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ANALYSIS OF PULSE DEFORMATION INDUCED BY PDL ON PROPAGATION OF CHIRPED SUPERGAUSSIAN PULSE IN SMF WITH AND WITHOUT PMD

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ABSTRACT

In this paper the effect of Polarization Mode Dispersion, Polarization Dependent Loss on the Chirped Super Gaussian pulse is analyzed and Pulse broadening in the presence and absence of PMD for up chirped and down chirped pulses in highly birefringent optical link at 1550nm is investigated by numerical simulation. Also maintaining PMD and PDL, the input light signal is launched at different States of Polarization such as Linear, Circular and Elliptical. It is found that the pulse broadening can be controlled by choosing an appropriate SOP of the input signal. Results show that pulse width increases for Linear SOP and it reduces when the input is launched at Circular and Elliptical State of Polarization.

Keywords: *Polarization Mode Dispersion(PMD) , Polarization Dependent Loss(PDL), Nonlinear Schrodinger Equation(NLSE), Split Step Fourier Method (SSFM), State of Polarization(SOP).*

1. INTRODUCTION

Today, telecommunication users are demanding more bandwidth. Two major dispersion that exist in single mode fiber are Chromatic Dispersion and Polarization Mode Dispersion that limits the bandwidth. Polarization related characteristics such as PMD, PDL in optical link degrades the system performance. Hence there is a need to control the states of polarization in randomly varying birefringent optical fibers. In an ideal single mode fiber light wave travel as two orthogonally independent degenerate mode. Birefringence in the optical fiber due to internal stress during fiber manufacture and external stress due to bend or twist leads to PMD. PDL occurs due to optical components such as Optical Amplifiers, Isolators, Circulators, Couplers etc. Both Polarization Mode Dispersion and Polarization Dependent Loss are pulse width dependent i.e., at higher data rates, the bit period is reduced and PMD becomes a very major issue. Effect of PMD was not considered at low data rates and as the data rate is 40Gb/s or above the influence of PMD becomes important.

Poole and Wagner [1] have introduced the concept of principal states of polarization to characterize the DGD for a given optical fiber when PDL is zero. For a fiber without PDL and a pulse with a very narrow band these two Principal State of Polarization are orthogonal and they represent the slowest and fastest propagation pulses. Pulses can be decomposed in terms of the principal states of polarization and will be broadened during propagation. The maximum broadening is given by the DGD which is the Differential Group Delay between the two PSPs. Gisin and Hutner[2] have extended the concept of PSPs to include the elements of PDL in the optical fiber.

Furthermore they have shown some rather surprising results involving interaction of PMD and PDL. For e.g. they showed that DGD of a concatenation of birefringence fibers and elements with PDL can produce a global DGD that is larger than the sum of the DGD's of all the trunks[3]. They also showed that even with zero DGD for a concatenation of birefringence fibers with PDL element there still exist finite pulse spreading[4].Tobias Gravemann and Jens[5] have derived formulas both for the effective pulse broadening and the eye opening penalty.

Ping Lu and Liang Chen [6] have showed that the probability of pulse broadening/narrowing strongly depends on two effects: frequency chirp

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induced spectrum broadening and higher order PMD induced effective chromatic dispersion. Ling-wei Guo and Ying-Wu Zhou [7] have studied the pulse broadening of optical signals in SMF theoretically in presence of PMD, PDL, Chromatic Dispersion and spectral Chirping.

Cristian Antonelli and Antonio Mecozzi[8] have numerically investigated the impairments due to PMD in Chaos-encrypted Communication Systems. They also showed that PMD could affect master-slave synchronization hence degrading system performance at typical PMD values of deployed fiber plants. Qi Sui and Alan Pak[9] have analyzed the OSNR monitoring in the absence and presence of PMD.

Manjit Singh and Ajay Sharma found that to decrease BER and timing jitter in the system, smaller width and third order super Gaussian pulse should be used. Also they have compared the performance of three compensating scheme such as pre, post and symmetrical dispersion compensation and found that to decrease dependency of BER and timing jitter in the communication system on the pulse width, the symmetrical compensation scheme should be implemented[10].

System suffers minimum penalty when Chirp- Hyperbolic Secant shape Optical pulse is used instead of Chirp- Gaussian shape pulse[11]. Jerzy Jasinski and Lukasz Michalik showed that the changes in the Supergaussian pulse order may change the pulse shape observed during numerical investigations of propagation over distances up to 20 nonlinear lengths[12].

