International Journal of Engineering Research and Development
e -ISSN: 2278-067X, **p**-ISSN : 2278-800X, www.ijerd.com
Volume 4, Issue 12 (November 2012), PP. 51-57

Photonic Band gap PCF Structures with Elliptical Holes Based on Dolph Tschebysheff Polynomials and Its Propagation Characteristics

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Abstract:-In this paper we propose some novel photonic bandgap fiber (PCF) structures whose physical dimensions/geometries are derived from Dolph Tschebysheff polynomials (DTP) based antenna array. The simulations of the proposed structures are carried out using OptiFDTD simulator with full vector mode solver using FDTD method and the results are compared with the PCF structures based on Pascal's triangle (PT). It is observed that the proposed structures exhibit almost negligible waveguide dispersion behaviour over a very large wavelength range and the order of dispersion of the PCF structures based on DTP is same as that of the PCF structures based on PT. These structures are therefore suitable candidates for applications demanding such behaviour such as long distance optical communications or high data rate data transfer applications. The birefringence of the structures based on DTP is, however, more than the structures based on PT.

Keywords:-Photonic crystal fiber, total internal reflection, effective refractive index, finite difference time domain, transparent boundary condition, dispersion, birefringence, normalized wavelength, confinement loss.

I. INTRODUCTION

Photonic crystal fibers (PCFs) have attracted a lot of attention of the research community in the last decade and many interesting results have been obtained [1]-[11]. The PCF consist of an array of air/dielectric filled holes running along its length and it has many unique properties which are not realizable in traditional optical fibers such as endless single mode operation, high birefringence and low nonlinearity, low dispersion etc.[5]-[8]. The parameters that affect the dispersion of the PCF include its profile shape, number of air holes, distance between two adjacent air holes and diameter of the air holes [13]. Several variations of the structure in terms of the above mentioned parameters of the PCFs have been investigated in the literature [1]-[8] from the point of view of improvement in the dispersion and attenuation and other important properties of the PCF. For instance in [9], many propagation properties of index guided PCFs with rhombic air holes have been discussed. A comparison of the effect of the changes in the hole structure from circular to elliptical in the hybrid square lattice PCF is done in [11]. For other structures of the PCF one can refer [14] and the references therein. Recently a PCF structure whose hole dimensions have been chosen as per PT is proposed in [15] and it is observed that this structure has negligible dispersion behaviour over a large wavelength range. In this paper we propose some new index guided PCF structures whose geometries are intermediate between a PCF with uniform hole dimension and the PCF with hole dimensions based on PT proposed in [15]. Here the dimensions of the holes in the PCF are derived from Dolph Tschebyscheff polynomial (DTP) [12] based broadside antenna array. The motivation for choosing the hole dimension based on DTP stems from the fact that the antenna array are based on DTP are optimum in the sense of maximising the directivity for a given side lobe ratio[12] and it would be interesting to investigate a PCF structure based on DTP and compare it with the PCF structure derived from PT or equivalently the binomial array [12]. The proposed structure is analysed with the full vector mode solver using FDTD method. The simulations are carried out using OptiFDTD simulator. It is observed that the proposed structures exhibit almost negligible waveguide dispersion behaviour over a very large wavelength range and the order of dispersion of the PCF structures based on DTP is same as that of the PCF structures based on PT. These structures are therefore suitable candidates for applications demanding such behaviour such as long distance optical communications or high data rate data transfer applications. The birefringence of the structures based on DTP is, however, more than the structures based on PT. The confinement losses in the proposed structures here is slightly more than the losses in the PCF structures based on PT. The rest of the paper is organised as follows. In section II, we present some new structures for the index guided PCFs. The simulation results of these structures are presented in section III. The conclusions are given in section IV.

