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Comparative Analysis of Diameter Dependence of Stimulated Raman Scattering Loss in Optical Fiber Communication System

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Abstract— *This paper highlights the effect of core diameter of different types of optical fiber cables on* Stimulated *Raman Scattering loss of an optical fiber communication system. This paper reports the numerical analysis of* Stimulated *Raman Scattering loss at three different windows of the operating wavelength of a laser for four types of optical fiber cables namely- Multi-Mode Step Index silica fiber, Multi-Mode Graded Index silica fiber and plastic fibers. This loss characteristic of the above mentioned types of optical fiber cable has been analyzed through numerical approach. From the numerical analysis of the present research work it is strongly revealed that although the* Stimulated *Raman Scattering loss is affected by the operating wavelength, it is also strongly governed by the core diameter and the type of the cable. From the rigorous investigation of the numerical analysis, it is ascertained that the* Stimulated *Raman Scattering loss declines with the application of Multi-Mode Graded Index silica fiber. And for Plastic fiber application Step Index fiber offers better performance*.

Index Terms— Core diameter, Graded-index fiber, Operating wavelength, Raman Scattering loss, Step index fiber,.

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1 INTRODUCTION

CONVEYING message from a sender to a receiver through a waveguide by means of a light wave through the optical fiber is referred to as Optical Fiber Communication [1, 2]. Numerous issues still exist in an Optical Fiber Communication System even in this modern era of technology. Among them, the major issues include attenuation, dispersion, short distance repeater spacing, and some other non-linear effects. The major limitations of the optical fiber communication system arise due to the dispersion effects among all these above-mentioned issues. Dispersion is referred to as a pulse spreading in an optical fiber cable. Dispersion is a function of the length of optical fiber cable. It varies with the variation of the length of the optical fiber cable. For the transmitted optical signals dispersion occurs for both digital and analog transmission through optical fiber cables using various types of analog and digital modulation techniques such as Amplitude Modulation, Phase Modulation, and Frequency Modulation, ASK, PSK, FSK, PCM and so on [3]. After dispersion, amplification of the transmitted light pulses passes in the direction of the optical receiver through the channel. Modal dispersion is a type of dispersion in which pulse broadening is originated due to the time delay. Chromatic dispersion is another type of dispersion in which pulse broadening occurs due to the transmission of light of different wavelengths as they possess different velocities through the optical fiber cable. The third type of dispersion is Material dispersion. It is caused by the limited line broadening of the laser, which is a source of an Optical Fiber Communication system.

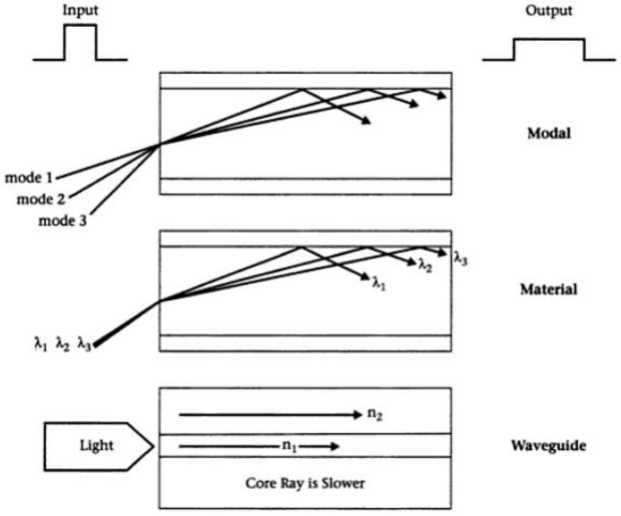

Figure 1: Different types of dispersions in Optical Fiber Communication System.

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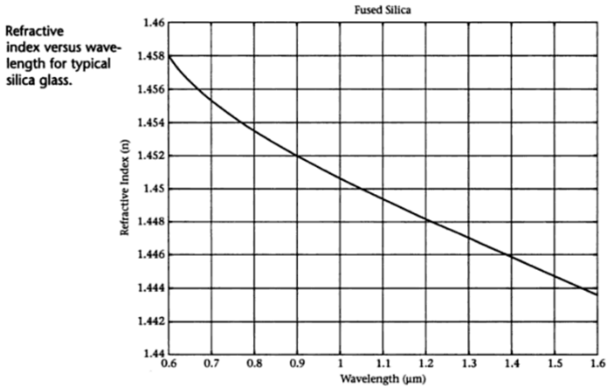

Figure 2: Wavelength dependence of refrective index Different types of dispersion in Optical Fiber Communication System.

