

Performance Evaluation and Enhancement of 2×2 Ti: LiNbO₃ Mach Zehnder Interferometer Switch at 1.3 μm and 1.55 μm

Nazmi A. Mohammed*, Huda S. Abo Elnasr* and Moustafa H. Aly an OSA Member

Department of Electronics and Communication, Faculty of Engineering Arab Academy for Science, Technology and Maritime Transport, Egypt

Abstract: In this paper, the electro-optic 2×2 switching devices using titanium (Ti) diffused lithium niobate (Ti:LiNbO₃) as a waveguide medium in the optical switch is designed based on integrated Mach-Zehnder interferometer (MZI) at 1.3 μm and 1.55 μm. Two major design parameters; insertion loss and extinction ratio are evaluated and tested in details. The novelty of this paper is obtaining the optimum, Ti, strip thickness on MZI switch that results in improving switching performance at 1.3 μm and 1.55 μm. We have optimized the switch design parameters in order to reduce the overall switch losses (≤ 0.0138 dB) and to achieve the best possible extinction ratio (= 30 dB). The designed switch has a very high switching capability and a high degree of reliability.

Keywords: Mach-Zehnder interferometer, Electro-optics, Directional couplers, Insertion loss, Extinction ratio, Lithium niobate, Planar lightwave circuit (PLC), Titanium.

1. INTRODUCTION

Wavelength Division Multiplexing optical switching network (also referred to as WDM cross-connect or WXC) provides interconnections between a group of input fiber links and a group of output fiber links with each fiber link carrying multiple wavelength channels [1]. Such an optical switching network can be used to serve as an optical cross-connect (OXC) in a wide-area communication network or to provide high-speed interconnections among a group of processors in a parallel and distributed computing system [2].

Large OXC switch fabrics can be constructed using 2×2 switches arranged in a multi-stage interconnection network, such as a Banyan network (a good candidate for further use in higher order switches) [3]. A 2×2 switch is a 2×2 directional coupler which can direct the optical signal on any input to any output [4]. For switching operation, some of mechanisms, such as thermo-optic and electro-optic [5, 6] can be used. But, in optical communications, all-optical devices realizing high performance and speed are preferred. For applying the directional coupler to all-optical purposes, materials with high nonlinear characteristics are suitable [5, 6]. One of the major advantages of all-optical switches is that they avoid the need for optic-electronic and electronic-optic (o-e-o) conversions to keep data in the optical domain. [7].

In spite of the mentioned subjects, an electro-optic switch based on integrated Mach Zehnder interferometer (MZI) is required in many optical switching systems. In recent years,

various materials and configurations have been employed for the development of MZI optical switches [8]. In [9], a 2×2 Si waveguide with a ferro-electric liquid crystal cladding based on MZI switch is designed with 15 dB extinction ratio at 1.55 μm biased at ±30 V. Shaochun Cao *et al.* [10] investigated a 2×2 optical MZI switch fabricated by GaAs GaAlAs with 2 dB insertion loss and 20 dB extinction ratio at 1.55 μm. In [11] 1×4 MZI switch based on hybrid configuration of silica-based planar lightwave circuit (PLC) and lithium niobate is explored with insertion loss of 4.2 dB and extinction ratio of 17 dB at 1.53 μm. Noriaki Koyama *et al.* [12] examined a 4×4 InAlGaAs/InAlAs MZI switch based on 2×2 structure with low polarization dependent loss and -20 dB crosstalk.

Titanium diffused lithium niobate based on MZI switches have the following distinct advantages over previously mentioned switches with mentioned fabricated materials: 1) compatible with large capacity and long-haul optical transmission systems operating above 40 Gbit/s [13], 2) lower complexity, and 3) their large electro-optic coefficient results in a small transition time. However, titanium diffused lithium niobate based on MZI switches have inherent drawbacks like cost of higher driving voltage, polarization dependent losses and crosstalk (to achieve full switching operation) compared with previously mentioned switches with mentioned fabricated materials [14].

In our work we will investigate basic (without adaptive structure) a 2×2 titanium diffused lithium niobate switch with two inexperienced contributions:

1) Performance evaluation for the switching operation of convention 2×2 titanium diffused lithium niobate switch at 1.3 μm (designed in [3, 14]) but with novel design parameters: insertion loss, extinction ratio and studying the effect of Ti strip thickness.

*Address correspondence to these authors at the Department of Electronics and Communication, Faculty of Engineering Arab Academy for Science, Technology and Maritime Transport, Egypt; Tel: +2-01006515131; Fax: +2-01143353528; E-mails: eng_huda_samir@yahoo.com; nazz_azz@yahoo.com

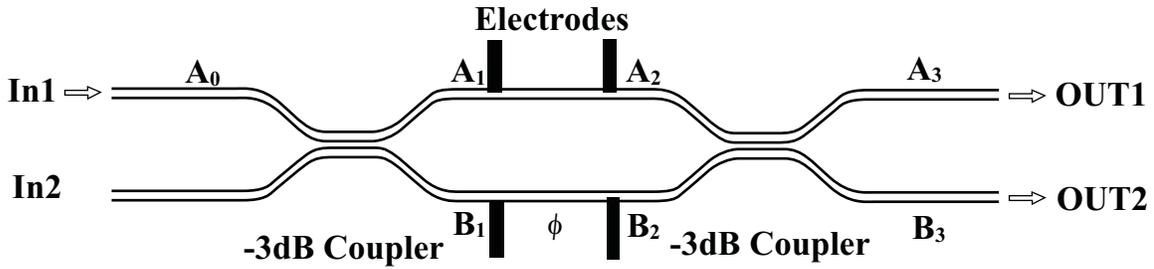


Fig. (1). MZI switch model.

2) A 2×2 titanium diffused lithium niobate switch operating at 1.55 μm will be investigated. We will introduce, for the first time, the following design parameters at 1.55 μm : electric field, power overlap integral, power in output waveguide and the previously three designed parameter mentioned in 1.

The remainder of the paper is organized as follows. In Section 2, we consider the basic mathematical and idea of operation of MZI switch. In Section 3, we will introduce the design and simulation results. Finally, in Section 4, main conclusions are summarized.

2. BASIC MATHEMATICAL MODEL AND IDEA OF MZI SWITCHING OPERATION

The basic (without adaptive structure) MZI switch cycles between the cross state, where most of the light appears in the waveguide on the same side as the input, and the bar state, where most of the light moves to the waveguide on the other side [13].

Fig. (1) represents the basic 2×2 MZI switch, where the electric field at (In1) is represented by $A(Z)$ and the electric field at (In 2) is represented by $B(Z)$, where $A(z)$ and $B(z)$ are given by [15]

$$A(Z) = \left\{ \left[\cos(qz) + j \frac{\delta}{q} \sin(qz) \right] \cdot A(0) - j \frac{k}{q} \sin(qz) B(0) \right\} \cdot \exp(-j\delta z) \quad (1)$$

$$B(Z) = \left\{ -j \frac{k}{q} \sin(qz) \cdot A(0) + \left[\cos(qz) - j \frac{\delta}{q} \sin(qz) \right] \cdot B(0) \right\} \cdot \exp(j\delta z) \quad (2)$$

where q is an integer that represents the number of local electric field peaks along the x- and y-axis directions.

$$q = \sqrt{k^2 + \delta^2} \quad (3)$$

and

$$\delta = 2\pi \left(\frac{\ell_1 - \ell_2}{\lambda} \right) \quad (4)$$

ℓ_1 denotes the coupling length of the upper waveguide, ℓ_2 denotes the coupling length of the lower waveguide and k denotes the wave number.

