An Optimum Design Of 3x3 Optical Switch Based On Integrated MZI, Including The Influence Of Electro Optic

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Abstract:- The influence of waveguide thickness on the output power according to the voltage applied to the electrodes based on Integrated Mach-Zehnder interferometer is investigated. Simulation result which are performed using BPM software, stress that there is an optimum value of 3x3 switching optical waveguide thickness at which the switch process and in turn the output power at 1300nm wavelength can be achieved. This is because the thickness affect significantly the coupling region between the waveguide, and also the effect of the Pockels and Kerr coefficients.

Key-words:- MZI(Mach-Zehnder interferometer), Electro-optics, Directional couplers, Kerr and Pockles coefficients, All-optical switch.

1 Introduction

Directional couplers consisting of two closely coupled waveguide are simple and essential elements in optical systems. One of the key elements that have many applications in optical wavelength division demultiplexing and routing, are all optical switches. There are some of works in the field of optical switching based on directional couplers. In recent years various materials and configurations have been employed for the development of optical switches. For switching operation, some of mechanisms, such as thermo-Optic [1] and electro-optic [2, 3] can be used. But in optical communication, 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. All-optical switches are desired devices in optical telecommunication. They can perform a variety of applications, particularly in single routing and time division signal processing. 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 [4]. In spite of mentioned subjects, an electro-optic switch based on integrated Mach-Zehnder interferometer is required in many optical switching systems. Recent developments include mode-locked lasers and a variety of all-optical switching based on different principles such as Mach–Zehnder interferometer structures, spin relaxation, inter-subband transitions, and ultrafast absorption recovery in organic thin films and semiconductor quantum dots[11]. To the best of our Knowledge, there is not any proposal for an electro-optic 3x3 switch based on integrated Mach-Zehnder interferometer that can work as switch. The proposed switch can have many interesting applications in optical telecommunication. Titanium diffused lithium niobate or the Ti:LiNbO3 waveguide is used as the waveguide medium in the optical switch design. The reason that of chosen this material is it has very low loss and switching voltage need to applied is small which is normally below 10V. In this work, we designed and simulated a new an electro-optic 3x3 switch based on integrated Mach-Zehnder interferometer. The device works based on electro-optic effects refer to changes in the refractive index of material induced by the application of an external electric field. The simulation of the structure is done using OptiBPM software. In the next 2 & 3 sections, we will present the design and simulation results then the analyze the influence of the electro-optic, respectively, and the paper will continue with conclusion, finally.

2 Design and Simulation Results

There is many ways to transmit any signal through fiber optic[13]. We assume that the integrated switch is produced on a z-cut wafer Lithium Niobate, and is surrounded by air cladding. The device is targeted at the Y-axis optical Lithium Niobate. Therefore, we define a a diffused material for the substrate and a dielectric material for cladding. The dielectric material chose is air with refractive index n_{air} =1.0. The waveguides of Mach-Zehnder interferometer are produced by diffusion of Titanium in Lithium Niobate substrate. Just one diffused profile is required (TiLiNbO3). All switches device is 33 mm long and not more than 100 microns wide. The waveguide has a width of 8.0 µm Ti – diffused profile. The wafer has same refractive index like that of Lithium Niobate. The 3D wafer properties include air as a coating material with a thickness of 2.0 µm. It has Lithium Niobate as a substrate with a thickness of 10 µm. The device was created with the layout designer in the software optiBPM Optiwave provided as shown in Fig. 1. The RI profile of the XY slice was audited. The region of the electrode on the substrate also defined. We have created the electrodes on a buffer layer. The buffer layer has a thickness of 0.3 µm and a refractive index of 1.47. It has a horizontal and vertical permittivity of 4 and the electrode has a thickness of 4.0 µm. The three regions defined electrode has several design parameters. First region has a width of 50 µm and a voltage of 0.0 V. The second electrode region has a width of 26 micrometers and a voltage of 0.0 V. The third electrode region has a width of 50 micrometers and a voltage of 0.0V. The gap of 1-2 and 2-3 is equal 6.0. The second electrode has a central position of 5.5. The input plane has been selected with MODE like the starting field and 0.0 like Z-offset. After the input plane defined data set is MODAL refractive index and wavelength of 1.3 µm comprehensively.

The 2D features have been put in TM polarization and 500 mesh points. PARAXIAL BPM solver, Finite Difference scheme of engine parameters 0.5, the propagation step of 1.3 and TBC as a boundary condition. We calculated the isotropic 2D simulation. We varied the voltage electrodes for the Region 2nd. First the switching voltage of 0.0 V, then 8.0 V was checked. Further studies electro-optical switches have been using the scripting language[6].

