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Design of 4x4 Banyan optical switch using optoelectronic MZI switches with low crosstalk

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Abstract: We introduce here a designing of 2x2 MZI (Mach-Zehnder Interferometer) optical switch. The switching of the optical signal is realized with the use of fast electro-optical effects. The designed model has a very high switching capability and is extremely reliable. Various design parameters have been varied to improve the performance of the switch. Then the basic 2×2 switch is exploited in design of 4×4 banyan switch. Banyan switch is a good candidate for further use in higher order switches. Simulation results are shown for 2x2 and 4x4 banyan architecture with low cross-talk values.

Keywords: Optical waveguides, MZI (Mach-Zehnder Interferometer), Banyan architecture, optical field.

Introduction

Electro-optic effect is a change in refractive index of the material with the variation of intensity of an electric field applied to it; this is the linear electro-optic effect. Speed of this effect is less than 1 ns. Lithium Niobate ($LiNbO_3$), Polymers, Lead zirconate titanate (PZT and GaAs-AlGaAs (Martin Nord, 2002) are the materials used in designing of switches with electro-opto effects. $LiNbO_3$ is based on its large electro- opto co-efficient (Ron A. Spanke, 1986). Directional couplers in Ti:$LiNbO_3$, have been under research for over a decade and recent progress has resulted in 8x8 arrays of switches being offered commercially (Erickson, 1989). Interferometric switches are based on Mach-Zehnder Interferometers (Lai *et al.*, 1998) shown in Fig.1, which consists of a 3 dB splitter and a 3 dB combiner, connected by two interferometer arms. By changing the effective refractive index of one of the arms, the phase difference at the beginning of the combiner can be changed such that the light switches from one output port to the other. 3-dB couplers were chosen to be multi-mode interference (MMI) couplers due to their polarization independence, fabrication- and wavelength tolerance. A 2x2 MMI switch with Banyan architecture with coupling loss of 5.38%. and the crosstalk of 6.99 $\times 10^{-05}$ has already been analyzed (Singh *et al.,* 2008).

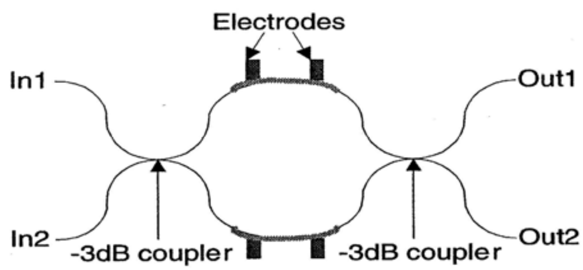

Fig. Scheme of 2x2 interferometric switch

Table I. Wafer properties

Substrate-$LiNbO_3$	Propagation direction-Y, crystal cut-Z	Thickness 10 micrometers
Wafer Properties		
Wafer Profile-	Wafer dimensions	
$LiNbO_3$	Length-33 mms	Width-0.1 mms
2 D Wafer Properties		
Material	Thickness	Refractive index
Air/Cladding	2 micrometers	1

Designing of 2x2 basic MZI switch

The wafer is a planar substrate on which we design devices. Its length is along Z-axis, horizontal on the screen and width is along X-axis, vertical on the screen. Thickness of the substrate is in y-direction, perpendicular to the screen and not shown on the layout interface. MZI switch is created on a z-cut wafer of Lithium Niobate and is surrounded by air cladding. Wafer is designed with 33mms of length, 10 micrometers of thickness and 0.1 mms of width (Table 1). The device is oriented along the Y-optical axis of the Lithium Niobate. We need to define a diffused material for the substrate and a dielectric material for cladding. Air is the di-electric material for cladding and its thickness is 2 micrometers. Titanium diffused waveguides in lithium Niobate are formed by the diffusion of titanium dopant into the lithium niobate host. To form a waveguide, a stripe of titanium with thickness before diffusion of .05 micrometers is deposited on the substrate. Waveguide has a width of 8.0 micrometers. S-Bend Sine and Linear waveguides are started by laying down these basic waveguide elements necessary for the construction of the switch. To provide electro-opto effects we used three electrode set with buffer layer on substrate. Buffer layer is introduced between electrodes and substrate to reduce the losses that are due to metallic cover of the waveguide. The buffer layer has thickness of 0.3 micrometers with horizontal and vertical permittivity of 4 micrometers. Electrodes are defined in three regions with different parameters. First region has electrode with width of 50 micrometers and zero voltage. Second and third electrodes have width of 26 micrometers and zero voltage. Gap between first and second electrode is 6 micrometers and between second and third electrode is 6 micrometers. Second electrode is placed with 5.5 micrometers of center position. Mode type input field which initializes the fundamental mode of a waveguide (Table 2) as the starting field has been selected at Z=0 position. The whole device is designed on layout designer of OPTIBPM tool of OPTIWAVE software. Fig. 2 shows basic 2x2 MZI switch.

