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Investigation of Four Wave mixing in high capacity and high speed WDM system

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Abstract- The major emphasis of this research article is to investigate Four wave mixing in detail on an ultra high capacity and ultra dense WDM system. In this work, We accentuated on the emergence of Four wave mixing in WDM system at different distances and to study behavior of the system for different WDM channels, frequency spacings, different optical fibers such as single mode fiber and dispersion compensation fiber, SMF effective areas. Performance of the proposed system is evaluated in terms of Q-factor, BER and FWM is analyzed at different distances. However, no optical amplifier is incorporated in the system and FWM in optical amplifiers is not investigated in this work.

Index Terms- **Wavelength Division Multiplexing, Four wave Mixing, Effective Area, Single Mode Fiber and Dispersion Compensation Fiber**

I. INTRODUCTION

As modern optoelectronics technology thriving, it enables researchers to realize high capacity multi-channel systems in the single mode fiber (SMF). Wavelength division multiplexing is an attractive technology that comes into picture to cater high speed and bandwidth hungry internet services [1]. Major parameters that limit the performance of wavelength division multiplexing are pulse broadening and fiber nonlinearities. Degrading effects based on nonlinearities becomes severe when the multiple channels co-propagating in the optical fiber simultaneously. Increase in some prominent factors that increases the nonlinear effects are, data speed, wavelengths, transmission without repeaters and launched power from intensity source [2]. High accumulative power levels in DWDM systems tend to manifest nonlinear effects due to change of refractive index of optical fiber. Nonlinear effects are characterized in optical fiber as intensity dependent effects or stimulated process such as Brillouin scattering and Raman scattering [3]. Another type of nonlinear effects is the due to the refractive index change of optical fiber as stated by Kerr’s effect. Four wave mixing (FWM), self phase modulation (SPM), cross phase modulation (XPM) are the main examples of nonlinearities arouse in fiber [4-6].

In silica fibers, Four wave mixing is a major system performance degrading parameter and a third order nonlinearity that is analogues to inter-modulation distortions. In FWM, generation of new frequencies takes place that is a major reason of crosstalk of channels [7]. The factors that contribute to change in FWM are as follows: spacing between adjacent channels of WDM systems, interaction of multiple channels along the long distances and high launched powers on each channel [8]. Numerous studies have been carried out to suppress FWM in DWDM system by incorporating dispersion management schemes [9], unequal frequency spacing [10], optical phase conjugation [11] and hybrid modulators [12]. However, nowadays DWDM and ultra dense WDM systems are popular due their many advantages of flexibility, transparency, bandwidth efficiency and high data carrying capacity. But, FWM is investigated so far on WDM systems that have less number of channels and capacity as compared latest scenario of UDWDMs.

In this research article, effects of four wave mixing are extensively investigated for different WDM channels, channel spacings, single mode fiber, dispersion compensation fiber, SMF effective area in high speed and high capacity UDWDM system. Performance of purposed system is analyzed for different link lengths, launched powers in terms of FWM power, Q-factor and BER.

II. FOUR WAVE MIXING

Nonlinearities in optical fiber are mainly emerges due to the power reliant characteristics of the refractive index, and is a type of optical parametric oscillation. Four wave mixing is also a Kerr's effect based nonlinearity that degrades the system performance of WDM systems. The physical origin of FWM induced crosstalk and the resulting system degradation can be understood by noting that FWM generates a new wave at the frequency as expressed in (1)

$$\omega_{ijk} = \omega_i + \omega_j - \omega_k \tag{1}$$

Whenever three waves at frequencies

$$\omega_i, \omega_j, \omega_k \tag{2}$$

co-propagate inside the fiber. In the case of equally spaced channels, the new frequency coincides with the existing frequencies leading to coherent in-band crosstalk. When channels are not equally spaced, FWM components fall in between the channels and lead to incoherent out of band crosstalk. In both cases, system performance is degraded because of loss of the channel power. For a WDM system with N channels, the number of four-wave mixing products, M, will be given as:

$$M = \frac{1}{2}(N^3 - N^2) \tag{3}$$

where N is the number of channels transmitted. If we assume that the three channels participating in the FWM process remain undepleted, and the fiber losses are included, then the amplitude A_F of the FWM component at the frequency ω_F is governed by

