2x800Gbps/wave Coherent Optical Module Using a Monolithic InP Transceiver PIC

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Abstract *We report on the development of a 2x800Gbps/wave coherent module based on a monolithic InP transceiver PIC and real-time 7nm DSP ASIC capable of 800Gbps data transmission over record 1000km SMF-28 link using a 96Gbaud, PCS-64QAM modulation format.*

Introduction

The drive for higher fiber capacity has been fulfilled by wavelength division multiplexing, higher baud rates and higher spectral efficiency enabled by coherent modulation schemes. Optical integration has played a key role in this transition by enabling high speed components for coherent communications that meet the required performance, cost, power and space efficiencies. Monolithic PICs have played a unique role by integrating all the functions including light sources for multiple wavelengths onto a single InP chip[1]. Achieving the optimum system performance requires a parallel and co-development of the photonic circuits, high-speed analog electronics and digital signal processing capabilities.

Earlier demonstrations of multi-channel coherent PICs used separate transmitter and receiver PICs with corresponding Mach-Zehnder modulator driver (MZMD) and transimpedance amplifier (TIA) SiGe ASICs[2]. We recently reported on integration of both the transmitter and receiver functions onto a single PIC[3], hybrid integration of a SiGe driver and TIA chip, a probe-level evaluation and back-to-back optical transmission. In this paper, we report on further integration of the two-wavelength PIC with a two-channel SiGe ASIC into a transceiver optical module, achieving greater than 50GHz bandwidth and subsequent integration with a real-time DSP[4], with a record error-free transmission over 1000km at 800Gb/s for each of the two wavelengths.

InP PIC and SiGe ASIC Architecture

The coherent transceiver PIC in a hybrid assembly with the SiGe ASIC is shown in Figure 1. The InP PIC integrates two full coherent transmitter channels and two full coherent receiver channels, each with an independent extended C-band tunable laser onto a single chip[3]. The nested high-speed I/Q modulators are designed to operate at a Vπ of 1.9V and have

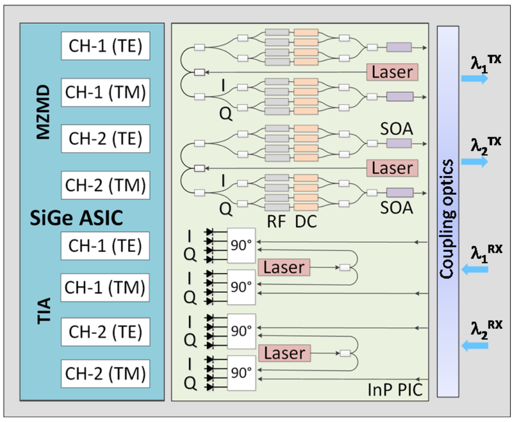

Fig. 1: Schematic of 2-channel transceiver with single Tx/Rx InP PIC, SiGe MZMD/TIA ASIC and array optics for fiber coupling.

integrated SOAs on each polarization to amplify and control the output power. The integrated on-chip amplifiers also enable higher launch OSNR by reducing the total optical loss prior to the first off-chip amplification stage. Each receiver channel on the PIC also integrates a dedicated tunable laser that feeds into a 90° optical hybrid, coupled to a pair of balanced high-speed photodiodes. Using separate Tx and Rx lasers allows completely independent tuning of the Tx/Rx channels on the PIC, enabling greater network reconfigurability and higher power for uncompromised performance of Tx and Rx functions. We have also reported previously on the performance of our integrated tunable laser sources, demonstrating capability to achieve <50kHz linewidth[3].

The matching monolithic 180nm BiCMOS SiGe driver ASIC includes multiple streams of MZMDs and TIAs. The MZMD consists of a 2-stage amplifier design featuring in-built equalization stages to provide broadband linear gain and low noise. The TIA circuit is designed with three stages and includes automatic gain control (AGC) amplifiers and in-built equalization.

The PIC and ASIC are co-packaged in a hermetic, multi-layer ceramic package along with

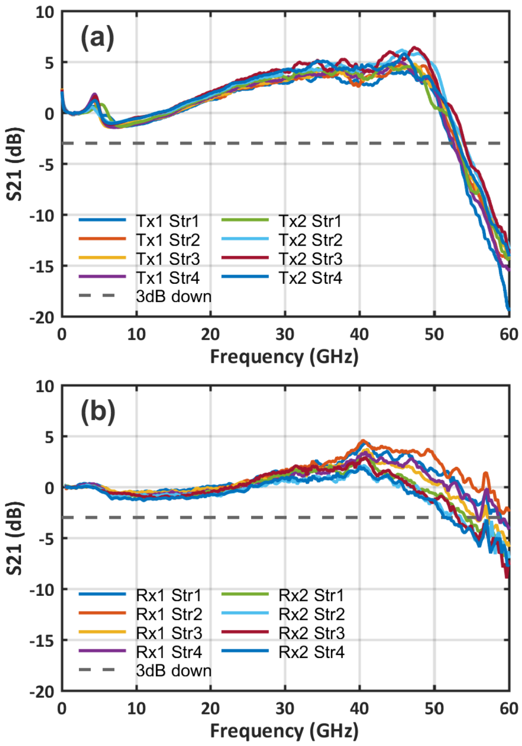

Fig. 2: Measured small-signal RF frequency response of the packaged module, including the DSP RF interconnect, demonstrating >50GHz bandwidth for both the Tx/Rx data streams.

the free space optical coupling and polarization control elements. The optical coupling utilizes prefabricated collimating and focusing lens arrays, as well as polarization splitter/combiner arrays to enable a single optical assembly step to couple to a single fiber v-groove array for all Tx/Rx channels. The use of array optics greatly reduces the package assembly complexity and enables significant savings in size for the entire transceiver.

