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The Detailed Study of Soliton Transmission Using Optisystem

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***Abstract*—Communication is a crucial part of our life and in today's technologically advanced times, there is a need for faster and more secure communication systems. Optical communication has been a topic of interest since time immemorial. In this paper, we have analyzed the working of an important phenomenon "Optical Soliton Communication" which is a very interesting proposition for fast and stable communication for long-haul systems. Soliton pulses form signals which can travel large distances without suffering distortion. The main barriers in any optical signal communication are "Group velocity dispersion" and "Self-phase modulation". These two phenomena are mainly responsible for producing distortions in the signal but if examined deeply then these can also be used for the formation of stable waves. Experiments have been performed on two types of pulses and the results prove that soliton pulses can be a better choice for optical communication. It makes communication faster and more efficient. The aim of our research is to study this interesting phenomenon in detail and explore the suitable values for which the soliton pulses give the maximum output on Optisystem-18 software.**

Keywords—Optical communication, GVD, Self-phase modulation, Optisystem, Solitons

I. Introduction

With the advent of technology, the demand for very high-speed communications has increased. In ancient times, very few modes of communication were available. If we talk about pre-historic times, the fire signal method was used by the greeks for communication. In 1837 Samuel Morse discovered the telegraph system. In 1876 Alexander Graham Bell invented the telephone [9]. As the technology evolved humans explored more secure and efficient methods of communication. The radio and microwave band of the electromagnetic spectrum is used for wireless transmissions. But the ever-increasing demand for increased bandwidth and data rates is an obstacle to this technology. Moreover, wireless communications are prone to weather disturbances and prove to be insecure. In the late 1970s optical communication systems made much progress. The near-infrared region and the visible band of frequencies of the electromagnetic spectrum were explored. The region of 770-1675 nm is used for optical communication. Today there is no barrier to staying connected to our family and friends living several kilometers away. Video and voice chats have turned the world into a global village. In this "Information age, it is a necessary attribute for transmission systems to be able to cover long distances effortlessly. Apart from communication, other activities like online shopping, gaming, downloading material from the internet, emails, etc are also equally important. So the modern communication system requires a high bandwidth network. This has also been made possible by the evolution of optical fiber communication which is often called the "Lightwave System," because it utilizes the visible light of the electromagnetic spectrum. Optical fiber is a very good choice for carrying a considerable amount of data. It has a much higher bandwidth than microwave systems and traditional co-axial cables. The high speed offered by optical fiber is owed to the fact that light is the fastest signal in nature and nothing can match its speed. So using a fraction of the speed of light will certainly make communication faster. But optical communication is also prone to many kinds of barriers while transferring data. The dispersion effects lead to a broadening of the pulse and its shape is easily distorted. If the power of the pulse is increased then the non-linear effects become stronger. To overcome this issue, soliton pulse formation is preferred. We can solve both the above-quoted problems by employing the soliton formation technique [7]. Optical solitons are very demanding and promising in the field of high-speed communication because it maintains their shape and characteristics up to large distances [1].

II. THEORY

Optical solitons can be considered as a wave or a pulse whose intensity and shape remain the same throughout the fiber channel. This is achieved when the group velocity dispersion and the self-phase modulation balance out each other. Once these effects cancel each other, the solitons continue to transmit the information in the form of bits. The significance of optical soliton communication lies in the fact that it naturally enables the light pulse to carry a considerable amount of data up to long distances without any distortion. Nowadays, the demand for such high-speed transmissions is at its peak. As the light wave travels inside the fiber, it suffers various performance-limiting phenomena such as group velocity dispersion (GVD), non-linear effects, and fiber losses. Among all, the non-linear effects are the most problematic in carrying out long-haul communication at high bit rates. With the advent of optical amplifiers, fiber losses can be compensated. The GVD can be compensated by various dispersion management techniques [1]. But the problem of non-linear effects remains unsolved. In single-channel systems, the dominant non-linear phenomenon is self-phase modulation (SPM) [8]. If the amplification is done even at 100-200 Km, the non-linear effects would still exist. This has been a subject of study over the years [2]. The non-linear Schrodinger equation explains the theory of solitons and is a mathematical representation of soliton transmission [1]. It is given as follows:

$$i\partial A/ \partial z - \beta_2/2\, \partial^2 A/ \partial T^2 + \Upsilon |A^2| A = 0 \qquad [1]$$

