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Simple Determination of Splice Loss in Single Mode Graded Index Fibers Using Gaussian Spot Size of Marcuse Formulation

Aswini Kumar Mallick [1, 2]

[1]Department of Electronics, Vidyasagar University, Midnapore -721102, INDIA
[2]Department of Electronic Science, University of Calcutta, A.P.C. Road, Kolkata -700009, INDIA
Email: aswini_kumar_mallick@yahoo.com

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ABSTRACT
A simple technique is presented to determine splice losses between two identical arbitrarily graded index single mode fibers for transverse and angular misalignments. The power transmission coefficients at the splice are calculated in terms of spot size using Marcuse formulation for graded index fibers. Our values of splice losses match excellently with the exact one and also other results available in literature. The technique should attract attention of experimentalist as a simple alternative of rigorous methods to estimate propagation characteristics.

***Keywords**:* Single mode fiber, Spot size, Splice loss.

1. Introduction

Processing of information through the fundamental mode is the basic criterion in graded index single mode fibers (SMF) as well as in photonic crystal fibers [1] with endlessly single moded merits. One of the major problems in optical communication system lies in the proper connectivity between two SMF so that maximum light energy can be transferred between them. There are three major misalignment losses i.e. longitudinal separation, transverse offset and angular misalignment exists in practice. We consider here transverse offset and angular misalignment losses as because longitudinal separation as splice loss is highly tolerant [2–4].

In the present work, we calculate transverse offset and angular misalignment by evaluating spot size using Marcuse formulation for graded index SMF. The Marcuse spot size is the parameter w.r.t. which the overlap of Gaussian modal field corresponding to fundamental mode is maximized. This spot size more accurately estimates the modal parameter in comparison to spot size determined by variational method. We compute these misalignment losses for triangular index and also parabolic index profile and compare our results with exact and other results available in literature [5]. The results are seen to match excellently.

2. Analysis

Although we can compute splice loss between two non-identical SMF, we consider two identical SMF for simplicity. The power transmission coefficients T_D for transverse misalignment of two identical SMF with Gaussian fundamental mode of spot size ω can be represented by [6],

$$T_D = \exp\left(-\frac{D^2}{\omega^2}\right) \tag{1}$$

where $D = d/\rho$ is the normalized transverse offset.
Also the power transmission coefficients T_P for angular misalignment of two identical SMF with Gaussian fundamental mode of spot size ω can be represented by[6],

$$T_P = \exp\left(-\frac{n_1^2}{n_2^2}\frac{P^2\omega^2}{4}\right) \tag{2}$$

where $P = p/\rho = k_0 n_2 \theta$ is the normalized angular misalignment. On the other hand the approximate formula of normalized spot size ω as derived by Marcuse [7] can be written as,

$$\omega = \frac{A}{V^{2/(g+2)}} + \frac{B}{V^{3/2}} + \frac{C}{V^6} \tag{3}$$

where the parameter A, B and C can be determined by parameter optimization routine and is given below,

$$A = \left\{\frac{2}{5}\left[1 + 4\left(\frac{2}{g}\right)^{5/6}\right]\right\}^{1/2} \tag{4}$$

$$B = e^{0.298/g} - 1 + 1.478(1 - e^{-0.077g}) \tag{5}$$

$$C = 3.76 + \exp(4.19 / g^{0.418}) \tag{6}$$

The formulas are valid for $1.5 < V < \infty$.

Now the spot size can be determined by using equation (3) for various profiles by varying the power low exponent g for a particular V value. Now we can calculate transverse offset and angular misalignment loss for a particular profile for a particular V value by putting the spot size value in relation (1) and (2) respectively.

3. Results and Discussions

First, we like to test our technique for determination of splice loss for transverse and angular misalignments for parabolic index SMF as because the exact results are available in the literature [4]. Then we calculate splice loss for another graded index profile viz. triangular index profile.

The results for power transmission coefficients of transverse offset are calculated for $V = 2.0$ and $V = 3.5$ for parabolic index SMF and are presented in Table I. The results are compared with the exact values [4] and also the results obtained by Meunier [5]. Our results match excellently with the available rigorous data. The results obtained from present technique are more accurate than the results available from single parameter Gaussian approximation [8, 9]. The plot in the Fig. 1 corresponds to power transmission coefficients vs. transverse offset for *V = 2.0*. Here we see that our curve almost matches with the exact one.

