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10 GBIT/S TRANSMISSION OVER 700 KM OF STANDARD SINGLE MODE FIBRE WITH A 10 CM CHIRPED FIBRE GRATING COMPENSATOR AND DUOBINARY TRANSMITTER

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Introduction

The advent of erbium-doped fibre amplifiers makes optical fibre transmission in the 1.55 μm wavelength window very attractive. However, with the large amounts of standard non-dispersion shifted fibres (NDSF) already installed, high bit rate transmission is restricted by the large dispersion of these fibres at 1.55 μm, unless compensating techniques are used. A number of approaches have been put forward to address this issue, such as dispersion compensating fibre[1], mid-point spectral inversion[2], dispersion-supported transmission[3], solitons[4], and chirped fibre Bragg gratings[5]. Of these, fibre gratings are attractive as they are passive, linear devices, highly dispersive yet compact and relatively easy to fabricate in large numbers. In recent years, progress in the use of fibre grating-based compensation for 10 Gbit/s transmission has been rapid, with distances reported from 160 km[6], 220 km[7], 270 km[8], 400 km[9] and most recently to 540 km[10]. In this work, we demonstrate that 10 Gbit/s transmission up to 700 km of NDSF is achievable with a single 10 cm long chirped fibre grating in combination with a reduced bandwidth phase-alternating duobinary transmitter.

Experiment

The experimental configuration is shown in Fig. 1. The transmission link is constructed with nominally 100 km (90-110 km) spans of NDSF, with an erbium fibre amplifier between each span. The average optical power launched into each span is 5.8 dBm. The 1558.8 nm duobinary transmitter is similar to that reported by Price et al [11,12], and Yonenaga et al[13]. It consists of a 10 Gbit/s pseudorandom bit stream filtered by a 3.7 GHz raised cosine electrical filter, which then drives a low-chirp $LiNbO_3$ external modulator biased about the point of maximum extinction. One attraction with this scheme is that the resulting optical intensity output from the transmitter is similar to conventional 10 Gbit/s binary data, making it compatible with standard 10 Gbit/s binary IM-DD receivers. However, two '1's which are separated by a '0' will be optically π-phase-shifted with respect to each other[13], and it is this alternating phase behaviour of the optical bit stream which results in a reduced optical bandwidth compared with conventional binary-encoded data.

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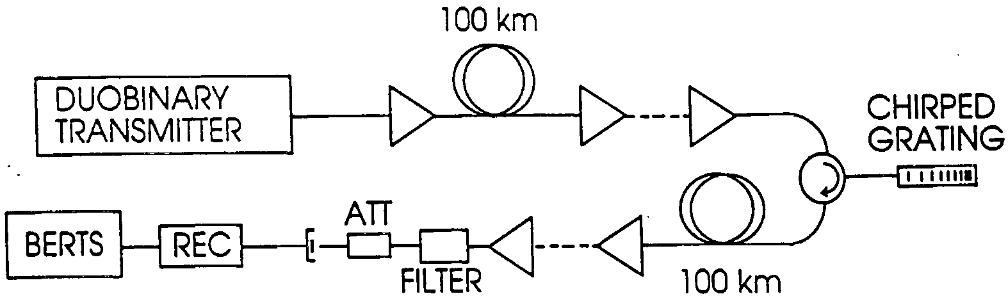

Fig. 1 Experimental Set-up. ATT: Attenuator, REC: Receiver, BERTS: Bit Error Rate Test Set.

Without compensation, the duobinary transmitter is capable of 200 km transmission in NDSF at 10 Gbit/s. The reduced optical bandwidth furthermore enables us to use very high dispersion 10 cm long chirped fibre gratings as compensators. Fig. 2 shows the characteristics of 2 apodised chirped fibre gratings fabricated from a 10 cm uniform phase mask with the moving fibre-scanning beam technique[14]. The first. grating 1. has a bandwidth of 0.12 nm and dispersion 5000 ps/nm, which would compensate for 300 km of NDSF. Grating 2, with a bandwidth of 0.073 nm, has a correspondingly higher dispersion of 8000 ps/nm. and is thus capable of compensating 500 km of NDSF. While grating 1 could also be used with conventional 10 Gbit/s binary transmission, the bandwidth of grating 2 would be too narrow except with the duobinary transmitter.