$$\frac{dA_F}{dz} = -\frac{\alpha}{2} A_F + d_F \gamma A_i A_j A_k \exp(-i\Delta kz) \tag{4}$$

where $A_m(z) = A_m(0)\exp(-\alpha z/2)$ for m = i, j, k and $d_F = 2-\delta_{ij}$ is the degeneracy factor defined such that its value is 1 when i = j but doubles when i ≠j. This equation can be easily integrated to obtain AF (z). The power transferred to the FWM component in a fiber of length L is given by

$$P_F = [A_F(L)]^2 = \eta_F (d_{F\gamma} L)^2 P_i P_j P_k \exp -\alpha L \tag{5}$$

where, $P_m = |A_m(0)|^2$ is the launched power in the mth channel and η_F is a measure of the FWM efficiency. The term η_F is given by

$$\eta_F = \left\{\frac{1-\exp(-(\alpha+i\Delta k)L}{(\alpha+i\Delta k)L}\right\}^2 \tag{6}$$

The FWM efficiency η_F depends on the channel spacing through the phase mismatch governed by

$$\Delta_k = \beta_F + \beta_k - \beta_i - \beta_j \approx \beta_2(\omega_i - \omega_j)(\omega_j - \omega_k) \tag{7}$$

Thus, as the number of input channel increases FWM will show its maximum contribution. So, it is necessary to take care of FWM for increasing the efficiency of DWDM system.

III. SYSTEM DESCRIPTION

The simulation of proposed Wavelength division multiplex system is investigated in Optiwave's Optisystem^{TM}. Figure 1 represents the proposed system setup. A continuous wave laser with 193.1 THz starting frequency is used to generate optical pulses of 0.1 ns and consists of 128 WDM channels at 6.25 GHz frequency spacing. Launched power and laser linewidth of CW laser are -20 dBm and 10 MHz respectively. Pseudo random bit sequence generator of 2^7-1 sequence is generating bits in the form of 1's and 0's. Binary data is fed to pulse generator Non return to zero (NRZ) and drive is given to Mach-zhender (MZM) modulator for electrical to optical conversion. An ideal multiplexer of 128:1 is placed after transmitter and carriers are analyzed with the help of optical spectrum analyzer (OSA). Multiplexed data is fed to single mode fiber (SMF-28) with attenuation 0.2 dB/km and dispersion 17 ps/nm/km in C-band (1530nm-1570nm). The WDM demultiplexer's work is to route particular frequencies to their respective output ports according to center frequency and spacing between channels is provided to filter. Receiver consists of photodetector, Low pass filter (LPF), 3-R regenerator and BER analyzer.

Table 1 System specifications of proposed WDM architecture

Parameters	Values
Data speed	10 Gbps
WDM channels	128, 96, 64 and 32
Frequency spacings	50 GHz, 25 GHz, 12.50 GHz, 6.25 GHz and 3.125 GHz
Distance	10 km- 50 km
Nonlinearity analyzed	Four wave mixing
Photo-detector	p-i-n
Dark current	10 nA

