# The Phenomenon of Total Internal Reflection and Acceleration of Light in Fiber Optics

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## ABSTRACT
Generally the light transmitted as a radiation in a certain velocity whose value depends on the type of the medium in which the transmission occurs, in fiber optics light transmits in the form of rays, and in order that the light be totally reflected, the incident angle should be greater than the critical angle so that continuous reflections would happen on the wall of the cladding inside the fiber optics. This depends on a physical phenomenon called the phenomenon of total internal reflection; the ray that enters the fiber with an angle less than the acceptance angle is reflected in an angle so that when the incident angle is change the exit angle will also be changed. When the incident angle is changed, a displacement will take place; this displacement affects the value of the exit angle, in such a case there will be a difference between the point of the incidence and the point of refraction, this difference will lead to a variance in the distance and the arrival time at the end point which is an indication of acceleration in the speed of light which will be discussed in this paper.

## General Terms
Communication media, network signally, physics.

## Keywords
Rays, Wavelengths, Acceleration, Fiber Optic, Total Internal Reflection, Numerical aperture

## 1. INTRODUCTION
The phenomenon of total internal reflection that happens inside the fibers works on transmitting the light universally with a high speed that exceeds all the transmission media [1] fiber optics is a tangible transmission medium that transmits data between two points by the light so it differs from other transmission media. The cable of fiber optics carries the data after transforming it from electrical signal into optical one. At the receiver terminal the transformation takes place and vice versa [2] optical fibers are glass strands so each group of strands is called optical fibers that are used to transmit optical signals [3] the fibers consist of a core surrounded by a shield it is cladding, so that the refractive index of the core is greater than the refractive index of the cladding. There are two types of optical fibers: single mode and multimode. By a mode it is meant that is a path for the light to take through the cable. Single-mode fibers have a small diameter cores and only a single pathway, or mode, for the light is possible [4] whereas multimode fibers have larger diametric core; the options for the angles at which the light can enter the cable are greater, and so multiple pathways, modes, are possible [5] Optical fibers could also be classified according to the variance of the refractive index: the stepped index fibers and the graded index fibers. The stepped index fibers have types: single mode and multimode as the refractive index is constant in stepped index fibers while it varies gradually in graded index fibers [6].

The composition of the single mode is of laser while the multimode is composed of laser and light. The multimode is manufactured from plastic whereas the single mode is manufactured from glass [7] the signals are transmitted in the multimode in a form in which the wave length is varying while in the single mode the wave length remains constant, the diameter of the core varies according to the mode [8] The refractive index is high in the core while it is smaller in the cladding; this difference causes the refraction of the entering light. The fiber optics transmit in multimode that is distributed at the same time so called multimode, the distance between two tops in the same wave is called the length of the wave and is measured in nanometers or one billion of the meter [9] the difference in the length of the waves will cause a difference in the speed when the light passes through the fibers[10] mentioned previously, that light and laser transmitted through the core in the form of beams or rays, but it varies in the speed of transmission and in the light [11] of this distances vary so the variation in the length of the waves will produce acceleration of the rays in arrival where the ray that is reflected with a larger angle than the others will arrive first[12].

## 2. MULTIMODE FIBERS
The multimode fibers is considered the most used in the field of networks as it uses light to transmit the signal, where the light is emitted in the form of multiple paths through the core, the multimode fiber transmit the light in one frequency or more at the same time, the core is made of glass with 62.5 micron up to 100 micron [13] the signal transmit in the multimode fiber with different modes, each mode has its longitudinal transmission field. From this it appears that each mode as a difference transmission speed and different time periods when passing through the core of the fiber [14].

