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Prediction of unknown aspect ratio of a single mode trapezoidal index fiber using splice loss technique considering angular misalignment

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ABSTRACT

We use the splice loss measurement technique in absence and presence of angular misalignment and report a simple and accurate method to predict the unknown aspect ratio of a supplied circular core trapezoidal index single mode fiber. We, first, propose to determine the spot size of the unknown fiber from splice between two such fibers with angular misalignment. Then using a known empirical relation of power transmission coefficient and a graphical technique, we employ this spot size in splice loss between a step index and trapezoidal index fiber in absence of angular misalignment to predict the unknown aspect ratio. The method should find wide use by system developers and system users.

1. Introduction

Single mode fibers (SMF) with trapezoidal index profiles (TIP) have raised considerable amount of recent interest in the field of fiber optics since this profile has the combined merits of step index fiber possessing rigidity and triangular index fiber showing dispersion shifted criteria [1,2]. Investigations on the trapezoidal index SMF (TISMF) in connection with dispersion, splice loss, bending loss [3,4] and other propagation characteristics in both linear and non-linear [5] regimes have gained considerable attention. Some works have, also, been performed on the performance of Raman gain fiber amplifiers with a trapezoidal index in the inner core [6,7]. Also, TISMF has been studied to investigate its propagation characteristics by variational analysis involving two simple approximations of the fundamental mode [8]. In this context, it is relevant to mention that the knowledge of spot size is very important in the process of determination of different propagation characteristics like splice loss, bending loss, dispersion etc. in case of conventional SMFs and, also of photonic crystal fibers (PCF) [9,10].

Recently, a simple and accurate empirical relation has been reported [11] for the spot size of a TISMF in terms of normalised frequency and aspect ratio of the trapezoid. In order to achieve long distance optical communication, it is necessary to analyse the optical power loss at the splice either between two conventional SMFs or PCFs or between a conventional SMF and a PCF [12,13]. It may be relevant to mention here that recently several works have been reported on yielding large birefringence of PCF [14,15]. The splice loss at the joint between two SMFs reduces the optical power coupled from one fiber to the other. Hence, for proper optical power budgeting, the knowledge of the power transmission coefficient (PTC) and, thereby, the splice loss, is a necessity. This splice loss arises either due to mismatch of the profile shapes or due to the presence of transverse, angular or longitudinal misalignments at

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the splice [16–21]. Several works have been reported on the evaluation and reduction of splice loss [22–26]. Further, different types of fiber sensors have been designed using the splice loss analysis [27,28].

Several works have been reported, so far, to study the propagation characteristics of TISMF on the basis of splice loss analysis. But there is no easy and simple method available in literature for accurate characterization of such fiber, to the best of our knowledge, in connection with prediction of the unknown value of the aspect ratio of a given TISMF. In a recent publication [29], an empirical relation is proposed for the prediction of PTC for a given normalised frequency, V and aspect ratio, S considering two, perfectly, aligned step index SMF and TISMF. With such a relation, the PTC can be calculated without the knowledge of spot size. A graphical technique, has, also, been proposed to predict an unknown aspect ratio of a TISMF from the knowledge of PTC. But, it is not pointed out how one can predict an unknown aspect ratio if any TISMF pool is supplied to system users.

In this paper, our main objective is to propose how the knowledge of angular misalignment between two identical pieces of supplied TISMFs can be applied, effectively, for the accurate determination of the unknown aspect ratio of TISMF for a set of V values. We, also, justify the formalism by cross-checking the values of S, thus, obtained from the available earlier relations [29].

2. Theory

2.1. Basic framework

The scalar wave equation governing light propagation in an optical fiber, under the weakly guiding approximation, is given as [16]

$$\frac{d^2\psi(R)}{dR^2} + \frac{1}{R}\frac{d\psi}{dR} + a^2(k_0^2 n^2(R) - \beta^2)\psi(R) = 0 \tag{1}$$

where $\psi(R)$ represents the modal field solution in the core ; $R = r/a$ is the normalised core radius; r is the radial coordinate and a is the core radius; $k_0 = 2\pi/\lambda$; λ being the free space wavelength. Here, β is the propagation constant.

The refractive index $n(R)$ in Eq. (1) for a weakly guiding graded index fiber [16] is given by

$$\begin{aligned} n^2(R) &= n_1^2(1 - \delta f(R)), \quad \text{for } 0 < R \le 1 \\ &= n_1^2(1 - \delta) = n_2^2, \qquad \text{for } R > 1 \end{aligned} \tag{2}$$

where, n_1 is the refractive index along the axis of the core and n_2 is the cladding refractive index. Here, $\delta = (n_1^2 - n_2^2)/n_1^2$ and $f(R) = R^q$ is the profile shape function. The exponent q gives the shape of the core index profile. Further, $q = 1, 2$ and ∞ correspond to triangular, parabolic and step index fibers, respectively. For TISMF, the profile shape function is given by

$$\begin{aligned} f(R) &= 0, \quad \text{for } 0 < R \le S \\ &= \tfrac{R-S}{1-S}, \quad \text{for } S < R \le 1 \end{aligned} \tag{3}$$

where S represents the ratio of the width of the trapezoid and core radius and is called the aspect ratio of the trapezoid. The two extreme values of S are $S = 1$ and $S = 0$ for which the core index profile becomes step and triangular indices, respectively.

Using $n(R)$ defined in Eq. (2) in Eq. (1), Eq. (1) becomes

$$\tfrac{d^2\psi(R)}{dR^2} + \tfrac{1}{R}\tfrac{d\psi}{dR} + (U^2 - V^2 f(R))\psi(R) = 0, \quad \text{for } 0 < R \le 1 \tag{4}$$

where $U = a(k_0^2 n_1^2 - \beta^2)^{1/2}$ and $V = k_0 a(n_1^2 - n_2^2)^{1/2}$ are the normalised propagation constant and normalised frequency, respectively.

In the cladding region, where $f(R) = 1$, Eq. (4) becomes

$$\tfrac{d^2\psi(R)}{dR^2} + \tfrac{1}{R}\tfrac{d\psi}{dR} - W^2\psi(R) = 0, \quad \text{for } R > 1 \tag{5}$$

where $W = \sqrt{V^2 - U^2}$ and is called the cladding decay parameter.

The modal field solution $\psi(R)$ for the above Eq. (5) is the standard modified Bessel function and is given as

$$\psi(R) = \psi(1)\tfrac{K_0(WR)}{K_0(W)}, \quad \text{for } R > 1 \tag{6}$$

with $\psi(1)$ as the modal field solution at the core-cladding interface.

Since it is, numerically, intricate to obtain a complete solution of Eq. (4) with Eq. (6), we can approximate the fundamental modal field $\psi(R)$, having any arbitrary profile shape function, by the Gaussian function, as

$$\psi(R) = Ae^{-R^2/\omega^2} \tag{7}$$

where ω gives the beam radius, up to which, the field reduces to $1/e$ times the field amplitude at the core axis and is called the normalised spot size or the normalised mode field radius.