METAS

Modelling of standard and specialty fibre-based systems using finite element methods

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Abstract

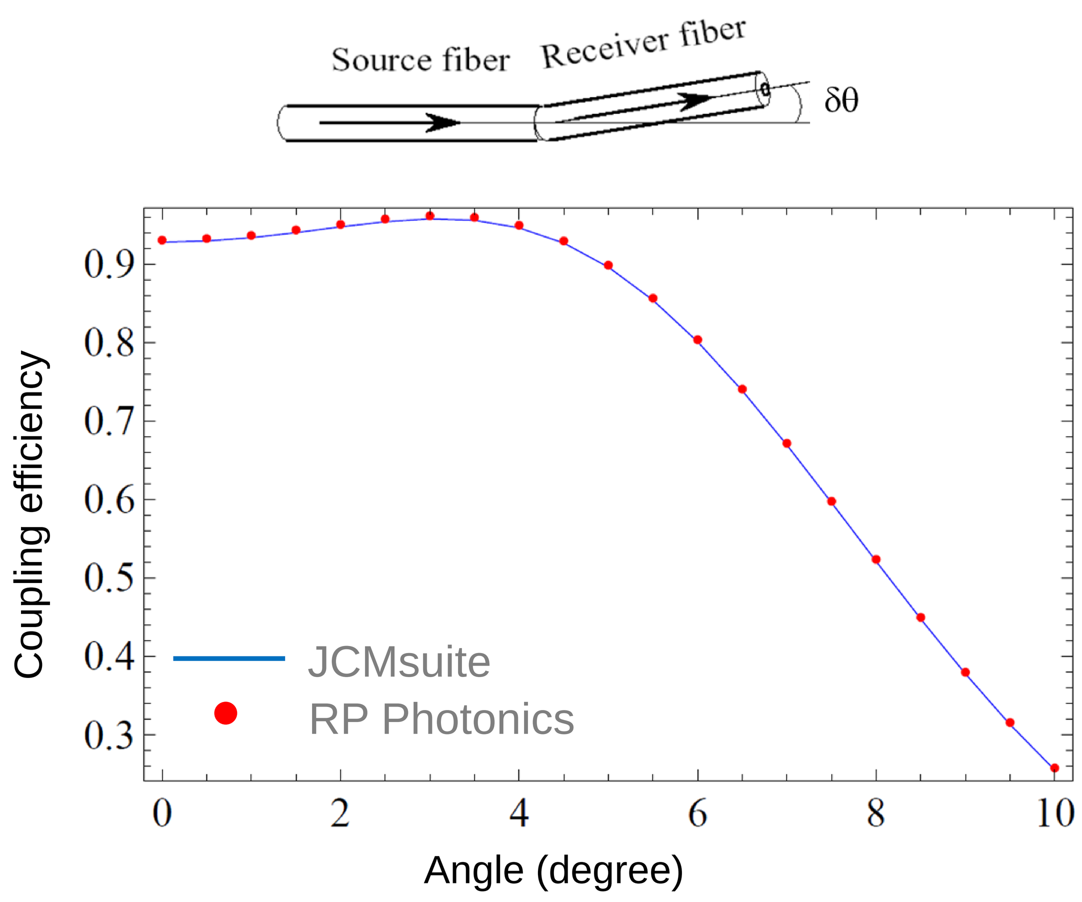
We report on the investigation of an approach for modelling light transmission through systems consisting of several jointed optical fibres, in which the analytical modelling of the waveguides was replaced by Finite Element Methods (FEM) simulations. To validate this approach we first performed FEM analysis of standard fibres and used this to evaluate the coupling efficiency between two singlemode fibres under different conditions. The results of these simulations were successfully compared with those obtained using classical analytical approaches, by demonstrating a maximum loss deviation of about 0.4 %. Further, we performed other more complex simulations that we compared again to the analytical models. FEM simulations allow addressing any type of guiding structure, without limitations on the complexity of the geometrical waveguide cross section and involved materials. We propose as example of application the modelling of the light transmitted through a system made of a hollow core photonic crystal fibre spliced between two singlemode standard optical fibres, and qualitatively compare the results of the simulation with experimental data.

