Duobinary Modulation Format in 10 Gb/s Ethernet Multi Mode Fibre (MMF) Transmission Systems

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Abstract *We compare experimentally the on-off keying (OOK) modulation format with the bandwidth efficient duobinary modulation format in 10 Gb/s Ethernet short haul transmission systems based on multi mode fibre (MMF). Thereby, the investigations are focussed on the robustness towards the influence of mode dispersion as limiting fibre effect. It is shown by experiments that the duobinary modulation format owns a better performance against the limiting fibre influences due to the narrower spectrum. Based on these experimental results, the duobinary modulation format seems to be a very promising candidate for short haul transmission systems based on multi mode fibre as well as on single mode fibre.*

Introduction

The constantly increasing demand for fast and cost efficient data transfer in local area networks (LAN) brought up that optical fibres seem to be a good alternative to coaxial cables. This development is mainly based on the high transmission capacity of optical fibres and additionally on the electromagnetic immunity (EMI) compared to classical transmission mediums [1].

Thereby, the multi mode fibre (MMF) and in the last years the plastic optical fibre (POF) gain more and more in importance due to cost aspects compared to single mode fibres which are commonly used in long haul transmission systems. Using MMF, the cost reduction consists in higher tolerances regarding the installation and in cheaper components (e.g. lasers, photodiodes etc.).

Nevertheless, the transmission length over MMF is mainly limited by mode dispersion [2] which is based on different transmission characteristics of the excited modes. There are several promising approaches to reduce the influence of mode dispersion by electrical as well as optical equalizers which are still characterized by high effort [3,4].

It was shown in several contributions [5,6] that the optical duobinary (ODB) modulation format owns an excellent robustness against chromatic dispersion influences in single mode fibre transmission systems (normally used in long haul transmission systems as well as in metropolitan area networks) due to its narrow spectrum. We compare in this paper the narrowband ODB format [5] to the classical on-off keying (OOK) format regarding the robustness towards the influence of mode dispersion in MMF. It is shown that the ODB format owns a significant higher tolerance compared to the OOK format due to the narrower spectrum.

The paper is structured as follows: in section 2 we describe precisely the transmission characteristics of the MMF for different launching positions at the transmitter side. Section 3 depicts shortly the used modulation formats including the realization in the chosen experimental setup. In section 4 the transmission performance of the modulation formats is analysed by the eye opening and section 5 concludes the paper.

Transmission characteristics of Multi Mode Fibre (MMF)

The transmission characteristics of a MMF should be clarified by fig. 1 where only the core of the MMF is sketched.

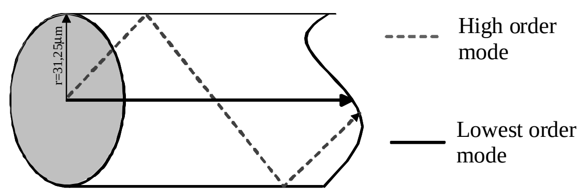

Fig. 1: Schematic sketch of a multi mode fibre (MMF) with the different transmission characteristics of high order modes (dotted grey line) and the lowest order mode (black line)

The profile of a MMF with a core diameter of 62.5 µm is shown with the transmission characteristics of a high order mode and the lowest order mode. It can be seen from the simplified geometrical drawing that due to the large core diameter different mode groups can be transmitted. Thereby, the high order mode groups own a much longer transmission distance due to many reflections at the core cladding border (dotted line) compared to the lowest order mode which is straight traveling in the centre of the core. The different transmission characteristics of the excited modes can be mathematically described by the following formula [3].

$$h(t) = \sum_{m=0}^{M} P_m \delta(t - \tau_m) , \qquad (1)$$

where the sum represents the superposition of the different excited modes m (M stands for the maximum mode number). P_m stands for the power which is carried by the mode m and τ_m for the time delay of mode m due to the transmission differences explained above.

After explaining the transmission characteristics of the MMF, we will describe in the following sections the excitement of different numbers of modes. The number and the order of the excited modes are strongly dependant on the launching position at the transmitter side as it is described in [2,3,4]. A small number of low order modes are excited if the restricted launching position is focused near the centre of the MMF's core. This is shown in fig. 2a, where the intensity distribution (determined by simulations based on formula 1) of the excited modes is drawn over the mode number. In fig. 2b the corresponding clearly wide opened eye diagram is shown after a transmission distance of 200 MMF (experimentally determined). The limiting influence of mode dispersion is very small for this launching position due to the low number of excited modes.

