OPTICAL SOLITONS SIMULATION IN SINGLE MODE OPTICAL FIBER OVER 40GB/S

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“I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering
(Power Electronic & Drives)”

Signature : ………………………………………………

Supervisor’s Name : MR. LOI WEI SEN

Date : 18TH JUNE 2013

I declare that this report entitle "Optical solitons simulation in single mode optical fiber over 40Gb/s" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

This report indicates about the optical solitons simulation in single mode optical fiber over 40 Gb/s. This project develops the optical solitons modeling and simulates the signal propagation by using OptiSystem software. Two different types of pulse generators are being used in the simulation which is the optical Gaussian pulse generator and optical sech pulse generator. In addition, both of the pulse generators will be simulated at different distances varied by the nonlinear dispersive fiber total field. Then the data achieved from the simulation is compared and analysed and included in the discussion and analysis section. This project is significant for the ultrafast communication system that is using optical fiber as it simulates optical solitons for over 40 Gb/s.

ABSTRAK

Laporan ini menunjukkan tentang simulasi soliton optik di dalam mod tunggal gentian optik untuk kelajuan 40 Gb/s. Projek ini merangka model soliton optik dan menghasilkan penyebaran signal optik melalui simulasi mengunakan perisian OptiSystem. Dua jenis penjana signal optik yang berlainan digunakan di dalam simulasi ini iaitu penjana nadi Gaussian optik dan penjana nadi sech optik. Disamping itu, kedua-dua jenis penjana optik yang digunakan akan dijalankan simulasi mengikut jarak yang berbeza dgn mengubah nilai di komponen serakan linear jumlah serat. Kemudian data yang diperoleh daripada simulasi tersebut akan dibandingkan dan dianalisis dan ditempatkan di dalam ruang diskusi dan analisis. Projek ini boleh member manfaat kepada system komunikasi had laju tinggi yang mengunakan gential optik kerana ianya menjalankan simulasi soliton optic pada had laju 40 Gb/s.

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$\propto$	-	Fiber loss
γ	-	Self-phase modulation
A_{eff}	-	Cross section area of optical fiber
B	-	Magnetic field density
β_2	-	Group velocity dispersion
D	-	Electric flux density
E	-	Electric field vector
H	-	Magnetic field vector
J	-	Current density vector
L_D	-	Dispersion length
n_2	-	Nonlinear reference index
P_N	-	Power value
ρ	-	Charge density
z_0	-	Soliton period

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Communication can be widely divided into voice communication (telephone, radio, mobile phone), video communication (pictures, moving objects, television broadcasting) and also data communication. Over the years, the medium through which the information for the communication is passed such as from mere smoke signals or reflecting sun rays as simple ways of communication between two points from long time ago has been greatly evolved to the advanced technology of wireless communication and even to the advancement technology of optic systems connecting continents for high speed data communication.

Solitons are a special type of optical pulses that can travel through an optical fiber undistorted for tens of thousands of kilometers. Optical solitons can be formed when dispersion and nonlinearity counteract one another. This project undergo optical solitons simulation in single mode optical fiber for over 40 Gb/s by using optical Gaussian and optical sech as pulse generator with different length of distance to analyse the effect of the nonlinear dispersive fiber.

1.2 Problem Statement

Nowadays, many countries are using optical fiber for the communication systems regardless for the internet connection, phone telecommunication or internet protocol television. This means that ultrafast optical solitons are in demand as it means higher speed of communication, lower losses and provides stability. In Malaysia, the leading communication systems that use optical fiber is most probably the UniFi provided by the TM Berhad. However, the highest bit/rate package available is only over 50Mb/s. Meanwhile, the demonstration from Thierry Georges on 1998 has shown that the highest speed that the optical solitons could be achieved is 1 terabit per second. This shows that there are lots of rooms for improvement in optical fiber communication systems. In fact, the bandwidth was increase exponentially after the millennium due to overwhelming demand of internet users and the broom of information technology (IT). Ultra-fast telecommunications was trend of the current telecommunication development which allows more data can be transfer from a part to another part.

