International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-2 Number-3 Issue-5 September-2012

An Efficient Wavelength variation approach for Bend Sensing in Single mode-Multimode-Single mode Optical Fiber Sensors

Abdul Samee Khan[1], Mohd. Sarwar Raeen[2]
All Saints' College of Technology, Bhopal[1,2]

Abstract

Several aspects of the SMS edge filters have been investigated, including the effect of bending the SMS fiber cores due to fabrication tolerances, polarization dependence, and temperature dependence. These aspects can impair the performance of a wavelength measurement system. There are several approaches which have been proposed and demonstrated to achieve high resolution and accuracy of wavelength measurement. Bending effects due to the splicing process on the spectral characteristics of SMS fibre structure-based edge filters are investigated experimentally with the help of MATLAB. A limit for the tolerable of the cores of an SMS fibre structure-based edge filter is proposed, beyond which the edge filter's spectral performance degrades unacceptably. We use Wavelength variation approach by which we reduce the power loss due to the bending in the optical fiber. Due to the power loss the power transmission is increases and efficiency reduces. So by wavelength variation approach we developed an efficient spectrometer capable of performing a wide variety of coherent multidimensional measurements at optical wavelengths. In this approach we fixed the power and perform variation in the wavelength to sense the bending accurately. The two major components of the largely automated device are a spatial beam shaper which controls the beam geometry and a spatiotemporal pulse shaper which controls the temporal waveform of the femtosecond pulse in each beam. By which we sense the distortion to reduce the power transmission. We apply our algorithm for performing several comparison considerations which shows the performance of our algorithm which is better in comparison to the previous work.

Keywords

Single mode Fiber, Multi-Mode Fiber, Power Loss, Bending

1. Introduction

Optical switching is considered one of the key functions in optical networking and communication applications. Power transformers are designed to transmit and distribute electrical power. Performing offline and invasive tests also add to the replacement cost. Hence, there is an increasing need to move from traditional schedule-based maintenance programs to condition-based maintenance. Various structures can be utilized for this purpose. However, most of these structures are suitable for working over narrow wavelength band. Designing an integrated optical switch that is capable of working over the different wavelengths of the optical communication systems without significant performance deterioration is of prime importance. The fabrication cost of optical systems can be reduced using such a switch.

Single mode multimode single mode (SMS) fiber structures have been investigated for use in several applications, e.g., as a refractometer, a band pass filter, and an edge filter [1][2][3][4]. An optical device based on the SMS fiber structure offers an all-fiber solution for optical communications and optical sensing applications with the advantages of simplicity of packaging and ease of interconnection to other optical fibers. Multimode interference-based devices (MMI) are considered suitable candidates for this application. MMI devices are utilized in different optical processing applications. This is mainly due to their wide wavelength band, ease of fabrication and integration, and fabrication tolerance. MMI devices have been utilized as optical power splitters, combiners, optical hybrid couplers, multiplexers, and demultiplexers [5][6][7][8][9].

Several aspects of the SMS edge filters have been investigated, including the effect of misalignment the SMS fibre cores due to fabrication tolerances, polarization dependence, and temperature dependence. These aspects can impair the performance of a ratiometric wavelength measurement system. Several approaches have been proposed and demonstrated to achieve high resolution and accuracy of wavelength measurement. Misalignment effects due to the splicing process on the spectral characteristics and PDL of SMS fibre structure-based edge filters are investigated numerically and experimentally. A limit for the tolerable misalignment of the cores of an SMS fibre structure-based edge filter is proposed, beyond which the edge filter's spectral performance degrades unacceptably. In this paper we analyse several aspects and then apply our algorithm for overcome the problems.

The remaining of this paper is organized as follows. We discuss MMI in optical fibre Section 2. In Section 3 we discuss about beam propagation analysis. The Evolution and recent scenario in section 4.In section 5 we discuss about proposed approach. The conclusions and future directions are given in Section 6. Finally references are given.

