ISSN: 2395-1680 (ONLINE)
DOI: 10.21917/ijme.2018.0106

PERFORMANCE ANALYSIS OF DWDM OPTICAL NETWORK WITH DISPERSION COMPENSATION TECHNIQUES FOR 4×8 GBPS TRANSMISSION SYSTEM

M.L. Meena and Deepika Meena
Department of Electronics Engineering, Rajasthan Technical University, India

Abstract

In this article, a new 4-channel dense wavelength division multiplexing (DWDM) optical transmission system model is proposed with dispersion compensation techniques. Dispersion compensation mechanism limits the pulse broadening effects of transmitted light in optical communication systems. To overcome dispersion problem; Pre, Post and Symmetrical dispersion compensation scheme are modeled, analyzed and compared for investigate the performance of DWDM system. The proposed model is designed for 8Gbps using non-return-to-zero (NRZ), return-to-zero (RZ) and Gaussian modulation format with erbium doped fiber amplifier (EDFA) over a length of 150km single mode fiber (SMF) and 30km dispersion compensation fiber (DCF). The performance of designed model is compared in terms of bit error rate (BER) & Q-Factor and it is observed that, the symmetrical dispersion compensation scheme with RZ pulse generator modulation gives best performance for long-haul transmission system.

Keywords:

Bit Error Rate, Dense Wavelength Division Multiplexing, Dispersion Compensation Fiber, Erbium Doped Fiber Amplifier

1. INTRODUCTION

Recently, the demand of optical fiber technology is increased day by day in telecommunication industry due to large bandwidth, high data rate and low cost reliable optical communication links. Dense wavelength division multiplexing (DWDM) system is currently adopting to increase the data carrying ability and an efficient utilization of optical fiber networks [1], [2]. DWDM is a method of transmission system that uses multiplexer at transmitter division for transmitting different wavelength multiple light signals and de-multiplexer at receiver division to spread the light signals separately over a single fiber as can be seen in Fig.1.

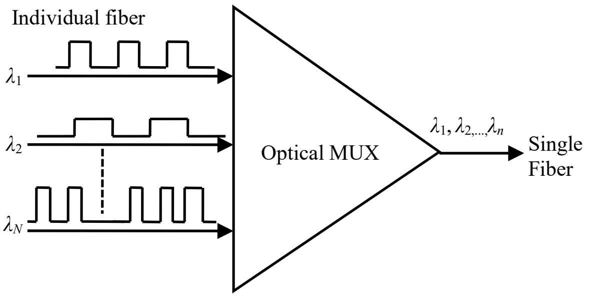

Fig.1. Basic building block of optical DWDM transmission system

The transmission in optical DWDM network system is mainly effected, when different wavelength signals are transmitted over an optical fiber, these optical signals travel with different speeds due to the variations in core and cladding refractive index. Therefore, the optical signals are overlap/broaden/spread out after travel a long distance through fiber. Hence the broadening of pulse causes dispersion and losses in transmitted signals which lead to error signal at receiver end [3]. Therefore, attenuation loss and dispersion are the major factor that affect DWDM optical network. In order to overcome the attenuation problem, erbium doped fiber amplifier (EDFA) is introduced as shown in Fig.2. To amplify the optical signal, EDFA is the most frequently used optical amplifier (OA) because it works on low loss 1550nm wavelength window of silica based fiber [4]-[6].

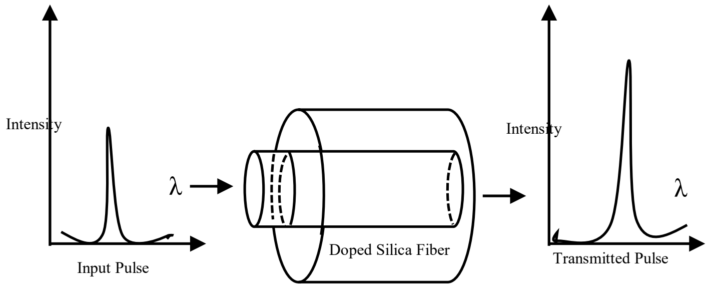

Fig.2. Basic principal of EDFA amplifier

In optical DWDM transmission system, dispersion is the key issue to restrict the long distance optical fiber communication [7, 8]. To overcome dispersion issue, the most efficient technique that is Dispersion Compensation Fiber (DCF) is introduced having negative dispersion coefficient to compensate the effect of positive dispersion in an optical fiber communication link [9]. However, DCF technique increases insignificant nonlinear effects but it is low cost, simplicity, highly reliable and easy to upgrade of already installed links of single mode fiber (SMF) in an optical network [10].