Optical solitons is nonlinear wave that exhibit dual nature properties, i.e. particle wavelike that travel in nonlinear dispersive fiber. Optical solitons is one of the idea of signal used to transfer despite of higher bandwidth, it can balance the effect of nonlinearity and dispersion in optical fiber that the undistorted signal travel over a distance.

This project examines the possibility of generating optical solitons propagation in fiber optics at the rate of 40Gb/s in nonlinear fiber optics by undergoing the simulation of optical solitons in single mode optical fiber with the use of OptiSystem software. Besides that, this project also determines whether the effect of the nonlinearity and dispersion could be observed with the use of sech pulse and Gaussian pulse signals over a distance.

1.3 Project Objectives

This project will embark on the following objectives:

1. To simulate the signal of optical solitons propagate in fiber optics at the rate of 40Gb/s.
2. To investigate the effect of the nonlinearity and dispersion in the optical fiber with sech pulse and Gaussian pulse signals over a distance.

1.4 Project Scope

This project cover the simulation of the optical solitons signal propagation for only the single mode nonlinear optical fiber with the transmission rate of over 40Gb/s. The optical soliton modelling is design and simulated using the OptiSystem software in order to study the physical properties of the optical solitons wave propagation. The simulation is simulated by using two types of optical generators only which are the optical Gaussian pulse generator and optical sech pulse generator with the nonlinear dispersive fiber total field varied from 3.9482 km to 10 km, 20 km and 30 km to study the effect of the nonlinearity and dispersion. The output parameters that will be analyze is the peak values, dispersion length, solitons periods, overshoots and undershoots.

1.5 Project Summary

From this chapter it can be summarised in short that the project is about the development of optical solitons wave propagations through the simulation of the optical solitons modelling by using two different types of optical pulse generators that are the optical Gaussian pulse generator and optical sech pulse generator. These two types of generators are simulated at different length of distances using the nonlinear dispersive fiber total field in order to examine the effect of the nonlinearity and dispersion in optical solitons wave propagations. As for that, the next chapter will explained in detailed on how optical solitons are formed theoretically along with their unique characteristics and also the predicted formed of the optical solitons simulation propagation.

CHAPTER 2

LITERATURE REVIEW

2.1 Solitons History

Solitons is formerly known as solitary waves and it is first introduced by James Scott Russel on 1834 in which he had noticed a mass of water in a canal travel undistorted for over several kilometer and he named it as Wave of Translation[1][2]. This particular wave was then recognized as solitary waves. But before 1960s their characteristics were not fully learned until the inverse scattering method is introduced [1][3].

In 1965 the word *solitons* was developed to imitate the particle-like nature of solitary waves that stay undamaged even after mutual collisions [4]. For nonlinear optics, solitons are characterized as being either *temporal* or *spatial*, depending on whether the captivity of light occurs in time or space during wave propagation.

Temporal solitons signify optical pulses that maintain their shape, while spatial solitons signify self-guided beams that stay confined in the transverse directions orthogonal to the direction of propagation. Both temporal solitons and spatial solitons are develop from a nonlinear change in the refractive index of an optical material induced by the light intensity in which it is the *optical Kerr effect* [5-7]. The intensity that depends on the refractive index causing spatial self-focusing (or self-defocusing) and temporal self-phase modulation (SPM), the two most significant nonlinear effects that are accountable for the development of optical solitons. The formation of spatial solitons happens when the self-focusing of an optical beam balances its natural diffraction-induced broadening.

However, it is the SPM that counteracts the dispersion-induced broadening of an optical pulse and leads to the formation of a temporal solitons [8]. For both situations, the pulse or the beam travel through an intermediate undistorted without changing its shape. It is later on studied when the group-velocity dispersion (GVD) is normal, optical fibers can support another type of temporal solitons which is the *dark solitons* and it usually appear as the intensity dips within clockwise background [9]. Besides that the standard pattern pulse-like solitons are known as *bright solitons*.

2.2 Spatial Optical Solitons

The bright or dark spatial solitons appear only when the nonlinear effects balance the diffractive effects accurately. The formation of spatial solitons in a self-focusing nonlinear medium can be studied by taking into account how light is restricted by optical waveguides. Optical beams are known that they have the inclination to diffract as they travel in any harmonized intermediate. But, by using refraction this diffraction can be fixed if the material refractive index is increased in the transverse region that is filled by the beam.

