All-optical integrated half adder/subtractor and full adder/subtractor using SOA-MZI based tree architecture

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The increasing demand of speed turns the optical network to ultra-fast optical processing techniques such as switching, signal generation, arithmetic operations and many more. Interferometric based Semiconductor optical amplifier (SOA)-based mach-zehnder interferometer (MZI) has been of great interest in the field of ultra-fast all-optical signal processing. In this paper, SOA-MZI configuration is used to implement all-optical integrated half adder/subtractor (A/S) and full A/S by using optical tree architecture (TA). Simulations to analyze the logic device operation are done at 40Gbps by using different input bit sequences.

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1. Introduction

The demand of higher bit rates (Tbps) data transfer has been rising with huge internet traffic [1-2]. To meet the continuing demand, Optical networking systems requires ultra-fast optical signal processing such as optical logic devices, clock recovery, wavelength conversion, optical arithmetic devices etc, which eliminates the expensive, time consuming and power hungry opto-electronic conversion processes [3].

From the last three decades, various architectures of arithmetic operations have been demonstrated [4-7]. Terahertz optical asymmetric demultiplexer (TOAD) provide the all-optical logic and arithmetic processing by using the data bits in bit differential mode to perform the modulo-2 addition and the carry bits addition. The bit-differential technique allowed complex binary functions to be performed at only the expense of latency [8]. Nonlinear optical loop mirror (NOLM) provides the switching mechanism based on fiber Kerr nonlinearities [9]. Compared to the fiber nonlinearity, SOA offer high nonlinear characteristics and is more promising nonlinear medium. Fiber based nonlinear technologies require long fiber length and high powers for high kerr nonlinear coefficient [10]. Various SOA based all optical bit logic gates and arithmetic devices have been demonstrated by employing its different nonlinear processes such as cross phase modulation (XPM), cross gain modulation (XGM) and four wave mixing (FWM) [11-14]. Among different nonlinear processes, SOA-XPM has been used in different methods to implement various switching devices that include MZI, Sagnac interferometer, NOLM, ultrafast nonlinear interferometer (UNI), and TOAD configuration [10,15]. SOA-MZI based switching is more promising because of its simplicity, compactness and low power operation [16]. A single channel optical time division multiplexing (OTDM) upto 168 Gbps has been demonstrated by making use of SOA-MZI based switching and even might be used for higher data rates [17]. All-optical Full A/S was successfully demonstrated by using SOA-MZI with analysis of various factors such as crosstalk, extinction ratio, and power imbalance [18]. In [19] quantum-dot semiconductor optical amplifiers (QDSOAs) have been used for realization of arithmetic devices. In the field of optical computing, optical interconnecting systems are the primitives that constitute various optical architectures. Optical tree architecture (OTA) plays an important role in this regard [20].

In this communication all-optical integrated Half A/S & Full A/S is realized at high bit rates using SOA-MZI based TA. Brief introduction is given in Section I. Section II describes implementation design. The results and discussions are discussed in Section III. Finally, conclusion is presented in Sections IV.

Basic concepts

A. MZI Switch

The schematic diagram of MZI switch is shown in Fig. 1. It is most promising technique to realize ultra-fast switching. The switch consists of two SOAs in each of its arm and both arms are coupled to each other by optical coupler. The incoming light signal at wavelength $\boldsymbol{\lambda}_1$ and control signal at wavelength $\boldsymbol{\lambda}_2$ are split by first coupler and propagates simultaneously in two arms. The presence of control signal makes the incoming light signal to appear at upper channel of MZI switch usually called bar port, but its absence makes the light signal to exit from lower channel, so called cross port. This is because of the cross phase modulation (XPM) which occurs as a result of carrier density variation [3]. The variation on the carrier density induces a change on both optical gain as well as refractive index. Here, the gain saturation induced by incoming signal reduces the carrier density inside one SOA which in turn induces change in refractive index. As a result phase of incoming light signal gets modulated and an additional π phase shift introduces on it, due to which it is directed toward bar port during each bit, so optical filters are used ahead of output ports in order to block the original incoming light signal [16, 18].

