Splice losses in holey optical fibres

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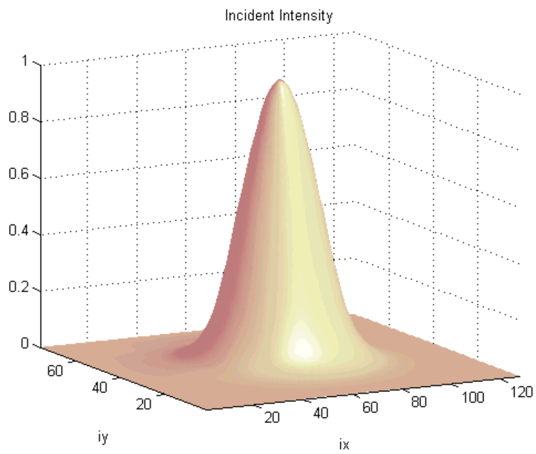
Abstract: Splice losses between standard step-index fibre and holey optical fibres were calculated for a range of fibre parameters and wavelengths using finite-difference time-domain simulations. The optimal holey fibre parameters for minimum splice loss were determined. These parameters were effectively predicted using analytical approximations incorporating the effective index model.

Holey optical fibre (HF) is an all-silica optical fibre with an array of longitudinal air holes providing the guidance mechanism [1]. HF is an exciting innovation in optical fibre technology, with the potential for realising a range of novel fibre devices and applications not possible with standard step index fibres (SIF). To be widely useful, HF must be interfaced with minimal loss to a range of other optical waveguides and devices. Consequently it is important to determine the splice losses between HF and other waveguides, and if possible to optimise the HF structure to minimise splice loss. We have numerically calculated such loss and optimum parameters for splices of SIF to refractive index guiding HF with hexagonal symmetry, ie. in which the absence of an air hole forms a core, and a hexagonal array of air holes, with diameter d and pitch Λ, forms a low index cladding. We also propose an efficient design method to minimise these losses.

Early analyses of HF properties used the equivalent step index approximation [2] or series expansion of the fields using localised basis functions [3]. More recently published models utilise other established methods such as the finite element method [4]. The latter approaches are restricted to modelling axially uniform fibres, though splice losses may be determined by evaluating the overlap integral of the guided modes of the spliced fibres. We have taken a more general approach, however, and used finite-difference time-domain (FDTD) [5] simulations to calculate the transmitted and reflected fields in axially nonuniform waveguides.

A substantially modified and significantly optimized version of publicly available software [6] was used to perform the FDTD simulations. A structure was defined containing short coaxial lengths of HF and a common SIF (ie. SMF-28) either side of a butt joint between them (ie. the splice). A short pulse input with optical carrier at the wavelength of interest was directed towards the splice from the SIF, and the transmitted and reflected waves monitored to determine the splice loss. Figure 1 shows the calculated field distributions at 1.55μm, if splicing from SMF-28 to HF with pitch 1.8μm, and filling factor 0.188. The loss calculated here was close to the 1.5 dB reported for an experiment with similar parameters [7].

Calculations of the splice loss were performed for a range of HF parameters and a range of wavelengths. The results are shown in figures 2 and 3, respectively, which also show analytical approximations of the splice loss [8] by the equivalent step index model [2]



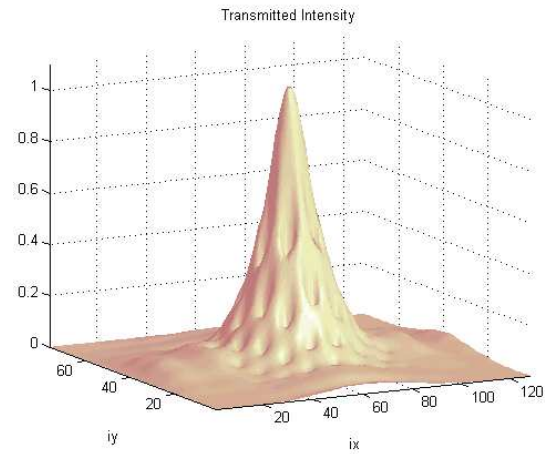


Fig 1. Mode-field distributions of a wave incident from SMF-28 fibre and transmitted into holey fibre. The holey fibre parameters were Λ=1.8μm, d/Λ=0.188, and the wavelength λ=1.55μm.

