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Selective Excitation of Circular Helical Modes in Graded Index Fibers

S. Al-Sowayan

***Abstract*—**The impact of selective excitation of circular helical modes of graded-index fibers on its capacity is analyzed using a model for propagation delay variation with launch offset and angle that resulted from misalignment of source and fiber axis. Results show promising technique to improve graded-index fiber capacities.

***Keywords*—**Fiber measurements, Fiber optic communications.

I. INTRODUCTION

VERTICAL CAVITY SURFACE EMITTING LASERS (VCSELs) and multimode fibers (MMFs) are widely used in local and storage area networks. It is a fact that when the bandwidth demand increased by the high bandwidth applications required from the networks, the capacity of the MMF will be a bottleneck for the system [1], [2]. Legacy MMF with 62.5μm core can have bandwidth as low as 160 MHz-km at 850nm wavelength, and the observed bandwidth can be sensitive to launch angle and offset [3]. If the launch condition makes perfect alignment between source and fiber axis, what is so called meridional modes will only be excited. Meridional modes are the propagation modes that follow a path cross the fiber axis. The axial mode, which is the lowest order mode, is the mode of propagation that travels along the longitudinal axis of the fiber. If there is misalignment in both angle and offset between the source and the fiber axis as in Fig. 1 what is called helical modes of propagation will be excited. Helical modes are the type of modes that propagate in a helix shape inside the core of the fiber along the longitudinal direction that do not cross the fiber axis and bounded by the total internal reflection inside the core of the fiber [4]

In particular, low angle, on-axis power excites a selection of low-order modes which can result in excessive and unstable pulse broadening relative to over filled launch conditions [5]. Since the bandwidth is sensitive to launch parameters, it is important to consider which group of modes is being excited by laser sources. Our previous work [6] showed how the beam divergence distributions of commercial VCSELs depend on the data pattern driving them. In this paper a computer model for propagation delay in graded index fibers was used to quantify the impact of selective excitation of circular helical modes only on link performance. Extended work to be done that utilizes experimental findings to verify and strength the model is proposed.

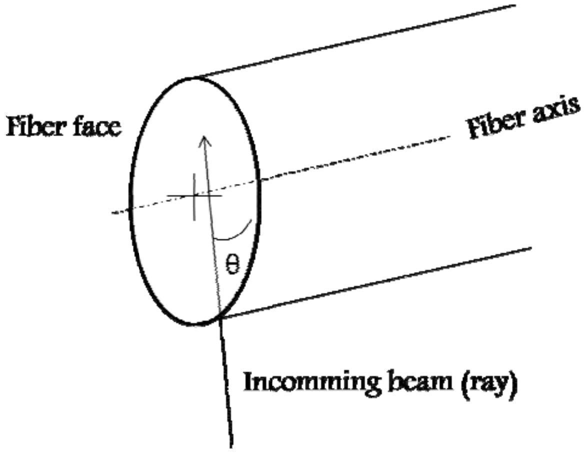

Fig. 1 Misaligned coupling in both offset and angle

II. COMPUTER MODEL AND RESULTS DISCUSSION

The model refers the coupling angle and offset from the center of the fiber to order of the helical path that the optical energy will follow; the equation of the circular helix is stated in (1).

$$x = A\cos t \qquad (1)$$
$$y = A\sin t$$
$$z = bt$$

where x and y are the transverse plane and z is the longitudinal direction of the fiber, A and b are the radius and frequency of the helical mode that will be determined by the coupling (entrance) angle to the fiber and the offset from the center of the fiber. In GI fibers the common refractive index profile is the power law profile which forms a parabola shape of refractive index with the peak at the center of the fiber. It has been shown that good approximation of the refractive index profile for a commercial 62.5/125μm GI fiber is what is introduced in [7] which we will use here. It states that in the manufacturing process of GI fibers there is a common defect that introduces a peak or dip at the center of the fiber which in turn reduces the capacity of the GI fibers when used with lasers. Because of that defect the entering rays will be offseted from the center by 2μm to avoid this defect. Without considering the defect at the center of the fiber the index profile is described in (2).

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

Dr. S. Al-Sowayan is with the Electrical Engineering Department, Al Imam Mohammad Ibn Saud Islamic University (IMSIU),Riyadh, Saudi Arabia (e-mail: sssowayan@imamu.edu.sa).

where n_1 is the refractive index of center of the core typical value for the glass is 1.5, Δ is the change in the profile typically 0.01, r is the radial position, and a is the radius of the core which is 31.25µm. The coupling between the optical ray source and fiber shall make an angle (θ) with the transverse plane of the fiber, to ensure no meridional modes nor elliptical helical modes are excited this angle shall make an entrance angle greater than the acceptance angle of the fiber (in this case it is 12^o), another condition is that the projection of the ray into the face of the fiber should be perpendicular to the radial vector from the center of the fiber to point of ray entrance to the core of the fiber. This means θ shall vary from $10^o$to 78^o, the 10 degrees are chosen for the helix to be realistic enough to propagate in the longitudinal direction. Table I shows for each entrance angle, measured from the transverse plane of the face of the fiber to the ray, the corresponding helical mode order for a certain offset of 6µm. Fig. 2 gives a bigger picture of the relationship between the launch offset from the center of the fiber, the angle of entrance and the helical mode path length (normalized to the longest one) which can be calculated from the resulting helix parameters of Table I and extending it to different offsets. Fig. 2 clearly shows that as the offset gets larger the path of the optical pulse increases and as the angle θ becomes larger the optical pulse path decreases.

