International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 3, Issue 2, pp: (618-625), Month: April - June 2015, Available at: www.researchpublish.com

Impact of Fiber Non-Linearities in Performance of Optical Communication

Narender Kumar Sihval[1], Vivek Kumar Malik[2]

M. Tech Students in ECE Department, DCRUST-Murthal, Sonipat, India

Abstract: **Non-linearity effects arise as optical data rates, transmission lengths, number of wavelengths, and optical power levels are increased. The only worries that plagued optical fiber in the early day were fiber attenuation and, sometimes, fiber dispersion; however, these issues are easily dealt with using a variety of dispersion avoidance and cancellation techniques. Fiber non-linearities present a new realm of obstacle that must be overcome. These non-linearities previously appeared in specialized applications such as undersea installations. System designers must be aware of these limitations and the steps that can be taken to minimize the detrimental effects of fiber nonlinearities. One of the most important changes in fiber-optic communication systems brought about by EDFA (Erbium-doped fiber amplifiers) is the expansion of regenerator spacing up to transoceanic distances. However, a new problem has arisen, e.g., the accumulation of fiber non-linearities along the links with the increase in optical power levels. In optical communication systems, the input signal to the fiber is usually a composite optical signal modulated with information bit streams. When all the input signal frequencies interact due to fiber non-linearities, the output bit stream may behave in a complicated way giving adverse effects on system performance. Therefore, it is important to understand fiber non-linearities and their effects on optical communication systems. Here, we investigate power effects on simulation of optical communication systems with self phase modulation (SPM) and cross phase modulation(XPM), by using the parametric run feature in OptSim (version 5.4). By varying the dispersion values, SPM grows and depletes the signal, and the measured power actually decreases with the increasing of the transmitted power. The eye diagram highlights the conversion due to the SPM and XPM. Specifically the eye opening decreases with increasing transmitted power.**

***Keywords*:** **SPM, XPM, Kerr effect.**

I. INTRODUCTION

In an optical fiber, light is confined to a small transverse region, so that even moderate optical powers leads to high optical intensities. In addition, light often propagates over considerable distances in a fiber. For these reasons, nonlinear effects due to fiber non-linearities often have substantial effects. This is particularly the case if fibers are used to transmit short pulses, and in fiber amplifiers for short distances. These non-linearity in the optical link causes crosstalk between subscribers on different wavelength [2]. When two or more optical field having different wavelength propagates inside the optical fiber at high data rate, they interact with each other and give rise to non-linearity effect. Such type of interactions can generate new waves under appropriate condition through a variety of Non-linear phenomena such as Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), Self-Phase Modulation (SPM), and Four Wave Mixing (FWM).

II. THE KERR EFFECT

The Kerr effect, also called the quadratic electro-optic effect (QEO effect), is a change in the refractive index of a material in response to an applied electric field. The Kerr effect in which the induced index change is directly proportional to the square of the electric field instead of varying linearly with it. All materials show a Kerr effect, but certain liquids display it more strongly than others. The Kerr effect was discovered in 1875 by john kerr, a Scottish physicist. Two special cases of the Kerr effect are normally considered, these being the Kerr electro-optic effect, and the optical Kerr effect. The simplest and most common non-linear effect in fibers is the optical Kerr effect. Essentially, this means that the phase delay in the fiber gets larger if the optical intensity increases. This can be described via an increase of refractive index in proportion to the intensity:

$$\Delta n = n_2 L \quad (1.1)$$

Here, the non-linear index n_2 is rather small for silica fiber– around $2.7 \cdot 10^{-16}$ cm^2/W for wavelengths around 1.5 µm. In numerical simulations, one usually uses a value according to the center optical frequency, i.e., tentatively higher values for shorter wavelengths. Other glasses, e.g. fluoride glasses or chalcogenide fibers, often have substantially stronger non-linearities. Therefore, the major nonlinear phenomenon affecting the performance of an optical system is SPM (Self Phase Modulation) and XPM (Cross Phase modulation). SPM is a manifestation of the intensity dependence of the refractive index in non- linear optical fiber, a phenomenon that leads to spectral broadening of optical pulse. XPM effect occurs only in multichannel (wavelength multiplexing) systems. Intensity variations in one pulse alter the phase of a signal in another channel via the non linear refractive index of the fiber. This leads to spectral broadening which may cause severe pulse distortion as in SPM.

