System Validation of Polymer-based Transmitter Optical Sub-Assembly for 100G/200G Modules

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Abstract: This paper experimentally demonstrates Polymer-based transmitter optical sub-assembly (TOSA) for CFP2-ACO modules running at 100G/200G Flexigrid WDM (37.5 GHz). Compared to LiNbO$_3$, the ultra-compact TOSA provides excellent performance both in back-to-back and over long-haul distances.

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1. Introduction

The backbone of any telecom infrastructure worldwide runs over WDM optical systems. Current deployed line interfaces with coherent optical technologies operate mostly in 100 Gb/s per $\lambda$ in long-haul and metropolitan networks.

The industry is currently adopting analog coherent optical (ACO) modules inside the CFP$_X$ form factor wherein the digital signal processing (DSP) application specific integrated circuit (ASIC) is outside the module for optimized power consumption and size (better port density). Next-generation line interfaces will most likely evolve to 200G, 400G (e.g. $2 \times 200G$ superchannels) and beyond, as detailed by the recent OIF white paper [1]. Therefore, integrated optics in the polarization-multiplexed quadrate modulator transmitter (PMQ-Tx) and coherent receiver (ICR) play major role as the CFP2-ACO modules [2] have to deliver the performance at 100G, 200G and beyond per $\lambda$ and comply with the stringent implementation requirements on the power dissipation and size.

Many photonic integration platforms have been proposed and demonstrated for the implementation of tunable transmitter optical sub-assembly (TOSA) including Indium phosphide (InP) [3], Silicon photonics [4] and Silicon-organic hybrid [5] such as thin film polymer on Silicon (TFPS) [6] to overcome the LiNbO$_3$ modulator physical limitations in size, $V_\pi$, extinction ratio etc. Although recent designs of polymer on silicon modulators have shown very promising results due their increased electro-optic coefficient in small footprints [6], the experimental investigation at system-level in a TOSA package for ACO modules in coherent 100G/200G WDM using commercially available devices has not been reported yet.

In this work, we exploit the performance limits, in spectrally-efficient Nyquist WDM, of an ultra-compact tunable TOSA packing a wide-range tunable laser (TL) with the polarization-multiplexed IQ modulator using TFPS integration platform. The system performance including a flexigrid WDM at 37.5 GHz, transporting $21 \times$ coherent 128 Gb/s – PM-QPSK or 256 Gb/s – PM-16QAM yielding net 2.66 bit/s/Hz or 5.33 bit/s/Hz, respectively, is characterized both in back-to-back (B2B) and over long-haul links. Compared to discrete LiNbO$_3$ plus external cavity laser (ECL) PMQ with the DSP-ASIC running at 100G, the Polymer-based TOSA shows negligible implementation penalty (required OSNR < 11 dB) and transmission reach close to 7000 km. At 200G rate, the penalty increased to $\sim 1$ dB, which represented a maximum transmission reach of 1600 km against 1900 km obtained with the LiNbO$_3$-based PMQ.

2. Experimental Setup

Fig. 1(a) shows the experimental setup for system validation of the 100G/200G TOSA provided by BrPhotronics. The TOSA package in Fig. 1(b) (dimension 38.5×22.5 mm$^2$) is efficiently designed to provide stable performance up to 75°C, heaters for modulator bias control, typical electro-optical (EO) bandwidth of 23 GHz, $V_\pi = 3.5$ V (differential mode), power dissipation of 2.5 W and narrow-linewidth TL ($\leq 100$ kHz).

