Dispersion Compensation Technique Analysis of DWDM

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Abstract

In today's technological age driven by enormous amounts of information being added to the networks daily, the need for greater bandwidths and enhanced speeds is growing with every passing day. With the introduction of dense wavelength division multiplexing technology, a single fiber can take care of multiple channels at the same time. They all have different wavelengths hence the interference between the signals is prevented. Dense wavelength division multiplexing (DWDM) technology has taken care of the increased bandwidth requirements and also the data speed. However, dispersion is one such problem which translates into the system performance degradations as the light pulses tend to expand thus affecting the transmission quality. In order to mitigate this, there is a need to evaluate and analyze different dispersion techniques in the DWDM systems. Critical factors including bit error rate and the quality factor need to be looked into in this research work to recommend most suitable dispersion compensation technique.

Keywords: Dense Wavelength Division Multiplexing, Dispersion Compensation, Fiber, Bit-Error-Rate

1.1. Dense Wavelength Division Multiplexing

Dense Wavelength Division Multiplexing (DWDM) passed through many evolutionary stages of multiplexing techniques including synchronous digital multiplexing, time division multiplexing and WDM (wavelength division multiplexing). The techniques which were used to reap the benefits out of the multiplexing were divided into following stages.

- Plesiochronous Digital Hierarchy (PDH)
- Synchronous Digital Hierarchy (SDH)
- Dense Wavelength Division Multiplexing (DWDM)

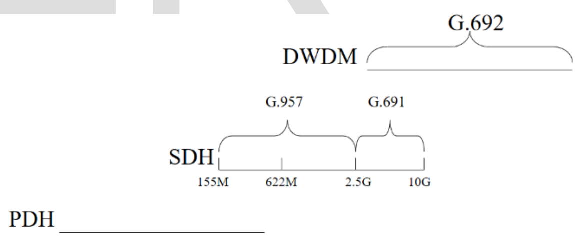


Figure 1.1: PDH, SDH and DWDM

The systems operated at different speeds as shown in the above figure. The relationship between DWDM and Other Services is shown below.

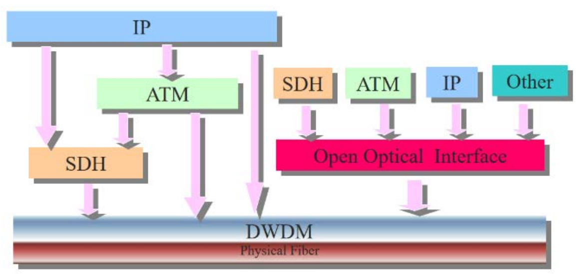
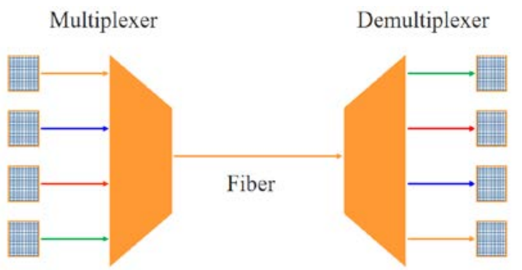
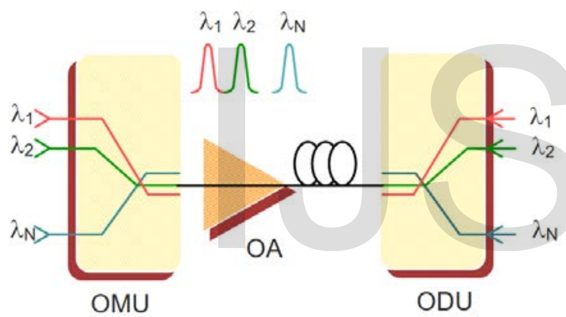


Figure 1.2: DWDM and Other Services

In wavelength division multiplexing, various optical signals are combined together and multiplexed at the optical multiplexing unit (OMU) and then sent over a channel. Optical Amplifiers (OA) [2] are used if the signal degrades below a certain threshold value. At the receiving end the optical distribution unit (ODU) demultiplexes the wavelengths and transfer them to the respective recipients.



(a)



(b)

Figure 1.3: Optical Multiplexing Principle

Dense wavelength division multiplexing concept is further shown in the figure below in relation to power and wavelength and the applicable wavelength intervals.

