Experimental Investigations of Mode Group Diversity Multiplexing on Multimode Fibre

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Abstract: We present experimentally the possibility of mode multiplexing using two launch positions and successful demultiplexing using two detection areas in order to double the data rate from 10 Gb/s to 20 Gb/s over multimode fibre.

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1. Introduction

Multimode fibre (MMF) is an attractive medium for broadband Local Area Networks (LANs) as well as for future in house networks due to cost efficient components and easy installation process compared to single mode fibre systems [1]. Recently, the general idea of using mode group multiplexing in MMF transmission links was presented [1,2] as a possible alternative to the wavelength division multiplexing method. Until now, a large research effort has been made to investigate necessary requirements for mode multiplexing at the transmitter side (e.g. several launch positions, excitement of different mode groups), on the MMF transmission line (e.g. mode dispersion, mode coupling) and the receiver side (e.g. different detection areas, electrical signal processing units). Thereby, the investigations were mostly focused on one part (transmitter , fibre or receiver) of the transmission system. In contrast to that, we show experimentally in this paper the mode multiplexing possibility for a complete transmission system consisting in a transmitter setup, 200 m MMF and a receiver setup.

The structure of the paper is as follows: In section 2 we describe the general idea of the chosen mode multiplexing approach. Section 3 depicts analytically in detail the mode exciting and mode separating processes at the transmitter and the receiver side, respectively. In section 4, the experimental setup and the results will be discussed. Section 5 concludes the paper.

2. General mode multiplexing and demultiplexing approach

The mode multiplexing approach is based on the idea to transmit independent digital data signals with different mode groups on the MMF [3]. Therefore, it is necessary to excite at the transmitter side different mode groups with each signal (e.g. signal 1 excites lower mode groups and signal 2 higher mode groups, respectively) which can be realized by different launch positions. At the receiver side the separation of these signals has to be realized by a mode selecting device. The general system setup will be explained exemplarily for the case of two transmitted signals in fig. 1.

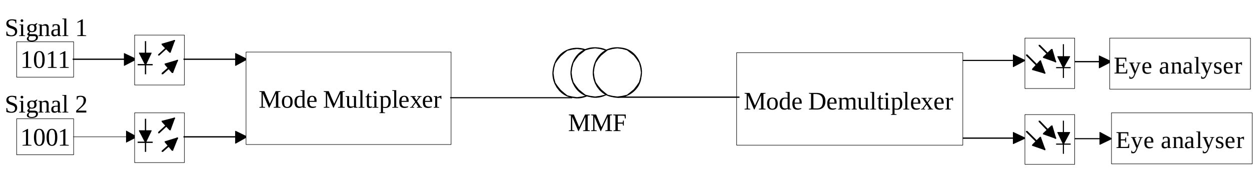

Fig: 1: General schematic setup for mode group multiplexing

Two data generators generate data signals with a data rate of 10 Gb/s each which are used for the direct modulation of two lasers with the same wavelength. Note that this assumption means that no wavelength division multiplexing approach is chosen. The outputs of the lasers are connected to the mode exciting device (Mode multiplexer) at the transmitter side. The output of this device is connected to a MMF transmission line characterized by mode coupling and mode dispersion processes and ends up in a mode selective device (Mode Demultiplexer). Finally, the two optical signals are detected by separate multi mode photo detectors which are connected to eye analysers. The essential characteristic of this chosen approach with two channels is that the mode exciting process at the transmitter side as well as the mode selecting process at the receiver side is done in the optical domain.

3. Mode multiplexing and demultiplexing principle

The mode multiplexing technique is realized by two different launch conditions at the front side of the core of the MMF as it is shown in fig. 2a.

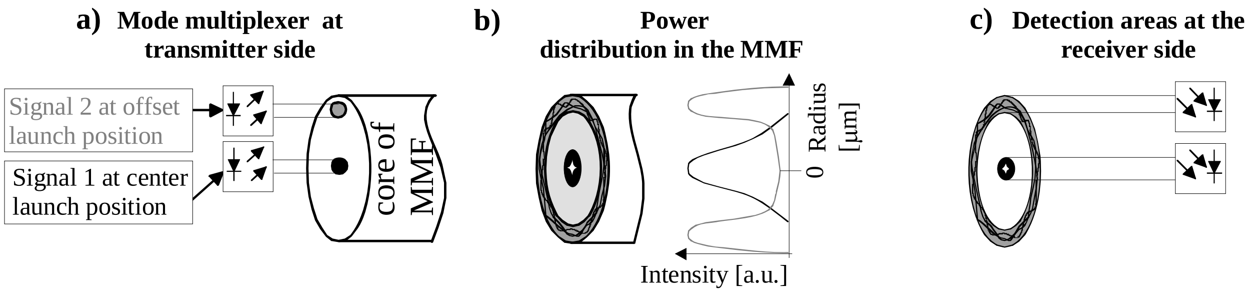

Fig. 2a: Mode multiplexing process at the front side of MMF with center launch position (signal 1) and offset launch position (signal 2); Fig. 2b: Propagating areas and power distribution (high order modes: outer region of core (grey), low order modes in center (black) in the MMF; Fig. 2c: Detection areas at the receiver side of high order modes (grey area) and low order modes (black)

