Split Step Fourier Method Application : Reducing Pulse Broadening Effect for a Single Mode Optical Fiber

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***Abstract* — An increasing needs of a high bit rate transmission systems encourage the communication engineers to design a better system. In practical, a 40 Gbps rate of transmission can only be achieved in a fiber optic system. Although this performance can be achieved through this media, the disturbances such as dispersion and non linearity which can be manifested into a pulse broadening may occur during the transmission system. Since this phenomenonis caused by the Group Velocity Dispersion (GVD) in a high bit rate fiber optic, a careful consideration on the effectiveness of the systems is needed. A numerical approach in this paper used a novel analysis method of high order NLSE with a Split Step Fourier Method. The aims of this proposed model is to find a suitable value of the dispersion constants in terms of β_2 and $\beta_3$which are assumed to be a part of second and third order dispersion respectively. To reduce the effect of pulse broadening, this paper proposed an novel approach through the value of pulse broadening ratio and intensity. Consequently, it is found that a negative pre-chirping in the averaged value of 1.8944 and C=-2 have the best result among others in a Gaussian signal simulation.**

Keywords - NLSE, SSFM, Symmetrized SSFM, attenuation, GVD, TOD, chirping, pulse broadening ratio, optical fiber, dispersion, nonlinear effects and spectral evolution, long-haul fiber.

I. INTRODUCTION

The rapid development on a high speed telecommunication technology has been reached its peak of demand. The user needs a super speed, real time, and a long distance transmission to full fill their needs of social media and daily needs. Internet, cable TV, and telecommunication network nowadays need at least 10 to 40Gbps to reach its stated requirements [1].

Several research on transmission and light wave waveguide has been done in laboratories worldwide and consequently only fiber optic which are compatible and reliable with the requirements since the total internal reflection system can ensure the stability of its speed [4]-[8]. The speeds are depend on the speed of light and its medium index. As it dependencies to the light speed and medium index, the non linear and high dispersion effects may occur. These effects can be manifested in several disturbance in the transmission signal. One of its significant effects is the pulse broadening. Further discussion and its characteristics will be discussed in the next sessions. This effect may occur in a long-haul and high speed fiber optics [27].Several research within the mathematical approach of Maxwell equation has been done to increase the efficiency of the transmitted signal.

Due to its complicated vector dimensions, the Non Linear Schrodinger Equation (NLSE) were attributed to simplify its forms into a sequence of equation [5],[7],[28]. The NLSE are represent the facts that the two main effects which are dispersion and non-linearity are occur through the transmission system and distort the input pulse signal [3]. As our concentration is the pulse broadening which is a part of the linear term of NLSE, so its sequence has to be classified and separated with respect to its non linear term. A numerical approach such as Split Step Fourier and Symmetrized Split Step Fourier Method were applied to the equation to have a better performance in terms of high orders accuracy. These methods may reach second and third order of accuracy to provide an easier way to analyze the effects within the numerical approach.

II. PULSE BROADENING AND GROUP VELOCITY DISPERSION (GVD)

Since the telecommunication has been developed, the users demands on bandwidth in all network areas from long-haul to network are growing continuously. Consequently, the more bandwidth needed for the required system, the more cost needed to develop the system. In this case, the telecommunication carriers may prefer to increase the capacity of their existing fiber transmission links within the dense wavelength division multiplexing (DWDM) system application or using a high bit rates system.

Nowadays, the highest bit rate of fiber optic links areup to 40 Gbps [27]. In this specification, the power input needed to transmit the signal were also high so that the system needs to be employed carefully due to several effects arise from this performance.

In fiber optic transmission system, quality of service for the user is one of the most critical issue over decades. One of its major obstacle to transmit a better quality of data transmission is chromatic dispersion. The chromatic dispersion is generated when an electromagnetic waves react with electrons which surround the sides of a dielectric boundaries, then it will lead to the dependence of the optical response of the medium to the frequency (ω) which is known as chromatic dispersion. The primary cause of the chromatic dispersion is the fact that different spectral components of light impulse propagate in the optical fiber at different speeds. That phenomenon leads to the different time of arrival to the end of the fiber, impulse width increases and inter-bit spaces narrowing. Consequently , the receiver may hard to recognize the logical value of the binary and the distortion of transmitted information will increase the BER.

The existence of chromatic dispersion differ into two common dispersion which are material dispersion and waveguide dispersion. The material dispersion cause changes in the medium index which are depend on the change in frequency. That is the basis for the formation of non-linear effects in optical fiber transmission systems. Basically, the chromatic dispersion is derived from the reaction which are generated when it absorbs the electromagnetic radiation while the resonant frequencies occured. The dispersion effects in a fiber has an important role in a short optical pulse propagation due to the differences in the spectral components associated with the different velocity of pulse propagation.

$$v = \frac{c}{n(\omega)} \tag{1}$$

It is clearly described by the equation (1) the velocity of its pulse propagation is directly proportional with speed of light c and depends on the medium index $n(\omega)$.

Furthermore, the waveguide dispersion is caused by the boundary condition at the fiber surface which are influenced by geometrical parameters along the fiber. The fiber geometrical parameters are the transversal profile of the refractive index and the fiber core radius with respect to the signal wavelength ratio [1]. Consequently, it leads to the decresing speed of light within the fiber optic.

