Semiconductor Optical Amplifiers (SOA) Performance Optimization in Optical Communication System

All-Optical Composite Logic Gates

Mr.Sachin Kumar
M.Tech Scholar : dept. of Electronics and Communication Engineering
Suresh Gyan Vihar University,Jaipur
Jaipur, India
Sachintalan86@gmail.com

Abstract— **The work has been focused on the XOR, AND, OR logic gate implementation, since it is a very versatile approach for implementing many functions in optical networks. The development and study of a novel architecture based on cascaded SOA-MZIs to perform the logic XOR operation between two input binary sequences. The experimental implementation and operation demonstration of the optical XOR logic gate at 10 Gbit/s. The extension and study of the SOA-MZI based logic-gate devices to perform other functions, like AND and OR operations with minor changes in the initial architecture.**

Finally, as an application of SOA-MZI wavelength convertor and all-optical composite logic gates with XOR, OR and AND functions using two parallel SOA-MZI structures are proposed and verified. The proposed design is optimized by adjusting the optical power, SOA bias current and phase differences in two SOA-MZI structures to obtain output pulses with maximum ER.

Keywords- All optical switch, Mach-Zehnder interferometer (MZI), Semiconductor optical amplifiers (SOA).

I. INTRODUCTION

All-optical logic gates become key elements in the realization of node functionalities, as add drop multiplexing, packet synchronization, clock recovery, address recognition, and signal processing. SOAs are very attractive nonlinear elements for the realization of different logic functions, since they can exhibit a strong change of the refractive index together with high gain. Moreover, different from fibre devices, SOAs allow photonic integration. The nonlinear behavior that is a drawback for the SOA as a linear amplifier makes it a good choice for an optically controlled optical gate[28-30].Gates with better performance are achieved by placing SOAs in interferometric configurations. In these gates, the optical input signal controls the phase difference between the interferometer arms through the relation between the carrier density and the refractive index in the SOAs by means of XPM. These interferometric SOA-based configurations are compact and offer stability. Mach-Zehnder interferometers (MZI) have been widely used to implement optical logic gates.

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In order to realize the logical gates, various configurations of optical logic gates have been reported that utilize the ultrafast non-linear properties of SOA's [26], including from single SOA structure using cross gain modulation (XGM) to interferometic structures, such as terahertz optical asymmetric demultiplexer (TOAD) and ultrafast nonlinear interferometer (UNI), etc. These schemes have been shown to have some advantages, but they are difficult to control or construct and polarization states or random phase changes are critical for their output performance. Among them, SOA-MZI structure using XPM is the most promising candidate due to its attractive features of low energy requirement, simplicity, compactness by integration capability, and stability. In addition, it has the merits of high ER, regenerative capability, high speed operation, and low chirp. So far, all-optical AND and XOR gates using SOA-MZI structure have been investigated. The all-optical AND gate is one of the fundamental logic gates because it is able to perform the bit-level functions such as address recognition, packet-header modification, and data-integrity verification. The all-optical XOR gate is a key technology to implement primary systems for binary address and header recognition, binary addition and counting, decision and comparison, encoding and encryption, and pattern matching. This gate has been demonstrated at 10 Gb/s.

In this paper, I propose and experimentally demonstrate all-optical composite logic gates with XOR, AND and OR functions using SOA-MZI structure at 10 Gb/s. The proposed design is optimized by adjusting the optical power and biasing current in SOA-MZI structures to obtain output pulses with maximum ER.

1.1 Logic gates based on nonlinearities on SOAs

The effects that make the SOA a very interesting device for applications in optical networks are the so called nonlinear effects. Nonlinear effects that have been characterized are: XPM and XGM.

1.2 Cross-gain modulation

The XGM effect consists on the variation of the SOA gain in function of the input power. The increase of the power of the input signal causes in the SOA a depletion of the carrier density, and therefore the amplification gain is reduced. The dynamic processes that take place in the carrier density of the SOA are very fast, of the order of picoseconds, so it is possible to use this variation on the gain with bit to bit fluctuations of the input power.

1.3 Cross-phase modulation

In fact, this latter effect is the principle of operation of XPM. The variation on the carrier density induces a change on the refractive index, and so the phase of the continuous wave is modulated. This phase modulation can be converted in intensity modulation by using a Mach-Zehnder interferometic configuration.

II. SOA-MZI BASED XOR GATE

The XOR gate has a special interest since it is the main building block for a wide range of functions. Due to its compactness and stable structure, SOA-MZI based XOR gate [26] seems an easy solution to achieve the integration level required for complex logic circuits [32]. Basically, the Boolean function gives a logic “1” if the two inputs that are being compared are different (combinations A=1, B=0, and A=0, B=1). On the other hand, if the inputs are the same (combinations A=1, B=1, and A=0, B=0), the XOR output signal is a logic “0”. In the case of optical gates, the logic “1” is represented by the presence of an optical pulse, whereas the logic “0” means absence of optical power.

