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10.7 Gbit/s Transmission over 220 m Polymer Optical Fiber using Maximum Likelihood Sequence Estimation

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Abstract: 10.7 Gbit/s NRZ-signals are transmitted for the first time over 220 m of multimode 120 µm core-diameter perfluorinated graded-index polymer optical fiber using an MLSE equalizer.

OCIS codes: (160.5470) Polymers; (060.2330) Fiber optics communications

1. Introduction

The rapid increase of data traffic in data communication applications has pushed the demand for high-capacity and low-cost photonic networks for use in local area networks (LAN), such as enterprise or datacenter backbones [1,2]. The use of 10 Gigabit Ethernet (10GbE) in such cases will often require a new installation, because the commonly installed CAT-5 copper cables are unsuitable. A viable solution is the use of fiber optic cables. In comparison to multimode silica fibers, the perfluorinated graded-index polymer optical fiber (GI-POF) with 120 µm core-diameter is a promising alternative because it allows large alignment and dimensional tolerances for components, while still coupling well to standard high-speed transmitters and detectors at wavelengths of 850 nm and 1300 nm. This GI-POF features easy use and installation with clip-on connectors requiring minimal training or specialized equipment to terminate the cables. Furthermore, cables made from GI-POF are extremely flexible, offering a bending radius of 5 mm compared with 25 mm for silica fiber cables and 30 mm for CAT-6A copper cables.

Up to now, 10 Gbit/s data transmission on such 120 µm perfluorinated GI-POF has been limited to distances not larger than 100 m [3]. This is due to bandwidth limitations caused by modal dispersion in large-core multimode fibers. Recent developments in standardization of 10 Gigabit Ethernet include electronic dispersion compensation (EDC) to counter such limitations of multimode silica fibers [4]. E.g., the recently developed IEEE 10GBASE-LRM standard enables 10GbE at distances of up to 220 m by applying a Decision Feedback Equalizer (DFE) [5].

In this paper, we demonstrate 10.7 Gbit/s data transmission over a 120 µm perfluorinated GI-POF up to a distance of 220 m using a maximum likelihood sequence estimation (MLSE) equalizer to compensate for modal dispersion. This distance complies with the novel IEEE 10GBASE-LRM standard, which is developed for the support of 10GbE on installed legacy multimode silica fibers.

2. Experimental Setup

The experimental setup of the GI-POF transmission system is shown in Fig. 1. A directly modulated 1300 nm distributed feedback (DFB) laser with standard single-mode fiber pigtail is used as the transmitter. This laser is modulated with a non return-to-zero 2^{15}-1 pseudorandom bit sequence at 10.7 Gbit/s. A variable optical attenuator is placed after the laser to adjust the power level. Before coupling into the GI-POF, a mode mixer is used. This mode mixer consists of 50 cm of the same type of GI-POF wound 10 times around a cylinder with 20 mm diameter. Using such a mode mixer stabilizes the transmission system, because of the over-filled mode launch.

After the mode mixer, the optical power is launched into different lengths of the GI-POF. The perfluorinated GI-POF used in the experiments is a commercial fiber with 120 µm core-diameter and 500 µm total diameter including cladding. The attenuation is approximately 40 dB/km at 1300 nm wavelength and the numerical aperture is 0.185. For the back-to-back measurements, the PF GI-POF is left out of the experimental setup (compare Fig. 1).

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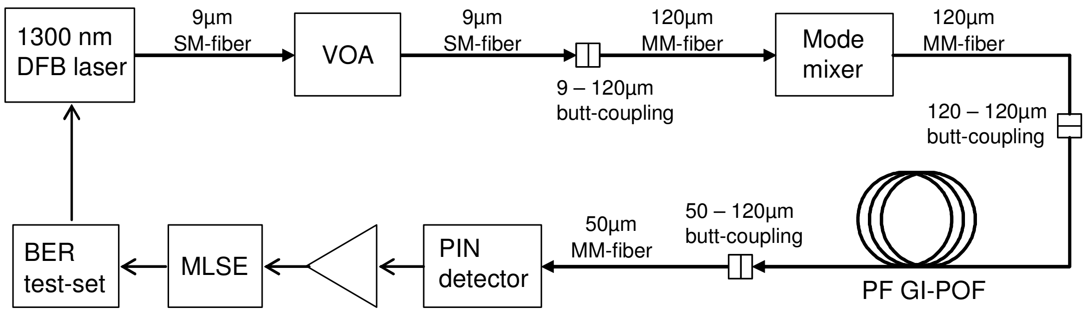

Fig. 1: Experimental Setup.

