108-Ch (12-Core×9-WDM) Self-Homodyne Transmission Using Only a Single Laser for 8.64-Tb/s Short-Reach Optical Links

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Abstract: We demonstrate 108-ch (12-core×9-WDM) frequency comb-based self-homodyne multi-core transmission with a net bit rate of 8.64-Tb/s. This demonstration shows the feasibility of high-capacity short-reach SDM/WDM systems using only a single laser. © 2023 The Author(s)

1. Introduction

Due to the exponential growth of network traffic, high-capacity optical systems have been required even in short-reach applications such as data-center and access networks [1-3]. However, conventional full coherent systems (i.e., dual-polarization (DP) IQ modulation and polarization/phase-diversity reception) cannot be directly applicable since cost reduction is the primary concern in such networks. In particular, temperature control of lasers in coherent transceivers consumes a lot of energy; therefore, uncooled operation is desirable to reduce transceiver power consumption. For this reason, self-homodyne systems have attracted significant attention since they eliminate the need for local oscillators (LOs) and wavelength synchronization between transmitters and receivers as well [2-8]. The laser linewidth requirement is also relaxed since signal and LO waves traveling over the same distance ideally do not induce any phase noise at the self-homodyne receiver regardless of laser linewidth [9]. This is especially the case when LO waves are polarization multiplexed with signal waves and transmitted over physically the same fiber channel. It should be noted that self-homodyne transmitters and receivers themselves may induce undesired path mismatch between the two polarization components, but this could potentially be minimized using photonic integrated circuits (PICs). Self-homodyne systems can further be extended to space-division multiplexed (SDM) systems such as multi-core fiber (MCF) links. In this case, LO waves can be shared among all cores by splitting a single light source, which enables uncooled operation among cores. This idea was first proposed and demonstrated in [10,11]. However, in the demonstrations, multiple laser diodes (LDs) were independently prepared as wavelength-division multiplexing (WDM) light sources. This requires precise wavelength control and thus undermines the original merit of self-homodyne systems i.e., the capability of uncooled operation.

In this paper, we demonstrate 108-ch SDM/WDM (12-core and 9-wavelength) self-homodyne transmission using only a single laser. In contrast to the previous demonstrations, we employ an optical frequency comb as WDM sources as shown in Fig. 1. As a result, temperature control of a massive number of lasers could be eliminated since all 108 SDM/WDM channels are generated from a single laser. For demonstration, we successfully transmitted 108 25Gbaud 16QAM signals over a 10.1-km MCF and confirmed that bit-error rates (BERs) of all the channels were below the threshold of the 20% soft-decision (SD-)forward-error correcting (FEC)

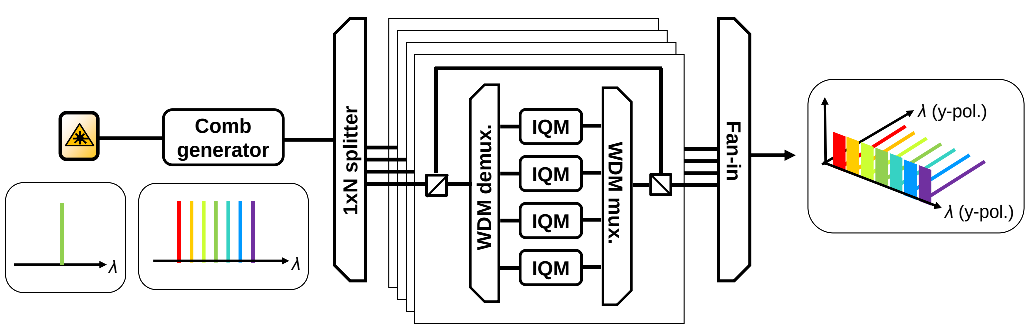

Fig. 1: Conceptual image of an uncooled SDM/WDM self-homodyne transmitter using a single laser.

code. As a result, we achieved a gross bit rate of 10.8 Tb/s and a net bit rate of 8.64-Tb/s. This demonstration shows the feasibility of high-capacity short-reach SDM/WDM systems using only a single laser.