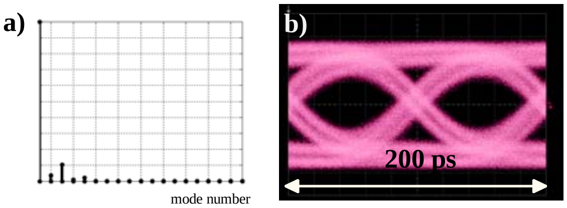

Fig. 2a: Intensity distribution of excited modes for launching at the centre of the core; corresponding eye diagram after 200 m MMF

In contrast to that, a large number of high order modes are excited if the restricted launch position is focused at an offset of several 10 µm. This is shown in fig. 3a.

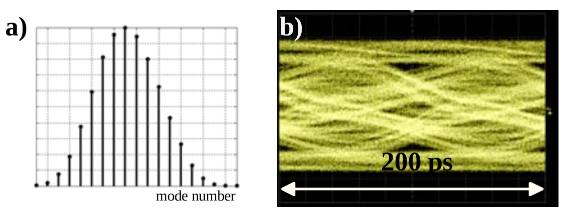

Fig. 3a: Intensity distribution of excited modes for launching with an offset of 20 µm to the core centre; corresponding eye diagram after 200 m MMF

Compared to fig. 2a, the number of excited modes is significantly larger. This implies a much stronger influence of mode dispersion which is underlined by the completely distorted eye after the transmission of 200 m of MMF.

In real transmission systems the influence of mode dispersion is additionally increased by environmental influences as temperature or pressure and by the age of the fibre because old fibres often suffer strongly from the influence of mode dispersion due to its producing process. An additional aspect is that cost efficient lasers which are used in MMF systems excite more than one mode which implies also an increased influence of mode dispersion. This means in summary that the nearly perfect case of a restricted launching area close to the centre shown in fig. 2 is not realistic in working LAN. Therefore, our investigations will be focused on the case with an offset of 20 µm which implies a significant influence of mode dispersion.

Experimental setup

In fig. 4 two experimental setups for the comparison of the traditional OOK and the ODB modulation format are shown.

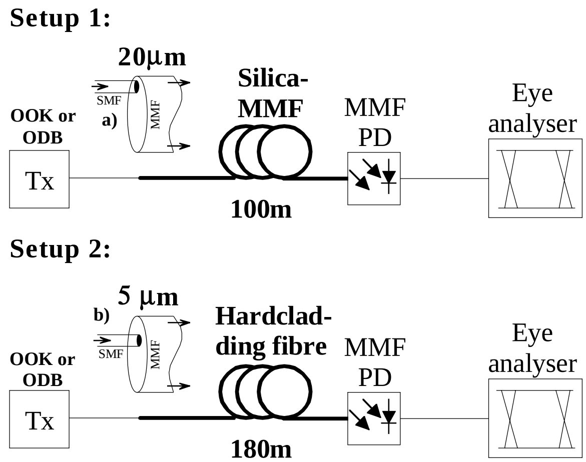

Fig. 4: Two experimental setups with transmitter (OOK or ODB modulation format), launch positions (setup 1: 20 µm; setup 2: 5 µm), transmission line (setup 1: 100 m silica multi mode fibre (MMF); setup 2: 180 m hardcladding fibre), multi mode photodiode (MMF PD) and eye analyser

After the transmitter where we can chose one of the two modulation formats the optical signal is launched from a single mode fibre (SMF) to the MMF with an offset of 20 µm in setup one and 5 µm in setup two as it is shown enlarged in fig. 4a and fig. 4b, respectively. This offset launch position (OLP) implies that a large number of high order modes are excited as it is explained in the previous section. Afterwards, the signal is transmitted over 100 m silica graded index (GI)-MMF with a core diameter of 62.5 µm in setup one and 180 m graded index hardcladding fibre with a core diameter 62.5 µm. This hardcladding fibre is characterized by a core consisting in silica and a cladding which consists in plastic which results in a high robustness against bending influences. The transmission characteristics of this fibre regarding mode dispersion and mode excitement are comparable to the silica fibre. Finally, the signals are then detected by a multi mode photodiode. We chose the length of 100 m MMF and 180 m hardcladding fibre to have a significant influence of mode dispersion on the one hand and still a clearly opened eye for analyzing purposes on the other hand. After the optical to electrical conversion the signal quality is analyzed by an oscilloscope.