TABLE I: POWER TRANSMISSION COEFFICIENT T_D AS A FUNCTION OF NORMALIZED TRANSVERSEOFFSET FOR SPLICING OF TWO IDENTICAL PARABOLIC INDEX FIBERS

V	D	Gaussian [9]	Ref. [5] for N=40	Present technique	Exact [4]
2.0	0.2	0.9784	0.9815	0.983482	0.9814
	0.4	0.9163	0.9288	0.935549	0.9287
	0.6	0.8216	0.8493	0.860795	0.8493
	0.8	0.7051	0.7531	0.766066	0.7530
	1.0	0.5793	0.6500	0.659426	0.6500
	1.2	0.4556	0.5488	0.549033	0.5488
	1.4	0.3430	0.4550	0.442145	0.4550
3.5	0.2	0.9383	0.9407	0.943225	0.9407
	0.4	0.7752	0.7843	0.791518	0.7843
	0.6	0.5639	0.5822	0.590932	0.5821
	0.8	0.3612	0.3877	0.392504	0.3877
	1.0	0.2037	0.2343	0.231943	0.2343
	1.2	0.1011	0.1303	0.121941	0.1303
	1.4	0.0442	0.0677	0.057036	0.0677

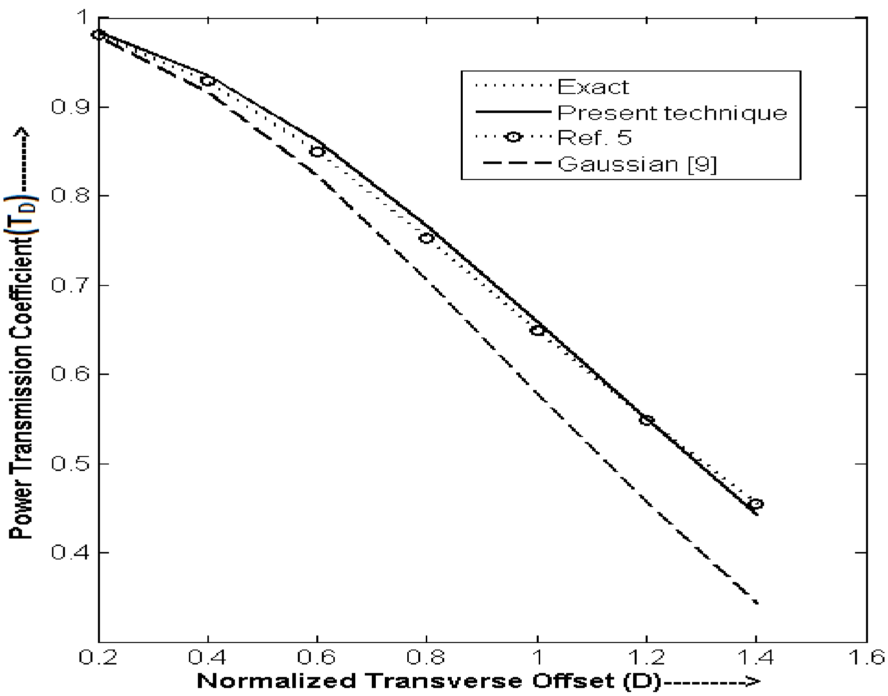

Figure 1: Power transmission coefficient T_D vs. Normalized Transverse Offset of two identical parabolic index fiber with $V = 2.0$

Then results for power transmission coefficients of angular misalignment are calculated for $V = 2.0$ and $V = 3.5$ for parabolic index SMF and are presented in Table II. Here also similarly we compare our results with exact values [4] and Meunier [5] and observe similar excellence. The results obtained from present technique are more accurate than the results available in single parameter Gaussian approximation [8, 9]. The plot in the Fig. 2 corresponds to power transmission coefficients of angular misalignment are calculated for $V = 2.0$ and establish effectiveness of our technique.

TABLE II: POWER TRANSMISSION COEFFICIENT T_P AS A FUNCTION OF NORMALIZED ANGULAR MISALIGNMENT FOR SPLICING OF TWO IDENTICAL PARABOLIC INDEX FIBERS

V	P	Gaussian [9]	Ref. [5] for N=40	Present technique	Exact [4]
2.0	0.2	0.9818	0.9715	0.975892	0.9716
	0.4	0.9293	0.8926	0.906999	0.8927
	0.6	0.8479	0.7799	0.802814	0.7799

