Experimental Equalization of Crosstalk in a 2 x 2 MIMO System Based on Mode Group Diversity Multiplexing in MMF Systems @ 10.7 Gb/s

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Abstract *We investigate experimentally a 2 x 2 MIMO system based on Mode Group Diversity Multiplexing over MMF. We show that the interference between co propagating signals is strongly reduced by using equalization.*

Introduction

Multi Mode Fibre (MMF) has been shown to be the most promising candidate for short 10 Gb/s high speed transmission lines due to cost efficient components compared to single mode fibre systems [1,2]. Additionally, the multi mode character of the MMF offers the possibility to transmit different signals by different mode groups (Mode Group Diversity Multiplexing, MGDM) as a MIMO approach with an enormous potential to increase the bandwidth distance product [1,3,4].

However, performance degradation by using MGDM due to mode coupling and crosstalk between the transmitted signals was reported in [3]. In [4] an analytical approach was shown to overcome this degradation by means of equalization with the zero forcing method. In this paper, we show experimentally the successful equalization of a 2 x 2 MIMO system over MMF @ 10.7 Gb/s.

Equalization Theory

The investigated 2 x 2 MIMO system can be described by equation 1 [4]:

$$\begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \cdot \begin{pmatrix} s_1(t) \\ s_2(t) \end{pmatrix}, \qquad (1)$$

where $s_{1,2}$ (t) and $y_{1,2}$ (t) stand for the two input and two received output signals, respectively. The transmission characteristic including the crosstalk (only power influence is taken into account) between the input signals and the output signals is represented by the transfer matrix which consist of the transmission coefficients h_{11}, h_{12}, h_{21} and h_{22}.

The equalization process of the crosstalk is described by equation 2:

$$\begin{pmatrix} y_{1,eq}(t) \\ y_{2,eq}(t) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix}, \qquad (2)$$

where $y_{1,2,eq}$ (t) stands for the equalized signals, which are determined by a multiplication of the inverse of the known transmission matrix (e.g. by a training sequence) with the received output signals.

Experimental Setup

The experimental setup is shown in fig. 1. The coherent light of the laser (λ=1540 nm) is externally modulated by two Mach Zehnder Modulators (MZMs). This is driven by a short PRBS of length 2^7-1 because of limited memory of our oscilloscope. The data rate is set to 5.35 Gb/s in each arm which implies that a standard FEC overhead of 7 % is taken into account. Afterwards the signals are decorrelated by means of different delays, amplified by EDFAs and attenuated with variable optical attenuators (VOAs). The first signal is launched with -3dBm at the centre (CLP) of the core. This is realized by a centre launch connector (CLC) with a direct connection between SMF (thin line) and MMF (thick line) (fig. 1a). The second signal is launched with +3dBm in Offset Launch position (OLP) with an offset of 20 um. This was realized by an offset launch connector (OLC) consisting of a patch cord from SMF to MMF (fig. 1b). Thereby, each of the two signals excites different mode groups with different power distributions in the MMF's core [5]. Afterwards, the MMF outputs from CLP and OLP are coupled together by a mode preserving coupler (fig. 1c) and transmitted over 100 m GI-MMF with a core diameter of 62.5 um. We chose this short length to be focused on the crosstalk and not on mode dispersion degradation.

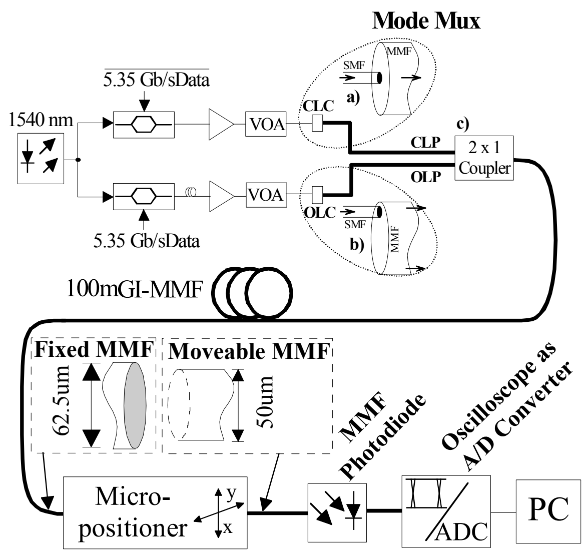

Fig. 1: Experimental setup with two different launched signals (a,b) transmitted over 100m GI-MMF

The receiver consists of a micropositioner with a fixed input MMF (core diameter of 62.5 um) and moveable MMF pigtail (core diameter of 50 um) to realize different detection positions. Finally, these received signals (dependant on detection position) are detected by a MMF photodiode. 25 bits of each signal are sampled with an oscilloscope (4050 samples) and saved on a PC where offline equalization process including inversion of the transfer matrix is done.

