10 Gbit/s Short-Reach Transmission over 35 m Large-Core Graded-Index Polymer Optical Fiber

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Abstract: In the paper we demonstrate robust 10 Gbit/s short-reach transmission over 35 m of 1-mm core-diameter graded-index polymer optical fiber with very low cost components and DMT modulation. With this scheme reliable high-speed short-reach interconnects are feasible that can be easily combined to fiber ribbons.

OCIS codes: (060.2330) Fiber optics communications; (200.4650) Optical interconnects

1. Introduction

The Polymer Optical Fibers (POF) is a cheap and convenient alternative to silica multimode fibers. The graded-index POF (PMMA-GI-POF) offers a relatively high bandwidth. The typical optical 3 dB bandwidth of 50 m GI-POF length is 1500 MHz (NA_{launch} = 0.34) [1]. Besides its robustness to mechanical stress and electromagnetic interference PMMA-POF benefits from easy installation and allows large connector tolerances, which make low-cost fiber ribbons feasible. The use of integrated transmitters and silicon based receivers enables a setup of parallel data links with passive alignment and large mechanical tolerances.

There are many POF-based Fast Ethernet systems available in the telecommunication market [1]. Several recent investigations have also shown really promising results connected with application of discrete multitone modulation (DMT) in POF-channels. Advanced modulation schemes allow a higher spectral efficiency and better performance of short standard- and graded-index POF links: Eye safe transmission of 5.3 Gbit/s over 50 m 1 mm core diameter PMMA-GI-POF [2]; 1.44 Gbit/s over 100 m of 1 mm SI-POF [3]; 10 Gbit/s over 25 m standard 1 mm core diameter POF [4] and 2.1 Gbit/s over 100 m multi core POF (POF-AC 2010).

In the given paper we demonstrate the transmission of 10 Gbit/s over 35 m of 1 mm core diameter GI-POF using a direct modulated laser diode. In order to achieve a good spectral efficiency, DMT modulation technique is applied. The combination of a POF-optimized receiver, a powerful laser diode and high bandwidth GI-POF allows to increase the transmission length up to 35 m compared to previously published results.

2. Transmission setup

The transmission setup is shown in Fig. 1. A pseudo-random bit sequence (PRBS) is mapped to a discrete multi-tone (DMT) signal with 256 subcarriers. The SNR per subcarrier has been estimated and Chow's rate adaptive bit-loading algorithm [5] has been used in order to maximize the bit rate subject to a fixed energy constraint.

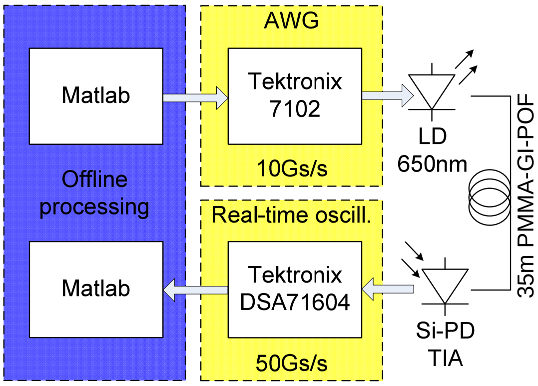


Fig.1: Schematic of the transmission setup

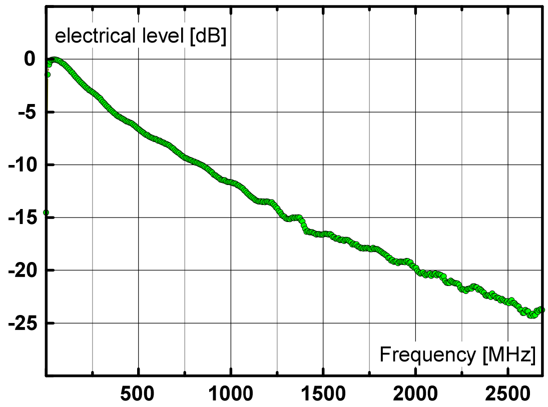


Fig.2: Frequency response of the system

An arbitrary waveform generator (AWG) with a resolution of 8 bit has been used to convert the digital data at 10 GS/s into an analog signal.

