Performance analysis of Soliton and Gaussian Pulse in Long Haul Communication

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***Abstract*—In recent days, optical communication has been playing a vital role in the communication sector because of its high speed transmission and larger efficiency. Especially in case of long haul communication, optical transmission of data is much more efficient than other means of communication systems. But, in long haul communication usage of amplifiers is making the whole system quite expensive. So, minimization of numbers of amplifiers with optimal transmission efficiency is one of the major research topics of current days. In this research paper, two types of optical pulses have been used to analyze performance in long haul communication in a virtual environment (Software). Here, it has been shown that, using Soliton pulse allows using less number of Optical Amplifiers rather than Gaussian Pulse for maintaining optimum optical transmission efficiency. Using both of the optical pulses, Quality Factor and Bit Error Rate (BER) has been compared and analyzed.**

***Index Terms*—OptiSystem, Soliton, Gaussian, Bit Error Rate, Long Haul Communication etc**

I. INTRODUCTION

In case of high speed communication within long distance optical communication is always a better choice to make. In recent days, for communication purpose, especially in long haul optical communication Gaussian Pulse is used. But, the number of amplifiers used in optical fiber is quite larger in using Gaussian pulse. Hence, the system becomes much more complicated and expensive. So, there researcher tried to find an option to make the system more efficient and cost effective. It has been found that, if the Soliton Pulse is used in case of optical fiber communication instead of Gaussian Pulse, the number of Amplifiers required decreases. Hence the system becomes more efficient and easy to design. Here, the researcher has implemented the system in OptiSystem (Version 13) Software to analyze and compare an optical communication system using both Gaussian Pulse and Soliton Pulse. And for both of the cases, Bit Error Rate (BER), Quality Factor and attenuation have been observed and compared.

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II. THEORETICAL DESCRIPTION

Soliton Pulse

Right from the very beginning the necessity of communication is felt by human beings. To establish communication channels are used. Fiber is one of the best channels that is used for communication. But there is a problem named dispersion which is evident for both high bit rate and as well as for long hauls communication system. In order to solve this problem we use optical solitons because it is the system where for very long distances pulses can preserve their shapes.[15]
Soliton can also be termed as a solitary travelling wave which is represented by a nonlinear partial differential equation. Soliton Path has following characteristics. [16]
In 1845, J. Scott Russell first discussed a solitary wave in his "Report of the British Association for the improvement of Science". During his travelling through a water channel he observed a solitary wave. [17] The historical background behind this invention is described in. [18]. The existence and importance of this invention can be realized when a complete account of solutions to the non-linear hydro dynamical equation was given by D.J. Korteweg and G. de Vries in 1895. [17].
In order to describe long-wave propagation on shallow water they derived the following nonlinear partial differential equation:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \frac{\partial^3 u}{\partial x^3} = 0 \quad [19]....(7)$$

This equation is also known as Korteweg-de Vries Equation (KdV Equation). This equation can also be written in the following form:

$$\frac{\partial u}{\partial t} = 6u\frac{\partial u}{\partial x} - \frac{\partial^3 u}{\partial x^3} \quad [20]......(8)$$

This equation can be termed as a nonlinear one because of $\frac{\partial u}{\partial x}$ term. (Because 2 times then this term will increase 4 times.)
Two scientists Zabusky and Kruskal did a detailed numerical study and they found that in a system described by KdV equation stable pulse-like waves could exist. An outstanding characteristic of this solitary wave is that even if they collide with each other still their shapes and speed do not get affected and they are preserved after the collision. Due to this nature Zabusky and Kruskal named such waves solitons. So the word solioton was first used by Zabusky and Kruskal in their research work. [21]
As a travelling wave a a solitary wave has a unique form of u(x, t) = f(x − ct) for some smooth function f. f function decays rapidly at infinity. Solitary wave solutions can be easilt admitted but nonlinear wave equations. However instance,

$$u_{tt} - u_{xx} = u(2u^2 - 1)...(9)$$

has solutions that is family of solitary waves

$u(x,t) = sech(x\, cosh\theta + t\, sinh\theta)$(10)
parameterized by $\theta \in \mathbb{R}$. [22]