The wavelength of the transmitted light is also affected by the refractive index of the material of the waveguide as shown in Figure 2. Last but not the least Waveguide dispersion is another type of dispersion. Most of the light passes through the core however some portion of the light passes through the cladding layer of the optical fiber cable. The light wave passes faster through the cladding layer than that in the core as the refractive index of the cladding is lower than that of the cladding layer. Due to this variance in refractive index in the waveguide, this dispertion occurs. It is referred to as Waveguide dispersion. It is one type of chromatic dispersion. It is a function of fiber core size, wavelength and light source linewidth and is only important in single mode fibers. [1, 3]. Figure 1presents the different type of dispersion in Optical Fiber Communication System.

Dispersion compensation is the most vital feature required in optical fiber communication system as a result of the absence of it results in pulse spreading that causes the output pulses to overlap [2,3]. The Nonlinear effects of optical fibers, for example, self-phase modulation and four-wave mixing, be able to provide an evident at high powers of optical in a fiber-based system. In self-phase modulation, the incorporeal and temporal modifications to optical pulses are possible to ascend. Another one is four-wave mixing; it is among the strongest parametric wave mixing nonlinearities. The nonlinear effects in optical fiber occur either due to intensity dependence of the refractive index of the medium or due to inelastic-scattering phenomenon. Various types of nonlinear effects based on the first effects such as self-phase modulation, cross-phase modulation, and four-wave mixing. Transmission of signal information through optical fibers rapidly improved due to the quality of transmission and broad bandwidth. This contribution covers modulation techniques employed in the optical transmission medium. The focus is on the negative influences of the optical environment.

The optical fibers, which are commonly used, may be divided into two groups depending on their modal properties, which are (a) single-mode fibers, and (b) multimode fibers. The Single-mode fibers are step-index. Multimode fibers are separated into two groups (1) step-index, and (2) graded-index. Step-index or graded-index indicate the variation of the index of refraction with radial space from the fiber orbit. These three forms of fibers namely (1) step-index multimode, (2) graded-index, and (3) single-mode. Their fibers formed by a core that surrounded by a cladding. In the core of the higher index of refraction likened to the cladding create a total inner reflection at the core-cladding interface in step-index fibers. From graded-index fibers, the step by step decrease in the index of refraction with rang from the fiber orbit create light cord to turn back into the axis as they extend. Multimode guides are determined by different propagation ways for the cord. A modal definition of multimode fibers indicates multiple propagation speeds for multiple modes. Consequently, when short pulse energy enters into the fiber combine into a multiple of modes, will come at the acceptance end of the fiber distributed over some time. The spreading out in time of the accepted pulse is because of the multiple propagation suspension of the multiple modes.

Among the three (0.89um, 1.3μm& 1.55μm) communication windows of optical fiber communication system, 1.55 μm offers the lowest attenuation, greater repeater spacing and higher bit rate. These phenomena made it possible to use coherent optical sources compatible with the Standard silicon fibers used in optical fiber communication [3]. Therefore, most of the recent work on light sources and detectors has been concentrated. Semiconductor sources and detector with Group-III-V compounds in active layers have been studied extensively and used almost exclusively for the present light-wave communication systems in these wavelength regions [5-9]. Efforts have been made to enhance the laser and photo-detector performances. However, the losses due to Stimulated Raman Scattering increases at the order of 2 with increasing wavelength of future generation of optical fibers, light sources, and detectors may will be operating at still longer wavelengths [10]. It has been reported that to reduce Stimulated Raman Scattering loss of optical fibers electronic filters are applied widely [17]. Conversely, to utilize the enormous potential, the prospect to take into consideration for an optical fiber communication system that offers minimum loss over an enormous potential bandwidth still required to be investigated effectively [11].

