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(71) Applicant (*for all designated States except US*): **FUJITSU NETWORK COMMUNICATIONS, INC.** [US/US]; 2081 Telecom Parkway, Richardson, TX 75082 (US).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **PARKER, Michael, Charles** [GB/GB]; 38 Byron Avenue, Colchester, Essex CO3 4HG (GB).

(74) Agents: **CRITTEN, Matthew, Peter** et al.; Abel & Imray, 20 Red Lion Street, London WC1R 4PQ (GB).

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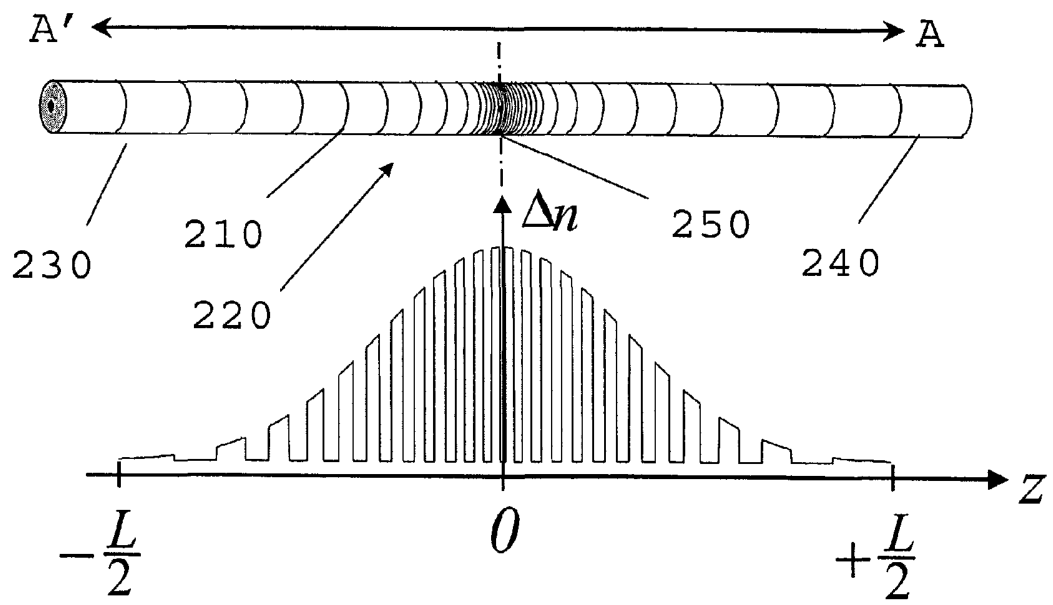
(54) **Title:** IMPROVEMENTS IN AND RELATING TO DISTRIBUTED GRATINGS



(57) **Abstract:** A distributed grating comprises a chirped arrangement of grating elements (comprising high-index regions) (210) arranged along a line (fibre) (220) characterised in that the arrangement of the elements (210) has a reflection symmetry about a plane (250) perpendicular to the line. Such a grating can provide dynamic dispersion with a reduced detuning as compared with prior art devices.

WO 03/034116 A2

Improvements in and relating to distributed gratings

This invention relates to the field of distributed gratings, also known as longitudinal gratings. Distributed gratings are a form of interference grating.

Distributed gratings are important elements in many wave-based systems; for example, fibre Bragg gratings (FBGs) are commonly used as filters in optical-fibre systems. As channel bit-rates in optical networks increase, physical layer temporal dispersion is becoming an important consideration in dense wave-division multiplexed (WDM) networks, and chirped FBGs have been established as a means of providing dispersion compensation. Dispersion compensation techniques are expected to be critical elements in the design of future high-capacity lightwave communication systems. Passive FBG dispersion compensators are well known, and dynamic devices have recently been demonstrated (B.J. Eggleton, J.A. Rogers, P.S. Westbrook and T.A. Strasser, "Electrically tunable power efficient dispersion compensating fiber Bragg grating", *IEEE Photonics Technology Letters*, **11**, 854 (1999)).

