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Photonic AND OR Gate by Using Fiber Coupler

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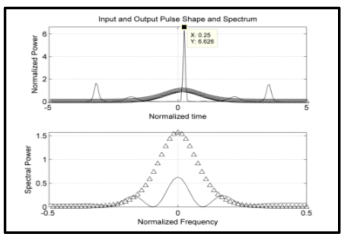
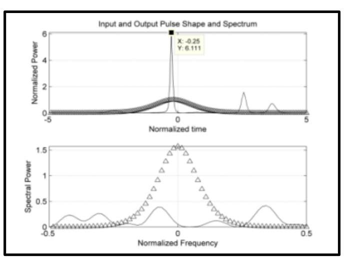
Graphical abstract





Abstract

The development of optical logic gate by using fiber coupler can be realized by properly determine the delay in Pulse Position Propagation (PPM) to set a logic bit in Time Domain Multiplexing (TDM) systems. Soliton has been used to maintain the pulse shape for a long haul distance connection up to 100km. In this study, a numerical modeling of secant hyperbolic soliton pulse based on Nonlinear Schrodinger Equation (NLSE) was performed in balance of Self-Phase modulation and Group velocity dispersion by normalized distance, time and field calculated by 1032 iteration step. Two picosecond soliton pulse transmission in anomalous dispersion region served as input generated inside fiber coupler and the code generator will encode signal within the altered time difference of ±0.25t. The signal would move in the fiber coupler and the phase modulator controls the phase of the bisoliton generation from 0 to 2π. The result is the formation of optical logic AND and OR gate at the phase difference of 0.4π and 1.1π with normalized power of ~6 and parameter offset ε=0.25.

Keywords: Optical logic gate, fiber coupler, soliton

Pembangunan get logik dengan menggunakan optik gentian pengganding boleh direalisasikan dengan betul menentukan sela Penyebaran Posisi Nadi(PPM) untuk menetapkan logik bit dalam sistem Multiplexing Domain Masa (TDM). Soliton telah digunakan untuk mengekalkan bentuk denyut untuk sambungan jarak jarak jauh sehingga 100 km. Dalam kajian ini, satu model berangka nadi soliton hiperbolik berdasarkan Persamaan Schrodinger Linear (NLSE) telah dijalankan dalam baki modulasi fasa sendiri dan Kumpulan halaju serakan dalam jarak normal, masa dan bidang dikira dengan 1032 langkah lelaran. Dua piko saat penghantaran nadi soliton di rantau penyebaran janggal bertindak sebagai input yang dijana di dalam pengganding gentian dan penjana kod yang akan mengeko disyarat dalam perbezaan masa yang agak berlainan sedikit ±0.25t. Isyaratakan bergerak dalam pengganding gentian dan pemodulat fasa mengawal fasa generasi bisoliton dari 0 hingga 2π. Hasilnya ialah pembentukan logik optik DAN dan get ATAU pada perbezaan fasa 0.4π dan 1.1π dengan kuasa daripada normal ~6 dan parameter pengimbang ε = 0.25.

Kata kunci: Get logik optik, serat pengganding, soliton

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1.0 INTRODUCTION

The fiber can be an optical amplifier, an optical switch converter wavelength, soliton in a source, a compressor noise, a filter, and optical memory. The directional couplers optical fibers are widely used in modern optical communications systems. Nonlinear effects in directional couplers were studied starting in

1982. Fiber couplers, also known as directional couplers, constitute an essential component of light wave technology. They are used routinely for a multitude of fiber-optic devices that require splitting of an optical field into two Coherent but physically separated parts. Although most applications of fiber couplers only use their linear characteristics, nonlinear effects have been studied since 1982 and can lead to all-optical switching among other applications [1]. The transfer of optical power between the modes of the two cores of the coupler is explained as evanescent field coupling between the modes of the individual cores of the coupler. The mechanism is characterized by a parameter known as the coupling coefficient where it arises from the coupling of the propagating fields inside the two cores.