In this paper, author presents the performance analysis of DWDM transmission system with pre, post and symmetrical DCF techniques for 4×8 GBPS optical communication networks. The optimized parameters of SMF and DCF are identified and after simulation, performance parameters of the proposed model are analyzed for each channel in terms of Q-factor, BER and eye-diagram for NRZ, RZ and Gaussian modulation scheme. Main aim of presented work is to improve the performance of proposed 4-channel model by reducing dispersion and attenuation phenomena through DCF & EDFA amplifier, respectively. The designed optical DWDM configurations are modeled and simulated using advanced tools of Optisystem 7.0 simulator.

2. DISPERSION COMPENSATION TECHNIQUES

Dispersion supervision plays an important role for designing of optical DWDM transmission systems because; dispersion degrades the performance of longer optical transmission link due to the fiber nonlinearity. So, dispersion compensation fiber (DCF) is the most universal technique to reduce the impact of dispersion. For this purpose, a special single mode fiber is designed to reverse the deleterious consequence of dispersion and improve the transmission quality of optical fiber. Therefore, the DCF has a higher negative dispersion coefficient around -85ps/nm-km fibers can be linked to the SMF having positive dispersion coefficient of 17ps/nm-km to compensate the dispersion effect as shown in Fig.3.

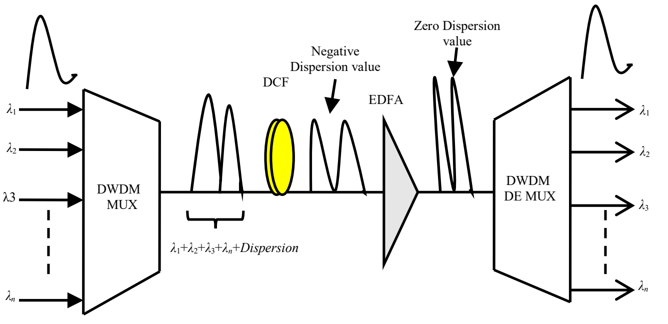

Fig.3. Basic principal of DCF Technique with EDFA-DWDM optical transmission system

Hence, dispersion compensation fiber is competent to compensating the group velocity dispersion (GVD) and insignificant nonlinear effect inside the fiber if optical power is kept small. The pulse propagation equation for optical signal propagates through the segments of SMF and DCF at L transmission distance can be given as [9]:

$$V(L,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{V}(0,\omega)\exp\left(\frac{i}{2}\beta\omega^2L-i\omega t\right)d\omega \tag{1}$$

where, $\tilde{V}(0,\omega)$ is Fourier transform of pulse amplitude $V(0,t)$ and β is GVD parameter, which is related to dispersion. Dispersion induced deficiency of optical signal is cause by the phase aspect, $\exp\left(\frac{i}{2}\beta\omega^2L\right)$, which can be acquired by signal during its transmit throughout the optical fiber. If the length of two fiber segments L_{SMF}, L_{DCF} are due to SMF and DCF, respectively then from the Eq.(1):

$$V(L,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{V}(0,\omega)\exp\left(\frac{i}{2}\omega^2\begin{pmatrix}\beta_{SMF}L_{SMF}+\\ \beta_{DCF}L_{DCF}\end{pmatrix}-i\omega t\right)d\omega \tag{2}$$

where, overall length of fiber segments is $L = L_{SMF} + L_{DCF}$ and β_{SMF}, β_{DCF} are GVD parameters for the segments of fiber length L_{SMF} and L_{DCF}, respectively. If we choose DCF then ω^2 term disappear thus original pulse shape can be recover. Therefore, perfect condition for dispersion compensation beside DCF can be given as:

$$\beta_{SMF}\,L_{SMF}+\beta_{DCF}\,L_{DCF}=0 \tag{3}$$

or

$$D_{SMF}\,L_{SMF}+D_{DCF}\,L_{DCF}=0 \tag{4}$$

and

$$D=-\frac{2\pi c}{\lambda^2}\beta \tag{5}$$

where, λ is wavelength of pulse signal, C is the light speed. Because in case of SMF, $D_{SMF} > 0$, Eq.(4) shows that dispersion coefficient D_{DCF} (in ps/nm.km) (at certain wavelength λ in nm) of DCF should be negative for dispersion compensation and length L_{DCF} (in km) of DCF must be satisfy as.

$$L_{DCF} = -L_{SMF}\,(D_{SMF}/D_{DCF}) \tag{6}$$

Further, to overcome remaining dispersion in very high speed optical transmission systems, the dispersion slop S_{DCF} of DCF must be satisfy as:

$$S_{DCF} = -S_{SMF}(L_{SMF}/L_{DCF}) = S_{SMF}(D_{DCF}/D_{SMF}) \tag{7}$$

where, S_{SMF} is dispersion slope of SMF. According to above analysis, the components/mechanisms of DCF are wide band-width performance, more stable and negligible temperature dependence/effect. Hence, DCF is the most appropriate technique for dispersion compensation. Therefore, the physical arrangement of SMF and DCF can be situated at three different positions in optical DWDM transmission system for dispersion pre-compensation, post-compensation and symmetrical compensate-ion. In section 3, we discussed a proposed 4-channels optical DWDM transmission model and evaluate the performance of designed model in terms of Q-factor, BER and eye-diagrams for each channel.

3. PROPOSED 4×8 GBPS DWDM TRANSMISSION SYSTEM MODEL

The four channels DWDM optical transmission system is designed on 8Gb/s per channel transmission speed based on pre, post and symmetrical dispersion compensation techniques. The proposed model is simulated by software Optisystem7.0 using three different modulation formats to investigate how dispersion altered the performance of optical DWDM transmission system. The basic principal of 4-channels DWDM optical transmission system model is shown in Fig.4. The 4-channel transmitter is constructed by data source, to produce a pseudo random sequence, RZ or NRZ or Gaussian pulse generator, to convert binary data into electrical pulse, continuous wave laser (CW) and Mach-Zehnder (MZ) modulator to modulate the CW laser signal. The central frequencies of each channel (for 4-channel simulation-starting from 1st to 4th channel) are selected from 193.1THz to 193.4THz according to recommendation of ITU-TG.694.1.

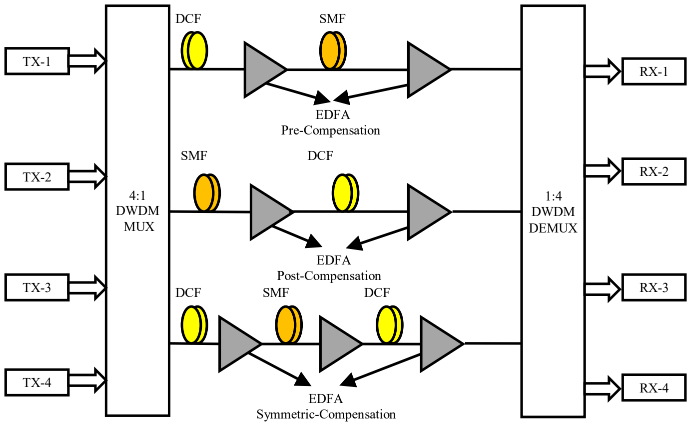

Fig.4. Principal of 4-channels DWDM optical transmission system

Four CW laser sources are used for generating different wavelength optical signals with 100GHz channel spacing. These optical input signals are combining through DWDM multiplexer and spread over a single optical fiber consisting of DCF and SMF. The length of SMF and DCF are 150km, 30km, respectively.