At the receive end, a 50 µm silica multimode fiber (MMF) pigtailed InGaAs PIN detector is used, leading to a 3.5 dB coupling loss due to core-size mismatch between the GI-POF (120 µm) and the silica MMF (50 µm). After electrical amplification, the received signal is fed into a commercial MLSE module [6]. This MLSE module comprises a 3 bit A/D converter operating at 21.4 GSamples/s and a four-state (2 symbols memory) Viterbi decoder. Finally, the output of the MLSE is fed back to the BER test-set.

3. Experimental results

Fig. 2a and b show the measured BER values after transmission at 10.7 Gbit/s over 100 m of GI-POF plotted against time without and with MLSE, respectively. These BER values are measured every second for a total time period of 900 seconds and a received optical power of -7.5 dBm. For the 100 m GI-POF transmission system, BER values around 10^{-3} are reduced to 10^{-7} when MLSE is employed. As the measured BER values with MLSE are several orders of magnitude better than the limit of forward error correction (FEC), error-free transmission can be achieved under all circumstances.

The measured BER curves depicted in Fig. 2c compare the performances of the system with and without MLSE in the same 100 m GI-POF transmission system at 10.7 Gbit/s. Each plotted BER value corresponds to the mean of 300 measured values obtained every second. At a BER of 10^{-4}, the 100 m GI-POF system with MLSE has a 6 dB better receiver sensitivity than without MLSE. For the back-to-back measurements without GI-POF, the system performs 2 dB better with MLSE as a result of impairments due to the directly modulated laser and modal dispersion introduced by the mode mixer.

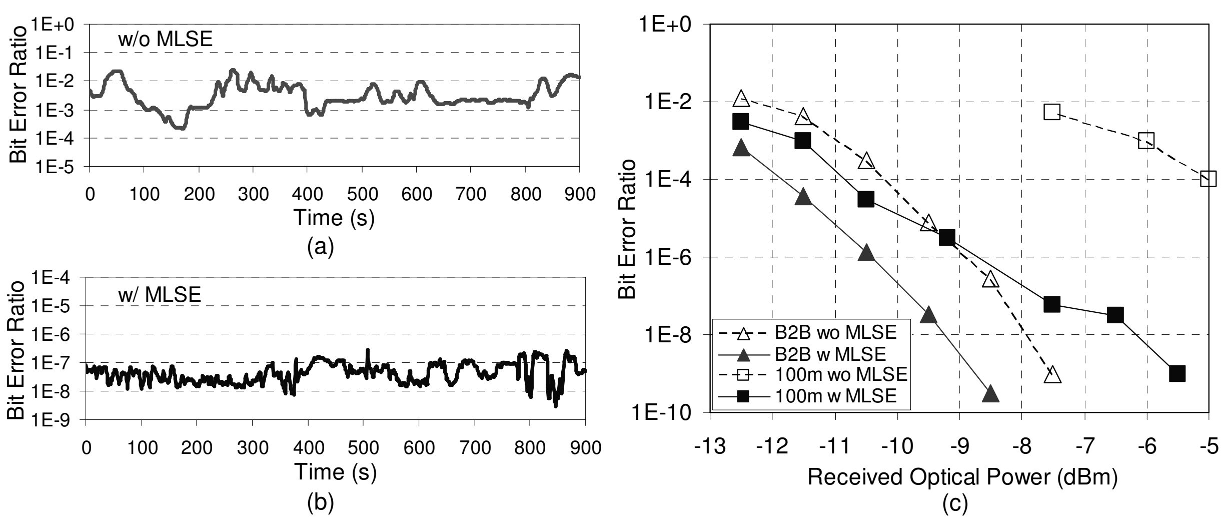

Fig. 2: (a) BER vs. time for 100 m GI-POF without MLSE at 10.7 Gbit/s (b) same as a., but with MLSE
(c) comparison of MLSE performance for back-to-back case and transmission over 100 m GI-POF.

