All-Optical Logic and Arithmetic Operators Designed by Modified Add-Drop Filter

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ABSTRACT

Optical micro-ring resonators (MRRs) element can be used in many applications. This paper we propose a photonics circuit design based on optical tree architecture (OTA) for all-optical elements by using the modified add-drop filter for an all-optical arithmetic logic unit (ALU) aimed for computing applications system. All-optical 2x4 decoder, all-optical comparator, all-optical half adder, all-optical half subtractor, all-optical full adder, all-optical full subtractor and proposed new design all-optical 4x16 decoder were proposed. We have studied the nonlinear effect in the modified add-drop filter system, which is control by injected the nonlinear pulses on top as an input for generated all-optical logic and arithmetic operations simultaneously at the through and drop port of modified add-drop filter. The optical input and control field of the modified add-drop filter circuit can be formed by nonlinear dark and bright pluses. The obtained simulation results have shown that the nonlinear pulse generated by the nonlinear modified add-drop filter can control the output consistency, which is important when the interconnect between each circuit output parts are required. The advantages of the modified add-drop filter are low power, ultra-fast switching, tuneable and high security which is compact size and footprint. It is suitable for the next generation of all-optical small-scale device and all-optical computing system requirements.

Keywords: All-Optical ALU, All-Optical Arithmetic and Logical Unit, Photonic Circuits, All-Optical Computing

1. INTRODUCTION

The computing technology has changed, the big data and information analysis for obtaining knowledge and regularity from the big data, terabytes/petabytes of data, to create a business value or make society more sophisticated and efficient. In terms of required processing of a big data. It can be classified into two types of methods, one is the batch processing and the other is the real-time data-stream processing. The distributed data processing technology and communication system toward to the limitation of electrical in copper wire, the all-optical technology are the key success for next generation of ultrafast data processing technology and data transmission, in which the speed of the all-optical unit is ultimately limited by the speed of electronic input and output [1]. The Optical or photonic computing allows a higher processing and bandwidth more than the electronic computers. The nonlinear add-drop filter has been used in various technology and applications circuits for replacing current electronic circuit and computer component with optical equipment. The advantages of the nonlinear add-drop filter are small, low power, low loss, high Q, ultra-fast switching, high security. However, most of the previous work have proposed various architectures, techniques and designs for replacing electronic devices with the all-optical device. The all-optical logic and all-optical arithmetic unit (ALU) proposed. such as using Semiconductor Optical Amplifier (SOA) [2-5], a Quantum Dot [6,7] , a Terahertz Optical Asymmetric de-multiplex (TOAD) [8,9], cascaded microring resonators [10,11], an all-optical arithmetic unit [12,13] , an all-optical binary counter [14], an all-optical adder [15, 16]. However, the new design and new techniques in research materials have become the challenge especial nonlinear material device and add-drop filter. The nonlinear add-drop filter and nonlinear signal processing system behaviours will produce new generation components. It is recommended and great of interest because the nonlinear add-drop ring resonator which the advantages for photonic integrated circuit and nonlinear pulses are better for carriers the big data information at high bit rates over long distances [17]. In this paper, we study the nonlinear effected of the nonlinear modified add-drop filter, which is control by injected the nonlinear pulses on top of the nonlinear modified add-drop filter for generated 1-bit optical logic and arithmetic operation simultaneously at through and drop port of the modified add-drop filter based on optical tree architecture (OTA), which can be used for replacing current computer components and an electronic logic replacement and im-

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provement overall performance. In simulation result show that the simultaneous logic operation of 1-bit binary based on nonlinear pulse control behaviours can be performed. The proposed scheme is based on a 1-bit binary, which logic "0" and "1" used the nonlinear dark pulse (D) and nonlinear bright pulses (B), respectively. This paper organized as follows in section 2 is the operation principle and the basic method of the proposed scheme. Section 3 illustrates the all-optical logic and arithmetic operations. Section 4 and 5 show the simulation result and proposed designed are demonstrated. The last section concludes of the proposed.

2. OPERATING PRINCIPLE AND THEORY

The schematic diagram of the modified add-drop filter as shown in Figure 1 when the coupling region is defined by the coupling factor kappa (κ). The optical pulse input into the Input port and split at coupled (κ_1) into the modified add-drop filter. The optical pulse circulate into the modified ring will split at coupled (κ_2) into the straight waveguide (medium) and output to drop port as shown in Figure 1.

