

4.7 Gbit/s Transmission over 50m Long 1mm Diameter Multi-core Plastic Optical Fiber

H. Yang⁽¹⁾, E. Tangdionga⁽¹⁾, S.C.J. Lee⁽¹⁾, C. Okonkwo⁽¹⁾, H.P.A. van den Boom⁽¹⁾, S. Randel⁽²⁾ and A.M.J. Koonen⁽¹⁾

(1) COBRA Research Institute, Technical University of Eindhoven, P.O. Box 513, 5600 MB, Eindhoven, the Netherlands. (2) Siemens AG, Corporate Technology, Information & Communications, Munich, Germany. E-mail: h.yang1@tue.nl

Abstract: We report, for the first time, 4.7 Gbit/s transmission over 50m long 1mm diameter multi-core step-index plastic optical fiber, employing discrete multitone techniques and low-cost optical transceiver. A spectral efficiency of 13 bit/s/Hz is demonstrated.

©2010 Optical Society of America

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation; (160.5470) Polymers

1. Introduction

Widespread deployment of FTTH/FTTB technology will enable prolific transmission of broadband services delivered via standard single mode fiber from the remote central office to many end users. However, the bottleneck in broadband access networks currently resides at the point of service delivery to in-home end users, especially for the multi-dwelling units (MDU). Different approaches have been proposed to provide cost-effective solutions for service delivery [1]. In recent years, the commercialized polymethyl-metacrylate (PMMA) step-index plastic optical fibers (SI-POFs) with large core diameters have gained popularity for Gbit/s short range in-building access networks, due to the cheap ‘do-it-yourself’ installation, easy maintenance and small bending radius. Moreover, compared with the traditional high-performance transceivers for data communication, the commercialization of low-cost and simple transceivers at visible wavelengths also provides cost-effective solutions for broadband in-home access networks using SI-POF.

1 Gbit/s transmission using a low-cost DVD laser has already been demonstrated over 100 m SI-POF using adaptive sub-carrier multiplexing in [2]. By employing feed-forward error (FFE) correction, 1.25 Gbit/s transmission has been shown [3]. Moreover, by using DMT techniques, 8 Gbit/s and 1.62 Gbit/s transmission systems have been reported for 5 and 100 m SI-POF, respectively [4, 5]. In contrast to SI-POF, PMMA graded-index POF (GI-POF) also attracts some attention due to its larger bandwidth when compared with SI-POF. Beyond 4 Gbit/s data rates have been reported using 50m PMMA GI-POF [6]. However, SI-POF systems still attract lots of interest for low-cost robust in-home access solutions. Recently, a novel kind of multi-core (MC) SI-POF has been commercialized due to its advantages of low bending loss and large bandwidth [7]. Fig. 1 shows a snapshot of the end face of the 19-core SI-POF used in our experiments. In this paper, by using a combination of a low-cost transceiver and discrete multitone modulation (DMT) techniques, we demonstrate 4.7 Gbit/s transmission over 50m \varnothing 1 mm PMMA 19-core SI-POF. The DMT technique is a baseband version of the orthogonal frequency division multiplexing (OFDM) technique [5], which is widely applied in digital subscriber copper lines (ADSL, VDSL, etc.) and power-line communication systems. Here, we employ the DMT technique with up to 32-level quadrature amplitude modulation (32-QAM) using Chow’s rate-adaptive bit-loading algorithm [8]. In this experiment, we present the transmission performance of the 19-core SI-POF. In addition, we compare the multi-core transmission

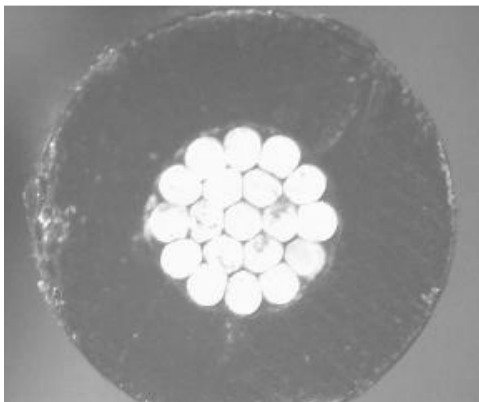


Fig. 1: 19-core SI-POF (illuminated by white light)

