Simulative Design of DWDM System Using Different Dispersion Compensation Techniques

By

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Abstract

Over the years the demand for more bandwidth has increased tremendously because of the growing bandwidth hungry applications. Subsequently the transfer of this heavy amount of data requires faster data speeds. With the advancement in optical fiber technology and its ability to carry greater bandwidth at much higher data rates has led to the development of advanced multiplexing techniques, namely, Dense Wavelength Division Multiplexing which lets several channels multiplexing and routing through the same optical fiber cable through the use of different wavelengths. The implementation of the DWDM technology has simply taken care of the bandwidth and data issue in a very effective and sustainable way. However the problem being faced in the DWDM multiplexing technique relates to the issue of dispersion. With dispersion, the overall system performance is degraded/ deteriorated.

In order to tackle this issue, there is a need to come up with a design using the most suitable dispersion compensation technique. Many dispersion techniques exist which includes pre compensation technique (PRCT), post compensation techniques (POCT) & symmetrical compensation techniques (SCT). Dense Wavelength Division Multiplexing system has been designed which will specifically take care of the BER& the Quality Factor. The simulated results have shown an improved system design, adopting symmetrical dispersion compensating technique.

Introduction

- **Fiber**

Fiber is made of SiO_2 (quartz). It also comprises few doped chemical, such as GeO_2, to improve refractive index (n1) of the fiber core. The diameter of the fiber core usually ranges 5 µm ~ 50 µm. Cladding is made of SiO_2, with outer diameter as 125 µm. The refractive index (n2) of cladding is less than that (n1) of fiber core. Coating layer of fiber is made of high molecular materials, such as epoxide resin and silicone rubber, with outer diameter as about 250 µm. Through adding coating, we can improve flexibility, mechanical strength and aging-resistance features of the optical fiber

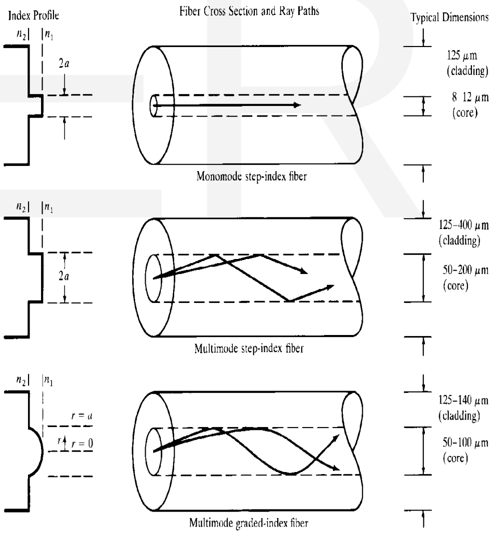

Figure 1: Structure of Index Fiber [32]

Work Principle of fiber (Snell's Law)

Snell's law (also known as Snell–Descartes law and the law of refraction) is a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different isotropic media, such as water, glass, or air.

In optics, the law is used in ray tracing to compute the angles of incidence or refraction, and in experimental optics to find the refractive index of a material. The law is also satisfied in meta materials, which allow light to be bent "backward" at a negative angle of refraction with a negative refractive index.

$$\sin \phi_c = \frac{n_2}{n_1}$$

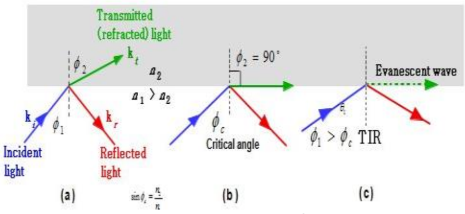

Figure 2: Work Principle of Fiber [32]

Types of Fibers

G.652 (ordinary SMF) It is also called dispersion non-shifted SMF, used in 1310 nm and 1550 nm windows. In the 1310 nm window, it has dispersion close to zero. But in the 1550 nm window, its loss is the smallest, with dispersion of 17 ps/km nm.

When it is used in the 1310 nm window, it is only applicable to the SDH system; when it is used in the 1550 nm window, it is applicable to both SDH system and DWDM system, requiring dispersion compensation when the single channel rate is over 2.5 Gbit/s.

G.653 (dispersion shifted SMF) It has the smallest loss and the smallest dispersion in the 1550 nm. Therefore, it usually works in the 1550 nm window. It is applicable to the high-rate and long-distance single-wavelength communication system. When the DWDM technology is used, serious non-linear Four Wave Mixing (FWM) problem will occur in zero-dispersion wavelength area, resulting in optical signal attenuation in multiplexing channels and channel crosstalk.

G.655 (non-zero dispersion shifted SMF) In the 1550 nm window, the absolute value of its dispersion is not zero and within a certain range (ensuring smallest loss and small dispersion in this window). It is applicable to the high-rate and long-distance optical communication system. In addition, non-zero dispersion suppresses the influence of non-linear FWM over DWDM system. Therefore, this kind of fiber is usually used in the DWDM system.

- **Optics and Optical Communication**

Optics is an old subject involving the generation, propagation & detection of light. Three major developments are responsible for rejuvenation of optics & its application in modern technology:

- Invention of Laser
- Fabrication of low-loss optical Fiber
- Development of Semiconductor Optical Device

As a result, new disciplines have emerged & new terms describing them have come into use, such as: Photonics reflects the importance of the photon nature of light. Photonics & electronics clearly overlap since electrons often control the flow of photons & conversely, photons control the flow of electrons. The scope of Photonics:
Generation of Light (coherent & incoherent) Transmission of Light (through free space, fibers, imaging systems, waveguides)
Processing of Light Signals (modulation, switching, amplification, frequency conversion) Detection of Light (coherent & incoherent).

There are many factors that outweigh the benefits of optical communication such as:

- Extremely wide bandwidth
- Small size & light weight.
- Immunity to Interference: Electromagnetic interference (high voltage transmission lines, radar systems, power electronic systems, airborne systems,)
- Signal Security
- Lack of EMI cross talk between channels
- Ruggedness and Flexibility
- Low Transmission loss
- System Reliability and ease of maintenance: high performance active & passive photonic components such as tunable lasers, very sensitive photodetectors, couplers, filters, Low cost systems for data rates in excess of Gbit/s.

- **Dense Wavelength Division Multiplexing DWDM**

A transmission technique used in fiber optics in which light wavelengths are used to transmit data either parallel by bit or serial by character is known as Dense Wavelength Division Multiplexing. Here dense means that the wavelength channels are very close to each other. The increasing demand of consumers lead to increased bandwidth and this is possible using DWDM. The data from various different sources is put together on optical fiber in which each signal travels at same speed on its own light wavelength. [8]
DWDM is a technology that combines large number of independent information carrying wavelengths onto the same fiber and thereby increases the transmission capacity of fiber. The "spectral bands" where the optical fiber and the transmission equipment can operate more efficiently are specified by ITU-T as O, E, S, C, L and U bands (from 1260 nm to 1675 nm). While setting up the transmission link, there is a need to ensure that the signal can be retrieved intelligibly at the receiving end. This can be done preferably by using optical amplifiers that serve as the key component of a DWDM system. [9].

In early 1970's, this multiplexing technology only uses two wavelengths: one in 1310 nm window and the other in 1550 nm window. It implements single-fiber dual-window transmission through the WDM technology. It is the initial wavelength division multiplexing case.

- ***DWDM***

In simple words, the DWDM technology refers to the WDM technology with small interval between adjacent wavelengths, with working wavelength in the 1550 nm window. It can bear 8 ~ 160 wavelengths on one fiber, mostly used in long-distance transmission system.

- ***CWDM***

The CWDM technology refers to the WDM technology with large interval (usually greater than 20 nm) between adjacent wavelengths. Usually, its wavelength quantity is 4 or 8 and16 at most (1270nm to 1610nm)

- **Characteristics of DWDM**

Dense Wavelength Division Multiplexing (DWDM) is a fiber-optic transmission technique. It involves the process of multiplexing many different wavelength signals onto a single fiber. So each fiber has a set of parallel optical channels each using slightly different light wavelengths. It employs light wavelengths to transmit data parallel-by-bit or serial-by-character. DWDM is a very crucial component of optical networks that will allow the transmission of data: voice, video-IP, ATM and SONET/SDH respectively, over the optical layer.