This kind of configuration becomes an optical waveguide and limits light to the high-index area by providing a balance between diffraction and refraction. The transmission of the light in an optical waveguide is described by a linear but inhomogeneous wave equation whose resolution produces a set of guided modes that are spatially restricted eigenmodes of the optical field in the waveguide that maintain their shape and met all boundary conditions. The similar effect is discovered before in which the restraint of diffraction through a local change of the refractive index can be created only by the nonlinear effects if they guide to a change in the refractive index of the intermediate in such a way that it is larger in the region where the beam intensity is large [10].

Basically, an optical beam can form its own waveguide and be trapped by this self-induced waveguide. On another note the creation of spatial solitons can also be learned by using the lens analogy. Diffraction forms a curved wavefront alike to that formed by a concave lens and spreads the beam to a wider area. The index gradient formed due to the self-focusing effect however, acts like a convex lens that tries to focus the beam toward the beam center. Fundamentally, a Kerr intermediate play role as convex lens and the beam can become self-trapped and travel without changing the shape if the
two lens effects cancel each other.

2.3 Temporal Optical Solitons

Some might ponder if solitons can be formed in a waveguide where an optical beam is restricted at both transverse dimensions. Although it is obviously impossible as far as spatial solitons are concerned but it turns out a new type of solitons can still be created in such waveguides if the occurrence light is in the form of an optical pulse. That particular temporal solitons signify optical pulses that preserve its own shape during propagation. In 1973, the existence of this specific temporal solitons was predicted in the context of optical fibers [11].

The most important thing that differentiate temporal optical solitons from the clockwise case explained in the spatial solitons before is that the pulse envelope has now become time dependent and can be expressed as

$$E\ (r,t) = \ A(Z,t)\ F(X,Y) exp(i\beta_0 Z) \qquad (2.1)$$

In which F (X, Y) is the transverse field distribution associated with the essential mode of a single mode fiber. Meanwhile, from the equation it is observed that the time dependence of A (Z, t) indicates that all spectral components of the pulse might not travel at the same pace inside an optical fiber because of the chromatic dispersion. This effect is included by modifying the refractive index

$$\tilde{n} = n(\omega) + n_2\ |E|^2 \qquad (2.2)$$

Where it can be said that the frequency dependence of n(ω) acts as a vital role in the development of temporal solitons. This creates the broadening of optical pulses in the nonexistence of the nonlinear effects and acts as the part corresponding to that of diffraction in the context of spatial solitons. By obtaining an equation satisfied by the pulse amplitude A (Z, t) it is useful to work in the Fourier domain for including the effects of chromatic dispersion and to treat the nonlinear term as a small perturbation [12].

2.4 Nonlinear Schrödinger Equation

The nonlinear effects in optical fibers are usually studied by using short optical pulses because the dispersive effects are improved for such pulses. The wave propagation of optical pulses through fibers can be examined by solving Maxwell's equations

$$\Delta \times H = J + \frac{\partial D}{\partial t} \tag{2.3}$$

$$\Delta \times E = - \frac{\partial B}{\partial t} \tag{2.4}$$

$$\Delta\, B = 0 \tag{2.5}$$

$$\Delta\, D = \rho \tag{2.6}$$

Where H and E are the magnetic and electric field vector, while B and D are magnetic and electric field vector respectively and J denotes the current density vector and ρ is the charge density in which if we slowly varying the envelope approximation, these equations will eventually lead to the following Nonlinear Schrödinger (NLS) equation [13].

$$\frac{\delta A}{\delta z} = \frac{\alpha}{2} A + \frac{j}{2}\beta_2 \frac{\partial^2}{\partial t^2} - j\gamma |A|^2 A \tag{2.7}$$

Where the linear part represents in the above equation is,

$$\frac{\partial \mathrm{A}}{\partial \mathrm{z}} = \frac{\propto}{2}\mathrm{A} + \frac{\mathrm{j}}{2}\beta_2 \frac{\delta^2 \mathrm{A}}{\delta \mathrm{t}^2} \tag{2.8}$$

In which it is the slowly varying envelope associated with the optical pulse and $\propto$ indicates the fiber losses meanwhile B_2 signify the group-velocity dispersion. However, the nonlinear part represent in the above NLS equation is,

$$\mathrm{j}\gamma |A|^2 A \tag{2.9}$$

As the γ is the self-phase modulation and from that govern the A_{eff} which is the cross section area of optical fiber [13][14].

