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Mitigation of Kerr Nonlinearity by setting Optimum Dispersion value and Unequal Channel Spacing

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ABSTRACT: The widespread use of internet has led to the tremendous increase of data traffic. So inorder to meet the growing needs, the capacity of fibers has to be increased. For that Dense Wavelength Division Multiplexing (DWDM) is used. However, Kerr nonlinearity degrades the transmitted signal which in turn decreases the fiber capacity. The Kerr-nonlinearities that occur in optical fiber are Self-Phase Modulation, Cross-Phase Modulation, Stimulated Raman Scattering and Four-Wave Mixing. In this paper, the Kerr nonlinearities are mathematically analyzed and arrived at a solution to mitigate these nonlinearities. Also it is found that the mitigation of fiber nonlinearities can be done by adding some chromatic dispersion in the fiber and by making the channel spacing uneven. Also an optimum dispersion value and optimum channel spacing has been found to mitigate these nonlinearities. The performance of the fiber optic link has been evaluated in terms of Quality factor and bit error rate (BER). The simulation of fiber optic link is carried out using OPTSIM software.

KEYWORDS: DWDM, Dispersion, Unequal channel spacing, SPM, FWM, SRS, XPM

I.INTRODUCTION

Nonlinearities in optical fiber give rise to many ubiquitous effects which will limit transmission reach of signal. Due to this, the output signal gets distorted. So inorder to have better performance, the optical fiber is designed in such a way that all the nonlinearities that are produced should be minimized and recover the original signal at the receiver. The reasons for nonlinearity in optical fiber may be due to inelastic scattering phenomenon and dependence of refractive index with optical power [1]. Inorder to increase the capacity of the fiber optic system, small amount of dispersion is added to the fiber and unequal channel spacing is used between the channels. Also other ways to increase the capacity are increasing data rate and increasing the transmitted power. But increasing the bit rate and transmitted power beyond a certain threshold will increase the nonlinearity.

In this paper, the fiber optic link has been analysed with 4, 8, 16, 32 and 64 channels. Also the channel spacing is kept uneven and the simulation is done by increasing the dispersion value. From the analysis, an optimum dispersion value and optimum channel spacing has been found.

II. RELATED WORK

Kumar.N, Sharma.A.K & Kapoor.V evaluated XPM-induced crosstalk in a SCM–WDM communication link at different modulation frequencies, transmission lengths and optical powers for variety of fiber. Results showed that XPM-induced crosstalk dominates at high frequency. As the dispersion and effective area of fiber (Aeff) decrease, crosstalk increases with increase in modulation frequencies, transmission lengths and optical powers.
Fang Juanni had discussed the model of the effect of SRS to error bit ratio in DWDM system. Through the way numerical of simulation, imitations to SRS to error bit ration of communication system and input Optical power, the number of channel and the spacing of channel are discussed.
Amarpal Singh, Ajay K. Sharma and T.S. Kamal investigated the methods for Four Wave Mixing (FWM) suppression. Modified techniques equal and unequal-channel spacing with polarization, equal channel spacing with alternate channel delay, optical coupling and varied laser power have been proposed to reduce the impact of FWM on Dense Wave

Length Division Multiplexing (DWDM) optical communication system. Further the comparison of reduction of FWM for existing and proposed techniques has been discussed by varying the dispersion of fiber from 0 to 16 ps/nm/km

III. KERR NONLINEARITY

The change in refractive index with optical intensity causes the Kerr nonlinearity [2]. The nonlinearities that affect the shape of pulse are Self-Phase Modulation (SPM) and Cross Phase Modulation (XPM) and that change energy of optical pulse are Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS) and Four Wave Mixing (FWM).

A. Cross Phase Modulation

The response of any dielectric to light becomes Non-linear for intense electromagnetic fields, and optical fibers are no exception. On a fundamental level, the origin of Non-linear response is related to a harmonic motion of a bound electron under the influence of an applied field [3]. XPM occurs in multi-wavelength systems. If the phase of the signal is modulated by optical intensity fluctuations of another pulse, cross phase modulation occurs [2]. XPM occurs if the channel spacing is very less. The nonlinear phase shift for N channels is given by

$$\phi_{1n1} = nl_{eff}\left(P_i + 2\sum_{n=1}^{N} P_n\right) \tag{1}$$

B. Four Wave Mixing

FWM is also known as Four Photon Mixing. It is a parametric interaction among optical waves [4]. In a multi-channel system the beating between two or more channel causes generation of one or more new frequencies at the expense of power depletion of the original channels [5, 6]. Let λ_1, λ_2 and λ_3 be the three wavelengths and these wavelengths are mixed together and give a fourth wavelength as follows

$$\lambda_{123} = \lambda_1 \pm \lambda_2 \pm \lambda_3 \tag{2}$$

FWM can be reduced by unequal channel spacing, adding small amount of dispersion in the fiber and increasing core effective area of fiber [7, 8].

