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Design of all-optical AND logic gate at 20 Gb/s based on SOA-MI with optimum injection current and length of TWA-SOA

Projeto da porta lógica AND totalmente óptica à 20 Gb/s baseada em SOA-MI com corrente de injeção e comprimento do TWA-SOA ideais

J. M. Oliveira[1,2*]; H. A. B. Silva[1,2]; F. B. Sousa[2]; J. E. Oliveira[2]; M. B. C. Costa[2]

[1]*CMI campus, Federal Institute of Education, Science and Technology of Pará, 68508-970, Marabá-Pará, Brazil*

[2]*Postgraduate Program in Electrical Engineering, Federal University of Pará, 66075-970, Belém-Pará, Brazil*

**jackson.oliveira@ifpa.edu.br*

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The manuscript presents Design of All-optical AND logic gate at 20 Gb/s using Semiconductor Optical Amplifier based on Michelson Interferometer (SOA-MI). The paper shows a comprehensive numerical simulation using OptiSystem software to examine two-input logical function (with 8-bit). Used the CW Laser, Dual Directional Coupler, 100% reflective linear Fiber Bragg Grating (FBG) and Optical Filter, and investigated the optimum injection current and length of the TWA-SOA for obtaining the best result Q-Factor and BER based on Eye diagram to logic gate. To the best of our knowledge, this is the first report on a numerical simulation of an All-Optical AND logic gate at 20 Gb/s with SOA-MI using co-propagating, structure with results ensure good performance of the proposed design.

Keywords: AND logic gate, Semiconductor optical amplifiers, Michelson interferometer.

O manuscrito apresenta o design da porta lógica AND totalmente óptica à 20 Gb/s usando um amplificador óptico semicondutor baseado no interferômetro de Michelson (SOA-MI). O artigo mostra uma simulação numérica abrangente usando o software OptiSystem para examinar a função lógica de duas entradas (com 8 bits). Usou o CW Laser, Acoplador Direcional Duplo, Fiber Bragg Grating (FBG) 100% refletivo linear e Filtro Óptico, e investigou a corrente de injeção e comprimento do TWA-SOA ideais para obter o melhor resultado Q-Factor e BER com base no diagrama de olho para porta lógica. Tanto quanto sabemos, este é o primeiro relatório sobre uma simulação numérica de uma porta lógica AND totalmente óptica à 20 Gb/s com SOA-MI usando co-propagação, estrutura com resultados que asseguram um bom desempenho do projeto proposto.

Palavras-chave: Porta lógica AND, Amplificador óptico semicondutor, Interferômetro de Michelson

1. INTRODUCTION

In this paper, all-optical AND logic gate is simulated, mainly based on Michelson interferometer (MI) with semiconductor optical amplifier (SOA) and mechanism of co-propagating SOA-MI configuration along with non-linear property to design AND gate using OptiSystem software.

The fiber optics are efficient and robust systems, essential that telecommunication systems at ultra-fast speeds with high bit rate, and the Semiconductor Optical Amplifiers (SOA) ensures high data rates, direct amplification of optical signals and energy efficiency, omit the need of converting the signal from optical to electric and vice versa [1].

Optical Amplifiers are designed to omit the need of converting the signal from optical to electrical and then again to optical, and direct amplification of optical signals is done by the amplifier [1]. Energy efficiency is also considered in all-optical systems, composed of light sources, optical fibers, photodiodes and amplifiers, among other passive devices, since there is no need for optical to electric conversion and vice versa, guaranteeing high transmission rates.

The all-optical functions needed in add–drop and cross-connect fabric are wavelength conversion, add–drop-multiplexing (wavelength and time), clock recovery, regeneration, and simple bit-pattern recognition [2]. The decrease in amplification gain and carrier density of the semiconductor optical amplifier is caused due to increment in input signal power [3]. Since the carrier density change in SOAs will affect all input signals, a signal at one wavelength can affect the gain of a signal at another wavelength [4].

Among these approaches, SOA is believed to be a key component, useful building blocks for all-optical gates, because it has the stronger gain nonlinearity characteristics than optical fibers and is easier for integration used to design the all-optical gates [5, 6].

