# Design of all-optical AND gate using bulk SOA turbo–switched Mach-Zehnder interferometer

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***Abstract-***
*A novel architecture to demonstrate an all optical AND gate that works on the use of bulk semiconductor optical amplifier based active Mach Zehnder Interferometer and the effect of Turbo switch is presented. The corresponding analysis of performance is predicted in terms of physical parameter and its respective power consumption is calculated. The numerical demonstration of AND gate, as a result error free operation at 160Gb/s is attained. The design criteria and the merits of the proposed architecture remain when combined with the turbo switched XOR gate and consequent resultant all optical half adder also operates error free and also boost the potential of interferometric turbo switched photonic structure as ultra fast all optical processing element.*

**Keywords**: *Cross phase modulation(XPM), AND logic gate, Mach-Zehnder Interferometer, Photonic circuit, Semiconductor optical Amplifier(SOA).*

## I. INTRODUCTION

Optical circuits may be the next generation of computational scheme and the highly nonlinear fiber and it become the major building block of optical transmission system. A modified MZI is proposed to carry out photonic AND operation between optical data streams. The continuous growing demand of bandwidth in current high capacity optical telecommunication networks is driving the development of faster electronic and opto-electronic components, but it is also propelling the introduction of all-optical elements where it is technically and economically feasible. The role of signal processing for the equalization of linear and nonlinear transmission impairments and the compensation of imperfections of the transmitter and the receiver front end in the optical communication system has become significant [1]. The fundamental building block for the realization of complex functional subsystems or wavelength converter [2], Bit counter [3], Half adder/ subtractor [4], Full adder/subtractor [5], Parity checker/ Generator [6], Encryption/ Decryption module [7], and even more complex circuits. The implementation of all optical logic gate relies on the nonlinear process that can be induced in semiconductor materials [8], in highly nonlinear optical fibers [9] and the other materials [10]. The approach for the design of all optical gate is expected to help reducing the number of time and power consuming opto electronics conversions and the physical layer[11]. Semiconductor optical amplifier is attractive due to its high nonlinearity ultrafast nonlinear response driven by intra band light -matter interactions, wide gain dispersion, stability, low power consumption ,short latency, relatively simple implementation and compactness/integration [12]. Development of SOA based all optical logic gate have been introduced taking the advantage from four wave mixing, cross phase modulation one of the most beneficial architecture is MZI because this employed with high stability compactness and simplicity [13,14]. Different scheme have been consider in order to evaluate the performance and analysis the all optical gates using SOA based MZI [15, 17]. The most prominent architecture is consider to be a high preferable is turbo switched MZI as it overcome the relatively slow phase recovery of the SOA, turbo switch is implemented by incorporating two cascaded SOA with broad optical band pass filter in between [18, 20]. Two wavelength converters working at the rate of 42.4 and 84.8Gb/s in which the resultant optical band pass filter is replaced in the turbo switch structure by an SOA based active MZI which is mentioned as integrated turbo switch which will produce the most promising result [21].

The ultra fast response exhibited by this nano metric structure when compared to the bulk SOA. The correct functionality of the proposed AND gate is numerically demonstrated our research work extended by combining XOR and AND gate to prove the technical feasibility operating at 160 Gb/s.

## II. TURBO-SWITCHED AND GATE

In order to validate our simulation approach and set a reference to compare the performance of the proposed structure, we first analyze the behavior of the conventional AND all optical logic gate when implemented using active MZI that relies on the differential scheme. The proposed structure represents a natural evolution from the MZI-DS; and the MZI-DS exhibits the fastest operation of all MZI based AND gates when bulk SOA are employed. The input optical signals A and B consist of two different arbitrary pseudo random bit sequence (PRBS). Here the presence of a Gaussian pulse represents logic '1' and the absence of light logic '0'. The logic levels of the output signals are represented in the same manner and contain the result of the AND operation between both inputs. Aided by a 3dB multi-mode interference coupler (MMI), input signal A is injected into the upper arm of the interferometer, while a delayed copy is injected into the lower arm after a time. Similarly, input signal B is injected into both arms of the interferometer, λAND is the output signal wavelength. Data A plays the role of "control" beam because it modifies the phase of the "probe" beam via XPM at the SOAs. Due to the delay between the waveforms that travel along both arms, a phase switching window is formed at the rightmost MMI. The duration of the switching window is not determined by the recovery time of the SOAs, but by delay $\tau$. On the presence of optical band pass filter and the PM-AM conversion characteristics a short pulse at λAND is released at the output port when suitable conditions are met. When B=0 no pulse is formed at λAND and output is null but when A=0 and B=1 no switching window is induced. Although in this case interferometer is tuned to achieve distractive interference at the output port and result no pulse is delivered but when a logic1 is present in both input the windowing action induced by the signal A allows the transmittance and regeneration of the B pulse at λAND, thereby resetting the MZI to its initial phase condition after the short period $\tau$. The phase dynamics of the SOA and MZI can be determined elsewhere.

