SOA-NOLM BASED AND, XOR, PARITY GENERATOR AND CHECKER

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ABSTRAK

Sistem optikal-sepenuhnya merupakan ciri tarikan didalam pemprosesan isyarat digital disebabkan jalur-lebarnya yang lebih tingi berbanding dengan litar-litar electronik konvensional. Para penyelidik telah menunjukan litar bersepadu photonic berkemungkinan menggantikan cara data dikendalikan didalam perlaksanaan logik. Get-get logik yang berdasarkan penguat optik separapengalir (SOA) dan gegelung optik tidak linear (NOLM) merupakan antara rekaan yang kompak bagi sistem-sistem optikal-sepenuhnya. SOA dipilih sebagai bahan tidak linear disebabkan kesan-kesan tidak linear seperti modulasi gandaan bersilang (XGM), modulasi fasa bersilang (XPM) dan campuran empat gelombang (FWM) yg dimilikinya. Ini hanya boleh dihasilkan dengan menggunakan dua isyrat yang dirambatkan kedalam bahan-bahan tidak linear seperti SOA ini. Di dalam kajian ini, dua sumber cahaya pada panjang gelombang yang berlainan 1542 nm dan 1555 nm digunakan sebagai aliran data dan juga pensuisan get. Kadar kecerahan cahaya pensuisan get adalah lebih tinggi daripada aliran data dan ini menyebabkan hanya ia dapat mengubah sifat-sifat optikal dengan memodulasi kepadatan pembawa di dalam SOA. Oleh itu, hanya isyarat aliran data akan berdepan dengan keadaan tidak linear SOA jika ianya merambat masuk ke dalam SOA hanya selepas kepadatan pembawa termodulsi oleh modulasi gandaan bersilang XGM dan modulasi fasa bersilang XPM. Dengan mengaplikasikan kesan-kesan XGM dan XPM kepada SOA-gegelung optik tidak linear (SOA-NOLM) boleh menyebabkan isyarat keluaran disuiskan ON atau OFF secara berulang-ulang. Secara keseluruhannya, kajian ini menumpukan kepada pencirian dan rekaan aplikasi-aplikasi berdasarkan SOA-NOLM. Selepas asas SOA-NOLM direka, penguat optik separapengalir (SOA) dicirikan dengan beberapa set simulasi bagi memperolehi nilai-nilai parameter yang optimum untuk pengoperasian get-get. Get primitif seperti get DAN direka dan kemudianya disimulasi bagi memastikan isyarat keluaranya bertepatan dengan persamaan Boolean bagi setiap isyarat masukan yang diberikan. Aplikasi kedua ialah get Ekslusif ATAU (XOR). Ianya direka berdasarkan get DAN yang dihasilkan sebelumnya dengan beberapa ubahsuai dikenakan kepada get. Get XOR ini bagaimanapun memerlukan satu lagi isyarat masukan jam tambahan bagi pensuisan isyarat keluaran. Akhir sekali, sistem pemeriksaan kesalahan optikal-sepenuhnya untuk transmisi penghantaran data optikal dibangunkan dengan menggunakan SOA-NOLM. Sistem ini terdiri daripada penjana bit pariti dan pemeriksa bit pariti optikal-sepenuhnya. Get-get XOR optikal-sepenuhnya digunakan sebagai elemen diskrit di dalam sistem ini. Selain daripada itu, rekaan sistem ini juga memerlukan pengubahah frekuensi. Pengubah frekuensi ini menukarkan frekuensi isyarat keluaran sebelum ianya di salurkan kepada get yang lain. Ini adalah untuk memastikan isyarat logik keluarannya sentiasa sepadan dengan persamaan Boolean. Bagi menganalisa prestasi get yang dihasilkan, tiga parameter digunakan untuk analisis seperti nisbah perbezaan (CR), nisbah kepupusan (ER) dan nilai modulasi amplitud (AM). Penyelidikan ini menujukan bahawa SOA-NOLM boleh dipilih sebagai konfigurasi utama di dalam get-get optikal-sepenuhnya disebabkan keputusan yang agak memberangsangkan ini.