Experimental Results

Fig. 2 shows the selected detection positions for the experiments. Nearly the complete centre of the core is detected in position 1 whereas in position 2 only a small part of the core is detected. With this detection constellation we expect that in position 1 s_1 (t) and in position 2 s_2 (t) owns the dominating power influence. This is based on the fact that the power of s_1 (t) is concentrated in the centre of the core (centre launch condition) whereas the power of s_2 (t) is distributed in a ring form close to the core cladding edge (offset launch condition) [4,5].

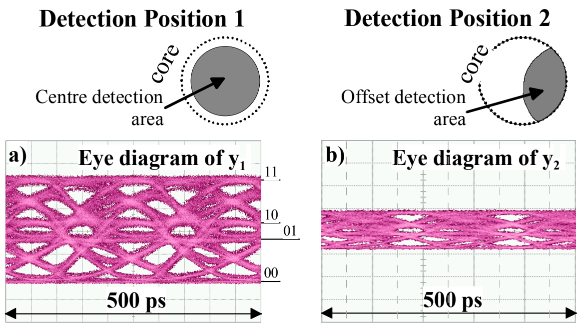

Fig. 2: Eye diagrams of $y_1(t)$ and $y_2(t)$ for two co propagating signals at two different detection position [a)centre detection area; b) offset detection area]

The corresponding eye diagrams of y_1 (t) and y_2 (t) for the described transmission system with two co propagating signals are shown in figs. 2a,b, respectively. We observe for both detection positions completely distorted eyes due to the interference of the two transmitted signals. In both eye diagrams we see four different power levels (indicated by 00, 01, 10 11 in the left eye diagram) which correspond to the four possible bit combinations of the two signals. The lower amplitude level of the right eye diagram is explained by the smaller detection area compared to detection position 1. However, we see for both detection areas nearly no influence of modal noise which may be explained by relatively large detection areas combined with a good mode group separation.

In the next step, we determine the transfer matrix H of the described transmission system. This is done by measuring different power influences of one signal to one of the detection areas (e.g. h_{11} of the transmission matrix is the determined power value which is transmitted only from signal s_1 to detection area y_1). By applying this method the following transmission matrix H was found:

$$H = \begin{pmatrix} 0.268 & 0.205 \\ 0.055 & 0.109 \end{pmatrix}$$

We observe the expected dominating influences of s_1(t) in detection area 1 ($h_{11} > h_{12}$) and of s_2(t) in detection area 2 ($h_{22} > h_{21}$). The inverted transfer matrix is calculated offline based on these transmission coefficients and multiplied by the received data sequences y_1 (t) and y_2 *(t)*. The equalized eye diagrams for detection position 1 and 2 are shown in fig. 3a and fig. 3b, respectively. In addition, we show the equalized data sequences of $y_{1,eq}$ (t) and $y_{2,eq}$ (t) (corresponding to eye diagrams) and the input data sequences of s_1 *(t)* and s_2 *(t)* in fig. 3c and fig. 3d.

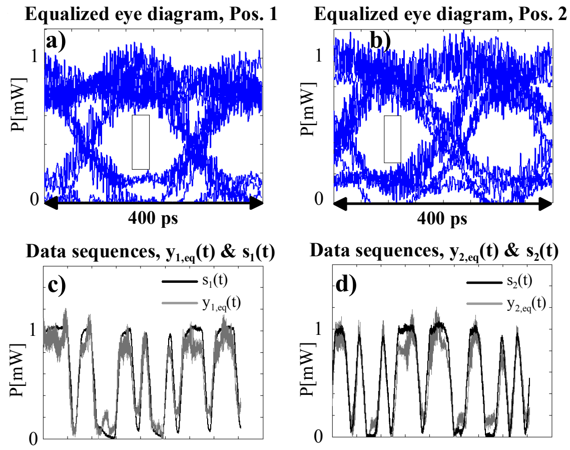

Fig. 3: Equalized eye diagrams for a) detection pos. 1 and b) pos. 2; c,d) comparison of inputs s_1 (t) & s_2(t) (black) and equalized (grey) outputs $y_{1,eq}$ (t) & $y_{2,eq}$ (t)

Compared to the distorted eye diagrams of fig. 2a,b we see clearly wide open eyes in fig. 3a,b based on the equalization process for both detection positions. In fig. 3c,d we observe only slight deviations between input data sequences s_1*(t)* and s_2*(t)* (black lines) and the equalized data sequences (grey lines) $y_{1,eq}$ *(t)* and $y_{2,eq}$ *(t)* which confirms that we separated two different signals at the receiver side successfully.

One possible implementation of this system with two detection areas would be a photodiode with two segments as presented in [6]. We expect that for this implementation unequal power levels at the transmitter side could be avoided, too.

Conclusions

We show by experiments successful equalization of crosstalk in a 2 x 2 MIMO MMF system based on Mode Group Diversity Multiplexing at a high data rate of 2 x 5.35 Gb/s.

Acknowledgement

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