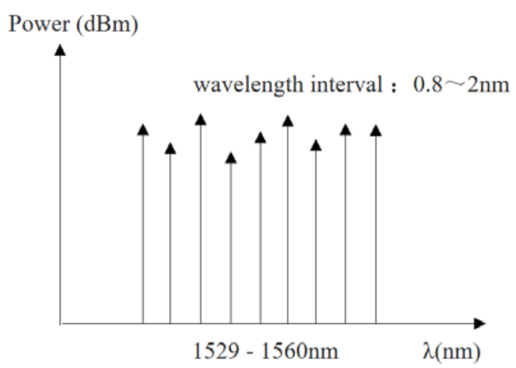


Figure 1.4: Concept Wavelengths Distribution

A typical DWDM system design [6] is shown below.

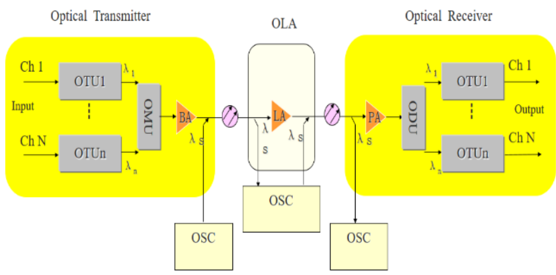


Figure 1.5: Concept Wavelengths Distribution

Typical network elements of a DWDM system are.

- OTM - Optical Terminal Multiplexer
- OLA - Optical Line Amplifier
- OADM - Optical Add/Drop Multiplexer

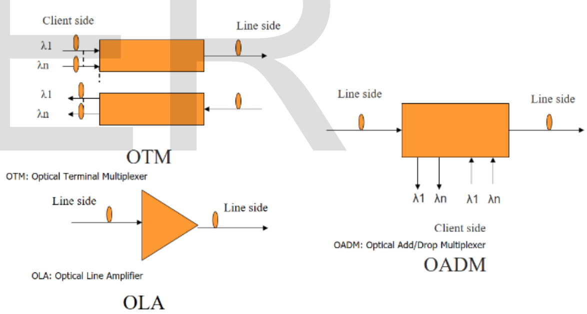


Figure 1.6: Network Elements in DWDM System

Key Components of DWDM include;

- Optical source
- Optical Multiplexer and Demultiplexer
- Optical Amplifiers [3]
- The Supervision of WDM System

The operation wavelength range is divided into various transmission bands.

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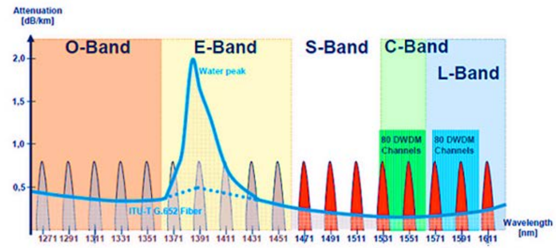

Figure 1.7: DWDM Wavelength Bands

(Source: https://community.fs.com/blog/from-o-to-l-the-evolution-of-optical-wavelength-bands.html)

1.2. DWDM Network Design

DWDM network can be designed in the following manner;

- Point-to-Point Network
- Chain Network
- Ring Network

The network architectures for these are shown below.

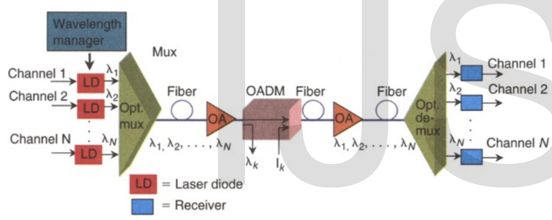

Figure 1.8: DWDM Point-to-Point Network

(Source: http://www.fiber-optic-solutions.com/dwdm-topology-design-make-right.html)

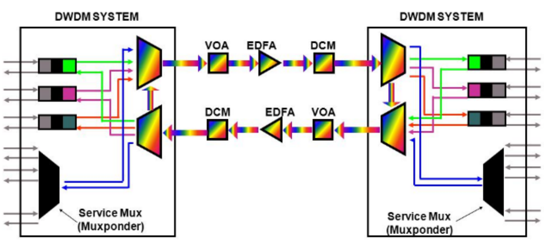

Figure 1.9: DWDM Chain Network

(Source: https://slideplayer.com/slide/4178969/)

Here EDFA stands for Erbium Doped Fiber Amplifies [1], DCM is the dispersion compensation module and VOA is the Variable Optical Amplifier.

