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Analysis of Effective Mode Index and its mode coupling in Three Core Linear Fibre Waveguide

Muppidathi@Saravanan.A, Hemadevi.N, Ayyanar.N

Abstract— **We investigate the various modes distribution and its mode index for various wavelength and propagation constant characteristics at three core fibre in linear waveguide structure and also measure the radial field pattern of fundamental modes and its higher order modes. The main optical characteristics such as dispersion are optimized to zero value order at the wavelength range of 1.45 to 1.6 µm. In conventional single mode fibre the dispersion has the values of 16 ps/nm/km at third window 1.5 µm and the zero dispersion is achieved at 1.3 µm with loss of attenuation coefficient and this loss coefficient is minimized by shifting the dispersion factor to the low attenuation coefficient at 1.5 µm. Here the entire wavelength range from1.45 to 1.6 µm has maintained with zero dispersion for three spatial core fibres.**

Index Terms- **Dispersion, Fibre, Optical Communication, Refractive index.**

I. INTRODUCTION

To satisfy the requirement of long transmission here mode division multiplexing system has been attracted as new generation optical fibre communication system. The mode multiplexing system is also called as spatial division multiplexing[1] with respect to mode field pattern and the scaling of bandwidth with high capacity. By the help of mode division multiplexing [2] conjugation with wavelength division multiplexing is rarely considered for integrated photonics. Because of the difficulty in coupling selectively to high order modes here we design three core single cladding fibre structures to transmit the data either in fundamental mode and its higher order modes. Each mode will travel with different velocity since differential mode delay (DMD) [3] is a measuring factor to compensate model dispersion. The fibre is created in linear waveguide structure the individual index profile is generated in radial distance each profile has been analyzed as three core with single cladding in supporting of fundamental modes. To create further higher order modes in general internal and external method is used where internal mechanism is distinguished over external mechanism.

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A.Muppidathi@Saravanan, *Department of ECE, Alagappa Chettiar College of Engineering and Technology , Karaikudi , Tamilnadu, India.*

N.Hemadevi, *Department of ECE, Alagappa Chettiar College of Engineering and Technology , Karaikudi , Tamilnadu, India.*

N.Ayyanar, *Department of ECE, Alagappa Chettiar College of Engineering and Technology, Karaikudi,Tamilnadu, India.*

In simple increasing of fibre diameter leads to support higher order modes along with fundamental modes and for external spatial light source is used to excite the higher order modes. But here the internal mechanism has been followed hence we could approach second order and third order mode etc., with adjustment of core thickness.

II. THEORETICAL BACKGROUND

In general there are lot of fibre types depending upon the refractive index profile and radial mode distribution. The major type of on optical fibre is conventional optical fibre and photonic crystal fibre. In long distance communication conventional fibre is involved in which single mode fibre [4] is the most preferred optical medium and similarly for short term communication [5] multimode fibre is the desired one. In respect of photonic crystal fibre which is used as optical component application to induce the nonlinear properties, laser and super continuum generation. In conventional fibre the major difference between one fibre to another fibre model is refractive index profile. It is the function of refractive index verse radius of the optical fibre. Many modifications has to be done on the refractive index profile to optimize the various parameter as dispersion, attenuation, confinement factor, group delay for desired application. In previous work they have done optimization of high negative dispersion through the adding of cladding layer and by varying the core diameter the number of modes generation will be restricted from the higher order modes. In similar way here we have design three core fibre model as made up of some variation in index profile which has three regions as a core of 1.45 refractive indices, diameter of 12µm and outer cladding boundary. In the modified step index profile has been generated of three fundamental modes. Each has same propagation constant and group velocity. To increase the mode order in further we could adjust the core size [6]. Along with that mode coupling also be achieved by reducing the distance between the core layers.