2. MMI in Optical Fibre

MMI is a useful basis for the implementation of a number of optical waveguide devices. MMI was investigated and proposed at first for planar waveguides. MMI based devices implemented in planar waveguides have been developed for optical signal processing applications and for optical sensing applications.

A useful basis for visualizing and gaining a better understanding of MMI in a multimode waveguide is the phenomenon of self-imaging. Self-imaging can be defined as a property of multimode waveguides by which an input field profile is reproduced due to constructive interference to form single or multiple images of the single mode input field at periodic intervals along the propagation direction.

In an optical fibre, MMI can be implemented using a fibre hetero-structure consisting of a single mode-multimode-single mode (SMS) fibre structure with a step index profile. An SMS fibre structure can be fabricated by splicing a precisely dimensioned multimode fibre (MMF) section between two singlemode fibres (SMFs). Figure 1 shows a schematic diagram of an SMS fibre structure. SMS fibre structures can utilize either a step index or a graded index profile MMF. SMS structures using a graded index profile MMF section have been demonstrated by several authors where the effects of beam interference were investigated and micro bend, strain, and temperature sensors were demonstrated.

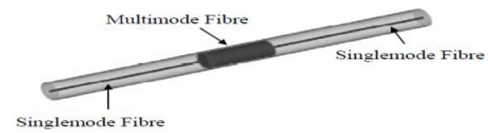

Figure 1: SMS fibre structure

The general requirements for an ideal discriminator in a wavelength measurement system are as follows: 1) high resolution (better than 10 pm) and high accuracy, 2) high measurement speed to allow measurement of dynamic strain, and 3) cost effectiveness. In addition a wide wavelength range (> 10 nm) is needed where wavelength division multiplexed FBGs are used.

3. Beam Propagation Analysis

The core aim of this research is to investigate all-fibre multimode interference (MMI) devices based on a graded index single mode-multimode-single mode (SMS) fibre structure for use as (1) a new type of edge filter for a ratio metric wavelength measurement system and as (2) sensors for bending sense. The MMF section can support many guided modes and the input field is reproduced as single image at periodic intervals along the propagation direction due to the interference between these guided modes. This is the so-called self-imaging principle and the distance at which self-imaging occurs is called the reimaging distance. The approach used here to analyze the field distribution in the MMF section is a beam propagation analysis.

To design the SMS-based edge filter, the MMF length needs to be determined. It has been shown that the re-imaging distance is wavelength dependent. If re-coupling into the output SMF takes place at the reimaging distance, then the MMF section of the SMS structure has by definition a length equal to the re-coupling distance and operates as a band pass filter. However, for the purpose of designing an edge filter, the band pass response can be considered as two spectral responses, on the either side of a center wave length. Consequently, the device can behave as an edge filter for a selected wavelength range. Two SMS-based edge filters with opposite slope spectral responses within a given wavelength range can be obtained by choosing two band pass filters with appropriate center wavelengths.

Multimode fiber optic cable has a large diametric core that allows multiple modes of light to propagate. Because of this, the number of light reflections created as the light passes through the core increases, creating the ability for more data to pass through at a given time. Because of the high dispersion and attenuation rate with this type of fiber, the quality of the signal is reduced over long distances. This application is typically used for short distance, data and audio/video applications in LANs. RF broadband signals, such as what cable companies commonly use, cannot be transmitted over multimode fiber. Multimode fiber is usually 50/125 and 62.5/125 in construction. This means that the core to cladding diameter ratio is 50 microns to 125 microns and 62.5 microns to 125 microns.

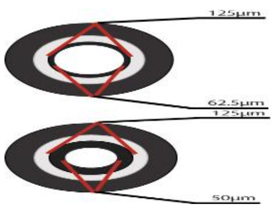

Figure 2: Multimode Construction

Graded-Index Multimode Fiber - Contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Due to the graded index, light in the core curves helically rather than zigzag off the cladding, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: digital pulse suffers less dispersion. This type of fiber is best suited for local-area networks.