We consider the case in which light is coupled into the upper waveguide of a MZI. Here, we assume that both arms have the same waveguide structures; i.e., we have $\delta=0$ which leads to $A(0)=A_0$ and $B(0)=0$. When the first coupler is a 3-dB coupler with $k\ell=\pi/4$, the light splitting ratios will be [15]

$$A_1 = A_0 \cos(k\ell) = \frac{A_0}{\sqrt{2}} \quad (5)$$

$$B_1 = -jA_0 \sin(k\ell) = -j \frac{A_0}{\sqrt{2}} \quad (6)$$

where ℓ is the coupling length.

After passing through the interferometer straight arms, A_2 and B_2 (see Fig. 1) will become [15]

$$A_2 = A_1 \exp(-j\beta L) = \frac{A_0}{\sqrt{2}} \exp(-j\beta L) \quad (7)$$

$$B_2 = B_1 \exp(-j\beta L + j\phi) = -j \frac{A_0}{\sqrt{2}} \exp(-j\beta L + j\phi) \quad (8)$$

L denotes the length of switching region and ϕ donates an excess phase shift at the lower arm.

Here, we assume that, the second coupler is also a 3-dB one having $k\ell=\pi/4$. So, the optical intensity in each output port is given by [15]

$$|A_3|^2 = |A_0|^2 \cdot \sin^2 \left(\frac{\phi}{2} \right) \quad (9)$$

$$|B_3|^2 = |A_0|^2 \cdot \cos^2 \left(\frac{\phi}{2} \right) \quad (10)$$

The impact of changing the voltage is enforcing to the electrodes, creating an electric field distribution within the substrate, which consequently changes its refractive index [15]. When the applied voltage is 0 V which is corresponding to $\phi = 0$, the output intensity will be switched totally to the lower port $|B_3|^2 \approx |A_0|^2$. At an applied certain voltage which is corresponding to $\phi = \pi$ depending on the nonlinear behavior of waveguide, the output intensity will be switched totally to the upper port $|A_3|^2 \approx |A_0|^2$. The full reflection or transmission of light is applied only in a theoretical model of 2×2 MZI switch [15].

But, in the real simulated model, there will be an insertion loss and an extinction ratio. Insertion loss of a switch is a part of power that is lost and has to be low for good performance and the extinction ratio is the ratio of output power in ON state to output power in OFF state which ideally must be very high [14]. Insertion loss and extinction ratio for each port, that are the important parameters for optical switching are given by [14, 17]

$$I.L.(dB) = 10 \log_{10} \left(\frac{P_{out}}{P_{in}} \right) \quad (11)$$

$$Ex.R.(dB) = 10 \log_{10} \left(\frac{P_{on}}{P_{off}} \right) \quad (12)$$

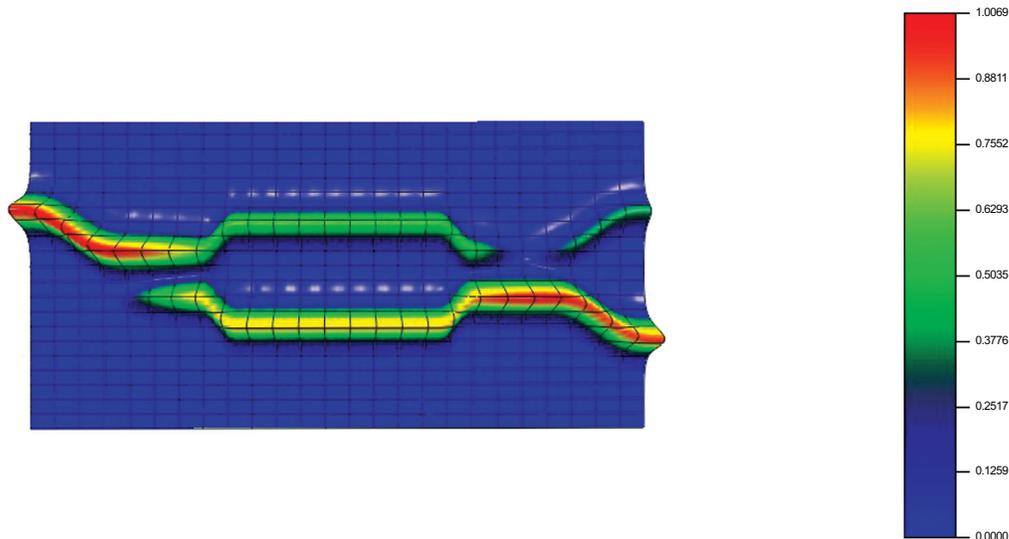


Fig. (2). Optical field propagation in XZ slice for 0 V.

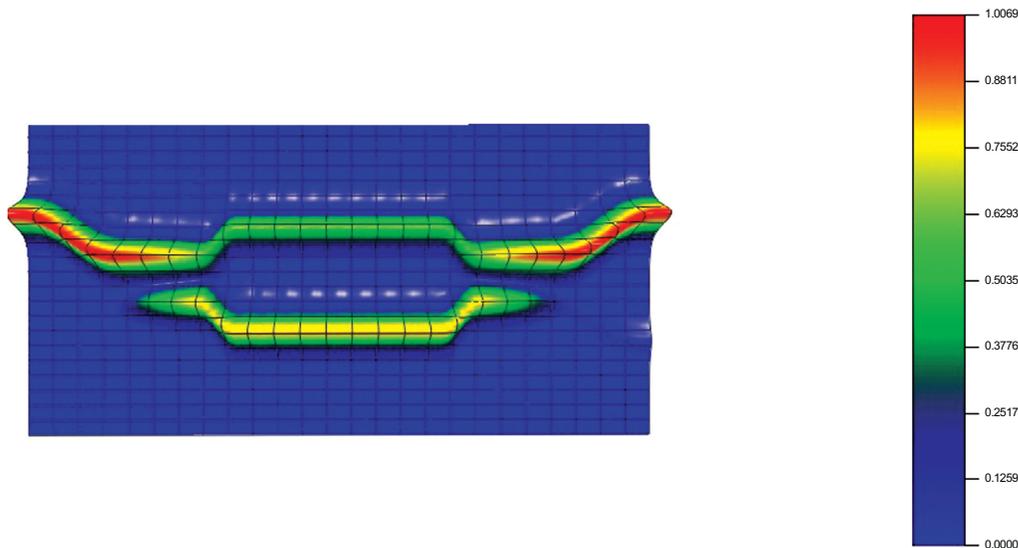


Fig. (3). Optical field propagation in XZ slice for 7.2 V.

3. DESIGN AND SIMULATION RESULTS

3.1. Introduction

Section 3.2 represents the common electro-optic coefficients, material and waveguide properties for all experiments. In Section 3.3, a performance evaluation for switching operation for basic Ti: LiNbO₃ 2×2 switch operating at 1.3 μm is presented. Section 3.4 explores the effect of titanium strip thickness on the performance of Ti:LiNbO₃ 2×2 switch operating at 1.3 μm. Finally, Section 3.5 represents a full investigation for the switching behavior for basic Ti:LiNbO₃ 2x2 MZI switch that operates at 1.55 μm.

3.2. Common Electro-optic Coefficients, Material and Waveguide Properties For All Experiments

Titanium diffused lithium niobate waveguide is used as the waveguide medium in the optical switch design. The wafer is a planar substrate. Its length is along Z-axis, horizontal on the

screen and width is along X-axis, vertical on the screen. The thickness of the substrate is in y-direction, perpendicular to the screen and is not shown on the layout interface. An example of that is showed in Figs (2, 3, 7, 8, 14 and 15).

The MZI switch is created on a z-cut wafer of lithium niobate and is surrounded by air cladding. The following Tables 1, 2 and 3 represent the electro-optic coefficients, material and waveguide properties which must be defined to simulate MZI switch at both 1.3 μm and 1.55 μm as in [3, 14].

