Simulations of SPM, XPM and FWM in Single-Mode Fiber Optic Networks

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1. Abstract

This paper presents a study of non-linear effects occurring in optical fibers, which are detrimental to optical communications using a commercial package based on the Split-Step Fourier Method (SSFM). The transmission rate was 10Gb/s and the system was analyzed in terms of Bit Error Rate (BER), of Q-factor as well the optical spectrum. The Kerr effect was studied in the propagation of modulated signals of NRZ with a modulator of MZI and a laser CW with 1550 nm wavelength in two systems being a with single channel and another 8-channel WDM.

2. Introduction

Without a doubt, fiber optics has revolutionized telecommunications systems, and when it comes to transmission capacity, energy efficiency, low cost and speed is far superior to metal cables. However, when a signal propagates from the transmitter to the receiver, its quality degrades due to obstructions in the physical layer of the network. Also at long distances the SMF is passive of dispersion, resulting in a widening of the pulses among other problems that could compromise the transmissions in systems of Wavelength Division Multiplexing (WDM).

The need to apply higher powers in the bond is a determining factor for the appearance of nonlinearities, giving rise to the interferences, distortions, increase of the dispersion [2]. Therefore it is important to know these phenomena, so that they are no more deleterious to fiber optic communication systems.

This research will use methods of analysis of the signal in a fiber optic link, through the results of the eye diagrams and the optical spectra presented in section 4, in order to verify what non-linear effects are manifested by varying the parameters of the network, such as power and spacing between channels.

3. SPM, XPM and FWM Simulation

The simulated networks in the Optisystem software were developed to study the effects of Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM) and Four-Wave Mixing (FWM). The SPM simulation layout shows an optical communication system with a pseudo-random bit sequence generator, a NZR modulator, a continuous wave laser (CW), a Mach-Zehnder amplitude modulator and an Erbium Doped Fiber Amplifier (EDFA) with 20 dB gain, all connected to two single-mode fiber segments of 50 km in length each. To generate and analyze the eye and optical spectrum diagrams, the BER and Optical Spectrum Analyzer are used. The transmission rate used is 10 Gb/s, the wavelength λ=1550 *nm* and the frequency is 193.1 THz. The receiver consists of photodiode, low pass Bessel filter whose cut off frequency is 0.7*bit rate Hz. The powers for the SPM, XPM and FWM simulations were varied as shown in section 4 A.

A WDM system with 8 transmitters and receivers will be used for XPM and FWM simulations, it has practically the same components as the previous system, the frequency for the first channel is also the same, but for the other channels there is a band of 100 GHz To 200 GHz.

4. Results and Discussions

In this section the results of SPM, XPM and FWM will be presented by the variations of the input power and channel spacing of the WDM syste. The same category graphics are arranged one side on the other for better visualization and comparison of the results.

A. Variation of Input Power in SPM, XPM and FWM

The input power is ranging from -10 to 20 dBm distributed in 10 interactions within 100 km of SMF, with a bit rate of 10 Gb/s. The quality factor and BER were measured as shown in figure 1.

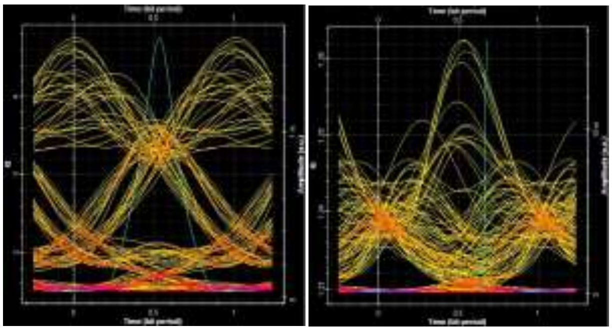

Fig. 1. *Eye diagrams for Self-Phase Modulation for -10 dBm (left) and 10 dBm (right) Input.*

Figure 1 shows that the BER increases from $9.8*10^{-7}$ to 0.07 when the input power increases and the Q-factor decreases from 4.8 to 1.3. The opening of the eye decreases (stressed) with the increase of the input power, that is, the SPM grows and the signal becomes degraded [2].

To analyze the effect of XPM the input power values were compared of 0 dBm and 16 dBm in an 8-channel WDM system, as shown in figure 2.

