DEVELOPMENT OF SOA-MZI BASED LOGIC GATES AND ALL-PHOTONIC FLIP FLOP OPERATION

by

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
CB	Conduction Band
C-band	Conventional wavelength band
CCW	Counter Clockwise
CW	Clockwise
DL	Delay Line
EDFA	Erbium-doped Fiber Amplifier
FTTH	Fiber-to-the-Home
FWHM	Full Wave at Half Maximum
FWM	Four Wave Mixing
HDTV	High Definition Television
L-band	Long wavelength band
MMF	Multi Mode Fiber
MZI	Mach Zender Interferometer
NLE	Non Linear Element
OEO	Optical-Electrical-Optical
OSNR	Optical Signal-to-Noise Ratio
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SOA-MZI	Semiconductor Optical Amplifier – Mach Zender Interferometer
SPM	Self Phase Modulation
SR	Set Reset
SRS	Simulated Raman Scattering
TOAD	Terahertz Optical Asymmetrical Demultiplexer
TIR	Total Internal Reflection
UNI	Ultrafast Nonlinear Interferometer
VB	Valence Band
WDM	Wavelength Division Multiplexer

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XGM	Cross Gain Modulation
XPM	Cross Phase Modulation

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LIST OF SYMBOLS

E_o	Electric field in y direction
H_o	Electric field in z direction
E	energy
h	Planck's constant, 6.63 x 10^{-34} joule-seconds
v	frequency
τ_{Fall}	falling time
$\partial_{CW}(t)$	phase shift for Clockwise direction
$\partial_{CCW}(t)$	phase shift for Counter Clockwise direction
G_{CW}	gain for Clockwise direction
G_{CCW}	gain for Counter Clockwise direction
P_{AB}	power for combined input pulses A and B
P_C	power for control pulse
P_{SAT}	saturation power
G_0	small signal gain
$\Delta\varphi$	nonlinear phase shift
α	line width enhancement factor
E	Electric field
k	loss of the loop

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Pembangunan Get Logik Berasaskan SOA-MZI Dan Operasi Flip Flop Semua-Fotonik

ABSTRAK

Get logik fotonik adalah sebenarnya get logik yang melakukan pelbagai fungsi logik seperti AND, OR dan NOT tetapi bukannya menggunakan elektron, sebaliknya mereka beroperasi menggunakan cahaya sebagai mekanisme utama. Get logik XOR pada kebiasaannya mengandungi pelbagai komponen seperti penguat optikal dan penggabung. Get logik XOR ini juga menggunakan beberapa efek optikal tak seragam seperti Modulasi Gandaan Silang (XGM) dan Modulasi Fasa Silang (XPM) sebagai operasi utama mereka. Tiga konfigurasi get logic fotonik XOR (XOR TOAD, XOR SOA-MZI XPM dan XOR SOA-MZI XGM) dianalisa dan dibezakan dalam konteks kuasa yang dihasilkan, nisbah isyarat-hingar optikal (OSNR) dan Kadar Ralat Bit (BER). Kuasa penghasilan yang paling tinggi dicatatkan oleh XOR TOAD ialah 23.5 dBm. XOR SOA-MZI XPM menghasilkan OSNR yang paling tinggi dengan 109.6 dB.dan catatan BER yang terbaik ialah daripada XOR SOA-MZI XGM dengan catatan 4.42×10^{-22}. Bagi corak rajah mata, XOR TOAD menunjukkan corak mata yang terbuka luas jika dibezakan antara semua. Flip-flop optikal memberikan pengeluaran 12 bilangan keadaan ON dengan penghasilan kuasa pada 0.75 mW berteraskan pada 20 Gbps. Bagi berteraskan pada 10 Gbps pula, hanya 6 bilangan keadaan ON dengan penghasilan kuasa pada 2.2 mW. Ini memberitahu yang mana menggunakan kadar data yang pantas akan menghasilkan bilangan keadaan ON yang banyak tetapi dengan penghasilan kuasa yang rendah. Empat konfigurasi SOA-MZI get logik AND, NOR, OR dan NAND telah dibezakan dalam konteks penghasilan kuasa. Get-get logik AND dan NOR SOA-MZI mencapai penghasilan kuasa yang rendah pada 1.220 dBm dan 2.446 dBm, masing-masing. Get-get logic OR dan NAND SOA-MZI mencapai penghasilan kuasa yang agak tinggi iaitu 21.738 dBm dan 21.018 dBm, masing-masing. Secara rumusannya, XOR SOA-MZI XGM menonjolkan prestasi yang terbaik di antara konfigurasi get logik XOR yang lain sejak ia mempunyai nilai penghasilan kuasa dan OSNR yang sederhana, nilai BER yang agak tinggi dan corak rajah mata yang mencukupi, yang mana konfigurasi tersebut mempunyai bising yang minima. Bagi pemerhatian flip-flop optikal, mempunyai kadar data yang tinggi menghasilkan keadaan ON berganda tetapi dengan penghasilan kuasa yang rendah. Akhir sekali, bagi get-get logik SOA-MZI yang mempunyai dua SOA di dalam sesuatu susunan, penghasilan kuasa adalah rendah kerana ianya disebabkan oleh efek penyekatan dalam oleh penepuan dalam SOA.

