Channel Capacity of Step-Index Polymer Optical Fibers: Experiments and Simulation with Realistic Parameters

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Abstract: Step-index Polymer Optical Fibers (SI-POF) are candidates for broadband in-house networks. For the first time, we give a comprehensive overview over the real channel capacity of POF links up to 100 m, based on experimental investigations and complex system simulations. More than 2 Gbit/s can be transmitted at very low BER with existing components. Improved devices will give place for further progress.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

It is well known, that the bandwidth of Step Index Polymer Optical Fibers is limited by mode dispersion. The typical 3 dB bandwidth of a 100 m POF length is 40 MHz (for full mode launch) to 60 MHz (laser launch).

A lot of different SI-POF based systems for Fast Ethernet (125 Mbit/s) are commercially available (see [1] for a detailed overview). The bandwidth of the POF is sufficient for that bit rate. A still open question is, if the installed POF can be used for the next generation 1 Gbit/s transmission as well. It is obvious that pure NRZ transmission can not be used for distances » 10 m due to the limited bandwidth.

Bandwidth efficient modulation formats and mechanisms for channel equalization are well known for different other transmission channels, like copper cables or radio networks. For POF, we investigated the following methods:

- Equalization of the POF channel with a passive high pass filter.
- DMT (Discrete Multi-tone) modulation.
- Digital FFE/DFE filtering and equalization.

2. Experimental Results

The maximum bit rate achieved over 100 m SI-POF for NRZ modulation and passive equalizing was 1.39 Gbit/s [2]. In the experiment, we used a low cost edge emitting laser diode (for DVD players) at a wavelength of 650 nm and a receiver with an 800 µm diameter pin-PD and a transistor based TIA [3]. The measured sensitivity of the receiver for 50 m SI-POF at 1.25 Gbit/s (Gigabit Ethernet with coding) is -16 dBm at a BER of 10^{-9} (Fig. 1/Fig. 2). In 2006, Siemens published the first 1 Gbit/s data transmission using SI-POF and DMT modulation [4]. The best present value is 1.51 Gbit/s (after FEC).

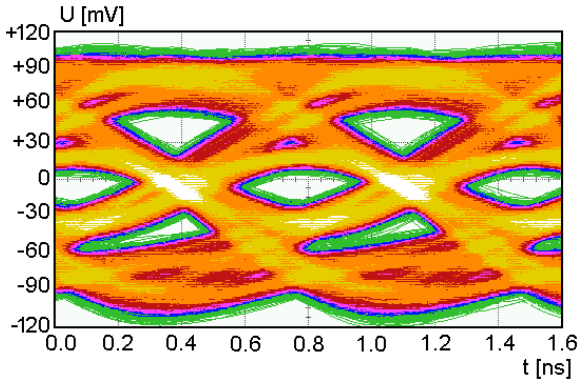

Fig. 1: Eye diagram at 1.39 Gbit/s over 100 m SI-POF

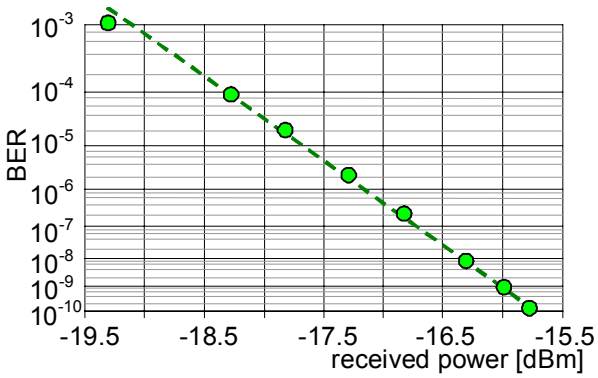

Fig. 2: Measured BER for 1.25 Gbit/s (50 m SI-POF)

3. Simulation Tool

In order to be able to simulate the measured system, a new tool was developed at POF-AC in 2008 and 2009 under the responsibility of R. Kruglov [5]. The tool is based on the program Simulink.

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We are able to modify a lot of different parameters for the transmitter, the fiber and the receiver. As an example, the tool contains a lot of measured transfer functions of POF in dependence of length and launch NA. Fig. 3 compares a simulated and measured eye diagram for the transmission of 1.25 Gbit/s over 50 m SI-POF.

