DAC-less and DSP-free 20 Gb/s PAM-4 transmission based on a dual modulation scheme using DML and external modulation

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Abstract: The generation of DAC-less 20 Gb/s PAM-4 using a DML and an external modulator is demonstrated. This dual modulation scheme has been transmitted up to 75-km SSMF with similar performance to PAM-4 DAC transmitter.

1. Introduction

Network capacities and latencies are two key issues for today's access and data center environments linked to constant traffic growth. To this aim, transmitter requirements are driving significant efforts in finding compact, low-cost and energy efficient solutions.

A popular solution proposed to respond to these requirements is to use externally modulated laser (EML) largely used for 10G-class on-off keying transmission. EML presents the advantages of low chirp, compactness, low cost, low driving voltage and high stability [1], [2], which makes this solution an ideal candidate for such optical communication system especially over 40–80 km fiber in 100 and 400 Gbit/s ER-4 systems [3]. To target 100G-class transmission, 4-level pulse amplitude modulation (PAM-4) using direct modulation (DM) and direct detection (DD) is preferred because of its high spectral efficiency and cost-effectiveness.

PAM-4 modulation of EML allowed to reach 112 Gb/s transmission [4] using digital-to-analog converter (DAC) to generate PAM-4 and complex digital signal processing (DSP) at the receiver side. To guarantee energy efficiency and low latency in network, DAC-less and DSP-free transmission will be preferred. Dual modulation schemes using external modulators in series (resonators in [5]) or parallel structures (Mach-Zehnder in [6] or electro-absorption modulator (EAM) in [7]) have been demonstrated. However, natively, the EML structure is not directly adapted to DAC-less PAM-4 generation as dual modulation is not possible on this device.

Recently, laser modulated EML (LM-EML) with dual modulation on electro-absorption section and on laser section has been used: modulation of the laser section was used as phase modulation to curb chromatic dispersion in a 20 Gb/s single-sideband PAM-4 experiment in [8]; whereas it allowed extinction ratio improvement in a 25 Gb/s NRZ transmission in [9].

In this paper, we demonstrate a proof of concept of a new dual modulation scheme allowing PAM-4 modulation without DAC, using direct laser modulation and external modulation. Combined with an optical filter, a 20 Gb/s dispersion- uncompensated transmission up to 75-km SSMF is demonstrated and compared to performance of classical PAM-4 obtained by DAC and direct modulation of an external modulator.

2. Principle of DAC-less PAM-4 transmitter and experimental set-up

To generate DAC-less PAM-4, we propose simply to use a LM-EML with direct modulation of the laser section (DML) to print the least significant bits (LSB) and to print the most significant bits (MSB) on the electro-absorption modulator section (EAM) as schematized in Fig. 1 a).

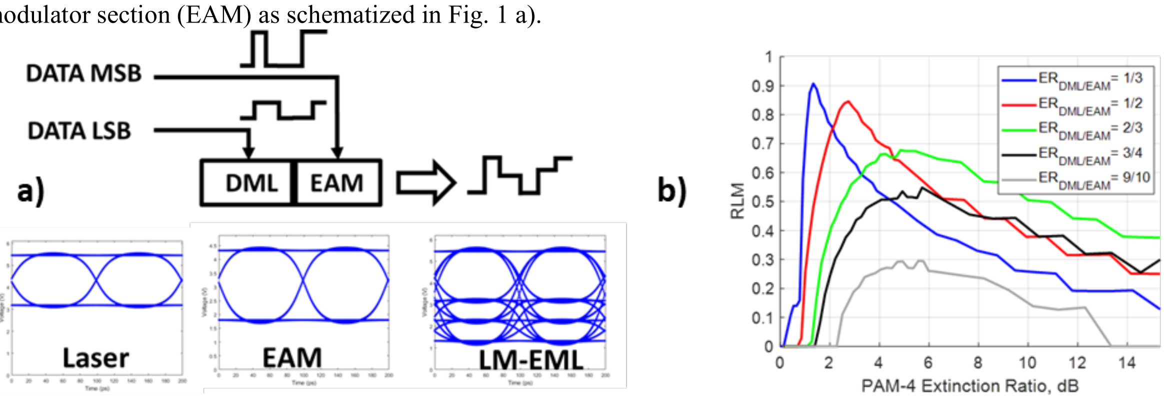

Fig. 1: a) Principle of DAC-less PAM-4 generation using LM-EML and b) level separation mismatch ratio (RLM) vs. PAM-4 extinction ratio for different ER on DML and EAM