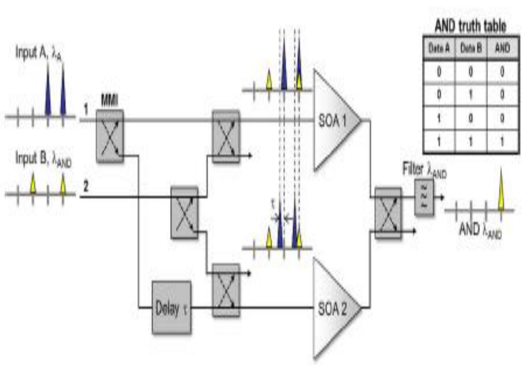


**Fig 1.Schematic diagram of a conventional AND gate using an SOA-based MZI-DS.**

The turbo-switched structure is expected to accelerate the overall active interferometer dynamical process, especially the phase recovery in the SOAs, leading to switching windows that will be less affected by data patterning. A lower amplitude jitters, and corresponding lower bit error rate value, are then anticipated at the interferometer output.

## III. NUMERICAL ANALYSIS

### *A. Simulation Details*

The above said analysis was carried out using well-tested photonic integrated circuit simulator. Among this modules MMI is used optical filter delay line random pulse generators and SOAs. The latter is based on a sophisticated uni-directional, time domain model of a bulk that takes into account multiple effects, including the ultra-fast response due to intra-band effects and the nonlinear dynamical behavior of the active device. In contrast to other SOA simulators, it efficiently incorporates the carrier density depletion produced by amplified spontaneous emission while preserving its input output nature. The outcome is based on analytic integration of the photon density propagation equation along the longitudinal coordinate and numerical integration of coupled rate equation that corresponds to the semiconductor material. All SOAs are considered identical with an active region length of 0.5 mm, a cross–sectional area of 0.7 μm2, and a confinement factor of 0.6. If not mentioned, the current injected into each SOA was set to 250 mA. For the sake of brevity, the rest of the SOA model parameters and the validation of other characteristics of the simulator are omitted; they can be found elsewhere.

The quality factor is calculated from the pseudo eye diagram in order to evaluate the performance of the logic gate it is defined as,

$$Q=P1-P0/\boldsymbol{\sigma}1+\boldsymbol{\sigma}0$$

Where P1 (P0) and σ1 (σ0) are the mean and standard deviation of an approximately Gaussian probability density function characterizing the detected marks (spaces) at the sampling instant. The Q and BER in the transmission system are related through.

$$BER=1/2erfc\ (Q/\sqrt{2}\ )$$

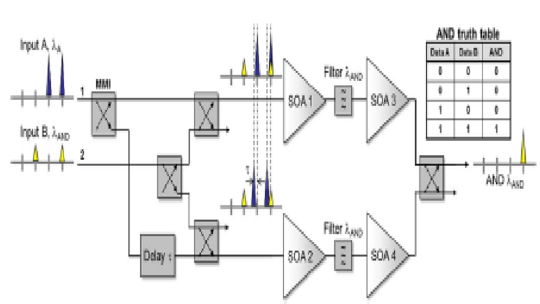


**Fig 2. Schematic diagram of the proposed AND gate using Turbo-Switched MZI with Differential Scheme(TS-MZI) .**

### *B. Simulation at 80 Gb/s*

The operation of conventional AND gate is numerically demonstrated two different 80 Gb/s PRBS 512 bits long and centered at λA =1569.6nm and λAND=1550.1nm where injected into the AND gate as input data A and B. A Q dB=8.45 dB, resulting to approximate BER of 1.2×10–12 was obtained. Although the PED shows appropriate operation of the AND gate, still there is a notorious amplitude jitter produced by the effect of data patterning that degrades the performance of the logic gate. The resulting PED after optimization is shown above. It exhibits a higher eye opening with a reduced jitter and consequently better average extinction ratio. A Q dB of 10.95db, corresponding to an approximate BER was measured from the eye. This simulation makes it evident the advantage of using the elaborated structures not only it increases the logic gate but it also increases the possibility of operating the logic gate at a faster bit rate.

