Optical MIMO-Processing and Mode-multiplexing: Experimental Achievements and Future Perspectives

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***Abstract*—We report on the feasibility of using the multiple modes of a MMF for MIMO processing with the goal to increase the transmission capacity by mode-multiplexing. Experimental results up to a 3x3 MIMO system are shown and the limitations as well as the potential of this technique are discussed.**

I. Introduction

Multimode optical fibre (MMF) is considered for short haul, limited speed and low cost optical communications today, as mode dispersion is fundamentally limiting the bandwidth distance product. Recently, several approaches for using the many different propagation modes of MMF for transmitting independent parallel data streams in order to increase the data throughput significantly are under investigation [1-6]. The parallel signals are used for exciting several mode groups and at the receiver side the mixed signals have to be demultiplexed. By such a mode group diversity multiplexing (MGDM) scheme, the capacity of MMF might exceed the capacity of single mode fibre, at least in theory. The MMF communications channel might thus be considered as a multiple input multiple output (MIMO) diversity channel and at the receiver side a source separation method must be applied.

Until now, several successful realizations of this approach have been presented. However the multiplexing order, shown so far by experiments is rather low. It is relatively easy to use centre launch and offset launch feeding [8] of a MMF and thus building a 2x2 MIMO environment [3,4]. In this paper, we discuss and review possibilities to increase the multiplexing order, where we concentrate on experimental work. Experimentally and by simulations a 3x3 MIMO system based on this approach is shown. Also a multi-segment photo detector, which might be used for spatial signal separation is discussed as well.

II. Experimental MIMO systems

A. 2x2 MIMO System

The experimental setup for a 2x2 MIMO system is described in detail in [4] and is roughly similar (except for two inputs and outputs) to Fig. 3. We launch channel 1 with 0 um offset at the centre of the MMF (center launch). Channel 2 is launched with an offset of 20 um (offset launch). The multiplexed signal is transmitted over MMF. The demultiplexing is realized by a micropositioner which gives the possibility to detect a part of one of the two detection areas by a movable SMF pigtail.

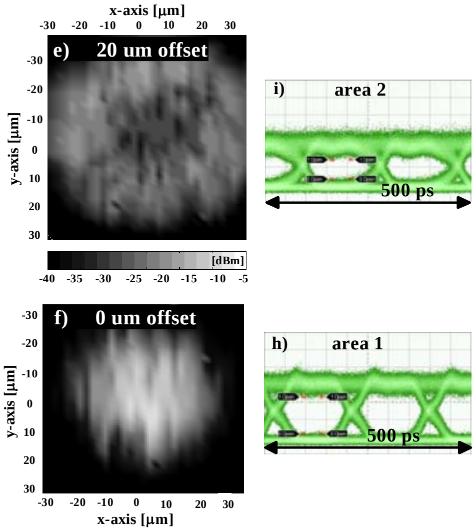

Fig. 1. Intensity distribution for 0 um and for 20 um launch offset and detected related eye diagrams.

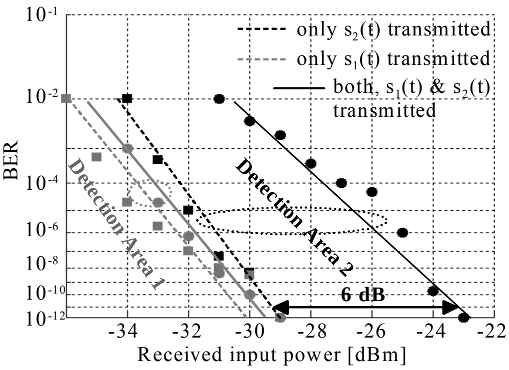

Fig. 2. BER for centre and offset launch detection areas for 2x 5.35Gb/s

Fig. 1 shows that there is a high power concentration in the core centre preserved even after 300m MMF for the centre launch signal and a donut-like shape outside of the core centre for the offset launch signal and both signals are detectable with open eyes. Fig. 2 shows that an error free detection of both signals is possible. The solid lines are the BER values if both signals are simultaneously transmitted and detected in the inner and outer region of the MMF core respectively.