III. DESIGN OF REFRACTIVE INDEX PROFILE

The index profile of the fibre decides about all optical characteristics such as group delay, dispersion, splice loss, attenuation loss, effective mode index and propagation constant. each types of fibre has its own index profile which gives the various information to the desired application .to construct the index profile for the respective fibre two main parameter has been involved. In general index profile has two region core and cladding respectively .the refractive index for the both region has been denoted by n_1 and n_2 where n_1 is the refractive of core,n_2 is the refractive index of the cladding(n_1>n_2), with adding of further region either core and cladding we could optimize the main parameters as we concerned for the different application. Here the linear waveguide structure based fibre is created with three core and single cladding. Since the corresponding index profile has been showed below.

In figure refractive index of core and cladding have different values. Core and cladding have the refractive index value 1.45 and 1.44 respectively and index difference [7] is 0.01 and the expression (1) is given by

$$\Delta_2 = (n_1 - n_2)/n_1 \quad \text{---------- (1)}$$

Where n_1 is the refractive index of the core

n_2 is the refractive index of the cladding

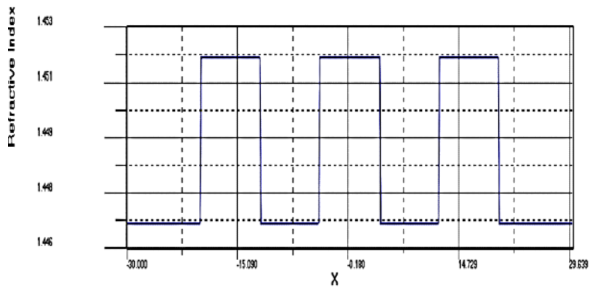

Fig.1.Refractive index profile with radial distance

IV. FIBRE DESIGN LAYOUT

The main layout has considered here as planar structure and the linear waveguide approximation takes place in order to create a three core spatial model, the wafer properties has been involved with TE polarization, BPM solver, finite difference engine and boundary condition .the wafer dimension is specified with dimension of length is 1000µm and width is 80µm. The core and cladding total thickness is 30 µm here the cladding could be constructed as material cladding and substrate cladding to differentiate layout and substrate parameters. The figure 2 as shown in below,

Fig.2. Layout structure of tricore fibre model

Refractive index of the core n1=1.45, $|r_1|$<9µm

Refractive index of the cladding n2=1.44, $|r_2|$<20µm,

The pulse propagation pattern in radial and cross sectional has been shown from figure 1, 2 respectively. The entire model has been designed with help of OptiBPM tool product by Optiwave Corporation.

V. MODE GENERATION IN TRI CORE FIBRE

The radiation field results from the optical power radiated from the core to cladding, Hence modes will appear in cladding. Mode coupling will be appears in higher order core modes because of electric field refracted to cladding region. If β values lies in between this condition $n_2k<\beta<n_1k$means, guided modes will appear.

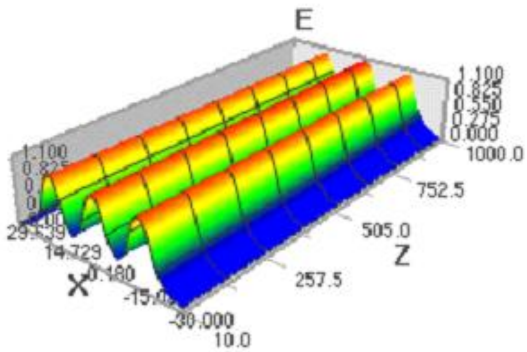

Fig.3. Pulse Propagation in 3D view on planar structure

If β values equal to n_2k means guided modes will not appears. Therefore unguided modes appear below the values of n_2k. The no of modes can be calculated from the parameters M which is given by [8],

$$M = M = v_2/2 \quad \text{--------- (2)}$$

Where v is the V number which has been related to the mode counting as follows [9]

$$V = 2\pi a(NA)\lambda \quad \text{-------- (3)}$$

Where,

a - radius of the fibre

NA - numerical aperture, λ - wavelength

Here, after drawing the layout structure on the planer substrate, the corresponding result is taken into consideration. The main relative result analysis will be the fundamental mode distribution and its coupling characteristics and each mode has in transverse direction to the propagation of light pulse. From the figure 3 we could notice that three possible fundamental modes [10] (LP01) is generated as follows, Figure 4 shows that each mode is generated for the constructed core region and the spatial distribution pattern is developed according to the width of the core region as well as refractive index of the core. Here mode degeneration is also takes place with the adjustment of core radius and the mode generation will be modified by varying the core size as well as thickness. Since, the V number is calculated as per the above expression (3).