Hence with the development of WDM technology, optical layer provides the only means for carriers to integrate the diverse technologies of their existing networks into one physical infrastructure. For example, though a carrier might be operating both ATM and SONET networks, with the use of DWDM it is not necessary for the ATM signal to be multiplexed up to the SONET rate to be carried on the DWDM network. Hence carriers can quickly introduce ATM or IP without having to deploy an overlay network for multiplexing [33].

Below figure describes how different channels connect to DWDM in parallel and then transmitted over physical fiber.

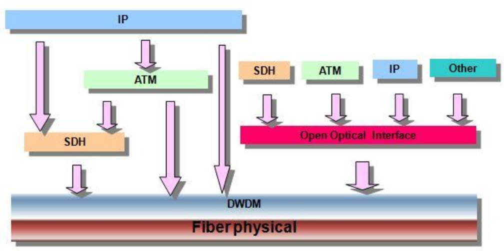

Figure 3: Working Model of Channels and DWDM over Physical Fiber

- **Working Wavelength of DWDM System**

In DWDM system, two bands of light are being used know as conventional band and long band. Conventional band, usually termed as C band ranges from 1530nm to 1565nm while Long band termed as L band ranges from 1565nm to 1625nm.

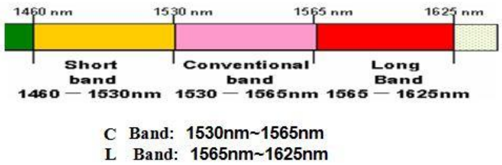

Figure 4: Working Wavelength of DWDM System

In these wavelength windows, different number of channels can be transmitted based on channel interval (spacing) and frequency offset between the two adjacent wavelengths.

Below tables show characteristics of 8/16/32/40, 80 and 160 channels DWDM systems based on working wavelength range, Frequency range, Channel interval and Central frequency offset.

Characteristic	Range
Working wavelength range	C band (1530 nm ~ 1565 nm)
Frequency range	192.1 THz ~ 196.0 THz
Channel interval	100 GHz
Central frequency offset	±20 GHz (at rate lower than 2.5 Gbit/s); ±12.5 GHz (at rate 10 Gbit/s)

Table 1: 8/16/32/40-wavelength system

Characteristic	Range
Working wavelength range	C band (1530 nm ~ 1565 nm)
Frequency range	C band (192.1 THz ~ 196.0 THz)
Channel interval	50 GHz
Central frequency offset	±5 GHz)

Table 2: 80-wavelength system

Characteristic	Range
Working wavelength range	C band (1530 nm ~ 1565 nm) + L band (1565 nm ~ 1625 nm)
Frequency range	C band (192.1 THz ~ 196.0 THz) + L band (190.90 THz ~ 186.95 THz)
Channel interval	50 GHz
Central frequency offset	±5 GHz)

Table 3: 160-wavelength system

- Advantages of DWDM

Fully utilizing fiber bandwidth resources and featuring large transmission capacity

The DWDM technology makes full use of the huge bandwidth (about 25 THz) resource of fibers to expand the transmission capacity of the system. Super-long transmission distance Through EDFA and other super-long distance transmission technologies, the channel signals in the DWDM system are amplified at the same time, for the sake of long-distance transmission of the system.

Abundant service access types

The wavelengths in the DWDM system are separated to each other, capable of transmitting different services in transparent way, such as SDH, GbE and ATM signals, for the sake of hybrid transmission of multiple kinds of signals.

Saving fiber resource

The DWDM system multiplexes multiple single-channel wavelengths for transmission in one fiber, greatly saving fiber resource and reducing line construction cost.

Smooth upgrading and expansion

Since the DWDM system transmits the data in each wavelength channel in transparent way and does no process the channel data, only more multiplexing wavelength channels should be added for expansion, which is convenient and practical.

Fully utilizing well-developed TDM technology

At present, the optical transmission technologies in TDM mode, such as SDH, have been well developed. Through the WDM technology, the transmission capacity can be enlarged by several times or even dozens of times, with expansion cost lower than that in the TDM mode.

- DWDM Performance Degradation

When the signal is amplified by the optical amplifier (OA), like EDFA, its optical signal to noise ratio (OSNR) is reduced. The performance of long-haul DWDM systems is mainly limited by two distinct phenomena:

1. Amplified spontaneous emission (ASE) noise accumulation
2. Generation of nonlinear interference (NLI) due to the Kerr effect in the fiber.

According with ITU-T G.652, contribution for coefficient of PMD have value of about 0.5 ps/√km, however value of PMD for high bit rate system with wavelength-division multiplexing (WDM) optical network has ≤0.04 ps/√km. Coherent detection optical channels in WDM system allows to decrease influence of nonlinear effects. Also, for high-speed (40-Gb/s and beyond) optical fiber communication systems, more powerful FEC codes have become necessary in order to achieve higher correction ability that FEC codes and compensate for serious transmission quality degradation [10].

Optical Parameter - OSNR (Optical signal-to-noise ratio)

The OSNR values that matter the most are at the receiver, because a low OSNR value means that the receiver will probably not detect or recover the signal. The OSNR limit is one of the key parameters that determine how far a wavelength can travel prior to regeneration.

OSNR serves as a benchmark indicator for the assessment of performance of optical transmission systems. DWDM networks need to operate above their OSNR limit to ensure error free operation. BER is defined as number of bits in errors / unit time. It is a unit less performance measure. It is mentioned in the form of %. Quality factor measures quality of transmitted signal in terms of OSNR. There exists a direct relationship between OSNR and bit error rate (BER), where BER is the ultimate value to measure the quality of a transmission [9].

$$OSNR = Pout - 10\log(M - L + 58 - NF) - 10\log N$$

Pout: In-fiber optical power (dBm).
M: Number of multiplexing channels of the WDM system
L: Loss between any two optical amplifiers, that is, sectional loss (dB)
NF: Noise index of the EDFA.
N: Number of the EDFAs between optical multiplexer and optical de-multiplexer of the WDM system.

The formula shows that when the other parameters keep unchanged, greater line loss leads to lower OSNR, which means decreased transmission quality of the optical line

- **Transport Characteristics of Optical Fibers**

Transport characteristics of optical fiber are categorized into three main categories which are further divided into sub categories. The brief explanation of all the categories is written below.
1. Attenuation (Loss)
2. Dispersion
3. Non-linear Effect

Attenuation

It is the reduction of signal strength or light power over the length of the light-carrying medium. Fiber attenuation is measured in decibels per kilometer (dB/km).
- Absorbency attenuation: While transmission some optical energy turn into heat energy.
- Scattering attenuation: While Optical signal is transmitted, it will scatter to other directions except its own transmission direction, for the asymmetry of the density or refractive index of transmission media.

Dispersion

As the optical pulse signals are transmitted for long distance, the pulse wave shape spreads by time at the fiber output end, this phenomenon is called dispersion. In today's DWDM systems high powers are required to obtain high transmission distances with a reasonable optical amplifier spacing. The optimization of the dispersion, the bandwidth of the filters and the signal power for a network plays a major role and even more the higher the data rates are. The effects of dispersion, self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) can be mitigated by proper dispersion management [15]

Chromatic Dispersion

Optical signals of different wavelength have different speeds in the optical fiber, and this will cause phenomena called chromatic dispersion.

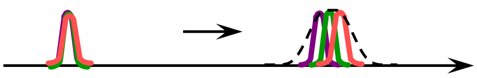

Figure 5: Chromatic Dispersion [34]

Influences of Chromatic Dispersion

(a) Pulse spreading

A major influence of chromatic dispersion to system performance when transmission distance is longer than fiber dispersion length, pulse spreading is too large. At this time, the system will have serious inter-symbol interference and bit errors.

(b) Chirp effect

Dispersion not only results in pulse spreading but also makes pulse generate phase modulation. Such phase modulation makes different parts of the pulse make different offset from the central frequency with different frequencies.

