A 224 Gbps/λ O-Band Coherent Link for Intra-Data Center Applications

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Abstract:
We present the first >200 Gbps/λ O-band optical link with integrated transmitter and receiver photonic and electronic ICs. 224 Gbps/λ DP-QPSK transmission is demonstrated below the $3.8 \cdot 10^{-3}$ HD-FEC threshold with 6.8 pJ/bit power consumption.

1. Introduction

As transceiver data rates continue to rise, coherent links are becoming increasingly attractive for replacing intensity modulation direct detection (IMDD) links inside data centers [1]. However, the characteristically high power consumption and cost of coherent links impede widespread adoption for short-reach applications. We have proposed an analog coherent detection (ACD)-based architecture that enables low-power coherent link operation by removing power-hungry DSP functions that are required for longer-reach conventional coherent links [2]. Transitioning from C-band to O-band operation eliminates the need for chromatic dispersion (CD) compensation in short-reach intra-data center links. O-band coherent transmitter (Tx) PICs (photonic integrated circuits) [3] and receiver (Rx) ICs [4] have been reported, and we previously demonstrated the first full O-band coherent link with integrated Tx and Rx PICs and EICs (electronic integrated circuits) [5]. In this work, we present a 224 Gbps/λ dual-polarization quadrature phase shift keying (DP-QPSK) link in the O-band with dual-polarization operation below the $3.8 \cdot 10^{-3}$ HD-FEC threshold. To our knowledge, this is a record single-λ data rate for an O-band link, either coherent or IMDD, that includes integrated photonics and electronics from the driver input to the Rx EIC output.

2. Design

The Tx and Rx PICs in this work were fabricated in Intel's silicon photonics process. Dual-polarization in-phase and quadrature Mach-Zehnder modulator (DP-IQ MZM) PIC operation with the DP-IQ MZM driver EIC, which was fabricated in GlobalFoundries 9HP 90 nm BiCMOS process, was previously reported in [5]. The DP coherent receiver PIC was packaged with a transimpedance amplifier (TIA) EIC fabricated in GlobalFoundries 45RFSOI 45 nm CMOS process. The PIC includes an integrated analog polarization controller circuit that allows for optical domain manipulation and demultiplexing of the received polarization channels. The Rx EIC is based on a record low-power inverter shunt-feedback TIA, and was previously reported in [6]. The total power consumptions of the Tx and Rx ICs were 1.3 W and 0.2 W, or 5.9 pJ/bit and 0.9 pJ/bit at 224 Gbps, respectively. PICs and EICs for both Tx and Rx were packaged on FR4 PCBs with wirebonded high-speed connections. In future designs, wavelength division multiplexing (WDM) can scale the transceiver data rate with 4 λs for 800G or 8 λs for 1.6T.

3. Results

A diagram of the link measurement setup and images of the packaged Tx and Rx are shown in Fig. 1(a) and (b), respectively. Since first-generation PICs that do not include integrated optical gain were used, a distributed feedback laser (DFB) (AeroDIODE 1310LD-4-1-1) was split into signal and local oscillator (LO) paths in a self-homodyne configuration. A bit-pattern generator (BPG) (SHF 12105A) drove the driver EIC with 500 mV PRBS15 signals, and a real-time oscilloscope (RTO) (Keysight UXR0702A) measured the recevier EIC output at 256 GSa/s with a 0.586 μs acquisition time. Due to limited RTO channels, only one Rx polarization channel was measured at a time, and the coaxial cable connections were swapped to characterize the other polarization channel. The measured constellations were post-processed to apply static constellation rotation, equalization, and