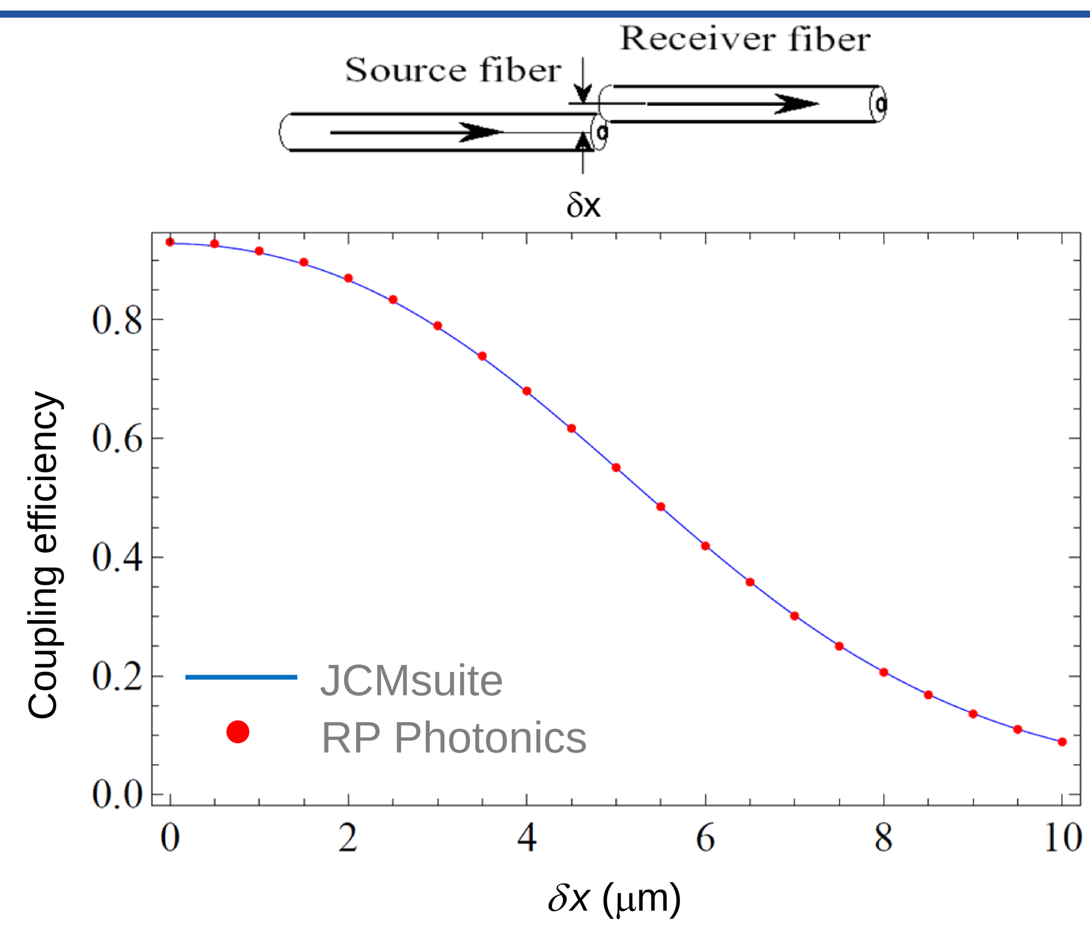
Coupling efficiency between two singlemode fibres

The coupling efficiency between two singlemode fibres was modeled by using the FEM software package JCMsuite. We considered two singlemode fibres, whose optical axis were misaligned, by applying either an angular, or a lateral offset.

Core diameter	9 μm
Cladding diameter	120 μm
Core refractive index	1.452
Cladding refractive index	1.443
Wavelength λ	1550 nm

