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Citation for published version (APA):
Randel, S., Lee, S. C. J., Breyer, F., Rohde, H., & Spinnler, B. (2006). Exploiting the capacity of 1mm PMMA step-index polymer optical fibers. In *proceedings of the joint international conference on plastic optical fiber & microoptics (POF/MOC2006), 11-14 September 2006, Seoul, Korea* (pp. 443-447).

Document status and date:
Published: 01/01/2006

Document Version:
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
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Exploiting the Capacity of 1mm PMMA Step-Index Polymer Optical Fibers

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Abstract

Three different techniques are discussed that are currently under investigation at Siemens Corporate Technology – Information and Communications in order to exploit the bandwidth capacity of 1 mm PMMA Step-Index Polymer Optical Fiber (SI-POF). By using Adaptive Multitone Modulation (AMTM) a record result of 540 Mb/s transmission over 100 m of SI-POF is achieved.

1. Introduction

The 1 mm PMMA Step-Index Polymer Optical Fiber (SI-POF) is a highly attractive candidate for wired communication links in application scenarios such as industrial automation, automotive and in-house networking. Its unique advantage is the easiness of handling, allowing relaxed connector tolerances together with the possibility of field installation by non-professionals. Compared to metallic media the optical fiber brings along the further advantage of EMC immunity.

Probably the most critical disadvantage of the 1 mm SI-POF is the limitation of its bandwidth-length product to approximately 100 MHz x 100 m mainly due to modal dispersion. This paper introduces different promising techniques for an efficient bandwidth use that are currently under investigation at Siemens Corporate Technology – Information and Communications.

2. Optical Mitigation of Modal Dispersion

In a first experiment [1] the capability of optical techniques to increase the maximum achievable reach for a standard 8B10B coded Gigabit Ethernet binary signal with a bit rate of 1.25 Gb/s is analyzed. For this purpose the setup depicted in Figure 1 is used. Its main features include a collimating lens in the transmitter and a photodiode that is placed at a distance of 3 mm from the fiber end. While the lens assures that only a few low order modes are exited, the displacement of the detector spatially filters out higher order modes. Both techniques lead to an increased system bandwidth by mitigation of modal dispersion.

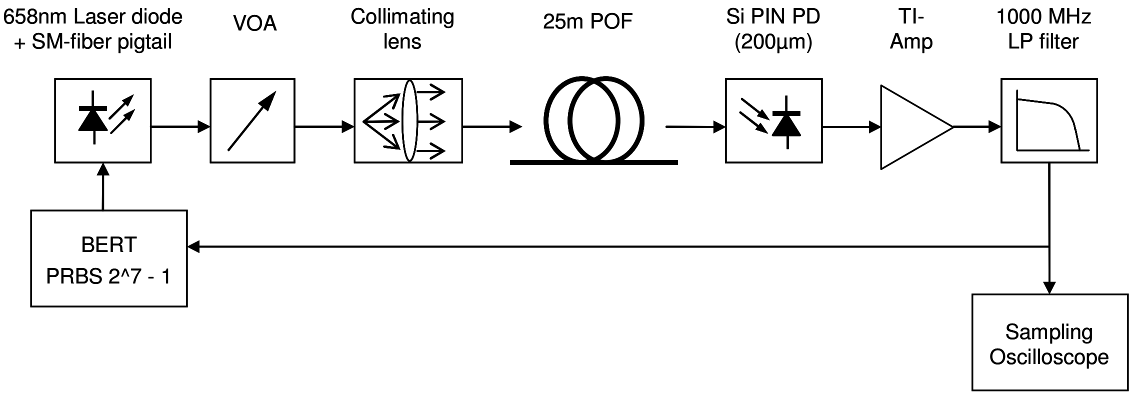

Figure 1: Setup for transmission of 1.25 Gb/s over 25 m PMMA SI-POF

The measured BER after transmission over 25 m of 1 mm SI-POF is shown in Figure 2. Compared to the Back-to-Back sensitivity, a Power Penalty of about 1.5 dB can be observed due to residual modal dispersion.