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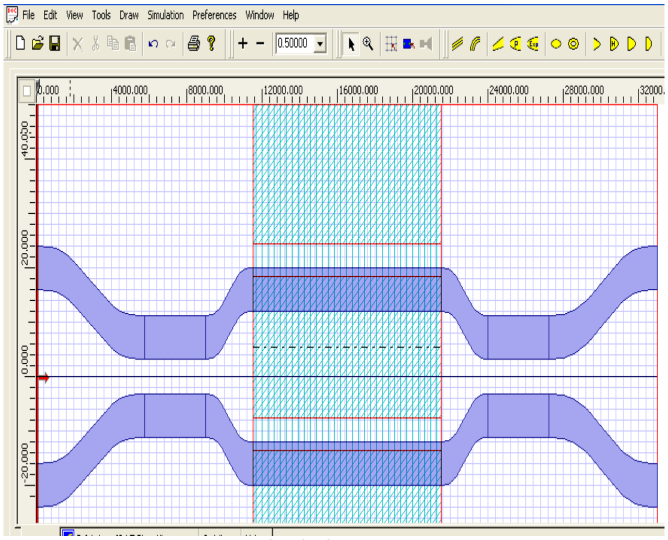

Fig.2. 2x2 MZI switch

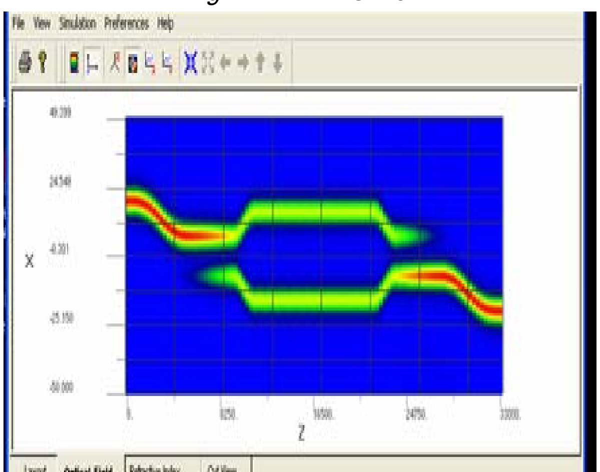

Fig.3. 2x2 MZI in cross state with zero electrode voltage

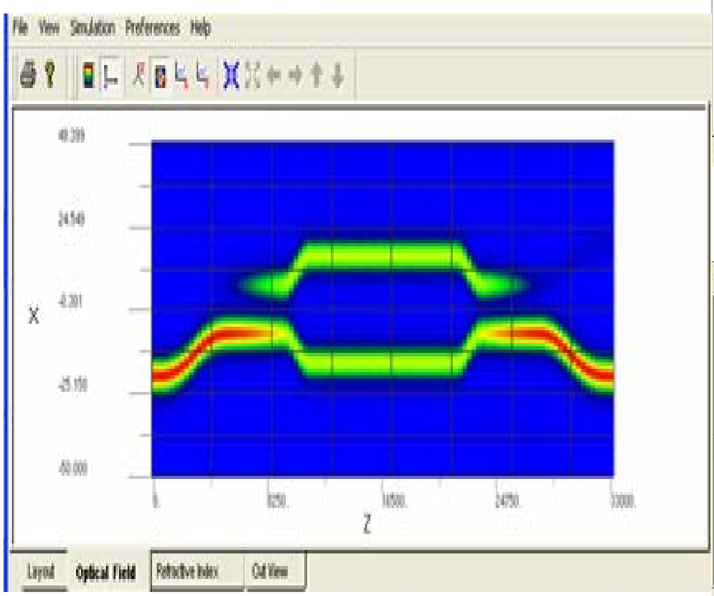

Fig.6. 2x2 MZI in bar state with 7.3 volts of electrode voltage

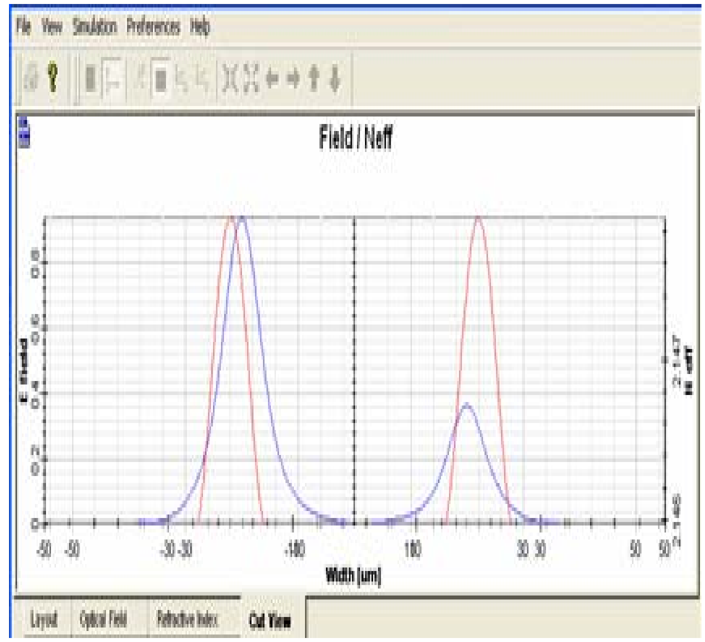

Fig.4. Optical field propagation in cross state

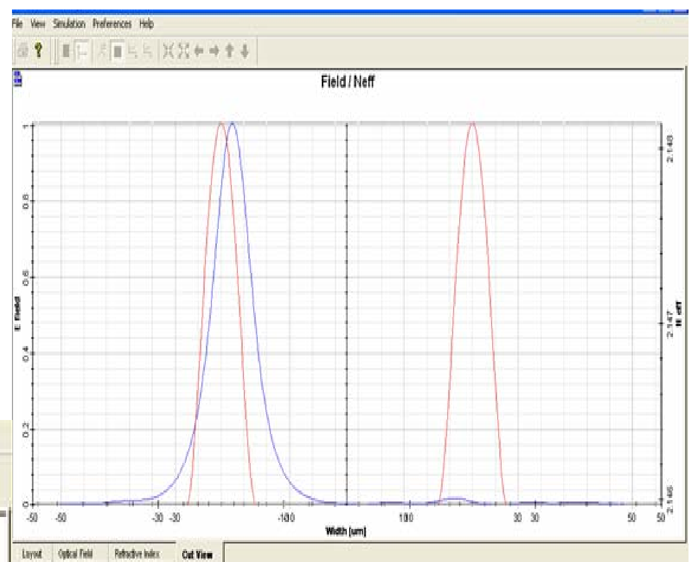

Fig.5. Optimized result of MZI in cross state for D_h of 3.5 micrometers and D_v of 3.7

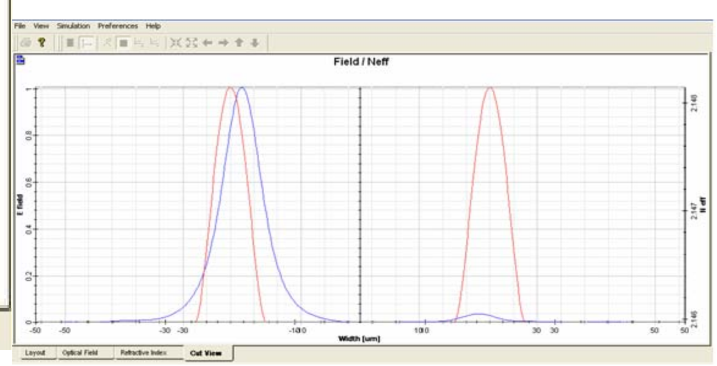

Fig. 7. Optical field propagation in bar state

Simulation

After the input plane has been defined the global data is set with refractive index MODAL. Wavelength selected for simulation is 1.3 micrometer. The 2D properties have been set with TM polarization and 500 mesh points. The simulation results could be sensitive to the number of mesh points. In general, the usage of more mesh points results in better precision. PARAXIAL BPM solver, FINITE DIFFE-RENCE engine is used. Finite Difference Taylor series expansions are used to derive finite-difference schemes to approximate the wave equations. BPM 2D provides TBC (Transparent Boundary Conditions) method to escape unwanted reflections from the boundaries. We did 2D isotropic calculation and observed switching results in Cross and bar states (Fig. 3-7).