B. 3x3 MIMO System

In the 3x3 MIMO approach based on MGDM in [5] three different signals $s_1(t)$, $s_2(t)$ and $s_3(t)$ are assigned to different mode groups (co-propagating over the fibre) by different launching positions at the transmitter. The received signals $y_1(t)$, $y_2(t)$ and $y_3(t)$ are detected at different areas of MMF's cross section. The correlation between the input and the output signals is described by a 3x3 transfer matrix. This matrix has to be determined in a first step by a training sequence. Afterwards, the matrix is used for off-line equalization of crosstalk between the co-propagating signals by matrix inversion. Fig. 3 shows the setup of the 3x3 MIMO system investigated in [5].

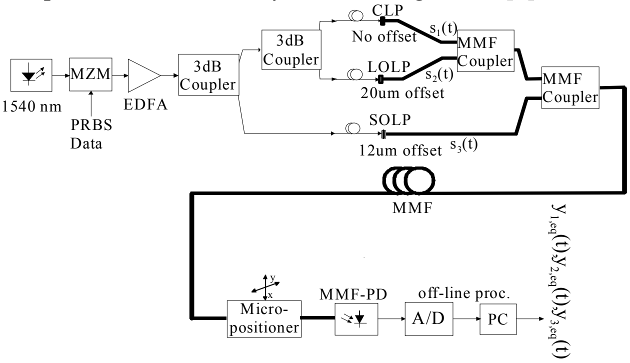

Fig. 3. Experimental Setup for a 3x3 MIMO system with centre (CLP), small offset (SOLP), large offset (LOPL) position launch.

The data rate is set to 2 Gb/s which gives a total data rate of 6 Gb/s (data rate is set to a low level due to the limited memory space of the oscilloscope). The three streams are decorrelated by means of appropriate delays. Three different restricted launching positions from SMF (thin line) to MMF (thick line) are chosen for assigning $s_1(t)$, $s_2(t)$ and $s_3(t)$ to different mode groups: $s_1(t)$ to centre launch position (CLP) with no offset, $s_2(t)$ to small offset launch position (SOLP) with 12 um offset realized by a micropositioner (MP) and $s_3(t)$ to large offset launch position (LOLP) with 20 um offset. The determination of the three output signals $y_1(t)$, $y_2(t)$ and $y_3(t)$ is realized by a micropositioner detecting at three different positions

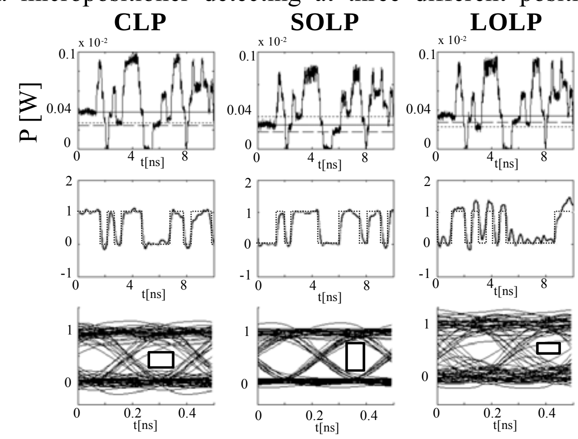

Fig. 4. Experimental results for 3x3 MIMO system.

of MMF's cross section. We show here the results for a MMF photo detector with a detection area close to 50 um diameter. Finally, the signals are saved with an oscilloscope as analogue to digital converter followed by a crosstalk equalization offline at the PC

Experimental results are shown in Fig. 4. The upper row represents the signal sequence saved by oscilloscope for three different detection positions of the MMF photo diode set by the micropositioner. The equalized and low pass filtered together with the original input data (dotted line) are shown in the centre row. The corresponding eye diagrams of the equalized signals are drawn in the third row. We observe open eyes, showing the feasibility of this 3x3 MIMO method.

C. Segmented Photo Detectors

Significant improvement in detecting MGDM signals is expected from special photo detectors with several separate detection areas. A two segment photo-detector was presented in [9]. A multi-segmented detector (MSD) is reported in [10] The MSD has a central circular area (with radius 7.8μm), a first ring (inner radius 10μm, outer radius 18.4μm) and a second ring area (inner radius 20.6μm, outer radius 32μm). It is designed to match the geometry of a MMF to perform mode group demultiplexing.

III. Conclusions

MGDM is a possible technique for improving data throughput in MMF. Some achievements as 3x3MIMO transmission and MSD are reviewed. A breakthrough for substantial capacity increase needs however advanced signal processing for source separation.

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