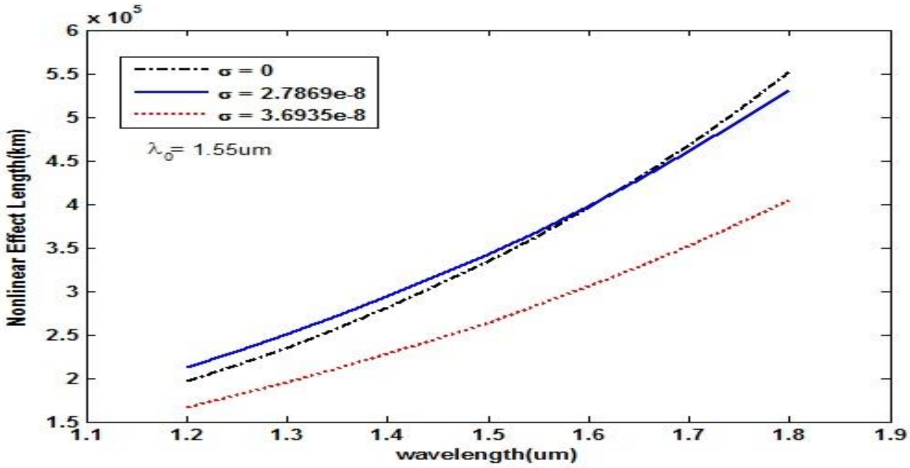

Fig. 1: Relationship of the non-linearity Vs wavelength of fiber

III. OVERVIEW OF SPM & XPM

One of the consequences of the Kerr effect is self phase modulation (SPM). This means that a light wave in the fiber experiences a non-linear phase delay which results from its own intensity. For a fiber mode, the phase change per unit optical power and unit length is described by the proportionality constant

$$\boldsymbol{\gamma}_{SPM} = 2\pi\, n_2/\boldsymbol{\lambda}\, A_{eff} \quad (1.2)$$

where A_{eff} is the effective mode area. Interestingly, for a nearly Gaussian mode shape with beam radius this value is only half the value for a Gaussian radiation in a homogeneous medium, where only the on-axis value is considered. In the fiber, we have lower phase changes away from the fiber axis, and the overall non-linear phase delay is only half the peak value. (Note that the wavefronts of a mode in the fiber are kept approximately plane despite SPM) the mode is "kept together" by the balance of diffraction and waveguiding, and the non-linear phase change is "spread" over the whole beam profile. If an optical pulse is transmitted through a fiber, the Kerr effect causes a time-dependent phase shift according to the time-dependent pulse intensity. In this way, an initial unchirped optical pulse acquires a so-called chirp, i.e., a temporally varying instantaneous frequency. As SPM refers to the phenomenon that occurs when a phase modulation occurs across a pulse due to its own intensity variations thus broadening the optical spectrum of the pulse. XPM is also similar to SPM as it is also due to the non-linear behavior of the refractive index on the optical intensity and it led to broadening of optical spectrum. However, in this case the total induced non-linear phase shift on a given channel is due to the combined intensities or power variations of all transmitted channels, since the index of refraction of the fiber depends on the total optical power of all channels, which can result in cross talk among WDM channels. XPM is a non-linear optical effect where one wavelength of light can affect the phase of another wavelength of light through the optical Kerr effect.

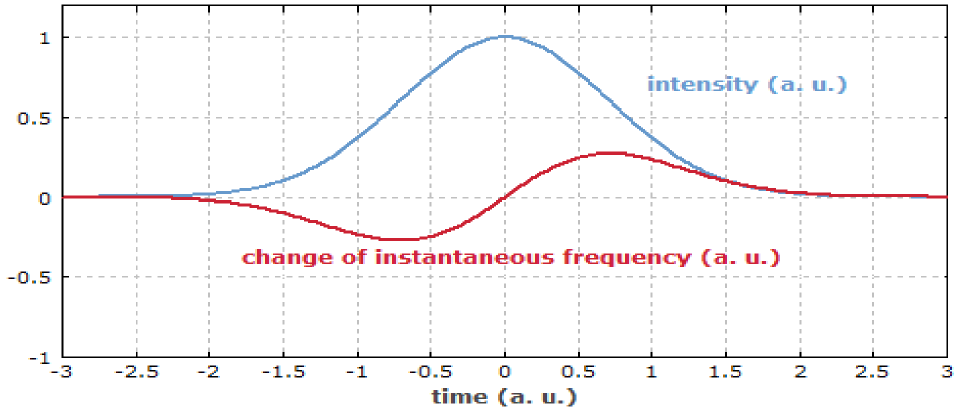

Fig. 2: Illustrates change in frequency due to SPM

In XPM, two pulses travel down the fiber, each changing the refractive index as the optical power varies. If these two pulses happen to overlap, they will introduce distortion into the other pulses through XPM Cross-phase modulation can be used as a technique for adding information to a light stream by modifying the phase of a coherent optical beam with another beam through interactions in an appropriate non-linear medium.

