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Optimum Parameters with Minimum Attenuation for Single Mode Light Ray Transmission

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Abstract – *Single Mode transmission is an important part in Fiber Optics, which is used for long range transmission with attenuation of 0.4dB between 1310 nm and 1550 nm with a maximum transmission distance of 10km at 10Gigabit. In this paper various parameters for the Single Mode have been optimized for the Original band (O-band) and Conventional band (C-band), these have the wavelength for minimum attenuation. Design parameters such as core thickness, numerical aperture, attenuation, dispersion are studied and calculated.*

Key Words: **Critical angle, acceptance angle, numerical aperture, SIS fiber, GI fiber, LED source, LD source**.

1. INTRODUCTION

Nowadays the large amount of data traffic required for multimedia applications, increases the demand for a transmission medium with high bandwidth. The large bandwidth, high security, low interference, low attenuation, ease of maintenance, and long life span are features for the fiber optics that enable it to support high data rate services.

If we talk about optical fiber, is a physical waveguide that used to transmit electromagnetic waves in the optical spectrum. They are used as components in integrated optical circuits, as the transmission medium in long distances for light wave communications, or for biomedical imaging. Fiber Optics can be designed to operate in single-mode or multi-mode depending on the number of lights rays transmitted simultaneously. According to the refractive index distribution, fiber optics can be classified into two types, step index fiber and graded index fiber. Different material can be used in the fabrication of the fiber optics such as glass, polymer, and semiconductors.

Use of fiber optics communication is mainly derived by the rapid increase in the demand for large telecommunication capacity and reliable communication systems. Compared to wireless and copper-wired transmission media, fiber optics technology is more efficient in providing the required information capacity. Due to advance in fiber optics technology, a single optical fiber can be used to carry more data over long distances.

Various techniques can be used to significantly improve the capacity of optical networks such as wavelength division multiplexing [1]. Signal Processing in the optical domain is more efficient than the electrical domain [2]. Therefore it is desired for future optical systems to have the ability of information processing exclusively in the optical domain. Signal processing includes amplification, multiplexing, switching, and filtering. An example of current type of optical communication system that processes the signal in optical domain is Code Division Multiple Access [3]. Despite the advantages of using optical fiber for communication systems, it is vital to conduct further research to improve fiber optics communication systems, and to address a number of challenges facing it [4].

In this paper the analysis of Single Mode optical fiber is presented and the design parameters are optimized with minimum attenuation.

2. Optical Fiber Structure

In the dielectric slab planer waveguide shown in Figure (1), the wave travels primarily in the central layer (core of radius a), which has refractive n_1 , this layer is so small often, less than a micrometer that it is referred to as a film, the film is sandwiched between a bottom layer and top layer having indices $n_{2.}$

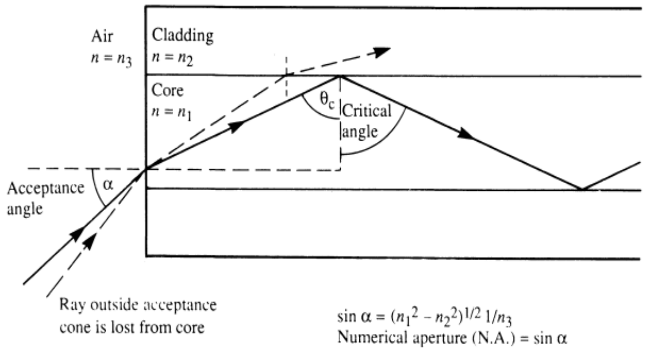

Figure (1)

Light rays are trapped in the film by total internally reflection. The critical angle ϕ_c value is given by [5]:

$$\phi_c = \sin^{-1}(\frac{n_2}{n_1}) \qquad (1)$$

The angle of incident rays in figure (1) must be equal or greater than the critical angle in order the lights propagates continuously through the core of the fiber to the destination. For efficient transmission, the materials used are must has small absorption on the basis of refractive indexes.

