50 Gb/s 4-PAM over 200 m of High Bandwidth MMF using a 850 nm VCSEL

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J. M. Castro[1], R. Pimpinella[1], B. Kose[1], Y. Huang and B. Lane[1]
K. Szczerba[2] , P. Westbergh[2], T. Lengyel[2], J. S. Gustavsson[2], A. Larsson[2], P. A. Andrekson[2]
(1) Panduit Laboratories, Panduit Corp. Tinley Park IL, US
(2) Dept. of Microtechnology and Nanoscience, Photonics Laboratory, Chalmers University of Technology, Göteborg, SE-412 96, Sweden
jmca@panduit.com

Abstract: Experiments for transmission of 50Gb/s, 4-PAM using direct modulated VCSEL over 100m and 200m of MMF with partial dispersion compensation properties are presented.

OCIS codes: *(060.2340) Fiber optics components (060.2360) Fiber optics links and subsystems; (060.2380) Fiber optics sources and detectors; (200.4650) Optical interconnects (060.2270) Fiber characterization; (060.2300) Fiber measurements;*

1. Introduction

Transceivers utilizing direct modulated 850nm vertical cavity surface emitting lasers (VCSELs) for communications over laser optimized multimode fiber (MMF) are predominant in data center optical channels due to their relatively low cost, power efficiency, and high reliability. Emerging standards specifying 100Gb/s Ethernet and 32Gb/s Fibre channel VCSEL transceiver requirements for serial data rates of about 25Gb/s and 28Gb/s respectively will soon be ratified for short reach MMF channels [1-3].

To support next generation Ethernet and Fibre Channel applications, serial data rates of at least 50Gb/s per wavelength will be required utilizing single-mode fiber (SMF) and employing OOK or a modulation format with higher spectral efficiency such as 4-PAM or DMT. For VCSEL-MMF channels however, these higher serial data rates are more challenging due to bandwidth limitations in both the transceivers and MMF. To enhance the frequency response of VCSELs a large bias current is needed which excites more VCSEL modes. This in turn increases the spectral width of the VCSEL and consequently, the chromatic dispersion of the channel. Due to these limitations, parallel optics using multiple parallel fibers (i.e., lanes) are used for higher speed short reach MMF applications. For example, the 400Gb/s Ethernet draft standard (IEEE 802.3bs), will define 16 lanes of 25Gb/s over MMF for channel reaches less than 150m. To date, the highest serial data rates and reaches reported for OOK using VCSELs at 850nm with BER <1E-12 are: 64Gb/s over 57m [4] and 43Gb/s over 100m [5]. For 4-PAM the highest reported data rates are 60Gb/s over 2m and 50Gb/s over 50m [6].

The use of MMFs with modal-chromatic dispersion compensation (MCDC) properties and forward error correction (FEC) can enable reaches greater than 100m with minimum penalties due to FEC overhead, latency, or power consumption.

In this paper we present experimental results for channel reaches up to 200m at an uncoded bit rate of 50Gb/s using 4-PAM with a direct modulated VCSEL and a high modal bandwidth MMF having partial MCDC properties. The effect of post linear equalization on performance is evaluated. This reported result is presently the longest reach evaluated using 4-PAM at 50Gb/s for a VCSEL-MMF equalized channel utilizing FEC.

2. Experimental Setup

The overall test setup is shown in Fig. 1. The 4-PAM signal were generated using two 25Gpbs binary signals from a SHF 12103 pattern generator coupled in a microwave combiner. An eye diagram of the 50Gbps 4-PAM signal is shown as an inset to Fig. 1. The VCSEL output was coupled to the MMF through a lens. A variable optical attenuator (VOA) was used to provide different optical power levels to a linear 22GHz bandwidth New Focus 1484-A-50 linear photoreceiver. Data was acquired using and a real time (RT) Tektronix DPO 70000 oscilloscope operating at 100GS/s. Characteristics of the VCSEL and fiber are described below.