Before modelling the chromatic dispersion into the simulation, the expansion of the mode propagation constant or β can modeled by describing the propagation constant (β) in a Taylor series as follows:

$$\beta(\omega) = n(\omega)\frac{\omega}{c} = \beta_0 + \beta_1(\omega - \omega_0) + \frac{1}{2}\beta_2(\omega - \omega_0)^2 + \frac{1}{6}\beta_3(\omega - \omega_0)^3 \quad \ldots \tag{2}$$

Where ω is the angular frequency and the $n(\omega)$ is the frequency dependent refractive index. For each row constants (βm) is expressed by the following equation:

$$\beta_m = \left(\frac{d^m\beta}{d\omega^m}\right)_{\omega=\omega_0} \; (m = 0,1,2,3,\ldots) \tag{3}$$

The parameter β_0 is involved in the phase velocity v_P of the optical carrier defined as :

$$v_P = \frac{\omega_0}{\beta_0} = \frac{c}{n(\omega_0)} \tag{4}$$

β_1 and β_2 parameters are related to the refractive index n and its derivatives within the following equation:

$$\beta_1 = \frac{1}{v_g} = \frac{n_g}{c} = \frac{1}{c}\left(n + \omega\frac{dn}{d\omega}\right) \tag{5}$$

$$\beta_2 = \frac{1}{c}\left(2\frac{dn}{d\omega} + \omega\frac{d^2n}{d\omega^2}\right) \tag{6}$$

From the equation (4)-(5) show the group index (n_g) and the group velocity (v_g). The β_1 determines the group velocity which is related to the mode propagation constant β. In addition, physically when the pulse envelope moves with the speed of group velocity, $\beta_2$constant represents the dispersion of the group velocity and responsible for the formation of the pulse shape widening (pulse broadening) [2]. This phenomenon is known as the group velocity dispersion (GVD) and $\beta_2$is the parameter of GVD.

In Fig.1, we see that the value of β_2 will be zero when the wavelength reaches 1.27 μm and has a negative value. This wavelength is known as the zero-dispersion wavelength and denoted by λ_D. Although β are negligible when it reaches $\lambda=\lambda_D$, the dispersion effects are still remain in the system.

The pulse propagation wavelength which approach this condition requires the additional cubic term of the Taylor series dispersion constants (β3)[3].

The Coefficient of β_3 which will be added in the equation is called the third order dispersion (TOD). The higher the order of dispersion equation, the higher the likelihood where an interference will occur on a short optical pulse in terms of linear and non-linear respectively. However, the presence of TOD (β_3) affects only when λ approaching λ_D within a few nanometers. The magnitude of the effect *D* depends on the constant of dispersion and described by the following equation:

$$D = \frac{d\beta_1}{d\lambda} = -\frac{2\pi c}{\lambda^2}\beta_2 \approx \frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \tag{7}$$

DOI 10.5013/IJSSST.a.16.06.08 ISSN: 1473-804x online, 1473-8031 print

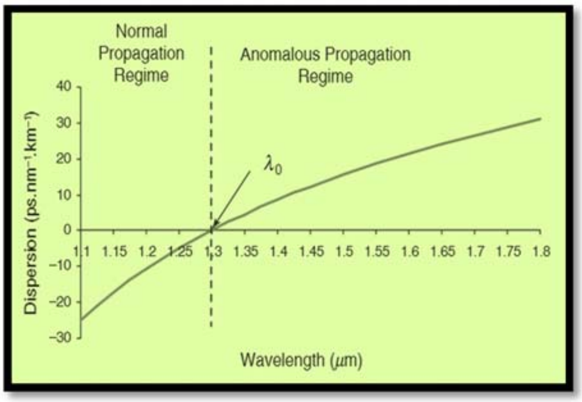

Fig.1.Wavelength value within the increasing value of β_2[2]

Pulse broadening effects may vary qualitatively and depend on the GVD value whether it is either negative or positive. That phenomenon are due to the nature of the magnetic field wave propagation *H*in a normal dispersion range. When the value of frequency is getting bigger (*blue-shifted*), it will propagates slower. In an opposite way, when the value of frequency is getting smaller (*red-shifted*), it will propagates faster. The nature of these waves are related to the optical propagation when the value of $\lambda < \lambda D$, the fiber will show a normal dispersion effect due to the value of $\beta 2 > 0$. However, for the value of $\lambda > \lambda D$, the fiber will show anomalous dispersion effects due to the value of $\beta 2 < 0$. The anomalous dispersion is the most important part of this study as the soliton may propagate with the balance between the dispersion and non-linear effect.

III. Length of Dispersion

One of the most critical parameter that govern the effects of chromatic dispersion imposing on the transmission length of an optical system is known as the dispersion length L_D. Conventionally, the dispersion length L_D corresponds to the distance after which a pulse has broadened by one bit interval. The chromatic dispersion coefficient $D(\lambda)$ is a primary parameter. It determines the size of the chromatic dispersion and described by the following equation :

$$D(\lambda) = \frac{dt_g}{d(\lambda)} \tag{8}$$

Within the transmission system, chromatic dispersion which is one of the most critical factor which affected the quality of service through the maximum length of transmission L_{max}. For a fiber assumed that it has no chromatic dispersion can be defined using the following equation :

$$L_{max} = \frac{104.000}{B^2 . D(\lambda)} \tag{9}$$

TABLE I. MAXIMUM REACHABLE DISTANCE FOR VARIOUS NRZ PULSE SPECTRAL WIDTHS AND FIBER.

Bit Rate [Gbps]	D[ps/nm.km]	L_{max}
10	1000	63
40	60	4
100	16.75	0.6

IV. Proposed Model

A. Non Linear Schrodinger Equation

As mentioned in the previous part, the dispersion and non-linear effects that occur during the process of light propagation in the optical transmission system. To maintain the length of propagation and its 40 Gbps high bit rate, the performance dependencies with respect to those effects are not able and continuously depicted within the NLSE model . This study uses a reference of Silica Glass Fiber as a reference of research because this type of fiber is widely used in several optical communication systems[5].

