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Implementation of Optical Logic Gates (Ex-OR AND and NOR) Using SOA-MZI Structure

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Abstract:
Within this work, all optical logic gates are demonstrated, these all gates are simulated on the basis of different types of nonlinearities in a single semiconductor optical amplifier and a detuning optical band pass filter, all-optical logic gates using simultaneous Four-wave mixing (FWM) and Cross gain modulation (XGM) and Cross phase modulation (XPM) .This scheme can be easily reconfigured to implement ultrafast AND, NOR, NOT, and XNOR gates operating at 10Gbit/s.Semiconductor optical amplifiers (SOAs) are very striking nonlinear instrument for the realization of different optical logic functions, since they can provide a strong change of the refractive index together with high gain. In this paper operation, simulation step and experimental result of different optical logic gates (Ex-OR Gate, AND Gate, NOR Gate) are well presented. These gates are based on the nonlinearities on SOAs. The experimental results are exactly matched with standard results.

***Keywords**: Semiconductor optical amplifier; MZI; Nonlinearity; Optisystem*

1. Introduction

A basic communication system consists of transmitter, receiver and an optical fiber cable connecting them. Optical fibers acts as a very good medium of signal transmission as the signals travelling in it undergo very less attenuation as compared to other medium, such as copper, but still there is a limit of distance (around 100 Km) upto which the signals can travel with minimum effects of noise.

Before optical amplifiers came into picture, for transmission over long distances it was required to convert the optical signal into electrical and cleaning and amplification was done electronically and then the signal was regenerated optically and send further for communication. This conversion was required to be done at every 80-100 Km distance. [11]

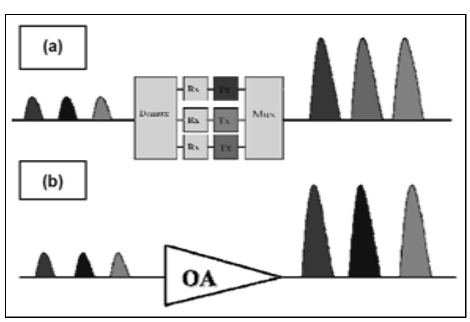


Figure 1: Block diagram of (a) an electronic signal regeneration station, in which channels are separated, detected, amplified and cleaned electronically, retransmitted, and then recombined.(b) an optical amplifier where all channels are optically and transparently amplified together.[6]

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. It is also independent of the number of number of channels, bit rate, protocol and modulation format used and so a single optical amplifier is capable of replacing the multiple components used

in amplification in a regeneration station. The replacement of optical amplifier is even not required at the time of when links are upgraded. [1][10].
Despite of the advantages mentioned above, optical amplifiers also have some disadvantages. The advanced components and control software make optical amplifier a complex sub-system. As it is an active constituent in the network, it requires electrical power supplies. Semiconductor lasers acts as optical pumps in WDM networks, producing output in the range of 20-33dBm. This high power can cause hazards like eye or skin damage, fire or explosions can happen if beams are not properly confined. "Fiber fuse effect" can even damage the fiber itself. In the signal which passes through an amplifier the bit error rate (BER) is increased and so signal to noise ratio (SNR) is reduced as amplifier also adds noise to the signal. Non-liner optical cross-talk can also be caused in the transmission fiber by the channel power. So minimizing the addition of noise and transmission of error free signal is a major challenge in optical networks. [2][3]

2. Optical Nonlinearities

For light waves, the propagation of waves from ordinary sources with small powers in any medium is linear. There will be no change in characteristics of Emerging light beam like frequency, phase and wave shape, with its intensity. As an example, referring to Figure 2, we see that the output of beam 1 is independent from beam 2. Thus, one light beam does not transform any of the properties of another light beam, even though they cross each other. This will take place whenever the intensities of the two light 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 extent that it can then affect its own propagation as well as that of other beams crossing it. This happens due to a nonlinear effect (called second harmonic generation) in which a light beam of frequency f creates a beam having double its frequency, 2f (half the wavelength). 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 are known as nonlinear optical effects.