Therefore, total transmission length of channel is 180km. Further, relative arrangement of DCF and SMF are preferred according to dispersion compensation techniques (pre, post and symmetrical) and EDFA amplifier is introduced to amplify the transmitted signals as shown in Fig.4. The receiver consists of DWDM de-multiplexer (DEMUX) to split the optical signals to four different channels/terminals. The outputs of DEMUX are given to PIN photo-detector and pass through low pass electrical Bessel filter and Eye/BER analyzer. The whole simulation model of 4×8 Gbps DWDM optical transmission system is shown in Fig.5 and parameters of simulation model components are given in Table.1.

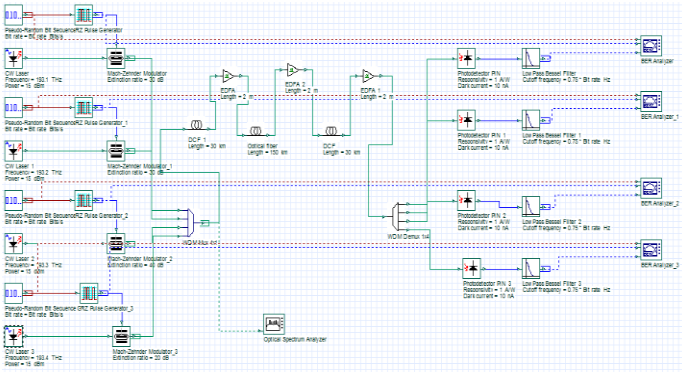

Fig.5. Proposed simulation model of 4×8 GBPS DWDM optical transmission system

Table.1. Basic components and their parameter values of simulation model

Components	Parameters of Four Channels
Data source	Data rate: 8Gbps
Line coder (RZ, NRZ, Gaussian)	RZ Duty cycle: 0.5
CW Laser	Output power: 15dBm FWHM line width: 10MHz 1st- 4th Channel central frequencies: 193.1THz-193.4THz Channel spacing: 100GHz
Mach-Zehnder (MZ) Modulator	Extinction ratio: 30dB
DCF	Length: 30km Attenuation Loss: 0.25dB/km Dispersion: -85ps/nm.km Dispersion slop: -0.3ps/nm^2/km Core effective area: 25µm^2
SMF	Length: 150km Attenuation Loss: 0.25db/km Dispersion: 17ps/nm.km Dispersion slop: 0.08ps/nm^2/km Core effective area: 85µm^2
EDFA Gain	Variable Gain (10-30dB)
Receiver	Photo-detector: PIN Diode Sensitivity: -100dBm Error probability: 10^{-9}
Low Pass Bessel Filter	-3dB Bandwidth: 10GHz

4. RESULTS AND DISCUSSION

The performance of 4-channel DWDM optical transmission model is simulated on Optisystem 7.0 simulator and quality factor (Q-factor), bit error rate (BER) are measured by BER analyzer. Therefore, total 9 simulations are completed using NRZ, RZ and Gaussian line codes with dispersion pre, post and symmetrical-compensation schemes to investigate the performance of proposed model. Hypothetically, $Q > 6$ and $BER \leq 10^{-9}$ are the acceptable values for enhanced optical communication system. In order to investigate the performance of 8 Gbps per channel transmission speed for 180 km link distance with satisfactory standards of Q-factor and BER. The Q-factor and BER values are obtained for different line codes corresponding to all four channel central frequencies using different DCF techniques as given in Table.2.

The effects of different dispersion compensation schemes on eye-diagrams of received signals are shown in Fig.6. It can be observed that, the eye opening is much clear for symmetric-compensation scheme with RZ line code due to high quality of received signal. Therefore, the proposed model offers reduced signal distortion. Further, the overall comparative performance analysis for pre-, post- and symmetric-compensation schemes with NRZ, RZ and Gaussian modulation formats are tabulated in Table.3.

