Analysis of Four Wave Mixing Effect at Different Channel Spacing in DWDM Systems Using EDFA with Single Pump Source

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Abstract. In this paper, the Four Wave Mixing (FWM) effect on sixteen channels Dense Wavelength Division Multiplexing (DWDM) optical communication system has been compared for different values of channel spacing. The effect of variation in input power of laser array has also been investigated. The effect of dispersion has also being considered in the optical spam of fiber and pre-dispersion compensation technique has been employed to mitigate its effect. The performance of optical communication system has been evaluated in terms of Q-factor, Bit Error Rate (BER) and output from the Optical Spectrum Analyzer. This paper simulates that the FWM effect decreases as the channel spacing increases.

Keyword: Return to Zero (RZ), Dense Wavelength Division Multiplexing (DWDM), Erbium Doped Fiber Amplifier (EDFA), Four Wave Mixing (FWM) and Dispersion Compensating Fiber (DCF)

1. INTRODUCTION

Future long haul optical communication systems required to operate at higher bit rates in order to meet the growing demands of bandwidth. Wavelength Division Multiplexing (WDM) system have ability to transmit multiple signals having different wavelengths simultaneously. The development of Erbium Doped Fiber Amplifier (EDFA) pushed WDM to next level, DWDM. The implementation of DWDM would not have been possible without the development of EDFA. The capacity and performance of optical system is fundamentally limited by several impairments in high speed optical communication system. The fiber nonlinearities like Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS), Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) degrades the system performance. Four Wave Mixing is one of the major limiting factor in WDM optical communication systems. When number of optical signals passing through the same fiber, they interact with each other very weakly and these weak interactions in fiber become significant over long fiber transmission distance. The FWM is due to change in the refractive index with optical power called optical kerreffect[6].

2. THEORY of FOUR WAVE MIXING

FWM is a third order non linearity in optical fibers. It is caused by the non linear nature of the refractive index of optical fiber itself. The FWM effect is similar to inter modulation distortion in electrical systems. Third order distortion mechanisms generate third order harmonics in systems with one channel. In multichannel systems, third order harmonics and a number of cross products. These cross products cause the most problems since they are often fall near or on top of the desired signals. FWM occurs when two or more signals propagate in the same direction in the same fiber. These signals mix to produce new signals at wavelengths which are spaced at the same intervals as the mixing signals[6][7].

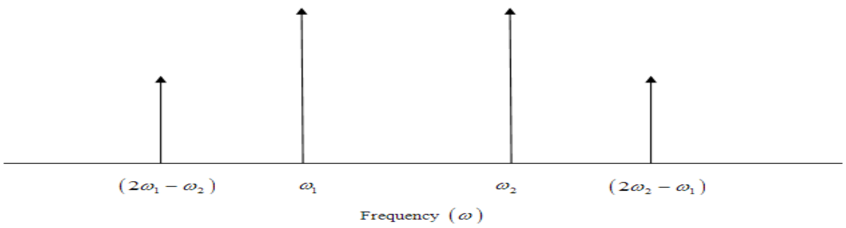

Fig. 1 Four Wave Mixing effect

As shown in fig. 1, a signal at frequency ω_1 mixes with a signal at frequency ω_2 to produce two new signals one at frequency $2\omega_2 - \omega_1$ and other at $2\omega_1 - \omega_2$. For a WDM system with N channels, the number of four wave mixing products$M$ will be given as[6].

$$M = \frac{1}{2}(N^3 - N^2) \quad \text{.......(1)}$$

3. DISPERSION COMPENSATING FIBER

Dispersion compensating fiber is an easy and efficient way to upgrade installed links made of single mode fiber. Dispersion compensating fiber has negative dispersion of -70 to -90 ps/nm.km. and can be used to compensate the positive dispersion of transmission fiber. The performance of optical WDM system is degraded due to group velocity dispersion. Kerr nonlinearity and accumulation of amplified spontaneous emission noise due to periodic amplification. Due to nonlinear nature of propagation, system performance depends on the parameters like power levels at the input of different types of fibers, position of the DCF and amount of dispersion. There are basically three types of compensation schemes namely – pre, post and mix compensation schemes where the DCF is placed before, after the Single Mode Fiber (SMF) or symmetrically across the SMF. The chromatic dispersion coefficient should be kept large (negative coefficient), so that the DCF of minimum length is used. By placing one DCF with negative dispersion after a SMF with positive dispersion, net dispersion should be zero, i.e., equation 2 should be satisfied[8].