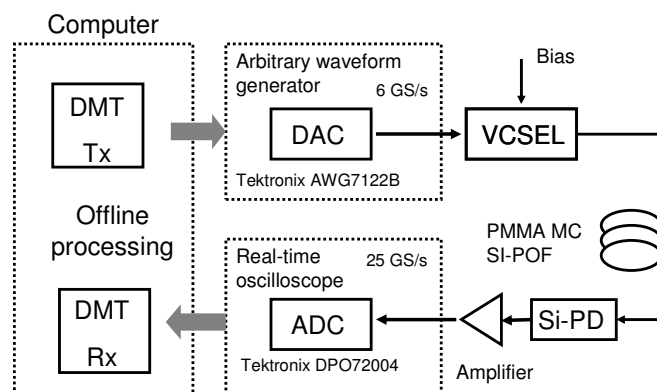


Fig. 2: Experimental setup

performance with single-core SI-POF and GI-POF for the same length. Due to the simplicity of the POF transceiver and the wide availability of DMT processors, we believe that a low-cost and robust solution for multi-Gbit/s transmission for in-home networks is feasible using this novel type of MC SI-POF. We thank POFAc and Firecomms for providing us with the MC SI-POF and VCSEL, respectively. This work is made possible by the Dutch program IOP-GenCom project IGC0507 Future Home Networks and the EU program FP7 project ICT-224521 POF-PLUS.

2. Experimental Results and Discussion

The experimental setup is shown in Fig. 2. The low-cost 667 nm wavelength VCSEL, with a bandwidth of 3 GHz, was directly modulated by the output of the arbitrary waveform generator (AWG) running at a sampling rate of 6 GHz. The bias current of the VCSEL was set to 3 mA, resulting in a peak-to-peak driving current of maximum 6 mA. The optical power launched into the POF was -2 dBm. After transmitting the signal over the \varnothing 1 mm 19-core SI-POF of 50meter, the optical power received was -12 dBm. After an optical focusing lens, a low-cost \varnothing 230 μ m APD with a -3 dB bandwidth of approximately 1.3 GHz was used to detect the signal. The signal was sent to a real-time oscilloscope running at a sampling rate of 25 GSamples/s for off-line signal evaluation.

In Fig. 3 we show the measured bandwidth of the 19-core SI-POF system. For comparison, we also present two other curves belonging to conventional single-core SI-POF and GI-POF. The maximum available bandwidth for the 50 meter links of 19-core SI-POF is approximately 350 MHz. We observed that the bandwidth of 19-core SI-POF is between the bandwidth of the single core SI-POF and the single core GI-POF, where the latter has a more complex index profile, thus requires a more complicated manufacturing process. It should be noted that the process of manufacturing MC SI-POF is simply putting together in parallel the same lengths of conventional SI-POFs, thus incurring slightly higher costs than single core SI-POF but remaining cheaper than GI-POF. In Fig. 3, the three vertical gray lines show the -3 dB bandwidth for three different POF systems.

By using the adaptive bit-loading algorithm, the limited bandwidth for 19-core SI-POF shown in Fig. 3 can be used optimally, hence increasing the system's bandwidth efficiency. As shown in Fig. 2, the DMT (de-)modulation is executed off-line for calculation the most efficient bit-loading parameters. In this experiment, we chose 512 subcarriers, ranging from 0 to 3 GHz. The algorithm measured the signal-to-noise ratio (SNR) per subcarrier. This SNR is a continuous function of frequency. Then, the algorithm allocated an appropriate number of bits per subcarrier to obtain the optimum overall transmission rate. Therefore, the received SNR values present a staircase-like curve truncated at frequencies where no bits are assigned. In Fig. 4a and 4b, no bits are assigned beyond the 275th subcarrier at 1.6 GHz. This truncation is largely caused by the system bandwidth (see Fig. 3). Moreover, we can see in Fig. 4a, that some of the carriers are loaded with the upper limit of 5 bits/symbol (i.e. 32-QAM), while others with less. The number of bits allocated matches the response of the system indicated in Fig. 3 for the 19-core SI-POF.

