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Suppression of Four Wave Mixing in 8 Channel DWDM System Using Hybrid Modulation Technique

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Abstract

The capacity of optical fiber communication system can be increased by the use of dense wavelength division multiplexing (DWDM). Using DWDM, multiple channel of information can be transmitted on single fiber. In DWDM based optical communication systems, fibre nonlinearities are limiting factors that limit the data rate and capacity. Besides this the nonlinear optical effects also degrade the system performance. Among the nonlinear effect four wave mixing (FWM) is a nonlinear process that generates new frequency components from existing frequency components. FWM is the main factor which ultimately limits the channel density and capacity of WDM systems. In this paper we have discussed the hybrid modulation techniques (combination of different modulators like Phase modulator followed by amplitude modulator, Mach-Zehnder modulator followed by an Amplitude modulator, optical dual port dual drive Mach Zehnder modulator followed by dual drive Mach-Zehnder and Amplitude modulator) for suppressing FWM non linear effect in dense wavelength division multiplexing system. Impact of FWM is analyzed for different types of hybrid modulation techniques (low level FWM reduction, high level FWM reduction and intermediate stage FWM reduction) in negative dispersion nonzero dispersion shifted fiber (ND NZDSF). Optimum reduction of FWM effect is achieved in intermediate stage FWM reduction technique.

Keywords: FWM (four wave mixing), DWDM (dense wavelength division multiplexing, negative dispersion nonzero dispersion shifted fiber (ND NZDSF).

1. Introduction

Optical fiber is the best channel for transmitting information from one place to another. In this modern era people need having high capacity network system. So the demand for transmission capacity and bandwidth become more and more challenging to the carriers and service suppliers. In optical fiber communication, wavelength division Multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber [1]. This helps to increase capacity and data rate of transmitter by proper utilization of fiber bandwidth. Multiplexers can be divided into two types based on channel spacing, Dense WDM and Coarse WDM. In CDWM system channel spacing is above 200 GHz. The channel spacing in the DWDM system is less than 200 GHz. [2]. In the Dense Wave length division multiplexing system (DWDM) the nonlinear effects plays important role due to limited channel spacing. The optimized design and application of optical fiber are very important for the transmission quality of optical fiber transmission system. So, it is necessary to investigate the transmission characteristics of optical fiber. There are several nonlinear effects in WDM systems, such as stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), self-phase modulation (SPM), cross-phase modulation (XPM), and four-wave mixing (FWM) [2]. FWM is the main factor which limits the channel density and capacity of WDM systems [3]**.** To reduce FWM effects in DWDM system many technologies are investigated such as change in channel spacing, use of RZ modulation format, use of dispersion management technique [6]. In this paper we have investigated hybrid modulation technique for suppressing FWM in DWDM system. Hybrid modulator is implemented using combination of different modulators like Phase modulator followed by amplitude modulation modulator, Mach-Zehnder modulator followed by an Amplitude modulator, optical dual port dual drive Mach Zehnder modulator followed by dual drive Mach-Zehnder and Amplitude modulator. The paper is outlined as follows. Section II deals with the general discussion on FWM effect. Section III consists of analysis of FWM effect in low level reduction, high level and intermediate level technique for fiber length of 50 to 100 km. Section IV discusses the comparative analysis of all hybrid techniques. Finally section V concludes the paper.

2. Four Wave Mixing

Four wave mixing is a process in which different frequencies interact with the nonlinear refractive index and by interactions a fourth wavelength of light is generated. The number of FWM products increased with the increase in number of input channel. FWM is originating from the dependence of fiber refractive index on the intensity of the optical wave propagating along the fiber. Two co propagating wave mix and generate sideband at f_1-f_2 and $2f_2$-f_1. Similarly, three waves of frequencies f_i & f_j and f_k generate the frequency $f_{ijk} = f_i + f_j - f_k$ (subscripts i, j and k select 1, 2 and 3).