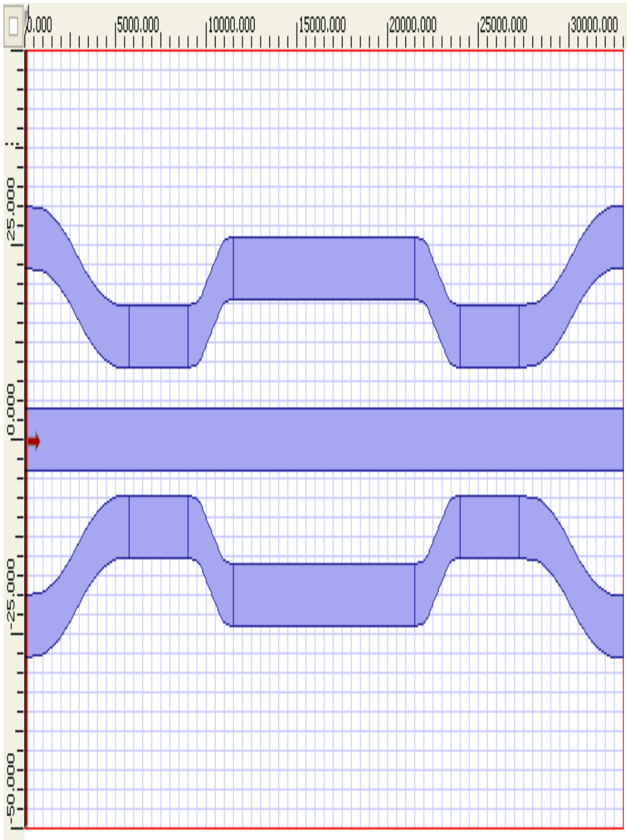


Fig. 1 A design of 3x3 optical switch of Mach-Zehnder Interferometer without electrode region

When we run a simple scan-script, we get a graphic representation of the optical field overlap in comparison to the number of iterations. It then became clear that the electro-optic switch is fully switching the total input signal from one output port to another for the second electrode voltage from -8.0 to 0 & from 0.0 to 8.0.

Scripting: (using VB script)

```
Const NumIterations = 10
ParamMgr.SetParam “V2”, -8.0
For x= 1 to NumIterations
ParamMgr.Simulate
ParamMgr.SetParam “V2”, 3.2* x
WGMgr.Sleep (50)
Next
```

A nonlinear dirctional coupler includes three waveguides that have a small distance and fully coupling takes place between them in one coupling length. One of these waveguides or all have the nonlinear behaviour means, we can change the refractive index of nonlinear waveguide by applying a voltage between the electrodes, the three guides experiences an applied field E in opposite directions and hence experience opposite changes in their refractive indices. The corresponding switching voltage V_o *is,*

$$V_o = \frac{\sqrt{3}\lambda d}{2n^3 r L_o} \qquad (1)$$

Where L_o is the transfer distance, which is depends on the efficiency coupling C between each two guides, d is the coupling separation, n is the refractive index of each guide which is equals, r is the appropriate Pockels coefficient, V_o depends on the refractive indices and the geometry of the guides.
The coupling efficiency can be controlled by external voltage level applied through the electrode. The proposed structure for an electro-optic 3x3 switch based on integrated Mach-Zehnder interferometer is shown in Fig. 2.
The applied voltage will determine the amount of optical power transmitted to a particular output port, and Fig.3 shows the output power vs. iterations according to the effect of changing the voltage. Mach Zehnder Interferometer can be used as active optical switch if a voltage is applied.
In the phase matched case, that means the input wave lenght and the refractive index of three waveguides are same, we will have maximum coupling decreased. The switching operation is done with changing the voltage exercised to the electrodes filed on the integrated Mach-Zehnder interferometer. The light, applied to the (single) input, can be switched from one output to the other by changing this effective refractive index such that the light is reflected or transmitted at the crossing. The impact of changing the voltage, enforce to the electrodes, creates an electric field distrbution within the substrate, which consequently changes its refractive index.
The effect of this changing is shown in Fig.5 (a)(b),Fig.6 (c)(d), and Fig.7 .(e)(f). The switching between the ports is work out by an electro-optic impress within such structure.

