Design of All-Optical Half Adder and Half Subtractor based on SOA-MI

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Abstract. An all-optical half adder and half subtractor is proposed using Semiconductor Optical Amplifier assisted Michelson Interferometer (SOA-MI) configuration along with two similar Fiber Bragg Grating (FBG) at the end of the interferometric arms to satisfy the truth table of half adder and half subtractor. SOA acts as an amplifier without the need for conversion to electrical signals. The proposed model is designed using all-optical NOR gates with cross-gain modulation (XGM) of SOA at bit rate of 10Gbps. Analysis of performance factors which includes Bit Error Rate (BER), OSNR and Q-factor have been discussed.

1. Introduction
In recent days, due to the rise in the usage of high speed internet, the necessity for advanced modulation techniques, coding and digital equalization in electronic processing have also increased. To overcome the disadvantage of electronic processing, all optical processing have been projected. Optical computing makes use of various laser sources [1] which have higher bandwidth when compared to electrons is most suited for computation purpose. In optical computing, electrical equivalents are replaced by optical components. All-Optical components remove the requirement of optical-electrical-optical conversion (OEO), in which the input datas are processed with less power consumption. For all-optical computing, all-optical gates acts as the basic element which can be designed using several approaches such as Semiconductor Optical Amplifier (SOA) [2-3], photonic crystal fiber [4-7], Erbium Doped Fiber Amplifier (EDFA) as an amplifier [8]. Since Semiconductor Optical Amplifier (SOA) based gates have increased photonic integration capability compared to gates based on photonic crystal fibers and EDFA. Optical logic gates can be used in the scheme of adders, subtractors, code convertors and latches. [9-12].

Semiconductor Optical Amplifier (SOA) is an optical amplifier used to strengthen optical signals based on the semiconductor gain medium. It helps to overcome the barriers with the non-linearity behavior. They play crucial role in amplification, increasing gain and efficient details of the refractive index and can be used in all-optical 3R-regeneration systems. It has the advantage of smaller in size, larger bandwidth, fast switching time, high power efficiency and photonic integration ability. The various non-linear effects of SOA include Self-Phase Modulation (SPM), Cross-Gain Modulation (XGM) [13], Cross-Phase Modulation (XPM), Four Wave Mixing (FWM), Cross Polarization Modulation (XPolM). XGM is simple to implement, have high conversion efficiency and unresponsive to the polarization of input information. All-optical gates may be constructed with SOA and without SOA. Based on interferometric configuration, all-optical logic gates based on SOA might be divided into various types. These types include Ultra Non-linear Interferometer (UNI) gates, Sagnac Interferometer (SI) gates, Michelson Interferometer (MI) gates, Mach-Zehnder Interferometer (MZI), Fabry-perot interferometer gates and Delay Interferometer (DI) gates. The interferometer is the
device that creates interferometric firms by merging the two or more sources of light. Using this firm we can understand or determine the type of the source and the distance from which the source is projected. Michelson Interferometer is the simple configuration which helps in splitting and merging of the light sources that capture the interferometry firms in camera or photo detectors. SOA’s are positioned at the arms of the interferometer.

In this paper, all-optical half adder and half subtractor have been suggested by means of SOA-MI structure with the aid of all-optical NOR gates. Section 2 describes about the operation of SOA-MI configuration. Section 3 presents the scheme of all-optical NOR gate. Section 4 explains the scheme of all-optical half adder and half subtractor. Section 5 describes the conclusion of the designed structure.

2. Proposed Method
In Michelson interferometer, using a ray splitter a light source is split into two arms in which each arm consists of a mirror. The light which falls on the mirror is reflected and once more combined to produce interference pattern and sent to the receiver. SOA is located at the arms of the Michelson Interferometer.

3. Design of All-Optical NOR Gate
NOR gate is one among the universal gates and it is the reverse of OR gate. It has bi or multiple inputs with single output. If data X and data Y of NOR gate are logic “0”, then the outcome is logic “1” or high. Otherwise, the outcome is logic “0” or low.

The representation of SOA-MI based NOR gate is depicted in Figure 1. Data X and Data Y acts as the probe signal. Both Input X and Y in addition with the control pulse are launched into SOA. The outcome of SOA is given as input to each Fiber Bragg Grating (FBG) and the outcome of FBG is fed to the input of SOA, in which the outcome of NOR gate is obtained.

![Fig.1 Schematic design of NOR gate](image_url)

The simulation considerations of NOR gate used in this scheme are listed in table 1.

| SI.NO. | PARAMETERS                  | VALUE   |
|-------|-----------------------------|---------|
| 1     | Input power of the pump signal | 0.3 mW  |
| 2     | Input power of the probe signal | 0.25 mW |
| 3     | Frequency of the pump signal  | 1556 nm |
| 4     | Frequency of the probe signal | 1550 nm |
| 5     | Injection current           | 0.2 A   |
| 6     | Length                      | 0.5 mm  |
| 7     | Width                       | 3 m     |
| 8     | Optical confinement factor   | 0.3     |
| 9     | Line width enhancement factor | 5       |
The model arrangement of SOA-MI based NOR gate is depicted in Figure 2. Data X also Data Y is generated using User Bit Sequence Generator at 10Gbps with optical Gaussian pulse generator and coupled using coupler. The control signal is generated using CW laser with power of 0.25 mW. Both the input signals and control signal is combined using power combiner and injected to travelling wave SOA with injection current of 0.2 A. The output of SOA is split to two FBG which have the frequency of 1550 nm. The output of each FBG is again injected to travelling wave SOA and the output signal is filtered using Gaussian optical filter. The optical signal is received using optical receiver.

