

First Demonstration of an O-Band Coherent Link for Intra-Data Center Applications

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Abstract We report two first-of-a-kind achievements for integrated O-band coherent subsystems: a full coherent link at 112 Gbps (56 Gbaud QPSK) with $2.1 \cdot 10^{-4}$ measured BER, and a record baud rate 128 Gbps (64 Gbaud QPSK) transmitter. © 2022 The Author(s)

Introduction

As data center network traffic continues to increase, future intra-data center optical interconnects must scale to higher data rates while improving overall cost and power efficiency. Through in-phase and quadrature (IQ) modulation with polarization multiplexing, coherent optical link technologies provide a path to increased data rates over intensity modulation direct detection (IMDD) technologies. Short-reach O-band applications with low chromatic dispersion make power-efficient coherent links an attractive replacement for IMDD technologies for the 1.6 Tbps generation and beyond^[1]. In an analog coherent detection (ACD)-based link architecture, power consumption is further reduced by performing carrier and polarization recovery in the analog domain without high-speed analog-to-digital conversion and digital signal processing (DSP). We previously reported an ACD link architecture analysis that showed 5-10 pJ/bit energy efficiencies are possible with 13 dB of unallocated link budget^[2]. ACD links with large unallocated link budgets enable data center networks with passive arrayed waveguide grating routers (AWGRs) or active optical switches, improving overall network latency, cost, and power consumption^[3].

We present here the first full-link demonstration of an O-band coherent link designed for intra-data center applications, with 56 Gbaud quadrature phase shift keying (QPSK) operation for 112 Gbps per polarization with a bit error rate (BER) of $2.1 \cdot 10^{-4}$. The achieved BER is below the threshold for KP4 forward error correction (FEC). We have designed and fabricated custom transmitter (Tx) and receiver (Rx) electronic and photonic integrated circuits (EICs and PICs) for an ACD-

based link. Previously reported O-band coherent results for either high-speed Tx PICs^[4] or Rx PICs and EICs^[5] have relied on test equipment in the absence of integrated photonics or electronics for the full link. Our custom Tx was also measured stand-alone, resulting in record-high 64 Gbaud operation with a BER $< 10^{-4}$ for a combined O-band coherent driver and modulator.

Design

The Tx and Rx PICs were fabricated in Intel's silicon photonics process. The Tx and Rx EICs were fabricated in the GlobalFoundries 9HP 90 nm and 8XP 130 nm SiGe BiCMOS processes, respectively. The driver has 2 Vppd output swing and 45 GHz bandwidth across four differential channels that drive a dual-polarization (DP)-IQ travelling wave Mach-Zehnder Modulator (MZM) on the Tx PIC. The output stage load resistor R_L is 200 Ω to enable back-reflection tolerance with low power consumption^[6]. A schematic of one channel of the driver circuit integrated with a MZM on the Tx PIC is shown in Fig. 1. The Rx EIC design was reported previously^[7]. Since the target modulation format is QPSK, the Tx and Rx both used power-efficient limiting electronics. The Tx and Rx EICs and PICs were packaged with wirebonds on FR4 PCBs, forming complete dual-polarization designs capable of capable of 224 Gbps/ λ .

Results

As integrated lasers were not included in these first-gen PICs, a 1310 nm external cavity laser (ECL) was split into local oscillator (LO) and signal paths in a self-homodyne link configuration. The link measurement setup is shown in Fig. 2 along with images of packaged Tx and Rx chips. 500 mV PRBS15 differential sig-

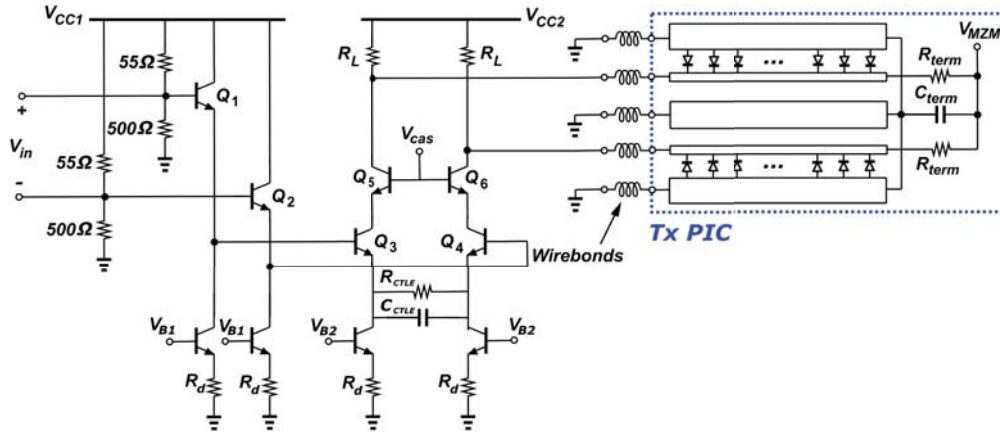


Fig. 1: Schematic of one differential driver and MZM channel. The full Tx includes 4 channels for the DP-IQ-MZM.