	0.8	0.7459	0.6531	0.676748	0.6531
	1.0	0.6325	0.5284	0.543303	0.5285
	1.2	0.5170	0.4162	0.415394	0.4163
	1.4	0.4074	0.3212	0.302470	0.3213
3.5	0.1	0.9984	0.9983	0.998263	0.9983
	0.3	0.9859	0.9849	0.984476	0.9849
	0.5	0.9614	0.9588	0.957470	0.9588
	0.7	0.9258	0.9210	0.918344	0.9210
	0.9	0.8804	0.8730	0.868651	0.8731
	1.1	0.8268	0.8171	0.810299	0.8170
	1.3	0.7667	0.7548	0.745428	0.7548

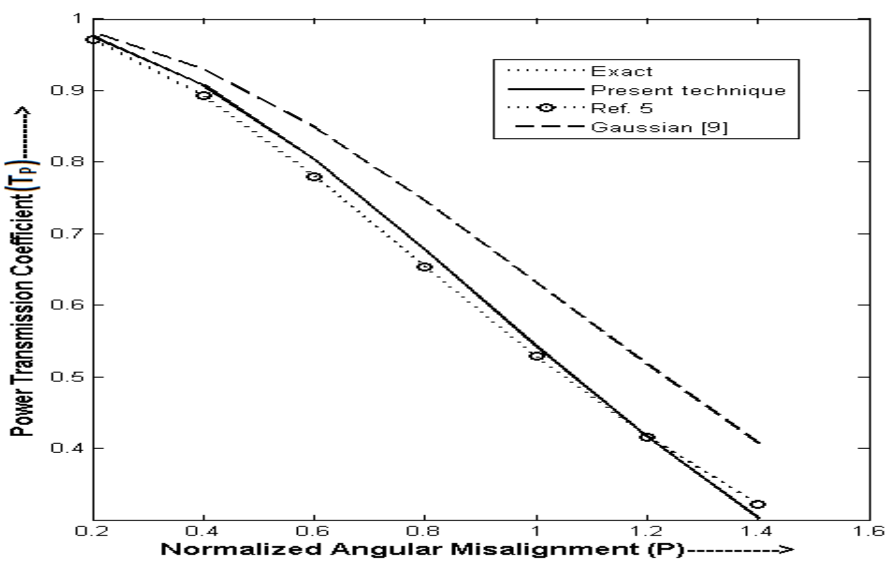

Figure 2: Power transmission coefficient T_P vs. Normalized angular misalignment of two identical parabolic index fiber with *V = 2.0*

Now, we like to verify our formulation for triangular index fiber. In Table III we calculate power transmission coefficient for triangular index SMF for *V = 2.7* and compare our results with Meunier [5] and observe similar excellence. The results obtained from present technique are more accurate than the results available in single parameter Gaussian approximation [8, 9] for both transverse and angular misalignment losses. Thus our technique can be used for other profile also with similar accuracy and simplicity.

Thus we see that when we use spot size based on Marcuse formula, we can predict our results tolerably excellently matches with the available rigorous results with superiority to variational formulation involving Gaussian function. Our method is simple and should be helpful to experimentalist to accurately estimate splice losses for graded index SMF even with pocket calculator.

TABLE III: POWER TRANSMISSION COEFFICIENTS FOR TRIANGULAR INDEX PROFILE WITH *V*=2.7.

P or D	T_P			T_D		
	Ref. [5]	Gaussian [9]	Present technique	Ref. [5]	Gaussian [9]	Present technique
0.1	0.9956	0.9969	0.996270	0.9928	0.9918	0.993226
0.3	0.9616	0.9729	0.966923	0.9377	0.9289	0.940660
0.5	0.8983	0.9265	0.910798	0.8389	0.8148	0.843726
0.7	0.8133	0.8610	0.832660	0.7146	0.6694	0.716728
0.9	0.7159	0.7809	0.738802	0.5835	0.5150	0.576623
1.1	0.6148	0.6911	0.636214	0.4601	0.3711	0.439354
1.3	0.5167	0.5969	0.531733	0.3530	0.2505	0.317045
1.5	0.4265	0.5031	0.431320	0.2650	0.1583	0.216676

4. Conclusion

In this paper we have presented a simple technique for evaluating the splice losses caused by transverse offset and angular misalignment between two identical graded index SMF with arbitrary profile distribution. This simple technique can be used as a ready reference to calculate splice losses between two identical arbitrarily graded index SMF with much less effort avoiding usual method of complex numerical evaluation of the overlap integral. Our next scheme of study is to evaluate propagation characteristics of graded index fiber with various profile and refractive index structure by using this technique.

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