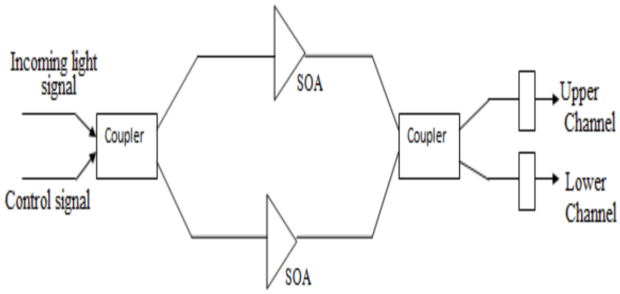


Fig. 1. SOA based MZI switch

B. Tree architecture

Tree architecture using SOA-MZI based switches is given in Fig. 2. To implement TA for half A/S and full A/S using SOA-MZI, seven switches of SOA-MZI configuration say S1, S2, S3, S4, S5, S6 and S7 are required. The working principle of these switches linked with control signals which are given as inputs to drive the required output operation.

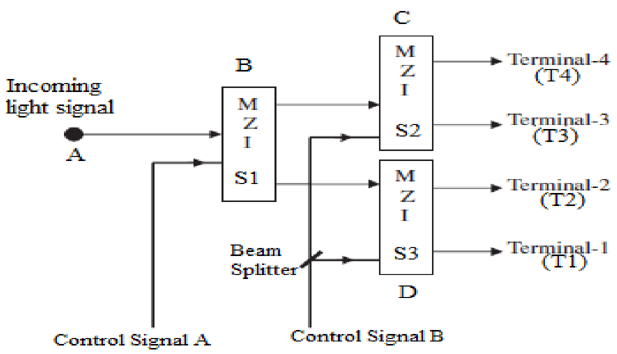


Fig. 2. Tree architecture using MZI switch

The switches control the light in such a way that, in the presence of control signal, the incoming light signal emerges from the upper channel of the switch whereas its absence makes the incoming light signal to emerge from the lower channel shown in Fig. 1. The continuous wave laser source can be taken as incoming light signal fall on the switch S1 first. Now this light can be obtained at any desired branches or sub-branches of TA by proper placement of control signals. Control signals are also light signal, its presence indicates logic 1 and its absence indicates logic 0. In half A/S, there are two input signals whereas three in case of full A/S, so two control signals A and B for Half A/S operation and three A, B and C for Full A/S operation is required. The placement of these control signals for integration Half A/S and Full A/S is shown in schematic diagram. The Half A/S can be control by control signals A & B in four ways as (A=0, B=0; A=0, B=1; A=1, B=0; A=1, B=1), similarly full A/S can be control in eight ways [3].

2. Implementation set up

The schematic diagram of integrated Half A/S and Full A/S is shown in Fig. 3. Simulation is carried out on OptSim version 4.7.1 in block mode specifications.

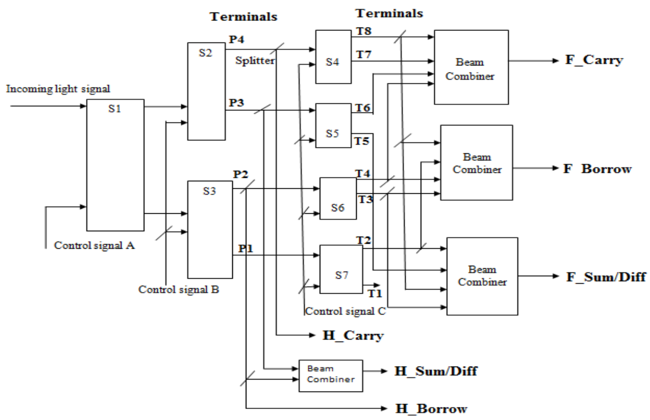


Fig. 3. Block diagram of integrated half A/S & full A/S using SOA-MZI based tree architecture

Four light signals of frequency 40GHz are taken, among these signals, one act as incoming light signals at wavelength 1550 nm and other three as control signals at wavelength 1500 nm. Seven MZI based switches, one in first stage, two in second stages and four in last stage are used to get integrated half A/S and full A/S operation. Half A/S outputs are derived from second stage whereas full A/S outputs are derived after third stage. Optical Gaussian filters at wavelength 1500 nm are used before taking the outputs of both half A/S and full A/S. Output is analyzed by checking the power level in spectrum analyzer.

3. Results and discussions

The outputs of Half A/S are obtained from terminal P1 to P4, whereas for Full A/S outputs are taken from terminal T1 to T8.The cases are given below:

A. Half A/S

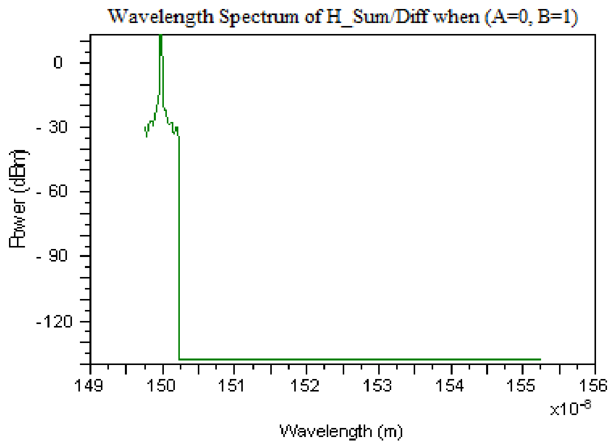
Case 1: when (A=0, B=0), incoming light signal is obtained at P1 terminal, whereas all other terminal are in off state. Hence P1 represents $\bar{A}\,\bar{B}$ logic.

