Enhancement of 43Gb/s DPSK Transmission Though 66 Wavelength Selective Switches Using Adaptive Channel Shape Optimization

M. Jordan (1,2), E. Granot (1,3), M. Caspi (1), Y. Stav (1), N. Narkiss (1), M. Roelens(4), S. Frisken(4), S. Poole(4), J.Leuthold (2), and S. Ben-Ezra (1)

(1) Finisar Israel, Nez Ziona,Israel, shalva.benezra@finisar.com
(2) Institute of Photonics and Quantum Electronics, University of Karlsruhe, Germany
(3) Department of Electrical and Electronics Engineering, Ariel University Center of Samaria,Ariel, Israel
(4) Finisar Australia, Sydney, Australia

Abstract *A 43Gb/s DPSK format data transmission is demonstrated through 66 Wavelength Selective Switches (WSSes). By optimizing the channel shape of one of the WSSes, the transmission distance was increased from 1600 km to 2640 km with improved BER*.

Introduction

Differential Phase Shift Keying (DPSK) is one of the most prominent modulation formats, and is ubiquitous in modern long reach 40G transponders. Contrary to ordinary On-Off-Keying (OOK) formats DPSK makes use of the phase of the electromagnetic field, and therefore a 3 dB in OSNR penalty is gained[1]. Moreover, the DPSK has advantage over PSK formats for it does not require a local oscillator and complicated coherent detection. The encoding is done by a delay interferometer (DI), which operates as a XOR element on the electric field of two adjacent bits. Therefore, best transmission results in Back-to-Back (B2B) operation are usually achieved for a delay, which is exactly equal to the bit length (symbol length in the case of DQPSK)[1].

In a DWDM network, there are various factors which impact the maximum transmission distance in a ROADM-enabled system including concatenation effects and coherent crosstalk in the ROADM. One important factor is limited spectral bandwidth due either to Reconfigurable Optical Add-Drop Multiplexers (ROADM's), which are responsible for routing the signals over the network or channel filtering at the mux/demux. While a single ROADM has a relative small effect on the passing signal, multiple cascaded ROADM's, which are present in almost any network, can cause considerable signal degradation[2]. Additionally the phase response of any filtering element can concatenate – potentially degrading the high frequency components of the signal. It has previously been proposed[3] that bandwidth narrowing can be partially overcome using a DI whose FSR is larger than the bit rate. This kind of treatment suggests that the degradation caused by the filtering effect can be partially compensated by spectral manipulations. Recently it was demonstrated that further improvement can be achieved when an optimized power imbalance is also applied[4].

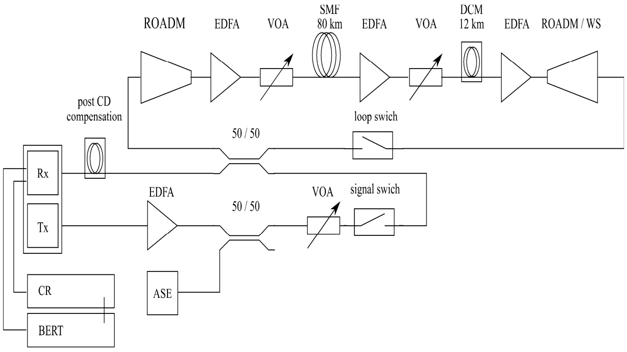

Fig. 1: Recirculating Loop Schematic. The system comprising a DPSK transponder (transmitter Tx + receiver Rx); an ASE source; optical loop containing two WSS, EDFA's , 80km of SMF-28 fiber and 12km DCM fiber; and a dispersion compensation element before the receiver.

In this paper we demonstrate mitigation of concatenation effects by adaptively optimising the channel shape in a Liquid Crystal on Silicon (LCoS)-based WSS[5]. For experimental convenience, we used a commercially available programmable WSS (WaveShaper 4000E) with sub-channel spectral resolution of the phase and amplitude response to tune the WSS parameters to compensate for the spectral deformation caused by the WDM filtering elements in the link.

Experimental Setup

The experimental setup is illustrated in Fig.1. The loop performance was first evaluated using two standard 50 GHz LCoS-based WSSes. WSS1 was configured as an "Add" whilst WSS2 was configured as a "Drop". The loop performance was characterized by BER measurements (both back to back and as a function of loop recirculation). The second WSS was then replaced by the WaveShaper 4000E configured as a Wavelength Selective Switch with a programmable spectral response. The optimal chromatic dispersion for WSS2 was then experimentally determined to be that shown in Fig 2.