In prior art systems, dispersion compensation is achieved using an FBG such as that shown in Fig. 1. Higher-refractive index regions 110 are written into the core of an optical fibre 120, typically by exposing photosensitive fibre material to ultra-violet (UV) light arranged to produce holographically the desired grating arrangement. The UV light produces long-lasting changes in the refractive index of parts of the fibre and the grating pattern is thus formed. The grating in Fig. 1 is chirped so that the high-refractive-index regions are closer together at one end 130 of the device (the input, in Fig. 1) than at the other end 140. The usual explanation for the device's usefulness for dispersion compensation is that shorter wavelengths (i.e., bluer wavelengths, indicated by λ_b in Fig. 1) resonate with and are reflected from the high-spatial-frequency end 130 of the grating whereas longer wavelengths (i.e., more redder wavelengths, indicated by λ_r in Fig. 1) resonate with and are reflected from the low-frequency end 140; thus, in the device of Fig. 1, longer wavelengths have longer round trip times in the device than do shorter wavelengths and so longer wavelengths are slowed relative to shorter wavelengths. (N. Matuschek, F. Kärtner and U. Keller, "Theory of Double-chirped Mirrors", *IEEE J. of Selected Topics in Quant. Electronics*, **4**, 197 (1998) have noted that this simple description is not correct. They modelled a chirped dielectric mirror as a weakly inhomogenous transmission line problem to reveal more complex reflective behaviour.) The different group delays experienced by longer and shorter wavelengths can be used for example to compensate for the chromatic dispersion of light that has propagated down hundreds of kilometres of single-mode fibre.

The separation of the high-refractive-index regions varies linearly with position z along the length of the device and such a variation results in a quadratic phase response and consequently a group delay having a linear variation with wavelength.

However, changes in the strength of the grating chirp, for example in dynamic devices such as that described in B.J. Eggleton *et al.*, *op.cit.*, have been found to result in a shift in the reflectivity spectrum of the FBG. Such detuning is undesirable in many systems.

An object of the invention is to provide a device that exhibits reduced detuning.

According to the invention there is provided: a distributed grating comprising a chirped arrangement of grating elements, arranged along a line characterised in that the arrangement of the elements has reflection symmetry about a plane perpendicular to the line.

A grating element may be any suitable variation of refractive index that can scatter incident light. For example, a grating element may be a binary element consisting of one region of higher refractive index and one region of lower refractive index; a scattering plane would then exist at the boundary between the regions. In a grating comprising such elements, scattering planes exist on either side of each region of higher refractive index; those planes together may be referred to as a "line pair" or simply a "line". Alternatively, a grating element may consist of a region having a slowly varying refractive index, such as a sinusoidal variation; scattering would then take place in a distributed manner over a plurality of planes in the element.

Preferably the grating is chirped such that, if a pulse of light were to be incident on the grating parallel to the line, a phase shift that varies quadratically with wavelength would be imparted to the light.

Preferably, the grating further comprises means for varying the grating chirp.

Preferably, in use, the varying means produces a variation in the chirp that shifts in wavelength the reflectivity power spectrum of the grating, the shift in wavelength being smaller than the shift of reflectivity power spectrum produced in an equivalent asymmetrically chirped grating by the same variation in the chirp.

More preferably, the varying means produces a variation in the chirp that does not, or does not substantially, shift in wavelength the reflectivity power spectrum of the grating.

The equivalent asymmetrically chirped grating is defined as the grating having the same length and chirp as the symmetric grating and a first half corresponding to one half of the symmetric grating. Thus, the equivalent asymmetric grating can be considered to be the grating obtained by cutting the symmetric grating in two at the symmetry plane, selecting the one half of the grating that provides dispersion D of the same sign as that of the symmetric grating, and extrapolating the arrangement of elements by adding elements to the lower-frequency end of the grating until the length of the symmetric grating is reached. The extrapolation will be according to a function describing the arrangement of the elements in the selected half of the grating. For example, the grating in Fig. 2 has positive dispersion D, and so the equivalent asymmetric grating is obtained by taking the right hand half of the grating (which gives positive dispersion D, considering light to enter from the left) and extrapolating it by adding further lines to the lower-frequency (right-hand) end, the spacing between the additional lines increasing linearly, until the length of the original symmetric grating is reached.

