Enhanced Optical Generation of 42.7 Gbps Phase Shaped Binary Transmission

Guillaume Ducournau, Olivier Latry, and Mohamed Ketata

ABSTRACT—A novel method for optical phase shaped binary transmission (PSBT) generation has been recently reported and experimentally evaluated. An amelioration of the optical signal-to-noise ratio (OSNR) sensitivity of the optical PSBT modulation format is proposed with the application of the concepts of enhanced electrical PSBT signal generation. Enhanced optical PSBT is proposed here as a modulation format producing a 0.7 dB gain in OSNR sensitivity compared to OPSBT, while maintaining a good robustness to group velocity dispersion: 100 ps/nm for enhanced optical PSBT and 120 ps/nm for optical PSBT, compared to 50 ps/nm for standard NRZ signals.

Keywords—Optical telecommunications links, Mach-Zehnder interferometers (MZI), phase shaped binary transmission (PSBT) modulation format, group velocity dispersion (GVD).

I. Introduction

Actual optical systems deployed use principally 10 Gbps for data transmission. In the future, and principally during systems upgrades, installation costs will be reduced by using the already installed optical links. In order to achieve this, various modulation formats have been proposed and compared in terms of spectral efficiency and robustness to non-linear effects and to polarization mode dispersion (PMD) [1], [2]. In particular, the PSBT format presents a well-known group velocity dispersion (GVD) robustness and is therefore of high interest for long haul applications [3]. The concept of PSBT was proposed for the first time in [4] and [5]. It consists of driving a Mach-Zehnder modulator (MZM) with an electrical non-return to zero (NRZ) signal filtered by an appropriate Bessel filter. This ensures a superimposed phase modulated signal in addition to the conventional amplitude signal. This amplitude/phase profile leads to an increased robustness towards GVD in optical fibers. Electrical PSBT has been theoretically demonstrated in [5] and after that, the experimental work of [6] and [7] confirmed the superior GVD tolerance of PSBT versus conventional NRZ signals.

Last year, an all optical solution for PSBT generation was proposed [8], still ensuring a higher tolerance to GVD. Such a solution presents a very attractive characteristic: one optical filter, a Mach-Zehnder interferometer (MZI), is needed for all ITU channels, due to the fact that the MZI has a 50 GHz free spectral range (FSR) equal to the ITU grid spacing. This wavelength division multiplexing (WDM) compliance is an advantage over electrical PSBT, which requires n Bessel filters for n channels encoding. The robustness of PSBT towards GVD effects is counter-balanced by a reduction of the OSNR back-to-back sensitivity. This penalty originates from the residual optical power (opposed in phase from neighboring bits) during low binary level encoding. This drawback has been overcome to some degree by the concept of *enhanced PSBT* [9]. Enhanced PSBT technique consists of remodulating a PSBT with an NRZ signal at the same data rate, with an x dB extinction ratio. The generated format has been called the “x dB E-PSBT.” In [9], it was also shown that a 3 dB E-PSBT was a very promising modulation format for long distance terrestrial WDM transmissions.

In this letter, the concepts of enhanced PSBT are applied to the optical generation of PSBT proposed in [8]. In the following, we call “x dB E-OPSBT” the generation of an all-optical PSBT partially remodulated by an x dB extinction ratio NRZ signal. The MZM used for remodulation is biased at maximum and is

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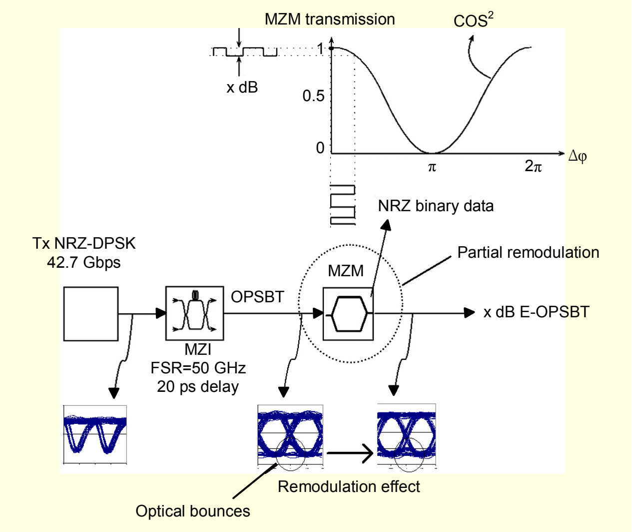

Fig. 1. Enhanced optical PSBT principle: partial remodulation of PSBT optical signal leading to reduced optical bounces in eye diagrams. The MZM after MZI is biased at the maximum of the transmission point.

driven with a low peak-to-peak signal (see Fig.1).