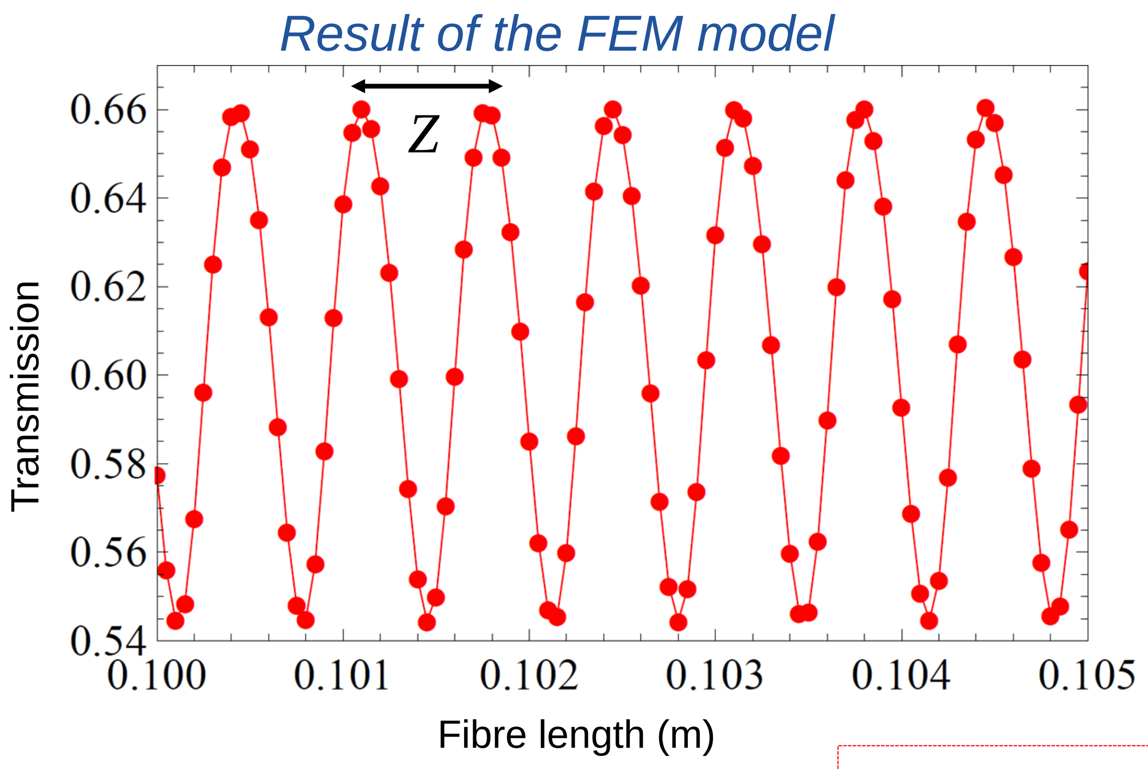
The FEM results were compared with those obtained with an analytical approach, using the RP Fiber calculator from RP Photonics, and by applying the same configurations and parameters. The agreement between the two approaches was high, with a maximum deviation of the coupling efficiency of about 0.4%.





Low-loss coupling between fibres: analytical vs FEM analysis

Result of the FEM model



Period length Z of the oscillating coupling efficiency:

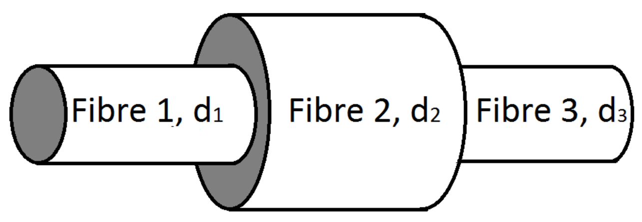
$$Z = \frac{\pi \cdot d_2 / 2}{\sqrt{2 \cdot \Delta}}$$

where

$$\Delta = \frac{n_c^2 - n_{cl}^2}{n_c^2}$$

$$Z_{[1]} = 0.7mm \qquad Z_{FEM} = 0.67mm$$

The coupling losses between two singlemode fibres with different mode-field diameters can be reduced, as demonstrated in [1], by inserting between them a piece of gradient-index multimode fibre having a well adapted length.



In [1] an analytical model was developed which allowed determining the coupling efficiency and its dependency with the length of the multimode fibre. We modelled the same optical configuration by using JCMsuite.

