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Vegas Olmos, Juan José; Suhr, L. F.; Li, Bomin; Tafur Monroy, Idelfonso

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10 Gbps Five Levels Polibinary Signaling for Short Range and Access Networks

J.J. Vegas Olmos, L.F. Suhr, B. Li, and I. Tafur Monroy

*Department of Photonics Engineering, Technical University of Denmark, Ørsted Plads 343, Kgs. Lyngby, 2800, Denmark
jjvo@fotonik.dtu.dk*

Abstract: This paper presents a novel five level polibinary signaling modulation and experimentally demonstrates 10 Gbit/s generation and transmission up to 20 Km utilizing only 1.8GHz bandwidth.

OCIS codes: (060.4510) Optical Communications; (060.4080) Modulation.

1. Introduction

Increasing capacity in optical channels is forcing technology to move from spectral inefficient non-return to zero (NRZ) to advanced modulation formats. Moreover, the complexity raise in the transmitter and receiver must be kept to the minimum in order to maintain the cost contained. There are two main scenarios that require high capacity with low complexity, short reach optical interconnects [1] and optical access networks [2]. These scenarios are currently requiring 400G and 40-100G solutions, respectively. Different techniques have been used for advanced modulation, such as discrete multitone (DMT) [3], carrierless amplitude/phase (CAP) [4], orthogonal frequency division multiplexing (OFDM) [3], and N-pulse amplitude modulation (N-PAM) [6]. Additionally, duobinary modulation has been extensively used in high-capacity backplanes [7], where the roll-off of the backplane itself matches the spectrum profile of the duobinary signal. Duobinary modulation is in fact a part of the family of polibinary signaling presenting three levels. Polibinary signals can actually have as many as M levels, as early identified [8-10]. A polibinary signal with five levels, $M=5$, presents a competitive advantage in terms of bandwidth usage: theoretically a bit rate of B can be sustained in a channel of single-sided bandwidth $B/8$ of the original bandwidth. The advantages of a five level polibinary signal stemming from a reduced bandwidth when considering transmission are very attractive: chromatic dispersion impairments are drastically reduced, along with stimulated Brillouin backscattering (SBS), which infers higher launch power into the fiber can be sustained.

In this paper we provide a proof-of-concept of polibinary signaling at 9.1 Gbps (10G class) with five levels using only 1.8GHz of bandwidth, which effectively provides a spectral efficiency of 5.05 b/Hz/s. Polibinary signaling of high order provides a technical solution to overcome bandlimited optical transmitters and receivers, and paves the way to bring multigigabit capacity to end users cost-effectively. To the best of our knowledge, no experimental assessment of optical five level polibinary has been reported before at any bitrate.

2. Background and experimental demonstration

Polibinary signaling is an advanced modulation format, also known as partial-response transmission format, which makes use of bit correlation to reduce the spectral width. This correlation is introduced through an amount of controlled Inter-Symbol Interference (ISI). This controlled ISI is introduced by a simple codification scheme [10] in which each output bit is modulo-2 of the previous three output bits and the current bit. By using this specific coding, not only ISI is introduced but also degeneracy in the recovery is avoided. Degeneracy would occur in an uncoded polibinary signal if the receiver provides a wrongful output which is later taken as an element to figure out further bits. Once the coding is conducted, a low pass filter (LPF) is generally used to remove the undesired frequency components. There have been many research efforts to optimize the LPF's bandwidth in duobinary systems [11-12]. As a rule of thumb, it is well known that for a duobinary signaling, fifth order low pass Bessel filters having a 3 dB bandwidth equal to the quarter of the data rate gives a satisfactory performance. For a five level polibinary, and based on sound assumptions, the bandwidth of the Bessel filter must be in the order of 1.8-2 GHz.

The receiver side using polibinary can be based on simple standard direct-detection (DD), and then either sampled and the signal recovered using digital signal processing (DSP) or by placing analog thresholds. Either approach is employed, the complexity is in the vicinity of 4-PAM and 8-PAM receivers, which are currently considered viable solutions for 100/400G solutions [13]. DSP processing offers the advantage of flexibility and reconfigurability on the spot, and because the bandwidth of the polibinary signal is extremely reduced in comparison to the original NRZ, the pressure on the processing power at the receiver is reduced drastically.