4. Evolution and Recent Scenario

In 2008, Qian Wang et al. [11] present an investigation on a single mode multimode–single-mode fiber structure. A one-way guided-mode propagation analysis for the circular symmetry waveguide is employed to model the light propagation and the approximated formulations are derived and evaluated concerning the accuracy. Phase conjunction of the multimode interference within the fiber structure is revealed. A simple way to predict and analyze the spectral response of the structure is presented through the space to wavelength mapping with the derived approximated formulations. The prediction of spectral response is verified numerically and experimentally.

In 2009, Agus Muhamad Hatta et al. [13] study about Misalignment effects on the spectral characteristics of edge filters based on single mode–multimode–single mode (SMS) fibre structures are investigated numerically and experimentally. A beam propagation analysis is used with a set of guided modes calculated using the finite-difference method to determine the transmission loss of the SMS-based edge filters. A limit for the tolerable misalignment of the SMS fiber-based edge filter is proposed, beyond which the spectral performance of the SMS structure degrades unacceptably. The numerical results are verified experimentally with good agreement.

In 2011, Ahmed Hisham Morshed et al. [14] repots multimode interference in optical waveguides has interesting self-imaging properties, which have extensively been investigated and utilized in many integrated optical devices. Although these investigations started with most interest in step index integrated waveguides, they have later included graded index waveguides, where the dependence of the interference images on the refractive index grading of the waveguides was observed and utilized in the design and optimization of devices. Later on, multimode interference has also been explored in optical fibers in order to realize fiber devices, including sensors. A basic structure of these devices has been the Single mode Multimode Single mode (SMS) fiber section concatenation, where multimode interference in the multimode section leads to the formation of a self-image of the single mode fiber excitation onto the output single mode fiber core.

5. Proposed Approach

After a deep observation and study of all the related research we observe that the bending sense in the optical fiber is not appropriate. The analysis is not better in the previous research, so the calculated efficiency is also not correct. So in our proposed approach we change the arrangement of the sensor. We apply bending sensor in both of the side which is transmitter and the receiver side. So we can calculate the actual observation of the power loss and which is comparable.

Self-imaging in symmetrically excited multimode optical fibers is analytically studied to explore the effects of refractive index grading on SMS fiber device characteristics. The operation of the SMS

structure explored here as a bending sensor by monitoring the optical power transmitted through the structure under static bending was difficult to achieve due to the fast beating spectral transmission peaks.
The power transmission spectra of the device under different bending conditions were measured and its operation as a bending sensor was investigated. The transmitted power spectra of the structure were measured using a broadband source and an optical spectrum analyzer and using the power spectrum measured without the structure; its transmission spectra were extracted and normalized to the maximum transmission value. So in our approach we consider the power as the constant factor and wavelength as a variable to sense more bending in comparison to the previous study.

In our proposed approach we taken 1000 samples then we count the refract min and refract max boundaries as a parameter. Then find the propagation constant. Then we apply different propagation constant which is shown below:
Propagation for

$$\text{BPM} = \frac{X_2(-x_1) - x_2.90(x_1^2) - 882(x_1)^{4+2598(x1)}}{X_1^2 + 651x_2}$$

$$\text{Propagation constant} = \frac{0.23r^6 + r^3 + r^2}{\lambda^3}$$

For sampling we produce a flowchart which is shown in Figure 3.

