IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 2, February 2015.
www.ijiset.com
ISSN 2348 – 7968

SOA Photonic Integration on MZI Switching Structures inrealizing Optical (XOR, AND, OR) Logic Gates in Optical Networks

Anyigor, I. S[1], James Eke[2], and Nweke, F. U[1]

[1]Ebonyi State University, PMB 053, Abakaliki, Nigeria (Industrial Physics Department)
[2]Enugu State University of Science and Technology, Enugu, Nigeria (EEE, Department)

Abstract

Due to the one general outstanding and widely accepted quality of nonlinearity in semiconductor optical amplifiers(SOA), has made it the finest attractive source for the actualization of all different kinds of optical logic functions in optical networks. This is because of their capabilities to provide strong change of their refractive index and high gain. In this work, ultrafast all optical logic gates are demonstrated and are simulated based on the different SOA nonlinearities and the detuning optical band pass filter using Cross gain modulation (XGM) and Cross Phase modulation (XPM). The scheme has been used to reconfigure and implement XOR, AND, and OR gates with their experimental results obtained using Optisystem which are well in tune with the standard global results.

Keywords: Logic gates, SOA, MZI, Nonlinearity, XGM, XPM, Photonics

INTRODUCTION

In Optical Communication network system, trasmtter, receiver and optical fiber form the building block in which the fibers act as the major medium of signal transmission with little or no attenuation losses as compared to other medium of transmission of signals. Before the advents of transmission of signals over a certain long distance was done by conversion of optical signals to electrical and then regenerated to optical again for further communication, which were being required to be done at certain intervals. Optical amplifier, does not only do direct amplifications of signals to avoid huge losses and excess cost but it is also independent of the number of channels, bit rates, protocol and modulation format used, thereby making a single optical amplifier capable of replacing the multiple components used in amplification and regeneration stations.[1-3]

Hence, Semiconductor optical amplifiers are good nonlinear elements for the realization of different logic functions because of their strong change of refractive index together with high gain, and with the facts that all-optical logic gates form the key elements in the realization of node functionalities such like as add/drop multiplexing, clock recovery, address recognition, packet synchronization and other signal processing. Moreover, SOAs being different from other optical devices allow photonic integrations. The nonlinear characteristics that is a bit drawback for SOA as a linear amplifier has it function as the best source for an optical control logic gates. Better gate performances are still actualized by placing the SOAs in the interferometric arms of MZI configurations. The optical input signal controls the phase difference between the interferometric arms through the synchronization of the carrier density and the refractive index in the SOAs by the use of XPM which in turn offers compactness and stability.[3-6]

BASES OF THE WORKING PRINCIPLES

Transmission and regeneration of free error signal is a mojor challenge in optical network communications and needs a high perfect features characterized devices like SOA-MZI which has been widely used to configure fast working optical logic gates. Here, XOR, AND, and OR gates operations are made up to 10 Gbits/s using SOA-MZI configurations.

For the gates to be made possible, so many configurations of logic gates have been cited that use ultrafast non-linearity properties of the SOAs ranging from the single structure that use XPM to interferometric structures such like tetrahertz optical asymmetric demultiplexers (TOAD) and Ultrafast nonlinear interferometer (UNI). They have shown to have some advantages, but as well difficult to control or construct due to polarization states or change of phases which are critical for their output performance. From their many list, SOA-MZI structure using XPM is the most favourable one due to its fine features of low energy requirements, simplicity, stability, compactness in functional integrations. It as well has high extinction ratio, regenerative capability with high speed operations. These gates, such as the *AND* gate is a fundamental logic gate because it is able to perform bit level functions such as the address recognitions, packet-header modifications, and data-integrity verification. The XOR gate is also still the key technology to implement primary system for binary address and header recognitions, binary counting and additions, decision and comparison, encoding and encryption with pattern matching. The designs are optimized orderly by the adjustments of the optical power and biasing current in the SOA-MZI structures to have the best output with maximum ER.

OPTICAL NONLINEARITY EFFECT OF SOA-MZI

The propagation of light waves from sources with small powers in any medium is linear. There will be nochange in characteristics of the emerging light beam like frequency, phase and wave shape, with its intensity.One light beam does not transform anyof the properties to another light beam, even if they cross each other which could take place whenever the intensities of twolight beams are small.

But for large intensities, the electric field associated with the light beam can modify the property of the medium to such an extentthat it can then affect its own propagation as well as that of other beams crossing it. This happens due to a nonlinear effect (calledsecond harmonic generation) in which a light beam of frequency f creates a beam having double its frequency, 2f (half thewavelength). Similarly, due to the large intensity of the beam, the refractive index of the medium can get changed; this change of refractive index would in turn change the phase with which a light wave emerges from a medium. These types of effects areknown as nonlinear optical effects.

Due to the nonlinear effects taking place within the optical fiber, the information carrying signal pulses can get modified due tothe presence of other channels, which can give increased errors in detection. Since nonlinearity depends on intensity,reducing cross section area increases the nonlinear effectsstronger and stronger for a given power. In the case of optical fibers, light isconfined to propagate within the core, and if the cross section area of the beam is small, then stronger nonlinear effects can beobserved. This is used for all-optical processing of optical signals which is the effect that makes the SOA a very good device in optical networks. They could be characterized as XPM and XGM.