2.1 Principle of operation

To perform the XOR Boolean function two optical beams carried by optical signals at the same or different wavelengths are sent through port #1 and #2 of the MZI separately. The wavelengths of the two data signals can also be the same. A train of pulses or a CW beam is coupled to port #3 as control signal. The control signal is split into two equal parts, one reaching the upper branch of the interferometer and the other reaching the lower branch. When data signals (bit sequences to be compared) are launched into the SOAs, the carrier density and, thereby, the medium refractive index is modulated. This causes a phase shift over the control signal counter-propagating through the SOAs (control signal) according to the intensity variations of the input data signals. This phase modulation experienced by the wave during propagation in the SOA is given by [33]:

$$\Delta\Phi = 2\pi n_0 \frac{L}{\lambda} + \alpha[\ln(G) - \ln(G_0)]$$

being λ the wavelength of the input data signal passing through the SOA, *L* the length of the active region of the SOA, α the SOA line width enhancement factor, the refractive index in the absence of optical power, *G* the saturated gain and the linear device gain. This equation is obtained from analytical models of wavelength converters under certain conditions such as the instantaneous response of the SOA and the adiabatic approximation. The control signal entering port #3 is split into two equal parts, one reaching the upper branch of the interferometer and the other reaching the lower branch. Initially, the MZI is balanced, that is the phase shift in both branches is the same.

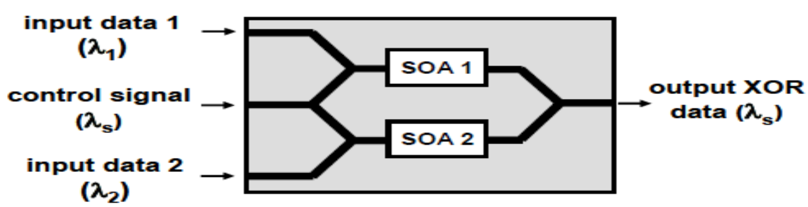


Fig 2.1 Mach-Zehnder interferometer used as an XOR gate

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

2.2 Simulation setup

In the cases in which A=0, B=0, the control pulse enters the SOA-MZI at port #3, and then is split into two pulses, one reaching the upper SOA, and the other reaching the lower one. At this point, due to the phase shift induced at the input coupler, the phases of the two versions of the control pulse are shifted π/2. The SOAs are under the same conditions, as no data pulse has arrived to neither of them, so the phase shift is still π/2. These two pulses, after passing through the SOAs, are recombined again at the output coupler were they suffer again an additional π/2 phase shift between them. So at the output port the two pulses are with the same amplitude and with a total phase shift of π, i.e. destructive interference, and no signal is obtained.

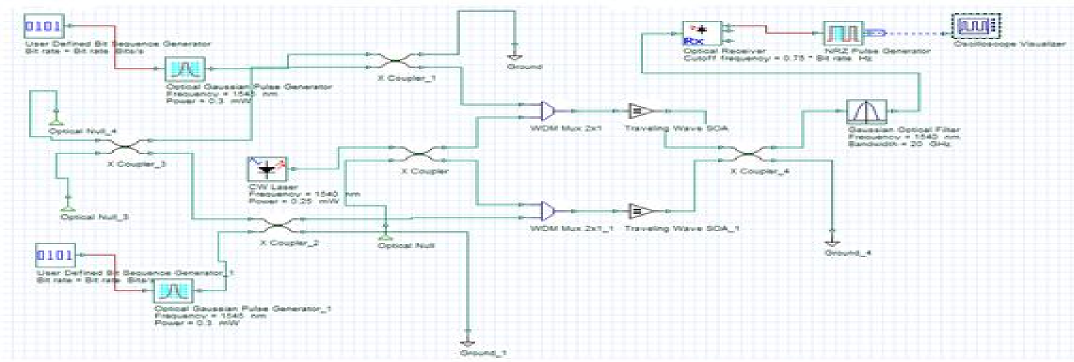
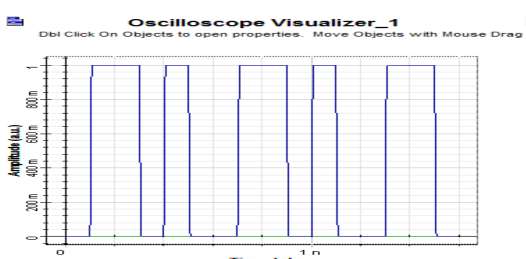