After the input plane has been defined, the global data is set with a refractive index Modal Solver [3, 14]. The 2D properties have been set with TM polarization and 500 mesh points as Paraxial BPM solver, a Finite Difference engine is used. Finite difference Taylor series expansions are used to derive finite-difference schemes to approximate the wave equations. BPM 2D provides Transparent Boundary Conditions (TBC) method to escape unwanted reflections from the boundaries [3, 14].

Power in Output Wave Guides

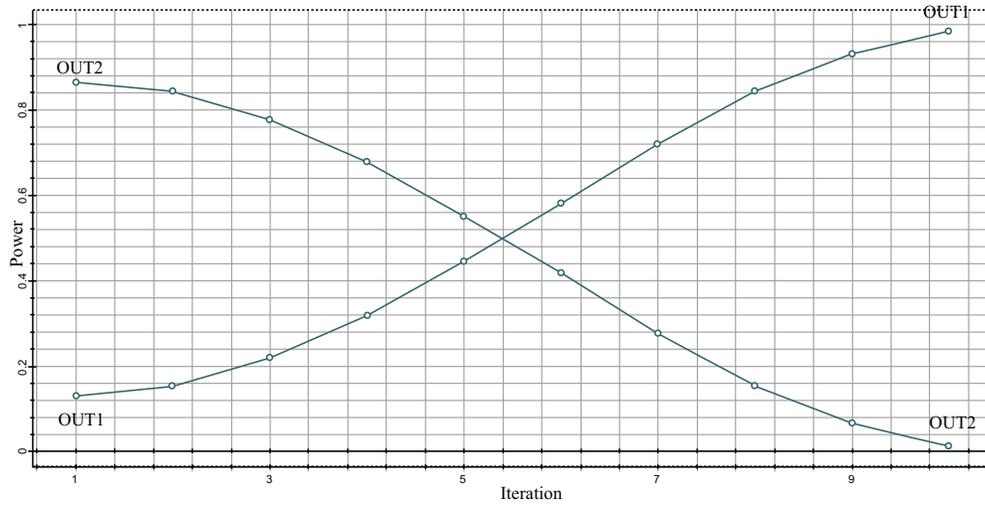


Fig. (4). Power in output Waveguides.

Power Overlap Integral

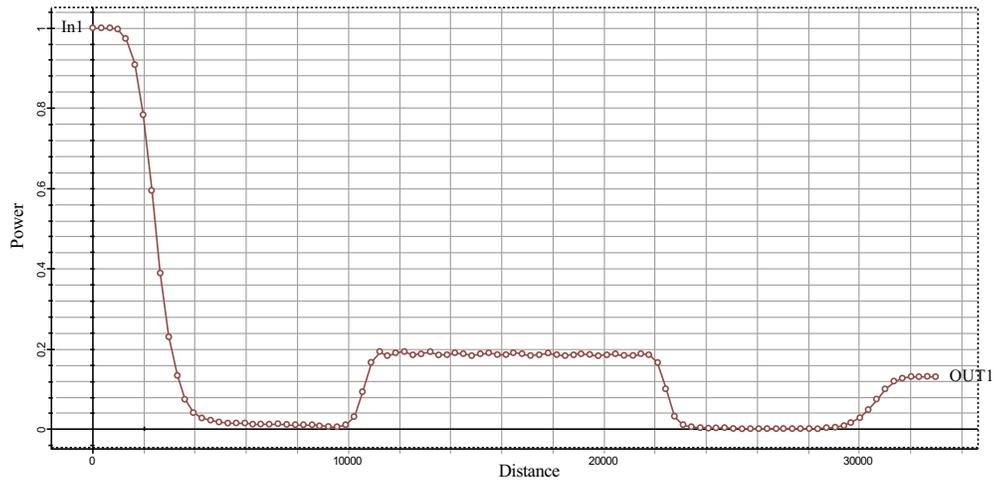


Fig. (5). Power overlap integral for 0 V.

Power Overlap Integral

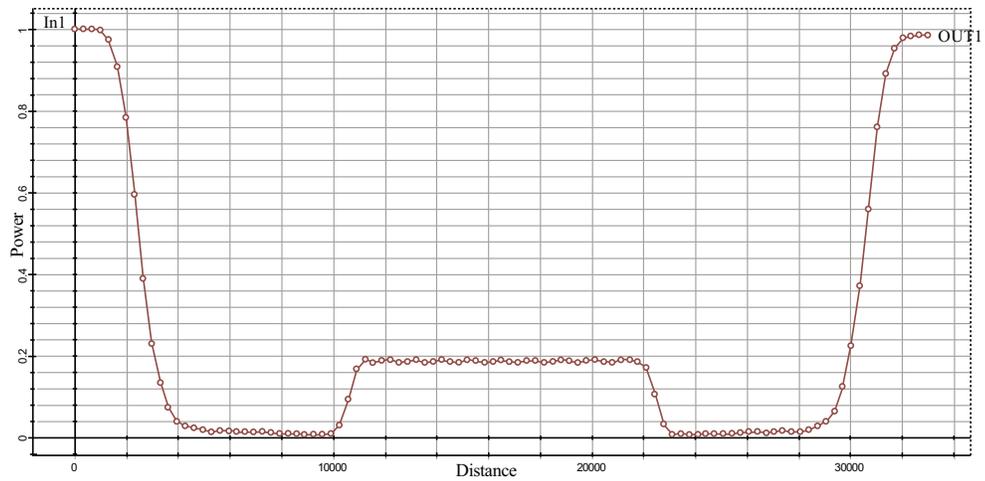


Fig. (6). Power overlap integral for 7.2 V.

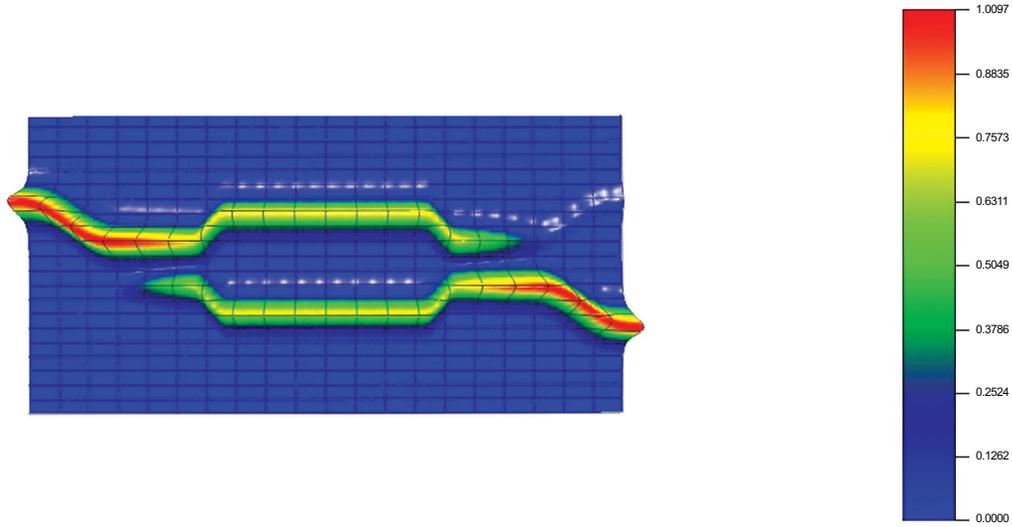


Fig. (7). Optical field propagation in XZ slice for 0 V.

