Simulation of 50GHz Transmission Over 50km of Standard Fibre using Mid-point Spectral Inversion for Dispersion Compensation

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Abstract

Transmission of 6ps linear pulse pairs over 50km of standard fibre is demonstrated by employing midpoint spectral-inversion (phase conjugation) of the data signal to compensate dispersion effects. Pulse broadening as low as 10% and faithful reconstruction of the pulse patterns is observed and confirms the applicability of this technique to bit-rates greater than 100 Gbits^{-1}.

Introduction

The advent of erbium-doped fibre amplifiers (EDFAs) has made high-capacity transparent optical networks operating around 1.55μm a reality. However, since the majority of the world's installed fibre is designed to operate around 1.3μm, the minimum dispersion region, there is strong commercial pressure to upgrade these links. At present there are two options; either to develop 1.3μm amplifiers based on Pr^{3+}- or Nd^{3+}-doped fibre[1,2] or to employ dispersion compensation[3-6] to allow the fibre to be uprated to operate around 1.5μm, where the EDFA operates.

Dispersion-compensation techniques include incorporation of a special dispersion-equalizing fibre (such as two-mode fibre[3]) to reduce the net link dispersion, or the use of optical phase conjugation (spectral inversion) of the data spectrum at the midpoint of the transmission link[4-6]. In the latter case, the pulse disperses in the first half of the link, at which point its spectrum is inverted such that the dispersion in the second half acts in the opposite sense and recompresses the pulse. Non-degenerate four-wave mixing (FWM) in both a semiconductor amplifier[4] and a dispersion-shifted fibre[5] (to obtain phase matching) has been employed to provide spectral inversion. By employing the latter the transmission of 10 Gbits^{-1} NRZ data over 360km of standard fibre has been demonstrated[6].

In a recent work we reported the (linear) transmission, spectral inversion and retransmission of individual, well-separated 6.2ps pulses over a total distance of 50km of standard fibre and observed temporal broadening by as little as 10% [7]. In this paper we time multiplex the source pulses and examine the propagation of 6ps pulse pairs (mark-space ratio tunable in the range 2-5) in order to assess the quality and linearity of the phase conjugation process with respect to data signal power and to demonstrate the potential of the technique for 50-100 GBit/s data transmission in high-dispersion fibres..

Experiment

The experimental configuration is shown in Figure 1. A polarisation-maintaining, passively mode-locked, figure-eight, erbium-doped fibre laser was employed to generate short pulses at an average repetition rate of ~200MHz and centre wavelength of 1532nm [8]. These pulses were then launched into a Michelson interferometer with a variable delay in order to generate individual pulse pairs with a well-defined inter-pulse separation. The pulse pairs were coupled through a short section (~30m) of standard fibre (lab-to-lab) and were attenuated before being passed through 500m of standard telecommunications fibre. This fibre section was used to compensate for the dispersion mismatch accumulated over the subsequent two passes of the 25km transmission fibre due to the discrete (≈4nm) wavelength change of the data at the phase conjugator. The pulse stream was then split-with an 80:20 coupler and launched into the transmission circuit at a reduced power level (-13dBm) to ensure that transmission was in the linear regime. The transmission circuit consisted of 24.6km of standard (ie non-dispersion shifted fibre) used in a double-pass configuration. The duration of the pulses as measured at the laser output were measured to be 6.0ps and to have a spectral halfwidth of 0.42nm, corresponding to a time-bandwidth product of 0.32. At the fibre output (ie after transmission over 24.6km) the pulse pairs were considerably dispersed (individual pulse duration ≈200ps) and were consequently extensively temporally overlapped.

At this point spectral inversion of the data spectrum was carried out using FWM. The dispersed pulses (with average power -25dBm) were combined with the output from a tunable single-frequency laser (1533-1535nm, -11dBm), with polarisations aligned to maximise 4-wave-mixing, and input to a 35m germano-alumino-silicate based EDFA counter-pumped at 978nm. The amplified output (~50mW) was propagated through a 2.2km section of dispersion-shifted fibre which had a dispersion zero at 1532nm and thus was phase-matched for efficient FWM between the reference (DFB) and data signals. The wavelength-upshifted and spectrally-inverted conjugate of the data was spectrally filtered using a grating having a 3dB filter width of ~1.5nm, before being retransmitted back down the same 24.6km of fibre. At the relaunch the power in the phase-conjugated data signal was ~-23dBm. After the second pass of the 24.6km fibre the reconstructed pulses were split via the 80:20 coupler, amplified and input to an autocorrelator. Polarisation controllers were included to maximise the signal in the presence of polarisation-dependent effects in the grating filter and the autocorrelator.

