# Influence of Birefringence on the Stability of Optical Soliton Pulses over Non-Linear Regime

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**Abstract**. The main objective of this paper is to represent the analytical solutions gleaned for the propagation of the soliton pulses through a birefringent optical fiber byusing Split Step Fourier Transform(SSFT). For 631.72km long fiber, the time delay of 200 and 400ps is observed between the X and Y polarization components which are generated due to birefringence properties, when the linearly polarized pulse is introduced into the non-linear fiber at an angle of 45° to the polarization axes. The Kerr non-linearity not only stabilizes the soliton spreading due to group velocity dispersion (GVD) but also maintains the level against spreading due to birefringence. The similar circumference occurs for birefringent walk-off distance. Further, it is observed that polarization components of soliton pulses move withcommon group velocity when X and Y components acquire blue and red shift respectively.This evolution scenario takes place in contrast with polarization mode dispersion (PMD) over a non-linear regime for a fiber length of 631.72 and 1264.344km with Θ=30°. The results are in direct proportion to the cross phase modulation (XPM) over two polarization components.

**Keywords**: Solitons, Birefringent fibers, GVD.

## 1. Introduction

The birefringence in the optical fiber makes the single mode fiber to act as bimodal. This leads to the origin of different group velocities of pulses propagating along two different principal axes. The presence of polarization components along both the X and Y axes leads to the spreading of pulse not only because of GVD but also due to the presence of birefringence.

Optical birefringence is an optical property of fiber having refractive index (R.I) dependent upon the polarization components of the pulse propagating through it. Theoretically the standard fiber should preserve the polarization components but practically, the pulse which enters the fiber with definite state of polarization, comes out dispersed due to various geometrical and material factors.

When the light wave travels through the birefringent fiber, the birefringence of fiber will lock the two orthogonal modes of light intobirefringent axes preserving therefore the polarization state of light. A guided polarized wave travelling over the axes of birefringent fiber that possess the two different birefringent axes termed as slow axes and fast axes. The pulse with high refractive index will propagate slowly on the slow axes than the guided polarized wave running on the fast axes. Along with the birefringent axes, two orthogonal components are also polarized with different phase velocities. If any of birefringent axes matches with the direction of polarization of pulse then the fiber will maintain the polarization state [5].

Birefringence of fiber is given by $B = n_s - n_f$ where $n_s$ and $n_f$ are the R.I of slow and fast axes and LB represents the length of the fiber corresponding to phase difference of 360° between two orthogonal components axes and is given as [2]:

$$L_B = \frac{\lambda}{n_s - n_f} = \frac{\lambda}{B} \quad (1)$$

Numerically, the propagation of ultra-short pulse was reported in [5], through a highly birefringent fiber using a Gaussian pulse. It was noted that when the orthogonal components of fundamental mode are provided the same angle of excitation in highly birefringent fiber by the Gaussian pulse, then the pulse amplitude will determine the direction of propagation of pulse components[3]. In the present work, numerical analysis has been done for the propagation of secant pulse in the birefringent fiber over linear and non-linear regime.

## 2. Theory

The mismatch between the group velocity of slow axes and fast axes cannot be neglected in the birefringent fiber when the input pulse is applied because it leads to the splitting of pulse into two components along two principal axes if the angle of polarization varies from 0° to 90° [7].

Mathematically, when no loss is considered, the propagation of pulse through the birefringent fiber isdescribed by the following pair of nonlinear Schrödinger wave equations:

$$\left(i\frac{\partial u}{\partial \xi}+i\frac{(\beta_x-\beta_y)T_0}{(2|\beta_2|)}\frac{\partial u}{\partial \tau}\right)+\frac{1}{2}\frac{\partial^2 u}{\partial \tau^2}+\left(|u|^2+\frac{2}{3}|v|^2\right)u\quad=0 \tag{2}$$

$$\left(i\frac{\partial u}{\partial \xi}+i\delta\frac{\partial u}{\partial \tau}\right)+\frac{1}{2}\frac{\partial^2 u}{\partial \tau^2}+\left(|u|^2+\frac{2}{3}|v|^2\right)u=0 \tag{3}$$

$$i\left(\frac{\partial u}{\partial \xi}+\delta\frac{\partial u}{\partial \tau}\right)+\frac{1}{2}\frac{\partial^2 u}{\partial \tau^2}+\left(|u|^2+\frac{2}{3}|v|^2\right)u=0 \tag{4}$$

Similarly, for *v*

$$i\left(\frac{\partial v}{\partial \xi}-\frac{\partial v}{\partial \tau}\right)+\frac{1}{2}\frac{\partial^2 v}{\partial \tau^2}+\left(|v|^2+\frac{2}{3}|u|^2\right)v=0 \tag{5}$$

where*u*and *v* are the amplitude of orthogonal components that propagate along the principal axes of the fiber[6]. In Eq. (3), $\delta=\frac{\beta_x-\beta_y T_0}{2|\beta_2|}$ is the birefringence parameter describing the mismatch between group velocities of polarized components.

$$\tau=\ t-\frac{\frac{1}{2}(\beta_x-\beta_y)}{T_0}\xi L_D \tag{6}$$

τ is the normalized time.