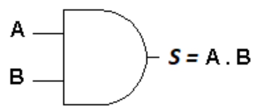
The paper is organized as follows: in section II we present the SOA-MI design of AND logic gate, in section III the results and discussions of the simulations and finally in section IV the conclusions, acknowledgments and references.

2. MATERIAL AND METHODS

In optical fibers the configuration of the Michelson interferometer can be obtained from the cascade association of two optical components: a directional coupler and 100% reflective linear Fiber Bragg Grating (FBG) [7].

The Boolean expression for AND gate is $\boldsymbol{S = A\,.\,B}$, where A and B are input signals and S is output. When any of the inputs of AND gate are bit “0”, then the output S is equal to “0”. The output will only be bit “1”, when both inputs are equal to “1”, according to the truth table in Table 1 [7].

Table 1: Truth table for AND gate.

Input A	Input B	Output $\boldsymbol{S = A.B}$	Symbol of AND gate
0	0	0	
0	1	0	
1	0	0	
1	1	1	

In the AND operation performed on the input data, the signals generated at a wavelength of λ_1 and a CW Laser at wavelength λ_2 injected as control beam, in this way, the result centered at λ_1 is the AND logic gate.

In the Figure 1 is shown the design, where the transmitter of AND gate is formed of a *Continuous Wave Laser* (CW laser) at frequency 193.2 *THz* with input power at 0 *dBm*, which passes through the *Fork 1x2* to combine by means of the coupler with the input signal A and by another coupler with the input B. The input signals A and B generated from the *Bit Sequence Generator* with the *Optical Gaussian Pulse generator* at frequency 193.1 *THz* with input power at 40 *dBm*. Both combinations pass through a *Power Combiner 2x1*, at a transmission bit rate of 20 *Gb/s*.

The signals from ports along with the control signal enters the SOA-MI, where are coupled by a *Power Combiner 2x1* whose output propagate is amplified in the *Traveling Wave SOA* (TWA) with injection current range from 0.05 to 1.0 *A* and length range from 0.0001 to 0.0010 *m*, which in turn is connected to a *Power Splitter 1x2* having both symmetrically identical FBGs with frequencies equal to those of the input signals (at 193.1 *THz*), where the output signals of the FBGs are again coupled through the *Pump Coupler Co-Propagating*, forming the SOA-MI of AND gate.

The receiver of AND gate consists of a *Gaussian Optical Filter* operates at 193.1 *THz* with a bandwidth of 40 *GHz*, rejecting interferences and noise, and then is optically converted to electrical form through the *Optical Receiver*, with a cut-off frequency of 0.75 * *bit rate Hz*, and is delivered to a *NRZ Pulse Generator*.

