International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 4
April 2017

Mach Zehnder Interferometer True Time Delay Line

Pradnya Sutar, Dr.Jyothi Digge
Terna Engineering College
Nerul, Navi Mumbai

ABSTRACT
In this paper we propose an optical true time delay (TTD) line for Phased array antenna beam forming, consisting of Mach-Zehnder Interferometer (MZI) switches on the silicon platform.The proposed delay line differs from the conventional delay line where electro optic effect is used to create the phase shift. The concept of variable width unequal arm MZI is used. The delay offered is one bit. More delay can be obtained using number of waveguides at the output with variable width. Finite difference Time Domain (FDTD) method is used for computation. If the cross talk level is high, a multimode interference coupler (MMI) can be added in series. The device is simulated for Transverse Electric (TE) polarized light at 1550nm.
Keywords-True Time Delay Line, Mach-Zehnder Interferometer, Microwave Photonics, Phased array antenna

1. INTRODUCTION

1.1 Microwave Photonics

Microwave photonics (MWP) is an emerging field, in which radio frequency (RF) signals are generated, distributed, processed and analyzed using the strength of photonic techniques. It is a technology that enables various functionalities which are not feasible to achieve only in the microwave domain. A particular aspect that recently gains significant interests is the use of photonic integrated circuit (PIC) technology in the MWP field for enhanced functionalities and robustness as well as the reduction of size, weight, cost and power consumption [1].

Microwave photonics (MWP), a discipline which brings together the worlds of radio-frequency engineering and optoelectronics, has attracted great interest from both the research community and the commercial sector over the past 30 years and is set to have a bright future. The added value that this area of research brings stems from the fact that, on the one hand, it enables the realization of key functionalities in microwave systems that either are complex or even not directly possible in the radio-frequency domain and, on the another hand, that it creates new opportunities for information and communication (ICT) systems and networks[1].

While initially, the research activity in this field was focused towards defense applications, MWP has recently expanded to address a considerable number of civil applications, including cellular, wireless, and satellite communications cable television, distributed antenna systems, optical signal processing and medical imaging. Many of these novel applications are as demand ever-increasing values for speed, bandwidth and dynamic range while at the same time require devices that are small, lightweight and low-power, exhibiting large tunability and strong immunity to electromagnetic interference. Microwave photonics offer this functionality, by exploiting the unique capabilities of photonics, to bring advantages in terms of size, weight and power (SWAP) budgets in radio-frequency signal processing [1].

1.2 True Time Delay(TTD) Line

The application of fiber optics in phased array radars has been visualized for many years. The operation frequencies of these radars are spreading into the millimeter-wave regime. Recently, the need to achieve large instantaneous bandwidths for wide aperture (>100λ) antennas further prompted the exploration of new concepts for broad-band beam steering. Conceptually, a fiber-optic time-delay system is extremely attractive because it is light weight, compact, non dispersive over multiple microwave bands, and immune to electromagnetic interference. Microwave transmission via fiber optics can be used to advantage in these radars for remoting the radiating elements, the control of their relative phase, and the strategic processing of return signals in various electronic warfare (EW) endeavours [2].

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 4
April 2017

1.3 Types of True Time Delay Lines

1. Fiber based delay line[3]
2. Optical delay line on silicon chip[4]
3. 2×2 - Optical MEMS based TTDL[5]
4. Polymer waveguide switch array based TTDL[6]
5. Ring resonator based optical beam forming[7]
6. Photonic crystal fiber(PCF) based TTDL[8]
7. Photonic Microwave Delay line using Mach-Zehnder Modulator[3]
8. Optical Mux/Demux based delay line[9]
9. PCW based AWG Demux /TTDL[10]
10. Sub wavelength grating enabled on-chip ultra-compact optical true time delay line [11]