For m number of input channel in DWDM system, the number of FWM signal generated is given by [2]

$$k = \frac{m^2}{2}(m-1) \quad (1)$$

Optical power P_{ijk} generated through the FWM process for the frequency component f_{ijk} is written as [2]

$$p_{ijk} = \frac{\gamma^2}{9} d_{ijk}^2 p_i p_j p_k e^{-\alpha L} L_{eff}^2 \quad 2)$$

Where $p_{ijk}$is the output power of the FWM product, γ is the non-linear co-efficient of the fiber, d_{ijk} is the degeneracy factor, α is the fiber loss co-efficient, L_{eff} is the effective length of the fiber, η is the mixing efficiency.

By FWM effect signal power is reduced due to generation of the new optical waves which is known as power depletion. In DWDM system several channels are transmitted with several equally spaced frequencies. So some of these mixing products will occur at or near some of the operating wavelengths. These new optical waves interfere destructively with the signal so it degrades the system performance and crosstalk is generated. Crosstalk can be of two types heterodyne and homodyne crosstalk. Heterodyne crosstalk is due to interferences of small power levels that appear outside the bandwidth of the channel and Homodyne crosstalk results from interferences inside the channel's bandwidth [8]. In this way FWM is a very serious issue and a major limitizing factor so this non-linear factor should be minimized to have a reliable fiber optical communication network.

3. FWM Reduction Techniques

FWM can be minimized by use of effective channel allocation technique and dispersion management techniques [5]. But bandwidth requirement is increased in effective channel allocation technique. The dispersion management technique is a linear process therefore it has minimum effect on FWM reduction [6]. Therefore hybrid modulation technique is used to reduce the effect of FWM. The hybrid modulation technique is divided into three parts low level reduction, high level reduction and intermediate reduction.

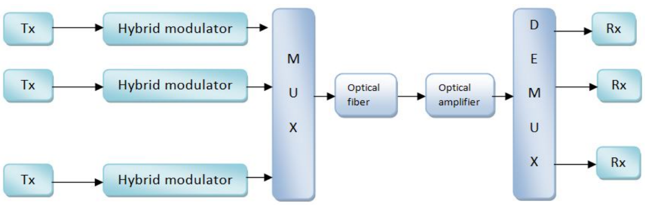

Fig. 1: Block diagram for hybrid modulation system.

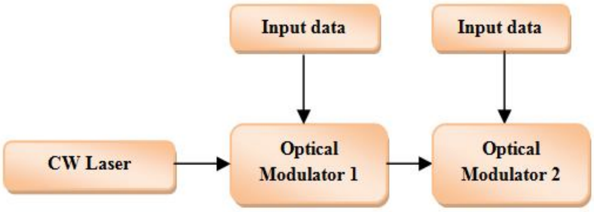

Fig. 2: Block diagram of hybrid modulator.

The proposed system (shown in fig 1) consists of 8 channel 2.5Gbps WDM transmitter with sample rate of 160 GHz, sequence length of 128bits and sequence sample rate of 64 samples per bit. Transmission link consist of 50-100Km negative dispersion nonzero dispersion shifted fiber followed by an optical amplifier with operating wavelength of 1550nm with 25db gain. The channel spacing in the DWDM system must be less than 1.6nm. 1nm channel spacing has been taken for above system. NRZ modulation format is used in transmitter. The block diagram of hybrid modulator is shown in Fig. 2. Low pass Bessel filter with a cut off frequency of 1.875 GHz is used at receiver side. The transfer function of Bessel filter depends on insertion loss, cutoff frequency, normalized 3db bandwidth and parameter order [10]. Optical spectrum analyzer is used to analyze the FWM effect at input and output of ND NZDSF. 3R regenerator is used at receiver side to generate electrical signal. BER analysis is performed to analyze the quality of output signal.