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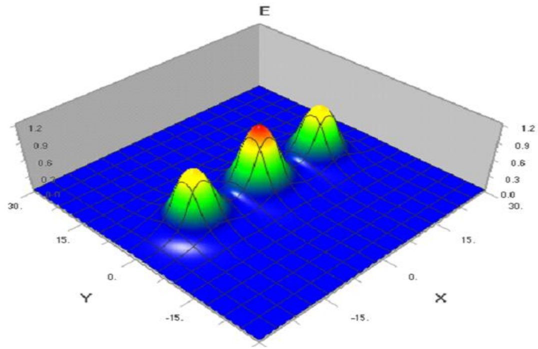

Fig.4. Mode generation in tricore fibre

The fundamental modes will be clarified with high order modes once it starting its traverse through the optical axis. The axis at which the light as pulse is propagated ,the another high order modes has been also discussed for the respective change in core diameter , if increase the mode number the mode delay parameter is to establish to deal about intramodal dispersion which will be accounted by DMD parameter (Differential Mode Delay). For mode division multiplexing with short term distance we could prefer few mode fibre such as fundamental mode and its high order modes around 4 to 5 whereas for long term communication we would say that the fundamental mode alone will be the effective way of approaching since it has low delay as well as zero dispersion at the third window communication.

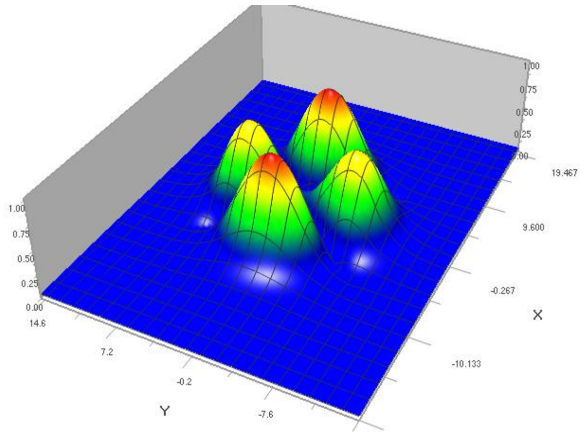

Fig.5. higher order propagation of modes with varying core size

Here figure 5 gives the modal distribution with varying core diameter from 12 to 14 µm and also shown there will be chance of mode coupling between those modes .the mode coupling could be achieved by placing the two waveguides in close proximity or by adjusting the distance between the two region either core by core or core by cladding respectively.

From the figure 6 the mode spatial cross section for the three core spatial fibre is analyzed as below, And its corresponding mode coupling plot will be shown in perceptual view in 3D as well as cross and near filed pattern with function of effective mode index.