2. MATHEMATICAL MODELING

2.1 Stimulated Raman Scattering

Stimulated Raman Scattering in an optical fiber has been the subject of intense research for over two decades; since Stimulated Raman Scattering processes are relevant to many aspects of optical communication systems, optical data processing systems, optical amplifiers etc [14]. Low loss optical fibers are currently being considered as transmission media for optical communication systems. At low power densities the losses of an optical fiber will be determined by spontaneous Raman Scatering in the case of forward Stimulated Raman Scattering. This principal effect is a frequency shift of the radiation transmitted by the fiber to lower frequencies. Sufficiently large frequency shifts could produce amplitude distortion at the receiver if the detector is intrinsically frequency sensitive or if narrow band filters are used. On the other hand backward-wave stimulated scattering processes (either Raman or Brillouin) will result in a severe attenuation of the forward traveling, information carrying wave, due to the transfer of energy to the stimulated backward wave Stimulated Raman Scattering is a nonlinear response of glass fibers to the optical intensity of light. This is caused by vibrations of the crystal (or glass) lattice. Stimulated Raman Scattering produces a high-frequency optical phonon, as compared to Brillouin scattering, which produces a low-frequency acoustical phonon and a scattered photon. Figure 3 prersents the process of Stemulated Raman Scatering.

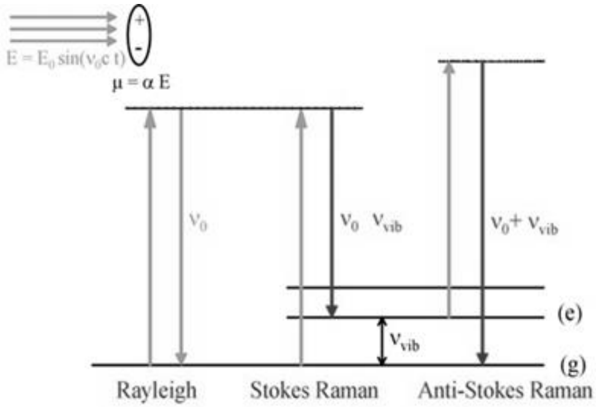

Figure 3: Simulated Raman Scattering.

When two laser beams with different wavelengths (and normally with the same polarization direction) propagate together through a Raman-active medium, the longer wavelength beam acknowledges optical amplification at the expense of the shorter wavelength beam. This phenomenon has been used for Raman amplifiers and Raman lasers.At high power level Simulated Raman Scattering leads to scattering of pump photons to first Stokes photons, then first Stokes acting as a pump generates second Stokes and so on. For many applications the suppression of higher-order Stokes or even first Stokes is desired. Various techniques to perform this have been used; among them are methods based on dual-frequency pumping or four-wave mixing [15, 16].

In Stimulated Raman Scattering, the scattering is predominately in the forward direction, hence the power is not lost to the receiver. Stimulated Raman Scattering also requires optical power to be higher than a threshold to happen. The formula below gives the threshold [1]:

$$P_R = 0.059 d^2 \lambda \alpha_{dB} \quad (1)$$

where,
P_R = Stimulated Raman Scattering optical power level threshold (Watts)
d = Fiber radius (μm)
λ = Light source wavelength (μm)
α = Fiber loss (dB/km).
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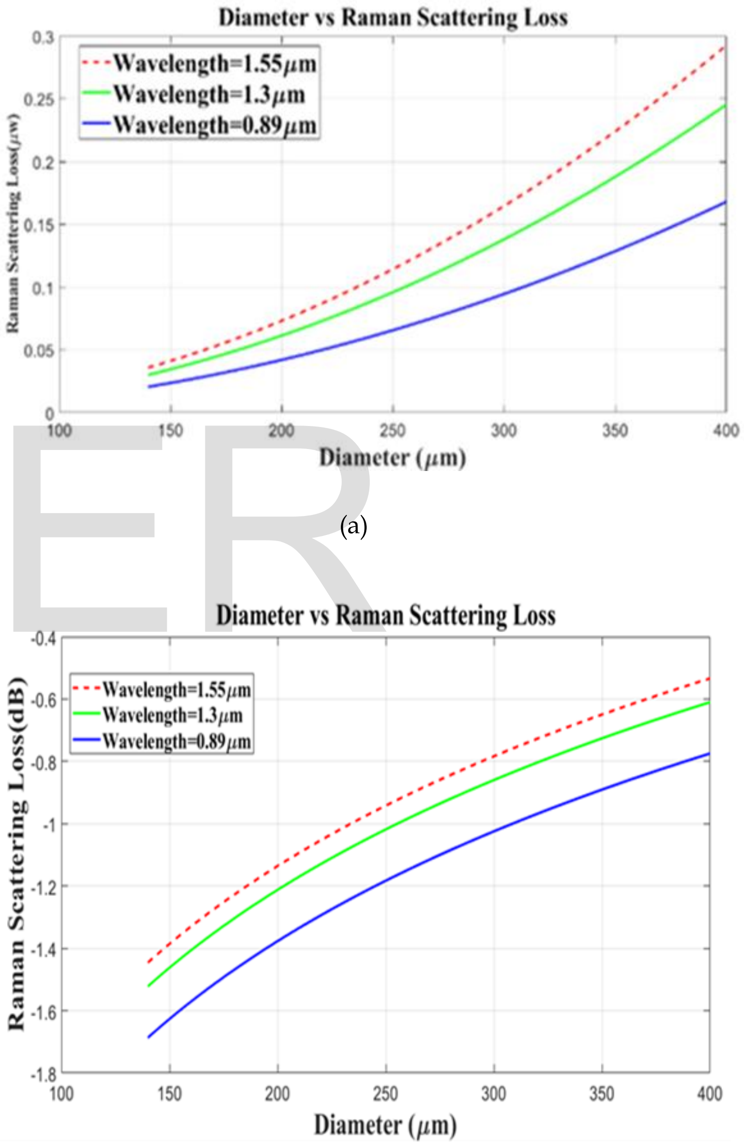
3 Result and Discussion

