Timing jitter tolerant OTDM Demultiplexing using a Saw-Tooth Pulse Shaper

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Abstract

Saw-tooth pulses, shaped using a fiber Bragg grating, provide timing jitter tolerant OTDM data demultiplexing in a scheme based on cross-phase modulation in fibre, with subsequent offset filtering.

Introduction

All-optical time-division multiplexed (OTDM) technology has developed significantly over recent years with rates well in excess of 1Tbit/s now reported. Whilst multiplexing of tributary signals via passive interleaving is reasonably straightforward, demultiplexing of the data at appropriate points within a network represents a significant technical challenge due to the ultrafast optical switching required. Among the various demultiplexing schemes so far reported, (see e.g. [1-3]), the approach based on cross-phase modulation (XPM) induced wavelength shifting in highly nonlinear fibres (HNLFs) is particularly attractive due to its relative simplicity [3].

According to this technique short intense control pulses (at the tributary rate) are used to impart a frequency shift through XPM onto the desired tributary channel of a co-propagating OTDM data signal. Demultiplexing is then completed by filtering the frequency-shifted bits using a narrowband optical filter. The extent of the frequency-shift is proportional to the intensity-gradient experienced by each data bit due to its interaction with the control pulse. This is a function both of the relative timing of the control and data pulses, and of the control pulse shape. Most work to date in this area has used either Gaussian or soliton control pulses which exhibit significant variations in intensity gradient across their profile. Since both have a uniform gradient over only a very limited time they provide a very narrow switching window resulting in acute timing-sensitivity, reduced switching-efficiencies and chirped output pulses. The optimum control pulses for such a demultiplexer have a saw-tooth (triangular) profile, since the uniform gradient associated with this pulse shape gives rise to a constant frequency shift across its leading (trailing) edge. This ensures minimal distortion of the switched signal since the entire switched data pulse experiences the same frequency shift. Moreover, by operating the system on the longer trailing/leading edge of the saw-tooth, far broader switching windows can be defined - ensuring that the system is far more resilient to temporal bit misalignment between the control and data signals.

We have recently demonstrated the generation of ~10ps saw-tooth pulses using a superstructured fibre Bragg grating (SSFBG) [4]. In this paper we demonstrate a demultiplexing system using saw-tooth control pulses and highlight the performance achieved relative to the use of the more conventional Gaussian pulses.

Experimental Set-up and Results

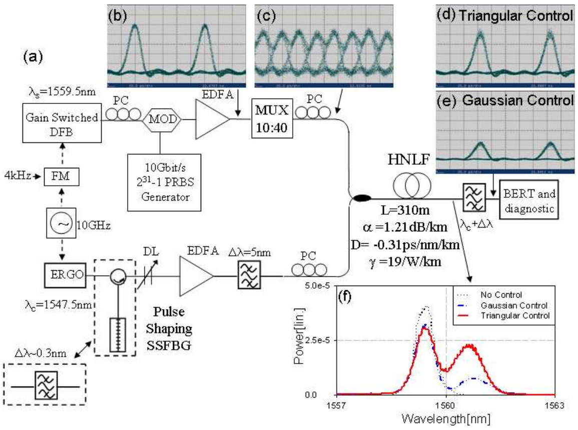

Figure 1: Experimental set-up of the demultiplexing system. FM: frequency modulation, MOD: amplitude modulator, EDFA: erbium-doped fibre amplifier, PC: polarisation controller, MUX: multiplexer.

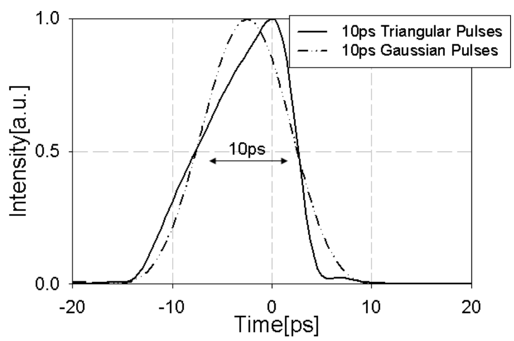

Figure 2: Saw-tooth and Gaussian intensity profiles with similar FWHM measured using I-FROG.

The experimental set-up is shown in Fig.1(a). The ~10ps (Full Width at Half Maximum, FWHM) saw-tooth pulses are generated by feeding 1.3 ps Gaussian pulses at 10GHz to the specially designed SSFBG. The central wavelength of the SSFBG is

~1547.5nm and its corresponding characteristics are reported in [4]. We characterized the shaped pulses using linear frequency-resolved optical gating (l-FROG). The corresponding temporal profile is plotted in Fig.2 together with a measurement of Gaussian pulses of similar FWHM obtained simply by replacing the SSFBG with a suitable narrowband filter. The saw-tooth pulses are then amplified to ~26dBm and launched into a HNLF through a 90:10 coupler. The HNLF parameters are shown in Fig.1(a). A 40Gbit/s data signal (Fig.1(c)) is then coupled into the HNLF using the 10% coupler port. This data signal is generated by interleaving a 10Gbit/s data signal (Fig.1(b)) generated from an externally modulated Gain switched DFB laser providing 10GHz, 7ps pulses at 1559.5nm. By appropriately adjusting the optical delay line (DL) it is possible to shift the wavelength of any one of the four 10Gbit/s tributaries, and to demultiplex it using a ~0.5nm filter.