Table1: Critical Angle for various Materials

Construction	Core (n_1)	Cladding (n_2)	$\phi_c = \sin^{-1}(\frac{n_2}{n_1})$
All Glass	1.48	1.46	80.56
PCS	1.46	1.4	73.51
All Plastic	1.49	1.41	71.13
Al GA As	3.6	3.55	80.43
Single mode	1.465	1.46	85.26

All ray angles ϕ for propagating waves lie between ϕ_c and 90^0 and the corresponding effective refractive indices are in the range

$$n_2 \le n_{effective} \le n_1$$

Where, $n_{effective} = n_1 \sin\phi \qquad (2)$

Obviously, all the waves having angles greater than ϕ_c and 90^0 will enters the fibers core but, actually the numbers of the waves propagates through the fiber will constraint by the following condition:

$$\nabla\phi = 2\pi m \qquad (3)$$

Where, $\nabla\phi$ denoting the round trip phase shift, m is an integer and represents the mode number.

For higher-ordered modes the normalized thickness can be calculated by [5]

$$\left(\frac{a}{\lambda}\right)_m = \left(\frac{a}{\lambda}\right)_0 + \frac{m}{4n_1\cos\phi} \qquad (4)$$

Where m is a positive integer and represents the mode number. In the boundary as the incident angle θ_1, approaches θ_{acc}, the internal angle reaches the critical angle for total reflection ϕ_c. Then, we obtain:

$$n_0 \sin\theta_1 = n_1 \cos\phi = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}$$

Where Δ represents fractional reflective indices

$$\Delta = \frac{n_1 - n_2}{n_1}$$

The equation describes the angle within which the fiber can accept and propagate light and is referred to as the "Numerical Aperture" (*NA*) that is defined by:

$$NA = n_0 \sin\theta_{acc} \qquad (5)$$

When the medium with refractive index n_0 is air, the equation (5) for the *NA* of the glass fiber is simplified to

$$NA = \sin\theta_{acc} = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta} \qquad (6)$$

Therefore the acceptance angle can be calculated from eq. (6) as:

$$\theta_{acc} = \sin^{-1} NA \qquad (7)$$

This equation states that for all angles of incident where the inequality $0 \le \theta_1 \le \theta_{acc}$ is satisfied the incident ray will propagate within the fiber.

Table2: Numerical Aperture (NA) and Acceptance Angle for various Materials

Construction	Core (n_1)	Cladding (n_2)	NA	θ_{acc}
All Glass	1.48	1.46	0.24	13.88
PCS	1.46	1.4	0.414	24.45
All Plastic	1.49	1.41	0.481	28.75
Al Ga As	3.6	3.55	0.597	36.65
Single mode	1.465	1.46	0.120	6.89

3. Modes in Optical Fiber

Many modes TE and TM modes (transverse electric and transverse magnetic modes) are generated in the cylindrical optical fiber in addition to HE and EH modes which are hybrid, and each contains components of electric and magnetic fields pointing along the fiber axis [6]. In the followings, these modes are discussed according to the types of optical fibers. Three basic types of optical fibers are used in communication systems: (a) Step-index multimode (SIM) fiber, (b) Step-index single mode (SIS) fiber, (c) Graded-index fiber (GI).

(a) The Step Index multimode (SIM) fiber
It consists of a central core where refractive index is n_1, surrounded by a cladding whose refractive index is n_2. Figure (2) illustrates its structure and the possible ray paths.

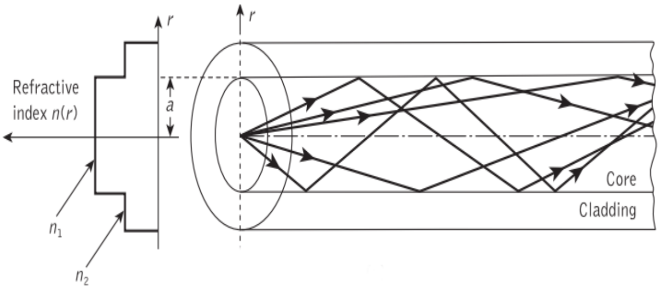

Figure (2): Step index fiber

Step Index Fiber has been normalized by plotting the effective refractive index as a function of the parameter v, called the normalized frequency that is giving by [6]:

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^{\,2} - n_2^{\,2}} \qquad (8)$$

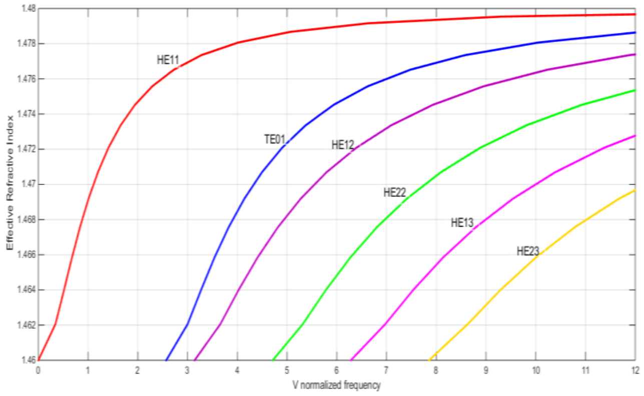

Figure (3): The effective refractive index as a function of normalized frequency v in Multi-Mode

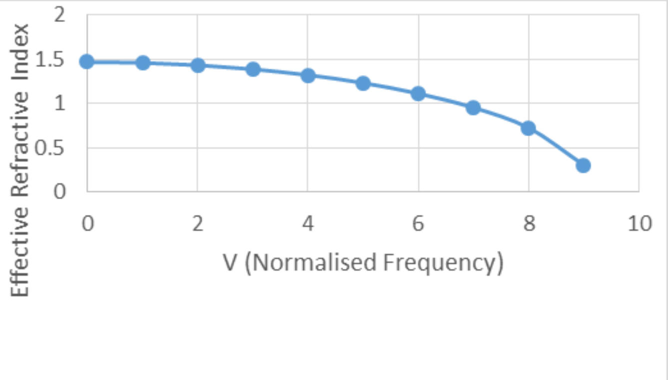

Figure (4): The effective refractive index as a function of normalized frequency v in Single Mode

(b) Step-index single mode (SIS) fiber
Single-mode propagation is assured if all modes except the HE11 mode are cutoff. Referring to Figure (3) it is noticed that this phenomenon will occur if v < 2.405. The core radius is calculated by:

$$\frac{a}{\lambda} < \frac{2.405}{2\pi\sqrt{n_1^{\,2} - n_2^{\,2}}} = \frac{2.405}{2\pi NA} \qquad (9)$$

As the condition of single mode propagation. This result is very similar to the single mode condition for the symmetrical slab. If eqn. (9) is satisfied, then only the HE11 mode can travel through the fiber, two orthogonally polarized HE11 waves can actually exist in the fiber simultaneously, but they have the same n_{eff} and therefore, travel the same velocity.

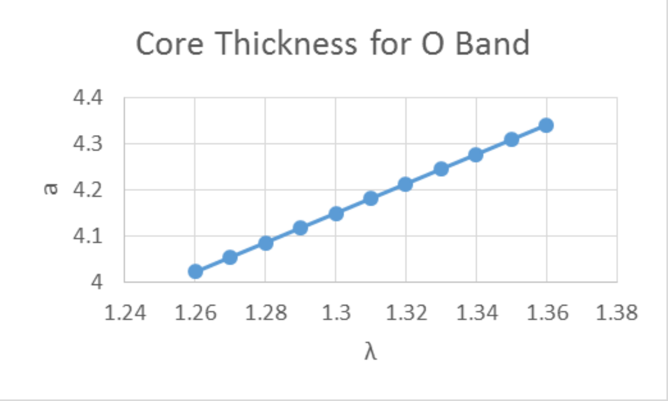

Figure (5): Core thickness for Original band having range of wavelength (1.260 to 1.360) with minimum attenuation