C. Stimulated Raman Scattering

SRS is due to the interaction of photons with fiber's molecular vibrations. As a result, output optical power is transferred from lower wavelength to the higher wavelength [9]. The threshold optical power for SRS is given by

$$P_{th} = 5.9 * 10^{-2}\lambda^2 d^2 \alpha \tag{3}$$

III. PROPOSED METHOD

From the mathematical analysis of the nonlinearities, it is found that all the nonlinearities depend upon channel spacing and dispersion. Hence the fiber optic link has been analysed by increasing dispersion value and making channel spacing uneven. In the proposed method, the fiber optic link has been analysed for 4, 8, 16, 32 and 64 channels. Fig.1 shows the experimental set up of N-channel WDM fiber optic link simulated in OPTSIM software. It consists of N WDM transmitters, optical fiber, photodiode, optical and electrical spectrum analysers.

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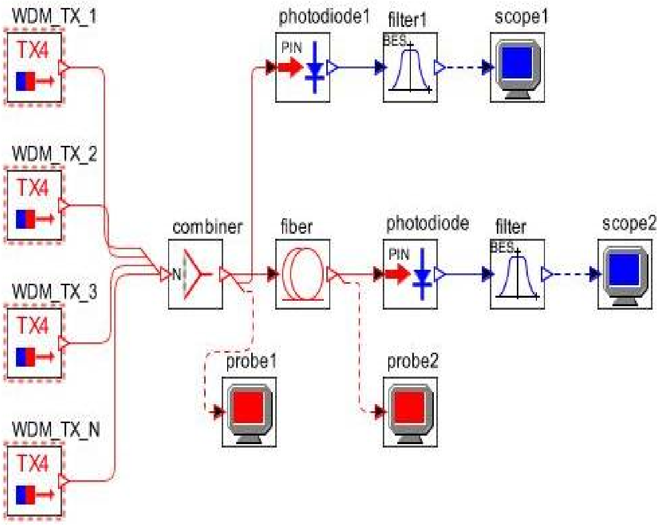

Fig. 1 N-channel WDM system

Fig.2 shows the look inside view of WDM transmitter. It consists of a pseudorandom sequence generator which generates the random sequence at a bit rate of 10 Gbps which is modulated with a continuous wave laser source. The modulation is carried out by Mach Zehnder modulator. Then the modulated output from all the WDM transmitters are combined and passed through the optical fiber of length 200 km. Then the resulting output is detected using photodetector to convert it to electrical signal. Then the results are analysed in terms of Q-factor and BER

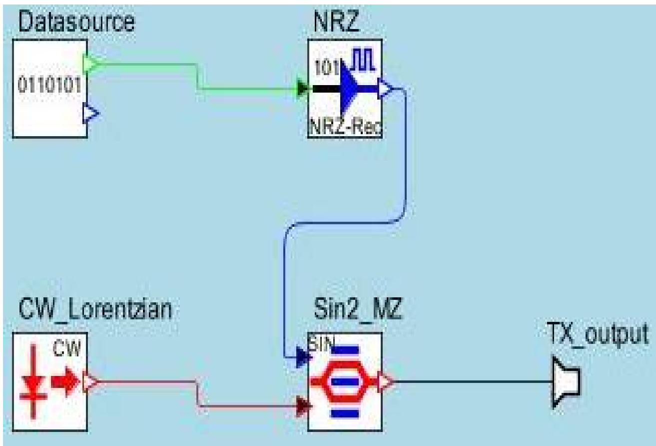

Fig.2 Look inside view of WDM transmitter

IV RESULTS AND DISCUSSION

The fiber optic link is simulated for 4-channel WDM system with unequal channel spacing. Fig.3 shows the multiplexed input optical spectrum with equal channel spacing. From the figure it can be seen that the channels are equally spaced with spacing of 0.1 nm. This multiplexed signal is then passed through the fiber having length of 200 km.