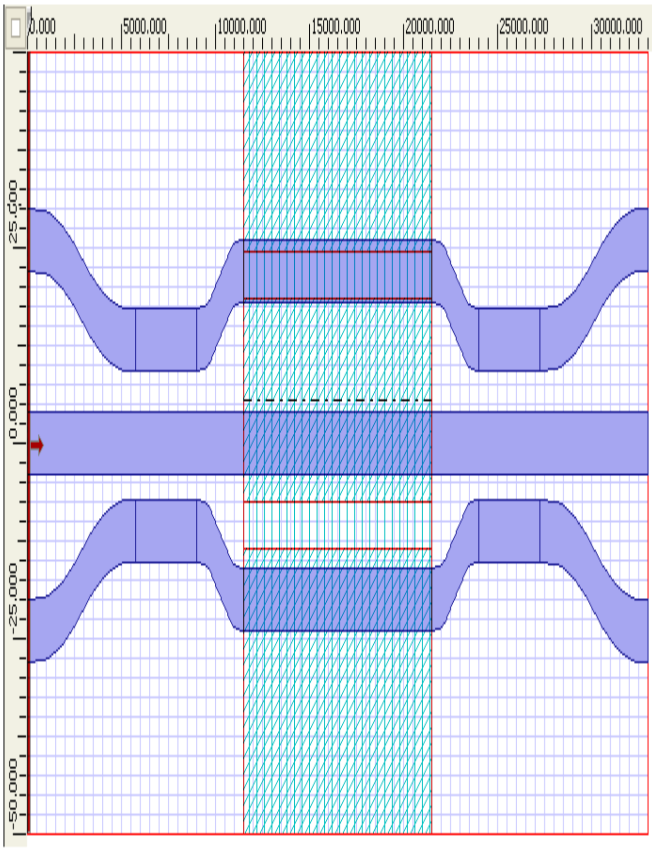


Fig.2 A design of 3x3 electro-optic switch based on Mach-Zehnder interferometer

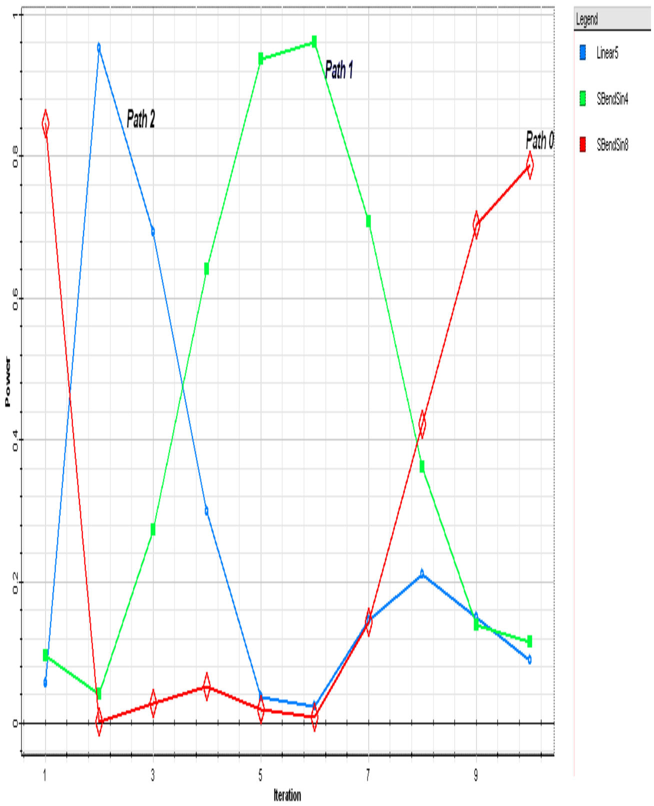


Fig.3 The output power vs. Iterations according to the effect of changing the voltage.

Table 1
The comparison and optimum result of the thickness of the waveguide according to Insertion Loss and Extinction Ratio of the Proposed structure

Thickness width(μm)	Switching State	Output Port	I.L.(dB)	Ex.R.(dB)
7.5	State 1	Out 1	-1.93	-11.07
		Out 2	-13.01	
		Out 3	-5.27	
	State 2	Out 1	-18.23	-17.43
		Out 2	-0.80	
		Out 3	-8.44	
	State 3	Out 1	-12.51	-19.22
		Out 2	-19.58	
		Out 3	-0.362	
8.0	State 1	Out 1	-0.70	-11.9
		Out 2	-12.6	
		Out 3	-10.3	
	State 2	Out 1	-23.0	-22.67
		Out 2	-0.34	
		Out 3	-11.7	
	State 3	Out 1	-23.0	-22.94
		Out 2	-21.4	
		Out 3	-0.06	
8.5	State 1	Out 1	-0.57	-12.89
		Out 2	-12.51	
		Out 3	-13.46	
	State 2	Out 1	-15.68	-14.43
		Out 2	-1.249	
		Out 3	-6.861	
	State 3	Out 1	-9.546	-7.277
		Out 2	-5.543	
		Out 3	-2.269	

The simulation results show good performance for this structure. Table 1 shows the insertion loss (I.L.), and the extinction ratio (Ex.R.) of the proposed optical switch. 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. Insertion loss and extinction ratio that are the important parameters for optical switching can be calculated by these equations:

$$\text{I.L.(dB)} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right) \quad (2)$$

$$\text{Ex.R.(dB)} = 10\log_{10}\left(\frac{P_{low}}{P_{high}}\right) \quad (3)$$

Where P_{out} and P_{in} are the output and input power and P_{high} and P_{low} show the higher and sum of lower levels in output in both state of ON and OFF[5]. As shown in Table 1, the output results of the device are acceptable for a good performance of all-optical switch.With choosing the exact reflecting index, this structure can work as 3x3 Switch Based On Integrated Mach-Zehnder Interferometer. In the future, with the materials that can have higher nonlinearity the outputs of the structure can increase to have an all-optical switch without any complicated materials or structure.