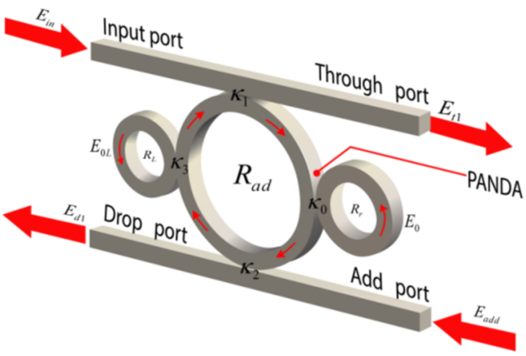


Fig.1: *Schematic diagram of the modified add-drop filter.*

The optical fields transmitted and circulated in modified add-drop filter can be written as [19, 20, 21, 28]. The mathematic model for optical field output of the modified add-drop filter at through port (E_{t1}) as shown in equation (1).

$$\mathrm{E}_{t1} = x_1 y_1 E_{in} + \left(j x_1 x_2 y_2 \sqrt{\kappa_1} E_0 E_{0L} E_1 - x_1 x_2 \sqrt{\kappa_1 \kappa_2} E_{0L} E_{i2}\right) e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n \frac{L}{2}} \quad (1)$$

The mathematic model of the intensity power output of the modified add-drop filter at through port (P_{t1}) as shown in equation (2).

$$P_{t1} = (E_{t1}).(E_{t1})^* = |E_{t1}|^2 \quad (2)$$

The mathematic model of the optical field output of the modified add-drop at drop port (E_{d1}) as shown in equation (3).

$$E_{d1} = x_2 y_2 E_{add} + j x_2 \sqrt{\kappa_2} E_0 E_1 e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n \frac{L}{2}} \quad (3)$$

The mathematic model of the intensity power output of the modified add-drop filter at drop port (P_{d1}) as shown in equation (4).

$$P_{d1} = (E_{d1}).(E_{d1})^* = |E_{d1}|^2 \quad (4)$$

The nonlinear optical pulse input and control fields at the input and add ports of the modified add-drop filter are formed by the nonlinear dark pulse (D) and nonlinear bright pulse (B), which are given by reference [18] as shown in equations (5) - (6), respectively.

$$E_{in}(t) = A_0 \tanh\left[\frac{T}{T_0}\right] \exp\left[\frac{z}{2L_D} - i\omega_0 t\right] \quad (5)$$

$$E_{in}(t) = A_0 \mathrm{sech}\left[\frac{T}{T_0}\right] \exp\left[\frac{z}{2L_D} - i\omega_0 t\right] \quad (6)$$

When optical/light pulse propagates within the nonlinear material (medium), the refractive index (n) of an optical/light pulse within the medium is given by equation (7), which is given by references [22, 23, 24].

$$n = n_0 + n_2 I = n_0 + \frac{n_2}{A_{eff}} P \quad (7)$$

An OTA is one very important in this field. The OTA system produces a single straight path into several branches and sub-branch as shown in Figure 2. [25], where signal input from point A, first step it will split into two parts B-C and B-D, in next step two beams will be split again into four parts, i.e. B-C to C-E, C-F and B-D to D-G and D-H, respectively. In this solution, multiple optical output channels could be obtained from the single input light pulse. An all-optical arithmetic logic unit operation in this paper is based on the OTA, which can be formed by the beam splitter (BS) and beam combiner (BC) to generated logic operation at each output port. The nonlinear pulse injection on top of the nonlinear modified add-drop filter for generated optical logic and arithmetic operation as shown in Figure 3.