Table 2. Waveguide properties

Stripe thickness before diffusion	.05 micrometers	
Waveguide Material	Diffusion parameters	
Ti:$LiNbO_3$	D_h	4.0
	D_v	3.5

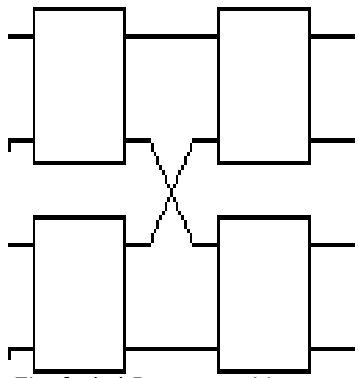

Fig. 8. 4x4 Banyan architecture

Simulation of 2x2 Banyan network

A 2x2 MZI network with Banyan architecture is realized and simulated in Optisystem of OPTIWAVE Software. Switches used in proposed architecture are in Bar state. A CW laser used as optical source is connected to first port of input by keeping other port at optical null. The basic parameters of optical source are frequency, linewidth and power. Fig. 9 shows this configuration with input power=10mw, line width =10MHZ and results show that 9.89 mws of power is obtained at bar state and 0.05 mws of power is obtained at cross port which is very small. Table 3 shows analysis of proposed set-up for different values of input power. Crosstalk value measured is -22.9 db.

Banyan Architecture

A typical Banyan architecture contains $\log_2 n$ stages each having n/2 , 2x2 switches. In Banyan network there is unique path between input and output and the no. of switching elements in each path is fixed and equal to $\log_2 n$. These characteristics have made banyan network very attractive for constructing switching networks with directional couplers because loss and attenuation of optical signal are proportional to no. of couplers that the optical signal crosses. Fig.8 shows a typical 4x4 Banyan network with 4, 2x2 MZI switches.

4x4 Banyan network with 2x2 MZI switches (Table 4)

A 4×4 Banyan switch is designed using 4, MZI binary (2×2) switches. Fig.10 shows power inputs of 10mW and 9.78 mws of power is obtained at first output port. Cross talk found for this set-up is -22.7 db.

Conclusion

An optimum 2x2 Mach-Zehnder interferometer optical switch based on electro-opto effects has been successfully designed for switching optical signal with wavelength 1300nm. The coupling efficiency of the 2x2 optical switch designed in cross and bar state is optimized by changing the design parameters of the switch. A 2x2 MZI switch in bar state with Banyan architecture has been designed and realized in Optisystem also. Thus a newly developed 4×4 blocking banyan optical switch is designed which is having extremely low crosstalk of -22.9 - 22.7 db. For future work It is recommend that the designing of 2x2 non-blocking banyan optical switch with lower losses can be done.Proposed 2×2 optical switch can also used for designing large switches using various architectures like Benes, Spanke-Benes, and Crossbar etc.