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \quad \text{.......(2)}$$

Where D_{SMF} and D_{DCF} are the dispersion coefficient of SMF and DCF in ps/nm.km
and L_{SMF} and L_{DCF} are length of SMF and DCF in km.

4. ERBIUM DOPED FIBER AMPLIFIER

An erbium doped fiber amplifier is the major means to boost an optical signal in WDM systems. EDFA has two distinguishing features: Its active medium is a piece of silica fiber heavily doped with ions of erbium and its external energy is delivered in optical not in electrical form, as in an SOA[11].

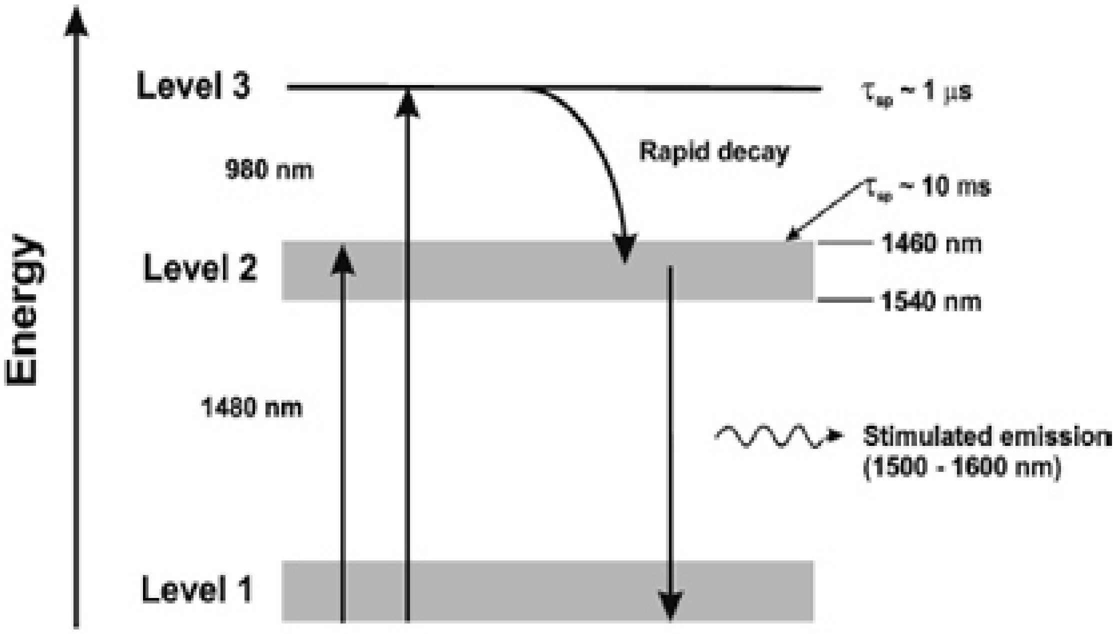

Fig. 2 Energy bands of erbium ions

Amplification in EDFA occurs through stimulated emission. The pumping is done by powerful laser diode radiating at 980 nm or 1480 nm. With pumping taking place at 980 nm, an EDFA utilizes three energy levels of erbium ions incorporated into a silica fiber. External light pumps erbium ions at the highest level, at which point they decay and fall to the intermediate level. The lifetime of erbium ions at this level is very long (more than 10 ms). This is why these ions accumulate at the intermediate level. When pumping occurs at 1480 nm, only two energy levels (intermediate and lower) are involved but the net result is same. Excited erbium ions accumulate at the intermediate level, creating population inversion. It is a fortunate coincident that the energy gap between the intermediates and lower levels in erbium corresponds to the 1550 nm wavelength range. Thus, when optical information signal appears, it will stimulate the excited ions to drop to the lower level, and this transition will result in the emission of photons having the same frequency as the stimulating (information) signal[11].