II. PROPOSED STRUCTURE

The photonic bandgap PCF basically consists of air holes surrounded by dielectric cores and work on different principles than the index guided PCF as discussed in [14]. In this section we present some new structures for the (hollow core) PCFs. In one of the proposed photonic bandgap structures shown in Fig.1(a) and Fig. 1(b) there are four rows of elliptical holes above and below the centre line. The dimension of the ellipse are chosen by calculating the value of major radii and minor radii by the following formula:

$$e_i = \frac{B_i}{A_i} \tag{1}$$

Where e_i is equal to 0.9, B_i is the major radius and A_i is the minor radius. The dimensions of the hole in the central line A_i, $i = 1, 2, ..., 5$ (radii) are selected in proportion of the amplitude of the broadside 10-element antenna array based on the Dolph Tschebyscheff polynomial as given in [12]. The values of the parameters A_i are as given by [12]:

$$A_1 = 0.357\mu m, A_2 = 0.485\mu m, A_3 = 0.706\mu m$$
$$A_4 = 0.89\mu m, A_5 = 1\mu m.$$

The dimensions of the holes in the rows above the central lines A_{ij} are scaled version of the dimensions of the holes in the central line A_i as given by

$$A_{ij} = A_i k_j \, , \qquad (2)$$

where k_j are scale factors. The scale factors are chosen as:

$$k_1 = 0.89, k_2 = 0.706, k_3 = 0.485, k_4 = 0.357 \, .$$

The dimensions of the hole below the central line are exactly the mirror image of the core dimensions above the central line. The other index guided PCF structure has hole dimensions in the central line identical with the hole dimensions in the central line of Fig. 1(a) but the dimensions in the other rows are obtained by deleting holes from the central line as shown in Fig. 2(a) and Fig. 2(b).

Similarly the third PCF structure is derived using the coefficients A_i, as shown in Fig. 3(a) and Fig. 3(b).

The motivation for choosing the dimensions from the DTP stems from the well known fact that it is a compromise between a PCF with uniform hole dimension [11] and a PCF with hole dimension derived from binomial array recently presented in [15]. Moreover if the coefficients in the antenna array are chosen in proportion to the DTP, there are side lobes of equal level in the array pattern [12]. It would be interesting therefore to study the dispersion behaviour, birefringence and confinement loss of PCFs having their geometries derived from DTP. The waveguide dispersion at different wavelength for the structures is calculated using the formula [13]:

$$D = -\frac{\lambda}{c} \frac{d^2 n_{eff}}{d\lambda^2} \qquad (3)$$

where D is the dispersion in ps/(nm-km), n_{eff} is the effective modal index number and λ is the wavelength in μm and c is the velocity of light in free space. The effective modal index is obtained from the simulations as a function of the wavelength and its second order derivative is computed using the three point difference formula for approximating the derivative.

The confinement loss of all the structure is calculated by using the formula [16]:

$$L_c = 8.686 \, \mathrm{Im}[k_0 n_{eff}] \qquad (4)$$

where k_0 is the free space number and is equal to $2\pi / \lambda$, λ is the corresponding wavelength, $\mathrm{Im}[n_{eff}]$ is the imaginary part of n_{eff} (effective modal index number).

Similarly the birefringence of all the three structure are calculated by using the formula [17]:

$$B = \left| n_x - n_y \right| \qquad (5)$$

where B is the birefringence, n_x and n_y are the effective refractive indices of two fundamental polarization mode $(HE^x{}_{11}$ and $HE_{11}{}^y)$.

