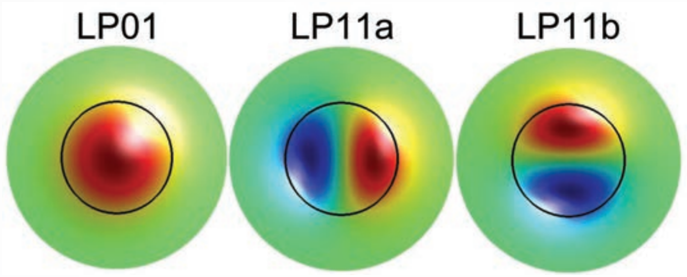
Mode-Diversity Multiplexing over Few-Mode Fibres

Mode-diversity multiplexing (MDM) over few-mode fibres (FMFs) has the potential to dramatically increase the transmission capacity per fibre, avoiding the impending capacity crunch of standard single-mode fibres. Two techniques to reduce the differential mode delay of FMFs are proposed, enabling the transmission of MDM signals over ultra-long haul distances.



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Funding Agencies	
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Indicators	
Journal Papers	4
Conference Papers	16
Two Main Publications	
F. Ferreira, D. Fonseca, and H. Silva, "**Design of Few-Mode Fibers With Arbitrary and Flattened Differential Mode Delay,"** IEEE Photon. Technol. Lett., vol.25, no.5, pp.438-441, March 1, 2013.	
F. Ferreira, D. Fonseca, A. Lobato, B. Inan and H. Silva, **"Reach Improvement of Mode Division Multiplexed Systems using Fiber Splices,"** IEEE Photon. Technol. Lett., vol. 25, no. 12, pp. 1091-1094, June 15, 2013	

PROJECT WEBPAGE URL
http://www.it.pt/project_detail_p.asp?ID=1804

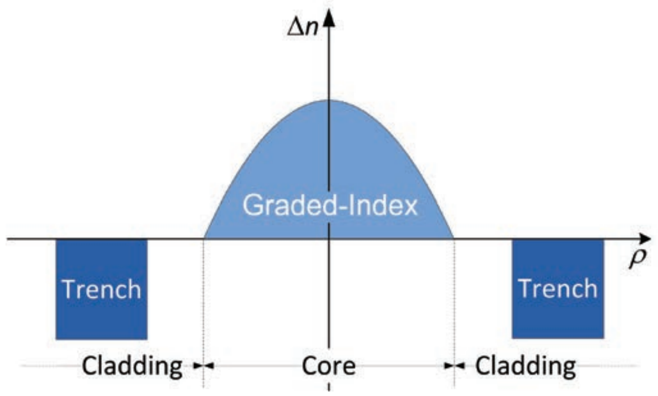

Fig. 1 Refractive-index profile composed by a graded-index core and a cladding trench.

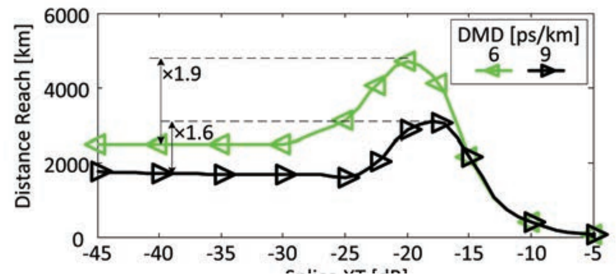

Fig. 2 Distance reach as a function of splice XT.

GENERAL MOTIVATION AND OBJECTIVE OF THE PROJECT

The ever growing demand for higher data rate is rapidly exhausting the capacity available for single-mode fibres (SMFs). During the last years, only a marginal increase in the maximum bit rate distance product using SMFs was observed, since the nonlinear Shannon limit is being reached. Moreover, it has been demonstrated that even if significant improvements of standard SMFs (SSMFs) are achieved, the capacity increase per fibre is limited.

Mode-division multiplexing (MDM) over few-mode fibres (FMFs) is emerging as an attractive solution for the required capacity increase with potential cost, space, and energy savings. An N-fold capacity increase, with N equal to the number of independent modes of the FMF, is obtained using MDM. However, FMFs require the usage of multiple-input multiple-output (MIMO) equalization as it needs to compensate for the combined effect of differential mode delay (DMD) and modal crosstalk (XT), which originates a channel impulse response (CIR) spread over time. In order to reduce the equalizer complexity the fibre DMD has to be reduced.

In the literature, different schemes to reduce or compensate DMD have been proposed: the usage of inherently low DMD FMFs (ILD-FMFs); the usage of FMFs with positive DMD followed by FMFs with negative DMD, usually referred as DMD compensated FMFs (DC-FMFs); or the usage of mode permutation within the transmission fibre, which averages the modes group velocities, thereby reducing the CIR length. The reported ILD-FMFs and DC-FMFs are not suitable for ultra-long haul transmission due to high DMD variation within the C+L band. Regarding the mode permutation scheme, an increase of the maximum distance reach by a factor of 5 has been shown. However, a practical implementation of mode permutation is still missing.

The main objectives of this work are the proposal of design rules for FMFs with an arbitrary DMD flattened over the C+L band, and the investigation of schemes for the practical implementation of mode permutation.

MAIN WORK DESCRIPTION AND ACHIEVEMENTS

The refractive index profile considered to obtain an arbitrary DMD flattened over the C+L band is composed by a graded core and a cladding trench (Figure 1). The proposed optimization process allows obtaining FMFs with negligible DMD over the C+L band (ILD-FMFs). Moreover, it has been shown that it is possible to obtain an arbitrary DMD (positive or negative) flattened over the C+L band (allowing the design of DC-FMFs), varying only the core grading exponent. This result allows establishing a simple design rule that eases the manufacturing process and the splicing of FMFs with different DMD levels. However, the existing manufacturing process does not have the required precision to guarantee the designed DMD.

In order to improve the distance reach of MDM transmission systems using ILD-FMFs or DC-FMFs with non-negligible levels of DMD, we propose the introduction of displaced core fibre splices along the transmission fibre as a practical scheme to implement discrete mode permutation. The fibre splices introduce modal XT which averages the modes group velocities, thereby reducing the CIR length. However, fibre splices also introduce mode dependent losses (MDL) degrading the receiver equalizer performance. The trade-off between splice XT and MDL was optimized. Figure 2 shows distance reach as a function of splice XT. The results show that the distance reach can be increased by a factor ranging from 1.6 to 1.9 for the ILD-FMFs and DC-FMFs transmission systems. The maximum distance reach achieved for the optimum configuration is higher than 5000 km.