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Simulation of the Effect of Relative Refractive Index for Light Transmission Through Double Cladding Step Index Optical Fibre

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Abstract: This work establishes computational analysis of relative refractive index property for light transmission via fiber optics using MATLAB simulation. Optical fiber is a dielectric wave guide which transmits signal with a low attenuation and dispersion at higher bandwidth or data rate. Recent advances in fiber optics introduced a largely new dimension into optical technology with the effect of improving transmission through the application of cladding system. Cladding in fiber communication is importantly applied to ease light transmission in the fiber-core interface by total internal reflection at the boundary between two light propagation region of a typical fiber. Optical fiber communication is a well recognized aspect of optical light transmission where clad fibers of different refractive indices recount for a measurable Numerical aperture and Acceptance angle in fiber networking and communication technology. This has lead to the efficient and effective optical transmission due to the adequate emergence and utilization of optical properties and parameters in optical fiber applications. A double cladding was set for the fiber and a maximum relative refractive index of 2.000% is obtained for an acceptance angle and numerical aperture range of 59°-64° and 0.859-0.900 respectively. This implies fast light transmission, high bandwidth and small bending sensitivity for fiber networking with applications in medicine and telecommunication compared to single cladding fiber.

Keywords: Refractive Index, Fiber Optics, Fiber Cladding, Step Index, Light Transmission

1. Introduction

For signal transmission via optical fiber, modeling of refractive index profile is a strong and useful tool, for which its significant effects establish pronounced and suitable applications such as optical diagnostics, laser surgery, and signal networking. Since cladding optical fibers is vital to the finishing model of refractive index for fiber technology and its applications, this then count for some varying optical parameters.

Therefore, arbitrary refractive index profiling has been used to model optical fiber [8], refractive index and dispersion was also determined for optical wave guides [6]. A paper has been presented on refractive index profile measurements of diffused optical wave guides measured using a reflection interferometric technique [9]. A new non-interferometric technique based on image phase gradient was utilized for determining the refractive index profiles of axially symmetric optical fibers [2]. The effect of refractive-index profile variations on the performance of two-mode fibers used as dispersion compensators in long-distance transmission systems operated near 1550 nm was evaluated [3]. As investigated in [1], the effect of a modified cladding

on the transmission of light through a step-index optical fiber using 3-D geometrical optics was established. They also measured the light transmission of the optical fiber as a function of the modified cladding refractive index and length for the case of focused illumination with 3-D ray theory comparison. Simulations and experiment has been used to show a significant effect of refractive index on measurement of optical properties in turbid media (latex spheres and intra-lipid suspensions) [10]. In addition, surrounding refractive index (SRI) sensitivity enhancement was demonstrated for double cladding fiber (DCF) [13]. More so, a research was made on optical fiber bend impact in fiber networking [11]. Consequently, bending and non-bending effect have been considered by calculating leakage losses for the design of double clad optical fiber [5]. A simultaneous measurement for refractive index and temperature was demonstrated for double cladding fiber sensor (DCFS) [7]. Lastly, large refractive index with vanishing absorption in optical fibers was proposed in [12]. In this work, a relative refractive index is modeled for double cladding optical fiber system owing to some parametric equations.

2. Background Theory

The optical fibers are dielectric waveguide which transmit the optical signal or data through them with a very low attenuation and very low dispersion, for example using solution laser pulse one can transmit the signal almost without any loss or dispersion. Thus one can achieve very much high bandwidth or high data rate using fiber optical cables. Improving transmission through fibers by applying a cladding was discovered in 1953 by Dutch scientist Bran Vain Heal, some fibers can support cladding modes in which light propagate in the cladding and core. Nowadays, a lot of dispersion free and dispersion fibers is available in the market. This made optical fiber communication more advantages than conventional system.

