1276

Continuously chirped, broadband dispersion-compensating fibre gratings in a 10 Gbit/s 110km standard fibre link

M J Cole, H Geiger, R I Laming, S Y Set, M N Zervas, W H Loh, V Gusmeroli[†]
Optoelectronics Research Centre, University of Southampton,
Southampton SO17 1BJ, UK; Tel: +44-1703-593136, Fax: +44-1703-593142, E-mail: mjc@orc.soton.ac.uk
[†]Pirelli Cavi SpA, Milano, Italy

Abstract
Dispersion compensation of a 110 km fibre link over 4 nm is demonstrated using two continuous, glitch-free 36 cm long chirped fibre gratings. A 10 Gbit/s system trial shows that compensation of lasers with large wavelength tolerance is possible.

1 Introduction
Dispersion compensation is a very important field allowing the upgrade of the existing installed standard fibre network to high data rates (eg 10 Gbit/s) at 1.5μm. These data rates would otherwise be prohibited due to the dispersion of ~17 ps/nm·km. Chirped fibre gratings are the most attractive technique for this application, because they are low-loss, compact, and polarisation insensitive.[1] Additionally, these devices do not suffer from optical non-linearity which is the primary drawback of the main competing technology, dispersion compensating fibre. For present practical applications chirped fibre gratings must exhibit both high dispersion, ~1700 ps/nm, sufficient to compensate for around 100 km of standard fibre at 1.55 μm, and large bandwidth, of the order of a few nanometres, a typical semiconductor laser diode tolerance. This implies the need for a chirped grating approaching 1 metre length. In this paper we report the application of two broadband (4 nm) glitch-free linearly-chirped and apodised 36 cm long gratings used in cascade as a dispersion compensator for a 10 Gbit/s 1.55 μm IM/DD system operating over 110 km standard fibre.

2 Background
To date, long gratings have been typically fabricated using the phase mask technique,[2] owing to the stability of the writing method. The length of the grating can be increased beyond the size of the UV beam by placing the fibre behind a long phase mask and scanning the beam along it. Although linear gratings are relatively straight forward to make, techniques for post-chirping these devices after fabrication are cumbersome, and have included applying strain[1] or temperature gradients.[3] These techniques are limited by the length of the initial grating (~ 10 cm from available phase masks) and the length over which linear gradients can be applied. Alternatively, complex step-chirped phase masks have been employed for specific grating requirements.[4] In addition to chirping the grating, it is desirable to apply apodisation to reduce multiple reflections within it and improve the linearity of the time delay characteristic. In the past we developed a powerful technique which allows chirped and apodised gratings to be written directly into a fibre, "the moving fibre/phase mask scanning beam technique".[5] This is based on shifting the phase mask relative to the fibre as the phase mask is scanned with the UV beam. Apodisation is achieved by dithering either the fibre or the phase mask at the edges of the grating during the

scan. Like all the previous techniques, the one drawback with this technique is that it is limited to gratings the length of the available phase mask.

The limitation caused by the size of the phase mask has been overcome in one approach using several 5 cm step-chirped phase masks.[4] These are scanned in series to obtain a longer grating. The phase glitches occurring between the sections is subsequently UV trimmed to reduce their impact.

Taking some of the ideas from our earlier work we have recently developed a continuos fabrication technique capable of producing fibre gratings up to 40 cm at present. The phase shift is continuously added and no glitches are present. Fabrication of each grating takes approximately 400 seconds. In this paper we discuss the characteristics of the first gratings fabricated, and demonstrate their application in dispersion compensation.