3 Analyze the influence of Electro-Optic

The influence of Electro-Optic refer to changes in the refractive index of material induced by the application of an external electric field, which therefore modulates the optical properties , the applied field is not the electric field of any light wave, but separate external field[8]. Ordinarily alteration in the refractive index are Slightly. The influence of electro-optic are categorized according to first and second order effects. The refractive index n have been taken as a function of applied electric field E, that is n=n(E), so it can be expand this as a Taylor series in E. The new refractive index n' would be:

$$n' = n + a_1 E + a_2 E^2 + \ldots \quad (4)$$

Where the coefficients a_1, and a_2 are called the linear electro-optic effect and second order electro-optic effect coefficients. The change in n due to the first E term is called the Pockels effect. The change in n due to the second E^2 term is called the Kerr effect, and the coefficient a_2 is generally written as λ*K*, where *K* is called the Kerr coefficient.
In the case of the Pockels effect, the precise effect of the applied electric field depends on the crystal structure and symmetry of the material under consideration. main contribution to birefringence to electro-optical crystal is due to Kerr's effect, it means[12]:

$$\Delta n_p << \Delta n_k$$

The Kerr electro-optical effect consists in the fact that, under the influence of an electric field, an optical anisotropy with an induced optical axis appears. The axis is directed along the applied electric field. When light radiation passes through a sample located in the electric field, a phase difference φ appears between the orthogonally polarized light components [10]:

$$\varphi = \frac{2\pi}{\lambda}\Delta nl = 2\pi KlE^2 \quad (5)$$

Where Δn is the induced birefringence; l is the length of the optical path in the zone of field application; in the zone of field application; λ is the light wavelength; E , V/m, is the electric field strength; and *K*, m/V^2, is the Kerr coefficient of the material. Assuming that the electric field is uniform, the field strength E can be expressed via the applied voltage V_o and the distance between the electrodes d . Expression (1) then takes the form:

$$\varphi = 2\pi Bl V_o^2 / d^2 \quad (6)$$

The Pockles effect expressed in this equation:

$$\Delta n = a_2 E \quad (7)$$

This is an over-simplification because in reality it must be consider the effect of an applied field along a particular crystal direction on the refractive index for light with a given propagation direction and polarization[8].

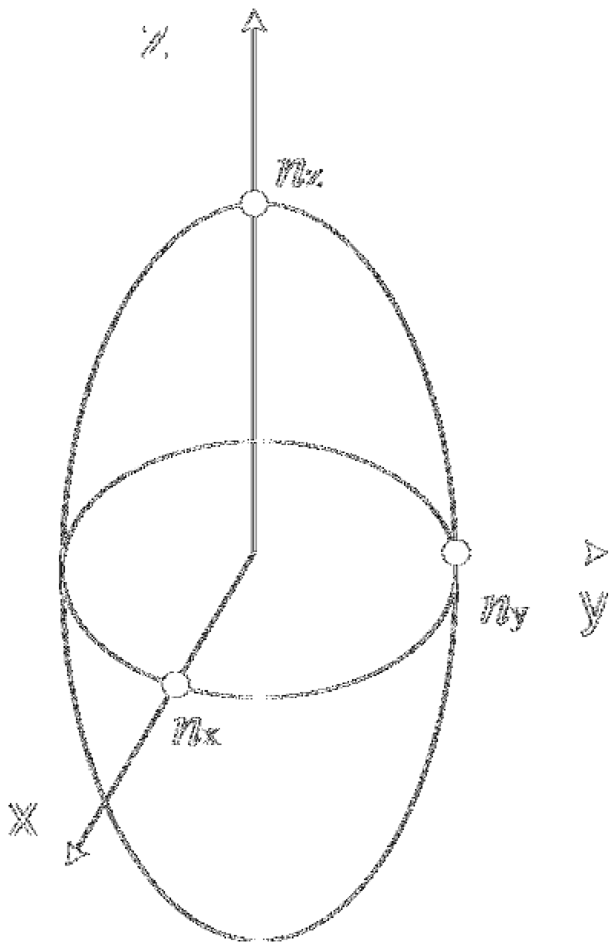


Fig.4 The index ellipsoid showing the principal axes of the dielectric (x,y,z) and the corresponding refractive indices(n_x, n_y, n_z)

3.1 Electric impermeability, index ellipsoid, dielectric constant and refractive index

In many optical fibre applications, such as interferometry, the effective refractive index of the guided modes is of great interest. In the case of electro-optic responses, it is often more informative to know how the refractive index responds to an incident electric field than to completely understand the non-linear polarisation. The electric displacement field **D** is defined by the relation:

$$\mathbf{D} = \varepsilon 0 \mathbf{E} + \mathbf{P} \quad (8)$$

where **E** is the electric field, ε0 is the permittivity of free space, and **P** is the dipole moment per unit volume or polarisation density. The electric displacement field **D** can be expressed in terms of the electric polarisability χ as:

$$\mathbf{D} = \varepsilon 0 \; 1 + \chi \; \mathbf{E} = \boldsymbol{\varepsilon} \mathbf{E} \quad (9)$$

where **ε** is the electric permittivity.

