Demonstration of the possibility of > 100 Gbit/s transmission over 77 km of standard fibre using a super-step-chirped fibre grating dispersion compensator.

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Abstract

3.8 ps pulses at 1556 nm are reconstructed after transmission over 77 km of standard fibre using a 20 cm long super-step-chirped fibre Bragg grating. We show that good results can be obtained despite the fact that the grating was untrimmed and unapodised, even when the full 1.5 nm reflection bandwidth of the grating is used. ©1998 Elsevier Science B.V. All rights reserved.

If currently installed optical communications systems are to be upgraded to operate at the high repetition rates now made possible with the commercial deployment of erbium-doped fibre amplifiers, it is necessary to develop ways of compensating for the effect of fibre dispersion on ultrashort pulse propagation at 1.55 μm in standard fibre. The two techniques that have attracted the most attention are dispersion-compensating fibre (DCF) [1] and chirped fibre Bragg gratings [2], both of which work by providing dispersion of an equal and opposite magnitude to that of a given fibre span.

DCF has the advantage that it can provide dispersion compensation over the complete erbium gain bandwidth, but it also has some inherent drawbacks. In general the dispersion profile of DCFs is achieved through designs which include a small core diameter and high germanium content, which lead to high intrinsic loss and high optical nonlinearity. Since the length of DCF required to compensate for typical inter-amplifier distances is generally a few kilometers, these factors tend to limit their applicability. Chirped fibre gratings have the advantages that they are compact, low loss and, above all, short. This means that effectively they do not suffer from optical nonlinearity. The main limitations of chirped fibre gratings are that it is technologically difficult to manufacture long (and hence broad bandwidth, high dispersion) gratings, and although the delay characteristic is approximately linear with wavelength it does tend to have an associated ’’ripple’’, which can lead to quite substantial variations in dispersion.

Until recently the length of fibre gratings has been limited to about 10 cm, due to the dimensions of the phase masks used in their manufacture, and this effectively limits the maximum differential delay (dispersion) and bandwidth attainable from a single grating. Possible solutions to this problem that have recently been proposed and demonstrated include an interferometrically controlled moving fibre technique producing 20 cm gratings [3]; a moving fibre/scanning beam technique, which has been used to produce gratings 40 cm long [4]; and the super-step-chirped (SSC) grating technique [5], in which a grating is simply fabricated using several step-chirped phase masks with...
Fig. 1. Experimental configuration. SSC: super-step-chirped grating, EDFA: erbium-doped fibre amplifier.

coincident stop and start wavelengths at each junction. Such a structure can, in principle, be fabricated with a user-selectable approximately linear phase delay over a continuous bandwidth, and has been successfully demonstrated with gratings up to 1.3 m long. Both types of grating have been shown to be adequate for narrowband (∆λ < 0.1 nm) systems using one [6] or multiple wavelength-division multiplexed (WDM) channels [7], where the broad bandwidth of the devices is required solely to accommodate wavelength drifts in the sources due to thermal changes or aging. The real challenge, however, is whether such gratings can be used for ultra-high bit rate (> 100 Gbit/s or greater) communications systems. Such systems require pulse durations of only a few picoseconds, with a correspondingly broad bandwidth of a few nanometers. This means that the dispersion of the grating must truly be accessed continuously over its bandwidth and the effects of any ripples or discontinuities cannot be neglected.

For this reason, it is not sufficient to simply consider the total bit rate and transmission distance achieved as an indication of the merit of fibre grating dispersion compensation for ultrahigh bit rate systems. Rather, we propose, a better indication of the potential of such a device is given by the product of the continuous useable bandwidth and transmission distance. Applying this criterion, the results in Refs. [6,7] have bandwidth–distance products (BDP) of 18.7 nm km and 17.0 nm km per channel respectively. Impressive results have been achieved recently, including transmission at 10 Gbit/s over 700 km of standard fibre [8], but this was only made possible by adopting a duobinary encoding scheme with a reduced bandwidth. In this case the bandwidth–distance product was still a fairly conservative figure of 35 nm km. The highest BDP reported, to our knowledge, is 46.2 nm km, which was achieved using a 40 cm long grating manufactured by the moving fibre/scanning beam technique in a 40 Gbit/s, 109 km system [9].

To date the behaviour of super-step-chirped gratings has not been investigated in which the dispersion of the grating is accessed continuously over its bandwidth using ultrashort optical pulses, and it has been asserted that only continuously chirped gratings are viable for this application because of assumed deleterious effects of the stitching between grating sections. In this paper we report our successful experimental results on the use of a SSC grating to compensate for the dispersion suffered by 3.8 ps pulses after propagating through 77 km of standard telecommunications fibre. This result not only proves that SSC gratings are viable dispersion-compensating elements in ultrahigh bit rate communications systems, but also constitutes the highest reported BDP to date of 54 nm km.

Fig. 1 shows the experimental configuration. The test pulses had a duration of 3.8 ps, a FWHM bandwidth of 0.7 nm and a time–bandwidth product of 0.32. They were generated using a spectrally stabilised ‘‘figure-of-eight’’ erbium fibre laser [10]. These pulses were then reflected off the SSC grating via a 3 dB fibre coupler. The grating used was 20 cm long, had a bandwidth of 1.5 nm and a central wavelength of 1.5566 μm, and was made in two sections. Through careful manufacture the gap between the two sections was known to be < 0.5 mm, but no post-pro-
duction processing was used to trim the delay characteristic or apodise the grating. Fig. 2 shows a high resolution measurement of the grating reflection spectrum and the delay, obtained by the technique described in Ref. [4]. The two sections are numbered, and it can be seen that there is some ripple present on the linear delay line. This deviation had an RMS value of 34.6 ps. Fig. 3 shows the grating spectrum together with the input pulse spectrum, illustrating that the full bandwidth of the SSC grating is being utilised. The inset to Fig. 3 shows the autocorrelation trace of the input pulses. After being reflected from the SSC grating the pulses were stretched to ~900 ps. They were then amplified to an average power of ~20 dBm and injected into the 77 km span. The optical spectrum at the end of the fibre span was compared with that immediately after reflection from the grating in order to confirm that they were identical, indicating that the pulses were propagating in the linear regime and no soliton-like effects could influence the results. At the output end the pulses were again amplified and measured.

Fig. 4 shows the output pulse autocorrelation and spectrum. The pulse spectrum has been narrowed slightly due to the non-uniform reflection of the grating and the output pulse can be seen to have broadened to 5.75 ps ($\Delta r/\Delta t = 0.41$) and be accompanied by a broad low level pedestal. This pedestal was determined to extend for approximately ±75 ps around the pulse and have an intensity level of ~10% of the pulse peak intensity, and results from incomplete recovery of the pulse due to the non-uniform phase delay between grating sections. The extent of the pedestal was in good agreement with that expected from previous high resolution measurements of the grating delay.

Although pulse recovery was not perfect, this result shows that the SSC grating is capable of broadband dispersion compensation over real telecoms distances and transmission over standard fibre at data rates as high as 100 Gbit/s (maximum rate determined by pulse width) is feasible. One problem with only partial pulse recovery is that as the overall bit rate increases the level of the uncompensated inter-pulse noise will also increase. The use of stitch-trimming [11] and apodising [12] techniques on these long gratings should help to reduce the delay ripple and so significantly reduce this problem, and an appropriately designed receiver decision circuit could compensate for the eye-closure resulting from any remaining pedestal, thus leading to the possibility of dispersion compensation over telecoms spans at bit rates well in excess of 100 Gbit/s. The results we present here constitute the highest bandwidth—distance product so far achieved using fibre gratings for dispersion compensation.

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References