

# Analysis Of Cross Phase Modulation In Hybrid Coherent WDM System

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**Abstract**—*In this paper we show the brief introduction about WDM system. Different types of nonlinearities found in optical fiber are taken into consideration among which Cross Phase Modulation is focused. Here we will analyse the Q-factor and BER at different values of optical dispersion. Effect of cross phase modulation on the optical fiber is presented by the graphs for the different values of Q-factor and BER. The XPM phase noise was generated by a linear system which was determined by the DWDM system parameters and whose inputs were undistorted pump channel intensity waveforms. Also we will see the effect of XPM in DQPSK modulation format. The modelling is done using a commercial optical system simulator named OptiSystem by Optiwave.*

**Keywords** - Wavelength Division Multiplexing (WDM), Cross Phase Modulation (XPM), Differential Quadrature Phase Shift Keying (DQPSK), On-Off Keying (OOK)

## 1. Introduction

The increasing demand for high-capacity communication links, and the speed limitation of single-wavelength links, has resulted in the increasing use of WDM technology. It is a technology of combining a number of wavelengths onto the same fiber which enables bidirectional communication and multiplication of capacity. The advantage of WDM is the highest rate of transmitted signal all the time. Another added advantage is transfer of information with minimum signal integrity loss [1-3]. Implementation of typical WDM link is shown in fig.1. WDM works well, with speeds eventually reaching to 2.5Gbps. However, when going to the next multiplexing level of 10Gbps, one starts to encounter effects that can seriously degrade WDM network performance [4]. Due to explosive growth of wireless communication, network operators are having tremendous difficulty in accommodating the increasing traffic. Among these effects are – fiber chromatic dispersion, which limits the bit rate by temporally spreading a transmitted optical pulse [5-6]; – nonlinear processes in a fiber that arise from modulation of the refractive index of silica by intensity changes Fig. 1. WDM System in the signal, thereby producing effects such as four wave mixing (FWM), self-phase modulation (SPM), and crossphase modulation (XPM) [7]; – polarization mode dispersion, which arises from orthogonal polarization modes traveling at slightly different speeds owing to fiber birefringence; – Reflections from splices and connectors that can cause instabilities in laser sources. WDM system suffers greatly from nonlinear effect in optical fiber. It causes crosstalk between subscriber on different wavelength. This

phenomenon is discussed in detail in next Section and forms the major consideration of this paper.

## 2. Non –Linear Effect

The terms linear and nonlinear in optics, means intensity independent and intensity-dependent phenomena respectively. In fiber optic communication systems linear impairments are caused by fiber loss, Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). Optical power loss due to light propagation inside the fiber results from absorption and scattering and can be easily compensated by optical amplifiers [8-9]. Effects of fiber nonlinearity are significantly more difficult to suppress. When two or more optical fields having different wavelengths propagate inside the optical fiber at high data rate, they interact with each other and give rise to phenomenon called non-linearity. Such 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). Fiber nonlinearities represent the fundamental limiting mechanisms to the amount of data that can be transmitted on a single optic fiber. Nonlinearity effects arise as optical fiber data rates, transmission length, number of wavelengths, and optical power levels increase. In high-speed WDM systems, the interaction of fiber nonlinearity and dispersion leads to many degrading effects, causing cross-channel interference, distortion, and attenuation of the signal carried by the fiber.

Major degrading effects due to fiber nonlinearity can be classified due to inelastic scattering phenomenon Stimulated Raman Scattering(SBS) and Stimulated Brillouin Scattering(SBS) or due to intensity dependence of refractive index of medium(A phenomenon called as Kerr-effect) [10] Self Phase Modulation(SPM), Cross Phase Modulation(XPM), Four Wave Mixing(FWM) .

### 3. Cross Phase Modulation

In future long-span, high-channel-count wavelength division-multiplexed (WDM) systems, (XPM) will be one of the most severe obstacles to error free transmission. As such, it has recently attracted a large amount of attention [11-12]. 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 [13]. Thus because of XPM the variation of intensity of one optical signal can change the refractive index of fiber, and modulate the phase of other optical signals co-propagating in the same fiber. Consequently only angle modulated system will be affected by XPM. Following fig.2 shows the interaction of different signal as they travel down the fiber.