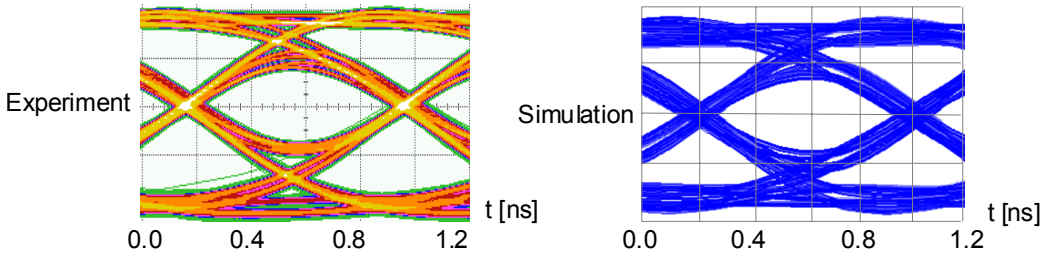

Fig. 3: Comparison of experiment and simulation

4. Post Processing

The use of DMT or FFE/DFE filters for Gigabit transmission on POF is difficult, because of the non availability of the electronic components. That's why we measured the signal with a fast oscilloscope. Signal detection was made with offline processing on a PC.

The first 2 Gbit/s experiment with digital DFE/FFE filtering on 100 m SI-POF was realized by the TU Munich and Siemens in 2008 (interpolated eye diagram Fig. 4). The BER was $2 \cdot 10^{-5}$. A 650 nm LD was used. The receiver was a 600 µm Si-pin-PD/commercial TIA. The same result was reached by the POF-AC in 2009 with a 800 µm PD (Fig. 5).

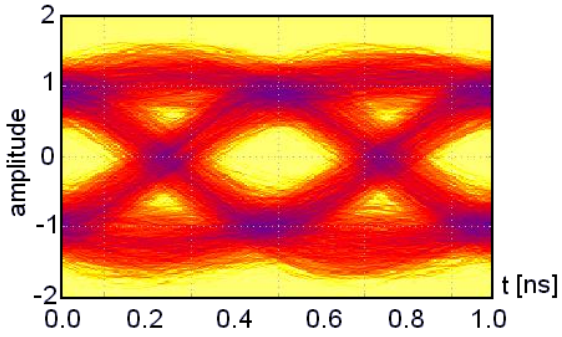

Fig. 4: Eye diagram for 2 Gbit/s over 100 m POF (TUM)

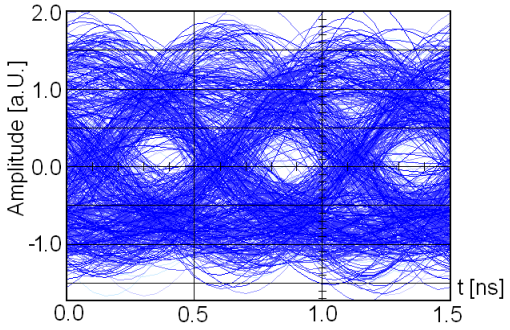

Fig. 5: Eye diagram for 2 Gbit/s over 100 m POF (POF-AC)

We have now measured the system at different bit rates up to 2.5 Gbit/s (with our 800 µm PD-receiver). The signal received was filtered with an optimized high pass filter first. Then a DFE/FFE receiver was used (both with post processing). Fig. 6 shows the counted BER for the two receiver structures

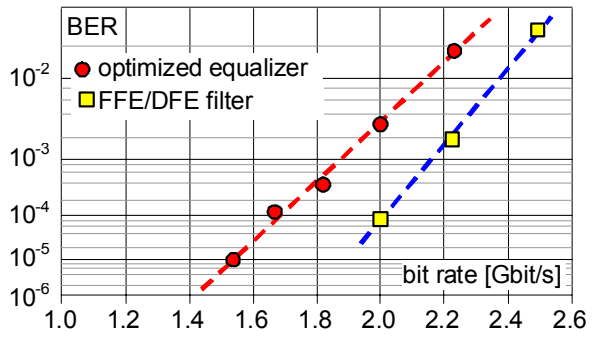

Fig. 6: BER for different receivers (100 m SI-POF)

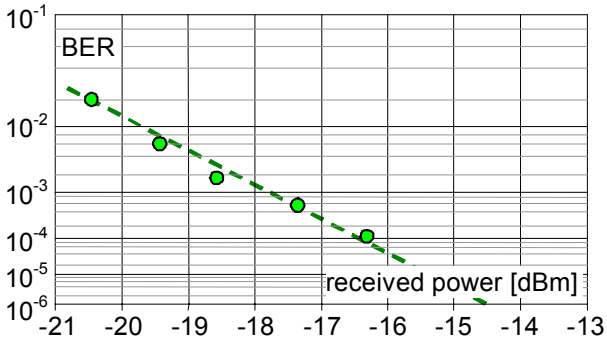

Fig. 7: Calculated BER for 1.25 Gbit/s (100 m SI-POF)

It can be seen, that the DFE/FFE receiver enables a higher bit rate, compared with the passive equalizer. The disadvantage is the required ADC and the signal processing. Moreover, the realization of burst mode transmission is difficult. Fig. 7 shows the BER dependent on the received power (optimized equalizer). The sensitivity is -12.0 dBm at 1.25 Gbit/s. (extrapolated to BER = 10^{-9}).