To simplify the modelling of dispersion and non linearity effects in NLSE, we assume that the input signals are in the form of Gaussian and it is necessary to analyze each of the dispersion and non linearity parameters before we combine them into a complex high order non linear schrodinger equation with Gaussian input. There are some effects parameters such as attenuation (α), dispersion (β), and non linearity (γ) . Those effects were then combined into a form of *slowly-varying envelope amplitude A(z,t)* [3], then transferred into a frequency domain by a *Fourier transform* and finally simplified into a form of differential function [7] is as follows :

$$\frac{\partial A(t,z)}{\partial z} = -\frac{\alpha}{2} A(t,z) + \frac{i}{2} \beta_2(z) \frac{\partial^2 A(t,z)}{\partial t^2} + \frac{i}{6} \beta_3(z) \frac{\partial^3 A(t,z)}{\partial t^3} - i\gamma |A(t,z)|^2 A(t,z) \tag{10}$$

One of the factors that limit the performance of transmission capacity of the fiber optics communication channel is the chromatic dispersion[4]. The rate at which the data can be transported on a single fiber is limited by a pulse broadening due to chromatic dispersion. In this paper, we present a mathematical approach that can be applied for analyzing higher-order chromatic dispersion in single mode Silica fibers. In this regard, at first a closed formula is presented for finding the exact values of the derivatives of the refractive index with respect to wavelength, then the Taylor expansion of the propagation constant were used at through the zero dispersion wavelength [3]. Our limitation to the high order dispersion are within the order of cubic terms as follows :

$$\beta(\omega) = n(\omega)\frac{\omega}{c} = \beta_0 + \beta_1(\omega-\omega_0) + \frac{1}{2}\beta_2(\omega-\omega_0)^2 + \frac{1}{6}\beta_3(\omega-\omega_0)^3 \quad (11)$$

TABLE II. EXPERIMENT CHARACTERISTICS OF HIGH DISPERSION SYSTEM.

Variables	Value [unit]
$P_0(peak\ power\ input)$	0.00064 W
$T_0(initial\ pulse\ width)$	1e-13 s
$\beta_2(2nd\ order\ dispersion\ )$	-10;-20;-30;-40;-50 ps2/km
$\beta_3(3rd\ order\ dispersion)$	0.1 ps3/km
$\gamma\ (nonlinear\ coefficient)$	0.003 W/m
$L'_D(dispersion\ length)$	0.0019;0.03;0.09; 0.1 s^2/m
$C\ (input\ chirp\ parameter)$	-3;-2 ; 0; 2;3

The parameters in (2) are the group velocity *Vg* parameter (β_1), GVD (*Group Velocity Dispersion*) parameter (β_2), and third order dispersion parameter (β_3). The other approach to reveal the effect due to the parameters are a chirping (when the C constants value are either positive or negative) from -3 to 3.

Furthermore, the Split Step Fourier Method (SSFM) were applied to the system within this equation :

$$\frac{\partial A}{\partial z} = (\hat{D} + \hat{N})A \quad (12)$$

B. Split Step Fourier Method (SSFM)

SSF method is an efficient numerical technique to model the NLSE [10]. In the assumption of SSF method, the effect of linear and non linear are divided into two parts respectively with respect to the length of propagation inside the transmission system. Within the mathematical approach and several Fourier transformation in the SSF method pre-formulation, the following equation were obtained :

$$\hat{D} = -\frac{i\beta_2}{2}\frac{\partial^2}{\partial T^2} + \frac{\beta_3}{6}\frac{\partial^3}{\partial T^3} + \frac{\alpha}{2} \quad (13)$$

$$\hat{N} = i\gamma\left(|A|^2 + \frac{i}{\omega_0}\frac{1}{A}\frac{\partial}{\partial T}(|A|^2 A) - T_R\frac{\partial |A|^2}{\partial T}\right) \quad (14)$$

In fact, both dispersion and non linear effects are actually occur simultaneously in the fiber optic transmission system. However, those effects are considered over a step size distance of signal propagation length which are described as h and z. The step size h in the implementation are defined as the divided total length of fiber propagation length. For each segment, the computations of the system are initialized within the process of each segment of the following equation :

$$A(z+h,T) \approx exp(h\hat{D})exp(h\hat{N})A(z,T) \quad (15)$$

The first step is done when the $\hat{D}$ operator assumed to be dominant upon the propagation signal and the $\hat{N}$ is assumed to be zero. The second step were done in the opposite way as in equation (16).

In this method the analysis will be performed in the maximum of the second order term of accuracy only. It is possible due to the number of Fourier integration parts which is equals to two step. Consequently, the numerical approach has a maximum of second order sequence.

$$exp(h\hat{D})B(z,T) = F_T{}^{-1}exp[h\hat{D}(i\omega)]F_T B(z,t) \quad (16)$$

C. Symmetrized SSFM

To improve the accuracy of the modelled system, then in the next method, each of the segment is further divided into two halves each of length *h/2* and the non linearity is lumped at the middle of each segment. This method is called symmetrized SSFM due to the half part of length propagation z are defined as the dispersion part and the middle one is assumed as the non linearity segment.