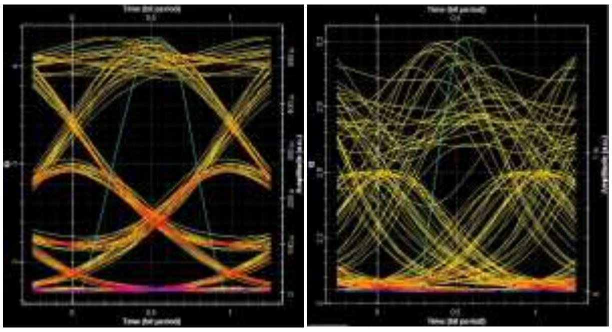

Fig. 2. *Eye diagrams Cross-phase modulation for 0 dBm (left) and 16 dBm (right).*

As a result, figure 2 shows that the BER increases from $53*10^{-6}$ to 0.0005 when the input power increases and the Q-factor decreases from 4.4 to 3.2. Therefore the XPM effect increases, thereby degrading system performance [2].

In Figures 3 and 4 (right) the results show that when the power varies from 0 to 20 dBm at the system output the FWM becomes significant, generating more products.

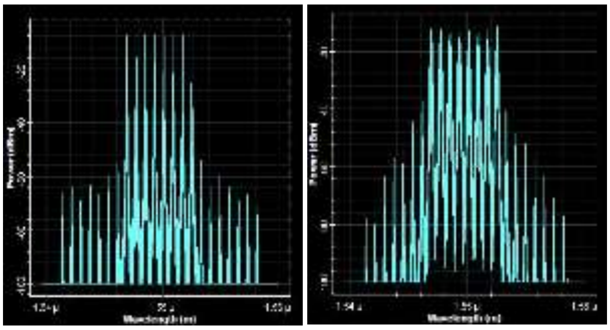

Fig. 3. *Optical Spectrum at Fiber Output When Input Power is 13 dBm (left) and 20 dBm (right).*

This shows that with increasing power the FWM also increases. It is worth noting that for this simulation the fiber parameters as dispersion and effective area remained unchanged at 16 ps/nm/km and 80 μm^2 respectively, because the sidebands due to FWM are reduced when the dispersion and effective area of the fiber are increased [2].

B. FWM Effect on System Input and Output

The figure 4 shows the XPM products at system input and output. After propagating in the fiber the waves generated 224 sidebands with powers ranging from approximately -64 to -87 dBm. These new bands are also called FWM products.

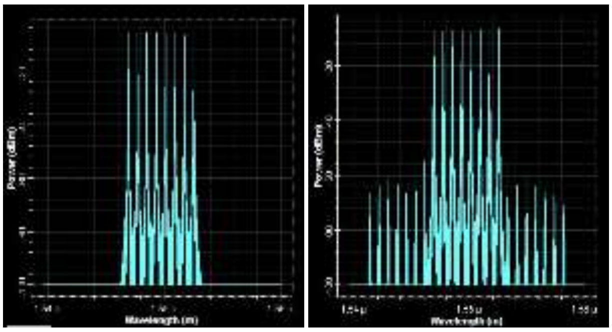

Fig. 4. *FWM circuit input and output optical signal at 0 dBm.*

C. Variation of Channel Spacing in XPM and FWM

In the analysis of the eye diagram, the Q-factor values obtained for spacings between 100 GHz and 200 GHz channels were 4.4 and 5.8 and the BER were $5.3*10^{-6}$ and $3.2*10^{-9}$ respectively, that is, when channel spacing is increased, the XPM decreases. Consequently with the increase in channel spacing there has been a reduction in the power of the sidebands, so the effect of FWM is also reduced.

4. Conclusions

In this paper we analyze the performance of Kerr nonlinearity in fiber optic communication systems through the Q and BER factors in the eye diagram and as well the optical spectrum. The behaviors of SPM, XPM and FWM versus input power and channel spacings were investigated. In general, non-linear effects may cause serious damage to the performance of fiber-optic telecommunication systems, but if used with special regeneration techniques they may no longer be problems. Here the Kerr effect increased with increasing values of the input power and decreased with the increased spacing between channels.

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