3. ALL OPTICAL LOGIC AND ARITHMETIC OPERATIONS

A modified add-drop filter for all-optical logic and arithmetic operations by a nonlinear pulse can be successfully operated with OTA as shown in Figure 4. In proposed scheme the nonlinear modified add-drop filter MRR1, MRR2 and MRR3 are used and as split point B, C and D as shown in Figure 2. in which an optical filter is applied at all output ports to reduce the power nonlinear formation and the switching

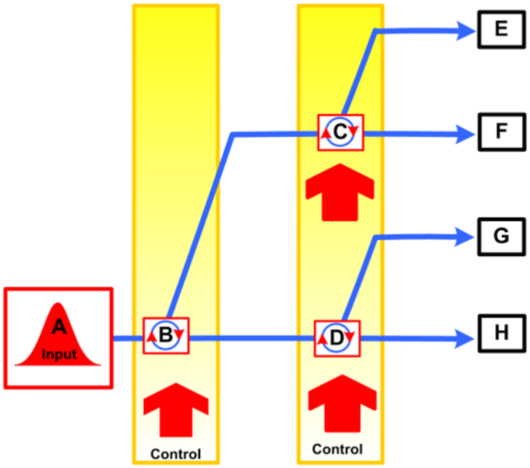


Fig.2: *Schematic diagram of Optical Tree Architecture (OTA).*

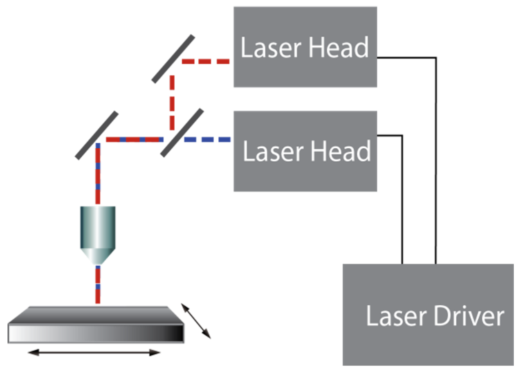


Fig.3: *The nonlinear pulse injection on top of the nonlinear modified add-drop filter.*

threshold output, which is shown in Figure 4, where the input and control field which is generated by nonlinear dark and bright pulse. By using nonlinear dark and bright pulse we can using for control switching threshold at the output, the CW is nonlinear bright pulse representing the logic "1" and dark nonlinear pulse input represent logic "0" we used wavelength λ_1, and bright nonlinear pulse λ_2 is used for represent logic "1". In this scheme, the nonlinear dark pulse is used to represent logic "0" and the bright nonlinear pulse represents the logic "1". The all-optical switch by applied optical pumping on top. The pumping energy near material bandgap energy and almost fully absorbed in the nonlinear modified add-drop filter [27]. The cross-phase modulation (XPM) is applied to the dark-bright nonlinear light pulse circumference into the nonlinear modified add-drop filter, which can be used to increase or decrease (forward and reverse bias) refractive index simultaneously, which is shown in Figure 5 (a)-(b). The optical signal output at through and drop ports can be controlled, which can make the optical signal at the through and drop ports out of phase of π [26] as shown in Fig. 6 (a) - (b). The nonlinear effect phenomena, the optical logic switching at the output port of ring resonator (throughput port and drop port) can be formed and represented the NOT gate, as shown in Figure 5 (a)-(b), the data can be concluded by the logic operation in Table1. results of the configuration by exciting on top of nonlinear modified add-drop filter using dark-bright nonlinear pulse switching are obtained simultaneously and seen at the drop and through ports by T2, D2, T3 and D3 for optical logic operation as shown in Fig. 7.

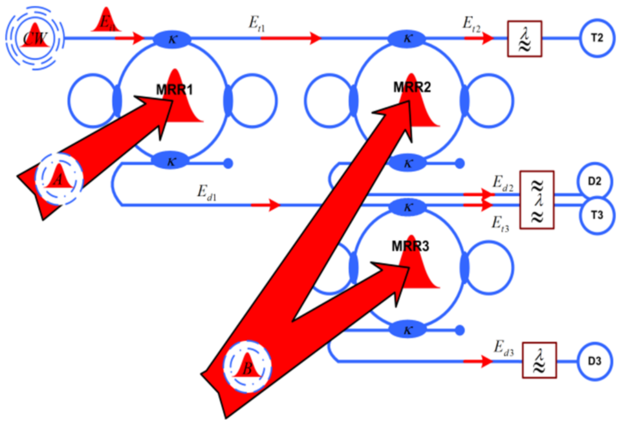


Fig.4: *The nonlinear modified add-drop filter circuit for all-optical logic and arithmetic operations based on an optical tree architecture.*

