

Chirped in-fibre Bragg grating dispersion compensators: Linearisation of dispersion characteristic and demonstration of dispersion compensation in 100km, 10Gbit/s optical fibre link

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Indexing terms: Gratings in fibres, Optical dispersion

An apodised chirped in-fibre Bragg grating that has a linear dispersion characteristic is reported. The frequency components of an optical pulse (centre wavelength 1551 nm; 10GHz bandwidth) incident on the grating are reflected with a relative delay that varies linearly from 0 to 130ps across the spectral width of the pulse. The dispersion compensator is used to correct for the dispersion in a 100km link (nondispersion shifted fibre) operating at a 10Gbit/s transmission rate and a wavelength of 1551 nm.

Introduction: It is well known that chirped (aperiodic) refractive index Bragg gratings can be used for compensating the dispersion of optical fibre waveguides [1]. More recently, the fabrication of chirped Bragg gratings using fibre photosensitivity [2] has been reported [3-5] in the literature.

The application of aperiodic gratings for dispersion compensation of optical fibres requires the compensator to have a linear dispersion characteristic. That is, the relative delay for the various frequency components contained in the optical pulse should be linear across the bandwidth of the pulse. Unfortunately, Bragg gratings with a linear chirp can have an oscillatory dispersion characteristic [3]. In [4], it is shown theoretically that the oscillations in the dispersion characteristic can be reduced (smoothed) by apodising the Bragg reflector. Apodisation consists of photoinducing a refractive index modulation with an amplitude along the length of the grating that has a bell-like-function shape and with an average pitch equal to the desired Bragg centre-resonance wavelength divided by twice the effective mode index. Apodisation also reduces the sidelobes in the spectral reflection response of the Bragg grating.

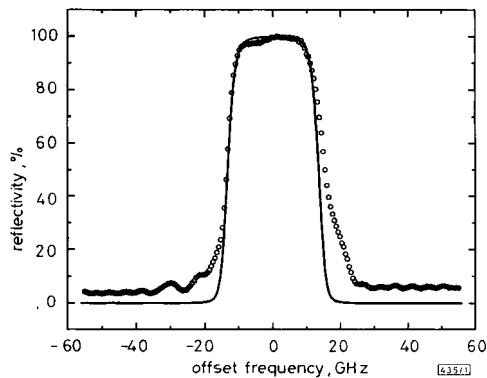


Fig. 1 Theoretical and experimental reflection response of apodised chirped Bragg reflector

— calculated
○ experimental

In this Letter, we describe the fabrication and characterisation of an aperiodic in-fibre Bragg reflector that has a linear dispersion characteristic. Also, we demonstrate the effectiveness of the Bragg grating dispersion compensator by correcting for the dispersion in

a 100km fibre link (with zero dispersion wavelength at 1300nm) operating at a wavelength of 1551nm and a transmission rate of 10Gbit/s.

Experiment and results: We fabricated an apodised chirped grating from standard Corning SMF-28 monomode telecommunication fibre that had been loaded with hydrogen. The apodisation and chirping of the grating is achieved using a double-exposure photoimprinting method [3]. The Bragg grating is 3.0 cm long, has a centre resonance wavelength λ_0 of 1551nm and linear chirp of 0.015%. The measured reflectivity of the chirped grating as a function of offset from the centre frequency is shown in Fig. 1. The peak reflectivity R at 1551 nm is 99.8%. As expected, the sidelobes in the grating spectral response are much lower in comparison to the spectral response of a similar Bragg reflector that has not been apodised [6].

Using the coupled-mode equations, we have calculated theoretically the reflection response of an apodised Bragg reflector with a linear chirp. The results of the calculation are shown as the solid line in Fig. 1. The parameters used in plotting the theoretical curve are $\lambda_0 = 1551$ nm, grating length $L = 3.0$ cm, reflectivity $R = 99.8\%$ and $\kappa L = 9.5$, where κ is the peak coupling coefficient of the grating.

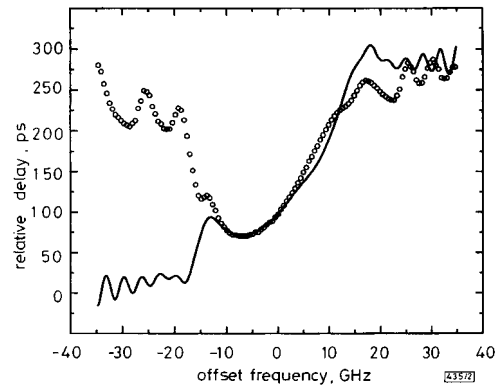


Fig. 2 Theoretical and experimental relative delay characteristic of in-fibre apodised chirped Bragg reflector