Table.2. BER and Q-Factor readings of simulation model at each channel using pre, post and symmetric DCF Techniques

Parameters	Scheme	Channel	Frequency (THz)	Pre-Compensation	Post-Compensation	Symmetric-Compensation
Max Q-Factor	NRZ	Channel-1	193.1	9.35026	10.7364	5.48693
		Channel-2	193.2	9.38978	7.07837	6.53653
		Channel-3	193.3	8.99449	7.25964	10.775
		Channel-4	193.4	8.47636	10.5368	10.795
Min BER		Channel-1	193.1	2.74e^{-21}	3.24 e^{-27}	2.03 e^{-08}
		Channel-2	193.2	1.99e^{-21}	7.10 e^{-13}	3.14 e^{-11}
		Channel-3	193.3	7.86 e^{-20}	1.86 e^{-13}	2.19 e^{-27}
		Channel-4	193.4	7.29 e^{-18}	2.88 e^{-026}	1.80 e^{-27}
Max Q-Factor	RZ	Channel-1	193.1	17.013	28.9424	33.7767
		Channel-2	193.2	14.7309	3.9847	23.0258

		Channel-3	193.3	16.1801	9.18162	22.0739
		Channel-4	193.4	22.8967	11.9364	22.8967
Min BER		Channel-1	193.1	$3.033e^{-065}$	$1.63\ e^{-184}$	$1.33\ e^{-250}$
		Channel-2	193.2	$1.91e^{-049}$	$3.33\ e^{-005}$	$7.24e^{-118}$
		Channel-3	193.3	$3.24e^{-059}$	$2.22\ e^{-020}$	$1.63e^{-108}$
		Channel-4	193.4	$2.22e^{-116}$	$3.76\ e^{-023}$	$2.42e^{-134}$
Max Q-Factor	Gaussian	Channel-1	193.1	8.37786	11.6445	21.1206
		Channel-2	193.2	8.43441	7.09696	19.8378
		Channel-3	193.3	8.12467	7.0651	21.2705
		Channel-4	193.4	7.59462	10.0343	20.0005
Min BER		Channel-1	193.1	$1.87e^{-017}$	$1.17\ e^{-031}$	$2.03\ e^{-099}$
		Channel-2	193.2	$1.18e^{-017}$	$6.14\ e^{-013}$	$5.41e^{-088}$
		Channel-3	193.3	$1.62e^{-016}$	$7.102\ e^{-013}$	$8.35e^{-101}$
		Channel-4	193.4	$1.05e^{-014}$	$5.24\ e^{-024}$	$2.35e^{-089}$

Table.3. Comparative performance analysis of proposed simulation model

Compensation Scheme / Modulation Format	Pre-compensation		Post-compensation		Symmetric-compensation	
	Q-factor	**BER**	**Q-factor**	**BER**	**Q-factor**	**BER**
NRZ	9.38978	$1.99176e^{-021}$	10.5368	$2.88377\ e^{-026}$	10.7952	$1.80195e^{-027}$
RZ	22.8976	$2.22817\ e^{-116}$	28.9424	$1.63132e^{-184}$	33.7767	$1.33746e^{-250}$
Gaussian	8.37788	$1.87382e^{-017}$	11.645	$1.17099\ e^{-031}$	21.1206	$2.03674e^{-099}$