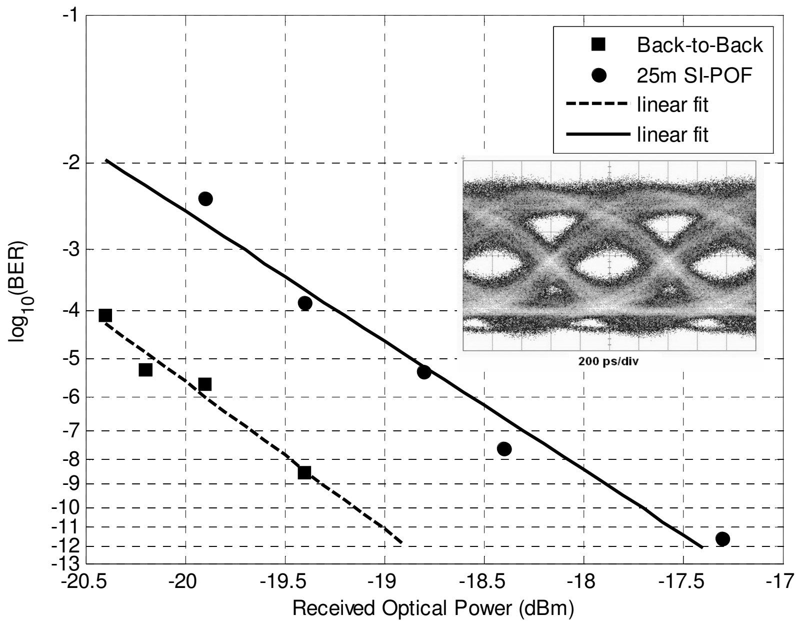

Figure 2: Measured BER versus received optical power for transmission of 1.25 Gb/s over 25m of SI-POF. The inlay shows the eye diagram obtained in case of error-free transmission.

3. Electronic Equalization

Electronic equalization allows for a dramatic mitigation of the impairments induced by bandwidth limitation due to modal dispersion [2]. In cooperation with Aspien GmbH numerical simulations were carried out in order to estimate the performance of their unique analog equalization technology [3]. The simulations are based on a channel model [4] whose validity is checked by a comparison with measured impulse responses in case of Uniform Mode Distribution (UMD) launch condition.

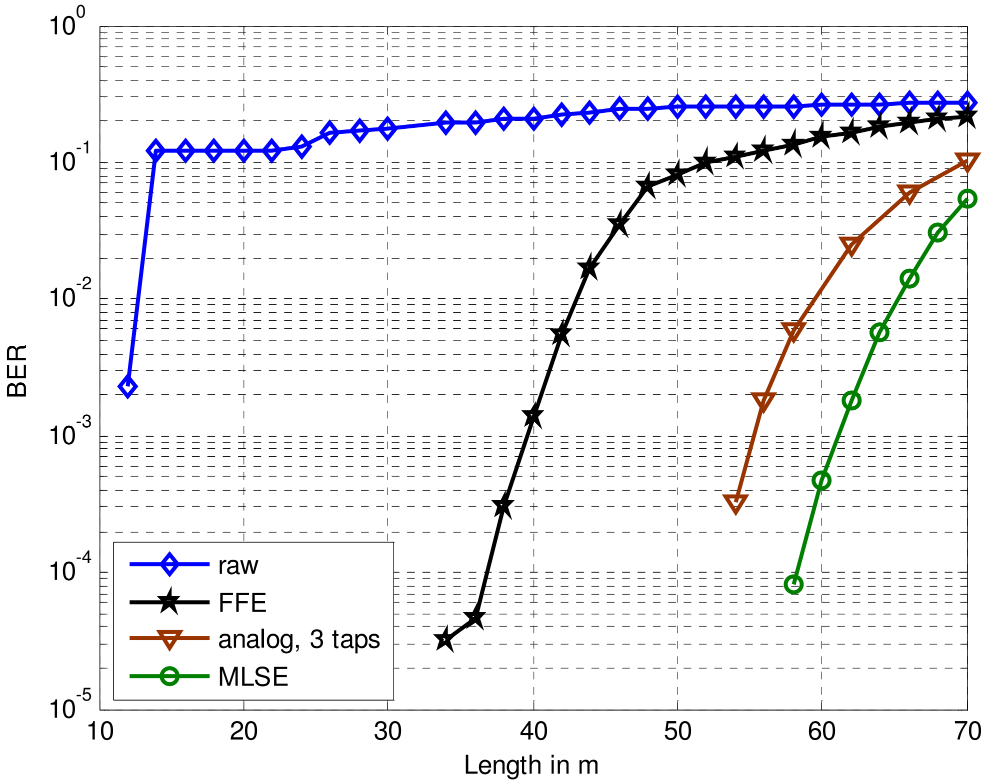

Figure 3: Simulated BER performance versus fiber length for 1.0 Gb/s transmission over 1 mm PMMA SI-POF.

Figure 3 shows the resulting bit error rates versus fiber length for 1.0 Gb/s transmission. Without equalization the error-free transmission length is limited to about 11 m. Three equalizers of different complexity and structure are investigated. Already the relatively simple linear Feed Forward Equalizer (FFE) with 15 T-spaced taps allows for fiber lengths of up to 35 m. Unfortunately due to zeros in the transfer function, the FFE can lead to instabilities even at shorter distances. The optimum reach of about 58 m can be achieved by full-state

Maximum Likelihood Sequence Estimation (MLSE). The major drawback of this technique is its high complexity on chip level. The 3 tap analog equalizer of Aspien GmbH circumvents both disadvantages at a reach of approximately 53 m.