The electric impermeability switch $\boldsymbol{\eta}$=ε0**ε** can be used to construct the index ellipsoid i.e.

$$\sum_{ij} \eta_{ij} x_i x_j = 1,\ i,j=1,2,3, \qquad (10)$$

where η_{ij} are the elements of the impermeability switch $\boldsymbol{\eta}$. The index ellipsoid and the electric impermeability tensor can be used to describe dielectrics and anisotropic materials such as crystals. The principal axes of the ellipsoid are the principal optical axes of the dielectric and the dimensions along these axes are the corresponding refractive indices (see Fig.4). In the case of optical fibre where the propagation direction or axis of the fibre may be assigned to the z direction, or axis, of the index ellipsoid and then the dimensions along the x and y axis are the refractive indices for x and y polarised modes. i.e.

$$\eta_x = \frac{\varepsilon_0}{\varepsilon_x} = \frac{1}{n_x^2},\ \text{and}\ \eta_y = \frac{\varepsilon_0}{\varepsilon_y} = \frac{1}{n_y^2} \qquad (11)$$

The presence of a DC electric field will alter the index ellipsoid so that elements of the index ellipsoid become a function of the electric field i.e $\eta_{ij}\mathrm{E}$. To include the non-linear response the electric impermeability switch can be expanded in a Taylor's series about E=0 as follows.

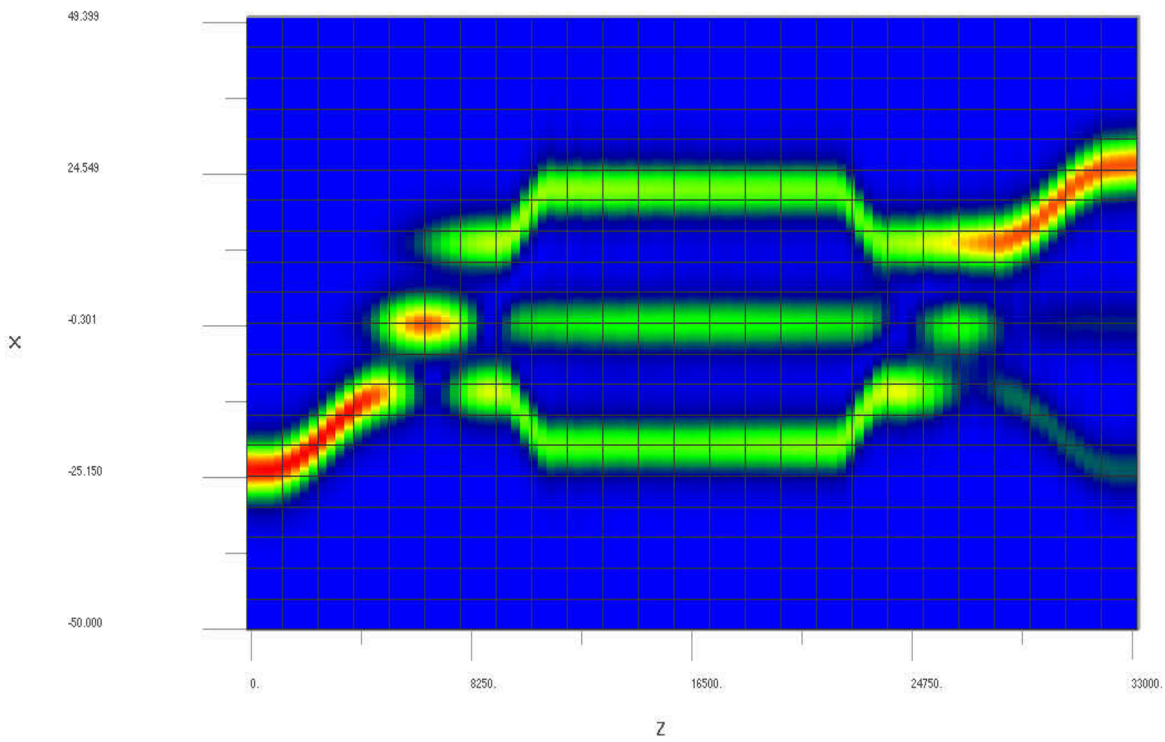
$$\eta_{ij}(\mathrm{E}) = \eta_{ij} + r_{ijk}\mathrm{E}_k + s_{ijkl}\mathrm{E}_k\mathrm{E}_l,\ i,j,k,l=1,2,3 \quad (12)$$

Where $\eta_{ij} = \eta_{ij}(0)$, $r_{ijk} = \frac{\partial \eta_{ij}}{\partial \mathrm{E}_k}$, $K_{ijkl} = \frac{1}{2}\frac{\partial^2 \eta_{ij}}{\partial \mathrm{E}_k \mathrm{E}_l}$

