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10-Gbps duobinary-4-PAM for High-Performance Access Networks

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Abstract: This paper reports on an experimental demonstration of a seven level duobinary-4-PAM signal operating at 10.16 Gbps, implemented analogically and featuring direct detection at the receiver side.

1. Introduction

The explosion of internet applications and media delivery over IP has fuelled the research for faster broadband connections in access networks. Fiber-based access networks are widely regarded as the main technological direction that can efficiently provide scalable bandwidth; copper-based and wireless-based solutions compete with fiber-bases solutions on the last few meters, yet fiber-based optical access networks are indeed bond to become the main skeleton of high-performance access networks. An issue under heavy study in this field is whether to put forward multilevel modulation formats. Multilevel or advanced modulation formats enable to increase the available bitrate of a system while keeping the bandwidth of the required photonic and electronic components and the deployed optical distribution network unchanged. Since optical access networks are extremely cost sensitive, and electronic/optic systems with bandwidth beyond 10 GHz become more complex, the introduction of multilevel modulation formats seem to be a matter of timing.

Proposed solutions include Orthogonal Frequency-Division Multiplexing (OFDM), in where spatial and frequency bit allocation schemes can be implemented, adding a new layer of reconfigurability [1]. Carrierless Amplitude Phase (CAP) [2] provides high spectral efficiency with simplified transmitter and receivers based on electrical passband filters. These two solutions, although relaxed in terms of electronic circuitry, placed some pressure on the optical side, as high extinction ratio or good linearity. Multilevel modulation formats based on well-known On-Off Keying (OOK) such as pulse-amplitude modulation (PAM)-4 or PAM-8 are also envisioned as possible candidates to increase the efficiency of the modulation format in access networks [3].

In this paper, we propose and experimentally demonstrate, the reduce further the bandwidth requirements on PAM-4 by using polybinary signaling [4]. A PAM-4 with an effective bitrate of 10 Gbps is converted into a polybinary signal, reducing the necessary electrical bandwidth. The complexity at the transmitter and receiver is low, enabling the usage of GPON class optics for 10 Gbps optical access networks.

2. Duobinary 4-PAM

Partial response signaling was first proposed to increase the spectral efficiency by exploiting Intersymbol Interference (ISI) Strong filtering of an on-off keying signal normally generates a polybinary signal. Strong filtering of the OOK induces ISI by removing the upper part of the spectra, effectively reducing the given bandwidth. Depending on the filter bandwidth, duobinary signals are obtained, or in the general case, M-levels signal streams. Lender, in 1964, predicted that multilevel signals can be also used to generate polybinary signals after strong filtering [5] Therefore, strong filtering can further boost the already increased spectral efficiency. In this work, we employed a 4-PAM signal as seed for a duobinary filter, effectively obtaining a duobinary-4- PAM 7-level signal. Because the generation method introduces correlation between adjacent bits, meaning that the current bit is also defined by the values of the k preceding bits, codification at the transmitter side is necessary in order to avoid error propagation at the receiver side. Considering a_k the original bit sequence, b_k a precoded 4-PAM sequence, and c_k the seven-level generated signal, it is possible to recover the original 4-PAM sequence from independent decisions on c_k, provided the following relationships are used:

$$b_k = a_k - b_{k-1} mod 4 \tag{1}$$

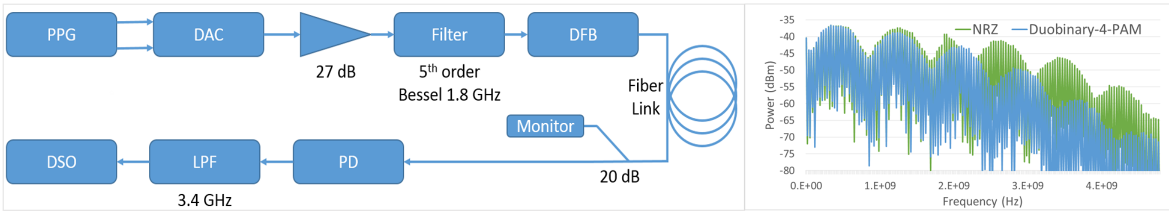

Fig. 1. On the left is the setup used for the experiment. On the right side a comparison of the 5.08 GBaud duobinary-4-PAM spectrum is compared to a 5.08 GBaud NRZ spectrum

$$c_k = b_k + b_{k-1} \tag{2}$$

$$a_k + c_k mod4 \tag{3}$$

The simplicity of the transmitter is outstanding; digital coding is a simple bit-to-bit operation and only analog filtering is needed after the 4-PAM generation. Analog solutions are already commercially available at low cost. The receiver side is equally frugal, as a simple sample point approach is used, avoiding the need for hungry digital signal processing (DSP) methods. The only necessary DSP processing consists in a mod4 operation.

3. Experimental setup

The experimental setup used to generate, transmit and receive the duobinary-4-PAM signal is shown in Fig. 1. One 5.08 Gbps Pseudo Random Bit Sequence (PRBS) and one logically inverted 5.08 Gbps PRBS was generated by a single Pulse Pattern Generator (PPG). Both streams were then multiplexed with a Digital-to-Analog Converter (DAC). After amplification the now 4-PAM signal, was filtered with a 1.8 GHz Bessel filter in order to generate the duobinary-4-PAM signal. The duobianry-4-PAM signal was then used to drive a Distributed Feedback laser (DFB) operating at 1550nm. The DFB was a commercial distributed feedback laser with a 10 GHz bandwidth with a bias current of 60 mA. After transmission over various Single-Mode Fibers (SMFs) the signal was detected by a 10 GHz Photodiode (PD). Before reception by a 40 Gsa Digital Storage Oscilloscope (DSO), the signal was filtered by a 3.4 GHz Low-Pass Filter (LPF) to remove out of band noise. Off-line processing was implemented in MATLAB with a single decision point in time per bit.

