NUMERICAL MODELING OF LOGIC GATE IN OPTICAL COMMUNICATION

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A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2012

To my beloved mother, father, lecturers,

and all my friend.

ACKNOWLEDGEMENT

I am grateful to my supervisor Professor Dr. Jalil Ali for giving me the opportunity to work on this research project. His patiently support and guidance extended far beyond the area of soliton. In addition to his features as a supervisor, I would like to thank for a group he bring together of most friendly, gracious, and helpful individuals

This work would not be a success without the tireless support of Dr. Saktioto. His willingness to sacrifice his time and to share his expertise with graduate students does much to brighten many of their days. I am indebted to Dr. Ong Chee Tiong for his guidance and invaluable insights, especially crucial in my study of optical soliton. The following people made significant contributions to various parts of my research project. Safwan Abd Aziz was my fellow physics undergraduate. During our graduate studies he shared with me his contagious energy and optimism. I was grateful to Azam Mohamad for all those times we spent working quietly on our projects as well as those time when we distracted ourselves with conversations. I truly enjoyed his sense of humor. Kunju Raman joined us briefly in our laboratory, and his friendship was very much welcome as well. Siti Khadijah inspired me with her focus and hard work. Thanks and wishes of good luck go to Mardiana Shahadatul Aini, my main collaborator on the optical logic unit cell project.

Many thanks are due to my family for their patience, support, encouragement, and help. Everything I ever achieved I owe to my parents, Roslan and Umi Kalshum. It is also hard to overestimate the support I always receive from my family and all of our grandparents and relatives.

ABSTRACT

The thesis comprehensively reviews the propagation of soliton pulse as a signal for communication. A theoretical model for the transmission of ultrashort soliton pulse is developed by numerical solution of Nonlinear Schrodinger Equation, NLSE by using Matlab programming. This study is able to demonstrate that soliton pulse can be generated as signal bit 1 and 0 as computational elementary signal. The signal produced is in the region of time domain, hence the system is compatible for the generation in the Time Domain Multiplexing (TDM) system. Linear and nonlinear directional couplers were used in fiber optics communications. The soliton pulse is based on the secant-hyperbolic model. Results show that the soliton pulse can maintain its power even after travelling for 100 km. The soliton pulse reduces its power when the Group Velocity Dispersion (GVD) parameter, β_2 is increased in the negative dispersion domain. The phase change of soliton pulse form 0 to π has shown an increase in the normalized power. However the soliton pulse exhibit chaotic behavior after a rapid increase of power at a phase of 0.8. Three models have been developed; the model of soliton code generator, soliton phase modulator, and bisoliton propagation. Two soliton input was generated inside fiber coupler and the code generator will encode its signal within the altered time difference of $\pm 0.25t$. The signal would move in the fiber coupler and the phase modulator controls the phase of the bisoliton generation from 0 to 2π. The result is the formation of optical logic AND and OR gate at the phase difference of 0.4π and 1.1π with normalized power of ~6 and parameter offset $\varepsilon=0.25$.

ABSTRAK

Satu kajian komprehensif dijalankan bagi mengkaji isyarat gelombang soliton sebagai isyarat untuk berkomunikasi. Satu model teori untuk penghantaran gelombang ultrapendek soliton telah dibangunkan oleh penyelesaian berangka Persamaan Schrodinger Tak Linear, NLSE dengan menggunakan perisian MatLab. Kajian menunjukkan bahawa gelombang soliton boleh dijana sebagai isyarat bit 1 dan 0 sebagai asas isyarat utama sistem komputer. Isyarat yang dihasilkan berada di dalam domain masa, maka sistem ini serasi untuk dihasilkan dalam sistem Pemultipleksian Domain Masa (TDM). Pengganding fiber linear dan tak linear digunakan dalam komunikasi gentian optik. Gelombang soliton adalah merujuk kepada bentuk secant-hiperbolik dan mempunyai kuasa yang stabil sepanjang 100 km. Gelombang soliton kehilangan kuasa apabila nilai parameter Serakan Halaju Kumpulan (GVD), β_2 bertambah di dalam domain serakan negatif. Perubahan fasa oleh gelombang soliton daripada 0 sehingga 2π menunjukkan peningkatan pada kuasa ternormal. Walaubagaimanapun, berlaku kacau-bilau pada fasa 0.8 apabila kuasanya meningkat secara mendadak. Tiga model telah dibangunkan; model penjana kod soliton, pembolehubah fasa soliton, dan perambatan dwisoliton. Dua input soliton telah dijana di dalam setiap input pengganding fiber dan penjana kod akan menghasilkan kod isyarat dalam perbezaan masa yang diubah (antara $\pm$ 0.25t). Dua isyarat akan bergerak dalam pengganding fiber dan pembolehubah fasa mengawal fasa di antara dwisoliton dari 0 hingga 2π. Hasilnya ialah pembentukan logik optik DAN dan ATAU pada perbezaan fasa 0.4π dan 1.1π dengan kuasa ternormal ~ 6 dan parameter pengimbang ε=0.25.

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LIST OF SYMBOLS

A	-	Amplitude
z	-	distance
T	-	normalized time
t	-	local time
τ_0	-	half-width of pulse
ε	-	coding parameter offset
ϕ	-	phase
L_D	-	Dispersion Length
u	-	complex amplitude
β_2	-	GVD parameter
P_0	-	peak power
γ	-	nonlinear parameter
α	-	loss coefficient
N	-	order of soliton
t_r	-	reference time
L_{NL}	-	nonlinear length
L_C	-	coupling length
P_C	-	critical power

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Optical soliton has been investigated as a good possibility for application in all-optical switching and logic. Such nonlinear couplers have been of interest in recent years for demonstrating the potential of glass fibers for ultrafast all-optical switching [1].