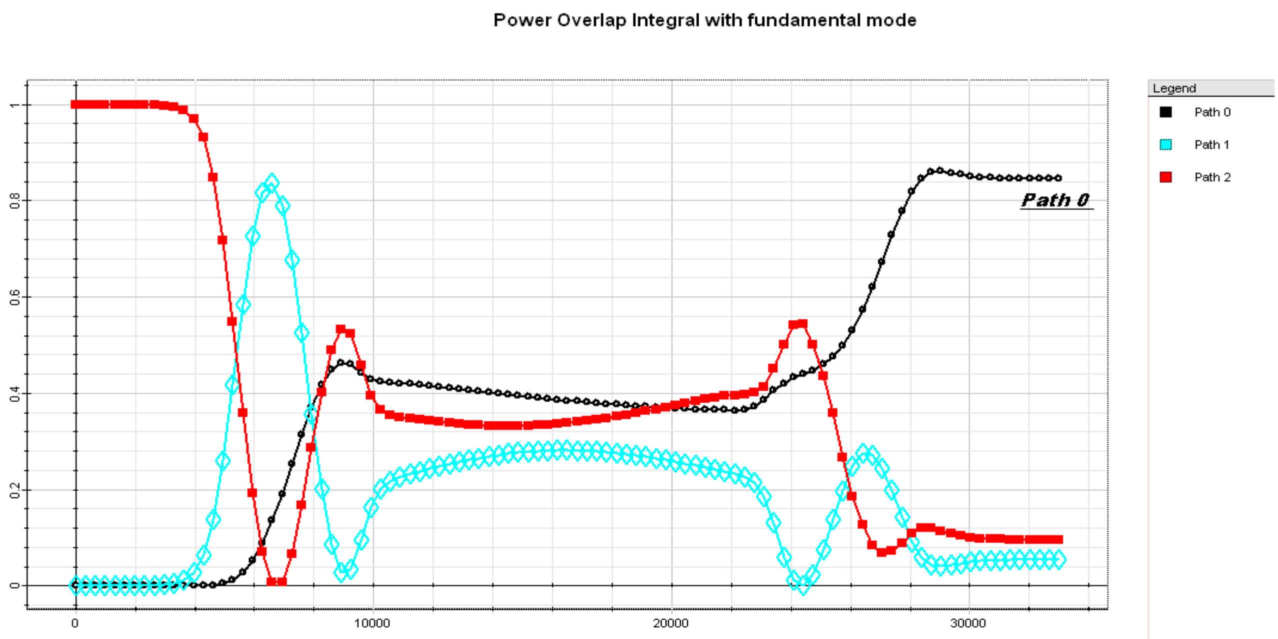
and the derivatives are evaluated at E=0. The summation notation over repeated indices is implied and the r_{ijk} and K_{ijkl} coefficients are called the Pockels and Kerr coefficients respectively.

4 Conclusions

An optimum 3x3 optical switch based on Mach-Zehnder interferometer was successfully designed using OptiBPM, for switching optical signal with wavelength 1300nm. The coupling efficiency of the 3x3 optical switch designed can be controlled by changing the voltage applied to the electrode region. When no voltage is applied, the switch acts as a passive optical switch in which the coupling efficiency is 100%. When switching voltage is applied to the electrode region of the 3x3 optical switch, on coupling occurs where the optical signal is switched to the same output waveguide. With this electro-optic effect, the 3x3 optical switch can act as an electro-optic switch to switch optical signal to desired output port.

