Impact of Cross Phase Modulation in Long Haul DWDM Fiber Optic Communication and its Suppression

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Abstract- The explosive growth of the Internet urges the quantum leap in the transmission capacity of the optical fiber network. In long-haul DWDM systems, Cross-phase modulation is the dominant nonlinearity that impairs the system's performance. Cross-phase modulation (XPM) will turn to intensity modulation by fiber dispersion and will cause the pulse's distortion. Hence, there is a need to suppress cross phase modulation in order to increase transmission capacity. Optical Phase Conjugation is one of the methods to reduce impairments due to cross phase modulation. Besides intensity modulation, DQPSK modulation is carried out to increase bit rate. The technique presented is the simplest and produces good results for high power laser source. This paper analyses the effect of cross phase modulation in DWDM system and it is experimentally analyzed using OPTSIM (Optical Communication Simulator).

Keywords- DQPSK (Differential Quadrature Phase Shift Keying), Cross Phase Modulation (XPM), DWDM, Optical Phase Conjugator (OPC), Kerr Non linearity.

I. INTRODUCTION

Due to the explosive growth of communication in recent years, network operators are having tremendous difficulty accommodating the increasing traffic. As demand on multimedia services including voice, data and video continue to grow, it is necessary to achieve a mature service with a high percentage of consumer use, lower and constant access charge, full time connectivity to service providers and higher bandwidth. But major restrictions in the transmission medium are the chromatic dispersion (CD) and Kerr nonlinearities[i] like self phase modulation cross-phase modulation (XPM) and stimulated scattering and their distribution over the propagation direction, which degrade the performance of wavelength division multiplexing (WDM) optical transmission systems.

In general, the nonlinear effect XPM is caused by the modulation of the nonlinear refractive index by the total optical power in the fiber. In the presence of CD this would result in the modulation of the optical phase and the intensity of various signals would be affected. The performance degradation caused by XPM on intensity modulation–direct detection (IM-DD) WDM systems have been investigated through computer simulations and experiments. The extent of the intensity fluctuations caused by XPM as a function of channel separation [ii] and has the dependence of XPM-induced intensity modulation on the fiber length and channel separation has been investigated experimentally in single segment fiber links.

II. CROSS PHASE MODULATION

In future long-span, high-channel-count wavelength division- multiplexed (WDM) systems, cross-phase modulation (XPM) will be one of the most severe obstacles towards error free transmission. In a dispersive fiber, the dominant fiber nonlinearity that causes crosstalk is cross-phase modulation (XPM). XPM can cause several undesirable effects that could be obstacles to high speed telecommunication optical fibers. Cross Phase modulation is one of the inter channel interference caused by intensity dependence of refractive index. When the light signal carrying information passes through the optical fiber, due to imperfections in the fiber during manufacture or change in composition of fiber materials affects the optical communication. The effects may be of either linear or nonlinear.

In WDM systems, the intensity dependent nonlinear effects are enhanced since the combined signal from all the channels can be quite intense, even when individual channels are operated at moderate powers. Thus the intensity dependent phase shift and consequent chirping induced by Self Phase Modulation (SPM) alone is enhanced because of the intensities of the signals in the other channels. Consider a WDM system with two channels

$$E(r,t) = E_1\cos(\omega_1 t - \beta_1 z) + E_2\cos(\omega_2 t - \beta_2 z) \quad (1)$$

The nonlinear polarization is given by

$$P_{NL}(r,t)=\varepsilon_0\chi^{(3)}\left(E_1\cos(\omega_1 t - \beta_1 z)+E_2\cos(\omega_2 t - \beta_2 z)\right)^3$$
$$= \frac{3}{4}\varepsilon_0\chi^{(3)}(E_1^2 + 2E_1E_2)\, E_1\cos(\omega_1 t - \beta_1 z) + \text{Remaining Terms} \quad (2)$$

