Experimental Verification of Mode Group Diversity Multiplexing over GI-POF at 21.4 Gb/s without Equalization

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Abstract

We show by experiments Mode Group Diversity Multiplexing (MGDM) over 10 m GI-POF at a total data rate of 21.4 Gb/s without any equalization at the receiver side. Thereby, mode multiplexing was realized by two different launching positions and a mode preserving coupler at the transmitter side whereas two different detection areas realized the demultiplexing of the signals at the receiver side.

1. Introduction

Plastic optical fibre (POF) seems to be an excellent candidate for the constant increasing demand for high speed end user (fibre to the home/desk (FTTx)) applications. Especially for in house installations and short high speed connections as local area networks (LANs) POF shows promising transmission characteristics [1]. Compared to common transmission as copper cables or coaxial cables, POF owns a very high bandwidth, a space and cost efficient installation process and a complete electro magnetic resistance. Nevertheless, the bandwidth distance product of POF is limited due to the effects of attenuation, mode dispersion and mode coupling. Therefore, easy and cost efficient solutions for increasing the bandwidth distance product of POF have to be found.

One possible solution for increasing the capacity of the POF is to use the mode group diversity multiplexing (MGDM) technique where different mode groups are used for transmitting different signals [2]. 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) [3], on the POF transmission line (e.g. mode dispersion, mode coupling) [4] and the receiver side (e.g. different detection areas, electrical signal processing units) [5]. 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, 10 m GI-POF and a receiver setup.

2. Mode Group Diversity Multiplexing (MGDM) Technique

The mode multiplexing approach is based on the idea to transmit independent digital data signals with different mode groups on optical fibres [6]. 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). This can be realized by different restricted launch positions as it is shown in fig.1 a. Thereby, low order modes or high order modes are excited if an optical signal is launched in the center of the fibre (Centre Launch Position (CLP)) or with an offset (Offset Launch Position (OLP)), respectively. In addition it was recently explored [7] that the low order modes traveling in the center of the core whereas high order modes traveling mostly in the outer region of the POF's core (separation in space between high and low order modes). This is indicated in fig. 1b where the intensity distributions for CLP and OLP are shown over the radius.

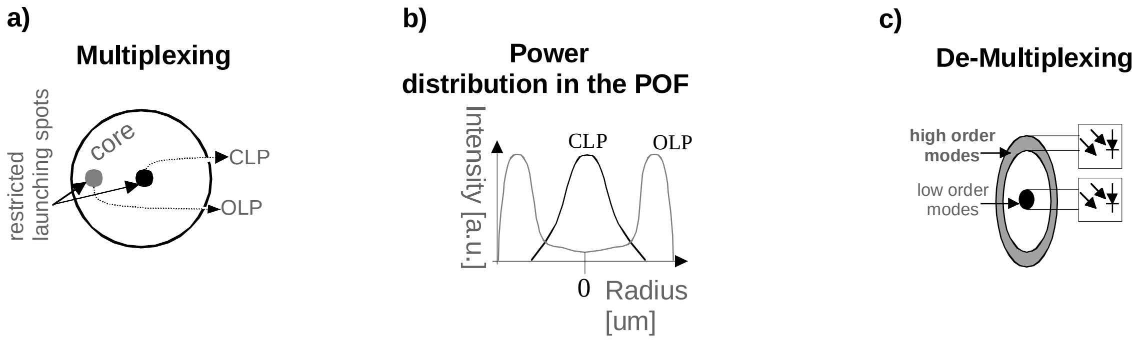

Fig.1: a) Mode multiplexing with restricted launching positions (center launch position (CLP) and offset launch position (OLP)); b) power distribution over the core radius for CLP and OLP; mode demultiplexing by different detection areas

These intensity distributions of the different transmitted signals are used for the mode demultiplexing process at the receiver side by two detection areas as it is shown in fig. 1c. Thereby, the low order modes (excited by signal 1 at CLP) are detected by an area that is located in the center of the core whereas the high order modes (excited by signal 2 at OLP) are detected by a ring area at the outer region of the core. Nevertheless, this ideal separation in space between the high and low order modes is disturbed by the effect of mode coupling during the transmission over the POF.

