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

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Abstract *Transmission of 1 Gbit/s over 100 m of SI-POF is demonstrated. To the authors' knowledge this sets a new record. The bandwidth limitation of the SI-POF is compensated by spectrally efficient adaptive multiple sub-carrier modulation.*

Introduction

With its widespread adoption in mass-markets like automotive and industrial Ethernet the 1 mm PMMA step-index plastic optical fibre (SI-POF) as defined in the IEC 60793-2 norm has been proven to be a robust, low-cost, and easy-to-install transmission medium. These unique features make the SI-POF a highly attractive candidate for in-building networks requiring data rates in the range of 1 Gbit/s (IEEE 1394b, Gigabit-Ethernet) to about 3 Gbit/s (uncompressed HDTV). Due to its large diameter, modal dispersion limits the bandwidth-length product of the SI-POF to approximately 100 MHz × 100 m, a relatively poor value compared to copper cable as well as multimode glass fibre. Recently, several new methods have been proposed to counter this bandwidth problem [1]-[6]. In this paper it is demonstrated that by using spectrally efficient adaptive multiple sub-carrier modulation, even the SI-POF is suitable for 1 Gbit/s transmission over a distance of 100 m. Similar modulation techniques are already applied in large scale to DSL, WLAN, and WiMax proving its potential for low-cost implementation in high-speed SI-POF networks.

Experimental Setup

Fig. 1 shows the experimental setup of the adaptive multiple sub-carrier transmission system. Two transmission bands - each of them divided into 40 sub-channels in a 2 MHz grid - are generated by the vector signal generator (VSG). The complex waveforms have been externally calculated and are repetitively output by the arbitrary waveform generators (ARB). After digital-to-analogue conversion the inphase and quadrature components are modulated onto RF-carriers at 50 MHz and 150 MHz for the first and the second transmission band, respectively. Subsequently, these two signals are combined and directly modulated onto a lensed 650 nm laser diode (LD) originally designed for use in DVD players. A DC-bias is introduced in order to allow for linear transmission. The output light is efficiently coupled into 100 m of SI-POF with a numerical aperture of 0.5, a diameter of 1 mm, and an optical loss of 14 dB. The receiver (RX) comprises a Si-PIN photodiode with an active diameter of 1 mm followed by a trans-impedance amplifier (TIA).

The electrical transfer function of the whole system (compare Fig. 2a) has a 3 dB bandwidth of 33 MHz and decreases smoothly to 32 dB relative attenuation at 200 MHz.

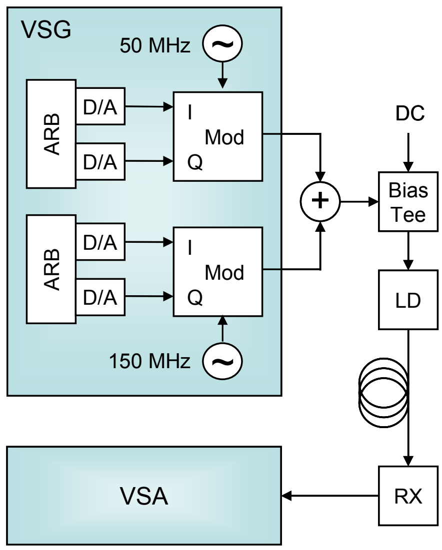

Fig. 1: Experimental setup.

By using adaptive multiple sub-carrier modulation the transmitted signal is optimized for this specific channel characteristic as described in the following. In the first step, pre-emphasis is accomplished by adjusting the relative power of the sub-carriers in a way such that constant signal-to-noise ratio (SNR) is achieved throughout each transmission band. The effect of the pre-emphasis becomes clear from a comparison of the transmitted and the received spectra shown in Fig. 2b.