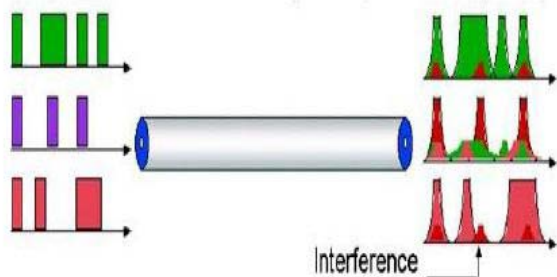


Fig. 2. Cross phase Modulation phenomenon

In WDM systems, XPM converts power fluctuations in a particular wavelength channel to phase fluctuations in other co-propagating channels. The effects of XPM can be illustrated as follows: \_ It leads to an interaction of laser pulses in a medium, which allows e.g. the measurement of the optical intensity of one pulse by monitoring a phase change of the other one. This is basis of a scheme for quantum no demolition (QND)measurements [14]. \_ The effect can also be used for synchronizing two mode locked lasers using the same gain medium, in which the pulses overlap and experience cross-phase modulation. \_ In optical fiber communications, cross-phase modulation in fibers can lead to problems with channel cross-talk[15].

\_ Cross-phase modulation is also sometimes mentioned as a mechanism for channel translation (wavelength conversion). XPM occurs because the effective refractive index seen by an optical beam in a nonlinear medium depends not only on the intensity of that beam but also on the intensity of other co-propagating beams the temporal overlap between the transmitted data patterns is continually changing along the fiber. This effect is commonly referred to as channel walk off. We will consider the interference induced by one interfering channel on another probe channel [16-17] Previous researches have clarified that the XPM is strongly dependent on system parameters such as data rate, fiber local dispersion, DWDM channel spacing and dispersion map. It is necessary to develop a simple method to analyze the XPM so that system designer is able to estimate XPM impact easily.

### 4. System Architecture

We will consider a common approach to study XPM effects where we investigate the phase impairment on a low power continuous wave (CW) probe caused by a strong co-propagating amplitude modulated pump signal . In such system, two or more narrow beams that propagate jointly interact via XPM and undergo mutual focusing, whereas a single beam propagating alone experiences linear diffraction. Such type of system is shown in fig.3

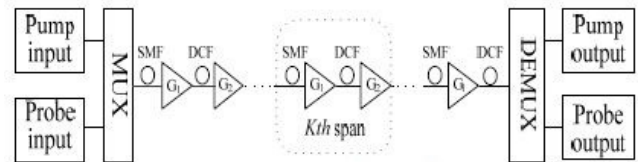


Fig. 3. Pump-probe model

### 5. Discussions

Calculation of XPM in Optical linkFigure 4 shows the simulation setup for the analysis of Cross phase Modulation in optical link. The XPM has been analyzed for the different value of dispersion. Transmitter section consists of data source, 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. The channel section consist of single mode fiber (SMF) and Dispersion compensated fiber (DCF) with different dispersion values. The receiver section consist of PIN receiver [18-19]

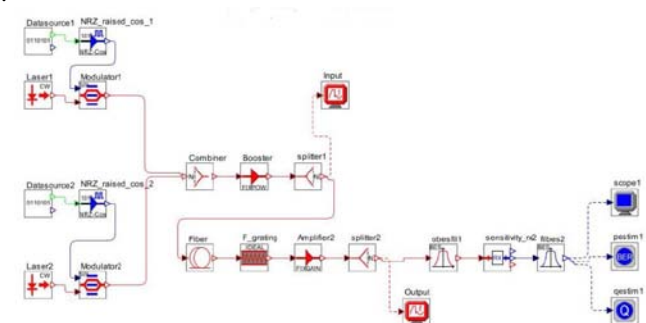


Fig. 4. Simulatuin setup for XPM

Two dispersion shifted fiber of spans 100km each is taken and two WDM channel have been launched over it. Dispersion is completely compensated at each span to better show the XPM phenomenon. Fiber dispersion was varied from 0 to -16 ps/nm/km through parametric runs. Since we had to focus on XPM, two channels are taken probe and pump. Probe had lower power and sent together with the stronger pump channel. Effect of XPM was visible as the enlargement of the received probe spectrum and distortion of the eye diagram.

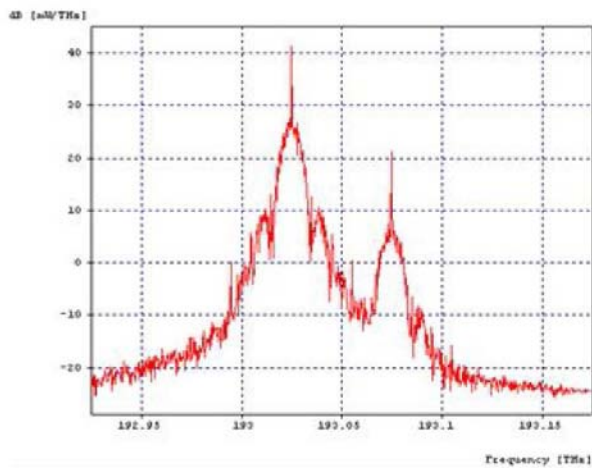


Fig. 5. XPM input pattern

Figure 6 shows the spectrum comparison for transmitter and receiver section in which green spectrum was representing transmitted signal, brown was representing received signal.

