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Effects of non-ideal group delay and reflection characteristics of chirped fibre grating dispersion compensators

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Abstract

The effect of non-ideal dispersion and reflection characteristics of chirped fibre gratings on the performance of 10Gb/s NRZ-transmission systems operating over standard fibre is investigated. Analysis of an experimental grating confirm that fabrication technology can meet the requirements for < 1dB-penalty.

I. Introduction

Chirped fibre gratings have been demonstrated as potential dispersion compensators to overcome the limitation of long-haul and high-bit-rate transmission over non-dispersion shifted fibre. They provide a simple and attractive optical fibre delay, which is polarisation-insensitive, inherently fibre compatible, relatively easy to produce, passive and low-loss[1]. However fibre gratings are, reflective, resonant devices. Uniform strength, chirped fibre gratings have side lobes in the reflection spectra and nonlinear dispersion characteristics, which are undesirable for optical communications. Fortunately these can be significantly suppressed by apodising the grating[2]. An optimized apodisation profile improves the compensator performance in the system[3], however, there still remains slight nonlinear group-delay characteristics (ripples). The period of these depends on the length of the grating and has roughly a range of 1pm to 10pm. In addition, the fabrication process introduces stochastic variations in the time delay and reflectivity response.

In this paper, we investigate the effect of these group delay and reflectivity ripples on the grating performance in high-speed optical communication systems. The modulation is modelled by a periodic function, with period in the picometer range. The effect of the modulation is found to depend on both the amplitude in reflectivity and the product of period and amplitude in the time delay. Their impact on the performance of a 10Gb/s linear transmission system is quantified by calculating the resulting eye-opening (EO) penalty.

II. Model Description

The linearly-chirped grating is modelled to compensate the group-velocity dispersion of 100km of standard fibre with a dispersion of 1700ps/nm at 1.55μm. To study the effects of the modulations, a periodic function is added to either the reflectivity or the time delay spectra. To focus on the effect of the

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ripples on the system performance, fibre nonlinearities were not included. NRZ pseudo-random data consisting of 2^7 -1 bits was investigated. Longer word lengths (PRBS 2^{10}-1) were investigated but only caused a ~2% system penalty variation.

The grating losses are corrected by an optical amplifier, with gain set to give a constant average power launched into the fibre. At the receiver, the signal is optically filtered by a 40GHz bandwidth Bessel filter, before being detected and electrically filtered by a 7GHz Bessel filter.

III. Results and Discussion

Fig 1 shows the effect of the modulation in the reflection spectra for a peak-to-peak amplitude of ~1dB. The time delay is linear. For periods less than ~100pm (12.5GHz), the maximum penalty is ~0.3dB, whilst for periods larger than the data bandwidth the imperfections have no effect. The magnitude of the EO-penalty is observed to depend on the phase (θ) of the modulation relative to the signal wavelength (λ_0). The minimum penalty (best case) occurs for $\theta = n\cdot\pi$ (n = 0,1,2...) whilst the maximum (worst case) occurs for $\theta = n\cdot\pi+\pi/2$. Transmission of 40Gb/s data was also investigated and as expected, the transmission performance for a given modulation period at 40Gb/s is equivalent to four times the period at 10Gb/s. That means for 40Gb/s data periods over 400pm has a negligible impact.

Fig 2 illustrates the effect of the amplitude of the reflectivity ripples. In this case, the period of the modulation is fixed at 10pm. For less than 0.5dB EO-penalty, the peak-to-peak amplitude of the modulation should be less than ~0.32 (~1.67dB).

To study the effect of the time delay imperfections, a constant reflectivity is considered. The maximum and minimum EO-penalties for ±60ps of time delay deviation (b_1) against the period (p) of the modulation are plotted in Fig 3. The EO-penalty is worst for periods comparable to the bit rate whilst for shorter periods the data effectively averages the modulations. The intensity of the effect is found to depend on the product $b_1 \cdot p$. Therefore, a similar EO-penalty is found for b_1 = 30ps and p = 15pm as for b_1 = 60ps and p = 7.5pm. Analogously to the effects of modulation in the reflectivity, the long period oscillation does not cause significant distortions in the compensated signal and the transmission bit rate can be scaled.

Fig 4 shows the effect of the modulation amplitude in the time delay on the EO-penalty for a fixed period of 10pm. For less than 0.5dB EO-penalty, the peak-to-peak amplitude of the modulation should be less than 170ps. Thus digital data is extremely tolerant to grating imperfections and well within the tolerances that can be manufactured[4].