In fig. 5 the different transmitter setups for the ODB and the OOK modulation format are shown:

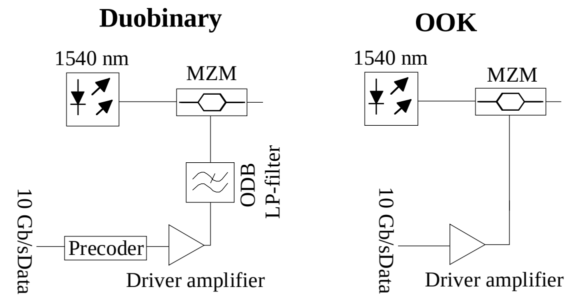

Fig. 5: Transmitter setup for the duobinary (left) and the on-off keying modulation format (right)

For both transmitter setups we used a 10 Gb/s pseudo random binary bit sequence (PRBS) which is amplified by a driver amplifier in the electrical domain. This electrical signal is used for modulating the coherent light of the laser (carrier wavelength of 1540 nm) with one Mach-Zehnder modulator (MZM) in push-pull operation (for ODB modulation: doubled driving voltage). For generating the ODB format, a precoder and a duobinary filter with a 3-dB bandwidth of 2.6 GHz has to be used been as it is described in [5]. The precoder was omitted in this experiment due to the characteristics of the PRBS. Thereby, the precoder output bit stream is identical to its time shifted input stream. The generated OOK and ODB signals for the back-to-back (b2b) transmission are shown by characteristic eye diagrams in fig. 6a and fig. 6b, respectively.

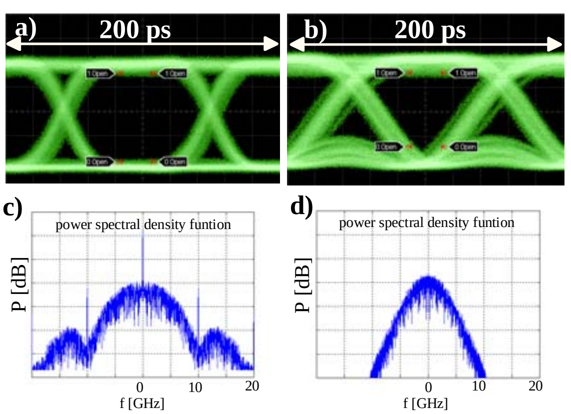

Fig. 6: Eye diagrams for the generated OOK (fig. 6a) and the ODB format (fig. 6b), spectra of the OOK (fig. 6c) and the ODB format (fig. 6d)

A typical eye shape of an ODB format can be seen which is based on the influence of the ODB low pass filter which results in a controlled intersymbol intereference (ISI). On the other hand the width of the spectrum is reduced nearly by a factor of two for the ODB format compared to the OOK format (fig. 6d and fig. 6c) which will be of advantage regarding the influence of mode dispersion

Experimental results

In fig. 7a and fig. 7b the received eye diagrams are shown for the experimental setup one.

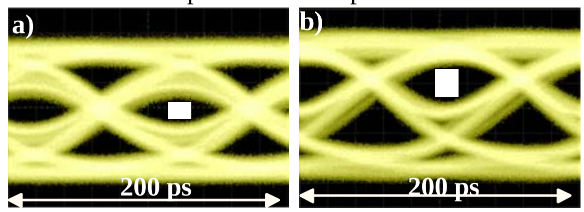

Fig. 7: Eye diagram after 100 m silica MMF using OOK format (left) and duobinary format (right)

We can see for both modulation formats a wide opened eye, whereas the eye opening for the OOK format (fig. 7a) is significant smaller compared to the duobinary modulation format (fig. 7b). The eye opening of the OOK format is approximately degraded by a factor of two which is explainable by the wider spectrum of the OOK modulation format.

In fig. 8 the received eye diagrams are shown for the second experimental setup with hardcladding fibre.

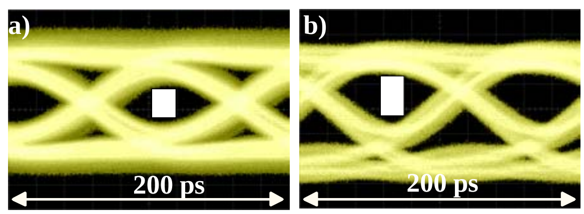

Fig. 8: Eye diagram after 180 m hardcladding fibre using OOK format (left) and duobinary format (right)

We observe again a superior performance of the ODB modulation format (fig. 8b) compared to the OOK format (fig. 8a) for this setup. Additionally, the analyzed eyes for setup two with a longer transmission distance are wider opened compared to setup one. This fact is explained due to the smaller offset of 5 µm which implies a lower number of excited modes.

Based on the results of these experimental setups, the duobinary modulation format shows a higher robustness towards the influence of mode dispersion compared to the classical OOK modulation format. This superior performance comes to a tolerable increase in implementation costs at the transmitter side with a precoder, an electrical filter and a doubled driving voltage.

Conclusion

We show by experiments that the optical duobinary modulation format owns a stronger robustness towards the limiting influence of mode dispersion in multi mode fibre transmission systems (Local area network, LAN). Two system setups with differn

MMFs, with different fibre lengths and different launching positions were investigated. For both setups the eye opening was improved by approximately a factor of two which is explainable due to the narrower spectrum of the duobinary modulation format.

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