Analysis of Third Order Dispersion and Four Wave Mixing in 16 × 25 Gbps DWDM Optical System with Variable Channel Spacing

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***Abstract* - In this paper, a 16 channel 25 Gbps DWDM optical network is simulated and analyzed for 120 km using dispersion compensating fiber. The system is operated on -10dBm of Input Power. NRZ-DPSK modulation format is used for transmission under symmetrical compensation schemes. Group velocity and third order dispersion are compensated to improve the Q-factor. Impact of Third Order Dispersion as well as Four Wave Mixing is observed on variable channel spacing such as 50 GHz, 100 GHz and 200 GHz. It is observed that stability of Q-Factor is better in case of 200 GHz channel spacing when effect of dispersion and four wave mixing is considered.**

***Index Terms* - Differential Phase Shift Keying (DPSK), Dense Wavelength Division Multiplexing (DWDM), Dispersion Compensating Fiber(DCF), Group Velocity Dispersion (GVD), Third Order Dispersion (TOD), Four Wave Mixing (FWM)**

I. INTRODUCTION

In the modern era, the information and communication networks are one of the emerging technologies in the world. As there is rapid growth in the number of internet users, the systems with more capacity are required. The key features that make a system effective are its availability and utilization of bandwidth. Fiber optics networks are such networks that can meet the growing needs of the communication field having huge bandwidth and good transmission performance. The main aim of these networks is to make them more effective which results in minimum loss in signal and good quality transmission with minimum error. The introduction of WDM systems has extended the application of optical fiber to fulfill the needs of high speed, high bandwidth and high capacity networks. The multiple users handled by the DWDM for the high data rate transmission with sufficient channel spacing. The bandwidth requirement of optical communication system depends upon the number of user. WDM networks have ability to transmit multiple signals having different wavelengths simultaneously. In these networks different signals from different users having different wavelengths are multiplexed [3].

II. THIRD ORDER DISPERSION

Dispersion is the major factor which affects the performance of optical fiber communication system. It is basically chromatic dispersion or group velocity dispersion which effects the pulse width i.e. pulse broadening. The pulse broadening takes place at long distance in optical fiber communication system. At lower data rate group velocity dispersion affects the system but at high data rate third order dispersion also comes into picture. So, to improve quality of signal third order dispersion compensation is required. Third order dispersion affects the system less as compared to second order dispersion but compensation will give better results[1, 6]. Higher-order dispersive effects are governed by the dispersion slope S = dD/dL. The parameter S is also called a differential-dispersion parameter and it can be written as

$$S = (2\pi c/\lambda^2)^2\beta_3 + (4\pi c/\lambda^3)\beta_2 \quad \text{.......(1)}$$

where $\beta_3 = d\beta_2/d\omega \equiv d_3\beta/d\omega^3$ is the Third Order Dispersion Parameter. At $\lambda = \lambda_{ZD}$, $\beta_2 = 0$, and S is proportional to β_3 [5].
In case of higher order dispersion, the effect becomes negligible but increases with increase in bit rate.

III. FOUR WAVE MIXING

The FWM is one of the major performance degrading factor in WDM and DWDM optical communication system. The most troublesome nonlinear phenomenon today in optical system is Four Wave Mixing (FWM). FWM is third order nonlinearity in optical fibers. It is caused by the nonlinear nature of the refractive index of the optical fiber itself. The FWM effect is similar to inter modulation distortion in electrical systems [5]. A signal at frequency ω_1 mixes with a signal at frequency ω_1 to produce two new signals one at frequency $2\omega_2 + \omega_1$ and other at $2\omega_2 - \omega_1$. The effect can also occur between three and more signals. In general if N- wavelengths are launched into the fiber, generated mixed products M are

$$M = \frac{N^2}{2(N-1)} \quad \text{.......(2)}$$

FWM effect increases as the channel spacing is reduced.FWM effect is nonlinear with signal power i.e. as power increases, the FWM effect increases exponentially. It also depends on fiber dispersion. As the dispersion varies with the wavelength, the signal waves and the generated waves have different group velocities which destroy the phase matching of the interacting waves [11, 13]