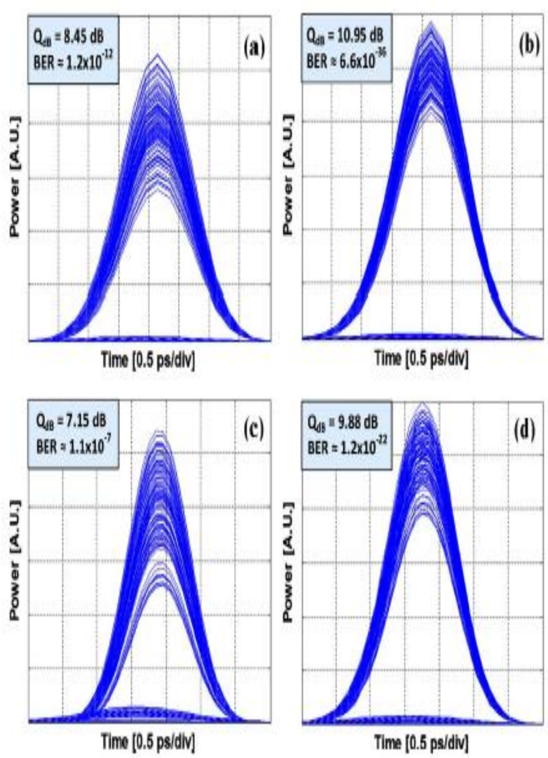


**Fig 3. PED of an all optical AND logic gate. (a) MZI-DS at 80 Gb/s. (b) TS-MZI at 80 Gb/s. (c) MZI-DS at 160 Gb/s. (d) TS-MZI at 160 Gb/s.**

### *C. Simulation at 160 Gb/s*

The performance of the conventional and turbo switched MZI structures operating at 160 Gb/s that is at a bit rate two times faster than in the already analysis case. Based on the analysis the duty cycle of the injected sequence was augmented to 28%, leading to the Gausssian pulses at the range of 1.75ps long and the consequent operating wavelength were set to λA=1580.4nm and λAND=1539.8nm. In the case of normal structure the Gaussian optical filter bandwidth was increased to 1800GHz and the consequent optimum value of $\tau$ was found to be 1.5ps. The TS-MZI simulation the optical filter bandwidth was also set to 1800GHz at the same time the delay $\tau$ was adjusted to 1.4ps and the same manner 80 Gb/s unbalanced of the MZI was achieved by 249.84mA into SOA4.

The presence of strong amplitude jitter is evident especially in the marks. This in turn leads to a low average extinction ratio and lowest measured Q dB which falls from 8.45 to 7.15 dB is corresponds to a bit error ratio of about 1.1×10−7, which decreases beyond currently adopted standards. The situation is different when the TS-MZI is driven at 160 Gb/s because despite the Q dB value also falls from 10.95 to 9.88 dB, the latter value is even higher than the one obtained when operating the conventional structure at 80 Gb/s. In fact it drives to a BER of around 1.2×10‑22 which is consider as a error free operation. Besides if we defined the maximum allowed BER value to be about 1.0×10‑13 which is objective set of forthcoming 400 Gb/s a maximum operating speed for TS-MZI to be about 260 Gb/s, while the average peak power at the output port of the 0.1mW. A better performance can be conformed presenting a higher eye opening the lower amplitude jitter on the sake of comparison between the two eye diagrams.

As calculated by the associated truth table the output sequence shows a Gaussian pulse only when both input bits corresponds to logic one and the space for any other combination of the input sequence. It can appreciate that the width of output Gaussian pulses is shorter than the one of the input pulses. This is the result of the switching window effect produced by the differential scheme. The perspective window act as a mold, shaping the output pulses, and therefore a high degree of synchronization between input data sequence is mandatory in order to accurately set an effective switching window.

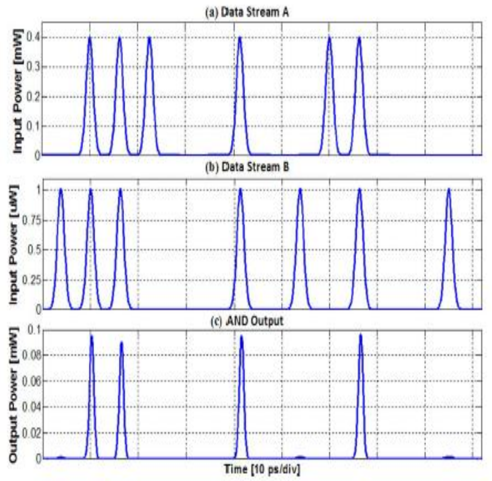


**Fig 4. The outcome of simulation to demonstrate AND operation at 160 Gb/s when using TS-MZI structure. (a) Input data stream A. (b) Input data stream B. (c) output from the AND logic gate.**