CROSS PHASE MODULATION (XPM)

In WDM system, pulses in optic fiber propagate at distinct wavelength. If we consider light beam at two different frequenciespropagating simultaneously through a fiber, change in refractive index brought about by each beam will affect the other beam. This is knownas cross phase modulation (XPM) in which signal pulsesrandomly overlap instantaneously.This givesrandom noise of the channel resulting penalty and high bit error rate. If pulses have different frequencies, then their velocity willbe different. So there would be walk-off between the two pulses. If they start moving together they will separate as they propagateresulting higher dispersion. To reduce the dispersion, their velocity should be close to each other.[2]

CROSS GAIN MODULATION (XGM)

The Crross gain modulation (XGM) effect consists of the variation of the SOA gain in function of the input power. The increase of the power of the input signal causes the SOA a depletion of the carrier density which reduces the amplification gain. The dynamic processes that take place in the carrier density of the SOA are the order of picoseconds which makes it possible to use the variations on the width of the bit to bit flunctuation of the input signal power.

IMPLEMENTATION OF SOA-MZI BASED *XOR* GATE

The XOR gate has a special interest because it is the building block for a wide range of functions in optical logic operations. The Boolean function gives the logic *1* if the two inputs that are being compared are of different combination, for instance; (A = 1, B = 0, and A = 0, B = 1). On the other hands, if the inputs are of the same combination like A = 1, B = 1, and A= 0, B = 0, the XOR output signal is a logic *0*. In the case of optical logic gates, the logic *1* is represented by the presence of an optical pulse, whereas the logic *0* means the absence of the optical power.

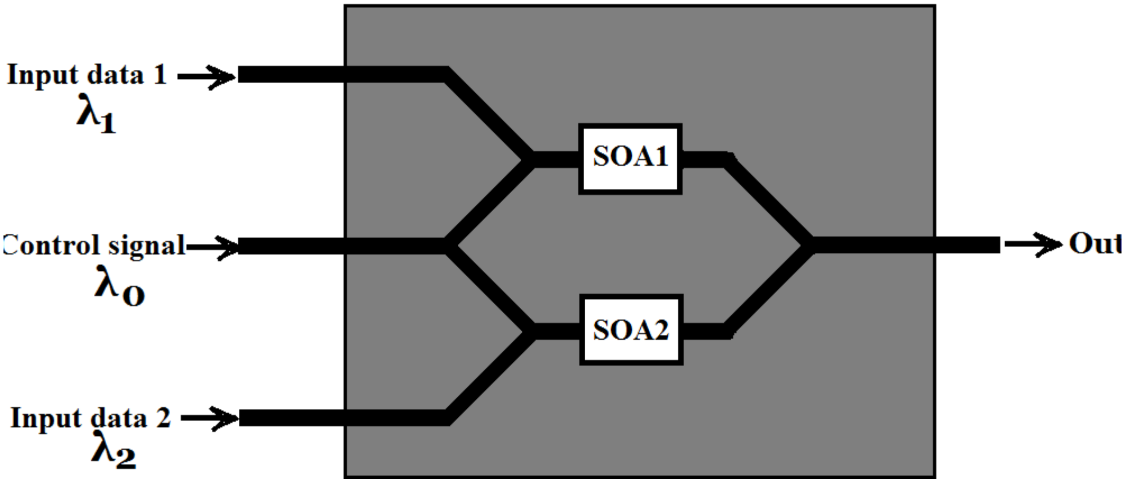
WORKING OPERATION

Performing the XOR Boolean functions, two optical beam carried by the optical signal at the same or different wavelengths are sent through the port 1 and port 2 of the MZI separately. The wavelength of the two data signal can as well be the same. A train of pulse or CW beam is coupled to port 3 as the control signal. The control signal splits into two equal parts, one reaching the upper branch of the interferometer and the other reaches the lower branch part. When the data signal is launched into the SOAs, the carrier density and the medium refractive index is modulated. This causes the phase shift over the control signal counter propagating through the SOAs according to the intensity variation of the input data signals.[10-12]. The phase modulation experienced by the wave during modulation in the SOA is given by:

$$\Delta\phi = 2\pi n\frac{L}{\lambda} + \alpha[\ln(G) - \ln(G_0)]$$

Where λ is the wavelength of the input data signal passing through the SOA, α is the SOA line width enhancement factor, n is the refractive index in the absence of the optical power, G is the saturated gain while the G_0 is the linear device gain. The equation is obtained from the analytical models of the wavelength converters under certain condition such as the instantaneous response of the SOA and the adiabetic approximation. The control signal entering port 3 splits into two equal parts, one goes to the upper branch as ussual while the other into the lower branch of the interferometer. At this point the phase shift in both of the MZI branches is the same making it balanced. Figure 1 below illustrates it diagramatically.

Fig. 1: Mach-Zehnder Interferometer used as XOR Gate.



The XOR gate, gives a *1* at the output if one and only one of the two inputs is a *1*. However, an XOR gate with an arbitrary number of the input gives *1* at the output if the parity of the input bits is *1*, i.e., the number of *1* is odd. This property of the XOR gate makes it suitable for a wide variety of applications related to bit-comparison and encryption.

SIMULATION STEPS

In a case where A = 0, B = 0, the control pulse enters the SOA-MZI at port 3 and then is split into two pulses, one gets to the upper SOA, and the other remaining one gets to the lower part of SOA. At this point due to the phase shift induced by the input coupler, the phases of the two versions of the control pulses are shifted byπ /2. The SOAs are under the same conditons as no data arrives to neither of them making the phase shift same as π /2. These two pulses after passing through the SOAs are recombined again at the output coupler where they suffer again an addititional π /2 phase shift between them. So at the output port the two pulses arewith the same amplitude and with a total phaseshift of π, hence destructiveinterference, andno signal is obtained (Figure 2). In case A=1,B=0 an optical pulses enters the SOA-MZI

through port 1 and changes the refractiveindex of the upper SOA whereas the lowerSOA remains unaffected. Thus, when the twoversions of the control pulses travels throughthe both SOAs, the phase difference betweenboth is shifted by π (the optimum phase shift).At port 4, the signals (part of the controlsignal) from the two SOAs are combined againand an optical pulse is obtained asconsequence of the constructive interference.The same phenomena happens if A = 0, B = 1. In the case of , A = 1, B = 1, data pulses reach both SOAs, and the phaseshift induced to the control pulse in eachbranch is the same. As a result, at port 4 nopulse is obtained in this case due to destructiveinterference between the signal pulses.