IV. DISPERSION COMPENSATING FIBER (DCF)

Dispersion compensating fiber is an easy and efficient way to upgrade installed links made of single mode fiber. Dispersion compensating fibers have negative dispersion and can be used to compensate the positive dispersion of transmission fiber. Performance degradation in optical WDM system is because of group velocity dispersion, Kerr nonlinearity, and accumulation of amplified spontaneous emission noise due to periodic amplification. Because of the nonlinear nature of propagation, system performance depends on the power levels at the input of different types of fibers, on the position of the DCF and on the amount of dispersion. There are basically three types namely- pre, post and symmetrical compensation schemes where the DCF is placed before, after the SMF or symmetrically across the SMF. A DCF should have low insertion loss, low polarization mode dispersion and low optical nonlinearity and also it should have large chromatic dispersion coefficient to minimize the size of a DCF. Smaller size of the DCF is preferable [6], [7]. By placing one DCF with negative dispersion after a SMF with positive dispersion, the net dispersion should be zero.

$$\beta_{SMF} \times L_{SMF} = - \beta_{DCF} \times L_{DCF} \quad (3)$$

Where β_{SMF}, β_{DCF} are dispersion coefficients and L_{SMF}, L_{DCF} are length in order of SMF and DCF. Compensation is done by three different methods depending on the position of the DCF.

i. Pre-Compensation
ii. Post Compensation
iii. Mix Compensation

i. Pre-Compensation: In this Compensation scheme, the dispersion compensating fiber of negative dispersion is placed before the standard fiber to compensate positive dispersion of the standard fiber.

ii. Post-Compensation: In this Compensation scheme, the dispersion compensating fiber of negative dispersion is placed after the standard fiber to compensate positive dispersion of the standard fiber.

iii. Symmetrical Compensation: In this Compensation scheme, the dispersion compensating fiber of negative dispersion is placed before and after the standard fiber to compensate positive dispersion of the standard fiber [12].

V. NRZ-DPSK MODULATION FORMAT

NRZ-DPSK format comes under the category of Phase shift keying modulation scheme. In this format, phase shift takes place from one bit to other. PSK based modulation format has better noise immunity as compared to ASK based modulation format.

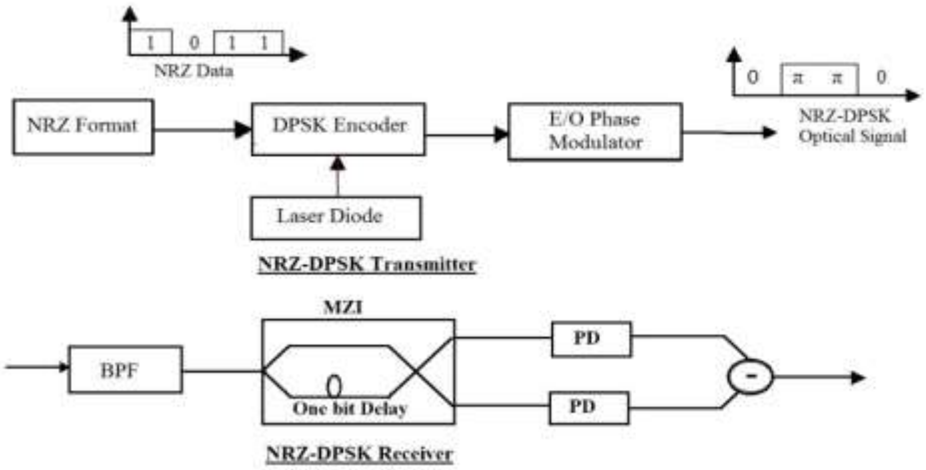


Figure 1 NRZ-DPSK Modulation Format

As shown in Fig 1, the output of NRZ is encoded by DPSK encoder. DPSK encoded signal operate the electro-optic phase modulator and produce optical signal. One bit MZI co-relate the each bit with immediate bit at receiver. When bits are same, it will add and gives high signal. If bit are not same there is phase shift of π takes place on the output which results low signal. DPSK signal is received by balanced detection in which two photo detectors are used. The photo current of photo diodes is combined which improve the sensitivity of receiver [2].