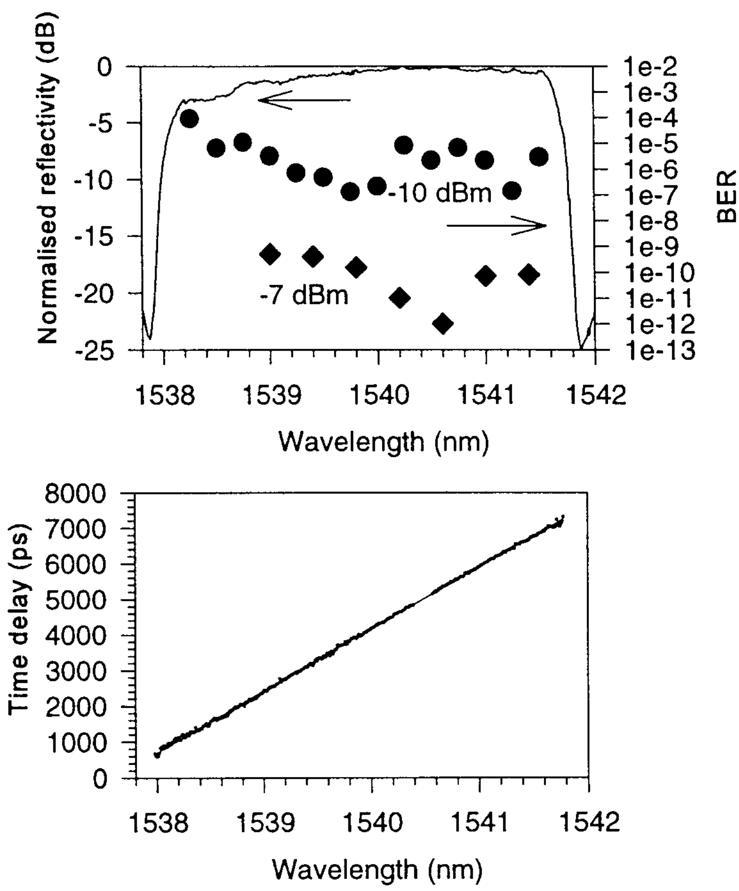

Fig 1 Reflectivity, time delay and BER against wavelength for the dispersion compensator

3 Experiment

Two 36 cm chirped gratings centred at 1540 nm were fabricated with a 4 nm linear chirp in a 0.2 NA, 1300 nm cutoff, hydrogenated SiGe fibre. 10% at each end is apodised with a raised cosine profile. The high NA fibre was selected to shift the induced cladding mode loss outside the operating bandwidth of the compensator. The gratings are written to give peak reflectivity of ~90%, when combined with a circulator their loss should be ~3 dB. The 3dB bandwidth of ~3.8nm is slightly less than the chirp owing to apodisation. The two gratings were combined with a 4-port circulator to give a 1735 ps/nm, 4 nm bandwidth dispersion compensator with an insertion loss of 10dB, where the excess loss is due to poor splices and modal mismatch between the circulator and gratings. From the characteristics shown in figure 1, it is clear that the time delay for the cascade is extremely linear, having a standard deviation of only 40 ps from the slope of 1735 ps/nm. This corresponds well to that anticipated for a 4 nm chirp over 72 cm. In addition a smooth reflection spectrum is observed, with a slight ~2dB slope due to induced OH^- loss as a result of hydrogenation.

The dispersion compensator was tested in a 10 Gbit/s IM/DD transmission system operating over standard fibre as shown in Fig 1. Output from a tunable laser operating around 1540nm was modulated with a balanced Mach-Zehnder $LiNbO_3$ modulator and a 2^{15}-1 pseudo-random pattern. The link was made up of 50km spans of standard fibre and erbium-doped fibre amplifiers (EDFAs). The short amplifier span length minimised amplifier noise and allowed the study of dispersion penalty. The grating/circulator combination was incorporated directly after the transmitter, due to it's polarisation sensitivity. The bit-error rate (BER) was measured as a function of the received optical power. The modulator is polarisation sensitive, and hence the laser output polarisation needed to be matched to the modulated polarisation. The fibre used for fabricating the gratings was found to be birefringent, hence the need for a polariser and a polarisation controller at the input to the compensator.

Figure 3 shows BER curves taken for four different wavelengths within the bandwidth of the dispersion compensator, each of which exhibits error free operation at approx -6 to -8 dBm of received optical power. In all cases an improvement in sensitivity compared to back-to-back is observed. The dispersion compensating bandwidth of the gratings was measured by tuning the transmitter wavelength. The link length was 110 km and the received power maintained constant. The transmitter was scanned from 1538 nm to 1541.5 nm and performance confirmed continously across the band (see figure 1).

