

240/160 Gbaud OOK Silicon Photonics MZM/RRM Transmitters for Short-Reach Applications

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Abstract—We demonstrate a record 240 Gbaud on-off keying, 150 Gbaud 4-level pulse amplitude modulation, and 100 Gbaud 6-level pulse amplitude modulation SiP MZM-based transmitter with performance below the 6.25% overhead HD-FEC threshold. We also show a 160 Gbaud on-off keying SiP RRM-based transmitter.

Keywords—silicon photonics, ring resonator modulator, Mach-Zehnder modulator

I. INTRODUCTION

Silicon photonics (SiP) is a key enabling technology for high-baudrate communication. An ultra-compact SiP slow light modulator with record-high bandwidth of 110 GHz shows the potential [1]. Multilevel pulse amplitude modulation (PAM) and on-off keying (OOK) should be considered. Recently, a SiP RRM was used to demonstrate 128 Gbaud OOK [2] and 120 Gbaud PAM4 [3]. Also, 80 Gbaud PAM4 transmission over 1 km single mode fiber was shown [4] using RRM. On the other hand, the SiP Mach-Zehnder modulator (MZM) offers differential drive benefits. O-band SiP MZM was used to achieve 134 Gbaud PAM4 and 115 Gbaud PAM8 [5]. SiP advantages have been demonstrated for 4 x 200 Gbps transmission using four-channel SiP MZM [6] and for 4 x 112 Gbps for SiP RRM [7].

In this paper, we demonstrate SiP MZM/RRM-based transmitters to achieve 240/160 Gbaud OOK and 150/85 Gbaud

PAM4 below 6.7% overhead (OH) hard-decision forward error correction (HD-FEC) threshold of 4.5×10^{-3} . We also managed to achieve 235 Gbaud OOK, 145 Gbaud PAM4, and 100 Gbaud PAM6 transmission with SiP MZM over 100 meters single mode fiber (SMF) which is better than the current state-of-the-art for SiP links.

II. EXPERIMENTAL CONFIGURATION

Figure 1(a) shows the experimental setup. The signal bit sequence is generated offline in MATLAB from a random binary sequence of >1 million bit-length obtained using the Mersenne Twister generator with a shuffled seed number. The obtained bit sequence is firstly digitally up-sampled to 4 samples per symbol, pulse-shaped with root-raised-cosine (RRC) filter with 0.4 to 0.45 roll-off factor, and down-sampled to 256 GSa/s to match the sampling rate of the arbitrary waveform generator (AWG, prototype of Keysight M8199B). The output voltage swing of the AWG is set to be 2.7 Vpp for RRM and 2.2 Vpp per arm for MZM resulting in a total swing of 4.4 Vpp for the differential drive. Both modulators are reverse biased using 110 GHz bias-tees at 1.15 V. The output power of the tunable laser is set to +15.5 dBm and coupled into the modulators using grating couplers. Insertion loss values for grating couplers, waveguides, MZM, and RRM (see Fig. 1(c)), as well as amplitude responses (see Fig. 1(b)) of both devices, are measured using Keysight Integrated Photonics Test Setup [8] at 2 V reverse bias for RRM and 1.15 V reverse bias for MZM. For

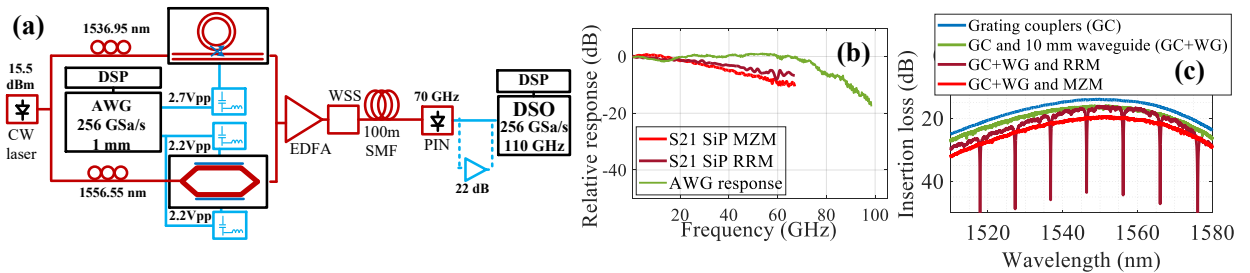


Fig. 1. (a) Experimental setup. (b) Measured amplitude responses for modulators. (c) Insertion loss for different parts of SiP chip.