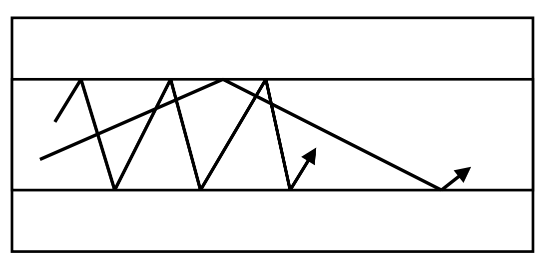

**Fig 1: light rays in an optical waveguide.**

The modes pass with limited distances in the fiber due to the interference between the different modes that are known as modal noise we can see in figure 1. It is clear that any a group of modes that pass by different distances the core of the fibers although it is emitted from the same source and at the same time. Time difference in sending signals which is known as wavelength is called the multipath time dispersion of wavelength that exits when light is used, but we can calculate the amount of time dispersion per unit length of fiber from expression (1)[15].

$$\text{Dispersion/length} = \frac{n_1 \Delta_n}{n_2 c} \qquad (1)$$

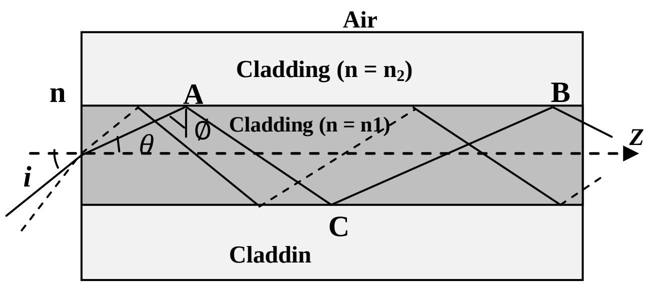


**Fig 2: Light rays incident on the core-cladding**

From figure 2 demonstrate how rays are reflected in greater angles with the axis where these rays move a longer pat and take more time in reaching the exit, through its passage it is reflected in an angle φ with the axis, equations (2) compute the distance between the two points ***A*** and ***B*** that is passed by the ray in a period of time.

$$t_{AB} = \frac{AC+CB}{c/n_1} = \frac{AB/\cos\emptyset}{c/n_1} \quad \text{Or} \quad t_{AB} = \frac{n_1\, AB}{c\ \cos\emptyset} \qquad (2)$$

$c/n_1$ represents the speed of light inside the medium, $n_1$ is the refraction index, c is the speed of light in vacuum. The path of the ray repeats itself. The time it takes the ray to pass a length of fiber (L) could be known by equation 3 from the expression one could know the time it took the ray to pass through the fibers and reflected in an angle with the axis forming pulses. But in the case when the rays lie between $\theta = 0$ and $\theta = \theta_c = \cos^{-1}(n_2/n_1)$, then the time consumed by the rays during it passage in the fibers on a certain length (L) could be known the expression (3, 4, 5).

$$t_L = \frac{n_1 AB}{c\ \cos\emptyset} \qquad (3)$$

$$t_{min} = \frac{n_1 L}{c} \quad \text{Corresponding } \theta = \theta_c \qquad (4)$$

$$t_{max} = \frac{n_1^2}{c n_2} \quad \text{Corresponding } \theta = \theta_c = \cos^{-1}(n_2/n_1) \qquad (5)$$

In the light of that it could be concluded that in the case when all the rays entered at the same time then all the rays of the optical does not appear at the output at the same time [16], which means that when the rays enter through the core of the fibers it enters in large numbers but some rays take longer paths than the others with the bottom position where it pass under the half of the fibers and reach the end before the top position. From this we conclude that light that pass in the bottom of the axis it took a longer and shorter pats, henceforth the signal transmits in certain time period, this case is called the model of dispersion show as in figure 3 which in turn will restrict the range of fibers and the distance the signal reaches in the fibers [17].