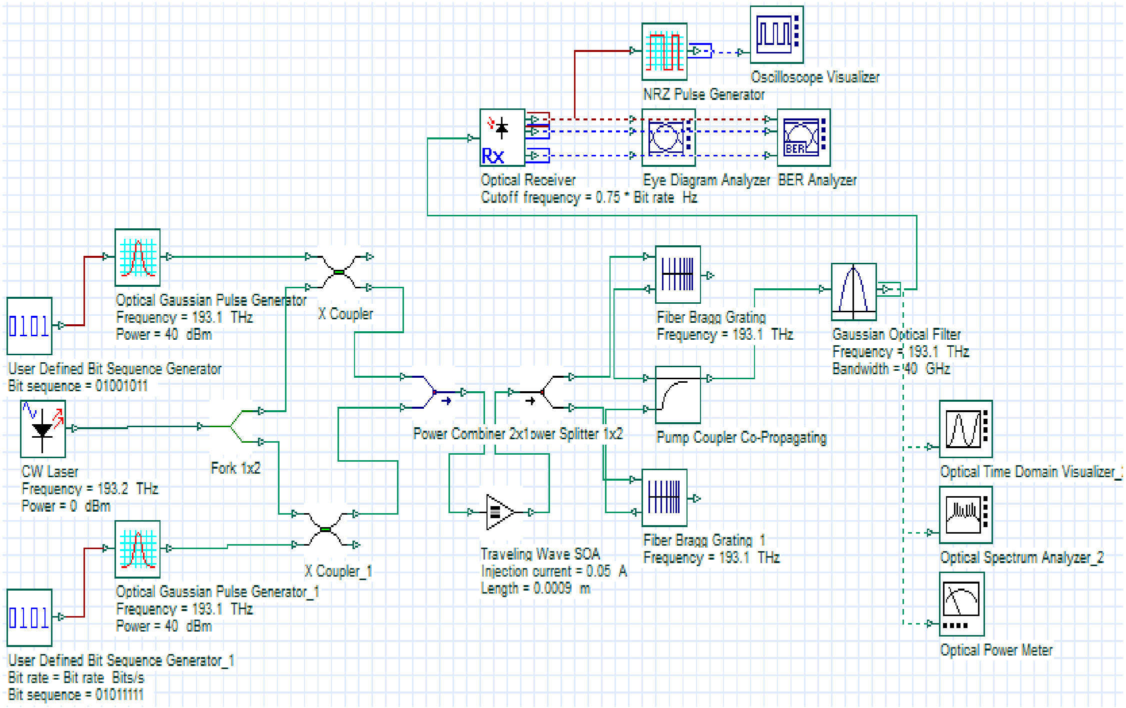


Figure 1: Project of All-optical AND logic gate with SOA-MI.

The Table 2 shows the parameters of the SOA used in this project, where the injection current and length varied to find the best result of the Q-Factor with different numbers of bits in the input signal.

Table 2: Parameters used for SOA in simulations.

SOA Parameters	**Assigned Values**
Injection current	$0{,}05 - 1.0\ A$
Length	$100 - 1000\ \mu m$
Width	$3\ \mu m$
Height	$80\ nm$
Optical confinement factor	$0{,}3$
Differential gain	$2{,}78\ \times 10^{-20}\ m^2$
Carrier density at transparency	$1{,}4\ \times 10^{24}\ m^{-3}$
Linewidth enhancement factor	5
Recombination coefficient of surface and defect	$1{,}43\ \times 10^{8}\ s^{-1}$
Recombination coefficient of radiative	$1 \times 10^{-16}\ m^3\ \cdot s^{-1}$
Recombination coefficient Auger	$3\ \times 10^{-41}\ m^6\ \cdot s^{-1}$
Initial carrier density	$3\ \times 10^{24}\ m^{-3}$

3. RESULTS AND DISCUSSION

The design has an injection current range and length range in the TWA SOA to find the best result and with the aid of the Eye diagram, the Max. Q-Factor, Min. BER are analyzed to performance of the AND gate with 8-bit binary input.

The Figure 2 shows the relationship between Q-factor vs Injection Current vs Length range, where it shows the Q-Factor for each Injection Current with different lengths of the SOA, from 0.0001 to 0.0010 *m*.

