All-Optical TDM to WDM Signal Conversion and Partial Regeneration Using XPM with Triangular Pulses

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Abstract

We propose a new all-optical, all-fibre scheme for conversion of time-division multiplexed to wavelength-division multiplexed signals using cross-phase modulation with triangular pulses. Partial signal regeneration using this technique is also demonstrated.

Introduction

Optical pulses with a triangular intensity profile can be used for various applications in optical signal processing and manipulation [1-3], which are important for future all-optical networks. Time-domain add-drop multiplexing based on cross-phase-modulation (XPM)-induced wavelength shifting in fibre using triangular pump pulses was examined in [1]. In [2] it was demonstrated that triangular pulses created using super-structured fibre Bragg grating technology lead to a two-fold improvement in the performance of a wavelength converter based on self-phase modulation (SPM) in fibre and offset filtering. Triangular pulses can also be produced by using fibre nonlinear effects. For instance, we have recently introduced a method of triangular pulse generation based on the nonlinear reshaping of sufficiently powerful, positively chirped pulses, which occurs upon propagation in a normally dispersive fibre (NDF) [3]. In this paper, we propose a new all-optical scheme for conversion of optical time-division multiplexed (TDM) signals to wavelength-division multiplexed (WDM) signals. The technique relies on XPM in the fibre and using triangular pulses as the pump signal to split an initial return-to-zero (RZ) on-off keyed (OOK) data signal into two data signals at half of the original repetition rate, with a simultaneous wavelength conversion of the data streams. We also demonstrate that partial regeneration of an initial noisy signal is possible by use of this technique.

Triangular pulse shaping characterisation

Without loss of generality of the proposed technique, here we consider pulses with a triangular shape generated by passive reshaping of initially chirped Gaussian pulses with a positive chirp parameter in a highly nonlinear fibre (HNLF) [3]. The use of a pre-chirping device and an optical amplifier allows control of the pulse chirp and power at the HNLF input. Similarly to the approach introduced in [4], we quantify the evolution of the initial pulse towards a triangular shape by the misfit parameter M between the pulse intensity profile and a triangular fit of the same energy and full-width at half-maximum (FWHM) duration: $M^2 = [\int dt\,(|u|^2-|u_T|^2)^2] / \int dt\,|u|^4$ with $u_T(t)$ corresponding to the intensity profile $|u_T(t)|^2 = P_{0,T}(1-|t/\tau|)\theta(\tau-|t|)$. An example of pulse reshaping is illustrated in Fig. 1 (top) for an initial pulse with the FWHM duration $T_{FWHM} = 2(\ln 2)^{1/2}\,T$ = 7ps and the chirp C = 0.11THz^2 propagated in a HNLF with the dispersion β_2 = 146ps^2/km, the nonlinear coefficient γ = 8.7(W km)$^{-1}$ and the length 121m. Figure 1 (top) shows the evolution of the misfit parameter versus the normalised distance $\xi = \beta_2 z / T^2$ and the energy parameter $N = (T^2\gamma P_0 / \beta_2)^{1/2}$ (P_0 is the input pulse peak power). We can see that the reshaping process to a nearly ideal triangular intensity profile is possible for sufficiently high energies (N ≥ 6 in this example). A triangular pulse generated at ξ = 0.33 (z = 40m) for N = 10 (P_0 = 95W) is shown in Fig. 1 (bottom). For this pulse the misfit parameter is as low as 0.029. The triangular fit is also plotted, showing indeed good agreement with the actual pulse shape. Note that the triangular shaping regime is peculiar to the nonlinear evolution of an initial positively chirped pulse in a NDF, and results from the addition of the positive initial chirp to the SPM-induced chirp [5].

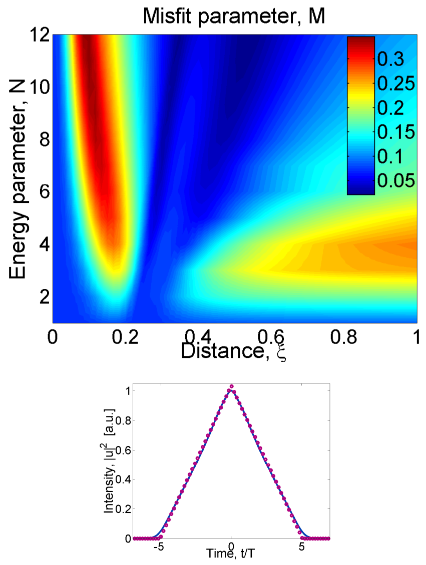

Figure 1: Top, evolution of the misfit parameter M versus ξ and N for C = 0.11 THz^2. Bottom, pulse intensity profile and triangular fit (circles) at ξ = 0.33 for N = 10.