ABSTRACT

All-optical systems are attractive in signal processing for digital logics due to its higher bandwidth than the conventional electronic based circuits. Researches have shown that photonic integrated circuits might replace the way data is handling in logical implementation. All-optical logic gates based on the integration of semiconductor optical amplifier and nonlinear optical loop mirror (SOA-NOLM) is one of the most compact design schemes in all-optical systems. The SOA is chosen as a nonlinear element since it has several nonlinearity effects such cross gain modulation (XGM), cross phase modulation (XPM), and four wave mixing (FWM). These effects can only be realized by having two signals propagating into the nonlinear medium such as the SOA. In this work, two optical sources at different wavelengths 1542 nm and 1555 nm are employed as data stream and gate switching respectively. The intensity of switching signal is set to be higher than data stream signal therefore only this signal is allowed to modify SOA optical properties by modulating the carrier density in the SOA. Thus the data stream signals will face gain nonlinearity if they enter into the SOA just after the modulation of the carrier densities by cross gain modulation (XGM) and cross phase modulation (XPM). Applying the XGM and XPM in the SOA-Nonlinear Loop Mirror configuration has caused the signal to be switched ON and OFF repeatedly. Generally, this study focuses on the characterization and application of the SOA-NOLM. Once the basic SOA-NOLM is designed, the semiconductor optical amplifier, SOA is characterized by a set of simulations in obtaining the optimum parameters for gates operation. Primitive gates such AND gate is designed then is simulated to ensure the produced signal meet the Boolean expression for the given input signals. The second application is the all-optical XOR gate. This is developed and based on previous AND gate with some modifications to the gate. The XOR gate however required one extra input clock to switch out an output signal. Finally, all-optical errors detecting system for optical data transmission line is developed by using the SOA-NOLM. This system consists of all-optical parity bit generator and checker. The all-optical XOR gate module is used as a discrete element in the system. Apart from that, the construction of this system also utilized the frequency conversion. These converters change an output signal frequency before it is connected to another gate. This is to ensure the produced output signals are always matched with Boolean equations. In analyzing the gate performance analysis, three parameters including contrast ratio (CR), extinction ratio (ER) and amplitude modulation (AM) values are investigated. This research produced promising results that show the SOA-NOLM can be selected as the main scheme for all-optical logic gates.

CHAPTER 1

INTRODUCTION

1.1 Early days of optical fiber and laser technology

The first success in the optical communication is over two centuries ago, or more precisely in the 1970s. But at that time the optical technology is limited. The first method of optical communication was developed by French Chappe brothers but it did not use an optical fiber optic and instead it was known as "optical telegraph". It was a system contains series of light towers where the operator closes and opens the light aperture to relay a message to the next tower nearby. This system only works for towers in sight of light. In 1854 John Tyndall, a British physicist verified that light can travel along continues flow of water and this proofed the light signal could be bent if use proper medium. From there in 1888 some dentist used bent glass rod to illuminate their patient’s mouth. Heinrich Lamm was the first person successfully transmitted an image of bulb filament through bunch of optical fibers in 1930. On 24 years later Abraham Van Heel created a cladded type of fiber system that significantly minimized signal interference and crosstalk between fibers.

After series of optical fiber improvement achieved in the past years, light source has become the researches priority to produce efficient light source. The concept was discovered by Charles Townes and Arthur Schawlow shows that Maser stands for "microwave amplification by stimulated emission of radiation" could be suited to operate in optical wavelength. The idea is by making light source travel forth and back in confined energized medium to produced light amplification. This process known as Laser stands for "light amplification by stimulated emission of radiation." Only in 1960, the first continuously gas laser operated by helium-neon medium is invented and tested. Then in next particular year 1961, an American Elias Snitzer found and published single mode fibers suitable used in medical purpose but the light loses is significantly high for communication used.

