Experimental Investigations of Mode Coupling as Limiting Effect Using Mode Group Diversity Multiplexing on GI-MMF

Stefan Schöllmann and Werner Rosenkranz
Chair for Communications, University of Kiel, Kaiserstrasse 2, 24143 Kiel, Germany, sts@tf.uni-kiel.de

Abstract *We investigate experimentally mode coupling as limiting effect in MMF transmission systems at 21.4 Gb/s. It is shown that this effect has only significant influence for high power levels over 300 m MMF.*

Introduction

Multi Mode Fibre (MMF) has been shown to be an excellent candidate for short high speed transmission lines due to cost efficient components and high tolerances regarding the installation compared to single mode fibre systems [1,2]. Recently, the general idea of mode group diversity multiplexing (MGDM) was introduced as a possible alternative to coarse WDM [1,3]. Thereby, different signals are transmitted by different mode groups (e.g. signal 1 with low order and signal 2 with high order modes).

Nevertheless, using this multiplexing technique high and low order mode groups are interacting to each other based on the effect of mode coupling which disturbs the signal quality in addition to the limiting effect of mode dispersion. It was shown by [3,4] that the mode dispersion could be strongly reduced by improved receiver structures. Therefore, we show in this paper the experimental investigation of mode coupling as an additional disturbing effect in a realized MGDM system with two data streams each at 10.7 Gb/s. It is underlined by experimental results that only very high power levels of 12 dBm over a distance of 300 m graded index (GI)-MMF are disturbing significantly the signal quality due to mode coupling.

Experimental setup

The investigation of the mode coupling effect was realized with the experimental setup shown in fig. 1.

The coherent light of the laser (λ=1540 nm) is split into two arms and is afterwards externally modulated by two Mach Zehnder Modulators (MZMs). These are driven with two Pseudo Random Binary Sequences (PRBS) of length 2^{31}-1. The data rate is set to 10.7 Gb/s which implies that a standard FEC overhead of 7 % is already taken into account. Both streams were decorrelated by means of different delays. After amplification with EDFAs and attenuation with variable optical attenuators (VOAs) the upper arm was launched at the centre (CLP) of the MMF. This was realized by a centre launch connector (CLC) with a direct connection between SMF (thin line) and MMF (thick line) (fig. 1a). The lower arm was launched in the Offset Launch position (OLP) with an offset of 20 μm. This was realized by an offset launch connector (OLC) consisting in a patch cord from SMF to MMF (fig. 2b). Afterwards, the MMF outputs from CLP and OLP were coupled together by a mode preserving coupler (fig. 2c). Finally, the mode multiplexed signal was given on the GI-MMF with a core diameter of 62.5 μm.

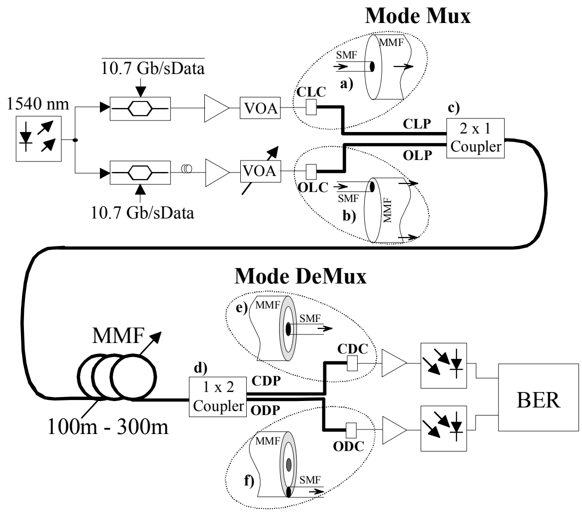

Fig. 1: Experimental setup with variable input powers at offset launch position (OLP) and variable fibre lengths

Thereby, the CLP excites low order modes which are mostly travelling in the centre of the core whereas the OLP excites high order modes which are travelling mostly in the outer region of the core [3,5]. This is underlined by the intensity distributions shown in fig. 2a for the CLP case and in fig. 2b for the OLP case, respectively.

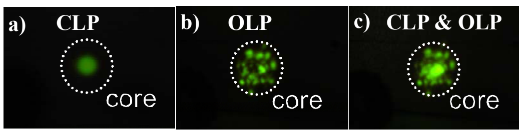

Fig. 2: Intensity distributions for Centre Launch Position (CLP) [fig.2a], Offset Lauch Postion (OLP) [fig.2b], superposition of CLP and OLP [fig.2c]

In fig. 2c the intensity distribution after coupling is shown. It seems that a good separation between high and low order modes is achieved.

After transmission, the demultiplexing of the different modes is realized by using a mode preserving coupler and two detection positions: Centre detection position (CDP) by central detection connector (CDC) realized with a direct connection from MMF to SMF (fig. 1e) and offset detection position (ODP) by offset detection connector (ODC) using a patch cord with

20 µm offset from the MMF to the SMF. After amplification with an EDFA, the optical signals are received by a photo diode and analysed with a BER analyser.