3. Experimental Setup

The investigation of the mode group diversity multiplexing approach was realized with the experimental setup shown in fig. 2.

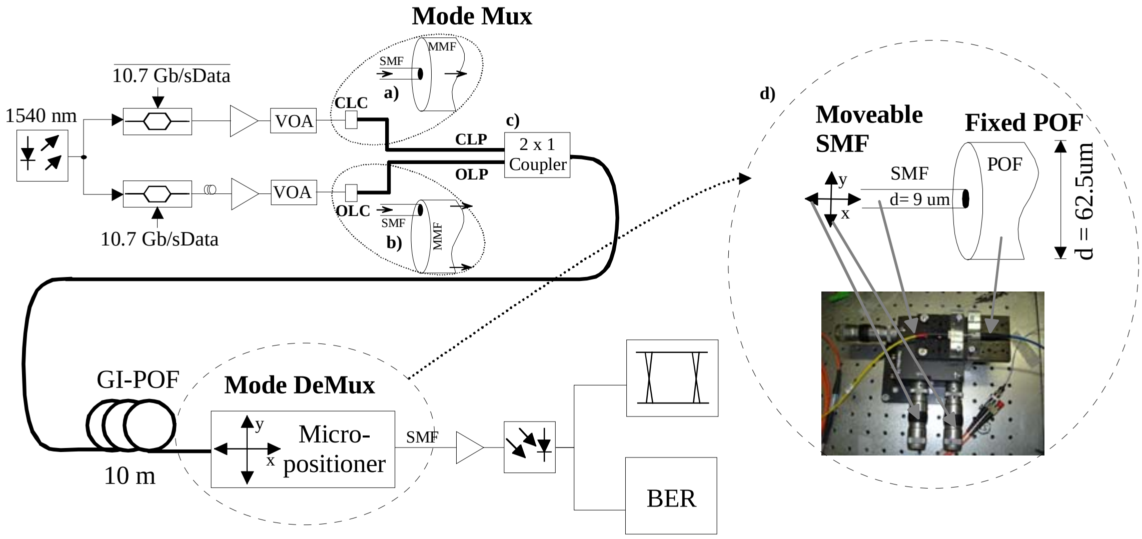

Fig.2: Experimental setup with mode multiplexer consisting in center launch connector (CLC) [a], offset launch connector (OLC) [b] and mode preserving coupler [c]; mode demultiplexer consisting in a micropositioner with a movable SMF

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) (both silica fibres) (fig. 2a). The lower arm was launched in the Offset Launch position (OLP) with a fixed offset of 20 um. 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-POF with a core diameter of 62.5 μm. 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 [7]. This is underlined by the intensity distributions shown in fig. 3a for the CLP case and in fig. 3b for the OLP case, respectively.

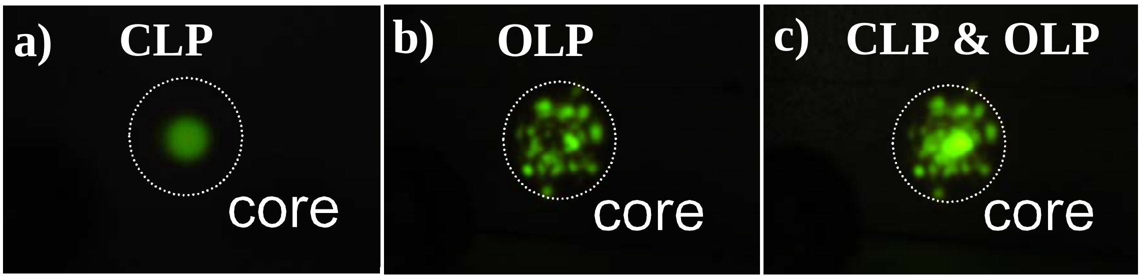

Fig. 3: Intensity distributions for Centre Launch Position (CLP) [fig.3a], Offset Launch Position (OLP) [fig.3b], superposition of CLP and OLP [fig.3c] after the mode preserving coupler

In fig. 3c the intensity distribution after the mode preserving coupler is shown. It seems that a good separation between high and low order modes is achieved.

