Subm. Elec. Lett. 15/4/95

1032

Dispersion compensation of 16ps pulses over 100km of step-index fibre using cascaded chirped fibre gratings

D.Taverner, D.J.Richardson, S.Barcelos, M.N.Zervas, L.Reekie, R.I.Laming
Optoelectronics Research Centre,University of Southampton,Southampton SO17 1BJ,
United Kingdom.
Tel: +703 592693 Fax: +703 593142

Abstract: We present the propagation of 16ps data pulses over 100km of step-index fibre utilising two cascaded chirped fibre gratings to achieve dispersion compensation. At the output the pulses are broadened slightly, to 20ps, indicating the potential for 50Gbit/s operation.

Dispersion compensation of 16ps pulses over 100km of step-index fibre using cascaded chirped fibre gratings

D.Taverner, D.J.Richardson, S.Barcelos, M.N.Zervas, L.Reekie, R.I.Laming

A major limiting factor in upgrading the currently installed network of step-index (SI) fibre to high capacity operation in the 1550nm spectral window is the high dispersion of the fibre in that region. Dispersion compensation using chirped photorefractive fibre Bragg gratings is one of the most promising techniques for overcoming this limitation [1,2,3]. Currently, the relatively short length of the gratings produced (<10cm) limits the amount of compensation possible. In this letter we demonstrate that by reflecting the data consecutively off several gratings it is possible to greatly increase this compensation and have obtained the propagation of 16ps pulses over 100km of SI fibre with minimal distortion.

The setup is shown in fig.1. The source was a mode-locked, 1km, polarisation switched, erbium-doped fibre (9m) ring laser producing transform limited solitonic pulses of 6-30ps duration at 1555nm. Two unchirped 4cm long gratings, written by a multi-pulse interferometric side-writing technique [4], of ≈35% and ≈65% reflectivity were cascaded between the source and SI fibre using a 4-port circulator. The gratings were controllably chirped by Peltier heat pumps mounted at each end to establish a linear temperature gradient (up to ~100°C), and hence a linear chirp (up to ~1nm), along their length [5].

Initially, pulses of 16-20ps duration (full-width at half maximum (FWHM) intensity) were reflected from a single grating and propagated over 28km, 60km, and 100km of SI fibre with ≈16ps/(nm.km) dispersion. For each case the temperature gradient along the grating was adjusted to create the optimum linear chirp to compensate the dispersive effects of the SI fibre. The resultant grating bandwidths were approximately 0.8nm, 0.35nm and 0.2nm respectively. Figure.2 plots the temporal broadening factor (determined from the input and output pulse autocorrelation function (ACF) halfwidths) against the ratio of the pulse and grating spectral FWHM bandwidths ($\Delta\lambda_{pulse}/\Delta\lambda_{grating}$) for the optimum case at each distance. It was found that almost perfect compensation could be achieved over 28km (see figure.3), whilst the 60km and 100km cases show a 15% and 92% temporal broadening in the output respectively. This broadening can arise from two effects; first as a result of the non-ideal phase response of the grating and second as a result of spectral filtering which results in the suppression of higher frequency spectral components as the pulse spectral width approaches the grating bandwidth. These effects were investigated by independently replacing the calculated phase and amplitude responses of linearly chirped gratings with perfect response characteristics (i.e. quadratic phase and unity amplitude responses) in a numerical simulation of the system. It was clear that these two effects were almost equally responsible for the observed broadening when $\Delta\lambda_{pulse}/\Delta\lambda_{grating}<0.5$ with their effects being closely interlinked. For $\Delta\lambda_{pulse}/\Delta\lambda_{grating}>0.5$ the imperfect phase response gradually assumed greater significance in the overall broadening of the pulse. Further numerical simulations with apodised index modulation profiles showed that the improved phase response achieved, although resulting in an increased broadening (for a fixed grating length and propagation distance), did result in less energy being shed from the pulse.