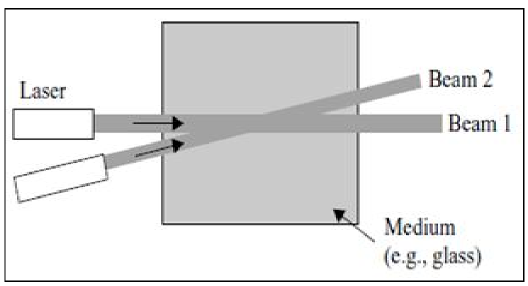


Figure 2: Linear medium showing two light beams travel independently ref

Due to the nonlinear effects taking place within the optical fiber, the information carrying signal pulses can get modified due to the presence of other channels, which can gives the increased errors in detection. Since nonlinearity depends on intensity, so as reduces cross section area, nonlinear effects become stronger and stronger for a given power. In the case of optical fibers, light is confined to propagate within the core, and if the cross section area of the beam is small, then stronger nonlinear effects can be observed. This is used for all-optical processing of optical signals.[15]

2.1. Type Of Nonlinear Phenomenon

2.1.1. Self Phase Modulation (SPM)

Normally refractive index is independent of optical intensity although refractive index depends on wavelength but at high optical intensity, refractive index is not independent with intensity. Refractive index for nonlinear medium is

$$n = n_0 + n_2 I$$

This is also known as Kerr effect. Since the phase of light beam depends on the refractive index of the medium and it is the beam itself that is changing the refractive index which it turn changes its own phase that why it is calledself phase modulation (SPM) [5].

2.1.2. Cross Phase Modulation (XPM)

In WDM system, pulses in fiber propagate at distinct wavelength. If we now consider light beam at two different frequencies propagate simultaneously through fiber, change in refractive index brought about each beam will affect other beam. This is known as cross phase modulation (XPM). Signal pulses are random, overlap at instantaneous point results the XPM [5].This gives random noise of the channel resulting penalty and high bit error rate. If pulse has different frequencies then velocity of them will be different. So there would be walk-off between two pulses. If they start moving together they will separate as they propagate, resulting higher dispersion. To reduce dispersion there velocity should close to each other but this results strong XPM

2.1.3. Four Wave Mixing (FWM)

The transmission of two or more waves in the same direction and in the same fiber is termed as FWM [5]. The signal which is also be termed as mixing signal are used to produce new signals at wavelengths which are spaced at the same intervals. This process can also be done with three or more signals. In a WDM system, FWM can cause the generation of spurious signals at frequencies corresponding to the other channels. Therefore, if there are signals present at any frequency corresponding to any of the newly generated frequency, then it gives the increased noise at these frequencies. This would result in severe crosstalk. Thus it is necessary that FWM effects are minimized in WDM systems.

2.2. Basic Optical Logic Gates Using SOA-MZI

In SOA-MZI many input/output ports are present on each side and all these ports are bi-directional, which means that same port can be used as input port or output port. This is possible only because of bidirectional operation of SOA. There are two branches in interferometer in which SOA is placed. SOA by performing the function of a non-linear element induces an additional phase change on one of the signals propagating through it. Another signal which is co-or counter-propagating through SOA can cause this phase change.