5. SIMULATION SETUP

The simulation setup is designed using OptiSystem 7.0 software by Optiwave. The DWDM system consists of 16 channels. Each channel operates at different frequency and data rate at 20 Gbps. The simulation model includes transmitter module, transmission link and receiver module.

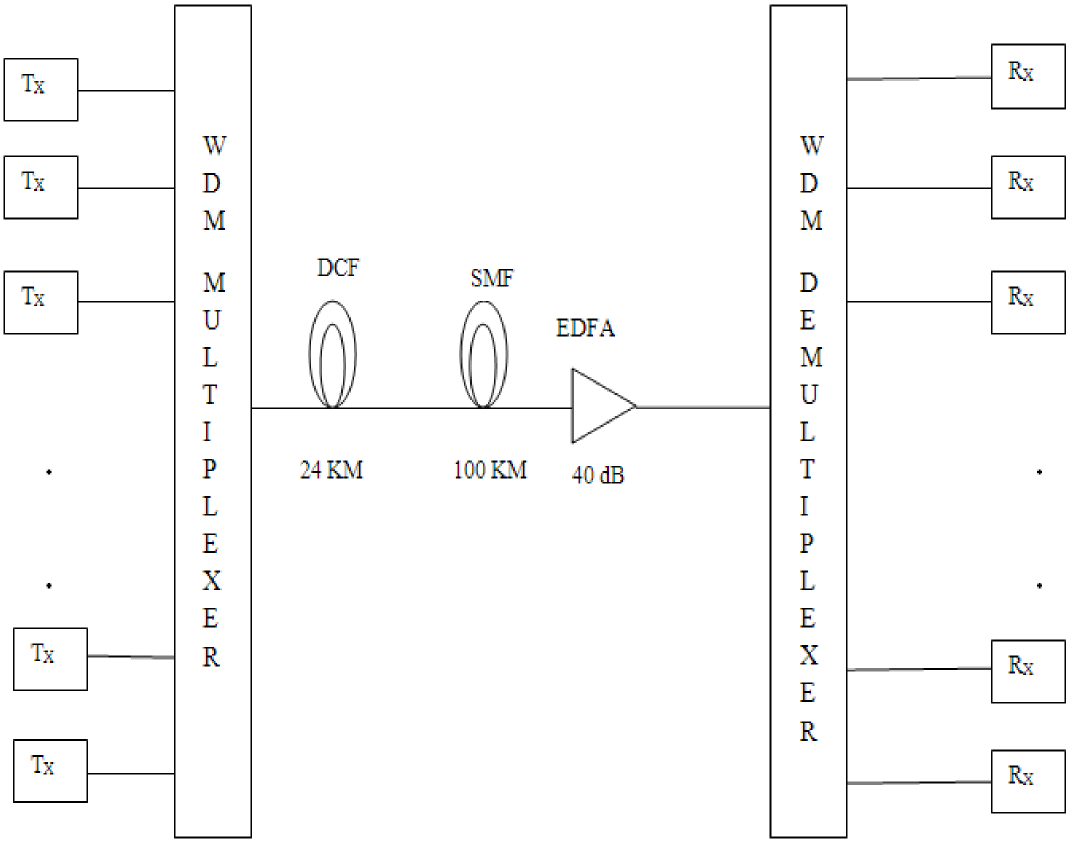

Fig. 3 Block diagram of simulation setup

The CW laser array is used for optical laser signal generation. The output of laser source array is feed to sixteen individual RZ subsystem modules. The 16x1 multiplexer is used to multiplex the different wavelengths. The transmission link uses Single Mode Fiber (SMF) of 120 km along with Dispersion Compensation Fiber (DCF) of length 24 km for dispersion compensation. The pre-compensation technique is employed for dispersion compensation in this thesis work. The Erbium Doped Fiber Amplifier (EDFA) having 5m in length along with one pump signal is employed in transmission link. The isolators are used to reduce the effect of Amplified Spontaneous Emission (ASE). In receiver module, 1x16 DEMUX is used to demultiplex the signal having different wavelengths. Then PIN Photodiode having responsivity 1A/W, is used which converts the optical signal into electrical signal. Low Pass Bessel filter follows the photodiode which filters the electrical signal. The outputs are viewed using BER analyzer. It gives measurement of Q-factor, BER and Eye diagram.