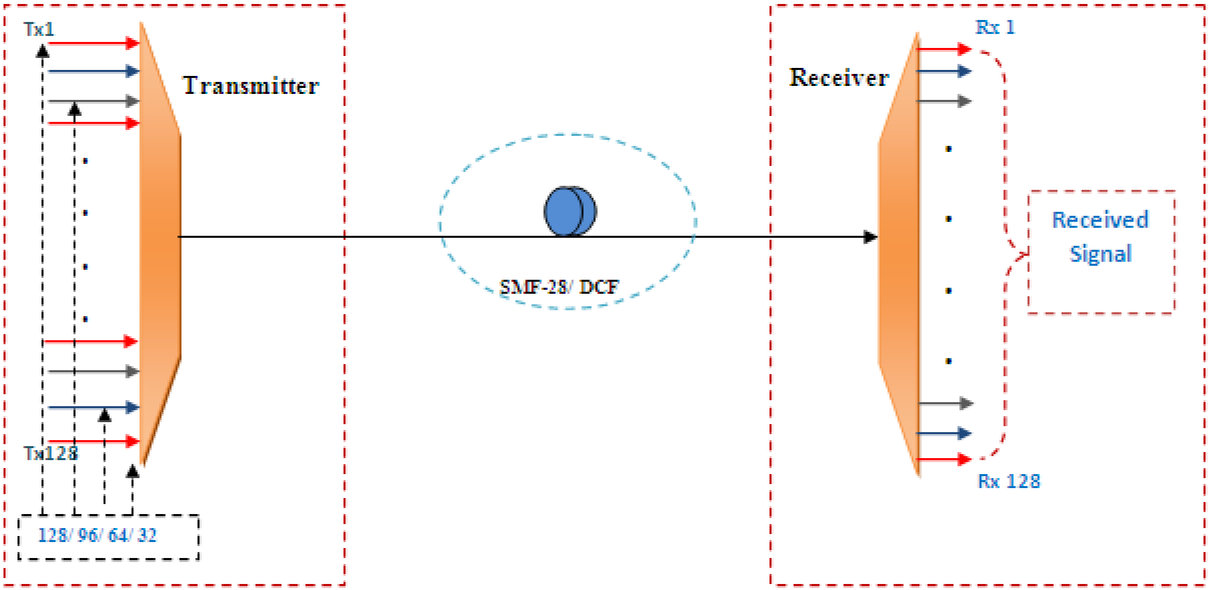


Figure 1 Block diagram of proposed WDM system

IV. RESULTS AND DISCUSSIONS

To investigate the FWM in high capacity WDM system, various parameters are considered such as number of channels, frequency spaings, different optical fibers and fiber effective are. Figure 2 depicts the performance of WDM channels in terms of Q factor under the influence of four wave mixing. It is prominently observed that as the length of optical fiber prolonged, Q factor decreases due to attenuation and pulse broadening along with nonlinear effects. WDM channels studied at different distances are 128, 96, 64 and 32 with 10 Gbps data rate at each channel. Maximum Q has been seen for the 32 channel WDM system and least of 128 WDM because of the reason the more channel cause more interference to adjacent channels. Optical spectrum for different channels before and after optical fiber is depicted in fig 3(a) (b) (c) (d).