In order to achieve increased bandwidth for a given total dispersion a second grating was then added to the system as shown in fig.1. Both gratings were then carefully tuned to the same central wavelength and the total chirp matched to that of the fibre. It was found that optimum compensation was achieved when both gratings were chirped to a spectral bandwidth of $\approx$0.37nm. After reflection, the 16ps pulses were propagated over 100km of SI fibre and the system output observed by either direct detection with a pin diode and sampling oscilloscope

(17ps FWHM resolution) or autocorrelation. The output pulses were measured to have broadened temporally by 25% (see figure.2), representing a significant improvement over the single grating case. Figure.4 shows that almost all of the energy was still contained within the main body of the pulse. This improvement comes from the reduced dispersion requirement placed on each individual grating, allowing chirping to greater spectral bandwidths; 0.37nm for the two grating case in comparison to 0.2nm required for a single grating to compensate for 100km of SI fibre. This increased bandwidth results in less spectral filtering and an improved phase response characteristic across the bandwidth of the pulse, hence operation in a significantly less disruptive regime.

In conclusion, the results show that cascading gratings offers a significant improvement in the amount of dispersion that can be compensated within current grating fabrication limitations. By utilising several shorter gratings instead of a single long grating it becomes unnecessary to push the fabrication process to it's limits and hence this technique offers benefits in the ease of manufacture and flexibility of use. By increasing the bandwidth of the gratings relative to the input spectral bandwidth we have shown that it is possible to significantly improve signal reconstruction and we have demonstrated minimal distortion of a 16ps pulse after propagation through 100km of SI fibre. These results suggests that larger cascades of broader bandwidth gratings could have great compensation potential for high data-rate (~100GBit/s) transmission.

References:

[1] R. Kashyap, S.V. Chernikov, P.F. McKee and J.R. Taylor: "30ps chromatic dispersion compensation of 400fs pulses at 100Gbit/s in optical fibres using an all fibre photoinduced chirped reflection grating", Electron. lett., 1994, 30, pp.1078-1080.

[2] D. Garthe, W.S. Lee, R.E.Epworth, T. Bricheno and C.P. Chew: "Practical dispersion equaliser based on fibre gratings with a bit-rate length product of 1-6TB/s.km", Proc. ECOC, 1994, 4, pp 11-14.

[3] B. Malo, K.O. Hill, S. Theriault, T. Kitagawa, D.C. Johnson, J. Albert, K.Takiguchi, T. Kataoka and K. Hagimoto: "Dispersion compensation of a 100km, 10Gbit/s optical fibre link using a chirped in-fibre Bragg grating with a linear dispersion characteristic", Proc. ECOC, 1994, 4, pp. 23-26.

[4] G. Meltz, W.W. Morey and W.H. Glenn: "Formation of Bragg gratings in optical fibers by a transverse holographic method", Opt.Lett. 1989, 14, pp.823-825.

[5] J. Lauzon, S. Thibault, J. Martin, F. Oullette: "Implementation and characterisation of fiber Bragg gratings linearly chirped by a temperature gradient", Opt.Lett., 1994, 19, pp2027-2029.

