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QUALITY CONSIDERATIONS OF CHIRPED FIBRE BRAGG GRATINGS FOR DISPERSION COMPENSATION IN WDM SYSTEMS

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Abstract: We evaluate the effect of imperfections both in long broadband fibre gratings and in cascades of shorter devices for multi-channel dispersion compensation. Similar performance levels are observed; the effect on transmission is predicted to be constant across the operational bandwidth.

Introduction

WDM transmission at data rates of 10Gb/s and above requires accurate compensation of fibre dispersion on each channel. The application of chirped fibre Bragg gratings (CFBGs) to dispersion compensation is well documented. Successful demonstrations are still tarnished, however, by the concern of many at the level of group delay ripple observed with such devices. In this paper we describe the effects of structural imperfections on the time delay characteristics of CFBGs designed for multi-channel WDM dispersion compensation. The effect of concatenating several short imperfect single-channel CFBGs is evaluated and compared to the characteristics of an equivalent long, broad-band CFBG. The *effect* of this noise in a transmission system is then discussed.

Effects of Structural Imperfections on CFBGs

Imperfections in the structure of CFBGs have been discussed previously for single channel devices [1]. The predominant effects are a low-level, spectrally-broad out-of-band reflectivity and a build up of group delay noise towards wavelengths reflected from deep into the structure. The performance of cascaded single-channel CFBGs is not simply determined by the group delay noise of each CFBG alone, but rather by the interplay of the spectral responses of *all* the CFBGs comprising the device.

The response of a CFBG is adversely affected by noise in any of the following: depth of index modulation (Δn); effective group index (n_{eff}); relative structural phase (ϕ). The absolute level of out-of-band noise is determined by the in-band reflectivity. An imperfect grating can be simulated by digitising a noisy structure and evaluating an appropriate cascade of grating transfer matrices [2].

A Single Imperfect Device in a Cascade of CFBGs

A CFBG has a highly dispersive response in reflection at wavelengths away from the band gap. Normally this is not problematic since the use of a suitable apodisation profile can suppress out-of-band response to < -60dB. The coherent addition of an out-of-band reflection from an imperfect grating with strong primary Bragg reflection of CFBGs on other ITU channels, however, leads to interferometric noise on the *effective* group delay response of otherwise perfect CFBGs in a cascade.

The effect on a perfect CFBG located after an imperfect grating was evaluated first with a range of different parameters for the structural noise. The basic design for the gratings was a length of 10cm, a chirp of 0.6nm and quarter-cosine apodisation profile over 1.7cm at either end. This gives a useable bandwidth of 0.45nm, less than -30dB reflectivity at ±0.4nm, and an in-band dispersion of ~1600 ps/nm (suitable for compensating ~95km of standard non-dispersion shifted fibre). The gratings were separated by 0.8nm (one channel on the ITU grid) and had a reflectivity of ~95%. The effect of the noisy grating is determined by the level of its out-of-band noise over the operational bandwidth of the perfect device (fig 1); the relative contributions of noise on Δn, n_{eff}, and ϕ are unimportant. For the parameters used an induced group delay noise of up to 30ps is observed when the imperfect grating exhibits a mean out-of-band reflectivity of no more than -35dB over the bandwidth of the perfect grating. The specific characteristics of the induced noise are determined by the bandwidth and length of the perfect CFBG.

The impact of a single imperfect grating on the overall response of a four-grating cascade was then assessed. The imperfect CFBG had sections of average length 20μm and a standard deviation (σ) of 25%. The noise on Δn and n_{eff} had σ=2.5%; phase shifts with $\sigma=0.0025*\Lambda_{Bragg}$ were inserted between each section. These figures were chosen as noise of this level barely affects the in-band group delay.

Four arrangements were evaluated, each with the imperfect grating taking a different location in the cascade. The results indicate that in CFBG cascades the location of an imperfect grating is critical. For in-band reflectivities approaching 100% only the channels reflected by CFBGs further into the cascade than the imperfect device are affected (fig 2). The level of