The small signal EO/OE S_{21} responses of the transmitter and receiver channels were measured with module RF connections soldered to a test board which was subsequently de-embedded from the total measurement. A commercially available high-speed photodetector with over 100GHz bandwidth was utilized for Tx EO tests and for a calibration of the heterodyne test system used for the Rx OE measurements. Figures 2(a) and 2(b) show the Tx EO and Rx OE S_{21} data, respectively, for a typical module. A 3dB bandwidth of greater than 52GHz and a peaking of 4-5dB at around 40-50GHz have been demonstrated with all 8 individual streams of both Tx and Rx sides.

Optical Back-to-Back Results

The transceiver module is assembled into a digital coherent optical engine (DCO) along with a 7nm DSP[4]. The performance of the optical engine is first evaluated for both waves in optical back-to-back mode at 95.6Gbaud PS-64QAM. The information rate is set to 10.5bit/sym to provide 800Gb/s net data rate per wave.

Figure 3(a) shows the transmitted optical spectrum of both waves after combining and sending them to an OSA. The optical bandwidth of both waves is set to 101.62GHz by adjusting the TX Nyquist roll-off to 6.25% in the DSP. The laser frequencies are set at 193.6THz and 193.8THz for channel 1 and 2, respectively. The output signal at the transmit ports are amplified with integrated Er-doped optical amplifiers (EDFA) followed by flat-top optical filters to suppress out-of-band ASE noise. The output signal is then attenuated to the optimum level and sent to both DCO receiver channels.

The optical constellations for both waves are shown in Figs. 3(b) and (c). Water-filling[4] across the different subcarriers[7] was used to ensure that all of the subcarriers are performing at similar BER. This feature allows the DSP to optimally

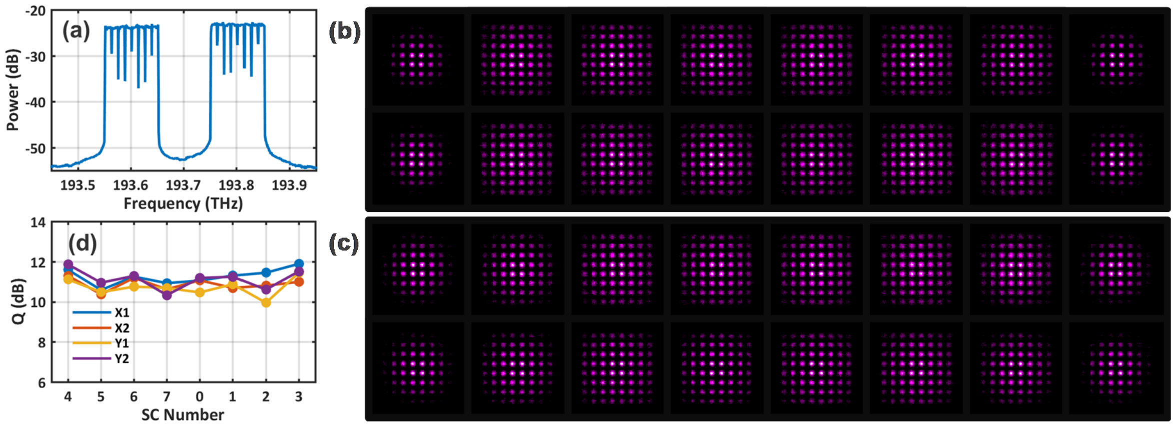

Fig. 3: (a) 2-channel transmitter output spectra, (b-c) optical back-to-back constellations for each of the two channels, and (d) measured Q-factors for each subcarrier of the 2x800Gb/s signal.