Due to balance between Group Velocity Dispersion (GVD) and Self-Phase Modulation (SPM) the existence of solitons in optical fiber is found. For mathematical descriptions,

Nonlinear Schrödinger (NLS) equations are employed by solitons, in presence of GVD and SPM they are satisfied by the pulse envelope. The equation is expressed by [23]

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

Here α includes fiber losses and β_2 and β_3 account for second and third order dispersion (TOD) effects.

In order to discuss soliton solutions let $\alpha = 0$ and $\beta_3 = 0$. In order to write the solution in normalized form we introduce

$$\tau = \frac{t}{T_0}, \qquad \varepsilon = \frac{z}{L_D}, \qquad U = \frac{A}{\sqrt{P_0}}$$

Here T_0 =*measurement of a pulse width,*

$$P_0 = Peak\ power\ of\ the\ pulse$$

$$L_D = \frac{T_0^2}{|\beta_2|}\ is\ the\ dispersion\ length$$

So equation (10) becomes

$$i\frac{\partial U}{\partial \varepsilon} - \frac{s}{2}\frac{\partial^2 U}{\partial \tau^2} + N^2|U|^2 U = 0 \ldots\ldots(11)$$

Where $= sgn(\beta_2) = +1\ or -1$, it depends on whether β_2 is positive (for normal GVD) or negative (for anomalous GVD). The parameter N can be defined by following equation

$N^2 = \gamma P_0 L_D = \gamma P_0 T_0^2/|\beta_2|$ …(12)

A dimensionless combination of the of pulse and fiber parameters are represented by this. [24]

Gaussian Pulse

In mathematics and physics Gaussian path is used quite regularly. The exceptional characteristics that it possess is that it can be exactly integrable over [-∞, ∞] but it cannot be evaluated in closed form over finite limits. [1]

In quantum field theory, Gaussian integrals can be of two kinds. In the first one ordinary real or complex variables are used, and in the second one Grassmann variables are involved. In order to calculate the path integral description of fermions (particles having half-integral spin) Grassman variables are used

A typical Gaussian path can be described by the following equation

y = exp ($-\frac{1}{2}ax^2$) …..(1)

Where ‘a’ can be termed as a constant. [1]

Another equation which can be termed as simplest Gaussian integral is

I = $\int_{-\infty}^{\infty} \exp(-x^2)dx$ [1] …..(2)

This equation can be solved very easily. Gaussian integral has some more complicated forms also. Some complicated integrals are stated below:

$\int_{\mathbb{R}^N} e^{\lambda.x} d\mu_A(x) = e^{\frac{1}{2}(A^{-1}\lambda\cdot\lambda)}\ \forall\,\lambda \in \mathbb{C}^N$[2]………(3)

$\int_{\mathbb{R}^N} f\,(x - \sqrt{t}\,y)\,d\mu_A(y) = (e^{t\frac{L}{2}} f)(x)$,[2]………(4)

$\int_{\mathbb{R}^N} f\,(x) d\mu_A\,(x) = \left(e^{\frac{L}{2}} f\right)(0)$, [2]……….(5)

Gaussian integrals can be calculated explicitly. A general example can be provided by the path integral representation associated to the quantum harmonic oscillator defined by the quantum Hamiltonian

$\widehat{H}=\frac{\hat{p}}{2m} + \frac{1}{2}\mathrm{m}\,\omega^2\,\hat{q}^2$ [3] .(3)

Where, m= mass of the particle and

2π/ω =period of the classical oscillations

Application of Gaussian Pulse

Applications of the Gaussian Pulse are:

- In motion planning Probability Roadmap Planners (PRMs) has got very bright potentials. Gaussian sampling strategy has been used for Probability Road Planners which has given a much better coverage of the difficult parts of the free configuration space.[4,5]
- Diffusion tensor imaging (DTI) is the imaging technology which is non-invasive and which generates a global mapping of local brain diffusivity. It is Tractography in diffusion tensor imaging which estimates connectivity in the brain through observations of local diffusivity. A probabilistic numeric has been used to estimate connectivity between regions of interest and contribute a Gaussian Process tractography algorithm. This process allows for both quantification and visualization of its posterior uncertainty. [6][7]
- In all semi classical calculations of fluctuating systems Gaussian path integral evaluation is mainly needed. Especially when we face a ratio of functional a ratio of functional determinants of second-order differential operators Gaussian path integral is needed [8]
- Gaussian path integral has different boundary conditions in quantum mechanical fluctuation problems. One example of such boundary conditions is Dirichlet boundary conditions. Gelfand and Yaglom have found a general result for this boundary condition. [9].The problem of Gefland and Yaglom’s method is, when we want to use periodic boundary conditions and also antiperiodic boundary conditions of quantum statistics (see Sections 2.12 in [8]) Gefland and Yaglom’s method has become ambiguous. That’s why it is not frequently used. Several papers have studied the functional determinants of second-order Sturm-Liouville operators with periodic boundary conditions [10]-[13], and related them to boundary-value problems Different papers have been used to solve the problem by studying the functional determinants of second-order Sturm-Liouville operators with boundary conditions [9]-[12]. But these papers also have their setbacks. These setbacks have been avoided by developing a method which is simple and systematic for finding ratios of functional determinants of second-order differential operators which has boundary conditions for both Dirichlet periodic ones as well as antiperiodic ones. [14]

Long Haul Communication

The optical communication channel can be divided few classes depending upon the distance between the source and the destination:

Short haul: This type of communication channel is used for very small range of kilometers.

Long haul: This is the optical communications which transmits visible light signals over optical fiber cable for the range of few hundreds of kilometers. This type of channel tries to establish communication without or with minimum use of communications.

Ultra-long haul: The length of channel is around thousand kilometers (Approximately 3000 km) for this kind of communication channel. “SEA-ME-WE 4 (South East Asia-Middle East-West Europe 4)” is an example of such communication channel. It is an optical fiber submarine optical fiber submarine communication cable and it provides the internet backbone between South East Asia and West

Europe via Middle East and Indian subcontinent. It has a very large length of approximately 20,000 km. [25]

This main challenge for long haul and ultra-long haul is the loss inherent in materials of the optical cable fiber. This loss can be overcome by using various methods like: boosting up the signal in the transmitter and using repeaters after particular distances. But most of these processes are not cost efficient.

III. RESEARCH METHODOLOGY

Two of the Optical Pulses have been used for propagation in a long haul communication system of almost about 420 Kilometers distance. For both Soliton Pulse and Gaussian Pulse, numbers of optical amplifiers have been calculated for optimum optical efficiency. It has been found that, number of amplifier is larger in case of Gaussian Pulse than Soliton Pulse. So, usage of Soliton Pulse is making the communication system more economical than using Gaussian Pulse keeping the optical efficiency at an optimum level.

IV. EXPERIMENTAL SYSTEM

The experimental setups for Optical & Soliton Pulses have been shown in the figure 1. A bit generator generates the bit then it provides the bit to Gaussian pulse to generate pulse from those bits. The optical fiber transfer these pulse to the output and amplifier has been used to amplify this signal to reduce the bit error rate (BER) and improve the quality factor of these signals in the output. A basel filter has been used to receive the expected signal and reduce the noise of this signals. Finally different types of out has been observed from the power spectrum, scope and BER Analyzer.

