Performance Analysis of Fiber with Solitons Parameters and Fiber Non-Solitons Parameters using OptiSystem paper

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Performance Analysis of Fiber with Solitons Parameters and Fiber Non-Solitons Parameters using OptiSystem

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***Abstract*—Communication technology is one of the fields of interest today. Optical fiber communication (OFC) is the only answer to overcome the rapid increase in bandwidth requirements. The OFC system offers high speeds up to several gigabits per second and also a very high bandwidth. Optical fiber is very light and has the ability to transfer information in large quantities. Unfortunately, optical fiber transmission systems have effects that can increase fiber signals such as attenuation, dispersion and nonlinearity. Optical solitons that can replace dispersive effects offer a better solution to this problem. Soliton communication systems do not widen along links such as non-soliton communication systems. In this paper will discuss the differences in the performance of fibers with solitons and non-soliton fibers. The results obtained based on eye diagram analysis and bit error rate analysis, it can be seen that fiber systems with soli-tons have minimum distortion, and non-soliton fiber systems have noise in the system.**

***Keywords*—Soliton, SPM, GVD, Optical Communication, OptiSystem**

I. INTRODUCTION

Information is a key factor in the communication process. Information is a field that is in great demand today, remembering that the development of the information process has developed very rapidly. Information that arrives at the right place, form and time is the ideal process of sending information. The use of light in communication technology has been developed and being used by many people. The advent of fiber optics has revolutionized telecommunications systems throughout the world, which allows the exchange of information to be very fast at an incredible speed of light. Nowdays, in addition to the use of exchanging information, people use the mobile phone for daily activities such as using online shops, playing games, downloading music or articles. In addition, people also communicate via e-mail, voice chat and video calls with anyone around the world. This situation ultimately demands high-bandwidth information transmission networks. Optical fiber communication (OFC) is the only answer to overcome the rapid growth in bandwidth requirements [1,2].

OFC systems offer very high bandwidth (of the order of Tb/s). Optical fiber is compact, lightweight and has the ability to transfer large amounts of information. Optical fiber has few advantages like 200 times lighter and having a bandwidth of 10,000 times greater than coaxial cable [3-5]. Another advantage is the OFC system has the very large data transmit speed compared to copper or co-axial cables. 3 OFC, the information that need to be send is coded first into a binary sequence of electric pulses which are then used to modulate the laser beam to produce a sequence of "one and zero" pulse which represents the presence and absence of light. The level of information 3ansfer is expressed as a bit rate, which is nothing but the number of bits sent per second [5].

Unfortunately, optical fiber transmission systems have few drawbacks that can affect fiber signals such as attenuation, dispersion and nonlinearity which may attack single-channel and multiple wavelength transmissions. This dispersion can be a major problem for systems that require high bit rates and for remote communication systems. Thus, dispersion can affect transmission capacity and bandwidth. The direct effect of dispersion is when the light travels across the fiber, its shape will broadened. Optical Solitons that can cancel the dispersive effect offer a better solution to this problem [6].

II. THEORY

A. Soliton Optics

The soliton system along the communication channel is stable and lossless [7-8]. The soliton communication system does not widen along the link as in a non-soliton communication system. Soliton waves which have unbroken characteristics, spread or lose strength along with distance, 1aking it ideal for fiber optic communication networks. Soliton in optics refers to a situation where light beam or pulse propagates through a nonlinear optical medium without any cahange in its shape and velocity [10]. Soliton power levels are always maintained to a certain extent. It can be concluded that the optical soliton can maintain its shape when moving with constant time and speed [9].

Solitons are formed due to interactions between Group Velocity Dispersion (GVD) and Self-Phase Modulation (SPM), each of which has a depreciation effect on propagating pulses [8]. To design optical fibers, we need to consider all possible non-linear effects, phenomena that can be the main limiting factors are non-linear effects especially SPM (self-phase modulation) [3,4]. The interaction between non-linear effects and GVD (dispersive effects) is very important for soliton propagation. The equation represents an optical pulse passing in the z-direction through an optical fiber exhibiting GVD and SPM can be written as [10]:

$$\frac{i\partial A}{\partial z} - \frac{\beta_2}{2}\frac{\partial^2 A}{\partial T^2} + \gamma |A|^2 A = 0 \tag{1}$$

with $A(z,t)$ is the slowly-varying amplitude of the pulse envelope. Equation (1) is referred to as Nonlinear Schödinger Equation (NLSE) because it resembles the Schödinger equation with a nonlinear potential term (variable z playing the role of time and vice-versa). The second term in (1) represents dispersion while the third term accounts for the nonlinearity of the fiber. β_2 is the GVD parameter while the parameter γ is a measure of the nonlinearity of the medium [10].