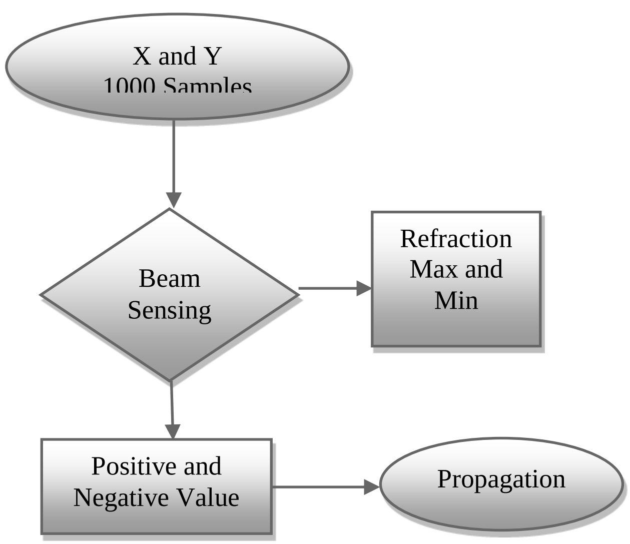

Figure 3: For Sampling

After that we apply the propagation that is laser propagation technique. Where we take maximum positive value and according to the requirement reduce to the lowest maximum so that to achieve the ideal observation.

$$\text{Laser coding:- Propagation power} = \frac{0.23\ r6 + \lambda^2}{C^2 + r^2 + r^6}$$

Where c = proportion constant

$$\text{Propagation function } f(y) = \frac{[f(x_1) + \alpha_1][f(x_2) + \alpha_2]}{f(x_1) + f(x_2)}$$

Where α_1 & α_2 are attenuation constant
Propagation constant $\gamma = 2\pi e^{-\lambda/2}$
$|\,power| = Ae^{-X/W^2}$
$|\text{Power}| = A \times e^{-x/w_0^2}$
Where
X_1 & x_2 are the limit
A= Amplitude =1
W_0= wavelength = 8
Propagation constant $\gamma = (n \times 2 \times \pi)/\lambda$
$\gamma = 2\pi/\lambda$
$|\text{Power}| = A \times e^{-(x+x_0)/w_0^2}$
Where , $w_0= 3\ e^{-6}$ & $X_0= 7\ e^{-6}$
For explaining our beam sensing and bending moment for the parabolic index we present an algorithm.

```
Algorithm:
Step 1: for j = 1:1:num_samples
Step 2:   if (x(j) >= x1) & (x(j) <= x2)
        n(j) = nmax;
    elseif (x(j) >= x3) & (x(j) <= x4)
        n(j) = nmax;
    else
        n(j) = nmin;

Step 3: for j = 1:1:num_samples
Step 4:  if (j >= 400) && (j <= 600)
        od(j) = 0;
    else
        od(j) = 3500;
Step 5: Print the value based on the formulla exp(-(od + i*(n -
nbar)*k0)*deltaz);

Step 6: for k = 0:1:zmax/10
Step 7:for j = 1:1:10
            modo = ifft((fft(modo).*Result1)).*Result 2;
        zz(k+1,:) = abs(modo);
 Step 8:[Comparison]
Step 9:eps0 = 1/(c0)^2/mu0;
Step 10: eta0 = sqrt(mu0/eps0);
Step 11:freq = c0/(lamda);
Step 12: In spite of the relatively small difference in the value
of the interference patterns and transmission spectrum
obtained are notably different.
```

A projection pattern with many beating sub-images, having different strengths in a cyclic strength pattern is observed. The difference between the values of the maxima and minima of transmission is much larger than the parabolic-index fiber case, exceeding 10 dB. So we consider the ranges in the positive direction. The transmission of the structure has maximum values very near to unity as well, but occurring only at the self-imaging positions, which repeat every specific number of beating sub-images. Then we produce a flowchart for the beam sensing for parabolic index which is shown in Figure 4.