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Development Of SOA-MZI Based Logic Gates And All-Photonic Flip Flop Operation

ABSTRACT

Photonics logic gates are actually logic gates that performs various logical functions such as AND, OR and NOT but instead of using electrons, they operate on using light as the main mechanism. XOR logic gates are commonly consist of various components such as optical amplifiers and couplers. These XOR logic gates also apply some of the optical nonlinear effects such as the Cross Gain Modulation (XGM) and Cross Phase Modulation (XPM) as their main operations. Three XOR photonics logic gate configurations (XOR TOAD, XOR SOA-MZI XPM and XOR SOA-XGM) are analysed and compared in terms of generated power, optical signal-to-noise ratio (OSNR) and Bit Error Rate (BER). The highest generated power is recorded by XOR TOAD at 23.5 dBm. The XOR SOA-MZI XPM yields the highest OSNR with 109.6 dB and the best BER is observed in the XOR SOA-MZI XGM with the value of 4.42 x 10^{-22}. Eye diagram pattern wise, XOR TOAD showed the widest eye compared to others. All optical flip-flop is also performed in this work which perceived 12 number of ON states with output power of 0.75 mW at 20 Gbps. Whereas at 10 Gbps, there are only 6 ON states with output power of 2.2 mW. This deduces that running at a faster data rate will yield a higher number of ON states but having lower output power. Four SOA-MZI logic gates configurations AND, NOR, OR and NAND are compared in terms of output power. The AND and the NOR SOA-MZI logic gates depicted low output power of 1.220 dBm and 2.446 dBm, respectively. While the OR and the NAND SOA-MZI logic gates demonstrated high output power of 21.738 dBm and 21.018 dBm, respectively. In summary, the XOR SOA-MZI XGM commemorated the best performance among other XOR logic gate setups since it has moderate values of generated power and OSNR, high BER value and comprehensive eye diagram pattern, which concludes minimum noise in the configuration. In all optical flip-flop observation, the higher data rate yields double ON states output but low output power. Finally, in the SOA-MZI logic gates utilizing two SOAs in the arrangement, the output power is small due to the limiting effect by the SOA's saturation.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter is to allow the readers to understand the concept of this project. This chapter explains an overview of photonics logic gates, the previous and current ongoing researches and further details are split into a few sub-topics such as the overview, problem statement, aim and motivation, objectives and scopes of work and research flow structure.

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1.2 Overview

The communication system is essential in human's daily lives. Ranging from transferring money via online banking, broadcasting HDTV (High Definition Television) content over airwaves or even using the mobile phones for conversation between distances, communication system has existed since the early times. One good example is the Red Indian people using fire and smoke to signal among themselves to send news, warn incoming danger or even to assemble their tribes that lives in great distances in the early 1800's.