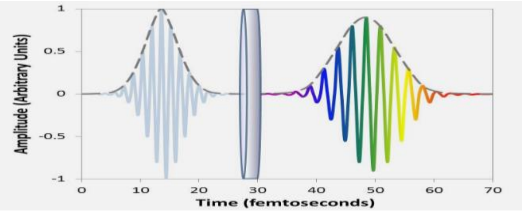

Figure 6: Chirp Effect [35]

Chirps can arise e.g. during propagation in a medium due to the effects of dispersion and nonlinearities. In laser diodes, the shift of the laser's center wavelength during single pulse durations.

(c) Dispersion Tolerance

Parameter of dispersion tolerance for laser source (Ds)
Dispersion parameter for optical fiber (D)
Longest transmission distance: Ds/D

Example

If Ds = 12800 ps/nm, SMF（G.652）dispersion is D = 20 ps/km/nm, and then the longest transmission distance of this optical source is 640km.

(d) Material Dispersion

The quartz glass, fiber material, has different refractive index for different optical wavelengths. While the light source has certain spectrum width, and different wavelengths results in different group rates, so the optical pulse spreading will occur.

(e) Waveguide Dispersion

For a transmission mode of the fiber, the pulse spreading caused by the different refractive indexes of the core and cladding of an optical fiber. This dispersion is related to the waveguide effect of fiber structure, so it is also called structure dispersion.

Nonlinear Effects

The third category of Transport characteristics of optical fiber is nonlinear effects which is further divided into sub categories. All these sub categories are explained below.

1. Stimulated Brillouin Scattering (SBS)
2. Stimulated Raman Scattering (SRS)
3. Four Wave Mixing (FWM)
4. Self-phase Modulation (SPM)
5. Cross-phase Modulation (XPM)

(a) Stimulated Brillouin Scattering (SBS)

SBS belongs to the stimulated non-elastic scattering process caused by non-linear effect. It comes of mutual action and energy exchange between photon and acoustic phonon (crystal vibration status).

(b) Stimulated Raman Scattering (SRS)

SRS belongs to the stimulated non-elastic scattering process caused by non-linear effect. It comes of mutual action and energy exchange between photon and optical phonon (molecular vibration status). SRS affect results in attenuation of signals with short wavelength and reinforcement of signals with long wavelength.

(c) Four Wave Mixing (FWM)

FWM refers to a physical process of energy exchange between multiple optical carriers caused by the non-linear effect of fiber, when multiple frequencies of optical carriers with high power are simultaneously transmitted in the fiber. FWM results in optical signal energy attenuation in multiplexing channels and channel crosstalk

(d) Self Phase Modulation (SPM)

Due to dependency relationship between refractive index and light intensity, refractive index changes during optical pulse continuance, with pulse peak phase delayed for both front and rear edges. With more transmission distance, phase shift is accumulated continuously and represents large phase modulation upon certain distance. As a result, spectrum spreading results in pulse spreading, which is called SPM.

(e) Cross Phase Modulation (XPM)

When two or more optical waves with different frequencies are simultaneously transmitted in a non-linear media, the amplitude modulation of each frequency wave will result in the corresponding change of the fiber refractive index, resulting in non-linear phase modulation of the optical wave with other frequencies, which is called XPM. In order to overcome dispersion effect in transmission over long distances, Dispersion Compensation fiber is widely used. This is because of the fact that it has a higher negative dispersion coefficient and can be attached with single mode fiber which exhibits a positive dispersion coefficient

Research Objective

The main objective of this research is to design a 32x40Gbps Dense Wave Division Multiplexing system (compensation technique) which will take care of the Bit Error Rate (BER) &Quality Factor (Q-Factor).

Research Methodology

A DWDM system compensation technique will be designed that will ensure reduction in the Bit Error Rate (BER) and improve the Q-Factor. Simulation will be done to come up with an improved system design, adopting a new dispersion compensating technique.

The simulator used is OptiSystem. This software design suite is used for planning, testing, and simulation of optical networks links.

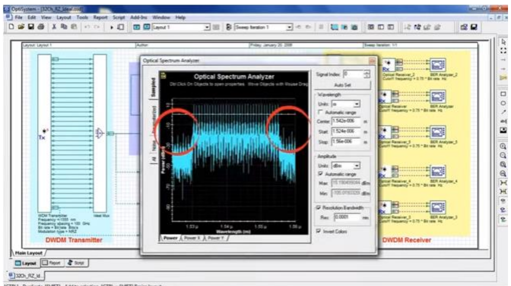

Figure 7: Snapshot of a generic OptiSystem [6]

OptiSystem Simulator has wide range of applications which includes Optical communication system design from component to system level at a physical layer.

- CATV or TDM/WDM system design.
- Passive Optical network (PON) based FTTx.
- Free space optic (FSO) system.
- Radio over fiber (ROF) system.
- SONET/SDH ring design.
- Transmitter, Channel, Amplifier and Receiver design.
- Dispersion map design.
- Estimation of BER and system penalties with different receiver models.
- Amplified system BER and link budget calculation.

Literature Review

DWDM

Development of optical communication technology has brought about a revolution in the field of communications. Higher bandwidth transmission at very high speed over large distances has been achieved. Dense wave Division Multiplexing (DWDM) is the technology of the future for many generations to come. Through the use of this technology, multiple streams of data are easily transmitted over single fiber. Usually the data rates of more than ten giga bits per second are achieved. However at this rate the dispersion factor needs to be managed so that long distance communication can take place. Various characteristics of DWDM can be categorized as;

- Higher bandwidth
- Higher Transmission capacity
- Performance Reliability
- Compatibility (with existing communication systems)

However there are certain major constraints which lead to system degradation i.e;

- Losses
- Dispersion Effect
- Non-Linear Effect

Extensive literature review was done, in which the following areas were specifically looked into;

1. Optical phase conjugation
2. Fiber Bragg Grating
3. Electronic Dispersion Compensation

4. Reverse Dispersion Compensation
5. Dispersion Compensation fiber [11] [12] [13] [14].
6. Simulation Long haul DWDM System
7. Optisystem [6]

Brief description of each of the above mentioned techniques and parameters is given as under

(a) Optical Phase Conjugation

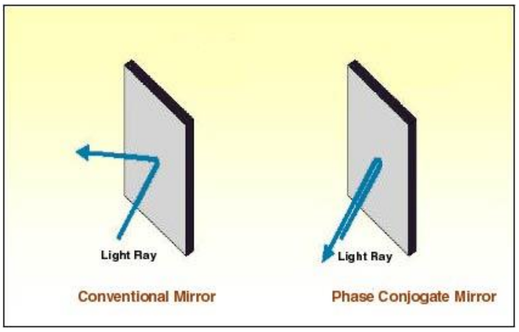

Figure 8: Optical Phase Conjugation [16]

Optical phase conjugation (OPC) is used as a generic term for a multitude of nonlinear optical processes. The common feature is that all these processes are capable of reversing both the direction of propagation and the phase factor for each plane wave component of an arbitrary incoming beam of light.

This means that a phase conjugator can be considered as a kind of mirror with very unusual reflection properties.
A PCM, changes the sign of the complete wave vector so that the reflected ray is always anti parallel to the incident ray, independent of the orientation of the mirror surface.

(b) Fiber Bragg Grating

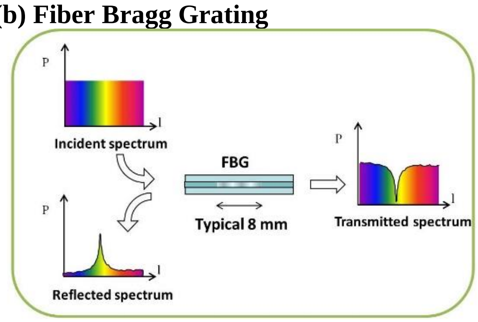

Figure 9: Fiber Bragg Grating [17]

Fiber Bragg Gratings are made by laterally exposing the core of a single-mode fiber to a periodic pattern of intense ultraviolet light. The exposure produces a permanent increase in the refractive index of the fiber's core, creating a fixed index modulation according to the exposure pattern. This fixed index modulation is called a grating.

