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4-PAM Dispersion-Uncompensated Transmission with Micro-Ring Resonator Enhanced 1.55-µm DML

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Abstract: Real-time transmission of 14-GBd 4-PAM signal is demonstrated by combining a commercial 1.55-µm DML with a silicon MRR. BER below the HD-FEC threshold is measured after 26-km SSMF transmission without offline digital signal processing.
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1. Introduction

The significant traffic growth in short-reach and inter-datacenter communications in recent years has been driving an increasing effort to provide low-cost high-speed integrated solutions for transmission distances in the range of few tens of km. Along this direction, several alternatives have been proposed, mainly focused on replacing expensive external modulators with directly modulated lasers (DMLs), thus enabling a significantly reduced footprint [1].

Additionally, in the quest for higher transmission rates, several impressive demonstrations have been reported by using more complex modulation schemes such as discrete multi-tone (DMT) signaling [2] and pulse amplitude modulation (PAM), including 4-PAM [1,3] and 8-PAM [3]. The use of n-PAM signals allows increasing the bitrate by a factor $log_2(n)$ for the same bandwidth usage, and enables a higher dispersion tolerance, compared to OOK transmission for the same bitrate. However, combining advanced signaling techniques with DMLs is particularly challenging due to the limited achievable extinction ratio (ER). A promising approach to tackle this challenge is optical spectral reshaping (OSR) by use of optical filters [4-8]. OSR has been shown to significantly enhance the achievable ER as well as to increase the dispersion tolerance for both OOK [4-7] and 4-PAM [8] signals. The use of micro-ring resonators (MRRs) to provide OSR is particularly beneficial as they can be fabricated on a silicon-on-insulator (SOI) platform as compact devices. Furthermore, the integration of a III/V hybrid DML and an MRR on the same chip has shown to provide a significant reach improvement for 10-Gb/s OOK transmission [7].

Moving to 4-PAM, however, many of the demonstrations reported so far rely heavily on off-line digital signal processing (DSP), for example by performing adaptive equalization [8], which increases the latency as well as adds the need for analog-to-digital converters (ADCs) leading to an increased power consumption and cost.

In this work, we report real-time directly-detected transmission of 14-GBd 4-PAM signals over 26 km of standard single mode fiber (SSMF), and demonstrate bit error ratios (BERs) below the hard-decision forward error correction (HD-FEC) threshold (BER=3.8×10^{-3}, at 7% overhead), by combining a commercial 10-Gb/s DML with OSR performed using a silicon MRR without any complex off-line DSP nor dispersion compensation.

2. Experimental setup

The experimental setup is shown in Fig. 1(a). A 4-PAM electrical signal was generated by feeding a pseudo random binary sequence (PRBS) of period 2^7-1 and its negated version (delayed by more than 10 symbols) into a 3-bit digital-to-analog converter (DAC, 19-GHz analog output bandwidth). The 4-PAM signal was then amplified by a linear electrical amplifier and combined with a DC bias in a 45-GHz bias-T to drive the DML. To enhance ER and dispersion tolerance of the 4-PAM signal, the laser output was coupled into an MRR used to provide a notch filter transfer function similarly to the OOK results of [5,6]. After spectral re-shaping the 4-PAM signal was transmitted through SSMF (D≈17 ps/nm·km at the DML wavelength) and characterized by real-time BER measurements.

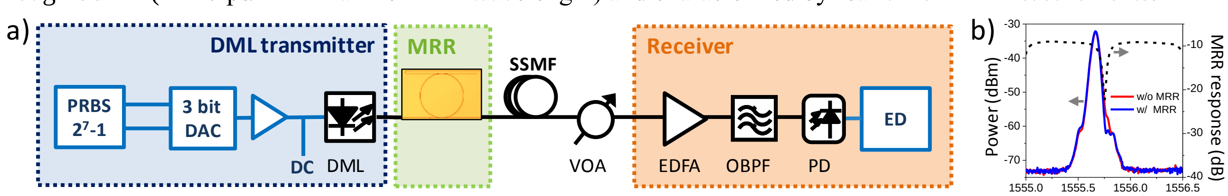

Fig. 1. a) Experimental setup for the transmission measurements; b) optical spectra without and with the MRR filter (solid) and MRR transfer function (dashed).

