Simulation of PMD Cause in WDM Systems

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Summary
The model of signal propagation for two channel WDM system called coupled nonlinear Schrodinger equations (NLSE) are introduced. We demonstrate effect of nonlinearities and birefringence in 2 channel WDM system. The simulation model and his numeric solution was designed including polarization mode dispersion (PMD). The coupled NLSE was applied on gaussian pulses.

Key words:
PMD, WDM, Simulation, Eye diagram.

1. Introduction

The transmission capacity of existing optical routes has limits and increasing the transmission capacity is needed. One way consist in using optical multiplexers or rising transmission speed. But when the bit rate reaches above 10 Gbit/s, the influence of polarization mode dispersion (PMD) is more important. Optical signal in fiber has two ortogonal polarizated modes, factors like temperature, stress of fiber and others cause that the polarized modes have not same group velocity and time delay between the two polarized modes is PMD. If we use optical multiplexers, nonlinearities like cross-phase modulation (XPM) come out. Effect of nonlinearities and PMD has influence on bit-error-rate and must be consider. That is the reason why we introduce coupled nonlinear Schroedinger equations (NLSE), which includes these effect.

2. Simulation model

General nonlinear Schroedinger equation (NLSE) describes signal propagation in optical fiber, but with transmission speed 10 Gbit/s or above, the general NLSE is deficient, because we need to include in influence of the polarization mode dispersion (PMD). We achieve this by creating two NLSE, which describes propagation of each polarized component. If we use optical multiplexers, we can define system of NLSE, where new nonlinear effects are added. Following coupled NLSE describes two channel WDM system.

$$\frac{\partial a_{1x}}{\partial z}+\frac{d_1}{2}\frac{\partial a_{1x}}{\partial t}+\mathrm{j}\frac{\beta_{21}}{2}\frac{\partial^2 a_{1x}}{\partial t^2}+\frac{\alpha}{2}a_{1x}=\mathrm{j}\gamma_1\left(|a_{1x}|^2+2|a_{2x}|^2+\frac{2}{3}|a_{1y}|^2+\frac{2}{3}|a_{2y}|^2\right)a_{1x}, \quad (1))$$

$$\frac{\partial a_{1y}}{\partial z}-\frac{d_1}{2}\frac{\partial a_{1y}}{\partial t}+\mathrm{j}\frac{\beta_{21}}{2}\frac{\partial^2 a_{1y}}{\partial t^2}+\frac{\alpha}{2}a_{1y}=\mathrm{j}\gamma_1\left(|a_{1y}|^2+2|a_{2y}|^2+\frac{2}{3}|a_{1x}|^2+\frac{2}{3}|a_{2x}|^2\right)a_{1y}, \quad (2)$$

$$\frac{\partial a_{2x}}{\partial z}+\frac{2d_2+d_1}{2}\frac{\partial a_{2x}}{\partial t}+\mathrm{j}\frac{\beta_{22}}{2}\frac{\partial^2 a_{2x}}{\partial t^2}+\frac{\alpha}{2}a_{2x}=\mathrm{j}\gamma_2\left(|a_{2x}|^2+2|a_{1x}|^2+\frac{2}{3}|a_{2y}|^2+\frac{2}{3}|a_{1y}|^2\right)a_{2x}, \quad (3)$$

$$\frac{\partial a_{2y}}{\partial z}+\frac{2d_3+d_1}{2}\frac{\partial a_{2y}}{\partial t}+\mathrm{j}\frac{\beta_{22}}{2}\frac{\partial^2 a_{2y}}{\partial t^2}+\frac{\alpha}{2}a_{2y}=\mathrm{j}\gamma_2\left(|a_{2y}|^2+2|a_{1y}|^2+\frac{2}{3}|a_{2x}|^2+\frac{2}{3}|a_{1x}|^2\right)a_{2y}. \quad (4)$$

The parameters in equations (1)-(4) introduce: $a_{1x,y}$, $a_{2x,y}$ - slowly developing optical intensity on 1st and 2nd wavelength, z - fiber length, t - time, α - fiber attenuation, β_{21} β_{22} - second order dispersion coefficients, $\gamma_{1,2}$ - nonlinear coefficients. d_1, d_2, d_3 - parameters of differentian group delay, which we express as

$$d_1=\frac{1}{v_{g1x}}-\frac{1}{v_{g1y}},\quad d_2=\frac{1}{v_{g2x}}-\frac{1}{v_{g1x}},\quad d_3=\frac{1}{v_{g2y}}-\frac{1}{v_{g1x}}. \quad (5), (6), (7)$$

The equations (5)-(7) gives the centre of time axis to the middle of pulse on 1st wavelength (equations (1), (2)). The brackets in right side of the equations (5)-(7) represents self-phase modulation (SPM) and cross-phase modulation (XPM). In each segment of a fiber, the polarized components has a random rotation and random phase-shift, we simulate these properties by following matrix [2]

$$\begin{bmatrix} a_{ix}' \\ a_{iy}' \end{bmatrix}=\begin{bmatrix} \cos\theta & \sin\theta\cdot e^{\mathrm{j}\varphi} \\ -\sin\theta\cdot e^{-\mathrm{j}\varphi} & \cos\theta \end{bmatrix}\cdot\begin{bmatrix} a_{ix} \\ a_{iy} \end{bmatrix} \quad (i=1,2),\ (8)$$

where $a_{ix,y}$ and $a_{ix,y}'$ is optical intensity in input and output of each fiber segment. Segment (or section) is short piece of fiber with constant birefringence. Segment length is usually from 0,1 to 1 km, it depends on fiber length. In matrix (8), θ is a random rotation and φ is random phase-shift between two polarized components. Because difference between 1st and 2nd wavelength is very small, then dispersive and nonlinear coefficient for both