3.1 Low level FWM reduction

In this FWM reduction technique hybrid modulator may be combination of a) Phase modulator (PM) followed by Amplitude modulator (AM) b) Mach-Zehnder modulator followed by an AM. Phase mismatch is introduced by PM modulator and mach-Zehnder modulator. Then output signal is added constructively or destructively by AM modulator [8]. Output spectrum of these modulators with input power of 0 dBm are shown in Fig. 3 & 4. Fig. 5 and Fig. 6 show the eye pattern for PM modulator followed by AM modulator and Mach-Zehnder modulator followed by an AM modulator respectively. The FWM product depends on input channel power as equation (2). The Q factor depends on FWM noise and performance of photo-detector and low pass filter. Fig. 7 summarizes the effect of FWM for various input power for fiber length of 50, 75 and 100km. Fig. 8 summarizes the effect of Q factor for various input power for fiber length of 50, 75 and 100km. The simulation results show that bit error rate is zero and by increasing the input power from -10 to 10 dBm the Q factor gradually increases while Q factor decreases as we increase input power from 10 to 20 dBm.

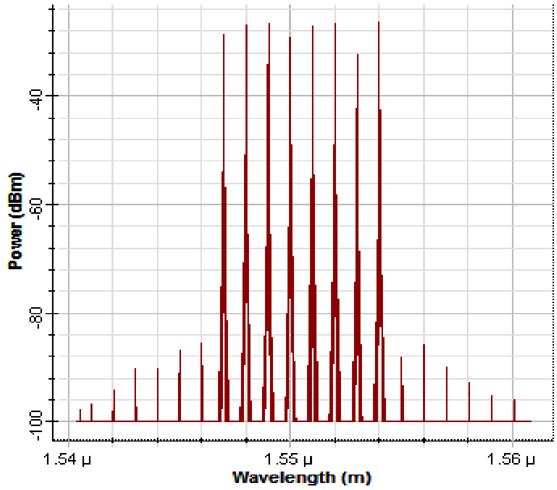

Fig. 3: Output spectrum for input power of 0dBm for low level reduction technique (PM modulator followed by AM modulator)

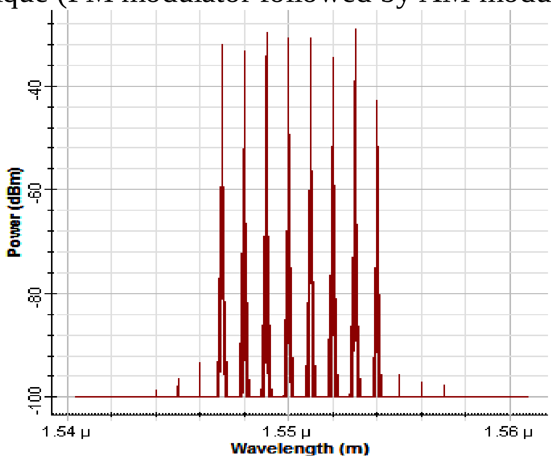

Fig. 4: Output spectrum for input power of 0dBm for low level reduction technique (Mach-Zehnder modulator followed by an AM modulator)

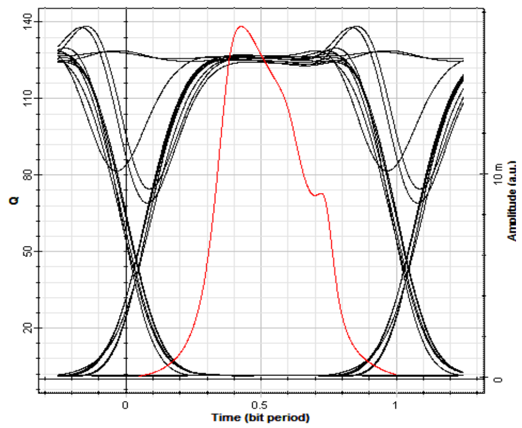

Fig. 5: Eye Diagram for low level reduction technique at channel 1 for PM modulator followed by AM modulator.