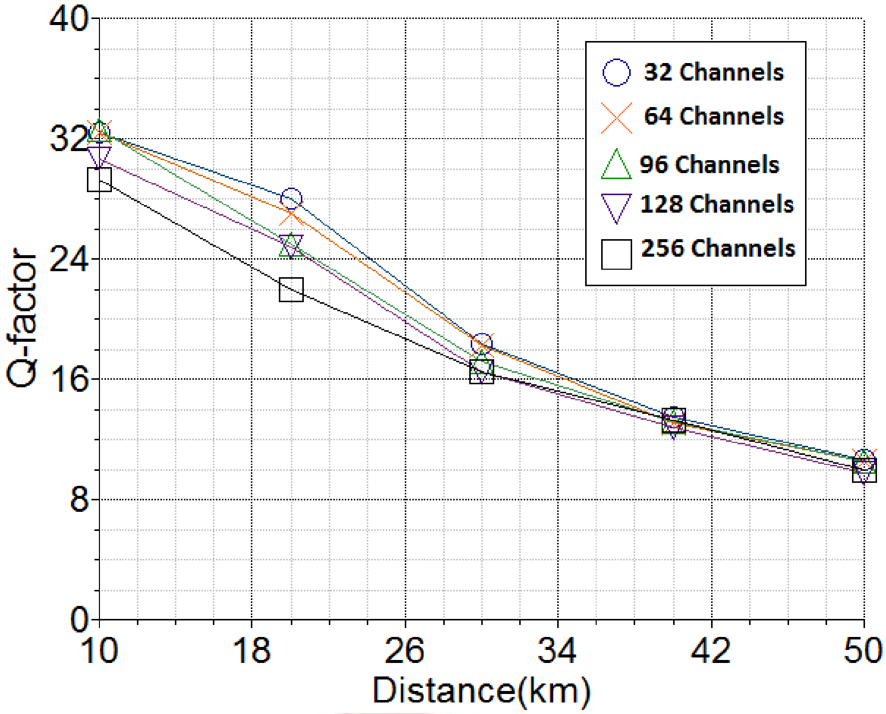
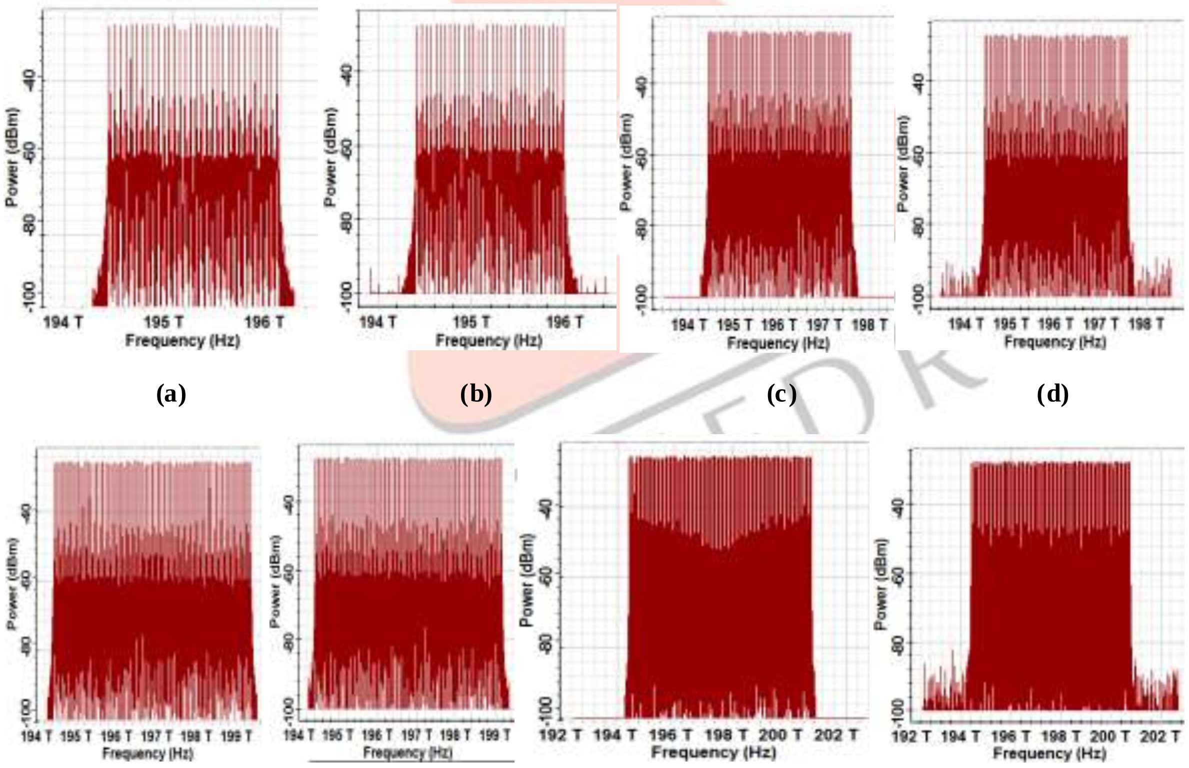


Figure 2 Q-factor versus distance for different WDM channels



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 3 Optical spectrum analyzer depictions before and after optical fiber respectively for (a) (b) 32 channels (c) (d) 64 channels (e) (f) 96 channels (g) (h) 128 channels

Figure 4 represents the illustration of Four wave mixing with respect to the distance. FWM reduces at 50 Km and maximum power of FWM is reported at less distance that is 10 km. Optical fiber has significant attenuation and as the fiber length is enhanced, attenuation becomes more degrading. As FWM is emerged due to high power in the SMF, so due to attenuation FWM observed less at higher distances. FWM is severe in case of 128 channels and reduces with the increase of distance and at less channels such as 32 WDM channels.