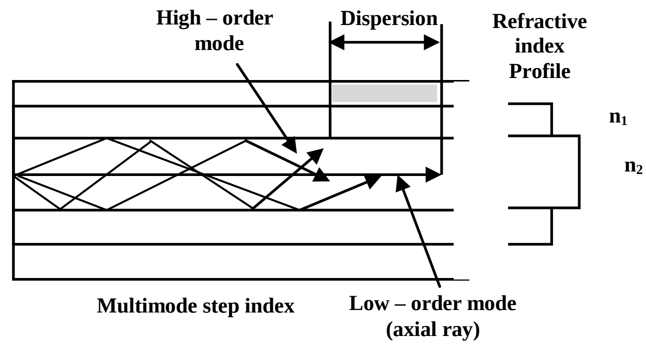


**Fig 3: Multimode Step Index Fiber**

## 3. PROPAGATION OF RAYS ALONG A FIBER

The principle of rays passage in fibers is a random one but takes the form of media, fibers support single mode and multimode from the [18] figure 4 rays spread in media with angles close to the critical angle which the upper media, while the lower media make the rays spread with angles lower than the critical angle, in the case of lower media the rays are distributed more towards a guiding wave and tend to transmit light energy to the cladding, while the upper media permits longer paths so rays take more time than in lower media, henceforth the upper media reach the end later than the lower media [19].

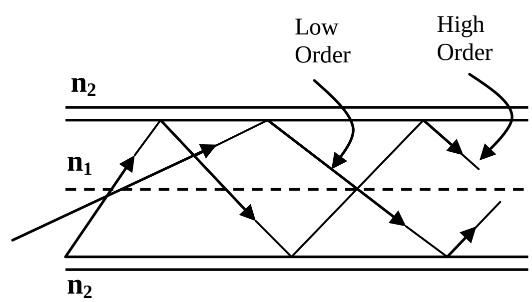


**Fig 4: Low and High-order ray paths in a multimode fiber**

When the light passes through fibers it will reflect in varied angles and follow varied paths where rays take small to large times to reach the end point, which means that the ray moving straightly arrive first wile zigzagging arrive late since it refracted at the sides of the core. In the light of this the rays that enter the fibers at the same time Arrive and leave at different times [20]

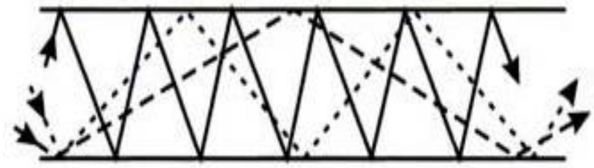

**Fig 5: Relatively thick fiber allows many reinforcing angles within the TIR condition**

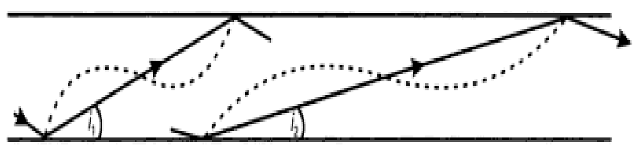

**Fig 6: Waveguide dispersion**

The Rays spread in fibers in different modes and follow different paths as in figure 5 in other words rays reach the other terminal with varied acceleration, forming pulse alongside of the fibers, in the case of single mode, the engineering of the rays forms one path and one wavelength and one angle at which the rays are reflected. In multimode it is permitted that the light move in different paths and with different speeds and the rays reflected in different angles which lead us to understand the case of dispersion of the wavelength so from figure 6 we notice that the refraction angle of the single mode is decreasing with the wavelength while the ray spread in the bottom direction of the axis in the fibers then the speed increases with the wavelength, When angle $i_2$ is smaller than $i_1$ for the longer wavelength which thus travels faster down the fiber [21].

as know that the light rays enter fibers in different angle and so that the light reflect and remain in paths inside the core it should enter through an imaginary acceptance cone where the ray enter with an angle of ($\theta_{NA}$ ) in order to match with the basic axis in the fibers but no ideal acceptance cone was determined to the optical fibers, but the digital opening is determined and the acceptance cone is associated with the expression (6):

$$NA = \sin\theta_{NA} = \sqrt{{n_1}^2 + {n_2}^2} \quad (6)$$

The numerical aperture controls the entering light by measuring the optimum angle of the entering angle of the rays such the total internal refraction could be achieved as shown in figure 7 which means that the entering light to the core should enter through the acceptance cone which make the angle ($\theta_{NA}$ ) relative to the axis of the fibers. So the acceptance cone of the optical fibers cannot be determined specifically. But the numerical aperture is specified from the expression (6), so that the expression explains the relationship between the acceptance cone and the numerical aperture [22].

