DISPERSION COMPENSATION GRATINGS

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Abstract: Broadband Chirped fibre gratings allow the upgrade of the existing non-dispersion shifted fibre network to high data rate operation within the 1.55μm low-loss window. The design, fabrication, performance and application of these devices is covered.

Summary: Erbium doped fibre amplifiers have effectively eliminated the propagation-loss barrier in modern telecommunication systems, providing high gain and low noise figure operation over a large (30-80nm) bandwidth 1.55μm, and have enabled high-bit-rate data transmission over transoceanic distances. However, to date the majority of the installed fibre shows a zero dispersion at ~1.3μm and exhibits a relatively high dispersion (~ +17ps/nm/km with a slope of +0.07ps/nm^2/km) across the erbium band. This implies that the upgrade of the existing network to make full use of the erbium bandwidth by either TDM or WDM techniques, will be severely limited by the effects of linear and third order dispersion. The dispersion effects become even more adverse when combined with the optical fibre non-linearities.

Efficient dispersion compensation schemes will be of paramount importance in al the future, high capacity optical networks. So far, a number of different dispersion compensation techniques, such as dispersion compensating fibres, linearly chirped fibre gratings and mid-point spectral inversion have been proposed and studied extensively. However, chirped fibre Bragg gratings are proving to be one of the most attractive devices for this application as 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 i.e. dispersion compensating fibre (DCF).

The length of the fibre grating limits the maximum time delay or, equivalently, bandwidth x dispersion product. For example a 10cm grating can compensate for 100km of standard fibre over approximately a 0.5nm bandwidth. To date there have been several techniques reported for producing chirped gratings. These include post-chirping uniform gratings using UV processing [2] or by applying either a linear temperature [3] or strain gradient [4]. Alternatively the chirp can be directly imposed during fabrication [5]. At present all these techniques are limited to gratings ~10cm in length, and thus narrowband compensation, by the length of available phase masks used in production. By employing such narrowband compensators 10Gbit/s transmission distances ranging from 100 to 700km of non-dispersion shifted fibre have been achieved demonstrating the viability of this technology [3,4,6-10]. In the latter case a 0.07nm bandwidth grating in combination with duobinary transmission was employed [10]. Sampling the grating can increase the effective number of channels compensated providing that the laser wavelengths and grating passbands are accurately matched.

Although in the future transmitter wavelength tolerances will improve and thus narrowband gratings may be employed, for present practical applications chirped fibre Bragg gratings must exhibit both high dispersion and large bandwidth. A time delay of around 1700ps/nm would be sufficient to compensate around 100km of standard step index fibre at 1.55μm and a bandwidth of the order 5nm would cover typical semiconductor laser diode wavelength tolerances. This implies the need for long gratings (of ~1m in length) with a constant dispersion profile and broad bandwidth.

Kayshap et al [11] have achieved 1.3 metre gratings by concatenating many shorter gratings. However the stitching errors between section cause time-delay and reflection spectra discontinuities which may limit their usefulness. Taking some of the ideas from our earlier work [5] we have recently developed a continuous fabrication technique capable of producing arbitrary profile fibre gratings of 1 metre at present, ultimately limited by the maximum length of high quality translation stages. The phase shift is continuously added during the entire writing process and hence no glitches are present in the time-delay and/or reflectivity spectrum. Fabrication time for each 1 metre device is typically 10 minutes depending on the photosensitivity of the fibre used. Figures 1(a,b) show the characteristics of a typical linearly chirped 1 metre gratings with apodisation to reduce the time-delay ripples. Theoretical simulations [12] of the wavelength dependence of the eye opening penalty for a 10Gbit/s NRZ dispersion compensated link are shown in figure 2. The results indicate that their is only a small degradation due to imperfections in the time delay characteristic of the latest gratings. This will improve further in the near future. Results from a 10Gbit/s transmission experiment confirm that the device works across the full bandwidth and confirms chirped gratings as a powerful component for use in networks [13]. Further operation of similar gratings has been demonstrated in a 4 x 10Gbit/s field trial by MCI and in a 40Gbit/s RZ experiment [14]

By periodically modulating the strength of the grating 'sampling' creates multiple reflection gratings for WDM applications [15, see also Ibsen et al at this conference]. The response of the super-structure can potentially be tailored to match/compliment the EDFA gain spectrum and compensate for linear and higher-order dispersion. In fact we have recently achieved 1 metre gratings optimised for third order dispersion [16] as shown in figure 3.

