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Feasibility Study for 111 Gb/s PolMux-Quadrature Duobinary with a SE of 4.2 b/s/Hz

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Abstract—We investigate, by means of simulations, polarization multiplexed (PolMux) quadrature duobinary (QDB) as a modulation format for transmitting 111 Gb/s signals with high spectral efficiency, robust performance and acceptable system complexity.

I. INTRODUCTION

The recent advances in coherent detection for optical telecommunications have triggered an intensive investigation for the most robust and spectrally efficient (SE) modulation formats [1-3]. Polarization multiplexed (PolMux)-return to zero (RZ)-quadrature phase shift keying (QPSK) seems to be the strongest candidate for first generation 100 Gb/s transponders [1]. This is due to its low OSNR requirements and relatively good tolerance to nonlinear transmission effects, which make it very suitable for long haul transmission links with a spectral efficiency (SE) of 2.2 b/s/Hz. The following generations of 100 Gb/s transponders are expected to have a higher SE compared to PolMux-RZ-QPSK. But on the other hand, they are expected to have a higher OSNR requirements and less robustness to the different transmission effects. This is due to the need for modulation formats with denser constellation diagrams. Therefore, it is critical to search for the modulation format that can guarantee a good trade-off between SE, robustness and OSNR requirements.

One of the many modulation formats studied recently is PolMux-quadrature duobinary (QDB) [4-6] due to its high SE and simple transmitter structure. In this paper, we will investigate by means of simulations the possibility of using PolMux-QDB as a modulation format that can achieve a data rate of 111 Gb/s per channel with a SE of 4.2 b/s/Hz. Furthermore, we will demonstrate that in comparison to PolMux-16QAM, PolMux-QDB has a less complicated transmitter, more tolerance to transmitter and receiver laser phase noise, as well as nonlinear transmission effects, but less tolerance to narrow band filtering.

II. SIMULATION SETUP

To simulate the 111 Gb/s PolMux-QDB signal, two conventional IQ-modulators with their outputs multiplexed on orthogonal polarizations have been modeled. The four electrical binary data streams driving the modulators at a data rate of 27.75Gb/s are first

duobinary encoded and afterwards passed through baseband electrical filters with bandwidth= $B/4$, where B is the symbol rate. These narrow band filters function as delay and add components through the inter-symbol interference they induce between adjacent bits, resulting in a three level electrical signal. The PolMux-QDB transmitter is depicted in Fig. 1a, where it can be seen that in each polarization two duobinary signals are generated independently and afterwards quadrature modulated [4-6]. The eye diagrams for DB (i), QDB (ii) and PolMux-QDB (iii) are shown in Fig. 1b. Four de Brillouin sequences with a length of 2^{10} and a relative delay of 170 bits between each other are used to drive the PolMux-QDB transmitter.

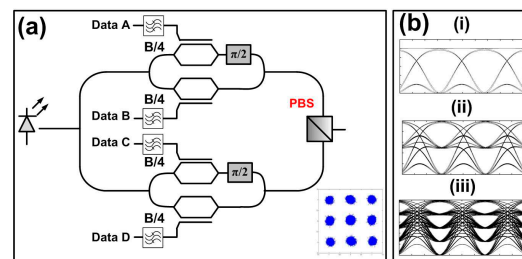


Fig. 1. PolMux-QDB system: (a) transmitter setup and constellation diagram (b) DB, QDB and PolMux-QDB eyediagrams

For detecting the signal, a coherent receiver consisting of an ideal local oscillator (LO), an IQ mixer and single ended photodetectors is simulated. Afterwards the signal is sampled with two fold oversampling, and further processed in the electrical domain. The algorithms employed for the detection and equalization of PolMux-QDB are described in details in [6].

For comparison purposes PolMux-16QAM and PolMux-RZ-QPSK signals are also simulated at a data rate of 111 Gb/s. To simulate the generation of the PolMux-RZ-QPSK signal, a transmitter similar to the one described in [1] has been modeled. On the other hand, the PolMux-16QAM transmitter is modeled in a similar way to the transmitter suggested in [7]. Coherent detection has been used for detecting both the PolMux-RZ-QPSK and PolMux-16QAM signals as well.

In order to test the tolerance of the PolMux-16QAM and PolMux-QDB signals to nonlinear fiber transmission effects, transmission over an SSMF link is simulated. The transmission link is composed of 30 non dispersion managed spans with a length of 95 km each and assumes EDFA only amplification. Such long transmission

distance is chosen merely to simulate strong nonlinear effects on the transmitted signals. In all of our simulations one block of 1024 symbols is transmitted over the link. At the receiver, 10^6 bits are generated from the received sequence using the overlap and add method and ASE noise is added to the signal in order to simulate different OSNR values.