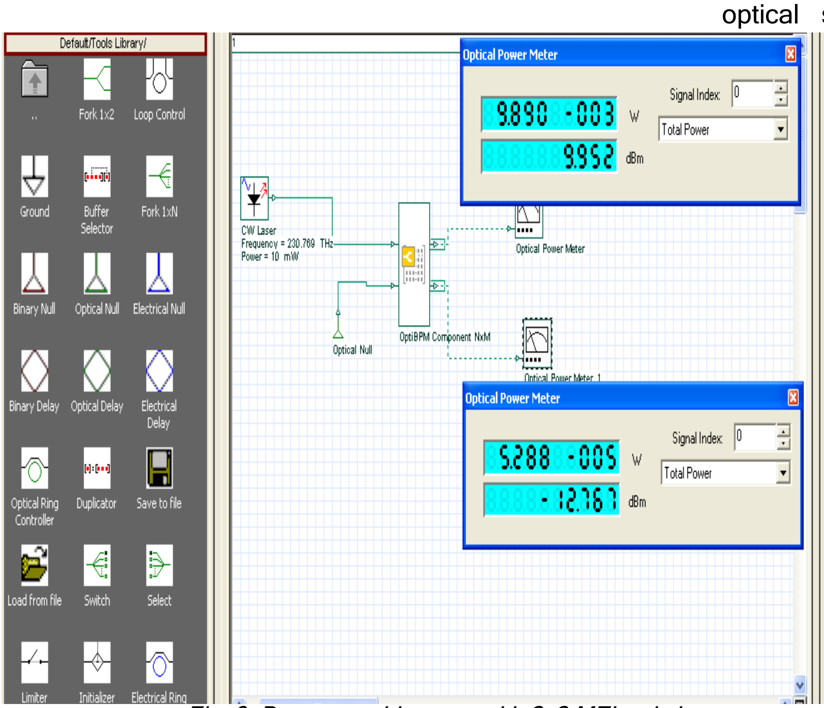

Fig. 9. Banyan architecture with 2x2 MZI switches

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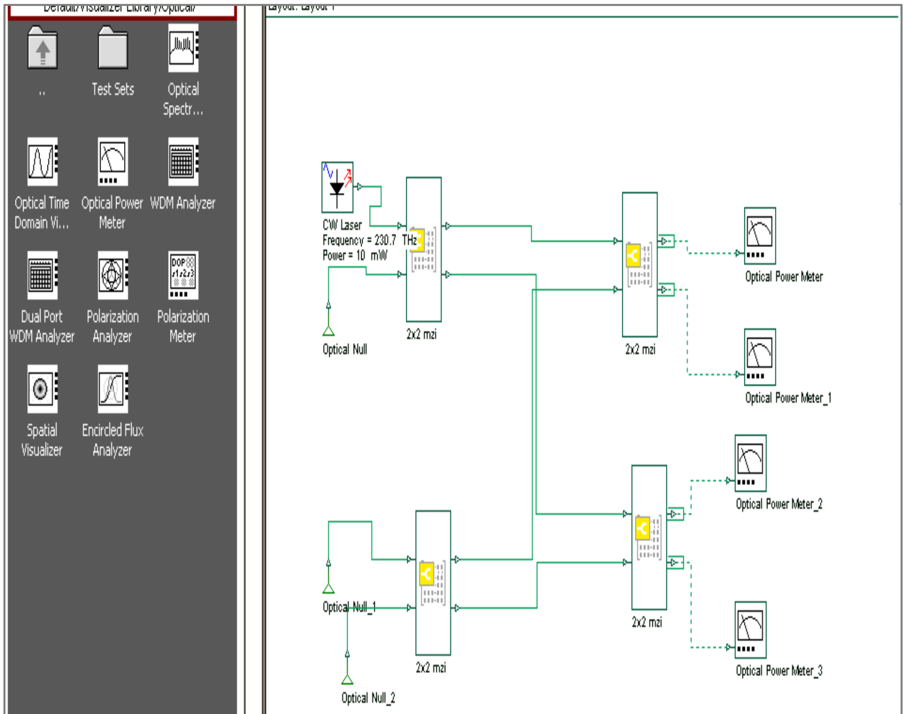

Fig. 10. 4x4 Banyan set-up for simulation

Table 3. Analysis of 2x2 set up for different input powers

Input power	Output in cross state	Output in bar state
20 mws	19.78 mws	0.1058 mws
30 mws	29.67 mws	0.1506 mws
40 mws	39.56 mws	0.211 mws

Table 3. Analysis of 2x2 set up for different input powers

Input power	Output in cross state	Output in bar state
20 mws	19.78 mws	0.1058 mws
30 mws	29.67 mws	0.1506 mws
40 mws	39.56 mws	0.211 mws

Table 4. Analysis of 4x4 Banyan set-up

Input Port	Input power in mws	Output power in mws	Output port
1	10	9.78	1
2	Optical null	0.052	2
3	Optical null	0.052	3
4	Optical null	0.0002	4

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