2. DESIGN

2.1 The schematic diagram of the proposed TTD line is shown the Figure 1.

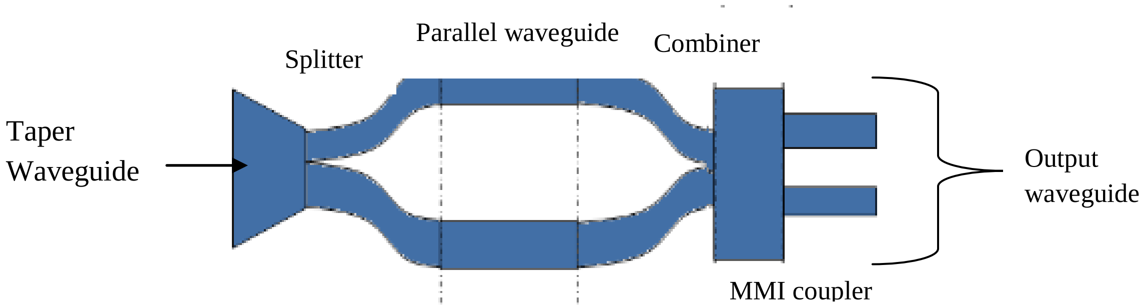

Fig.1: Unequal arm MZI based True Time Delay Line

2.2 The building block is a silica based ridge waveguide as shown in the Figure 2.

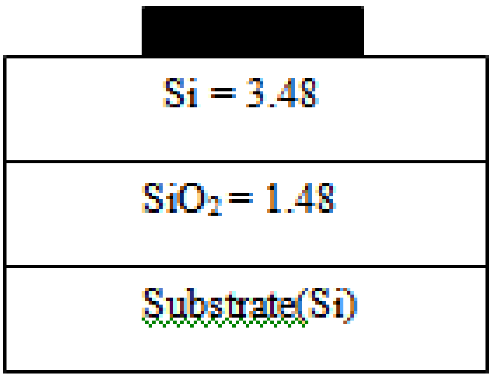

Fig.2: Silica on Silicon Ridge waveguide

The width of the waveguide is 3µm.The linear taper waveguide which tapers from 8-4.5µm and spans 10µm is used at the input. This is followed by two “S” bend arcs with 2µm and 3µm is used in the upper and lower arm connecting 2µm and 3µm.At the output a MMI coupler with width 6µm and 5µm is used at the output. The two waveguides with variable width 2 µm and 2.5µm.The first section is a power splitter followed by unequal arms and the output coupler. Optimum positioning of the output waveguides is done to avoid cross talk.

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 4
April 2017

2.3 The simulation set up for antenna beam forming is as shown in the Figure 3.

The field distribution and the device is computed using FDTD method.

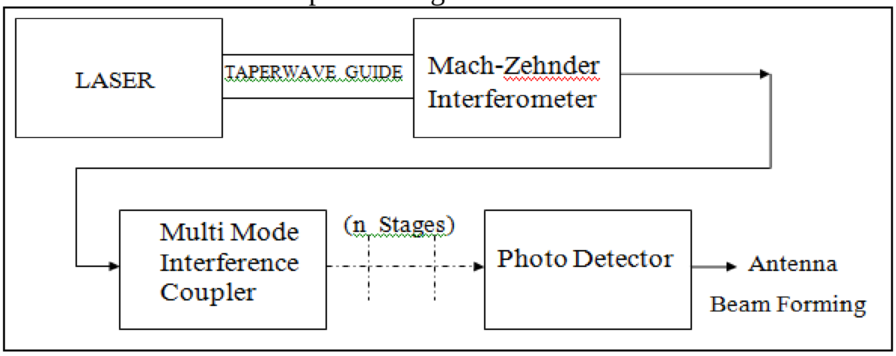

Fig.3: Simulation set up for antenna beamforming

A 1550nm, TE polarized light is launched through a taper waveguide as shown in the Figure 3. Figure 1 shows the basic building block. Figure 2 shows the diagram of MZI delay line. The device can be viewed in five parts. The first part corresponds to power splitter followed by two parallel waveguides which differ in width. The third part is a combiner. The combined output is fed to the MZI coupler. Where the light divides and incidents on the different points on the output coupler. The output light is intercepted by the two output waveguides positioned as shown in the Figure 1.The width of the output waveguide is varied. There is a difference in the output path length due to variation in the width of the waveguide due to the variation in the effective index.