$$A^{DN}(z+h,t) = exp\left(h\hat{D} + h\hat{N} + \frac{h^2}{2}[\hat{D},\hat{N}] + \frac{h^3}{12}\left[\hat{D}-\hat{N},[\hat{D},\hat{N}]\right] + \cdots\right)A(z,t) \quad (17)$$

$$A^{ND}(z+h,t) = exp\left(h\hat{D} + h\hat{N} - \frac{h^2}{2}[\hat{D},\hat{N}] + \frac{h^3}{12}\left[\hat{D}-\hat{N},[\hat{D},\hat{N}]\right] + \cdots\right)A(z,t) \quad (18)$$

This paper used this terms of SSF method to determine the propagation terms inside the fiber optic communication for maximum third order accuracy as in equation (17) . The high accuracy is possible due to the existence of three fast Fourier transform operator in the modelled equation. In the symmetrized SSFM, the NLSE were also divided into two terms which are :

$$A(z+h,T) \approx exp\left(\frac{h}{2}\hat{D}\right)exp\left(\int_z^{z+h}\hat{N}(z')dz'\right) exp\left(\frac{h}{2}\hat{D}\right)A(z,T) \quad (19)$$

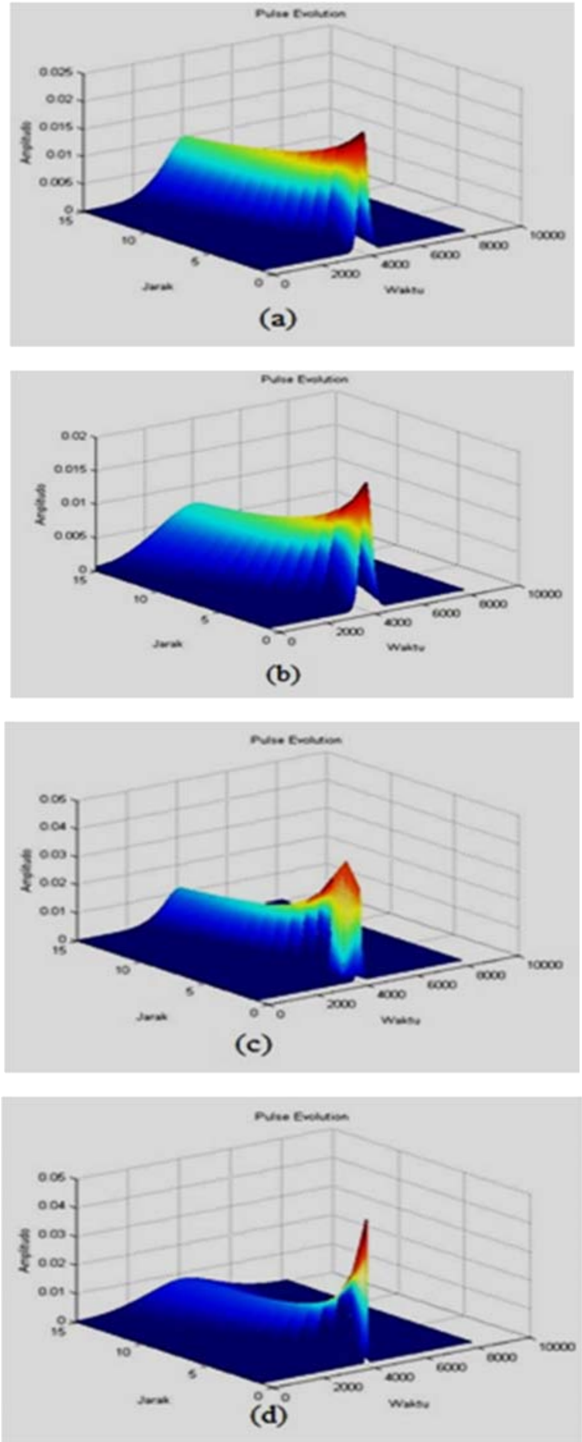

Figure 2. (a) Soliton pulse with chirping C=2. (b) Soliton pulse with chirping C=3 (c) Soliton pulse with chirping C=-2. (d) Soliton pulse with chirping C=-4

In that equation, several mathematical approach were applied to the equation and the result show that the most likely form of trapezoidal rules of numerical approach were applied to the system due to its form of h/2 part of symmetrical propagation length of z in the small scale of propagation length unit h.

$$E(jh,t) \approx \mathcal{F}^{-1}\left\{exp\left(\frac{h}{2}\hat{D}(i\omega)\right)\mathcal{F}\left\{exp\left(\int_z^{z+jh}\hat{N}(z')dz'\right)\mathcal{F}^{-1}\left\{exp\left(\frac{h}{2}\hat{D}(i\omega)\right)\mathcal{F}\{E((j-1)h,t)\}\right\}\right\}\right\} \quad (20)$$

In the symmetrized SSFM, computations are started with the slowly varying envelope A(z,t) propagate along the distance of *h/2* and for the first assumption the dispersion and fiber loss are considered to be first calculation. Furthermore, the output field at the mid plane *(z+ h/2)* is multiplied by the non linear terms (11) in the whole segments over z. Through these processes, the performance degradation can be revealed.

V. Results and Analysis

This research aims are to determine how the influence of high order dispersion effects and non-linear occur in an optical fiber transmission system with the bit rate of 40 Gbps and long distances (long-haul and high bit rate transmission). The need for specification is certainly a challenge ones because to maintain signal quality at high speed and far distances require special attention to prevent loss in the transmitted signal. It is intended for users who use fiber optics for a variety of applications able to enjoy a good quality of service. To that end, various methods performed to determine the interference process that occurs in the transmission line.