VI. SYSTEM DESIGN AND SIMULATION

The simulation tool used for comparing the different dispersion compensation techniques under study is OPTISYSTEM 7.0. WDM System consisting of 16 channels, each channel having 25 Gbps bit rate is designed for making the total bit rate of 400 Gbps. system setup as shown in Fig 2.

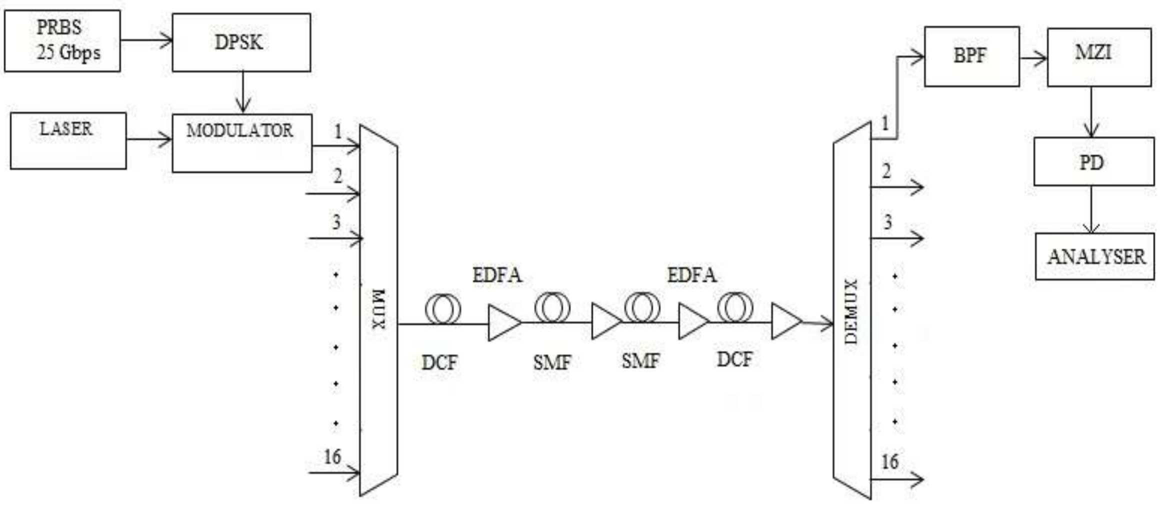


Figure 2 Block Diagram for 16x25 DPSK with Symmetrical Compensation Scheme

In transmitter module, each single channel consists of Pseudo Random Bit Sequence (PRBS) generator having 25 Gbps bit rate followed by NRZ pulse generator. CW laser having power -10 dBm is used. Each channel uses laser at different frequencies ranging from 193.1 to 196 THz followed by Mach Zender modulator. 16×1 MUX is used to multiplex different wavelengths. The transmission link is made using 120 km SMF in which dispersion is compensated using DCF. DCF of length 10 km is used for 50 km SMF. EDFAs (Erbium Doped Fiber Amplifier) of gain 5 dB are used after span of 50 km SMF and 10 km DCF. EDFA with gain 5 dB is used before DEMUX.

In a practical DPSK receiver, both constructive port and destructive port of MZI are used, which is called balanced receiver. In a DPSK balanced receiver, a photodiode is used at each MZI output and then the two photocurrents are combined to double the signal level. In this configuration, the receiver sensitivity is improved by 3dB compared to using only one single photodiode in either constructive port or destructive port [8], [4]. The simulation parameters are selected for experimental setup are presented in Table 1.