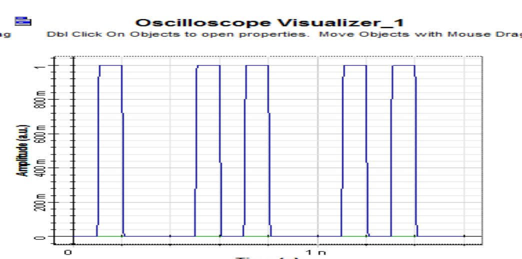
Fig 2.2 Simulation setup of SAO-MZI based XOR gate

In the case A=1, B=0, an optical pulse enters the SOA-MZI through port #1 and changes the refractive index of the upper branch SOA whereas the lower SOA remains unaffected. Thus, when the two versions of the control pulse travel through both SOAs, the phase difference between both is shifted (π is the optimum phase shift). At port #4, the signals (parts of the control signal) from the two SOAs are combined again and an optical pulse is obtained as a consequence of the constructive interference (note that the optical coupler imposes an additional π phase shift between the input signals, so the total phase shift is 2π). The same phenomenon happens if A=0 and B=1. In the case A=1, B=1, data pulses reach both SOAs, and the phase shift induced to the control pulse in each branch is the same. As a result, at port #4 no pulse is obtained in this case due to destructive interference between the signals pulses.

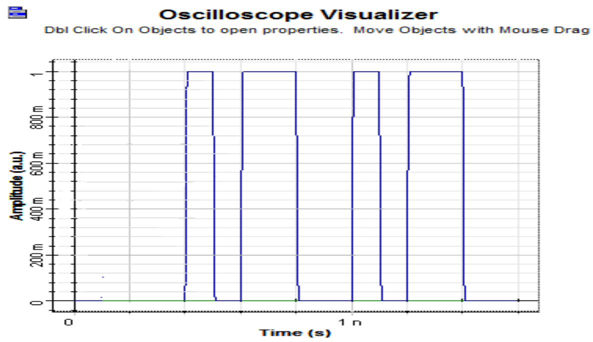
2.3 Experimental results



(a) Data A (011010)



(b) Data B (010001)



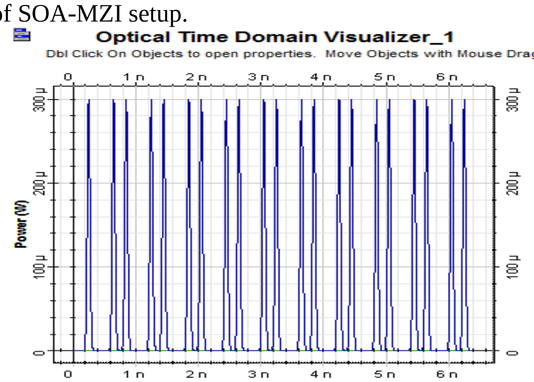
(c) Output (001011)

Fig 2.3 Results (a) & (b) input data signals that has to be compared. (c) Compared XOR data signal.

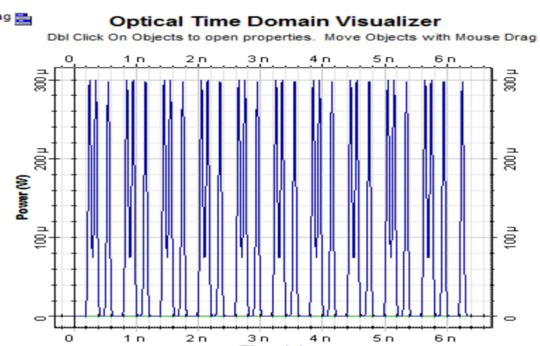
Table 2.1 Peak power values for data signals involved in the XOR logic operation

Signal	Peak power(mW)
Data A	0.30 mW
Data B	0.30 mW
CW	0.25 mW
Output	60 mW

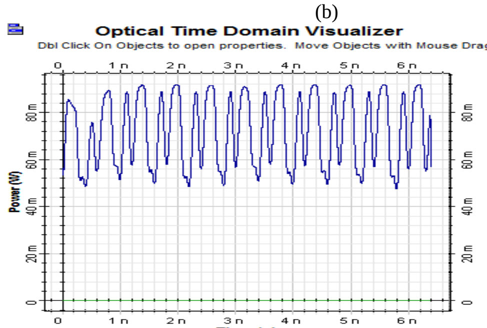
In this simulation we have generated two data signal as shown in fig 2.3 (a) and (b). The SOA-MZI setup is used to perform the XOR operation. These two data signals are generated at 1545 nm wavelength with the help of optical Gaussian pulse generator. A continuous wave is also generated at a wavelength of 1540 nm. These signals are given to the SOA-MZI ports for performing XOR operation. A Gaussian optical filter with 20 GHz bandwidth is used for filtering purpose. This filter is centered at 1540 nm wavelength so that we obtain only the desired signal. This resultant signal is the XOR operation between the two data signals applied at port 1 and port 2 of SOA-MZI setup.



