Performance Optimization in SMF with PMD and PDL using MPO Technique

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Abstract

Polarization Mode Dispersion and Polarization Dependent Loss in Single Mode fiber can cause significant pulse broadening and leads to system degradation. In this paper, Multi Parameter Multi-output optimization technique is proposed to improve the system performance. Chirped and Unchirped Super-gaussian pulses launched through this fiber model are analyzed and simulations are carried out by varying the States of Polarization. Pulse Width Reduction between different algorithms are analyzed. Simulation results are obtained for Circular and Linear SOP and it is found that using Multi Parameter Multi-output optimization an improvement in pulse width reduction is achieved for Circular State of Polarization.

Keywords: Polarization Mode Dispersion (PMD) , Polarization Dependent Loss (PDL), Single Mode Fiber(SMF), Differential Group Delay(DGD), Multi-parameter Multi-Output optimization(MPO)

1. Introduction

Polarization Mode Dispersion (PMD) and Polarization Dependent Loss (PDL) is a very serious problem for Long Haul Optical Fiber transmission System. Thorough study of Polarization characteristics is necessary for system engineers to achieve a reliable communication over the Fiber Optic Transmission Link. Several research works on PMD and/or PDL Compensation have been carried out in recent years. Interaction of Polarization Mode Dispersion and self-phase modulation (SPM) in single channel may lead to large performance degradations and performance improvement may be achieved by bit-synchronous polarization scrambling [8].

Electronic PMD Compensation in the form of Decision Feedback Equalizer consisting of a 3-tap feed forward equalizer and a 2-tap feedback equalizer has been used to mitigate PMD effectively. Here Least Mean Square algorithm is used for Electronic Dispersion Compensation [2]. PMD Compensation performance of Differential Quadrature Phase Shift Keying is better than that of On- Off Keying and Differential Phase Shift Keying [5]. Particle Swarm Optimization is used as the searching algorithm and an adaptive dithering algorithm is employed in tracking process. Here searching process is completed within several hundreds of ms and response time is less than 20ms [10].

Automatic Polarization Compensation tracking method is suitable for compensating the polarization fading of two independent interference path interferometric sensors [9]. Also Particle Swarm Optimization is used as a control algorithm for Adaptive PMD Compensation since it converges rapidly to the global optimum and is good robustness to noise [6]. In this paper, description of PMD and PDL are presented in Section 2. Simulation Model and Results are shown in Section 3. Finally conclusion is given in Section 4.

2. PMD and PDL Analysis

Impairments in the optical link can be classified into two types such as Linear and Non Linear Impairments. The major linear impairments are PMD and PDL. PMD mainly exist from fiber birefringence. Manufacturing defects, temperature variation, vibration creates the fiber birefringence. Here optical signal in single mode fiber is resolved into two orthogonal polarization modes with different propagating velocities. The difference in propagation time between two orthogonal modes is known as Differential Group Delay (DGD) and the average value of DGD is PMD.

Birefringence can be considered uniform in short fibers. Long fibers can be modeled as a concatenation of birefringent sections. Losses of an optical fiber link depend on states of polarization of the signal propagating through it. Hence this dependency is known as Polarization Dependent Loss (PDL). PDL is defined as the ratio between the maximum and minimum transmission power [3].

A polarized signal can be described by Jones vector. In the presence of Chirp, the Jones vector of a supergaussian pulse with Linear and Circular States of Polarization at the fiber input can be written as

$$E_1(t) = \sqrt{A_O}\, \exp\left[\frac{-1+iC}{2}\left(\frac{t}{t_o}\right)^{2m}\right]\begin{bmatrix}\cos\theta_{in}\\ \sin\theta_{in}\end{bmatrix} \tag{1}$$

$$E_2(t) = \sqrt{A_O}\, \exp\left[\frac{-1+iC}{2}\left(\frac{t}{t_o}\right)^{2m}\right]\begin{bmatrix}1\\ 1e^{j\frac{\pi}{2}}\end{bmatrix} \tag{2}$$

Here C represents the linear frequency Chirp parameter, A_o is the input power in mW, θ_{in} is the input polarization angle, t_o is input pulse width, $E_1(t)$ and $E_2(t)$ are the input fields. When m=1 the pulse is Gaussian and m>1 the pulse become Supergaussian . Optical pulses used in practice are more rectangular than Gaussian. Hence Supergaussian pulses are considered for analysis.

