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Record 5.3 Gbit/s Transmission over 50m 1mm Core Diameter Graded-Index Plastic Optical Fiber

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Abstract: We report multi-Gbit/s capacity in 1-mm diameter graded index plastic optical fiber exploiting low-cost eye safe compliant transceivers. Transmission rates between 5.3 and 7.6 Gbit/s are achieved for lengths between 10 and 50m using DMT.

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1. Introduction

In recent years, commercial graded-index (GI) polymethylmetacrylate (PMMA) plastic optical fibers (POFs) with large core diameters have gained in popularity for multi-Gbit/s in-home network applications. The large core diameter POF offers the advantages of ‘do-it-yourself’ installation, easy maintenance, and small bending radius compared with conventional silica single- and multi-mode fibers. In addition, compared with the traditional high-performance transceivers for data communications, the commercialization of low cost and simple transceivers at visible wavelengths also provides a cost-effective solution for broadband in-home networks using POFs [1,2]. Transmission records using POF transmission medium in combination with discrete multitone (DMT) modulation are as follows: 40 Gbits/s transmission over 100m perfluorinated graded-index POF (diameter 50 μ m) using high-performance and high-cost infrared transceiver [3], 6 Gbit/s transmissions at visible lights over 35m of graded-index POF (diameter 1mm) [4], 10 Gbit/s over 25m of step-index POF (diameter 1mm) using high power laser [5].

Using the same DMT technique, we demonstrate multi-Gbits/s transmission capacity over 1 mm core diameter PMMA POF. Transmission performance over 50m is shown in this paper. The results present a record for short-range large core POF link using transceivers which comply with consumer eye safety regulations. In this work, we used bit-loading algorithms in order to obtain maximum transmission rates. We applied the DMT technique with up to 32 level quadrature amplitude modulation (32 QAM) using the rate adaptive bit-loading algorithm as proposed by Chow et al. [6]. For 50m a record spectral efficiency of 4.1 (bits/s)/Hz is achieved. Owing to the wide availability of simple POF transceivers and DMT processors, we believe that this paper demonstrates a state-of-the-art solution for multi-gigabit transmission for short-link in-home networks.

2. Experimental Setup and Discussion

Fig. 1 Experimental setup

Fig. 2 Frequency response of the system including transceivers and the POF link

The experimental setup used is shown in Fig. 1. The low-cost 667 nm wavelength vertical-cavity surface-emitting laser (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 4.5 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 0 dBm which corresponds to the levels set for consumer eye safety regulations. After transmitting the signal over the $\varnothing 1\text{mm}$ PMMA GI-POF of 50 meter, the optical power received was -15 dBm due to the large attenuation in the POF. A low-cost silicon photodetector with a photosensitivity area of diameter 400 μm and a responsivity of 0.5A/W at 660nm is used to receive the signals. In addition, it is equipped with a trans-impedance amplifier (TIA) with a trans-impedance gain (R_F) of 10k Ω . Optimized for DMT, the receiver has a bandwidth of more than 1.6 GHz. The received signal is evaluated using a real-time oscilloscope running at a sampling rate of 50 GSamples/s for off-line processing in Matlab.

