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ASSESSMENT OF MULTIPATH INTERFERENCE IN BEND-INSENSITIVE FIBERS AND PATCH CABLES FOR NGANs

M. Olivero, G. Perrone*, R. Orta*, A. Vallan*, L. Greborio†, P. Regio†, P. Pellegrino†*

* Dept. of Electronics and Telecommunications, Politecnico di Torino, c.so Duca degli Abruzzi 24, 10129 Torino, Italy.

† Telecom Italia Lab, via Reiss Romoli 274, 10148 Torino, Italy
massimo.olivero@polito.it

Multipath interference in bend-insensitive optical fibres is experimentally evaluated in the 1300 nm wavelength range. The main issues concerning the setups for its measurement are discussed. The characterization of some bend-insensitive fibres is presented; the measured fibres exhibit a negligible MPI for lengths ≥ 10 m, whereas jumpers with length ≤ 2 m can produce multipath interference at detrimental levels above -30 dB. The phenomenon is even more evidenced in the cascade of offset-spliced short jumpers made of bend-insensitive fibre; preliminary results showed a large rise of the MPI when two or more jumpers are shortly spaced.

Introduction

Next Generation Access Networks (NGANs) are based on ultra-broadband technologies requiring optical fibre deployment in the access segment. In many cases, fibre-to-the-home/curb (FTTx) networks have to be implemented upon existing infrastructures; therefore, telecommunication operators are working to find and test new solutions and components that cope with installation constraints. One of the main issue in a real FTTx network is wiring of existing buildings, since this often implies tight bends and high stresses, which result in unacceptable losses for conventional single mode fibres (SMFs). To help solving this problem, manufacturers have developed a new class of fibres – known as bend-insensitive fibres (BIFs) [1] – characterized by compatibility with standard SMFs [2], but with a lower propagation loss when tightly bent. These fibres have been classified in a specific ITU Recommendation [3], which defines the main structural parameters and performances, such as the tolerated attenuation for different curvature radii. For instance, while for a SMF an acceptable bending loss requires a curvature radius equal or above 30 mm, this parameter is reduced to 10÷5 mm for a BIF. The reduced sensitivity to bending loss in BIFs is obtained by increasing the field confinement; however, this may imply an insufficient attenuation of the first higher order mode (HOM) LP₁₁ around 1300 nm, one of the wavelengths used in FTTx and close to the usual cut-off of standard SMFs. The beating between the fundamental mode LP₀₁ and the HOM triggered by discontinuities (e.g. connectors or poor-quality splices) produces the so-called multipath interference (MPI), which is defined as the power carried by the LP₁₁ coupled into the

fundamental mode LP₀₁, resulting in an undesired power fluctuation.

In details, the MPI level can be evaluated at a given wavelength from the measurement of the power fluctuation on the fundamental mode of the BIF, through the following expression[4]:

$$MPI|_{dB} = 20 \cdot \log_{10} \frac{\sqrt{\frac{P_{max}}{P_{min}}} - 1}{\sqrt{\frac{P_{max}}{P_{min}}} + 1}$$

where the ratio P_{max}/P_{min} is evaluated as a function of the polarization (there is an optimum polarization state for highest power transfer between the two modes). Since the MPI depends on the received power versus polarization, its measure is strongly affected by the noise floor of the measurement system that is, the polarization dependent loss (PDL) of the measurement setup. Different measurement procedures have been developed to characterize the MPI in a convenient way.

This work is focused on the analysis of two setups for MPI characterization and the measurement of different BIFs, in order to forecast their impact on future access network installations.

Setup and measurements

Following the ITU Recommendations [5], two setups for MPI characterization were developed, based on a broadband source-optical spectrum analyser configuration and on a tuneable laser-optical receiver configuration, as illustrated in Fig. 1. A third setup, based on controlled fibre stretching, was not evaluated because it requires the fibre under test to be fastened straight to a pulling arrangement, resulting in some technical issues for the characterization of long (≥ 2 m) or very short (few cm) fibres; moreover it does not allow for the characterization of bent fibres, which would be the most probable condition. Both setups of Fig. 1 produce the LP₁₁ excitation and recoupling to LP₀₁ by misaligned splices to SMFs and the polarization sweep is performed by a polarization scrambler; mode strippers are inserted before and after the fibre under test to guarantee a controlled coupling to the BIF by the fundamental mode of the SMF.