The standard pre-amplified receiver used consisted of an erbium doped fiber amplifier (EDFA) a 2-nm wide optical bandpass filter (OBPF) to remove the out-of-band amplified spontaneous emission noise and a 45-GHz photodiode (PD). A variable optical attenuator (VOA) at the receiver input was used to vary the received power, and measure the BER versus received power. After the PD, a real-time error detector (ED) measured the BER. Since the ED was designed for OOK modulation, i.e. considering only one threshold level, three error rates ER_i were sequentially measured, one for each of the three eye openings of the 4-PAM signal, labelled from top to bottom. The overall BER was then calculated as $BER = 0.5 \cdot ER_1 + ER_2 + 0.5 \cdot ER_3$ [3,9].

3. Transmission results

The principle of OSR with the MRR filter is highlighted in Fig. 1(b) reporting the optical spectra with and without MRR (100-GHz free spectral range [6]). The notch-filtering provided by the resonance of the MRR reshapes the spectrum of the optical signal and thus enhance the modulation ER as shown in the eye diagrams of Fig. 2(a) for a 14-GBd 4-PAM signal both in back-to-back and after 26-km and 40-km transmission. The BER performance as a function of the received power is reported in Fig. 2(b). The DML transmitter with the MRR was benchmarked against the performance of the simple DML both in back-to-back conditions and after dispersion-uncompensated transmission.

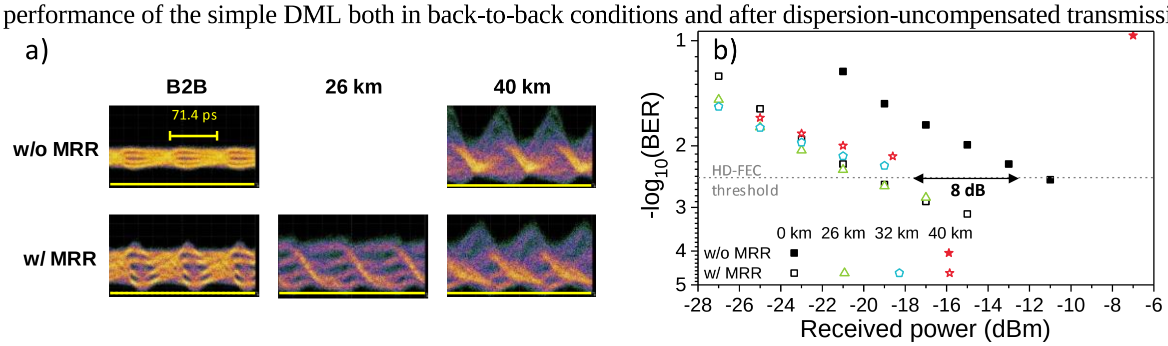

Fig. 2. Dispersion-uncompensated SSMF transmission of 14-GBd 4-PAM: a) Electrical eye diagrams in back-to-back and after SSMF transmission with and without MRR (Yellow lines provide the references for the zero levels.); b) BER versus received power.

The BER as a function of the received power is reported in Fig. 3(b). Adding the MRR provided 8-dB of sensitivity improvement at the HD-FEC threshold already in back-to-back condition. The enhancement in dispersion tolerance allowed transmitting over 26 km of SSMF with no penalty compared to back-to-back, maintaining the 8-dB of sensitivity improvement. Further transmission (32 km and 40 km) led to received power limitations as well as a tilt in the slope of the BER curves due to the temporal broadening and distortion of the eye diagram (Fig. 2(a)).

However, comparing the results for 40-km transmission with and without the MRR, the significant benefit from using the MRR is evident, resulting in a factor 15 decrease in BER at maximum received power. Although the signal could not be received below the standard HD-FEC threshold (7% overhead, [10]) after 40-km transmission, a stronger FEC code could still enable successful transmission at the cost of higher overhead or latency.

4. Conclusions

We have demonstrated real-time dispersion-uncompensated transmission of 14-GBd 4-PAM signals up to 26-km SSMF, without dispersion compensation or offline DSP. The ER and dispersion tolerance enhancements enabling such transmission reach are provided by OSR with a passive MRR. The improvement enabled by the MRR allowed an 8-dB increase in the receiver sensitivity at the HD-FEC threshold even after 26-km SSMF transmission.

5. Acknowledgements

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