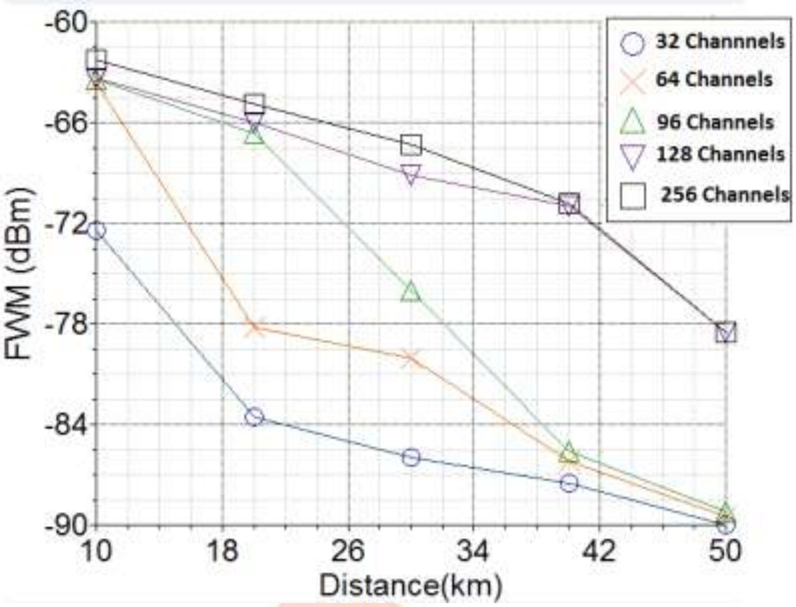


Figure 4 Representation of FWM power at different distances

Figure 5 depicts the variation of LoG (BER) as a function of fiber length. At larger optical fiber length, more bit errors arises and tends to decrease when distance decreases. BER is inversely proportional to Q factor and it is noted that at maximum values of Q, BER is less and vice versa. 128 WDM exhibits maximum errors and 32 channels WDM system show minimum BER.

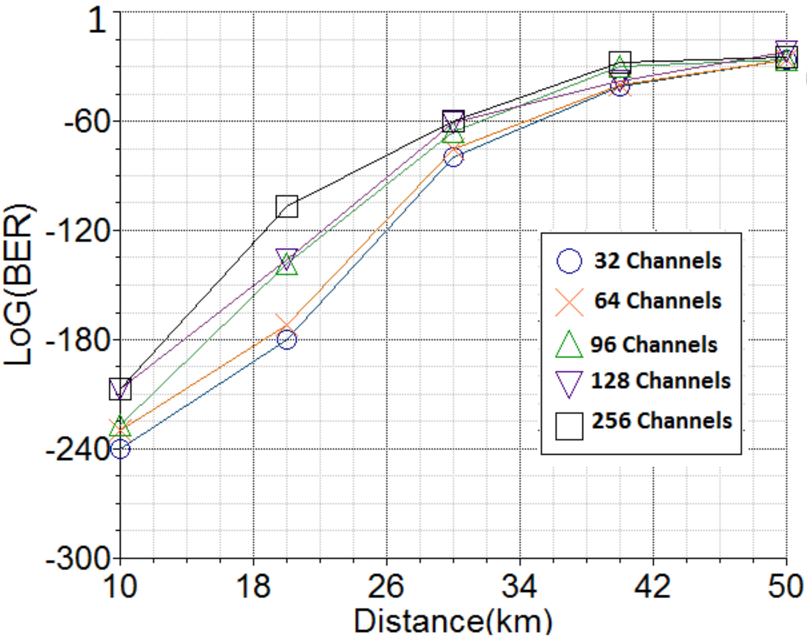
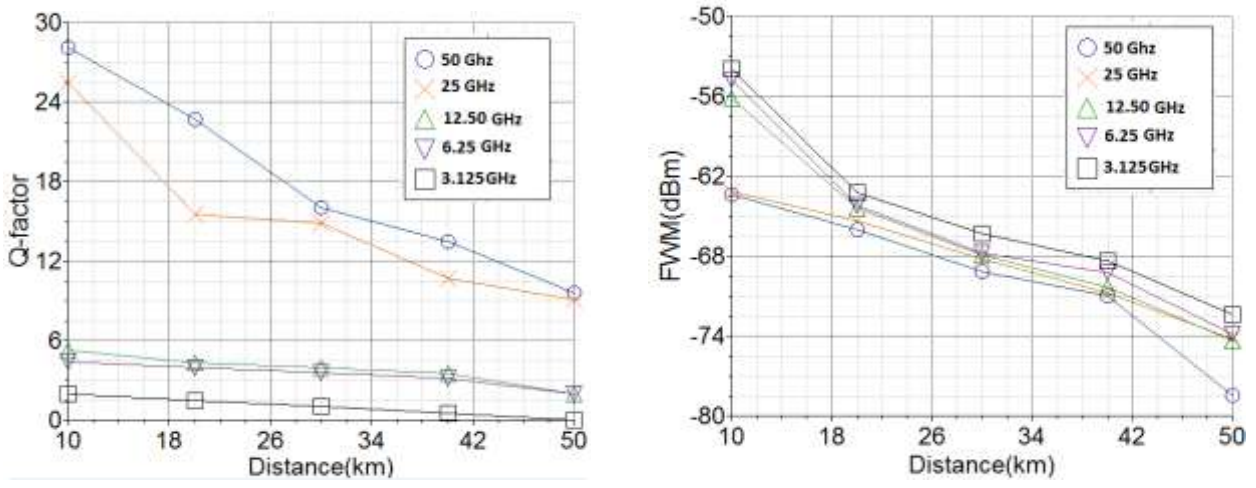