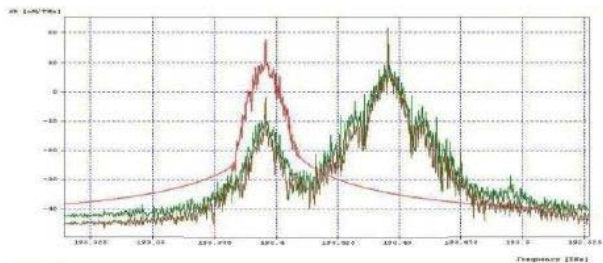


Fig. 6. Spectrum comparison of Transmitter and Receiver Section

Eye diagram at different dispersion value has been shown in figure 7 and 8.

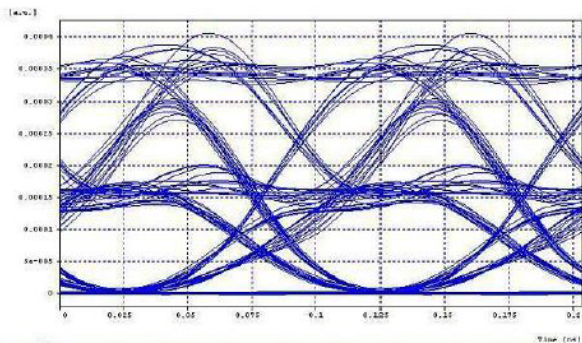


Fig. 7. Eye diagram at 0ps/nm/km Dispersion

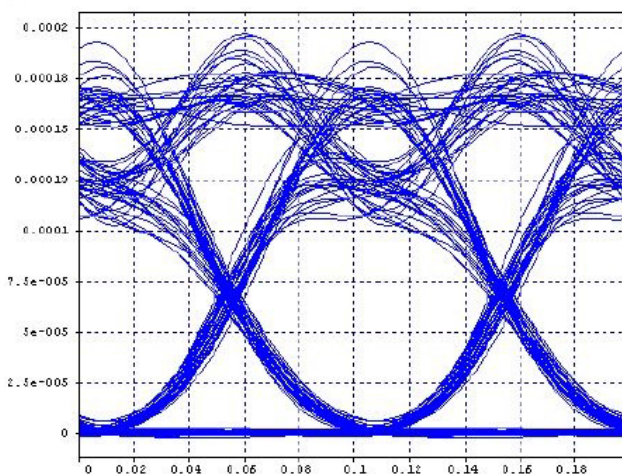


Fig. 8. Eye diagram at 2ps/nm/km Dispersion

It is seen that as the values of dispersion varies nonlinearities in the optical fiber also varies, which gives result to XPM [23]. Thus due to XPM the Q-factor become nonlinear. In fig.9 we have shown a graph comparing Q-factor with dispersion and in fig. we have shown a graph comparing BER with dispersion.