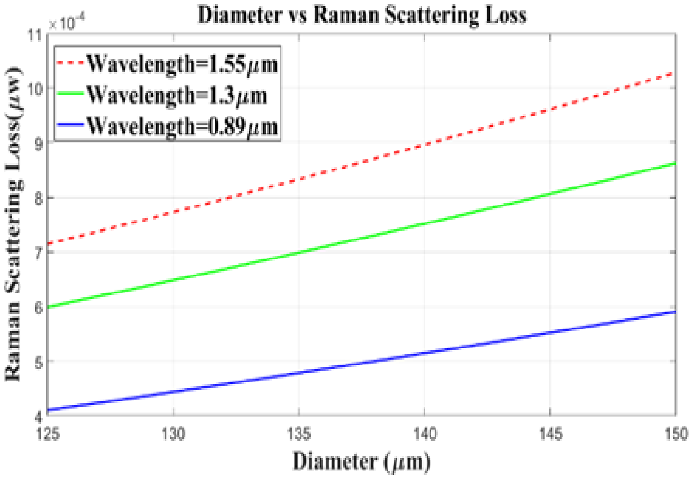
This section presents the detail description of the obtained results throughout the comparative analysis of the effect of the diameter of optical fiber cable on the Stimulated Raman Scattering loss for the three optical fiber windows. The variation of Stimulated Raman Scattering loss has been investigated numerically for four different types of cables. These are-Multi-Mode Step Index, Multi-Mode Graded Index silica fiber and plastic fibers. This characteristic has been presented in Fig. 4-7.



(a)

(b)

Figure 4: Diameter dependence of multi-mode step index Silica fiber for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89μm, 1.3μm& 1.55μm wavelength respectively.



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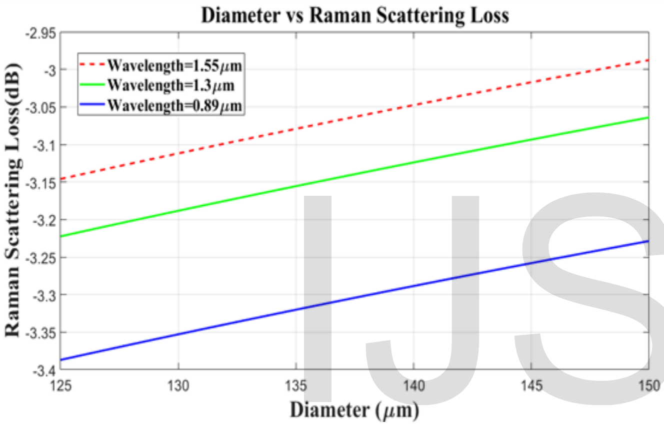
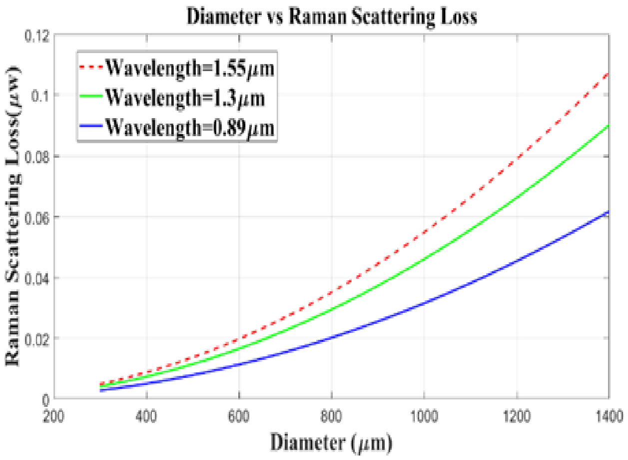