II. Transmitter Description

The transmitter is composed of a 193.4 THz CW laser, in which data (42.7 Gbps with 2^7–1 bit sequence length) is encoded in NRZ or OPSBT format corresponding to the experimental setup described in [8]. An NRZ format is obtained with an MZM biased at half the power of the transmission curve, and driven with a V_π amplitude electrical signal. The OPSBT format is obtained from an NRZ-differential phase shift keying (DPSK) signal filtered with an MZI optical filter. The MZI filter has a 50 GHz FSR, a 25 dB isolation ratio, and a 0.5 dB insertion loss. The transmission line is first composed of 100 GHz interleavers (90 GHz bandwidth at 3 dB) for NRZ signals and 50 GHz (50 GHz bandwidth at 3 dB) interleavers for OPSBT. These interleavers are used to ensure the WDM possibilities of the proposed modulation format (x dB E-OPSBT). More precisely, the 50 GHz interleaver is used for evaluation of the OPSBT or x dB E-OPSBT format's capability to be deployed in 10 Gbps network architectures. At the receiver side, a 1.0 nm optical pass band filter (OPBF) is used for noise limitation, and after that, an intensity detection with a PIN photodiode is performed. The eye diagrams presented in Fig. 3 are obtained with a fifth order electrical Bessel filter with a 0.75R bandwidth (R is the bit rate). Gaussian statistics are used for BER evaluation.

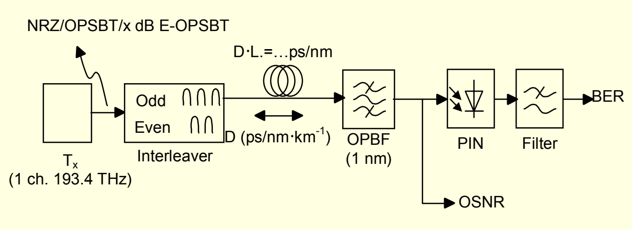

Fig. 2. Simulated system for 42.7 Gbps NRZ, OPSBT, and x dB E-OPSBT: generation, propagation, and reception.

III. Back-to-Back OSNR Sensitivities

Figure 4 presents the compared evolutions of log (BER) with OSNR values. The OSNR values are calculated in a 0.1 nm band centered at the carrier frequency. As can be seen, the evolution of the remodulation ratio (x) is linked to a reduced OSNR sensitivity. Table 1 gives the calculated OSNRs for each modulation format for a 1E-9 BER achievement.

It is known that the OSNR depends on the pseudo-random binary sequence (PRBS) length used. In particular, when 2^7–1 data sequences are used, the OSNR required at a fixed BER is lower than for 2^{23}–1 sequence lengths [8]. For example, in [8] the OSNR required for 1E-9 BER is 22 dB for 2^7–1 and 23.8 dB for 2^{23}–1 PRBS length (OPSBT format), showing the sequence length effect. The value obtained here for OPSBT (2^7–1 PRBS length) is 19.7 dB. The difference between the OSNR values of 19.7 dB (simulated) and 22 dB (experimental value in [8]) can be explained by the difference between the MZI insertion losses (2.5 dB in [8] and 0.5 dB in the simulations presented here). Finally, PRBS lengths are constant; therefore, the OSNR comparisons between modulation formats are relevant.

Figure 4 shows that the OSNR required for 1E-9 BER achievement is higher for OPSBT and EOPSBT compared with the NRZ case. Such a result can be explained by the presence of optical bounces in the OPSBT eye diagrams (see Fig. 3). As the optical bounces do not occur at the decision instant, the sampled optical power at the decision instant is reduced, leading to the requirement of a superior OSNR for the same BER performance compared to NRZ. Moreover, as the remodulation coefficient (x) increases, the OSNR required for 1E-9 BER achievement decreases. This can be explained by the fact that when x increases, the size of the optical bounces in the x dB OPSBT eye diagram is reduced and the eye shape becomes closer to the NRZ one. For this reason, the OSNR required is reduced.