Results

In figure 2 we show the spectrum and autocorrelation function (ACF) of the pulse pairs for the reasonably-wide pulse duration to separation ratio of 1:4.5, as measured at the 80:20 coupler. A sech^2 pulse form is assumed and thus the pulse halfwidth is a factor of 1.56 shorter than the ACF halfwidth. At this point the pulses have already broadened slightly from 6.0 to 8.8ps because of the 500m section of standard fibre. The pulse separation is observed to be 31.5ps, corresponding to a repetition rate of 32GHz. The optical spectrum of the pulses is modulated at a period of 0.24nm, in agreement with the observed pulse separation. The ratio of the cross to self-correlation peak heights is 2.3 to 1, instead of exactly 2 to 1, owing to a slight mismatch in powers from the two arms of the interferometer. The cross-correlation half-width (8.8ps) is the same as that of the self-correlation half-width, confirming the linearity of the autocorrelator scan.

The corresponding ACF after propagation over the full 50km is illustrated in figure 3 and shows a clear trace of the pulse pair. The self and cross-correlation widths are identical (~7.4ps) and the intra-pulse separation (~31ps) is preserved, indicating that no additional jitter has developed, or that significant deformation of the transmitted pulse pairs has occurred. Note that without the spectral inversion at the mid-point, individual pulses were observed to broaden to 400ps over the 50km span.

Similar data were obtained for inter-pulse separations ranging from 5:1 to 2.5:1 and the autocorrelation traces agreed well with their predicted forms, although at separations less than 2.5:1 (~70GHz) it was difficult to quantify the quality of the pulse train reconstruction owing to the relative insensitivity of the ACF shape to changes once the pulses are packed closely together. An example of a 50GHz trace is presented in figure 4, where we have resolved a pair of 7.1ps pulses at a separation of 20ps. Once again the self and cross-correlation widths are identical and the period agrees well with the repetition rate predicted on the basis of the 0.37nm spectral modulation observed on the input pulse spectrum.

Conclusions

These results confirm that the mid-point spectral-inversion scheme for dispersion compensation is capable of accurately reconstructing pulse patterns, even when they have temporally smeared to the point of extensive pulse overlap. Our results directly demonstrate the potential of the technique to extend to repetition rates greater than 100Gbit/s for NRZ data format. A demonstration to even higher rates should readily be achievable by reduction of the input pulse width.

Acknowledgements

The authors wish to thank York Fibres and Pirelli General plc for providing fibre used in these experiments. In addition the Royal Society is acknowledged for the provision of University Research Fellowships (RIL and DJR). The ORC is a SERC-funded Interdisciplinary Research Centre. This work was partly funded by EEC RACE program R2015 (ARTEMIS).

References

1. Y. Miyajima et al, Electron. Lett., 1991, **27**, pp. 1706-1707.
2. E. Ishikawa et al, Electron. Lett., 1992, **28**, pp. 1497-1498.
3. C. D. Poole et al, in Proc. OFC'92, PD14, San Jose, 1992.
4. S. Murata et al, IEEE Photonics Tech. Lett., 1991, **3**, pp. 1021-1023.
5. S. Watanabe et al, IEEE Photonics Tech. Lett., 1993, **5**, pp. 92-94.
6. R. M. Jopson et al, in Proc. OFC/IOOC'93, PD3, San Jose, 1993.
7. R.I. Laming et al. Submitted ECOC'93, 1993.
8. D. Taverner et al. submitted Nonlinear Guided Wave phenomena 1993.

