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Cross Phase Modulation: Good or Threat to Optical Fiber Communication System

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Abstract— Cross Phase Modulation is often regarded as being threat for optical communication systems. This Paper shows the effect of Cross Phase Modulation, a type of non-linearity found in optical fibers. We will compare the impact of Q-factor, BER and Timing Jitter due to Cross Phase Modulation (XPM) for the fiber. We will also focus on its useful application related to optical switching, pulse compression and pulse retiming.

Keywords— BER (Bit Error Rate), Eye diagram, Dispersion, Jitter, Walk off effect, WDM (Wavelength Division Multiplexing) and XPM (Cross Phase Modulation)

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1 INTRODUCTION

Cross Phase Modulation (XPM) is the phenomenon in which intensity fluctuations in one channel propagating in the fiber modulate the phase of all the other channels or alternately all the WDM channels (at different wave lengths) in the fiber modulate the phase of any one channel. [1], [2].For fiber optic communication systems, fiber nonlinearities have long been regarded as being mostly dangerous[3].However the nonlinear effects in fibers are rapidly being used for practical applications, over the last few years. Cross Phase Modulation (XPM) covers special attention from the major nonlinear effects occurring inside optical fibers [4], also XPM effect comes from SPM. The nonlinear phenomenon of XPM occurs when variation in reflective index will produce a phase shift in the pulse, leading to a change in the pulse frequency spectrum. This feature has been used in recent years for application such as soliton formation, pulse compression and spectral broadening [5].

2 CROSS PHASE MODULATION

In a multichannel system, the excess bandwidth generated by the XPM effect is given by,

$$\Delta B = \frac{d\phi_{NL}}{dt} = \gamma L_{eff}\frac{dp_1}{dt} + 2\gamma L_{eff}\frac{dp_2}{dt}$$

Where P is the optical power and ϕ_{NL} is the phase change due to optical power .The nonlinear parameter γ is related to material parameter n_2 as $\gamma = k_0 n_2 / A_{eff}$, where $k_0 = 2\pi/\lambda$ and A_{eff} is the effective more area for light of wavelength λ launched into the fiber. L_{eff} is the effective nonlinear length of the fiber that accounts for the fiber loss and it is given by $L_{eff} = \frac{1 - e^{-\alpha L}}{\alpha}$,α is the fiber attenuation loss. The XPM induced chirp is twice as much as that of the SPM induced chirp [1], [2].Therefore, it appears that XPM can impose more severe limitation than SPM for WDM System because effect is twice as large for each interfering channel and there can be a lot of interfering channels. Theoretically, for a 100 channels system, XPM imposes a power limit of 0.1mW per channel. However, fiber dispersion plays a significant role in the system impact of XPM [1].In normal dispersion regime (D<0), a longer wavelength travels faster while the opposite occurs in the anomalous dispersion regime (D>0) [6]. This feature leads to a walk off effect that tends to reduce XPM effect.

In a WDM system, XPM converts power fluctuation in a particular wavelength channel to phase fluctuations in other co-propagating channels. This leads to broadening of pulse. It can be greatly mitigated in WDM system operating over standard non-dispersion shifted single mode fiber [7], [8]. One more advantage of this kind of fibers the effective core area which typically $80\mu m^2$.This effective area is helpful in reducing nonlinear effects because K_{nl} is inversely proportional to A_{eff}, K_{nl} is the nonlinear propagation constant.

Because of the non-resonant nature of the fiber non linearity, the XPM and SPM effects can occur at an ultra fast time scale (<10 fs). Propagation of pulses inside optical fiber is governed

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by the following Schrodinger equation [4]:

$$i\frac{\partial A}{\partial z}+\frac{i\alpha}{2}A-\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2}+\gamma|A|^2A=0 \qquad (1)$$

Where, A is the amplitude of the pulse envelope and the parameters α, β_2 and γ govern the effects of fiber losses, dispersion and XPM, respectively.

Numerical solution of equation (1) shows that dispersion induced broadening of optical pulses is considerably reduced in the case of anomalous dispersion [9]. In fact, an optical pulse can propagate without distortion if the peak power of the pulse is chosen to correspond to a fundamental soliton.

3 SIMULATION FOR XPM

To compare the relative significance of the intensity and timing jitter distortions caused by XPM, we simulated the transmission of 10-Gb/s NRZ channels over 100 km of nonzero dispersion-shifted fiber with wavelength of 0.8 nm. The transmission of the probe channel alone did not exhibit significant Eye-distortions. Figure 1depicts the received eye-diagrams with one interfering channel, where the clock of the interfering channel is delayed relative to the probe by 100km of fiber. The horizontal eye closure due to timing jitter is obvious in the simulated eye-diagrams. The amount of closure is approximately 23ps. The BER for 100 km is 0.0024621. From eye diagram in fig 1 the calculated Q-factor is 2.728 db for 100 km. Here we have seen that the Q-factor is not better for 100 km fiber that's why the signal can be transmitted better for small length of fiber. Fig 2 shows the comparison of optical spectrum at input and output for 100km of fiber. This is the ideal response and Lorentz response separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