Research has shown that the analysis of full set of logic gates that could be used in all-optical applications [2]. A number of papers have appeared in which the particle-like nature of soliton has been exploited in order to derive, from conservation laws, ordinary differential equations (ODE's), for the adiabatic variation of some soliton parameters during the propagation [3]. The practical interest in using two-mode fiber coupling structures in the anomalous-dispersion regime and with pulses whose values of peak power and width are sufficiently close to the values required for the formation of soliton is the possibility of avoiding the breakup of the output pulse profile, which typically occurs in the quasi-continuous-wave regime [4].

A substantial improvement in the switching characteristics may result when square pulses are used [5]. It has been pointed out and recently experimentally demonstrated that the particle-like behavior of soliton pulses may inhibit pulse breakup in different examples of ultrafast all-optical switching devices [6].

The fiber can be operated as an optical amplifier, an optical switch, wavelength converter, soliton in a source, a compressor noise, a filter, and optical memory. The fiber optics directional couplers are widely used in modern optical communications systems. Nonlinear effects in directional couplers were studied starting in 1982. Fiber couplers, also known as directional couplers, constitute an essential component of light wave technology. They are used routinely for a multitude of fiber-optic devices that require splitting of an optical field into two coherent but physically separated parts. Although most applications of fiber couplers only use their linear characteristics, nonlinear effects have been studied since 1982 and can lead to all-optical switching among other applications [7]. The transfer of optical power between the modes of the two cores of the coupler is explained as evanescent field coupling between the modes of the individual cores of the coupler. The mechanism is described by a parameter known as the coupling coefficient,κ where it determined the coupling ratio between both fibers. It arises from the coupling of the propagating fields inside the two cores. In this study, we use the normal coupling ratio of 50% or coupling coefficient, $\kappa=0.5$.

The nonlinear directional coupler can be used as optical switching and logic function [8].The optical power is switched between coupler fibres by intensity level of the input signal. Kerr effect changes the refractive index of the waveguides and cause the birefringence phenomena bring up the signal to crossover another waveguide. The result is signal switching. Kerr effect is a nonlinear effect which occurs in a nonlinear material and it speeds up the switching process in the coupler [9, 10]. The soliton pulse width is within the range of picosecond (10^{-12}), so it is assumed to be in the anomalous group velocity dispersion. In this condition, at the higher order of dispersion, the shock effect and the other higher order of nonlinear dispersion can be neglected.

Realization of optical logic gate from a directional coupler has been done [2]. Development of ultrafast all-optical logic requires accurate and efficient modelling of optical components and interfaces [11]. The model proposed is related to the pulse

propagation along coupler interfaces. The setup is a model for straight waveguide couplers with a mathematical state foundation that is consistent with the physical notions going beyond the mere abstract theoretical model. We derive the governing equations of soliton pulse from Nonlinear Schrodinger Equation (NLSE), and then the position modulation, phase modulation, and logical gate formation. This work is approaching the reliable and efficient numerical implementation of the mathematical solution of soliton wave signal.

1.2 Problem statement

Using a fiber coupler as an optical gate for large bandwidth data transmission is a challenging problem. Our aim is to optimize this optical gate by using soliton pulse as bit signal. The finding in this study is to describe the details nature of soliton propagation inside the fiber coupler as well as two soliton signals interact. The linear and nonlinear effect has taken into account to find the answer. Numerical modelling technique is used as mathematical approach to model the soliton signal interaction.

1.3 Objectives of the study

General objective:

To investigate by employing theory and modelling the soliton pulse propagation and its interaction in optical logic gate by using nonlinear directional coupler and to optimize the device parameter of time, power, and dispersion length.

Specific objective:

1. To setup the model of soliton pulse, code generator, phase modulator, and fiber coupler.
2. To calculate and derive the soliton wave pulse equation as it enters fiber coupler.
3. To validate the result of soliton signal by forming signal bit 1 and bit 0.
4. To form the optical gate model by using nonlinear fiber coupler.

1.4 Scope of the study

Many studies have shown optical logic gate by using fiber coupler. However many did not mentioned the bit logic parameters. The interaction of soliton pulse inside the fiber coupler is also not clear. This study will expand the interaction of soliton bit pulse inside the fiber coupler including the linear and nonlinear effects to find the solution on how to create the basic signal soliton signal of bit 1 and 0 according to the Time Division Multiplexing (TDM) signal regeneration. The implication of the study is to optimize the fiber coupler so the optical gate can operate within it faster speed and has large capacity. This follows the bandwidth equation as B=1/T. As the time of signal is getting smaller into picosecond range, the bandwidth will increase up to hundreds Gbit/s.

1.5 Significance of the study

Our study has shown the potential of using soliton signal can be used for long haul transmission, high switching speed, decreasing in size and increasing the complexity of the system, and higher spectral efficiency that will bring up high bit rate per spectral bandwidth transmission to be achieved.

1.6 Organization of thesis

This report is organized as follows. Chapter 1 is the research framework. This chapter contains some discussion on the introduction to our study, a description to the problem, the objectives of the study, the scope of study, the significance of the study and finally the chapter organization. Chapter 2 will brief about the theory that pertains to this work covering past research that has been done related to the study.

Chapter 3 will elaborate a complete account on the research methodology and the basic theory is used in this study. Chapter 4 is the report on analytical and numerical modelling result and its discussion. Chapter 5 gives the conclusions of the study followed by recommendations for future works.

The next chapter will review on the the fiber coupler and the couple mode theory.

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