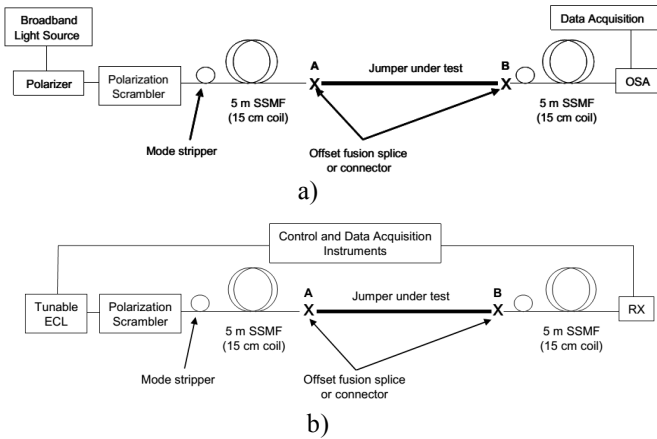
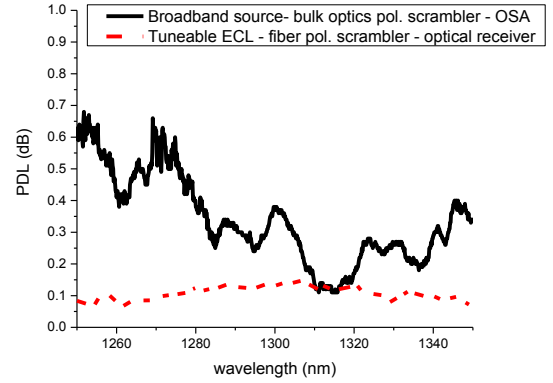


Fig. 1 MPI measurement setups, according to ITU-T G.650.1, relying on: a) broadband source-optical spectrum analyser and b) tuneable laser-optical receiver. SSMF=standard single mode fibre; OSA=optical spectrum analyser; ECL=external cavity laser; RX=optical receiver.

In the case of the broadband source-optical spectrum analyser setup, a polarized LED provides the signal over the measurement range - usually 1250-1350 nm that is the most critical for the excitation of the first high order mode LP_{11} - while the transmitted spectrum is collected in one shot by an optical spectrum analyser. The tuneable laser-optical receiver setup uses a narrow band external cavity laser (ECL) to perform the spectral analysis, whereas an optical receiver records the max and min received power at each wavelength. The larger measurement time of this technique is counterbalanced by the larger measurement dynamics achievable by this setup. This is due to the typically lower PDL of optical receivers than that of OSAs. Actually, another source of PDL that can impair the accuracy of the measurement is the polarization scrambler; this can be reduced by employing an all-fibre instrument where the change of polarization is obtained by piezoelectric stress of the fibre that connects input and output of the device. Whereas initial measurements were performed with the setup of Fig. 1a because it enabled quick measurements, most of the characterizations were made with that of Fig. 1b, since it exhibited a low intrinsic PDL in our case, as demonstrated in Fig. 2, where it can be observed that our tuneable laser setup exhibits a PDL level of 0.1 dB, ~ 0.5 dB lower than the intrinsic PDL of the broadband source setup.



Such a low intrinsic PDL enabled to quantify MPI levels down to -48 dB over the entire 1250-1350 nm range. Repeated measurements with the setup of Fig. 1b, carried out without any fibre under test (that is, terminations A and B spliced together without misalignment) allowed for an estimation of the MPI curve uncertainty, which turned out to be ± 2.6 dB.

Former measurements on BIFs were devised to quantify the critical length and critical misalignment that focused on the identification of a critical length at which the MPI increases to undesired values. A MPI of -30 dB was chosen as an acceptable limit, since previous studies stated that this value ensures a power penalty lower than 0.5 dB for a signal-to-noise ratio of 10 dB and a BER of $10E-9$ [6]. Figure 2 reports an example of MPI measurement of a commercial G.657.B3 fibre cut at different lengths, showing an overall negligible MPI (close to the -48 dB detection limit) for a length of 10 m, whereas it rises to about -35 dB when the length is cut at 2 m. Since the G.657.B3 series [3] is designed for the best bending loss performance among BIFs and tested for radii down to 7.5 mm, it appears that this fibre fulfil the requirements from access network operators both in terms of bending performance and MPI response. The graph also depicts the same sample measured in two operational conditions, i.e. loosen vs coiled. The two resulting MPI curves do not exhibit remarkable differences, indicating that the coiling (which used to be a standard technique to get rid of high order modes in legacy installations) is not effective for this type of fibre.

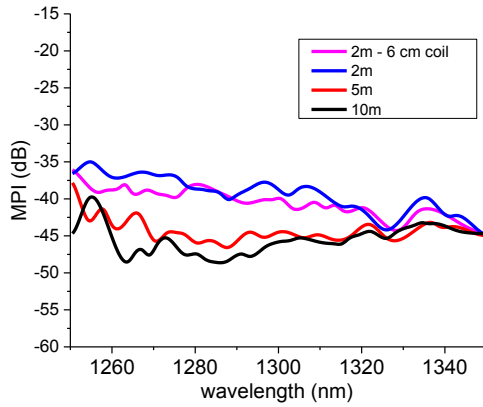


Fig. 3 MPI of a G.657.B3 fibre at different lengths and misalignment of 2 μm . The graphs also compares the same 2m fibre jumper loosen vs coiled to a 6 cm diameter.

The characterization of other commercial fibres (not reported here) highlighted an MPI level always below -30 dB for lengths equal or above 10 m, whereas some of them reached or crossed the threshold when the length was set around 2 m. The length of 2 m was then chosen as the reference to compare different BIFs in terms of MPI. The effect of the misalignment on the MPI was evaluated on 2 m-long samples at 1300 nm, as depicted in Fig. 4. It can be observed the -30 dB limit is crossed for misalignments $\geq 2 \mu\text{m}$. This value is also compatible with that produced in installations by unskilled technicians and/or poorly-maintained splicing machines. Therefore, 2 m length and 2 μm misalignment were used as standard parameters to compare different BIF, either spliced or connected through field installable connectors [7].