Fig. 5 shows the measured values of maximum bit rates for 50m single-core SI-POF, 19-core SI-POF and single-core GI-POF with a bit error rate (BER) of less than 10^{-3} taken as the target. This target BER is based on the forward error correction (FEC) limit of error-free operation. For a length of 2m (considered here as a back-to-back setup), the performance of MC SI-, single-core SI- and GI-POF are very similar, due to the fact that the fiber bandwidth does not play a major role for this length. For a length of 50m, the advantage of MC SI-POF over

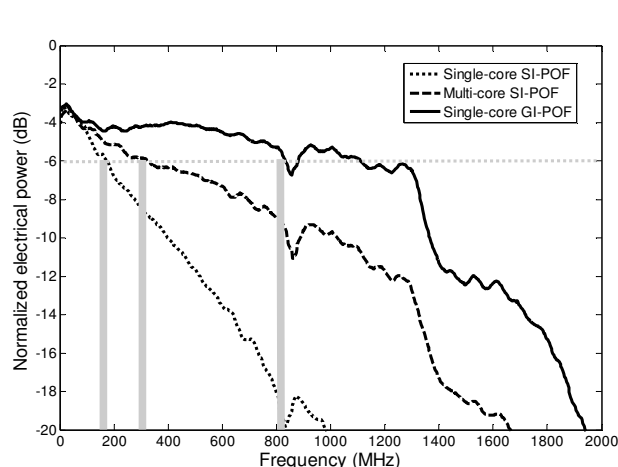


Fig. 3: Normalized frequency response of the system

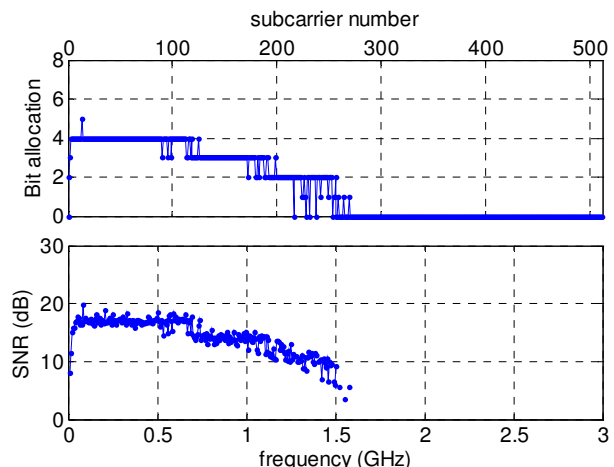


Fig. 4: Transmission performance for 50m: (top) bit allocation and (bottom) SNR

single-core SI-POF is clearly shown in terms of transmission rate. For single-core SI-POF, less than 2 Gbit/s transmission rate was achieved. However, MC SI-POF is able to transmit more than twice the bit rate achieved with single-core SI-POF. Moreover, it is worthwhile to note that the maximum transmission rate of MC SI-POF is only 0.7 Gbit/s less than the GI-POF rate. Considering the overall performance and cost issues, MC SI-POF can be presented as an attractive candidate for short-range user access networks. All bit rates mentioned here include the 7% FEC bits, cyclic prefix and preambles. In Fig. 5, we also include a data cluster for the -3 dB bandwidth of the 50m length POF systems. These numbers validate the curves shown in Fig. 3. By employing the bit-loading algorithm, we transmit 4.7 Gbit/s within the -3 dB bandwidth limitation of 350 MHz for MC SI-POF, resulting in a spectral efficiency of 13 bit/s/Hz.

Finally, the demodulated signal constellation diagrams are shown for two sub-carrier index groups in Fig. 6. As shown in Fig. 6a, 4 bits are allocated for the 41th to 50th sub-carrier, corresponding to the 16-QAM constellation while in Fig. 6b only 2 bits (4-QAM) are assigned for the 201th to 210th sub-carrier. Sub-carrier indices are shown in Fig. 4.

3. Conclusions

By using off-the-shelf low-cost components in combination with the use of DMT technique, we have demonstrated for the first time an FEC-limited error-free and robust transmission of 4.7 Gbit/s over 50m large core diameter PMMA 19-core SI-POF, with a gross spectral efficiency of up to 13 bit/s/Hz. This transmission capacity is more than twice the transmission capacity of a single-core SI-POF. The performance of MC SI-POF has also been compared with a single-core GI-POF, resulting in a capacity difference of only 0.7 Gbit/s. Considering the overall performance and cost issues, MC SI-POF is an attractive candidate for low-cost high-speed in-building access networks.