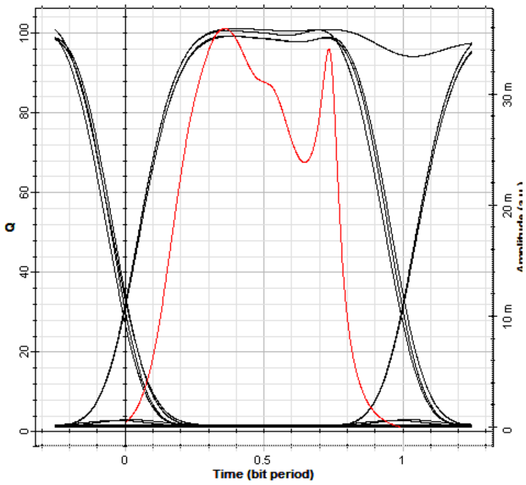

Fig. 6: Eye Diagram for low level reduction technique at channel 1 for Mach-Zehnder modulator followed by an AM modulator.

Table 1: Variation of Low level FWM factor with input power.

Input Power	Q Factor	BER	Eye Height	FWM Power
-10	63.897	0	0.023960	0
-5	110.509	0	0.0320003	0
0	156.640	0	0.0359849	-93.34
5	419.293	0	0.0376409	-83.40
10	281.040	0	0.0369210	-74.42
15	243.798	0	0.0359000	-66.83
20	101.136	0	0.0344000	-61.95

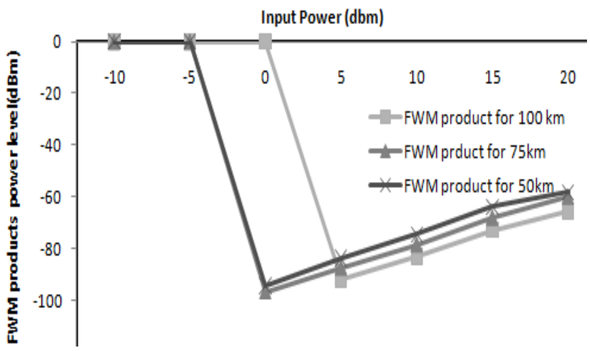

Fig. 7: FWM product vs. input power

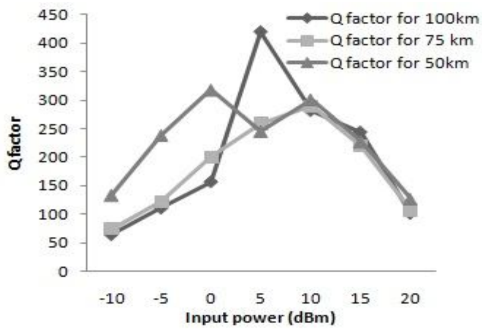

Fig. 8: Q factor vs. input power for low level reduction

3.2 High level FWM reduction

In this FWM reduction technique hybrid modulator used is combination of optical dual port dual drive Mach Zehnder modulator followed by dual drive Mach-Zehnder and AM modulator. This technique is used for low power and short distance. In dual port dual drive Mach Zehnder modulator the dependence of the measured absorption and phase on applied voltage is specified for a Mach-Zehnder modulator. It has double sided electrical inputs. Output spectrum of these modulators with input power of 0 dBm is shown in Fig. 9. Fig. 10 shows the eye pattern at channel 1.

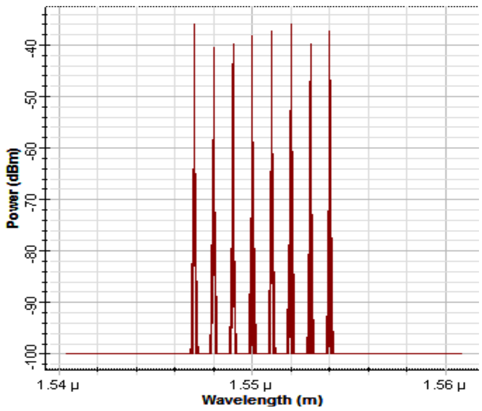

Fig. 9: Output spectrum for input power of 0dBm for high level reduction technique.