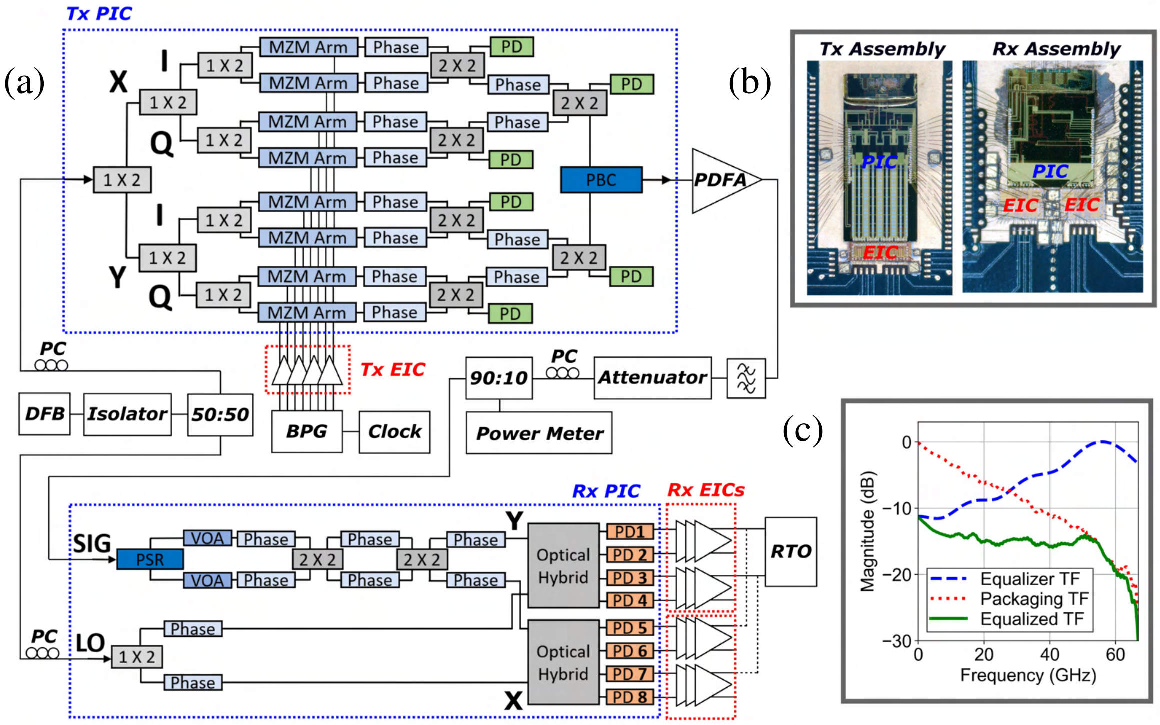

Fig. 1. (a) Block diagram of measurement setup and Tx and Rx PIC components. (b) The packaged Tx and Rx with custom EICs and PICs. (c) Measured packaging frequency response compared to post-processing equalizer and resulting equalized frequency responses.

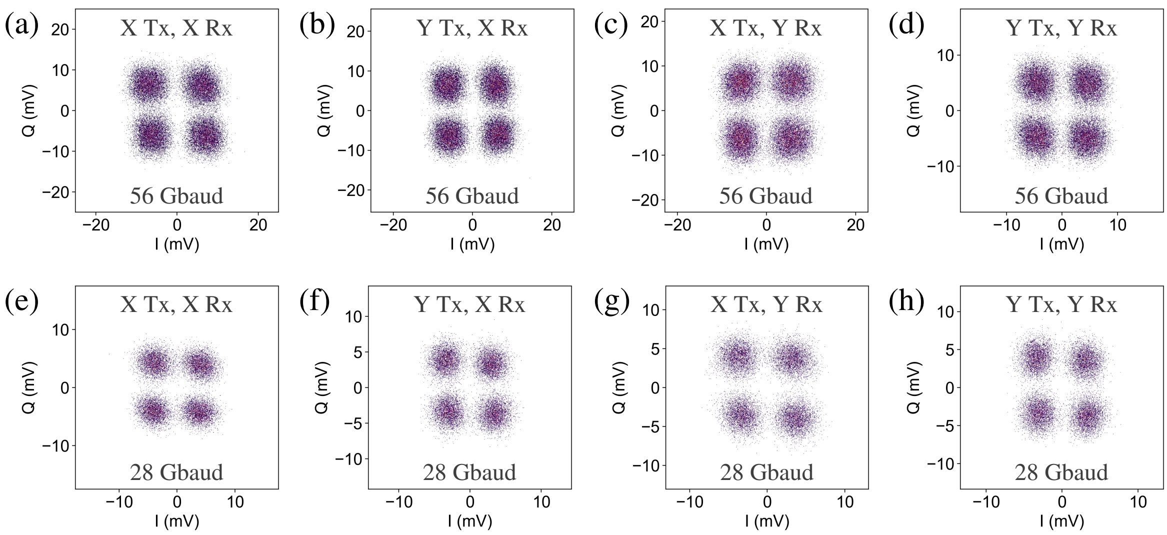

Fig. 2. Measured DP-QPSK constellations for (a-d) 56 Gbaud and (e-h) 28 Gbaud full-link operation. Individual constellations are shown for the X and Y polarization channels in the Tx and Rx.