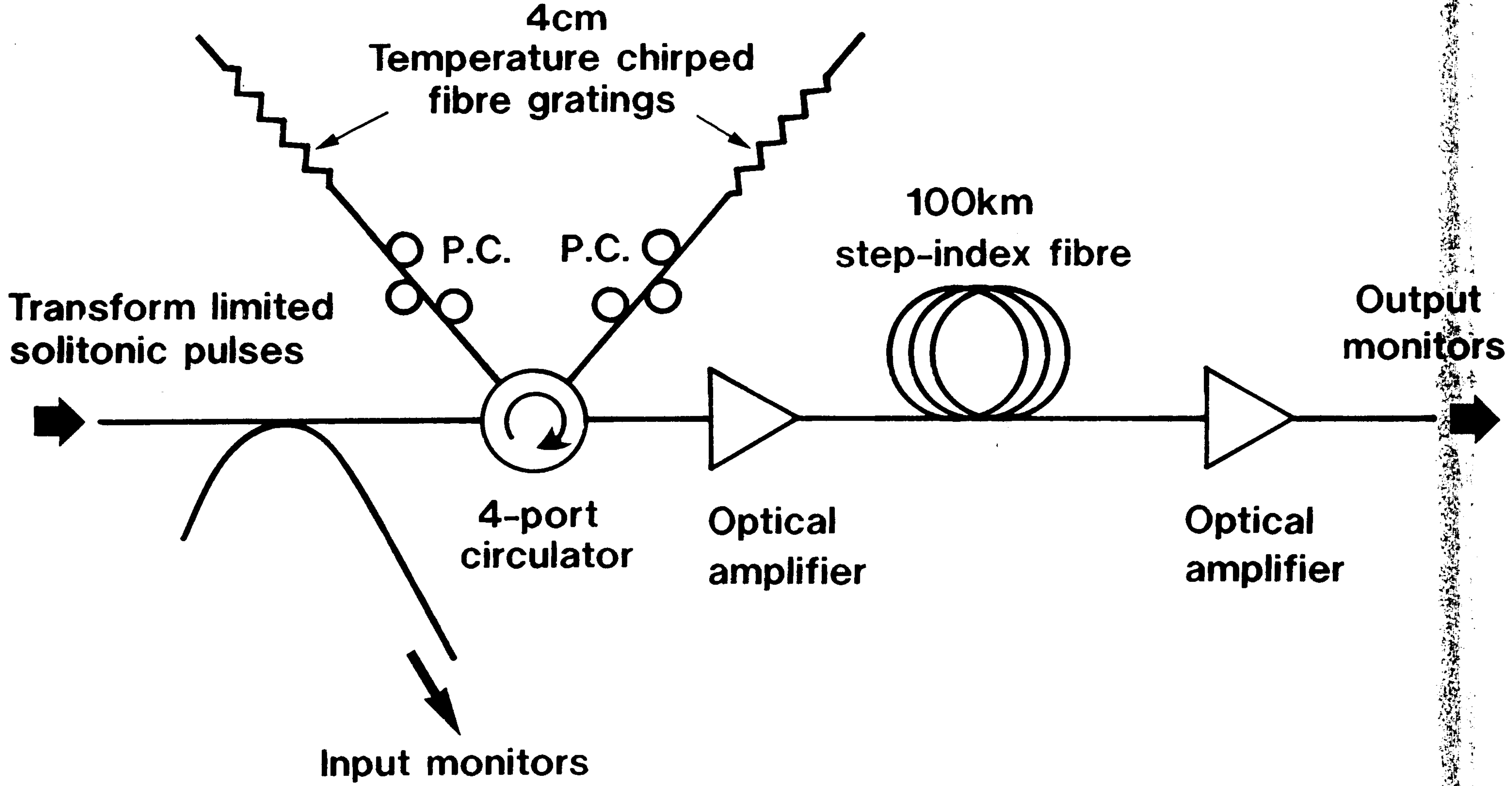
Captions:

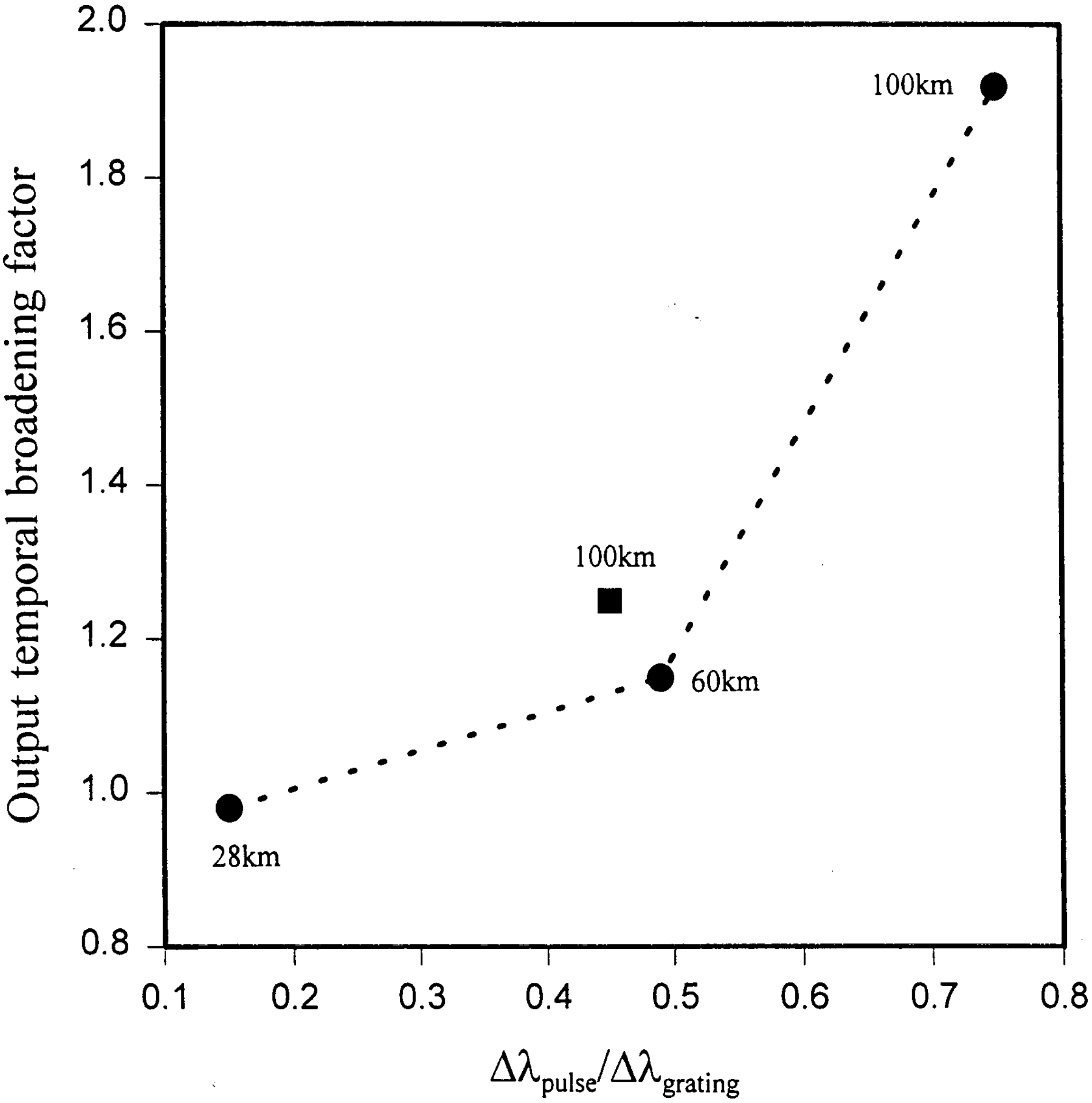
Figure 1: Experimental setup.