A. Second Order Analysis Method (SSFM

Based on the simulation results obtained with respect to the second order dispersion and non-linear effects, it was found that in Table 3 which is a simulation of Pulse Brodening Ratio (PBR) calculation. As the value of each PBR are obtained, the mean value can be determined using the simple mean statistics formula which is the ratio between the summation of all PBR values over the number of PBR value obtained. The best PBR mean were obtained when the chirping value is negative C=-2 and the value of non-linear value remain constant at 0.003W/m.

$$PBR = \frac{FWHM\ of\ propagating\ pulse}{FWHM\ of\ first\ pulse} \quad (21)$$

$$\overline{PBR} = \sum_{i=1}^{n}\frac{PBR_I}{n} \quad (22)$$

Where the average value of PBR at the time of the negative Chirpie C=-2 and non-linear constant value which remains shows the average PBR with a value of Area2.The average value is the lowest of the overall results of the simulation. So it can be said that the negative chirping operation on the input pulses in optical fiber transmission with a constant non linearity value remains constant is the best solution to reduce the effects of pulse broadening and non linear oscillations.

TABLE III. PBR VALUE FOR CONSTANT NON LINEAR VARIABLE

POSITIVE CHIRP (C=2) ($\gamma = 0.003$)		**POSITIVE CHIRP (C=3) ($\gamma = 0.003$)**		**NEGATIVE CHIRP (C=-2) ($\gamma = 0.003$)**		**NEGATIVE CHIRP (C=-3) ($\gamma = 0.003$)**	
β_2	PBR	β_2	PBR	β_2	PBR	β_2	PBR
-10	3.2924	-10	5.1171	-10	2.0861	-10	3.5849
-20	3.9731	-20	5.5975	-20	2.4513	-20	3.8814
-30	4.1566	-30	5.7394	-30	2.5742	-30	3.9763
-40	4.2429	-40	5.8032	-40	2.6339	-40	4.0219
-50	4.2927	-50	5.8438	-50	2.6710	-50	4.0518

For the next simulation, when the simulation systems has some modifications where the non linearity constants became inconstant variable and the β_2 were being the constant variable so that simulation results are listed in the following table :

TABLE IV. PBR VALUE WITH CONSTANTβ_2 VARIABLE

POSITIVE CHIRP(C=2) ($\boldsymbol{\beta_2 = 20}$)		**POSITIVE CHIRP (C=3) ($\boldsymbol{\beta_2 = 30}$)**		**NEGATIVE CHIRP (C=-2) ($\boldsymbol{\beta_2 = -20}$)**		**NEGATIVE CHIRP (C=-3) ($\boldsymbol{\beta_2 = -30}$)**	
γ	PBR	γ	PBR	γ	PBR	γ	PBR
0.01	1.9306	0.01	4.2429	0.01	1.5487	0.01	3.1288
0.00975	2.0251	0.00975	4.3089	0.00975	1.5876	0.00975	3.1600
0.009	2.3116	0.009	4.4983	0.009	1.6779	0.009	3.2554
0.005	2.6782	0.005	5.2879	0.005	2.2063	0.005	3.6838
0.003	3.9731	0.003	5.5975	0.003	2.4513	0.003	3.8814

From the results of the simulation which are illustrated in Figure2 (a)-(d),Table 3and Table 4. It can be seen that along with some variation of Chirp parameter, β_2, and γ, the negligible Chirp value (C =0) then a pulse does not apply the chirping process. This causes the dispersion induced broadening does not depend on the sign GVD parameter (β_2) for both negative and positive value. However, the opposite occurs when pulse chirping process were applied to the system, for the value C=2 (where C>0) shows that the instantaneous frequency linearly increases from its leading edge to trailing edge. The opposite occurs when C=-2(where C<0) which shows that the instantaneous frequency decreases linearly from the leading edge to trailing edge. It can be concluded that when a pulse does not applied a chirping process the spectral width will be limited and satisfy the equation $\Delta\omega T_0 = 1$ and with the following equation:

$$\frac{T_1}{T_0} = \left[\left(1 + \frac{C\beta_2 z}{{T_0}^2}\right)^2 + \left(\frac{\beta_2 z}{{T_0}^2}\right)^2\right] \tag{23}$$

It is indicated that the pulse broadening depends on the sign of the GVD parameter (β_2) and the parameter Chirp (C). Where in a Gaussian pulse widen monotonically with respect to zifβ_2C>0 and the opposite way may occur that the Gaussian pulses narrows monotonically when the value β_2C<0.

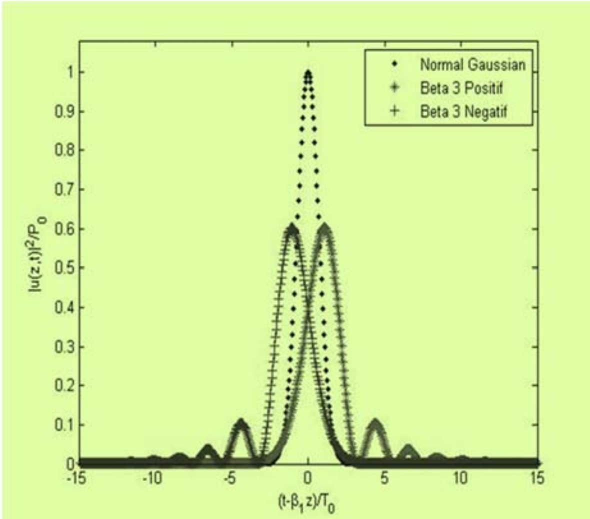

Figure 3. TOD implementation to Gaussian Results

It can be seen from Table 4 that the best value of the average PBR is in the simulation within the Chirp value of C=-2. All of these values is being the smallest values when compared with the other average PBR-chirping simulation results. This proves that the value of the positive and negative chirping can affect the state of the signal in the transmission line. The negative chirping method was implemented in the signal where a higher wavelength are delayed ("Red shifted") and has the benefit of lowering the pulse broadening effect and oscillation. This is because the "delay" of a higher wavelength may inhibit the effect of GVD. At a normal incidence, part of the pulse which has a higher wavelength has a higher value of GVD. When the value of GVD is getting lower due to the existence of delay, the pulse broadening effects will be minimized.