The nonlinear directional coupler can be purposed as optical switching and logic function [2] since the optical power is switched between coupler fibres by intensity level of the input signal when the Kerr effect has important role in waveguides. Kerr effect is most nonlinear effect occur is nonlinear material [3, 4] and speed up the switching process in the coupler [5, 6]. The soliton pulse is in the range of picosecond, so it is assumed to be in the anomalous group velocity dispersion. In this condition, at the higher order of dispersion, the shock effect and the other higher order of nonlinear dispersion can be neglected.

Realization of optical logic gate from a directional coupler has been done [7]. Development of all-optical logic requires accurate, ultrafast and ultrashort pulse transmission system by using soliton and efficient modelling of optical components and interfaces thus it require soliton pulse to operate the high performance system [8]. The model proposed is related to the pulse propagation along coupler interfaces. The setup is a model for straight waveguide couplers with a mathematical state foundation that is consistent with the physical notions. We derive the governing equations from first principles of soliton pulse, then the position modulation, phase modulation, and coupling derivation. Going beyond the mere abstract theoretical model, another objective of this work is the reliable and efficient numerical implementation of the approach.

2.0 EXPERIMENTAL

2.1 Split-Step Fast Fourier Transform Soliton Model

The basic partial differential equation for Nonlinear Schrodinger Equation (NLSE) is defined as;

$$i\frac{\partial A}{\partial z} = \frac{\beta_2}{2}\frac{\partial A^2}{T^2} - \gamma|A|^2 A \tag{1}$$

where A is the amplitude, z is the space, T is the time and γ is the nonlinear parameter. By using normalization of the equation, U= $\frac{A}{\sqrt{P_0}}$, $\xi = \frac{z}{L_D}$, and $\tau = \frac{T}{T_0}$ where it introduce dimensionless unit variation. After replacing all the normalized equation and take the dispersion and nonlinear length to be $L_D = \frac{T_0^2}{|\beta_2|}$ and $L_{NL} = \frac{1}{\gamma P_0}$

$$i\frac{\partial u}{\partial \xi}\frac{\sqrt{P_0}}{L_D} = \frac{\beta_2}{2}\frac{\partial^2 u}{\partial \tau^2}\frac{\sqrt{P_0}}{T_0^2} - \gamma|u\sqrt{P_0}|^2 u\sqrt{P_0} \tag{2}$$

$$i\frac{\partial u}{\partial \xi}\frac{1}{L_D} = \frac{\beta_2}{2}\frac{\partial^2 u}{\partial \tau^2}\frac{1}{T_0^2} - \gamma|u\sqrt{P_0}|^2 u \tag{3}$$

Then use some approximation to count the order of the wave, $N^2 = \frac{L_D}{L_{NL}} = \frac{\gamma P_0 T_0^2}{|\beta_2|}$

Where the β_2 sign can be used for both sign either positive for normal dispersion or negative sign for anomalous dispersion that is used for soliton propagation. The solution of equation 3 by using inverse scattering method has been solved elsewhere [5]

$$u(0,\tau) = \mathrm{sech}(\tau)e^{-i\frac{C\tau^2}{2}} \tag{4}$$

where the secant hyperbolic will show the profile of the pulse and the exponent will show the chirp parameter of the pulse. This equation is used for initial condition of the pulse for modeling.

3.0 RESULTS AND DISCUSSION

3.1 Pulse Position Modulation (PPM)

Pulse position modulation, (PPM) is modeled by considering each soliton pulse must be in its time frame as long as it travels. So that to model the PPM, addition in the periodical time, τ must been made. In our research, the PPM was modeled by

$$u(z,\tau) = \mathrm{sech}(\tau \pm \Delta\tau)e^{-i\frac{C\tau^2}{2}} \tag{5}$$

where $\Delta\tau$ is referred as the difference time for each pulse to differ from its reference time to make the bit of the pulse to be either bit 1(-$\Delta\tau$) or 0 (+$\Delta\tau$) where the pulse would experience an increment or decrement of time.