Photonics logic gates are essentially logic gates that perform various logical functions such as AND, XOR and NOT but operating using light instead of using the conventional electrons (hence the term conventional electronics logic gates). Min Zhang, Ling Wang and Peide Ye (2005) pointed out that Photonics logic gates by far pose faster operating speed, good integration with other devices and having low energy operation requirements. With the advent researches of photonics logic gates nowadays, it is not by far the perfect device yet. Bulky device, complex device structures and still costly due to this research is still not yet fully matured are among the limitations faced in doing the research in photonics logic gates. But as stated by Louis E. Frenzel (2000), the demand for bandwidth in optical networks are increasing, the limitation of electronics has unfortunately has been reached by the speed of telecommunication systems. Thus the need to explore the possibilities of using photonics logic gates in all future communication system.

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1.3 Problem Statement

XOR photonics logic gate research has been going on for a while. Currently, there are a few configurations that successfully yielded XOR output signals such as XOR using XGM in SOA-MZI (Sachin Kumar, 2012), UNI-based XOR (Bintjas, Kalyvas, Theophilipoulus and Statpholous, 2000) and XOR using FWM in SOA (Chun-Kit, Lian and Tong, 2004) to name a few. In certain configurations, the XOR output signals produced average operation speed, moderate energy and weak integration potentials. Hence, this research investigates other possible configurations that give the best output signals qualities.

1.4 Aim and Motivation

The aims of this project are to compare three main configurations (XOR SOA-MZI using XPM versus SOA-MZI using XGM versus TOAD-based XOR) and analyze them in terms of power generated, OSNR and the quality of the signals (BER value), to compare the logic gates designed based on SOA-MZI configuration and to compare the all-photonics flip-flop running at different data rates.

1.5 Objectives

The main objectives of this project are to design and simulate an XOR photonics logic gate operating in C-band region and achieving an output signal that adheres to XOR logic properties, as well as to design and simulate various SOA-MZI based logic gates all-photonics flip-flop and various SOA-MZI based logic gates. Specific objectives of this project are listed as below:

i. To design and simulate an XOR photonics logic gate with the configuration of TOAD, SOA-MZI using XGM and XPM nonlinear effects as well as to analyze the output of each three configurations in terms of power generated, OSNR and quality of signals (BER value).

ii. To design and simulate various SOA-MZI based logic gates namely AND, NOR, OR and NAND and to analyze the output signals and generated output powers.

iii. To design and simulate an all-photonics flip-flop and to analyze the output signal running at different data rates.

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1.6 Scope of Work

The scope of this project is to focus on the output signals and analyze them in few main parameters. The parameters that are needed to be considered are power generated, OSNR and quality of signals (BER value).

i. Output power generated

ii. OSNR

iii. Quality of signals (BER value).

By interpreting the eye diagram, the quality of output signals is easily obtainable.

1.7 Overview of Project Development

This project mainly uses photonics simulation software called Optisystem where it is a special software design tool that enables to design, test and optimize almost all type of photonics applications. The flow chart shown in Fig. 1.1 displays the overall project flow from start to finish.