The first term is due to SPM [iii] whereas the effect of the second term is called cross phase modulation (XPM) and remaining terms are neglected. If $E_1 = E_2$ so that the two fields have the same intensity, the effect of XPM appears to be twice as bad as that of SPM. . In optical systems, XPM has been traditionally believed to be always accompanied by SPM. The nonlinear phase shift is indicated by

$$\varphi_{NL}=(2\pi L/\lambda)n_2[I_1(t)+bI_2(t)] \quad (3)$$

Where L is the length of the fiber, λ is the wavelength of the fiber, I_1 is the intensity of channel 1 and I_2 is the intensity of channel 2. Figure 1 shows that the total XPM-induced phase shift is the integral of the phase shift contributions from all frequency components of co-propagating waves. However, scattering losses in actual fibers reduce the signal power such that the frequency shift induced by the first interfering edge is much larger than the opposite shift created by the following edge. Therefore, the frequency shift is not fully compensated, and timing jitter due to the frequency shift accumulates along the whole length of the fiber. This is true even for fibers with relatively high dispersion where the edges walk off more quickly, since there is a fairly high probability in realistic data patterns that the rising and falling edges are separated by several bit periods.

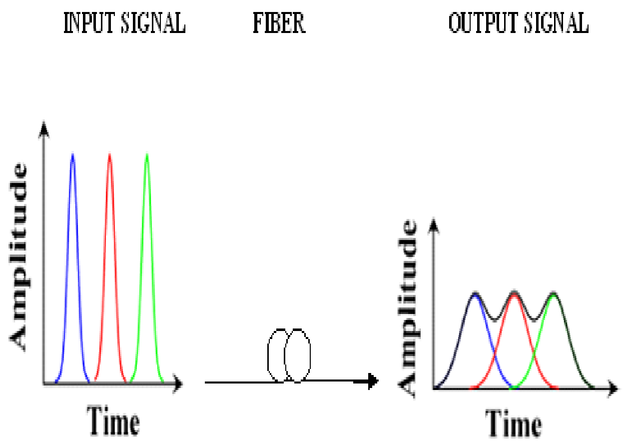

Fig 1 Pulse broadening for different length of the fiber

In pump-probe Configuration, when the probe pulse is launched simultaneously with an intense pump pulse,the probe spectrum is generally broadened and develops an oscillatory structure. This occurs because XPM imposes a frequency chirp on thr probe pulse in a manner similar to that induced by SPM. However the probe spectrum can be symmetric or asymmetric depending on the initial delay between the pump and probe pulses.The pump and the probe pulses walk-off from each other as a result of their slightly different group velocities. In practice, the effect of XPM in WDM systems operating over standard single mode fiber can be significantly reduced by increasing the wavelength spacing between the individual channels.

III. CONCEPTUAL ANALYSIS

Fiber nonlinearities such as Cross Phase Modulation (XPM) may generate significant amounts [iv] of nonlinear crosstalk between adjacent channels because they are very closely spaced. Number of methods has been recommended to compensate or reduce the influence of XPM in fiber optic systems. The main problem is the phase change of the signal characteristics, which requires any compensation technique to dramatically adapt to changes while the system is in service. The Compensation technique used to reduce Cross Phase Modulation is Optical Phase Conjugator.

It is a promising technology to compensate deterministic impairments in long haul transmission systems. By placing phase conjugator at the middle of the fiber link, it optically conjugates the phase of the signal from first part of the fiber link .Hence, impairments that occurred in the first part of the link can be cancelled by impairments that occurred in the later part of the fiber link. In order to get the clear understanding of Optical Phase Conjugator functionality [v], consider the signal propagation in non linear, lossy media which is expressed by Non Linear Schrodinger Equation (NLSE),

$$\frac{\partial A}{\partial Z} = -\frac{\alpha}{2}A - \frac{i}{2}\beta_2\frac{\partial^2 A}{\partial T^2} + \frac{1}{6}\beta_3\frac{\partial^3 A}{\partial T^3} + i\gamma|A|^2A \quad (4)$$

Where A is the amplitude of the signal, Z is the propagation distance in Km, α is the attenuation coefficient, γ is the non linearity coefficient, and T is the time and β terms indicate group velocity dispersion. In order to restore input signal, phase conjugator is placed at the middle of the link which reverses the imaginary part of the signal propagation after first half of fiber. The complex conjugate of above equation is expressed as,

$$\frac{\partial A^*}{\partial Z} = -\frac{\alpha}{2}A^* + \frac{i}{2}\beta_2\frac{\partial^2 A^*}{\partial T^2} + \frac{1}{6}\beta_3\frac{\partial^3 A^*}{\partial T^3} - i\gamma|A^*|^2A^* \quad (5)$$