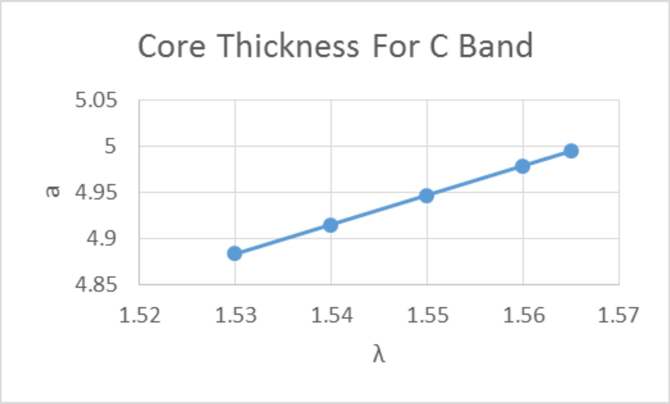

Figure (6): Core thickness for Conventional band having range of wavelength (1.530 to 1.565) with minimum attenuation

(c) Graded Index Fiber

The graded index fiber has a core material whose refractive index decreases continuously with distance r from the axis. This structure, illustrated in Figure (7) appears to be quite different from the SIM fiber. The index variation is decreased by:

$$n(r)=n_1\sqrt{1-2\left(\frac{r}{a}\right)^{\alpha}\Delta}\ ,\ r\le a \qquad (10)$$

Where α is the profile parameter which represents the refractive index profile of fiber optics core.

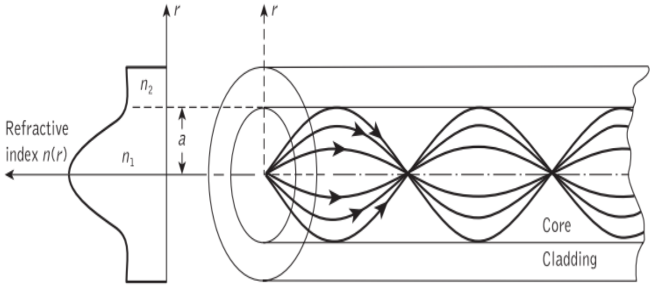

Figure (7): The multimode graded index fiber

$$n(r)=n_1\sqrt{1-2\left(\frac{r}{a}\right)^{3}\Delta} \qquad (11)$$

This index distribution is called the cubic profile. For cubic profile the numerical aperture is determined as

$$NA=n_1(2\Delta)^{1/2}\sqrt{1-\left(\frac{r}{a}\right)^{3}} \qquad (12)$$

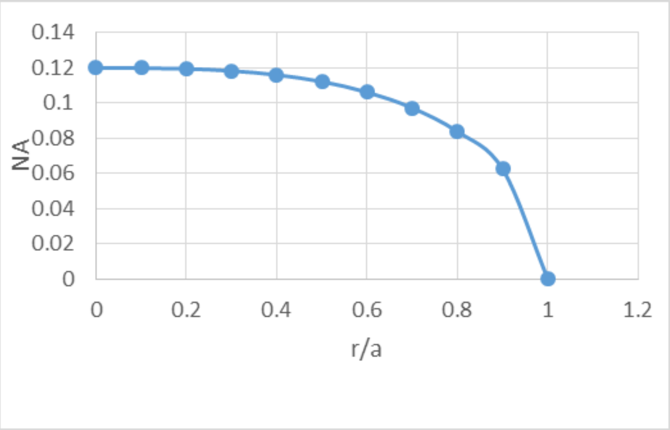

Figure (8): Numerical aperture NA as a function of r for n1=1.465 and Δ=0.0034

The condition for graded-index single mode propagation is given by [ref]:

$$\frac{a}{\lambda}<\frac{1.4}{\pi\sqrt{n_1(n_1-n_2)}} \qquad (13)$$

4. Optimized Parameters

4.1 Operating Wavelength

Table3: ITU regulations bands [6]

Name	**ITU band**	**Wavelength λ µm**
Original band	O-band	1.260 to 1.360
Conventional band	C-band	1.530 to 1.565

According to (ITU) the International Telecommunications Union regulations the bands allocated for both intermediate-range and long-distance optical fiber communications are specified by the letters O and C which are defined in Table3. The more common usable bands are O-band and C-band giving minimum attenuation through the fiber length. The lowest attenuation happens at wavelengths around 1.310 µm and 1.550 µm.