4 FIGURES AND RESULTS

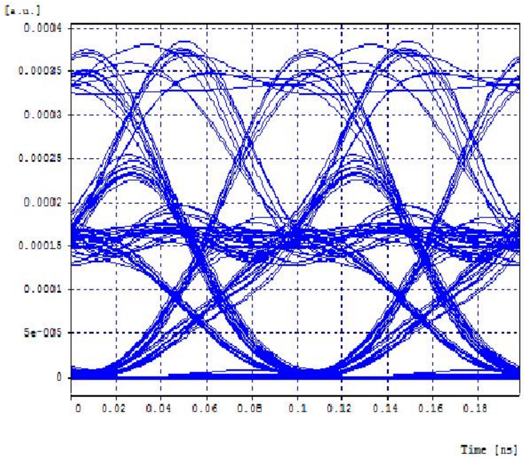
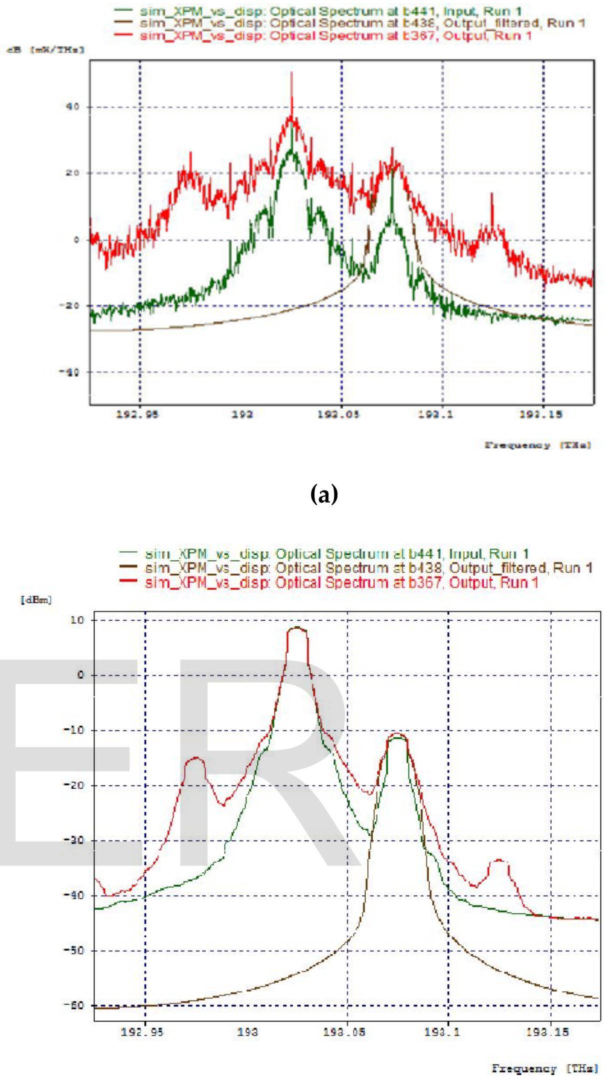


Fig 1 Noise-averaged experimental probe signals: Single-channel eye diagram transmission over 100km NDFS



(a)

(b)

Fig 2 Comparison of optical spectrum at input and output for 100km of fiber (a) For ideal response (b) For Lorentz response

5 APPLICATION OF XPM

5.1. Optical Switching

Phase shift, in an optical pulse, due to XPM phenomenon can be used for optical switching. To take advantage of XPM-induced phase shift for ultra-fast optical switching many interferometer methods have been used [1]. Consider an interferometer designed in such a way that a weak signal pulse, divided equally between its two arms, experiences identical phase shifts in each arm and is transmitted through constructive interference. When a pump pulse at different wavelength is injected into one of the arms, it will change the signal phase through XPM phenomenon in that arm. If the XPM-induced phase shift is large (close to π), this much phase shift results in destructive interference and hence no transmission of signal pulse. Thus an intense pump pulse can switch the signal pulse.

5.2. Pulse Compression

The XPM induced frequency chirp can also be used for pulse compression. The SPM techniques require the input pulse to be intense and energetic, but the XPM is able to compress even weak input pulses because co-propagating intense pump pulse produces the frequency chirp. The XPM induced chirp is affected by pulse walk-off and depends critically on the initial relative pump-signal delay. As a result the use of XPM induced pulse compression requires a careful control of the pump pulse parameters such as its width, peak power, wavelength and initial delay relative to the signal pulse.

5.3. Pulse Retiming

In an anomalous-dispersion polarization-maintained fiber ultra-fast optical pulses can be retimed by utilizing cross-phase modulation phenomenon. With help of this phenomenon spectral, temporal and spatial properties of ultra-short pulses can be controlled [10],[11].

6 DISCUSSION

The phenomenon of Cross Phase Modulation in optical fiber is reported in this paper. We have shown by simulation in the case of NRZ transmission, the Q-factor, Jitter, BER, and eye opening for different length of fiber. The contribution to the system performance penalty of the BER is much larger than that of the XPM induced timing jitter. Finally, we have shown that a better estimate of the system penalties due to XPM can be found from measurements of BER of CW probe that is co-propagating with the interfering channels.

7 CONCLUSION

We can reduce the Cross Phase Modulation up to some extend but we are still not able to completely remove the Cross Phase Modulation from the optical fiber specially at higher bit rates which is a topic of research and a challenge for the researchers in the optical fiber field.

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