In this paper performance degradation induced by PMD, PDL and Frequency Chirping in high capacity long haul system is investigated. Pulse deformation in the presence and absence of PMD has been carried out to analyze the propagation of Super Gaussian pulse in SMF. Simulation is carried out using SSFM and is found that the pulse is least sensitive to the effect of PDL. In addition maintaining PMD and PDL, pulse broadening/narrowing at the end of the fiber is analyzed.

The rest of the paper is organized as follows. In Section 2 PMD, PDL and Chirping effects are studied. Pulse deformation caused by PDL in the presence and absence of PMD are investigated in Section 3. Results of simulations are presented in section 4. Finally the Conclusion is given in section 5.

2. THEORY

Polarization dispersion is very serious problem in long range multigigabit systems. Ideally single mode fiber is circular symmetric, two polarization modes are degenerate i.e. light in either mode propagate with same speed. In a real single mode fiber, various asymmetries which results from manufacturing defect such as nonsymmetrical cylindrical core shape, bending, twisting, thermal stresses and environmental variation such as temperature, wind, vibration etc remove degeneration of both orthogonal polarization and they propagate with different velocities instead of same velocity. One eigen mode propagate more slowly as compared to other.

Each fiber deformation changes the direction of the principal axes. The single mode fiber with different velocities of propagation of the eigen modes are called birefringent fiber. Birefringence in the fiber creates differential group delay (DGD) between two modes.

$$\Delta\tau = \left| \frac{L}{V_{gx}} - \frac{L}{V_{gy}} \right| \qquad (1)$$

where $\Delta\tau$ is DGD in ps, L is the Length of the fiber and V_{gx} and V_{gy} are group velocities of two orthogonally polarized modes. Higher the difference more is the polarization dispersion. This leads to large pulse spreading which may affect the transmission capacity of optical network. Fiber birefringence is the physical origin of Polarization Mode Dispersion (PMD). The mean value of DGD is PMD. PMD is a vector quantity with magnitude DGD and a direction PSP. Birefringence change the SOP of the light wave as it travels along the fiber. Pulse broadening depends on the State of Polarization (SOP) of the input signal.

Polarization Dependent Loss (PDL) mainly occurs in passive optical components such as circulators, Add drop multiplexer, Erbium Doped Fiber Amplifiers etc whose insertion loss is dependent on polarization state of input signals. A network component attenuates light selectively depending on its SOP, thus randomly changing the

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intensity of the propagating signal. Hence PDL in dB is

$$PDL = 10\log\frac{I_{\max}}{I_{\min}} \tag{2}$$

where I_{max} and I_{min} are the maximum and minimum Intensities. PDL in optical fiber induces fluctuation of Optical Signal to Noise Ratio(OSNR) and cause optical power variation.

All the effects such as chromatic, PMD, PDL are all linear because their mechanism are not the function of power. They are dependent on fiber material. An optical effect is called nonlinear if the parameters depend on Light Intensity [13]. As the input signal power is increased, nonlinear effect also increases. Nonlinearity Parameter (γ) is

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \tag{3}$$

where A_{eff} is the cross sectional area of the fiber and n_2 is the nonlinear index coefficient.

The input field of Super Gaussian pulse at a distance z = 0 is described by

$$E(0,t) = \sqrt{P_O}\exp\left[\frac{-1+iC}{2}\left(\frac{t}{t_o}\right)^{2m}\right] \tag{4}$$

where the parameter m controls the degree of edge sharpness. In case of m = 1, we get the Gaussian pulse. For larger values of m the pulse become rectangular shaped with sharper leading and trailing edges. Here C represents the chirp factor which determines the degree of chirp of the pulse, P_0 is the input power in mW and t_o is the initial width of the incident pulse.

Pulses emitted by the semiconductor laser when they are directly modulated are chirped and have rectangular profile with much sharper leading and trailing edges. A pulse is said to be chirped or frequency modulated if its instantaneous frequency is time varying.

Injected current modulates directly the carrier density of the emitting layer. Hence carrier density varies strongly at the leading and trailing edges of a near rectangular pulse. This cause the refractive index change in the emitting layer which induces the frequency chirp at both the leading and trailing edges. From the leading edge to the trailing edge frequency chirp increases linearly and is called the Up Chirp and if it decreases, it is called Down Chirp [14].