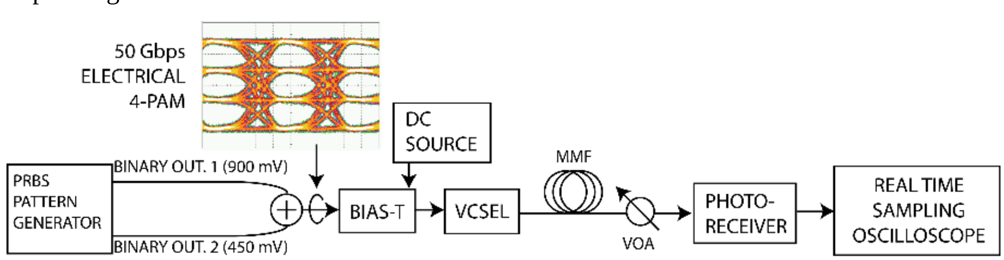

Fig. 1. Overview of the experimental setup with an eye diagram of the electrical 4-PAM signal at 50 Gbps as an inset.

2.1 VCSEL

The VCSEL used in this work was of the type described in detail in [7]. The epitaxial material was grown by MOCVD at IQE Europe. The VCSEL was designed with low resistance p- and n-DBRs, a short 0.5-λ cavity for high optical confinement and efficient carrier transport, and an active region made of five strained InGaAs quantum wells for high differential gain at 850 nm. Two primary oxide layers form the approximately 8 µm diameter electrical and optical apertures. Four secondary, shallow oxide layers reduce the parasitic capacitance. To optimize the photon life time for a large modulation bandwidth and flat frequency, response the thickness of the topmost DBR layer was fine-tuned by a shallow surface etch post fabrication [8]. In the experiments the VCSEL was biased at 12mA. The VCSEL spectrum at this bias current is presented in Fig. 2a. The magnitude of the frequency response of the VCSEL at the chosen bias current is shown in Fig. 2b. The -3 dB bandwidth of the laser is around 20GHz.

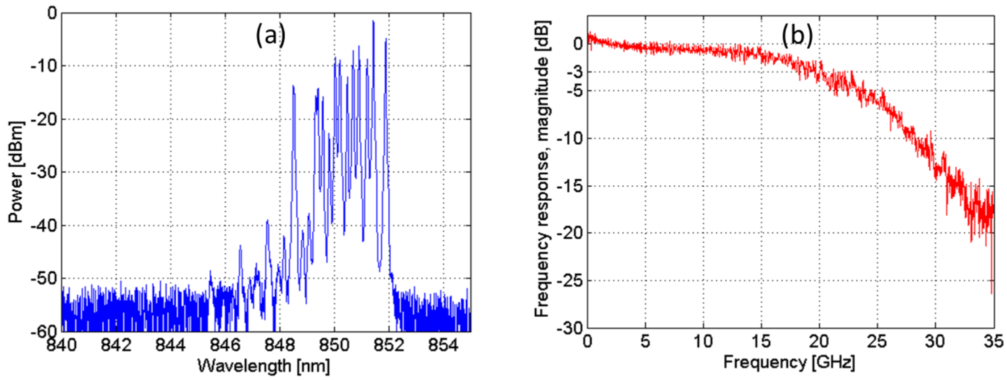

Fig. 2. (a) VCSEL Spectrum. (b) VCSEL Bandwidth at 12mA bias current

2,2 Multimode Fiber

The refractive index profile of the high bandwidth MMF was selected to provide partial MCDC for higher order VCSEL modes when operating in the 850nm ±20nm spectral window. The principle of MCDC in MMF has been described elsewhere [9]. The bandwidth of the laser-optimized MMF was characterized using a Titanium:Sapphire mode-locked laser by measuring its differential mode delay (DMD) and effective modal bandwidth (EMB); metrics standardized within domestic and international standards organizations [10]. The standardized test methods describe a procedure for launching a temporally short and spectrally narrow pulse (reference pulse) from a SMF into the core of a MMF at several radial offsets and measuring the resultant pulses after propagating through the MMF under test [9]. The DMD profile for the MMF is shown in Fig. 3(a). The EMB of this fiber is about 7GHz·km as shown in Fig. 3(b), and the chromatic bandwidth for the VCSEL, with rms spectral width 0.815 nm, is about 2.3GHz·km.