III. SIMULATION RESULTS

At first, a back-to-back OSNR sensitivity simulation is carried out in order to compare the OSNR requirements for the different modulation formats. The results for these simulations are depicted in Fig. 2. Compared to PolMux-RZ-QPSK, PolMux-QDB and PolMux-16QAM require a ~ 2.2 dB and ~ 4.2 dB higher OSNR respectively, at a BER of 10^{-3} . In Fig. 3 the narrow band filtering tolerance for the different modulation formats is demonstrated using a 4th order Gaussian filter with a 3 dB BW varying between 20 GHz and 50 GHz. The results in Fig. 3 are shown in terms of the OSNR penalty to achieve a BER of 10^{-3} compared to the back-to-back performance. The results show that PolMux-16QAM has the highest tolerance to narrow band filtering, as it can tolerate a filter BW of 14 GHz with a penalty of 1 dB. Despite that PolMux-QDB does not exhibit as much tolerance to narrow-band filtering (22 GHz with a penalty of 1 dB) it can give an advantage compared to PolMux-RZ-QPSK (26 GHz with a penalty of 1 dB). We will exploit this improved filtering tolerance of PolMux-QDB to reduce the channel spacing to 25 GHz in order to obtain a SE of ~ 4.2 b/s/Hz.

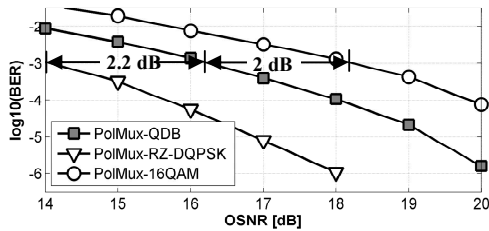


Fig. 2. Back-to-back performance for the different modulation formats.

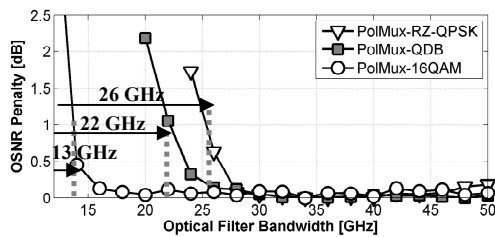


Fig. 3. Back-to-back performance for the different modulation formats.

Fig. 4 reports on the tolerance of the three modulation formats to the linewidth of the LO laser. The carrier recovery algorithm described in [8] has been applied to the three modulation formats. The figure shows the penalty in required OSNR for a BER of 10^{-3} vs. the linewidth x symbol duration. According to the results, PolMux-RZ-QPSK has the highest tolerance to the LO linewidth and can tolerate a linewidth of 28 MHz at a data rate of 111 Gb/s. On the other hand, PolMux-QDB and PolMux-16QAM have a linewidth tolerance of

12.6 MHz and 2.8 MHz respectively. Once again, this shows the superior performance of PolMux-QDB over PolMux-16QAM.

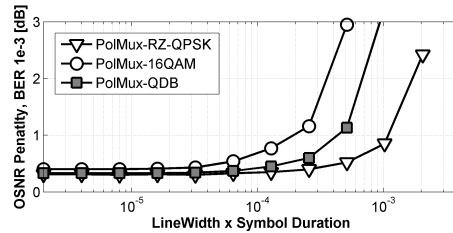


Fig. 4. Tolerance to LO laser Linewidth.

Finally, in order to exploit the high tolerance to narrow band filtering for PolMux-QDB, we simulated the transmission of nine 25 GHz spaced WDM PolMux-QDB channels, and we compared the performance to a PolMux-16QAM signal under the same conditions. The simulated transmission link is described in the previous section. Noise loading at the receiver side is used to calculate the required OSNR to achieve a BER of 10^{-3} at different launch powers. Fig. 5 shows that both modulation formats are not very robust against inter-channel nonlinear effects, and they have the same performance at a penalty of 1 dB. However at the 3 dB penalty, PolMux-QDB has 1 dB of advantage over PolMux-16QAM regarding the input power. Note that for PolMux-QDB the required OSNR at low launch powers is increased by 2 dB compared to the back-to-back case due to the use of two 22 GHz filters for multiplexing and de-multiplexing the channels at 25 GHz spacing (Fig. 3).

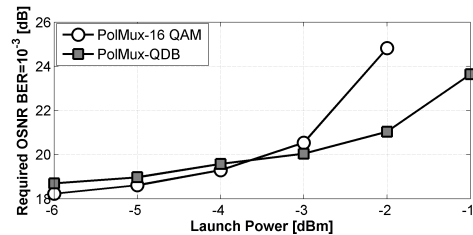


Fig. 5. Transmission results of nine 25 GHz spaced channels.

IV. CONCLUSIONS

In this paper we demonstrate by means of simulations the feasibility of using PolMux-QDB for transmitting a data rate of 111 Gb/s with a SE of ~ 4.2 b/s/Hz. Compared to PolMux 16QAM with the same data rate and SE PolMux-QDB has a simpler transmitter structure and a better tolerance to both nonlinear transmission effects and LO laser linewidth.

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