## IV. THE ROLE OF PHYSICAL PARAMETERS

The current inserted into the SOA and the bandwidth of the optical fibers was not changed. The average peak power of sequences B was set in all cases to 1mw.The variation of Q dB is a function of t points out that the optimum delay that maximizes Q dB as a function Q dB to almost 10dB is 1.4 ps. Shorter values of t that represents to a sharp fall of Q dB values since under these situation the differential scheme and corresponding phase window practically disappears in an simultaneous manner. For relatively high power values Q db value decreases due to patterning effects similarly to what it observed in the MZI DS case. This must be due to the fact that since the peak power of the input PRBs is being predicted effectively. As τ increases, the relativity between input and delayed pulses decreases, lowering the magnitude of the phase switching window, and corresponding Q dB. Our outcome coincide with the behavior shown by the MZI-DS, As plotted in the graph, the input power of sequence A should be strong enough to saturate the SOA and induce XPM in the active device, but at the same time allow a fast recovery of the consequent phase of the waveform to reduce patterning effects. For the case of low power values no nonlinear process is induced and the switching effect disappears. For the case high power values, Q dB decreases due to patterning effects. Similarly to what it is observed in the MZI-DS case demonstrates that when the TS-MZI is employed, input data pulses with shorter width lead to better gate performance. This must be due to the fact that, since the peak power of the input PRBS remains constant, shorter pulses have lower energy. As a result shorter pulses will induce a weaker depletion of the SOA carrier density, leading to a faster recovery of the SOA gain, and hence to lower amplitude jitter and higher Q dB. Infect the use of very narrow pulses becomes impractical due to the complexity of their generation and because higher synchronization is required. So, this practicality sets a lower bound to the pulse widths available for experimental implementation. Effective refractive index in bulk semiconductors is strongly coupled to gain dynamics. This effect is usually modeled more often, the line width enhancement (or Henry) factor, αN. Modeling of the refractive index evolution in an SOA is necessary to determine the instantaneous frequency deviation, or chirp, that occurs when a transient is injected into that of the amplifier. This is exactly relevant in the application of the analysis of photonic switches because adequate of photonic switches and tailoring of photonic switching exhibited by the output signal may lead to the better performance of the overall switching elements such as optical amplifier or filters.

The variation of α0 in the same interval results in Q dB values ranging from 6.6 to 7.2 dB, corresponding to unacceptable BER values that are above $7.7\times10{-}8$. Even when the restriction of maintaining an average peak power at the output port of 0.1mW is relaxed, the performance of the MZI-DS structure remains below 8.2 dB for an output power of 0.05mW and an extremely low α0=1, which does not correspond to typical Henry factor values measured in bulk SOAs. The simulation results thus indicate that there is a clear benefit in terms of output waveform chirp control when the TS-MZI scheme, instead of the usual architecture, is employed at the stated performance level.

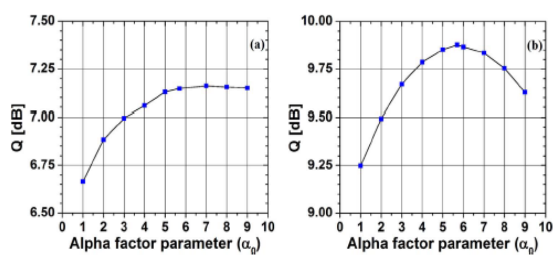


**Fig 5. Dependence of Quality factor on the Alpha factor parameter when (a) MZI-TS. (b) TS-MZI structure employed at data rate of 160 Gb/s.**

## V. CONCLUSION

The optimization of performance of all optical logic AND gate implemented by means of MZI that includes the bulk SOA based turbo switches in both arms. The simulation is carried out by means of an advance photonic circuit simulator, it was verified that when operated at 80 and 160 GB/s the fore coming proposed structure operates in an error free manner. Thus augmenting its potential to outperform as similar subsystem built upon a normal differential scheme. This eventually comes as a result of shorter carrier density recovery time produced by a turbo switched effect in the cascaded SOA structure. In view of explored work two similar turbo switched structure can be combined to create a high performance photonic circuit. The representation of the starting point in the design of high speed turbo switched photonic circuit that rely the ongoing effects aimed to built an all optical communication network.

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