IV. SIMULATION SET UP (OPTSIM 5.4)

Self-phase modulation is a nonlinear optical effect of optical light phenomenon. When ultra short pulse travelling in a medium, will induce a varying refractive index of the medium due to the optical Kerr effect. This variation in refractive index will induce a phase shift in the optical pulse, leading to a change of the pulse's frequency components. Self-phase modulation is an important effect in optical systems that use short, intense pulses of light, such as lasers and optical fiber communications systems. The simulation setup shown in figure 3 for the analysis of SPM optical link having single channel where SPM is analysed for different values of dispersion from -5ps/nm/km to 10ps/nm/km. The setup is shown as transmitter and receiver sections which are connected by the dispersive fiber link. The transmitter section consists of data source, modulator driver, laser source and modulator. Data source produces a (PN) pseudo-random sequence of bits at a rate of 10Gbps. The output of data source is given to optical modulator driver which produces a NRZ (Non return to zero) format pulse train. The transmitted signal is formed by modulating the light carrier by the NRZ data source, confinement factor is 0.35, insertion loss is 3 dB and output insertion loss is 3 dB with fiber length is 10 km. The light carrier wave is generated by Lorentzian laser source at the 1550 nm wavelength. The transmitter output is boosted up by the fixed gain Erbium Doped Fiber Amplifier (fixed_output_power).

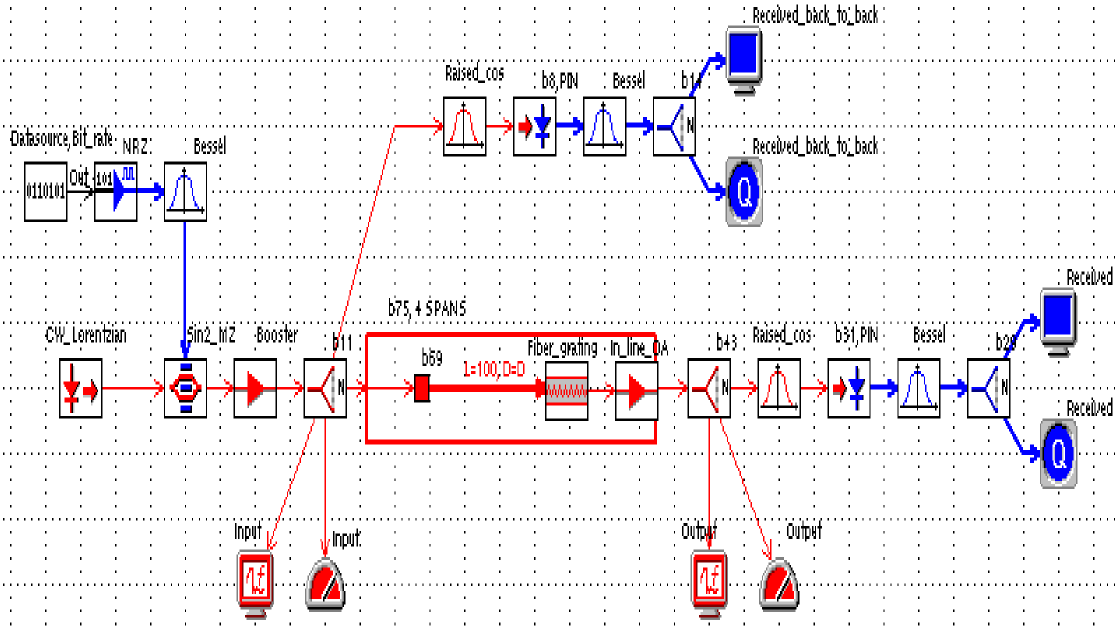

Fig. 3: Simulation set up for SPM

The output of the receiver section is feed to the different measurement devices electrical splitter, the electrical scope and the Q estimator. The optical spectrum of the modulated signal is observed from optical spectrum analyzer (input and output) by splitting the signal from fiber link with the use of optical splitters. Firstly the Q-factor is analysed using simple single mode fiber with zero dispersion and then it will compare with Q-factor obtained after using different values of dispersion effects.