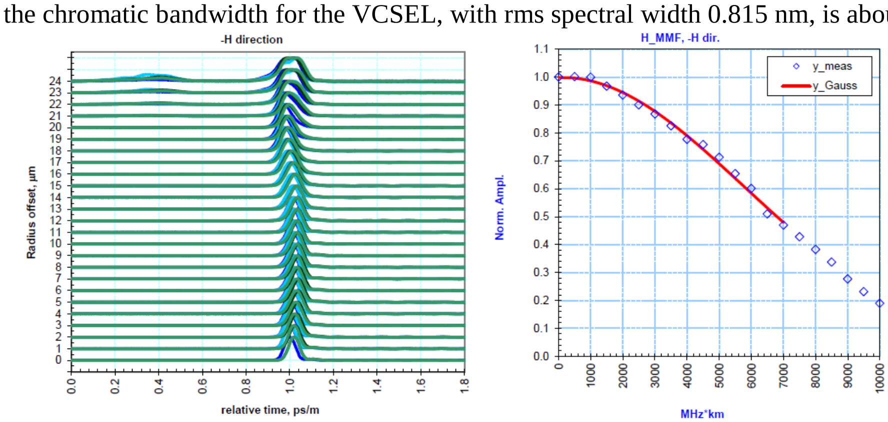

Fig. 3. (a) DMD profile of the 4 quadrants of the MMF. (b) Worst case transfer function of the MMF.

3. Test Results

The 50Gb/s system performance was quantified with BER measurements against received optical power using PRBS15 over several fiber lengths. The BER was estimated offline from the RT scope data acquisition.

Equalization using minimum mean square error (MMSE) linear equalizers was implemented in MATLAB. The BER results for back to back (BTB), 100m, and 200m are shown in Fig. 4 for the non-equalized and the equalized cases.

The feasibility of achieving BER 1E-12 using FEC code with low overhead and latency such as RS(544,514) or the RS(528,514) is evaluated. The latter, which has negligible overhead, is already utilized in the standards [1-2]. The effective data rates excluding the FEC overhead of the given codes would be, respectively, 48.67Gbps and 47.24Gbps. The input BER limits to achieve an output BER of 1E-12 is shown also in Fig. 4. The black and gray dashed lines represent the pre FEC BER limits for RS(528,514) and RS(544,514) respectively. Here we only considered the case for random errors since the effect of a decision feedback equalization has not been evaluated.

Test results indicate that transmission over 100m is feasible with a five tap equalizer using RS(528,514). For 200m, which shows a close eye, significantly more equalization (15 taps) or the utilization of RS(544,514) is required.

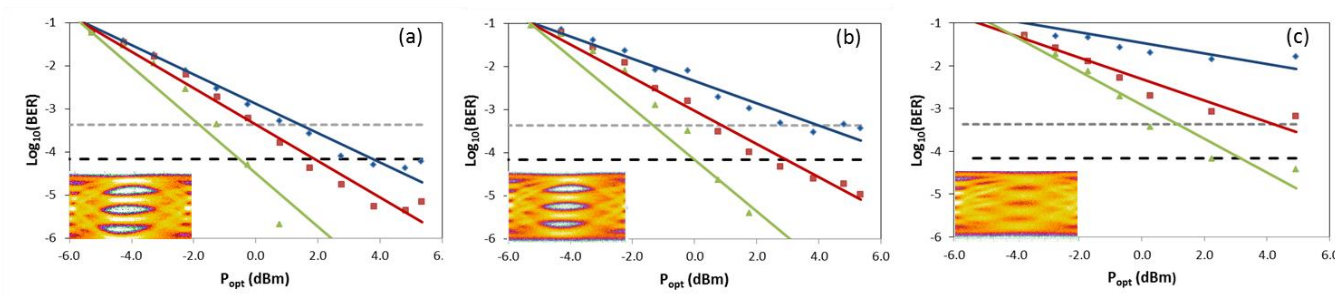

Fig. 4. BER test results. Blue trace non equalized, red trace MMSE-LE with 5 taps, greeen trace MMSE-LE with 15 taps.
(a) BTB (b) 100m. (c) 200m. Insets: eyes diagrams captured with a sampling scope with 50GHz sampling head without attenuation

4. Conclusions

The feasibility of 50Gb/s transmission per wavelength using 4-PAM and direct modulated VCSEL over 100m and 200m of MMF was evaluated. These short reaches can support >85% of data center optical channel links and 4-PAM can provide higher data rates needed for future applications [3]. Results showed that 100m MMF channel reach using 4-PAM with a direct modulated 850nm VCSEL can achieve pre-FEC BER below 1E-6. Extended reaches up to 200m can be achieved with a higher degree of equalization and/or using FEC with more error correction capabilities. These reaches have been achieved with the utilization of a high performance VCSEL and a high bandwidth MMF with partial modal chromatic dispersion compensation properties.

5. Acknowledgment

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