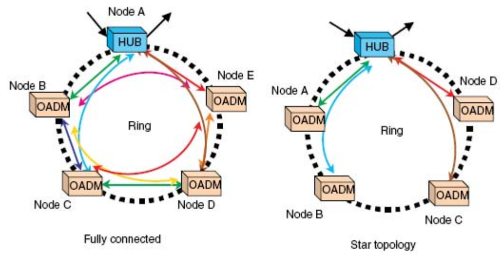

Figure 1.10: DWDM Ring Network

(Source: https://www.globalspec.com/reference/21551/160210/chapter-4-2-dwdm-network-topologies-review)

Optical Supervisory Channel works at operating wavelength of 1510nm with 2Mb/s full management with order wire phone and a guaranteed long distance transmission without amplification. Traditionally DWDM protection is at SDH level however in newer DWDM systems, new cards are used which send signal in both directions and works on the principal of sending in both directions and receiving them in optimum way. This makes it possible to directly send Ethernet Traffic on DWDM.

Protection is based on self-healing concepts. When main working route somehow fails, services are switched to protecting path automatically (less than <50ms). Following is the DWDM protection mechanisms.

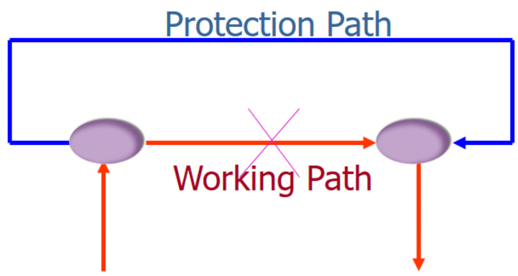

Figure 1.11: DWDM Self-Healing Protection Mechanism

1.3. Transmission of Light in DWDM System

The transmission of light signals in DWDM system follows the basic rules of the transmission of light in fiber. There are two phenomena's used;

- Total Internal Reflection of Light

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When light is reflected from a surface, the angle of reflection is equal to the angle of incidence.

- Total Internal Refraction of Light

Bending of light rays due to changes in the speed of propagation when light enters from one medium to another.

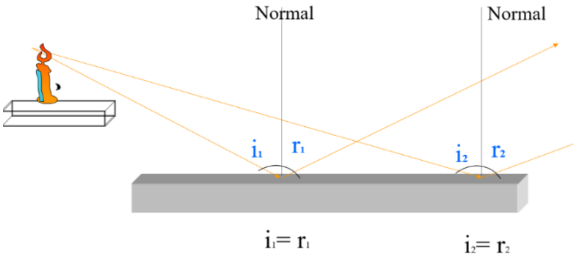

Figure 1.12: Total Internal Reflection of Light

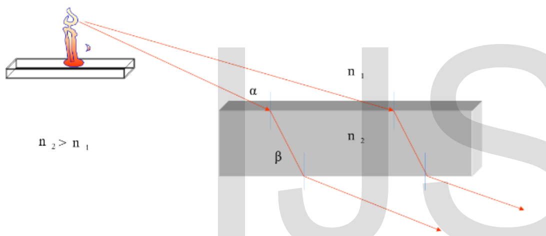

Figure 1.13: Total Internal Refraction of Light

1.4. The research problem

DWDM systems encounter the issue of wide spread dispersion which causes bit error rates thus affecting the quality parameters and leads to speed degradation and error transmissions. This leads to dispersion, and affects the overall system performance [4].

1.5. The purpose of the study

To design DWDM system (compensation technique) which can take care of the BER & Q-Factor. In addition, it will look at Pre, Post and Symmetrical compensation parameters.

1.6. The objectives of the study

Following objectives will be achieved through this research work.

- Design of a DWDM Model
- Design of an innovative DWDM Compensation [5] technique
- Bit Error Rate Reduction
  - Pre Compensation
  - Post Compensation
  - Symmetrical Compensation
- Improving the Quality Factor
  - Pre Compensation
  - Post Compensation
  - Symmetrical Compensation

1.7. The Research Questions

Following are the research questions.

- How can we design a DWDM system having less dispersion?
- Which compensation technique can be used for an efficient design?
- How is the bit error rate reduction achieved?
- How can we increase the Quality Factor?

1.8. Literature Review

A lot of literature has been studied which relates to the development taking place in this area. The below table list the documents studied in this regards.

Research Topic	Reference	Authors
Capacity expansion of fiber optic networks with WDM systems: problem formulation and comparative analysis	Elsevier 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	Yogesh Chaba
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, Sukhbir Singhand Ameeta Seehra
Performance Analysis of Dispersion Compensation in WDM Optical Communication Systems	International Journal of Science and Research (IJSR) , Volume 4 Issue 2, February 2015	Barza Badar , Anisha A.P.

Table 1.1: Literature Review

1.9. Simulator

OptiSystem simulator is used for planning, testing, and simulation of designed optical networks links.

