Possibility of Minimizing the Effect of Transfer Parameters on the Transmitted Signal in the Spiral Optical Fiber

AL-GAWAGZEH MOHAMMED YOUSEF

Faculty of Engineering, Computer Engineering Department
Balqa Applied University
JORDAN
gogazeh@bau.edu.jo; malgawagzeh@su.edu.sa

Abstract: - This paper will Analyzing the components of dielectric permittivity tensors ε_{ij} according to the parameters and ν in the system of coordinates r, φ.also analyze the dependence of tensor components ε_{ij} on the bending parameters R and ρ for possibility of minimizing the transfer parameters (attenuation and dispersion) . The dependence of attenuation transient in the optical fiber for beating length (1 km) on spiral parameters (curvature and spinning)will be studied also.

Key-Words: - dielectric permittivity, Optical fiber, attenuation transient, anisotropy, bending, spiral.

1 Introduction

Currently, in the optical fiber transmission systems to use the properties of anisotropy which caused by mechanical stress (voltage), it's necessary to have full information about such data as: characteristics of dielectric permittivity tensor, relationship between the ordinary wave HE_{11}^{o} and extraordinary wave HE_{11}^{e},photo elasticity effect on the basic parameters of optical fibers(attenuation and dispersion).then to solve this problem, we require a comprehensive analysis for all properties of fibers under the influence of mechanical stress(voltage).

Optical anisotropy is the dependence of optical properties of the medium on the direction of wave propagation and its polarization due the dependence of the dielectric or magnetic properties of the medium on the direction [1, 8, 9].

In the works [2, 3, 4, 5, 6, 7], it was researched the elements of dielectric permittivity tensor ε of bending on spiral optical fiber depending on the step and radius of spiral. also it was shown that throughout bended on spiral single mode optical fiber (SSOF), there is an exchange of power between waves HE_{11}^{e} and HE_{11}^{o} and the polarized dispersion was also studied. but there is no any direct dependence for elements of dielectric Permittivity tensor of (SSOF) depending on the coefficient (A) which show the relationship between spiral parameters (curvature and spinning) and polarization angle for the waves HE_{11}^{e} and HE_{11}^{o}.also in these related works, the analyze of attenuation transient in the (SSOF)was not finished as a must.

The transmission over the bending on spiral single mode optical fiber (such as curvature and spinning), there is an exchange of power between the waves HE_{11}^{e} and HE_{11}^{o},and this is a reason for appearance the attenuation and dispersion in the transmitted signals. So there are no equations or expressions to calculate the optimal values of spiral parameters in the signal transmission process for long distance to minimize the effect of attenuation and dispersion on the quality of transmitted signals.

This study aim to research the tensor of dielectric permittivity ,and attenuation transient when the power transferring between the waves HE_{11}^{e} and HE_{11}^{o} on the half beat length ζ_1.also to research the attenuation transient in the optical fiber sections that bended on spiral. for this study case the wave length range is selected between (1.565 up to 1.625 micron).

2 METHOD AND PROCEDURE

2.1 Defining and analyzing the elements of dielectric tensor.

The inclination angles for the waves HE_{11}^{e} and HE_{11}^{o} to the x axis are rotating with angular velocity of winding spiral as follows:

$$\varphi^{e} = -arctg\frac{\rho}{4\pi R};\varphi^{o} = \varphi^{e} + \frac{\pi}{2} \quad (1)$$

Where R -spiral radius, ρ -twisting step.

The direction of power pumping is changing in opposite with equal intervals, and called half-lengths of the beat ξ_m which given by:-

$$\xi_m = \frac{m\pi}{\left|\beta_1^{e} - \beta_1^{o}\right|} \quad (2)$$

Where β_1^{e} , β_1^{o} -the spreading phase coefficients for the ordinary and extraordinary waves respectively.

m -integer, which indicate the held quality of power moving to the optical fiber section. so if $m = \pm1,\pm3,\pm5$ then the power will moving from HE_{11}^{e} to HE_{11}^{o} wave, and if $m = \pm2,\pm4,\pm6$,the induced power in HE_{11}^{o} will be pumped back to the wave HE_{11}^{e}.