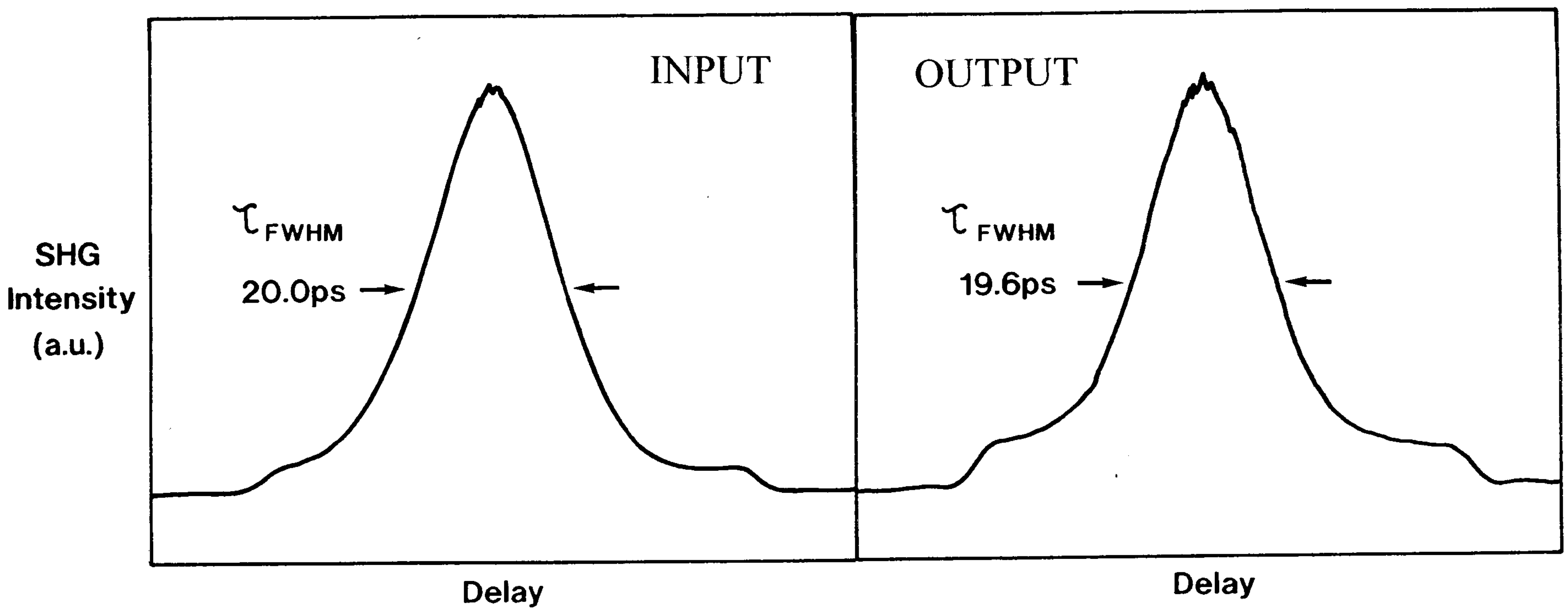
Figure 2: Output broadening factor against the optimum ratio of the pulse and grating FWHM for transmission through various lengths of SI fibre.The circles represent compensation by a single chirped grating, reflection from a pair of gratings was used to obtain the square data point.