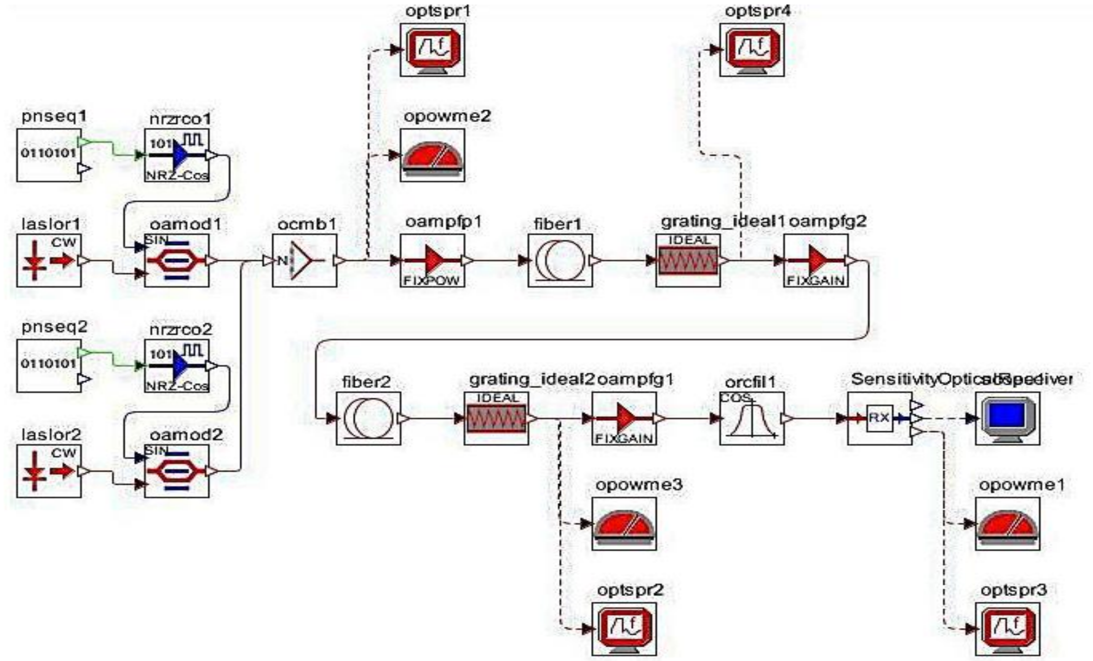

Fig. 4: Simulation set up for XPM

As shown in the figure 4 the simulaton setup for the analysis of Cross phase Modulation in optical fiber link. The cross phase modulation effect is analyzed for the different value of dispersion from -5ps/nm/km to 10ps/nm/km. Also it consists both transmitter and receiver section in which transmitter section consists of source of data, optical modulator driver, laser source and modulator. Data source produces a bit of pseudo random sequence of bits at the rate of 10Gbps. The output of the data source was given to modulator driver which produces NRZ format pulse train. The transmitted signal was formed by modulating the light carrier by NRZ data source. The light carrier is generated by lorentzian laser source. Transmitter output boost up by the fixed gain erbium doped fiber amplifier (EDFA). The channel section consists of single mode fiber (SMF) and fibers brags grating (FBG) with different dispersion values.

V. RESULTS

SIMULATION RESULTS FOR SPM:

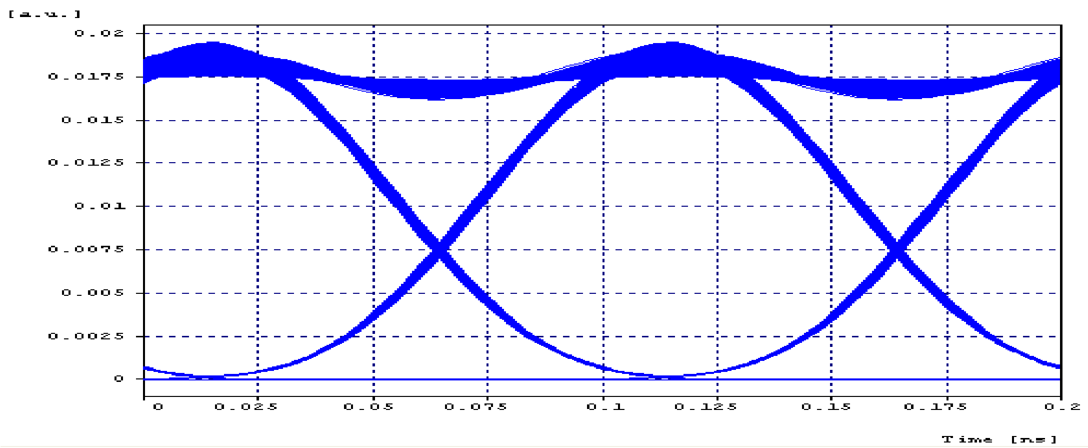

Fig. 5(a): Eye diagram for 0ps/nm/km dispersion

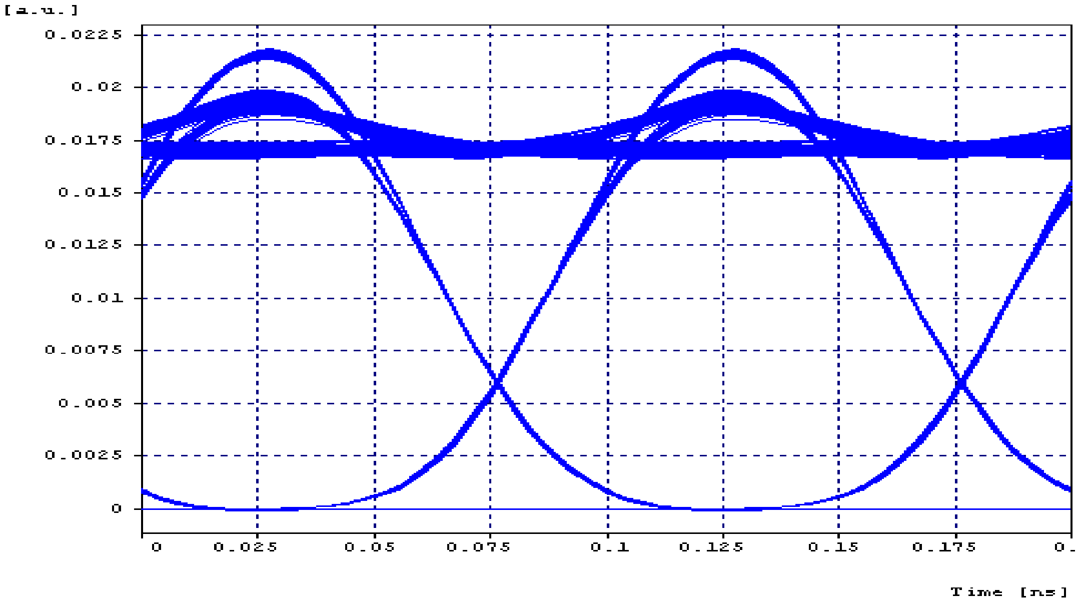

Fig. 5(b): Eye diagram for -5ps/nm/km dispersion

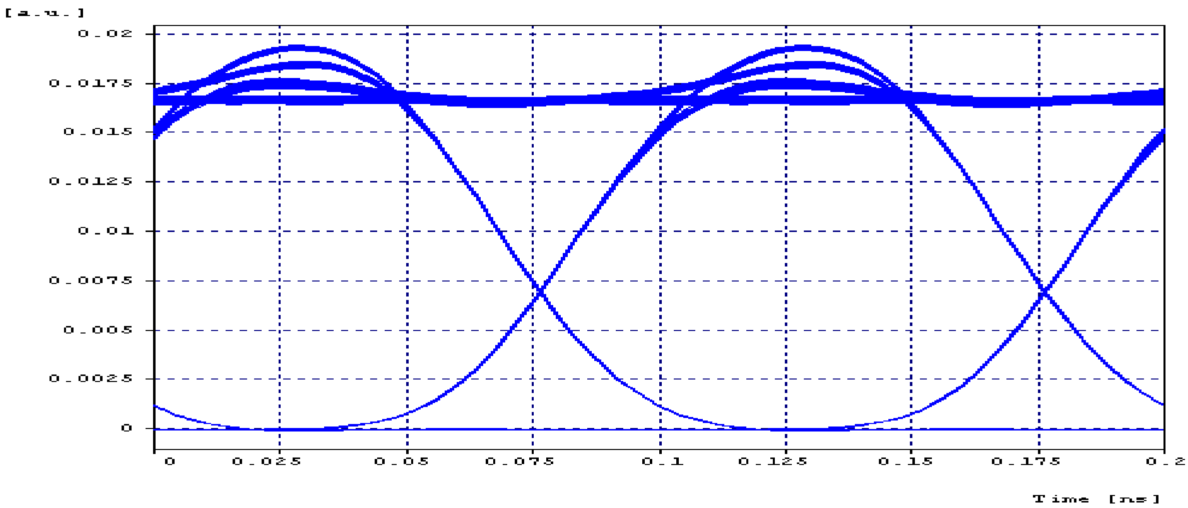

Fig. 5(c): Eye diagram for -1ps/nm/km dispersion