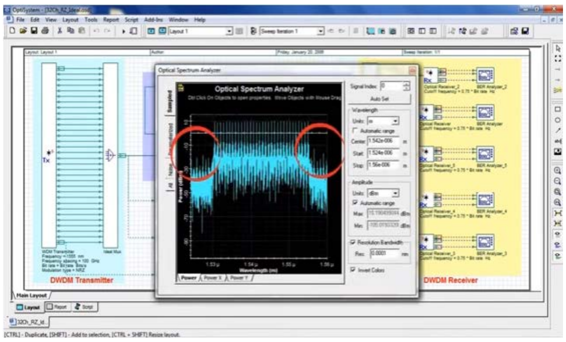

Figure 1.14: Optisystem

2.1. Design Environment

A DWDM system needs to be designed comprising of "A" Channels and capacity of "B" Gbps. The conceived design has to be simulated in the selected Optisystem software. The number of channels can be 32 or 64 and the capacity can be 40 or 10 Gbps. If we are looking for a 32 x 40 Gbps DWDM System, the channel spacing will be around 0.1 GHz. The wavelength and the frequency for 32 channels can be calculated for a DWDM System as per the standard developed.

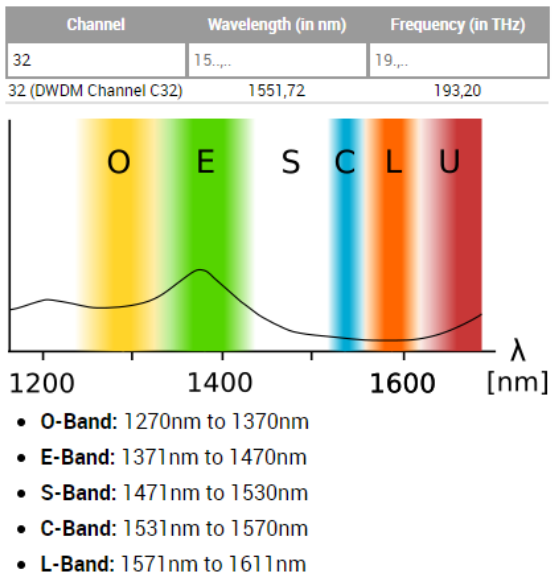

Figure 2.1: DWDM Wavelength and Frequency Calculator

(Source: https://www.flexoptix.net/en/dwdm-channels/)

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Our selected wavelength lies in the C-Band having a value of 1551.72 nm and frequency of 193.20 THz. If we go for 64 x 10 Gbps DWDM System, the wavelength will be 1526.44 nm and frequency of 196,40THz. The designed system has a transmitter with data source which generates the Pseudo Random Bit Sequence having a data rate of 40 Gbps. The block diagram of the conceived model is shown below for clarity.

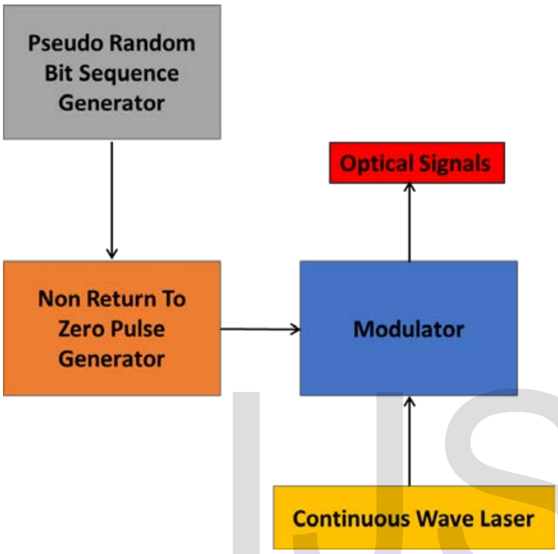

Figure 2.2: DWDM Transmitter

The pulse generator converts the binary data into electrical pulses that modulates the laser signal from the continuous wave laser and gives optical signals as an output. In this way 32 different channels are combined together by optical multiplexing using a multiplexer and then transmitted over the optical fiber link. In our design we have used single mode fiber having a length of 100 Km and Dispersion Compensating Fiber length of 18 Km. The number of spans taken are two for pre/post compensation technique.

No of Spans = 2
Spans Length = 100 Km x 2 = 200 Km
Dispersion Compensating Fiber length = 18 Km x 2 = 36 Km
Total Link Length = 236 Km

The 3 dispersion compensation techniques are;

1. Pre-Compensation Technique
2. Post-Compensation Technique
3. Symmetrical-Compensation Technique

Additionally, Erbium Doped Fiber Amplifiers are used. At the receiving end, demultiplexing is done through de-multiplexer. The receiver setup is shown below.