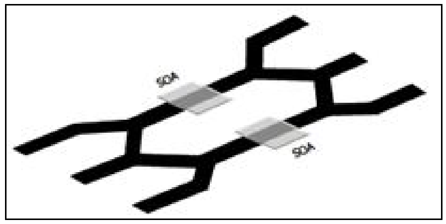


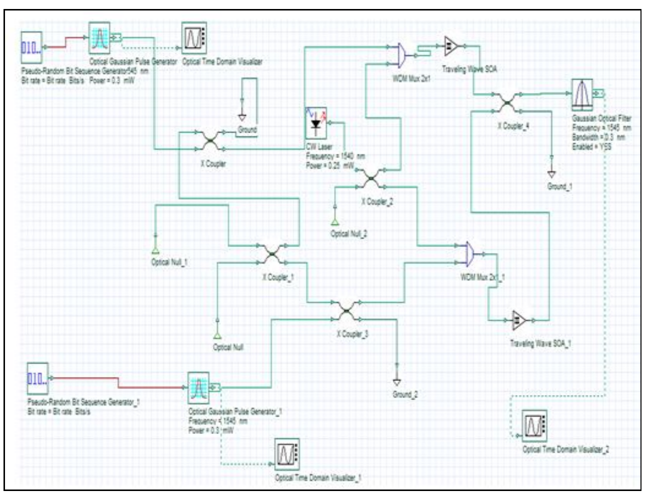
Figure 3: Mach-Zehnder interferometer with one SOA in each arm

2.2.1. Optical XOR Logic GATE

The XOR gate can be considered as the main building block for a number of functions, because of it is a compact and stable structure. This Boolean function will give a logic “1” if the two inputs being compared are different (combinations A=1, B=0 and A=0, B=1). Logic “0” will be obtained when both the inputs are same (combinations A=0, B=0 and A=1, B=1). The logic “1” will be marked by the presence of optical pulse, whereas when logic “0” is to be represented the optical pulse will be absent.[8]

2.2.1.1. Simulation of XOR Gate Using SOA on Opti System

In this simulation we have generated two data signal. The SOA-MZI setup is used to perform XOR generated at 1545 nm wavelength with the help of optical Gaussian pulse generator. A continuous wave is also generated at 1540 nm. In this power of data signal is 0.3 mw and it is slightly greater than control signal pulse (.025 mw) These signals are given to the SOA-MZI ports for performing XOR operation between the two data signals applied at port 1 and port 2 of SOA-MZI setup.



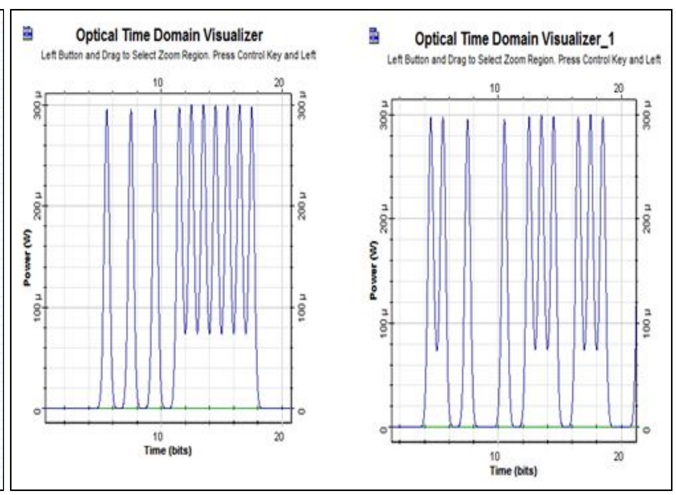


Figure 4: Implementation of XOR gate using SOA on OptiSystem[13][14]
Figure 5: Input signal for XOR gate

