80 to 10 Gbit/s Demultiplexing using Fiber Cross-Phase Modulation and Optical Filtering

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Introduction

Future ultra high bit-rate optical time division multiplexed (OTDM) systems may require all-optical demultiplexing to down convert high bit-rate data to e.g. 10 Gbit/s or 40 Gbit/s where electronic circuits can be used. Many suggestions of such demultiplexers have been proposed over the years. The most common device is the nonlinear optical loop mirror (NOLM) that allows switching due to cross phase modulation (XPM) in either a fiber [1] or a semiconductor optical amplifier (SOA) [2]. Another approach is to use four wave mixing (FWM) in either a SOA or a fiber [3]. In all these schemes the switch window for the demultiplexed OTDM channel can usually not be shorter than the pulse width of the control pulse that initiates the XPM or FWM, and thus a very short, high quality, optical pulse is required [4]. Here we demonstrate a new demultiplexer based on XPM in a fiber that utilizes the derivative feature of XPM induced spectral broadening. The basic idea is that the leading edge of the control pulse generates a red shift of the spectrum of the XPM modulated input signal, and the trailing edge generates a blue shift. We have previously reported wavelength conversion using this technique where the incoming data phase modulate continuous wave (CW) light with subsequent conversion to amplitude modulation [5]. Here, only one of the OTDM data channels in the high bit-rate data is spectrally broadened and that channel can then be extracted with a narrow band optical band-pass filter at either side of the original spectrum. Thus, only one edge of the control pulse governs the width of the demultiplexing switch window, if dispersive walk-off is neglected. Therefore a control pulse broader than the actual bit slot can be used for demultiplexing. Another important feature of this demultiplexer compared to the NOLM is that it is not an interferometer, which makes the device completely insensitive to environmental disturbances even though a long length of fiber is used.

Experiments

The experimental set up is shown in figure 1. An actively mode-locked fiber ring laser generated 6 ps pulses at 1538.5 nm wavelength with 10 GHz repetition rate. 10 Gbit/s data, PRBS 2^{31}-1, was subsequently encoded, followed by a passive 10 to 80 Gbit/s split, delay, and time interleave multiplexer to achieve an 80 Gbit/s data stream. The control pulses were generated using an electro-absorption modulator that gave 14 ps pulses at a wavelength of 1534 nm. The 80 Gbit/s data and the control pulses were combined in a 50:50 coupler and amplified in an Erbium-doped fiber amplifier (EDFA) to +18 dBm average output power. A 5 km dispersion shifted fiber (DSF) was used to induce XPM from the control pulses to one of the 10 Gbit/s data channels in the 80 Gbit/s data stream. Thus the optical spectrum was broadened only during the time slot of one 10 Gbit/s channel and that channel was extracted by using a narrow, 0.2 nm, optical band-pass filter (BPF) positioned at a center wavelength of 1538 nm. The output from the BPF was then send to an optically preamplified receiver to be investigated on a sampling oscilloscope as well as for bit-error rate (BER) measurements. Figure 2 shows the optical spectra in various points of the system. The solid trace shows the spectrum after the 50:50 combiner. The power ratio between the control pulse and the 80 Gbit/s data was about 20 dB to avoid data to saturate of the EDFA in front of the DSF. The dashed trace shows the spectrum after the DSF, where the spectrum of the 80 Gbit/s data is broadened due to XPM from the control pulse. The dotted trace in figure 2 shows the filtered XPM broadened spectrum, leaving the demultiplexed channel at the output. Since the BPF is only 0.2 nm, the output pulse width

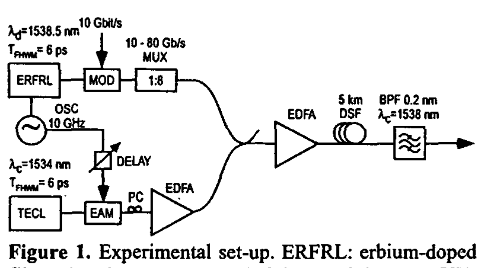

Figure 1. Experimental set-up. ERFRL: erbium-doped fiber ring laser; MOD: LiNbO3 modulator; MUX: passive 10 to 80 Gbit/s multiplexer; TECL: tunable external cavity laser; EAM: electroabsorption modulator; PC: polarization controller; EDFA: erbium-doper fiber amplifier; DSF: dispersion shifted fiber; BPF: optical band-pass filter.

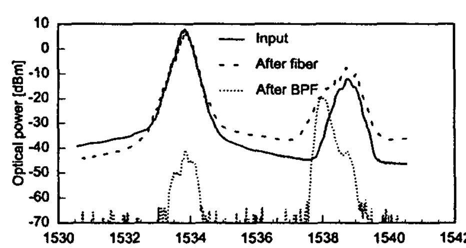

Figure 2. Optical spectrum at the input of the DSF, after the DSF and after the 0.2 nm BPF.

