7×149 Gbit/s PAM4 Transmission over 1 km Multicore Fiber for Short-Reach Optical Interconnects

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Abstract: We transmit 80 Gbaud/λ/core PAM4 signal enabled by 1.55 µm EML over 1 km 7-core fiber. The solution achieves single-wavelength and single-fiber 1.04 Tbit/s post-FEC transmission enhancing bandwidth-density for short-reach optical interconnects.
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1. Introduction

Intra-datacenter interconnects have been experiencing a tremendous growth of capacity to enable web-based high-performance applications [1-3]. High capacity demand from datacenter applications has become the technology driver for high bandwidth (BW) short-reach communications [4]. Earlier demonstrations, e.g. [5-7], include two-lanes 400 GbE client-side links interconnecting the high bandwidth systems and providing a smaller footprint while consuming less power. Pulse amplitude modulation with four levels (PAM4) is the modulation format of choice for physical layer specifications of 400 GbE interfaces [3]. Line side optics need to scale on faster pace to support tremendous bandwidth growth. Therefore, digital signal processing enhancements are critical factors for the optical devices to enable higher linearity, extinction ratio, and tighter integration with electronics [1]. Space-division multiplexing (SDM) used today in datacenters is in the form of parallel single mode fibers thanks to less dominant fiber cost for short-reach links [8]. Meanwhile, SDM fibers are actively explored to scale up system capacity through spatial efficiency [2]. A combination of high bandwidth devices and spatial efficiency through multicore fibers (MCFs) seems to be a viable solution to enable high bandwidth-density, having enormous potential to increase the throughput per single-wavelength and single-fiber to 1 Tb/s for short-reach optical interconnects [4, 9,10].

In this paper, we demonstrate 80 Gbaud/λ/core PAM4 signal transmission using a monolithically integrated externally modulated laser (EML). We achieve below 7% overhead (OH) hard-decision forward error correction (HD-FEC) performance over 1 km single mode 7-core MCF with a negligible inter-core crosstalk and a low-loss fan-in/fan-out device. The solution enables terabit scale (7×149 Gbit/s) post-FEC transmission speed over 1 km single-wavelength and single-fiber, greatly enhancing bandwidth-density for short-reach optical interconnects.

2. Experiment setup

Figure 1(a) shows the experimental setup for signal generation, transmission and direct detection and includes the 7-core fiber cross section as inset. The 80 Gbaud PAM4 signal is generated offline using a 2^{15}-1 long pseudorandom binary sequence. Then it is up-sampled and filtered with a root-raised-cosine filter having 0.15 roll-off factor. Frequency domain channel pre-equalization is applied for channel frequency response calibration (up to 46 GHz due to the limitation of the arbitrary waveform generator (AWG)). The calibration is based on the end-to-end system measurement as shown in Fig. 1 (b). After pre-equalization 80 Gbaud PAM4 signal is loaded to a 92 GSa/s AWG. Then it is amplified in a 65 GHz electrical amplifier with 11 dB gain. A monolithically integrated 1.55 µm EML (3 dB BW >100 GHz [11]) is used to generate optical the PAM4 signal.

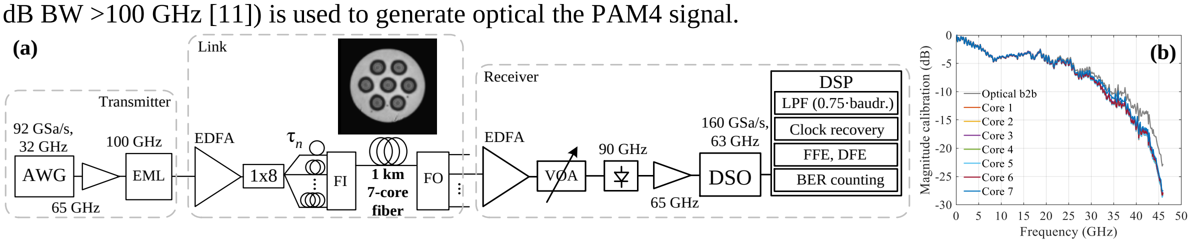

Fig. 1. Experimental setup (a), 7-core fiber cross section (b), channel magnitude calibration frequency response (c)