The above equation indicates that the sign of Chromatic dispersion term and Kerr effect term are both inverted. It can be concluded that the impact of the Cross Phase Modulation (Kerr effect) is proportional to the optical signal power $|A|^2$. The nonlinear coefficient in above equation is expressed in $[W^{-1}km^{-1}]$ and defined as

$$\gamma = \frac{n_2\omega_0}{c\,A_{eff}} \quad (6)$$

The Kerr effect increases along the transmission line and the sign of Kerr effect term is inverted by OPC, the Kerr effect that occurs after OPC cancels the effect that occurs before OPC. Kerr effect is a non linear impairment which depends on the optical power of the signal. The degree in which cross phase modulation is compensated depends on the design of the transmission link. In such transmission line, OPC is capable of compensating both chromatic dispersion and non linear impairments. The effect of cross phase modulation [vi] is prevalent for 10 Gbps OOK signals and it is reduced by phase conjugator. Besides 10 Gbps OOK signals, DQPSK signals are also analyzed with the help of Optical phase conjugator which provides good potency against non linear effects.

DQPSK is a multilevel modulation format that has received good attention [vii] in optical communications. Each transmitted symbol is mapped into four (quaternary) possible phase change transitions. By transmitting two bits for each symbol, it results in reduced spectral occupancy and bandwidth requirements. Another advantage of DQPSK is the extended chromatic dispersion and PMD tolerances.

IV. EXPERIMENTAL ANALYSIS

We implemented the method to reduce cross phase modulation in a transmission experiment over 2x100-km NZDSF in optical communication simulator. As many channels are used in dense wavelength division multiplexing, the power of first channel affects the phase of remaining channels which contribute non linearity in optical transmission systems.

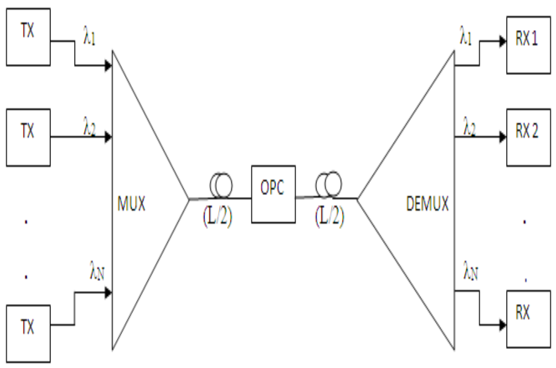

Fig 2 Block Diagram for XPM Compensation

The above figure shows the block diagram of XPM compensation where many transmitters are multiplexed and passed through first span of fiber link and the signal from the fiber is passed to the compensator and again is passed to the second part of fiber link. At receiver side, the signals are demultiplexed and provided to the receiver. From the receiver, the signal is examined with the help of Eye diagram for easy interpretation of signal impairments in terms of amplitude and time distortion.

The above diagram in Fig 2 shows that the transmitter includes a laser source, pseudo random bit sequence (PRBS) generators at 10 Gb/s for OOK modulation. They are externally modulated via $\sin^2$ modulator. For higher data rates, the transmitter comprises of a laser source, data source (40 Gbps), precoder, filters, phase shifter and DQPSK modulator. The modulated signal are combined together and passed to first fiber span of length 100 Km and the output from the first fiber span is corrupted by cross phase modulation. Now this corrupted signal is passed through the compression technique referred as Optical Phase Conjugator which reverses the phase of the corrupted signal. The phase reversed signal from the conjugator is passed to the second span of fiber link of length 100 Km. By passing phase reversed signal over the second fiber span where non linear effects again make phase reversal as similar to that of the input signal. Hence the received signal is visualized by means of Eye diagram and it is similar to that of original signal transmitted with some loss.