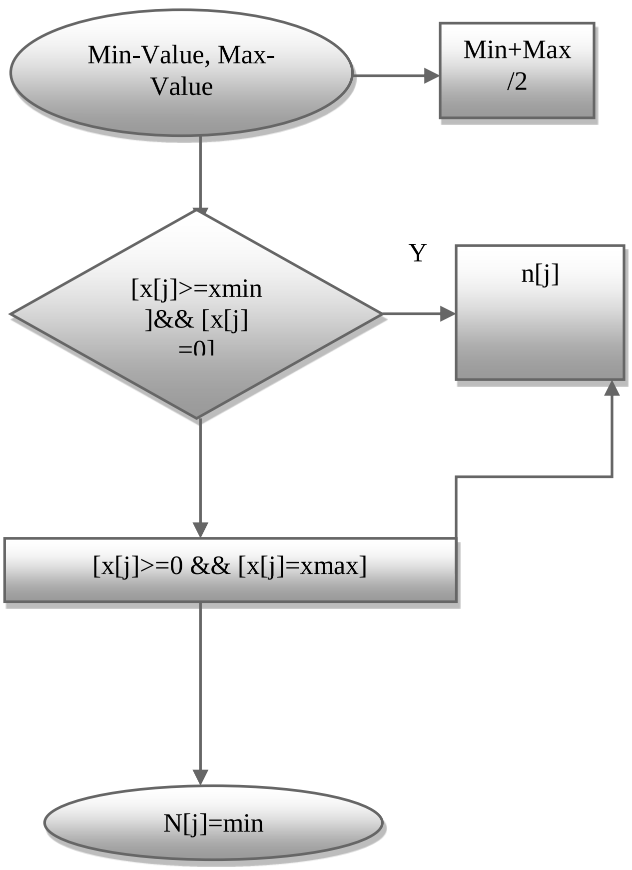

Figure 4: Beam sensing for parabolic Index

An SMS fibre structure has been shown to be an effective approach for both the interrogation of optical fibre and for the development of new sensor types. By comparison to other edge filter for use in an interrogation system for an FBG, several advantages have been demonstrated such as the ability to implement X-type edge filters responses. Several successful sensors implementations have also been demonstrated and the potential exists for other sensing applications, for example for vibration sensing, bend sensing, and refractive index sensing. Finally, the use of MMI for sensing has been proved which potentially expands the range of applications for other photonic devices that are based on MMI. Overall, the work has expanded and improved understanding and knowledge of optical sensing, for a diverse range of potential applications, including structural health monitoring, industrial processes and power system measurement.

The step by step process is shown below:

where $h = z_j - z_{j-1}$ and $L_j = \sqrt{\partial_x^2 + k_0^2 n^2(x, z_j)}$.

$$w = \sum_{k=1}^{q} \alpha_k v_k \quad \text{for} \quad (1 + \beta_k X_{j-1/2}) v_k = u_{j-1}$$

$$u_j = w + \sum_{k=1}^{p} d_k r_k \quad \text{for} \quad (1 + c_k X_j) r_k = X_j w.$$

$$u_j = L_j^{-1} L_{j-1/2} e^{ihL_{j-1/2}} u_{j-1},$$

$$\ell_1^+(r, s, \xi) = \sqrt{k^2\gamma^2N^2 - \gamma^2\xi^2 + i\gamma N^2 \partial_r(\gamma N^{-2})\xi},$$

$$\widetilde{L}_1 = \sqrt{\gamma N^2 \partial_r \left(\frac{\gamma}{N^2}\partial_r \cdot\right) + k^2\gamma^2N^2}.$$

$$\widetilde{L}_{2,2} = \widetilde{L}_1 + \frac{i}{2}\gamma N^2 \widetilde{L}_1^{-1} \partial_s \left(\frac{1}{\gamma N^2}\widetilde{L}_1\right).$$

$$E(r, 0) = \sum_{m=1}^{M} c_m F_m(r).$$

Whre C_m is the excitation coefficient of each mode nad it can be calculated by the overlap integral between E(r,0) and $F_m(r)$.

$$c_m = \frac{\int_0^\infty E(r, 0) F_m(r) r dr}{\int_0^\infty F_m(r) F_m(r) r dr}.$$