The maximum available bandwidth after 50m is approximately 1.3 GHz as shown in Fig. 2. By using the adaptive bit and power-loading algorithm, the limited bandwidth can be used efficiently, hence increasing the spectral efficiency. As shown in Fig. 1, the DMT (de-)modulation is executed offline to calculate the most efficient bit-loading parameters. In this experiment, we chose 256 subcarriers, ranging from 0 to 2.25 GHz. The algorithm measured the signal-to-noise ratio (SNR) across the specified frequency range. Based on this profile, the algorithm then allocates the bits per subcarrier which is shown as a function of frequencies in Fig 3a. Notice that the resulting SNR values present a stair-like curve shown with a truncation at 1.4 GHz after which no bits are assigned due to the response of the system shown in Fig 2. Fig. 3a shows that 5 bits are mainly allocated until the 73rd subcarrier, 4 bits until 113th and 3 bits until 135th subcarrier and reducing to 0 bits assigned from the 163rd subcarrier or 1.4 GHz. By using a low number of subcarriers and bits per subcarrier, less processing effort is required making the implementation of a low-cost system feasible. In Fig. 4, the measured values of maximum bit rate achieved for 10-50m POF for a bit error rate (BER) of less than 10^{-3} is shown. This BER target is chosen based on the forward error correction (FEC) limit for error-free operation. Successful transmission of more than 7.6Gbit/s, 7.2Gbit/s and 6.2Gbit/s is achieved over 10, 20 and 35m respectively. For the 50m target, we are still able to achieve 5.3 Gbit/s which is demonstrated for the first time. All bit rates mentioned in this paper includes the 7% FEC bits, cyclic prefix and preambles.

Fig. 3: Transmission performance for 50 m POF link: (a) bit allocation, (b) Signal to Noise Ratio

Fig. 4 Bit rate for different POF lengths (note that all BER are below 10^{-3})

Fig. 5: Bit-error-rate (BER) for different subcarriers

Fig. 6: Constellation of received signal: (a) 32 QAM subcarriers,

(b) 4 QAM subcarriers

It is shown in Fig. 5 that despite not all subcarriers achieving BER values less than 10^{-3} , it is still possible to obtain a resulting BER of 8.5×10^{-4} for transmission over 50m.

Finally, the demodulated signal constellation diagrams are shown for two sub-carrier index groups in Fig. 6. The sub-carriers with more than 20 dB SNR (see Fig. 3) are shown with 5-bits allocated, corresponding to 32-QAM constellation in Fig. 6a. Fig. 6b shows received 4-QAM constellation corresponding to subcarriers with 10dB SNR. Based on BER performance inset in Fig. 4, we conclude that excellent performance is achieved for the transmitted signals demonstrating the robustness of this solution for in-home environments.

4. Conclusions

In this paper we employ low cost, simple and eye safety compliant VCSEL transmitter and a 400 μ m active area silicon photoreceiver to transmit high data rates over 50m PMMA large-core graded-index POF. It is demonstrated that by using these simple components in combination with spectrally efficient DMT modulation techniques, FEC-limited error-free and robust transmission of 5.3Gbit/s over 50m PMMA large core POF is possible. This excellent performance has been obtained exploiting a system bandwidth of less than 1.3 GHz, corresponding to a spectral efficiency of 4.1 bit/s/Hz. We believe that this work demonstrates for the first time a robust and high-performance transmission over realistic link lengths proving that a large-scale cost-effective deployment for “do-it-yourself” in-home network scenarios at multi-gigabit rates is feasible.

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References

- [1] I. Mollers et al., "Plastic optical fiber technology for reliable home networking: overview and results of the EU project pof-all," IEEE Comm. Mag. **47**, 58-68 (2009)
- [2] R. Gaudino, "High speed optical transmission over plastic optical fibers," ECOC 2009, Paper 3.5.3 (2009)
- [3] H. Yang et. al., "47.4 Gb/s Transmission Over 100 m Graded-Index Plastic Optical Fiber Based on Rate-Adaptive Discrete Multitone Modulation" IEEE J. Lightw. Tech. **28**, 352-359 (2010)
- [4] H. Yang et. al., "Record high-speed short-range transmission over 1 mm core diameter POF employing DMT modulation" OSA Optics Letters **35**, 730-732 (2010)
- [5] S. Loquai et. al., "10 Gbit/s over 25m Plastic Optical Fiber as way for extremely low-cost optical interconnection", OFC 2010, Paper OWA6
- [6] P. S. Chow, J. M. Cioffi, and J. A. C. Bingham, "A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels," IEEE Trans. Commun. **43**, 773-775 (1995)