In the second step, the modulation format of each transmission band is chosen according to the achievable SNR. In order to optimize the spectral efficiency each carrier is modulated by M-symbol quadrature amplitude modulation (M-QAM) with a symbol rate of 1.8 MBaud. By using root-raised cosine (RRC) filters with a roll-off factor of 0.1, spectral interference between adjacent sub-channels is avoided. The crest factor (peak to average power ratio) is minimised by proper adjustment of the relative phases of the sub-carriers. While the lower band allows for 256-QAM modulation, the SNR performance of the upper band still allows 64-QAM modulation. The total bit rate thus amounts to 40 Ch × 1.8 MBd/Ch × (8 bit/symbol + 6 bit/symbol) = 1.008 Gbit/s. As the electrical transmitted signal occupies a total bandwidth of two times 80 MHz, this corresponds to a spectral efficiency of 6.3 bit/s/Hz.

In the experiment each sub-channel is demodulated by using a commercial vector signal analyzer (VSA) and a block of 8000 sampled symbols is recorded.

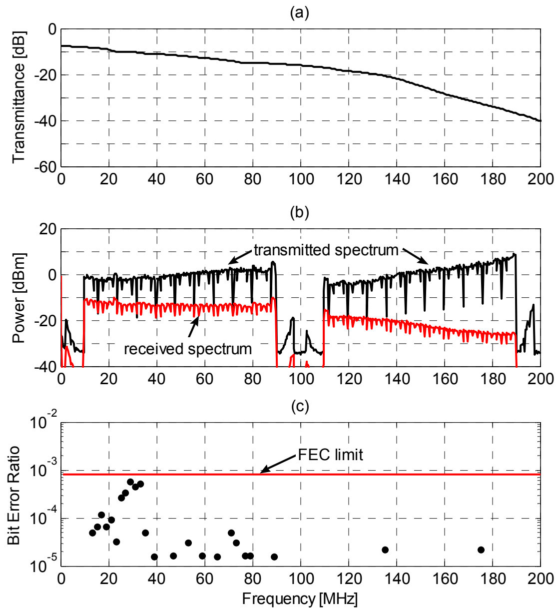

Fig. 2: a) Transfer function of the system, b) transmitted and received signal spectra, c) measured BER of each sub-carrier.

Results

The performance of each sub-channel is assessed offline by comparing the 8000 de-mapped received symbols with the transmitted pseudo random binary (PRBS) sequence of length 2^9-1. The resulting bit error ratios of all individual sub-channels are depicted in Fig. 2c. No error was found at all those sub-channels where no dot is plotted. By using a Reed-Solomon (511, 479) code a BER below 10^{-9} is achieved for all sub-channels, resulting in a net bit rate of 945 Mb/s. To the authors' best knowledge, this is almost twice the highest bit rate reported so far for transmission over 100 m SI-POF (531 Mb/s was demonstrated in [7]). The constellation diagrams shown in Fig. 3 further illustrate the efficiency of the modulation technique as well as the linearity of the system.

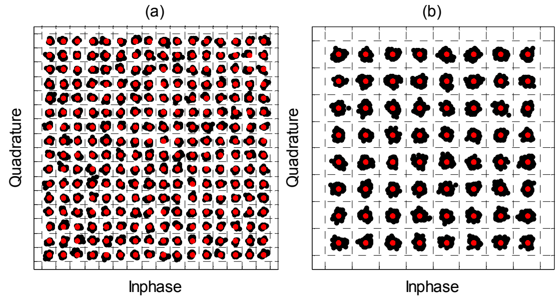

Fig. 3: Constellation diagrams received after transmission over 100 m SI-POF of a) 256-QAM modulated carrier at 11 MHz, and b) 64-QAM modulated carrier at 111 MHz.

Conclusions

Error-free transmission of a net bit rate of 945 Mbit/s has been shown. To the authors' knowledge this represents almost twice the rate of the former record result [7]. The severe bandwidth limitation of the SI-POF is compensated by highly spectral-efficient adaptive multiple sub-carrier modulation. A further increase in bit rate can be expected by exploitation of the full spectrum and improved adaptation schemes. The results demonstrate the potential of SI-POF based systems permitting bit rates well above 1 Gbit/s over distances of up to 100 m. Together with the unique features - namely its robustness and the easy handling - SI-POF becomes a serious option for application in in-building networks, like e.g., networks in homes, schools, hospitals, and airports as well as industrial Gigabit Ethernet. As proven by widely deployed wireless applications all components required in the proposed system have the potential for low-cost manufacturing, whereas the envisaged applications open the door to large-scale production.

Acknowledgements

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