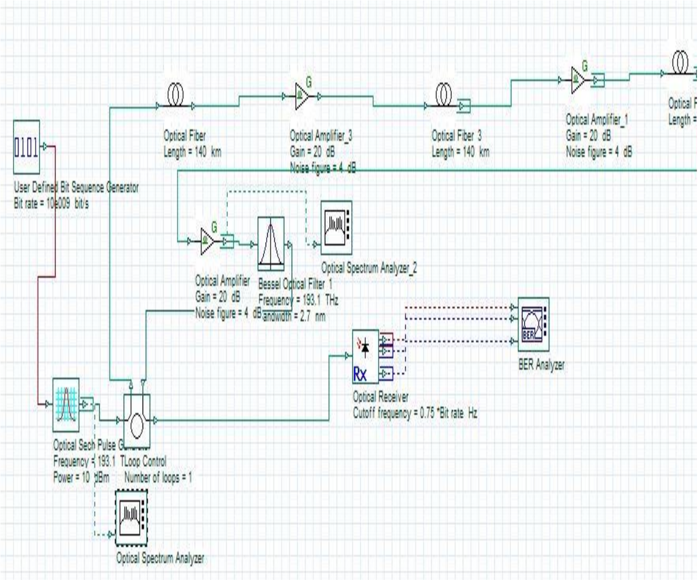


Figure 1: Optical Soliton Transmission System over 420 Kilometers of total distance.

In figure 2, Soliton Pulse have been used to analyze the system. First of all a User Defined Bit Generator have been used to generate a sequence of Bit at 10GBPS. It has been fed into an Optical Sech Pulse generator at a frequency of 193.1THz (wavelength of 1550nm) with an optical power of 0dBm to generate a soliton pulse. The distance can be varied by varying the value of loop control (Here loop control is considered as 1). Bit Error Rate and Spectrum Power (Pulse Peak Power) have been observed in BER analyzer and Optical Spectrum Analyzer of OptiSystem software respectively.

Using the same distance (420Km), an optical transmission system has been designed using Gaussian Pulse in the figure below:

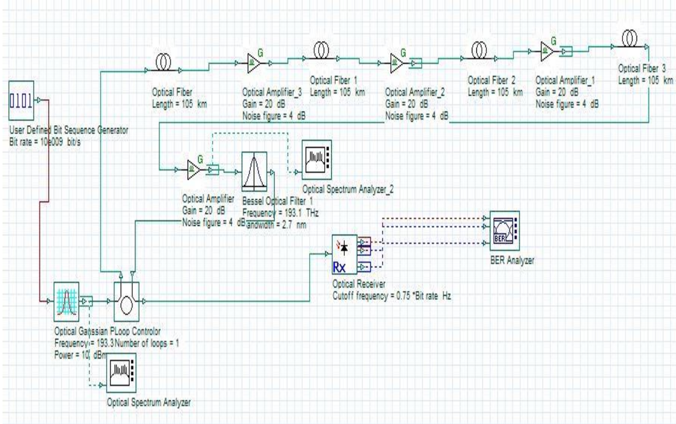
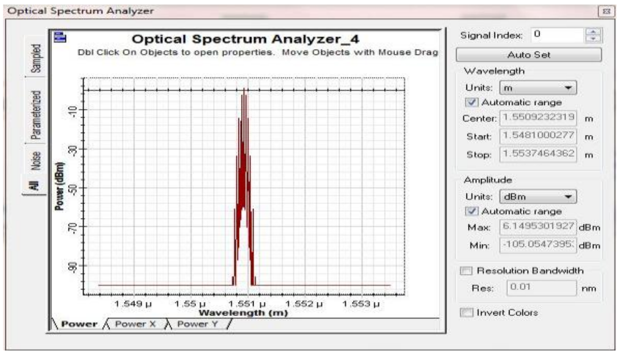