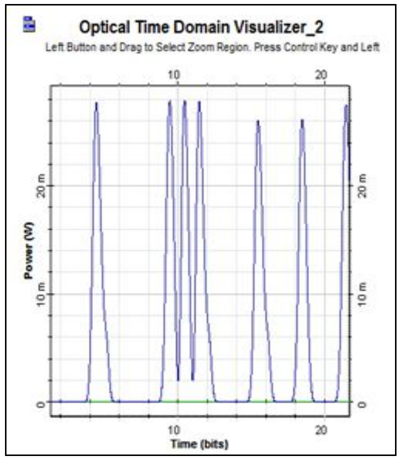


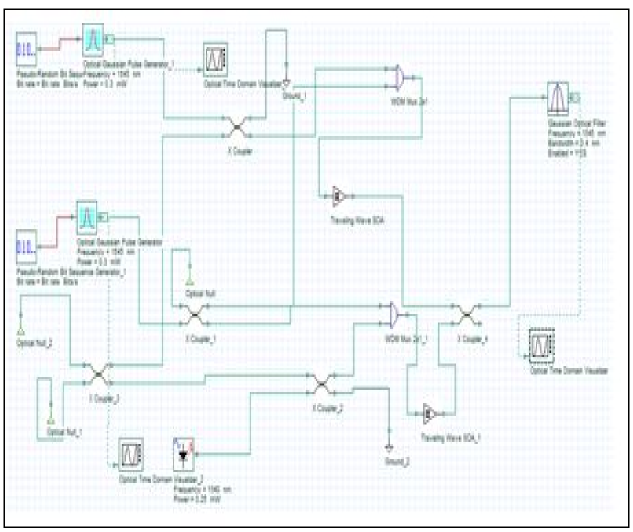
Figure 6: Output signal for XOR gate

2.2.2. Optical AND Logic Gate

Boolean AND function is very useful in optical signal processing. In this Boolean function logic "1" is obtained only when both the input signals which are under comparison are at logic "1", else logic "0" is obtained. [8]

2.2.2.1. Simulation of Optical AND Logic Gate

The data signals required for input will be generated with the help of a CW laser and two Optical Gaussian Pulse Generators. The CW laser will have frequency of 1545 nm and power of 0.30 mW. The control signal is generated by using Optical Gaussian Pulse Generators will have frequency of 1540 nm and power will be set at 0.25 mW. The data bits from these sources will be coupled and then multiplexed. The multiplexed signals will then pass through two SOAs. The SOAs will be having 0.15 A injection current. The output signal from these two SOAs will be coupled and then passed through the Optical Gaussian Filter to obtain the final output of AND gate. The Optical Gaussian Filter will be having frequency of 1545 nm and bandwidth of .4 nm.



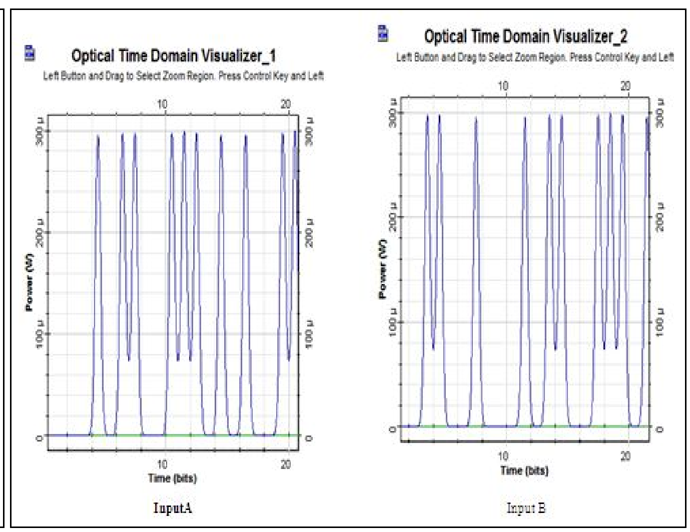


Figure 7: Simulation of AND logic gate using SOA on OptiSytem[13][14]
Figure 8: Input signal for AND gate

