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TIMING SHIFT OF OPTICAL PULSES DUE TO INTER-CHANNEL CROSS-TALK

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Abstract—This paper considers the influence of interchannel crosstalk on pulse timing shift and optical power due to the propagation of optical pulse through a nonlinear dispersive fiber. The numerical results are shown. An influencing parameter of the pulse distortion through the fiber is the eye opening penalty.

1. INTRODUCTION

In the modern times in telecommunications systems, the usage of optical fibers is a good transmission medium [1–20]. The optical wavelength-division-system (WDM) consists of a transmitter, transmission medium and a receiver and almost every component in the entire system introduces crosstalk. Optical crosstalk has a great influence on transmission quality and it may occur due to reflections, fiber and amplifier nonlinearities, add-drop components, multiplexers and de-multiplexers in WDM etc. There are numerous reasons for the crosstalk. One reason is the imperfection of the transmitter and a system of mirrors that are reflecting the beam into the optical fiber which leads to the possibility of interference of unwanted pulse at a different frequency that interact with the useful signal. Another reason for crosstalk is induced by leakage or insufficient insulation.

In this paper, the influence of interchannel crosstalk timing shift and optical power on the propagation of the optical solitons through a single mode nonlinear dispersive optical fiber is considered. Both the crosstalk and the useful signal are Gaussian shape but with different wavelengths. The pulse distortion through the fiber for different crosstalk optical powers and crosstalk timing shifts.

2. DETERMINATION OF USEFUL SIGNAL INFLUENCED BY CROSS-TALK SIGNAL

The propagation of short optical pulses in nonlinear dispersive medium is considered. The cross-talk pulses being at different wavelengths than useful signal, so called interchannel cross-talk distort the useful pulses. It is assumed that the cross-talk occur at the transmitter output (fiber input). The useful signal is modeled as

$$s_1(z,T) = A_1(0,T)\cos(\omega_1 T) \tag{1}$$

while the interchannel cross-talk signals is considered to be given by

$$s_2(z,T) = A_2(0,T)\cos(\omega_2 T) \tag{2}$$

where ω_1 is the central frequency of a desired channel and ω_2 represents the central frequency of interchannel cross-talk.

In this paper, the input optical pulse envelope is assumed to be unchirped whose shape is given by

$$A_1(0,T) = \sqrt{P_1} f\left(-\frac{T^2}{2T_0^2}\right) \tag{3}$$

The envelope of the interchannel cross-talk pulse is assumed to be given by

$$A_2(0,T) = \sqrt{P_2} f\left\{-\frac{(T-T_s)^2}{2T_0^2}\right\} \tag{4}$$

where P_1 and P_2 are the peak powers of useful optical pulse and interchannel cross-talk, respectively and T_s is the interchannel cross-talk time shift. Also f represents the pulse shape. It could be Gaussian, super-Gaussian, sech or super-sech as the case may be. It is assumed that $-T_b/2 \leq T_s \leq T_b/2$ as in this paper the interest is confined to one bit period T_b.

The useful optical pulse and the above modeled interchannel cross-talk will co-propagate simultaneously through the optical fiber. This propagation is governed by the set of two coupled nonlinear Schrödinger's equation which, in the dimensionless form, is given by

$$\frac{\partial A_1}{\partial z} + \frac{i}{2}\beta_{21}\frac{\partial^2 A_1}{\partial T^2} = i\gamma_1\left(|A_1|^2 + 2|A_2|^2\right)A_1 \tag{5}$$

$$\frac{\partial A_2}{\partial z} + \frac{i}{2}\beta_{22}\frac{\partial^2 A_2}{\partial T^2} = i\gamma_2\left(|A_2|^2 + 2|A_1|^2\right)A_2 \tag{6}$$

where $\gamma_j = n_2\omega_j/cA_{eff}$ and $\beta_{2j} = -D\lambda_j^2/2\pi c$ for $j = 1, 2$ are the coefficients of dispersion and nonlinear terms respectively and $T = t - z/v_g$ is the normalization factor. Also $A_{eff} = \pi w^2$ is the effective core area. It needs to be noted that A_{eff} is typically $10^{-20}\,\mu\mathrm{m}^2$ in the visible region but it can be in the range of 50–80 $\mu\mathrm{m}^2$ in the 1.55 μm region, so that γ can vary over the range 2–30 $\mathrm{W}^{-1}\mathrm{km}^{-1}$ depending on n_2 and frequency. Also it is assumed that the fiber losses are small and therefore neglected.