In the communication purpose long distance fiber system is necessary because the fiber routes can be thousands of miles long. Signal loses is a main culprit for this long distance fiber route. An opto-electrical repeater used previously to regenerate weak signal too costly and external electrical power is needed. Top of that some delay time in data transmission also take place. This is of course degrading the transmission speed. So in 1986 the erbium-doped fiber amplifier was introduced to eliminating the need of opto-electrical repeater by David Payne and Emmanuel Desurvire. In the modern age of communication technology the first all-optic fiber cable uses optical amplifier named TPC-5 was laid in Pacific Ocean in 1996. Then in the following year the longest single-cable network in the world named FLAG stand for “Fiber Optic Link Around the Globe” has been prepared for next generation of internet facilities.

1.2 Optical nonlinearity

Nonlinear effects firstly discovered not in optical field [1] but it’s in electronics nonlinear phenomena such rectification, inversion, modulation, harmonic generation and heterodyning. This is the outcome from frequency mixing by a nonlinear characteristic of the medium such as amplifiers or speakers. The nonlinearity also can occur in radio frequency or microwave wavelength region.

Nonlinearity in optics is observed when optical properties in the medium changes with the increasing intensity of applied field. Kerr effect also known as one of the optical nonlinearities. The optical properties in the wave guide such as index of refraction or absorption coefficient changes as the intensity of the input light increases into a very high amount. This phenomenon was realized after the invention of high intensity compressed light source or laser.

1.3 All-optical processing

The use of photons without involving electrons in optical processing is a great achievement over the decades. Because exclusive of opto-electrical or electro-optical conversion in the conventional system it can potentially be more cost effective. Furthermore, with all-optical processing the signal bandwidth can be significantly larger compared to electrical processing. Higher bit rates in all-optical processing propose by elimination of opto-electrical and electro-optical conversion time. All of these clearly proved the important of technology migration from conventional to all-optical systems. Therefore to achieve higher bandwidth and stable operation, the all-optical signal processing should be fabricated in integrated devices [2].

1.4 Research objectives

This research has several parts required for the development of all-optical gates base on the SOA-NOLM scheme. It is included the characterization of the nonlinear element, time delay parameter, input power requirement, gates performance analysis and finally the gates simulations and results. The main work is separated into three chapters (3, 4 and 5) that represent the gates design.

First part is focused on the characterization of nonlinear element and continued with the design of all-optical AND gate. The nonlinear element in this research is the semiconductor optical amplifier (SOA). The SOA characterization in nonlinear optical loop mirror (NOLM) is crucial and important. The results of this characterization are necessary as initial parameter for SOA-NOLM applications design. The SOA characterizations include current gain dependency, wavelength gain dependency, gain saturation and the SOA recovery time. Once the SOA parameters are obtained, the design of all-optical AND gate can be started. As soon as the design is completed, there is post-design characterization and analysis must be performed to validate the design. The validation is included time delay characterization for optimum output of SOA-NOLM. It is in balance condition if there is no signal transmitted from the input port. Furthermore, the gate input power must be characterized to obtain an appropriate power level for the gate operation. Next analysis is to study the gate performance in term of output signal quality. Three parameters are used to identify the gate performance. First is the contrast ratio (CR) that indicates the ratio between ON and OFF signal intensity. The second parameter is extinction ratio (ER) that measures the ratio of gap between minimum intensity of logic ONE and maximum of logic

ZERO. The last parameter is amplitude modulation (AM) value which represents how uniform the level of the logic ONE.

The second part is concentrated in all-optical XOR gate design based on previous AND gate. This gate will be used as district component for next application such parity generator and checker that is normally operated in digital transmission line. In the beginning, the design of XOR gate must be characterized in several standpoints in order to get correct operational output. The first step is to understand how the physical dimension of the SOA can be manipulated for carrier density effect. Next step is to characterize the gate input power, since this is required to study the behavior of output signal based on alteration made to the input signals. Further analysis is conducted to study XOR gate switching speed, the result will determine the maximum switching speed of XOR-NOLM to produce correct XOR Boolean operation. The same gate performance analysis conducted in previous AND gate is used back here. There are three parameters CR, ER and AM values use to identify an output signal quality. Final part in this chapter is to run a full simulation of all-optical XOR gate with all obtained parameters. The result of waveform is analyzed and must be matched with the XOR truth table.