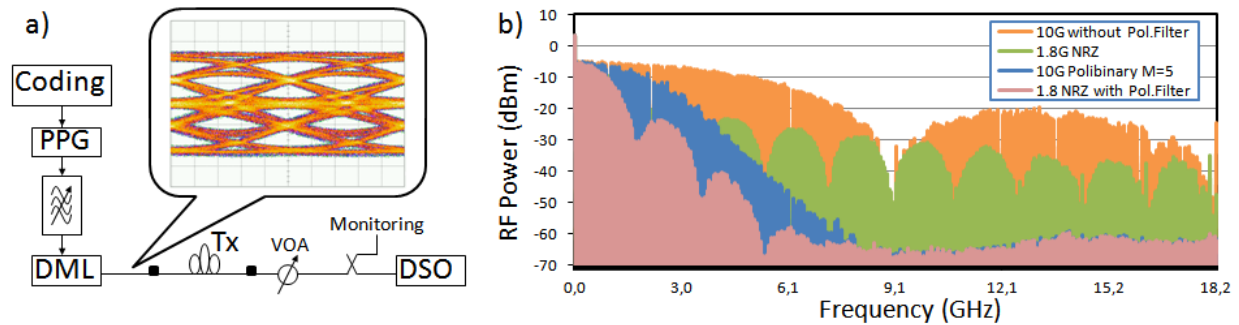


Fig. 1. Experimental setup (a) and electrical spectrum of different signals after optical generation (b). PPG: pulse pattern generator. DML: directly modulated laser. Tx: transmission link. VOA: variable optical attenuator. DSO: Digital sampling oscilloscope.

Figure 1(a) shows the experimental setup employed to demonstrate five level polibinary modulation and an inset of the eye diagram back-to-back five level polibinary signal. The setup consisted of a pulse pattern generator (PPG) loaded with the precoded five level polibinary bit stream. The signal from the PPG was strongly filtered by a 5th order Bessel filter with a 1.8 GHz frequency cut-off and then used to modulate a directly modulated laser (DML) operating at 1550.2nm. The optical polibinary signal was then transmitted through different fiber spans, and sampled and stored by a digital sampling oscilloscope with 13GHz bandwidth at 40 Gsamples. Fig.1(b) the electrical spectrum of different optical signals to benchmark the spectra utilization of the five level polibinary signal. As it can be observed, the 10 Gbps NRZ and the 1.8 Gbps signals present lobules occupying 10 GHz and 1.8 GHz, respectively. These measurements were then completed by adding the Bessel filter; the filtering allows transferring the first three lobules of the 1.8 Gbps NRZ signal, which at practical effects does not impact its shape. However, when a five level polibinary 10 Gbps is generated, we can observe the spectra is severely reduce and contained within the first 2 GHz.