sampling, and then to count bit errors. A 7-tap feed-forward equalizer (FFE) was used in post-processing to de-embed the insertion loss due to Tx and Rx packaging. The packaging losses from the PCB microstrip transmission line, mini-SMP connector, and coaxial cables are unfortunately unavoidable for link characterization with a BPG and RTO, but they would not be present in an integrated transceiver module. As shown in Fig. 1(c), this equalizer does not compensate bandwidth impairments beyond measured off-chip packaging losses.

Constellations for full-link DP-QPSK transmission are shown in Fig. 2(a-d) for 56 Gbaud and Fig. 2(e-h) for 28 Gbaud. The on-chip polarization controller was used to switch between Rx polarization channels. A constel-

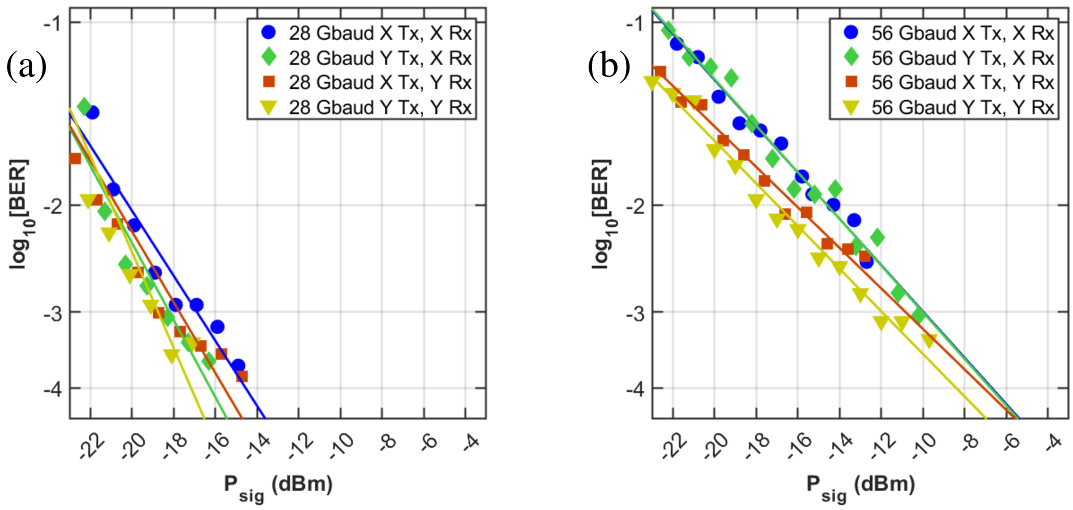

Fig. 3. Measured BER vs Rx input power for (a) 28 Gbaud and (b) 56 Gbaud DP-QPSK operation. Plotted trend lines are fit from the data.

lation is shown for each configuration of Tx and Rx X and Y polarization channels with operation below the $3.8 \cdot 10^{-3}$ HD-FEC threshold in each case. Corresponding BER sensitivity curves for each polarization configuration for 28 Gbaud and 56 Gbaud DP-QPSK are shown in Fig. 3(a) and (b), respectively. All of these measurements are for dual-polarization transmission in the presence of polarization crosstalk effects, with Rx input power reported as the power on the fiber of the polarization channel being measured and 3.8 dBm average LO power incident on each photodiode (PD).

4. Conclusion

We have demonstrated DP-QPSK link operation in the O-band at 224 Gbps/λ (56 Gbaud) below the $3.8 \cdot 10^{-3}$ HD-FEC threshold. To our knowledge, this is the first demonstration of a >200 Gbps/λ O-band optical link, either coherent or IMDD, that uses custom integrated electronics and photonics for the Tx and Rx. The link power consumption in this work was 1.5 W (6.8 pJ/bit), and <10 pJ/bit power consumption is expected for a next-generation link using PICs that include integrated optical gain. This result shows that O-band coherent links can support per-λ data rate scaling with attractive energy efficiency for future intra-data center networks.

Acknowledgement

The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000848. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Thanks to T. Latavic, N. Cahoon, and M. Peters at GlobalFoundries for their support with EIC fabrication.

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