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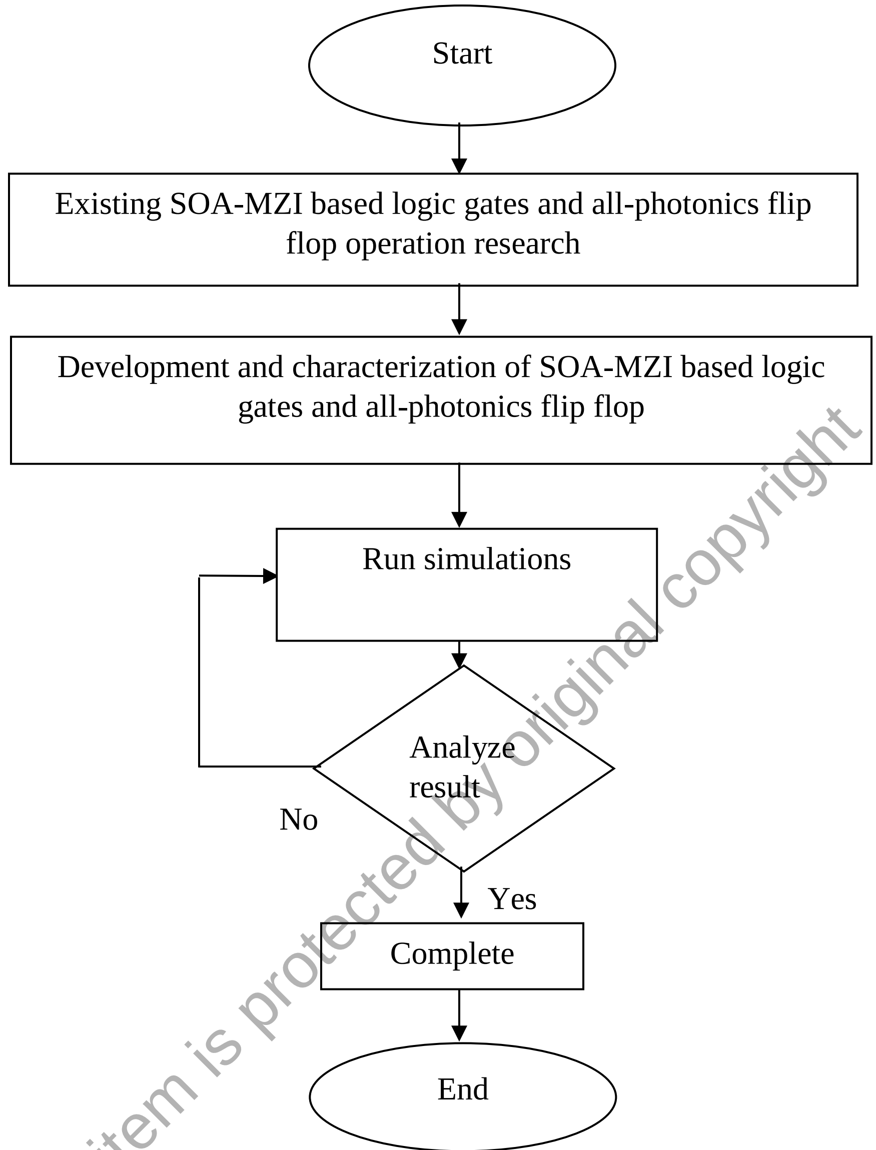

Figure 1.1: Project flow.

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1.8 Research Structure

Chapter 1: In this chapter, an overview or inspiration for the project was given by stating the project objectives, problem statement and project development.

Chapter 2: This chapter shall cover the previous researches that have been done in the area of photonics logic gate. Also, literature review of important concept and theory regarding the three configurations of XOR photonics logic gates are summarized.

Chapter 3: Research methodology of this project is discussed in this chapter. All the related simulation data and parameters pertaining to the three configurations are discussed in detailed here.

Chapter 4: The simulation results of each XOR photonics logic gate's configurations are deeply explained in this chapter. XOR output signals power, OSNR and BER eye diagram pattern are shown and explained.

Chapter 5: This chapter explains on comparison of various SOA-MZI based logic gates namely the AND, OR, NOR and NAND. Comparison in terms of output powers and the output signals are discussed here.

Chapter 6: This chapter covers some overview on all-photonics flip-flop logic gate. The comparison of output signal using 10 Gbps versus 20 Gbps data rate are discussed here as well.

Chapter 7: The final conclusion of this project is covered in this chapter. Results will be evaluated based on the findings and objectives of the project. Future works are mentioned too.

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