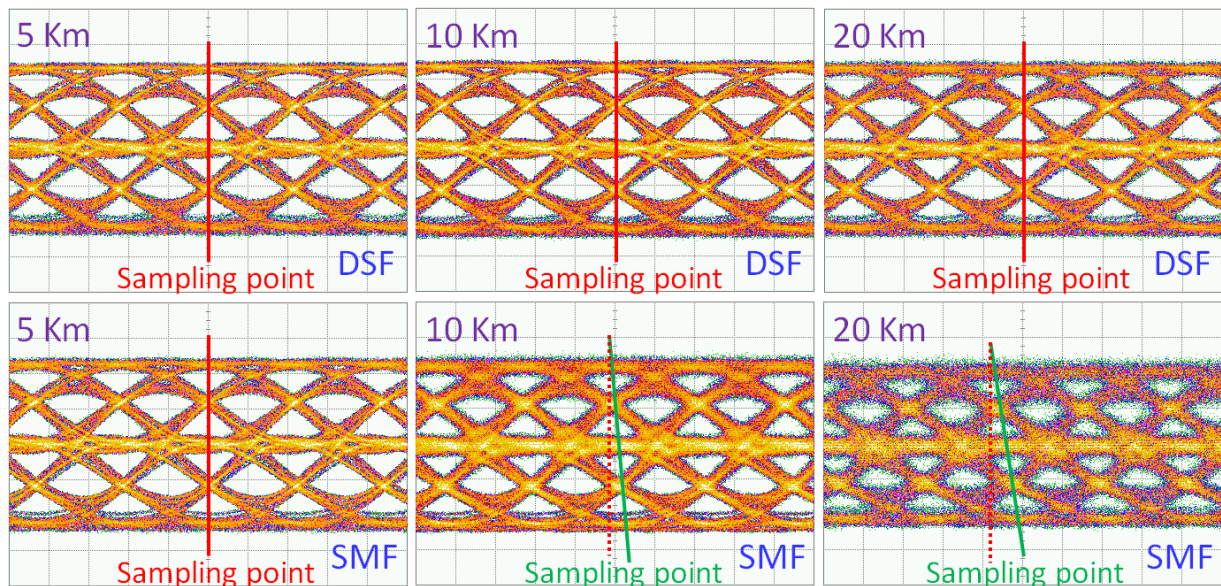


Fig. 2. Eye diagram of the back-to-back five level polibinary signal and the eyes diagrams after transmission through different length spans of DSF and SMF. Due to dispersion, the eye diagram skews after transmission in SMF beyond 10 Km.

Figure 2 shows the eye diagram after transmission through different length spans, specifically 5-, 10- and 20 Km. The fibers were chosen to be dispersion shifted fiber (DSF) and single mode fiber (SMF), which are arguably the most commonly deployed types of fiber. As it can be observed, the eye diagrams after 5-, 10- and 20 Km of DSF remain faithful to the back-to-back (Fig.1(a)). Due to dispersion, SMF shows a skewing of the eye diagram after 10- and 20-Km, which forces the DSP to adjust the sampling point. This effect can be therefore overcome although it inherently impairs the signal. The dispersion effect is clearly observable in the bit error rate (BER) curves, which are presented in Figure 3. The BER curves were measured for 10- and 20-Km, as we expected an identical performance of the 5 Km transmission. As it can be observed, DSF transmission and SMF of 10 Km produce BER with an

identical performance as the back-to-back case, whereas transmission through 20 Km of SMF incurs in a 2 dB power penalty.

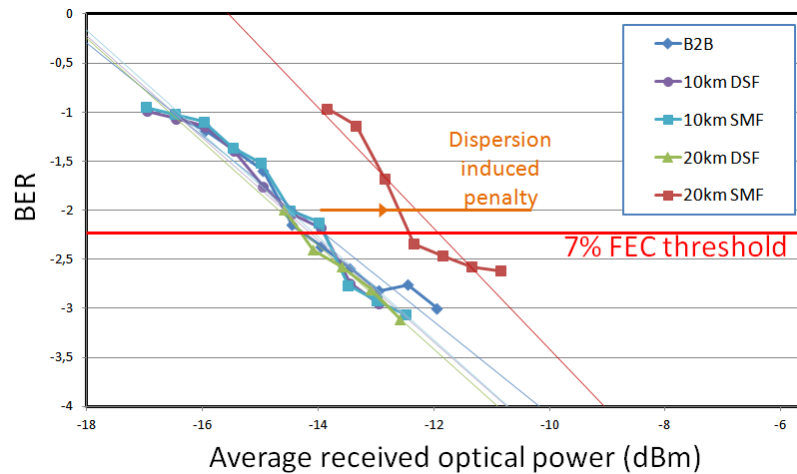


Fig. 3. Bit error rate (BER) performance of the five level 10 Gbps polibinary signal after different transmission links.

5. Conclusions

In this paper, we present a five level polibinary signaling for high-capacity optical access networks and short range systems. We experimentally demonstrated a polibinary signaling at 10Gbit/s using only 1.8GHz of bandwidth, which effectively provides a spectral efficiency of 5.5 bit/s/Hz. The complexity of the transmitter, compared to regular NRZ systems, lies in the need of precoding the signal and placing a low pass band filter. However, the savings in terms of bandwidth is more than fourfold when compared to regular NRZ signaling. Therefore, polibinary signaling of fifth order, provides a technical solution to overcome band limited optical transmitters and receivers with a contained complexity, and paves the way to bring multigigabit capacity to end users cost-effectively. Similarly, short-range systems for interconnects and data centers, which require high-capacity and requirements on optical signal to noise ratio (OSNR) are not as strict as in long transmission links, polibinary signaling can enable the way to simple 100G/400G communications.

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