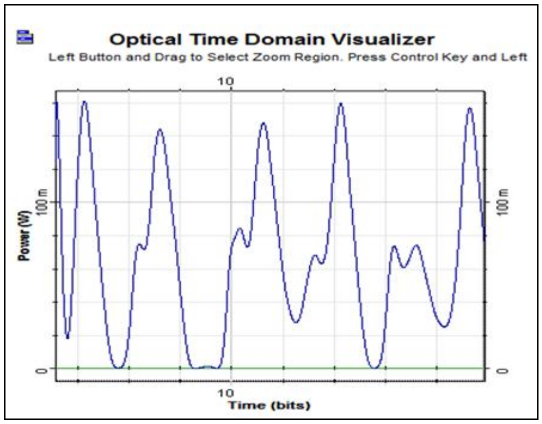


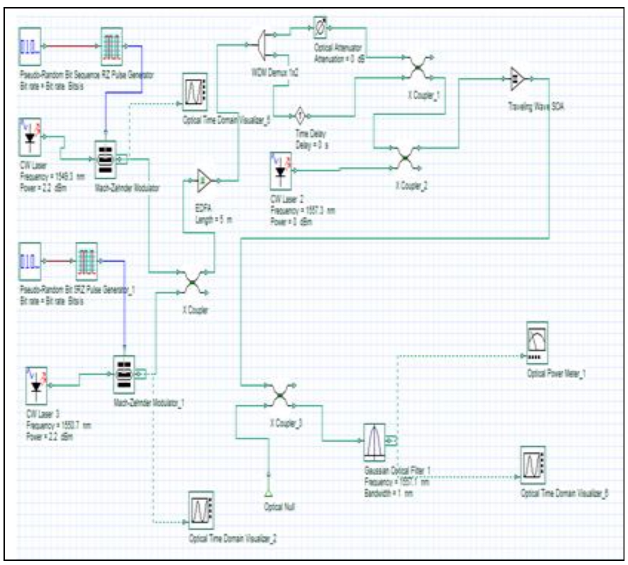
Figure 9: Output signal of AND gate

2.2.3. Optical NOR Logic Gate

For NOR gate implementation, bandwidth of band pass filter is set at 1 nm. The wavelength of band pass filter is set at 1557.1 nm. The BPF is detuned (0.2 nm) from the control signal wavelength

2.2.3.1. Simulation of Optical NOR Logic Gate

because this detuning is very helpful in determination of the logic NOR gate. In this NOR gate simulation EDFA is not required because the output have sufficient power in compared to AND gate.[8]



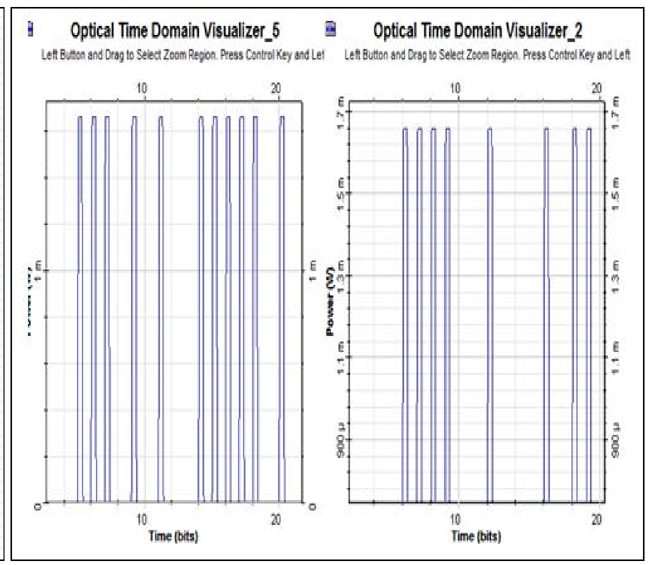


Figure 10: Simulation of NOR logic gate using SOA on OptiSytem[13][14]

Figure 11: Input signal for NOR Logic gate

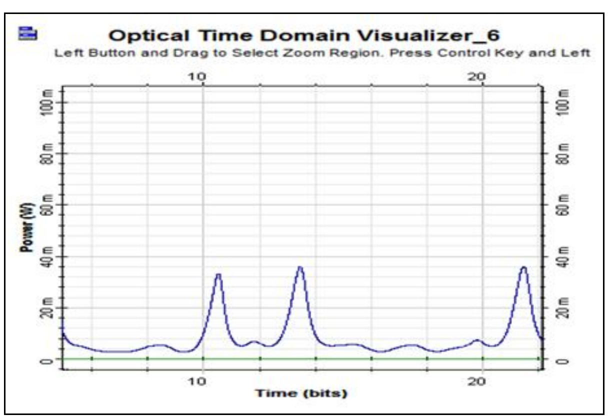


Figure 12: Output signal of NOR gate

3. Conclusion

Due to its compactness and stable structure, SOA-MZI based gate seems an easy solution to achieve the integration level required for complex logic circuits. In this paper, all optical logic gates are implemented. The principle of operation and simulation step described in detailed way. Its experimental outputs are exactly matched with standard outputs. These gates are widely used in the optical networking.

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