The last objective in this research is to integrate those XOR gate design into more complex system, such as is all-optical parity generator and checker. First step is to configure the design of parity generator and checker. Both of the system contains XOR-NOLM as the core component. However the integration of SOA-NOLM needs additional circuitry in order to regulate power level and wavelength conversion. This is because the output signal has different wavelength and intensity. The same steps are used in designing both parity generator and checker. Once the designs are completed, performance analysis and full simulation are conducted respectively. Performance analysis is led to identify an output signal quality based on CR, ER and AM values. Whereas, the full design simulation is performed to verify the correct Boolean logic.

The research is structured in such a way since all parts contain different interests. However there are several common elements such as input power characterization, gates performance analysis and full design simulation. This part is common since all the design use optical signals that must be measured at the input and output ports. The last element in this study is to review the design operation by full simulation.

1.5 Thesis summary

This thesis is presented in six chapters. First chapter explains a brief historical of optical communication, invention of optical fiber and laser, optical nonlinearity, all-optical processing and the research objectives. In the second chapter, reviews from previous researches and findings in similar field are pointed out. Third chapter discusses about design, simulation and characteristic of all-optical AND gate based on SOA-NOLM. Fourth chapter continues with an application design for all-optical XOR gate and follows by its characterization. For the fifth chapter, error detecting system consisted of all-optical parity generator and checker employed all-optical XOR gate modules are discussed. Chapter six discusses and summarizes all finding in this work.

CHAPTER 2

LITERATURE REVIEW

2.1 Problem statement

The demand of huge digital data in various media such photos, music and videos are dragged to the requirement of higher bandwidth data processing. The conventional logic gates used today seems sooner or later will approaching the operational speed limit. In transition from electrical to all-optical digital system there is a hybrid technology so-called optical-electronic. However, optoelectronic devices will lose 30% of their energy for converting electrons into photons and back. Therefore, the researchers are selecting all-optical digital systems as their research priority. This system will eliminate the need of optical-electrical-optical conversions. Apart from the energy saving, the processing time can be minimized since the conversion time is abolished, thus it will translated into higher processing bandwidth for the system. More than that, this system wouldn't require any complex electronic circuit for data processing. Thus it relatively reduced the system cost.

However, the all-optical system has dozens of proposed scheme. Few of it such ultra-high nonlinear interferometer (UNI), Sagnac interferometer (SI), Michelson interferometer (MI), Mach-Zehnder interferometer (MZI), and delay interferometer (DI). Each of the schemes has its own advantages and disadvantages. There are three criteria important in selecting the proper scheme. There is the Extinction Ratio (ER), operating speed (Gb/s) and integration difficulty [3]. From those mentioned criteria, the Sagnac Interferometer (SI) scheme is preferred in this research.

Overall, this research is focused to elaborate those mentioned problems. At the end of the research we could verify the results and it benefits by choosing all-optical gates based on Sagnac interferometer.

2.2 The research methodology

This research is established with the process of information collection by reviewing all-optical gates schemes through the research papers and journals. From the reviews there are couples of criteria concerned in this work such as the extinction ratio ER, operational speed (Gb/s) and the integration factor in selecting the preferred scheme. Once the scheme is selected, the design is drafted and configured. The complete design is simulated and the achieve results are observed and verified. The design and simulation is a repetitive step since it needs to readjust the parameters and re-simulate in order to obtained the correct gate operation. Once the correct waveform is produced, the next step is to characterize the gates properties. The research methodology is presented as in Figure 2.1. However, this is a general research methodology since different applications may contain different approaches. The complete design methodology for the design applications is clearly explained in each chapter such AND, XOR and error detecting system in chapter three, four and five respectively in this thesis.