3. ANALYSIS OF MZI TRUE TIME DELAY(TTD)

1. A continuous wave of 1550nm is launched through the linear taper waveguide.
2.Phase Length “l”=ZX Effective index……………………………………………………(1)
   Phase shift $\Delta\phi$ is proportional to “l”
   The signal at the output is having a phase shift $\Delta\phi_1$ and $\Delta\phi_2$
3.The delay obtained is proportional to the phase shift. This will be analyzed using FDTD method.
4.Finally this delayed signal will be fed to the phase array antenna and the radiation pattern will be observed.

4. SIMULATION RESULTS

4.1 The propagation of light in the equal and unequal arm MZI TTD line is shown in Figure 4 and Figure 5

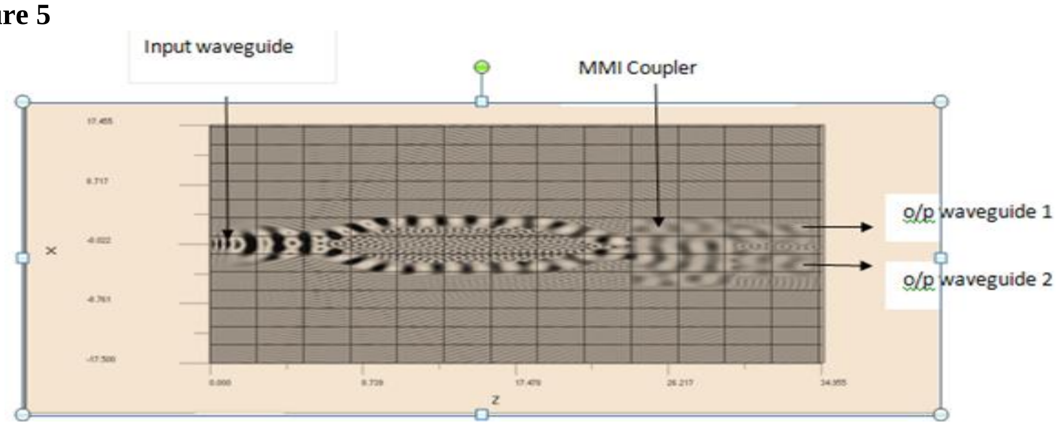

Fig.4: Propagation of light in the equal arm MZI TTD line

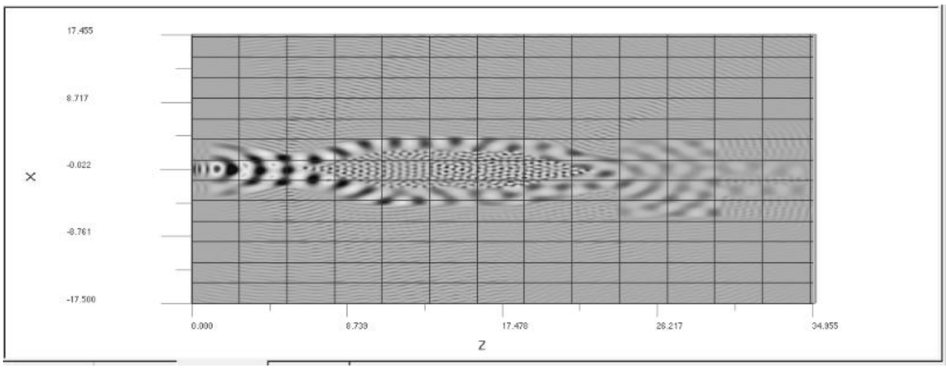

Fig.5 Propagation of light in the unequal arm MZI TTD line

From Figure 4 and Figure 5 it is observed that the propagation of light is straight in the MZI with equal arm and it takes a long path in unequal MZI TTD due to change in the effective index leading to optical path length difference.