Case 2: when (A=0, B=1), here the incoming light signal reaches at P2 terminal only. Thus, P2 denotes $\bar{A}B$ logic.

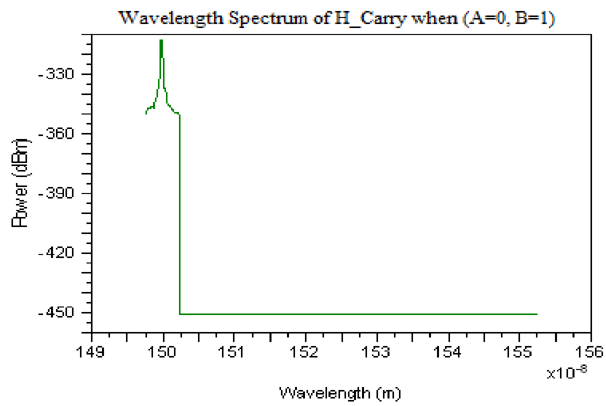
Case 3: when (A=1, B=0), only P3 terminal receives the light signal. Hence P3 represents $A\bar{B}$ logic.

Case 4: when (A=1, B=1), incoming light signal reaches at P4 terminal, whereas all other terminal are in off state. Thus, P4 represents AB logic.

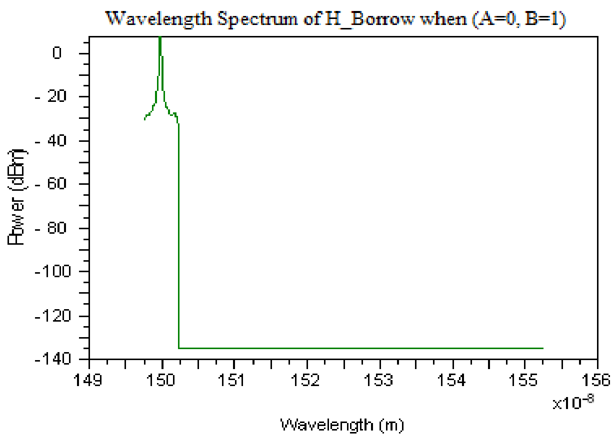
Half A/S has four outputs carry and sum for addition operation, borrow and difference for subtraction operation. Carry output is taken from P4 terminal. P2 and P3 combined to give the sum and difference output, whereas only P2 terminal provides borrow output. For demonstration, the simulation results of input combination (A=0, B=1) is given below.



(a)



(b)



(c)

Fig. 4. Wavelength Spectrums of Half A/S for (A=0, B=1) (a) Sum/Diff, (b) Carry & (c) Borrow

In the taken input combination, the control signal A is absent and only B control signal is present; due to which the incoming light signal falls on switch S1, emerges out from the upper channel in the first stage to fall on switch S2 and follows the path of upper channel to exit finally from terminal P2 in second stage. So, the sum, difference and borrow shows logic 1, whereas carry show logic 0 which is also clear from the wavelength spectrums given in Fig. 4. In the wavelength spectrum if the intensity of optical signal has negative power indicates logic 0 is detected whereas logic 1 when optical signal has power in terms of positive values or even when zero value.

B. Full A/S

Case 1: when (A=0, B=0, C=0), incoming light signal is obtained T1 terminal, whereas all other terminals are in off state. Thus, T1 denotes $\bar{A}\,\overline{BC}$ logic

Case 2: when (A=0, B=0, C=1), only T2 terminal receives the incoming light signal. Hence, T2 represents $\bar{A}\bar{B}C$ logic.

Case 3: when (A=0, B=1, C=0), incoming light signal reaches at T3 terminal only. Thus, T3 depicts $\bar{A}B\bar{C}$ logic

Case 4: when (A=0, B=1, C=1), light from incoming signal reaches at T4 terminal. Hence, T4 denotes $\bar{A}BC$ logic.