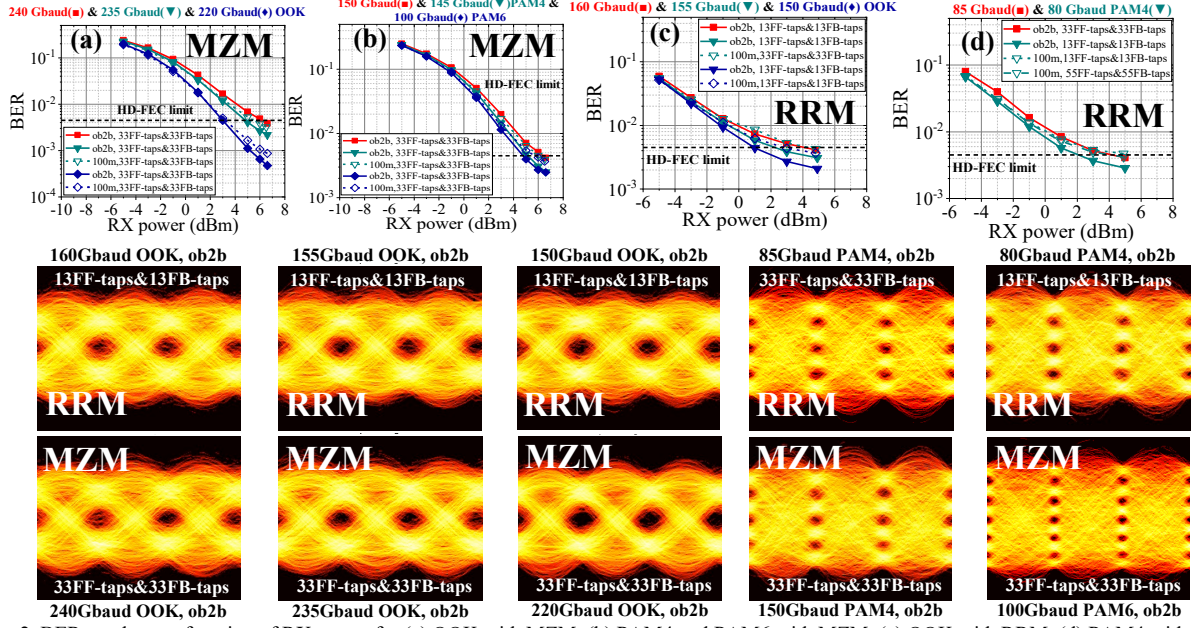


Fig. 2. BER results as a function of RX power for (a) OOK with MZM, (b) PAM4 and PAM6 with MZM, (c) OOK with RRM, (d) PAM4 with RRM. Eye diagrams for both RRM and MZM shown as insets.

both modulators, at 67 GHz we measure less than 10 dB attenuation. The smooth roll-off in the frequency transfer function makes the usable modulator bandwidth far beyond 67 GHz. For Si MZM tunable laser wavelength is set to 1556.554 nm. The heater current is set to 6.65 mA for MZM to set the optimal operation point (4 dB) after optimization. After optimization to determine the best resonance for modulation, Si MRM tunable laser wavelength is set to 1536.947 nm, which corresponds to 7.6 dB detuning. To avoid MRM instability due to self-heating, the heater current is set to 3.6 mA. After optical modulation the signal is transmitted over 100 m of SMF. An Erbium-doped fiber amplifier (EDFA) with an output power of 13 dBm is used to overcome coupling losses. Wavelength selective switch (WSS) is used to filter out the amplified spontaneous emission noise, resulting in up to 6.6 dBm optical power on 70-GHz PIN photodiode (PD). The signal from PD is delivered to a 110-GHz real-time digital storage oscilloscope (DSO, 256 GSa/s, Keysight UXR1104A). For RRM PAM4 transmission a packaged electrical amplifier with a gain of 22 dB is used after PD. Finally, the signal is processed with a matched filter, a timing recovery and down-sampling process based on maximum variance, a symbol-spaced decision-feedback equalizer (DFE) with different feedforward (FF)-taps and feedback (FB)-taps, and the BER performance is counted after the offline demodulation.

III. EXPERIMENTAL RESULTS

In Fig. 3, we show BER as a function of received optical power for both SiP transmitters. Eye diagrams are showed as insets. As one can see from Fig. 3(a), we managed to generate 240 Gbaud OOK signal with SiP MZM modulator. We also achieve transmission of 235 Gbaud and 220 Gbaud OOK over 100 meters of SMF. DFE with 33 FF-taps & 33 FB-taps was used to achieve performance below a 6.25 % OH HD-FEC

threshold. In Fig. 3(b) we show the performance of 150 Gbaud PAM4 and 100 Gbaud PAM6. We managed to transmit 145 Gbaud PAM4 and 100 Gbaud PAM6 over 100 meters of SMF. RRM-based transmitters performance is shown in Fig. 3(c) and (d). We generate 160 Gbaud OOK signal with only 13 FF-taps & 13 FB-taps for the DFE.

IV. CONCLUSIONS

We generate a record 240 Gbaud OOK, 150 Gbaud PAM4, and 100 Gbaud PAM6 signals with performance below the HD-FEC threshold using SiP MZM-based transmitter. We also show a 160 Gbaud OOK SiP RRM-based transmitter.

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