At each periodic refraction change a small amount of light is reflected. All the reflected light signals combine coherently to one large reflection at a particular wavelength when the grating period is approximately half the input light's wavelength. This is referred to as the Bragg condition, and the wavelength at which this reflection occurs is called the Bragg wavelength

(c) Electronic Dispersion Compensation (EDC)

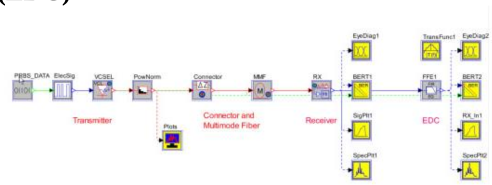

Figure 10: Electronic Dispersion Compensation (EDC) [18]

Electronic Dispersion Compensation is a method for mitigating the effects of chromatic dispersion in fiber-optic communication links with electronic components in the receiver
Systems for optical fiber communications can be affected by the effect of chromatic dispersion of the fibers used. Dispersion in a fiber-optic link broadens and distorts the features of the bit symbols, making it more difficult to decode the signal. Dispersion compensation is normally be done in the optical domain, i.e., before photo detection. However, there are also methods of *electronic dispersion compensation*, utilizing electronics for that purpose.

Above figure demonstrate the application of Electronic Dispersion Compensation in a multimode link.

(d) Reverse Dispersion Fiber

Below figure demonstrate erbium-doped fiber amplifier (EDFA)-repeated system which use the combination of a single-mode fiber (SMF) and reverse dispersion fiber (RDF) as a dispersion compensation device.

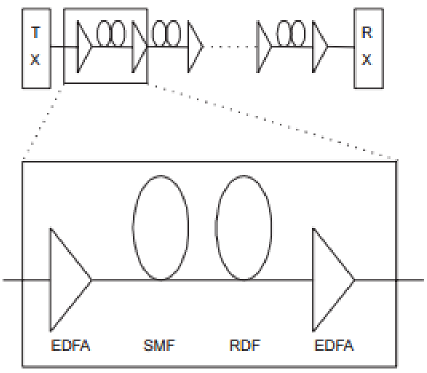

Figure 11: Reverse Dispersion Fiber (RDF) [19]

Reverse dispersion fiber (RDF) has several advantages compared with DCF, including lower loss, lower nonlinearity, and lower PMD. It has been reported that a desired zero dispersion can be constructed by using SMF and RDF combination in digital light wave transmission systems.

(e) Dispersion Compensation Fiber

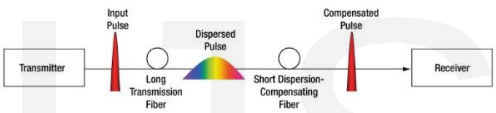

Figure 12: Dispersion Compensation Fiber [20]

Since dispersion is inevitable in optical fibers, dispersion-compensating fibers can be incorporated into optical systems. The overall dispersion of these fibers is opposite in sign and much larger in magnitude than that of standard fiber, so they can be used to cancel out or compensate the dispersion of a standard single-mode fiber, such as a nonzero dispersion-shifted fiber.

A negative dispersion slope enables effective cancellation of dispersion over a larger wavelength range, since the dispersion slope of standard fiber is usually positive. Generally, a short length of dispersion-compensating fiber is spliced into a longer length of standard fiber to compensate for dispersion, as shown in above figure.

In order to decrease the overall dispersion in the optical fiber link, Dispersion Compensating Fiber (DCF) is used. It is used because of the fact that it has a higher negative dispersion coefficient and can be attached with single mode fiber which exhibits a positive dispersion coefficient.

Then we have certain impairments because of non-linearity. These can be minimized by using Erbium Doped Fiber Amplifiers (EDFA), Semi Conductor devices and Raman Amplification described as under

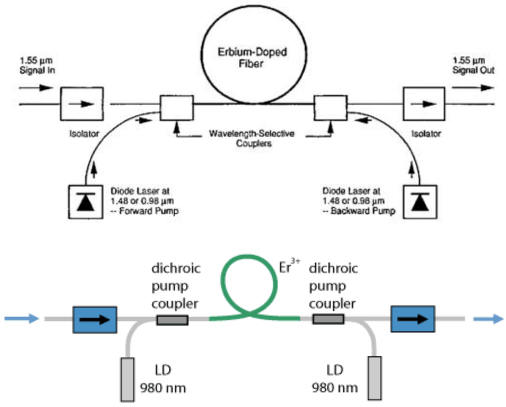

Figure 13: Erbium [1]

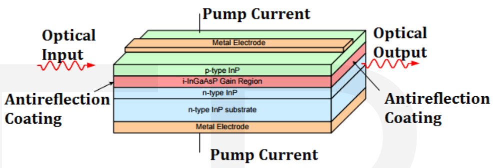

Figure 14: Semi-Conductor [2]

A typical setup of a simple erbium-doped fiber amplifier (EDFA) is shown in above Figures 1.6 & 1.7. Its core is the erbium-doped optical fiber, which is typically a single-mode fiber. In the shown case, the *active fiber* is "pumped" with light from two laser diodes (bidirectional pumping), although unidirectional pumping in the forward or backward direction (co-directional and counter-directional pumping) is also very common.

The pump light, which most often has a wavelength around 980 nm and sometimes around 1450 nm, excites the erbium ions (Er^{3+}) into the $^4I_{13/2}$ state (in the case of 980-nm pumping via $^4I_{11/2}$), from where they can amplify light in the 1.5-µm wavelength region via stimulated emission back to the ground-state manifold $^4I_{15/2}$.

The setup shown also contains two "pig-tailed" (fiber-coupled) optical isolators. The isolator at the input prevents light originating from amplified spontaneous emission from disturbing any previous stages, whereas that at the output suppresses lasing (or possibly even destruction) if output light is reflected back to the amplifier. Without isolators, fiber amplifiers can be sensitive to back-reflections.[21]

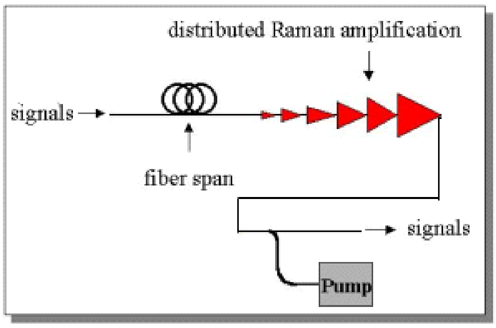

Figure 15: Distributed Amplification [3]

Raman amplification can be used to provide gain in the transmission fiber itself, a technique known as distributed amplification. This technique reduces the signal-to-noise ratio (SNR) degradation of the system, compared with a system that uses only discrete amplifiers.

Furthermore, Raman can provide gain in a bandwidth which is only limited by the available pump powers and wavelengths. Finally, these amplifiers also benefit from a very linear gain, which means that the Raman gain is less inclined to saturate and induce crosstalk between channels, when faced with high input powers, compared to EDFAs. A Distributed Raman Amplification is shown in above figure 1.8 [3].