The coupled equations in (5) and (6) is a nonlinear partial differential equation. This system is solved by using the split-step Fourier method that is extensively used in solving pulse propagation problem in a nonlinear dispersive medium. In a lot of cases this method shows high accuracy. Although, in general, the dispersion and nonlinearity act together along the fiber, the split-step Fourier method gives an approximate solution by assuming that in the propagation of optical field over a small distance h one can pretend that dispersive and nonlinear effects act independently. Hence, propagation from z to $z + h$ is carried out in two steps. In the first step, nonlinearity acts alone while in the second step dispersion acts alone. Thus the name split-step method. Although the method is relatively straightforward to implement, it should be noted that it requires the step size h along z and time discretization to be selected carefully to maintain the required accuracy.

The interchannel cross-talk level is defined by signal-to-interference ratio (SIR) i.e., the ratio of useful signal optical power to cross-talk to cross-talk signal optical power. It is defined as

$$\mathrm{SIR} = 20\log\frac{P_1}{P_2} \tag{7}$$

3. NUMERICAL SIMULATION OF PULSE EVOLUTION

Pulse evolution pictures and dependences of useful optical pulse distortion from timing shifts (T_s) and SIR are considered in this section.

In the propagation of optical pulses, the following factors are taken into consideration $T_{FWHM} = 12.5\,\text{ps}$, $\lambda_1 = 1550\,\text{nm}$, bit rate $R = 20\,\text{Gb/s}$, $P - 1 = 50\,\text{mW}$ through the SMF in the regime of normal dispersion ($D = 0.2\,\text{ps/nm-km}$) with parameter $A_{eff} = 50\,\mu\text{m}^2$. The interchannel cross-talk wavelength is taken to be $\lambda_2 = 1551.5\,\text{nm}$. The fiber length is taken to be 60 km in all the simulations.

The contour plot is used as a very illustrative way to show variations of power and distortion of pulse during propagation through the nonlinear dispersive SMF. In the worst case SIR = 0 dB, i.e., the useful signal has an equal magnitude to cross-talk signal, is considered.

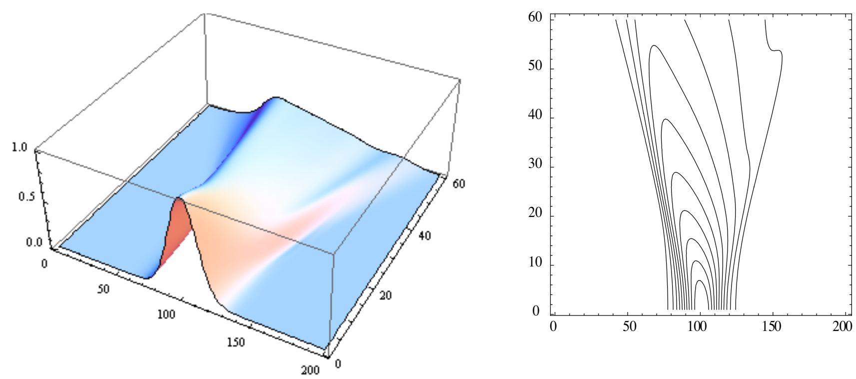

Figure 1. Pulse evolution picture and corresponding contour plot (Gaussian pulse).