The chirp of the equivalent asymmetric grating is the same as that of the symmetric grating and the same variation in chirp as that produced by the varying means in the symmetric grating is used on the asymmetric grating to determine the relative sizes of the wavelength shifts associated with the symmetric grating and the asymmetric grating. The chirp resulting from the variation will be the same in the symmetric and asymmetric cases.

Preferably the phase shift imparted to the light after the chirp has been varied is a phase shift that varies quadratically with wavelength.

The grating may have a linear chirp, which will result in a propagating pulse experiencing a quadratic phase shift which, in turn, results in a linear chirp being imparted to the pulse. In a dispersion-compensation scheme, that chirp may be used to cancel out temporal dispersion that the pulse has acquired in other parts of an optical system; for example, it may be used to cancel out temporal dispersion acquired by propagation through a telecommunications fibre.

Distributed gratings will exhibit a reflectivity spectrum of some kind. It may be advantageous for the reflectivity spectrum to be tailored to have a particular profile; for example, it may be substantially flat over the pass band of the grating.

Preferably, the grating is comprised in an optical fibre. Preferably, the line along which the grating elements are arranged is parallel to the longitudinal axis of the fibre.

The grating chirp may result from differences in the refractive indices of the elements or in their refractive-index profiles. The grating chirp may also or alternatively result from differences in the geometric lengths of the elements.

The grating elements may be binary elements. The refractive index profile of the grating may be a substantially rectangular wave. Preferably, adjacent corresponding scattering planes of the substantially rectangular wave are separated by a distance that varies linearly along the length of the grating (such a case being an example in which the grating chirp results from differences in the geometric lengths of the elements).

The means for varying the grating chirp may comprise thermal means (for example, a heating element that is heated to change the refractive index of an element by the thermo-optic effect). The means for varying the grating chirp may comprise electrical means (for example, electrodes, which carry a current that can change the refractive index of an element by the electro-optic effect). The means for varying the grating chirp may comprise mechanical means (for example, tensioners that stretch or compress an element and thereby change its geometric structure or change its refractive index by the photo-elastic effect).

Preferably the mechanical means is a tensioning means. Alternatively, the mechanical means is a compression means. Preferably the mechanical means produces a symmetric strain along the grating. Preferably the mechanical means produces a uniform strain along the grating.

Preferably, the grating has a modulation depth that is apodised along the length of the grating. It is known that such apodisation can reduce unwanted ripple in the reflectivity spectrum. The apodisation may be a linear, sin, tan, tanh or Gaussian variation in the modulation depth or any other variation that follows a suitable geometric function.

Preferably, the reflectivity spectrum is substantially flat over the pass band of the grating.

Preferably, the optical path lengths of the elements are shorter at the centre of the grating than at the ends of the grating.

Alternatively, the optical path lengths of the elements are longer at the centre of the grating than at the ends of the grating.

Also according to the invention there is provided an optical device including a distributed grating as described above. Also according to the invention there is provided a telecommunications system including an interference grating as described above. Preferably, the dispersion-compensation of the grating is dynamically adjustable in response to changes in the telecommunications system.

Also according to the invention there is provided a method of dispersion compensation comprising: propagating a pulse of light in a direction parallel to a line so that the light is incident on a distributed grating comprising a chirped arrangement of grating elements arranged along the line, characterised in that the elements are arranged in an arrangement having reflection symmetry about a plane perpendicular to the line, the method including step of varying the grating chirp and the variation resulting in a shift in wavelength of the reflectivity power spectrum of the grating, that shift being smaller than the shift of reflectivity power spectrum produced in an equivalent asymmetrically chirped grating by the same variation in the chirp.

Preferably, the grating is used to cancel out temporal dispersion acquired by propagation through a telecommunications fibre.

Also according to the invention there is provided a method of dispersion compensation using a distributed grating as described above.