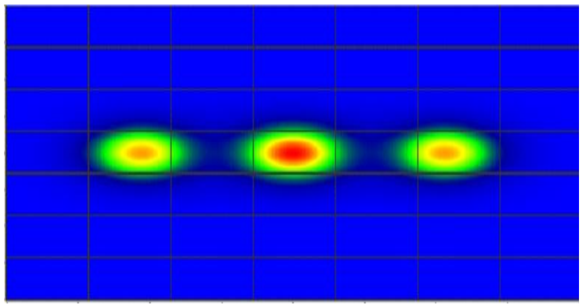

Fig.6. Cross sectional view of the three core fibre

The filed pattern with normalized by effective mode index is shown by

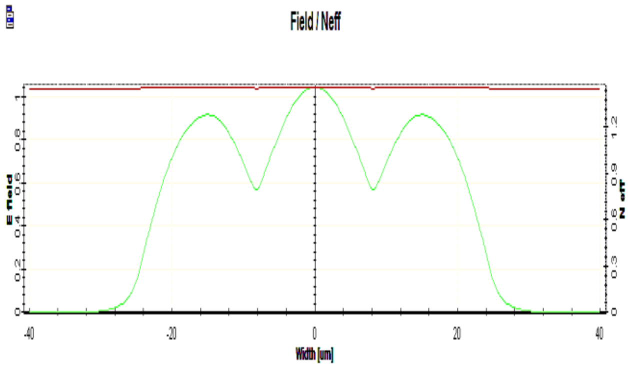

Fig.7. Field distribution of coupled mode along the optical axis

As per shown figure 7 is given by each peak intensity distribution is correlated by the another field of the mode, so with that proximity we might ensure that the mode coupling is taken place as response of core- cladding width modifications. The exact spatial pattern for mode coupling is shown as follows,

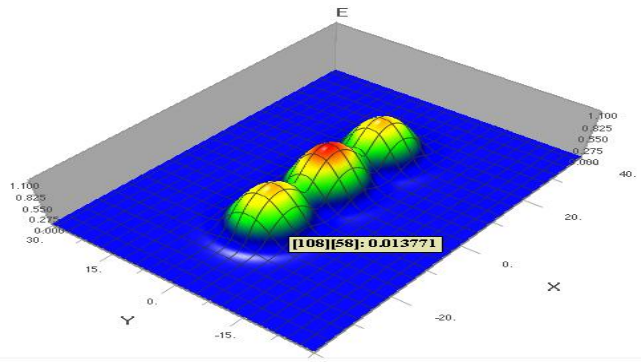

Fig.8. Mode coupling between the core regions

The mode coupling can also be defined as the uniform effective mode index for the any region is same with function of wavelength. Here transverse pattern gives as that each mode is to chance of coupling in further. Hence by calculating the effective mode index for each mode with function of wavelength, the exact mode coupling at wavelength regime is being found out.

VI. EFFECTIVE MODE INDEX AND PROPAGATION CHARACTERISTICS

The mode generation through the fibre is radially symmetric with central core axis. Each mode has its own spatial pattern and field propagation, LP01 is preferred over other modes due to having of high peak power distribution around the core axis. The filed distribution and evanescent filed is analyzed by the parameters known as effective mode index. Each mode (fundamental mode and its higher order modes) has its own refractive index since varying velocity in the propagation medium. That effective mode index can also be varied with function wavelength; here we plotted the variation of mode between one core to another to study about the leaky modes. Hence we measured and analyzed that no leaky modes not being contribute to the pulse propagation which could be shown as follows,

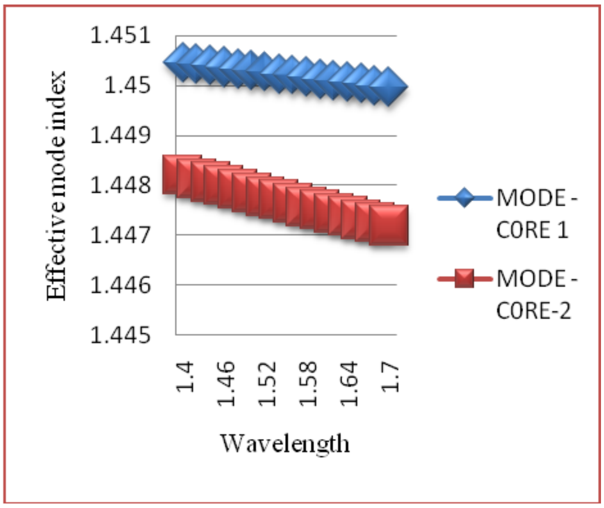

Fig.9. Variations of effective mode index vs. wavelength

From the above figure 9 the effective mode index is linearly decreasing since the velocity is increased as far from the starting point of the optical axis. If effective mode index gets reducing as wavelength increases the corresponding modal distribution is rising to the end point of the linear waveguide structure. The effective mode index is the basic parameter to calculate the propagation characteristics and dispersion parameter. The n_{eff} [11] is related to above parameters as shown below,

$$\beta = 2n_{eff} / \lambda - - - - - - - - (4)$$

Where, β – propagation characteristics,

λ - Operational wavelength.