Thereby, signal 1 is launched into the fibre in center launch position. This includes that only a few low order modes (in the ideal case the lowest mode will carry the most of the energy) are excited [1,4]. Additionally, it was recently explored [1] that for this launch position the low order modes travel during the transmission over the MMF mostly in the inner region of the core (shown in fig. 2b with the profile of the MMF by a black circle). This includes that for this launch condition most of the energy is concentrated in the middle of the core as it shown in the plot in fig. 2b by the black line where the intensity is drawn over the radius. In contrast to signal 1, signal 2 excites high order modes in the offset launch position which are mainly travelling in the outer region of the MMF's core (dark grey area in the profile of fig. 2b with different curves representing various high order modes). Note that with this launch position much more modes are excited than in the center launch position. Based on this approach at the transmitter side, it seems to be possible to transmit separately two different signals by high order modes close to the cladding and by low order modes in the center of the core.

However, the two transmitted signals have to be separated in a mode demultiplexing process at the receiver side as shown in Fig. 2c. Therefore we choose two different detecting areas, one in the outer region of the core and one in the center of the core. Thereby, the separating and receiving process for center launch position is much easier due to the fact that only a low number of modes are excited which implies a nearly negligible mode dispersion as main limiting effect of the MMF. The mode dispersion influence to the high number of excited high order modes in the case of offset launch position has to be reduced by a separating and selecting process of several power carrying modes.

4. Simulative and experimental results

The proposed multiplexing and demultiplexing concept for mode multiplexing in optical transmission systems was investigated by experiments and simulations based on the transmission system setup shown in Fig. 3.

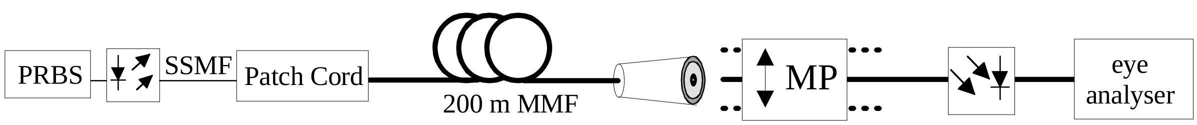

Fig. 3: Experimental and simulative setup for investigating the mode multiplexing (realized with a patch cord) and demultiplexing (realized by a micro postitioner [MP]) approach with 200 m MMF (core diameter of 62.5 µm) in a 10 Gb/s environment

A PRBS sequence is given on a directly modulated laser which is connected to the multiplexing part at the transmitter side by a SSMF. The multiplexing is practically realized with a mode conditional patch cord (MCPC) where the center launch as well as the offset launch with 20 µm offset (optimal offset condition [5]) could be chosen. The output of the MCPC is connected to 200 m of MMF (core diameter of 62.5 µm) characterized by a graded refractive index profile (exponent around 2). The mode dispersion influence on the MMF is the main limiting factor. After transmitting over the fibre, the light beam is widened and parallized by a collimator and is then given by a free space transmission to the demultiplexer at the receiver side which is realized by a mechanical micro positioner (MP). With the help of the MP it is possible to detect different regions of the beam which implies different mode groups and therefore different transmitted signals as it was explained above. Finally the signal is received by a multi mode photo detector and is given to an eye analyser to characterize the transmission quality.

The simulation and the experimental results for two different launching conditions are shown in fig. 4.