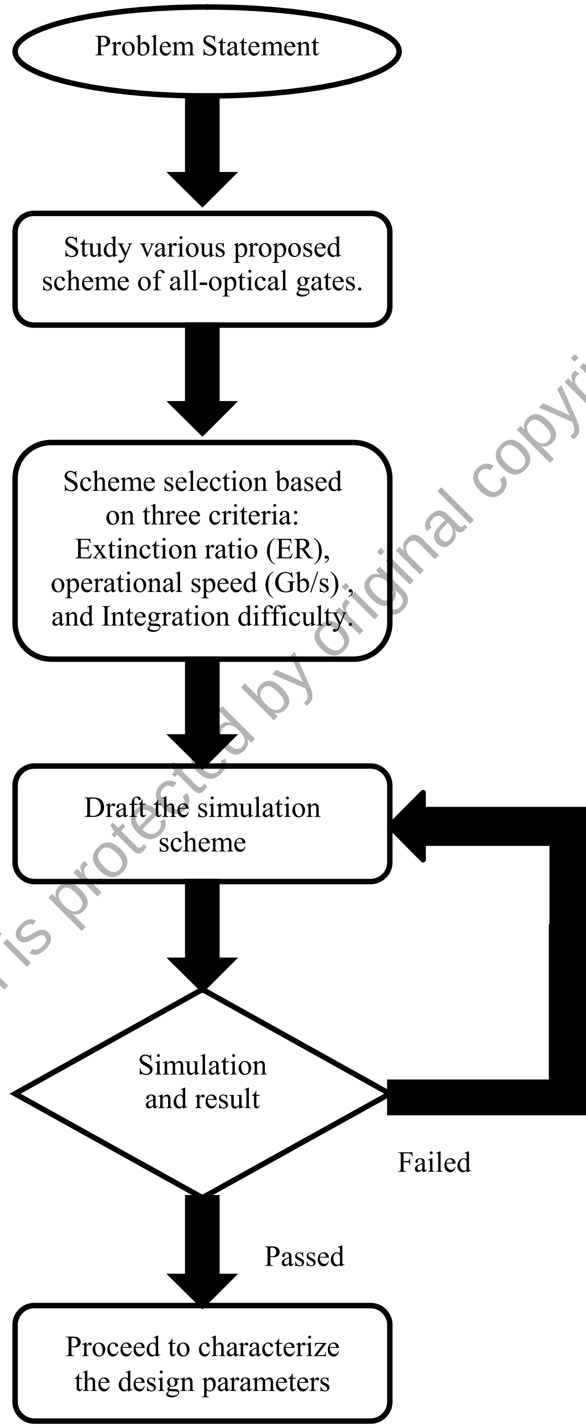

Figure 2.1. General research methodology

2.3 Optical switches

Optical switches can be designed based on two applications. First is designed with ON-OFF switch in between one input and output port. The second type is a routing switch in which the many output ports are connected to one input ports. The ON-OFF switches are commonly used in optical modulation system, digital optical system and also in all-optical processing. The routing switches are mainly used in managing connections of many points in networks. There are a few methods to control an optical switch, and it can give significant changes in term of switching performance. Conventional control mechanisms include electro-optical effect, acousto-optic effect, magneto-optic effect, thermo-optic effect, piezoelectric effect, and electromechanical actuation. However the switching speed based on these methods are approximately around 50 Gb/s and it's below than required in optical communications system. It is also not suitable for applications that require very limited space, because these methods usually use bulky and difficult to integrate switches system. New method and approach has led to nonlinear all-optical switches, based on optical nonlinearities. It can be used for many applications in digital optical signal processing, and can achieve over 100 Gb/s. Furthermore, this switching system is much smaller, lighter, faster, and cheaper than their bulk counterparts, and also suitable to be integrated by existing semiconductor fabrication processes.

2.4 The all-optical AND gate

There is a lot of research conducted in relation to all-optical switching base on Sagnac or Mach-Zehnder interferometer. One of published works is 80 Gb/s all-optical logic AND