2.1. Double Clad Step Index Optical Fiber

This is a fine glass core and it is surrounded by claddings of glass with a lower refractive index to that of the core. This means that light shone into the core at an angle greater than the critical angle will totally and internally reflect at the boundary between the core and the cladding. The light then travels down the fiber through a series of reflection before exiting at the other end.

However, the cladding is useful as it protect the core and prevents the leakage of light. As shown in figure 1, the design of double clad optical fiber consists of one core and two cladding that is, the inner and the outer cladding. The refractive index of the core and the outer cladding is the same and the value of refractive index of the core is greater than that of the inner cladding.
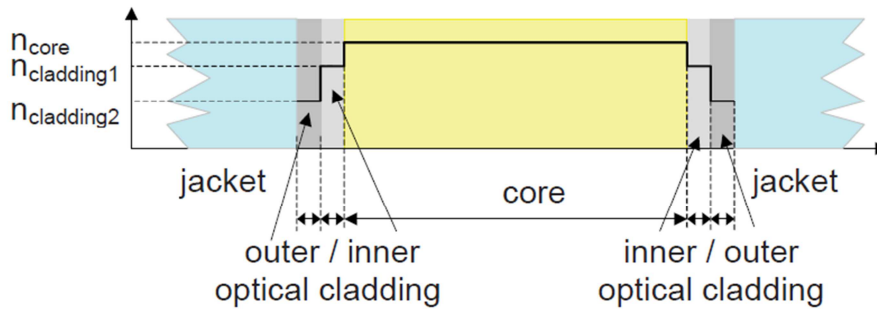

Figure 1. *Double Clad Step Index Fiber.*

2.2. Parameters of Light Transmissions

Light transmission is the moving of electromagnetic wave (whether visible light, radio waves, ultraviolet etc) through a material. This transmission can be reduced or stopped, when light is reflected off the surface or absorbed by the molecules in the material. However, this accompanied by some important parameters such as:

2.2.1. Relative Refractive Index (RRI)
The refractive indices of the core and cladding (η_1 and η_2 repectively) differ only slightly so that the fractional refractive index change, and it is given by [4]

$$\Delta = \frac{\eta_1 - \eta_2}{\eta_1} \times 100\% \qquad (1)$$

2.2.2. Acceptance Angle (ACA)
The acceptance angle of an optical fiber is based on a purely geometrical consideration (Ray Optics). It is the maximum angle of a ray (against the fiber axis) hitting the fiber core which allows the incidents light to be guided by the core. Applying Snell's law at the air-core boundary where θ_a is the incident angle in the air corresponding to the acceptance angle of the fiber, θ_c is the angle in the core we have,

$$\eta_1 = \frac{Sin\theta_a}{Sin\theta_c} \qquad (2)$$

$$Sin\theta_a = \eta_1(1 - Cos^2\theta_c)^{1/2} \qquad (3)$$

$$Since, Cos^2\theta_c = \left(\frac{\eta_2}{\eta_1}\right)^2 \text{ we have,}$$

$$Sin\theta_a = \eta_1\left[1 - \left(\frac{\eta_2}{\eta_1}\right)^2\right]^{1/2} \qquad (4)$$

$$Sin\theta_a = (\eta_1^2 - \eta_2^2)^{1/2} \qquad (5)$$

$$\theta_a = Sin^{-1}(\eta_1^2 - \eta_2^2)^{1/2} \equiv Sin^{-1}NA \qquad (6)$$

2.2.3. Numerical Aperture (NA)

This is a measure of how much light can be collected by an optical system such as an optical fiber or a microscope lens. This is related to the acceptance angle which indicates the size of a cone of light that can be accepted by the fiber. Hence, it is mathematically given by [4]

$$NA = (\eta_1^2 - \eta_2^2)^{1/2} \qquad (7)$$

3. Methodology

The relative refractive index (RRI) [equation 1], numerical aperture (NA) [equation 7] and acceptance angle (ACA) [equation 6] which are linear, polynomial and trigonometric function respectively, were simulated using MATLAB version 7.1 and Microsoft office excel 2007 in order to show their parametric and numerical relationships for optical fiber technology design with the under-listed procedures.