B. Third Order Analisys Method 9Symmetrized SSFM)

Chriping method is one of the substantial factor that affect the pulse broadening effect. In this case, the chirping

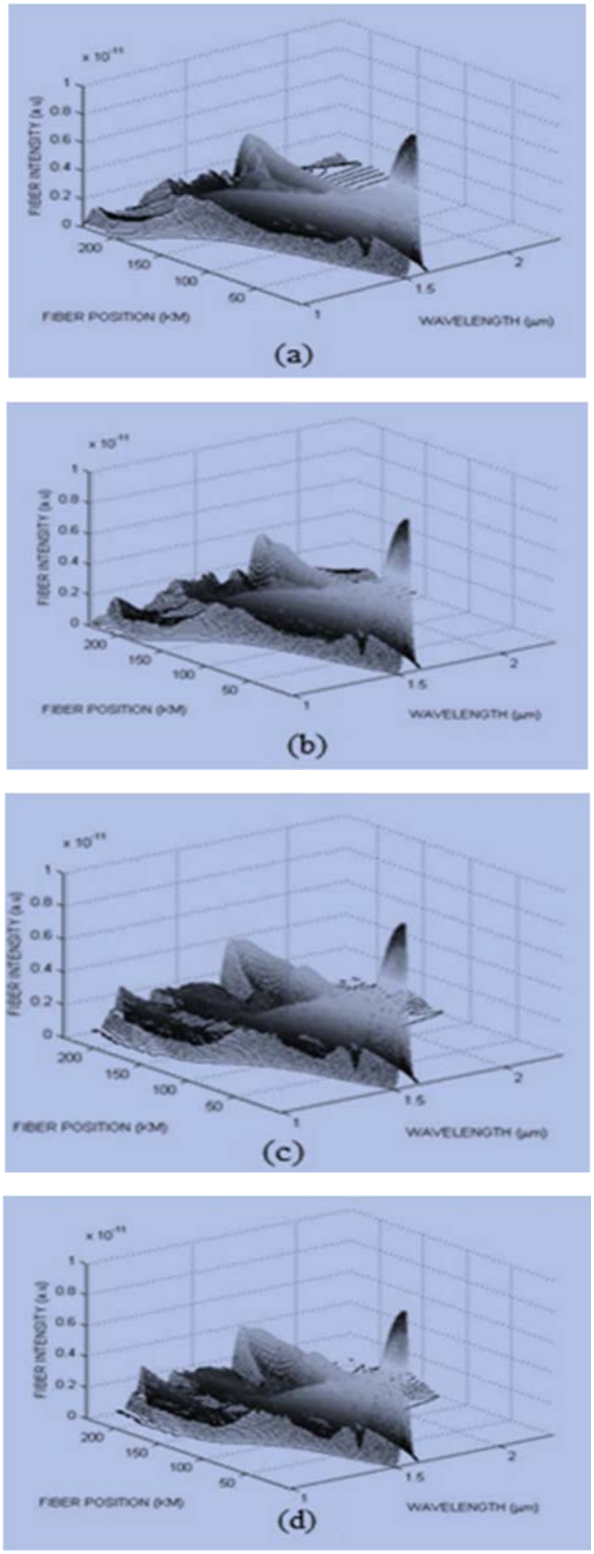

Figure 4. *Pulse shape evolution* with certain values of L'_D: (a) L'_D = 0.019. (b) L'_D = 0.03. (c) L'_D = 0.09. (d) L'_D = 0.1 .

constant take a role in the output result of the system as in Figure2 (a)-(d),described how variation of parameters in NLSE affect the pulse shape due to the significance of chirping method.