Table 1 Simulation Parameters

PARAMETERS	**VALUE**
Bit Rate	16 x 25Gb/s = 400 Gb/s
Channel Spacing	50 GHz, 100 GHz, and 200 GHz
Input Power	-10dBm
Modulation Format	NRZ-DPSK
Dispersion Compensation Technique	DCF
Dispersion Compensation Schemes	Pre, Post, Symmetrical
Length of SMF	50 Km
Length of DCF	10Km
EDFA Gain	5 dB
Transmission Distance	120 km
No. of Span	2
Group Velocity Dispersion-Coefficient (β_2)	10-25ps^2/km (Variable)
Third Order Dispersion-Coefficient (β_3)	10-25ps^3/km (Variable)

VII. RESULTS AND DISCUSSION

In DWDM systems, Q-Factor is one of the most important features to measure the performance of the system. The readings are taken for sixteen channels of the DWDM system. For sake of simplicity, three channel are shown in the graph. The graph is plotted between Q-Factor and third order dispersion coefficient by varying the dispersion coefficient and measuring the Q-Factor at each value. The other effect i.e. Four Wave Mixing is also observed using Optical Spectrum Analyzer. This analysis is done using variable channel spacing i.e. 50 GHz, 100 GHz and 200 GHz.

For 50 GHz channel spacing, the group velocity dispersion is analyzed and compensated using dispersion coefficient β_2. The Q-factor is observed at each value of β_2 and a particular value of β_2 is selected at which Q-factor is maximum. This value is fixed for compensation of group velocity dispersion and β_3 is varied for analysis of third order dispersion. the graph is plotted between Q-Factor and Dispersion Coefficient β_3 as shown in Fig 3.

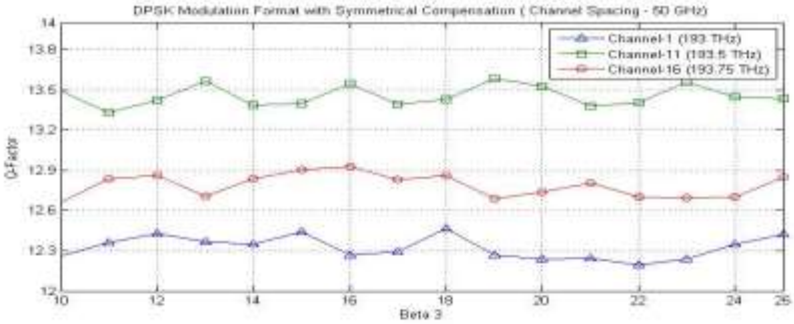


Figure 3 Q-Factor vs. Dispersion coefficient β_3 in 50 GHz Channel Spacing

The maximum Q-factor observed in eleventh channel. But some variation is present with change in β_3. It is observed that Q-factor has some improvement with compensation of third order dispersion but some variation is also present. Other non linear effect i.e. Four Wave Mixing also comes into picture due to less channel spacing. Due to FWM effect, side lobes are increased in the optical spectrum as shown in Fig 4.