1) We utilized output functions such as RRI, ACA and NA for input parameters such as (η_1, η_2).
2) We generated a script for the output functions in the editors script by defining each of the functions (linear, poly and trig) for the input parameters as in:
3) Function (RRI) = linear (η_1, η_2);
4) Function (NA) = poly (η_1, η_2);
5) Function (ACA) = Trig (NA),
6) We set refractive index of the core (ηc) as 1.50 at [1.000, 1.2000, 1.2500, 1.2450, 1.3100, 1.3400, 1.3700, 1.3800, 1.4130, 1.4400, 1.4500, 1.4600, 1.4850, 1.4880, 1.4940, 1.4970] for cladding 1 and [1.000, 1.230, 1.260, 1.285, 1.320, 1.350, 1.1.370, 1.395, 1.425, 1.450, 1.460, 1.475, 1.485, 1.488, 1.494, 1.497] for cladding 2.
7) A script is then used to run a linear, polynomial and trigonometric functions in the command window.
8) We then obtained the output value for RRI, ACA and NA of cladding (1 and 2) for a reasonable optimization.
9) We plotted a 2D graph RRI against ACA, and against NA (RRI against ACA for cladding 1 and cladding 2, RRI against NA for cladding 1 and cladding 2) using a plot command which contains grid and legend as in:
10) Plot (RRI1, NA1 'b–'), Plot (RRI2, NA1 'r–'), Plot (RRI1, NA2 'b–'), Plot (RRI2, NA2 'r–'), Plot (RRI1, ACA1 'b–'), Plot (RRI2, ACA1 'r–'), Plot (RRI1, ACA2 'b–'), Plot (RRI2, ACA2 'r–')
11) Finally, the display of 2D graphics plots shows the optimum effects of relative refractive index over optical light transmission in fiber communication network.

4. Results

In figure 2, the relative refractive index of the core and claddings (cladding 1 and 2) increase with the numerical aperture for cladding 1. Therefore, relative refractive index has a maximum value of 2.000% between the two

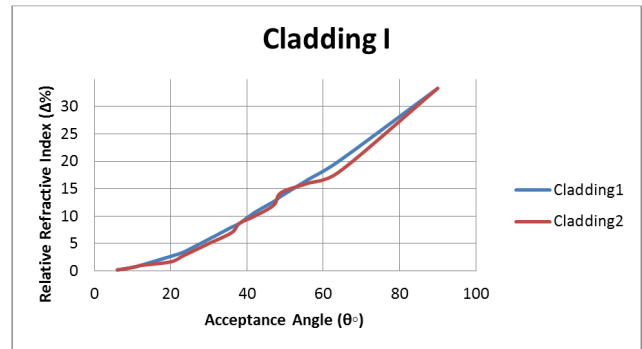claddings at a minimum value of 0.900 numerical aperture.

Figure 2. *Relative Refractive index I and II against Numerical Aperture I $\eta c=1.50$.*

In figure 3, the relative refractive index of the core and claddings (cladding 1 and 2) increase with the numerical aperture for cladding 2. Therefore, relative refractive index has a maximum value of 2.000% between the two claddings at a minimum value of 0.859 numerical aperture.
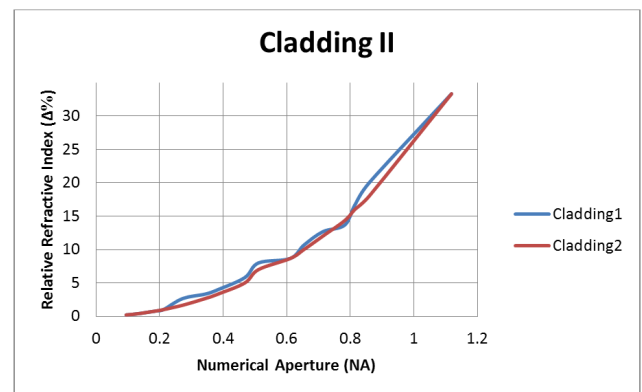