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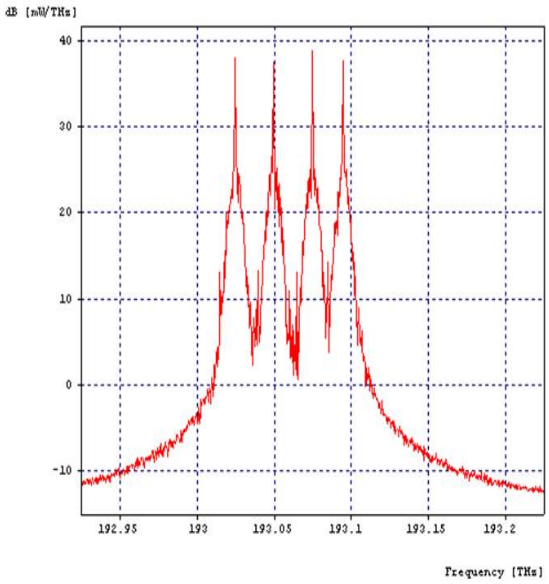

Fig.3 Multiplexed input optical spectrum with equal channel spacing

Fig.4 shows the output obtained after fiber for D = 0 ps/nm/km with equal channel spacing. From Fig.4, it can be seen that the FWM products are formed inside and outside the band. Also it is difficult to eliminate the inband products than outband products. So inorder to eliminate the inband FWM products unequal channel spacing is done between the channels.

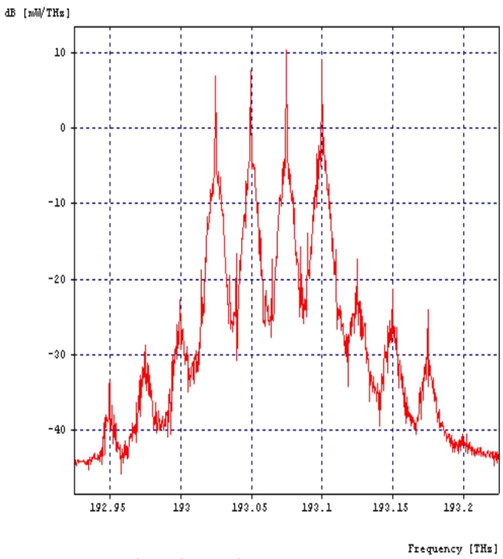

Fig.4 Output spectrum obtained after fiber for D = 0 ps/nm/km with equal channel spacing

The unequal channel spacing is set as 0.01 nm, 0.02 nm and so on in ascending order. Fig. 5 shows the multiplexed input optical spectrum with unequal channel spacing and Fig.6 shows the output spectrum obtained after fiber for D = 0 ps/nm/km with unequal channel spacing.

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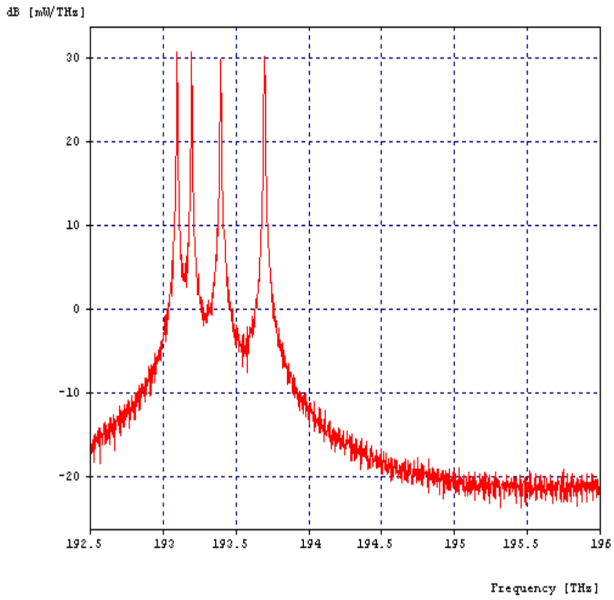

Fig.5 Multiplexed input optical spectrum with unequal channel spacing

From Fig.6 it can be seen that the inband FWM products are almost eliminated due to unequal channel spacing. Inorder to eliminate other nonlinear effects, the dispersion value is increased from 0 ps/nm/km to 14 ps/nm/km and arrived at an optimum dispersion value. Also optimum channel spacing is found.

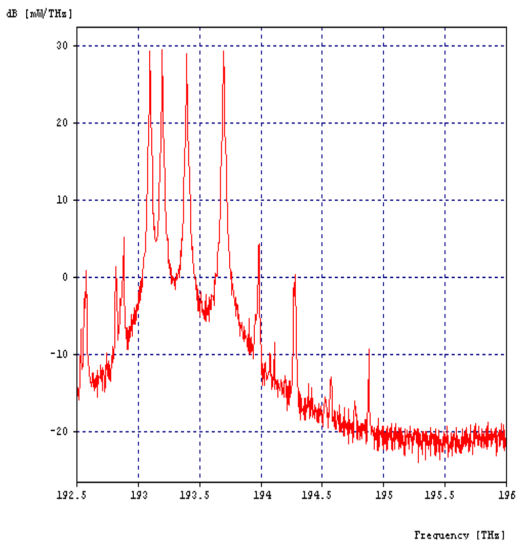

Fig.6 Output spectrum obtained after fiber for D = 0 ps/nm/km with unequal channel spacing

Table 1 shows the effect of increasing dispersion for unequal channel spacing in 4-channel WDM system. The value of dispersion has been increased from 0 to 14 ps/nm/km. From the analysis it can be seen that for dispersion of 5 ps/nm/km, the value of power tilt and power of FWM product is less. The power tilt and power of FWM product obtained at D = 5 ps/nm/km are 0.267 dB and -8.80 dBm respectively. Also the Q-factor of 17.59 dB and BER of 7.95×10^{-13} are obtained.