EXPERIMENTAL RESULTS

In this simulation we have generated two datasignal as shown in Figures 3(a) and 3 (b). TheSOA-MZI setup is used to perform XORoperation. These two data signals aregenerated at 1550nm wavelength with thehelp of optical Gaussian pulse generator. Acontinuous wave is also generated at 1545nm.These signals are given to the SOA-MZI portsfor performing XOR operation (Figure 3(c))between the two data signals applied at port 1and port 2 of SOA-MZI setup when compared.

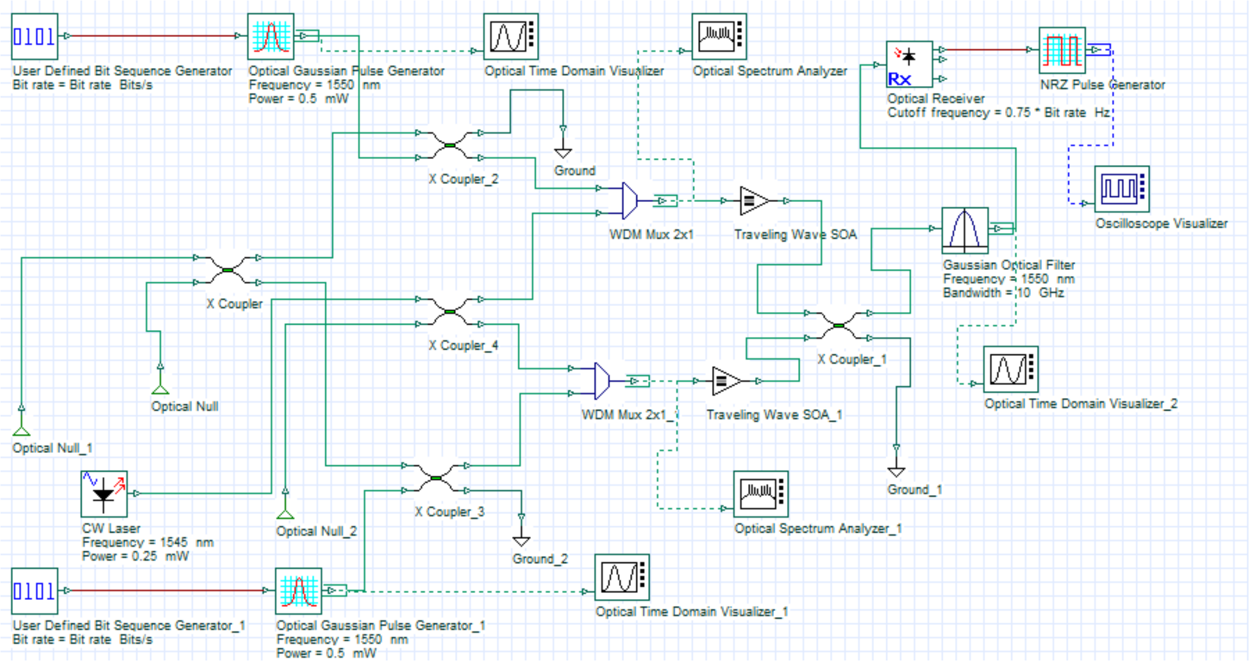
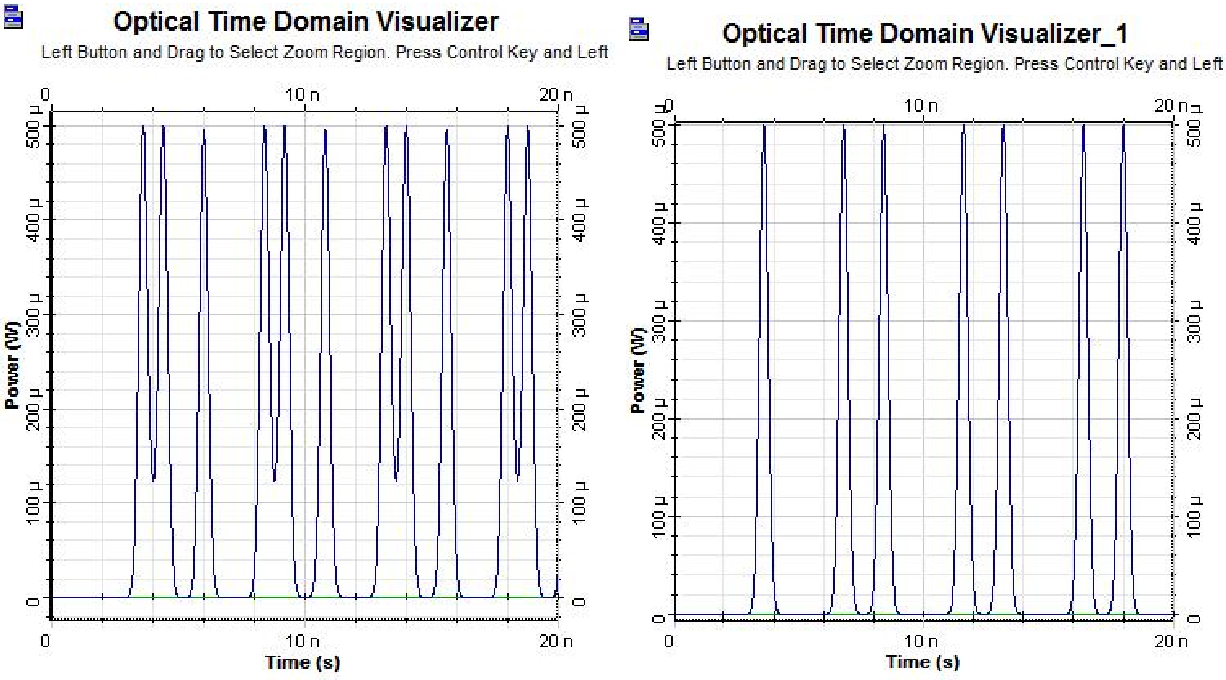
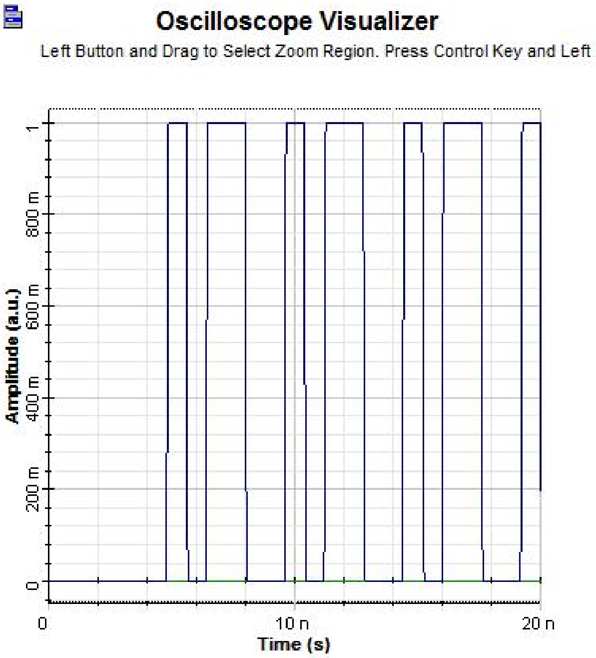