The Nonlinear Schödinger Equation (NLSE) is a fundamental equation in soliton theory and appears in many branches of science. There exist different analytical method to solve nonlinear partial differential equation. Zakharov and Shabat in 1971 solved Nonlinear Schödinger Equation (NLSE) using inverse scattering method. Introducing dimensionless variables, $U = (a/\sqrt{P_0})$, $\xi = (z/L_D)$, $\tau = T/T_0$, equation (1) can be written as [10]:

$$i\left(\frac{\partial U}{\partial \xi}\right) = \beta_2 \frac{1}{2}\left(\frac{\partial^2 U}{\partial \tau^2}\right) - N^2 |U|^2 U \tag{2}$$

where P_0 is the peak power, T_0 is the width of the incident pulse and the parameter N is introduced as with $N^2 = \frac{L_D}{L_{NL}} = \frac{\gamma P_0 T_0^2}{|\beta_2|}$. For anomalous dispersion regime $\beta_2 < 0$, while for normal dispersion regime $\beta_2 > 0$. In the normal dispersion regime the high frequency components of an optical pulse travel slower than the low frequency components. The anomalous regime plays an important role in nonlinear fiber optics, in particular, for the formation of highly stable and distortionless soltion. The dispersion length is defined as $L_D = (T_0^2/|\beta_2|)$, while the nonlinear length is defined as $L_{NL} = (1/\gamma P_0)$ [9]. For the anomalous dispersion regime, (2) now takes the form [10], putting $u = NU$,

$$i\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0 \tag{3}$$

The solution of this equation is given by $u(\xi,\tau) = \operatorname{sech}(\tau)\exp(i\xi/2)$, it is called fundamental soliton solution of (3) and has a bell-shaped form. In the context of optical fibres, this solution indicates that if a hyperbolic secant pulse whose the peak power P_0 and width T_0 is launched into an ideal lossless optical fiber, the pulse will propagate undistorted without any change in shape for fickle long distances. The peak power to support the fundamental soliton inside an optical fiber is given by $P_0 = (|\beta_2|\gamma T_0^2) \approx 3.11|\beta_2|\gamma T_{FWHM}^2)$, where the FWHM (full width at half maximum) of the soliton is $T_{FWHM} \approx 1.76T_0$ [9-10].

B. Group Velocity Dispersion

Group Velocity Dispersion (GVD) is a phenomenon that describes light waves that move in optical fibers gradually pulse widening and peak power decreases with time and distance. So that it overlaps with other pulses and makes the recipient's input unable to distinguish between pulses. In this way the dispersive characteristics determine the fiber carrying capacity of the information [11-12].

The group delay (τg) per unit length in direction of propagation is given by [6]:

$$\frac{\tau g}{L} = \frac{1}{v_g} = \frac{1}{c}\frac{d\beta}{dk} = -\frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda} \tag{4}$$

where L is the distance traveled by the pulse, β is the propagation constant along fiber axis, wave propagation constant $k = 2\pi/\lambda$ and group velocity $v_g = c\left(\frac{d\beta}{dk}\right)^{-1}$.

The factor of $\beta_2 \equiv d^2\beta/d\theta\omega^2$ is the GVD parameter, which determines how much a light pulse broadens in time as it is transmitted over the fiber [6].

C. Self-Phase Modulation

Self-phase modulation (SPM) is a phase shift in pulses caused by changes in frequency. Variations in frequency can also be called the chirping phenomenon. SPM can arise because the refractive index on fiber has components that depend on intensity. Another part of the pulse experiences a phase shift caused by the dependence of the intensity of phase fluctuations. Therefore the main effect of SPM is to expand the pulse spectrum, keeping the temporal shape unchanged [5].