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Table 1: Effect of increasing dispersion for unequal channel spacing in 4-channel WDM system

Dispersion (ps/nm/km)	Power Tilt (dB)	Power of FWM Products (dBm)	Q-Factor (dB)	BER
0	3.15	19.55	16.98	3.17×10^{-11}
2	0.665	-7.77	16.84	2.73×10^{-12}
5	**0.267**	**-8.80**	**17.59**	**7.95×10^{-13}**
10	1.486	17.42	15.96	2.13×10^{-10}
14	1.212	1.463	13.77	5.20×10^{-07}

Table 2 shows the effect of increasing dispersion for unequal channel spacing in 8-channel WDM system. From the analysis it can be seen that for dispersion of 5 ps/nm/km, the value of power tilt and power of FWM product is less. The power tilt and power of FWM product obtained at D = 5 ps/nm/km are 0.966 dB and -7.32 dBm respectively Also the Q-factor of 17.45 dB and BER of 7.96×10^{-13} are obtained.

Table 2: Effect of increasing dispersion for unequal channel spacing in 8-channel WDM system

Dispersion (ps/nm/km)	Power Tilt (dB)	Power of FWM Products (dBm)	Q-Factor (dB)	BER
0	7.723	6.823	16.11	6.45×10^{-11}
2	1.089	0.502	16.27	5.96×10^{-12}
5	**0.966**	**-7.32**	**17.45**	**7.96×10^{-13}**
10	0.414	-6.998	15.15	1.04×10^{-08}
14	0.158	-5.723	12.29	2.17×10^{-05}

Table 3 shows the effect of increasing dispersion for unequal channel spacing in 16-channel WDM system. From the analysis it can be seen that for dispersion of 5 ps/nm/km, the value of power tilt and power of FWM product is less. The power tilt and power of FWM product obtained at D = 5 ps/nm/km are 0.359 dB and -8.291 dBm respectively Also the Q-factor of 17.15 dB and BER of 2.95×10^{-13} are obtained.

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Table 3: Effect of increasing dispersion for unequal channel spacing in 16-channel WDM system

Dispersion (ps/nm/km)	Power Tilt (dB)	Power of FWM Products (dBm)	Q-Factor (dB)	BER
0	1.188	3.869	16.53	2.43×10^{-12}
2	0.699	-7.472	16.89	1.13×10^{-12}
5	**0.359**	**-8.291**	**17.15**	**2.95×10^{-13}**
10	0.523	-7.321	16.46	2.90×10^{-11}
14	0.613	-8.625	12.75	7.35×10^{-06}

Table 4 shows the effect of increasing dispersion for unequal channel spacing in 32-channel WDM system. From the analysis it can be seen that for dispersion of 5 ps/nm/km, the value of power tilt and power of FWM product is less. The power tilt and power of FWM product obtained at D = 5 ps/nm/km are 0.23 dB and -14.12 dBm respectively Also the Q-factor of 15.08 dB and BER of 8.87×10^{-09} are obtained.

Table 4: Effect of increasing dispersion for unequal channel spacing in 32-channel WDM system

Dispersion (ps/nm/km)	Power Tilt (dB)	Power of FWM Products (dBm)	Q-Factor (dB)	BER
0	2.29	-11.34	13.98	1.81×10^{-06}
2	1.42	-11.306	14.11	2.97×10^{-07}
5	**0.23**	**-14.12**	**15.08**	**8.87×10^{-09}**
10	1.57	-13.72	11.84	7.20×10^{-05}
14	2.11	-13.38	8.56	3.63×10^{-03}

From the analysis made for different number of channels with unequal channel spacing, the optimum dispersion value is found to be 5 ps/nm/km and the optimum unequal channel spacing is found to be 0.01nm with incremental spacing of 0.01 nm.

VI.CONCLUSION

Simulation studies were carried out in OPTSIM software for fiber optic link with 4, 8, 16 and 32 channels. The channel spacing’s were kept uneven and the fiber optic link is analysed by increasing dispersion value. It is found that the optimum dispersion value is 5 ps/nm/km and optimum channel spacing is incremental value of 0.01 nm in ascending order inorder to suppress the nonlinearities that are present in the fiber optic link.

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