It is obtained from the result of research that to generate bit positive (bit 1) the model of soliton pulse must follow the model of,

$$u(z,\tau) = \mathrm{sech}(\tau - 3.0\Delta\tau)e^{-i\frac{C\tau^2}{2}} \tag{6}$$

where we will get the output result of soliton bit pulse of increment of time +0.25t from the reference time, t_r. On the other hand, the model of bit negative (bit 0) soliton pulse must follow the model of,

$$u(z,\tau) = \mathrm{sech}(\tau + 2.8\Delta\tau)e^{-i\frac{C\tau^2}{2}} \tag{7}$$

where the results of soliton bit pulse are obtained for decrement of time -0.25t from the reference time, t_r as shown in Figures 1 and 2 respectively.

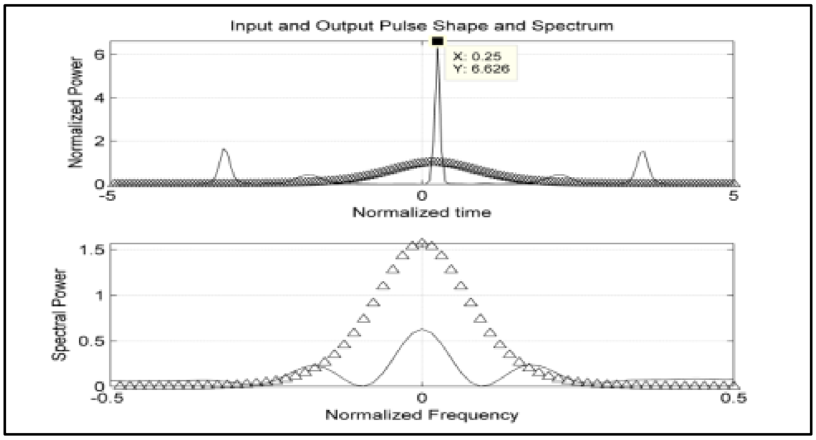


Figure 1 Soliton pulse signal of logic bit 1

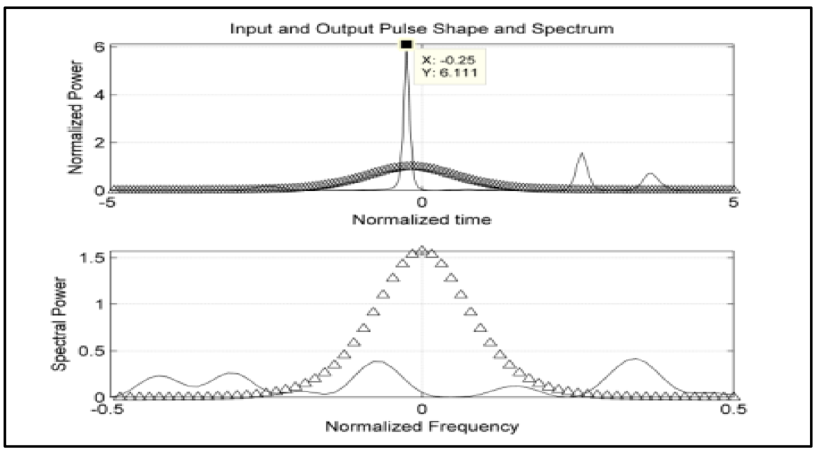


Figure 2 Soliton pulse signal of logic bit 0

3.2 Optical Logic Gate by Fiber Coupler

The input pulse is given in the form: U (0, t) = N sech (t), with N = 1 nonlinear pulse solitary fundamental. Four combinations of two input signal has been made to test the model of the soliton pulse and the result is formation of optical gate AND and OR at phase difference of the pulse 0.4π and 1.1π. The truth table of basic gate is shown in Table 1 and the corresponding soliton pulse signals within fiber coupler for AND and OR gate configuration are shown in table 2.