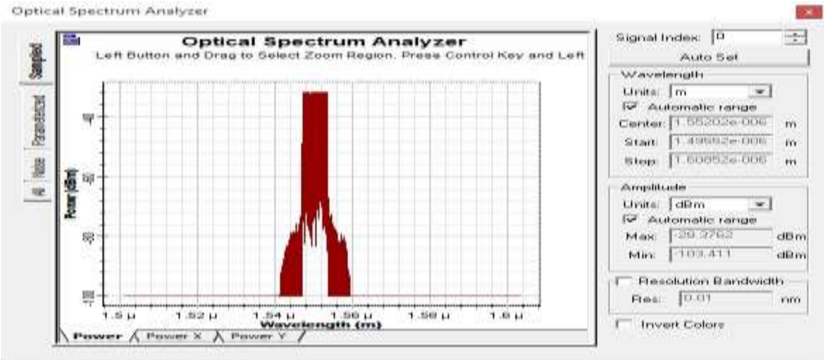


Figure 4 Optical Spectrum at 50 GHz Channel Spacing

In case of 100 GHz channel spacing, first of all group velocity dispersion is compensated by choosing a particular value of β_2. This value of β_2 is fixed and third order dispersion is analyzed by varying the value of β_3 as presented in Fig 5. The maximum value of Q-Factor achieved on eleventh channel. The stability of Q-Factor is improved by some amount as compared to 50 GHz spacing.

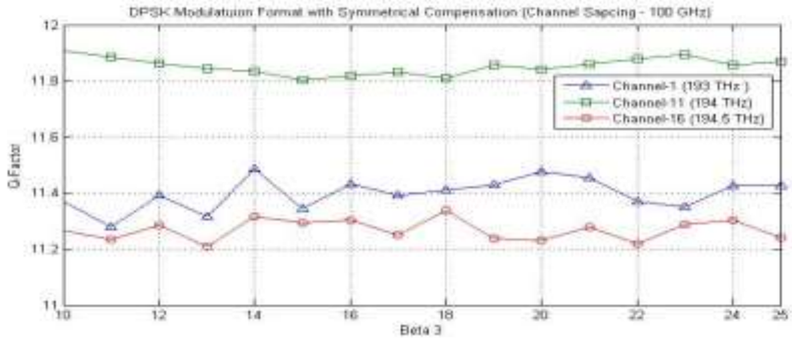


Figure 5 **Q**-Factor vs. Dispersion Coefficient β_3 in 100GHz Channel Spacing

Fig 6 shows the effect of four wave mixing in 100 GHz channel spacing using optical spectrum analyzer. In optical spectrum, number of side lobes are decreased as compared to 50 GHz spacing. Optical spectrum analyzer shows power level in specific wavelength region.

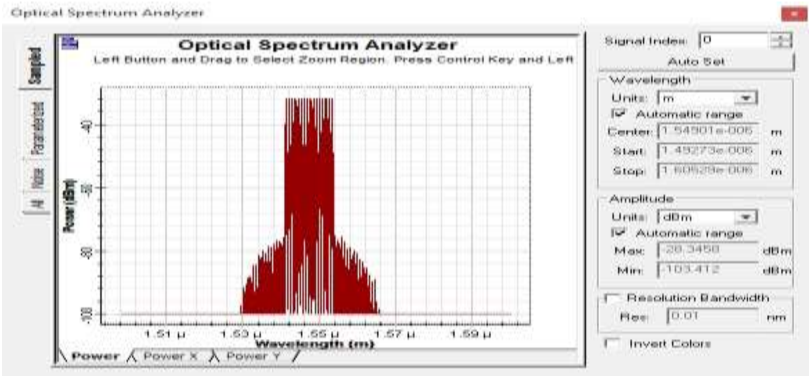


Figure 6 Optical Spectrum at 100 GHz Channel Spacing

For 200GHz channel spacing, The value of β_2 is selected according to acceptable value of Q-factor. The group velocity dispersion is compensated and third order dispersion coefficient (β_3) is varied from 10 to 25. The graph is plotted between Q-factor and β_3 as shown in Fig 7.