A(z,t) is the amplitude of the pulse envelope. This equation is called Nonlinear Schödinger Equation (NLSE) and it is a very important equation for studying soliton effects. The second term in the equation stands for dispersion while the third term stands for the nonlinearity of the fiber. β_2 is the GVD parameter and the parameter Υ is a symbol of the nonlinearity of the medium. An important parameter for the formation of soliton pulses is that the value of β_2 should be less than zero. The condition $\beta_2 < 0$ has to be satisfied. The Non -linearities are introduced when the pulse is very intense. The fiber losses can be compensated using optical amplifiers.

a. GROUP VELOCITY DISPERSION

Group velocity dispersion is a pulse-widening phenomenon in which the pulses overlap and the signal at the receiver side is distorted. If the dispersion length is less than the physical length of the fiber then the dispersion effects dominate throughout the channel. In that case, nonlinear effects are ignored. The group delay (τg) per unit length in direction of propagation is given by the following equation:

$$\tau g / L = 1/V_g = 1/c\ \partial\beta/\partial k = - \lambda^2/2\pi c\ \partial\beta/\partial\lambda \qquad [2]$$

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

$$\beta_2 = \partial^2 \beta/ d\theta\omega^2 \qquad [3]$$

Here β_2 represents the GVD parameter. Based on the value of the GVD parameter dispersion regime is decided. Initially, when a pulse enters the fiber it is undistorted. The carrier frequency is the same along the envelope of the pulse. Now if the value of β_2 of the pulse is negative then the higher frequencies will be on the leading edge of the wave whereas the lower frequencies will be on the trailing edge. This means the frequency chirp will be negative. This is the anomalous regime of dispersion. This happens if the wavelength of the pulse is more than 1350nm [7]. If β_2 is positive then the frequency chirp is positive. This means the higher frequencies are on the trailing edge. This is called the normal dispersion regime. In this case the wavelength is less than 1350 nm. The GVD imposes a positive and a negative chirp on the pulse. The negative pulse chirping gives rise to "Bright Solitons" as discussed further. The positive chirping will lead to "Dark Solitons".

b. SELF-PHASE MODULATION

Let us consider that the dispersion is negligible and only non-linear effects are dominant. So when the intensity of the pulse is increased in order to increase the transmission distance, it affects the refractive index of the fiber [7]. As the wave propagates the difference in the refractive indices of the pulse at the core and at the edges of the fiber leads to differences in the velocities of the different frequency components. The refractive index is different at different locations. This leads to a phase change in the pulse. The new frequencies are generated due to the own nature of the pulse itself. This is why it is called "Self-phase modulation" as the pulse undergoes a change due to its own self-induced changes in phase. For fibers containing high transmission power,

$$\Phi = 2\pi/\lambda\, (\eta_l - \eta_{nl})\, L_{eff} \qquad [4]$$

The SPM always brings a positive chirp. Single-mode fibers mainly exhibit self-phase modulation as a dominant non-linearity. The interesting part is that we can utilize this phenomenon to sustain a stable pulse. Now if we compare the dispersion and non-linearity regimes, we see that in the case of dispersion, the pulse shape changes in the time domain but the spectrum remains constant. Whereas in a non-linear regime the pulse shape changes in the time domain and the frequencies are generated. The idea behind soliton formation is to exploit the performance degrading factors while transmission in such a way that we get a sustainable and stable pulse up to long distances. This is a very attractive proposition because if a pulse otherwise travels in the normal regime, it will undergo pulse broadening after covering some distance. If non-linearity and dispersion cancel out each other than the optical transmission system will work 10 times better than in the normal case. Consider the following equation

$$i\,(\partial U/ \partial\zeta) = \beta_2\, 1/2\ (\partial^2 U/ \partial\tau^2) - N^2 |U|^2 U$$

where

$$\zeta = z/ L_d \qquad [5]$$
$$\tau = T/T_0$$

In the above equation putting u = NU and considering anomalous dispersion with $\beta 2<0$ the equation becomes

$$i\partial u/\partial \zeta + 1/2(\partial^2 u/ \partial\tau) - |u|^2 u \qquad [6]$$