2. Experiment

Figure 2 shows the experimental setup of the SDM/WDM self-homodyne system. We first generated a frequency comb using two sections: an electro-optic (EO) comb section and a parametric comb section. We drove cascaded phase and intensity modulators using a 40-GHz sinusoidal electrical signal in the first section. Subsequently, the limited number of comb channels generated by the first section was further expanded by four-wave mixing of a highly nonlinear fiber (FNLF) in the second section. Note that this second section could be eliminated if the modulators in the first EO comb section had enough modulation efficiencies. Nine comb components near the center wavelength were extracted using an optical bandpass filter (OBPF) as WDM sources. Figure 3(a) shows the optical spectrum of the extracted frequency comb. Then IQ modulation was performed (Fig. 3(b)) using an arbitrary waveform generator (AWG). For IQ signal generation, we generated a 25-Gbaud 16QAM signal and filtered it using a raised-cosine filter with a roll-off factor of 0.5. Note that we had no correlation impact on channel performance although the same signals were loaded in all WDM channels, as proven in [12]. On the other hand, unmodulated WDM sources before IQ modulation were split and polarization-multiplexed with the IQ signals by a polarization-beam combiner (PBC) as LO components (Fig. 3(c)), and they were split by the number of the core. Although IQ modulation and polarization multiplexing was performed using bulky components in this experiment, they can be integrated into a single PIC chip, and the pass mismatch can be mitigated. Then, all signals were input to a fan-in module after they were amplified using an erbium-doped fiber amplifier (EDFA) and transmitted over a 10.1-km MCF. The launched power for each core was set at 3 dBm. It should also be noted that WDM filters may require additional temperature control; however, this should still be power efficient compared to that of a massive number of SDM/WDM lasers.

On the receiver side, each core was separated using a fan-out module and a WDM signal was subsequently extracted using an OBPF. After the signal was pre-amplified using an EDFA, its polarization state was manually adjusted. Finally, the signal and LO components were demultiplexed using a polarization-beam splitter (PBS) and were input to a single-polarization (SP) coherent receiver. It should be noted that the polarization controller and coherent receiver can also be integrated into a single PIC chip as well as the transmitter. Alternatively, the polarization controller and coherent receiver can be replaced with a single integrated Stokes-vector receiver [13,14]. In this case, the polarization demultiplexing can be digitally performed using a 3x2 (or 3x3) multiple-input and multiple-output (MIMO) process [15]. The electrical signals from the coherent receiver were captured using a digital oscilloscope running at 80GS/s and processed using offline digital signal processing (DSP). At the receiver DSP, the received IQ signal was equalized using a least-mean-square (LMS) algorithm. The tap coefficients were first updated with a training sequence and then switched to a decision-directed mode after the coefficients converged. Finally, bit-error rates (BERs) of all 108 channels were calculated.

Figure 4 shows the measured BERs. Although we found the performance variation among the 12 cores, the BERs around the center channel tend to be better than those at the edge-side channels. This is because of the uneven spectral shape of the frequency comb. However, the flatness of the comb could be improved by properly designing the driving condition of a Mach-Zehnder modulator (MZM) [16]. We also found that the polarization state at the