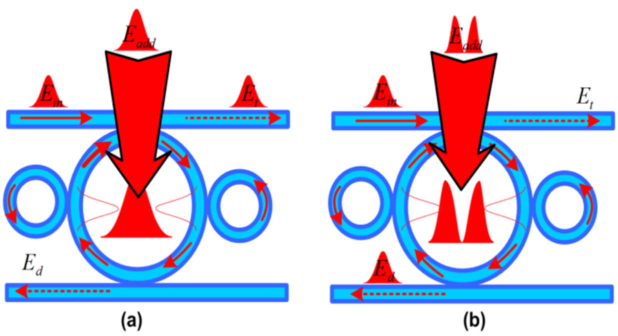


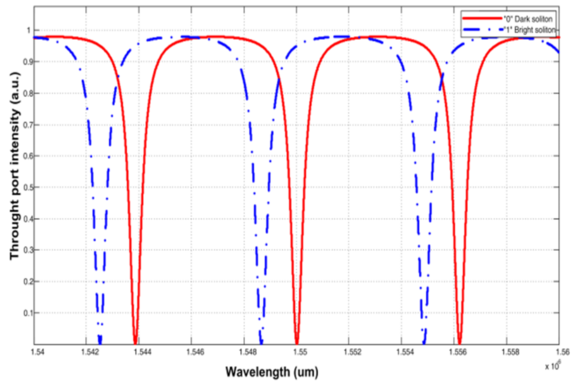
Fig.5: *Nonlinear pulse pump on top for optical control switch(a) nonlinear Bright pulse 'B', (b) nonlinear Dark pulse 'D'.*

Table 1: *Nonlinear dark and bright pulse control switch.*

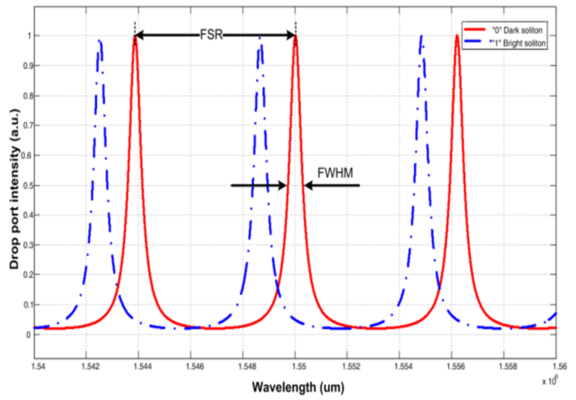
E_{in}	E_{pump}	E_{th}	E_{drop}
0	0	0	0
0	1	0	0
1	0	1	0
1	1	0	0

4. MODIFIED ADD-DROP FILTER SIMULATION RESULT AND DISCUSSION

In the simulation result for all-optical logic and arithmetic operations we using the parameters of



(a)



(b)

Fig.6: *Resonance shift (a) Through Port (b) Drop Port.*

modified add-drop filter are fixed to be κ = 0.5, κ_1 = 0.25, κ_2 = 0.25 and κ_3 = 0.5, respectively. The ring radii R_{ad}= 5 μm, R_r= 1.5 μm, R_L = 1.5 μm. In order to make the system associating with the practical device [28], the selected parameters of the system are fixed to n_0 = 3.34 (InGaAsP/InP), A_{eff} = 0.50 μm^2 and 0.25 μm^2 for a add-drop filter, respectively, α = 0.5 $dBm m^{-1}$, γ = 0.1. The nonlinear refractive index of the add-drop filter used is n_2 = 2.2 x 10-17 m^2/W. In this case, the attenuation of light propagates within the system (i.e. wave guided) used is 0.5dBmm-1. From Fig.4, the nonlinear dark pulse and nonlinear bright pulse with wavelength (λ_1) at 1.55 m for input and control signal, respectively. The nonlinear bright pulse input with wavelength (λ_2) at 1.25 μm, pulse width of 50 fs, peak power at 1 mW. The simulation result signal output as shown in Figure 7 (a-e), the simultaneous optical output logic gate is seen, which can be configured as following details.

In the first scenario, we added optical pulse input for represent logic "00" by using "***DD***" is added (A=0 and B=0) , the obtained simulation result output logic "1" appear at port D3 , then we can represent the optical logic status output at T2, D2, T3, D3 is ***0001*** "***DDDB***" , respectively as show in Fig.7 (b).