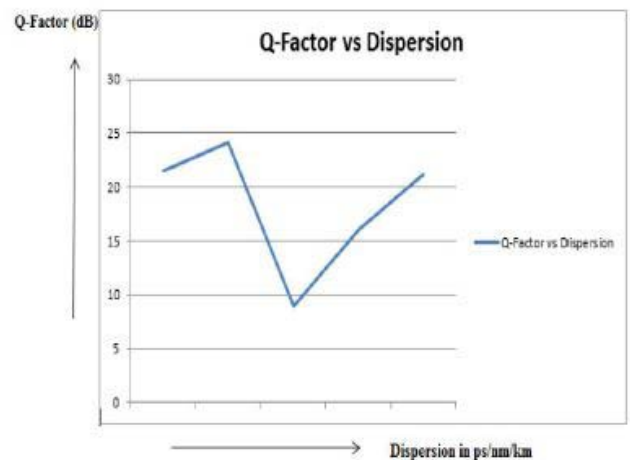


Fig. 9. Graph for Q-factor Vs Dispersion

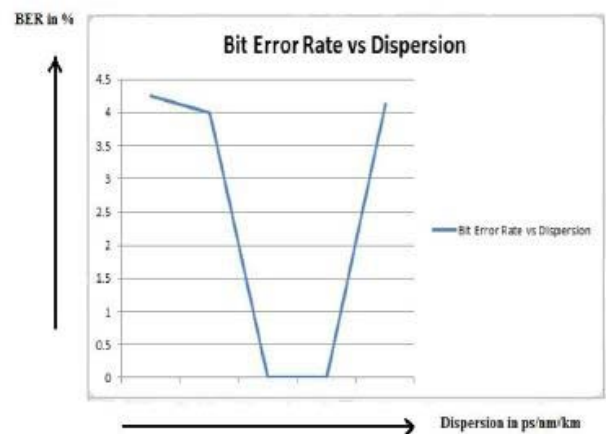


Fig. 10. Graph for BER Vs Dispersion

## 2. Calculation of XPM Phase Noise

The frequency response of XPM was analyzed by the pump and continuous-wave (CW) probe model. Every rising and falling transition in the interfering channel introduces an optical frequency shift to those parts of the probe with which it overlaps temporally while propagating in the fiber. A brief introduction of a simplified XPM model where the distributed XPM was reduced to a lumped phase modulation was reported in [20]. With this model, impact of XPM in a phase shift keying (PSK) and on-off keying (OOK) hybrid optical coherent system and statistical characteristics of XPM phase noise are able to be estimated from system configurations. This function facilitates the system design significantly. The model is shown in fig.11



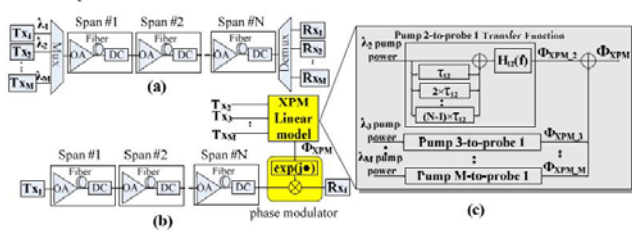


Fig. 11. Simplified model of XPM phase noise

Figure 11(a) shows a schematic diagram of an N-span, M-channel, amplified and inline dispersion compensated DWDM system. Figure 11(b) shows the proposed model corresponding to the system. Without losing the universality, the probe channel is assumed to be channel 1, and all the other channels are assumed as pump channels. In the model, the distributed inter-channel XPM of channel 1 is reduced to a lumped phase modulation at the end of fiber link. Figure 11(c) illustrates how to build the modulating signal  $\Phi_{XPM}$  applied to the phase modulator. In this paper, probe channel is assumed to be QPSK modulated because QPSK is one of the major modulation formats for coherent system. The pump channel is assumed to be OOK modulated, since such hybrid system induces the largest XPM impact. We assume that CW probe is channel 1 and sinusoid ally modulated pump signal is channel 2. The XPM phase noise induced in one transmission span has the spectrum of:

$$H_{12}(f) = -2\gamma \frac{1 - \exp(-\alpha L + j2\pi f d_{12}L)}{\alpha - j2\pi f d_{12}} \quad (1)$$

where  $\gamma$  is the fiber nonlinear coefficient,  $\alpha$  is the fiber loss coefficient,  $L$  is the fiber length of each span,  $d_{12} = D(1-2)$  is the inter-channel walk-off with  $D$  as dispersion coefficient and 1, 2 as the channel wavelengths.  $H_{12}(f)$  described in Eq.(1) represents the transfer function corresponding to the phase noise induced by pump channel 2 in one fiber span.  $d_{12}$  is the accumulated relative group delay between the probe and the pump in one span that is related to the dispersion map and expressed as:

$$\tau_{12} = -[d_{12}L + D_{DCF}L_{DCF}(\lambda_1 - \lambda_2)] \quad (2)$$

where  $D_{DCF}$  and  $L_{DCF}$  are dispersion coefficient and length of dispersion compensation fiber (DCF) in each span. The phase noise associated with one of the pump channels is simple assumed to be the sum of all spans. Eventually, the total XPM induced phase noise  $\Phi_{XPM}$  is the sum of  $\Phi_{XPMi}$  for all the pump channels.

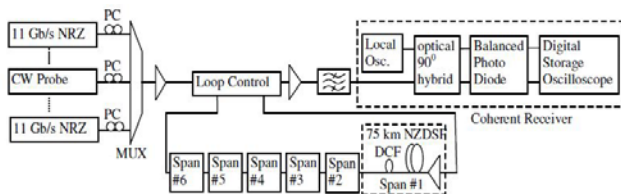


Fig. 12. System setup for hybrid transmission

GHz spacing DWDM transmission system. The CW probe channel lay in the middle, and the pump channels were 11 Gb/s NRZ modulated. The 900 km fiber link consisted of 12 spans. Each span had 75 km non-zero dispersion shifted fiber with a local CD coefficient of 4ps/nm/km. The span launch power was -4dBm/ch. The coherent receiver, including the

carrier phase recovery, was assumed to be ideal. With such ideal coherent receiver, the output of digital storage oscilloscope was the XPM phase noise directly, and the autocorrelation could be calculated accordingly. Fig. 13 shows auto-correlation of the XPM phase noise.