By way of example only, an embodiment of the invention will now be described, with reference to the accompanying drawings, of which:

Fig. 1 shows a prior art chirped FBG for dispersion compensation;

Fig. 2 shows an FBG according to the invention and its refractive-index profile;

Fig. 3 is a plot of the variation of normalised dispersion D at the Bragg wavelength with degree of chirp F and apodisation parameter α for an FBG such as that of Fig. 2;

Fig. 4 comprises plots of (a) spectral reflectivity and (b) dispersion of a chirped, weakly coupled ($\kappa L=0.4$) FBG, having F = 12, α = 2, refractive index n = 1.5 and length L = 30 mm.

The dispersion-compensating FBG of Fig. 1 has been described above. The FBG of Fig. 2 also comprises grating elements consisting of higher-refractive-index regions 210 separated by lower-refractive-index regions, the length of the latter varying linearly with distance z along the device. The higher-refractive-index regions could be formed by the UV holographic method described in relation to the prior art. In the FBG of Fig. 2, the linear variation is symmetric along the device; that is, the region of minimum line separation is at the centre 250 of the device and there are two regions of maximum line separation, one at each end 230,240 of the device. If one were to consider the dispersion compensation properties of the FBG of Fig. 2 using the same approach as was used in considering the prior art FBG, one would expect that the two halves of a symmetrically chirped FBG would merely cancel each other out or even would cause a total disruption of the signal as a consequence of longer wavelengths experiencing two different delays (associated with the two end sections 230,240) while shorter wavelengths experience a single delay from the centre 250 of the device. However, the intuitive description of the operation of FBGs is an over-simplification based on the convenient fact that a Gaussian function Fourier Transforms into another Gaussian. In fact, it must be remembered that a FBG is inherently a distributed reflection system, with wavelengths being reflected throughout the length of the grating rather than merely at particular localised positions. Consequently, calculation of the dispersion characteristic of an FBG is a much more complex process than the above description suggests. Furthermore, we have discovered that counter-intuitive properties are exhibited in the symmetrically chirped grating of the invention.

The FBG of Fig. 2 has a Gaussian-apodised relative refractive index profile: the refractive index contrast between grating elements and the regions separating them is greater at the centre 250 of the device than at the ends 230,240.

The refractive index profile of the FBGs of Figs. 1 and 2 can be changed by applying tension or compression to the fibre along its longitudinal axis (the z direction in Fig. 2). Such tension or compression can be used to vary the phase shifts imparted to incident light by the grating, and hence to vary the dispersion compensation provided by the device. For example, the fibre 220 can be clamped in two regions beyond grating ends 230, 240 and one clamp can be translated in direction A whilst the other clamp remains stationary. Thus, the fibre can be stretched to produce a different quadratic phase profile that provides a different chirp. Alternatively, the fibre can be heated to produce a different quadratic phase profile. Thermal means for providing dynamic dispersion compensation are described, for example, in B.J. Eggleton, *op.cit*. However, in comparison with the behaviour of prior art asymmetric gratings, varying the phase profile to produce a different quadratic phase shift results in a reduced shift in wavelength of the reflectivity power spectrum of the symmetric grating. We shall explain that unexpected behaviour in the following analysis.

In analysing the behaviour of the FBG of Fig. 2, we use the formalism of H. Kogelnik, "Filter response of non-uniform almost-periodic structures", *Bell System Technical Journal*, **55**, 109 (1976). Although the analysis is carried out using weak-coupling theory, we expect a strongly coupled device to have a qualitatively similar response and therefore to fall within the scope of the invention. In support of that expectation, we note that K.O. Hill and G. Meltz, "Fiber Bragg Grating Technology Fundamentals and Overview", *IEEE J. Light. Tech., Special issue on Fiber Gratings, Photosensitivity and Poling*, **15**, 1263 (1997) suggest that use of Fourier Transforms provides in general a good guide to the properties of FBGs. Furthermore, Kogelnik, *op. cit.*, notes that the filter response as given by the Riccati equation (which is valid for both the case of strong coupling and the case of weak coupling) is symmetric if both the coupling co-efficient κ and the grating phase ϕ are symmetric. Detuning is essentially an asymmetry in the FBG response and for a symmetric chirp, reduced detuning occurs as the chirp parameter F is varied.