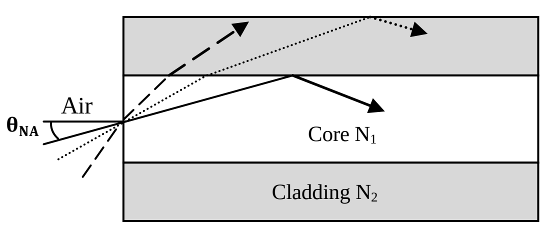


**Fig 7: Numerical aperture (NA) properties**

the numerical aperture is challenged so that the light enters the core of the fibers is limited with an angle before the numerical aperture (NA) of the fibers themselves, so if the value of the numerical aperture is 0.22, it will permit the cone to accept up to 22.4 degree which is the maximum possible angle. The exit from the fiber is the same as the entrance, as the rays are restricted by the maximum exit angle from the fibers [23].

## 4. THE RELATIONSHIP BETWEEN TOTAL INTERNAL REFLECTION AND DISTANCE

When the light passes in the middle of a refractive index $n_1$ up to the center with a lower refractive index $n_2$, it makes a reflection and this is what we call total internal reflection, the angle at which the light enters is specified and the light is reflected when $n_1$ is larger than $n_2$, the critical angle can be defined by expression (7):

$$\sin\theta_c = \frac{n_2}{n_1} \quad \text{For} \quad n_1 > n_2 \quad (7)$$

When light enters with an incidence angle $\theta_1$ greater than the critical angle $\theta_c$, this is one of the conditions for total internal reflection phenomenon [24] the paths travelled by the rays in an optical fiber with stepped refractive index are different, depending on the angles of their proximity of the axis, i.e., the difference in the media leads to the difference in time to reach the end point, and this index affects the rate of data transfer in optical fibers [25] the fibers can be classified by the number of media, including single medium (single mode) counting for zero as the rays moved lower, while multimode which carry rays in the high position, the number of media is determined according to the numerical aperture of the fiber and the acceptance angle in addition to diameter of the core and the wavelength of the light, the number of media could be approximated by the expression (8).

$$Nm = 0.5\left(\frac{\pi D * NA}{\lambda}\right)^2 \quad (8)$$

Where (D) is the diameter of the core, (λ) is the wavelength and (NA) is the numerical aperture [26].

In the case of calculating the number of modes and it found that it was less than or equal to (2,405), this means that the fiber is of the single mode type, if we want to count the number of mode this could be done by the expression (9)

$$V_m = \frac{V^2}{2} \quad (9)$$

In the multimode category, the number of rays is multiple where these rays enter with different incident angles and reflected in different refraction angles, this difference in angles of reflection leads to the passage of rays at different tracks and varying in time and space [27] through the critical angle we can determine the greatest possible incident angle according to the surface of the core and the cladding ($\theta \geq \theta_c = \sin^{-1} n_2/n_1$ but if the angle of incidence and the critical angle is equal ($\theta = \theta_c$) then the ray spreads slowly, the fastest ray spreads toward the axis of the fiber ($\theta = \pi / 2$), and from here we can estimate the maximum income dispersion pattern through the difference in propagation delay between both slower and faster the rays that the maximum difference in delay recalled of fiber length and the unit of income dispersion pattern (NS/km2).[28]

## 5. THE GEOMETRIC FIBER OPTICS

The geometric fiber in the multiple reflections the rays which represent the shape of waveguide, in figure 8 where the dotted line represents the path broken by the rays in the upper and lower interface in the core, incidence and reflection angles are identical in all reflections, and also bold represents the path of the rays and in meanders under the laws of reflection, the incidence angle rays grow by multiple reflections and frequency and when the rays at the exit point, the angle of reflection equals the angle of refraction when another exit point, and have greater measuring angle at the beginning of the entry [29].