Fig. 2: Simulation Setup of SOA-MZI Based XOR Gate.



(a) (b)



(c)

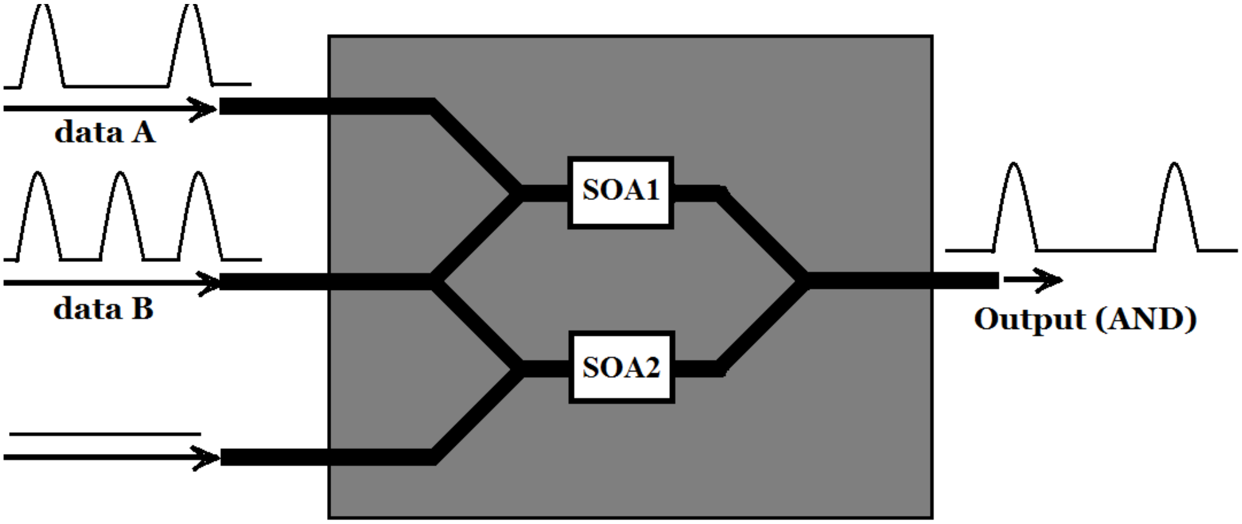
Fig. 3: (a) First Iput Data (011010) (b) Second Iput Data (0100010) (c) Result Compared of XOR Gate Signal.

IMPLEMENTATION OF SOA-MZI BASED *AND* GATE

Boolean AND gate operation is also agood choice in optical signal processing. Thelogic functionality, gives logic “1” only whenthe two input signals under comparison arelogic “1”. In other cases, the output is logic“0”. The AND gate is unbalanced like the ORgate, as it only gives a “1” at the output in theevent that both inputs are “1”. From the truthtable it is clear that the AND operationcorresponds to sampling one signal with theother, and thus all optical sampling techniquesmay be applied to obtain the AND functions.This has been demonstrated with the MZI atthe 10 Gb/s using same PRBS data and otherparameters like power and bias current.[8-9]