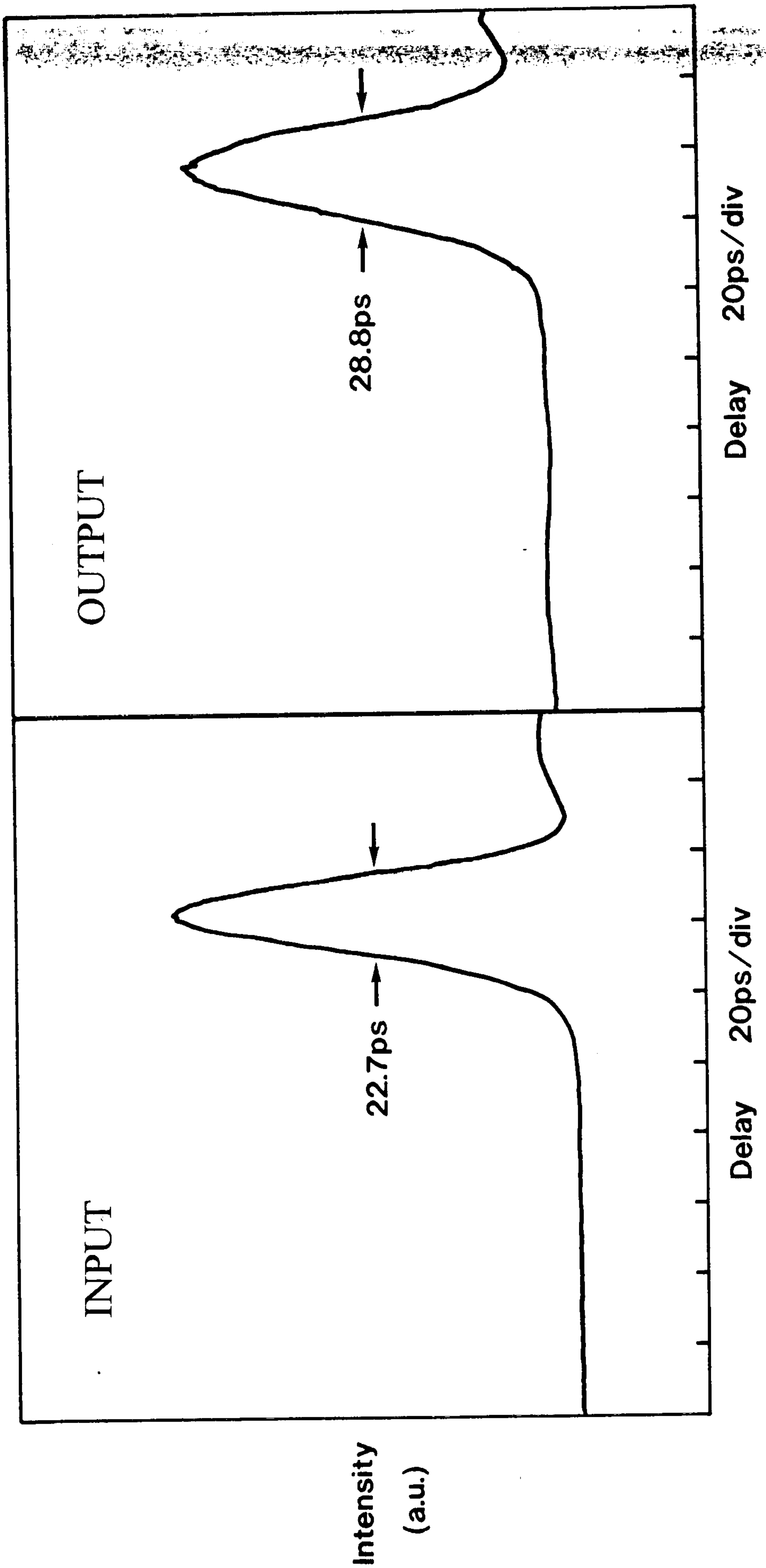
Figure 3: Autocorrelations of almost-perfectly reconstructed pulses after propagation over 28km SI fibre. The pedestal level was produced by the source laser when operated at the extreme of it's pulse duration range.

Figure 4: Directly detected intensity profiles of the input (left) and output (right) pulses after propagation over 100km fibre with 2 grating compensation. The ripples occuring after the pulses are due to detector ringing.


4cm
Temperature chirped
fibre gratings
P.C.
P.C.
100km
step-index fibre
Transform limited
solitonic pulses
Output
monitors
4-port
circulator
Optical
amplifier
Optical
amplifier
Input monitors


Output temporal broadening factor
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
$\Delta\lambda_{pulse}/\Delta\lambda_{grating}$
100km
100km
60km
28km


SHG
Intensity
(a.u.)
INPUT
τ_{FWHM}
20.0ps
Delay
OUTPUT
τ_{FWHM}
19.6ps
Delay


INPUT
22.7ps
Delay 20ps/div
OUTPUT
28.8ps
Delay 20ps/div
Intensity
(a.u.)