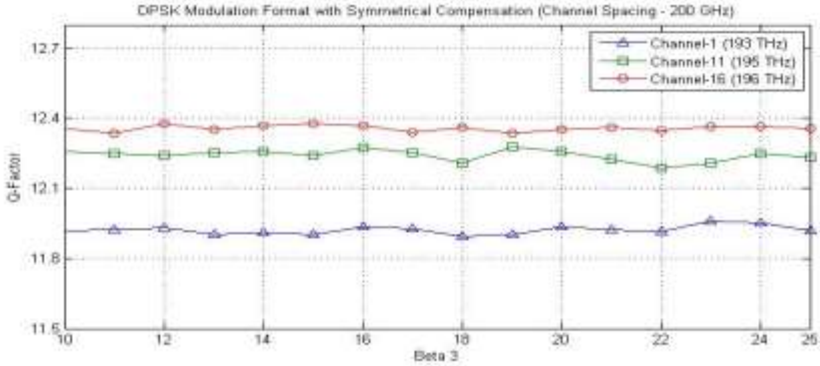


Figure 7 Q-Factor vs. Dispersion Coefficient β_3 in 200GHz Channel Spacing

In case of sixteenth channel, maximum Q-factor measured is 12.35 and stability also improved. It is observed that there is better improvement in stability of Q-factor by compensation of third order dispersion in 200 GHz channel spacing as compared to 100 GHz channel spacing.

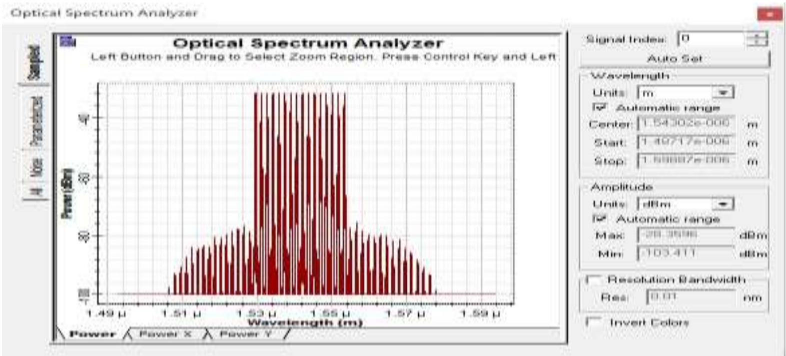


Figure 8 Optical Spectrum at 200 GHz Channel Spacing

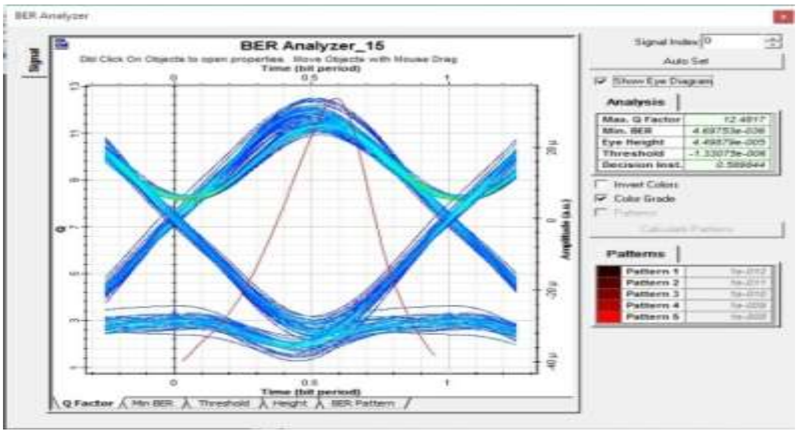
The other non linear effect i.e. FWM is less due to increased channel spacing. Four wave mixing effect is observed on optical spectrum analyzer as shown in Fig 8. The side lobes are less in optical spectrum as compared to 100 GHz channel spacing. With increase in channel spacing, interference between channels is decreased. Therefore, four wave mixing effect is decreased. It is concluded that 200 GHz channel spacing gives better performance when effect of dispersion as well as four wave mixing is considered.

The results have been carried out by varying channel spacing and presented in Table 2 as follows. The Q-Factor is acceptable in 200 GHz channel spacing with better signal quality. Each channel has maximum Q-factor at different value of dispersion coefficient (β_3). The Q-factor of desire channel can increase by varying the value of β_3.