6. RESULTS AND DISCUSSION

The simulations are carried out on OptiSystem 7.0 software. The RZ modulation technique is used for analysis purposes. The WDM system consists of sixteen channels each operating on 20 Gbps data rate.

6.1 Effect of Channel Spacing

The channel spacing of WDM system is varied from 50 GHz to 200 GHz. Firstly the spacing between the two consecutive channels is kept at 50 GHz and the simulations results are obtained. The output of Optical Spectrum analyzer is obtained. The same process is repeated for channel spacing 100 GHz, 150 GHz and 200 GHz. The output of Optical Spectrum Analyzer for different channel spacing is shown in fig. 4 to 7 given below.

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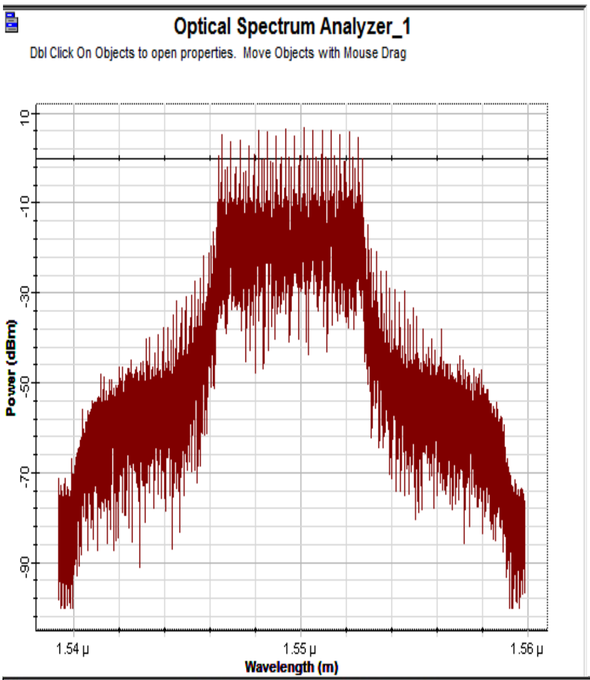


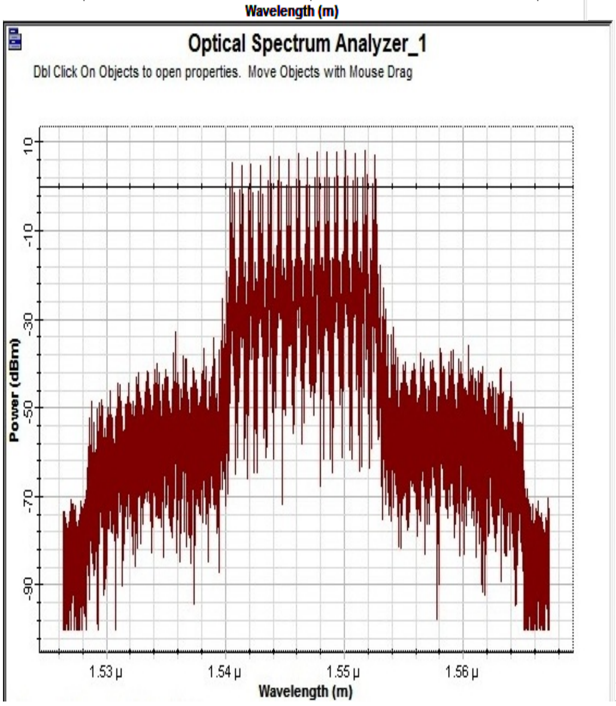
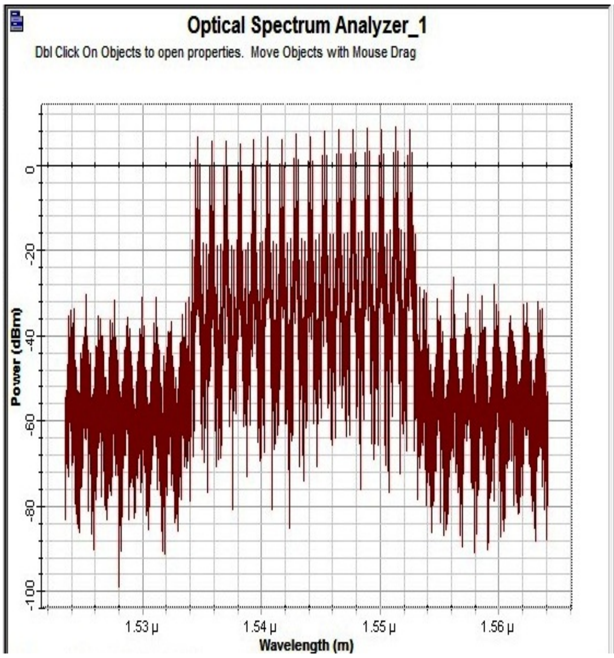