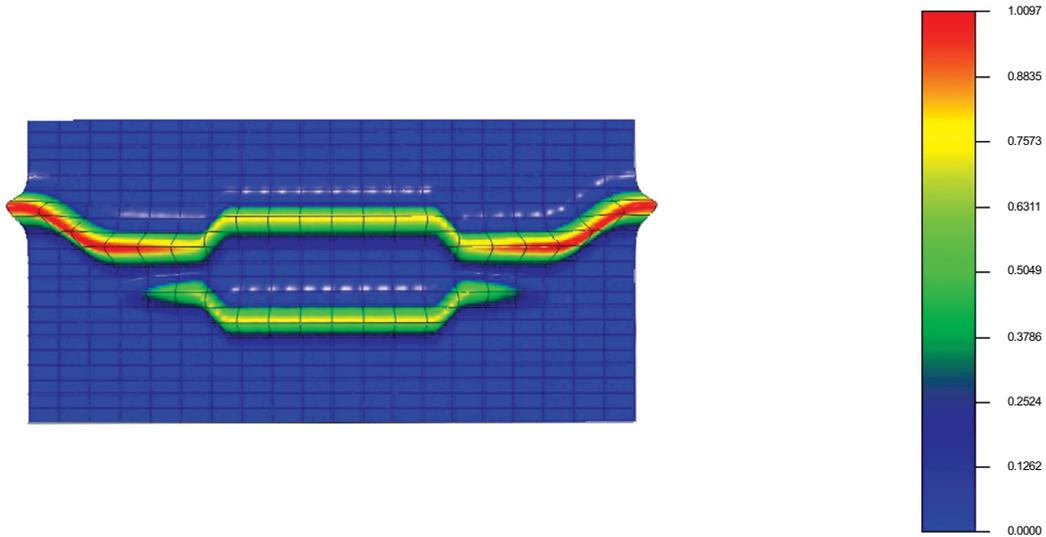


Fig. (8). Optical field propagation in XZ slice for 7.2 V.

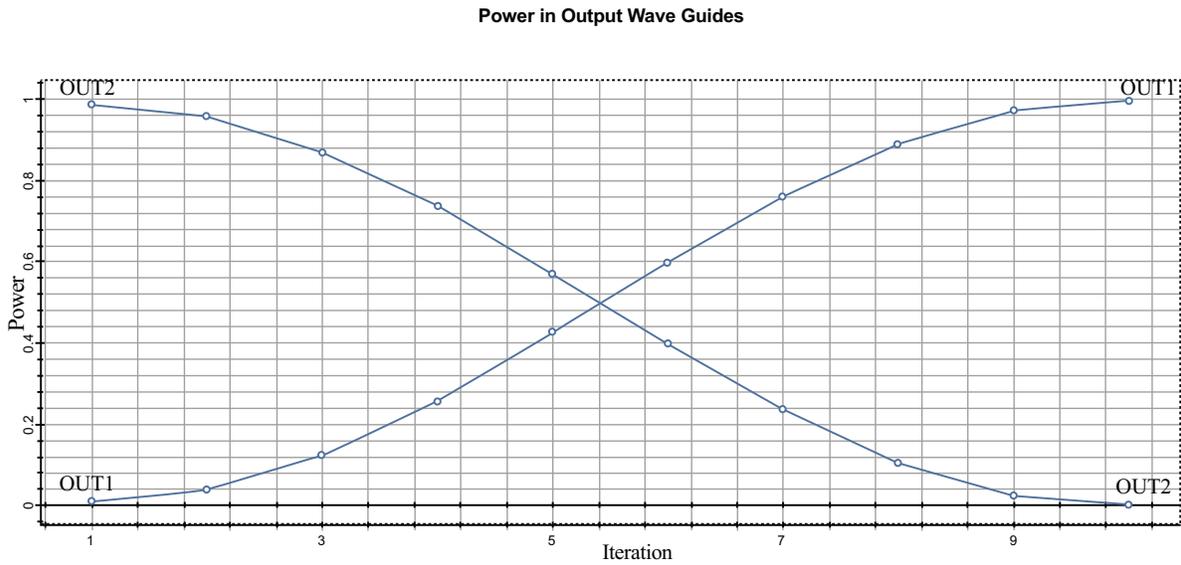


Fig. (9). Power in output waveguides.

Power Overlap Integral

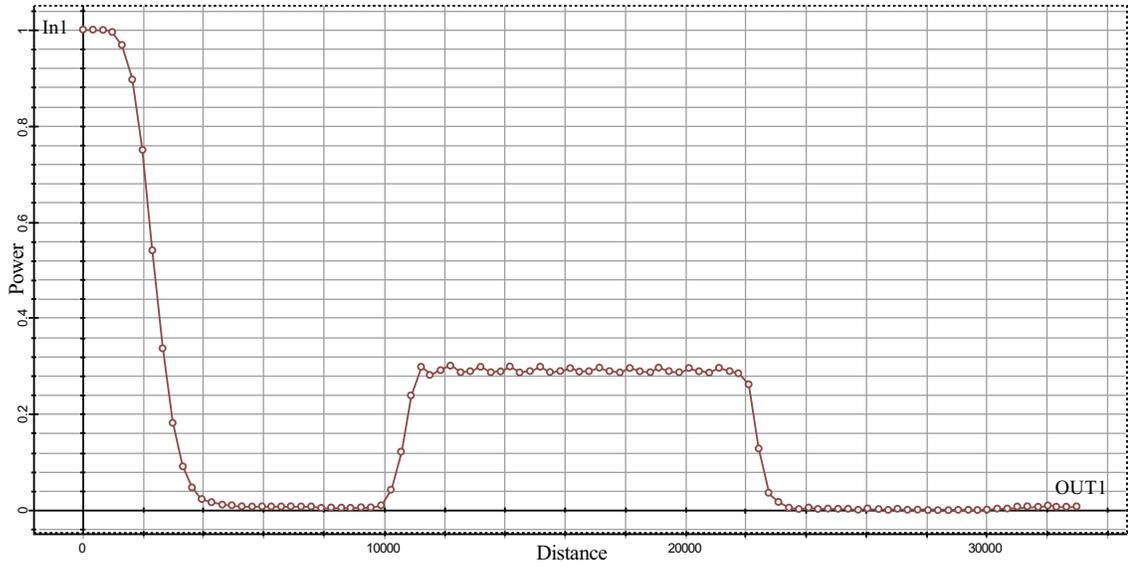


Fig. (10). Power overlap integral for 0 V.

Power Overlap Integral

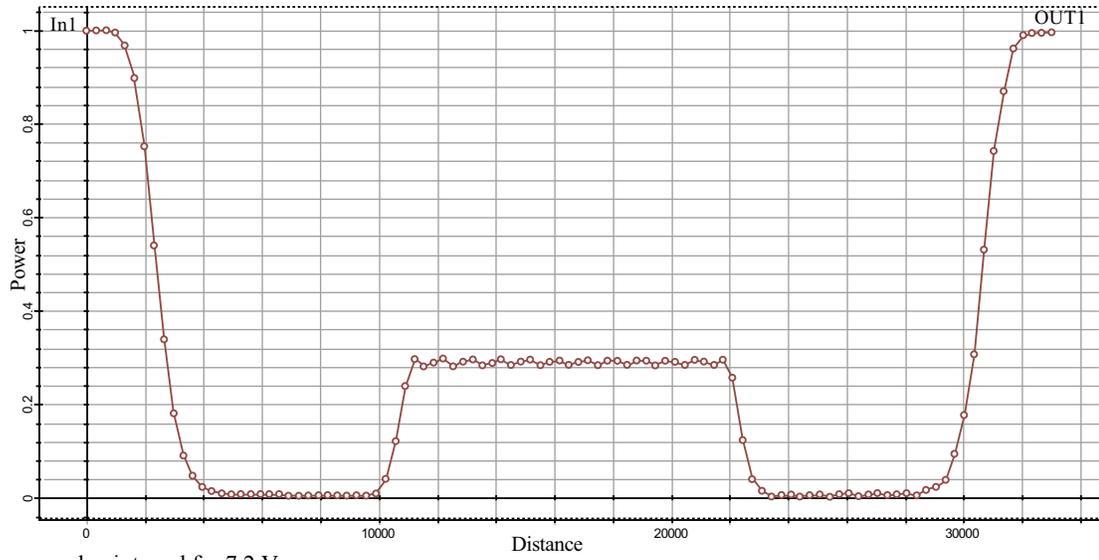


Fig. (11). Power overlap integral for 7.2 V.