The XPM broadened spectra of the data signal at the output of the HNLF are shown in Fig.1(f) when either the saw-tooth or Gaussian pulses are used to control the switch. As expected, the spectral density of the wavelength-shifted component is much higher when using the saw-tooth control pulses; moreover the bandwidth is narrower due to the constant time-derivative of the pulse shape. This implies that most of the energy of the wavelength-shifted drop channel passes through the offset filter (offset by ~1.3nm from the central wavelength of the data) and is efficiently detected. Eye diagrams of a demultiplexed channel, when either saw-tooth or Gaussian control pulses are used, are shown in Fig.1(d) and Fig.1(e) respectively, where a common vertical scale is used for the two different pulse shapes to emphasize the different output power levels. Note that for the same wavelength-shift the Gaussian pulses require ~2dB less average power compared to the saw-tooth pulses due to the fact that Gaussian pulses have a larger gradient (albeit more localised) at their optimal operating point.

To confirm the benefit of using saw-tooth control pulses in this demultiplexing scheme, we performed bit-error rate (BER) measurements. At first, we measured BER curves for the demultiplexed channels for a clean OTDM signal, see Fig.3. Error free demultiplexing was achieved using saw-tooth pulses for all the 4 channels with a ~0.5dB penalty compared to the 10Gbit/s back-to-back. Error free operation was also achieved using Gaussian pulses albeit with a slightly higher power penalty (~1.5dB). It was immediately evident in our measurements though that using Gaussian pulses required much tighter timing control between the control and data signals. To illustrate this point, we artificially introduced ~2.2ps RMS timing jitter (tj) to the OTDM signal by frequency modulating the 10GHz RF drive signal to the gain-switched laser with a 4kHz tone (see Fig.1(a) and Fig.3(b)). The 10Gbit/s signal at the input of the MUX did not show any degradation with respect to the clean signal due to the relatively low bandwidth of the receiver. When saw-tooth pulses were used for demultiplexing error-free operation was achieved for all OTDM channels. By contrast an error floor was observed at a BER of 10^{-8} and a power penalty of more than 5dB was obtained for Gaussian pulses. The eye-diagrams for the two cases are shown in Fig.3(c) and (d) respectively, demonstrating that unlike the case of Gaussian pulses, the timing jitter is not converted into amplitude noise when saw tooth shaped pulses are used.

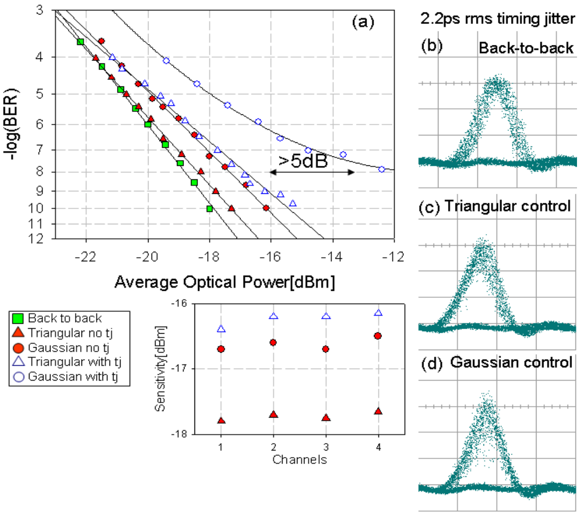

Figure 3: a) BER curves and power sensitivity for all the demultiplexed channels with and without added tj. b-d) Eye diagrams at different points of the system when timing jitter is added to the data signal. Scale: 20mV/div.

Conclusions

We have experimentally demonstrated the performance benefits of using saw-tooth shaped control pulses in a TDM demultiplexing system based on XPM in a HNLF and subsequent offset filtering. Error-free operation and a significant improvement in the receiver sensitivity was achieved relative to the use of Gaussian control pulses with a similar width. We believe that this approach could be applied to much higher bit rate systems by properly scaling the width of the shaped pulses and the bandwidth and offset of the filter.

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References

1. A. I. Siahlo et al., CLEO, (2005) CTuO1.
2. V. Marembert et al., OFC, (2006) OWI12.
3. J. Li et al., J. Lightwave Technol., vol. 23 no.9 (2005), pp.2654-2661.
4. F. Parmigiani et al., OFC, (2008) OMP3.