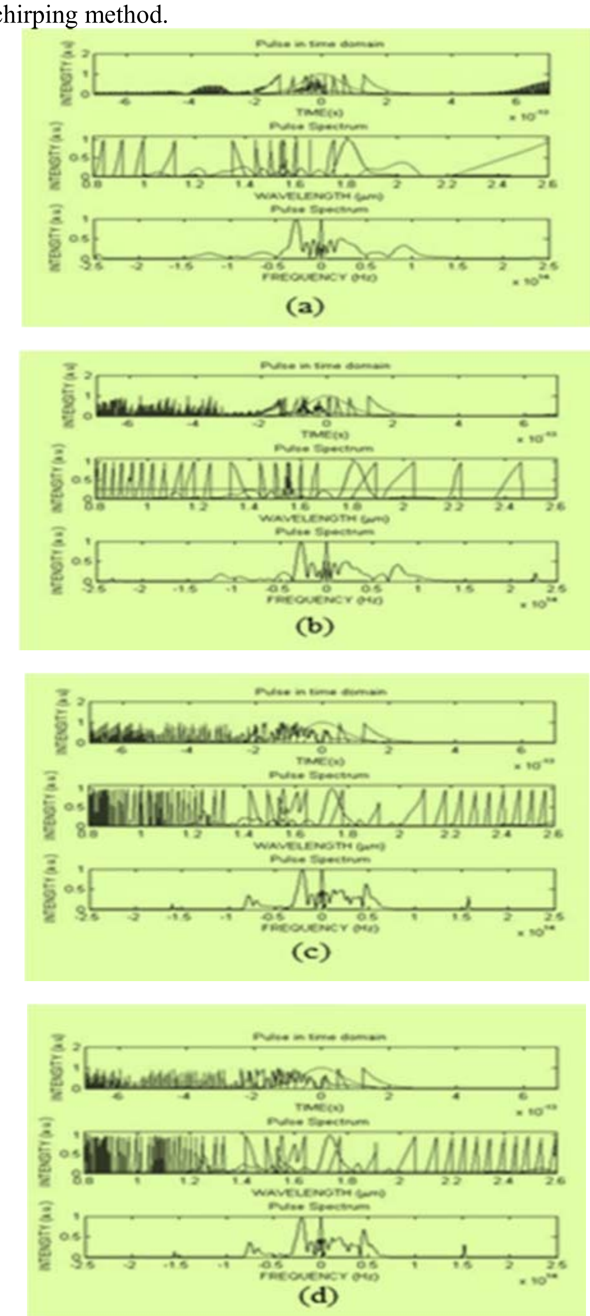

Figure 5. Pulse spectrum for various dispersion slopes: (a) L'_D = 0.019 (b) L'_D = 0.03. (c) L'_D = 0.09. (d) L'_D = 0.1

The accuracy of Symmtrized SSFM can reach as high as third order. This accuracy may facilitate the simplicity of analyzing the influence of β_3 presence in NLSE modelling. The existence of β_3 is being significant when the value of β_2 became much smaller or negligible with respect to the value of β_3 . For a positive β_3 constant value as shown in

DOI 10.5013/IJSSST.a.16.06.08 ISSN: 1473-804x online, 1473-8031 print

the previous simulation in figure 3 , the oscillations were occur in the trailling edge. Within the Symmetrized SSFM, the same phenomenon were occur with a detail shape of solitons in figure 4 (a)-(d). In the figure stated, the oscillation were always occur except when the value of L_D slope L'_D is equal to 0.019 s^2/m in figure 5 (a).

The simulation was also carried between the variations of L'_D which are equal to 0.019 s^2/m, 0.03 s^2/m, 0.09 s^2/ m, and 0.1 s^2/m. The variations of L'_D were done due to the directly proportional values of variabels L'_D and the value β_3 so that the numerical approach can fit the computation needs. In Table 5it can be seen that the largest intensity value is belong to the biggest value of L'_D is directly proportional to β_3 that numerical approximation can be done. Can be seen in Table 3 that the largest intensity value falls to the value of L'_D which is 0.1 s^2/m.

It also can be analyzed that the β_3 value is directly proportional to L'_D and the β_3 value determinationwere indeed have a good value of intensity along the long haul fiber within thestandard value of 0.019 to avoid the high-intensity oscillations that can interfere the information signal quality which are transmitted through the fiber optic long-haul and high bit rate transmission system.

The SSFM method and Symmetrized SSFM in this case clearly described the function of β_2 and the existence of gamma in the NLSE. It is found that certain chirping value and constant value of gamma affected the ratio of pulse broadening and resulting in the average value of 1.8944 when the $\beta_2$are constant and the value of chirping C=-2.When the chirp value is set to be zero valued, then it means that the input pulse does not applya chirping method on.As the chirping method is not applied to the input pulse (C = 0), this leads to the dispersion induced broadening does not depend on the sign of GVD parameter (β_2) neither negative or positive. However, the opposite ways occurs when a chirping method is applied to the input pulse. For the value of C = 2 (where C> 0) it was found that the instantaneous frequency increases linearly from the leading edge to the trailing edge.

TABLE 5. THE SIMULATION RESULTS FOR THE VARIATION OF L'_D

POSITIVE CHIRP $T_{FWHM} = 8.10^{-14}$ $L_D = 10^{-9}$	
$L'_D \left[\frac{s^2}{m}\right]$	**Intensitas (a.u)**
0.019	3.2924
0.03	3.9731
0.09	4.1566
0.1	4.2429

VI. CONCLUSIONS

As we obtained the simulation results, it can be concluded that the order of the dispersion parameter variation takes effect where chirping method was done in the input pulse of propagation process. If the process of chirping was not done, then the effect within propagation channel due to the second-order dispersion. Furthermore, it was found that the negative chirping has the best value among all result in the terms of PBR ratio which is in the average of 1.8944 when the chirping value C= -2 and the value of $\beta_2$were constant and the value of $\gamma = 0.003$ were on its standard form. To that end, not only the chriping approach are proposed, but also the dispersion parameters, non linearity, and power inputs should be determined due to the shape, quantity, speed, and amplitude of the input pulse were affected by those factor respectively

REFERENCES

[1] Pincemin, E. Poignant, H. 2010. “Paradigms of 40/100 Gbps deployments on France Telecom long-haul transport network: Overcoming transmission impairments while adapting network architecture and analyzing economical impact” .Optical Communication (ECOC), 2010 36th European Conference and Exhibition 2010.

[2] Endra. 2005. “Studi efek pre-chirping optical soliton pada single mode dispersion-shifted fiber”. Thesis of Electrical Engineering – Universitas Indonesia.

[3] P. Agrawal, G. 2002. Fiber-Optic Communication Systems. NY: John Wiley, Inc. USA.

[4] P.Agrawal, G. 1995. Non Linear Fiber Optics 3rd edition. California, USA : Academic Press.

[5] Goorjian, P. 1992. “Computational Modelling of Femtosecond Optical Solitons from Maxwell’s Equations”, IEEE journal of Quantum Electronics, Vol.28 No.10.