IV. Tolerance to GVD Effects of x dB E-OPSBT

Figure 5 shows the BER evolution with an accumulated dispersion. In these curves, all modulation formats have a 16.9 dB Q factor at $D\cdot L = 0$ ps/nm (back-to-back performance). In [9],

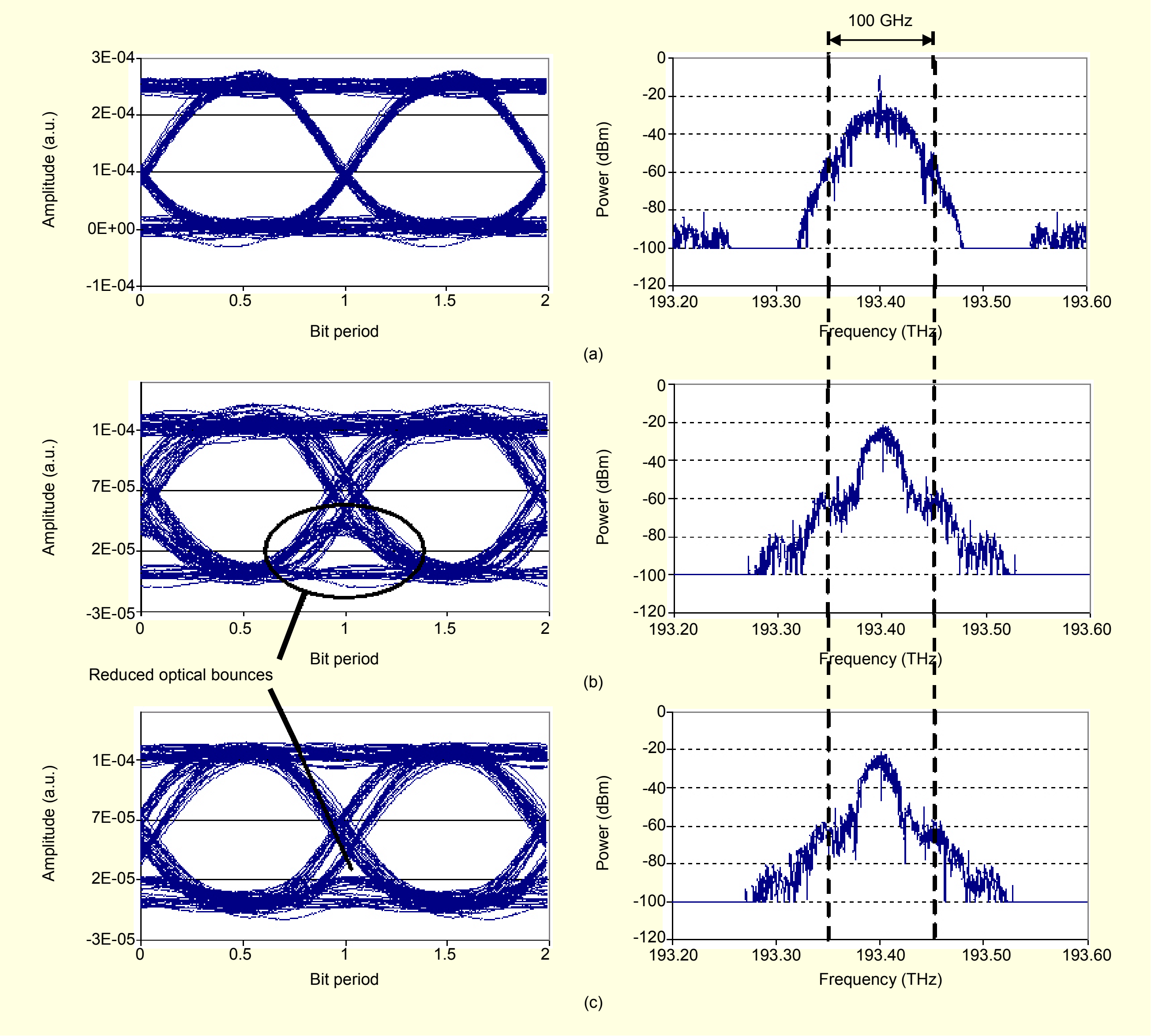

Fig. 3. Eye diagrams and optical spectra obtained for (a) NRZ with a 100 GHz interleaver, (b) OPSBT with a 50 GHz interleaver, and (c) 3 dB E-OPSBT with a 50 GHz interleaver.