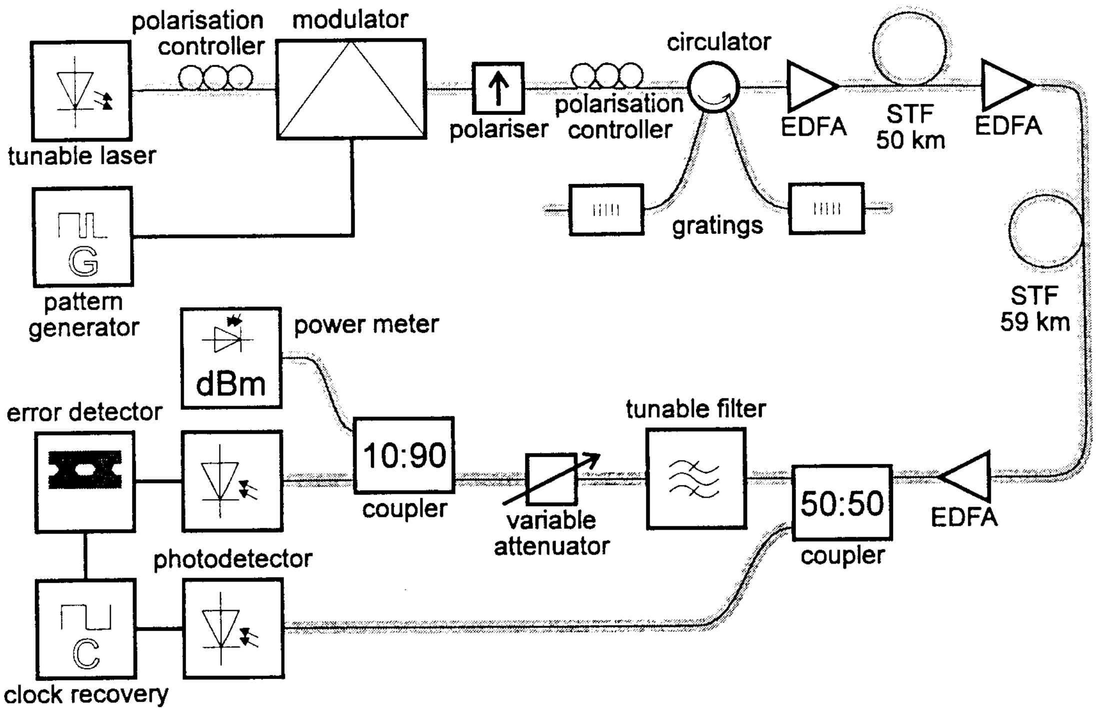

Fig 2 Schematic of the experiment

4 Conclusion

We have fabricated two 36 cm, 4 nm bandwidth linearly chirped gratings. Combined they exhibit a dispersion of 1735 ps/nm and an insertion loss of 10 dB (including the 4-port circulator). The combination has been tested in a 10 Gbit/s IM/DD transmission link operating over a distance of 110 km and shown to be effective in compensating the dispersion of 110km of standard fibre over a 4nm bandwidth. Although further optimisation of the fabrication technique is required, we have demonstrated the largest dispersion-wavelength product for any continous, glitch-free grating dispersion compensator reported to date.

Acknowledgements

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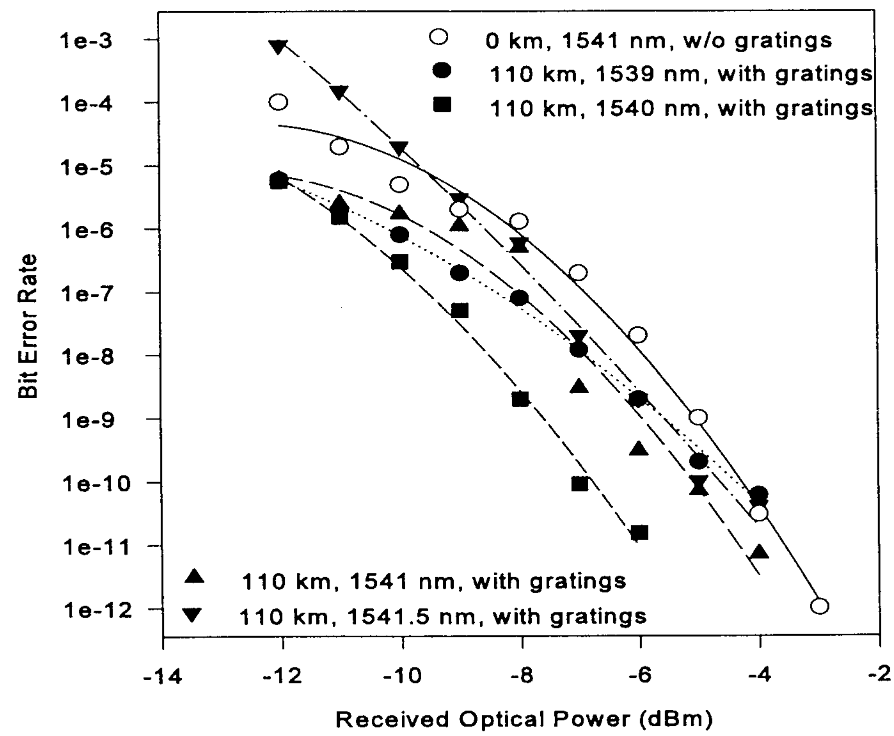

Fig 3 BER plots for different wavelengths and distances