In the second scenario, we added optical pulse input for represent logic "01" by using "***DB***" is added (A=0 and B=1), the obtained simulation result output logic "1" appear at port T3, then we can represent the optical logic status output at T2, D2, T3, D3 is ***0010*** "DDBD" , respectively as show in Fig.7 (c).

In the third scenario, we added optical pulse input for represent logic "10" by using "***BD***" is added (A=1 and B=0), the obtained simulation result output logic "1" appear at port D2, then we can represent the optical logic status output at T2, D2, T3, D3 is ***0100*** "DBDD" , respectively as show in Fig.7 (d).

In the fourth scenario, we added optical pulse input for represent logic "11" by using "***BB***" is added (A=1 and B=1), the obtained simulation result output logic "1" appear at port T2, then we can represent the optical logic status output at T2, D2, T3, D3 is ***1000*** "BDDD" , respectively as show in Fig.7 (e).

The conclusion of the simulation result as show in Table 2. The assumption symbol for represents the logic state when optical pulse trains input A, B are fed into MRR1, MRR2 and MRR3 represent by logic AND, then the optical logic state that appear at the through and drop ports of MRR2 and MRR3 have shown that the output logic $A.B$ at port T2 , $A.\bar{B}$ at port D2, $\bar{A}.B$ at port T3 and $\bar{A}.\bar{B}$ at port D3, respectively.

Table 2: *Truth table of the dark-bright nonlinear control .*

CW	Input		Output			
	A	B	E_{th2}	E_{dr2}	E_{th3}	E_{dr2}
1	0	0	0	0	0	1
1	0	1	0	0	1	0
1	1	0	0	1	0	0
1	1	1	1	0	0	0
Logic status			AB	$A\bar{B}$	$\bar{A}B$	$\bar{A}\bar{B}$

nonlinear dark pulse (D) represent logic '0', nonlinear bright pulse (B) represent logic '1'

5. SIMULTANEOUS ALL-OPTICAL LOGIC AND ARITHMETIC OPERATION

The proposed scheme for designed all-optical logic operation of the coupled waveguide for convenience, we replace Figure 8(a) by Figure 8(b).

The truth table of the 2×4 decoder as shown in Table 3. It can be the use of AND gate and NOT gate as show schematic in Fig.9 From the simulation results of a modified add-drop filter circuit, we can generate the all-optical decoder by using modified add-drop filter based optical tree architecture as shown in Fig. 10.

The truth table of the comparator for data comparison in the computer system and circuit as shown in Table 4 and Fig.11, respectively. From the simulation results, we can generate the all-optical data com-

