

Reconfigurable Kerr-Comb for Enhanced Link Margins in >1 Tb/s Direct-Drive DWDM Links

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Abstract: We demonstrate a Kerr comb reconfigurable to 100/200/300 GHz spacing, enabling channel count–data rate tradeoffs for >1 Tb/s DWDM links. Direct-drive modulation at 16–32 Gb/s shows the 300 GHz state yielding >4.5 dB link-margin improvement.

1. Introduction

The demands for AI/machine learning workloads have placed dramatic importance on the need for high-bandwidth, low-energy interconnects for intra-datacenter communication. Silicon photonics (SiP) has emerged as a leading platform towards meeting this demand due to its high compatibility with existing commercial CMOS processes and integration in dense wavelength-division multiplexed (DWDM) systems. Coupled-resonator based Kerr frequency combs are a promising companion in the design space for resonator-based SiP transceivers, capable of delivering more than a hundred coherent and equally spaced wavelength channels for selective modulation and filtering by buses of cascaded resonant modulators and filters [1]. The channel spacing of the coupled-resonator comb, also referred to as the comb’s free spectral range (FSR) state, is set by the location of the avoided mode crossing relative to the pump frequency [2]. Prior studies have demonstrated the promise of Kerr comb–driven links in ultra-broadband architectures [3, 4]. However, previous experiments relied on Kerr comb devices optimized for a fixed channel spacing and operating with limited power output beyond the pump frequency, requiring amplification.

Here, we demonstrate modulation of an unamplified, reconfigurable high-power Kerr comb—with exceptional spectral flatness and power uniformity across 100, 200, and 300 GHz FSR states generated from the same device—at 16, 24, and 32 Gb/s per channel. We study the implications of operating in different FSR states in the optical link budgets of three transceiver link configurations with a fixed aggregated data rate of >1 Tb/s. The resonant modulators and filters have an FSR of 26 nm, thus requiring interleaver stages to circumvent resonance aliasing [4]. Notably, we find that a nonlinear power-per-line enhancement at the 300 GHz comb FSR state allows for improved link budget margins by >4.5 dB compared to the 100 GHz state, enabled by improvement of pump-to-comb efficiency and reduction of accumulated off-resonance insertion loss (OIL). This substantially improves design flexibility for photonic link designers and offers key insights into tradeoffs for Kerr comb–based SiP links.

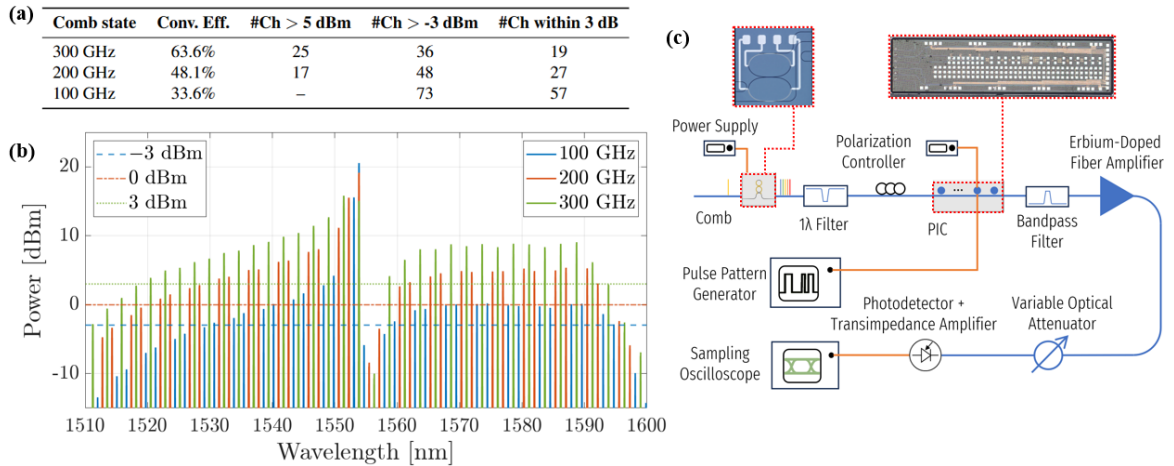


Fig. 1: (a) Measured efficiency, line power metrics, and (b) spectra for the 100, 200, and 300 GHz comb states. (c) Experimental setup for eye diagram measurements with highlighted micrographs of the comb and transmitter PICs.

2. Experimental Results

The experimental setup is shown in Figure 1c. The coupled-resonator-based Kerr comb photonic integrated circuit (PIC) is fabricated at the Cornell Nanofabrication facility, while the transmitter PIC is fabricated through AIM Photonics. The transmitter chip features a bus of eight microdisk modulators and is edge coupled and probed electrically at the die-level for simultaneous RF junction modulation and DC thermal resonance tuning via an integrated doped silicon heater. Integrated resistive heaters on-board the Kerr comb enable tuning of the coupled main and auxiliary resonance locations and deterministically control the channel spacing of the comb. Using this approach, we achieve clean eye diagrams of the selected 1573.6 nm comb line at 16 Gb/s for the 100 GHz comb state, 24 Gb/s for the 200 GHz comb state, and 32 Gb/s for the 300 GHz comb state (Figure 2b) and measure a modulation power penalty of 6.45 dB with 1.3 V_{PP}.