Principle of Operation

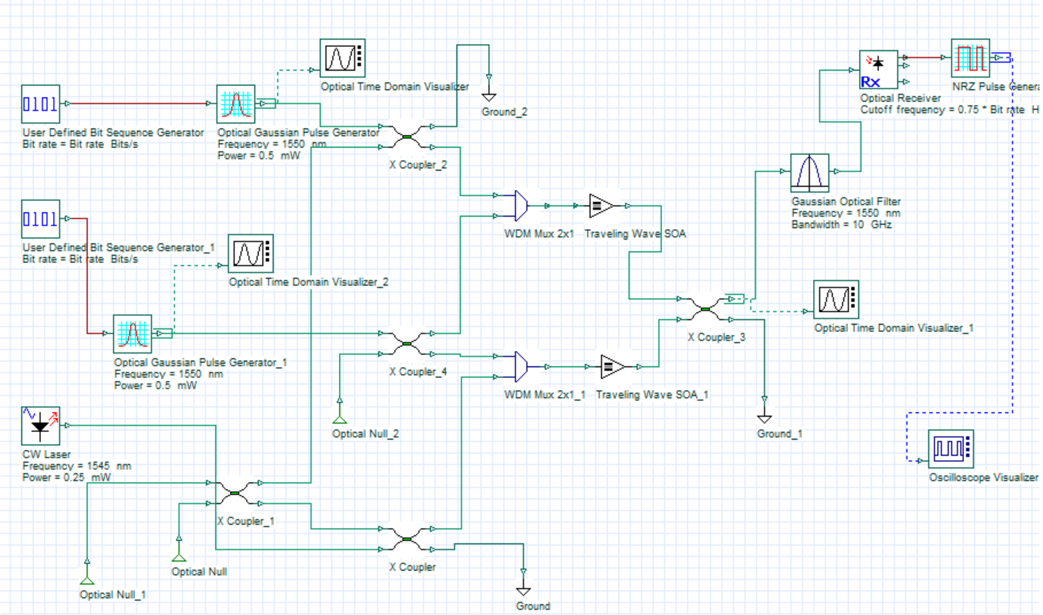
The principle of operation for the AND gate isbasically the same like thatof the XOR logicfunction. In this case, the datasequences to be compared are driven to theSOA-MZI as shown in 4. The data signalenters the device at the port 1 and port 3.While in port 2 a zero level signal must beensured. There is no need of an additionalcontrol signal as the data signals entering thecommon port enables or disable the device.Following a similar principle like that of theXOR gate, an optical pulse will be obtained atthe output only in the case that both the datasignals are “1”. In this case (A = 1, B = 1), the pulses of data B enables the operation. Inan alternative way, the AND operation can beseen as performing the XOR comparisonbetween data A and a zero level signal. WhenB=0, the gate does not produce any signal at theoutput as it has no signal at port 3. In the lastcase in which B = 1 and A = 0, thecomparison is enabled, but as the signal at port1 and the signal at port 2 are zero, no power isobtained at the output device (Figure 4).



Fig,4: Mach-Zehnder Interferometer used as *AND* Gate

SIMULATION SETUP FOR SOA-MZI AS * AND* GATE

The principle of operation for the AND gate(Figure 5) is, basically the same like that of the XOR logic function. In this case, the datasequences to be compared are driven to theSOA-MZI. The signals enter the device atports 1 and port 3, while in port 2 a zero levelsignal must be ensured. There is no need of anadditional control signal as the data signalsentering the common port enables or disablesthe device.Following a similar principle thanthat of the XOR gate, an optical pulse will beobtained at the output only in the case thatboth data signals are “1”. In this case (A = 1, B = 1), the pulse of data B enables theoperation. In an alternative way, the ANDoperation can be seen as performing the XORcomparison between data A and a zero levelsignal. When B=0, the gate does not produceany signal at the output as it has no signal atport 3. In the last case in which B = 1 and A = 0 the comparison is enabled, but as thesignal at port 1 and the signal at port 2 arezero, no power is obtained at the output of the device.



User Defined Bit Sequence Generator
Bit rate = Bit rate Bits/s

Optical Gaussian Pulse Generator
Frequency = 1550 nm
Power = 0.5 mW

User Defined Bit Sequence Generator_1
Bit rate = Bit rate Bits/s

Optical Gaussian Pulse Generator_1
Frequency = 1550 nm
Power = 0.5 mW

CW Laser
Frequency = 1545 nm
Power = 0.25 mW

Gaussian Optical Filter
Frequency = 1550 nm
Bandwidth = 10 GHz

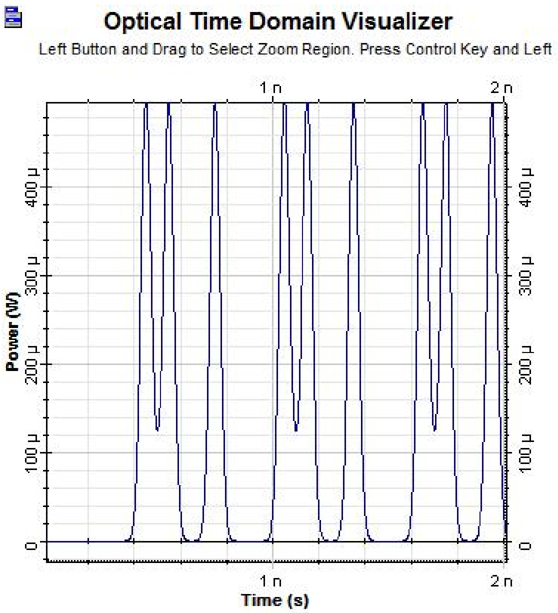
Optical Receiver
Cutoff frequency = 0.75 * Bit rate H