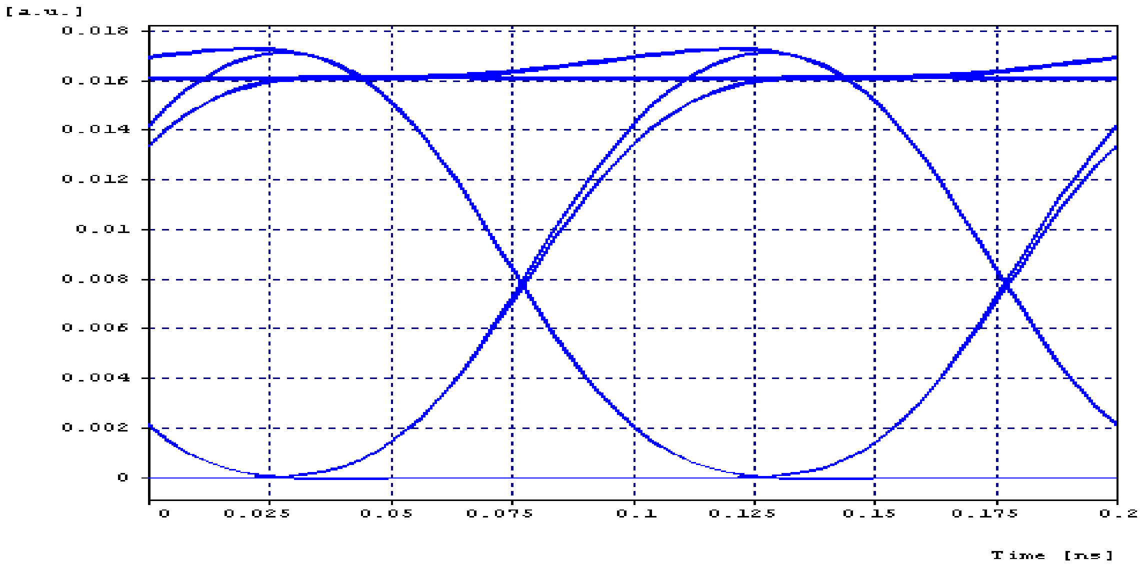

Fig. 5(d): Eye diagram for 2ps/nm/km dispersion

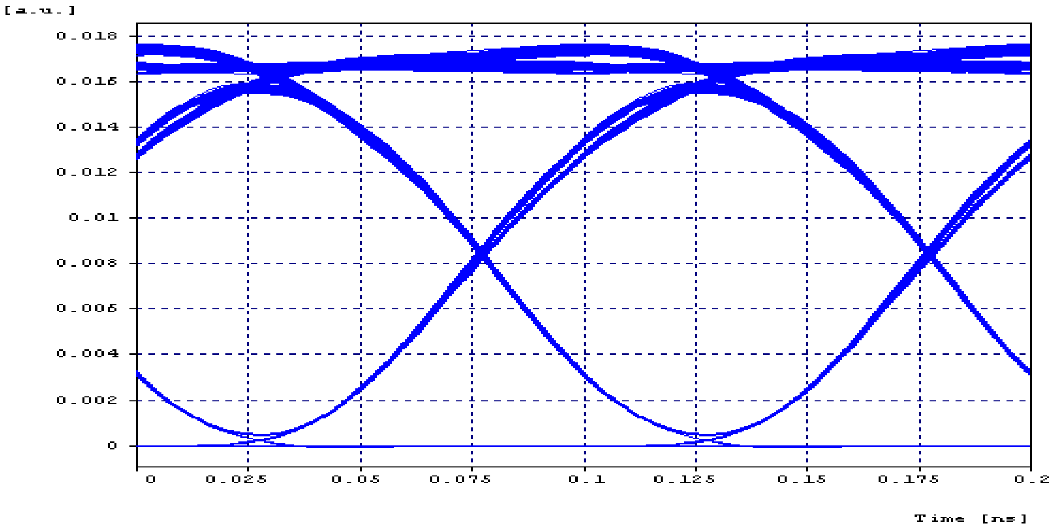

Fig. 5(e): Eye diagram for 5ps/nm/km dispersion

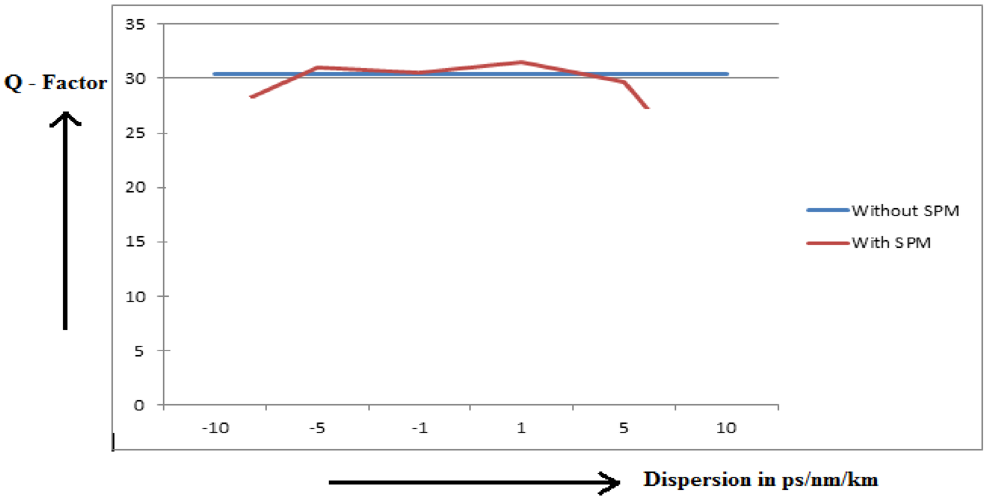

Fig. 5(f): QF Vs Dispersion trend

SIMULATION RESULTS FOR XPM:

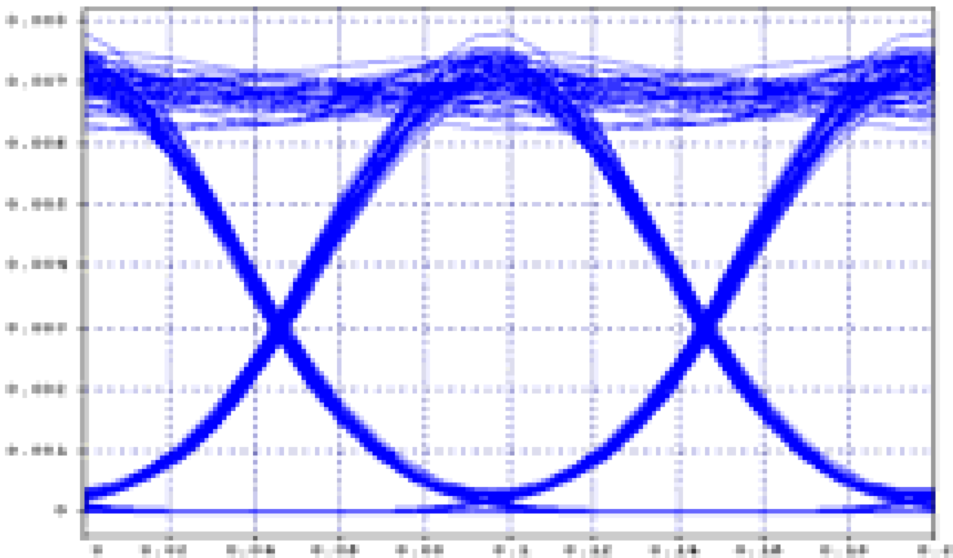

Fig. 6(a) Eye diagram for 0ps/nm/km dispersion

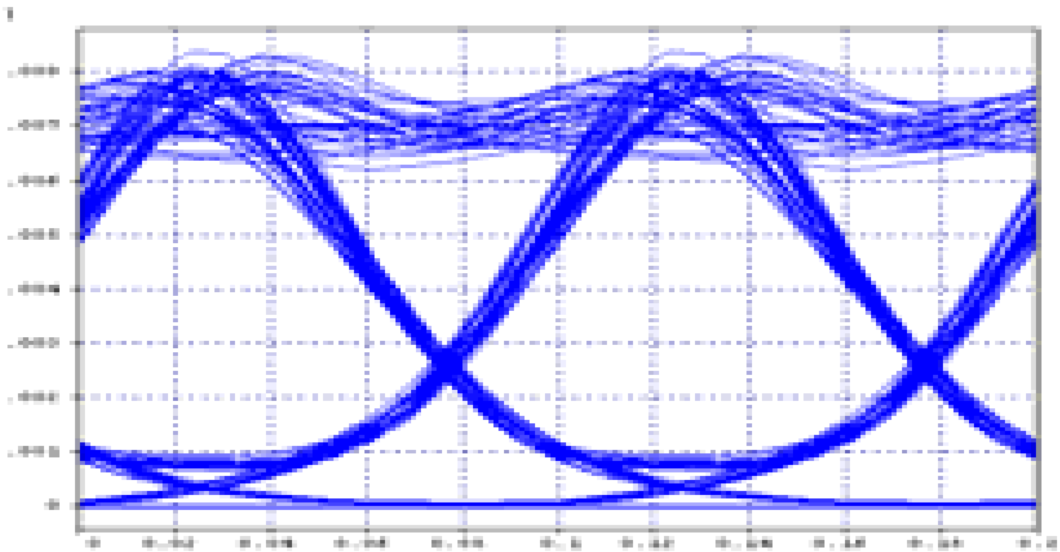

Fig. 6(b) Eye diagram for 3ps/nm/km dispersion

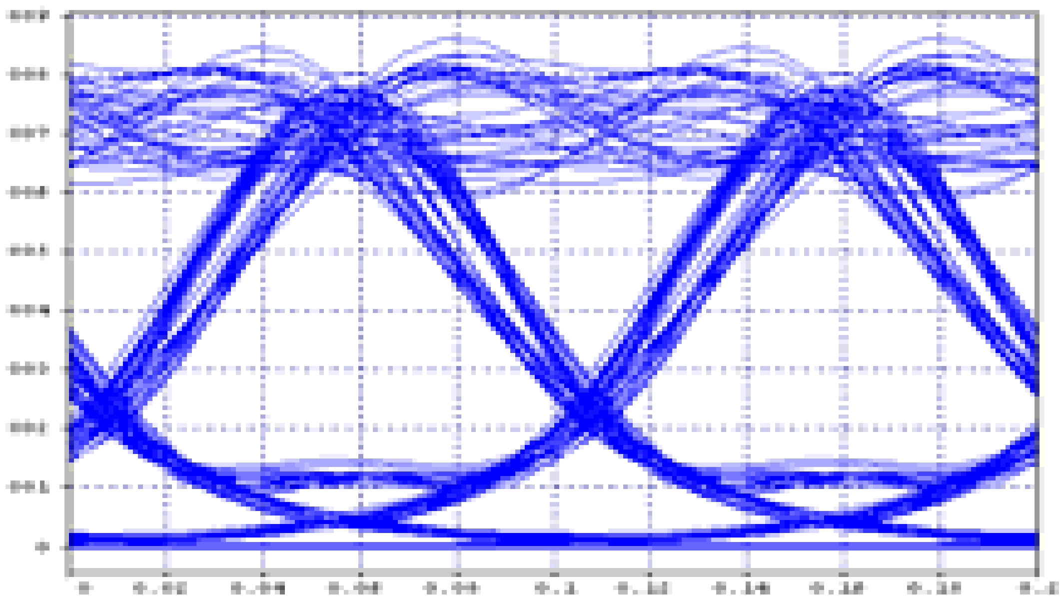

Fig. 6(c): Eye diagram for 5ps/nm/km dispersion

VI. CONCLUSION

The behaviour of SPM versus the optical power for two spans amplified system has been investigated. A 10 Gb/s NRZ signal is launched over two DS fiber spans (D=0.4 ps/nm/km) of 50 km, each. The power at the input to each span is varied from 10 to 17.5 dbm by using the parametric run feature in OptSim. EDFA noise has been turned off in order to simplify the analysis of SPM. By increasing the power, SPM grows and depletes the signal, and the measured power actually decreases with the increase of the transmitted power. Specifically the eye opening decreases with increasing transmitted power. Cross-phase modulation (XPM) is a nonlinear optical effect where one wavelength of light can affect the phase of another wavelength of light through the optical Kerr effect.The behavior of XPM for two spans amplified system has been investigated. Two WDM channels are launched over two DS fiber spans of 100 km, each.The dispersion parameter to each span is varied from 0 to 6 ps/nm/km, by using the parametric run feature in OptSim. In order to focus on XPM, lower power probe channel is sent along the link together with the stronger power, pump channel. Both the probe and pump channels are modulated by digital NRZ signal at 10Gb/s. EDFA noise has been turned off in order to simplify the analysis. Impact of cross phase modulation(CPM) by varying the dispersion parameter can be seen by the results.