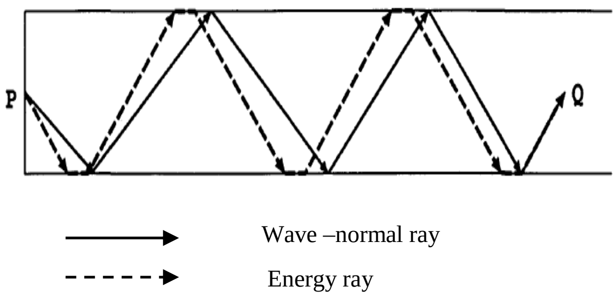


**Fig 8: Ray paths in a waveguide.**

When the rays in the fiber, the rays only achieved full internal reflection where repeated a specific number of knowledge, through optical fiber along a path (L) as in figure. 9, i.e. the beam enters at an angle in the direction of the axis and refract within the fiber of a point at an angle when reflected from point B and then heading to the surface and passes through the axis of point C is reflected by a certain angle and duplicated that session and a full internal reflection phenomenon where you can count the number of Full internal reflection, hope the distance between points AC = $l_s$ is a skip (offset), this distance represents the distance between two successive repercussions, as described in expressions (10, 11).

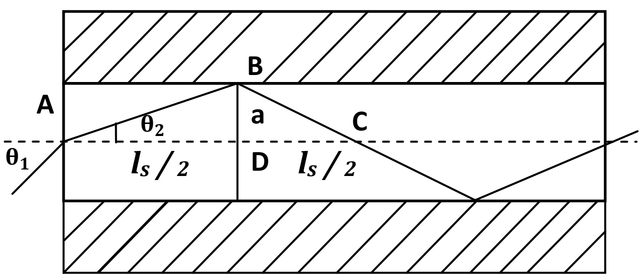


**Fig 9: Skip Distance $l_s$**

$$\Delta^{le}\ ABD, AD = \frac{1}{2}\ AC = \frac{l_s}{2}, BD = a \text{ And } \angle BAD = \theta_2 \quad (10)$$

$$\tan\theta_2 = \frac{BD}{AD} = \frac{a}{l_s/2} \quad \text{Or} \quad l_s = \frac{2a}{\tan\theta_2} \quad (11)$$

So you can count the number of full internal reflection in optical fiber by expression (12) [30]

The number of total internal reflection in the total fiber length is given by:

$$N = \frac{Total\ length\ of\ the\ cable}{The\ distance\ travelled\ during\ on\ reflection} = \frac{l}{l_s}$$

$$N = \frac{L\ \tan\theta_2}{2a}$$

$$N = \frac{L}{2a\left[\left(\frac{n1}{\sin\theta_1}\right) - 1\right]^{1/2}} \quad (12)$$

To measure the distance between successive repercussions to the rays that enter the incidence angle θ ', this distance is the distance skip L as shown in figure 10 can be calculated from the expression (13, 14) [31]

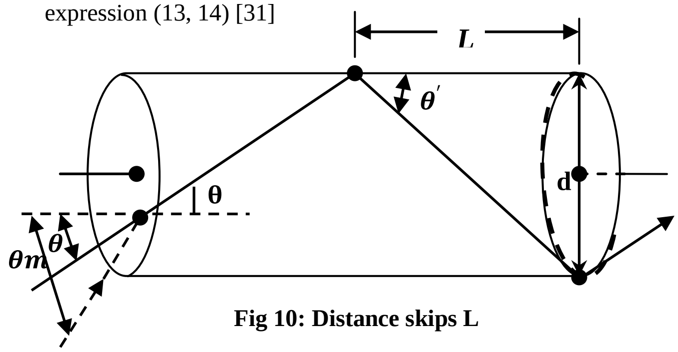


**Fig 10: Distance skips L**

$$L_s = d\cot\theta' \quad Or\ L_s = {}^{d}\sqrt{\left(\frac{n_1}{n_{0\ \sin\theta}}\right)^2 - 1} \quad (13)$$