4. Adaptive Multitone Modulation

A further promising technology that is under investigation at Siemens Corporate Technology - Information and Communications is the Adaptive Multitone Modulation (AMTM). The idea of this technique is to maximize the spectral efficiency in bit/s/Hz in order to optimally exploit the limited channel bandwidth. Similar techniques are used in wireless communication standards such as the 802.11 WLAN family and have also been proposed for communication over multimode glass fibre [5].

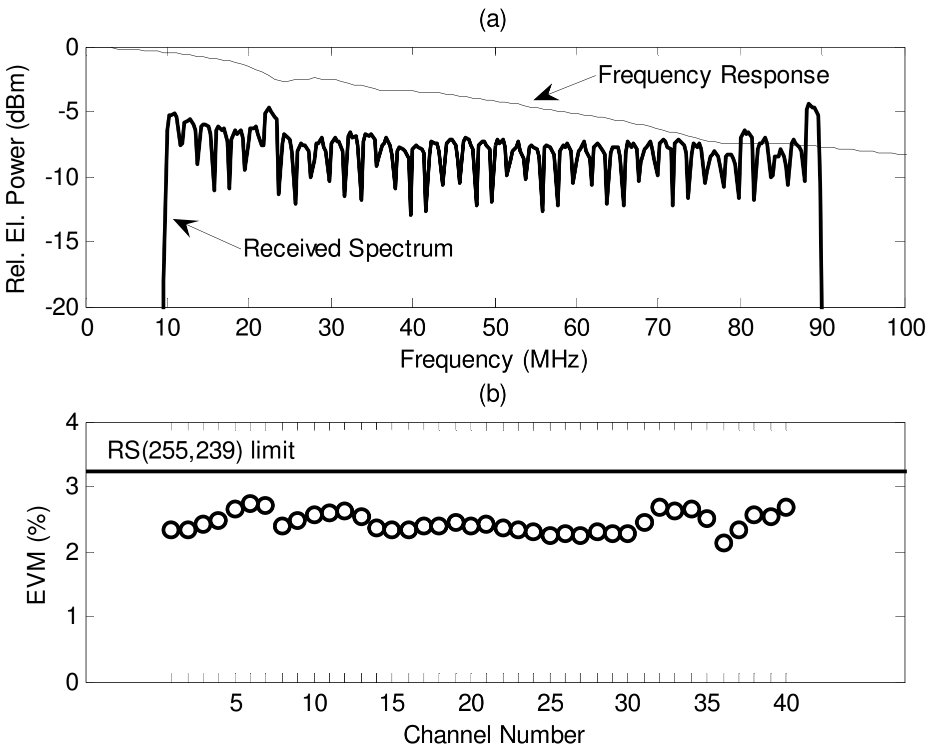

Figure 4: (a) Frequency response of 100m PMMA SI-POF transmission system as well as received optical spectrum of AMTM modulated Signal with total bit rate of 576 Mb/s. (b) Error Vector Magnitude for the individual 256-QAM modulated channels together with calculated FEC limit.

By modulation of 40 equally spaced discrete tones between 11 MHz and 89 MHz with decorrelated 1.8 MS/s 256-QAM signals, an analogue signal was generated carrying a total bit rate of 576 Mb/s at spectral efficiency of 7.2 bit/s/Hz. In order to compensate the systems frequency response the relative power of the channels has been adapted within the transmitter, resulting in a flattened received spectrum (compare Figure 1Figure 4a). In a first step, the symbol error rate P_M for the M-QAM modulated signals is estimated from the measured Error Vector Magnitude (EVM) according to the relation [6]

$$P_M = 2\left(1-\frac{1}{\sqrt{M}}\right)erfc\left(\sqrt{\frac{3}{2(M-1)EVM^2}}\right)\times\left[1-\frac{1}{2}\left(1-\frac{1}{\sqrt{M}}\right)erfc\left(\sqrt{\frac{3}{2(M-1)EVM^2}}\right)\right] \quad (1)$$

By using a conventional Reed-Solomon (255,239) code the EVM limit for a corrected BER of 10^{-12} is increased to 3.24 %. In Figure 4b the measured EVM values for all 40 channels are shown to be well below FEC limit after transmission over a 100 m long 1mm-PMMA SI-POF. We therefore achieved error-free transmission with an effective bit rate of 540 Mb/s. To the author's knowledge, this is the highest bit rate reported in literature so far.

5. Conclusions

Three different techniques that allow for the increase of the amount of data that can be transmitted over 1 mm SI-POF are discussed. Optical techniques for the mitigation of modal dispersion have been shown to enable transmission of Gigabit Ethernet over distances of up to 25 m. Their main disadvantage lies in the increased transceiver complexity. The second technique is electronic equalization. Here numerical simulations predict the possibility of transmission distances in excess of 50 m at a bit-rate of 1 Gb/s by using low-complexity analogue equalization. Probably the most promising technique is AMTM allowing highly spectral efficient record transmission of 540 Mb/s over 100 m of 1 mm SI-POF.

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