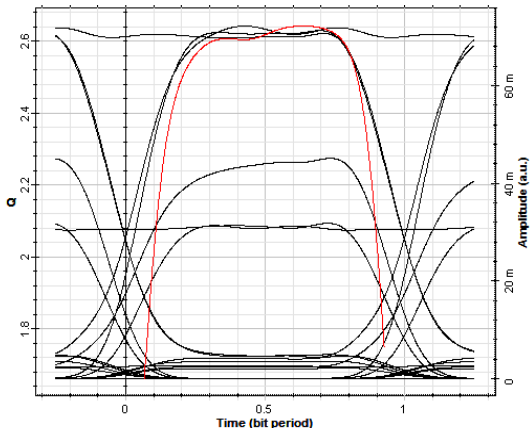

Fig. 10: Eye Diagram for high level reduction technique at channel 1

Fig. 11 summarizes the effect of FWM for various input power for fiber length of 50, 75 and 100km. Fig. 12 summarizes the effect of Q factor for various input power for fiber length of 50, 75 and 100km. The FWM product depends on input channel power as equation (2). The Q factor depends on FWM noise and performance of photo-detector, and low pass filter. The simulation results shows that bit error rate is zero and by increasing the input power from -10 to 15 dBm the Q factor gradually increases while Q factor decreases as we increase input power from 15 to 20 dBm with a fiber length of 100 km.

Table 2: Variation of High level FWM with input power.

Input Power	Q factor	BER	Eye Height	FWM Power
-10	5.2946	6.844e-008	0.0120	0
-5	5.4807	2.115e-008	0.0212	0
0	5.6515	7.888e-009	0.0286	0
5	5.7688	3.863e-009	0.0326	-92.00
10	5.8186	2.818e-009	0.0337	-82.98
15	5.8853	1.851e-009	0.0336	-72.87
20	2.6426	0.00116	-0.0070	-65.42

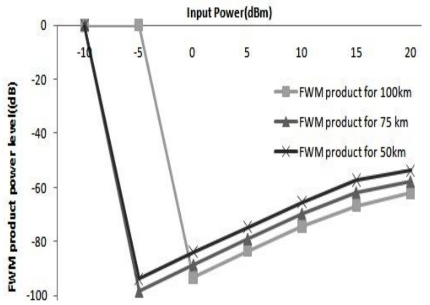

Fig. 11: FWM product vs. input power

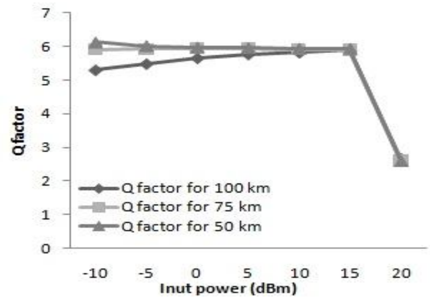

Fig. 12: Q factor vs. input power for high level reduction technique

3.3 Intermediate level FWM reduction

In this FWM reduction technique hybrid modulator used is combination of Mach Zehnder modulator followed by dual drive Mach Zehnder modulator and AM modulator. The dual drive Mach Zehnder modulator has matching electro-optic amplitude and phase response, low drive voltage and single sided electrical input [8]. Output spectrum of these modulators with input power of 0 dBm is shown in Fig. 13. Fig. 14 shows the eye pattern at channel 1. Fig. 15 summarizes the effect of FWM for various input power for fiber length of 50, 75 and 100km. Fig. 16 summarizes the effect of Q factor for various input power with fiber length of 50, 75 and 100km.

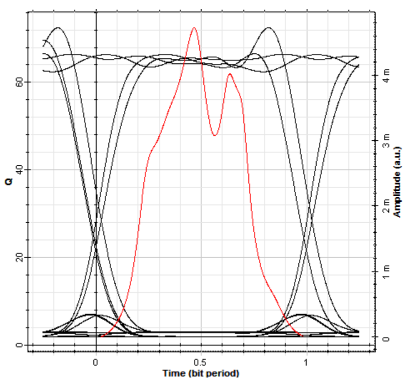

Fig. 13: Eye Diagram for intermediate stage reduction technique at channel 1.