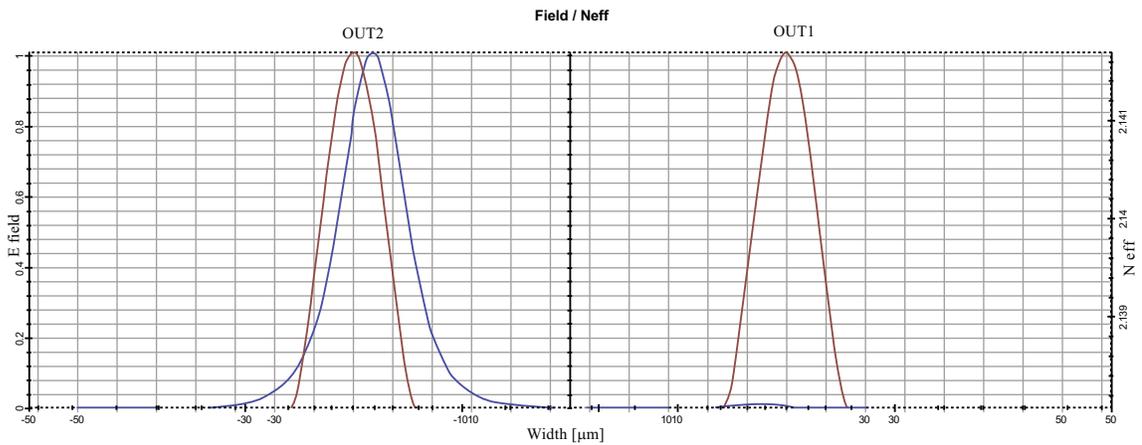


Fig. (12). Electric field at 0 V.

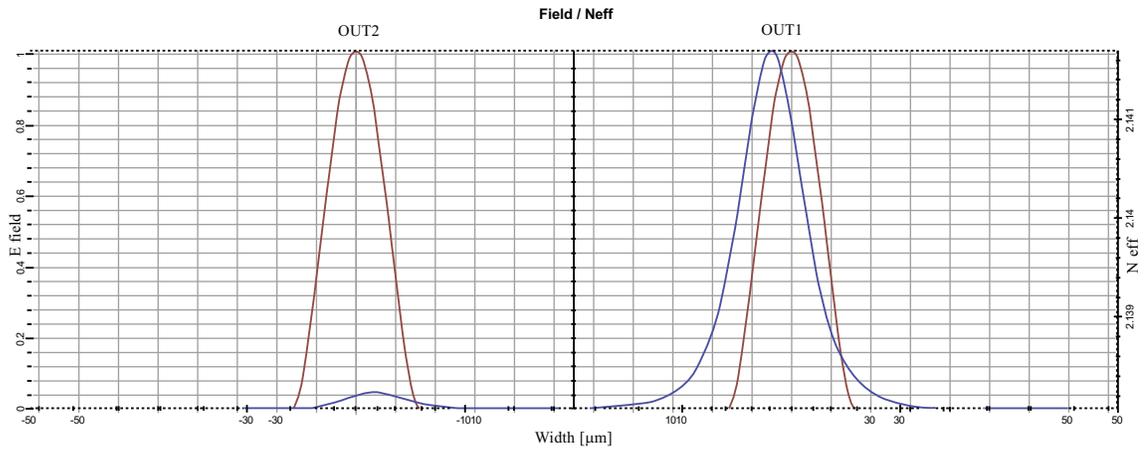


Fig. (13). Electric field at 8 V.

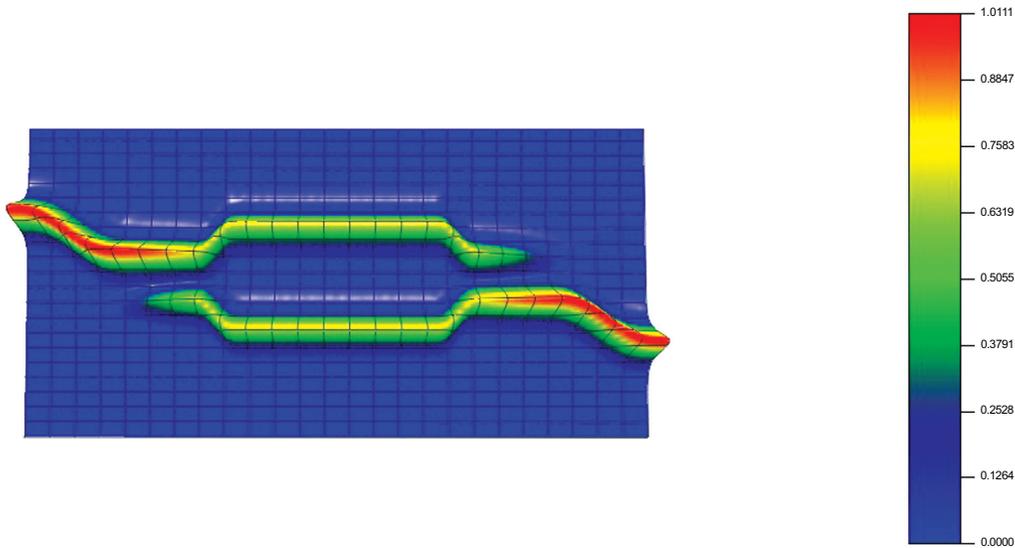


Fig. (14). Optical field propagation in XZ slice for 0 V.

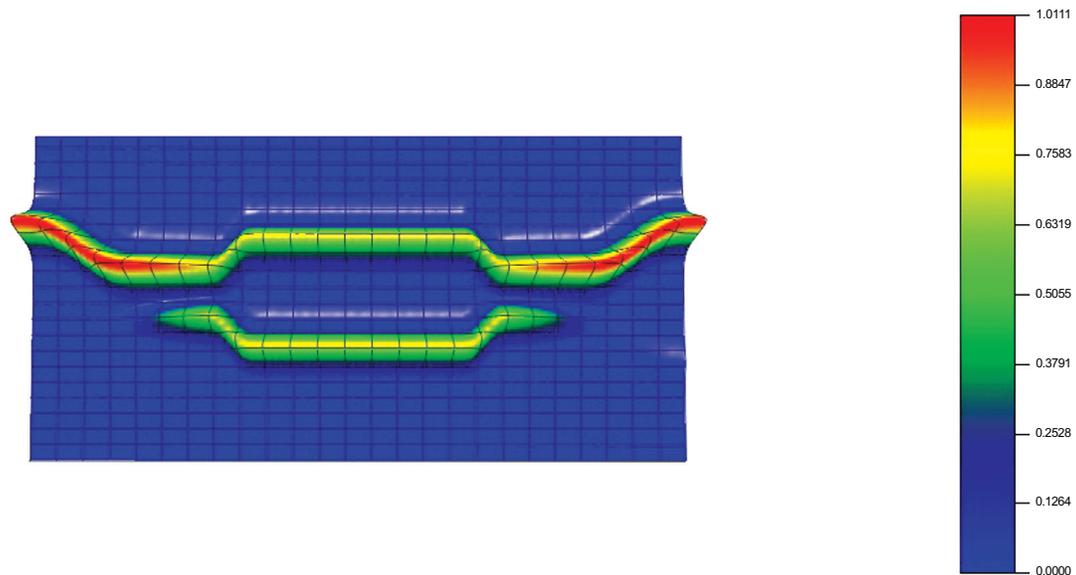


Fig. (15). Optical field propagation in XZ slice for 8 V.