Fig.5: Simulation setup for AND Gate of SOA-MZI Based

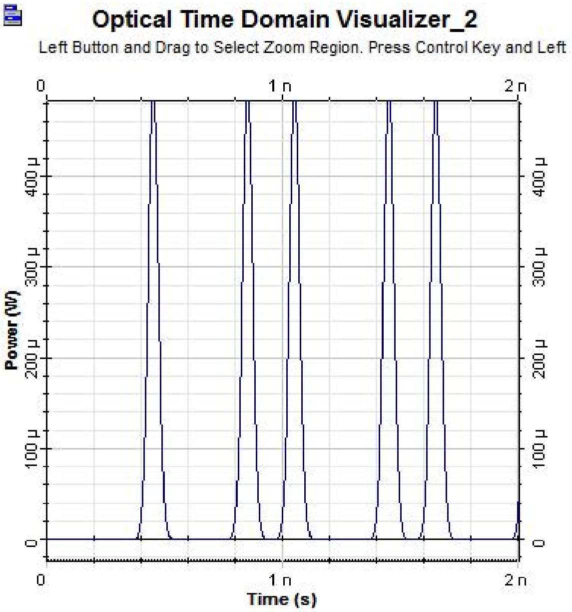
EXPERIMENTAL RESULTS

In this simulation, we have generated two datasignal as shown in Figures 6 (a) and (b). TheSOA-MZI setup is used to perform the ANDoperation. We have used the same parametersfor simulation that we used in XOR gateimplementations. We have generated the datasequences at same wavelength and same optical power. These two data signals aregenerated at 1550 nm wavelength with thehelp of optical Gaussian pulse generator. Acontinuous wave is also generated at a wavelength of 1545 nm.

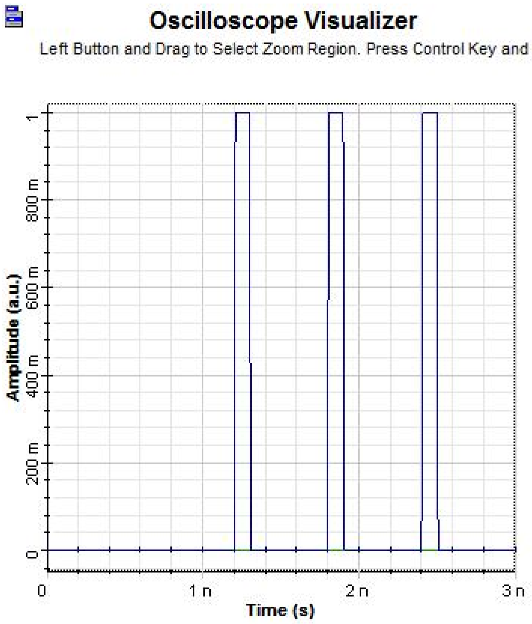
These signals are given to the SOA-MZI portsfor performing AND operation. A Gaussianoptical filter with 20 GHz bandwidth is usedfor filtering purpose. This filter is centered at1545 nm wavelength so that we obtain onlythe desired signal. This resultant signal is theAND operation between the two data signals applied at port 1 and port 3 of SOA-MZIsetup. Figure 6 (c) shows the AND operationsignal between the two data signals when compared.



(a)



(b)



(c)

Fig. 6: (a) Input Data A (011010) (b) Input Data B (10001) (c) Compared Output Data Signal

IMPLEMENTATION SETUP FOR *OR* BASED SOA-MZI GATE

The architectures are again based on SOA-MZI. This is a simplest case in whichno wavelength conversion is used. In this case,the principle of operation is quite intuitive.The two data signals are coupled at the sameport, in this case port 1. After passing throughone of the two SOAs which is the upperone, the amplified signal is coupled out atport 4, carrying the OR operation betweenthe two inputs. In this case, the two inputs must be at the same wavelength and the outputsignal is at the same wavelength too.[4-5]

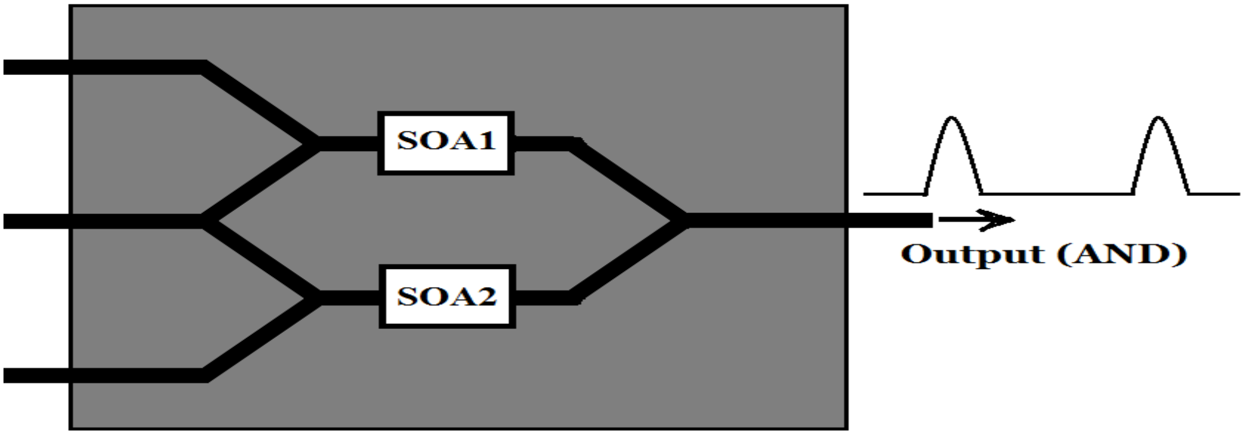


Fig.7: OR Based SOA-MZI Gate

EXPERIMENTAL SIMULATION SETUP AND RESULTS FOR*OR* BASED SOA-MZI

In this setup we have used only two datasignals as stated ealier. Figures 9, (a) and (b) on which wehave to perform OR operation are shown blow. There is noneed to use a CW for performing thisoperation. In this case, the two inputs must beat the same wavelength and the output signalis at the same wavelength like the inputsignals. No wavelength conversion is done because is not needed.The output is obtained at the same wavelengthat which the data signal is generated. The twodata signals are generated at 1550 nm and 0.5mW power. These two signals are coupled atthe two ports of coupler and given to SOA(Figure 9(c)). Here, the concept of cross gainmodulation (XGM) is used to perform the ORoperation.