The above equation is solved by using the inverse scattering method. The final equation becomes

$$u(\zeta,\tau)=\mathrm{sech}(\tau)\exp(i\zeta/2) \qquad [7]$$

The final equation says that a fundamental soliton pulse will be formed if only the pulse will be of hyperbolic secant shape. It will not form a fundamental soliton for any arbitrary function. Sometimes a pulse is not deliberately shaped as a hyperbolic secant. In that case, if the non-linearity is high enough then some of the energy may get dispersed and the pulse gets readjusted to form the hyperbolic secant pulses.

$$A(0,t) = \exp[-1/2(T/T_0)^{2m} \quad [8]$$

The different values of "m" in the above equation determine how much energy is dispersed by a wave to form a fundamental soliton. For example, if the pulse shape is gaussian m = 1 and 99% of the energy is retained in the pulse for the evolution of a hyperbolic secant pulse. If the pulse is super gaussian then m = 3 and 92% of energy is retained by the pulse. This beautiful phenomenon of a pulse evolving itself to form stable signals gives great results. However, if we talk about a train of soliton pulses then it behaves very differently from the solitary soliton pulse. Two soliton pulses behave as trains of charged particles. They come together and collapse and after a certain distance, they again separate. They periodically merge into each other and get separated. There are a number of factors that account for the stability of the simultaneous soliton pulses. The interaction must be kept as less as possible. Our topic of study in this paper is the behavior fundamental solitons.

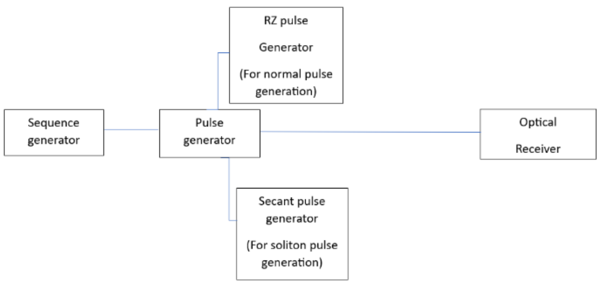

Fig.1. Block diagram of the Set up

III. METHODOLOGY

The experiment is performed on the latest Opti system 18 and the significance of the soliton transmission has been demonstrated. We have tried to achieve the best possible combination of the data rate and the optical fiber length for which the Q-factor comes out to be the best. For the setup, the list of components is given below:

1. CW laser
2. User-defined bit sequence generator
3. RZ pulse generator
4. Mach- Zehnder modulator
5. Optical time domain visualizer
6. Optical spectrum analyzer
7. Optical Fiber
8. Optical receiver
9. Eye diagram analyzer
10. Optical secant pulse generator
11. Optical amplifier
12. Optical Bessel filter
13. Loop control
14. BER analyzer

The Opti system software is an optical communication simulation software. It is used to test and analyze different optical transmission models in the physical layer and check their efficiency. It comes with a rich library of components that can be selected by double-clicking on the component. Any kind of optical link can be tested on this platform. After selecting the components the connections are made and the output of the analyzer and visualizer is noted down. It is also used to design WDM systems.

a. Q-Factor

Q- factor is a parameter that determines the quality of the signal. It must be as high as possible. Our aim to study soliton transmission is to improve the Q- factor[8] . It is measured by taking into account the SNR of the system.

b. Ber

The bit error rate is also an important parameter that decides the performance of a system. It should be as low as possible. It is the ratio of the error-prone bits to the total number of bits transmitted. It basically gives us an idea about how many bits are left to be transmitted.

c. Eye Diagram

An eye diagram is a pictorial representation of the signal in the time domain. It provides information about signal distortion, timing jitter, and system rise time [8]. The opening of the eye represents the signal distortion. The wider the opening, the less the inter-symbol interference hence better the signal quality.