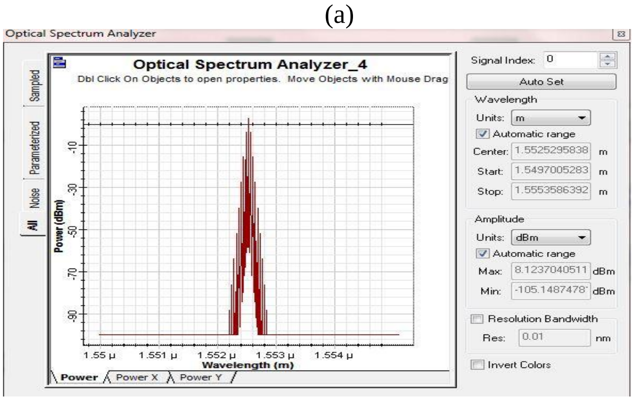
Figure 2: Optical Gaussian Transmission System over 420 Kilometers of total distance.

V. SIMULATION & RESULT

At first the spectrum of Soliton and Gaussian pulse has been analyzed in figure 3 (a) & (b). Here the input power for both Soliton and Gaussian has been analyzed.



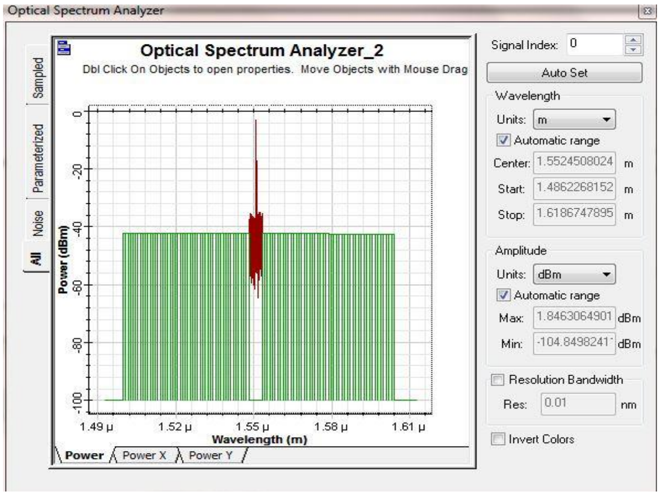
(a)



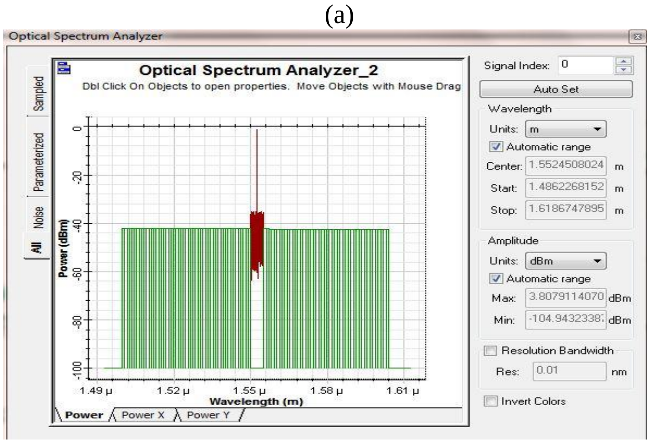
(b)

Figure 3 (a) & (b): Comparison of input power in case of Gaussian & Soliton Pulse

Compared to figure 3 (a) & (b) this is clearly visible that Soliton has higher input power than Gaussian pulse. After propagating 420 Km distance and cascade amplification figure 4 (a) & (b) shows that Soliton provides better results than Gaussian because of low dispersion character.