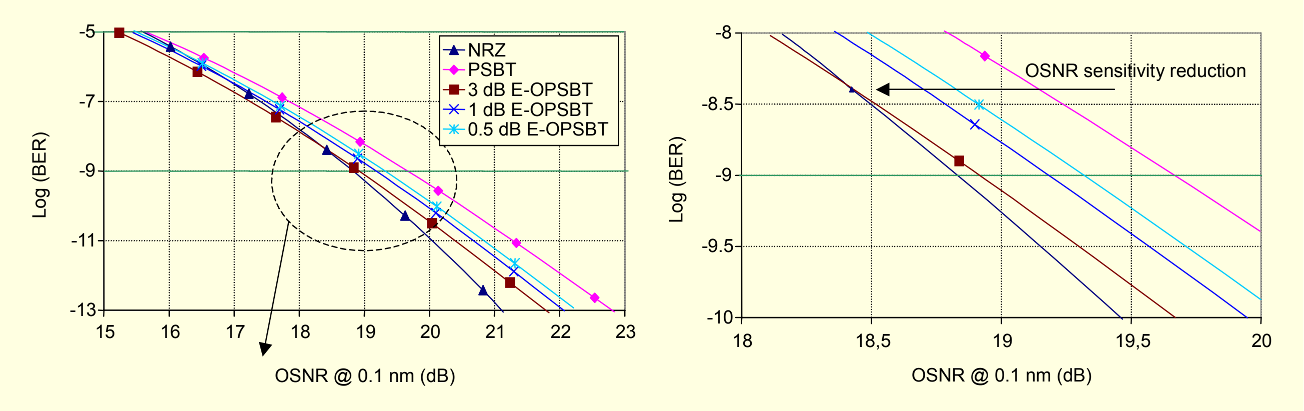

Fig. 4. Evolution of log(BER) with OSNR values. NRZ: 100 GHz interleaver. OPSBT and E-OPSBT: 50 GHz interleaver.

Table 1. Calculated OSNR (dB) for 1E-9 BER achievement. The PRBS lengths are $2^7 - 1$.

Modulation format	OSNR @ 0.1 nm
NRZ	18.8
OPSBT	19.7
1 dB E-OPSBT	19.2
3 dB E-OPSBT	19

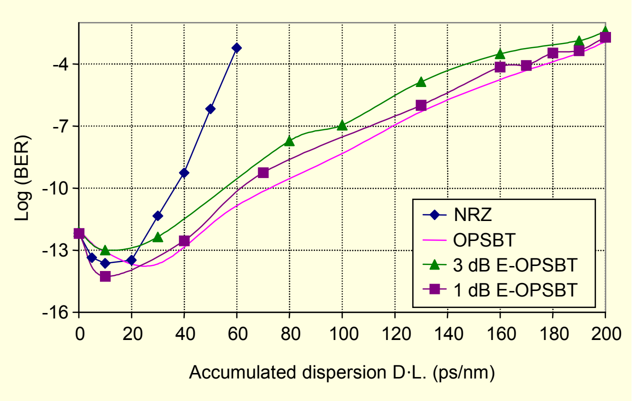

Fig. 5. Evolution of log (BER) with an accumulated dispersion.

it was demonstrated that the GVD tolerance of electrical enhanced PSBT is reduced compared to PSBT. Similarly, the GVD tolerance of x dB E-OPSBT can be expected to be smaller than the tolerance of OPSBT. This degradation can be explained by the fact that optical bounces (see Fig. 3) in OPSBT eye diagrams are reduced in amplitude by the NRZ remodulation. As the phase profile of PSBT is contained in these optical bounces, the “PSBT effect” should be reduced if the amplitude of optical bounces is reduced, resulting in a poorer performance towards the accumulated dispersion. Nevertheless, better performance should be obtained compared to the standard NRZ modulation format.

As can be observed, the strongest robustness to GVD effect is obtained with the OPSBT format. As expected, when x increases, a poorer accumulated dispersion tolerance is achieved for a given Q factor penalty, resulting in a lower achievable distance. By considering a 2.5 dB penalty on the Q factor, the 16.9 – 2.5 = 14.4 dB Q value (log (BER) = –7) is obtained for a 50 ps/nm accumulated dispersion for NRZ. A 100 (respectively 110) ps/nm tolerance is obtained for 3 (respectively 1) dB E-OPSBT, and 120 ps/nm for OPSBT.

V. Conclusions

The concepts of enhanced electrical PSBT have been applied to all-optical PSBT signal generation. With 3 dB E-OPSBT, a 0.7 dB reduction of OSNR at BER = 1E-9 can be achieved. Even with a 3 dB NRZ remodulation, the greater tolerance to GVD is maintained (100 ps/nm) compared to standard NRZ (50 ps/nm). The reduction of the maximal accumulated dispersion achievable by 3 dB E-OPSBT is only 20 ps/nm less than that achieved by OPSBT (120 ps/nm). Concepts of enhanced electrical PSBT have been shown to be relevant for an all-optical PSBT modulation format, leading to the same conclusions: The OSNRs required for OPSBT at fixed BER can be reduced by an NRZ remodulation without much reduction in GVD robustness.

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