5. Multi Core POF

Multi core (MC) POF consists of several but tight connected single cores. The special structure enables a much smaller bending sensitivity without changes of the fiber NA. All other parameters are nearly equal to the standard POF, offering full compatibility. The highest possible experimental bit rate with a passive equalizer is shown in Fig. 8. Calculations of the possible bit rate with a theoretically optimized passive filter and with DFE filtering are summarized in Fig. 9. The loss of the MC-POF is slightly higher than the loss of the SI-POF. On the other hand side, the bandwidth is a little bit higher. The combination of both effects gives a comparable total capacity.

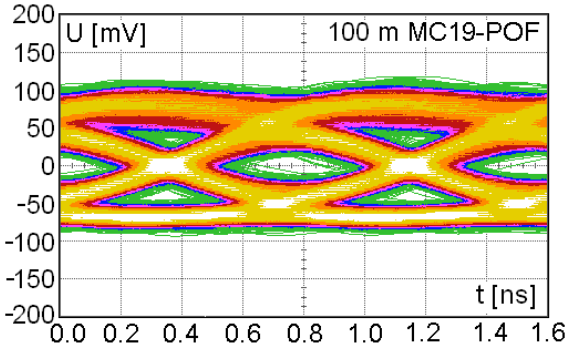

Fig. 8: 1.26 Gbit/s over 100 m MC-POF with NRZ/pass. filter

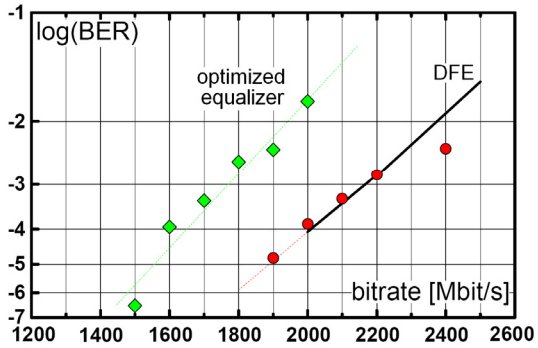

Fig. 9: Calculated BER for 100 m MC-POF (pass. filter, DFE/FFE filter)

6. Future Improvements and Conclusions

We have investigated the channel capacity of 100 m SI-POF experimentally and in simulation. Two different experiments using different fibers and components have shown the same capacity of about 2 Gbit/s (BER $\approx 10^{-5}$) using NRZ and DFE receivers. NRZ modulation with passive filtering and DMT modulation offer similar capacity.

Our new computer tool is able to simulate the different modulation formats and systems with very small differences to the experiment.

We expect a much better system performance with improved components. The integration of the receiver will reduce the parasitic elements and thus the noise. Our calculations show, that for a 50 m fiber link the transmission of Gigabit-Ethernet is possible with more than 10 dB margin, giving a very robust system.

MC-POF can be used as bend insensitive POF with about 2 mm bending radius and offer the same capacity and can be used with the same components, tools and cable constructions.

In other experiments (not described here) we have also successfully tested the transmission of 10 Gbit/s over up to 25 m of SI-POF and MC-POF.

Acknowledgements

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References

[1] O. Ziemann, J. Krauser, P.-E. Zamzow: “POF-Handbook - Short Range Optical Transmission Systems”, Springer 2008

[2] O. Ziemann, O. Lednicky, J. Vinogradov, R. Gaudino, H. Kragl , S. Randel, J. Lee, B. Offenbeck: „The Development of Gbps over SI-POF Systems in the POF-ALL Project“, POF’2008, Santa Clara, 26.-28.08.2008

[3] J. Vinogradov, E. Bluoss, O. Ziemann, Ch. Sapper, W. Eischer, E. Hartl, J. Meier, J. Wittl, H. Hurt, G. Steinle, H. Althaus, N. Schunk: „Gbps data communication on SI POF and glass fibre“, POF2004, Nürnberg, 27.-30.09.2004, pp. 405-411

[4] S. Randel, S. C. J. Lee, B. Spinnler, F. Breyer, H. Rohde, J. Walewski, A. M. J. Koonen, A. Kirstädter: “1 Gbit/s Transmission with 6.3 bit/s/Hz Spectral Efficiency in a 100 m Standard 1 mm Step-Index Plastic Optical Fibre Link Using Adaptive Multiple Sub-Carrier Modulation”, ECOC’06, post deadline, Sept. 2006

[5] J. Vinogradov, R. Kruglov, S. Loquai, O. Ziemann, C.-A. Bunge: “POF System Simulation – Showing the real Potential of POF links“, POF-Day, OFC San-Diego, 22.-26.03.2009