The frequency change is related to the phase derivative and is given by

$$\delta w(t) = -\frac{\partial \phi}{\partial t} = \frac{C}{t_O^2}t \tag{5}$$

3. SYSTEM MODEL

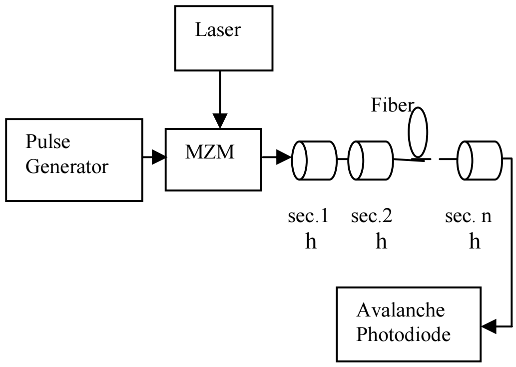

Figure.1: Simulation Model Of An Optical System

In Figure.1.Transmitter section consists of Laser source, Pulse Generator, Mach-zehnder modulator and is assumed to produce chirped super Gaussian pulse at a wavelength of 1550nm with carrier frequency of 193.548THz. At the receiver, Avalanche Photodiode is used. Simulation may be performed by dividing the fiber into small sections. Section is short piece of fiber with length h.

In each section nonlinear and linear effects are considered separately in time domain and frequency domain. We assume that PMD and PDL in each segment are fixed. Signal power of 2mW is fed into optical communication link. Figure.2 shows input pulse.

SuperGaussian input Pulse is launched into the optical fiber distorted by PMD and PDL. As shown in Figure.2 this pulse was nearly rectangular in shape. Pulse broadening in a system mainly depends on the pulse width of the launched input signal.

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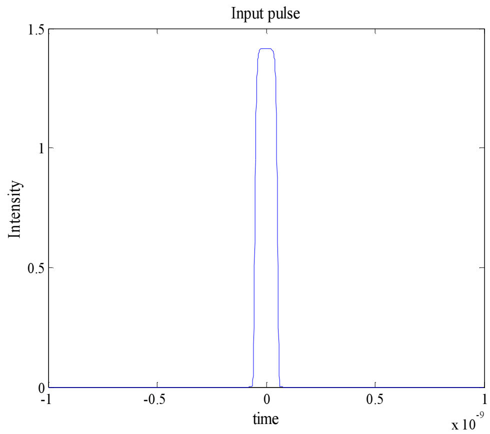

Figure.2: Super Gaussian Pulse

3.1 Optical System with PDL and without PMD

Propagation of optical pulse inside single mode fiber is governed by Nonlinear Schrodinger (NLS) equation [15] and is given by

$$\frac{\partial E(z,t)}{\partial z} = -\frac{\alpha}{2}E(z,t) + \frac{i\beta_2}{2}\frac{\partial^2 E(z,t)}{\partial t^2} - i\gamma\,/E(z,t)/^2\,E(z,t) \qquad (6)$$

The equation can be split into a linear term (α & β_2) and nonlinear term (γ). The different terms in the equation describe the different effects like GVD (β_2), PDL (α), and nonlinearity (γ). Pulse propagation is simulated by numerically solving NLSE using Split Step Fourier Method (SSFM) [16] with fixed step size. SSFM is more efficient, faster, more flexible, very accurate method compared to that of other methods such as finite difference method, perturbation method etc.

Split Step Fourier Algorithm:

We split the computation of E(z,t) over distance h into 4 Steps:

Step 1: Non linear step:
Compute $A_1 = \exp(h N)\, E(z,t)$

Step 2: Forward Fourier Transform:
Perform the FFT on A_1: $A_2 = F A_1$

Step 3: Linear Step:
Compute $A_3 = \exp(h L)\, A_2$

Step 4: Backward FT :
Perform the backward FFT on A_3:
$A(z+h, t) = F^{-1} A_3$

After step 4 pulse amplitude for one section of length h is obtained. To determine the amplitude at the end of the fiber the above algorithm is repeated for many numbers of iterations.

