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30 Gbps 4-PAM transmission over 200m of MMF using an 850 nm VCSEL

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Abstract: Real time, error free 4-PAM transmission at 25 Gbps and 30 Gbps over 300 m and 200 m of multimode fiber, respectively, using a VCSEL operating at the wavelength of 850 nm.

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1. Introduction

The ever-increasing demand for capacity in short-range optical communication areas, such as optical interconnects and local area networks, motivates the development of fast and low cost optical solutions using vertical cavity surface emitting lasers (VCSELs) and multimode fiber (MMF). Graded index MMF has been successfully used to reduce the impact of modal dispersion and extend the reach, but recent development of VCSELs, which are capable of operating at bit rates of up to 40 Gbps at the wavelength of 850 nm [1] and 44 Gbps at the wavelength of 980 nm [2], show that the transmission distance at this high bit rate is very limited, if on-off keying modulation (OOK) is used. Multi-level modulation, with higher spectral efficiency, is a way of extending the reach of multimode fiber at high bit-rate. Because of cost constraints, intensity modulation and direct detection (IM/DD) are appealing in short range optical networks. There are two main possibilities for spectrally efficient modulation formats in IM/DD links, pulse amplitude modulation (PAM), and subcarrier modulation (SCM). 4-PAM was investigated theoretically up to 20 Gbps and experimentally at 10 Gbps for use with directly modulated DFB lasers [3]. In [4], 4-PAM eye diagrams with electronic predistortion at 32 Gbps are reported, although without bit error rate measurements. Single cycle subcarrier modulation with 16 level quadrature amplitude modulation was also demonstrated in links using VCSELs and multimode fibers [5], the transmitter was operating in real time and the receiver was off-line. Discrete multitone modulation was demonstrated at 30 Gbps for the same type of link [6], with off-line processing.

Complexity is critical in datacommunication links and PAM offers the lowest implementation complexity of all the multilevel modulation format with spectral efficiency of 2 bits/second/Hz. Real-time hardware for transmitters and receivers for 4-PAM has already been developed [7, 8]. In this paper, we present results of real-time transmission at 25 Gbps and 30 Gbps using 4-PAM over 300 m and 200 m of MMF, respectively. The 4-PAM signal was generated in real time, the BER measurement was also done in real time. A directly modulated VCSEL operating at 850 nm was used. No equalization was used in the receiver, nor was any predistortion used in the transmitter.

2. Experimental setup

The 4-PAM signal is generated from two binary PRBS data signals of length 2^7-1, at 12.5 Gbps and 15 Gbps for 25 Gbps and 30 Gbps 4-PAM, respectively. The short PRBS pattern is chosen to model the short run length codes used in datacommunication links [4]. The amplitudes of the binary signals are approximately 900 mV and 450 mV, but they are tuned slightly to adjust the resulting 4-PAM signal level spacing. The two binary signals are decorrelated and phase matched before being coupled together. The generated 4-PAM signal is fed to a VCSEL through a bias-T. The VCSEL, having approximately 20 GHz modulation bandwidth, was reported in an earlier publication [9]. The VCSEL was biased at 7 mA. Low bias current translates to low current density, which in turns improves reliability [9]. The VCSEL is operated without cooling, at room temperature. Between the VCSEL and the photoreceiver, OM3+ multimode fiber is used, with a bandwidth-distance product of 4700 Mhz·km. A variable optical attenuator is used to vary the optical power. At the receiver, an amplified photoreceiver (PR) with 12 GHz bandwidth is used, which is the most bandwidth-limiting component in the experiment, apart from the transmission fiber. Bit error rate measurement is done by measuring the error probability in each of the three threshold levels applicable to the 4-PAM. The error analyzer is programmed with binary patterns corresponding to each level, to measure the symbol error rate (SER) on each level, which is then used to calculate the aggregate SER and BER. Assuming that the probability of making a detection error between two 4-PAM levels is constant for adjacent levels and negligible between other levels, the BER can be well approximated as $2/3$ of the SER, provided that natural bit-to-symbol mapping is used, which is the case in this experiment. The experimental setup is shown in Fig. 1.

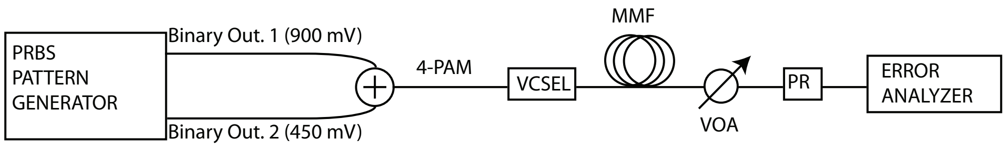
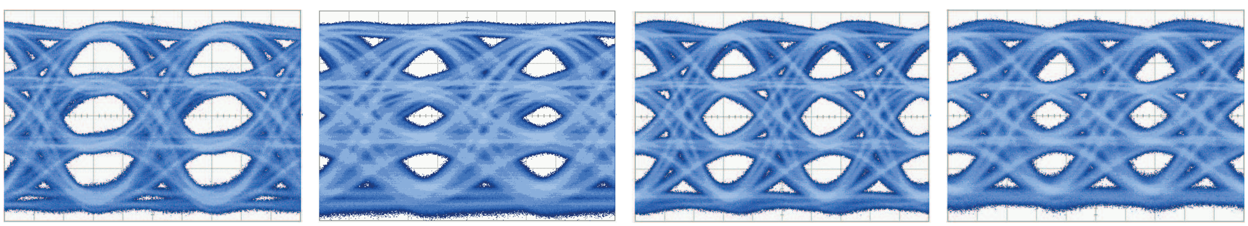