(a)



(b)



(c)

Fig 2.4 (a) & (b) input signals Gaussian waveform at 1545 nm wavelength (c) XOR waveform at 1540 nm.

III. SOA-MZI BASED AND GATE

Boolean AND operation becomes also a good choice in optical signal processing. This logic functionality, gives logic "1" only when the two input signals under comparison are logic "1". In other case, the output is logic "0". The AND gate is unbalanced like the OR gate, as it only gives a "1" at the output in the event that both inputs are "1". From the truth table it is clear that the AND operation corresponds to sampling one signal with the other, and thus all-optical sampling techniques may be applied to obtain the AND function. This has been demonstrated with a MZI at 10 Gb/s using same PRBS data and other parameters like power and bias current.

3.1 Principle of operation

The principle of operation for the AND gate is basically the same than that for the XOR logic function. In this case, the data sequences to be compared are driven to the SOA-MZI as shown in Fig 4.5. Data signals enter the device at ports #1 and #3, while in port #2 a zero level signal must be ensured. There is no need of an additional control signal as the data signals entering the common port enables or disables the device. Following a similar principle than that of the XOR gate, an optical pulse will be obtained at the output only in the case that both data signals are "1". In this case (A=1, B=1), the pulse of data B enables the operation. In an alternative way, the AND operation can be seen as performing the XOR comparison between data A and a zero level signal. When B=0, the gate does not produce any signal at the output as it has no signal at port #3. In the last case in which B=1 and A=0 the comparison is enabled, but as the signal at port #1 and the signal at port #2 are zero, no power is obtained at the output of the device.

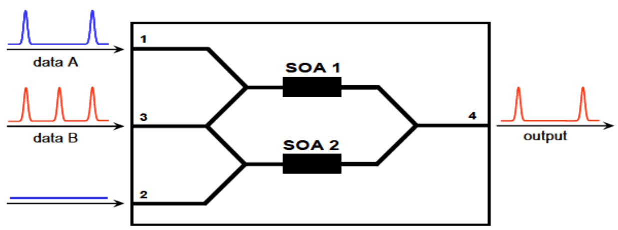


Fig 3.1 Mach-Zehnder interferometer used as an AND gate

3.2 Simulation setup

The principle of operation for the AND gate is basically the same than that for the XOR logic function. In this case, the data sequences to be compared are driven to the SOA-MZI as shown in Fig 4.6. Data signals enter the device at ports #1 and #3, while in port #2 a zero level signal must be ensured. There is no need of an additional control signal as the data signals entering the common port enables or disables the device. Following a similar principle than that of the XOR gate, an optical pulse will be obtained at the output only in the case that both data signals are "1". In this case (A=1, B=1), the pulse of data B enables the operation. In an alternative way, the AND operation can be seen as performing the XOR comparison between data A and a zero level signal. When B=0, the gate does not produce any signal at the output as it has no signal at port #3. In the last case in which B=1 and A=0 the comparison is enabled, but as the signal at port #1 and the signal at port #2 are zero, no power is obtained at the output of the device.

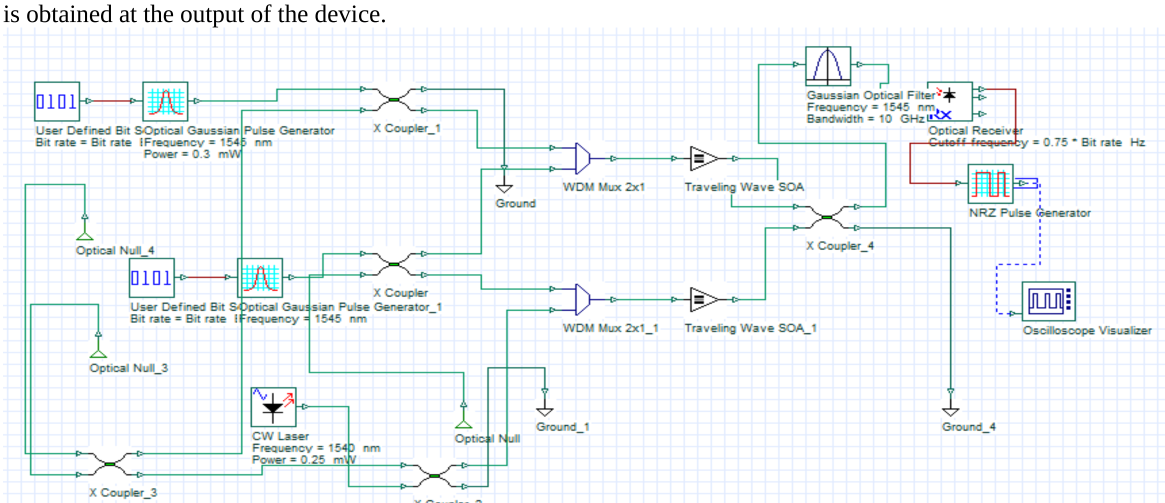
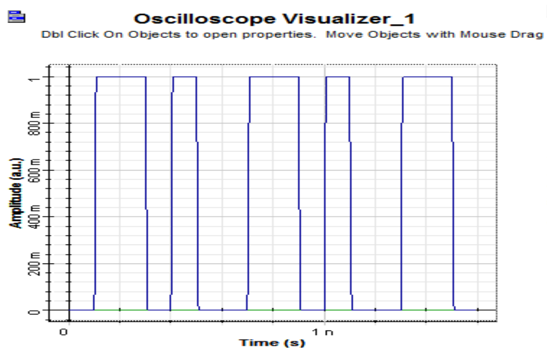
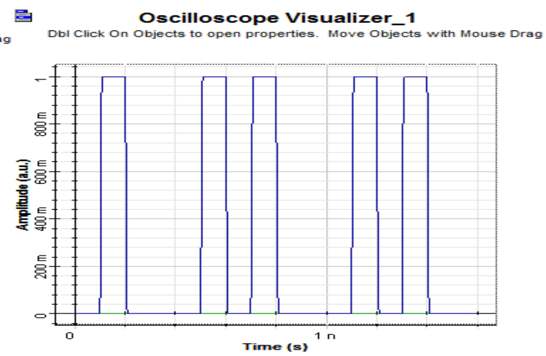