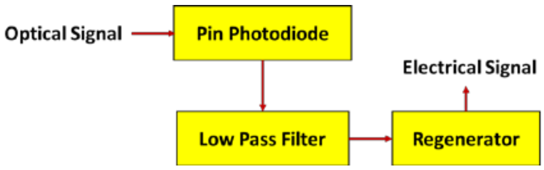

Figure 2.3: DWDM Receiver

PIN Photodetector is used to detect the optical signal and passed through the low pass filter and the regenerator to receive back the electrical signal as was the input of the receiver to start with. The demultiplexing has a ratio of 1:32 (hence 32 channels system design).

The table below shows various parameters set for our DWDM System simulation.

Defined Parameter	Value
Number of Channels (A)	32
Capacity (B)	40 Gbps
Frequency	193.20 THz
Channel Spacing	0.1 GHz

Table 2.1: Parameters for DWDM System Simulation

Similarly, the parameters of the fiber used for the dispersion compensation techniques needs to be defined.

Defined Parameter	Single Mode Fiber	Dispersion Compensation Fiber
Length	100 Km	18 Km
Attenuation	0.19	0.59
Dispersion (ps/nm/km)	16	-80
Dispersion Slope (ps/nm/km)	0.07	0.28
Differential Group Delay (ps/nm)	0.49	0.49
Polarization Mode Dispersion Coefficient (ps/km)	0.49	0.49

Table 2.2: Parameters for Fiber used for Dispersion Compensation Techniques

2.2. Simulated Architectures

Now we will draw the architectures for dispersion compensation techniques.

- Pre-Compensation Technique

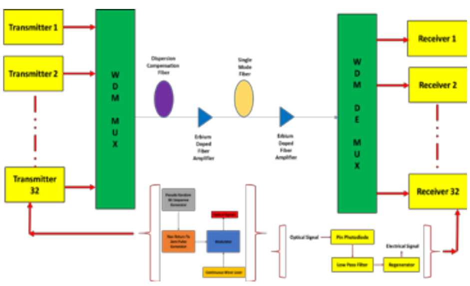

Figure 2.4: Pre-Compensation Technique

In the above network architecture dispersion compensation fiber is in front of the multiplexer followed by erbium doped amplifier, single mode fiber and then again the erbium doped fiber. The placement of dispersion compensation fiber before the single mode fiber achieves pre-compensation to the transmitted signals over the communication link.

- Post-Compensation Technique

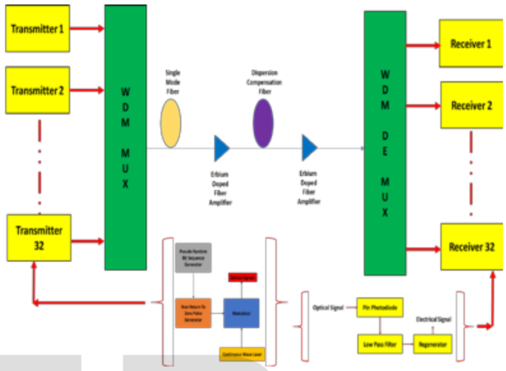

Figure 2.5: Post-Compensation Technique

In Post-Compensation technique, single mode fiber is in front of the multiplexer followed by erbium doped amplifier, dispersion compensation fiber and then again the erbium doped fiber. The placement of dispersion compensation fiber after the single mode fiber achieves post-compensation to the transmitted signals over the communication link.

- Symmetrical-Compensation Technique

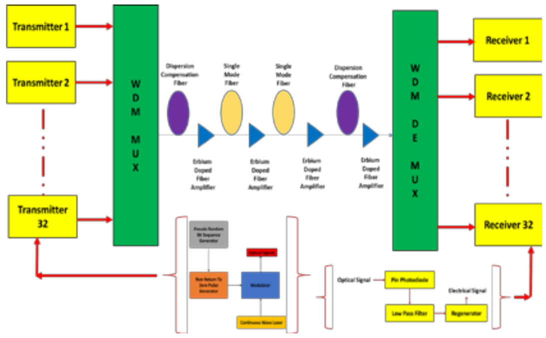

Figure 2.6: Symmetrical-Compensation Technique

In the case of symmetrical compensation technique two single mode fibers, each of length 100 km and two dispersion compensation fibers, each of length 18 km are used, hence the total length of link is 236 km in all of the three techniques for compensation. Erbium doped amplifiers, dispersion compensation fiber are used to adjust the input power levels by adding gain and noise figures. Erbium doped amplifiers are used for the amplification of the optical signals.