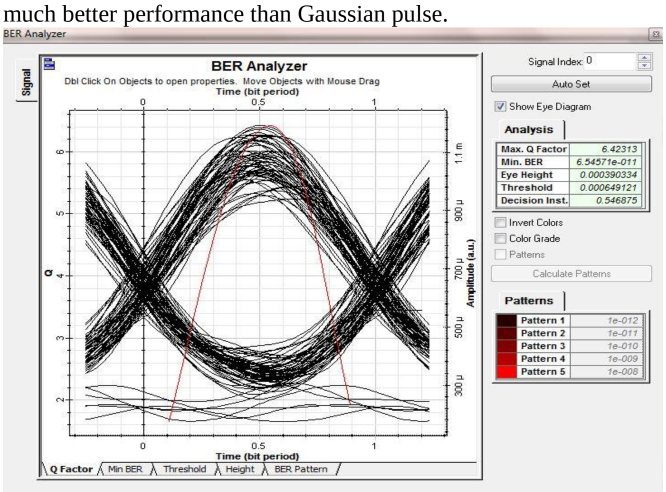
(a)



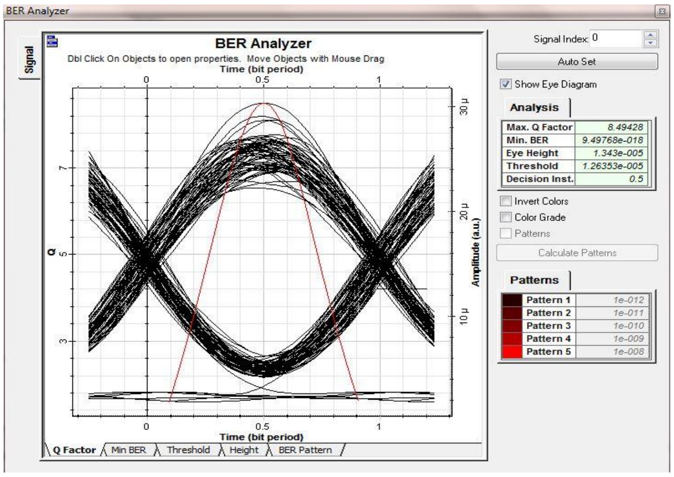
(b)

Figure 4 (a) & (b): Comparison of input power in case of Gaussian & Soliton Pulse after 420 km.

Compared to figure 4 (a) & (b) this is clearly visible after propagating 420 Km distance and cascade amplification Soliton pulse provides higher peak power than Gaussian pulse. Hence this pulse attenuates less due to less dispersion character. On the other hand Gaussian pulse gives higher attenuation of peak power hence Soliton has 2 dB more power at receiving end. Figure 5 (a) & (b) shows that in terms of Quality factor and bit error rate (BER) Soliton provides much better performance than Gaussian pulse.



(a)



(b)

Figure 5 (a) & (b): Comparison of Q factor and BER in case of Gaussian & Soliton Pulse after 420 km.

Evaluate to figure 5 (a) & (b) this is clearly visible after propagating 420 Km distance and cascade amplification Soliton pulse provides higher Quality factor and bit error rate (BER) Soliton provides much better performance than Gaussian pulse. In case of Soliton pulse Q factor is much higher than Gaussian pulse where as in case of BER Soliton provides much lower value.

Parameters	Gaussian	Soliton
Max. peak power (input)	6.149	8.124
Max. peak power (420 Km)	1.846	3.807
Q factor	6.423	8.494
BER	6.5457e-011	9.497e-018

After analyzing peak power, Q factor and BER this is clearly visible that Soliton provides better performance compared to Gaussian pulse. This simulation provides better results in case of 420 km so for long haul communication such as around 2400 km (e.g. Dhaka to Chennai) Soliton provides much better performance, moreover the number of amplifier should be increased in case of Gaussian pulse. So Soliton pulse also remains the system cost effective as well by keep the number of amplifier fewer.

VI. Conclusion

Considering the results, it is observed that for long haul optical communication performances with Soliton pulse outweighs the Gaussian pulse. For a certain distance (e.g. 420 Km) using Soliton Pulse number of amplifiers required is three. But, in case of the Gaussian Pulse for the same distance, number of amplifiers required is four, which clearly indicates that, Gaussian Pulse System is much more expensive than Soliton Pulse System.

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