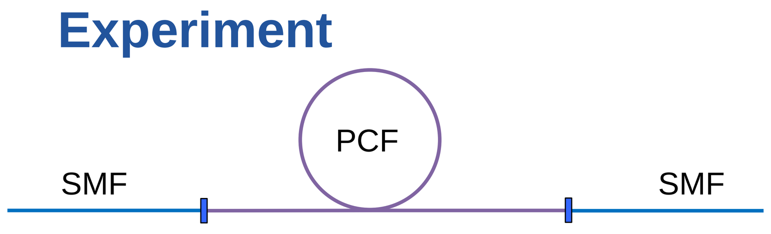
Core diameter $d_1 = d_3$	8.3 μm
Core diameter d_2	50 μm
Core refractive index n_c	1.452
Cladding refractive index n_{cl}	1.443
Wavelength λ	1550 nm

[1] Mafi, A. et al.,"Low-loss coupling between two single-mode optical fibers with different mode-field diameters using a graded-index multimode optical fiber", Opt. Lett. 36(18), (2011).

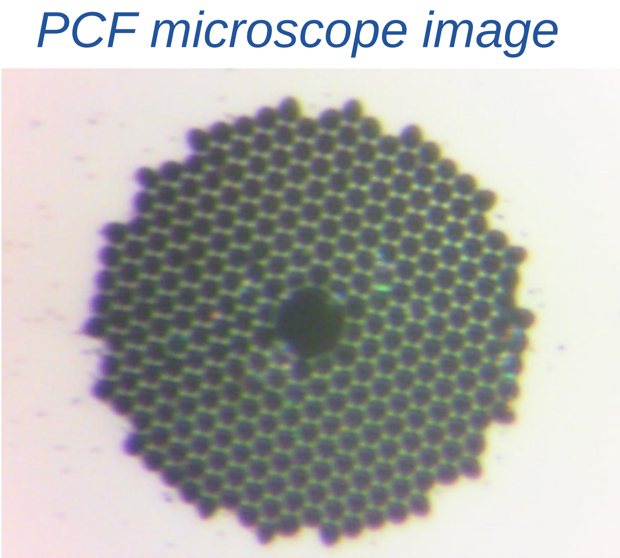
FEM application to specialty fibres

We modelled the light transmission through a setup including a photonic crystal fibre (PCF) which is spliced to a standard single mode fibre (SMF) on both sides. We have performed experimental transmission measurements of this setup with the PCF filled with acetylene.