Experimental results

The influence of mode coupling is analysed by a feature of the bit error ratio tester (BERT) which determines the tolerable decision threshold deviation for given BERs. As we are primarily interested in the investigation of the mode coupling influence, only the signal transmitted by the low order modes is analysed. This means that only the mode coupling from OLP signal to the CLP signal is investigated. This was done due to the fact that by analysing the CLP signal the limiting effect of mode dispersion is very low [3]. If the OLP signal would be analysed, the eye opening would be limited by mode dispersion and not by mode coupling. For the experiments the input power level at CLP was set to 0 dBm and the input power level at OLP was varied in a range between 0 dBm and 12 dBm. In fig. 3 the tolerable decision threshold deviation for given BERs is shown for a length of 100 m GI-MMF and variable power levels.

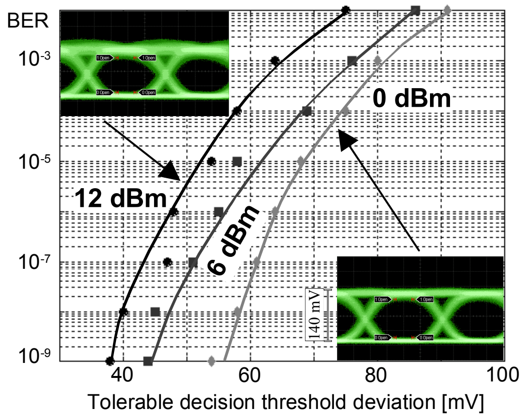

Fig. 3: Tolerable decision threshold deviation of centre launch position (CLP) signal for transmission length of 100 m GI-MMF and variable power levels of co-travelling offset launch signal (fixed given BER)

The three curves representing different power levels own the same negative gradient due to lower tolerable threshold deviation for lower given BERs. Additionally, the tolerable threshold deviation is decreased for higher input power levels which is explainable due to higher mode coupling effects. Nevertheless, even for power levels of 12 dBm at the OLP a wide open eye can be observed (left corner).

In fig. 4 the experimental results for longer transmission distances up to 300 m are shown. The right group of lines represents the results for an input power of 0 dBm at OLP and the left group of 12 dBm. For the low input power level of 0 dBm we observe that the influence of the transmission length on the disturbing effect of mode coupling is very low. This is also clarified by the eye diagram for a transmission length of 300 m in the right corner. Contrarily to that, we observe that for a high power level the influence of the transmission length is significantly higher. This is underlined by the eye diagram shown in the left corner where a strongly widened one level due to mode coupling can be seen. Nevertheless, even for these bad conditions an error free transmission with a tolerable decision threshold deviation of 28 mV (peak to peak power: 140 mV) is achieved.

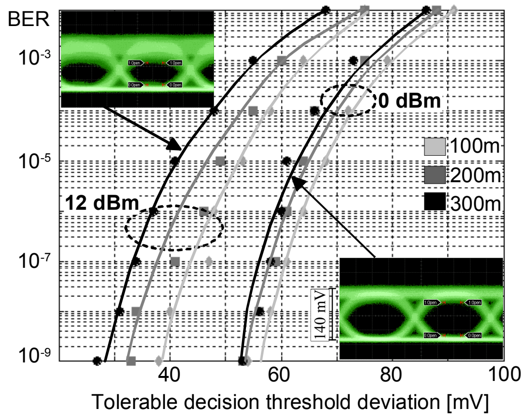

Fig. 4: Tolerable decision threshold deviation of centre launch position (CLP) signal for given BERs (variable power levels of 0 dBm and 12 dBm for co-travelling offset launch signal and variable transmission lengths of 100 m – 300 m)

That means that high power levels are the main reason for mode coupling from high order modes to low order modes in MGDM systems. The transmission length has negligible influence for low power levels and gains in importance for high levels.

Conclusions

We investigated experimentally the mode coupling process on a graded index (GI)-MMF. The results are based on mode group diversity multiplexing system with a total data rate of 21.4 Gb/s for different input power levels and different transmission lengths. It was shown that even for a high input power level of 12 dBm and a transmission distance of 300 m GI-MMF an error free transmission with a clearly open eye is achieved. Additionally, it was shown that the variation of power influences significantly the signal quality. The influence of variable transmission lengths is significant only for high power levels.

References

1 A.M.J. Koonen et al., OFC 2004, FG 4
2 P. Matthijsse et al., OFC 2006, OWI 13
3 Schoellmannm et al., OFC 2006, OWR 3
4 Xia et al., OFC 2005, OFO 5
5 L. Raddatz et al., Journal of Lightwave Technology, March 1998, pp.324-331
6 C.P. Tsekrekos, ECOC 2005, We4.P.113