This solution would fulfill main transmitter requirements described above. The main issue of this technic is the trade-off between the PAM-4 extinction ratio (defined as ratio of outer levels) and the level separation mismatching. Indeed on the contrary to parallel dual modulation schemes which sum the two modulated signals, here the signal is modulated twice in each device in series. We studied numerically this compromise in Fig. 1 b). The metric known as level separation mismatch ratio (RLM) [10], which quantifies the effect of level compression, is represented versus PAM-4 extinction ratio. The PAM-4 transmitter can be considered perfectly linear when RLM = 1. In this study, the EAM extinction ratio varies between 1 and 10 dB and the DML extinction ratio is adjusted in order to vary the ratio of extinction ratio between DML and EAM sections ($ER_{DML/EAM}$) between 1/3 and 2/3. First observation, whatever $ER_{DML/EAM}$, RLM is closer to 1 for poor PAM extinction ratio (< 2 dB). Secondly, the RLM drops strongly when PAM extinction ratio increases.
On Fig. 2 a), two eye diagrams are represented for RLM of 0.9 and 0.7 respectively. The PAM-4 extinction ratio is clearly more favorable for a RLM of 0.7. Therefore, the dual modulation scheme requires trade-off between PAM-4 extinction ratio and levels compression to guarantee sufficient performance on receiver. An extinction ratio of 5 dB seems a good compromise leading to a maximum RLM of 0.7 when the modulation ratio between DML and EAM is equal to 2/3.

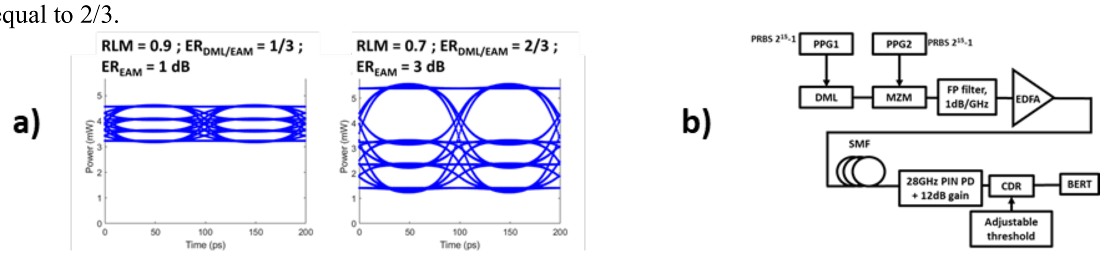

Fig. 2: a) Simulated eye diagrams at the output of the LM-EML for two operating points and b) experimental setup.

In this work, as no LM-EML was available for the experiment, we demonstrate experimentally the proof of concept using two discrete components knowing a directly modulated laser (DML) followed by an external modulator.
Fig. 2 b) shows the experimental setup. Two pulse pattern generators (PPG1 and PPG2) are used to generate two 10 Gb/s electrical signal with delayed patterns of pseudorandom binary sequence of length 2^{15}-1. The LM-EML is emulated by a DML with an E/O bandwidth of 15 GHz [11] followed by a $LiNbO_3$ Mach-Zehnder modulator (MZM). A Fabry-Pérot filter with a slope of 1 dB/GHz is used to improve the DML extinction ratio and dispersion tolerance as proposed in [11]. An erbium-doped fiber amplifier (EDFA) was placed after the filter to preamplify before transmission through a standard single-mode fiber (SSMF). An optical attenuator and optical power monitoring allows to adjust the power received by the 28 GHz PIN photodiode electrically amplified with a gain of 12 dB. A clock and data recovery (CDR) is used to carry out PAM-4 demodulation thanks to decision adjustable threshold and to feed the error counter of a bit-error-rate tester (BERT). No DSP is applied in this study.

3. Results and discussion

As explained in previous section, dual modulation scheme allows to generate PAM-4 signal thanks to a first NRZ modulation on DML and a second NRZ modulation on MZM. Fig 3 presents the different eye diagrams at each modulation stage. In the case of LM-DML, the modulation of laser section presents a lower intensity modulation efficiency than EAM section. So, in our case, MZM modulation would then act as the most significant bit (MSB) and DML modulation as the least significant bit (LSB). As seen on Fig 2 a), the operating point has been chosen from the simulation results allowing a trade-off between an extinction ratio of 5 dB and RLM of 0.7 thanks to a rate modulation ratio of 2/3 between DML and MZM.