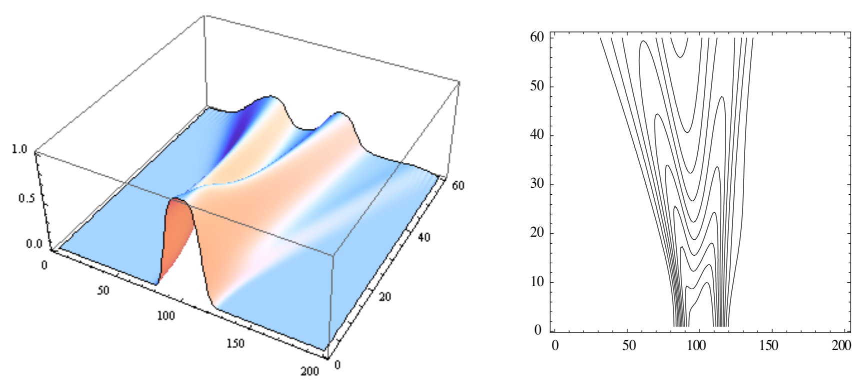

Figure 2. Pulse evolution picture and corresponding contour plot (super-Gaussian pulse).

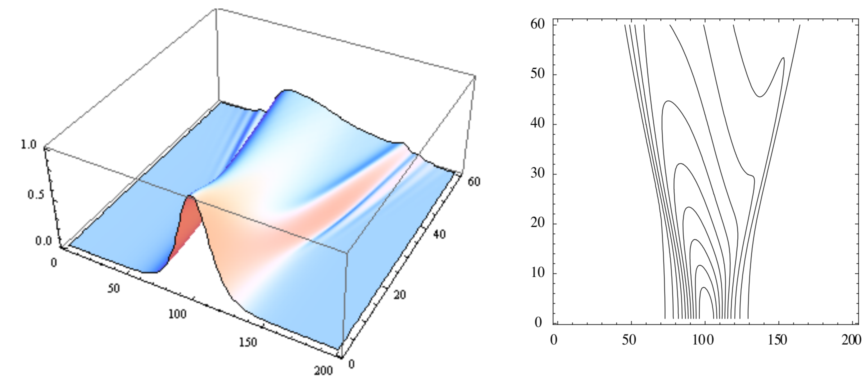

Figure 3. Pulse evolution picture and corresponding contour plot (sech pulse).

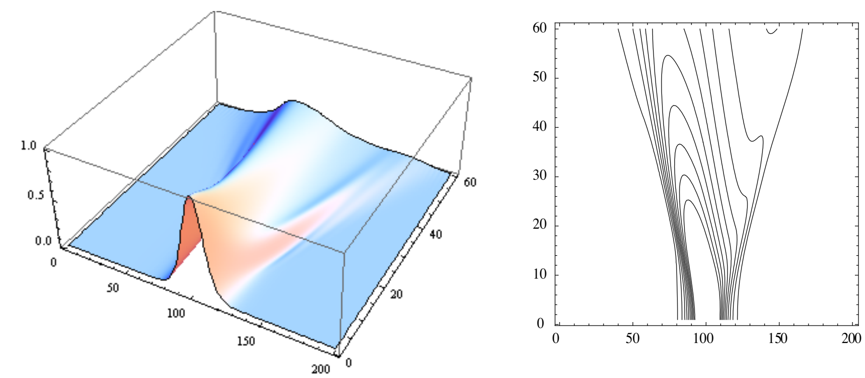

Figure 4. Pulse evolution picture and corresponding contour plot (super-sech pulse).

These figures are respectively due to Gaussian, super-Gaussian, sech and super-sech pulses.

4. EYE OPENING PENALTY

The influence of crosstalk occurring at the input of transmission link is obtained by estimating the eye opening penalty (EOP). The EOP is a performance measure considering the dynamic propagation effects, such as the dispersion, nonlinearities and other such nonlinear influences that distort the pulse shape. The EOP is especially useful for noise-free system evaluations, as it gives an useful measure of deterministic pulse distortion effects. EOP is defined as a ratio of an initial eye opening (EO_{before}) to the eye opening after transmission (EO_{after}). The initial eye opening is the eye opening that is measured at the fiber input.

The analysis of the influence of interchannel crosstalk occurring at the fiber input for a different useful signal optical powers and for the worst case when SIR = 0 dB by estimating the EOP and changing T_s. The influence of interchannel cross-talk by estimating EOP and changing SIR is also analysed in Figures 5–8, for various types of pulses.