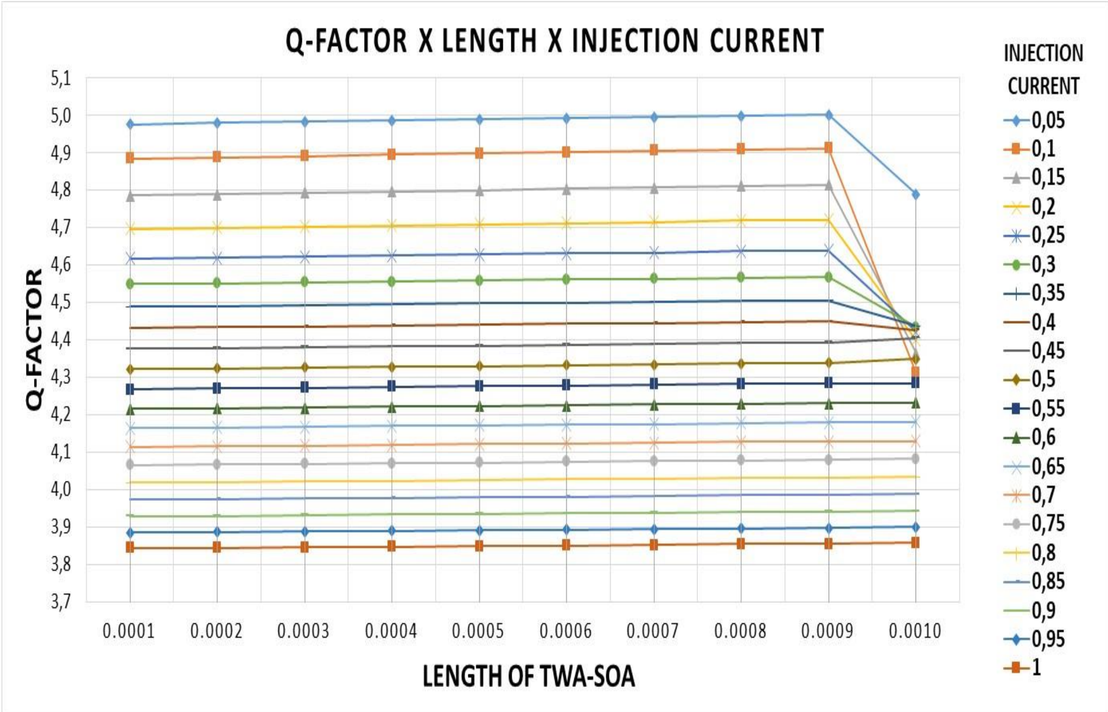
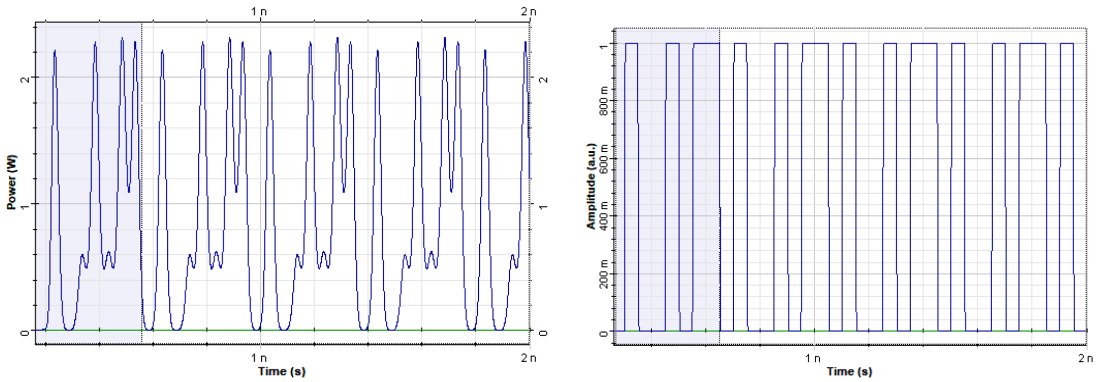


Figure 2: Results of Max. Q-Factor x Injection Current range x Length range for AND gate.

A. *The result output of the AND logic gate for 8-bits input signal*

The input signal 01001011 for port A and input signal 01011111 for port B, in the transfer from 8-bit at 20 Gb/s bit rate. The Optical Time Domain Visualizer and Oscilloscope Visualizer are shown in figure 3 with output of the AND gate 01001011.

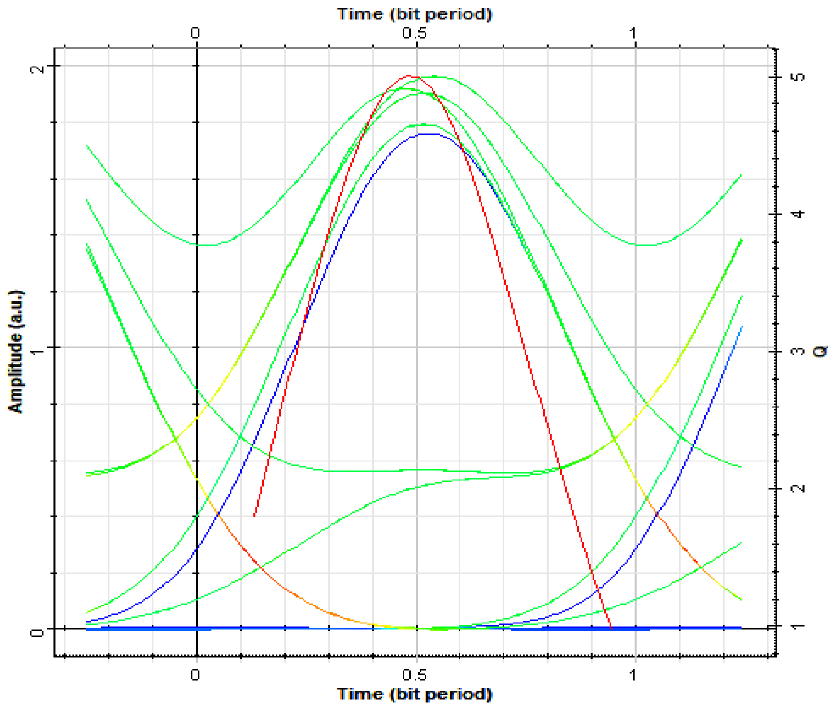


(a) (b)