4. Results

Fig. 2 shows the measured Bit Error Rate (BER) for 10, 20 and 40 km Standard Single-Mode Fiber (SSMF), and 5, 10, 20 and 40 km for Dispersion Shifted Fiber (DSF) and Non-Zero Dispersion Shifted Fiber (NZDSF). The needed BER

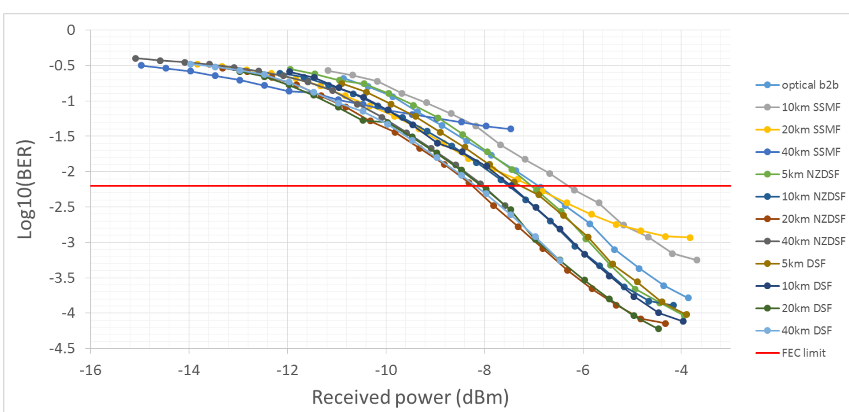

Fig. 2. The BER for the experiment

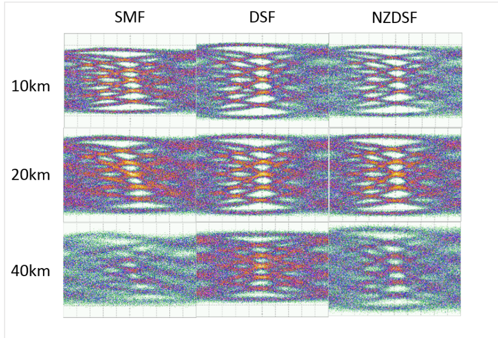

Fig. 3. The eye-diagrams for the 10, 20 and 40 km transmission lengths over different types of fibers. Dispersion is noticeable in the SMF, as the eye diagram is skewed

for error free recovery through %7-overhead Forward Error Correction (FEC) is $2.2 \times 10^{2.2}$. Some of the measured points in the BER from -2.5 towards -0.5 were affected by scaling of the DSO, therefore an off-set penalty has been added to these points for all the measurements to form a consistent BER curve. The receiver sensitivity for this BER is between -8 and -6 dBm all fiber types except 40 km SSMF which was not recoverable.
In the experiment only a single sampling point in time was used per bit. This means that dispersion induced skewing of the eye caused the 40 km SSMF to be unrecoverable.

5. Conclusion

This paper presents a seven-level duobinary-4-PAM signal that has been successfully generated and transmitted over a 40 km optical link. The total bitrate obtained is 10.14 Gbps using only a single wavelength and direct detection. The transmitter relies on a simple setup, consisting of a PPG with two outsput ports, a DAC and a 1.8 GHz low pass filter to generate the duobinary signal, which means the implementation is extremely simple. The receiver side is based on direct detection with a simple Digital Signal Processing (DSP) recovery scheme. The receiver sensitivity is reduced because of the extra generated levels compared to a standard 4-PAM signal, but the reduced spectral usage is sufficient to compensate for this penalty in optical access networks, or eventually, in short range access networks and data center interconnects.

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References

1. E. Giacoumidis, A. Kavatzikidis, A. Tsokanos, J. M. Tang, and I. Tomkos *"Adaptive Loading Algorithms for IMDD Optical OFDM PON Systems Using Directly Modulated Lasers"* IEEE Journal of Optical Communications and Networking 4 (10),769-778 (2012)
2. M. B. Othman, X. Zhang, J. B. Jensen, and I. T. Monroy *"Using CAP Dimensionality for Service and User Allocation for Optical Access Networks"* Asia Communications and Photonics Conference, paper AS3C.5. (2012)
3. N. Cheng, X. Yan, N. Chand, and F. Effenberger *"10 Gb/s Upstream Transmission in TWDM PON Using Duobinary and PAM-4 Modulations with Directly Modulated Tunable DBR Laser"* Asia Communications and Photonics Conference, paper ATh3E.4. (2013)
4. J. J. Vegas Olmos, Lau Frejstrup Suhr, Bomin Li, and I. Tafur Monroy *"Five-level polybinary signaling for 10 Gbps data transmission systems"* Opt. Express 21, 20417-20422 (2013)
5. A. Lender *"Correlative digital communication techniques"*. IEEE trans. commun. Technol. 12 (4), 128-135 (1964)