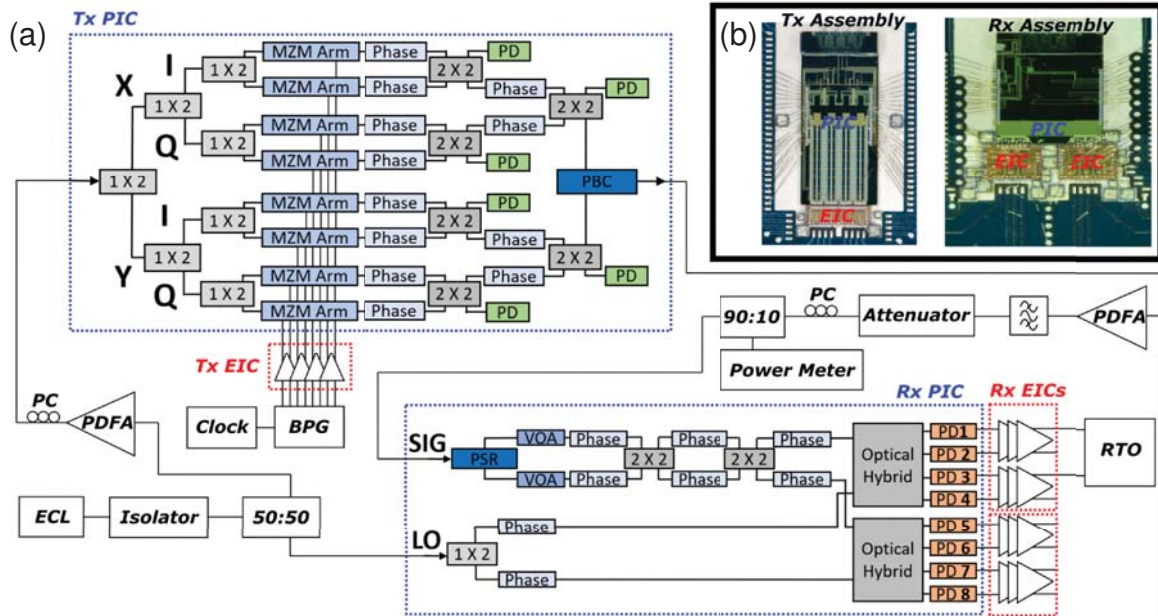


Fig. 2: (a) Schematic of the full link measurement setup, including optical component block diagrams of Tx and Rx PICs. (b) The assembled Tx and Rx showing packaged custom EICs and PICs.

nals from a bit pattern generator (BPG) (SHF 12105A) drove the Tx EIC, and Rx EICs outputs were detected by a real-time oscilloscope (RTO) (Keysight UXR0702A) with a $0.875 \mu\text{s}$ acquisition time at 256 GSa/s. A post-processing script corrected static constellation rotation, then sampled and counted bit errors. No external equalization or additional post-processing was performed. These results are for the first Tx and Rx subsystems we have built, and due to assembly yield we are reporting dual-polarization QPSK transmission with only single-polarization 112 Gbps receiver operation. Future assemblies will be capable of full dual-polarization 224 Gbps/ λ operation.

A sampled constellation for single-polarization 56 Gbaud QPSK full-link operation is shown in Fig. 3. A constellation for dual-polarization transmission is plotted in Fig. 4 to show the impact of crosstalk between polarization channels. Both

constellations correspond to received signal powers with $\text{BER} < 10^{-3}$. BER vs average signal power at the Rx input for the full link is plotted in Fig. 5 for 28 and 56 Gbaud. The measured power penalty from polarization crosstalk is 1 dB, and the achieved BER is $2.1 \cdot 10^{-4}$. Total power consumption with both polarization channels on was 2.1 W. Although external optical amplifiers were employed in this first demonstration, received photocurrents were kept below levels expected from next-gen PICs designed with integrated lasers and SOAs. The average LO power incident on each photodiode (PD) was -3.3 dBm , and the received signal power sensitivity values plotted here are expected to improve with higher LO power. We expect 2.8 W (12.5 pJ/bit) power consumption for the full 224 Gbps/ λ link with no external amplification required.