Figure 1. Effect of an Imperfect CFBG on a Perfect CFBG

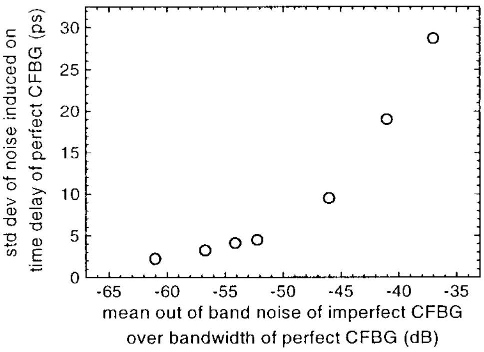


Figure 2. Effect of an Imperfect CFBG in a Cascade

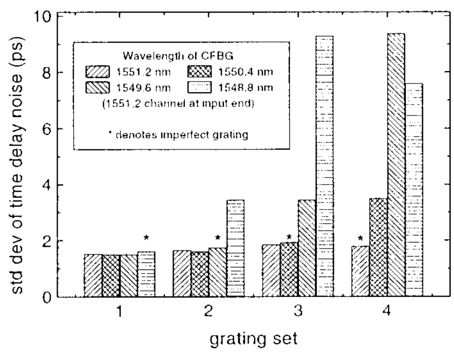
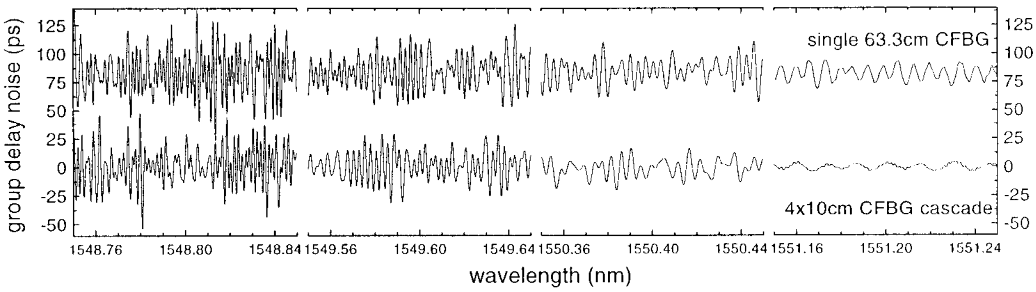


Figure 3. Evaluation and Comparison of Imperfect Multi-Channel CFBG Arrangements



group delay noise *induced* over the central 0.1nm of CFBGs located after the imperfect grating has a standard deviation of as much as 9ps despite no apparent noise on the group delay of the imperfect grating itself. The magnitude and frequency of group delay noise increases with the spatial separation of a given CFBG from the imperfect device. These results indicate that it is imperative for *any* optical element (not just CFBGs) with a detectable broad-band response to be located at the end of a grating cascade.

Comparison of Single Broadband CFBGs to Cascades of Single-Channel CFBGs

Finally the response of a cascade of four equally-imperfect CFBGs was evaluated and compared to that of an equivalent single long, broadband CFBG. Each CFBG had 100μm long sections with σ=1% for Δn and n_{eff}; inter-sectional phase shifts with $\sigma=0.001*\Lambda_{Bragg}$ were included. The long CFBG had a length of 63.3cm and a chirp of 3.8nm to give ~1600ps/nm of dispersion compensation over four adjacent ITU channels. The response of both devices was assessed from the long wavelength end in 0.1pm steps over four 0.1nm wavelength windows centred at 1548.8nm, 1549.6nm, 1550.4nm, and 1551.2nm (fig3). A linear increase in group delay noise with penetration into the grating is observed for both devices; the product of the standard deviation and period of the noise ($\sigma{\cdot}p$), however, remains approximately constant over the four channels of each device. The long CFBG has $\sigma{\cdot}p$=35.9ps.pm, and the cascade has $\sigma{\cdot}p$=31.7ps.pm

Discussion of Results

The tolerance for group delay noise is often quoted as ±10ps for 10Gb/s data. More recent work, however, suggests that the effect of group delay noise on NRZ data is determined by a resonant condition between the spectral period of the noise and the pulse width [3]. The worst eye-opening penalties (EOP) are observed for noise with a period equal to the pulse data (100pm for 10Gb/s), whilst the EOP is shown to be constant for a certain $\sigma{\cdot}p$ for noise periods much less than the pulse width (<0.5dB EOP is observed for $\sigma{\cdot}p$ <1700ps.pm). The effect of grating imperfections can thus be evaluated from the $\sigma{\cdot}p$ product.

From our results we conclude that although the magnitude of group delay noise is seen to increase significantly with penetration into the grating, its *effect* on NRZ data should be approximately constant across band. It is also apparent that the level of group delay noise observed should have almost no effect because of its short period. The $\sigma{\cdot}p$ product is ~12% larger for the 63.3cm grating than for the 4x10cm cascade despite the 58% greater length and ~100% filling factor of the former.

The first results of partial dispersion compensated transmission systems also suggest a greater tolerance to group delay noise than for equivalent NRZ systems [4].

Summary

Noise in the structure of a CFBG leads to group delay noise and a raised out-of-band reflectivity. Interference between primary Bragg reflections and out-of-band noise from different CFBGs makes the total noise of a CFBG cascade much worse than that of each device alone. The negative effect of an imperfect CFBG on other CFBGs in a cascade is determined both by its out-of-band reflectivity and by its spatial location. Any optical element with a detectable broadband reflection should be located at the end of a CFBG cascade to minimise induced group delay noise.

The group delay noise of a 4x10cm single-channel CFBG cascade has a similar level to that of an equivalent long, broadband CFBG. The magnitude-period product of the group delay noise was found to be constant in each channel. The *effect* of the noise should be thus consistent (and small) across the device bandwidth, despite its apparent spectral asymmetry.

Further results will be presented at the conference.

Acknowledgement

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