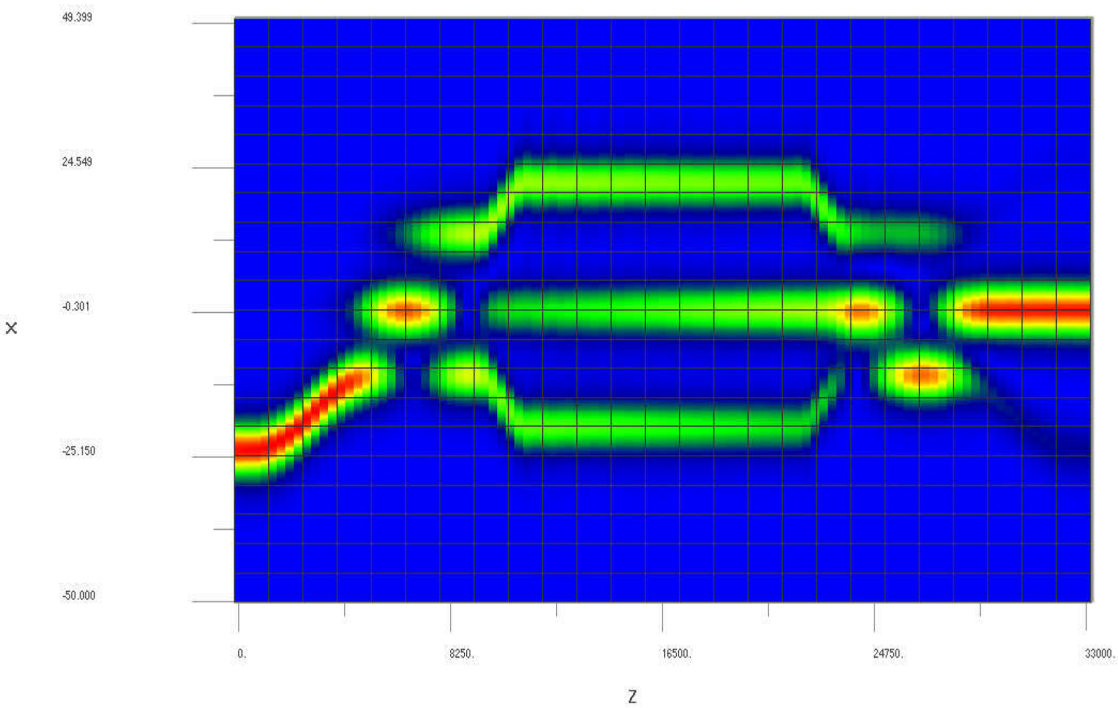


(a)

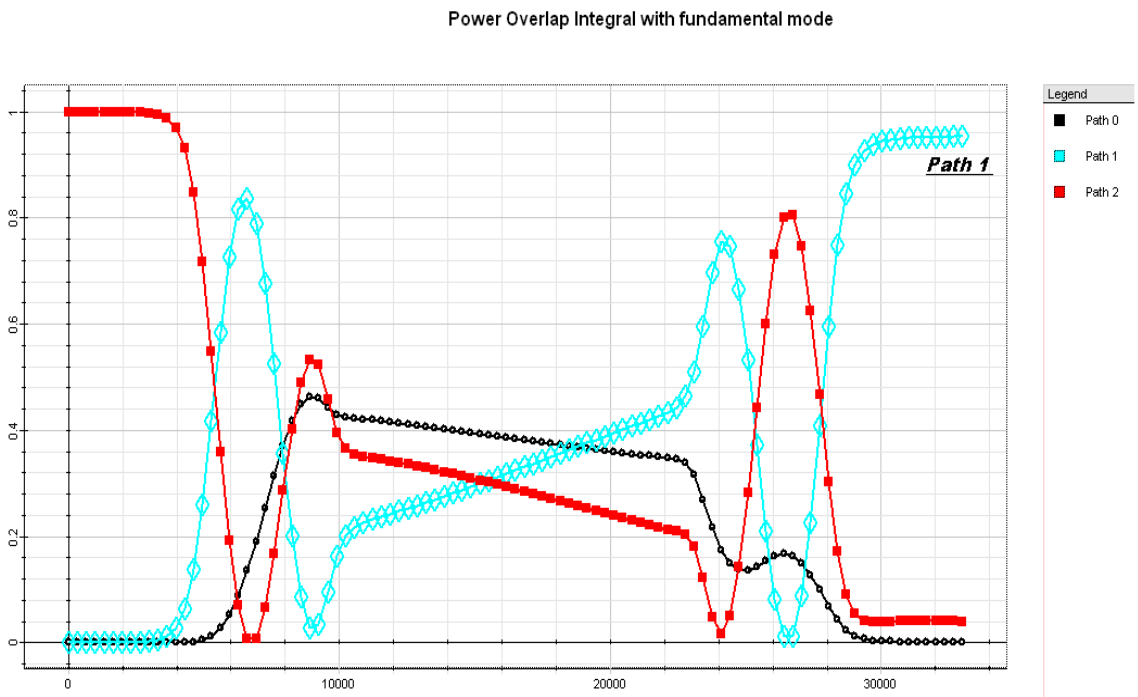


(b)

Fig. 5 (a) Beam propagation simulation and the normalized output power of the proposed structure in the first state of the switching operation.(b)The output power vs. Iterations in the first state according to the effect of changing the voltage -8.0V.