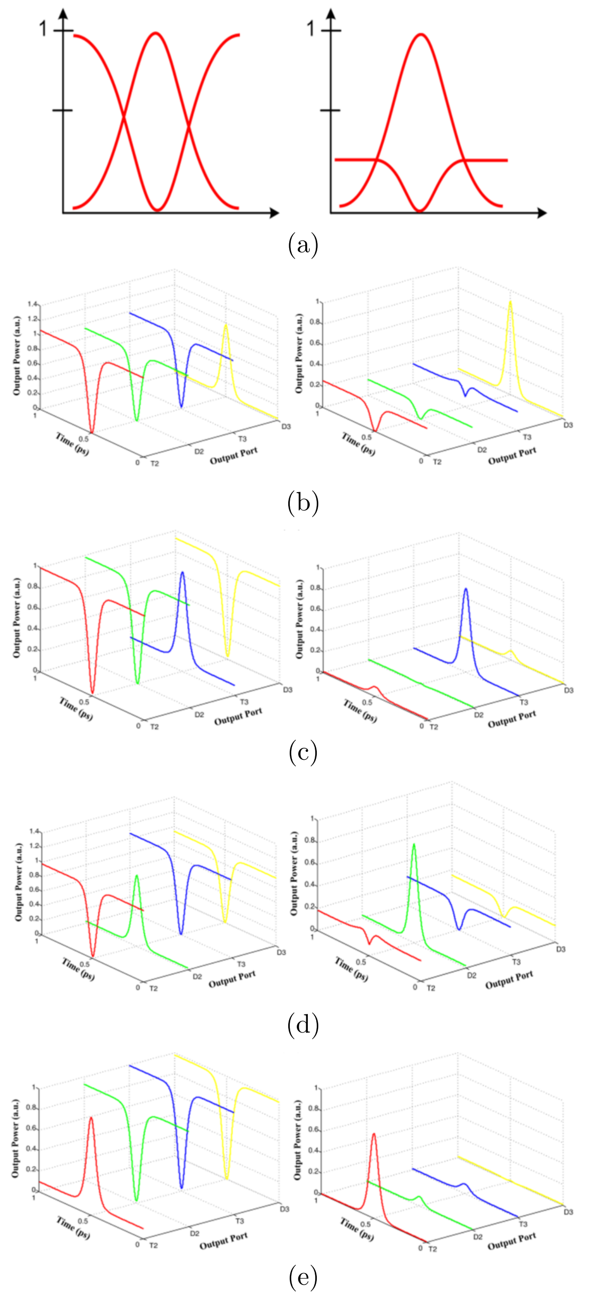


Fig. 7: *The 1-bit all-optical logic simulation results of modified add-drop filter circuit the output logic when the input logic is (b) 00 "DD", (c) 01 "DB", (d) 10 "BD" and (e) 11 "BB".*

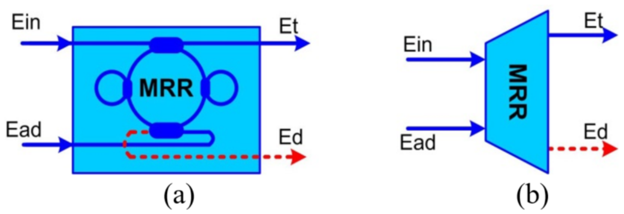


Fig. 8: *A schematic diagram of modified add-drop filter.*

Table 3: *Truth table of the decoder.*

A	B	D_0	D_1	D_2	D_3
0	0	1	0	0	0
0	1	0	1	0	0
1	0	0	0	1	0
1	1	0	0	0	1

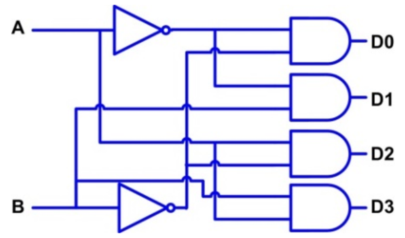


Fig. 9: *Schematic diagram of the logic gate decoder.*

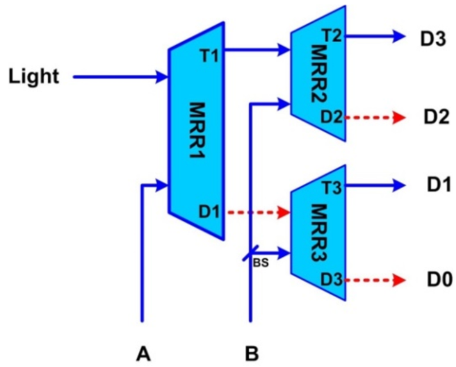


Fig. 10: *Schematic diagram of all-optical 2x4 decoder using modified add-drop filter based OTA.*

parator by using the modified add-drop filter based optical tree architecture as shown in Fig. 12.

Table 4: *Truth table of the comparator.*

Input		*Output*		
A	B	$A > B$	$A = B$	$A < B$
0	0	0	1	0
0	1	1	0	0
1	0	0	0	1
1	1	0	1	0

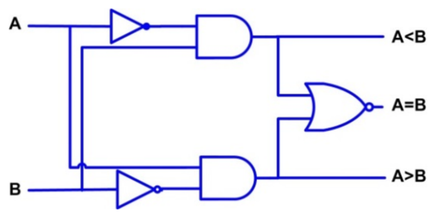


Fig. 11: *Schematic diagram of the logic gate comparator.*

In the half adder and half, subtractor truth table

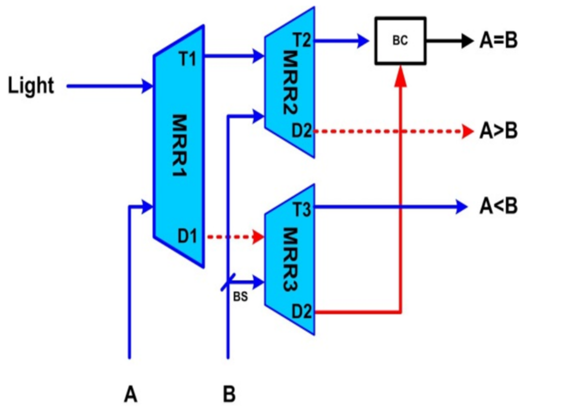


Fig.12: *Schematic diagram of an all-optical comparator using the modified add-drop filter based OTA.*