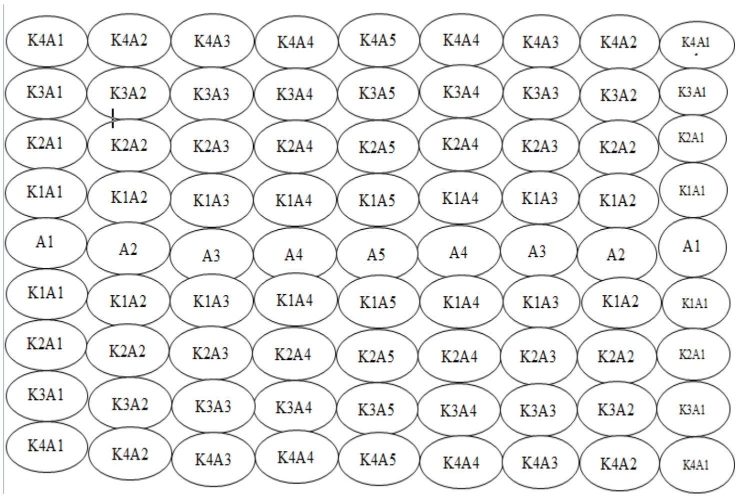

Fig. 1(a) Structure I with Dolph Tschebyscheff

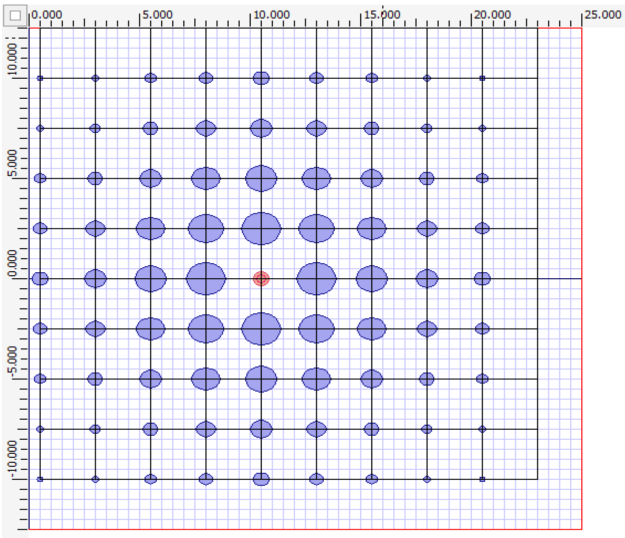

Fig. 1(b) PCF structure related to structure I

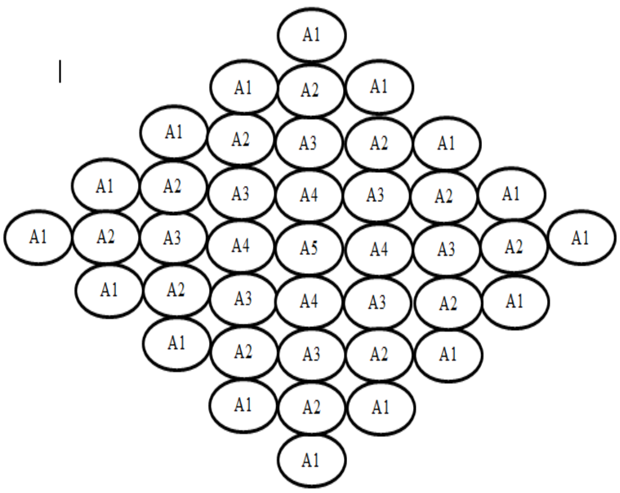

Fig. 2(a) Structure II

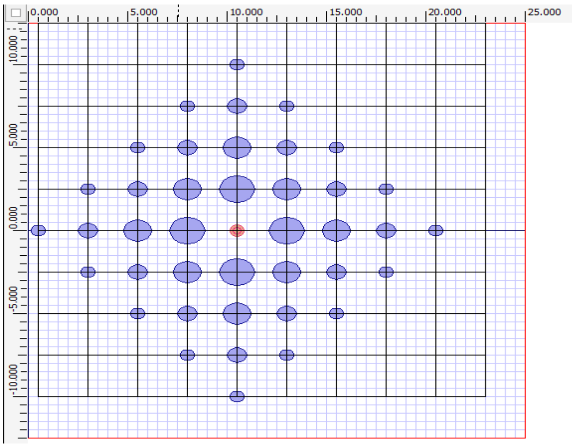

Fig. 2(b) PCF structure related to structure II

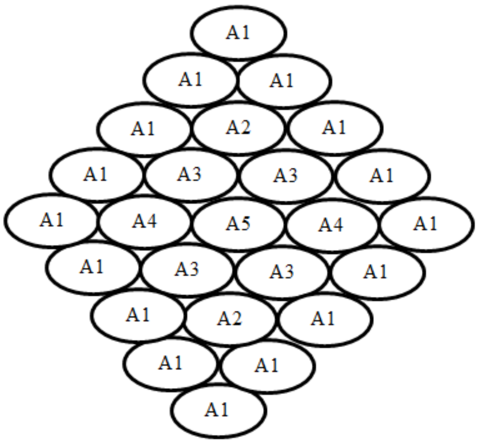

Fig. 3(a) Structure III

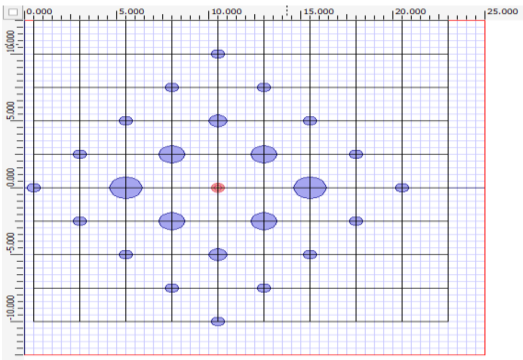

Fig. 3(b) PCF structure related to structure III

III. SIMULATION RESULTS

In this section we present the simulation results of the proposed structures carried out in the OptiFDTD software. The wafer dimensions in the simulation are chosen for each structure in a manner to accommodate all the air holes of the proposed structure while maintaining the pitch factor uniform throughout the structure. The pitch factor Λ, which is centre to centre spacing between two nearest air holes, gives the characteristics of lattice of the PCF. The wafer chosen is of pure silica and is set to be of refractive index $n=1.1$ and that of hole is set to be $n=1.45$. The boundary condition chosen is TBC. The mesh size for the finite difference time domain (FDTD) simulations is $\Delta x = \Delta z = 0.106$ µm. The pitch factor Λ is chosen as $\Lambda = 2.5\mu m$.

For simulations of the structure shown in Fig 1(a), Fig 2(b) and Fig 3(b) the wafer length is chosen as $25\mu m$ while the width is taken to be $25\mu m$.