The amplitude of electric field envelope is normalized as $(u,v)=\ \sqrt{\gamma L_D}(E_x E_y)$

The initial condition used is$(z=0)$ for

$$u(z=0,\tau)=N\cos\theta\,\mathrm{sech}\,\tau$$

and

$$u(z=0,\tau)=N\sin\theta\,\mathrm{sech}\,\tau$$

Where *N* is the soliton order and is given by

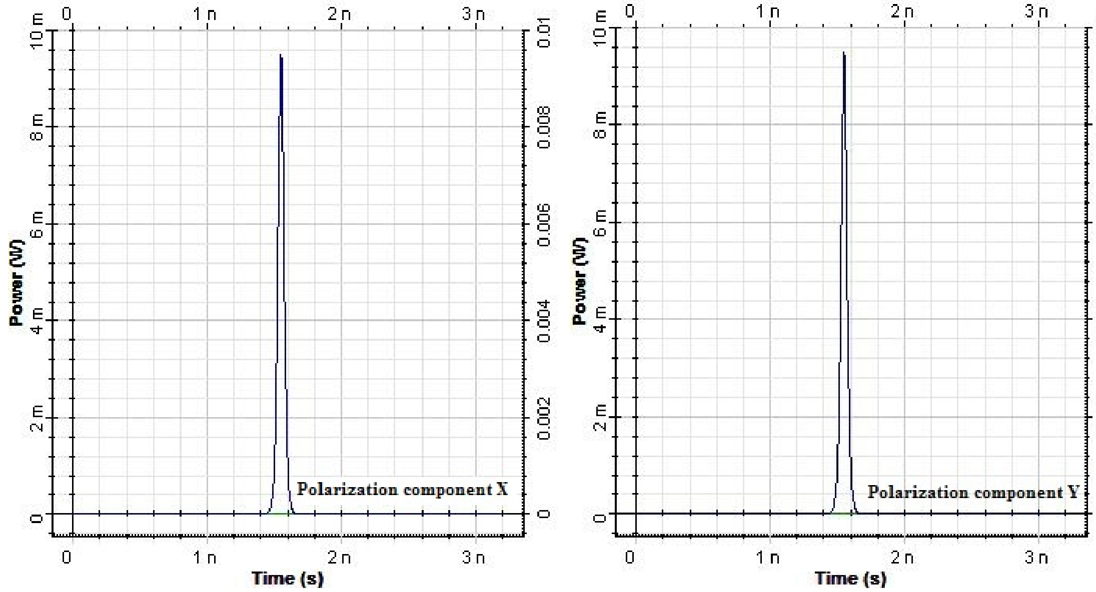
$$N^2=\frac{L_D}{L_{NL}}=\gamma\frac{P_0{T_0}^2}{|\beta_2|} \tag{7}$$

$L_D$ and $L_{NL}$ are the dispersion and non-linear length respectively. When *N>>1*, the effects of SPM are dominant and when *N<<1*, those of GVD dominate.

## 3. Results And Discussion

In the simulation model, the parameters are set as bit rate = 10 Gbps, pulse width of sech pulse = 0.5bit, $n_2 = 3\times10^{-20}\mathrm{m^2/W}$, $A_{eff} = 93\mu\mathrm{m}^2$ and $\beta_2 = 20\mathrm{ps^2/km}$.