Giving a minimum skip distance for a guided wave of

$$L_{s,min} = {}^{d}\sqrt{\left(\frac{n_1}{NA}\right)^2 - 1} \quad (14)$$

From the point of view of geometrical optics, conclude that the radiation entering and Propagating in different angles during passing through optical fiber, optical fiber in rays into skew rays and meridional rays, as in figure 11 shows that radiation does not care about the central axis and does not adhere to a certain level on fiber length, these rays know skew rays , A simplified special case is the Meridional rays shown in figure 12 see the rays interested in central spine and adhere to a certain level on fiber length where they pass through a axis, The rays know Meridional rays [32]

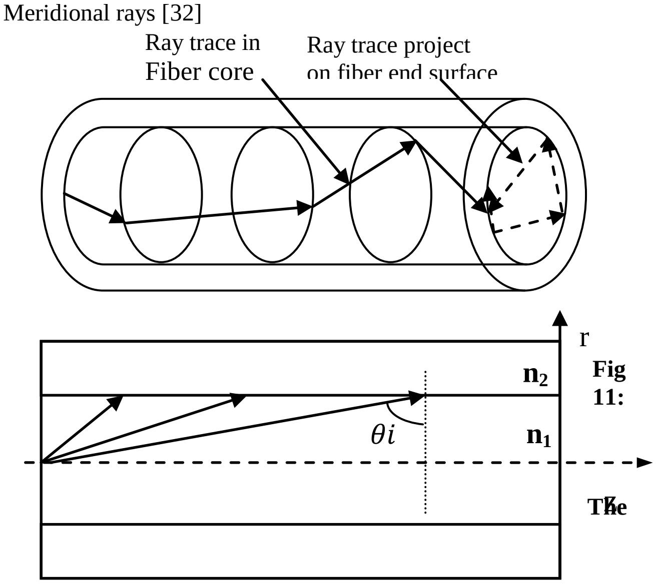


**Fig 11: The**

**Skew rays trace**

**Fig 12: The Meridional rays trace**

**Table 1. The angles posed by the ray passing in core**

| Rays | $\theta_1$ | $\theta'_{1\text{-}n}$ | $\theta i_{1\text{-}n}$ | $\theta r_{1\text{-}n}$ | $Ls_1$- $s_n$ |
|---|---|---|---|---|---|
| 1 | 2.28 | 1.58 | 88.42 | 88.42 | 10.00 |
| 2 | 4.55 | 3.16 | 86.84 | 86.84 | 10.02 |
| 3 | 6.79 | 4.71 | 85.29 | 85.29 | 10.03 |
| 4 | 8.98 | 6.22 | 83.78 | 83.78 | 10.06 |
| 5 | 11.12 | 7.70 | 82.30 | 82.30 | 10.09 |
| 6 | 13.2 | 9.12 | 80.88 | 80.88 | 10.13 |
| 7 | 15.18 | 10.48 | 79.52 | 79.52 | 10.17 |
| 8 | 17.07 | 11.76 | 78.24 | 78.24 | 10.21 |
| 9 | 18.83 | 12.95 | 77.05 | 77.05 | 10.26 |
| 10 | 20.47 | 14.06 | 75.94 | 75.94 | 10.31 |
| 11 | 21.96 | 15.05 | 74.95 | 74.95 | 10.36 |
| 12 | 23.29 | 15.94 | 74.06 | 74.06 | 10.40 |
| 13 | 24.44 | 16.70 | 73.30 | 73.30 | 10.44 |
| 14 | 25.4 | 17.33 | 72.67 | 72.67 | 10.48 |
| 15 | 26.17 | 17.83 | 72.17 | 72.17 | 10.50 |
| 16 | 26.72 | 18.19 | 71.81 | 71.81 | 10.53 |
| 17 | 27.05 | 18.41 | 71.59 | 71.59 | 10.54 |