Let us start with a normal optical communication system with
length of the optical fiber to be 19Km:

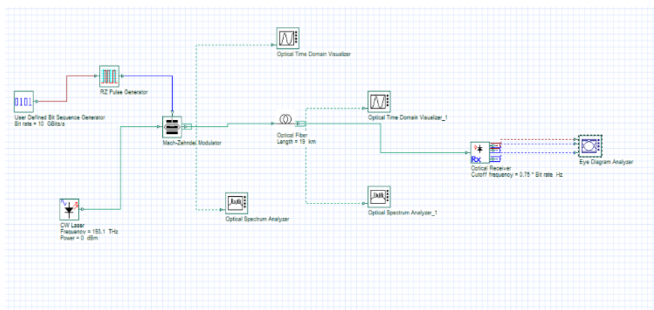

Fig.2.Optisystem model for non-soliton transmission

The following setup is for the injection of soliton pulses by using a secant generator:

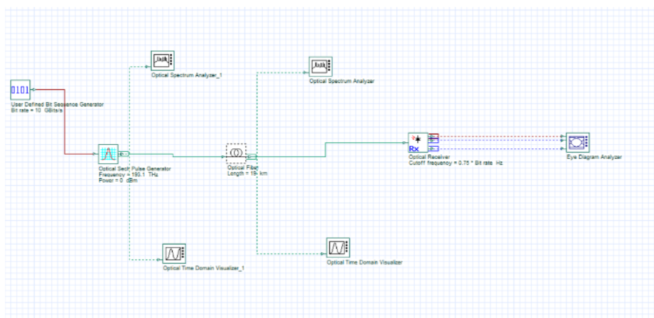

Fig.3. Optisystem model for soliton transmission

The fiber length in both cases is 19Km but there is a need to install amplifiers to support increased bit rate and length. At 19Km we got the best Q-factor for soliton pulses.

The system with increased bit rate and fiber length using optical amplifiers:

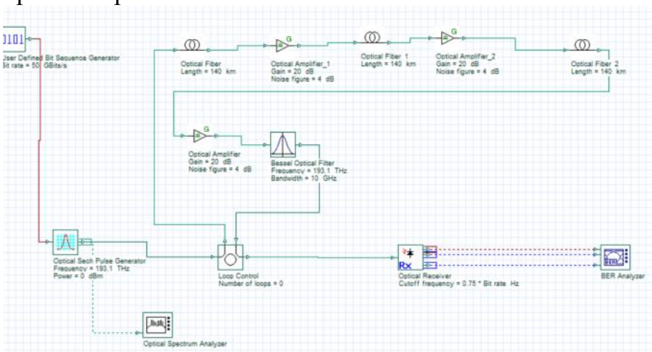

Fig.4. Optisystem model of soliton transmission using amplifiers

IV. RESULTS

The output of the BER analyzer in Fig 2 (Non-soliton) is as
follows:

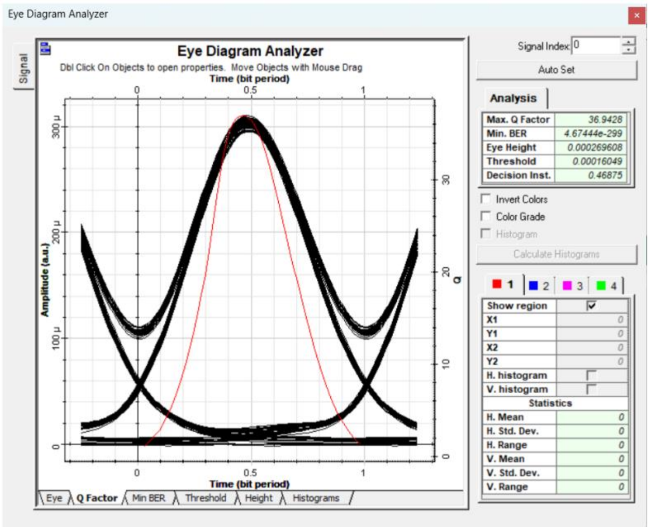

Fig .5. BER analyzer (Non-soliton transmission)

This Q factor is not a desirable output for effective long-distance communication. Due to the broadening of the pulse, the results are not satisfactory. The value of BER is poor. For a small distance of 19 Km, the Q- factor is very low. If we use a secant generator in place of RZ pulse generator, then the output is much better. The BER comes out to be 0 in the case of solitonic transmission, which is the optimum value for BER.