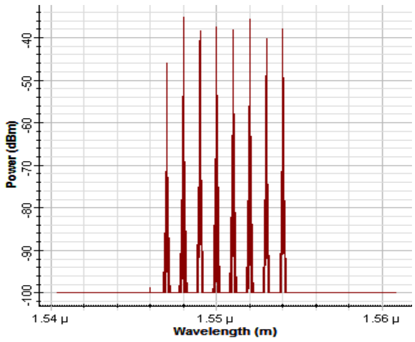

Fig. 14: Output spectrum for input power of 0dBm for intermediate stage reduction technique.

Table 3: Variation of Intermediate level FWM factor with input power.

Input Power	Q factor	BER	Eye Height	FWM Power
-10	7.54429	1.61754e-014	0.00121	0
-5	13.9797	2.8987e-045	0.00250	0
0	22.8852	9.2751e-117	0.00360	-98.87
5	53.2817	0	0.00420	-93.30
10	37.2519	1.8406e-304	0.00412	-84.00
15	96.9306	0	0.04300	-71.33
20	72.4858	0	0.04040	-65.00

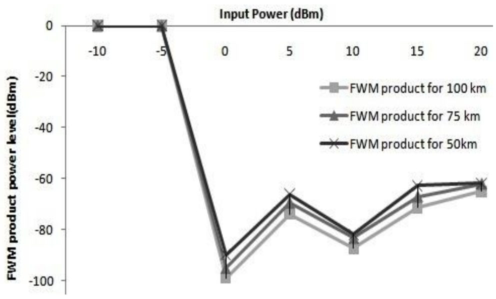

Fig. 15: FWM product vs. input power

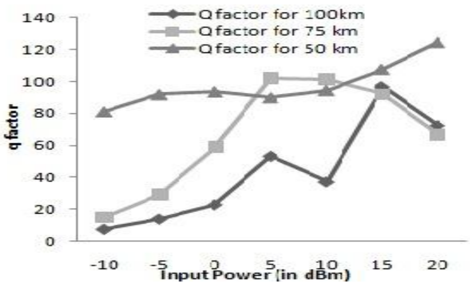

Fig. 16: Q factor vs. input power for intermediate stage reduction

4. Comparison

Simulation result of above hybrid techniques is compared in this section. FWM product is decreased in high level reduction technique but it results in high distortion and non negligible bit error rate. Quality factor for this technique is very low. So this technique is used for short distance communication. The low level reduction partially affects the FWM product but it results in low distortion and zero bit error rate.

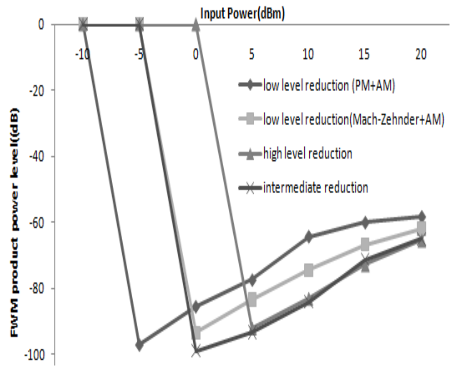

Fig. 17. FWM product vs. input power.

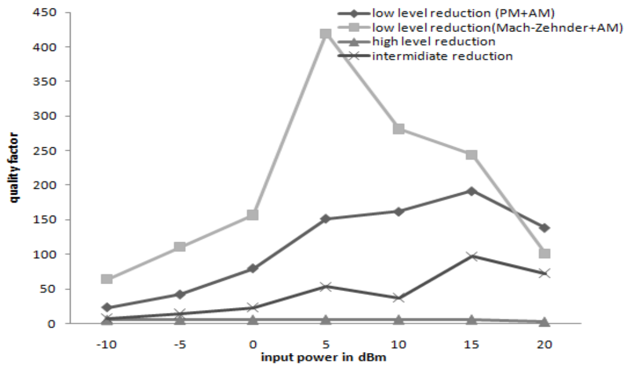

Fig. 18: Q factor vs. input power.