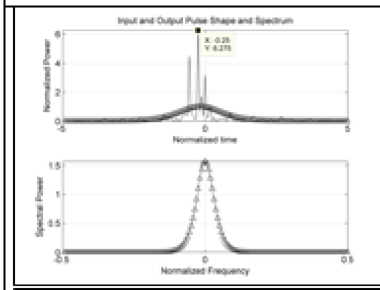
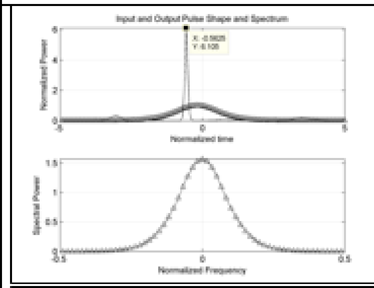
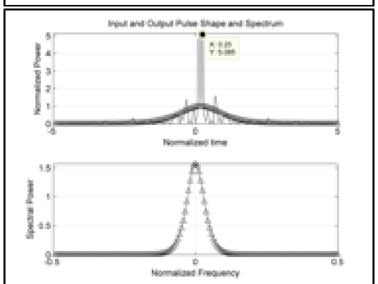
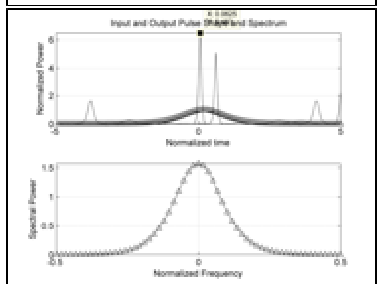
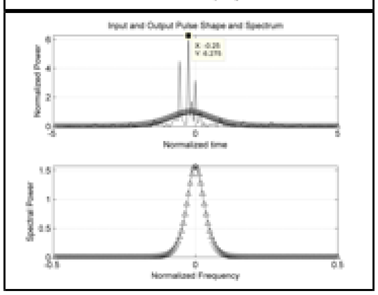
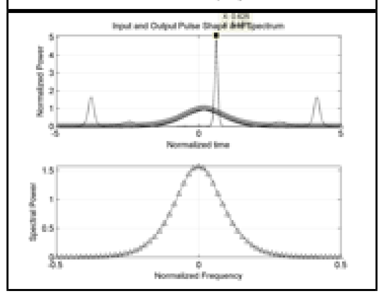
Table 1 Truth table for logic AND and OR

Input (A)	Input (B)	Output OR (1.1π)	Output AND (0.4π)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	1	1

The physics behind all-optical switching can be understood by noting that when an optical beam is launched in one core of the fiber coupler, the SPM induced phase shift is not the same in both cores because of different mode powers. As a result, even a symmetric fiber coupler behaves asymmetrically because of the nonlinear effects. The situation is, in fact, similar to that occurring in asymmetric fiber couplers where the difference in the mode-propagation constants introduces a relative phase shift between the two cores and hinders complete power transfer between them. Here, even though the linear propagation constants are the same, a relative phase shift between the two cores is introduced by SPM.

At sufficiently high input powers, the phase difference-or SPM-induced detuning-becomes large enough that the input beam remains confined to the same core in which it was initially launched thus maintain soliton pulse propagation inside fiber.

Table 2 Result output of soliton pulse signal within fiber coupler for AND and OR gate configuration

AND	OR	Input logic
		A=1 B=0 or A=0 B=1
		A=1 B=1
		A=0 B=0

4.0 CONCLUSION

In summary, so far we had obtained the model of soliton wave pulse. The pulse has properties to move in increment of time or decrement of time, so it can be treated as signal pulse either bit '1' or bit '0' as it moving in order of increment of time or decrement of time refer to the reference time. Then, the study is expended to the change of phase of the soliton pulse. It has shown that the phase change varies from 0 to 0.49π where the amplitude of the pulse decreases in positive region where in negative region, the amplitude increase. This result had shown that the bit pulse of soliton has ability to perform as logic gate parametric in the region of [(0-0.49π) and (1.5π-2π)].

The numerical calculation of the soliton interaction in the fiber coupler has shown that the fiber coupler will be able to operate as the OR and AND gate as the soliton signal in the both input has the phase difference at 0.4π and 1.1π.

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