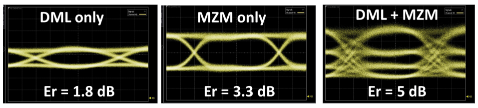

Fig. 3: Experimental eye diagrams.

For a quantitative assessment, the bit-error-rate (BER) is measured and compared to the reference of a standard PAM-4 obtained with a 3 bit DAC to generate the electrical PAM-4 signal feeding the MZM modulator. In this case, the DML is driven continuously and an extinction ratio better than 10 dB is obtained on PAM-4 signal.
In the reference case, the back to back (B2B) curve shows an error floor around 1×10^{-8} (Fig. 7) owing from a lack of sensitivity of our photodiode coupled to the CDR. Using the dual modulation the error floor jumps to 8×10^{-5} because of a reduction of the extinction ratio in this case (5 dB compared to 10 dB for the reference).

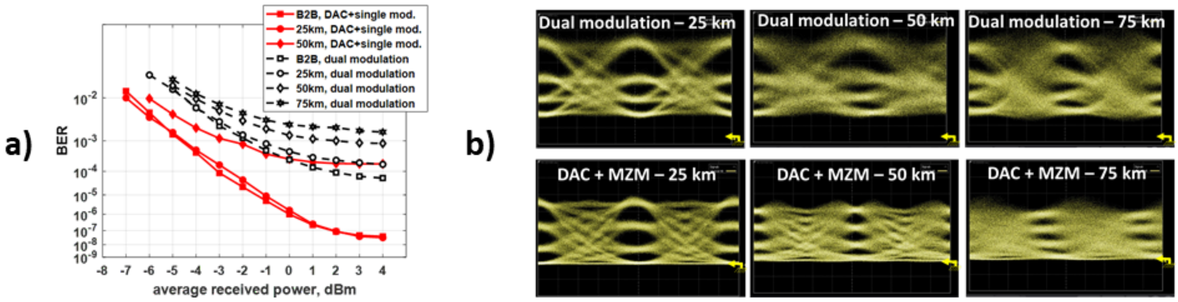

Fig. 4 a) BER vs. received optical power for 10Gbaud PAM-4 and b) Eye diagram after transmission for DAC-less PAM-4 generation using dual modulation and PAM-4 generation using DAC with MZM

After 25 km propagation, the BER performance for dual modulation and standard PAM-4 reference are very close to B2B results. In both cases, a shifted optical filter was used. Even for PAM-4 reference, the optical filter indeed allows a better dispersion tolerance provided essentially by a slight side-band filtering. To avoid an overload of the article, only cases including filter are reported.

After 50-km propagation, the dual modulation and PAM-4 reference are very close with an error floor of 8.5×10^{-4} and 2×10^{-4} respectively. The BER in the dual modulation case decreases by one decade after 50 km while PAM-4 reference losses four decades.

After 75-km, it was impossible to have pattern lock for the reference curve. In the case of dual modulation, an error floor of 1.7×10^{-3} is measured thus demonstrating a better robustness to chromatic dispersion.

We can see on Fig. 8, the eye diagrams associated to dual modulation and PAM-4 reference after 25, 50 and 75-km. In the reference case after 75-km we observe a time skew on the eye diagram which is linked to chromatic dispersion effect also explaining the impossibility to measure any BER. In the case of dual modulation, the time skew is less present thanks to the combination of laser chirp and shifted optical filter as observed in previous work [11].

4. Conclusions

We demonstrate experimentally the use of a dual modulation scheme, using direct laser modulation and external modulation, to generated a DAC-less, DSP-free, 20 Gb/s PAM 4 signal. The transmitter assisted by optical filtering allowed transmission over 75 km SSMF with an error floor of 1.7×10^{-3}. The BER performance measured after 50 km SSMF are near to classical PAM-4 scheme using DAC and external modulator. Considering previous works on integrated LM-DML [8], we are confident on the success of the method using an integrated LM-DML as DAC-less PAM-4 transmitter.

5. Acknowledgments

The DML used in this paper has been provided by III- V lab in the framework of French ANR project DIQDOT (ANR-11-INFR-0003). This work was supported in part by the Contrat de Plan Etat-Région SOPHIE and the French Ministry of Research.

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