The intermediate scheme removes the drawback of low level and high level reduction scheme. FWM reduction is good with this technique. It provides considerable value of Q factor with zero bit error rate.

The Fig. 17 shows the FWM product for different value of input power. FWM power increases as increase in input power. The Fig. 18 shows the effect of input power on Quality factor. Quality factor gradually increases for input power of -10 to 5 dBm while decreases as we increase the input power from 10dBm to 20dBm. The quality factor for high level reduction is almost constant for all value of input power.

5. Conclusion

This paper presents the analysis of FWM effects for different hybrid modulators in DWDM fiber optics communication system. The analysis is based on the simulation results obtained using optisystem simulation tool. Different combinations of hybrid modulators were discussed in previous papers like PM modulator followed by AM modulator for low level reduction and intermediate stage reduction using non zero dispersion shifted fiber (dispersion 16.75 ps/nm/km) [8]. In this paper negative dispersion non-zero dispersion shifted fiber (dispersion -7.5 ps/nm/km) is used. Here Combination of Mach-Zehnder modulator followed by AM modulator is used for low level reduction technique and intermediate stage reduction technique. FWM product is reduced effectively in Low level reduction technique if the input power is low. The BER analyzer gives efficient result in this reduction technique. FWM products are greatly reduced with high level reduction but there are distortions in Eye diagram. Then intermediate technique to reduce FWM products is used to overcome above difficulty. Comparative study shows that intermediate level FWM reduction is more efficient.

References

[1] Govind P. Agrawal, "*Fiber Optic Communication System,*" third edition, a john wiley & sons, inc., publication.

[2] Katsunari Okamoto, "*Fundamentals of Optical Waveguides*", second edition, academic press is an imprint of Elsevier.

[3] Govind P. Agrawal, "*Non Linear Fiber Optics,*" third edition, academic press.

[4] Bijayananda Patnaik and P.K.Sahu, "*Optimization of Four Wave Mixing Effect in Radio-over-Fiber for a 32-Channel 40-GBPS DWDM System,*" international symposium on electronic system design, 2010.

[5] Antonella Bogoni and Luca Poti, "*Effective Channel Allocation to Reduce in band FWM Crosstalk in DWDM Transmission Systems,*" IEEE journal of selected topics in quantum electronics, vol. 10, no. 2, April 2009.

[6] S. P. Singh and and N. Singh, "*Nonlinear Effects in Optical Fibers: Origin, Management and Applications,*" progress in electromagnetic research, PIER 73, 249–275, 2007.

[7] Iftikhar Rasheed, Muhammad Abdullah, Shahid Mehmood, Mahwish Chaudhary, "*Analyzing the non linear Effects at various Power Levels and Channel Counts on the Performance of DWDM Based Optical Fiber Communication System,*" 2012.

[8] Iftikhar Rasheed, Muhammad Abdullah, Qazi Md. Hamza Mansoor, Zia-ur-Rehman, "*Novel Approaches for Suppression of Four Wave Mixing in WDM System Using Concocted Modulation Techniques,*" International Conference on Frontiers of Information Technology, 2012.

[9] J. Toulouse, "*Optical Nonlinearities in Fibers,*" review, recent examples and systems applications journal of light wave technology, vol. 23, no. 11, November 2005.

[10] Optisys Design, Optiwave Corporation 7 Capella Court Ottawa, Ontario, Canada.

[11] Sawsan A. Abdul- Majid. "*Software Simulation FWM in WDM Optical Communication Systems,*" Journal of kirkuk university scientific studies, vol.6, No.1, 2011.