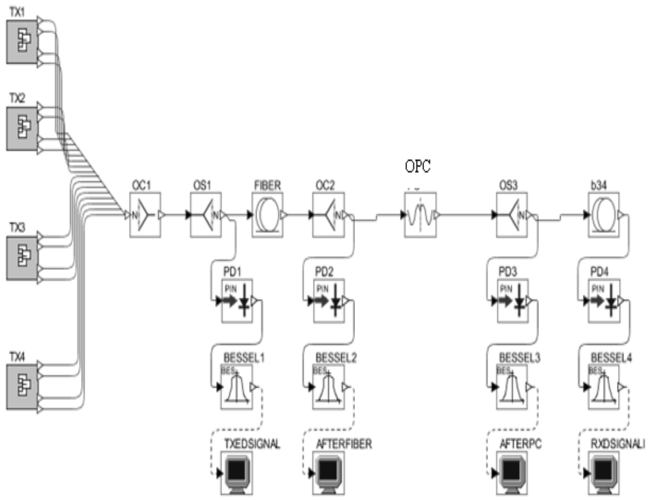

Fig 3 Optsim layout for 16 channel XPM compensation

Figure 3 shows the layout for 16 channel DWDM system has 4 transmitters each having 4 laser sources and the layout is analyzed for different channel spacings and its performance were analyzed with the help of eye diagram. Eye diagram at Figure 4 and Figure 5 shows that Q factor is obtained as the performance measure. In 16 channel WDM system, the Q factor obtained before passing in to the fiber is 40 dB and after passing in to the fiber, it has been reduced to 6.02 dB. When the distorted signal is passed to the phase conjugator, the signal is reshaped to its original form and hence the Q factor is 25.3 dB for 0.2 nm channel spacing. Q factor is analyzed for various channel spacing's.

We can also increase this experiment to larger number of channel counts, and this model is found to be good accord. Consider the transmission of sixteen 100-GHzspaced channels at 10 Gb/s with 9 dBm power per channel over a 2X100-km NZDSF transmission. Similarly the transmission of thirty two, sixty four, one twenty eight 50GHZ and 100 GHZ spaced channels for different power levels over different Km of fiber lengths have been experimented for OOK modulation . These experiments are simulated by Optical Communication Simulator "OPTSIM". This method suggest that fiber

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characteristics identical to whole transmission line and symmetrical distribution of power along fiber line.