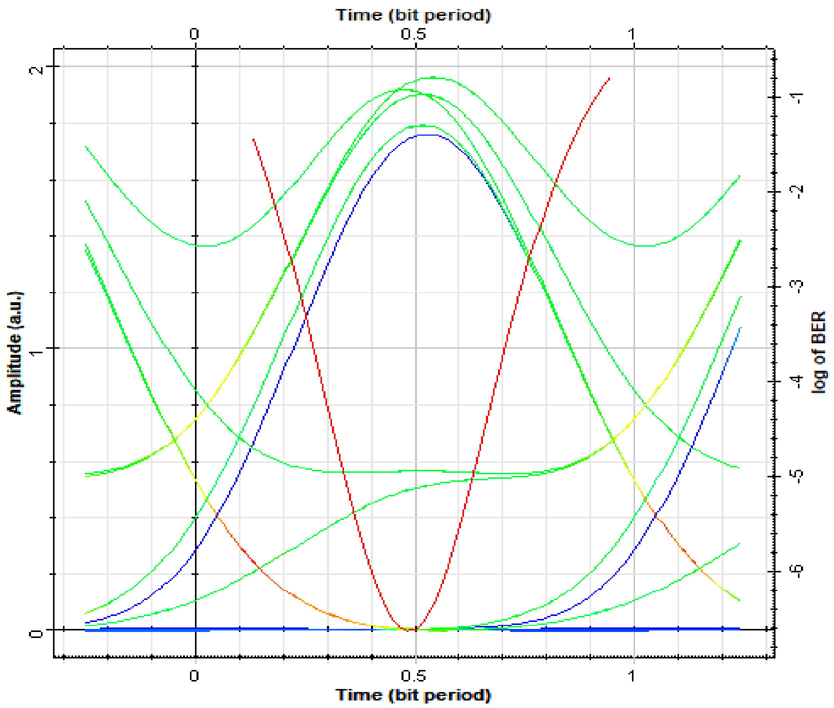
*Figure 3: (a) Optical Time Domain Visualizer; (b) Oscilloscope Visualizer with result of signal to AND gate (01001011) with **8-bits** input and injection current of **0.05 A** and **0.0009 m** at 20 Gb/s.*

B. *The first best results of Max. Q-Factor and Min. BER for 8-bits input signal*

The Eye Diagram with the first best results of Q-Factor and BER shown in Figure 4. It was observed in figure 2 the injection current from 0.05 and 0.1 *A*. Among the results for 8-bits sequence, the 0.05 *A* to injection current and 0.0009 *m* to length in the TWA-SOA, are the best values, with max. Q-Factor equal to 5.00144, min. BER equal to 2.35277e-007.



(a)