ACKNOWLEDGEMENTS

We are deeply indebted to **Dr Amit Kumar Garg**, Chairman and Professor, Department of Electronics and Communication Engineering, Deenbandhu Chhoturam University of Science and Technology,Murthal, Sonipat (Haryana) for his sincere and honest advise in carrying out this paper. We are also thankful for his moral support and encouragement. We would also like to express our sincere thanks to our esteemed and worthy supervisor, Sh. Rajesh Kumar, senior lab incharge for his valuable guidance in carrying out simulation work for this paper.

REFERENCES

[1] Mukherjee B. WDM-based local lightwave networks part-1: Single-hop systems. IEEE Network. 7(5) :12. 1992.

[2] Kikuchi K., and Lorattanasane C., “Compensation for Pulse Waveform Distortion in Ultra-long Distance Optical Communication Systems by Using Nonlinear Optical Phase within a 150Conjugation," in Proc OAA, 1993.

[3] Tang J. et al., “The Multispan Effects of Kerr Nonlinearity and Amplifier Noises on Shannon Channel Capacity of a Dispersion Free Nonlinear Optical Fiber,”Journal of Lightwave Technology, vol. 19, No.8 pp. 1110-1115, August 2001.

[4] R.H. Stolen and C. Lin, Self phase modulation in silica optical fibers, Phs. Rev. A, Vol. 17, pp. 1448-1453, 1978.

[5] Pinault S.C. and Potasek M.J., “Frequency broadening by self-phase modulation in optical fibers,” Journal of optical Society of America, B,vol. 2, no. 8, pp.1318-1319.2000.

[6] A. W. Snyder, ‘Understanding monomode optical fibers’ proc. IEEE,69(1), pp. 6-13, 1981.

[7] Agrawal, G. P. Nonlinear Fiber Optics. San Diego: Academic Press, 452 p, April 2001.