Fig. 4 Optical spectrum at 50 GHz channel spacing**Fig. 5** Optical spectrum at 100 GHz channel spacing



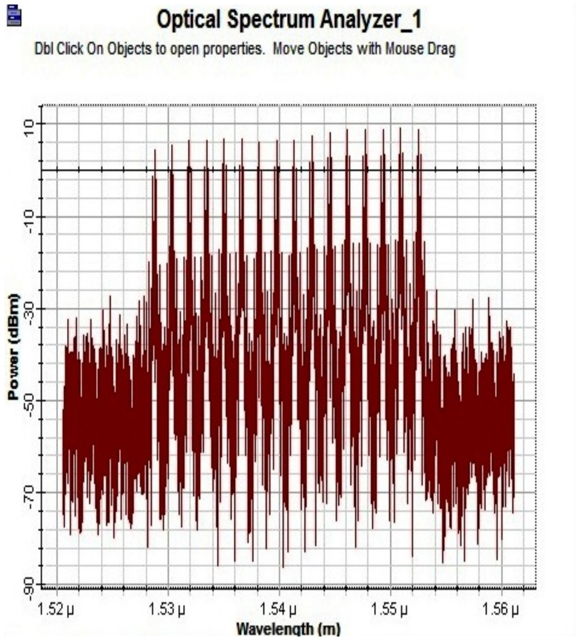


Fig.6 Optical spectrum at 150 GHz channel spacing **Fig.7**Optical spectrum at 200 GHz channel spacing

As it is clear from the figures that the number of side lobes decrease as the channel spacing increases. Hence, the FWM effect decreases as the channel spacing increases.

6.2Effect of Input Power

The input power of CW laser array has been varied from -25 dBm to 15 dBm for analysis purposes. All other specifications have been kept constant. The channel spacing is kept at 200 GHz. It is observed that Q-factor increases as the input power increases. The outputs of BER analyzer are shown in fig. 8 and 9 given below.