After the transmission, the demultiplexing of the different transmitted modes/signals is realized by a micropositioner as it is shown enlarged in fig. 2d. Thereby, a single mode fibre (SMF) with a core diameter of 9 um is fixed on top of a micropositioner. Additionally, the GI-POF is positioned directly next to the micropositioner. This implies that different restricted areas of the GI-POF's core can be detected by the moveable (due to the micropositioner) SMF. Fig. 4 shows nine different restricted detection areas.

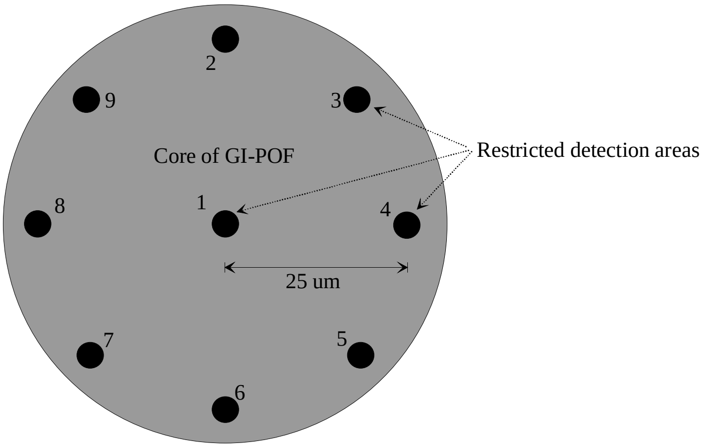

Fig. 4: Nine different restricted detection areas of the GI-POF; detection area 1: center detection area for detecting low order modes; detection areas 2-9: ring detection area for detection high order modes

Thereby, the detection area 1 should detect on the one hand mainly the low order modes in the centre of the core. The areas 2-9 arranged in a ring form should detect mainly the high order modes on the other side. After amplification with an EDFA, the optical signal is received by a photo diode and analysed with a bit error ratio tester (BERT) and an oscilloscope.

4. Experimental Results

First of all, we confirmed by detecting the beginning (seven ‘1’ bits and six ‘0’ bits) of a very short PRBS sequence of 2^7-1 bits that we really receive two different signals, data and $\overline{\text{data}}$ by the restricted detection positions 1 (fig. 5a) and 9 (fig. 5b). In the next step, we investigated the transmission characteristics by analysing the eye diagrams for the restricted detection areas. The received eye diagrams of the restricted detection positions 1, 4, 8 and 9 are shown in fig. 5c – 5f.