For fibers containing high transmission power, phase (ϕ) is introduced by field $E = E_0\cos(\omega t - kz)$ over a fiber length L is given by [6]:

$$\phi = \frac{2\pi}{\lambda}(n_l + n_{nl})L_{eff} \tag{5}$$

with effective length $L_{eff} = (1 - \exp(-\alpha L))/\alpha$. For n_l is linear refractive indices and n_{nl} is nonlinear refractive indices. The first term on right hand side refers to linear portion of phase constant (ϕ_l) and second term provides nonlinear phase constant (ϕ_{nl}). Changes in spectrum frequency are caused by phase variations with time.

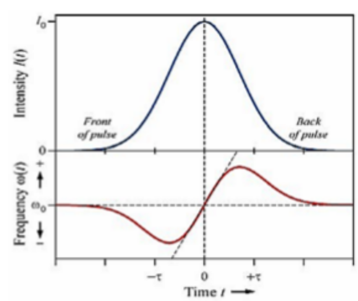

Fig. 1 Spectral broadening of a pulse due to SPM. [6]

As mentioned earlier, SPM produces chirping phenomenon (frequency variation), which leads to the expansion of spectral pulses without any changes in the temporal distribution. Chirp generated by SPM can be used to modify the effect of pulse expansion from dispersion [6].

D. Return-to-zero (RZ) modulation

Optical fiber communication has the main purpose of sending the maximum number of bits per second over the maximum possible distance with the fewest error [13]. In fiber optic communication, signal modulation systems are the main problem that determines the quality of transmission. The optical communication format affects the other parameters of system such as optical spectral bandwidth, tolerance to chromatic dispersion, resistance to nonlinear crosstalk and other system performance measures are directly related to the optical modulation format. The optical modulation formats is also an important parameter to optimize the system performances, as it can increase the speed of optical transmission. The main aim of modulation formats is for the reduction of non-linear impact and improvement of the spectral efficiency at high bit rate in optical systems [14].

There are many modulation schemes that are come into existence for long-haul systems. The most simple one is the non-return-to-zero (NRZ) format. The pulse of NRZ format is on for the entire bit period. In addition to the NRZ format, there is also an RZ format whose pulse is only for a portion of the bit period. RZ pulses are less susceptible to inter-symbol interference and better nonlinear resistance. The popular solution for the 10Gb/s system is RZ modulation because it has a higher peak power compared to NRZ. Also, it has a lower bit error rate encoded and a higher signal-to-noise ratio. [13-15].

III. Methodology

This study will discuss the differences in performance between soliton fibers and non-soliton fiber parameters. The system designed using the OptiSystem software. The analysis was carried out using two simulation tools namely BER (Bit Error Rate) analyzer and Optical Time Domain Visualizer (OTDV). BER Analyzer is used to look at q-factor, minimum bit error rate, and eye height. Optical Time Domain Visualizer is used to see pulses in the time domain.

A. Bit Error Rate, Q-Factor and Eye Height

In terms of telecommunications transmission, the bit error rate (BER) is the percentage that has an error relative to the total number of bits received in a transmission. BER is an indication of how often data must be retransmitted due to an error [16]. By using optical software, the bit error rate can be calculated using a formula [17]:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{6}$$

with Q is q-factor, which is a dimensionless parameter that shows energy in the resonance element. Elements can form anything, for example from a mechanical pendulum, an element in a mechanical structure, or in an electronic circuit such as a resonance circuit. The Q factor indicates energy relative to the amount of energy transferred in the system. The higher the Q the lower the energy level and the higher it decreases, the higher the attenuation rate gets lower [18]. By using optical software, the q factor can be calculated using the formula [17]:

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \tag{7}$$

with μ_0, μ_1, σ_0 and σ_1 are average values and standard deviations of the sampled values respectively.