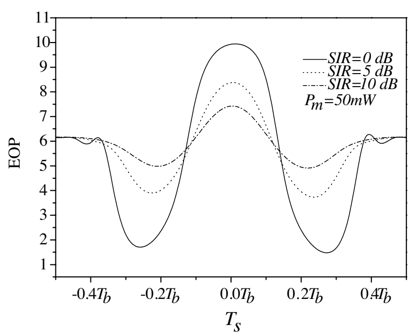

Figure 5. EOP vs T_s for Gaussian optical pulse and different SIR.

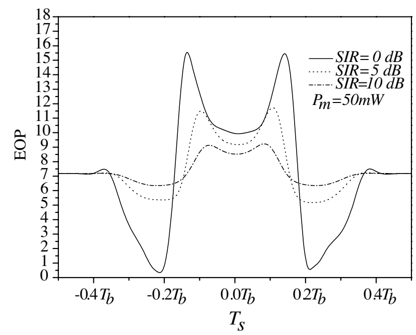

Figure 6. EOP vs T_s for super-Gaussian optical pulse and different SIR.

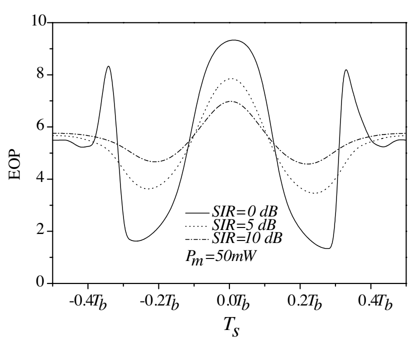

Figure 7. EOP vs T_s for sech optical pulse and different SIR.

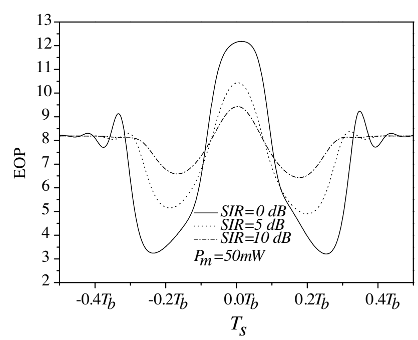

Figure 8. EOP vs T_s for for super-sech optical pulse and different SIR.

It is be seen that interchannel cross-talk occurring at the fiber input greatly reduce eye opening by increasing the useful signal optical power. The 3-D plots of Figures 1–4 illustrate this. The very same conclusion can be drawn from Figures 5–8. The eye opening is rising with the increase of SIR and decreases with the increase of the useful signal optical power.

5. CONCLUSIONS

Although the interchannel cross-talk can be filtered if it occurs at the fiber input, it not uncommon that this cross-talk can be induced somewhere, rather anywhere, in the transmission link. In this paper, the investigation of the interchannel cross-talk was investigated that occurs at the fiber input. The analysis is performed for the interchannel cross-talk model where the interchannel cross-talk position relative to the useful signal position is considered and it was concluded that T_s influences EOP. It can be seen that the interchannel cross-talk position at the center of the useful signal $T_s = 0$ has the greatest influence. As the position of the cross talk pulse is changed left or right ($0 \leq |T_s| \leq T_b/2$), the useful signal pulse becomes additionally distorted but the influence on the EOP becomes smaller as observed in Figures 5–8. The SIR level is also changed from 0–20 dB and numerically simulated EOP and it is seen that for SIR = 0 dB, one has the greatest influence on optical pulse propagation. This means that when interchannel cross-talk optical power is equal to the signal optical power, it gives rise to nonlinear effects that additionally distorts the pulse shape. A thorough analysis is very useful for improving the existing transmission links or designing the new ones. It is also very useful in designing wavelength-division-multiplexed (WDM) systems as this type of cross-talk is pretty common. So, in the case of WDM system two or even four nearest wavelengths (channels) should be taken into consideration. It needs to be noted that EOP gives an useful information for bit-error-rate evaluation.

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