First, we calculate the complex reflectivity spectrum seen by light incident on the grating. We assume that the fibre grating chirp is linear and symmetric about $z = 0$ (z

representing position along the fibre).

A regular grating can be mathematically described in the following manner:

$\underline{G} = T_G(\underline{z})$ where $\underline{G}$ = Regular Grating;
T_G = Grating Transformation/Matrix function;
$\underline{z}$ = spatial dimension.

The Grating Transformation/Matrix function may be any function which produces a regular grating in the spatial domain.

A binary regular grating has regions of constant refractive index having one of two possible values. A sine wave is another example of a regular grating.

However, a chirped grating can be described by the regular grating transformation function T_G operating on some 'simple', continuous function of the spatial dimension $f(\underline{x})$,

$\underline{H} = T_G(f(\underline{x}))$

Thus, a linearly-chirped or stretched regular grating can be described thus

$\underline{C} = T_G(\underline{x}^2)$ where $\underline{C}$ = resulting chirped grating.

A linear chirp corresponds to a quadratic phase profile and so the grating chirp can be expressed by

$$\phi(z) = -F\frac{z^2}{L^2}, \qquad (1)$$

where *L* is the total length of the FBG and *F* is the strength of the chirp. Likewise, we assume that the FBG is Gaussian apodised, so that the coupling coefficient $\kappa(z)$ varies as

$$\kappa(z) = \kappa_0 \exp\left(-4\alpha\frac{z^2}{L^2}\right), \qquad (2)$$

where α is called the apodisation parameter and κ_0 is the coupling coefficient at z = 0. For weak coupling, we can, following Kogelnik, *ibid.*, express the reflectivity of the FBG at $z=-\frac{L}{2}$ (i.e., at the input of the FBG) as the Fourier transform of the coupling coefficient (thus linking the spatial phase profile of the grating lines to the optical phase profile seen by light reflected from the grating), yielding

$$\rho(\delta)=-j\exp\left(-j(L\delta+\frac{F}{4})\right)\int_{-\frac{L}{2}}^{\frac{L}{2}}[\kappa(z)\exp(j\phi(z))]\exp(-j2z\delta)dz\ , \quad (3)$$

where δ is the detuning deviation from the Bragg condition, given by:

$$\delta=\beta-\frac{K}{2}\ , \quad (4)$$

$\beta=\frac{2\pi n}{\lambda}$ being the propagation constant at wavelength λ of the guided mode within the fibre of refractive index n; $\beta_0=\frac{K}{2}$ is the propagation constant at the centre (Bragg) wavelength. An analytical expression for the reflectivity can be obtained by substituting Equations (1) and (2) into Equation (3) and using the Fresnel sine and cosine integrals of the first kind (see for example M. Abramowitz and I.A. Stegun, "*Handbook of Mathematical Functions*", Dover Publications, 9th Edn., pp. 300, §7.3.3.1 & §7.3.4.1), giving

$$\rho(\delta)=-j\frac{\kappa_0 L}{2}\sqrt{\frac{\pi}{2}}\frac{\exp(-j\left(L\delta+\frac{F}{4}-a^2\right))}{b}\{C_1[a+b]-C_1[a-b]-jS_1[a+b]+jS_1[a-b]\} \quad (5)$$

where the normalised parameters a and b are given by

$$a=\frac{L\delta}{\sqrt{F-j4\alpha}} \quad (6a) \qquad \text{and} \qquad b=\frac{1}{2}\sqrt{F-j4\alpha}\ . \quad (6b)$$

As the parameters $F,\alpha \to 0$ (so that the FBG becomes unchirped and unapodised) the spectral reflectivity expression given as Equation (5) can be shown to collapse into the standard *sinc* expression that would be expected for a simple grating, *viz*.

$$\rho(\delta)_{F,\alpha\to 0} = -j\kappa_0 L \operatorname{sinc}(L\delta)\exp(-jL\delta)\,. \tag{7}$$