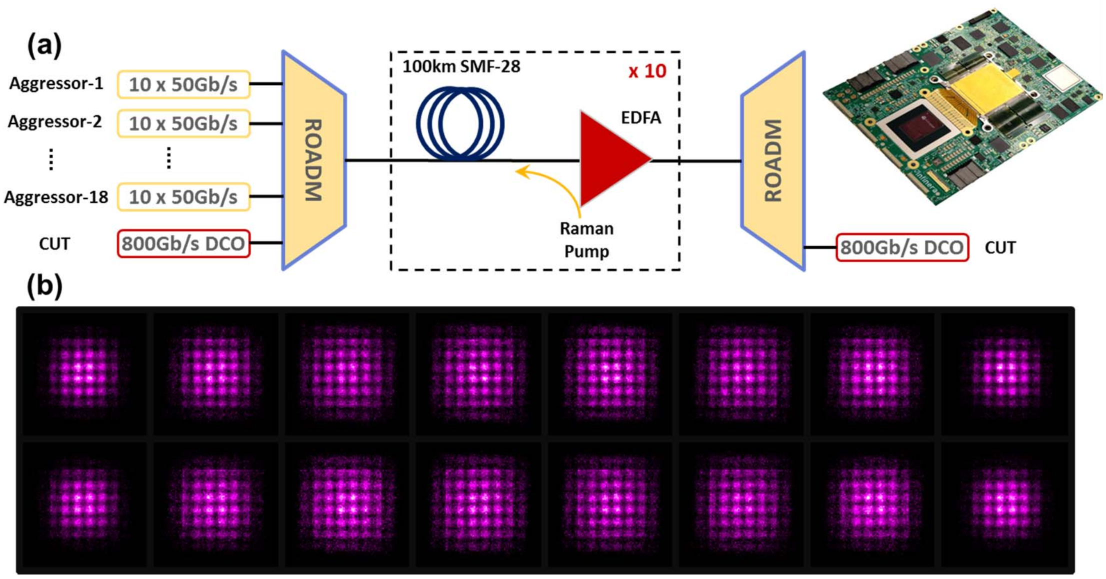

Fig. 4: (a) Experimental setup and (b) final constellation of the 800Gb/s DCO CUT for 1000km transmission.

distribute the data across the different frequency bands based on the SNR profile. Therefore, the inner subcarriers, which have the highest SNR, are set to carry the highest information rates and hence densest modulation format, while the outer subcarriers are allowed to operate at lower bits/symbol.

Figure 3(d) shows the experimentally recorded Q-factor for all waves, polarizations, and subcarriers which ranged between 10-12dB. The mean Q-factor measured by the FEC engine for channels 1 and 2 are 10.46dB and 10.37dB.

Transmission Results

The setup for the full C-band transmission experiment is shown in Fig. 4(a). The 800Gb/s DCO wave 2 is selected as the channel under test (CUT) and tuned to 193.7025THz. It was then multiplexed with 18 coherent 10x50Gbit/s QPSK superchannels as aggressors onto the line system using a reconfigurable optical add-drop (ROADM), in which the entire WDM channels are amplified and gain and spectrally flattened. The total launch power for the WDM channels was 19dBm and the CUT launch power was set to 4dBm. The line system was 10x100km SMF-28 fiber spans. The entire C-band is amplified using a commercially available hybrid Raman/EDFA booster amplifier at the end of each span.

After traveling 1000km of SMF-28 link, another ROADM was utilized to drop the transmitted 800Gb/s channel and feed it into the receiver port of the DCO. The receiver attenuator adjusted the dropped signal power to between -5 and -6dBm and sent it to the receiver.

The 800Gb/s constellation after transmission is shown in Fig. 4(b). The mean pre-FEC Q-factor was 5.85dB, providing a margin of >0.5 dB OSNR margin and thus zero post-FEC errors.

Conclusions

We reported record performance of a 2x800Gb/s coherent optical engine consisting of a 2-channel monolithic InP PIC, a high-speed SiGe driver/TIA in an optical module operating with a 7nm DSP chip. The high level of performance was achieved through use of separate and narrow linewidth lasers, low-noise amplifiers, a high level of signal integrity in the integration platform, and advanced DSP capabilities, including 64-QAM PCS, subcarrier modulation and water-filling. We also demonstrated transmission of 800Gb/s channel with >0.5 dB OSNR margin over 1000km SMF-28 link.

References

[1] F. Kish, et al., "System-on-Chip Photonic Integrated Circuits," IEEE J. Selected Topics in Quantum Electronics, Vol. 24, no. 1, Jan 2018.

[2] V. Lal, et al., “Extended C-band Tunable Multi-Channel InP-Based Coherent Transmitter PICs,” J. Lightwave Tech. Vol. 35, no. 7, 2017.

[3] V. Lal et al., "1.6Tbps Coherent 2-Channel Transceiver using a Monolithic Tx/Rx InP PIC and Single SiGe ASIC," 2020 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2020, pp. 1-3.

[4] H. Sun, et al., “800G DSP ASIC Design Using Probabilistic Shaping and Digital Sub-Carrier Multiplexing,” J. Lightw. Technol., Vol. 38, No. 17, Sep, 2020.

[5] C. R. Doerr, et al., “Single-Chip Silicon Photonics 100-Gb/s Coherent Transceiver,” OFC, Th5C.1, 2014.

[6] R. Going, et al., “1.00 (0.88) Tb/s per Wave Capable Coherent Multi-Channel Transmitter (Receiver) InP-Based PICs With Hybrid Integrated SiGe Electronics,” IEEE J. of Quantum Electronics, Vol. 54, no. 4, Aug, 2018.

[7] D. Krause, et al., “Design Considerations for Digital Sub-carrier Coherent Optical Modem,” OFC, Th1D.1 2017.

[8] J. Rahn, et al., “DSP-Enabled Frequency Locking for Near-Nyquist Spectral Efficiency Superchannels utilizing Integrated Photonics,” OFC, W1B.3 2018