The excited mode number of the LP_{0m} multimode fiber M is approx V/ Π where $V=\{2\Pi/\lambda\}$ a $\sqrt{n^2_\infty - n^2_d}$. Where a is the radius of the multimode fiber core. n_∞ and n_d is refractive index for the core and cladding of the multimode fiber respectively and λ is the wavelength in the free space.

$$E(r, z) = \sum_{m=1}^{M} c_m F_m(r) \exp(i\beta_m z).$$

$$L_s(z) = 10 \log_{10} \left(\left| \sum_{m=1}^{M} c_m^2 \exp(i\beta_m z) \right|^2 \right).$$

For a step-index multimode fiber,it is known the propagation constant of the mth mode can be approximated by:

$$\overline{\beta}_m \approx k_0 n_{co} - \left(2m - \frac{1}{2}\right)^2 \frac{\pi^2}{8 k_0 n_{co} a^2}$$

Where K_0= 2Π/λ

Substituting the approximate propagation which is

$$E(r, z) = \exp(\beta_1 z) \sum_{m=1}^{M} c_m F_m(r) \times \exp\left(-i\left(\frac{(2m+1)(2m-1)\pi}{L_z}\right) z\right)$$

Where $L_z = 16 n_{co} a^2 / \lambda$

In practical application the common phase factor (exp ($\beta_1 z$)) can be dropped. Correspondingly , with the approximation of propagationconstants, the transmission of SMS fiber structure can be calculated by

$$L_s(z) = 10\log_{10} \times \left(\left| \sum_{m=1}^{M} c_m^2 \exp\left(-i \left(\frac{(2m+1)(2m-1)\pi}{L_z} \right) z \right) \right| \right.$$

The beat length between the first two eigen modes is:
$L_\Pi = 16\ n_\infty a^2 / 10\lambda$

The result for beam sensing in multimode fibres are shown in Figure 5, 6,7. Refracted Index is shown in Figure 5.

$$L_s(\lambda, z) = 10\log_{10} \times \left(\left| \sum_{m=1}^{M} c_m^2 \exp(-i((2m+1)(2m-2)\pi) g(\lambda, z)) \right|^2 \right)$$

Where $g(\lambda,z) = \lambda z / 16\ n_\infty a^2 / 10\lambda$

When the refractive index of multimode fiber is to be change $N_1 = N_0 + \Delta N$, the shift of peak wavelength $\Delta\lambda$ can be calculated by
$\Delta\lambda = -\Delta N / N_0 \lambda_0$