The transmitter used in the experiment is a commercially available red edge emitting laser diode operating at a wavelength of 650 nm and an optical output power of +7 dBm. The laser diode is driven in its linear region with a modulation index of approximately 0.9.

The used POF-optimized receiver comprises a silicon pin photodiode with an active diameter of 400 µm and a commercially available trans-impedance amplifier.

A non-imaging optic is used to couple the light efficiently to the diode's active area. This non-imaging element permits a higher coupling efficiency compared to a lens. In our case a dielectric taper was used due to its high performance and ease of production [4].

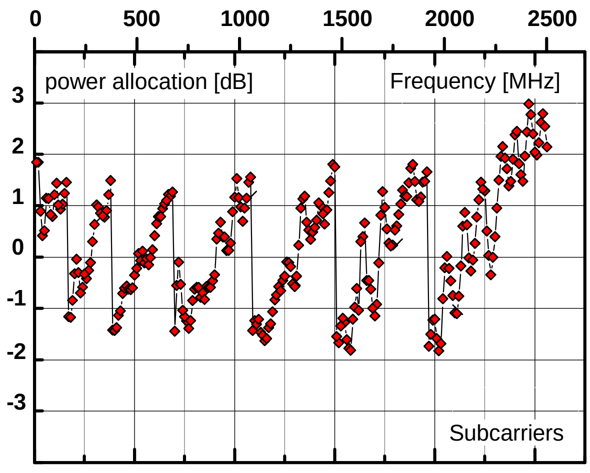
In order to synchronize the AWG and the real-time oscilloscope, the received signal was recorded with oversampling. The real-time oscilloscope captures the analog electrical signal with 50 GS/s and a resolution of 8 bit. The bit error ratio is then evaluated by error counting using a PC.

The available 3 dB-bandwidth of the system after 35 m PMMA-GI-POF was 240 MHz (see Fig. 2). The bandwidth used for the transmission of the DMT signal was 2.5 GHz.

3. Measurement results

For the transmission of 10 Gbit/s we used a DMT signal with 256 subcarriers distributed over the available bandwidth. The aggregate bit rate is higher and includes 7% forward-error correction (FEC) bits and DMT transmission overhead. The clipping level of the signal was set to 9.5 dB. The maximal level of QAM applied in the experiment was 256. For the high-frequency group of subcarriers 4-QAM was used.

As a result of Chow's rate adaptive bit-loading algorithm the power spectrum of the transmitted signal has a saw tooth shape. The power allocation and corresponding bit loading scheme are shown in Fig. 3.



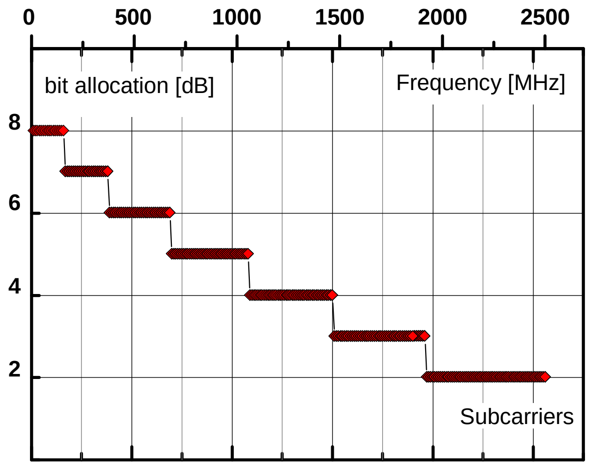


Fig. 3: Power allocation and bit allocation of the subcarriers

Fig. 4 shows that the SNR of the received signal is constant within each group of subcarriers with a certain modulation format. This provides a constant BER for all subcarriers of the received signal. Fig. 5 shows the measured bit-error ratios, averaged over subcarriers with the same modulation format. The total average BER of the system is BER = 10^{-3} which is sufficient for FEC.