All the above compensation techniques have been designed to reduce the bit error rates and for improving the Q-factor. Simulation is done to design an improved system through the adaptation of some new dispersion compensating technique. The following traditional simulation flow chart will be used.

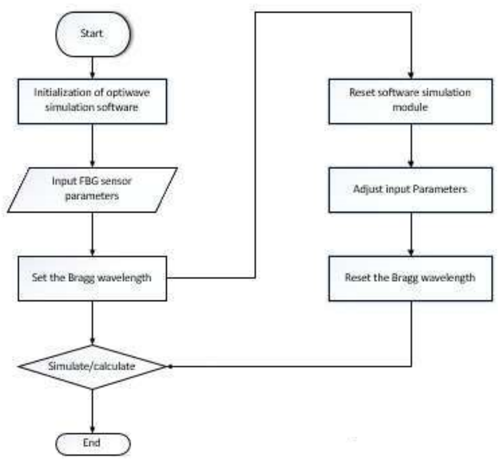

Figure 2.7: Simulation Flow Chart

(Source: https://www.researchgate.net/figure/Software-flow-chart_fig2_318881372)

Data Analysis & Research Findings

The three compensation techniques have been designed in the previous chapter and the simulation results and findings are presented in this chapter. The two factors analyzed relate to the following;

- Bit Error Rate
- Q-Factor

The frequency range is from 191 to 195.1 THz. The results at the specific channel at a certain frequency are analyzed.

3.1. Simulation for Sixth Channel (191.50 THz)

Pre, post and symmetrical compensation techniques were analyzed for the sixth channel in the 32 channel designed DWDM system. The figures below show the results.

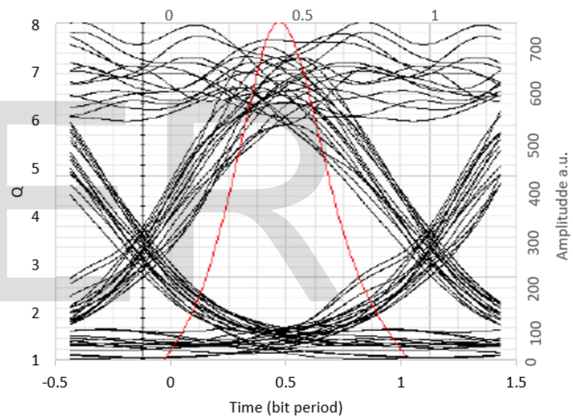

Figure 3.1: Pre-Compensation (Sixth Channel)

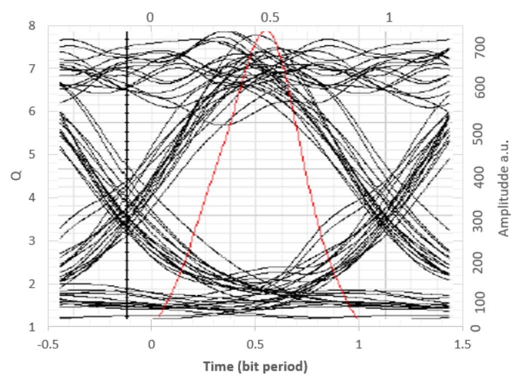

Figure 3.2: Post-Compensation (Sixth Channel)

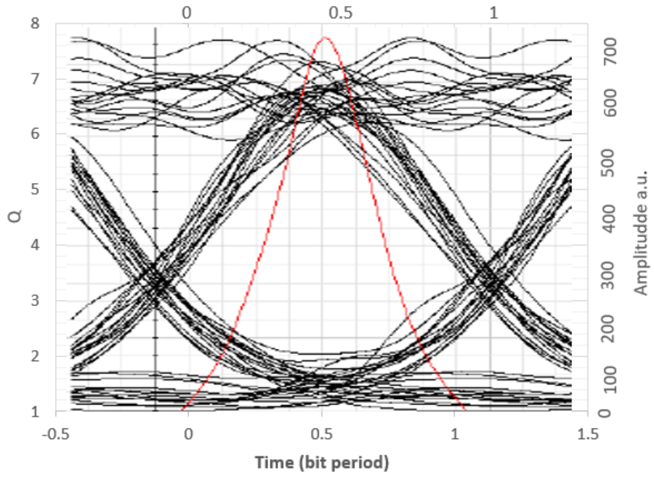

Figure 3.3: Symmetrical-Compensation (Sixth Channel)

As can be seen in the above Eye diagrams [7], pre-compensation technique provides the Q-factor value of 7.989 and BER 4.62785e-015. For post-compensation technique, the Q-factor is 7.5778 and BER 6.443e-014. The symmetrical-compensation technique gives the Q-factor 8.9875 and BER of 5.0221e-020.