3.2 Optical System with PMD and PDL

Pulse propagation within each section in single channel long haul transmission link is described by Coupled NLSE [17]. Simulation model takes into account PMD, GVD, PDL and Nonlinearity.

$$\left[\frac{\partial}{\partial z} + \frac{\alpha_{x,y}}{2} + \beta_{1x,y}\frac{\partial}{\partial t} - i\frac{\beta_2}{2}\frac{\partial^2}{\partial t^2}\right]E_{x,y}(t,z) = -i\gamma\frac{8}{9}\left[/E_{x,y}(z,t)/^2 + /E_{y,x}(z,t)/^2\right]E_{x,y}(t,z) \qquad (7)$$

The group velocities of the two polarization modes are related to the fiber PMD coefficient D_{PMD}.

$$\beta_{1x} = -\beta_{1y} = \sqrt{\frac{3\pi}{8}}\frac{D_{PMD}}{\sqrt{h_n}} \qquad (8)$$

Each section is randomly rotated and random phase shift is added between two polarized component of the signal. Angle of rotation and phase shift are chosen in $(0,2\pi)$.

The resultant transfer matrix T(w) is

$$T(w) = \prod_{n=1}^{N}\begin{bmatrix} e^{j(\sqrt{3\pi/8}\,D_{PMD}w\sqrt{h_n}/2+\phi_n)} & 0 \\ 0 & e^{-j(\sqrt{3\pi/8}\,D_{PMD}w\sqrt{h_n}/2+\phi_n)} \end{bmatrix}\begin{bmatrix} \cos\theta_n & \sin\theta_n \\ -\sin\theta_n & \cos\theta_n \end{bmatrix} \qquad (9)$$

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where
N – no of sections
h_n – length of the n^{th} section
φ_n – random phase shift in the n^{th} section
θ_n – random orientation of the birefringent axes of the n^{th} section

3.3 Representation of SOP

System performance can be analyzed by launching the input light at different States of Polarization.

If a Linearly polarized signal is launched into an optical fiber the output electric field is given as

$$E_{out}(w) = T(w)\begin{pmatrix}\cos\theta_{in}\\ \sin\theta_{in}\end{pmatrix}E_{in}(w) \qquad (10)$$

where $E_{in}(w)$ is the Fourier transform of E(z,t), θ_{in} is the input polarization angle.

If a Circularly Polarized signal is launched into an optical fibre, the output electric field can be written as

$$E_{out}(w) = T(w)\begin{pmatrix}1\\ 1e^{j\frac{\pi}{2}}\end{pmatrix}E_{in}(w) \qquad (11)$$

If an Elliptically Polarized signal is launched into an optical fibre, the output electric field can be written as

$$E_{out}(w) = T(w)\begin{pmatrix}\frac{\sqrt{3}}{2}\cos\frac{\pi}{3}\\ \frac{1}{2}\sin\frac{\pi}{3}e^{j\frac{\pi}{4}}\end{pmatrix}E_{in}(w) \qquad (12)$$

4. RESULTS AND DISCUSSION

In the proposed system, analysis is carried out for a super Gaussian chirped pulse in the absence of PMD and the pulse broadening is observed for different values of PDL. Figure.3. shows the pulse broadening for up chirped super gaussian pulse with PDL and without PMD. From the result it is found that pulse broadening remains the same till 0.5 and it increases with increase in PDL and again remains constant from 1 to 1.5. This result is consistent with the result reported in[18]. Here pulse broadening at the fiber end is observed by propagating gaussian pulse. We find that when there is no PMD, broadening induced by PDL can be effectively reduced whereas the presence of PMD enhances the pulse broadening and is very difficult to compensate.

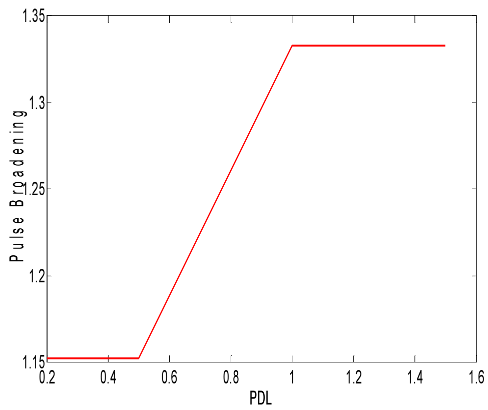

Figure.3:Pulse-Width Broadening Due To PDL

In the Figure.4, m = 2,3,4 indicates supergaussian pulses and the pulse broadening is observed for different values of chirp parameter. If the values of chirp goes on increasing,broadening also increases with the propagated distance and it is found that broadening is more for upchirped pulse than down chirped pulse. For negative chirped pulse, broadening reduces for m =2 whereas for positive chirped pulse for the same value of m, increase in pulse width is observed.