At the Tx side, the device under test (DUT) (TOSA or LiNbO$_3$) was mounted on a dedicated evaluation board (EVB) (Fig. 1(c)), providing TL power and optical wavelength control, along with automatic optical modulator bias control. The DUT was driven by 32-GBd signals from a 28-nm ASIC including a 64-GSa/s digital to analog converter (DAC) (ClariPhy CL20010, $\sim 16$ GHz electrical bandwidth, 8-bit resolution). The ASIC on the EVB also performs in...
real-time the generation of $2^{31}-1$ pseudo-random bit sequence (PRBS) with 20%-overhead soft-decision forward error correction (SD-FEC), QPSK/16QAM constellation mapping, quasi-Nyquist shaping with root raised cosine filtering (roll-off=0.1), bandwidth pre-compensation and transmitter deskew. The four differential RF outputs from the ASIC’s DAC, corresponding to the I and Q components of the X and Y polarization, were then amplified by two 35-GHz RF quad-drivers, before being sent to the modulator. The same signals were used to drive a 30-GHz dual-polarization LiNbO$_3$ IQ modulator ($V_\pi \approx 3.5$ V), for performance comparison, as shown in Fig. 1(c). The optical source used to feed the LiNbO$_3$ modulator was a 100-kHz ECL. The optical wavelength of the channel under test was set at 1550.11 nm (193.4 THz) as in Fig. 1(d). Due to the modulators’ loss, the optical channel was then amplified by a low noise optical pre-amplifier before being sent to the Tx optical booster and then to the optical fiber. Single channel and WDM transmission tests were carried out in order to extensively validate the TOSA performance. The WDM channel grid was generated by 20 ECL (100-kHz linewidth), divided in two separate arrays of 10 channels each, and interleaved in a 37.5 GHz flexible grid. Each group of ten lasers was sent to a dual-polarization LiNbO$_3$ optical modulator, driven by 32-GBd QPSK or 16QAM signals, generated off-line by a 63-GSa/s DAC (Fujitsu, ∼14-GHz bandwidth, 8-bit resolution). The 20 modulated WDM channels were coupled with the channel under test by a 90/10 optical coupler, before being amplified by the Tx booster EDFA and transmitted into the fiber link. The WDM optical spectrum is shown in Fig. 1(d).

The fiber link consisted of an optical recirculating loop, with five 50-km spans of ultra low-loss, large effective area fiber (Corning® Vascade EX2000) and five amplification stages (6-dB noise figure EDFAs). A programmable optical filter (POF) in the middle of the loop was used for out-of-band ASE noise filtering. At the receiver (Rx) side, the channel under test was band-pass filtered and pre-amplified before being sent to the coherent receiver, consisting of a polarization diversified 90° optical hybrid, followed by four balanced photodetectors (PD) with 40-GHz bandwidth, and a digital oscilloscope (80 GSa/s, 33-GHz bandwidth, 8-bit resolution) as analog-to-digital conversion (ADC). Offline DSP was then performed for signal demodulation and bit error rate (BER) evaluation.

Fig. 1. (a) Experimental setup for the TOSA system-level validation. (b) TOSA package. (c) Evaluation boards for the device under test and DSP-ASIC. (d) Nyquist WDM spectrum.

3. Experimental Results

Fig. 2 shows the experimental results at 100G–QPSK and 200G–16QAM, obtained with the TOSA package and LiNbO$_3$ PMQ, both in back-to-back (Figs. 2(a) and 2(b)) and after fiber transmission (Figs. 2(c) and 2(d)).

At 100G, B2B curves in Fig. 2(a) show no OSNR penalty between the TOSA and LiNbO$_3$ PMQ (OSNR < 10.4 dB), both in single channel and in WDM. A 0.6-db penalty is observed between single-channel and WDM, at the BER of $2.4 \times 10^{-2}$ (SD-FEC limit), for both transmitters due to the reduced effective number of bits (ENOB) in the oscilloscope for the channel under test in the latter case. Transmission results in Fig. 2(c) at the optimal launch power show a maximum distance of ∼7500 km for single-channel, and ∼7000 km for WDM transmission, with either transmitters.

At 200G, B2B results show a slight OSNR penalty for the TOSA (OSNR < 19.5 dB), compared to its LiNbO$_3$ (OSNR < 18.5 dB) counterpart. This penalty was mainly due to the the carrier board that the TOSA was mounted reducing its overall EO bandwidth (∼11 GHz). Although a three-tap digital pre-compensation filter was used in the DSP-ASIC to minimize this bandwidth penalty, 200G-16QAM signals are more sensitive and still showed a residual penalty reflected in the BER floor. However, around the FEC limit, the penalty is lesser than 0.5 dB for the single-channel case and ∼1 dB for WDM. The 1-dB OSNR penalty between the two optical transmitters is also reflected in
the transmission results in Fig. 2(d): the system reach for the 200G channel under test was ∼1600 km when using the TOSA whereas the transmission over ∼1900 km was achieved when using the LiNbO$_3$ modulator.

Fig. 2. B2B measurements and transmission results for (a),(c) 100G and (b),(d) 200G rates.

4. Conclusion

We experimentally demonstrated a Polymer-based TOSA compatible with coherent optical modules in spectrally-efficient Nyquist WDM at 37.5 GHz grid, transporting 21×32-GBd PM-QPSK and PM-16QAM over long-haul distances, i.e. 7000 km (2.66 bit/s/Hz) and 1600 km (5.33 bit/s/Hz), respectively. The system-level results show comparable performance against LiNbO$_3$ technology with an advantage of having an ultra-compact package to be deployed in CFP2-ACOs running in 100G and beyond.

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References