Case 5: when (A=1, B=0, C=0), incoming light signal is obtained at T5 terminal only. Thus, T5 represents $A\overline{BC}$ logic

Case 6: when (A=1, B=0, C=1), only T6 terminal receives the incoming light signal. Hence, T6 denotes $A\bar{B}C$ logic.

Case 7: when (A=1, B=1, C=0), incoming light signal reaches at T7 terminal only. Thus, T7 depicts $AB\bar{C}$ logic

Case 8: when (A=1, B=1, C=1), only T8 terminals receives the incoming light signal. Hence, T8 denotes ABC logic.

For Full A/S, sum and difference output is obtained by combining terminals T2, T3, T5 and T8 as $(\bar{A}\bar{B}C + \bar{A}B\bar{C} + A\overline{BC} + ABC)$. Carry output is taken by combining T4, T6, T7 and T8 terminals as $(\bar{A}BC + A\bar{B}C + AB\bar{C} + ABC)$ and borrow is obtained by combining terminals T2, T3, T4 and T8 as $(\bar{A}\bar{B}C + \bar{A}B\bar{C} + \bar{A}BC + ABC)$. The simulation results for some of the input combinations are shown below: For demonstration, the simulation results of input combination (A=0, B=1, C=1) is shown below:

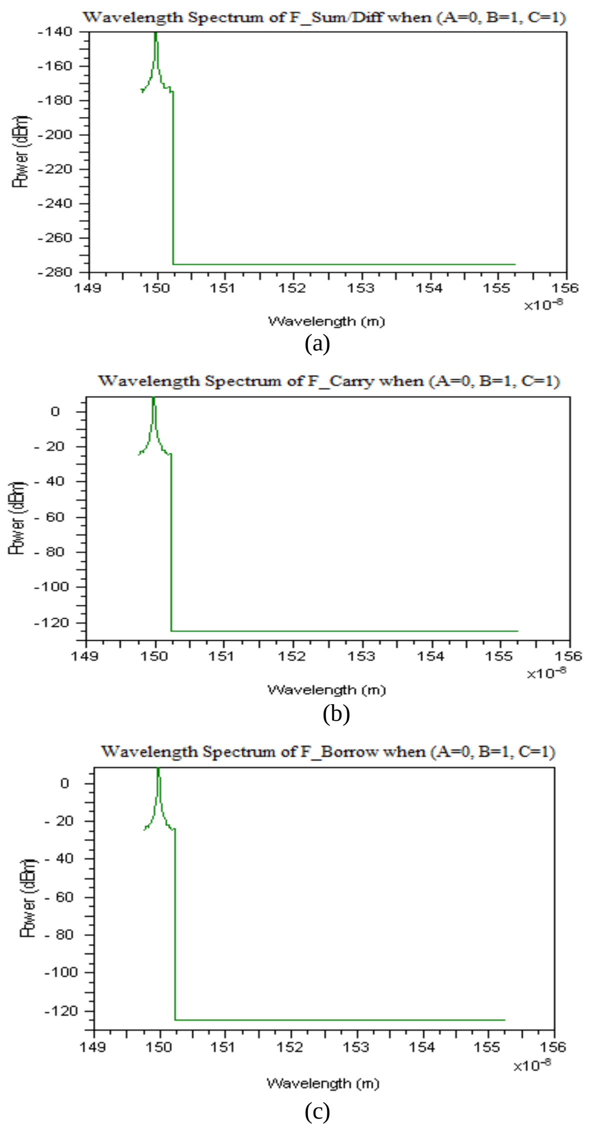


Fig. 5. Wavelength Spectrums of Full A/S (a) Sum/Diff, (b) Carry & (c) Borrow when (A=0, B=1, C=0)

When the input combination is (A=0, B=1, C=1), the incoming light signal when falls on switch S1, due to the absence of control signal A, it emerges out from the lower channel to fall on switch S3. Here, the presence of control signal B makes the light signal path to the upper channel and reaches switch S6. Finally, the light signal exits out from terminal T4 due to the presence of control signal C in third stage. Thus terminal T4 receives light only whereas all other terminals are in off state. So, the output signals borrow and carry is high i.e. logic 1, but sum and difference output signals are low i.e. logic 0. The wavelength spectrums of output signals namely sum, difference, carry & borrow are shown in Fig. 5.

4. Conclusion

An all-optical integrated Half A/S and Full A/S is implemented using SOA-MZI based Tree architecture. MZI along with tree architecture makes the system capable to work even at higher bit rates. The same architecture can be further extended for complex logic operation by proper incorporation of optical MZI switches, horizontally and vertically extension of the tree and by suitable branch selection.

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