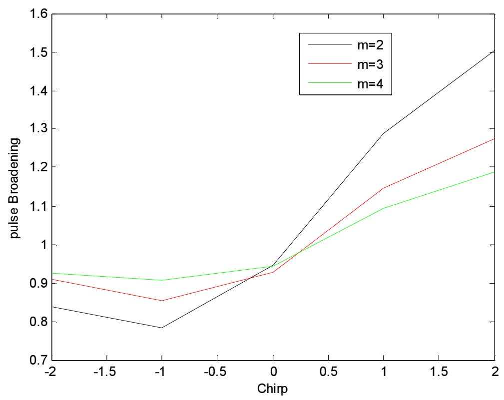

Figure.4: Pulse Broadening Due To Different Values Of Chirp

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Next the analysis is carried out in the presence of PMD and PDL. At the end of the optical link, system performance can be observed and it is found that the presence of PMD and PDL increase the pulse broadening. When the effect of PMD are included, pulse broadening depends on the states of polarization of the input signal.

Figure.5. shows the pulse broadening for super Gaussian pulse with different values of PMD and it is found that PMD in the fibre is strong enough to cause pulse broadening. Pulse broadening is more for Linear SOP and there is no considerable difference in pulse width for Circular and Elliptical SOP. Also as PMD increases, pulse width broadening also increases. However broadening reduces compared to that of Linear SOP.

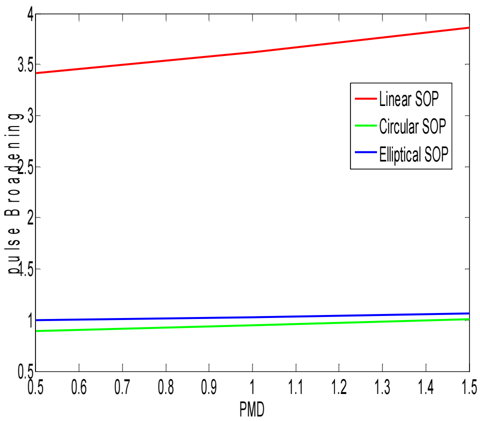

Figure.5: *Pulse Broadening For Various Values Of PMD*

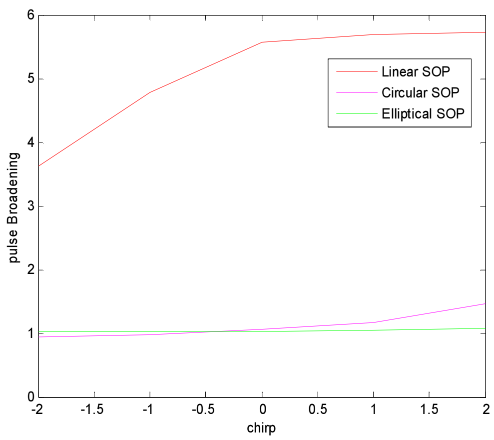

Figure.6: *Pulse Broadening For Different SOP In The Presence Of Chirp*

Figure.6 shows the pulse width broadening with various chirp values. It is found that in the presence of PMD and PDL, for negative chirp there is a linear increase in broadening and it is almost constant for positive chirp in case of Linear SOP. For Circular and Elliptical SOP, pulse width is reduced and it remains same for negative chirped pulse whereas a small difference occurs for positive chirped pulse. Hence Pulse width reduction is achieved for Circularly and Elliptically polarized signal than that of Linear State Of Polarization.

5. CONCLUSION

Results clearly show that broadening is reduced for down chirped pulse without PMD than that for up chirped pulse with PMD. Also it is found that the pulse width broadening is greatest for a PMD of 1ps, a PDL of 0.2 and an input pulse width of 50ps , C=2 for Linear SOP and it reduces when the pulse is launched at Circular and elliptical SOP. It is clear that the pulse suffers when it is subjected to combined action of Polarization Mode Dispersion, Polarization Dependent Loss and Chirping. .

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