A separate Tx subassembly variant without

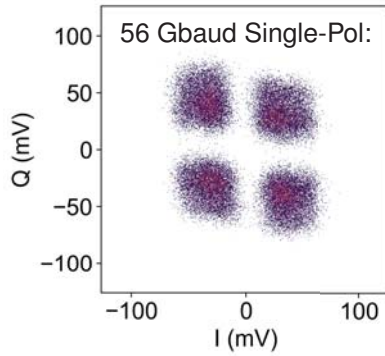


Fig. 3: Measured sampled constellation for single-polarization 56 Gbaud QPSK full-link transmission.

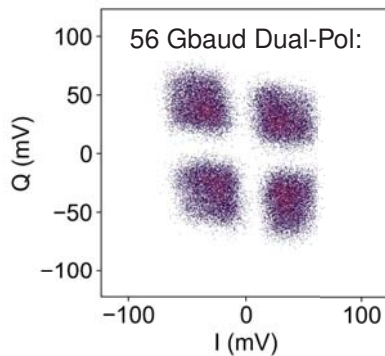


Fig. 4: Measured sampled constellation for dual-polarization 56 Gbaud QPSK full-link transmission.

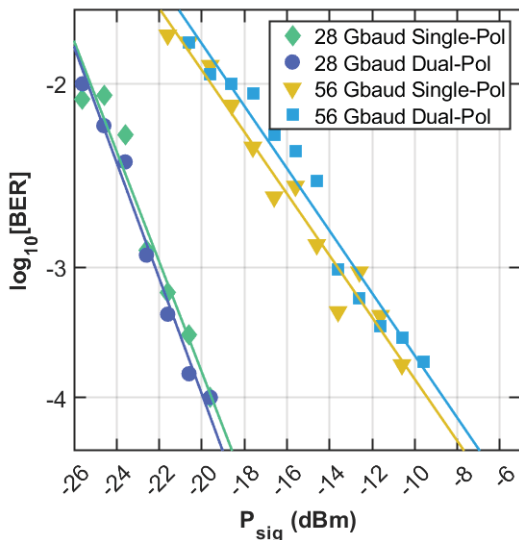


Fig. 5: Measured BER vs Rx input power (per polarization) for the full Tx + Rx link with and without polarization crosstalk.

CTLE in the driver was also characterized with a reference optical hybrid (Kylia COH28X-FCAPC-1300nm) and balanced 70 GHz PDs (Finisar BPDV3320R) resulting in 64 Gbaud sampled constellations with $\text{BER} < 10^{-4}$ as shown in Fig. 6. BER sensitivity curves for this standalone Tx and reference Rx are shown in Fig. 7.

Conclusion

We have demonstrated the first full O-band coherent link, including custom driver and receiver

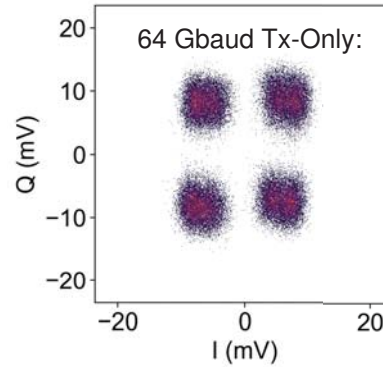


Fig. 6: Measured sampled constellation for single-polarization 64 Gbaud QPSK standalone Tx characterization with $1 \cdot 10^{-4}$ BER.

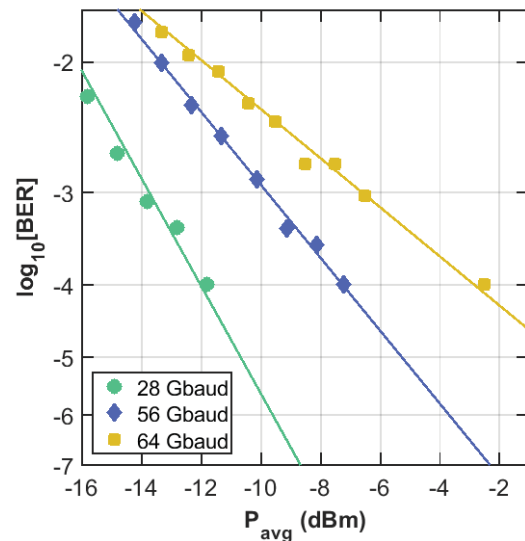


Fig. 7: Measured BER vs Rx input power for the standalone Tx with a reference receiver with -2 dBm LO power per PD.

EICs integrated with Tx and Rx PICs. 56 Gbaud dual-polarization QPSK transmission was shown with a BER of $2.1 \cdot 10^{-4}$, with 12.5 pJ/bit power efficiency expected for the full 224 Gbps/ λ link with integrated gain. We further demonstrated standalone O-band coherent Tx operation at a record 64 Gbaud. These results show the potential of a low-power ACD architecture and pave the way for bringing coherent links inside data centers.

Acknowledgements

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 Ned Cahoon and Mike Peters at GlobalFoundries for their support with EIC fabrication.

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