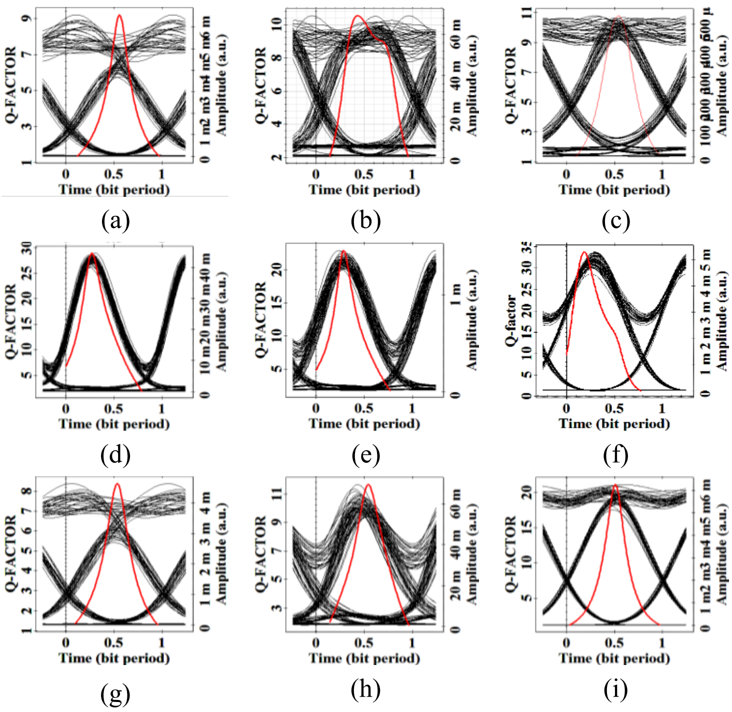

Fig.6. Eye-diagrams for: (a), (b), (c) pre, post, symmetric-compensation with NRZ; (d), (e), (f) pre, post, symmetric-compensation with RZ; (g), (h), (i) pre, post and symmetric-compensation with Gaussian lone codes, respectively

5. CONCLUSIONS

The presented work is highlighted on performance analysis of four channels DWDM optical transmission system speed at 8Gb/s. The proposed model is designed and simulated using pre, post and symmetric dispersion compensation schemes having EDFA amplifier in order to compensate the dispersion and attenuation phenomena. The performance of designed 180km length optical link is investigate on each channel in terms of parameters Quality Factor, BER and Eye-diagram for NRZ, RZ and Gaussian modulation schemes. Further, the comparative analysis of pre, post and symmetric-compensation schemes is evaluated and it is found that the performance of symmetric dispersion compensation technique with RZ gives the better performance. In future, the proposed techniques can be applied to a complex optical system with large number of channels to compensate the dispersion and attenuation complications.

REFERENCES

[1] B. Mukherjee, "WDM Optical Communication Networks: Progress and Challenges", *IEEE Journal on Selected Areas in Communications*, Vol. 18, No. 10, pp. 1810-1824, 2000.

[2] B. Chomycz, "*Planning Fiber Optic Networks*", McGraw-Hill, 2000.

[3] R. Ramaswami, K.N. Sivarajan and G.H. Sasaki, "*Optical Networks*", Morgan Kaufmann, 2000.

[4] P. Anuseetal and S. Singh, "Analysis of EDFA based 16-Channel C-band optical WDM System for Different Pumping Schemes", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 5, No. 6, pp. 4709-4715, 2016.

[5] S. Semmalar and S. Malarkkan, "Output Signal Power Analysis in Erbium-Doped Fiber Amplifier with Pump Power and Length Variation using Various Pumping Techniques", *ISRN Electronics*, Vol. 2013, pp. 1-6, 2013.

[6] B.H. Choi, H.H. Park and M.J. Chu, "New Pump Wavelength of 1540-nm Band for Long-Wavelength-Band Erbium-Doped Fiber Amplifier (L-Band EDFA)", *IEEE Journal of Quantum Electronics*, Vol. 39, No. 10, pp. 1272-1280, 2003.

[7] R.S. Kaler, Ajay K Sharma and T.S. Kamal, "Comparison of Pre, Post and Symmetrical Dispersion Compensation Schemes for 10Gb/s NRZ Links using Standard and Dispersion Compensated Fibers", *Optics Communication*s, Vol. 209, No. 1-3, pp. 107-123, 2002.

[8] P. Singh and R. Chahar, "Performance Analysis of Dispersion Compensation in Long Haul Optical Fiber using DCF", *International Journal of Engineering and Science*, Vol. 3, No. 2, pp. 18-22, 2014.

[9] Govind P. Agrawal, "*Fiber Optics Communication Systems*", 3rd Edition, Wiley, 2002.

[10] P. Neheeda, M. Pradeep and P.J. Shaija, "Analysis of WDM System with Dispersion Compensation Schemes", *Procedia Computer Science*, Vol. 93, pp. 647-654, 2017.