Fig 3.2 Simulation setup of SAO-MZI based AND gate

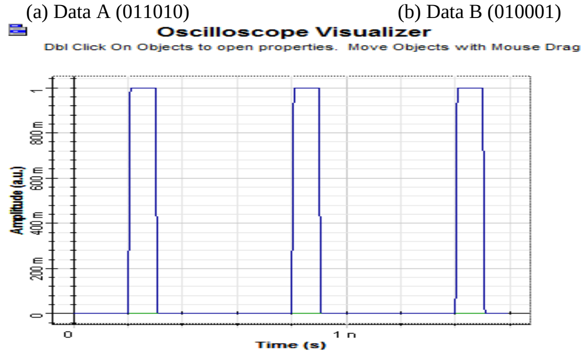
3.3 Experimental results



(a) Data A (011010)



(b) Data B (010001)



(c) AND gated output (010000)

Fig 3.3 Results (a) & (b) input data signals. (c) Output data signal.

Table 3.1 Peak power values for data signals involved in the AND logic operation

Signal	Peak power(mW)
Data A	**0.30 mW**
Data B	**0.30 mW**
CW	**0.25 mW**
Output	**11 mW**

In this simulation we have generated two data signal as shown in fig3.3 (a) and (b). The SOA-MZI setup is used to perform the AND operation. We have used the same parameters for simulation that we used in XOR gate implementation. We have generated the data sequences at same wavelength and same optical power. These two data signals are generated at 1545 nm wavelength with the help of optical Gaussian pulse generator. A continuous wave is also generated at a wavelength of 1540 nm. These signals are given to the SOA-MZI ports for performing AND operation. A Gaussian optical filter with 20 GHz bandwidth is used for filtering purpose. This filter is centered at 1540 nm wavelength so that we obtain only the desired signal. This resultant signal is the AND operation between the two data signals applied at port 1 and port 3 of SOA-MZI setup. Fig 3.3 (c) shows the AND operation signal between two data signals.

IV. SOA BASED OR GATE

Another logic function that may be optically implemented using the SOA-MZI based architecture is the OR. This Boolean operation, whose truth table gives a logic “1” each time one (at least) of the input data bits is “1”. So the output of this operation only will become a “0” in the case A=0 and B=0. Since the two-input OR gate only gives a "0" at the output if both input are "0", the function may be realized with a saturable device, i.e. a device for which the output power level is independent of whether the input level increases by a factor of two. The inverted OR gate, may be realized by simple XGM. The power level in the two data signals is such that if just one of the two goes high, the SOA gain is completely saturated, which pulls the output probe power low. If both inputs are high at the same time the outcome is the same. Interferometric switches are also compatible with

OR due to the nonlinear transfer function, which is flat around the maxima. This function has been demonstrated at 10 Gb/s using SOA.

4.1 Principle of operation

The architectures is again based on SOA-MZI. This is a simplest case in which no wavelength conversion is used. In this case, the principle of operation, which is depicted in Figure, is quite intuitive. The two data signals are coupled at the same port, in this case port #1. After passing through one of the two SOAs (in this case, the upper one), the amplified signal is coupled out at port #4, carrying the OR operation between the two inputs.