The system performance is degraded substantially over longer distances because of the dispersion effect, hence, requiring some compensation techniques. Based on where Dispersion Compensating Fiber resides, compensation techniques can be categorized as;

- Pre Compensation Technique [4]
- Post Compensation Technique [5]

Research Topic	Reference	Authors
Capacity expansion of fiber optic networks with WDM systems: problem formulation and comparative analysis	Elseiver Computers & Operations Research 31 (2004) 461–472	Belen Melian , Manuel Laguna , Jose A. Moreno-Perez
Dispersion Compensation Dense Wavelength Division Multiplexing (DC DWDM) for Nonlinearity Analysis at Various Propagation Distance and Input Power	IEEE 2015 International Conference on Computer, Communication, and Control Technology (I4CT 2015), April 21 – 23	N.M.Nawawi
Simulation of high capacity 40Gb/s long haul DWDM system using different modulation formats and dispersion compensation schemes in the presence of Kerr's effect	Optik 121 (2010) 739–749	Anu.Sheetal
The Simulation of the Dense Wavelength Division Multiplexing System Based on Hybrid Amplifier	International Symposium on Electronic Commerce and Security(ISECS) Volume 02, 22-24 May, pp. 249-251(2009)	Gao Yan, Cui Xiaorong, Du Weifeng, Zhang Ruixia
Inter-channel nonlinear effects in dispersion compensated DWDM optical networks	Advanced Semiconductor Laser and Applications/Ultraviolet and blue Lasers and Their Applications/Ultralong Haul DWDM Transmission and networking /WDM components.(2001)	A.Nolaso Pinto
Simulation results for DWDM systems with ultra-high capacity	Int. J. Fiber Integrated Opt. 21 (5) (2002)	R.S. Kaler, A.K. Sharma, T.S. Kamal
Comparison of various dispersion compensation techniques at high bit rates using CSRZ format	Optik 121 (2010) 813–817	YogeshChaba
Long-Haul DWDM Transmission Systems Employing Optical Phase Conjugation	IEEE Journal of selected topics in Quantum Electronics Volume 12,Issue 4,(2006)	S.L. Jansen," Long-Haul
An Analysis of 10Gbits/s Optical Transmission System Using Fiber Bragg Grating (FBG)	IOSR Journal of Engineering (IOSRJEN) ISSN:2250-3021Vol 2, Issue 7,pp 55-61,(2012)	M.A .Othman ,M.M. Ismail
Electronic dispersion compensation for a 10-Gb/s link using a directly modulated laser	IEEE Photonics Technology Lett., Vol. 15, no . 12 , pp. 1788–1790, (2003)	M. D. Feuer, et al
Performance comparison between DCF and RDF dispersion compensation in fiber optical CATV systems	IEEE Trans. Broadcast.vol. 48,issue 4,pp 370–373, (2002)	Hai-Han. Lu
Analysis on Dispersion Compensation with DCF based on Optisystem	2nd International Conference on Industrial and Information Systems ,vol:2,pp 40-43 (2010)	Bo - Ning HU , Wang Wei
Novel Optical Flat-Gain Hybrid Amplifier for Dense Wavelength Division Multiplexed System	IEEE photonics technology letter,vol 26, no.2 (2014)	Simranjit Singh and R.S kaler
Investigations on order and width of RZ super Gaussian pulse in different WDM systems at 40 Gb/s using dispersion compensating fibers	Optik 125, 4270-4273, (2014)	Gurinder Singh, SukhbirSinghandAmeetaSeehra
Performance Analysis of Dispersion Compensation in WDM Optical Communication Systems	International Journal of Science and Research (IJSR) , Volume 4 Issue 2, February 2015	BarzaBadar , Anisha A.P.

Various researches have been carried out in this area including Capacity expansion of fiber optic networks with WDM systems: problem formulation and comparative analysis by Elseiver Computers & Operations Research 31 (2004) 461–472 Belen Melian , Manuel Laguna , Jose A. Moreno-Perez, Dispersion Compensation Dense Wavelength Division Multiplexing (DC DWDM) for Nonlinearity Analysis at Various Propagation Distance and Input Power at IEEE 2015 International Conference on Computer, Communication, and Control Technology (I4CT 2015), April 21 – 23 (N.M.Nawawi), Simulation of high capacity 40Gb/s long haul DWDM system using different modulation formats and dispersion compensation schemes in the presence of Kerr's effect Optik 121 (2010) 739–749 by Anu Sheetal, Simulation of Dense Wavelength Division Multiplexing System Based on Hybrid Amplifier at the International Symposium on Electronic Commerce and Security(ISECS) Volume 02, 22-24 May, pp. 249-251(2009) by Gao Yan, Cui Xiaorong, Du Weifeng, Zhang Ruixia, Inter-channel nonlinear effects in dispersion compensated DWDM optical networks Advanced Semiconductor Laser and Applications/Ultraviolet and blue Lasers and Their Applications/Ultralong Haul DWDM Transmission and networking /WDM components.(2001) by A.Nolaso Pinto.

Similarly other researches include Simulation results for DWDM systems with ultra-high capacity Int. J. Fiber Integrated Opt. 21 (5) (2002) by R.S.Kaler, A.K. Sharma, T.S. Kamal, Comparison of various dispersion compensation techniques at high bit rates using CSRZ format, Optik 121 (2010) 813–817 by YogeshChaba, Long-Haul DWDM Transmission Systems Employing Optical Phase Conjugation at IEEE Journal of selected topics in Quantum Electronics Volume 12,Issue 4,(2006) by S.L Jansen," Long-Haul, An Analysis of 10Gbits/s Optical Transmission System Using Fiber Bragg Grating (FBG) in IOSR Journal of Engineering (IOSRJEN) ISSN:2250-3021Vol 2, Issue 7,pp 55-61,(2012) by M.A .Othman ,M.M. Ismail, Electronic dispersion compensation for a 10-Gb/s link using a directly modulated laser at IEEE Photonics Technology Lett., Vol. 15, no . 12 , pp. 1788–1790, (2003) by M. D. Feuer, et al, Performance comparison between DCF and RDF dispersion compensation in fiber optical CATV systems at IEEE Trans. Broadcast.vol. 48,issue 4,pp 370–373, (2002) by Hai-Han. Lu, Analysis on Dispersion Compensation with DCF based on Optisystem at 2nd International Conference on Industrial and Information Systems ,vol:2,pp 40-43 (2010) by Bo - Ning HU , Wang Wei, Novel Optical Flat-Gain Hybrid Amplifier for Dense Wavelength Division Multiplexed System at IEEE photonics technology letter,vol 26, no.2 (2014) by Simranjit Singh and R.S kaler, Investigations on order and width of RZ super Gaussian pulse in different WDM systems at 40 Gb/s using dispersion compensating fibers,Optik 125, 4270-4273, (2014) by Gurinder Singh, Performance Analysis of Dispersion Compensation in WDM Optical Communication Systems in the International Journal of Science and Research (IJSR) , Volume 4 Issue 2, February 2015 by BarzaBadar , Anisha A.P.

Simulation Design

Simulation Setup

The research work is aimed at designing 32 x 40 Gbps system. What it means is the simulation and design of a thirty two channel system having speed of forty giga bits per second each channel. Following are the parameters;

Number of Channels = 32
Channel Spacing = 100
Frequency Range =191-194.1 Tera Hertz

The transmitter consists of a data source which will generate bits sequence (having forty giga bits per second rate/each). This is then followed by a pulse generator (Non return to Zero) the purpose of which is to translate the binary data into the electrical pulses. These electrical pulses are used to modulate the Laser signal. This is done through the use of a modulator.

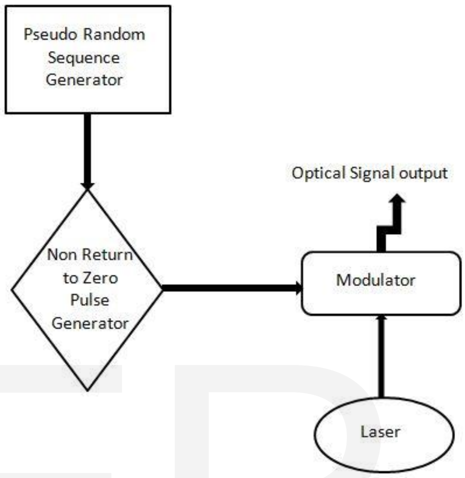

Figure 16: Designed Transmitter Setup

The above figure shows transmitter setup of simulated design. The output of pesduo random sequence generator is fed into a non return to zero pulse generator. The NRZ Generator pulse generator creates a sequence of non-return to zero pulses coded by an input digital signal. NRZ pulse generator output the signal to the input of modulator. A Mach-Zehnder modulator is used for controlling the amplitude of an optical wave. At modulator, laser is accumulated and hence modulator output the signal which is a combination of output of NRZ pulse generator and laser.

Now we have thirty two input channels which are fed into a multiplexer, which in turn combines them together and transmit the signal on the single fiber link. Following are some of the dimensions used;

Type of Fiber	=	Single Mode Fiber		
Length of Fiber	=	100 Kilometers		
Dispersion Compensating Fiber Length	=	16 Kilometers		
No of Spans (Single Mode Fiber)	=	2		
Length of 2 Spans	=	2 x 100 Km	=	200 Km
Dispersion Compensating Fiber Span	=	2 x 16	=	32
Total Length of Link	=	200 + 32	=	232 Km

It should be noted that the number of spans is taken to be 2 in pre & post compensation technique.