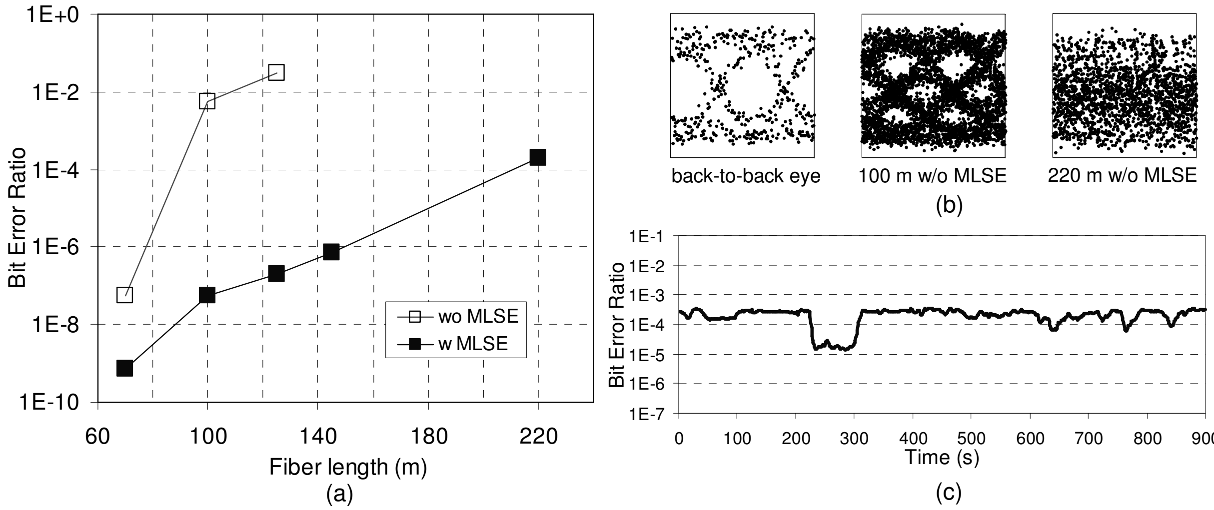

Fig. 3: (a) BER values for different lengths of GI-POF with and without MLSE, at 10.7 Gbit/s and constant received optical power of -7.5 dBm (b) eye diagrams for back-to-back, 100 m without MLSE, and 220 m without MLSE (c) BER vs. time for 220 m GI-POF with MLSE.

The performance improvement due to MLSE equalization after 10.7 Gbit/s transmission is further illustrated by measuring the BER at a constant received optical power of -7.5 dBm for different lengths of GI-POF with and without equalizer (Fig. 3a). Each plotted BER value corresponds to the mean of 900 measured values, obtained every second. While transmission over 220 m is impossible for a system without equalization, the system with MLSE is able to cover this distance yielding a BER of 10^{-4}. Furthermore, the feasible transmission distance using GI-POF is more than doubled from 90 m without MLSE to 220 m with MLSE for a BER of 10^{-4}.

Fig. 3b shows the 10.7 Gbit/s eye diagrams of the back-to-back case, and after transmission over 100 m and 220 m of GI-POF without MLSE. The eye after 100 m is taken at a BER of 10^{-4}. After 220 m, the received signal is totally distorted. BER measurements over a period of 900 s (Fig. 3c) show a worst performance of $3.6 \cdot 10^{-4}$ for 10.7 Gbit/s transmission over 220 m GI-POF. By using Reed Solomon (511, 479) FEC with 7% overhead, the BER can be corrected to values below 10^{-12}.

4. Conclusions

For the first time, 10.7 Gbit/s data transmission is demonstrated over 220 m of commercial 120 µm perfluorinated GI-POF by using MLSE. This shows, that the large-core 120 µm perfluorinated GI-POF has the potential to meet the distance requirements of the recently approved IEEE 10GBASE-LRM standard for installed silica MMFs. Together with the additional advantages of mechanical robustness, relaxed alignment tolerances and easy, low-cost installation this makes the GI-POF a promising solution for future enterprise and datacenter backbone networks.

5. References

[1] C.M. DeCusatis, "Fiber optic cable infrastructure and dispersion compensation for storage area networks," IEEE Communications Magazine, vol. 43, pp. 86-92, March 2005.
[2] S. Randel, S.C.J. Lee, B. Spinnler, F. Breyer, H. Rohde, J. Walewski, A.M.J. Koonen, and 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," Proc. ECOC'06, PDP Th4.4.1 (2006).
[3] G. Giaretta, W. White, M. Wegmueller, R.V. Yelamarty, T. Onishi, "11Gb/sec Data Transmission Through 100m of Perfluorinated Graded-Index Polymer Optical Fiber," Proc. OFC'99, PDP, PD14-1 (1999).
[4] C. Xia, M. Ajgaonkar, and W. Rosenkranz,"On the Performance of the Electrical Equalization Technique in MMF Links for 10-Gigabit Ethernet," IEEE J. Lightwave Technol., vol. 23, pp. 2001-2011, June 2005.
[5] Institute of Electrical and Electronics Engineers, IEEE P802.3aq Draft4.0 (10GBase-LRM), http://www.ieee802.org/3/aq, to be published end of 2006
[6] A. Färbert, S. Langenbach, N. Stojanovic, C. Dorschky, T. Kupfer, C. Schulien, J.P. Elbers, H. Wernz, H. Griesser, C. Glingener, "Performance of a 10.7 Gb/s Receiver with Digital Equaliser using Maximum Likelihood Sequence Estimation," Proc. ECOC'2004, PD-Th4.1.5 (2004).