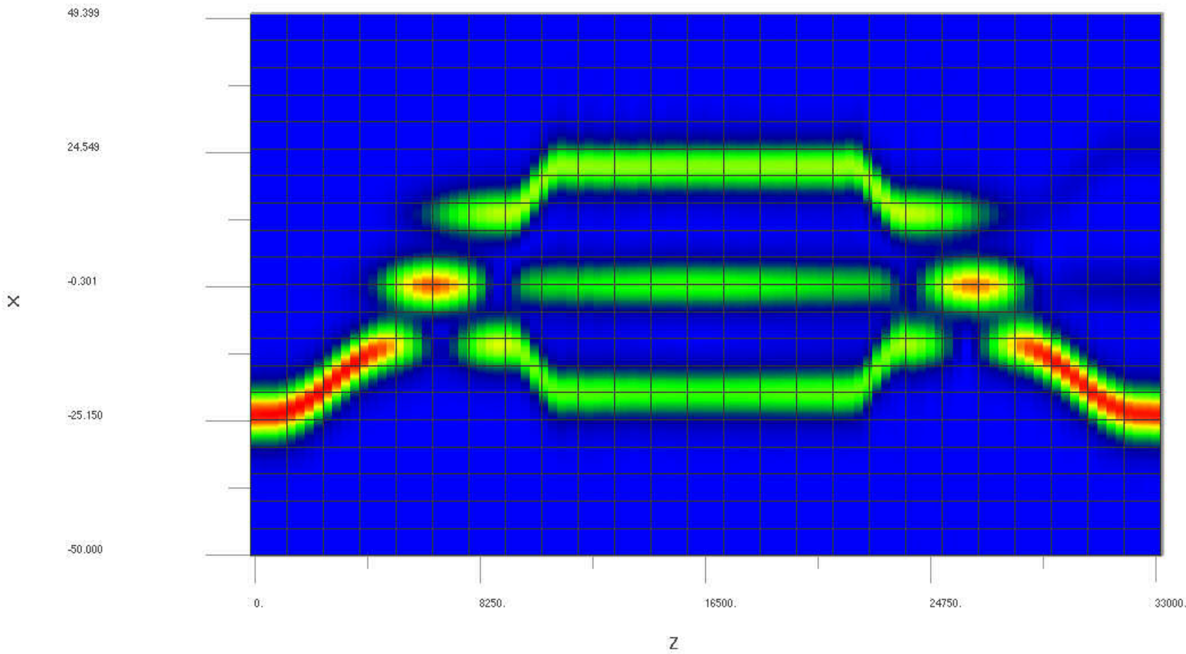


(c)

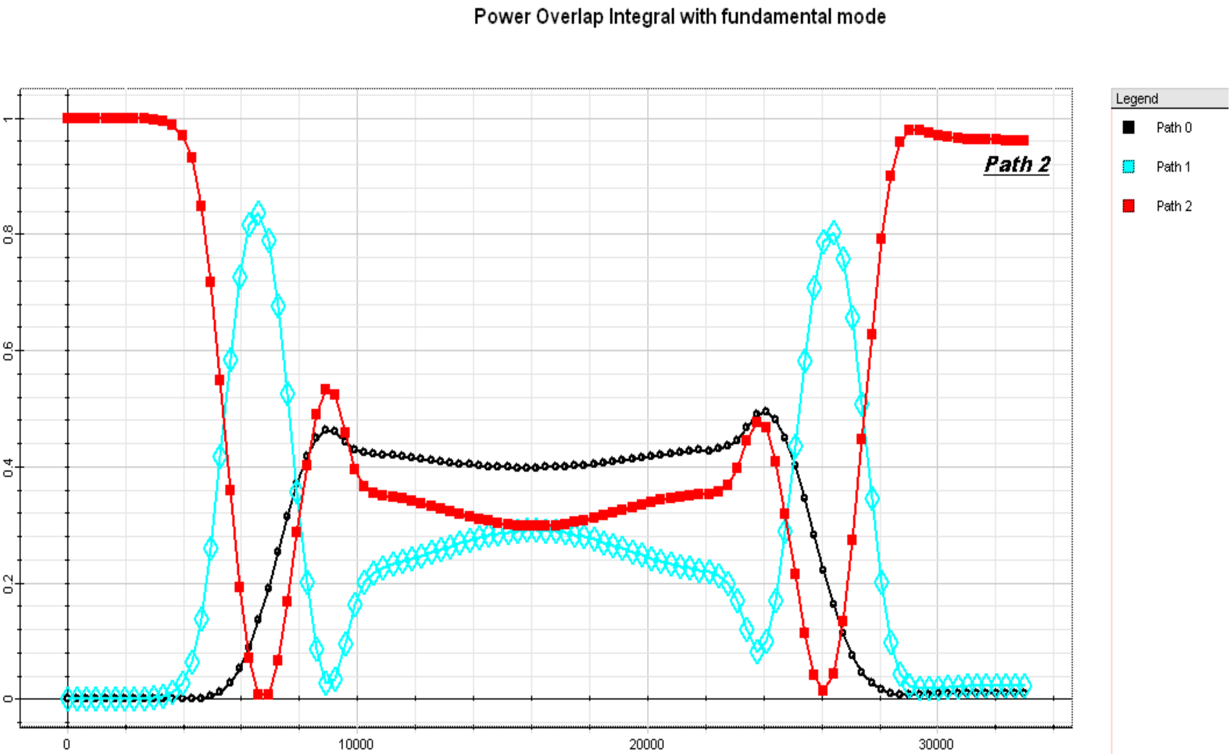


(d)

Fig. 6 (c) Beam propagation simulation and the normalized output power of the proposed structure in the second state of the switching operation.(d)The output power vs. Iterations in the second state according to the effect of changing the voltage 0.0V.



(e)



(f)

Fig.7 (e) Beam propagation simulation and the normalized output power of the proposed structure in the third state of the switching operation.(f)The output power vs. Iterations in the third state according to the effect of changing the voltage 8.0V.

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