The output field is given by

$$E_o(w) = T(w)E_1(w) \tag{3}$$

Optical Link is modeled as a concatenation of N segments. Each section has linear elements such as PMD and PDL. Hence the resultant Jones matrix of fiber T (w) is [1]

$$T(w) = \prod_{n=1}^{N} T_{PMD}(w)T_{PDL}(\beta_n) \tag{4}$$

Now,

$$E_o(w) = \left[\prod_{n=1}^{N} T_{PMD}(w)T_{PDL}(\beta_n)\right]E_1(w) \tag{5}$$

Each PMD element has a Transfer Matrix T_{PMD} (w) defined as the product of delay matrix and rotation matrix.

$$T_{PMD}(w) = \begin{bmatrix} e^{i(\Delta\tau_n \Delta w/2)+\phi_n} & 0 \\ 0 & e^{-i(\Delta\tau_n \Delta w/2)+\phi_n}\end{bmatrix}\begin{bmatrix}\cos\theta_n & \sin\theta_n \\ -\sin\theta_n & \cos\theta_n\end{bmatrix} \tag{6}$$

$$\Delta\tau_n = \Delta\tau\sqrt{L_n} \tag{7}$$

where $\Delta\tau_n$ is the birefringence of the n_{th} trunk, $_n$ represent the random phase shift in the n_{th} section, θ_n is the random orientation of the birefringent axes of the n_{th} section, $\Delta\tau$ is the PMD coefficients, L_n is the length of n_{th} trunk.

T_{PDL} (β_n) defines the Polarization Dependent Loss and β_n describes the random angle of the partial polarizer.

$$T_{PDL}(\beta_n) = \begin{bmatrix} e^{-\alpha}\cos^2\beta_n + e^{\alpha}\sin^2\beta_n + & (e^{\alpha}-e^{-\alpha})\sin\beta_n\cos\beta_n \\ (e^{\alpha}-e^{-\alpha})\sin\beta_n\cos\beta_n & e^{\alpha}\cos^2\beta_n + e^{-\alpha}\sin^2\beta_n + \end{bmatrix} \tag{8}$$

where α is the PDL loss coefficient.