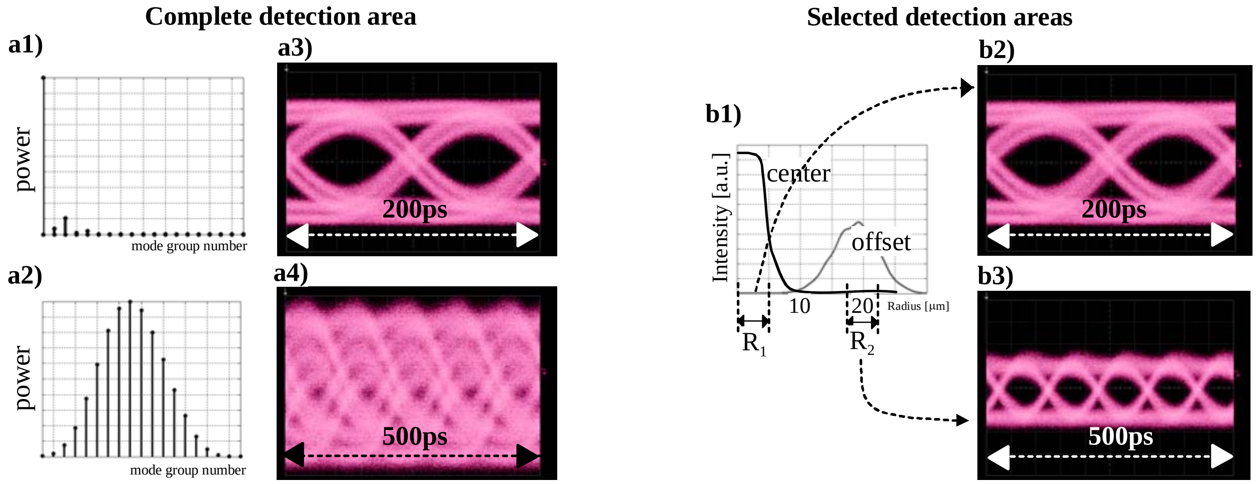

Fig. 4a1: Mode distribution for center launch and fig. 4a2) offset (20μm) launch; Fig. 4a3) eye diagram after 200 m MMF transmission for center launch and fig. 4a4) for offset launch (large number of modes are received); Fig. 4b1) Intensity gradient over core radius for center launch (black line) and offset launch (grey line), power receiving area for center launch (R_1) and offset launch (R_2); Fig. 4b2) eye diagram for detection area R_1 (center launch); Fig. 4b3) eye diagram for detection area R_2 (offset selective launch)

In fig. 4a1 and fig. 4a2 the simulated mode distribution for the center launch position (CLP) and for the offset (20μm) launch position (OLP) are shown, respectively. It is obvious that in the OLP much more modes are excited compared to the CLP. Therefore the transmitted power is significantly more distributed to several modes in the offset case than in the center case. In fig. 4a3 and fig. 4a4 the experimentally determined eye diagrams (for CLP and OLP) after 200 m MMF transmission are shown for the case that the complete area of the MMF is detected. A clearly wide opened eye was observed for the CLP whereas for the OLP a totally distorted eye was received. This result is explainable by the mode dispersion process on the fibre. Due to the fact that many modes are excited in the OLP the influence of the mode dispersion is much higher compared to the low number of excited modes in the CLP.

Figs. 4b1-4b3 show the simulative and experimental results for selected detection areas realized by the MP. In fig. 4b1 the intensity distribution (determined by simulations) is drawn over the radius of the core for the CLP (black line) and the OLP (grey line) after 200 m MMF transmission. Thereby, it is obvious that the power of signal 2 is distributed over a wider range of the core radius (from 10 μm to 30 μm) than the power of signal 1 (from 0 μm to 10 μm). In addition, the two different detection areas R_1 for the CLP and R_2 for the OLP are indicated in the figure. Using these selected areas, the eye diagrams shown in figs. 4b2 and 4b3 are experimentally determined. In fig. 4b2 the eye diagram for area R_1 which implies the detection of low order modes in the center of the core is shown. Nearly no difference is observed compared to fig. 4a3, which is explainable due to the fact that nearly all energy is transmitted by the lowest mode in the center. Fig. 4b3 shows a clearly wide opened eye with a reduced amplitude for the OLP setup with the detection area R_2. The extraordinary improvement to fig. 4a4 can be explained by detecting only a restricted area. Due to that few power carrying modes are selected and therefore a significant reduction of the influence of mode dispersion occurs. The mode selecting detection area explains also the reduced amplitude.

Based on these results it seems to be possible to multiplex two signals by different launching conditions at the transmitter and to demultiplex at receiver side. Mode coupling in the MMF is assumed to be very small due to the fact that both signals are nearly perfectly separated (see fig. 4b1; black and grey line) even after 200 m MMF transmission. This assumption is additionally underlined by experimental results presented in [3].

5. Conclusion

We present experimental results for a mode multiplexing approach in a MultiMode fibre link. We verified by experiments that it is possible to excite and to receive low and high order mode groups separately by different launch positions at the transmitter side and selected detection areas at the receiver side. It was shown that with this setup the limiting effect of mode dispersion of the MMF can be significantly reduced.

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