In order to adjust the input power levels, the following will be used in front of transmission fiber;

- Two Erbium Doped Fiber Amplifiers (Gain 15 db)
- Dispersion Compensating Fiber (Gain 5 db)
- Noise Figure 4 db

Erbium Doped Fiber Amplifiers are used in the optical communication network to amplify the optical signals.

Now let's discuss the receiver part. De-multiplexer is used which uses the PIN Photodetector, a filter (low pass) and 3R regenerator (category "three") for optical regeneration (in addition to re-amplification/reshaping, retiming of data pulse is also done). Here 1 ratio32 (1:32) splitting is done by the de-multiplexer i.e. one signal is divided into 32 different channels. The output of the de-multiplexer is given to the photodetector (PIN Photo Diode), which then passes through LPF and the regenerator. The setup is shown in the below figure.

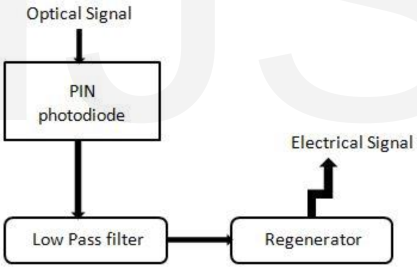

Figure 17: Reciever Block Diagram

The above diagram shows receiver part of simulated design. Optical signal first arrives at PIN photodiode. PIN photodiode is a kind of photo detector, it can convert optical signals into electrical signals. Output of photodiode is fed to a low pass filter in order to block the noise signal. At regenerator end, original electrical signal is regenerated.
For simulation, the following parameters along with the respective values are set as shown in the table below;

32 Channel DWDM	
Parameters	**Values**
Channels	32
Capacity	32 x 40 Gbps
Channel Spacing	100 GHz
Bit rate	40 Gbps
Sequence Length	64
Central Frequency (1st channel)	191 THz
Samples Per Bit	256

Table 4: Simulation Setup Parameters (Dispersion Compensation Fiber)

The fiber parameters used for Single Mode Fiber & Dispersion Compensating Fiber (dispersion compensation techniques) are;

Parameters	Single Mode Fiber	Dispersion Compensating Fiber
Length	100	16
Attenuation	0.20	0.60
Dispersion	17 ps/nm/km	-85 ps/nm/km
Dispersion Slope	0.08 ps/nm^2/km	0.30 ps/nm^2/km
Differential Group Delay	0.50 ps/nm	0.50 ps/nm
Polarization Mode Dispersion Coefficient	0.50 ps/km	0.50 ps/km

Table 5: Fiber Parameters

The following DWDM dispersion techniques will be analyzed through the simulation setup;

Pre Compensation Technique
Post Compensation Technique

After their analysis/simulation, they will be compared with a new compensation technique, which we will call a "symmetric compensation technique".

As we can see in figure below, in the Pre-Comp Tech the DC fibers before the SM Fiber for the compensation of dispersion.
In Pre-Comp design, all 32 channels are fed into MUX of DWDM. After multiplexing all 32 channels, a single output is fed into DC fiber before incident to EFDA with a ratio of 32:1. The signal is then transmitted over Single mode fiber. At receive side, signal is de multiplexed with a ratio of 1:32.

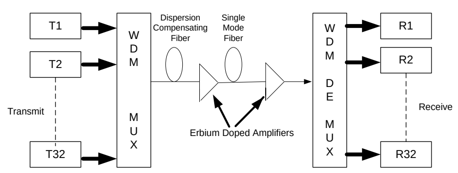

Figure 18: Pre-Compensation Technique

Now have a look at the Post-Compensation Technique. Here the DC Fiber is placed after the SM Fiber.

In Post-Comp design, all 32 channels are fed into MUX of DWDM. After multiplexing all 32 channels, Here SMF is placed before DC fiber. At receive side, signal is de multiplexed and analyzed.

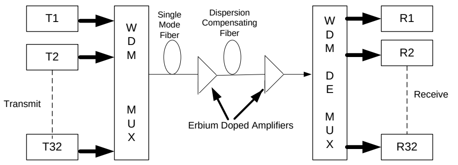

Figure 19: Post-Compensation Technique

We have designed a new Symmetric-Compensation technique/concept in which a mix is generated whereas the Dispersion Compensating Fiber is placed before and after the Single Mode Fiber in order to compensate the dispersion in the standard fiber. The figure below shows the designed system.

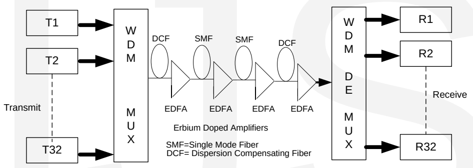

Figure 20: Symmetric-Compensation Technique

Data Analysis and research Findings

Simulation & Analysis

The simulation setup was done which included the following essential tools;

- Continuous wave (CW) Laser
- DPSK Sequence Generator
- Optical Spectrum Analyzer
- Low Pass Filter
- PIN Photo Detector
- BER Analyzer
- Mach-Zehnder Modulator
- Optical Power Meter Visualizer
- Oscilloscope Visualizer

The figures below show three different dispersion compensation techniques which have been analyzed in terms of Bit Error Rate (BER) and the Q-factor.

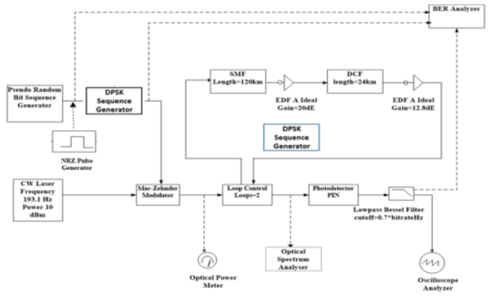

Figure 21: Simulation Snapshots (Pre Compensation Techniques)

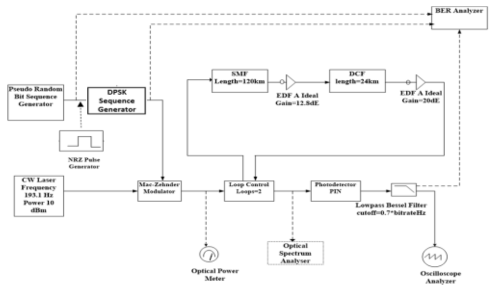

Figure 22: Simulation Snapshots (Post Compensation Techniques)

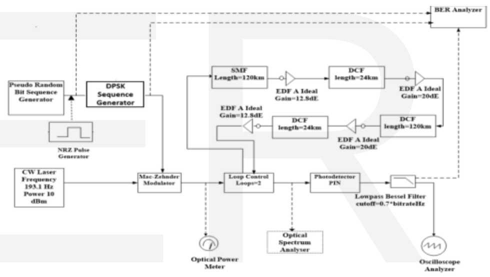

Figure 23: Simulation Snapshots (Symmetric Compensation Techniques)

In figure above, the simulation of pre, post and symmetric compensation are shown. Pseudo Random bit Sequence generator produces a non-return to zero pulse which is fed into the Mach-Zehnder modulator with its input from a CW laser. The results are analyzed by the bit error rate analyzer. Various other stages of the process includes the loop control, DCF, SMF, EDF and the photo detector, this producing an output at the oscillator output after passing through the low pass Bessel filter.

Eye Diagram [7] is used. An eye diagram is an oscilloscope display in which a signal from a receiver is repeatedly sampled and then applied to the input. The data rate is used for triggering. It indicates quality of signals. Eye diagram is generated through overlaying different segments of data flows. These are driven by a master clock.