We now consider three transceiver architectures where each comb FSR state is paired with a different data rate to fix the aggregated data rate at >1 Tb/s. Due to the finite 26 nm FSR of the modulators used and the >50 nm wavelength spans for all cases, we introduce MZI-based interleaver stages that double the usable optical bandwidth per-stage to meet the wavelength span requirements and reduce the accumulated OIL by reducing the number of resonators along a single bus (Figure 2a). Using previously measured device insertion losses and methods found in [5], our optical link budget analyses show an improvement in margin by more than 4.5 dB in the 300 GHz comb FSR state over the 100 GHz configuration (Figure 2c), afforded by improved pump-to-comb conversion efficiency and reduced cumulative OIL, despite the increased optical power requirements from the receiver. This link margin improvement can well tolerate coupling and fabrication variations and permit more aggressive modulator doping concentrations on the transmit side to further extend modulator bandwidths for higher data rates.

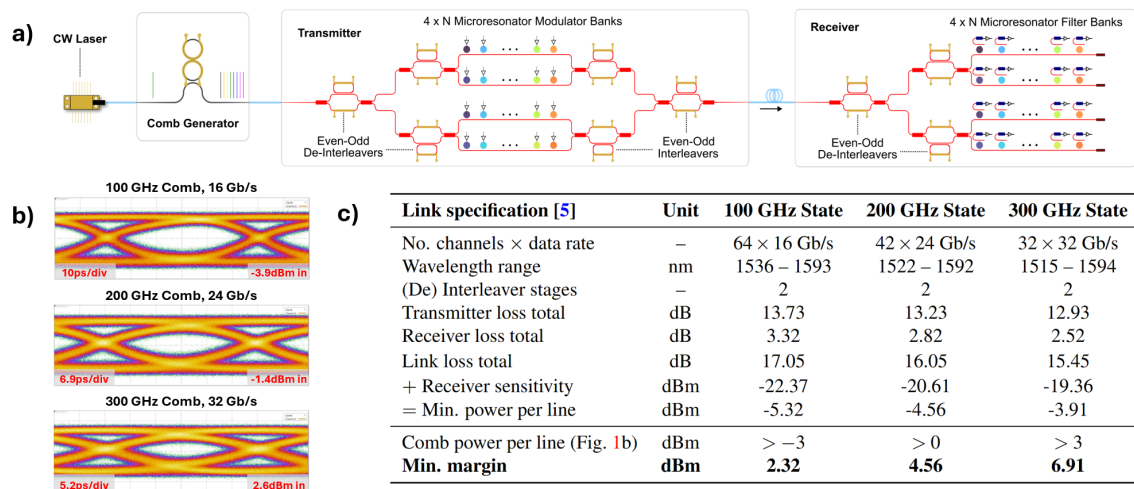


Fig. 2: (a) Link schematic demonstrating the transceiver architecture, where N is the number of resonators per de-interleaved bus and N = 16, 11, 8 for the 100, 200, 300 GHz comb states, respectively. (b) Eye diagrams measured across comb states for the same channel at 1573.6 nm with 1.3 V_{PP}. (c) Link budget calculation for different >1 Tb/s transceiver configurations at 1.3 V_{PP} and measured line power thresholds from Figure 1b.

3. Conclusion

A high-power Kerr frequency comb was reconfigured across three FSR states and modulated without amplification by resonant modulators with an aggregated data rate >1 Tb/s. Optical link budget analyses show that higher comb FSR states may be desirable by offering a >4.5 dB improvement in margin and informing future broadband multi-Tb/s SiP DWDM link designs.

References

1. B. Y. Kim *et al.*, “Turn-key, high-efficiency Kerr comb source,” *Opt. Lett.* **44**, 4475 (2019).
2. S. Sanyal *et al.*, “Nonlinear Dynamics of Coupled-Resonator Kerr Combs,” *Phys. Rev. Lett.* **134**, 123801 (2025).
3. V. Gopal *et al.*, “Concurrent error-free modulation of adjacent Kerr comb lines on a silicon chip,” in *CLEO*, (2022).
4. A. Rizzo *et al.*, “Massively scalable Kerr comb-driven silicon photonic link,” *Nat. Photonics* **17**, 781–790 (2023).
5. Y. Wang *et al.*, “Co-designed silicon photonics chip i/o for energy-efficient petascale connectivity,” *IEEE Trans. on Components, Packag. Manuf. Technol.* **15**, 1581–1591 (2025).

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