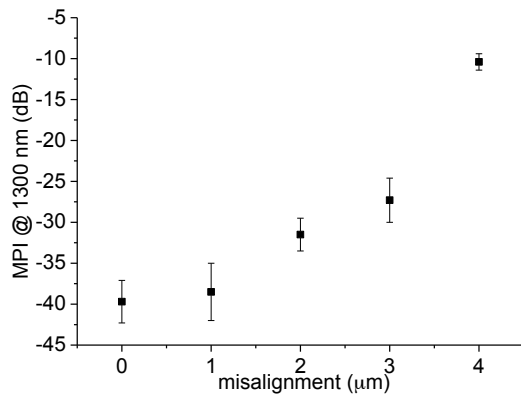
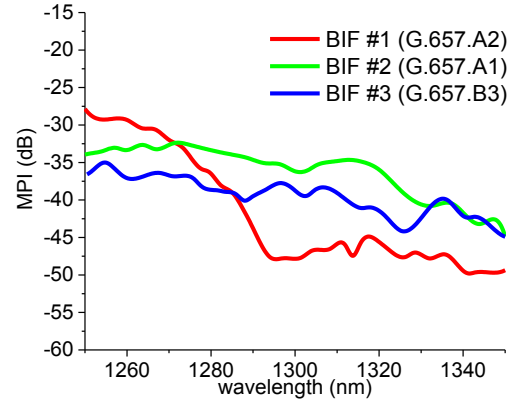
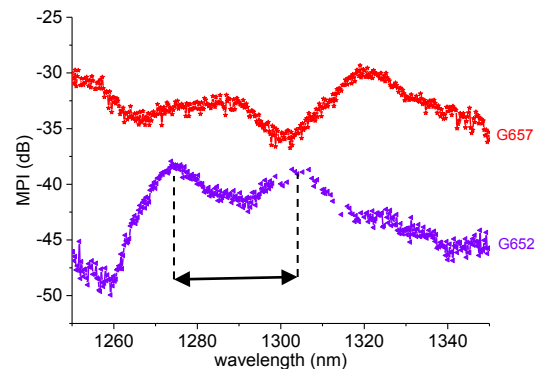


Fig. 5 depicts the MPI of three BIFs from different manufacturers compliant to the ITU-T G.657 specification. All fibres but BIF#1 exhibit a MPI level well below the -30 dB threshold in the measurement range. The curves also show the same decreasing trend at longer wavelength as expected from theory, since the attenuation of the LP_{11} mode becomes

higher near the theoretical cut-off, expected to be around 1300 nm.



In order to evaluate operational conditions occurring in optical access networks, a set of 2 m-long patchcords was characterized. The patchcords had been connectorized with SC-type field-installable connectors [7] containing a short pigtail, either BIF or SMF. The summary of these measurements is reported in Fig. 6. Although ten patchcords were characterized, the graph only reports two curves for clarity. The outcome of these measures is that patchcords equipped with connectors that contained a SMF pigtail (G.652 fibre) showed a lower MPI than that of patchcords with connectors containing BIF pigtails (G.657 fibre). The curves also depict large spectral oscillations. These are due to the beating between LP_{01} and LP_{11} , whose spectral period is inversely proportional to the length of the fibre where the modes propagate. A field installable connector, either equipped with a BIF or a SMF, contains a pigtail with length of 2-3 cm: simple calculations demonstrated that this length produces a modal beating with spectral period of $\sim 30 \text{ nm}$, as experimentally observed in Fig. 6.



The results reported in Fig. 5 and Fig. 6 suggest that the MPI can reach values above the conventional threshold of -30 dB because of the presence of field installable connectors equipped with BIF pigtails, whereas wiring of access

networks with BIFs can be beneficial due to the tolerated tight bends and the acceptable MPI level introduced when the fibre connections have lengths ≥ 2 m.

Conclusion

Multipath interference (MPI) in bend-insensitive fibers (BIFs) has been investigated to quantify its effect in access networks that are being installed in curbs and buildings. Two measurement setups have been evaluated, highlighting the related measurement issues like the intrinsic polarization dependent loss (PDL) that sets the measurement sensitivity. An optimized measurement setup has been realized based on a tuneable laser, evaluating its capability in terms of MPI detection limit to be ~ -48 dB over the range 1250–1350 nm. It has been found that the MPI becomes critical for BIFs patchcords having short lengths up to 2 m, whereas its effect is negligible in fibers with length ≥ 10 m. Commercial BIFs have been measured and compared in the same conditions, showing that the MPI value is normally below the threshold limit of -30 dB required by network operators. Patchcords equipped with field-installable connectors containing BIF pigtails have been characterized. It has been experimentally proven that these short pigtails can rise the MPI level to unacceptable values, and their employment should be carefully evaluated.

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