We believe that this work, in which high-performance short-reach transmission is obtained from the combination of low-cost transmitter and receiver, efficient modulation techniques and POF infrastructures, proves that a large-scale and low-cost deployment of in-home broadband access networks at multi-Gbit/s is feasible.

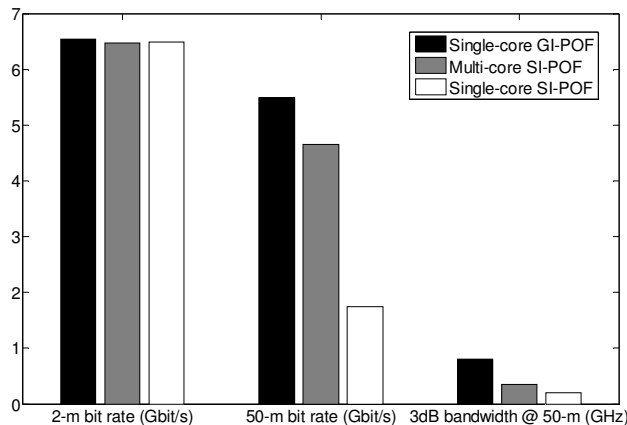


Fig. 5: Maximum transmission rate for 2 and 50 m single-core SI-, MC SI- and single-core GI-POF, including the -3 dB bandwidth for 50 m POF systems as marked in Fig. 3.

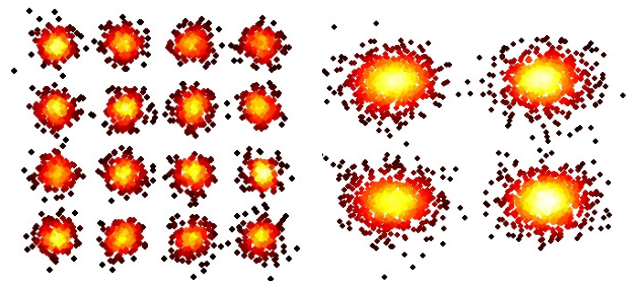


Fig. 6: Constellation diagrams of the demodulated signal: (a) 64-QAM for 41th to 50th and (b) 4-QAM for 201th to 210th subcarriers

4. References

- [1] K. White, "Bringing FTTH to Low-Rise MDUs: Thinking Outside the Box Means Thinking Outside the Building", FTTH council, white paper, <http://www.ftthcouncil.org/en/knowledge-center/white-papers>.
- [2] S. Randel, et al, "1 Gbit/s transmission with 6.3 bit/s/Hz spectral efficiency in a 100m standard 1mm step-index plastic optical fiber link using adaptive multiple sub-carrier modulation," *ECOC'06*, Cannes, France, 2006, PDP Th4.4.1.
- [3] F. Breyer, et al, "1.25 Gbit/s transmission over up to 100 m standard 1 mm step-index polymer optical fiber using FFE or DFE equalisation schemes," *ECOC'07*, Berlin, Germany, 2007, paper 9.6.6.
- [4] S.C.J. Lee, et al, "Discrete Multitone Modulation for Maximizing Transmission Rate in Step-Index Plastic Optical Fibers", *IEEE Journal of Lightwave Technology*, vol. 27, no. 11, June, 2009.
- [5] S.C.J. Lee, et al., "High-speed transmission over multimode fiber using discrete multitone modulation," *Journal of Optical Networking*, vol. 7, no. 2, Feb., 2008.
- [6] H. Yang, et al, "4 Gbit/s over 50-m Large Core Diameter GI-POF using Low-cost VCSEL," *ECOC'09*, Vienna, Austria, 2009, paper 3.5.1.
- [7] <http://www.asahi-kasei.co.jp/pof/en/index.html>.
- [8] P. S. Chow, et al, "A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels," *IEEE Trans. Commun.*, vol. 43, no. 2, pp. 773-775, Feb. 1995.