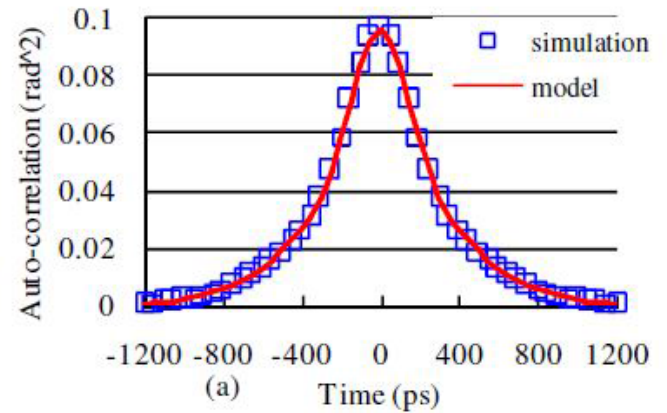


Fig. 13. auto-correlation of the XPM phase noise

### 3. Cross Phase Modulation induced by OOK channel on DQPSK and QPSK Channels:

Optical communication systems have predominantly used some form of on/off keying (OOK) as a modulation format, namely NRZ or RZ modulation. As data rates increase, the inefficiency of these modulation formats from a bandwidth point of view is becoming more apparent. With data rates moving to 40 Gbps and beyond, dispersion in the fiber limits the distance over which the data can be transmitted. Other impairments such as polarization mode dispersion or PMD become significant at 40 Gbps. Thus, inter-city transmission, which requires long-distance transmission of more than several hundred kilometers, has not been possible. Transmission links are rapidly evolving from point-to-point links to inter interconnected optical networks. This requires the flexibility to pass multiple optical add-drop multiplexer (OADM) nodes along the transmission link. Today, most transmission systems have a 50 GHz WDM channel spacing, which implies a 0.8 bit/s/Hz spectral efficiency for 40 Gbps transmission. For binary formats, duobinary and differential phase shift keying (DPSK) are close to the theoretical limit, which makes it difficult to cascade multiple OADM's along transmission link. The narrower optical spectrum of multilevel formats such as QPSK and differential quad phase shift keying (DQPSK) therefore enables both a high spectral efficiency as well as the possibility to cascade multiple OADM's. But the main limitation of QPSK operated in a hybrid scenario, i.e., with two or more different formats mixed on the WDM comb, lies in its limited tolerance to cross phase modulation (XPM) caused by neighboring intensity modulated OOK channels [21-24]. Following fig.14 shows XPM-induced phase variance on the reference DQPSK channel in a 15-span 5-channel hybrid dispersion managed system with either Non-Zero Dispersion Shifted Fiber (NZDSDF) or Single Mode Fiber (SMF). Channel spacing is 50GHz(squares) and 100GHz(circles).

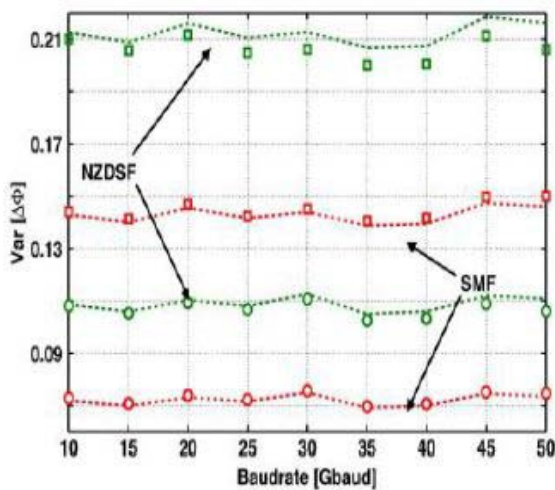


Fig. 14. XPM-induced phase variance on DQPSK channel

## 6. Conclusion

In this paper we see that presence of non linear effects in the optical fiber communication system can adversely affect the communication between two receiving end. XPM causes distortion in WDM system since it leads to inter channel crosstalk. Study shows that XPM not only depends on fiber length but it also depends on channel separation and fiber dispersion. XPM analysis is done using eye pattern with respect to Q-factor and BER. The above discussed result shows that due to XPM the Q-factor become nonlinear. A theoretical model called pump probe model have been provided to explain the detailed mechanism of XPM induced performance degradation by neighbouring OOK channel on QPSK channel.

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