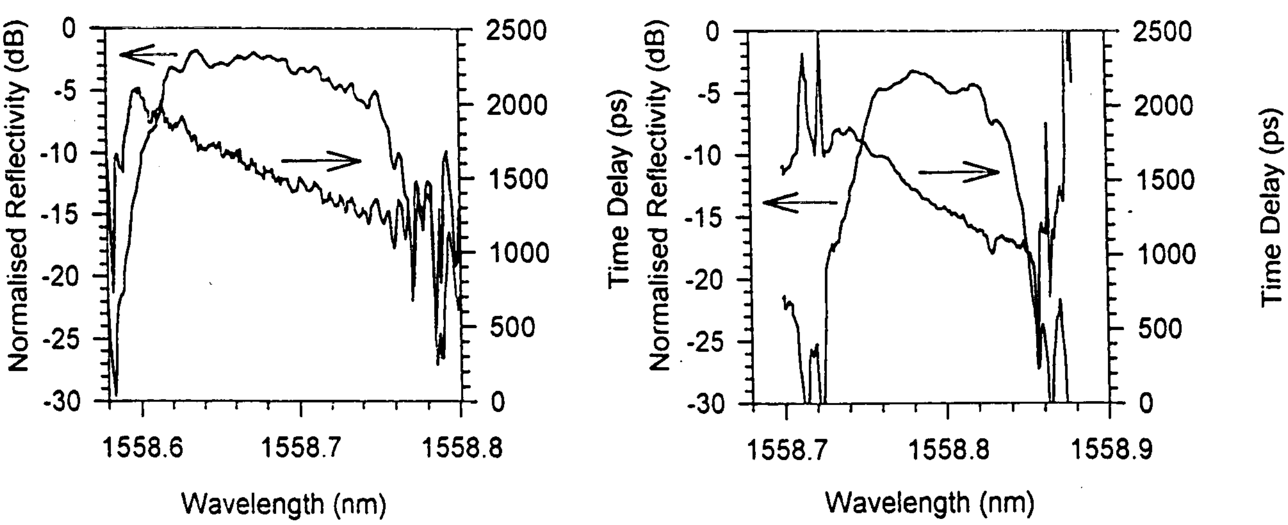

Fig. 2 Reflection and dispersion characteristics of (a) grating 1 and (b) grating 2.

Results

Fig. 3(a) shows the BER (Bit Error Rate) data obtained for transmission over various distances up to 500 km. For transmission over 100 km, no compensation is necessary, and there is actually a 1 dB improvement in sensitivity (at BER=10^{-9}). For transmission to 400 km, pre-compensation was provided by grating 1, with a 0.5 dB improvement in sensitivity over the back-to-back case. For 500 km transmission, however, we discovered that pre-compensation with grating 2 resulted in a severe penalty of about 6 dB. Numerical simulations indicate that this degradation in the system performance is a consequence of nonlinearities in the transmission fibre, and that proper positioning of the compensating grating is crucial to reducing this penalty. Indeed, by simply moving the compensating grating from the beginning to near the middle of the link, near-penalty-free transmission was recovered, as shown in Fig. 3(a), confirming the numerical predictions. Details of these simulations discussing the optimum positioning of the compensating grating(s) will be discussed in the paper immediately following this one.

Fig. 3(b) shows the BER data for the longest grating-compensated transmission distances obtained to date. At 600 km, the system performance is still similar to the back-to-back case, showing that the tolerances needed for matching the total length of the fibre link to that dictated by the grating dispersion is quite relaxed with this configuration. Increasing penalties are however observed for 650 km and 700 km, as the total fibre dispersion continues to exceed the grating dispersion. For these long distances, the compensating grating was situated in or near the middle of the link.