4. Design of All-Optical Half Adder and Half Subtractor

4.1 All-optical half adder using NOR gate

Half adder is a combinational circuit which adds binary information and produces double outcomes i.e. sum and carry. Here, half adder is implemented using five NOR gates.

Table 2 Truth Table.

| Input X | Input Y | Sum (X XOR Y) | Carry (X AND Y) |
|---------|---------|---------------|-----------------|
| 0       | 0       | 0             | 0               |
| 0       | 1       | 1             | 0               |
| 1       | 0       | 1             | 0               |
| 1       | 1       | 0             | 1               |

The schematic design of half adder using NOR gate is represented in Fig.3.
The model arrangement of SOA-MI based half adder using NOR gate is represented in Figure 4. The data X and Y is generated using User Bit Sequence Generator and the output of half adder is visualized using oscilloscope visualizer.

When data X is 0011 and data Y is 0101, corresponding sum outcome is 0110 and the carry outcome is 0001. The outcome, eye diagram and Q-factor of half adder are depicted in Figure 5, 6, 7.
Q-Factor is explained as in (1),
\[ Q = \frac{\text{Stored energy}}{\text{Dissipated energy}} \]  
per oscillation cycle.
Q-Factor is also explained as follows [15] in (2).
\[ Q = \frac{\bar{P}_1 - \bar{P}_0}{\sigma_1 + \sigma_0} \]  
where,
\( \overline{P}_1 \)-average power of output signal 1
\( \overline{P}_0 \)-average power of output signal 0
\( \sigma_1 \)-standard deviation of all logic 1
\( \sigma_0 \)-standard deviation of all logic 0

![Figure 7: Q-factor of half adder](image)

**Fig.7** Q-factor of half adder

Bit Error Ratio (BER) and Optical Signal to Noise Ratio (OSNR) depend on the Q-factor which is explained as in (3) and (4) [15].

\[
\text{BER} = \frac{1}{2} \text{erfc} \left( \frac{Q}{\sqrt{2}} \right) \quad (3)
\]

where \( \text{erfc} \) is the complementary error function

\[
\text{OSNR} = \frac{1}{2} Q \left( Q + \sqrt{2} \right) \quad (4)
\]

From the eye pattern, Q-factor, BER and OSNR values have been analyzed and the values are depicted in table 3.

| Parameters | Q-factor | BER        | OSNR |
|------------|----------|------------|------|
| Sum        | 6.54986  | 2.61332e-11 | 26.08 |
| Carry      | 4.08144  | 1.99265e-005 | 11.215 |

4.2. All-Optical Half Subtractor using NOR Gate

Half subtractor is a combinational circuit which subtracts binary inputs and produces two outcomes i.e. difference and borrow. In this proposed model, half subtractor is also implemented using five NOR gates.
Table.4 Truth Table.

| Data X | Data Y | Difference (X XOR Y) | Borrow (X AND Y) |
|--------|--------|---------------------|-----------------|
| 0      | 0      | 0                   | 0               |
| 0      | 1      | 1                   | 1               |
| 1      | 0      | 1                   | 0               |
| 1      | 1      | 0                   | 0               |

The schematic representation of half subtractor using NOR gate is represented in Figure 8.

Fig.8 Diagrammatic illustration of half subtractor.

The model arrangement of SOA-MI based half subtractor using NOR gate is represented in Figure 9. The data X and Y is generated using the same process as half adder.

Fig.9 Model arrangement of SOA-MI based half subtractor

When data X is 0011 and data Y is 0101, the corresponding borrow output is 0100 and the difference output is 0110. The output, eye diagram and Q-factor of half subtractor are depicted in Figure 9, 10, 11.
Fig. 10 Outcome of half subtractor

a) Borrow

b) Difference

Fig. 11 Eye diagram of half subtractor

a) Borrow

b) Difference
a) Borrow  

b) Difference  

Fig. 12 Q-factor of half subtractor

From the eye pattern, Q-factor, BER and OSNR values have been analyzed and depicted in table 5.

| Parameters | Q-factor | BER       | OSNR      |
|------------|----------|-----------|-----------|
| Borrow     | 3.81055  | 6.81475e-005 | 9.9546    |
| Difference | 3.84236  | 5.62946e-005 | 10.0988   |

5. Conclusion

All-optical signal processing decreases the power consumption by rejecting the necessity for opto electronic conversion. The all-optical half adder and half subtractor is designed with the aid of SOA-MI based NOR gates at bit rate of 10Gbps. The proposed design is analyzed from the values of BER, Q-factor and OSNR using Optisystem platform. The designed all-optical half adder and half-subtractor is well suited for Arithmetic and logical operations.

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