As an example, two received constellation diagrams are shown in Fig. 6 to illustrate the quality of the signal.

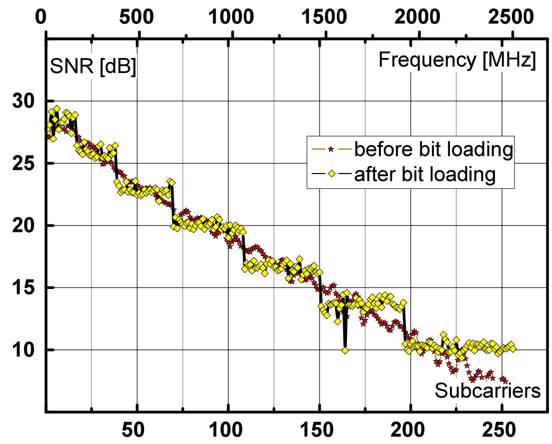


Fig. 4: Measured SNR per subcarrier, before and after bit-loading

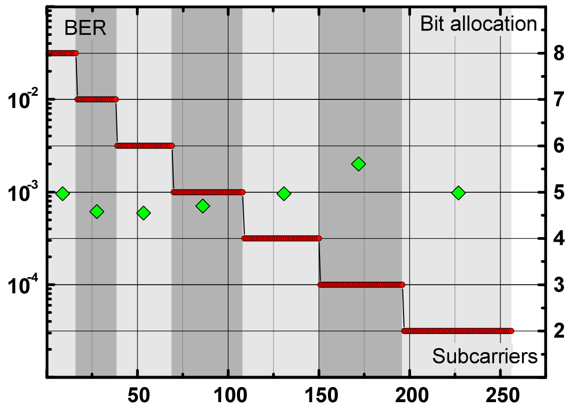


Fig. 5: BER averaged within groups of subcarriers (total BER is 10^{-3})

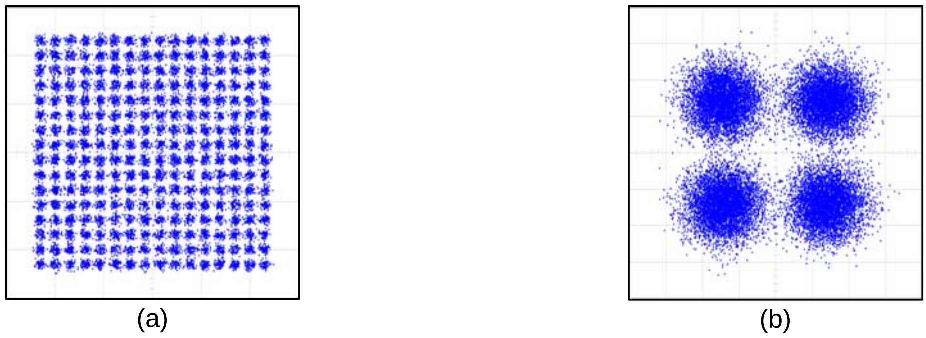


Fig. 6: Received constellations: 256QAM, subcarrier's number 1-16 (a); 4QAM (b), subcarrier's number 197-256

The averaged SNR of the two signals shown in Fig. 6 is 28.4 dB (256 QAM) and 9.8 dB (4 QAM) correspondingly. The given SNR distribution allows to get a constant performance for all subcarriers of the DMT signal.

4. Conclusion

With an optimized system for large-area polymer optical fibers and using DMT modulation, 10 Gbit/s were transmitted over 35 m of 1 mm large-core PMMA-GI-POF. A spectral efficiency of 4.28 bit/s/Hz has been achieved.

With these promising results the demonstrated transmission system is a powerful competitor to current high-speed copper solutions. The robustness and low component costs makes it the preferred choice for next generation broadband in-house communication and short reach optical interconnects in computer and network systems.

Acknowledgments

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