating has been examined, and it is depicted that post configurations of all the three dispersion compensation schemes provided outstanding results for transmission at 120Km at 100Gbps over single mode fiber. Evaluation of all these schemes is then done by comparing with the hybrid model, to examine the optimum approach for dispersion compensation. Evaluation of performance is explored by using simulation models and graphs. The immense outcomes show that Hybrid model has marvelous outcomes for compensation of dispersion at a higher bit rate of 100Gbps over 120Km transmitting distance in comparison with existing techniques of DCF, IDCFBG and UFBG.

KEYWORDS: Opti system 7.0, Uniform Fiber Bragg grating (UFBG); Dispersion Compensating Fiber (DCF); Chromatic Dispersion (CD); Q-Factor; Bit Error Rate (BER)

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I. INTRODUCTION

With the invention of laser in 1960, optical communication system developed quickly. These days, correct and fast trade of data has been an important requirement for individuals. Thus, the promotion of optical fiber is needed to transport the signals at longer distances with higher data rates and high capacity. With bringing it into rehearse, we found that the information carrying capacity of a system in optical fiber communication are affected by the losses in fiber, dispersion, polarization impacts, nonlinear impacts and distinct factors. The fundamental variables have dispersion and losses in the fiber. In this manner, how to lessen these two negative factors and wind up noticeably are critical issues in optical fiber communication systems. In the present days, with the development of EDFA (erbium doped fiber amplifiers), fiber loss is no longer the primary constraining component. At that point, dispersion has moved toward becoming the main consideration.

Dispersion in fiber yields mutilation of the communicating signal and corresponding dropping of the quality of signal, thereby, limiting the channel capacity. In this way, how to successfully regulate the dispersion is the highlighting concept in fiber optics [1, 2,

Performance Comparison of DCF and FBG as Dispersion Compensation techniques at 100Gbps over 120Km using SMF

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***Abstract*— The fusion of EDFA and optical fiber causes an expansion in the transmission capacity over the large distances and thus making optical fiber a prevalent broadband communication technique. The practical execution of EDFA offers long transmission distances with less attenuation. However, in order to get high transmission range with high data rates using existing SMF then techniques must be there to compensate the dispersion caused by fiber non linearity. In optical fiber communication, DCF and FBG are the trending dispersion compensation techniques. The use of DCF and FBG as a method of compensation of dispersion can notably heighten the overall performance of the system. In this paper, DCF and FBG as dispersion compensator are compared in terms of Q-factor and BER at 100 Gbps launched over a SMF of 120 Km by using Optisysem 7.0 software. On the basis of results, it is suggested to use DCF as a best chromatic dispersion compensation technique in pre compensation mode.**

***Keywords*— Dispersion; Dispersion Compensation; Optisystem 7.0; Fiber Bragg Grating; Dispersion compensating fiber (DCF); Bit error rate (BER); Chromatic Dispersion (CD); Q-factor.**

INTRODUCTION

After T.H. Maimam invented laser in 1960, the optical communication developed swiftly. Today the precise and brisk exchange of information has become a required need of the people. This demand of people encourages the use of optical fiber as a communication medium and to expand it as a large capacity, high transmission bit rate, high speed and long distance transmission medium with low amount of noise and attenuation present in it. While considering all these requirements, it is found that information carrying capacity of these optical fibers are affected by dispersion, attenuation and other fiber non linearity. Among these, attenuation and dispersion are the dominating elements to degrade the signal quality over optical fiber. Therefore, how to bring down and abolish these elements has become a major issue of concern. In past years with the disclosure of EDFA, attenuation is no longer a capacity limiting issue. But dispersion is still a major concerning factor which corrupts the signal quality.

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