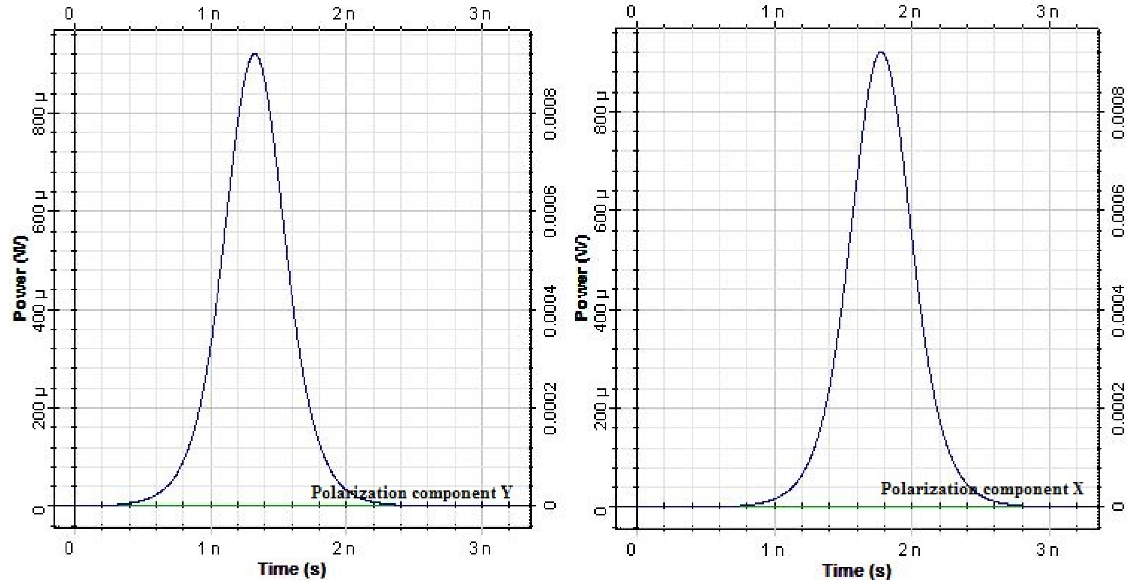
The power required to launch the soliton pulse of fundamental order is calculated as $P_0$=19.0155mW corresponding to 1550nm wavelength in the linear regime with soliton period $Z_o$=63.172km. The birefringence is calculated as $\Delta n = n_x - n_y = 2.1187\times10^{-7}$ where $n_x$ and $n_y$ are the mode indices of polarization components X and Y respectively.



(a)(b)

**Fig. 1**. Input sech pulse in linear regime at transmission distance of 631.72kmhaving Polarization components (a) X and (b) Y

The variation induced in the group delay for the polarization components per unit length of fiber is considered as $\Delta n/c$ =0.7067ps/km. The mismatch factor of group velocity $\delta$= 0.5 for $T_0$= 28.3607ps. It is necessary for birefringence to induce time delay between both the axes so that pulse remains undistorted. So, we set the azimuth angle equal to 45° in the sech pulse generator and maintained the fiber length to 631.72km.

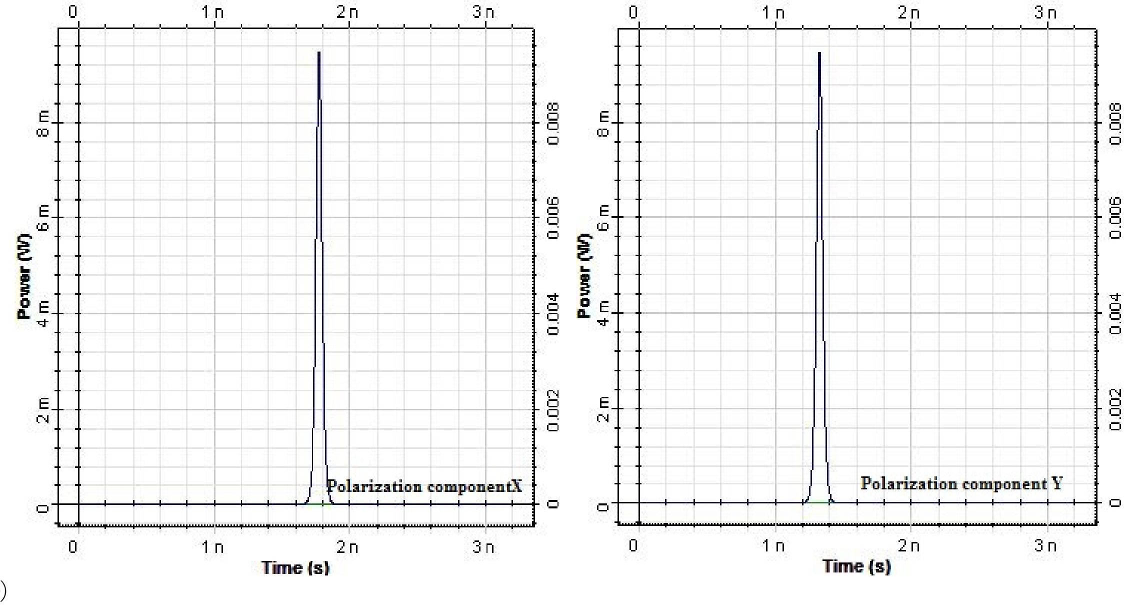


(a) (b)

**Fig.2.**Output sech pulse in linear regime at transmission distance of 631.72kmhaving polarization components (a) X and (b) Y

Figure 1 and 2 shows the input and output pulse after propagating in loss free fiber for 631.72km. The pulses along the X and Y axes spread by GVD and shifted in time domain by 440ps. The difference in arrival time is considered as 0.7ps for 1 km of fiber length. This leads to birefringent walk-off[5].