Table 1. LiNbO₃ Parameter

Crystal Name		LiNbO ₃	
Electro-optic Coefficients 10 ⁻¹² (m/V):			
r ₃₃	30.8	r ₁₃	8.6
r ₅₁	28	r ₂₂	3.5

Table 2. Material Properties

Wafer Dimensions (μm)		Width (μm)	Wafer Profile
breadth	Length	8.0	Ti LiNbO ₃
100	33000		
2D Wafer Properties			
Wafer Refractive Index: lithium niobate			
3 D Wafer Properties			
Substrate		Cladding	
Thickness(μm)	Material	Thickness(μm)	Material
10	LiNbO ₃	2.0	Air

Table 3. Waveguide Properties

Dielectric Material		Diffused Material		
Refractive Index	Material	Propagation Direction	Crystal Cut	Crystal Name
1	Air	Y	Z	LiNbO ₃
Diffused Profile				
Ti LiNbO ₃				

Table 4. Titanium Strip Specifications

0.05 μm		Strip Thickness Before Diffusion	
5.67e+022 per cm ³		Dopant constant	
3.5 μm	Dv	4.0 μm	Dh

We performed 2D isotropic calculation by using a scripting language for 1.3 μm as follows. This language is used in OptiBPM 9.0 to identify the simulation method required to obtain the switching operation for the design.

```
Scripting: (using VB script)
Const NumIterations = 10
ParamMgr.SetParam "V2", 0.0
For x= 1 to NumIterations
Param Mgr. Simulate
Param Mgr. Set Param "V2", 0.8* x
WGMgr.Sleep (50)
Next
```

This script identifies number of iterations corresponding to step voltage in simulation. Then a set of commands for ordering a start of simulation, linking steps with the electrode and ending the program is presented.

There is a direct relation between the number of iterations (corresponding to the step increase in the applied volt-

age of electrodes i.e. 0.8 V for each iteration in the following simulations) and the switching behavior. This behavior is analyzed initially from iteration 1 with 0 V to final iteration until the switch provides a best observable switching operation. This operation depends on the operating wavelength, material and dimension (size) of the switch [16].

To create channel waveguides of titanium diffused lithium niobate, a titanium strip of a definite thickness is placed on the substrate and is heated for few hours at a temperature ranging from hundreds to few thousand degrees Celsius so that the titanium diffuses into the host lithium niobate. The resultant change in the refractive index is a function of parameters like titanium strip thickness, lateral diffusion length (Dh), vertical diffusion length (Dv), and other process parameters [3, 14].

3.3. Simulation For Basic Ti:LiNbO₃ 2×2 Switch Operating at 1.3μm

For this experiment, the titanium strip specifications are defined in Table 4 as in [3, 14].

The simulation for 2D isotropic calculation with the previous specifications will provide the following results (Figs. 2-6):

Table 5. Comparison Between MZI Switches in both their Insertion Loss and Extinction Ratio

Thickness Width (μm)	Switching Voltage (V)	In / Out Ports (mW)		Insertion Loss (dB)	Extinction Ratio (dB)
0.048	0	In 1	1	1.7	Out2 15.7
		Out 1	0.310114		
		Out 2	0.676059		
	7.2	In 1	1	0.136	Out1 4.9
		Out 1	0.96927		
		Out 2	0.0181763		
0.05	0	In 1	1	0.649	Out2 19.9
		Out 1	0.126739		
		Out 2	0.861148		
	7.2	In 1	1	0.09	Out1 8.88
		Out 1	0.979251		
		Out 2	0.00876452		
0.0525	0	In 1	1	0.0997	Out2 29.4
		Out 1	0.0101976		
		Out 2	0.977295		
	7.2	In 1	1	0.053	Out1 19.9
		Out 1	0.987682		
		Out 2	0.00111463		
0.055	0	In 1	1	0.048	Out2 30
		Out 1	0.005898		
		Out2	0.989002		
	7.2	In 1	1	0.022	Out1 22.3
		Out 1	0.995005		
		Out 2	0.00099521		
0.062	0	In 1	1	1.398	Out2 28.6
		Out 1	0.266379		
		Out 2	0.724723		
	6.4	In 1	1	0.026	Out1 5.72
		Out 1	0.993998		
		Out 2	0.001002		

Figs. (2 and 3) represent a 2D isotropic optical field distribution for XZ cut for the designed switch. In Fig. (2), the MZI switch is represented in its cross state at 0 V and in its bar state for the best observed switching operation with 7.2 V at Fig. (3). This result shows a fair agreement with the previously published literature at same wavelength and design parameter as in [3, 14].

Optical field overlap versus the number of iterations is shown in Fig. (4). This graph provides a valuable information on the following: 1) the trace of output power for distinct iteration for OUT1 and OUT2 and 2) the data required to evaluate the losses within the wave guiding structure of the switch (mainly the insertion loss). An ideal representation for this graph should be a unity value for power at OUT2 and a value of 0 at OUT1 in first iteration (when no voltage is applied). While at the final iteration, the whole input light must be fully switched to OUT1 to get a unity power at this port and no power at OUT2.

Fig. (4) practically provides a best switching operation after 10 iterations (7.2 V). For iteration1 (0 V), OUT2 provides only a power of 0.861148 mW and a power of 0.126739 mW is provided by OUT1. When light is switched after 10 iterations, the output power at OUT1 is 0.979251 mW and 0.00876452 mW at OUT2 (Noting that these results are part of those which will be discussed with wider ranges in the following section-in Table 5).

Remembering that, results in Sec.3.3 was done by using same values and design parameters of [3, 14] to provide ability to compare. However, the following three design parameters are not investigated in details in previous published literatures. They are insertion loss, extinction ratio and the effect of titanium strip thickness. In the following, the insertion loss and extinction ratio will be studied under the same parameters of [3, 14]. Results will show a server performance relating to insertion loss and extinction ratio under these parameters.

Table 6 Titanium Strip Specification

Strip Thickness Before Diffusion		0.0825 μm	
Dopant Constant		5.67e+022 per cm^3	
Dh	4.0 μm	Dv	3.4 μm

According to Sec. 2, Eq. (11) and Fig. (6) the insertion loss is calculated to be 0.649 dB at OUT2 and to be 0.09 dB at OUT1. Secondly, the extinction ratio is represented in Figs. (5 and 6). Both figures contain the power overlap integral versus distance of propagation of waveguide for the first iteration and the final iteration, respectively. At iteration 1 in Fig. (4), the power distribution along the effective distance of switch, especially at its end, shows undesired considerable value for output power at the output of linear OUT1 waveguide which has to be 0 in ideal MZI switching performance. While, in Fig. (5) at iteration 10 (when its fully switched at 7.2 V), the distribution of power along the waveguide experienced a significant losses at its boundaries especially at the end of linear OUT1 waveguide. These losses lead to a severe decrease in output power preventing it to be unity (the default is to be unity for ideal performance). This results in an undemanding decrease in the extinction ratio to be 8.88 dB for OUT1 port and 19.9 dB for the other port.

From the previous results, it is clear that extinction ratio and insertion loss are major drawbacks for titanium diffused lithium niobate switches under the previous parameters. Previous literature suggested that, these two drawbacks can be enhanced by controlling titanium strip thickness before diffusion [18]. This will be investigated in the following section.

3.4. Exploring the Effect of Titanium Strip Thickness on the Performance of Ti:LiNbO₃ 2×2 Switch Operating at 1.3 μm

In this section, we are going to investigate the effect of titanium strip thickness on for titanium diffused lithium niobate switch using a sample of suggested range from 0.048 μm to 0.062 μm in [18].

Table 5 represents the results of studying important design parameters under the samples of suggested Ti strip thickness range. A remarkable performance (insertion loss and extinction ratio) is observed for the switch at 0.055 μm for titanium strip thickness compared to that in [3, 14] and in Sec. 3.3.

Figs. (7-11) show the simulation for 2D isotropic calculation for the proposed switch with 0.055 μm for titanium strip thickness that provided a remarkable performance throughout the simulation.