4.2 The refractive index distribution of the proposed device is shown in Figure 6.

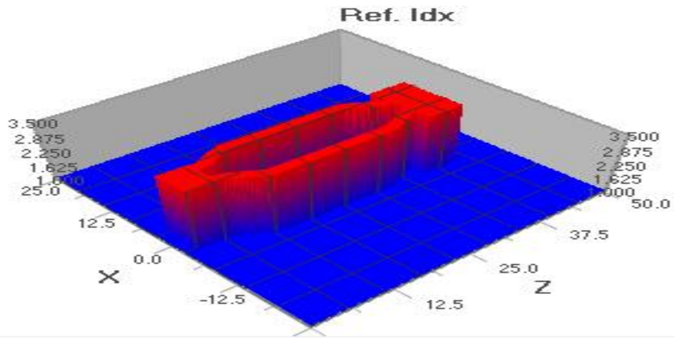

Fig.6 Propagation of light in the unequal arm MZI TTD line

4.3 The modes present in the device are shown in the Figure 7.

The proposed device supports number of modes. However the fundamental mode is considered for the simulation. Number of modes present in the device is computed using Full vectorial method

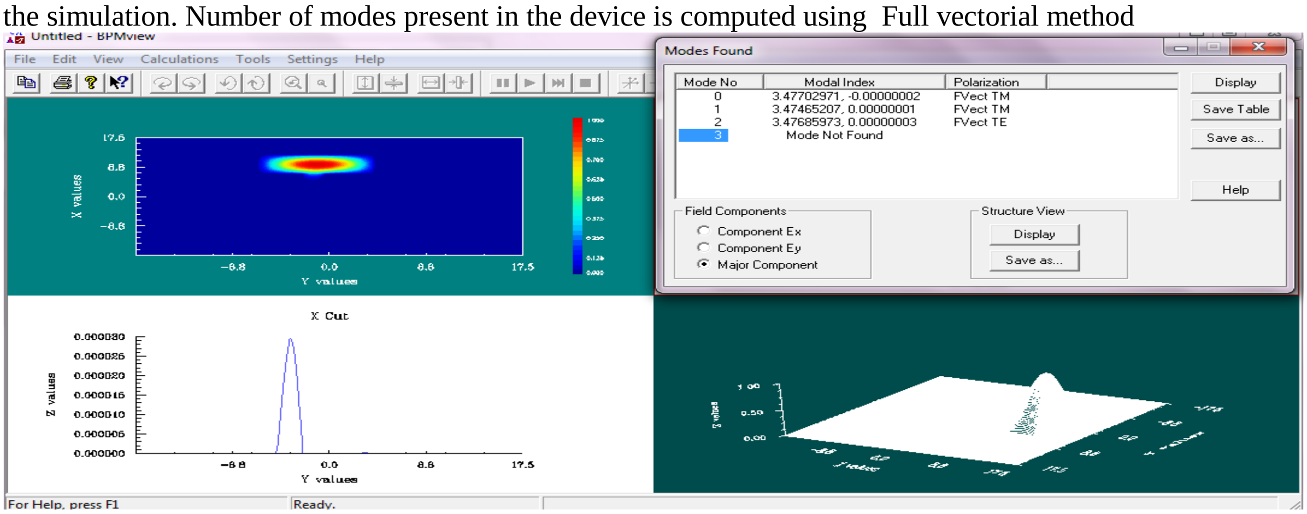

Fig.7: The fundamental and the higher order modes present in the device

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 4
April 2017

4.4 The phase shift is observed at the two output waveguides is shown in the Figure 8

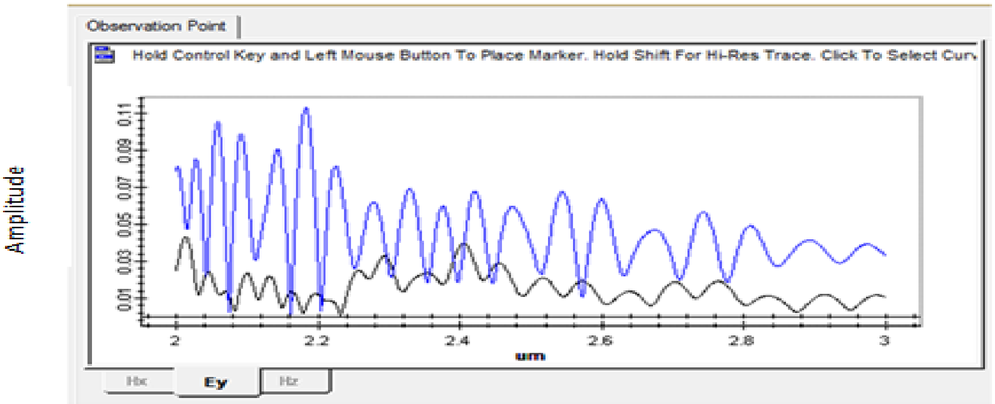

Fig.8: The phase shifted signal at the two output waveguide

5. CONCLUSION

Using an unequal MZI TTD line without electro optic effect thus makes it possible to realize a compact TTD on silica platform. Using the photo detector at the output, the signal can be used for steering the beam. However delay required for a Phased array antenna delay with number of elements requires further engineering of waveguide parameters. To obtain further delay we can also use an electro optic effect based on MZI TTD which will span in micrometer and not in millimeter as reported earlier.

REFERENCES

[1] David Marpaung, Chris Roeloffzen1,Rene Heideman , Arne Leinse ,Salvador Sales , and Jose Capmany , 2012, Laser & Photonics Reviews
W. Ng, A. A.Walston, G. L. Tangonan, J. J. Lee, I. L. Newberg, and N.Bernstein,1991,The first demonstration of an optically steered microwave phased array antenna using true-time- delay," J.Lightw. Technol., vol.9, pp. 1124–1131
[3] Jianping Yao,2009, Microwave Photonics, J.Lightw. Technol,vol.27, NO.3, pp 314- 335