## 6. ANALYSIS AND RESULTS

When the ray enters at an angle θ ,it is refracted at an angle θ', which fall on the incidence angle $\theta_i$ If the angle of incidence greater than the critical angle is reflected at an angle of reflection angle $\theta_r$.
The concept acceleration is defined by the amount of order is defined by the where at speed over speed is considered as the amount at change of distances over the time [33] this paper discusses the acceleration optical fiber through the increasing amount in the reflection angle. This amount represents the displacement all the ray movements, which leads to specified increasing on the length. The distance L between the reflection amount on both surfaces which produces acceleration between all rays passed through the core , which is illustrated in figure 13 this figure gives a clear observation about reflection angle, such that the larger angle will increase the distance. Thus, the time required for particular ray to reach the other side will be changed accordingly changes between angle of reflection with core to distances are presented in table 1

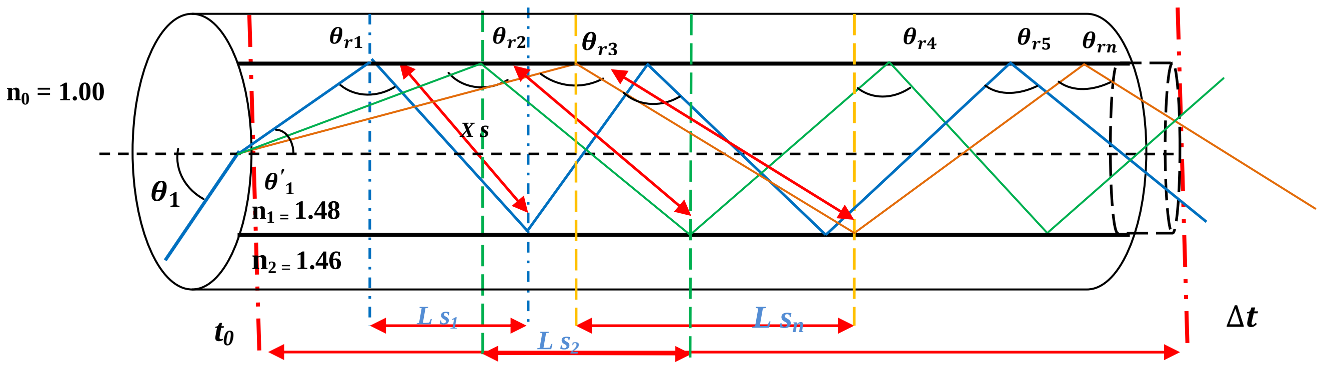


**Fig 13: The path of rays in the core of the optical fiber**

Accordingly it is quite clear that any increasing in reflection angle will form shift (displacement) which increase the distance between any successive reflections throughout the fiber core as hown in figure 14.

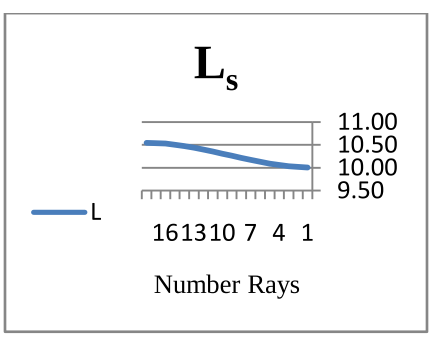


**Fig 14: The relationship between angle of reflection and the distance**

## 7. CONCLUSION

Acceleration is produced from the variations in speed according to the time, the disparity in the distance traveled by radiation with the difference in arrival time. This acceleration which occur in optical fibers, where rays enter in different incidence angle and reflected in different angle this difference results in a shift in the distance within different time periods. In this paper it total reflection phenomenon has been studied in fibers and it was concluded that the acceleration in optical fiber could be calculated by several variables, including the angle of incidence and angle of reflection and skip(offset) Distance and time of radiation group in the optical fiber, and show that when increasing the angle of incidence so the angle of reflection, this increase leads to a displacement which push the beam to converge to an end so ray with higher reflection angle will arrive earlier .

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