(b)

Figure 5: Diameter dependence of Silica graded index optical fiber for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm& 1.55µm wavelength respectively.



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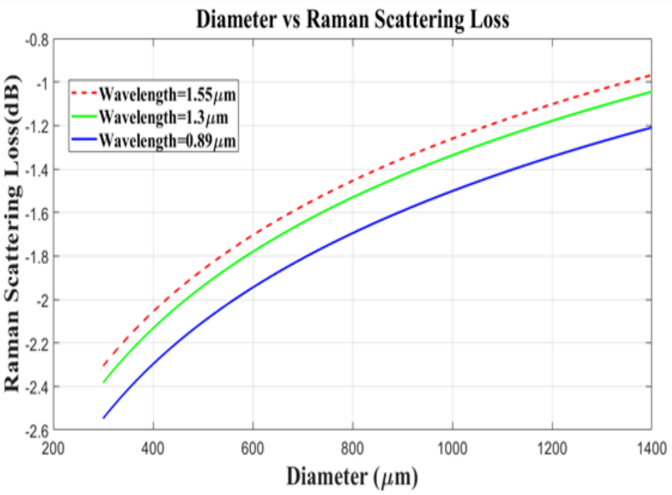
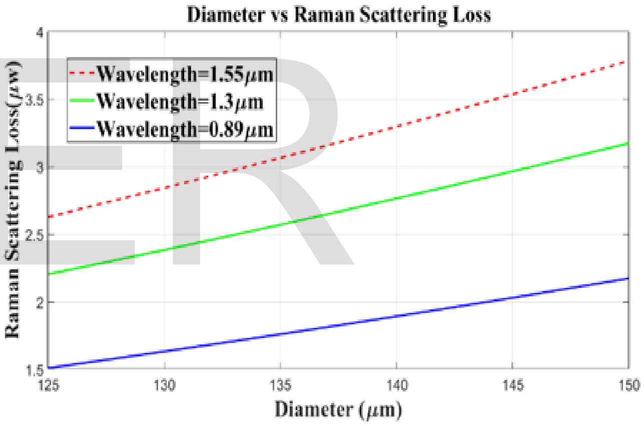


(b)

Figure 6: Diameter dependence of plastic step index optical fiber for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm& 1.55µm wavelength respectively.



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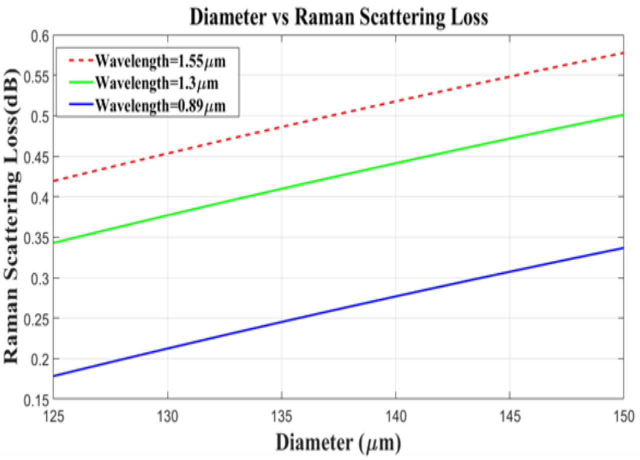

(b)

Figure 7: Diameter dependence of Plastic graded index optical fiber for three windows of optical fiber communication system. The Blue line, Green Line and Red line represents the Stimulated Raman Scattering loss

for 0.89µm, 1.3µm& 1.55µm wavelength respectively.