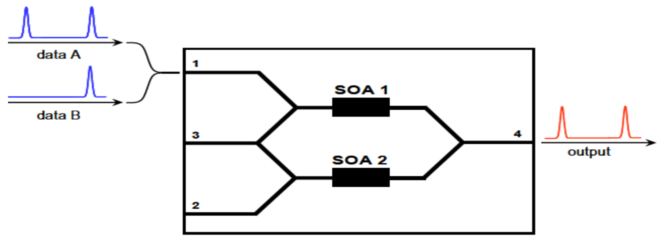


Fig 4.1 Operation of the OR logic gate using a SOA-MZI without wavelength conversion.

In this case, the two inputs must be at the same wavelength and the output signal is at the same wavelength than the input signals.

4.2 Simulation setup

The architectures is again based on SOA-MZI. This is a simplest case in which no wavelength conversion is used. In this case, the principle of operation, which is depicted in Figure, is quite intuitive. The two data signals are coupled at the same port, in this case port #1. After passing through one of the two SOAs (in this case, the upper one), the amplified signal is coupled out at port #4, carrying the OR operation between the two inputs.

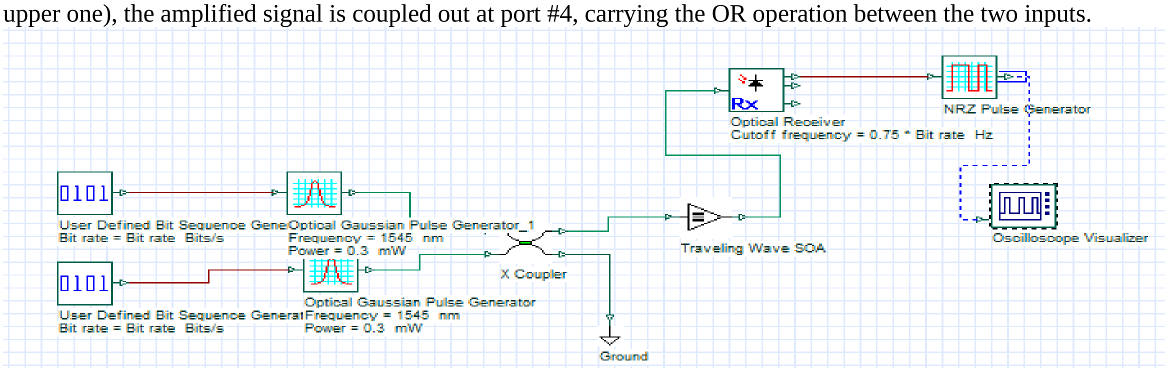
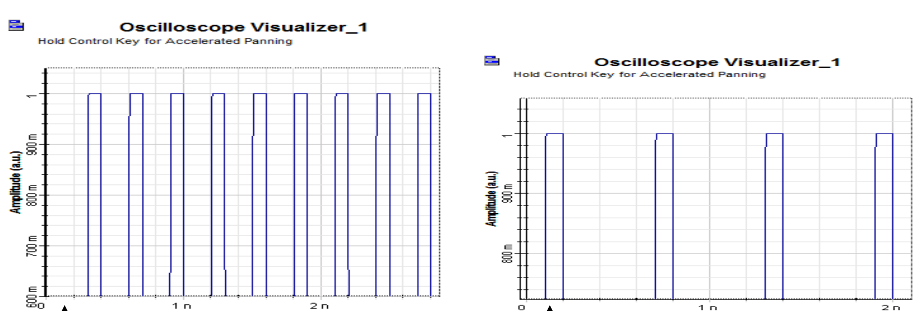


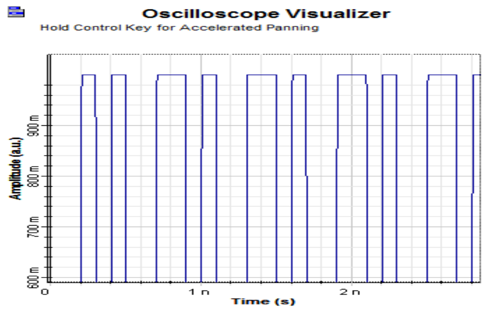
Fig.4.2 Simulation setup of SOA based OR gate

In this case, the two inputs must be at the same wavelength and the output signal is at the same wavelength than the input signals.

4.3 Experimental results



(a) Data A (001001) (b) Data B (100000)



(c) Output data signal (101001)

Fig 4.3 Results (a) & (b) input data signals (c) Output data signal.

Table 4.1 Peak power values for data signals involved in the OR logic operation

Signal	Peak power(mW)
Data A	0.30 mW
Data B	0.30 mW
Output	4 mW

In this setup we have used only two data signals on which we have to perform OR operation. There is no need to use a CW for performing this operation. In this case, the two inputs must be at the same wavelength and the output signal is at the same wavelength than the input signals. No wavelength conversion is done. The output is obtained at the same wavelength at which the data signal is generated. The two data signals are generated at 1545 nm and 0.3 mW power. These two signals are coupled at the two ports of coupler and given to SOA. Here the concept of cross gain modulation (XGM) is used to perform the OR operation.