Let us analyze the dependence of tensor elements ε_{ij} on the coefficient $A = \frac{\rho}{4\pi R}$ in the (r,φ,z) coordinates system. the diagonal tensor elements ε_{rr}, $\varepsilon_{\varphi\varphi}$, ε_{zz} are defined from[4]as:

$$\varepsilon_{rr} = \varepsilon_{\varphi\varphi} = \varepsilon(r) \quad (3)$$

Where $\varepsilon(r)$-the dielectric permittivity of isotropic optical fiber.

$$\varepsilon_{zz} = \varepsilon(r) - 2\chi r\cos\varphi + \chi^2 r^2\cos^2\varphi + \nu^2 r^2 \quad (4)$$

Where the parameters χ and ν are the curvature and torsion of spiral axis ξ and defined as:

$$\chi = \frac{R}{R^2 + \left(\frac{\rho}{2\pi}\right)^2} \quad (5)$$

$$\nu = \frac{\rho}{2\pi}.\frac{1}{R^2 + \left(\frac{\rho}{2\pi}\right)^2} \quad (6)$$

the non-diagonal elements will be as follow:

$$\varepsilon_{r\varphi} = \varepsilon_{\varphi r} = \varepsilon_{rz} = \varepsilon_{zr} = 0 \quad (7)$$

$$\varepsilon_{\varphi z} = \varepsilon_{z\varphi} = -\nu.r \quad (8)$$

The tensor elements ε_{ij},that located on the main diagonal are characterized the distribution of dielectric permittivity along i axis, caused by mechanical deformations in this direction(compression or extension).so the compression complies the positive values of tensor elements which leads to increasing the value ε_{ij} in the direction of given coordinates, and the extension leads to reducing ε_{ij} [4].

In the work [6], the expressions for determining the curvature and torsion through the coefficient A are as follow:

$$\nu = \frac{2}{R}.\frac{A}{1+4A^2} \quad (9)$$

$$\chi = \frac{1}{R(1+4A^2)} \quad (10)$$

Substituting the expressions (9), (10) in the expression (4) and considering that $r = \frac{w}{\sqrt{2}}$,we get an expression for ε_{zz}:

$$\varepsilon_{zz} = \varepsilon(r) - \frac{\sqrt{2}w\cos\varphi}{R(1+4A^2)} + \frac{w^2\cos^2\varphi}{2R^2(1+4A^2)^2} + \frac{2A^2w^2}{R^2(1+4A^2)} \qquad (11)$$

Where w - the modal field radius for the wave HE_{11} in isotropic straight waveguide [6] and equal:

$$w = \frac{a}{\sqrt{V-1}};V = \frac{2\pi a}{\lambda}.NA \qquad (12)$$

Where a - the optical fiber radius, λ -wave length of transmitted signal, NA -numerical aperture of optical fiber glass.

The elements $\varepsilon_{z\varphi}$ and $\varepsilon_{\varphi z}$,can be represented as follows:

$$\varepsilon_{z\varphi} = \varepsilon_{\varphi z} = -\frac{2w}{\sqrt{2}R}.\frac{A}{1+4A^2} \qquad (13)$$

After the calculations of $\varepsilon_{zz}(A)$,where $\varepsilon_{\varphi z}(A) = \varepsilon_{z\varphi}(A)$ for the wave lengths(1.565,1.595,1.625 micron)of pure quartz material and the coefficient $(A)$was chosen from(0 to 1)and spiral radius R=2 mm,these calculation results are plotted on figure.1 and figure.2.