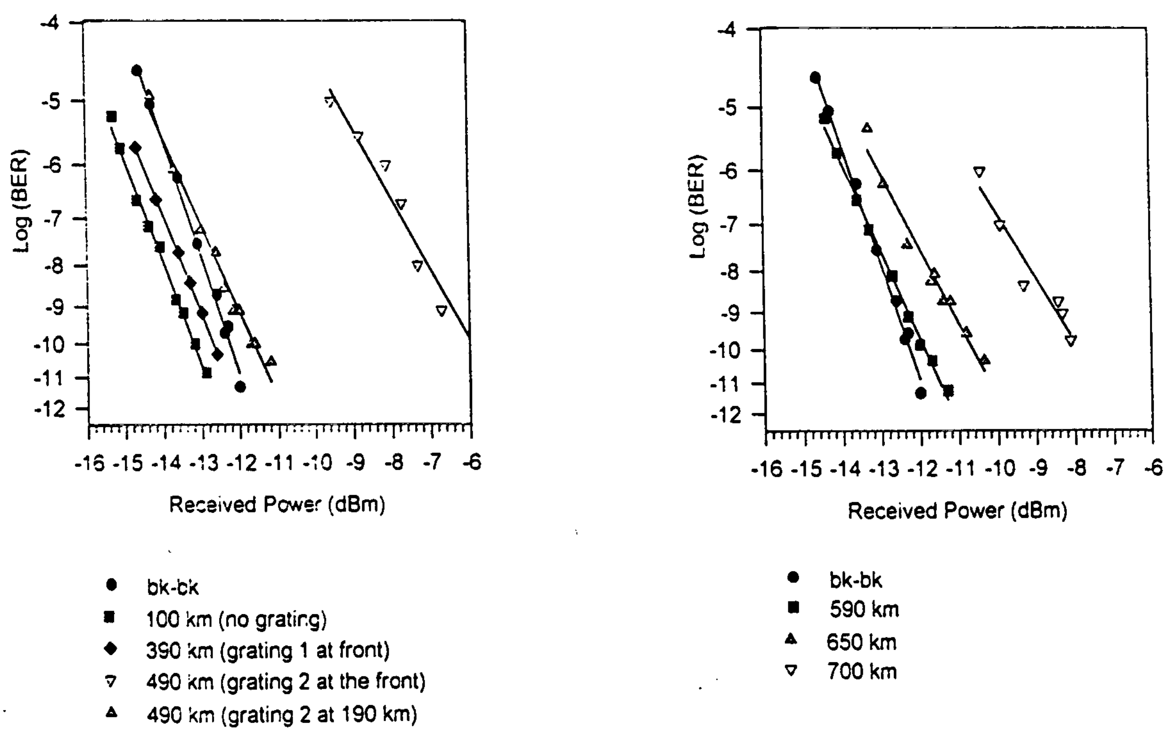

Fig. 3 Bit error rate data obtained for transmission over distances (a) up to 500 km, and (b) to 700 km.

Discussion

Fig. 4 summarises the results of this work, demonstrating that near-penalty-free 10 Gbit/s transmission at distances up to 600 km is now achievable, with the use of the duobinary transmitter and a single, properly positioned, grating compensator. However, for the longer distances, some polarisation sensitivity in the link was observed. At 590 km, this was investigated by placing several polarisation controllers in the link, and for what we determined to be the worst case, a 1.5 dB penalty (at BER = 10^{-9}) relative to that presented in Fig. 4 was obtained. This polarisation sensitivity is the combined effect of all the optical elements in the link: however, it is worth pointing out that the chirped fibre grating itself will have a contribution due to birefringence. It is not difficult to see that the associated differential group delay (DGD) will be given by DGD = $2B\Lambda D$, where B is the birefringence of the fibre containing the grating, Λ the grating pitch, and D the grating dispersion. We note that the grating DGD is not dependent on the grating length, but scales with both the birefringence and the dispersion. In our current case, the birefringence of the fibre used to fabricate the gratings was estimated as 0.8×10^{-6}, which yields a DGD of 7 ps. It is thus clear that for compensation over long distances, the birefringence of the grating fibre should be kept as low as possible.

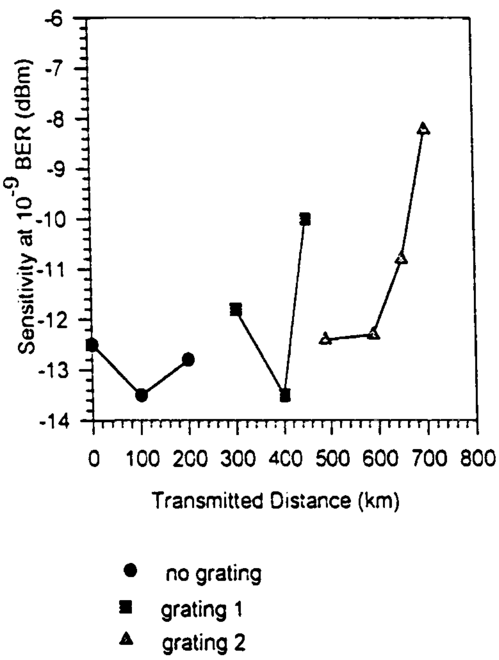

Fig. 4 Plot of sensitivity (at BER = 10^{-9}) against transmitted distance.

Conclusion

Up to 700 km transmission at 10 Gbit/s in standard non-dispersion shifted fibre has been demonstrated using a phase alternating duobinary transmitter and a single 10 cm chirped fibre grating. This is the longest distance achieved by chirped fiber gratings, and, to our knowledge, also the longest distance achieved at 10 Gbit/s using a single dispersion compensating element to date. To achieve these long distances, the proper positioning of the compensating grating is crucial.

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