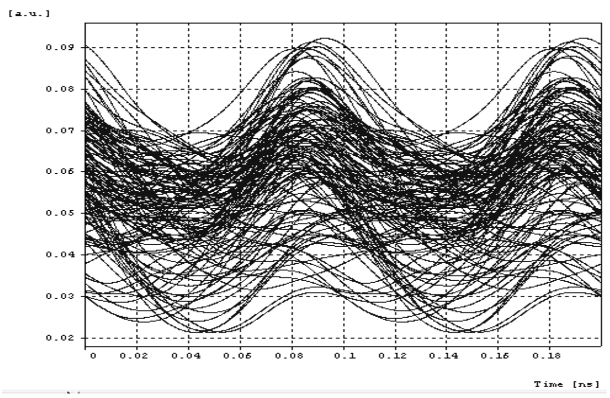

Fig 4 Eye diagram for 16 channel WDM System with XPM compensation

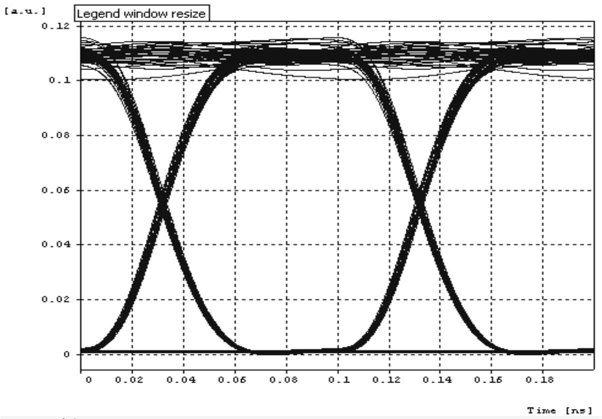

Fig 5 Eye diagram for 16 channel WDM System with XPM compensation

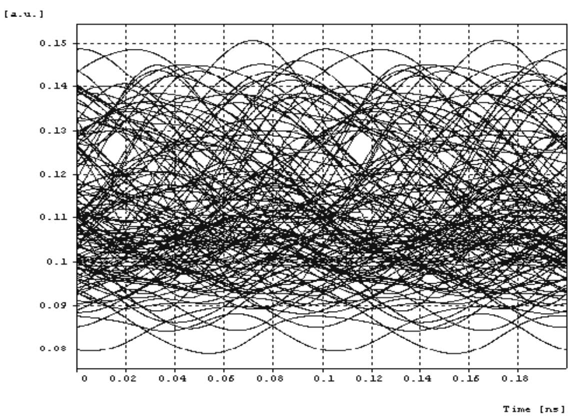

Fig 6 Eye diagram for 32 channel DWDM system without XPM compensation

Figure 6 shows that 32 channel DWDM systems without XPM compensation, the Q factor of the signal before passing in to the fiber is 40 dB and after the fiber is 6.02 dB. Figure 7 shows the reduction of XPM by means of phase conjugator for 0.8 nm and Q factor has been increased to 36.15dB. In 32 channel DWDM system, the Q factor of the signal before passing in to the fiber is 40 dB and after the fiber is 6.02 dB and it has been increased to 32.58dB by means of phase conjugator for 1 nm channel spacing.

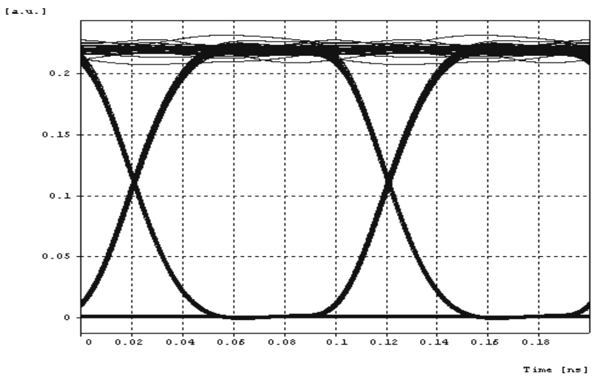

Fig 7 Eye diagram for 32 channel DWDM system with XPM compensation

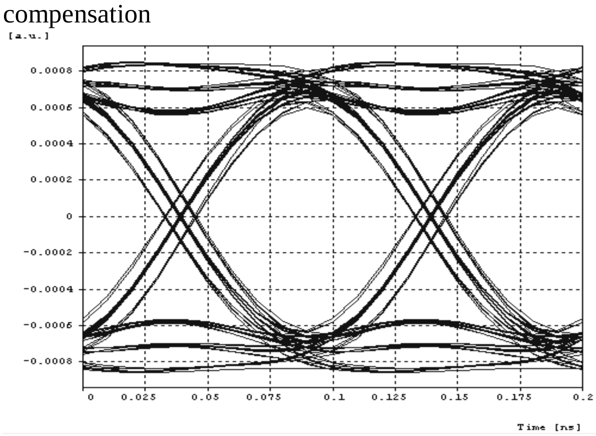

Fig 8 Eye diagram for 2 channel WDM system for DQPSK Modulation

The above eye diagram shows that DQPSK modulation is analyzed for 2 channels with OPC and found to be good for high data rates. In 2 channel WDM system, the distorted signal is passed to the phase conjugator, the signal is reshaped to its original form and hence the Q factor is 22.65 dB for 0.2 nm channel spacing. From the below table, it shows that when number of channels increases the Q factor decreases and bit error rate increases. For different channel spacings, XPM effect is analyzed and it is reduced with the help of optical phase conjugator.

Table 1: XPM reduction for 16 channel WDM system for OOK Modulation

Number of Channels (N)	Channel Spacing (nm)	Q factor (dB)	Eye Opening (a.u)
16	0.2	25.3	0.0011
	0.4	38.5	0.001
	0.8	32.9	0.1081
	1	30.07	0.1089

Table 1 shows XPM reduction for 16 channel WDM system for 0.2nm, 0.4nm, 0.8nm and for 1 nm Spacing's. The Q factor for 0.2nm is 25.3 dB, 38.5dB for 0.4nm, 32.9dB for 0.8nm and 30.07dB for 1 nm spacing.