Eye height is one parameter of eye diagram. By using eye diagrams, signal quality can be seen with one view. In addition, it can diagnose problems such as attenuation, noise, jitter and dispersion that appear or characterize certain parts of a system. The eye height is a measure of the vertical opening of an eye diagram. An ideal eye opening would be a level to zero level. However, the noise on the eye will cause the eye to close. The eye height measurement determines eye closure due to noise [19]. By using optical software, the eye height can be calculated using the formula [17]:

$$E_H = (\mu_1 - 3\sigma_1) - (\mu_0 + 3\sigma_0) \tag{8}$$

System fiber non-soliton was design using the Optisystem software as the Fig. 2 shown below:

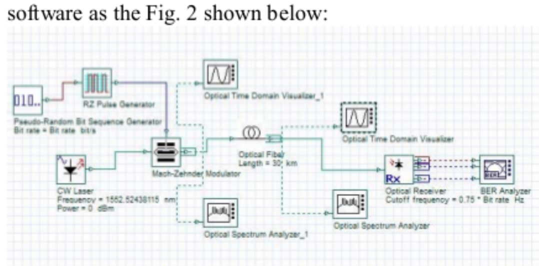

Fig. 2 Design Fiber non-soliton parameters [1].

Design of a fiber system without solitons uses a return-to-zero pulse generator as its input pulse which will then pass through 30km of optical fiber. In contrast to those without solitons, system fiber with soliton was design with a secant pulse generator as its input. Both of these designs are using the Optisystem software. Soliton system fiber with is in the Fig. 3.shown below:

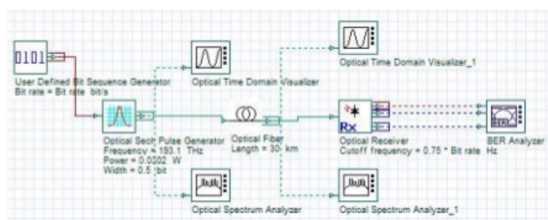

Fig. 3 Design Fiber with soliton parameters [1].

TABLE I. Fiber With Soliton Parameters

Parameter	***Symbol***	***Value***	***Unit***
Wavelength	λ	1.55	nm
Bit Rate	B	40	Gbps
Non-linear coefficient	γ	1.3	1/kmW
GVD	β_2	-20	ps^2/km
Width Parameter	T_0	13.2	ps
Peak Power	P_0	36.68	mW
Losses	α	0.2	dB/km

IV. RESULT AND ANALYSIS

This project was previously carried out by [1]. Non-soliton fiber systems use RZ pulses as signal generator while fiber with soliton systems use hyperbolic secant pulses.

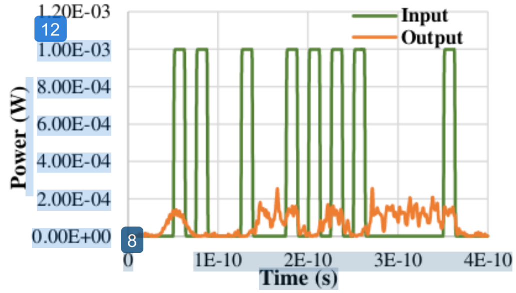

Fig. 4 Input and output of Fiber non-soliton parameter (using RZ pulse)

In Fig. 4 it can be seen the output produced by the non-soliton fiber system has pulses broadening and decreasing power. In other words, the output pulse is dispersed after passing through the fiber. One method that can overcome this problem is by utilizing soliton pulses that use nonlinear effects to maintain their shape and width in anomalous dispersion regimes.

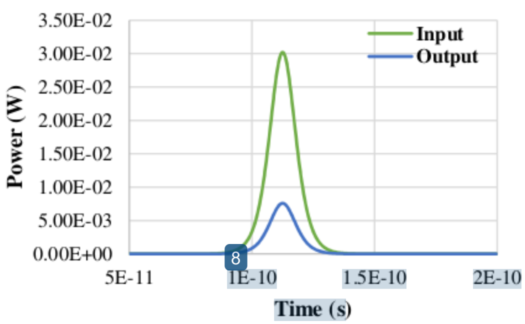

Fig. 5 Input and output of Fiber with-soliton parameter (using secant hiperbolic pulse)

The fiber with soliton system design was carried out using the OptiSystem software. The input used is a secant hyperbolic pulse. It can be observed that the output of this system in Fig. 5 that pulses do not broadening, and the power has decreased. this can show that fiber with soliton systems have a fixed shape after passing through optical fiber. It can be said that pulses do not experience dispersion. Regarding the declining power, this is influenced by attenuation included in this simulation.