4.2 Core Radius

The size of optical fibers plays crucial role in the light wave propagation through fiber. Therefore, radius of the core is significant to decide mode of propagation in fiber as:

$$\frac{a}{\lambda} < \frac{2.405}{2\pi NA}$$ For step-index single mode fiber.

$$\frac{a}{\lambda} < \frac{1.4}{\pi\sqrt{n_1(n_1-n_2)}}$$ For graded-index single mode fiber

Otherwise the multi modes will propagate. The thickness/diameter of the core can be measured in spite of measurement of radius. The standard core sizes are 50 µm and 62.5 µm for multi-mode fiber while 5-10 µm for single mode fiber.

4.3 Numerical Aperture

Numerical aperture (NA) is a light gathering property of optical fiber, which gives the quantity of light that brought into the center of optical fiber in terms of incidence angle. The value of the numerical aperture is about 5% lower than the value of the maximum theoretical numerical aperture NA_{max} which is resulting from a refractive index measurements trace of the core n_1 and cladding n_2 .

4.4 Acceptance Angle

It is a semi vectorial angle that formed by the set of incident rays at the center of fiber, which helps to decide the size of core or the numerical aperture.

4.5 Attenuation

The most important transmission characteristic is attenuation or loss. The transmission losses bound the total length of the fiber communication system.

Rayleigh scattering losses is proportional to λ^{-4}, it becomes increasingly important as the wavelength diminishes, and Rayleigh scattering loss can be approximated by the expression:

$$L_{SC} = 1.7(\frac{0.85}{\lambda})^4 \qquad (14)$$

Where, λ is in micrometer and L_{SC} is the loss in dB/km due to Rayleigh scattering. It is clear that the scattering severely restricts use of fibers at short wavelength below 0.8 µm. Glass fibers generally have lower absorption than plastic fibers, so they are preferred for long-distance communication.

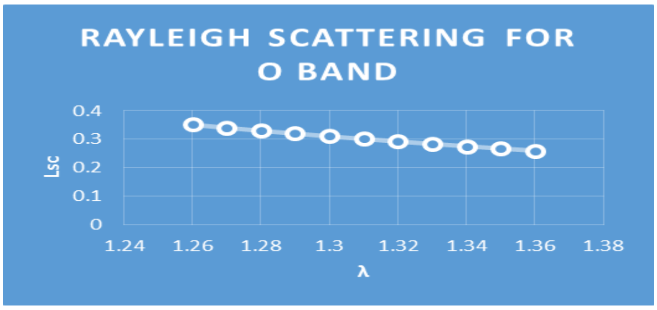

Figure (9): Rayleigh Scattering for Original band having range of wavelength (1.260 to 1.360) with minimum attenuation

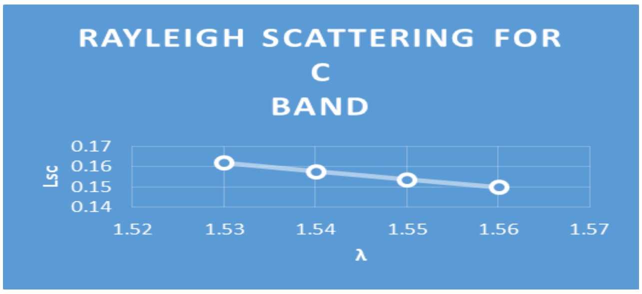

Figure (10): Rayleigh Scattering for Conventional band having range of wavelength (1.530 to 1.565) with minimum attenuation

4.6 Dispersion

The distortion of digital and analog signals which, are transmitted in optical fibers results from dispersion. When fiber optic transmission is implemented with its essential part which involves some form of digital modulation, due to dispersion mechanisms within the fiber the transmitted light pulses spreads as they travel along the channel. It can say that the dispersion is a light spread out during transmission on the fiber. The dispersion may be categorized into two major types [7]: **intermodal (modal)dispersion** which exists only in multimode fibers and **intra modal (chromatic) dispersion** which exists in all types of fibers (single mode and multimode) which basically divided into types: Waveguide dispersion and Material.