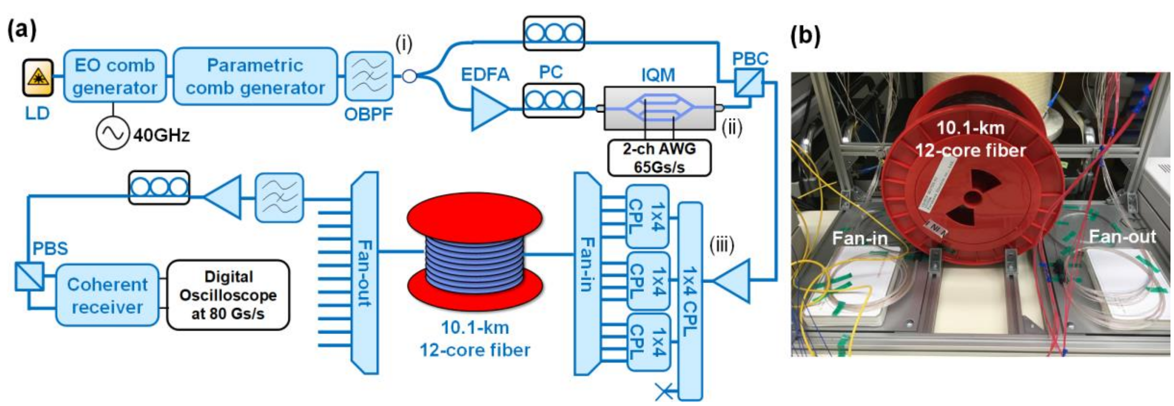

Fig. 2: (a) Experimental setup and (b) external appearance of the 12-core fiber.

receiver significantly affected the receiver's performance. In fact, if the polarization state was imperfectly aligned, signal and LO components are mixed at both the *x*- and *y*-polarization branches. As a result, the electrical output from the coherent receiver includes an undesired signal-to-signal beat interference (SSBI) component. Since the polarization state varied during the measurement, the BER performance also varied due to the SSBI. (This could be mitigated using real-time polarization tracking either in the optical or electrical domain.) However, we could achieve the BERs of all the channels below the threshold of 20%-OH FEC (0.04 [17]). In this case, the achieved gross bit rate was calculated as 12 (core) x 9 (WDM) x 25 [Gbaud] x 4 [bit/s/Hz] = 10.8 Tb/s. If we exclude the 20% overhead, we achieved the net bit rate of 8.64 Tb/s.

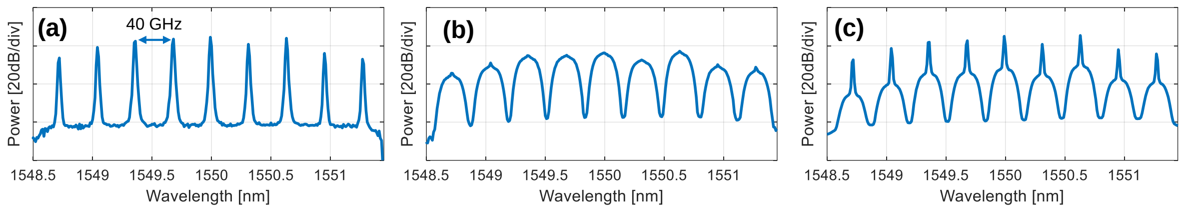

Fig. 3: Optical spectra of (a) the frequency comb, (b) IQ-modulated signals, and (c) polarization-multiplexed signals.

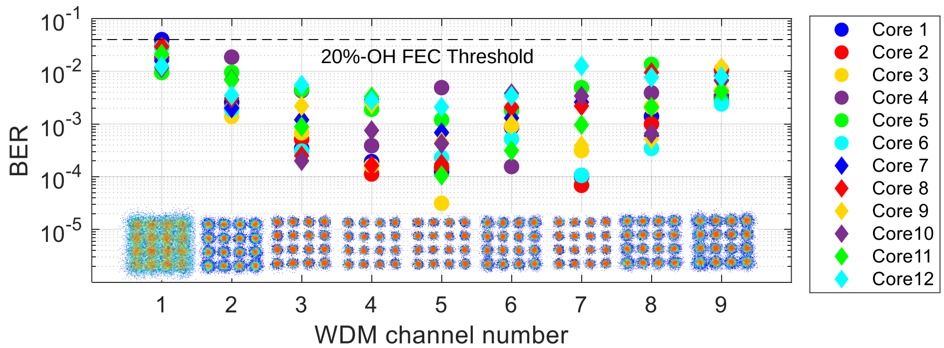

Fig. 4: Measured BERs.

3. Conclusion

We have demonstrated 108-ch frequency comb-based self-homodyne multi-core transmission and achieved a net bit rate of 8.64 Tb/s. This demonstration shows the feasibility of high-capacity short-reach SDM/WDM systems using only a single laser.

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4. References

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