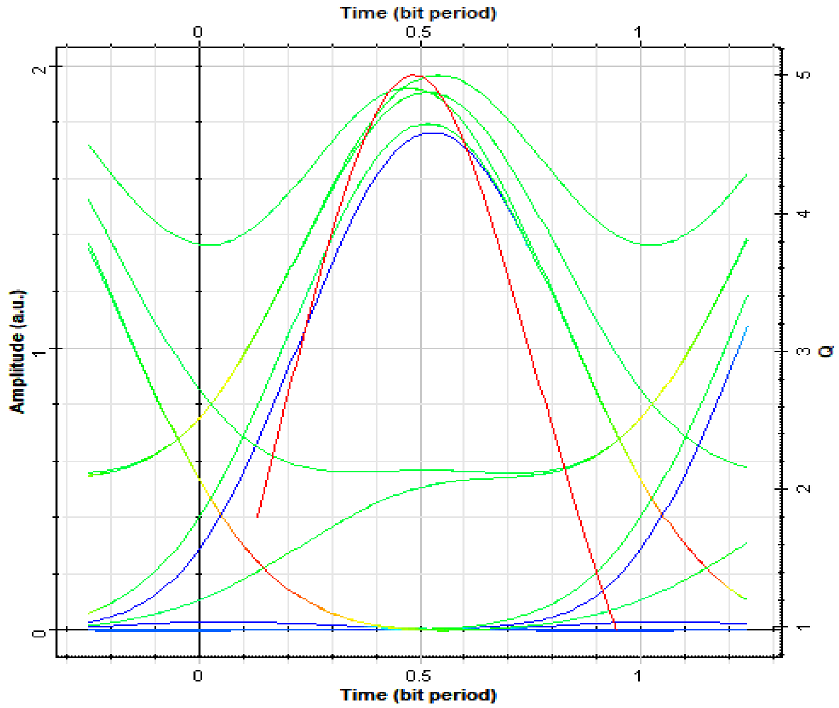


(b)

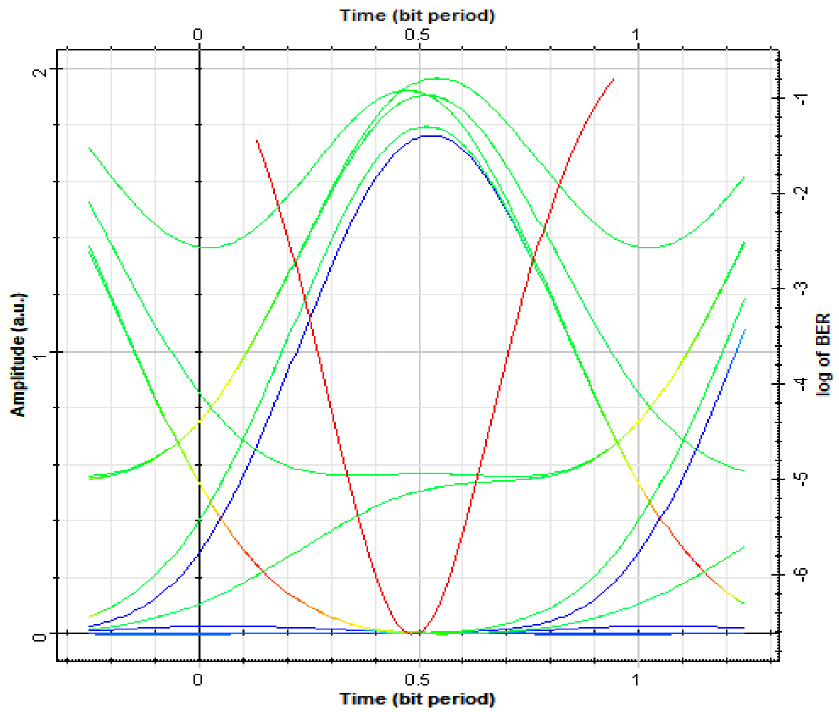
*Figure 4: (a) Eye Diagram and Max. Q-Factor; (b) Eye Diagram and Min. BER, first best result of signal to AND gate with injection current of **0.05 A** and length of **0.0009 m** at 20 Gb/s.*

C. The second best results of Max. Q-Factor and Min. BER for 8-bits input signal

The Eye Diagram with the second best results of Q-Factor and BER shown in Figure 5. Among the results for 8-bits sequence, the 0.05 *A* to injection current and 0.0008 *m* to length in the TWA-SOA, are the second best values, with max. Q-Factor equal to 4.999364.



(a)



(b)

Figure 4: (a) Eye Diagram and Max. Q-Factor; (b) Eye Diagram and Min. BER, second best result of signal to AND gate with injection current of ***0.05 A*** *and length of* ***0.0008 m*** *at 20 Gb/s.*

4. CONCLUSION

The Design of All-optical AND logic gate, have been simulated at 20 Gb/s using co-propagating. The obtained SOA-MI structure with results ensure good performance of the proposed design, using 8-bit in the input signal, with the best quality factor (Q-factor) to optimum injection current and length of TWA-SOA.

5. ACKNOWLEDGMENT

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