V Conclusion

In this paper, I have proposed and experimentally demonstrated all-optical composite logic gates with XOR, AND and OR functions using a parallel SOA-MZI structure that enables simultaneous operation of various logical functions. The proposed design is optimized by adjusting the optical gain and phase differences in SOA-MZI structures in order to obtain maximum ER. The SOA-MZI turns out as a very promising candidate to implement all-optical logic gates because of its advantages of low energy requirements, compactness, high ER, regenerative capability and low chirp. These configurations show a very good stability on power level fluctuations of the input signals, data as well as control signals, and on synchronization issues. The Boolean functionalities have been successfully demonstrated using low energy levels and without any additional pump signal. SOAs required low injection current which leads to a low value on the total power consumption of the gate.

REFERENCES

[1] Agarwal G.P.,"Applications of Nonlinear Fiber Optics," Academic Press, San Diego, CA, 2001.

[2] Y. Yamamoto, Characteristics of AlGaAs Fabry-Perot cavity type laser amplifiers, IEEE J. Quantum Electron., **16**, 1047-1052 (1980).

[3] Blahut R. E., "Theory and Practice of Error Control Codes," Addison Wesley, 2000

[4] lumenthal D. J. and Kothari N. C., "Coherent Crosstalk in Multichannel FSK/DD Light wave Systems Due to Four-Wave Mixing in Semiconductor Optical Amplifiers, IEEE Photonics Technology Letters, Vol.8, No.1, January 2004, pp.133-135.

[5] Borghesani A., Fensom N., Scott A., Crow G., Johnston L., King J, Rivers L., Cole S., Perrin S., Scrase D., Bonfrate G., . Ellis A, Lealman I., Crouzel G., Kee Chun L. H. K.L. How, Lupu A., Mahe E., and Maigne P., "High saturation power (>16.5 dBm) and low noise figure (<6 dB)semiconductor optical amplifier for C-band operation," Optical Fiber Communication Conf. OFC 2003, vol. 2, Atlanta, GA, March 23–28,2003, pp. 534–536.

[6] Brackett C. A. et al., "Dense Wavelength Division Multiplexing Networks: Principles and Applications," IEEE Journal on Selected Areas in Communications, Vol.8, No.6, August 2004, pp.948-964.

[7] S. Okamoto and K. Sato. "Optical path cross-connect systems for photonic transport networks." in Proc. IEEE Global Telecommun. Conf, Nov. 2003, pp. 474-480.

[8] F. Derr, M. N. Huber, G. Kettler, and N. Thorweihe. "Kev issues of an optical FOM transport network," iu Proc. OFC'95.'San Diego, CA, Feh. 1995, paper Th12.

[9] A. Jourdan, G. Soul age, G. Da Loura, n. Clesca. P. Doussiere, C.

[10] Duchet, D. Leclerc, and J. F. Vinchant, M. Sotom. "Experimental assessment of a 4x4 four-wavelength all-optical cross-connect at a 10Ghit/s lin~ rate," in Proc. OFC'95, San Diego, CA, Feb. 2005, paper ThI7.

[11] C. A. Brackett, A. S. Acampora, J. Schweitzer, G. Tangonan, M. T.

[12] Smith, W. Lennon, K. C. Wang, R. H. Hobbs, "A scalable multi wavelength multihop optical nctwork: A proposal for research on all-optical networks," J. Lightwave Technol., vol. 11, pp. 736-752, MaylJune 2003.

[13] N. Wauters and P. Demester, "Wavelength requirements and survivability in WDM cross-connected networks," in Proc. ECOC '94, Fircnzc, Italy, Sept. 2004, vol. 2, pp. 589-592.

[14] J. O'Mahony, 'Thc potential of multiwavelength transmission," in proc. Of ECOC'94, Firenze, Italy, Sept. 2004, Vol. 2, pp. 907-913.