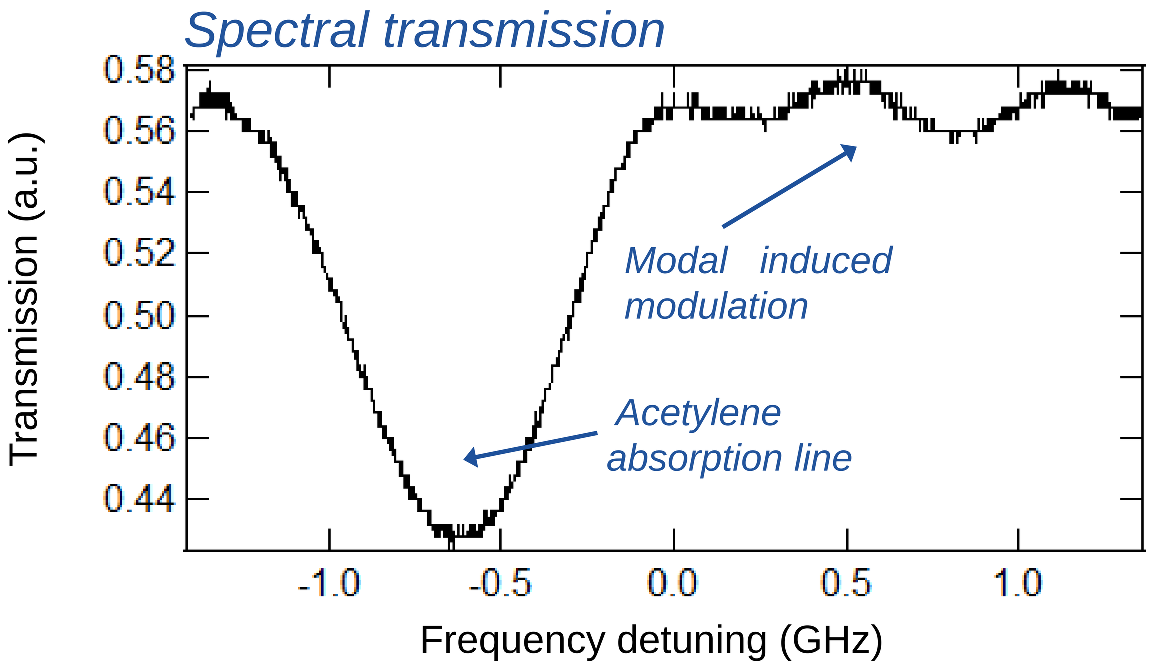
Experiment



PCF microscope image



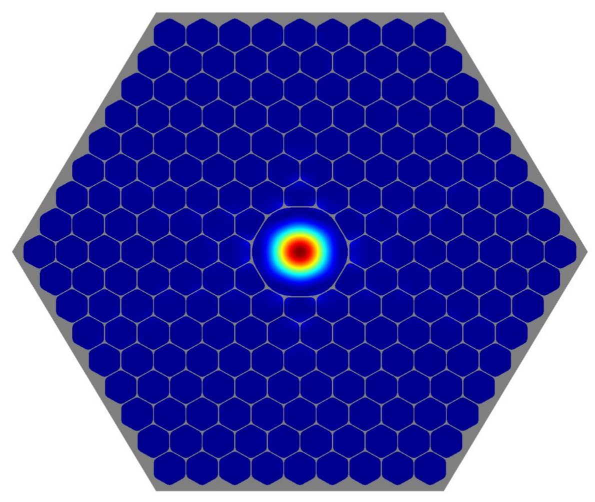
Spectral transmission



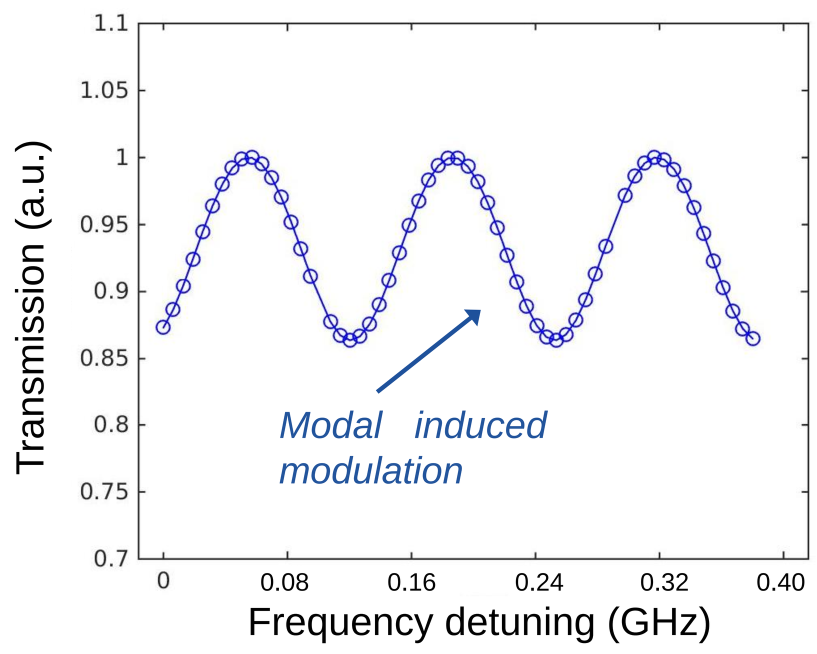
PCF core diameter	7.3 μm
PCF cladding periodicity length	2.52 μm
SMF core diameter	8.2 μm
Wavelength λ	1542.4 nm

FEM

Fundamental mode intensity distribution in the PCF



Spectral transmission



Model parameters: only the two fundamental modes contribute. All higher-order propagation modes of the structure exhibited damping losses at least one order of magnitude larger than the damping losses of the fundamental modes. Moreover, a slight asymmetry of the structure was assumed (ellipticity of 2%).

[2] Pomplun, J., Zschiedrich, L., Klose, R., Schmidt, F., Burger,S., “Finite Element simulation of radiation losses in photonic crystal fibers”, *Phys. stat. sol. (a)* 204, (2007).
[3] Burger, S., Zschiedrich, L., Pomplun, J., Herrmann, S., Schmidt, F., “Hp-finite element method for simulating light scattering from complex 3D structures”, Proc. SPIE 9424, (2015).

Acknowledgments

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JCMwave PhotInd EMPIR EURAMET

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