The following Table II are the results obtained on fiber non-soliton parameters and fiber with soliton parameters.

TABLE II. RESULTS FOR THE SYSTEM FIBER NON-SOLITON AND FIBER WITH SOLITON USING OPTISYSTEM SOFTWARE.

Parameter	*Fiber non-soliton*	*Fiber with soliton*
Signal Generator	RZ pulse	Secant Hiperbolic
Max. Q-Factor	14.63	207.897
BER	8.763e-049	0
Eye Height	8.597e-005	0.0056

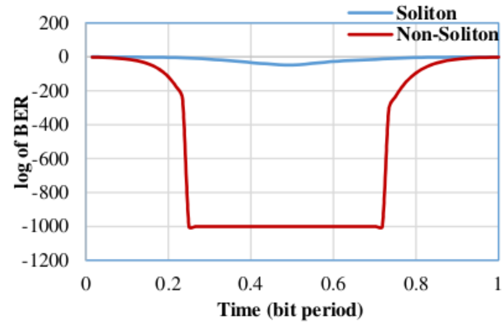

Fig. 6 Minimum Bit Error Rate (BER) of fiber non-soliton parameter and fiber with soliton parameter.

The minimum bit error (BER) value obtained from the BER analysis on optical system software shows quite a number between non soliton fibers and fibers with solitons. According to the Table II the fiber system with soliton has a 0 error bit and a non-soliton fiber system 8.76e-049. Graphs can be seen as soliton and non-soliton parameters selected in Fig. 6. Less signal power is lost along the transmission path when the BER is lower which directly improves system performance [19]. This means that fiber with soliton system has better performance.

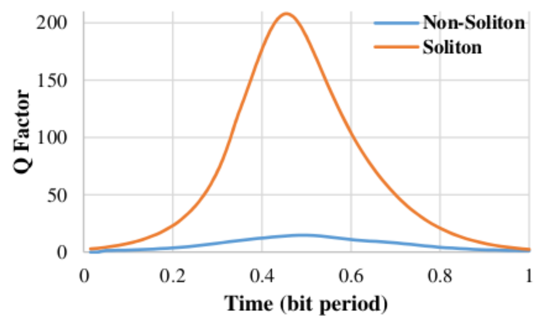

Fig. 7 Q-factor of fiber non-soliton parameter and fiber with soliton parameter.

Fig. 7 shows Q-factor of fiber non-soliton parameter and fiber with soliton parameter. The q factor allows simplified analysis of system performance [20]. As the value of Q factor increases, less signal power is loss and more error is produced due to lower value of Q-factor. A fiber non-soliton system has a maximum q factor value of 14.63 which means having more error in the system. While fiber with soliton system has a maximum value of q factor of 207.897 which means having less power loss.

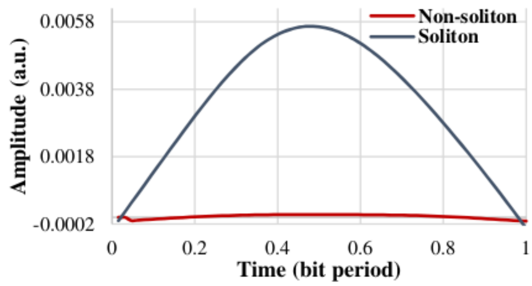

Fig. 8 Eye Height of fiber non-soliton parameter and fiber with soliton parameter.

Fig. 8 show eye height for fiber non-soliton systems and fiber with solitons system. The height of the eye opening at the specified time interval shows the noise margin or noise immunity of the system [20]. Fiber with soliton has an eye height of 0.005686 while the system fiber non-soliton has an eye height of 0.005686. It can be seen that a system with a soliton has a maximum eye height, which indicates that the signal distortion is minimum. A fiber non-soliton system has a poor eye opening, which shows noise in the system.

V. Conclusion

Optical fiber communication system with pulse soliton has better performance compared to non-soliton fiber. Based on the analysis of the eye diagram, it can be said that the soliton fiber system has minimum distortion, and the non-soliton fiber system has noise in the system.

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