Although fibre gratings can compensate the dispersion of several hundred km's of fibre with one device, numerical simulations have shown that it is preferable to distribute compensators throughout the link to reduce the effects of fibre non-linearity. Employing this approach high-bit-rate error-free transmission over distances in excess of 1000km are predicted using linear transmission [17,18] and further using soliton transmission. Recent experiments confirm this potential [19] as shown in figure 4.

In summary, chirped gratings have been shown to be ideal for upgrading the installed standard fibre network to the 1.55µm wavelength window and high bit-rate operation. This talk will cover various aspects of their design, performance and network application.

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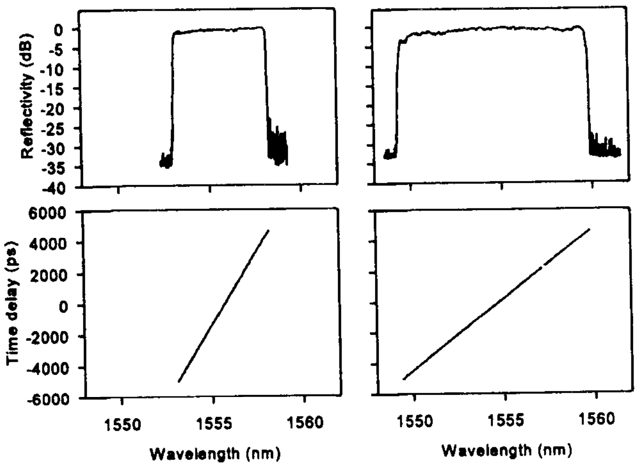

Figure 1. Characteristics of two 1 meter chirped gratings.

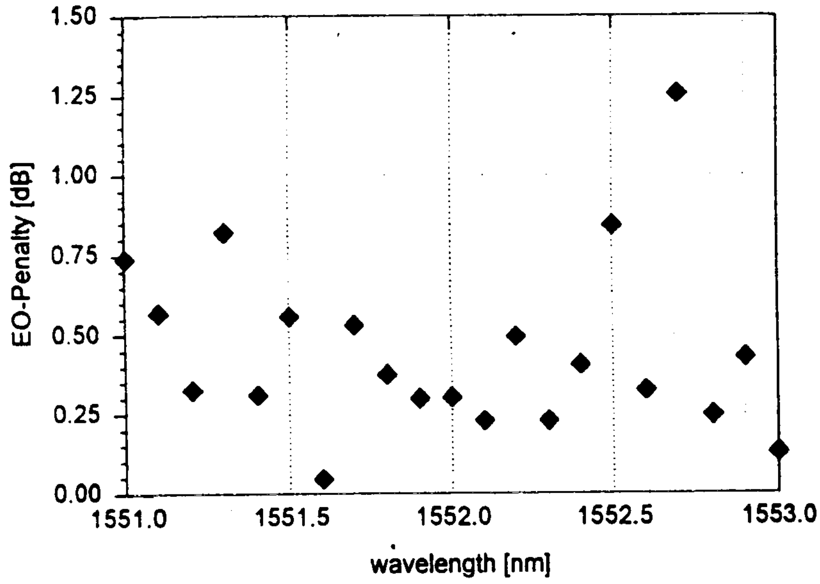

Figure 2. **Simulated EO-penalty for a 1 meter grating operating in a 100km 10Gbit/s dispersion compenated link as a function of transmitter wavelength.**