According to the results, we obtain a low insertion loss of 0.048 dB for OUT2 and 0.022 dB for OUT1 is achieved. While, high extinction ratio of 30 dB for OUT2 and 22.3 dB for OUT1 are obtained with maintaining same switching voltage.

These results can be understood when 1st: indicating that the resultant change in the refractive index (that effect the switching operation and hence the losses levels) is a function of parameters like Ti-strip thickness, lateral diffusion length

(Dh), vertical diffusion length (Dv), and other process parameters [16, 18].

The ranges of Ti-strip thickness (as in Table 5) have been selected because in these ranges the Ti atoms cause sufficient changes in the refractive index of lithium niobate substrate, needed for the switch to remain in the bar state for zero voltage and cross state for 7.2 voltage for the switching operation described before. This shows fair agreement with basic switching operation of Ti-LiNbO₃ S-bend switch in [18]

Little increment in Ti-strip thickness, provisioning of concentrated optical power through the channel waveguides enhances, which results in reduction of insertion losses of the switch as indicated clearly in Table 5 till reaching the optimum thickness then a reverse characteristic is observed. We think after exceeding the optimum thickness some power radiates resulting on small increase in the insertion losses.

Based on the definition of extinction ratio provided in section 2 Eq.12, at higher values of Ti-strip thickness, extinction ratio can be maintained comparatively at higher levels. We think this is because increasing the thickness of the strip results in more power confinement in the switch waveguide, which results in low coupling losses, thereby reducing the possibility of power leakage to undesired path and higher extinction values till reaching the optimum strip thickness.

3.5. Simulation for Basic Ti: LiNbO₃ 2×2 MZI Switch Operating at 1.55 μm

3.5.1. Introduction, Modified Specification and VB Scripting

To the best of our knowledge it will be the first time to fully investigate a 2×2 titanium diffused lithium niobate switch operating at 1.55 μm . The novelty of this work is based on optimizing the thickness of titanium strip (for basic 2×2 switch) to successfully switch a light of 1.55 μm to targeted output. To approach this target, we applied a certain range (0.0725 μm – 0.09 μm) for the titanium strip thickness before diffusion [18]. We finally reached to optimum strip thickness which gives the least possible losses especially for insertion loss and highest possible extinction ratio.

We will also introduce the following design parameters that evaluate the switching performance: Electric field, Power overlap integral, Power in output waveguide at 1.55 μm . For this experiment, the titanium strip specifications are defined in Table 6. A 2D isotropic calculation is performed using the following VB script in OptiBPM 9.0 but with slightly increasing in range of voltage (8 V required to switch the light successfully).

Scripting: (using VB script)

Const NumIterations = 10

ParamMgr.SetParam "V2", 0.0

Table 7. Comparison between MZI Switches in both their Insertion Loss and Extinction Loss

Thickness Width (μm)	Switching Voltage (V)	In / Out Ports (mW)		Insertion Loss (dB)	Extinction Loss (dB)
0.0725	0	In 1	1	2.3	Out2 24.6
		Out 1	0.400972		
		Out 2	0.587884		
	8.8	In 1	1	0.053	Out1 3.9
		Out 1	0.987971		
		Out 2	0.002018		
0.0775	0	In 1	1	0.439	Out2 29.8
		Out 1	0.903844		
		Out2	0.085898		
	8.8	In 1	1	0.046	Out1 10.6
		Out 1	0.989355		
		Out 2	0.000945		
0.08	0	In1	1	0.117	Out2 26.8
		Out1	0.0152184		
		Out2	0.973531		
	8.8	In1	1	0.024	Out1 18.2
		Out1	0.994428		
		Out2	0.0020552		
0.0825	0	In 1	1	0.0138	Out2 30
		Out 1	0.0010134		
		Out 2	0.996823		
	8	In 1	1	0.0129	Out1 29.9
		Out 1	0.997042		
		Out 2	0.00099879		
0.085	0	In1	1	0.12	Out2 27.4
		Out1	0.0161005		
		Out2	0.972719		
	8	In1	1	0.0306	Out1 17.9
		Out1	0.992989		
		Out2	0.001774		
0.0875	0	In1	1	0.354	Out2 27
		Out1	0.0680115		
		Out2	0.92171		
	8	In1	1	0.034	Out1 11.6
		Out1	0.992262		
		Out2	0.001811		
0.09	0	In1	1	0.68	Out2 26.4
		Out1	0.134775		
		Out2	0.854289		
	8	In1	1	0.039	Out1 8.67
		Out1	0.991077		
		Out2	0.00195232		

```

For x= 1 to NumIterations
ParamMgr.Simulate
ParamMgr.SetParam "V2", 0.8* x
WGMgr.Sleep (50)
Next
    
```

3.5.2 Results and Discussion

In Table 7, we repeated the previous analysis of Sec. 3.4 to discover the optimum titanium strip thickness that leads to the following unique switching capability with acceptable insertion loss and extinction ratio. A range from 0.0725 μm – 0.09 μm [18] is tested as follows.

Power in Output Wave Guides

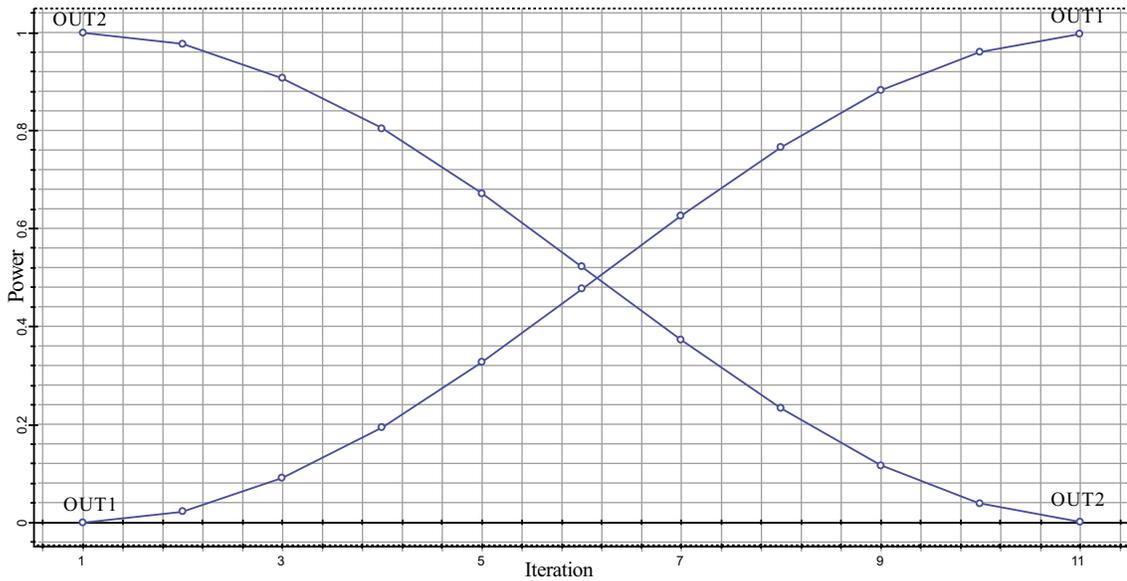


Fig. (16). Power in output Waveguide.