is given and shown in Table 5 and Fig.13, respectively. The simplified output of sum and difference can be also implemented with XOR gate as shown in Fig. 13(a-b), in which the addition and subtraction operations can be combined into one circuit with one common binary.

Table 5: *Truth table of the Half Adder/Subtractor.*

Input		*Half Adder*		*Half Substractor*	
A	*B*	*Sum*	*Carry*	*Diff.*	*Borrow*
0	0	0	0	0	0
0	1	1	0	1	1
1	0	1	0	1	0
1	1	0	1	0	0

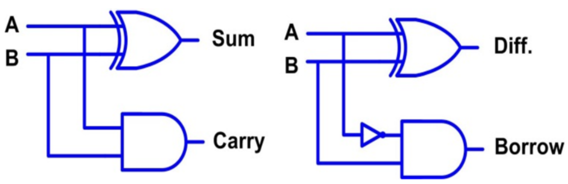


Fig.13: *(a) Schematic diagram of logic gate half adder (b) Schematic diagram of logic gate half subtractor.*

From the simulation results of the modified add-drop filter circuit, we can generate the simultaneous all-optical half adder and all-optical half subtractor combined into one circuit with one common circuit by using optical tree architecture as shown in Fig. 14.

From the simulation results, we can form 16 logic operation from two input logic base OTA by using the beam combiner (BC) and beam splitters (BS), where the interconnection between each port output (T2,D2,T3,D3) can be concluded in Table 6. The plus (+) sign is used to represent the combined signal output from the expected port.

The all-optical full adder by using modified add-drop filter based OTA can be thought of as two half adders connected together, with the first half adder passing its carry to the second half adder as shown in Fig.15.

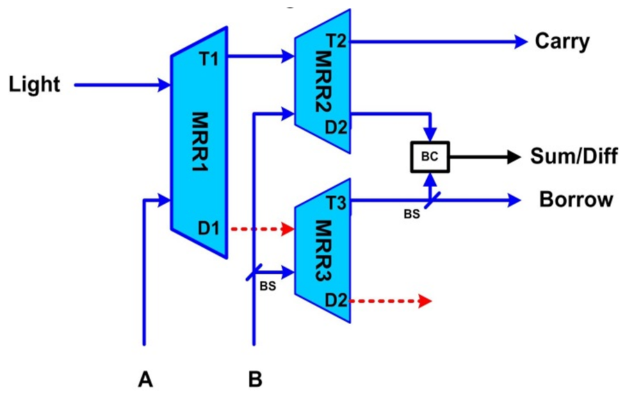


Fig.14: *Schematic diagram of an all-optical half adder and all-optical half subtractor using the modified add-drop filter based OTA.*

Table 6: *All-Optical logic operations form by modified add-drop filter circuit based on optical tree architecture.*

No.	Logic	All-Optical Tree Architecture
1	A	T2+D2
2	B	T2+T3
3	$\bar{A}$	T3+D3
4	$\bar{B}$	T3+D2
5	XOR	D2+T3
6	$\overline{XOR}$	T2+D3
7	$A + B$	T2+D2+T3
8	$A + \bar{B}$	T2+D2+D3
9	$\bar{A} + B$	T2+T3+D3
10	$\bar{A} + \bar{B}$	D2+T3+D3
11	AB	T2
12	$\bar{A}B$	T3
13	$A\bar{B}$	D2
14	$\bar{A}\bar{B}$	D3
15	$TRUE$	T2+D2+T3+D3
16	$FALSE$	No Signal