Experimental data from a 70cm, 7nm bandwidth, 1000ps/nm dispersion chirped grating (see Fig. 5) has been analysed. The grating data was obtained with a wavelength resolution of 1pm and time resolution of ~1ps. Transmission over 60km is evaluated and EO-penalty over the grating bandwidth plotted in Fig. 6. The EO-penalties are typically less than 0.5dB and always less than 1.25dB. At present the imperfections are not fundamental to the grating but dominated by the fabrication process. Thus it is likely that these results will be improved with further refinements in grating fabrication.

IV. Conclusion

The effect of non-ideal dispersion and reflection characteristics of chirped fibre grating dispersion compensators on 10Gb/s NRZ linear fibre transmission systems has been investigated. The system degradation depends on the period and amplitude of modulation in both the reflectivity and time delay spectra. However, for high frequency (10pm period) modulations 10Gb/s NRZ data is extremely tolerant and peak-to-peak amplitudes up to 1.67dB in reflectivity and 170ps in time delay can be tolerated for less than 1dB EO-penalty. Analysis of an experimental grating confirm that chirped gratings can now be fabricated meeting these requirements.

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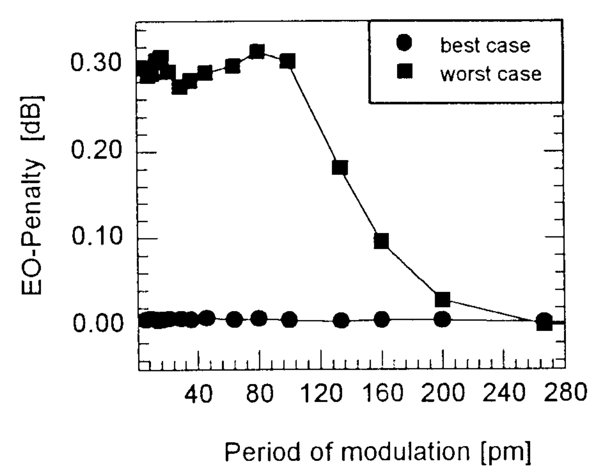

Fig. 1: Maximum and minimum EO-penalty as a function of the period of modulation in the reflection spectra. Peak-to-peak amplitude of modulation is ~1dB.

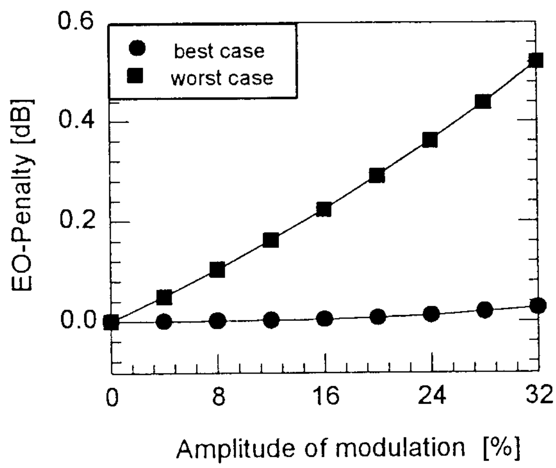

Fig. 2: Maximum and minimum EO-penalty as a function of the peak-to-peak amplitude of modulation in the reflection spectra. The period of the modulation is 10pm.

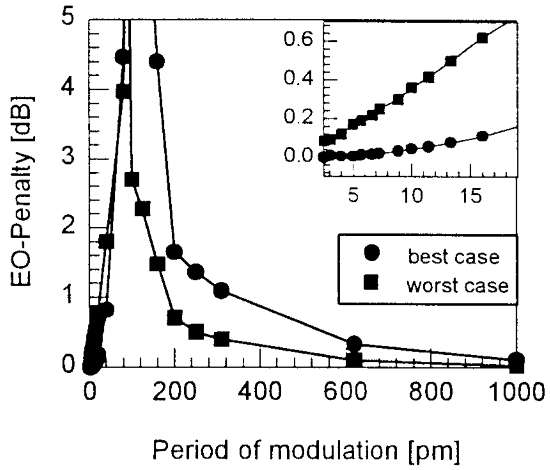

Fig. 3: Maximum and minimum EO-penalty as a function of the period of modulation in the time delay. The maximum time delay deviation is ± 60ps. The insert is a blow-up of data for small periods.