We calculate the waveguide dispersion of the structures of Fig 1(b), Fig. 2(b), Fig 3(b) by using (3) and we show the corresponding results in Fig 4(a), 4(b) and 4(c) respectively. It may further be mentioned that the order of dispersion observed in the PCF structures presented in this paper is approximately the same for PCF structures based on Pascal's triangle presented in [15].

It can be observed from the results shown in Fig. 5 that all the structure proposed having elliptical holes have negligible waveguide dispersion behaviour and have the most negative dispersion in between $3\mu m$ to $4\mu m$.

We also show the effective modal index versus normalised wavelength curve in Fig 6 for all the structures where normalised wavelength is defined as λ / Λ. As seen from Fig. 5, the value of modal index number decreases with the increasing value of normalised wavelength showing good agreement from theory [14].

The birefringence versus the wavelength curves calculated using (5) for all the three proposed structures is shown in Fig. 7. From Fig. 7, it can be observed that the (data1) birefringence of the structure I is more compared to the other structures considered in this paper. The proposed structure II has a low birefringence as compared with other structures in most of the wavelength range of the simulations. It may further be mentioned here that the PCF structure III has more birefringence than the PCF structures based on Pascal's triangle presented in [15].

The confinement loss as a function of the wavelength calculated using (4) of all the three proposed structures is shown in Fig. 8. It can be noted from this curve that all the three structures have almost zero confinement losses. The structure I has the lower confinement loss than the other structures considered in this paper.