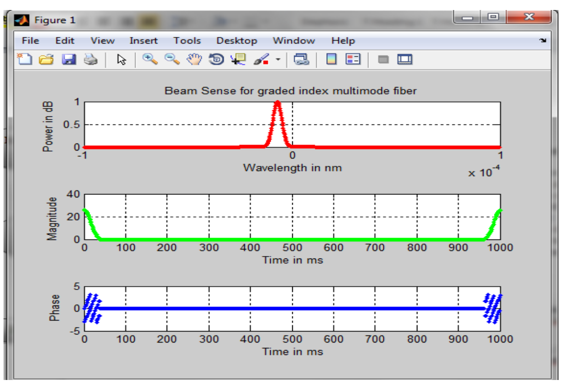

Figure 5: Beam Sense for graded Index

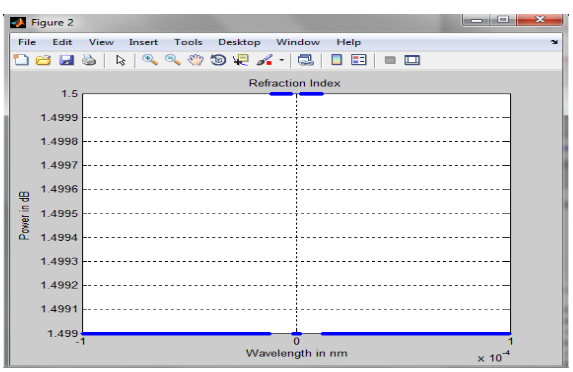

Figure 6: Refractive Index

Without bending is taken or considered from bothe the values which is lower and the higher. The effect of bending on the spectral response of an SMS-based edge filter has been investigated. An MPA with a calculated set of guided modes using beam propagation is employed to analyze the misalignment effect. It is shown that the performance of the SMS-based edge filter degrades when the lateral misalignment is larger than a misalignment limit equal to the core radius of the SMF used. The effect of propagation is shown in Figure 7. It is propagated as multimode graded index.

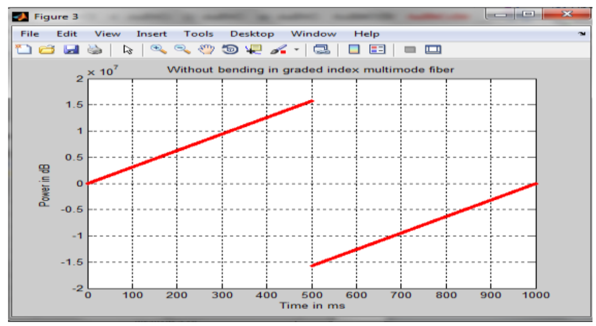

Figure 7: Without Bending in the graded index

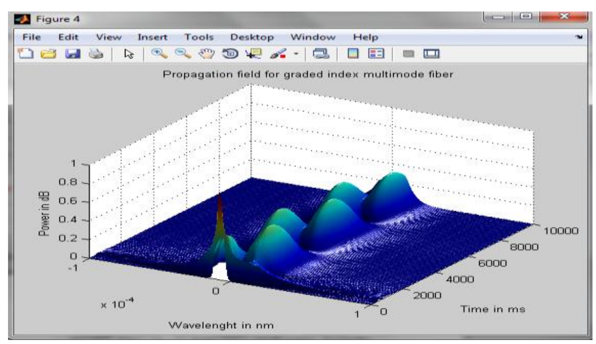

Figure 8: Propagation field for graded index

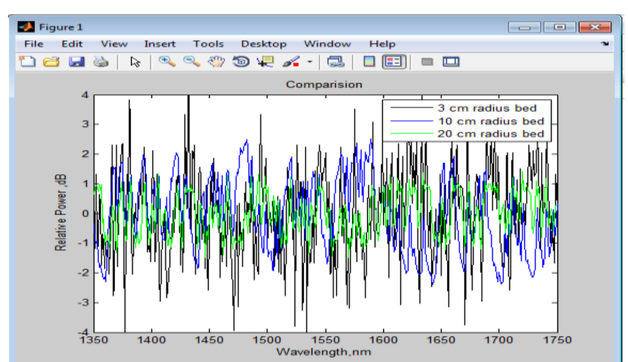

Figure 9: Comparison at different bendings

The first comparison is take place with the lower value so it shows the inclination in the positive direction. Second shows the move in the max or positive value so the inclination is in the minimum positive.

6. Conclusion and Future Directions

Multimode interference in optical waveguides has interesting self-imaging properties, which have extensively been investigated and utilized in many integrated optical devices. Although these investigations started with most interest in step index integrated waveguides, beam propagation they have later included graded index waveguides, where the dependence of the interference images on the refractive index grading of the waveguides was observed and utilized in the design and optimization of devices. But there are several drawbacks including the weak sensing of ben and one sided interference is possible. So we adopt beam propagation with constant power method with two way sensing mechanism which is better adaptation in bend sensing.

References

[1] Q. Wang and G. Farrell, "All-fiber multimode-interference-based refractometer sensor: Proposal and design," Opt. Lett., vol. 31, no. 3, pp.317–319, 2006.