Figure 5 Graphical representation of BER versus distance for different WDM channels

Further investigation has been carried out for diverse frequency spacing's among WDM 128 channels. Frequency spacing is altered from 50 GHz, 25 GHz, 12.50 GHz, 12.25 GHz and 6.125GHz. Figure 6(a) depicts the performance of WDM system for diverse freq. spacings at different loop lengths. Q factor for 50 GHz freq. spacing is maximum and for 3.125 GHz is minimum. Also as shown in fig 6 (b), FWM emerged for 3.125 GHz is high and less for 50 GHz.



(a) **(b)**

Figure 6 Graphical representation of WDM system for (a) Q factor versus Distance (b) FWM versus Distance

Table 2 expresses the values of FWM at different distances for different optical fibers such as single mode fiber and dispersion compensation fiber. Readings shows that FWM is more in DCF and less in SMF. But at higher distance due to more attenuation of DCF, FWM do not exceed SMF. Table 3 shows the values of FWM at different effective areas of optical fiber. It is seen that at high effective areas, FWM is less and vice versa.

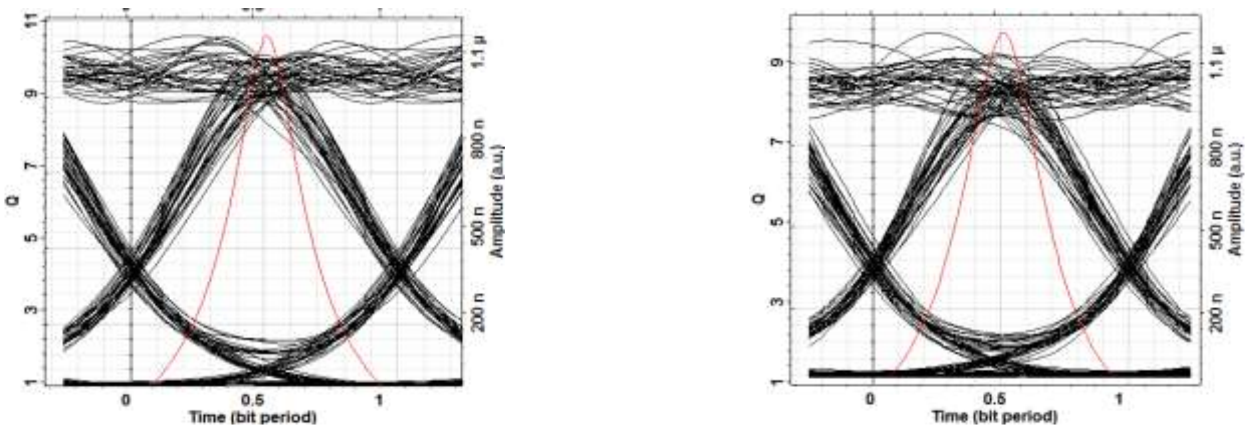
Table 2 FWM values for SMF and DCF

Distance (km)	SMF FWM	DCF FWM
10	-86.51	-75.18
20	-87.1	82.03
30	-86.4	-85.92
40	-90.2	-91.46
50	-91.92	-97.16

Table 3 FWM values for different effective areas

Distance(km)	70um^2	75 um^2	80 um^2	85 um^2	90 um^2
10	-83.32	-86.4	-86.51	-88.98	-90.87
20	-84.77	-86.97	-87.1	-89.2	-93.48
30	-86.42	-87.52	-86.4	-92.09	-93.91
40	-89.17	-90.35	-90.2	-94.5	-94.93
50	-91.79	-91.84	-91.92	-95.59	-98.19

Also effect of power is also investigated and it is found that there is more FWM at higher launched powers due to power dependent refractive index of optical fiber. Figure 7 represents the Eye diagrams for WDM channels 128, 96, 64 and 32 channels. Eye opening is more in case of 32 channels and eye closer is more in 128 channels. Jitter is high for prolonged distances and due to FWM at 128 channels. Less jitter is seen in the case of 32 WDM channels.