Figure 3. *Relative Refractive index I and II against Numerical Aperture II at $\eta c=1.50$.*

In figure 4, the relative refractive index of the core and claddings (cladding 1 and 2) increase with the acceptance angle for cladding 1. Therefore, relative refractive index has a maximum value of 2.000% between the two claddings at a minimum value of 64° acceptance angle.
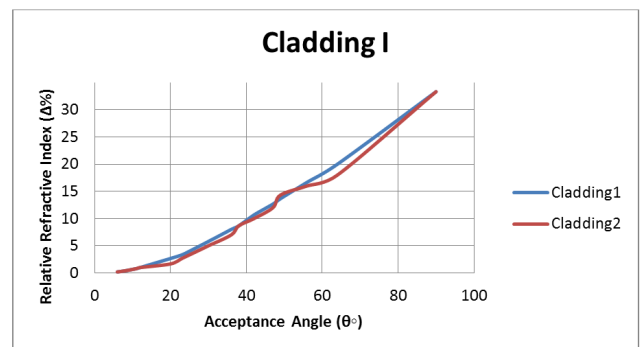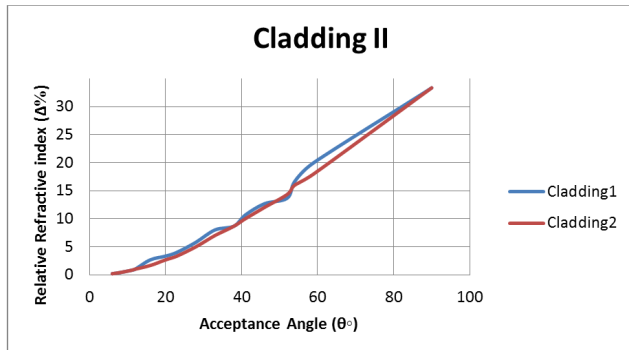

Figure 4. *Relative Refractive index I and II against Acceptance Angle I $\eta c=1.50$.*

In figure 5, the relative refractive index of the core and claddings (cladding 1 and 2) increase with the acceptance angle for cladding 2. Therefore, relative refractive index has a maximum of 2.000% between the two claddings at a minimum value of 59° acceptance angle.

Figure 5. *Relative Refractive index I and II against Acceptance Angle II* $\eta c = 1.50$.

5. Discussion

In this work, simulation result with MATLAB and excel were established with the series of analysis and graphical plots. Figure 1 shows that relative refractive index has a maximum value of 2.000% between the two claddings at a maximum value of 0.900 numerical aperture. Also, figure 2 shows the same value between the two claddings at a maximum value of 0.859 numerical aperture for cladding 2. Moreover, figure 3 estimates a maximum value of 2.000% between the two claddings at a maximum value of 64° acceptance angle for cladding 1. Lastly, figure 4 shows the same value of 2.000% between the two claddings at a maximum value of 59° acceptance angle for cladding 2. Therefore, optimization obtains a constant relative refractive index of 2.000%. This implies light lunching over optical fiber transmission, high bandwidth and high reduction in less fiber to bending sensitivity.

6. Conclusion

In this work, a computational method have been adopted for the analysis of relative refractive index of claddings (cladding 1 and 2) in optical fiber light transmission via simulation with MATLAB. A maximum refractive index difference of 2.000% was obtained for the double cladding with an absolute numerical aperture and acceptance angle value of 0.859-0.9 and 59°-64° respectively. This implies that the refractive index, numerical aperture and acceptance angle cause high bandwidth and small bending sensitivity of fiber claddings for fiber networking system in communication and medicine.

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