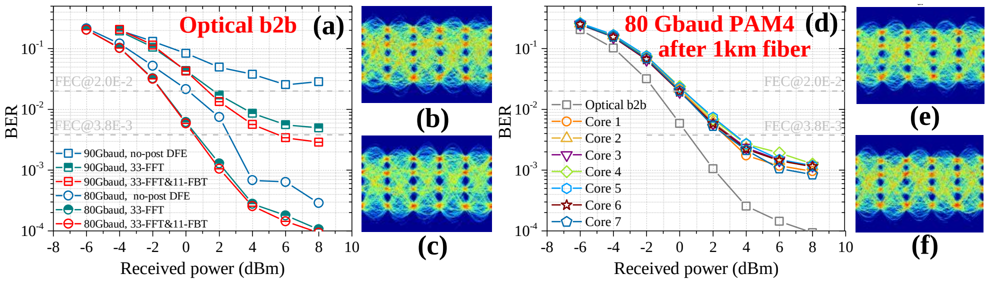

Fig. 2. BER curves for 80 Gbaud and 90 Gbaud PAM4 signal for b2b with different post-equalization (a), 90 Gbaud PAM4 eye diagram with 33-FFT&11-FBT DFE (b), 80 Gbaud PAM4 eye diagram with 33-FFT&11-FBT DFE (c), BER curves for 80 Gbaud PAM4 signal for b2b and after 1 km single mode 7-core MCF transmission (d), 80 Gbaud PAM4 eye diagram for worst core (e) and best core (f).

The distributed feedback laser drive current is set at 115 mA and the electroabsorption modulator is biased at minus 1.85 V for linear regime operation [7]. An erbium doped fiber amplifier (EDFA) is used to amplify the signal before 1×8 splitter, decorrelation stage and fan-in (FI) device. The signal is transmitted over an uncompensated 1 km single mode 7-core fiber. The cladding diameter of the hexagonal MCF is 150 µm and the core pitch is 42 µm. The average attenuation per core is less than 0.2 dB/km at 1550 nm and the crosstalk between adjacent cores is −45 dB/100 km. A fan-out (FO) device is used to couple the signals to single core fibers. A variable optical attenuator (VOA) is used to adjust the optical power after the pre-amplifier and before a PIN photodetector (3 dB BW >90 GHz, R=0.2 A/W). The signal is captured with a 160 GSa/s 63 GHz digital storage oscilloscope (DSO). The sampled signal is processed offline using digital signal processing (DSP) routine consisting of a low-pass filter (LPF), a maximum variance timing recovery, a symbol-spaced feed forward equalizer (FFE) and decision-feedback equalizer (DFE) with different configurations of feed-forward taps (FFT) and feedback taps (FBT), and an error counter.

3. Results and discussions

In Fig. 2, we show quantitative and qualitative measures for 80 Gbaud and 90 Gbaud PAM4 signals for optical back to back (b2b) and after 1 km transmission. Bit error rate (BER) curves captured for optical b2b are shown for both baud rates (see Fig. 2(a)), while for the lower baud rate BER after 1km transmission over a 7-core MCF are given (see Fig. 2(d)). In all cases, different post-equalizer configurations are used. In addition, we show eye diagrams of 90 Gbaud and 80 Gbaud PAM4 signals for b2b in Fig. 2(b)&(c) and 80 Gbaud PAM4 signal after 1 km single mode 7-core MCF transmission for the worst and the best core in Fig. 2(e)&(f) at 8 dBm Rx power. One can observe in Fig. 2(a) that the PAM4 signals are impacted by the limited bandwidth of the AWG. For the 90 Gbaud PAM4 signal, both pre-equalization and post-equalization is necessary to reach just below the BER limit of 3.8e-3 for 7% OH HD-FEC. The baud rate was therefore reduced to 80 Gbaud for transmission experiments since in this case pre-equalization works better improving the performance sufficiently.

4. Conclusions

In this paper, we successfully demonstrate a transmission of 80 Gbaud/λ/core PAM4 signal over 1 km single mode 7-core MCF. Single-wavelength and single-fiber 1.04 Tbit/s post-FEC transmission has been achieved, having an enormous potential to enhance bandwidth-density for short-reach optical interconnects.

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