Fig. 1: The experimental setup. The outputs of the pattern generator are individually adjustable with regard to amplitude and delay and also phase matched.

3. Results

The quality of the 25 Gbps 4-PAM signal in the back-to-back (B2B) configuration is illustrated by the eye diagram in Fig. 2a. No predistortion or equalization was done to the signal. The eye diagram of the signal after propagation through 300 m of MMF is illustrated in Fig. 2b. In Fig. 2c, the eye diagram of the 30 Gbps signal in the B2B case is illustrated, and in Fig. 2d for propagation over 200 m of MMF. Note that because the transimpedance amplifier in the photoreceiver was inverting, the top modulation level is at the bottom of the figures. The top modulation level is the most broadened. It could be due to the relative intensity noise (RIN) or modal noise, since more modes are excited in the VCSEL itself at higher output powers. There is also level splitting at the top level. More detailed analysis is required to accurately determine the origin of these impairments.



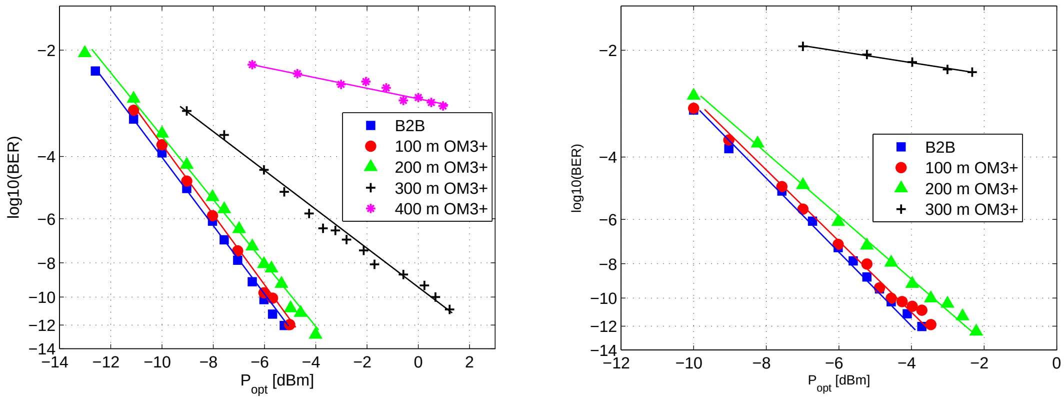
(a) 25 Gbps, B2B (b) 25 Gbps, after 300 m of MMF (c) 30 Gbps, B2B (d) 30 Gbps, after 200 m of MMF

Fig. 2: Recovered eye diagrams at 25 Gbps and 30 Gbps, in B2B and after propagation in MMF. The eye diagrams were taken at around 0 dBm received optical power.

The BER results for the 25 Gbps transmission are illustrated in Fig. 3a. The maximum practical distance of the OM3+ MMF over which error free transmission can be achieved is 300 m. For the length of 400 m, there is an error floor, due to the modal dispersion. The BER for 30 Gbps transmission is shown in Fig. 3b. In this case, the maximum propagation distance is 200 m of the same MMF, and there is an error floor for 300 m of MMF. The propagation distance is beyond what would be expected for OOK, which would be about 190 m for 25 Gbps OOK and 160 m for 30 Gbps OOK in OM3+ MMF (calculated from the 4700 MHz·km bandwidth distance product). It could also be improved by adding electronic equalization, as proposed in [4]. The sensitivity is improved, compared to the 25 Gbps and 30 Gbps results reported in [9]. Because of the lower symbol rate, and thus lower bandwidth of the signal, the available lower speed amplified photoreceivers can be used.

4. Conclusions

We show 25 Gbps and 30 Gbps, error free, 4-PAM transmission over 300 m and 200 MMF respectively using directly modulated VCSELs. The BER is measured in real time down to 10^{-12} and there is a large power margin for error free operation. The VCSEL itself is not a limiting factor. Due to the better spectral efficiency, the transmission distance



(a) 25 Gbps

(b) 30 Gbps

Fig. 3: BER results for 25 Gbps and 30 Gbps transmission.

in MMF is improved over what would be expected from transmission using OOK. The 4-PAM format has also lower complexity than subcarrier formats, which were demonstrated at a higher bitrate [5], but with only the transmitter working in real time. The 4-PAM bit-rate could be further increased, if higher speed photoreceivers would become available.

5. Acknowledgements

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