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wavelength is practically same ($\beta_{21}=\beta_{22}, \gamma_1=\gamma_2$). We can count these coefficient by equations [1]

$$\beta_{21,22} = -\frac{\lambda^2}{2\pi \cdot c} D \quad , \quad \gamma_{1,2} = \frac{2\pi \cdot n_2}{\lambda \cdot A_{ef}} \quad . \qquad (9), (10)$$

In (9), (10) are D [ps/nm.km] dispersion parameter of fiber (chromatic dispersion), λ - wavelength, n_2 - nonlinear parameter of fiber core, A_{ef} - effective area of fiber core.

3. Results

For numerical solution of NLSE we used split-step Fourier method (SSFM), which consist in splitting calculation of dispersive and nonlinear effects and using principles of Fourier method. Optical signal (or slowly developing electric fiel on optical transmitter) is the gaussian pulse without chirping, [1]. His width T0 is pulse width for normalized power level $1/e \approx 0{,}37$. In all simulations we neglect fiber loss for comparing with input pulse, α = 0 dB. Next fiber parameters in all simulations are n2 = 3,2.10-16 cm2/W, Aef = 50 μm2.

If we have only 1st wavelength, $a_{2x,y}$ = 0, and we take following parameters, we can see on figure 1 how the PMD caused closing eye diagram. The initial pulse width T0 = 12 ps, peak pulse power P0 = 1 mW, chromatic dispersion D = 1 ps/nm.km, fiber length z = 20 km, segment length Δz = 0,1 km, polarization mode dispersion DPMD = 1 ps/√km (it matches with d1 ≈ 34,3·10-16 s/m, [3]).

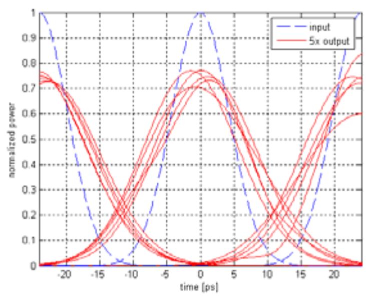

Fig. 1 Eye diagram corresponding with 40 Gbit/s

If we consider multiplex system – equation (1)-(4), two wavelength 1550 nm and 1551 nm, the input pulses on different wavelengths was launched in the same time. Fiber length 50 km (Δz = 0,25 km), T0 = 12 ps, D = 1 ps/nm.km and P0 = 1 mW (0 dBm). We chose value of next parameters as d1 = -20.10-16 s/m, d2 = 5.10-16 s/m, d3 = 30.10-16 s/m. Figure 2a,b shows the pulse propagation. The pulses has not same time position and different broadering factor. Effect of nonlinearities is not obvious.

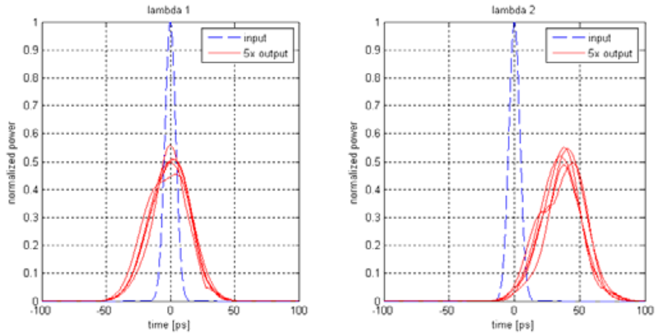

Fig. 2 Transmission of optical pulses on two different wavelengths with P0 =1 mW

If the peak pulse power is increased to 60 mW (18 dBm), then output signal is on figure 3a,b. The effect of nonlinearities is now obvious and we can particularly see it on both sides of outpul pulses. The nonlinearities (known as Kerr effect) can partly compensate chromatic dispersion.

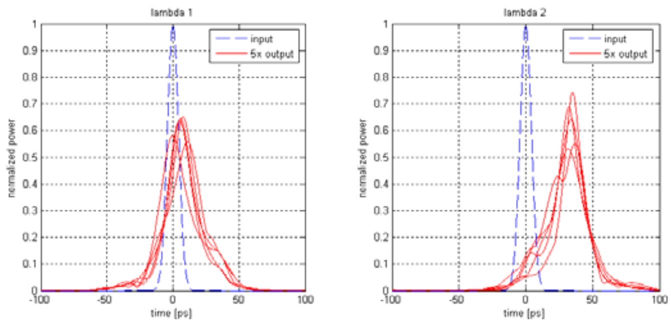

Fig. 3 Transmission of optical pulses on two different wavelengths with P0 = 60 mW

3. Conslusion

We introduced principles of signal propagation in two channel WDM system. In multiplex systems is the influence of nonlinearities more important and it is needed to be monitoring. For example, a high output power on start of the system can increase bit-error-rate from allowed value and the communication system may not be usable. Transmission speeds above 10 Gbit/s are very sensitive on PMD, that is the reason for using new coding schemes then RZ coding in our simulations.

References

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