Figure 4 presents the effect of diameter of multi-mode step index Silica fiber on the Stimulated Raman Scattering loss in optical fiber cable for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm & 1.55 µm wavelengths respectively. The Stimulated Raman Scattering loss is calculated in µW and in dB as shown in Figure 4 (a) and 4(b) respectively. The Stimulated Raman Scattering loss within the optical fiber cable increases with the increase of diameter for the Multi-mode step-index fiber. However, from the numerical comparison result, it is ascertained that the Stimulated Raman Scattering loss of the optical fiber is the lowest for 0.89µm.

Figure 5 presents the effect of diameter of multimode graded index Silica fiber on the Stimulated Raman Scattering loss in optical fiber cable for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm & 1.55 µm wavelengths respectively. The Stimulated Raman Scattering loss is calculated in µW and in dB as shown in Figure 5(a) and 5(b) respectively. The Stimulated Raman Scattering loss within the optical fiber cable increases with the increase of diameter for the four different types of cables. However, from the numerical comparison result, it is ascertained that the Stimulated Raman Scattering loss of the optical fiber is the lowest for 0.89µm.

Figure 6 presents the effect of diameter of step index Plastic fiber on the Stimulated Raman Scattering loss in optical fiber cable for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm & 1.55 µm wavelengths respectively. The Stimulated Raman Scattering loss is calculated in µW and in dB as shown in Figure 6(a) and 6(b) respectively. The Stimulated Raman Scattering loss within the optical fiber cable increases with the increase of diameter for the Multi-mode step-index fiber. However, from the numerical comparison result, it is ascertained that the Stimulated Raman Scattering loss of the optical fiber is the lowest for 0.89µm.

Figure 7 presents the effect of diameter ofMulti-mode graded index Plastic fiber on the Stimulated Raman Scattering loss in optical fiber cable for three windows of optical fiber communication system. The Blue line, Green Line and Red line represent the Stimulated Raman Scattering loss for 0.89µm, 1.3µm & 1.55 µm wavelengths respectively. The Stimulated Raman Scattering loss is calculated in µW and in dB as shown in Figure 7(a) and 7(b) respectively. The Stimulated Raman Scattering loss within the optical fiber cable increases with the increase of diameter for the four different types of cables. However, from the numerical comparisonresult, it is ascertained that the Stimulated Raman Scattering loss of the optical fiber is the lowest for 0.89µm.

The current analytical research work show that the performance improvement of optical fiber network is possible by reducing the diameter ofthe optical fiber cable at any operating wavelength of laser. The range of Stimulated Raman Scattering loss for the considered four types of cables at three windows of optical fiber communication system is tabulated in Table 1.

TABLE 1
RANGE OF STIMULATED RAMAN SCATTERING LOSS FOR FOUR TYPES OF OPTICAL FIBER CABLES AT THREE WINDOWS OF OPTICAL FIBER COMMUNICATION SYSTEM.

Types of Fiber	*Optical Source and Detector Operating Wavelength (µm)*	*Range of Losses (µW)*
Multi-mode step index Silica Fiber	0.89	0.02088-0.1676
	1.3	0.03038-0.2456
	1.55	0.03585-0.2891
Multi-mode graded index Silica Fiber	**0.89**	**0.0004102-0.0005907**
	1.3	**0.0005992-0.0008629**
	1.55	**0.0007145-0.001029**
Step index Plastic Fiber	0.89	0.002854-0.06175
	1.3	0.004394-0.09007
	1.55	0.005004-0.1075
Graded index Plastic Fiber	0.89	1.508-2.172
	1.3	2.203-3.172
	1.55	2.626-3.782

From the ranges it is clear that Multi-mode graded index Silica fiber offers lowest Stimulated Raman Scattering loss. The numerical findings ofthis research work can be a doorway for the researchers to facilitate the design of optical fiber cable that offers lowest Stimulated Raman Scattering loss after the experimental validation.

4. Conclusion

A comparative analysis of effect of diameter of optical fiber cable on Stimulated Raman Scattering loss in Optical Fiber Communication System has been presented in this paper. The diameter dependence of Raman scattering loss at the three windows of Optical Fiber Communication system has been analyzed considering Multi-Mode Step Index, Multi-Mode Graded Index silica fiber and plastic fibers as the transmission media. From the outcome of the comparative analysis through numerical approach it is it ascertained that the lowest Stimulated Raman scattering loss has been reported for Multi-Mode Graded Index silica fiber. This research work reports that the Raman scattering loss is affected by the core diameter and the type of the cable.

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