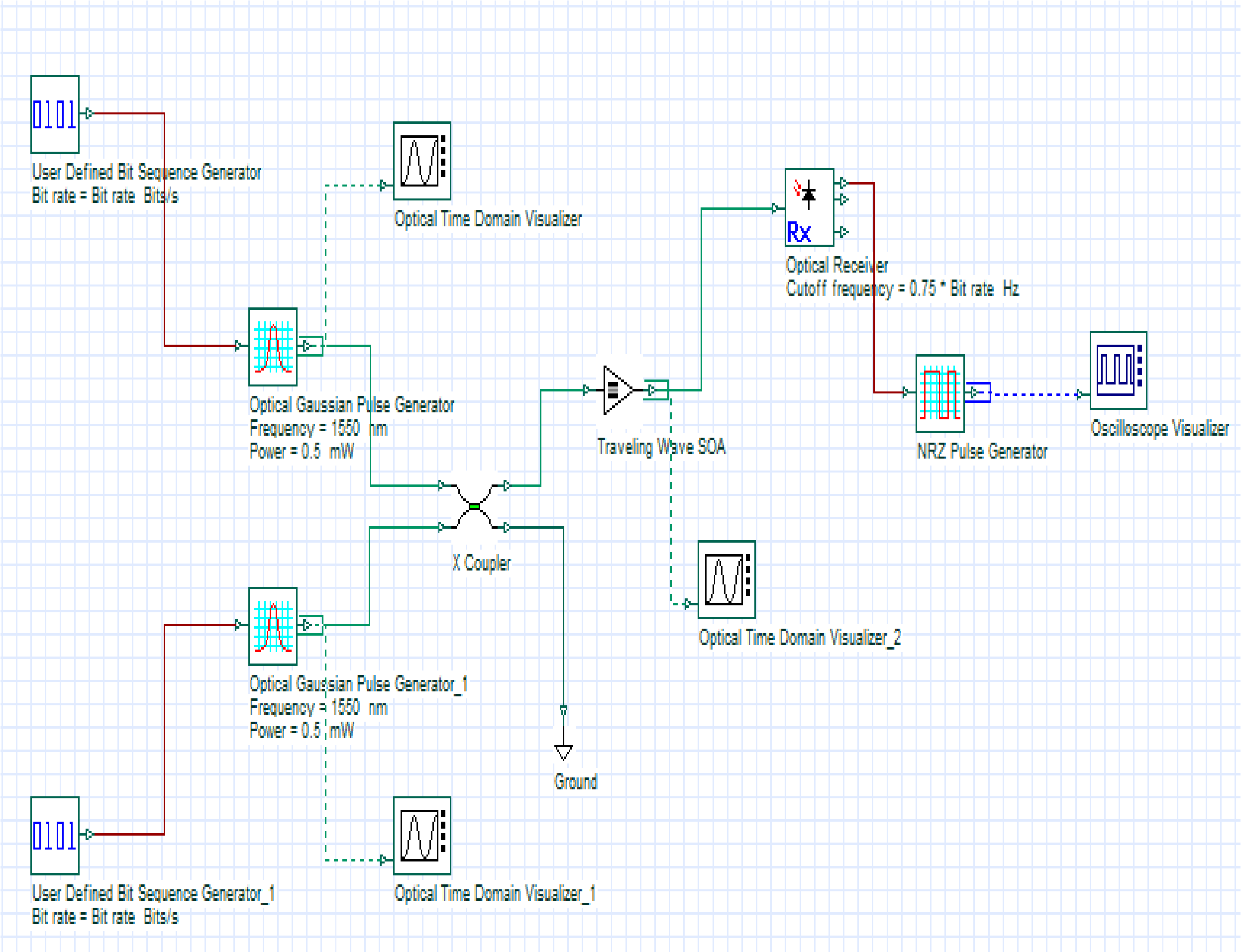
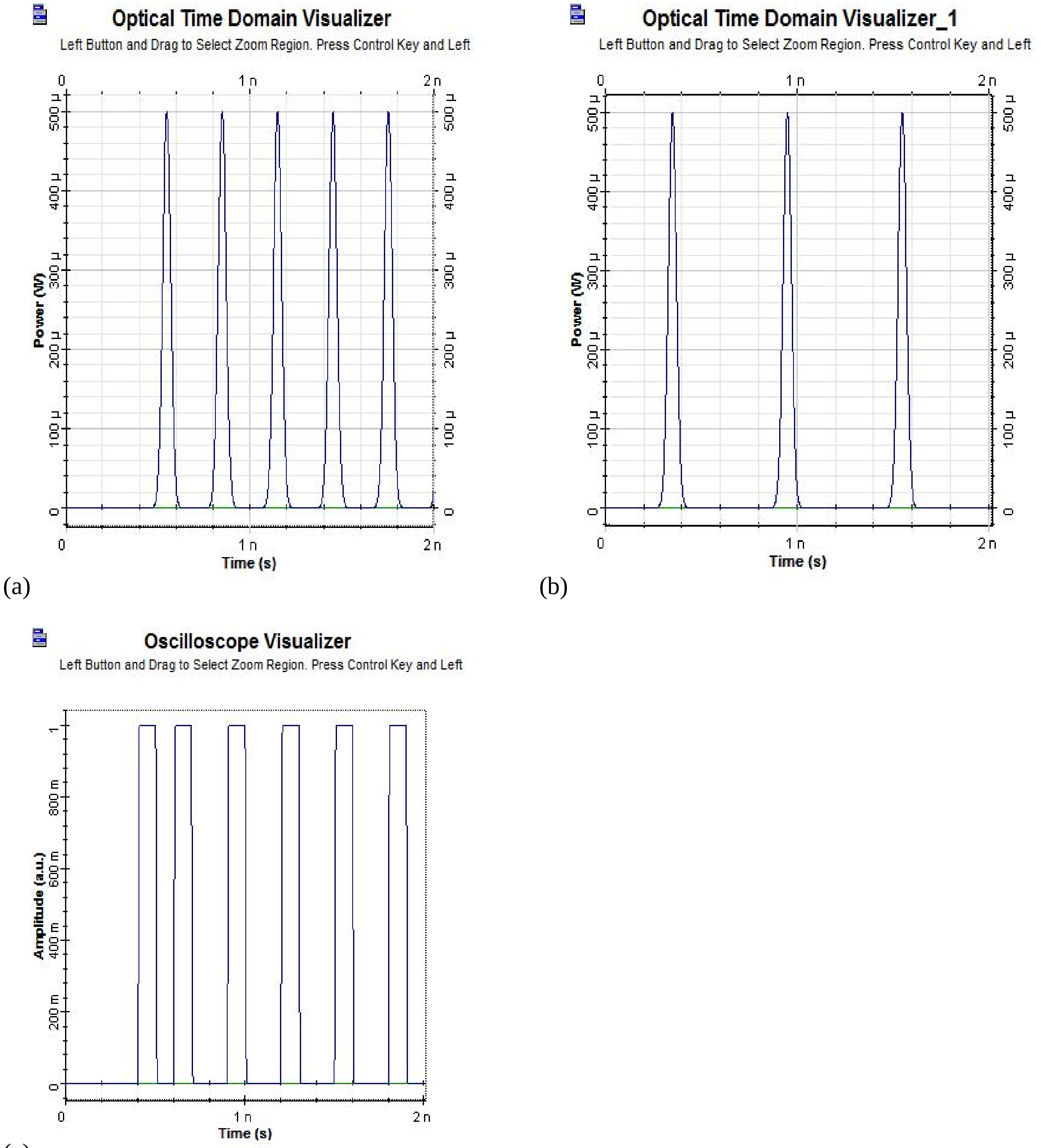