[2] W. S. Mohammed, P. W. E. Smith, and X. Gu, "All-fiber multimode interference bandpass filter," Opt. Lett., vol. 31, no. 17, pp. 2547–2549,2006.

[3] Q.Wang and G. Farrell, "Multimode-fiber-based edge filter for optical wavelength measurement application and its design," Microw. Opt. Technol. Lett., vol. 48, no. 5, pp. 900–902, 2006.

[4] Q. Wang, G. Farrell, and W. Yan, "Investigation on singlemode–multimode–singlemode fiber structure," J. Lightw. Technol., vol. 26, no. 5, pp. 512–519, May 2008.

[5] K. C. Lin and W. Y. Lee, "Guided-wave 1.30/1.55 m wavelength division multiplexer based on multimode interference," Electron. Lett., vol. 32, no. 14, pp. 1259–1261, Jul. 1996.

[6] B. Li, G. Li, E. Liu, Z. Jiang, J. Qin, and X.Wang, "Low-loss 12multimode interference wavelength demultiplexer in silicon-germanium alloy," IEEE Photon. Technol. Lett., vol. 11, pp. 575–577, May 1999.

[7] S. L. Tsao, H. C. Guo, and C. W. Tsai, "A novel 12 single-mode 1300/1550 nm wavelength division multiplexer with output facet-tilted MMI waveguide," Opt. Commun., vol. 232, pp. 371–379, Mar. 2004.

[8] L. B. Soldano and E. C. M. Pennings, "Optical multimode interference devices based on self-imaging: principles and applications," J. Lightw. Technol., vol. 3, no. 4, pp. 615–627, Apr. 1995.

[9] J. Xiao, X. Liu, and X. Sun, "Design of an ultracompact MMI wavelength demultiplexer in slot waveguide structures," Opt. Express, vol. 15, no. 13, pp. 8300–8308, Jun. 2007.

[10] Cicero Martellil , John Canning , "Self-Imaged Omnidirectional Fresnel Fibres Cicero Martellil", COIN - ACOFT 2007 24 - 27 June 2007, Melbourne, Australia.

[11] Qian Wang, Gerald Farrell, and Wei Yan , "Investigation on Single-Mode–Multimode–Single-Mode Fiber Structure", Journal of Light wave Technology , VOL. 26, NO. 5, MARCH 1, 2008.

[12] Mohamed A. Swillam, Mohamed H. Bakr, and Xun Li, "Design Optimization of Compact Wideband Optical Switch Exploiting Staircase Index MMI", Journal of Lightwave Technology, VOL. 27, NO. 2, JANUARY 15, 2009.

[13] Agus Muhamad Hatta, Gerald Farrell, Pengfei Wang, Ginu Rajan, and Yuliya Semenova , "Misalignment Limits for a Singlemode–Multimode– Singlemode Fiber-Based Edge Filter", Journal of Lightwave Technology, VOL. 27, NO. 13, JULY 1, 2009.

[14] A.H. Morshed, Cairo, Egypt, "Self-imaging in single mode –multimode-single mode optical fiber sensors. APRIL 2011.

Mohd. Sarwar Raeen Received the B.E. in Eletronics and Communication Engineering From RGPV Bhopal and M.Tech. In Digital Communication From MANIT Bhopal, India, in 2003 and 2008 Respectively. He is Currently an Associate Professor With the Department Of Electronics and Communications Engineering in All Saints' College Of Technology ,Bhopal,India. From June 2008 To Till Date, He His Professional Research Interests Involve VLSI In Communication And Optical Communication.

Abdul samee Khan recieved the B.E. degree in Electronics and Communication Engineering from Rajiv Gandhi Ptodyogiki Vishwavidyalaya, Bhopal, M.P. India in 2009. Presently he is pursuing here M.Tech. Degree in Digital Communication engineering from Rajiv Gandhi Ptodyogiki Vishwavidyalaya, Bhopal, M.P. India.