(a) **(b)**

Figure 7 Eye diagrams for (a) 32 WDM channels (b) 128 WDM channels

CONCLUSION

An ultra dense and high capacity WDM system implementation has been investigated to analyze Four wave mixing and also results are evaluated in terms of Q-factor and BER. Distances for FWM emergence is considered as 10 km – 50 Km and it is observed that FWM show maximum degrading effects at 10 km and decreases as the distance increases due to attenuation. It has been observed that reduction in channel spacing to accommodate more optical channels, in the presence of FWM, results in degradation of the performance of dense-optical links. Results revealed that FWM is less for 32 WDM channels, 50 GHz frequency spacing, single mode fiber, large effective area of SMF (80 um^2). Launched power should be kept low to quell the effects of FWM and it is prominently observed that at high launched powers, FWM emerges more. However, in this work, no optical amplifier is incorporated in the system and FWM in optical amplifiers is beyond the scope of this work.

REFERENCES

[1] Gurmeet Kaur, M.L. Singh, M.S. Patterh, “Impact of fiber nonlinearities in optical DWDM transmission systems at different data rates”, Optik, vol. 121, no. 23, pp. 2166–2171, 2009.

[2] M. Noshada, A. Rostamia, “FWM minimization in WDM optical communication systems using the asymmetrical dispersion-managed fibers” , Optik, vol. 123, no. 9, pp. 758-760, 2012.

[3] Guodong Zhang, Joseph T. Stango, Xiupu Zhang, Chongjin Xie, “Impact of fiber nonlinearity on PMD penalty in DWDM transmission systems” , IEEE Photonics Technol. Lett., vol. 17 , no. 2, pp. 501-503, 2005.

[4] Amarpal Singh, Ajay K. Sharma, T.S. Kamal, “Investigation on modified FWM suppression methods in DWDM optical communication system” , Opt. Commun., vol. 282, no. 3, pp. 392–395, 2009.

[5] Rajneesh Kaler and R. S. Kaler, “Investigation of four wave mixing effect at different channel spacing”, optik, vol. 123, pp.352-356, 2012.

[6] Jameel Ahmed, Ashiq Hussain, M. Y Siyal, Habibullah Manzoor and Abdullah Massod, “Parametric analysis of four -wave mixing in DWDM system”, optik, vol. 125, pp.1853-1859, 2014.

[7] Vishal Sharma and Ramandeep Kaur, “Implementation of DWDM system in the presence of Four wave mixing (FWM) under the impact of channel spacing”, optik, vol. 124, pp.3112-3114, 2013.

[8] S. Betti, M. Giaconi, and M. Nardini, “Effect of Four-Wave Mixing on WDM optical systems: A Statistical Analysis”, IEEE Photonics Technology Letters, vol. 15, no. 8, pp. 1079-1081, 2003.

[9] T. Matsuda, M. Murakami, T. Imai, “Dispersion management scheme for suppressing FWM in DWDM transmission”, Lasers and Electro-Optics Society Annual Meeting, 1998. LEOS '98. IEEE, 1998.

[10] A. Rouf , M. S. Islam, “A new approach of unequally spaced channel allocation for FWM crosstalk suppression in WDM transmission system, Electrical & Computer Engineering (ICECE), 2012 7th International Conference, 2012.

[11] Morteza H. Shoreh, “Compensation of Nonlinearity Impairments in Coherent Optical OFDM Systems Using Multiple Optical Phase Conjugate Modules”. IEEE, vol. 6, no. 6, 2014.

[12] S Sugumaran, Neeraj Sharma, “Effect of Four-wave Mixing on WDM System and its Suppression Using Optimum Algorithms”, International Journal of Engineering and Technology, vol. 5, no. 2, 2013.