3. Simulation Model and Results

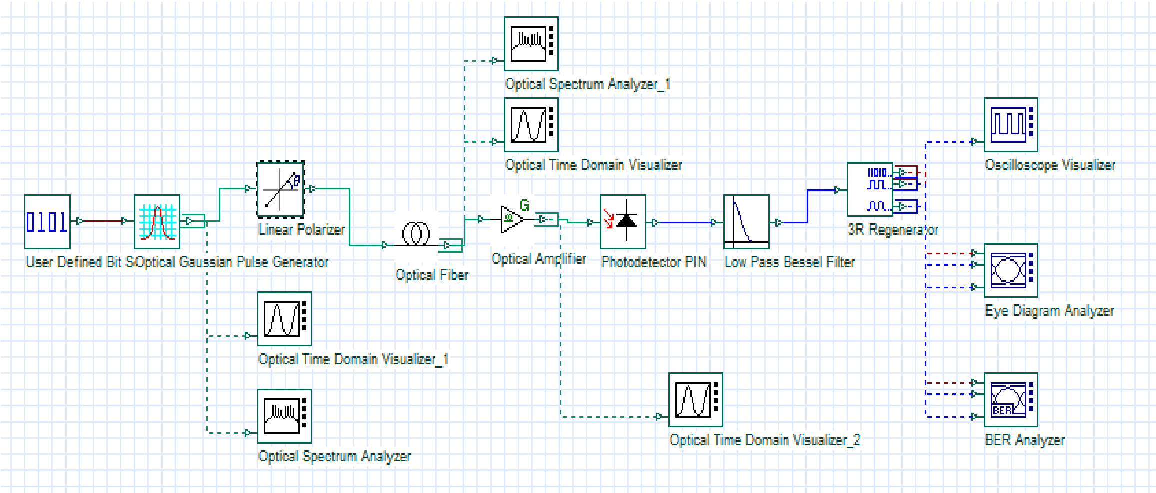

Fig.1. Simulation model of an optical system for linear state of polarization

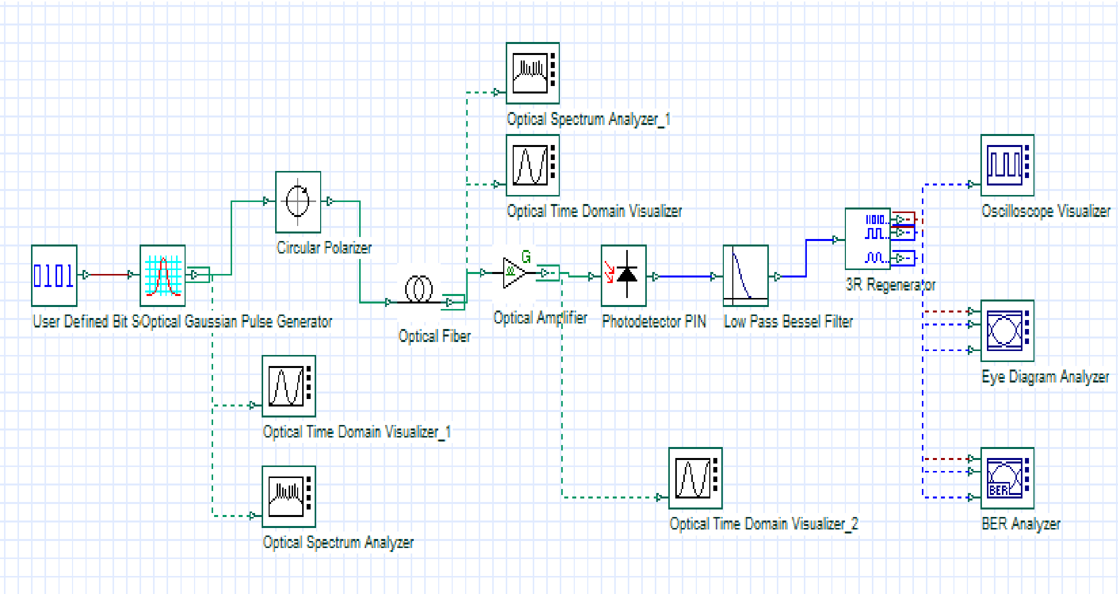

Fig.2. Simulation model of an optical system for circular state of polarization

Chirped Supergaussian pulses are generated according to the bit sequence by the optical Gaussian pulse generator. Here the order is varied. Suppose if the order is 1, then the pulse generated will be Gaussian pulse and if the order is greater than one then the pulse is supergaussian pulse. Also chirp parameter can be varied such as C = -2, 0 2. Here C= -2 represent the negative chirped parameter, C = 2 is positive chirped parameter and C = 0 is unchirped. Linear polarizer transmits the linear sop. In Fig.1. the input linear polarization can be varied from 0 to $\pi/2$.

In Fig.2 the polarization is adjusted to a circular state by the circular polarizer. Optical fiber simulates the propagation of optical field with PMD and PDL taken into account. The optical fiber is represented by a concatenation of several sections and optical signal in each section is simulated by the Split Step Fourier Method (SSFM). Then the signal is amplified by an optical amplifier. Optical time domain visualizer and spectrum analyzer calculate and displays optical signal in time and frequency domain. PIN photo detector converts optical signal into electrical signal. Then it is filtered through low pass Bessel filter and 3R regenerator generates the original bit sequence. Oscilloscope visualizer calculates and displays electrical signal in time domain. BER analyzer calculates the bit error rate of an electrical signal and eye diagram analyzer displays the electrical signal eye diagram.

Table.1. shows signal ratios for different sop

Input States of Polarization	Signal ratio	Unchirped supergaussian Pulse with C=0	Chirped Supergaussian pulse with	
			C=2	C = -2
Linear State Of Polarization	Compression Factor	1.2614	1.1871	1.4355
	Pulse Width Ratio	0.7927	0.8423	0.6966
	Pulse Width Reduction in %	20.72%	15.76%	30.33%
Circular State Of Polarization	Compression Factor	1.3268	1.3398	1.4416
	Pulse Width Ratio	0.7382	0.7463	0.6440
	Pulse Width Reduction in %	26.17%	25.36%	35.59%

Pulse width depends on 3 parameters such as θ_{in}, α, λ. The results were obtained by varying PDL(α), input polarization angle(θ_{in}) and wavelength(λ) PMD of 1ps is kept fixed. It can be seen from the simulation result that the signal ratios such as compression factor, pulse width ratio and pulse width reduction for unchirped and chirped supergaussian pulse are calculated for different states of polarization. Compression Factor is nothing but the ratio of full width half maximum of the input supergaussian pulse to that of the compressed pulse.

Table.2 shows the various parameters and its range

Parameters	**Range**
PDL(α)	[0.1 : 0.6] dB
θ_{in}	[0 : π/2]
λ	[1530 : 1560] nm

Table.2. shows the corresponding ranges for different parameters. Minimum and maximum values of the parameters are chosen to be $0.1 \le \alpha \le 0.6$; $0 \le \theta_{in} \le \pi/2$; $1530 \le \lambda \le 1560$.

Table.3 shows comparison of PWR for different algorithm

Different algorithms	**Pulse Width Reduction in %**
Controlling input SOP (2000) [3]	10%(with PDL)
Single variable search algorithm (2001) [4]	31.4%(without PDL)
Multi variable search algorithm (2006) [7]	33.49%(with PDL)
Multi –parameter Multi-output Optimization	35.59%(with PDL)

Table.3 shows the comparison of pulse width reduction for various algorithms. In MPO optimization, multiple parameters and multiple results are considered for analysis whereas earlier single parameter is used in single variable search algorithm which resulted in 31.4% reduction. Later Multivariable search algorithm (Random Walk Method) resulted in further reduction of 2.09%. Using MPO optimization, parameters are adjusted and optimum values are found to be $\alpha = 0.215$, $\theta_{in} = \pi/4$ and $\lambda = 1550.65$. A maximum pulse width reduction of 35.59% is achieved for circular sop with C= -2. Multivariable Optimization tool adjust the signal parameters before each run based on previous results obtained using the optimization algorithm. If proper parameters are selected, optimization procedure can find the optimum parameters after reasonable number of iterations. Number of iterations depends on the number of parameters selected, no of target values and complexity of the system.

4. Conclusion

Using MPO Optimization, a maximum pulse width reduction was achieved in the presence of PMD and PDL. Optimum values of input parameters are obtained for maximum pulse narrowing and the results are compared with previous algorithms. On analysis it is found that negative chirped supergaussian pulse can reduce pulse broadening with Circular SOP and hence the proposed method significantly improves the system performance.

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