[4] Siva Yegnanarayanan, P. Trinh, F. Coppinger, and B. Jalali,1997,Compact silicon-based integrated optical time-delay network ,From Conference Volume 3160, 10.1117/12.283940, October,pp.1-10
[5] J. D. Shin, B. S. Lee, and B. G. Kim,2004, Optical true time-delay feeder for x-band phased array antennas composed of 2×2 optical MEMS switches and fiber delay lines, IEEE Photon. Technol. Lett. 16(5), pp 1364–1366
[6] X. Wang, B. Howley, M. Y. Chen, and R. T. Chen,2007, Phase error corrected 4-bit true time delay module using a cascaded 2×2 polymer waveguide switch array,Appl. Opt.46(3),pp.379–383
[7] M. Burla et al., 2008, Multiwavelength optical beam forming network with ring resonator-based binary-tree architecture for broadband phased array antenna systems, in Proc. LEOS Benelux Symp.,Nov. 27–28,Enschede, The Netherlands, pp 99–102
[8] Harish Subbaraman, Maggie Yihong Chen, Member, IEEE, and Ray T. Chen,2008, Photonic Crystal Fiber-Based True-Time-Delay Beamformer for Multiple RF Beam Transmission and Reception of an X-Band Phased-Array Antenna", J. Lightw.Technol, vol. 26, NO. 15,2008
[9] Maurizio Burla,David A. I. Marpaung,Leimeng Zhuang,Muhammad Rezaul Khan,Arne einse, Willem Beeker,Marcel Hoekman,Ren´e G.Heideman, and Chris G. H.Roeloffzen, ,2014,Multiwavelength-Integrated Optical Beamformer Based on Wavelength Division Multiplexing for 2-D Phased Array Antennas", J. Lightw. Technol,,vol. 32,NO. 20, pp.3509-3518
[10] Jyothi Digge, B.U.Rindhe, S.K.Narayankhedkar,2014,Photonic Crystal based Arrayed Waveguide Grating demultiplexer for Optical Network" IJESIT ,vol.3,.
[11] Junjia Wang, Reza Ashrafi, Rhys Adams, Ivan Glesk, Ivana Gasulla, José Capmany & Lawrence R. Chen,2016,Subwavelength grating enabled on-chip ultra-compact optical true time delay line", Nat.Commun.,6:30235,10.1038/srep30235