Now let's have a look at the eye diagrams for the three scenarios;

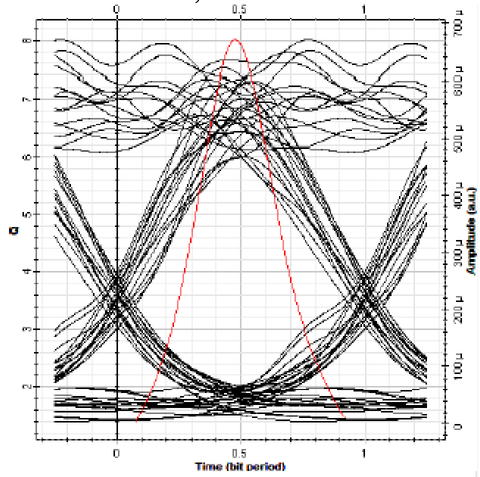

Figure 24: Pre- Compensation Technique (191.50 Tera Hertz)

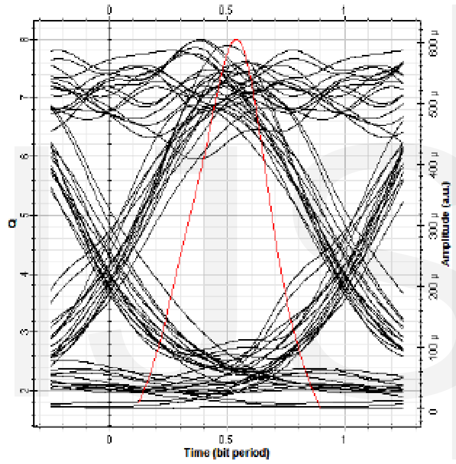

Figure 25: Post- Compensation Technique (191.50 Tera Hertz)

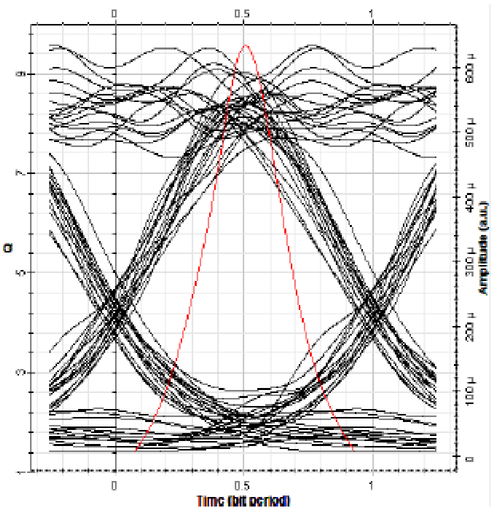

Figure 26: Developed Symmetric- Compensation Technique (191.50 Tera Hertz)

As we know that the center frequency (channel-one) is one hundred and ninety one terra hertz. The above eye diagrams were captured at the sixth channel having a frequency of one hundred and ninety one point five terra hertz. Analyzing the plot between Time, Amplitude and the Q factor, we find the following results;

Technique	Q Factor	BER
Frequency of 191.50 THz (6th Channel)		
Pre-Compensation Technique	8.02367	$4.62356e^{-017}$
Post-Compensation Technique	8.07345	$6.48635e^{-018}$
Developed Symmetric Compensation Technique	9.78537	$5.56137e^{-023}$

Table 6: Simulation Results (191.50 Tera Hertz, 6th Channel)

We again do the simulation for the fourteenth channel i.e. at one ninety two point three zero terra hertz.

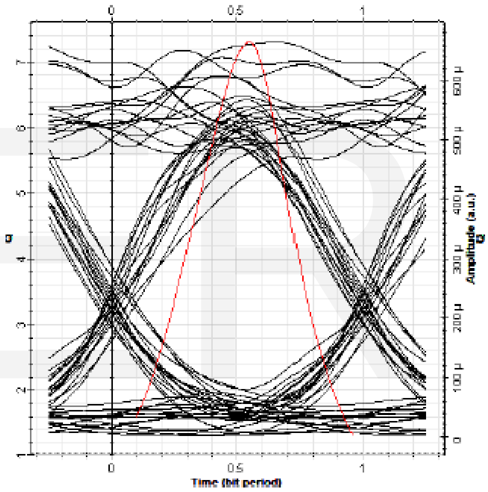

Figure 27: Pre Compensation Technique (192.30 Tera Hertz)

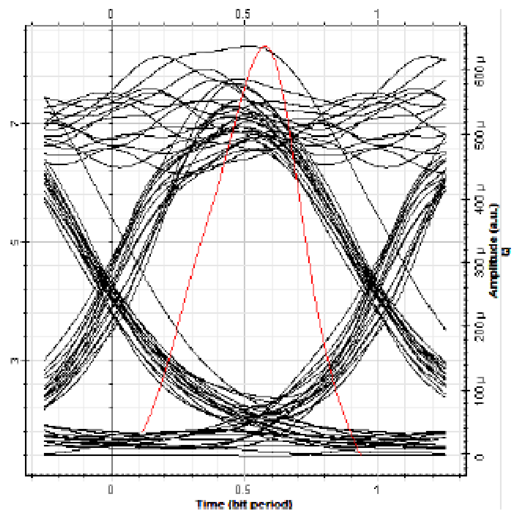

Figure 28: Post- Compensation Technique (192.30 Tera Hertz)

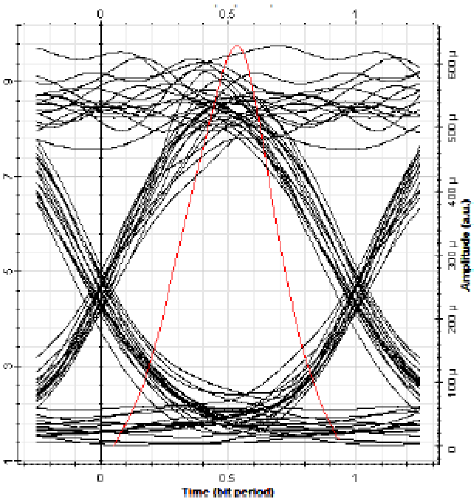

Figure 29: Developed Symmetric- Compensation Technique (192.30 Tera Hertz)

The results of the eye diagram for 14th channel simulation at a frequency of 192.30 THz is shown in the table below;

Technique	Q Factor	BER
Frequency of 192.30 THz (14th Channel)		
Pre-Compensation Technique	7.38462	$1.27433e^{-014}$
Post-Compensation Technique	8.40212	$4.42238e^{-015}$
Developed Symmetric Compensation Technique	9.79874	$8.901215e^{-024}$

Table 7: Simulation results (192.30 Tera Hertz, 14th Channel)

We again do the simulation for the twenty sixth channel i.e. at one ninety three point five zero terra hertz.

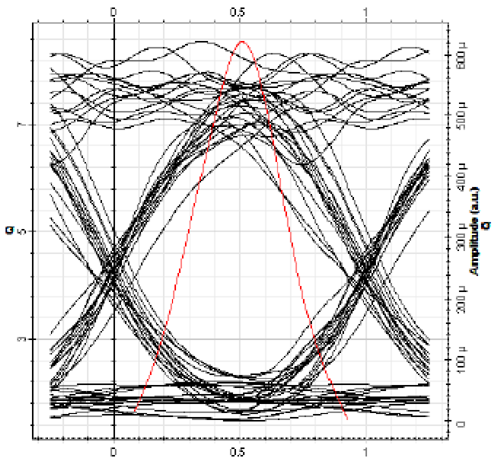

Figure 30: Pre- Compensation Technique (193.50 Tera Hertz)

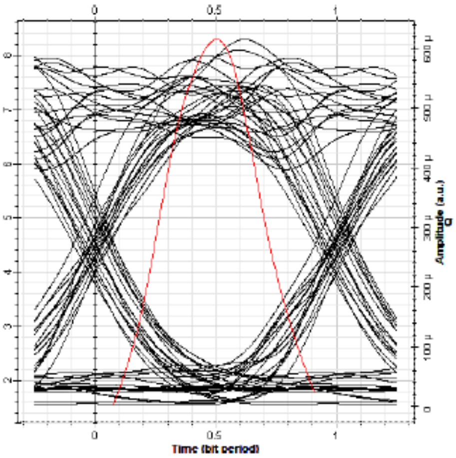

Figure 31:Post- Compensation Technique (193.50 Tera Hertz)