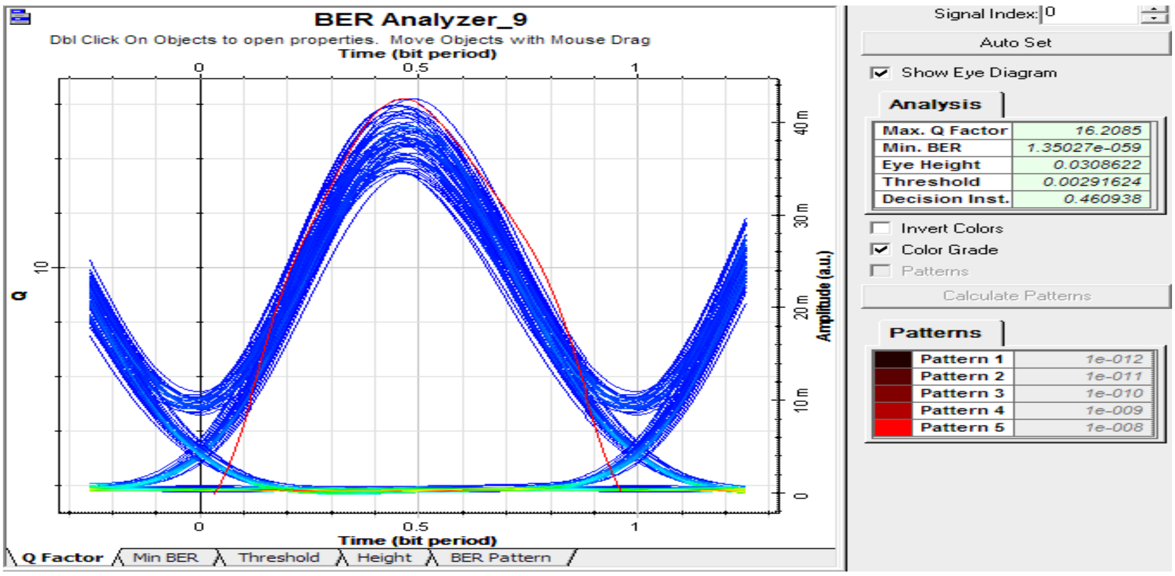


Fig. 8 eye diagram at -10 dBm input power

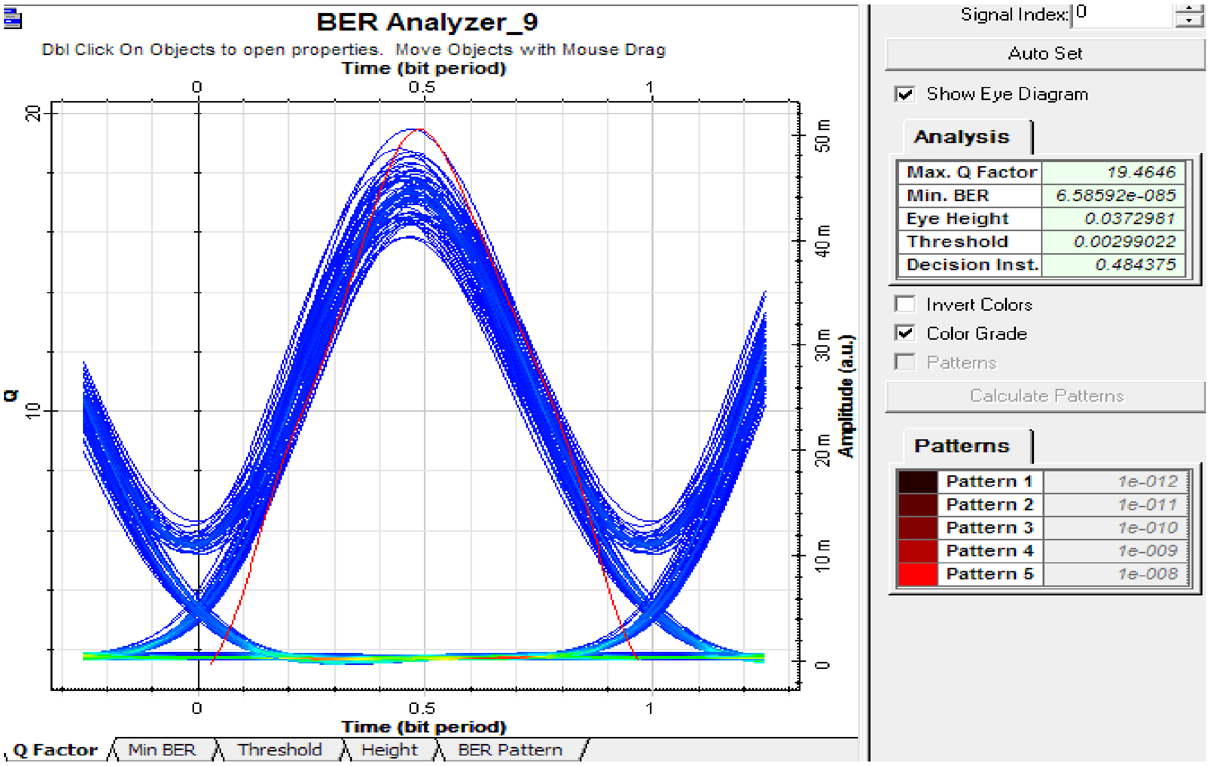


Fig. 9 eye diagram at 0 dBm input power

For the sake of simplicity of work, Q-factor and BER values for only two channels out of total sixteen channels are presented in the table 1.