3.2. Simulation for Fourteenth Channel (192.30 THz)

Pre, post and symmetrical compensation techniques were analyzed for the fourteenth channel in the 32 channel designed DWDM system. The figures below show the results.

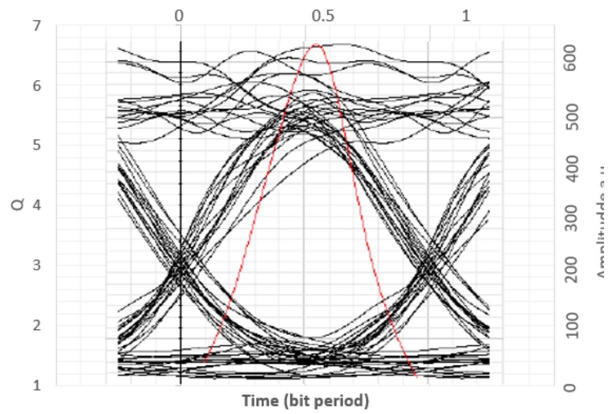

Figure 3.4: Pre-Compensation (Fourteenth Channel)

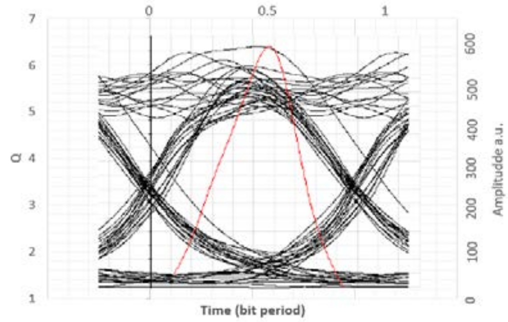

Figure 3.5: Post-Compensation (Fourteenth Channel)

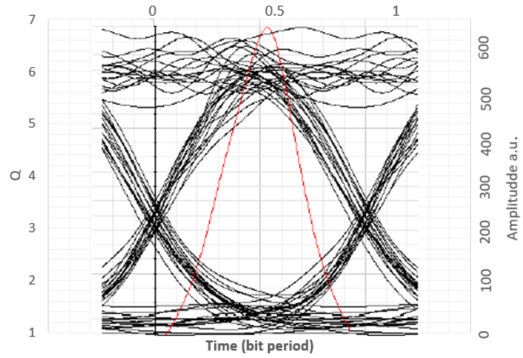

Figure 3.6: Symmetrical-Compensation (Fourteenth Channel)

Eye diagram for pre-compensation technique gives Q-factor of 6.9873 and BER 1.3289e-012. For post-compensation and Symmetrical-compensation technique, the obtained vales are Q-factor 7.912, BER 4.589e-016 and Q-factor 9.9873 and BER 8.90213e-022 respectively.

3.3. Simulation for Twenty-Sixth Channel (193.50 THz)

Pre, post and symmetrical compensation techniques were analyzed for the twenty-sixth channel in the 32 channel designed DWDM system. The figures below show the results.

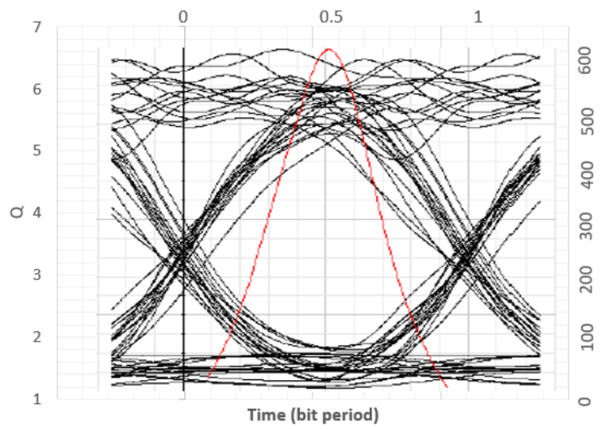

Figure 3.7: Pre-Compensation (Twenty-Sixth Channel)