Moreover according to Thomas E. Murphy in 2001 [14] it is stated that by solving the following mathematical modeling expression,

$$u(z,t) = \sqrt{\frac{|\beta_2|}{\gamma {T_0}^2} sech\left(\frac{t}{T_0}\right) exp\left(j\frac{\beta_2 z}{2{T_0}^2}\right)} \qquad (2.10)$$

The optical solitons pulse shape obtained is approximately as shown in Figure 2.1 below,

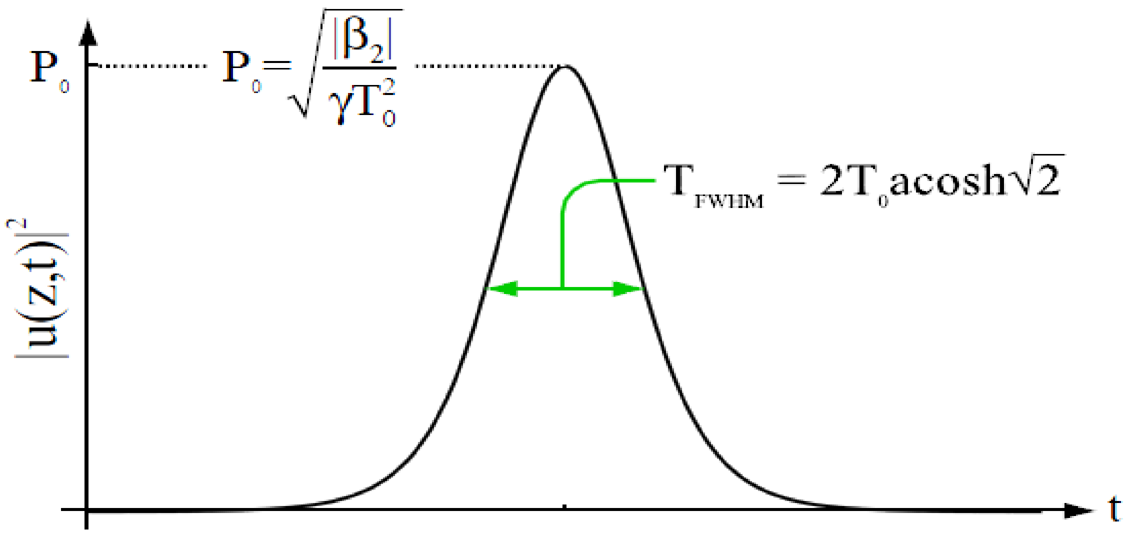

Figure 2.1: Pulse shape of optical soliton

From the figure 2.1 it can be determine that in contrast with the amplitude, solitons phase which is

$$exp\left(j\frac{\beta_2 z}{2{T_0}^2}\right) \qquad (2.11)$$

Where the above equation is not stationary and this phase evolution is known as solitons period. Besides, solitons period which is nominated as,

$$z_0 = \frac{\pi {T_0}^2}{2|\beta_2|} \qquad (2.12)$$

can be one of the parameter for a soliton [14].

2.5 Full Width at Half Maximum

A pulse has an optical power *P* which is energy per unit time that is substantial only within some short time intermission and is close to zero at all other times in the time varying domain. The pulse duration is usually defined as a full width at half maximum (FWHM) which is the width of the time interval within which the power is as a minimum half the peak power. The pulse shape of power versus time usually has a rather simple shape, explained for example with a Gaussian function or a sech^2 function, even though complicated pulse shapes can occur, in instance, as the effect of nonlinear and dispersive distortions, when a pulse travel through some intermediate [15].

Besides that FWHM could also be defined as a parameter normally used to explain the distance across of a "bump" on a curve or function. It is given by the length between points on the curve at which the function reaches half its maximum value [16].