Table 1. ESSENTIAL SOLITON PARAMETERS

Parameter	Symbol	Value	Unit
Wavelength	λ	1.55	nm
Bit Rate	B	40	Gbps
Non Linear coefficient	ϒ	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

The BER analyzer for such transmission is given as follows :

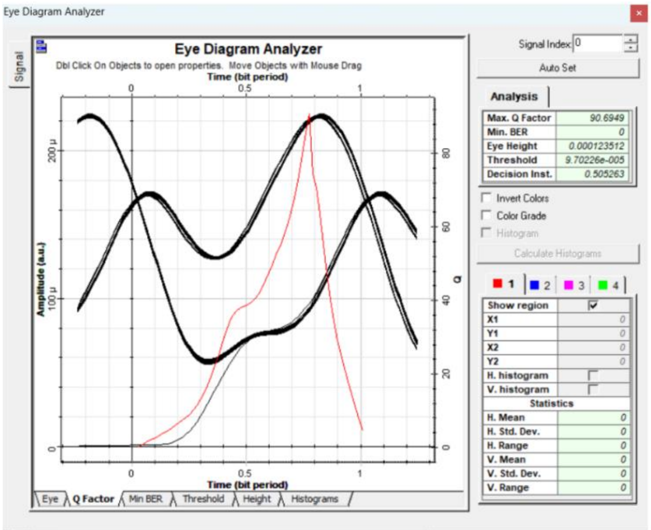

Fig. 6. BER analyzer (Soliton transmission)

The length of the fiber in this case, is also 19 Km. But the Q-factor is 90. If we further increase the length of fiber to 20 Km or increase the bit rate then we again notice the decrease in the Q factor. So the results show that there is a trade-off between the optimum bit rate and the length of the fiber [5]. To increase the bit rate and distance we have to introduce the optical amplifiers into the system. The amplifier spacing is between 100-200 Km. Over the years, efforts have been made to reduce the amplifier spacing. The bit rate can be even increased to 1Tb/s over several thousand kilometers by the use of techniques like WDM [6].

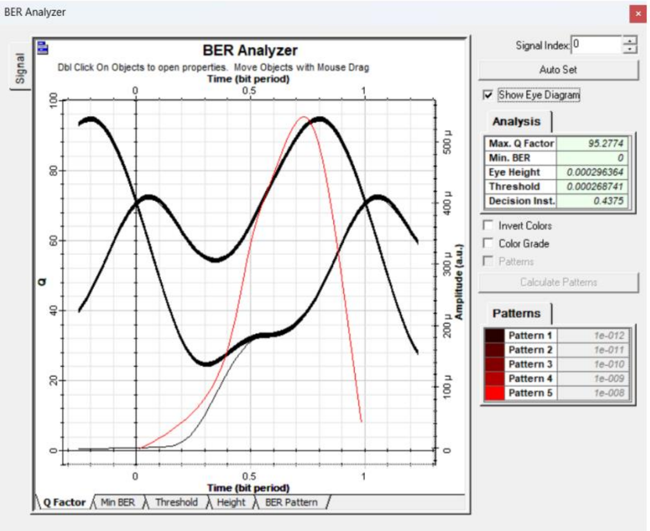

Fig. 7. BER analyzer (solitons with amplification)

By conducting these experiments on the optisystem software we notice a considerable change in the signal quality when we use soliton pulses. The bit rate has to be increased for long-haul communication and for that purpose amplification is needed. So we can conclude that soliton pulses can be a very beneficial replacement. By recognizing some suitable combinations of data rate and length of fiber, we can achieve phenomenal results.

V. CONCLUSION AND FUTURE SCOPE

An optical system using solitons has a much better performance and the integrity of the data is also maintained as it is distortion free. The results show a considerable and remarkable change in the quality of communication achieved through soliton transmission. Solitons can solve the problem of long-haul communications and increase the figure of merit that is the product of bit rate and amplifier spacing. The goal is to achieve higher data rate transmission up to long distances. Solitons are very promising in the field of modern communications as they demand robust and fast systems. Also, the demand for high bandwidth makes optical communication a preferable choice over any other technology. Optical solitons can be considered as a wave or a pulse whose `intensity and shape remain the same throughout the fiber channel. This is achieved when the group.

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