[15] K. Sato, "Transport network evolution with optical paths," in Proc. ECOC '94, Fircnzc, Italy, Sept. 2002, vol. 2, pp. 919-926.
[16] D. Chiaroni et aI., "Rack mounted 2.5 Gbitfs ATM Photonic switch demonstrator," in Proc. ECOC'93, Montreux, Switzerland, Sept. 2003, vol. 3, paper ThP 12.7.
[17] Dagenais M., Heim P., Saini S., Wilson S., Leavitt R., Yu A., Horton T., Luciani V., Stone D., and Hu Y., "High power C-band semiconductor booster optical amplifier," Optical Fiber Communication Conf. OFC 2003, vol. 1, Atlanta, GA, March 23–28, 2003, pp. 85–87.
[18] Brosson Philippe et al,"Analytical Model of A Semiconductor Optical Amplifier," Journal of Light Wave Technology , Vol. 12,No. 1,January 2004,pp-49-54.
[19] Cho Pak S., Achiam Yaakov, Yurista Guy Levy-,Margali Moti t, Gross Yoav, and Khurgin Jacob B.," Investigation of SOA Nonlinearities on the Amplification of DWDM Channels With Spectral Efficiency Up to 2.5 b/s/Hz," IEEE Photonic Technology Letter, Vol. 16, No. 3, March 2004, pp. 918-920.
[20] S. Okamoto and K. Sato. "Optical path cross-connect systems for photonic transport networks." in Proc. IEEE Global Telecommun. Conf, Nov. 2003, pp. 474-480.
[21] K. Sato, "Transport network evolution with optical paths," in Proc. ECOC '94, Fircnzc, Italy, Sept. 2002, vol. 2, pp. 919-926,
[22] K. Sato, S. Okamoto, and H. Hadama, "Network performance and integrity enhancement with optical path layer technologies," J. Select. Areas Commun., vol. 12, pp. 159-170, Jan. 2001.
[23] T. Dorhuus, C. Joergensen, B. Mikkelsen, R. J. S. Pedersen, and K. E. Stubkjaer, "All optical wavelength conversion by SOA's in a Mach-Zehnder configuration," IEFF: Photonics Techno/. Left., vol. 6, pp. 53-55, Jan. 2004.
[24] M. Eiselt, W. Pieper, and H. G. Weher, "Decision gate for all-optical data retiming using a semiconductor lascr amplificr in a loop mirror configuration," Electron. Left., vol. 29, pp. 107-109, Jan. 2003
[25] G. Grosskopf, R. Ludwig, R. Schnahel, and H. G. Weber, "Frequency conversion with semiconductor laser amplifiers for coherent optical frequency division switching," in Proc. /OOC '89, Kobe, Japan, July 2001, paper 19C4-4.
[26] M. C. Tatham, " All-Optical XOR Gate Based On XGM Properties of SOA", IEEE Photonics 1echno/. Lett., vol. 5, pp. 1303-1306, Nov. 2001.
[27] B-K. Kang, J.H. Kim, Y.H. Park, S. Lee, Y.M. Jhon, D.H. Woo, S.H. Kim, and S-H. Park; "All-optical logic AND in a SOA-based Mach-Zehnder all-optical wavelength converter", in *Proc. 13th Laser and Electro-Optics Society*, Rio Grande (Puerto Rico), vol. 1, pp. 117-118, 2000.
[28] J.H. Kim, Y.M. Jhon, Y.T. Byun, S. Lee, D.H. Woo and S.H. Kim, "All-optical XOR gate using a semiconductor optical amplifiers without additional beam", *IEEE Photon. Technol. Lett.*, vol. 14, no. 10, pp. 1436-1438, 2002.
[29] S.H. Kim, J.H. Kim, B.G. Yu, Y.T. Byun, Y.M. Jeon, S. Lee, D.H. Woo and S.H. Kim, "All-optical NAND gate using cross-gain modulators in semiconductor optical amplifiers", *Electron. Lett.*, vol. 41, no. 18, pp. 1027-1028, 2005.
[30] M. Schilling, K. Daub, W. Idler, D. Baums, U. Koerner, E. Lach, G. Laube and K. Wünstel, "Wavelength converter based on integrated all-active three-port Mach- Zehnder interferometer", *Electron. Lett.*, vol. 30, no. 25, pp. 2128-2130, 1994.
[31] X. Pan, J.M. Wiesenfeld, J.S. Perino, T.L. Koch, G. Raybon, U. Koren, M. Chien, M. Young, B.I. Miller, and C.A. Burrus, "Dynamic operation of a three-port, integrated Mach-Zehnder wavelength converter", *IEEE Photon. Technol. Lett.*, vol. 7, no. 9, pp.995-997,1995.
[32] T. Fjelde, D. Wolfson, P.B. Hansen, A. Kloch, C. Janz, A. Coquelin, I. Guillemot, F.Gaborit, F. Poingt, B. Dagens, and M. Renaud, "20 Gbit/s optical wavelength conversion in all-active Mach-Zehnder interferometer", *Electron. Lett.*, vol. 35, pp. 913-914, 1999.
[33] E. Iannone, R. Sabella, L. de Stefano and F. Valeri, "All-optical wavelength conversion in optical multicarrier networks", *IEICE Trans. Commun.*, vol. 44, no. 6, pp. 716-724, 1996.
[34] K. E. Stubkjaer, "Semiconductor Optical Amplifier-based All-Optical Gates for High-Speed Optical Processing", *IEEE J. select Top. Quantum Electron.*, Vol. 6, No. 6, pp. 1428-1435, 2000.