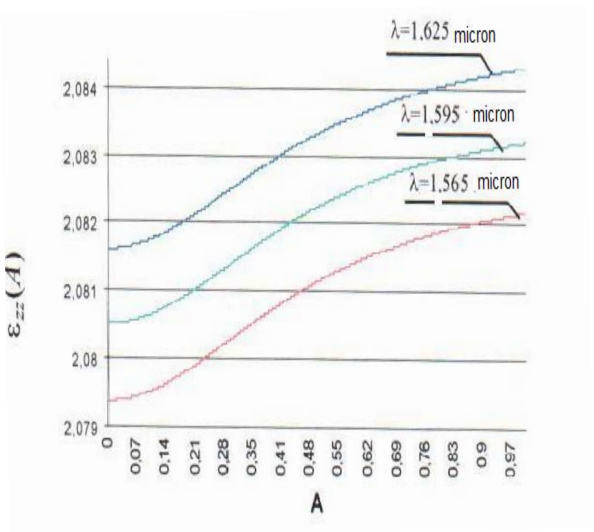

Fig. 1. Dependence of tensor element ε_{zz} at A

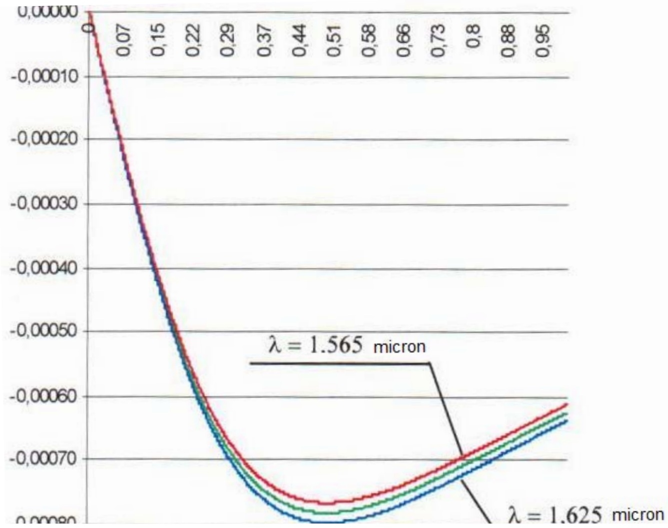

Fig. 2. Dependence of tensor elements $\varepsilon_{\varphi z}$, $\varepsilon_{z\varphi}$ at A

It is clear from the above figures that by increasing the (A) value , the ε_{zz} will tends to the value of dielectric permittivity of isotropic optical fiber $\varepsilon(r)$ and we can notice that for $\lambda = 1.565$ micron $\varepsilon(r)$=2.084683,and for $\lambda = 1.595$ micron $\varepsilon(r)$=2.083643,and for $\lambda = 1.625$ micron $\varepsilon(r)$ =2.082573.since this reduces the effect of second ,third and fourth summands in expression (11).

according to expression (9),if A>1 then the curvature of optical fiber will be decreases, and the non diagonal elements $\varepsilon_{\varphi z}$ and $\varepsilon_{z\varphi}$ will be decreasing also according to expression (8).

Consequently, by increasing (A) coefficient, the diagonal elements of tensor are equal to $\varepsilon(r)$,and the non diagonal element tends to Zero. and this mean that the characteristic of (SSOF) will be closer to isotropic.

2.2 Attenuation Transitive in SSOF

If we analyzing the losses due exclusively anisotropy of optical fiber without attention to: scattering attenuation, resonance field absorption in the shell and core, radiation in the open space, the value of half-length beats can be calculated using the next expression [6]:

$$\xi_1 = \frac{\sqrt{2}\lambda n_1 R}{w} \cdot \frac{(1+4A^2)\sqrt{1+A^2}}{\left|A^2+A-1\right|} \quad (14)$$

The expression for calculating the transient attenuation when the power pumping from HE_{11}^{e} wave into HE_{11}^{o} wave on a plot of half-length beat $\alpha_{n1}^{eo}(\xi_1)$ [6]:

$$\alpha_{n1}^{eo}(\xi_1) = 10\lg \frac{\sqrt{2}\lambda n_1}{w} \cdot \frac{A\sqrt{1+A^2}}{\left|A^2+A-1\right|} \cdot \{.\}^{eo} \quad (15)$$

And conversely, from HE_{11}^{o} wave into HE_{11}^{e} $\alpha_{n1}^{oe}(\xi_1)$ [7]:

$$\alpha_{n1}^{oe}(\xi_1) = 10\lg \frac{\sqrt{2}\lambda n_1}{w} \cdot \frac{A\sqrt{1+A^2}}{A^2+A-1} \cdot \{.\}^{oe} \quad (16)$$

where $\{.\}^{eo}$-the expression in the braces from equation (29) [6], $\{.\}^{oe}$ from (35) [7], these expressions are not listed here because of their unwieldiness.