Table 2:

XPM reduction for DWDM system for various Spacings

Number of Channels (N)	Channel Spacing (nm)	Q factor (dB)	Eye Opening (a.u)
32	0.2	37.156	0.00217
	0.4	37.7	0.00218
	0.8	37.38	0.00217
	1	37.15	0.00219

Table 2 shows XPM reduction for32 channel WDM system for 0.2 nm, 0.4 nm, 0.8 nm and for 1 nm Spacing's. The Q factor for 0.2 nm is 37.156 dB, 37.7dB for 0.4 nm, 37.38dB for 0.8 nm and 37.15dB for 1 nm spacing.

V. CONCLUSION

In long-haul DWDM systems, a noisy perturbation due to XPM will accumulate together with noise and other impairments limiting capacity and distance. Optical Phase Conjugation is one of the methods to reduce impairments due to cross phase modulation. The compensation method permits restoration of signal whatever phase aberrations present on optical path of laser beam. This method is simple and analysis showed that XPM effects are more serious for small channel spacing's. It is seen that for 32 channel 32 x 10 Gb/s, 64 channel 64 x 10 Gb/s, 128 channel 128 x 10 Gb/s, XPM compensation is achieved and the Q factor obtained is 36.15 dB, 32.58 dB and 19.39 dB respectively for intensity modulation . Similarly, the experiments could be analyzed for DQPSK with various channel spacings, different input power levels and more number of channels.

References

i. *Mark D. Pelusi ,"WDM Signal All-Optical Pre compensation of Kerr Nonlinearity in Dispersion- Managed Fibers", IEEE Photonics Technology Letters, Vol. 25, No. 1, January 1, 2013.*

ii. *Rongqing Hui,Kenneth R. Demarest and Christopher **T.** Allen," Cross-Phase Modulation in Multispan WDM Optical Fiber Systems" , Journal of Lightwave Technology ,Vol. 17, No. 6, June 1999.*

iii. *Rajiv Ramaswami, Kumar N. Sivarajan, "Optical Networks: A Practical Perspective"Academic Press, 2002.*

iv. *Aakash Kashyap ,Naresh Kumar,Pooja Kaushik, "XPM-induced Crosstalk in SCM-WDM Passive Optical Networks", International Journal of Computer Applications (0975 – 8887) Volume 51, No.2, August 2012.*

v. *S. L. Jansen, D. van den Borne, P. M. Krummrich, S. Spalter, G.D. Khoe and H. de Waardt," Long-Haul DWDM Transmission Systems Employing Optical Phase Conjugation", IEEE Journal Of Selected Topics In Quantum Electronics, Vol. 12, No. 4, July/August 2006.*

vi. *Manuel Schuppert, Christian Weber, Christian-Alexander Bunge and Klaus Petermann," Origins of Cross-Phase Modulation Impairments in Optical Transmission Systems without In-Line Dispersion Compensation", Journal of Lightwave Technology, Vol. 28, No. 15, August 1, 2010.*

vii. *A.Chalorkunwat, P.Kaewplung, "Nonlinear noise enhancement in 40-Gbps DQPSK optical fiber transmission",10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 15-17 May 2013*

viii. *P.J.Winzer,R.Essiambre, "Advanced Optical Modulation Formats", Proceedings of the IEEE Volume 94, Issue 5, May 2006.*

ix. *Jochen Leibrich, Christoph Wree and Werner Rosenkranz," CF-RZ-DPSK for Suppression of XPM on Dispersion-Managed Long-Haul Optical WDM Transmission on Standard Single-Mode Fiber", IEEE Photonics Technology Letters, Vol. 14, No. 2, February 2002.*

x. *G. L. Woods, P. Papaparaskeva, M. Shtaif, I. Brener and D. A. Pitt," Reduction of Cross-Phase Modulation-Induced Impairments in Long-Haul WDM Telecommunication Systems via Spectral Inversion", IEEE Photonics Technology Letters, Vol. 16, No. 2, February 2004.*

xi. *Mark Shtaif, Michael Eiselt and Lara D. Garrett," Cross-Phase Modulation Distortion Measurements in Multispan WDM Systems", IEEE Photonics Technology Letters, Vol. 12, No. 1, January 2000.*