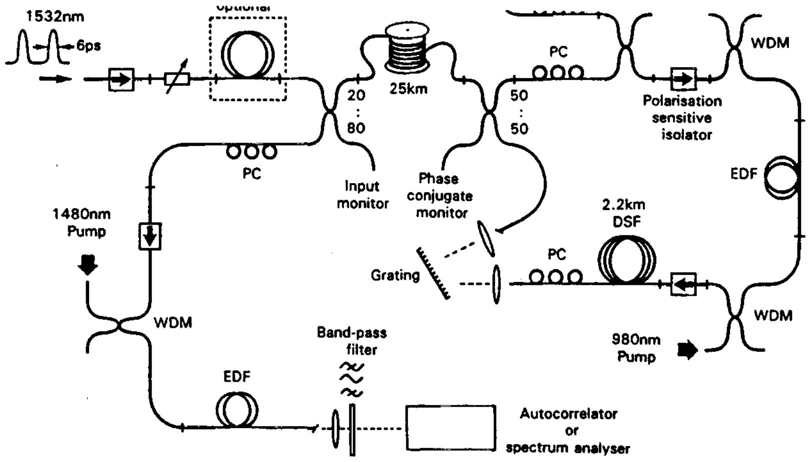

Figure 1 : Experimental configuration

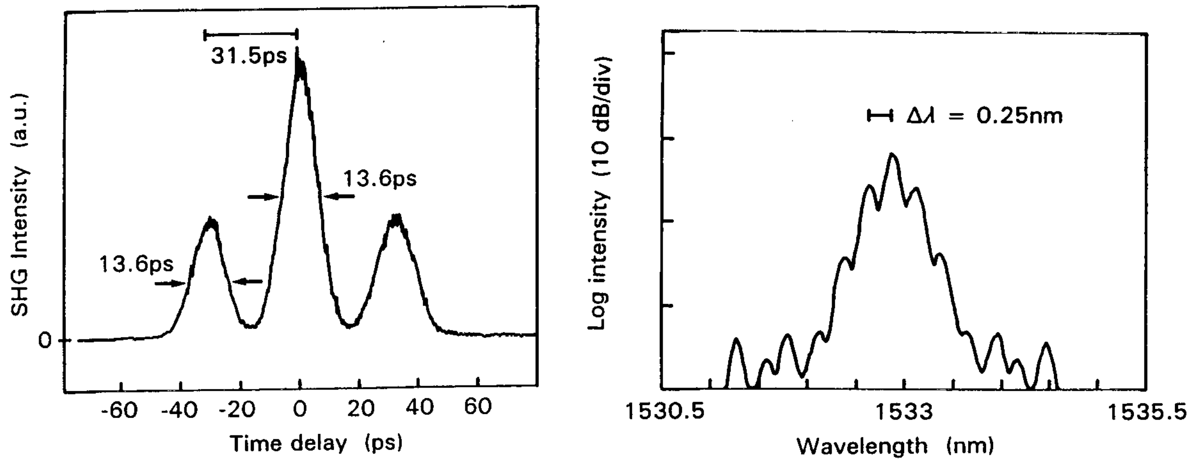

Figure 2 : (a) Autocorrelation trace and (b) spectrum of the pulse pairs at the 24.6km transmission fibre input

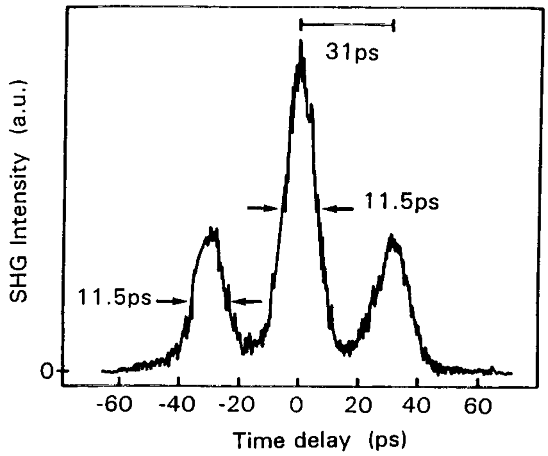

Figure 3 : Autocorrelation trace of the reconstructed pulse pairs illustrated in figure 2 after transmission through the 50km circuit

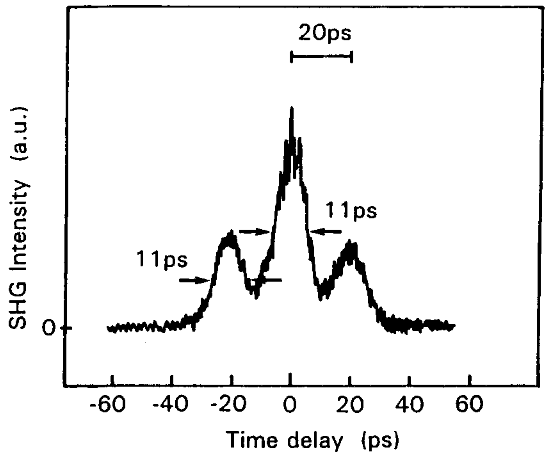

Figure 4 : Autocorrelation trace of the reconstructed 50GHz pulse pairs after transmission through the 50km circuit.