[6] Tian, Bo. 2011. “Symbolic Computation on Soliton Solutions for Variable-Coefficient nonlinear Schrodinger Equation in Nonlinear Optics”. Springer LLC (Opt. Quantum Electron 2012).

[7] Xu, Bo. 2003. “Study of Fiber Nonlinear Effects on Fiber Optic Communnication System". A P.hD Dissertation – University of Virginia

[8] Wentworth, S.M. 2005. “Fundamentals of Elcetromagnetics with Engineering Applications”. New York : John Wiley & Sons, Inc.

[9] J-P Laude, DWDM Fundamentals, Components, and Applications, Artech House, 2002.

[10] Fernandez, A., “Overview of adaptive step-size techniques when solving the non linear Schrodinger Equation for simulating light-wave propagation in optical fibers”, Universite de Toulouse, UPS, Toulouse, France (2013).

[11] M.Miyagi and S. Nishida, *Appl. Opt* B **18**, 678 (1979).

[12] RF photonics.2014.”Introduction to Femtosecond Laser Optics”.

[13] A.Hasegawa, “Tranmission of stationary nonlinear optical pulses in dispersive dielectric fibers: Anomalous dispersion”, Appl.Phys. Lett.23,142 (1973).

[14] J.P Gordon.1986. “Theory of the Soliton self-frequency shift”, Opt Lett.11(10),662.

[15] N.N Akhmediev et al., (1998) “Stable soliton pairs in optical transmission lines and fiber lasers”, J. Opt. Soc. Am. B 15 (2), 515.

[16] V.N Serkin and A.Hasegawa, (2000) "Novel soliton solution of the Non Linear Schrodinger Equation Model", Phys. Rev. Lett. 85 (21), 4502.

[17] N. Nishizawa and T. Goto, (2001) "Widely tunable femtosecond soliton pulse generation at a 10-GHz repetition rate by use of the soliton self frequency shift in photonic crytal fiber", Opt. Lett. 28 (19), 1760.

[18] L. G. Cohen and C. Lin, "Pulse delay measurements in the zero material dispersion wavelength region for optical fibers", Appl. Opt. 16 (12), 3136 (1977).

[19] A. Sugimura and K. Daikoku, "Wavelength dispersion of optical fibers directly measured by 'difference method' in the 0.8–1.6 μm range", Rev. Sci. Instrum. 50 (3), 434 (1979).

[20] M. Tateda *et al.*, "Interferometric method for chromatic dispersion measurement in a single-mode optical fiber", IEEE J. Quantum Electron. 17 (3), 404 (1981)

[21] I. A. Walmsley *et al.*, "The role of dispersion in ultrafast optics", Rev. Sci. Instrum. 72 (1), 1 (2001)

[22] Garret.1990."Nonlinear effects in fibre communications: an overview". The british telecom research laboratories. Suffolk, UK.

[23] Qun Zhang. 2008. "Symmetrized Split-Step Fourier Scheme to control global simulation accuracy in fiber-optic communication". IEEE Journal of Lightwave Technology Vol 26, No.2.

[24] Qun Zhang. 2013. "An efficient Split-Step Optical Fiber Simulation Package with Global Simulation Accuracy Control". The 2nd IEEE/CIC International Conference on Communications in China (ICCC): Optical Systems (OCS).

[25] Binh, L.H. (2009), "MATLAB Simulink Simulation Platform for Photonics Transmission System".I.J Communications, Network and System Sciences,2009,91-168.

[26] UCLA. 2007. BCH formula sheet. 7. Baker-Campbell-Hausdorff formula.

[27] Xie, T. 2014. "Reparation of Chromatic Dispersion using Dispersion Compensation Bank and Bit-Error Rate Analysis at Various Power Levels in 40 Gbps Fiber Optics system". Image and Signal Processing (CISP), 2014 7th International Congress.

[28] Sultana, N.2013. "The Effects of Cross-Phase Modulation and Third Order Dispersion on Pulses and Pulse Broadening Factor in The WDM Transmission System". Advances in Electrical Engineering (ICAEE) 2013.

[29] Zhang, Q. 2013. "An efficient split-step optical fiber simulation package with global simulation accuracy control".China - ICCC 2013 Pages 158-164.

[30] Zaki, F. 2013. "Impact of third-order dispersion in ultra high spee long haul optical fiber communication system". ICIEV 2013 International conference Page 1-5.

[31] Shao, J. 2014."Comparison of split step fourier schemes for simulating fiber optic communication systems".IEEE Photonics Journal. Vol.6 Article 7200515.

[32] Abdullah, M.F. 2014. "Frequency domain technique for reducing chromatic dispersion". EECCIS 2014 pages 56-61. IEEE Conference Publications.

[33] Wen,H. 2015. "Analof fiber-optic links using high order fiber modes". ECOC 2015 Pages 1-3.IEEE Conference publication on optical communication.

[34] Asvial,M. 2015. "Analysis of high order dispersion and non linear effects in fiber optic transmission with Non Linear Schrodinger Equation model" Page 145-150. International Conference on Quality in Research Lombok QiR 2015.

[35] Zhen, K. 2016."A high order 2- D CPITD Method for electrically large waveguide analysis". Page 83-85 Vol.26 IEEE Journals & Magazine – Microwave and wireless compnent letters.

[36] Tao, S. 2016. "Ultra-high repetition rate harmonic mode-locking generated in a dispersion and nonlinearity managed fiber laser". Journal of Lighwave Technology Vol PP, Page 1-1 IEEE Early Access Articles.