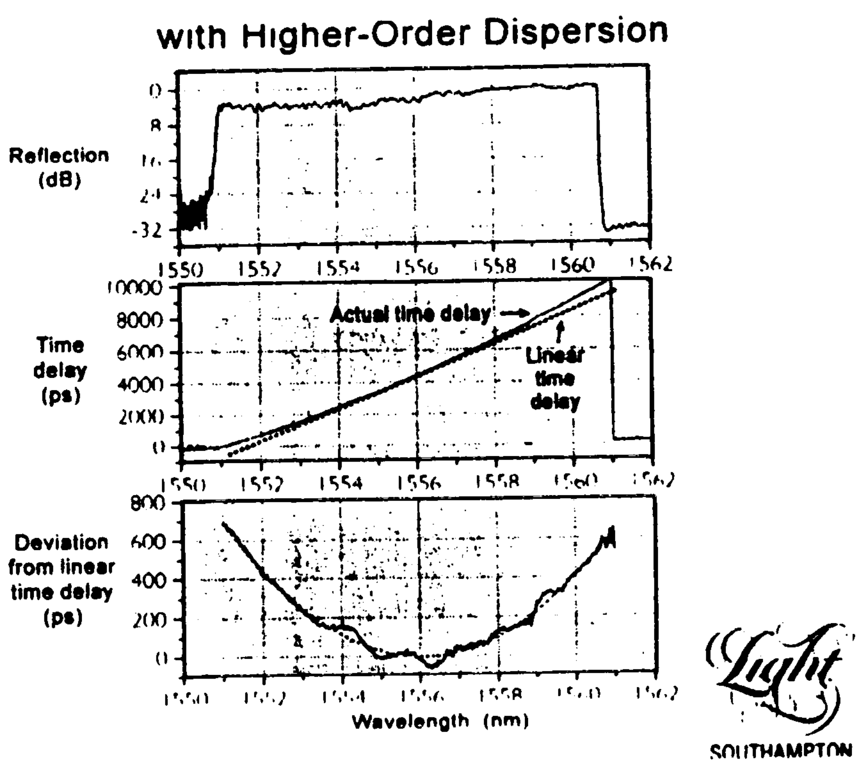

Figure3. **1 metre grating with third order dispersion.**

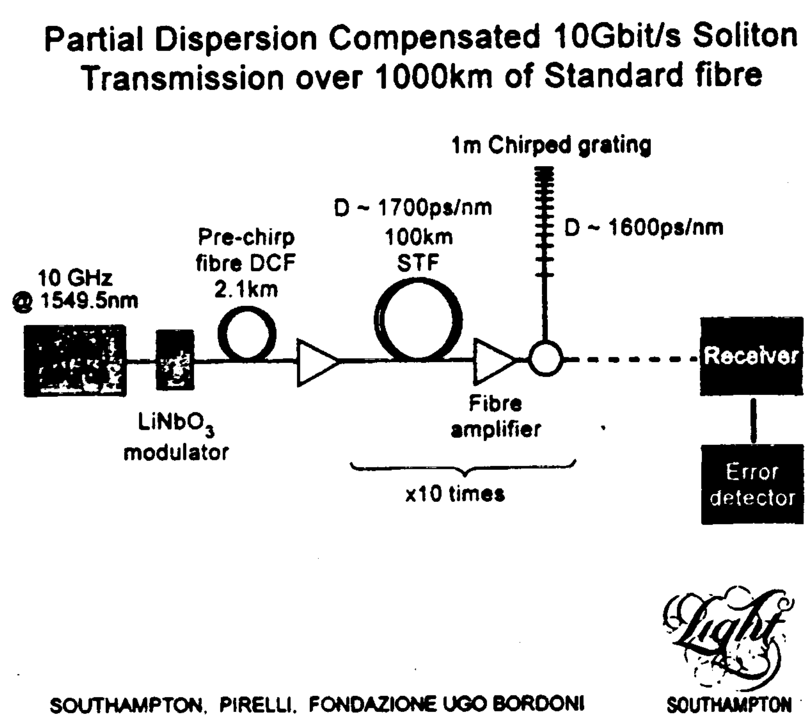

Figure 4. **1000km straight-line 10Gbit/s soliton experiment over standard fibre.**