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System description and results

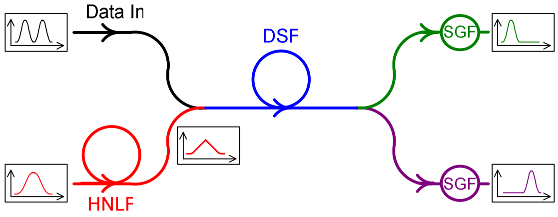

Figure 2: Scheme of the TDM-WDM converter.

The basic configuration of the proposed TDM-WDM converter is shown in Fig. 2. For the purpose of illustration, we generate a 40Gbit/s RZ-OOK pulse train formed with transform-limited Gaussian pulses with the FWHM duration 7ps and the peak power 1mW, at the wavelength of 1540nm. These pulses are subsequently distorted by the addition of amplified white Gaussian noise, thus forming the data signal to be processed. First, a 20Gbit/s triangular pulse train is created from a Gaussian pulse train in a HNLF (the triangular pulse shaper) as described in the previous section. The shaped pulses have a FWHM duration of 23.7ps and a peak power of 28.9W (note that the power can be scaled down using different nonlinear fibres). The central wavelength of the triangular signal is set to 1550nm, so that the spectrum does not overlap with that of the data signal. The data signal pulses are then coupled together with the triangular pulses such that they are temporally centred on the slopes of the triangular pulses, before launching into a span of dispersion-shifted fibre (DSF). Figure 3 shows the temporal and spectral intensity distributions of the data (upper figure) and triangular pulses (middle).

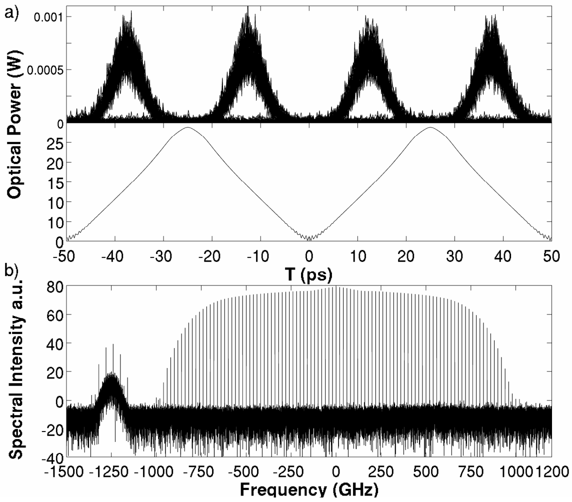

Figure 3: a) Temporal and b) spectral intensity distributions of noisy 40Gbit/s RZ-OOK signal and 20Gbit/s triangular signal.

The DSF has the nonlinear coefficient $\gamma = 8.7(\mathrm{W\ km})^{-1}$ and the length L = 60m. After propagation in the DSF, due to XPM induced by the stronger triangular pulses and assuming small DSF dispersion, the effective phase modulation $\delta\varphi = 2\gamma|\sum_n u_{T,n}(t-2nT_b-T_b/2)|^2 L$ is applied to the data signal. Here, $u_{T,n}$ are the triangular pulse amplitudes and T_b is the bit period of the data pulse train. As a result, at the output of the DSF the data signal is split into two signals centred at the wavelengths 1539nm and 1541nm and with one containing the even bits and the other containing the odd bits of the original signal that is, with half of the original repetition rate. The triangular pulses are filtered out by two super-Gaussian filters centred on the centres of the newly created signals. Figure 4 shows the spectral and temporal intensity distributions of the two obtained signals. The notable feature of Fig. 4 is that the signal splitting process entrains some form of noise suppression and signal regeneration.

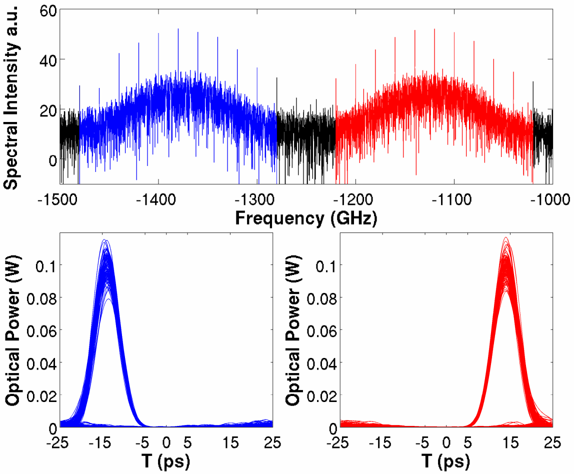

Figure 4: Spectral (top) and temporal (bottom) intensity distributions of the two generated 20Gbit/s RZ-OOK signal WDM channels.

Conclusions

We have proposed a new all-optical conversion scheme for converting optical TDM signals to WDM signals which relies on XPM in the fibre with a NDF-shaped triangular pump pulse train. The technique has been applied to the separation of a 40Gbit/s RZ-OOK signal into two WDM channels at 20Gbit/s. It has been also demonstrated that noise suppression and partial signal regeneration are achievable by the use of this technique.

References

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