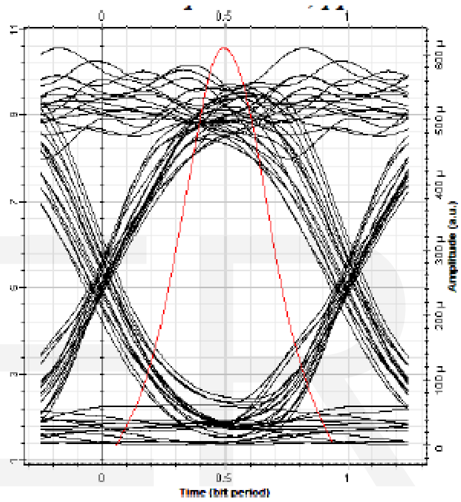

Figure 32: Developed Symmetric- Compensation Technique (193.50 Tera Hertz)

The results of the eye diagram for twenty sixth channel simulation at a frequency of one ninety three point five zero terra hertz is shown in the table below;

Technique	Q Factor	BER
Frequency of 193.50 THz (26th Channel)		
Pre-Compensation Technique	8.60621	$6.11276e^{-019}$
Post-Compensation Technique	8.16223	$5.30988e^{-018}$
Developed Symmetric Compensation Technique	10.6893	$2.60136e^{-027}$

Table 8: Simulation results (193.50 Tera Hertz, 26th Channel)

The results of the eye diagram for all channels simulation at all the frequencies are shown in the table below;

32 Channel DWDM System	Frequency THz	Pre-Compensation		Post Compensation		Proposed/Designed Technique Results	Symmetrical	
		Q-Factor	BER	Q-Factor	BER		Q-Factor	BER
1	191	9.57423	4.17243E-23	10.66941	7.94117E-22		10.05263	1.53455E-24
2	191.1	7.88624	1.29663E-16	8.48356	4.88433E-15		8.48305	3.15350E-17
3	191.2	7.69231	4.58370E-16	8.36525	1.26420E-14		8.19223	3.51249E-17
4	191.3	7.72118	3.13170E-16	9.18212	1.85480E-13		9.20136	7.23760E-19
5	191.4	7.79235	6.53421E-16	8.38338	9.33426E-15		8.22734	2.67650E-17
6	191.5	8.02367	4.62356E-17	8.07345	6.48635E-18		9.78537	5.56137E-23
7	191.6	7.16899	5.23567E-14	8.540621	3.21230E-15		8.08731	8.14325E-17
8	191.7	7.43993	4.58283E-15	9.406141	2.85450E-18		9.9143	5.51835E-24
9	191.8	8.88345	4.23776E-20	8.440331	6.11463E-15		9.06345	1.89657E-21
10	191.9	8.06032	4.46254E-17	9.280241	7.62256E-17		8.59606	1.14783E-18
11	192	7.99687	6.70870E-17	9.754741	1.39151E-19		9.39987	8.52945E-22
12	192.1	9.19298	7.23032E-21	9.358371	4.23567E-18		12.6176	8.33350E-31
13	192.2	7.43257	1.18744E-14	8.706991	8.61121E-16		9.46593	4.69682E-22
14	192.3	7.38462	1.27433E-14	8.40212	4.42238E-15		9.79874	8.90122E-24
15	192.4	8.96422	2.53328E-20	9.83337	7.00680E-20		9.79609	1.87451E-23
16	192.5	10.1737	3.56530E-25	8.67081	9.87856E-16		10.73652	1.23113E-27
17	192.6	7.90324	1.96976E-16	9.79329	9.05832E-20		9.13437	9.73834E-21
18	192.7	7.83175	4.82239E-16	10.34541	6.40356E-22		10.34021	9.19322E-25
19	192.8	8.75564	2.49663E-19	10.65727	3.11817E-23		11.66553	3.82224E-32
20	192.9	8.26479	1.58240E-17	9.41596	2.65535E-18		9.97494	3.19885E-24
21	193	10.1782	3.58711E-25	9.95462	2.26787E-20		12.11661	1.94437E-26
22	193.1	7.60148	1.41234E-15	10.53461	2.21227E-20		11.33277	4.73358E-29
23	193.2	8.71426	2.76362E-19	10.27327	1.22247E-20		9.42864	6.72632E-22
24	193.3	7.18136	7.43421E-14	10.67658	2.78760E-22		9.92363	5.42432E-24
25	193.4	9.36217	1.29152E-21	11.01559	9.43655E-24		11.04193	1.26575E-26
26	193.5	8.60621	6.11276E-19	8.16223	5.30988E-18		10.6893	2.60136E-27
27	193.6	9.16842	5.57674E-20	9.35602	9.46222E-17		9.40224	8.23863E-22
28	193.7	8.59879	8.46571E-18	9.27185	8.82639E-17		9.77609	2.23339E-23
29	193.8	8.75427	2.28784E-18	8.07024	1.28473E-15		9.43544	5.75760E-22
30	193.9	9.19898	1.14327E-20	9.07454	6.97730E-16		9.968467	3.36397E-24
31	194	8.48924	2.65638E-17	10.39581	1.39352E-15		9.87843	9.93455E-19
32	194.1	8.90123	4.87537E-19	9.74347	1.54556E-18		10.4759	1.95426E-25

Table 9: Simulation Results (All Frequencies, All Channels)

The results clearly indicate that the designed technique (for thirty two channel DWDM system) has improved Q-Factor values. Similarly when we look at the bit error rates, they are also reduced as compared to the other two schemes.

We can look at the respective comparison graphs (pre & post compensation technique) with our symmetrical designed technique.

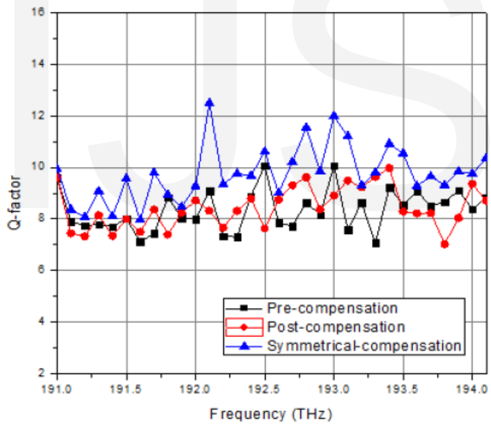

Figure 33: Q-Factor Comparison with Symmetrical Designed Technique

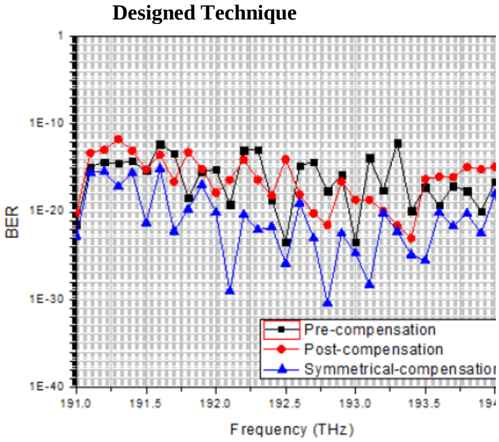

Figure 34: BER Comparison with Symmetrical Designed Technique

Models/Calculations

Model Development

In this research developed new model is show in the figure below.

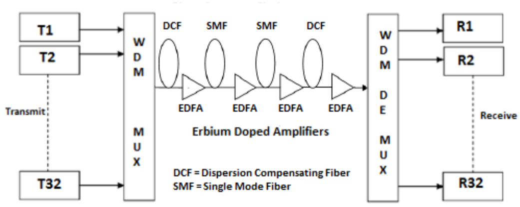

Figure 35: Developed Model "Symmetrical Compensation Technique"

Conclusions

The developed model is giving better results. Dispersion is the main hurdle faced when we are looking at the long distance optical fiber transmission systems used for high data rates/speed transmissions. This research was focused on thirty two channel, forty giga bits per second transmission system. Pre & post dispersion techniques were studied, simulated and analyzed.

Dispersion Compensation Fiber is used. Q-factor values/data was analyzed after getting the simulation results. Bit error Rate was looked at after simulation.

After analyzing the simulation results, it is shown/proved that the newly designed compensation technique is giving much better results in terms of Q-factor and the BER.

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