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Published in:

Published: 01/01/2009

Document Version
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Download date: 27. Dec. 2018
4 Gbit/s over 50-m Large Core Diameter GI-POF using Low-cost VCSEL

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Abstract We report record transmission systems over 50 metres of 900-μm core diameter graded-index POF using a low-cost VCSEL at 667 nm. A net bit rate of 4 Gbit/s is achieved with BER < 10^{-3}.

Introduction
After fibre-to-the-home (FTTH) starts to overcome the bottleneck of the last-mile service delivery, broadband access using optical fibre particularly plastic optical fibre (POF) to extend the broadband capacity for in-building network, has been attracting more attentions. The large core diameter POF offers the advantages of ‘do-it-by-yourself’ installation, easy maintenance and smaller bending radius (5 mm), over conventional silica single-mode or multi-mode fibres. Meanwhile, compared with the traditional high-performance light source for data communication, the commercialisation of low power consumption and broadband transceivers at visible wavelength also provide a potential solution to the low-cost broadband access networks over POF [1].

In recent years, Giga-bit transmission based on low-cost transmitter has been demonstrated over 100-m step-index POF using adaptively sub-carrier multiplexing [2]; 10 or 40 Gbit/s transmission over graded-index (GI) POF has also been shown using a high output power laser diode [3, 4]. In this paper, we report a 4 Gbit/s transmission over 50-m ∅900-μm core poly-methylmetacrylate (PMMA) GI-POF, using an eye-safe broadband red vertical cavity surface emitting laser (VCSEL) diode at 667 nm wavelength. We employ the discrete multitone modulation (DMT) technique with up to 16-level quadrature amplitude modulation (16-QAM), to enable high spectral-efficient transmission. Due to the absence of optical/electrical amplifiers and the use of the low output power VCSEL, it therefore predicts a promising solution for low-cost, robust and high capacity Gigabit POF transmissions for future in-building networks.

Discrete multitone modulation using bit-loading
As a baseband version of orthogonal frequency division multiplexing (OFDM), DMT has already been widely applied in large scale asymmetrical digital subscribers lines (ADSL) and powerline communication systems, providing the possibility of low-cost implementation in combination with the existing network infrastructure [4, 5]. An important advantage of DMT is the possibility to allocate the number of bits per subcarrier according to its corresponding signal-to-noise ratio (SNR), typically known as bit-loading. In the present study, we employ Chow’s rate-adaptive bit-loading algorithm [6] to maximise the achievable bit rate for a given bit-error rate (BER). In comparison to the adaptive modulation shown in [5], Chow’s algorithm enables us to achieve near-optimum channel capacity, resulting in higher possible bit rates.

Experimental results
The experimental setup is shown in Fig. 1. The low-cost 667 nm wavelength VCSEL from Firecomms, which is designed to have a bandwidth of 3 GHz, is directly modulated by the output of the arbitrary waveform generator (AWG) sampling at 5 GHz. The bias current of the VCSEL is set to 6 mA, resulting in a peak-to-peak driving current of maximum 12 mA. The optical power of the VCSEL launched into the POF is measured as -2 dBm. After transmitting the direct modulated signal over the ∅900-μm core PMMA GI-POF of maximum 50 metres, we received a -17 dBm optical power due to the 7-nm deviation from the POF minimum loss. An APD receiver is used to detect the signal. The received signal is sent to a real-time oscilloscope running at a sampling rate of 25 GSamples/s for off-line evaluation.

The bandwidth of the investigated system is very...
much limited by the APD detector, which has a 3 dB RF bandwidth of 1.3 GHz (see Fig. 2). By using the DMT technique in combination with the bit-loading algorithm, we can use this limited bandwidth in a most efficient manner. As described in Fig. 1, the DMT (de)modulation is executed offline to calculate the most efficient bit-loading parameters in an adaptive way. In this experiment, we choose 256 subcarriers, ranging from 0 to 2.5 GHz. In Fig. 3a, it is observed that there are no bits assigned to the 160th sub-carrier and beyond, therefore there is almost zero SNR beyond 1.6 GHz as shown in Fig. 3b. This is due to the strictly limited system bandwidth (see Fig. 2). Still, we can see in Fig. 3a, that some of the carriers are allocated 4 bits of information at maximum (i.e. 16-QAM), while others have 3 or less; this adaptive allocation is leading to the stair-like SNR shown in Fig. 3b.

Fig. 4 shows the measured maximum bit rates which can be transmitted over 3, 15, 25, 35 and 50 metres of GI-POF, respectively, with BER values of less than $10^{-3}$. This target BER is chosen based on the forward-error-correction (FEC) limit for error free operations. After 50-m transmission, we are still able to achieve 3.9 Gbit/s net bit rate (corresponding 4.5 Gbit/s including overhead). Meanwhile, for less than 30-m links, we realise the successful transmissions of more than 5 Gbit/s even though the system has only 1.3-GHz bandwidth. The inset of Fig. 4 presents the electrical spectra of the received signals, for (a) 3 (b) 50-m transmission and (c) noise due to APD for comparison. It is noted that the SNR becomes less than 20 dB after 50 metres.

Finally, we present in Fig. 5 two sets of constellations of the demodulated signals at different sub-carrier indices. From the sub-carrier 5 to 25, 4 bits/sub-carrier are allocated, corresponding to the 21 constellations of 16-QAM (see Fig. 5a), whereas from 120 to 130 only 2 bits/sub-carrier are allocated, giving 11 constellations of 4-QAM (see Fig. 5b).

Conclusions
By employing DMT technique with bit-loading, we have achieved an excellent (BER<10$^{-3}$) transmission of 4 Gbit/s netto bit rate (or 4.6 Gbit/s gross bit rate) over 50-m long ∅900-μm core PMMA GI-POF using a low-cost VCSEL emitting at 667-nm wavelength. The system 3-dB bandwidth is limited by the photodetector, i.e. <1.3 GHz, giving 3-bit/s/Hz spectral efficiency, by employing the adaptive bit-loading. Moreover, the transmission is demonstrated with only -2 dBm transmitted (6-mA bias and 12-mApp driving current) and -17 dBm received optical power.

Therefore, the use of an eye safe VCSEL in combination with the low-cost GI-POF infrastructure, provide a promising solution for in-building broadband access networks at bit rates beyond 4 Gbit/s.

Acknowledgement
This work is supported by the Netherlands program IOP-GenCom IGC0507 on Future Home Networks and the EU program FP7 ICT-224521 POF-PLUS.

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