The dispersion parameter [12] is related by,

$$D = -2\pi c \beta_2 / \lambda^2 \qquad \text{------- (5)}$$

Where,

C is velocity of light in free space

β_2 second order dispersion in frequency domain or group velocity dispersion. The corresponding calculated values with plot is following,

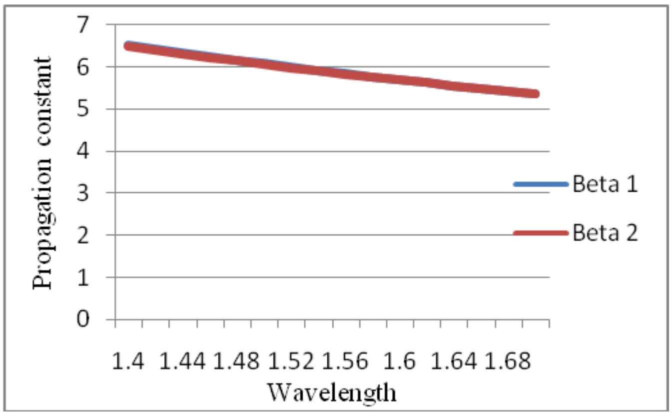

Fig.10.Variation of propagation characteristics vs. wavelength

Here the propagation characteristics are same for both cores due to having of only fundamental modes LP_{01} thorough out the optical axis. The dispersion plot could also be discussed as follows,

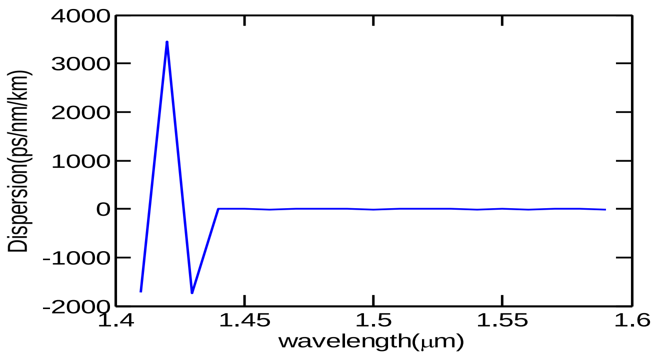

Fig.11.Dispersionvs. wavelength

Figure11 shown to us that the dispersion will be optimized to zero order at the wavelength range for 1.45µm to 1.6µm hence the third window has the major role in spatial division multiplexing long haul communication as well low loss coefficient.

VII. Conclusion

Thus, the tricore fibre has been successfully designed with the help of OptiBPM. Moreover, in this paper we have analyzed the effective mode index, dispersion, and propagation constant all varies with respect to the wavelength. In addition, we have also achieved zero dispersion at third window frequency range and therefore the entire wavelength range from1.45 to 1.6 µm.

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A.Muppidathi@Saravanan received a bachelor's degree in electronics and communication engineering from PSNA College of Engineering and Technology, Dindigul, Tamilnadu, India. He is pursuing his master's degree in Optical Communication from Alagappa Chettiar College of Engineering and Technology. He is working in the area of optical fiber communication. He is a member of OSA. He has published 2 research papers in reputed international journals and presented 2 research papers in national and international conferences.

N. Hemadevi received a bachelor's degree in electronics and communication engineering from Cauvery College of Engineering, Trichy, Tamilnadu, India. She is pursuing her master's degree in Optical Communication from Alagappa Chettiar College of Engineering and Technology. She is working in the area of optical fiber communication. She has presented 1 research paper in international conference.

N.Ayyanar received a bachelor's degree in electronics and communication engineering in Tamilnadu, India and a master's degree Optical communication from Alagappa Chettiar College of Engineering and Technology. He is working in the area of optical fiber communication and Fibre Optic Sensors.