Table 1. Variationof Q-factor with input power

Input Power (dBm)	Channel No. 5		Channel No. 10	
	Q-factor	BER	Q-factor	BER
-25	7.81386	1.84114e-015	8.04406	2.85291e-016
-20	13.9334	1.27436e-044	14.4335	1.05654e-047
-15	16.7144	3.11182e-063	15.3763	7.3179e-0054
-10	17.9538	1.35572e-072	16.2085	1.35027e-059
-5	18.3797	5.65913e-076	17.6237	4.86544e-070
0	18.4671	1.13316e-076	19.4646	6.58592e-085
5	19.2615	3.52607e-083	20.592	9.48226e-095
10	17.4352	1.4224e-068	17.8006	2.04146e-071
15	13.1349	6.90439e-040	16.3478	1.37548e-060

7. CONCLUSION

In this paper, the effect of different channel spacing on four wave mixing in sixteen channel WDM system is demonstrated. The FWM effect is studied on 50 GHz, 100 GHz, 150 GHz and 200 GHz channel spacing with the help of output from Optical Spectrum Analyzer. It is observed that the number of side bands decrease as the channel spacing increases. The numbers of side bands are minimum when channel spacing is 200 GHz as compared to 50 GHz. This is due to the fact that interaction between various frequencies decreases as the channel spacing increases. The power of laser source array increases from -25 dBm to 15 dBm. It is observed that the Q-factor increases as the power of laser array source increases but up a to certain power value. In case of RZ modulation format the Q-factor increases with input power varying from -25 dBm to 5 dBm. But, if input power is increased further the Q-factor decreases. It is due to the fact that the other nonlinear phenomenon increase as the input power is increased above 5 dBm power.

REFERENCES

[1] Monika, Amit Wason, R.S. Kaler, "Investigation of four wave mixing effect with different number of input channels at various channel spacing", *Optik* 124(2013) pp. 4227-4236.
[2] Vishal Sharma, Ramandeep Kaur, "ImplementationofDWDM system in the presence of four wave mixing under the impact of channel spacing", *Optik* (2012), pp. 1-3.
[3] Rajneesh Kaler, R.S. Kaler' "Investigation of four wave mixing at different channel spacing", *Optik*123(2012) pp. 352-356.
[4] T.Sabapathi, S.Sundaravadivelu, "Analysis of bottlenecks in DWDM fiber optic communication system", *Optik*122(2011) pp. 1453-1457.
[5] Jing Huang, "Impact of ASE in WDM systems", *Optik*122(2011) pp. 1376-1380.
[6] S. P. Singh and N. Singh, "Nonlinear effects in optical fibers: origin, management and applications", *PIER* 73, 2007, pp. 249-275.
[7] J. Toulouse, "Optical Nonlinearities in Fibers: Review, Recent Examples, and Systems Applications", *Journal of Lightwave Technology*, Vol 23. No. 11, November 2005, pp. 3625-3641.
[8] Rupinderjit Kaur, "Performance Analysis of WDM Link Using Different DCF Techniques at 20 Gb/s", *IJARECE* Volume 4, Issue 4, April 2015, pp. 867-871.
[9] Prabhpreet Kaur, Kulwinder Singh, "Analysis of Four Wave Mixing Effect at Different Channel Spacing in Multichannel Optical Communication System", *IJEIT* Volume 3, Issue 5, November 2013, pp. 320-323.
[10] Prabhpreet Kaur, Kulwinder Singh' "Investigation of Four wave mixing effects using different modulation formats in optical communication system", *IJERA* Vol. 4, issue 1(Version 2), January 2014, pp. 176-181.
[11] Djafar K. Mynbaev, Lowell L. Scheiner, "Fiber-Optic Communication Technology". 2nd ed. Pearson Education Inc, 2002.