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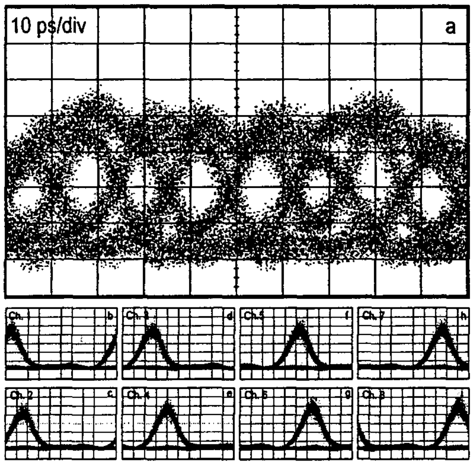

Figure 3. 80 Gbit/s eye diagram (a) and demultiplexed 10 Gbit/s channels (b-i).

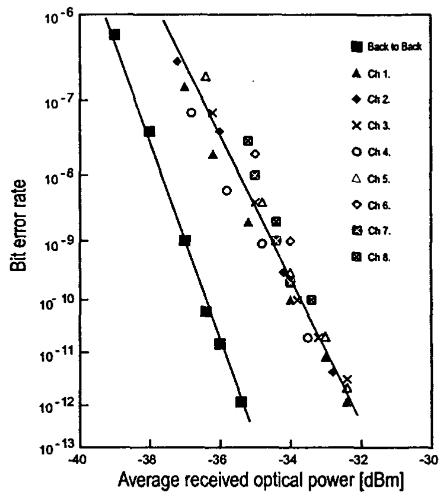

Figure 4. Bit-error rate measurements for 80 to 10 Gbit/s demultiplexing.

of the demultiplexed data is 17 ps. Figure 3a shows the input 80 Gbit/s data eye-pattern as measured with a 40 GHz detector on a 50 GHz sampling oscilloscope. Figure 3b-i show the eight demultiplexed 10 Gbit/s channels. No crosstalk was present even though the control pulse width was 14 ps and the bit-slot at 80 Gbit/s is 12.5 ps. This proves that the derivative effect of XPM gives a much shorter switch window in the demultiplexer than the input pulse width. The net polarization dependence of the demultiplexer was about 3 dB even though the polarization dependence of XPM in standard DSF is 5 dB. The reason for this is that for orthogonal relative polarization of data and control pulses, the spectral broadening is at its minimum, and for decreased orthogonality the spectrum gets broader but still leaving energy within the filter band width. However, the polarization dependence depends heavily on the available pump power as well as the position of the BPF. Figure 4 shows BER measurements of the demultiplexed data. Full BER plots are shown for channel 1 to 4 and BER measurements around 10^{-9} are shown for channel 5 to 8. All channels performed almost the same, giving a penalty of about 2 dB. This penalty is believed to arise primarily due to non-optimal filtering of the narrow bandwidth demultiplexed 10 Gbit/s data in the receiver. The optically preamplified receiver included a 0.6 nm optical band pass filter which is close to optimum for 6 ps pulses and thus gives a very low receiver sensitivity for the original 10 Gbit/s data. After demultiplexing the pulse width is 17 ps with a spectral width of 0.2 nm, which is far from optimum for this particular receiver. In fact, sending the original 10 Gbit/s data with 6 ps pulses through the 0.2 nm filter before entering the receiver gave also about 2 dB penalty but with a slightly better slope of the BER plot.

Conclusions

A new all-optical demultiplexer is described, based on XPM in a fiber followed by a narrow optical band-pass filter. 80 Gbit/s was successfully demultiplexed to 10 Gbit/s with <2 dB receiver penalty using a control pulse of 14 ps. Due to the derivative effect of XPM, a control pulse broader than the bit-slot of the high bit-rate data can be utilized. The demultiplexer is insensitive to environmental disturbances and can be made polarization independent by using diversity [6] or circular birefringent fiber [7].

References

[1] K. J. Blow, N. J. Doran, P. B. Nelson, "Demonstration of the nonlinear fibre loop mirror as an ultrafast all-optical demoultiplexer," *Electron. Lett.*, vol. 26, pp. 962-964, 1990.

[2] J. P. Sokoloff , P. R. Prucnal, I. Glesk, M. Kane, "A terahertz optical asymmetric demultiplexer (TOAD)," IEEE Photon. Technol. Lett., vol. 5, pp. 787-790, 1993.

[3] P. A. Andrekson, N. A. Olsson, J. R. Simpson, "16 Gbit/s all-optical demultiplexing using four-wave mixing, " *Electron. Lett.*, vol. 27, pp. 922-924, 1991.

[4] M. Jinno, "Effects of crosstalk and timing jitter on all-optical time division demultiplexing using a nonlinear fiber Sagnac interferometer switch," *J. of Lightwave Technol.*, vol. 30, pp. 2842-2853, 1994.

[5] B. E Olsson, P. Öhlén, L. Rau, D. J. Blumenthal, "A Simple and Robust High-Speed Wavelength Converter using Fiber Cross-Phase Modulation and Filtering," *Proc. Opt. Fiber Comm. Conf.*, Baltimore, USA, paper WE1, 2000.

[6] B. E. Olsson, P. A. Andrekson, "Polarization independent Kerr-switch using a polarization diversity loop," *Proc. European Conf. On Opt. Comm. (ECOC)*, Madrid, Spain, pp. 185-186, 1998.

[7] Y. Liang, J. W. Lou, J. K. Andersen, J. C. Stocker, O. Boyraz, M. N. Islam, "Polarization-insensitive nonlinear optical loop mirror demultiplexing with twisted fiber," *Opt. Lett.*, vol. 24, pp. 726-728, 1999.