— calculated
○ experimental

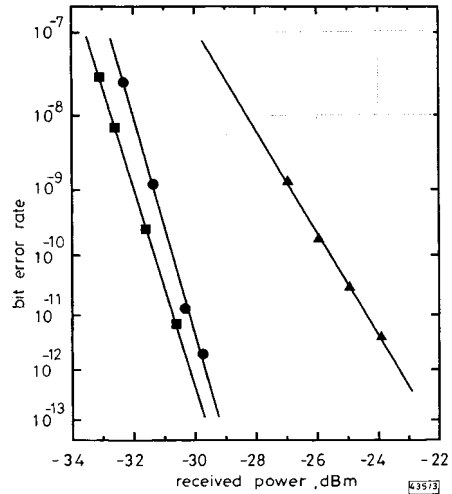


Fig. 3 Results of BER measurements of 100km optical link operating at 10Gbit/s

● back to back
▲ without equaliser
■ with equaliser

The experimental and calculated dispersion characteristics of the same chirped Bragg grating are shown in Fig. 2. The technique used to measure the dispersion characteristic has been described previously [7]. The measured relative delay response is seen to be in good agreement with the response obtained by numerical calculation of the coupled-mode equations used to model the Bragg grating dispersion compensator. At a wavelength corresponding to the peak of the reflectivity spectrum, the dispersion characteristic is linear (1300ps/nm) over more than 10GHz.

Fig. 3 illustrates the performance of the dispersion compensator. The Figure shows the results of bit-error-rate (BER) measurements carried out on an optical fibre transmission link (bit rate = 10Gbit/s; link length = 100km; optical fibre chromatic dispersion = 1700ps/nm; operating wavelength = 1551nm) as a function of power incident on the receiver (a) with, and (b) without dispersion compensation. Also shown in Fig. 3 are the BER measurements for the receiver and transmitter arranged back-to-back in order to provide a baseline for a link with no dispersion. The performance of the dispersion compensated link is actually slightly better than the performance of the link with no dispersion (back-to-back configuration) because the LiNbO₃ Mach-Zehnder modulator has a residual blue-shift chirp.

In summary, we have fabricated an apodised chirp grating that has a linear dispersion characteristic. The device was used successfully to equalise the dispersion of a 100km, 10Gbit/s, optical fibre data transmission link.

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Compact 1 × 16 power splitter based on symmetrical 1 × 2 MMI splitters

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Indexing terms: Optical couplers, Optical waveguide components

First experimental results of compact 1 × 16 splitters based on single 1 × 2 multimode interference (MMI) power splitters in alumina waveguides on silicon are reported.

Introduction: Power splitters are essential components in many optical applications, as for instance in broadcasting-type integrated optical networks. The various components that have been developed to realise optical power splitting can be classified as either inter-waveguide coupling splitters, Y-branch splitters, diverging beamsplitters, or multimode interference (MMI) power splitters.

In general the key performance parameters are uniformity, loss and wavelength characteristics of the components and their reproducibility.

Interwaveguide coupling splitters suffer from poor reproducibility, large dimensions, and a large frequency sensitivity. Shani *et al.* [1] and Yanagawa *et al.* [2] report flattened frequency responses, which is obtained at the expense of either larger size or higher excess loss. Y-branch splitters perform better. However, 1 × N trees based on this splitter tend to be very large. The Y-branches reported by Adar *et al.* [3] for example with an excess loss of 0.4dB are 3mm long, including access waveguides. Hence for the purpose of 1 × N power splitting, diverging beamsplitters and MMI-power splitters seem to be more promising. Diverging beamsplitters have an inherent nonuniformity which must be compensated for. A uniformity of 1.3dB has been reported for a 1 × 16 diverging beamsplitter with a worst case loss of 16.8dB, including 12.0dB intrinsic splitting loss, waveguide loss of 0.3dB/cm and fibre waveguide interface loss of 0.5dB per interface [4].

The 1 × 2 MMI power splitters recently introduced by Soldano *et al.* [5] that are based on self-imaging effects can be used to realise more compact, inherently balanced, low-loss power splitters with good frequency characteristics and low polarisation sensitivity, using a tree structure of cascaded 1 × 2 MMI power splitters. Such a tree structure has a much larger bandwidth than a single wide MMI coupler with the same splitting ratio. In this Letter we present results of the first application of 1 × 2 MMI power splitters in a 1 × 16 power splitter.

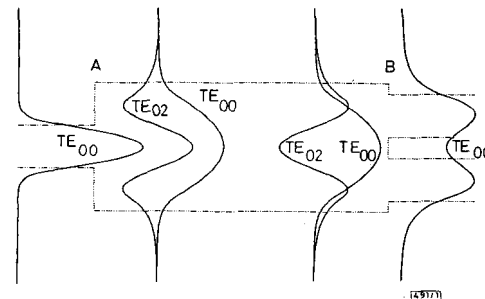


Fig. 1 Principle operation of MMI splitter

Operation principle: Fig. 1 shows the 1 × 2 MMI power splitter that has been used to construct the 1 × 16 power splitter. The 1 × 2 MMI splitter operates as follows. If the fundamental mode in the input channel waveguide arrives at the beginning of the multimode section, it excites the symmetrical modes, which will propagate along the MMI section, each with a different propagation constant. With a proper design most of the power is coupled to modes 0 and 2. When a phase difference equal to π is built up, the total profile will present two lobes that couple with high efficiency to the pair of output waveguides at the end of the MMI section.

The facts that only two symmetrical modes are involved and