Novel scheme for code preserving regenerative NRZ-DPSK wavelength and format conversion

M. Presi, N. Calabretta, G. Contestabile and E. Ciaramella

Scuola Superiore Sant'Anna, Via G. Moruzzi 1, I-56124 Pisa, Italy, email: marco.presi@sssup.it

Abstract: We propose a novel code-preserving NRZ-DPSK wavelength and format converter. It is based on optical filtering and a bi-stable device. It can be applied both to continuous and packet/burst traffic. Regenerative capability is also demonstrated.

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1 Introduction

Interned traffic boosted the study of sub-systems that, interconnecting transparently the layered networks, enable the realization of high capacity and flexible optical networks. Indeed, while OOK signals will be more likely used in metro-access network, DPSK signals, owing its higher resilience to propagation impairments [1], will be probably used in long-haul-metro networks. Beside the several all-optical circuits for packets manipulation, wavelength conversion (WC) and format conversion (FC) are key functions for transparent packet routing and interconnecting different layered optical networks. Critical issues in developing practical DPSK-WC and FC for optical networks are the differential coding preservation, due to the unpredictability of the number of crossed nodes by the packet, and the regeneration capability that allows cascability of the circuits. DPSK-WC based on four-wave-mixing preserves not only the encoding, but also the modulation format [2]. However, limited cascability, high operating power, and polarization dependency strongly limit this technique. Alternative DPSK-WC solutions are based on non-linear processes in SOA-MZI structures [3]. They first demodulated the original DPSK signal obtaining an OOK signal (and its inverted copy), and then used those as push-and-pull signals in an SOA-MZI structure, acting as an optical phase modulator (OPM), for OOK to BPSK converting the signal at different wavelength. In [4] the OPM was implemented by exploiting the Kerr effect in a non-linear fiber. An optical DPSK encoder should be used to retrieve the original information, but it has never been demonstrated. Here, we present a novel technique that allows the first implementation of a coding-preserving DPSK-WC with no optical DPSK encoder. The basic idea is to use the information contained in the phase-transitions of the original DPSK signal to drive an optical bistable circuit (OBC). The obtained OOK signal contains the same pattern (in intensity) of the phase pattern of the original DPSK signal, and can directly drive an OPM to complete the WC processing.

Fig. 1. a) Operating principle of the DPSK-WC. b) Experimental set-up.

2 Experiments

The schematic of the proposed DPSK-WC is shown in fig. 1-b. It consists of a notch filter, a bistable device and a phase modulator. The operating principle is illustrated in fig. 1-a, where, for better clarity, we report also the well-known NRZ-DPSK constellation diagram. In NRZ-DPSK format, the phase-modulation is achieved by moving the optical field $E(t)$ over the magnitude-constant path shown in fig. 1-a, thus realizing a constant envelope signal. The phase is changed continuously between 0 and π , thus every transition brings high-frequency components. These can be isolated from the DPSK signal by using an optical notch filter centered at the signal carrier wavelength. The notch-filter output is composed by an optical pulse at every phase-transition in the incoming signal, as sketched in fig. 1-a (see also the measurements in fig. 2-b). Such pulses should drive a OBC (such as an optical set-reset flip-flop), thus creating an intensity NRZ binary pattern (see fig. 2-c) that matches exactly (either in direct or inverse logic) the phase pattern of the incoming signal (see fig. 2-a). By using an OPM, the intensity pattern at the output of the bistable element can be

converted to a phase pattern at one or multiple different wavelengths. The converted signal preserves the coding of the original DPSK signal. The experimental setup is reported in fig. 1-b. A CW source at 1549.8 nm was modulated by a LiNbO_3 phase-modulator, producing no spurious intensity modulation. An user pattern bit sequence (see fig. 2-a) was used to easily show the effectively coding preserving along different points in the set-up. The data bit-rate was 10 Gb/s. The DPSK signal was amplified and fed into the notch filter, which consisted of an athermal FBG. The FBG had a Gaussian profile with a 3-dB bandwidth of 6 GHz and an almost flat phase response and no spurious dispersion. The output of the FBG is reported in fig. 2-b, which clearly show the optical pulses occurring at every phase-transition of the DPSK signal. The optical pulses had a pulsewidth of 45 ps and an extinction ratio of around 12 dB. Those pulses were fed into a OBC. In our demonstration, the lack of an optical flip-flop forced us to use an electrical flip-flop (FF). The optical pulses were then converted to electrical pulses by a fast photodiode before to be fed into a toggle FF with 20 GHz maximum operating rate. The electrical signal at the FF output is reported in fig. 2-c. The figure clearly

Fig. 2. Right: a) Input electrical DPSK signal. b) FBG optical output pulses. c) Output of the electrical flip-flop. Left: Bit error rate measurements of the d) input, e) degraded, and g) converted DPSK signals.

shows the match between the original electrical coded DPSK signal and the signal after the FF. This confirms that our proposed WC preserves the differential encoding. To complete the WC operation, the electrical signal provided by the FF was used to drive a phase modulator, which modulated the phase of one (or multiple) CW source at different wavelength. Note that in case an optical FF would have been available, the produced FF output would be an optical NRZ-OOK that may all-optically used to drive an OPM similar as that employed in [4]. The performance of the DPSK-WC was also quantified by the BER measurements, reported in fig. 2. To investigate the regenerative capability of this WC, we degraded an input DPSK signal by adding in-band ASE noise produced by an EDFA. The OSNR was degraded to 23 dB. Due to the added noise, the degraded signal presented a penalty at 10^{-9} . After the wavelength conversion, no appreciable penalty was measured. Indeed, the figure clearly shows that the added noise is cleaned after the conversion stage (see eyes in the of fig. 2). This is due to the decisional and limiting characteristic of the FF: once the FF was switched its state, any bit noise fluctuations were completely eliminated. The removal of the penalty and the regenerated OSNR due to wavelength conversion confirm a regenerative capability and the potential cascability of the proposed circuit.

We demonstrated a novel technique that allows the implementation of a phase preserving DPSK-WC without an optical DPSK encoder. The device can be of high interest in wavelength conversion for DPSK signal in optical networks where optical packets cross an unpredictable number of nodes. Error-free operation of the wavelength converter was experimentally demonstrated, even for input signals with a degraded OSNR of 23 dB. This indicates the potential cascability of the circuit. Finally, we point out that although the proof-of-principle was demonstrated also by means of optoelectronics components (namely the electrical FF and the phase modulator), those could be replaced by all-optical components, which were all already demonstrated (an optical set-reset flip-flop [5] and an optical phase modulator [4], respectively).

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