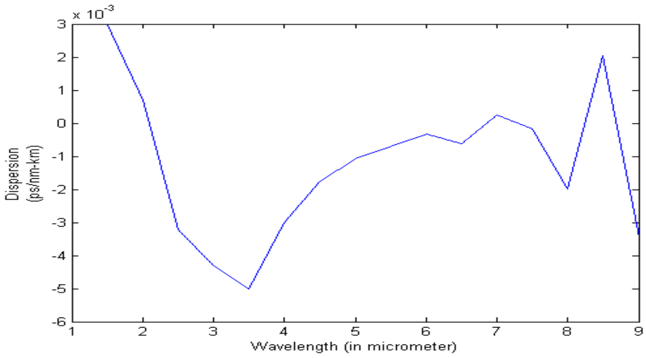

Fig. 4(a) The curve between dispersion and wavelength of structure of Fig 1(b).

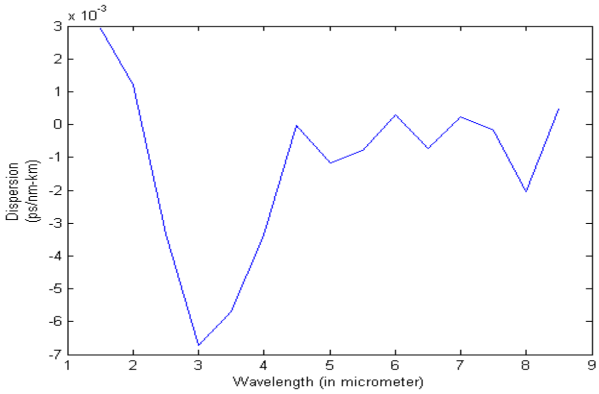

Fig. 4(b) The curve between dispersion and wavelength of the structure of Fig 1(b).

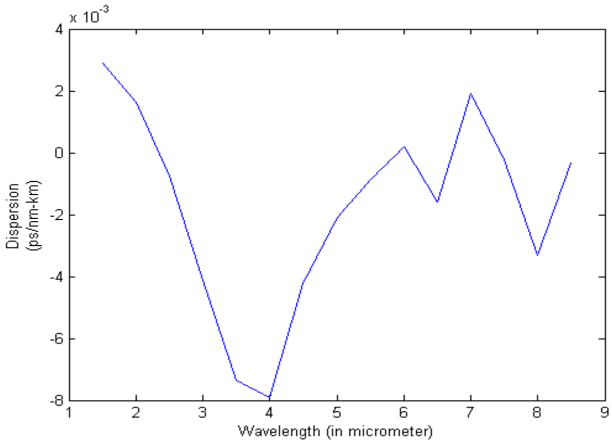

Fig. 4(c) The curve between wavelength and dispersion of structure of Fig 3(b).

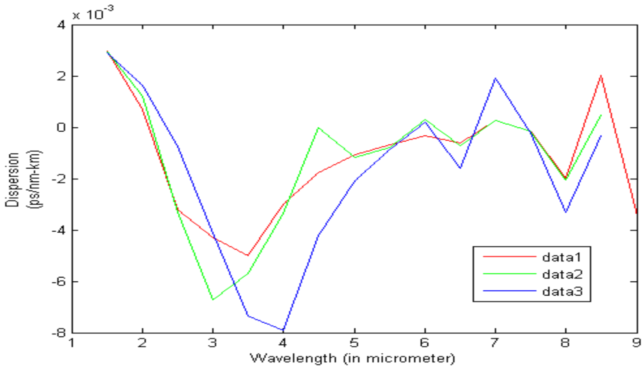

Fig. 5 The curve between dispersion and wavelength of all the proposed structure in this paper. (Data1, data2 and data3 represents the structure of Fig. 1(b), 2(b) and 3(b) respectively).