Waveguide dispersion: The optical fiber can be considered as circular wave guide where refractive index varies with modes of propagation with wavelength causes wave guide dispersion.

Material dispersion: The refractive index of core causes the changes in the wavelength/frequency called material dispersion. If narrow pulse passes through fiber, causes broadening of pulse width due to material property. It can be overcome by highly monochromatic source of light. The single mode fiber could reduce the material dispersion to maximum extent.

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5. RESULTS AND DISCUSSION

For this study, different fibers are selected to determine their design parameters and to compare the results with those of different sources. The sources are considered to be light emitting diode LED and laser diode.

Firstly, it is chosen different structures for step index fibers representative of all glass, plastic cladded silica fiber PCS, and all plastics constructions. Numerical aperture, acceptance angles, core thickness for O band and C band, Rayleigh scattering for O band and C band, fractional refractive index changes are computed.

For different light sources various types of fibers, losses are calculated and the characteristics of the studied fibers are illustrated in Table 4.

Table 4: Characteristics of studied fibers

Description	**Core size µm**	**NA**	**Source**	**λ µm**	**Loss dB/km**
SI(GLASS MM)	50	0.24	LED	850	1.7
GI(GLASS MM)	50	0.24	LED	850	1.7
GI(GLASS MM)	50	0.24	LED	1320	0.29
GI(GLASS MM)	50	0.24	LED	1550	0.15
GI(GLASS MM)	50	0.24	LED	1600	0.15
SI (PCS)	200	0.41	LED	800	2.2
SI(GLASS SM)	5	0.12	LD	820	1.96
GI(GLASS SM)	5	0.12	LD	1550	0.15
SI(GLASS SM)	10	0.12	LD	1600	0.14

It is noted that the losses of longer wavelength are lower than those of shorter ones. The plastic fibers are cheap and used for shorter distances while glass fibers are used for long distances due to their low attenuation.

6. CONCLUSIONS

The large amount of data traffic, required for nowadays multimedia applications, increases the demand for a transmission medium with high bandwidth. The analysis of optical fiber structure has been introduced in this paper and its design parameters, such as Effect of O band and C band, core radius, numerical aperture, attenuation, Rayleigh scattering, dispersion have been studied and calculated for different sources. In general for distance, beyond 1km, single-mode optical fiber of LD source is necessary for high bit rate.

Despite the advantages of using optical fiber for communication systems, such as the large bandwidth, high security, low interference, low attenuation, ease of maintenance and long life span. It is vital to conduct further research to improve fiber optics communication systems, and to address a number of challenges facing it.

7. REERENCES

[1] A. M. Jassim and K. A. AL-Khateeb, "Optical Wavelength Division Multiplexing Device," in Proceeding of 37 the International Ilmenau Conference, Germany, 21-24 September, 1992.

[2] F. Idachaba, D. U. Ike and O. Hope, "Future Trends in Fiber Optics Communication," in Proceedings of the World Congress on Engineering (WCE), London, U.K, 2 - 4 July, 2014.

[3] B. Wu, B. J. Shastri and P. R. Prucnal, "Secure Communication in Fiber-Optic Networks," Emerging Trends in ICT Security, Elsevier Inc., 2014.

[4] G. Ezeh and O. Ibe, "Efficiency of Optical Fiber Communication for Dissemination of Information within the Power System Network," IOSR Journal of Computer Engineering (IOSR-JCE), vol. 12, no. 3, pp. 68-75, Jul. - Aug. 2013.

[5] J. C. Palais, Fiber Optic Communications, 5th ed., Prentice Hall, 2005.

[6] J. M. Senior, Optical Fiber Communications Principles and Practice, 3rd ed., Prentice Hall, 2009.

[7] M. Raghavendra and P. V. Prasad, "A Novel Approach for Optimized Dispersion in Optical Fiber Communication," International Journal of Research and Reviews in Applied Sciences IJRRAS, vol. 4, August, 2010.

[8] Asaad M. Al-Hindawi and Salim Qadir Mohammed, “Study of Optical Fiber Design Parameters in Fiber Optics Communications,”Kurdistan Journal of Applied Research (KJAR), Vol. 2, August, 2017.