Fig.8: Simulation Setup of OR Gate SOA-MZI Based Gate.



(a) (b)

(c)

Fig.9: (a) Input Data A (001001) (b) Input Data B (100000) (c) Output Data Signal Compared of OR Gate

CONCLUSION

Due to its compactness and stable structure,SOA-MZI based gate seems an easy solutionto achieve the integration and compactibility level required forcomplex logic circuits for upgrading of optical networks. In this paper, allopticallogic XOR, AND and OR gates are implemented. Theprinciple of operation and simulation steps aredescribed in their details. Its experimentalresults are exactly matched with standardresults. These gates are widely used in theoptical networking.

REFERENCES

1. M.J. Connelly, “Semiconductor Optical Amplifiers”, Kluwer Academic Publishers.
2. ArezNosratpour, Mohammad Razaghi, “Optical and Logic Gate Implementation using Four Wave Mixing inSemiconductor Optical Amplifier for High Speed Optical Communication Systems”, 2011 International Conference onNetwork and Electronics Engineering IPCSIT vol.11 (2011) © (2011) IACSIT Press, Singapore.
3. AsierVillafranca, Miguel Cabezón, David Izquierdo, Juan J. Martínez, Ignacio Garcés, “Programmable All-OpticalLogic Gates Based on Semiconductor Optical Amplifiers”, ICTON 2011.
4. Z. Li, and G. Li, “Ultrahigh-speed reconfigurable logic gates based on four-wave mixing in a semiconductor opticalamplifier,” IEEE Photon. Technol. Lett., 18, 917- 919, 2006.
5. KadamBhambri, GagandeepKaurJayjee, Neena Gupta, DivyaDhawan, ‘‘A novel approach for SOA based all opticalAnd gate”, IEEE conference,2011.
6. Robert Last,‘‘Semiconductor Optical Amplifier Design and Applications”.
7. Harold Kolimbiris, “Fibre optics communications”, Pearson Education, 2004.
8. OptiSystem7 optical communication system and amplifier design simulation software, OptiWave ystems Inc. © 2007,http:// www.optiwave.com.
9. Ajay Kumar, Santosh Kumar, S. K. Raghuwanshi, “Implementation of All-Optical Logic Gate using SOA-MZIStructures,” STM Journals 2013, ISSN: 2231-0401.
10. J. Dong, X. Zhang,Y. Wang, J. Xu and D. Huang, ‘‘40 Gbit/s reconfigurable photonic logic gates based on variousnonlinearities in single SOA’’, Electronic Letters 2nd August 2007 Vol. 43 No. 16.
11. S. Kumar, S. K. Raghuwanshi, A. Kumar,Implementation of Optical Switches byusing Mach-Zehnder Interferometer, *Opt.Eng.* 2013; 52: 097106p.
12. J. Y. Kim, J. M. Kang, T. Y. Kim, and S. K. Han, “All-optical multiple logic gates with XOR, NOR, OR, and NANDfunctions using parallel SOA-MZI structures: Theory and experiment,” J. Lightw. Technol., vol. 24, no. 9, pp. 3392–3399, Sep. 2006.