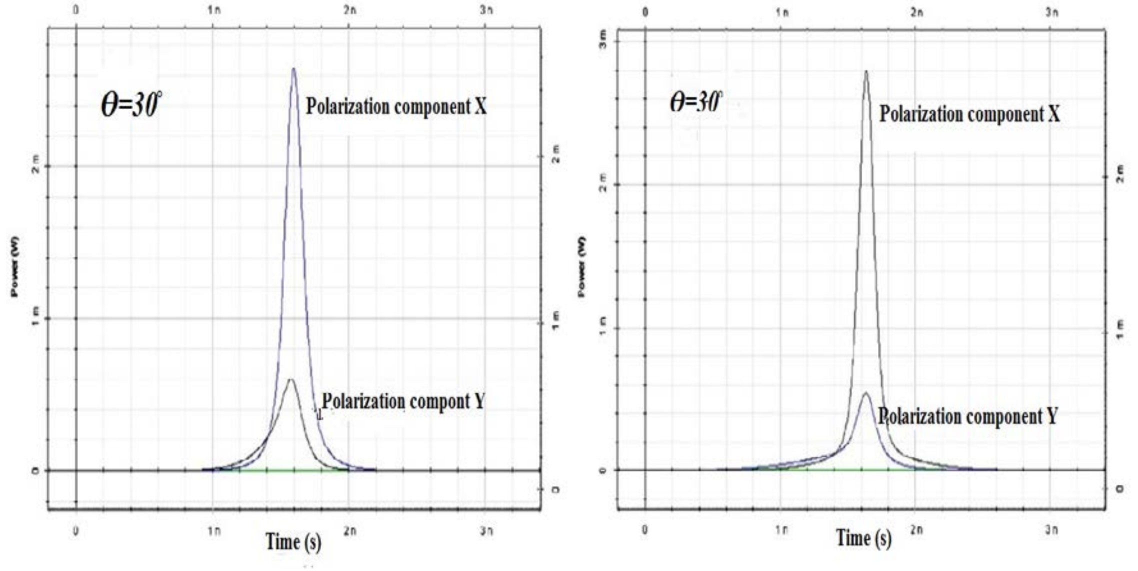
When the non-linear effects are considered in the transmission of sech pulse then the polarization components will stay together to preserve their state with the increase in soliton order to $N_{th}$.This is experimentally shown in Fig. 3 that the consideration of non-linear effects gives the output pulse with delay less than that of present in the linear effects[11].



(a) (b)

**Fig.3.**Output sech pulse in non-linear regime at transmission distance of 631.72kmhaving polarization components (a) X and (b) Y

From Fig. 2 and 3, we can compare the output the pulse in linear and non-linear regimes respectively. The impact of non-linear effects is observed to be useful as they reduce the broadening of pulse by GVD and also reduce the time delay between the polarization components [12]. The time delay is reduced to 200ps from 400ps which is comparatively smaller than the delay introduced in the linear regime. It can be concluded that the reduction in the birefringent walk-off is possible, as the polarization components on fast axes slowed down with respect to the polarization components on slow axes due to the presence of XPM[15].



(a) (b)

**Fig.4.** Output polarization components X and Y for sech pulse with Θ=30° at transmission distance (a) 631.72km and (b) 1264.344km

When the angle of polarization is 45° and $\delta$= 0.5, the small amount of energy is introduced into smaller pulse by larger pulse and remaining part is dispersed during propagation[5].

If the parameters are changed and new polarization angle is considered as 30° with $\delta$=0.15, the power noted is 12.1699mW, then the two orthogonally polarized components of the soliton pulses move with the same velocity irrespective of the difference in their modal indices as the smaller pulse is captured by the larger pulse and two move together [9].

## 4. Conclusion

In this paper, simulative analysis of soliton pulse propagating over birefringent fiber has been carried out for the linear and non-linear transmission. The time delay between X and Y polarization component is calculated as 200ps and 400ps for linear and non-linear regimes. Hence, it is concluded that the non-linear effects results in the reduction of birefringent walk-off as time delay is reduced. The comparison for polarization components has been performed at $\Theta$= 45° and $\Theta$=30° for fiber length 631.72 and 1264.344km in linear and non-linear regimes. As a result of XPM, the soliton trapping occurs when the angle of polarization becomes 30° where both the polarization components of soliton pulses move together and results in the stability of soliton pulses in birefringent fiber.

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