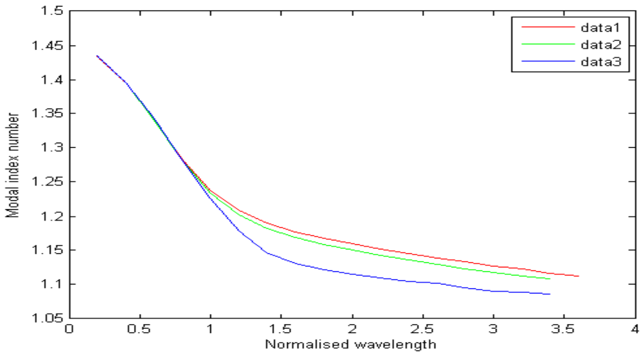

Fig. 5 Modal index number versus normalized wavelength curve. (Data1, data2, and data3 represent the structures in Fig 1(b), 2(b) and 3(b) respectively)

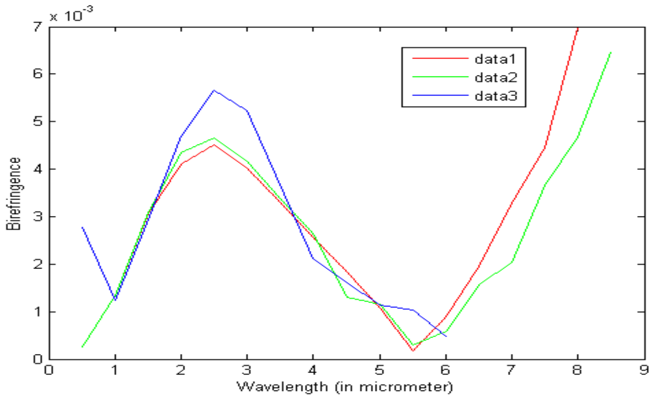

Fig. 6 The curve between birefringes and wavelength . (Data1, data2 and data3 represents the structure of Fig. 1(b), 2(b) and 3(b) respectively)

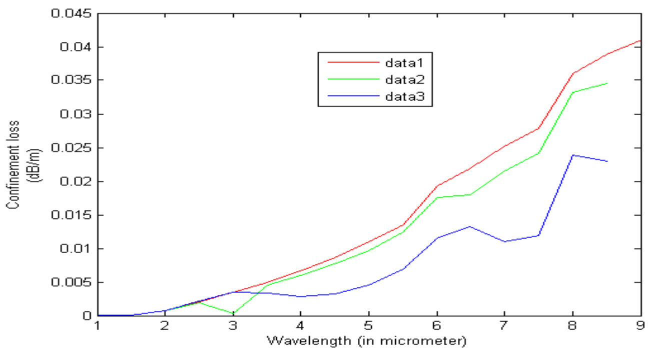

Fig. 7 The curve between confinement loss and wavelength. (Data1, data2 and data3 represents the structure of Fig. 1(b), 2(b) and 3(b) respectively).

IV. CONCLUSIONS

In this paper we have proposed some novel PCF structures whose geometries are derived from Dolph Tschebesheff polynomials (DTP). It is observed that the proposed structures exhibit almost negligible waveguide dispersion behaviour over a very large wavelength range and the order of dispersion of the PCF structures based on DTP is same as that of the PCF structures based on PT. These structures are therefore suitable candidates for applications demanding such behaviour such as long distance optical communications or high data rate data transfer applications. The birefringence of the structures based on DTP is, however, more than the structures based on PT**.** The confinement losses in the proposed structures here is slightly more than the losses in the PCF structures based on PT**.**

REFERENCES

[1]. J. C. Knight, J. Broeng, T. A. Birks, and P. S. J. Russell, "Photonic bandgap guidance in optical fibers," Science, vol. 282, pp. 1476-1478, Nov. 1998.