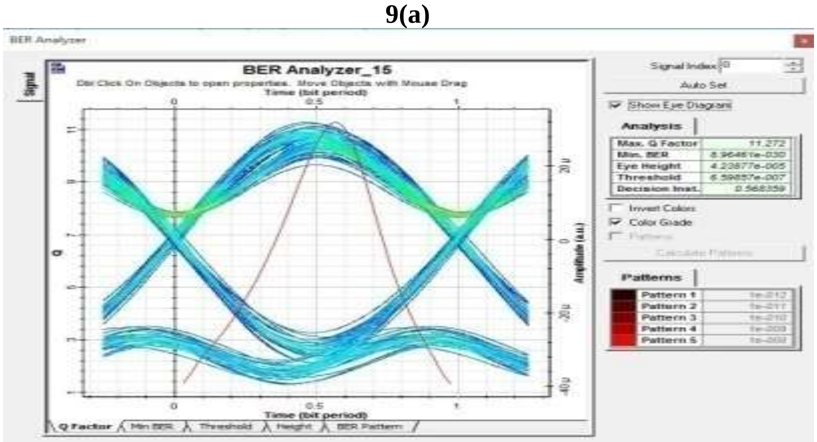
Table -2 Q-Factor for Variable Channel Spacing on Three Different Channels.

Channel No.	Q-Factor (Channel Spacing-50GHz)	Q-Factor (Channel Spacing -100GHz)	Q-Factor (Channel Spacing-200GHz)
1	12.50	11.50	12.10
11	13.50	11.90	12.30
16	12.48	11.27	12.35

The Fig 9(a), (b), (c) shows eye diagrams of Channel No.-16 under channel spacing of 50 GHz, 100 GHz, and 200 GHz. Maximum is the opening of eye diagram, better is the performance of the communication system. The results show that dispersion compensation in 200 GHz channel spacing is better as compared to 100 GHz and 50 GHz channel spacing.



9(a)



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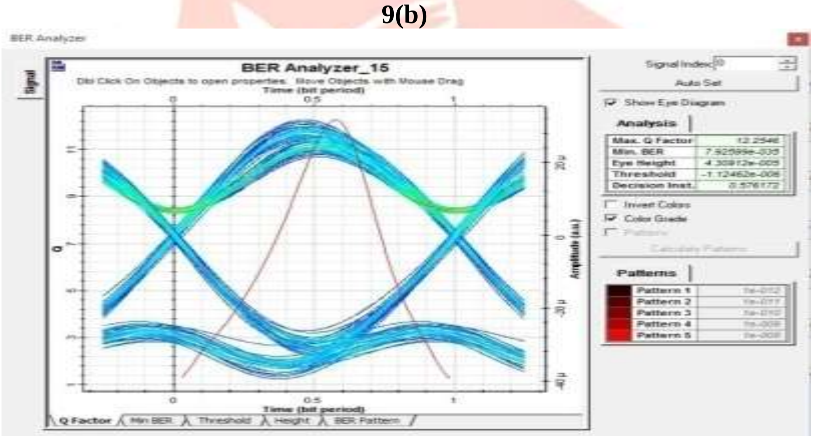

9(c)

Figure 9 Eye Diagrams for Channel No. 16 with Variable Channel Spacing: (a) 50 GHz (b) 100 GHz (c) 200 GHz.

VIII. CONCLUSIONS

NRZ-DPSK based 16 x 25 Gbps DWDM system is implemented using symmetrical compensation scheme. The length of optical span is 120 km. This system has suitable performance for dispersion compensation, when effect of both group velocity and third order dispersion are considered. The effect of Third Order Dispersion and Four Wave Mixing are analyzed on 50 GHz, 100 GHz and 200 GHz channel spacing with the help of Q-factor. The stability of Q-Factor is observed with variation in dispersion coefficient. It is observed that dispersion as well as four wave mixing effect is improved with increase in channel spacing due to less interference between two consecutive channels. Maximum performance is observed on 200GHz channel spacing as compared to other.

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