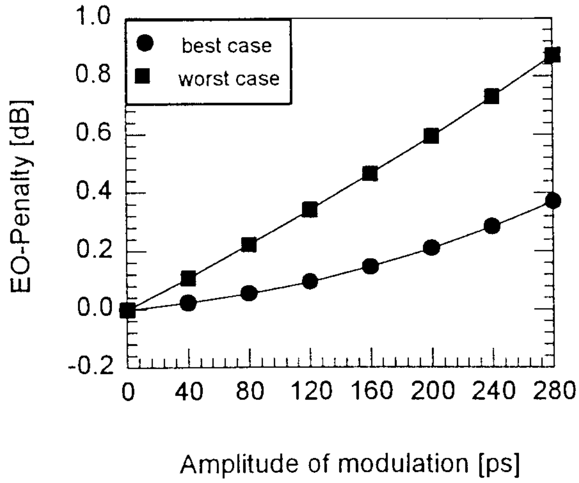

Fig. 4: Maximum and minimum EO-penalty as a function of the peak-to-peak amplitude of the modulation in the time delay. The period of the modulation is 10pm.

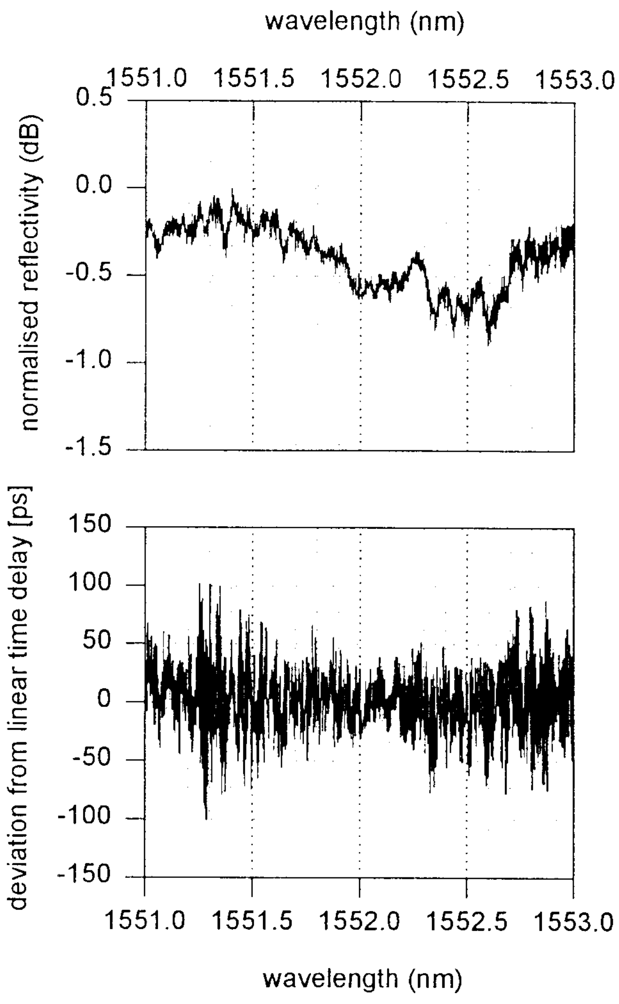

Fig. 5: Reflectivity and deviation from linear time delay of 1000ps/nm for the measured grating

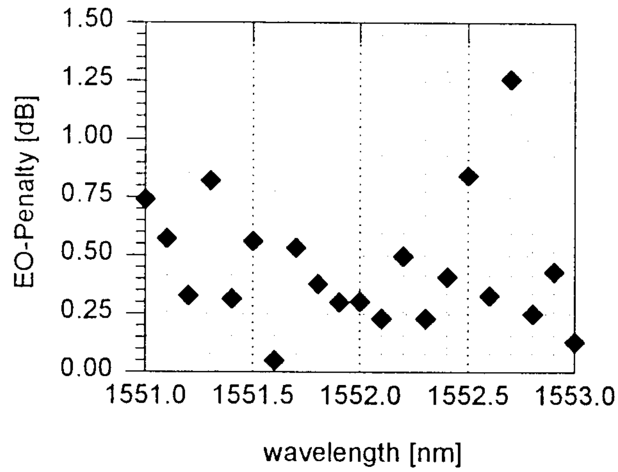

Fig. 6: System EO-penalty of the experimental grating data as a function of the transmitter wavelength.