Power Overlap Integral

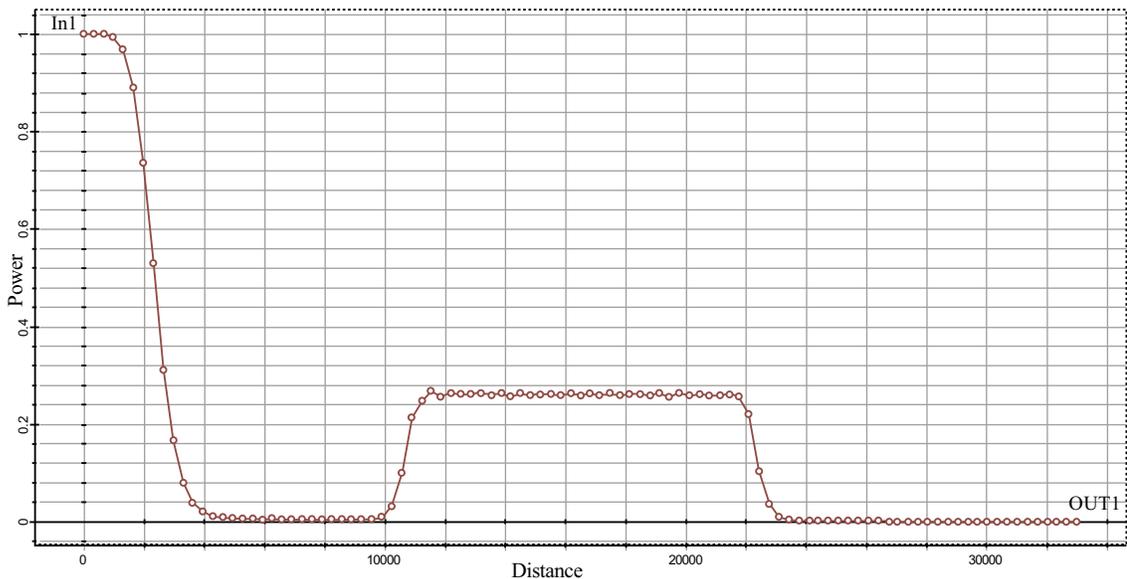


Fig. (17). Power overlap integral for 0 V.

From the table, the optimum titanium strip thickness is 0.825 μm . This will be verified clearly in the following discussions. In the following Fig. (12-18), we represent a performance evaluation for the switch's important design parameters (as in Sec. 3.3) at 1.55 μm with the optimum chosen titanium strip thickness of 0.825 μm .

Figs. (12 and 13) represent the electric field for both OUT1 and OUT2 at first iteration and final iteration, respectively. The ideal operation is represented by the red graph, while the blue one represents the operation of the proposed switch.

In Fig. (14) MZI switch is represented in its cross state at 0 V and in its bar state for the best observed switching opera-

tion with 8 V at Fig. (15). It is observed that, full switching behavior at 1.55 μm requires a more switching voltage (8 V) than 1.3 μm (7.2V).

The analytical result in Fig. (16) provides the best inexperienced switching capability but after 11 iterations (8 V). Iteration1 (0V), provides a power of 0.996823 mW at OUT2 and only a power of 0.0010134 mW is provided by OUT1. While, for iteration 11 (8 V), the light is fully switched to target OUT1 to output power of 0.997042 mW and only a power of 0.00099879 mW at OUT2. This leads an insertion loss of 0.0138 dB for OUT2 and 0.0129 dB for OUT1. Comparing this result with previous results for switches operating

Power Overlap Integral

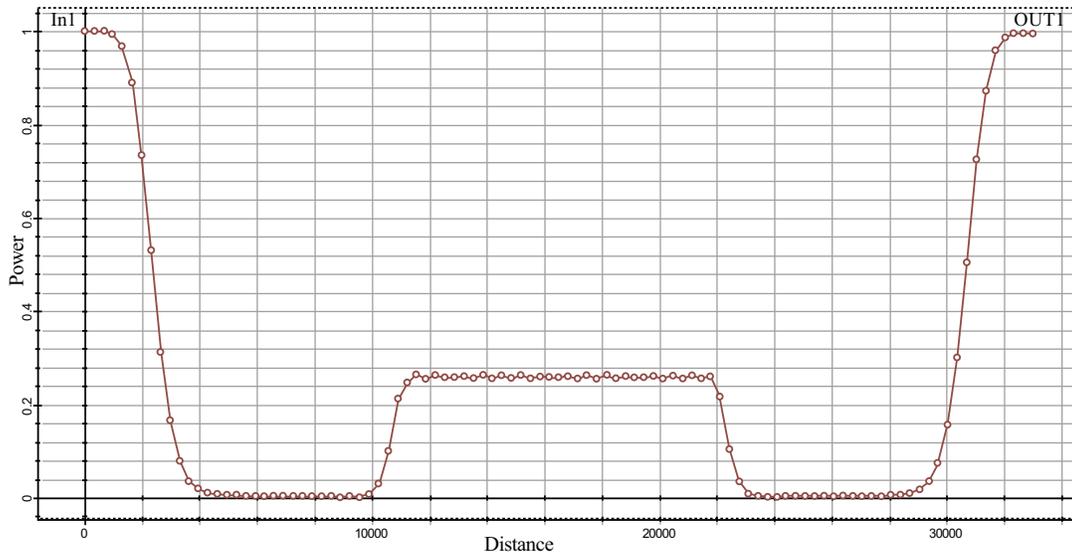


Fig. (18). Power overlap integral for 8 V.

at 1.55 μm in Table 7 and for other ones operating at 1.3 μm in Sec. 3.4, a better switching performance is observed.

Figs. (17 and 18) contain the power overlap integral versus distance of propagation of waveguide for the first iteration and the final iteration, respectively. The high extinction ratio of 30 dB for OUT2 and 29.9 dB for OUT1 are obtained. By comparing this ratio with other previous ratios for switches operating at 1.55 μm in Table 7 and also for other ones operating at 1.3 μm in Sec. 3.4, the best performance with higher ratio is achieved.

Switch operation at 1.55 μm (this section) provides similar behavior to the switch operation at 1.3 μm but with better performance. This is clear when observing the behavior of insertion loss and extinction ratio. When viewing insertion loss we found a common decrease in the insertion loss with increasing Ti strip thickness until reaching optimum value of thickness then the behavior is reversed. Reasons for such behavior stated clearly in section 3.4 (under Fig. 11). Noting that level of insertion loss at both output ports at 1.55 μm are lower than the case of 1.3 μm switching operation.

Other similarity in behavior can be observed for extinction ratio, it increases with increasing Ti strip thickness until reaching optimum value of thickness then the behavior is reversed. This indicates that beyond the optimum thickness lower power confinement results in decreasing the extinction ratio. More details can be found in end of section 3.4

In 1.55 μm from Table 7 we observe at optimum case we need 8 volt (11 iterations) to make full switching operation with the mentioned remarkable low insertion loss and high extinction ratio. In 1.3 μm we notice that we need slightly lower voltage (7.2 volt -10 iterations) to get its optimum performance values which generally worse than that observed from 1.55 μm switching operation.

4. CONCLUSION

An optimum 2x2 MZI optical switch based on electro-opto effects has been successfully designed for switching

optical signal at both wavelengths 1.3 μm and 1.55 μm . An optimum titanium strip thickness is tested and performance evaluation is performed.

Insertion loss and extinction ratio show a performance enhancement at 1.55 μm with an optimum titanium strip thickness of 0.0825 μm but with a higher driving voltage (8 V) compared to that of 1.3 μm (7.2 V) operation. The simulated insertion loss is 0.0138 dB for OUT2 and 0.0129 dB for OUT1 with extinction loss of 30 dB for OUT2 and 29.9 dB for OUT1 at 1.55 μm these values are better than that for 1.33 μm optimum switching case.

A comparative study on the effect of titanium strip thickness on the switching capability at 1.3 μm shows a remarkable improvement in reduction of insertion loss to be 0.048 dB for OUT2 and 0.022 dB for OUT1 for the optimum thickness. Also, a high extinction ratio of 30 dB for OUT2 and 22.3 dB for OUT1 is achieved. These results are better than those observed from previous literatures [13, 14] dealing with the same structure and design parameters but we get the previous better performance with optimizing the Ti-strip thickness. Noting that all these results still lower than that observed for 1.55 μm cases in the price of increasing the electrode voltage.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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