As can be seen from Figure 2, the chromatic dispersion spectrum of WSS2 was adjusted for optimum performance and it has almost a mirror image of the rest of the loop with respect to zero chromatic dispersion. For each circulation of the loop, a different optimum filter shape (both phase and amplitude) was required, indicating the impact of both linear and non-linear effects in the loop. Clearly, for different WSS types or link designs an optimized spectral filter response would be calculated.

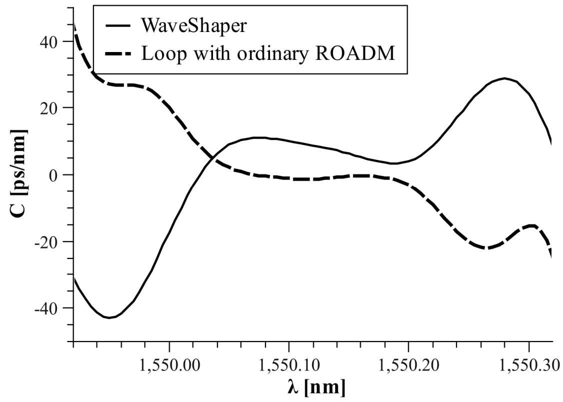

Fig. 2: Chromatic dispersion Spectra of the loop with WSS1 (dashed curve) and Programmable WSS (solid curve)

In both cases, the transmission channel was surrounded by blocked channels as this provides a 'worst case' scenario which provides maximum channel narrowing in a recirculating loop. In practice, the channel narrowing will be less severe for an LCoS-based system as the spectrum is continuous and there will be a statistical spread of add-drop channels.

Results

Fig.3 shows a typical BER curve measured in which the triangles correspond to the measurements of 10 recirculations through the loop (i.e. 20 ROADMs) with identical WSSes, while the circles are measurements of following 10 recirculations when WSS2 was optimized for BER performance. As can be seen, the OSNR penalty is reduced below 0.9 dB at a BER of 1E-4 and is significantly less at lower BER.

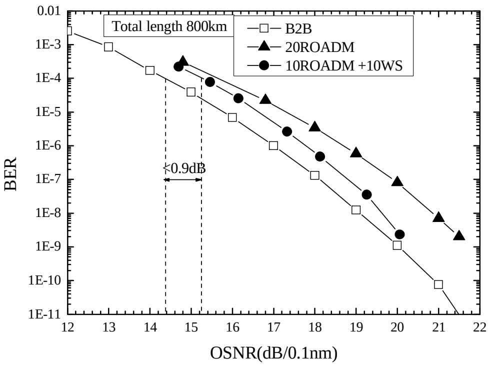

Fig. 3: BER measurement as a function of signal OSNR for three scenarios: Back-to-Back (squares), 10 loops with overall 20 standard WSSes (triangles) and 800 km fiber, and 10 loops where one of the WSSes was replaced by a programmable WSS (circles).

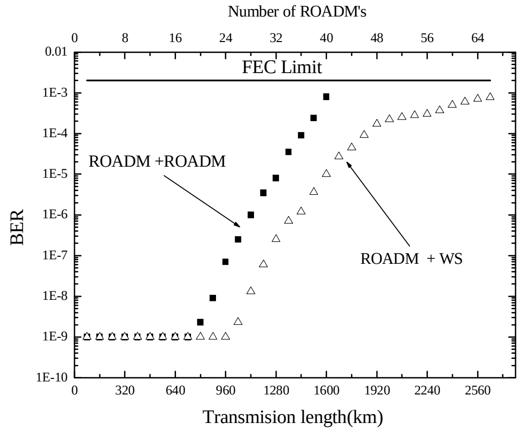

Fig. 4: BER comparison with the loop containing two standard LCoS-based WSSes (squares) and with WSS2 optimised for transmission performance (triangles). The data is plotted as a function of the number of loop recirculations which corresponds to either transmission length or number of WSSes.

Fig. 4 shows the BER measurements of the entire system as a function of number of passes around the loop (which is equivalent to either the number of WSSes or the overall distance). For standard WSSes (squares) transmission through 40 WSSes was possible before the FEC limit was reached whilst for the adjustable configuration (triangles) transmission through 66 WSSes was possible, corresponding to a distance of 2640 km without reaching the FEC limit.

As noted above, the WaveShaper 4000E was used to control both the channel amplitude and phase response. In the data presented here, a quadratic phase response was employed but it is likely that a non-quadratic phase could provide a further improvement to the system performance.

Conclusions

We have demonstrated that in optical links with multiple WSS-based ROADMs, a spectrally programmable WSS can compensate for signal degradation in a DWDM network. Two orders of magnitude improvement in BER measurement were achieved and the signal passed through 65% additional ROADMs and distance without reaching the FEC limit.

References

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