The transient attenuations are the product of the function of spectral dependence of transient attenuation of major waves, bending geometry, and material polarization angles.

The expressions (14),(15),(16) are depends on dimensionless parameter A,and after passing the length of $2\xi_1$,the power will be pumped from one wave to another and then pumped back to the initial wave.

So the losses for 1 km of the length will be:

$$\alpha_{n1}(1km) = \frac{1000(\alpha_{n1}^{eo}(\xi_1) + \alpha_{n1}^{oe}(\xi_1))}{2\xi_1} \quad (17)$$

The results of calculation are shown on figures (3, 4).

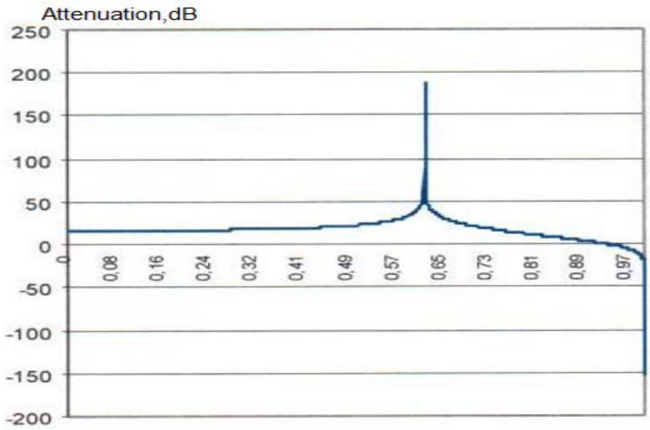

Fig. 3. Transient attenuation dependence with length of $2\xi_1$ at A

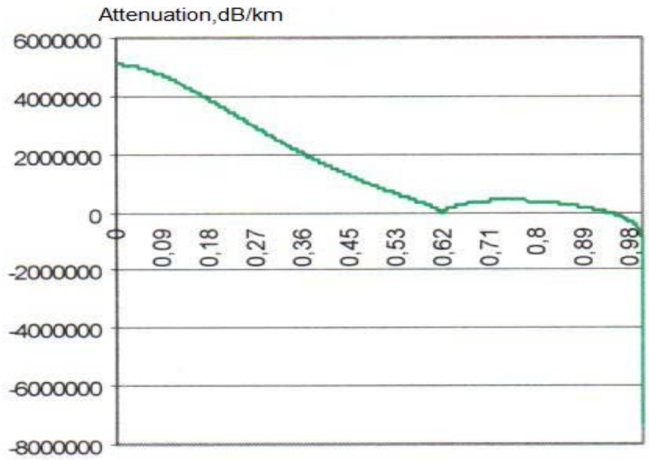

Fig.4. Transient attenuation dependence with length of (1 km) at A

3 Result and Discussion

When $A \to 0.617999$, the value $\alpha_{n1}(2\xi_1) \to \infty$, and $\xi_1 \to \infty$, since the denominator in the expression (14) tends to zero. this is due to the fact that the phase coefficients for ordinary (β_1^{o}) and extraordinary (β_1^{e}) waves are approximately equal to each other and their difference is the minimum, thus the material of (SSOF) is anisotropic.

Therefore, the power over the length (1km) not has time to pump from one wave to another. then as the calculations shown the loss per (1 km) will be the minimum if $A \approx 0.618$ and A>0.931.and to provide a minimum transient attenuation, it is necessary that the value of A must close to 1 ($\rho \cong 4\pi R)$ .thus practically no power pumping flows from wave to another.

4 Conclusion

From the analysis of tensor elements of dielectric permittivity dependence on the coefficient (A), we can conclude that by increasing the coefficient (A), the effect of anisotropy will be reduced .and it was shown for which values of A ,the loss will be the minimum. also it was researched the transient attenuations when the power pumped from one wave to another. these research results can be used to minimize the effect of transfer parameters (attenuation and dispersion) on the signal transmission through the spiral optical fiber by the development of directional couplers, optical isolators, light modulators, dispersion compensators.

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