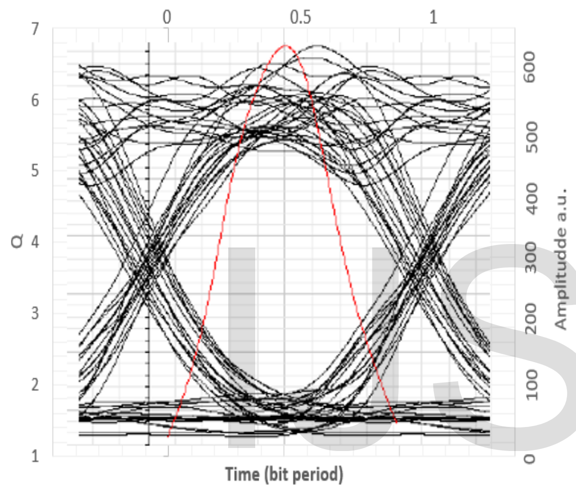

Figure 3.8: Post-Compensation (Twenty-Sixth Channel)

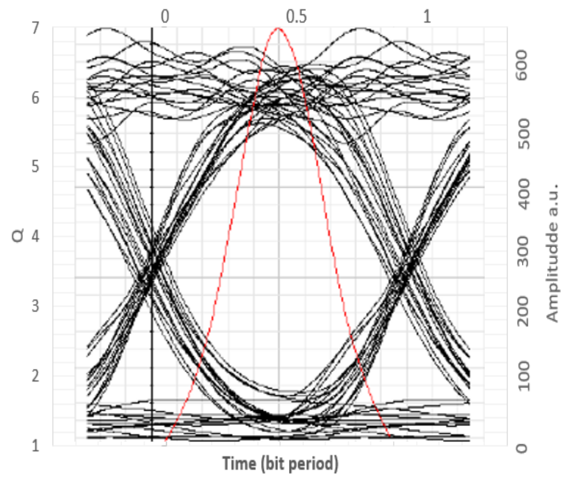

Figure 3.9: Symmetrical-Compensation (Twenty-Sixth Channel)

Eye-diagram of for pre-compensation technique provides Q-factor of 8.4935 and BER 6.00123e-017. Post-compensation technique has Q-factor of 8.10114 and BER of 5.1976e-016 with symmetrical compensation technique providing Q-factor 9.0124 and BER of 2.5789e-025.

It is seen from the above analysis that the Q-Factor for the symmetrical compensation technique is better as compared to that of pre and post compensation network architecture design. It should be remembered that the analysis is being done for a 32 x 40 Gbps DWDM system. Similarly the bit error rate of symmetrical compensation technique is found to be better. The simulation is run for all the channels and they conform to the result of channel 6, 14 and 26, thus showing consistency in our findings.

The Q-Factor and BER comparison for all the three dispersion compensation techniques is plotted below for clarity.

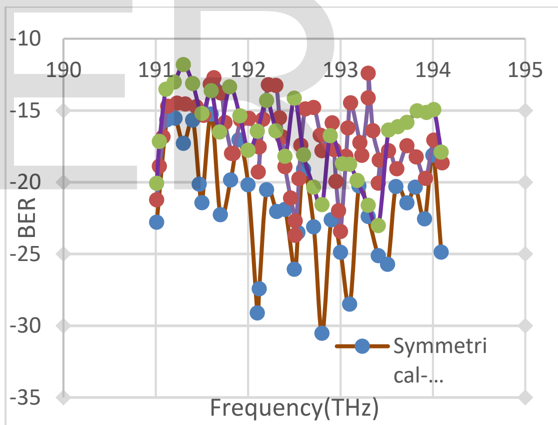

Figure 3.10: Q-Factor Comparison for three techniques

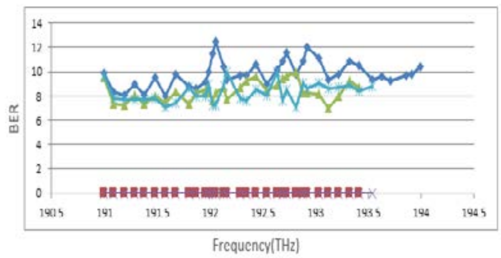

Figure 3.11: BER Comparison for three techniques

4.1. Conclusions

Following are the observations from our research findings;

- Dispersion is the main reason for the degradation of the performance when we are concerned with long distance high speed transmission on the optical fiber channels.
- The researcher looked at a 32 x 40 Gbps DWDM system and investigated different compensation techniques architectures.
- Bit-Error-rate and Q-Factors for all the designed compensation techniques were evaluated through simulation.
- It was proved through the simulation results that the symmetrical compensation technique is considerably better than pre and post compensation techniques.

4.2. Contribution to Knowledge (Academic Contribution)

Through this research work the researcher has designed an improved system by adopting most effective and suitable dispersion compensating technique. The designed compensation technique gives good results in terms of Q-factor and the BER.

4.3. Statement of Significance (Practical Contribution)

The research focused on thirty-two channel, forty giga bits per second transmission system which is practically used in optical fiber communications.

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