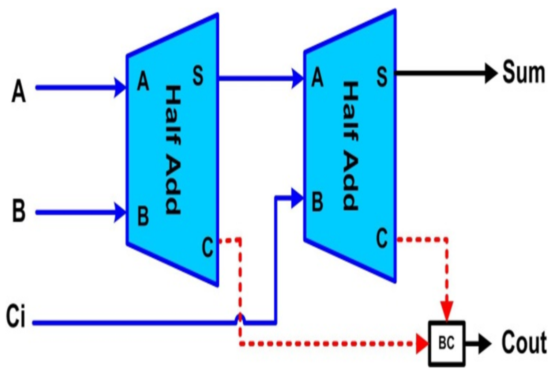


Fig.15: *Schematic diagram of all-optical full Adder.*

Just like the all-optical full adder circuit, the all-optical full subtractor by using modified add-drop filter based OTA can also be thought of as two half subtractors connected together, with the first half subtractor passing its borrow to the second half subtractor as follows as shown in Fig.16.

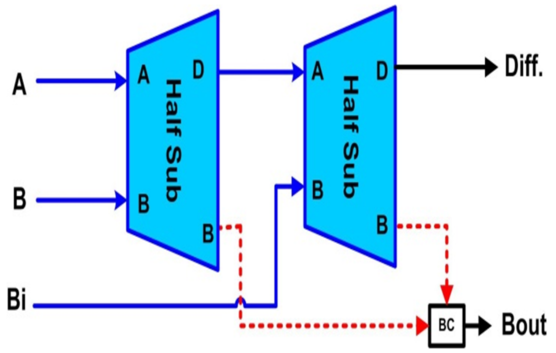


Fig.16: *Schematic diagram of all-optical full subtractor.*

A new designed for all-optical 4×16 decoder has 4 inputs and 16 outputs, with the outputs going high for the corresponding 4-bit input. Similar is the case of a 2×4 decoder except for its 2 inputs and 4 outputs. The all-optical 4×16 decoder as shown in Fig.17.

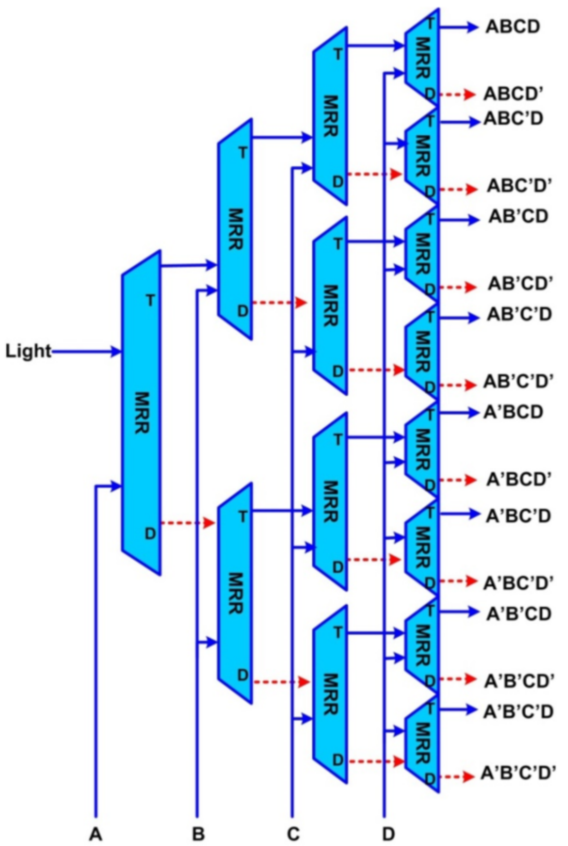


Fig.17: *Schematic diagram of all-optical 4×16 Decoder.*

6. CONCLUSIONS

This work we presented a new designed circuit of the ALU for an all-optical 2×4 decoder, all-optical comparator, all-optical half adder, all-optical subtractor, all-optical full adder, all-optical full substrate and all-optical 4×16 decoder by using the modified add-drop filter based optical tree architecture for big data processing, higher speed, computation and processing. The simulation result shows that we can generate simultaneous all-optical logic and arithmetic operations at the through and drop ports, respectively. The design system is simple and flexible for the all-optical integrated circuit, where the advantages of the device are switching speed, low power, stability and tunable.

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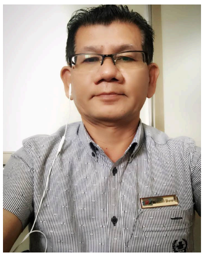

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