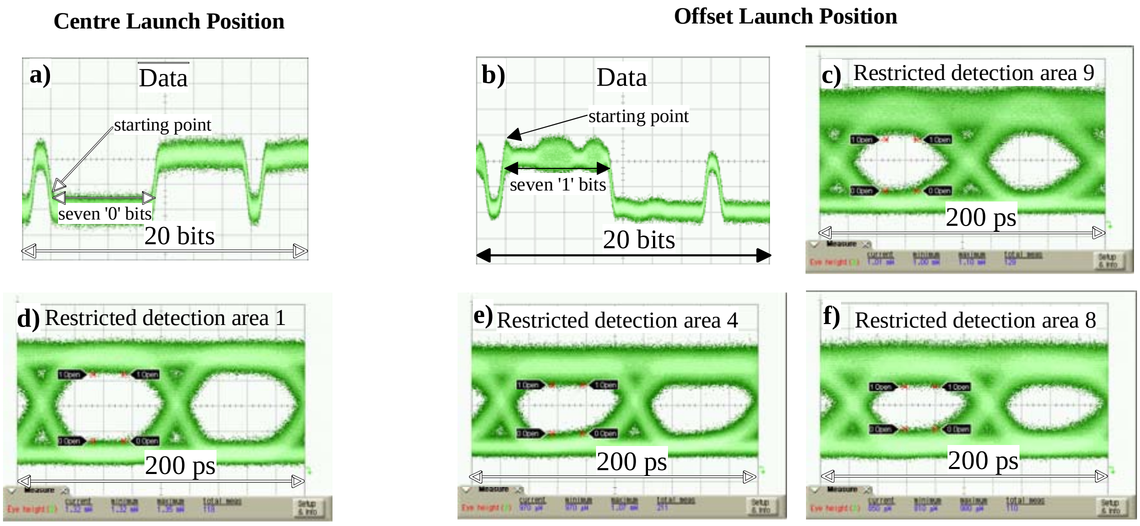

Fig. 5: Received eye diagrams for the transmitted signals in the restricted detection areas 1, 4, 8 and 9

A clearly wide open eye is observed in fig. 5d by detecting the signal in the centre of the core (detection area 1). The disturbing influence of mode coupling and mode dispersion is very low for this case. In contrast to that, a widened ‘1’ level is visible in the fig. 5c,e,f for the detection areas 4, 8 and 9 which are detecting the high order mode groups. This widened one level is explainable due to mode coupling effect from the low order mode groups which is the limiting effect in this system setup. Nevertheless, we achieved error free transmission (measured by the BERT) for both transmitted signals by detecting in the selected areas (see fig. 4). Thereby, the optimum launching powers were found to be 6 dBm at CLP and 12 dBm at OLP for this setup.

5. Conclusions and Outlook

We showed by experiments Mode Group Diversity Multiplexing (MGDM) over 10 m GI-POF at a total data rate of 21.4 Gb/s without any equalization at the receiver side. Thereby, two different signals were launched at the transmitter at two different positions (centre and 20 um offset) into the POF. The successful demultiplexing of the signals was realized by different detection areas using a micropositioner. An error free transmission over 10 m GI-POF was achieved for an input power of 6 dBm at CLP and 12 dBm at 20 um offset. Further investigations have to be focused on the limiting mode coupling effect for longer transmission distances and varying power levels.

References

[1] H.P.A. van den Boom, W. Li, P.K. van Bennekom, I. Tafur Monroy, G.-D. Khoe: " High-Capacity transmission Over Polymer Optical Fiber", IEEE Journal on Selected Topics in Quantum Electronics, Vol. 7, No. 3, May/June 2001

[2] A.M.J. Koonen, H. v.d.Boom, I.T. Monroy, G.-K. Khoe; "High Capacity Multi-Service In-House Networks using Mode Group Diversity Multiplexing", Proc. of OFC, 2004; FG 4

[3] L. Raddatz, I.H. White, D.G. Cunningham, M.C. Nowell; "An experimental and theoretical study of the offset launch technique for enhancement of the bandwidth of multimode fibre links", IEEE Journal of Lightwave Technology., Mar. 1998, pp. 324-331

[4] T. Ishigure, M. Kano, Y. Koike; "Which Is a More Serious Factor to the Bandwidth of GI POF: Differential Mode Attenuation or Mode Coupling?", Journal of Lightwave Technology, Vol. 18, No. 7. July 2000

[5] K.M. Patel;" Spatially Resolved Equalization: A New Concept in Intermodal Dispersion Compensation for Multimode Fiber", PhD thesis, Georgia Institute of Technology, http://etd.gatech.edu/theses/available/etd-11162004-114639/

[6] C.P. Tsekrekos, A. Martinez, F.M. Huijskens, A.M.J. Koonen; "Mode Group Diversity Multiplexing Transceiver Design for Graded Index Multimode Fibres", Proc. of ECOC; Glasgow, 2005, We4.P.113

[7] K. Ohdoko, T. Ishigure, Y. Koike; "Propagating Mode Analysis and Desing of Waveguide Parameters of GI POF for Very Short Reach Network Use", IEEE Photonics Technology Letters, Vol. 17, No. 1, Jan. 2005