[2]. J. C. Knight, P. S. J. Russell, "Photonic crystal fibers: new ways to guidelight," Science, vol. 296, pp. 276-277, Apr. 2002.

[3]. K Suzuki, H. Kubota, S. kawanishi, M. Tanaka and M. Fujita, "Opticalproperties of a low-loss polarization-maintaining photonic crystal fiber", Opt. Express, vol. 9**,** pp. 670-676, July 2001.

[4]. T. A. Birks, J. C. Knight, and P. S. J. Russell, "Endless single-mode photonic crystal fiber," Opt. Lettl., vol. 22 , pp. 961-963, July1997

[5]. T. Matsui, J. Zhou, K. Nakajima, and I. Sankawa, ''Dispersion flattened photoniccrystal fiber with large effective area and low confinement loss," J. Lightw. Technol., vol. 23, pp. 4178–4183, Dec. 2005.

[6]. N. Florous, K. Saitoh, and M.Koshiba, ''The role of artificial defects

[7]. For engineering large effective mode area, flat chromatic dispersion, and low leakage losses in photonic crystal fibers: Towards high speed reconfigurable transmission platforms,'' Opt. Exp. , vol. 14, pp. 901-913, Jan. 2006.

[8]. S. Yang, Y. J. Zhang, X. Z. Peng, Y. Lu, and S. H. Xie, ''Theoretical study and experimental fabrication of high negative dispersion photonic crystal fiber with large area mode field,'' Opt. Exp., vol. 14, pp. 3015-3023, Apr. 2006.

[9]. S. M. A. Razzak and Y. Namihira, ''Proposal for highly nonlinear dispersion-flattened octagonal photonic crystal fibers,'' IEEE Photon. Technol. Lett., vol. 20, pp. 249--251, Feb. 2008.

[10]. Y. Hai-Feng, YU Zhong-Yuan, L. Yu-Min, T. Hong-Da H . Li-Hong "Novel Propagation Properties of Total Internal Reflection Photonic Crystal Fibres with Rhombic Air Holes"Chin. Phys. Lett., vol. 28, no. 11(2011) 114210.

[11]. Ritu Sharma ,Vijay jaynyani , Rahul gupta "Effect of wafer dimension on the mode profile in PCF" International Journal of Recent Trends in Engineering, vol2,no. 6,November 2009.

[12]. Ritu Sharma, Vijay Janyani, Anuradha Sharma " Design of Elliptical Air Hole PCF with Hybrid Square Lattice for High Birefringence and a Lower Zero Dispersion Wavelength", International Journal of Computer Science & Emerging Technologies , vol. 2, Issue 2 , pp.283-241, April 2011.

[13]. C.A .Balanis , Antenna theory analysis and design, 2nd edition, John Willey and Sons , Inc. , 1997.

[14]. Mann M Shaker, Mahmood Sh Majeed, Raid W. Daoud "A new approach for representing photonic crystal fiber index profile to determine their optical characteristics" 2010 1st International Conference on energy, power and control, Basrah,Iraq, Nov. 30-Dec. 2,2010

[15]. John D. Joannopoulos, Steven G. ohnson, Josgua N. Winn, Robert D. Mede, Photonic crystal fiber: Molding the flow of light, 2nd edition, Priceton University Press, 2008.

[16]. K.K.Sharma, Pranaw Kumar, "Some novel photonic crystal fiber structures based on Pascal's triangle and their dispersion behaviour" ICECT 2012, Kanyakumari, India, april6-8,2012.

[17]. Razzak, S.m abdur,Namihira, Yoshinori, "Simultaneous control of dispersion and confinement loss with octogonal PCF for communication system", The international conference on electrical engineering 2008, No-064.

[18]. H.Ademgil, S.Haxha, "Highly birefringent PCF with ultralow chromatic dispersion and low confinement loss", Journal of light wave technology,vol 26,no 4,feb 15, 2008.