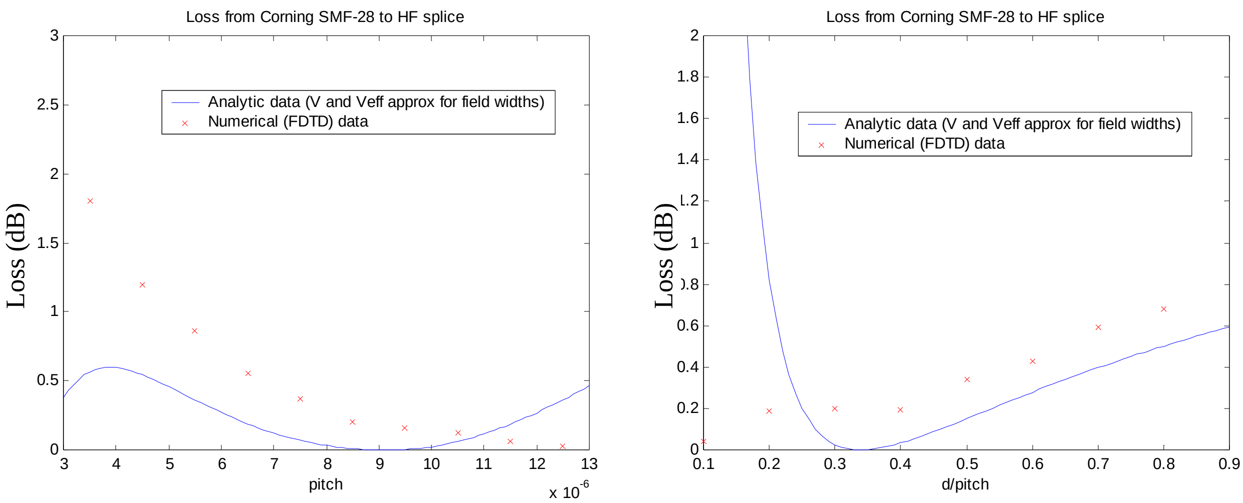


Fig. 2. Calculated splice loss between SMF-28 fibre and silica holey fibre as a function of holey waveguide parameters, ie. pitch (with d/Λ=0.35, λ=2μm) and fill factor (with Λ=6.56μm, λ=1.55um).

using effective core radius ρ = 0.64Λ [4]. The analytical approximations slightly underestimated the splice losses determined by numerical simulation, but displayed the same trends evident in the numerical calculations.

Using the latter results we determined the optimum holey fibre parameters for minimum splice loss to SMF-28 fibre at 1.55μ. The optimum fill factor was determined with hole pitch Λ=6.56μm, and the optimum hole pitch determined with fill factor d/Λ=0.35.

Using an FDTD model we have numerically determined the splice loss for standard step index fibre to holey optical fibre splices over a range of parameters. Consequently, we determined optimal holey fibre parameters (with respect to splice loss) in given situations. We also found that the equivalent step index model provided a simple and effective guide in predicting these parameters.

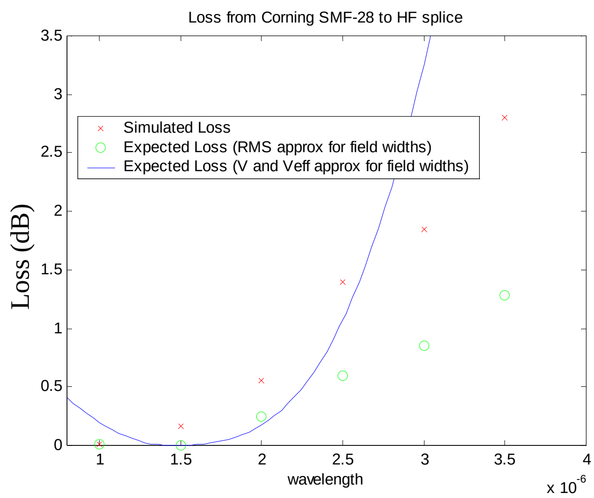


Fig. 3. Calculated splice loss between SMF-28 fibre and holey fibre (Λ=6.56μm, d/Λ=0.35) as a function of wavelength.

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