TABLE I
COUPLING ANGLE WITH CORRESPONDING HELIX PARAMETERS

θ	Normalized helix parameters (A, b)
10	$(6, 28 * 2\pi)$
30	$(6, 13.1 * 2\pi)$
50	$(6, 5.6 * 2\pi)$
75	$(6, 1.3 * 2\pi)$

As continuation to this work, it is of interest to consider the experimentally generated short optical pulse that was generated by gain switching an 850nm laser to produce a ~200 ps pulse shown in Fig. 3 as an input parameter to the model, the model then shall consider the arrival time of the mentioned pulse by calculating the required propagation time down the fiber normalized to the maximum time. The propagation time will be calculated based on the distance the pulse shall travel and the optical pulse group velocity which will defiantly be affected by the refractive index faced by the propagating mode. It will be published later that exciting a group of circular helical modes with certain offset from center of fiber and angle perpendicular to the radial distance from the center of the fiber with a particular narrow beam waist, in orders of 4 µm like the one used in [8], will improve the capacity of the GI fiber.

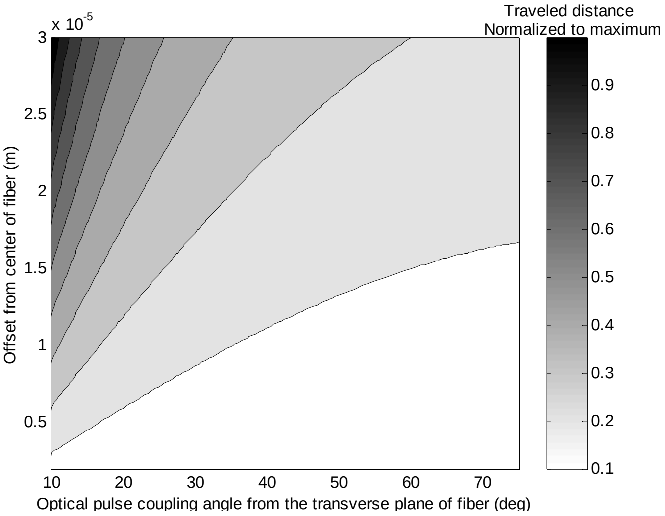

Fig. 2 Distance travelled in one rotation of circular helix for a particular coupling angle and offset

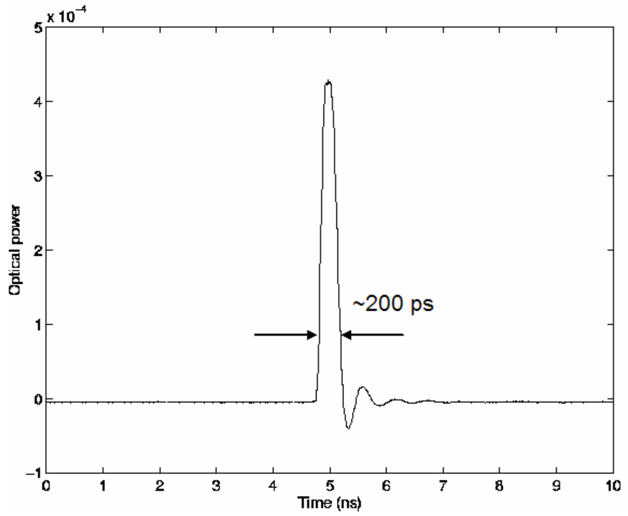

Fig. 3 Optical pulse from an 850nm gain-switched laser

III. CONCLUSION

In this paper a study of the excitation of helical modes of propagation in GI fibers has been presented by implementing a computer model that relates the launch offset and angle to the helical mode order. Continuation work is proposed that will clearly show the improvement of the capacity of GI fibers when selectively excite few number of helical modes of propagation.

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Dr. Sulaiman Al-Sowayan received his B.Sc. in electrical engineering in 1994 form king Saud University in Riyadh, Saudi Arabia (with honor), he got his M.Sc. and Ph.D. form Colorado state University, USA in 2000 and 2004 respectively. He published several papers in the field of using wavelet analysis with radar data and signal processing methods in fiber optic communications. After earring his Ph.D. he worked for one year as post doctorate in EE department at Colorado State University then he joined college of telecom and information in Riyadh as assistant professor. Three years later (until now) he joined the electrical engineering department at Al-Imam Muhammad Ibn Saud Islamic University as assistant professor.