We can now calculate the dispersion seen by incident light. The dispersion of an optical element is proportional to the second differential, with respect to wavelength λ, of its phase response. From Equation (5), the phase response of the FBG of Fig. 2 is given by

$$\theta = -L\delta - \frac{F}{4} + \mathrm{Re}\left\{a^2 - \tan^{-1}\left(\frac{S_1[a+b]-S_1[a-b]}{C_1[a+b]-C_1[a-b]}\right)\right\}, \tag{8}$$

where the final arctan expression is similar to the phases of the Cornu Spiral (see, for example, M. Born and E. Wolf, "*Principles of Optics*", Pergamon, 6th Edn., pp. 428-433). The group delay response at a wavelength λ (and angular frequency ω) is given by $\tau_d = -\frac{d\theta}{d\omega} \approx \frac{\lambda^2}{2\pi c}\frac{d\theta(\lambda)}{d\lambda}$ and the device dispersion is given by $D(\lambda) = \frac{d\tau_d}{d\lambda}$, where c is the speed of light. We have, therefore, an analytical expression for the dispersion of the FBG of Fig. 2 at the centre of the Bragg condition, $\lambda = \lambda_0$:

$$D_{\lambda=\lambda_0} = \frac{1}{c}\left(\frac{nL}{\lambda_0}\right)^2 \mathrm{Re}\left\{\frac{\pi}{b^2} - \frac{\sqrt{2\pi}}{b}\left(\frac{C_1[b]\cos b^2 + S_1[b]\sin b^2}{C_1^2[b]+S_1^2[b]}\right)\right\}. \tag{9}$$

That rather complicated expression can be approximated for an unapodised device (i.e., a device having $\alpha = 0$) and low values of F (i.e., weak chirp) to yield

$$D_{\lambda=\lambda_0} = \frac{1}{c}\left(\frac{nL}{\lambda_0}\right)^2 \frac{2\pi}{45} F + O\left(F^3\right). \tag{10}$$

It is interesting to note that, for low values of F, Equation (10) shows that the dispersion D is proportional to F and can therefore be made positive or negative according to the sign of F. Thus the FBG dispersion can be increased or decreased merely by appropriate tension or compression along the length of the device.

Figure 3 shows a three-dimensional mesh plot of the dependence of the normalised dispersion $\frac{D}{\frac{1}{c}\left(\frac{nL}{\lambda_0}\right)^2}$ at the centre Bragg frequency on the degree of chirp F and the Gaussian apodisation parameter α. The graph shows close agreement with the approximation of Equation (10) for α = 0, showing the expected linear relationship with F. It also shows that the device dispersion decreases asymptotically to zero as the FBG becomes more strongly apodised $(\alpha \to \infty)$, as would be expected.

We have modelled an FBG according to the invention, having length L = 30 mm, refractive index n = 1.5, apodised to α = 2, and with chirp parameter F = 12. Figure 4(a) shows the calculated reflection spectrum, while Fig. 4(b) shows the associated dispersion characteristic, with D = 2.3 ns/nm at the passband centre. It is interesting to note that for weak coupling (κL = 0.4 for Fig. 4) the chirped FBG provides a relatively high dispersion compensation that is essentially independent of the coupling strength. However, a low reflection power results from such weak coupling.

We can now compare the behaviour of the FBG of Fig. 2 with that of the FBG of Fig. 1, in order to explain why the reflectivity spectrum of the prior art FBG exhibits a greater wavelength shift when the chirp parameter F is varied (for example, by stretching or compressing fibre 120). It is relatively straightforward to show that the dispersion characteristics of Equations (9) and (10) are identical for an asymmetrically chirped FBG. The chirp is expressed as

$$\phi(z) = -F\frac{\left(z+\frac{L}{2}\right)^2}{L^2}, \qquad (11)$$

(c.f. Equation (1)) and the reflectivity spectrum is therefore given by

$$\rho_{asymmetric}(\delta) = \exp\left(j\frac{F}{2}\right)\rho_{symmetric}\left(\delta+\frac{F}{2L}\right), \qquad (12)$$

where $\rho_{symmetric}$ is the reflectivity as given in Equation (5) for an FBG having a chirp as given in Equation (1). The term $\exp\left(j\frac{F}{2}\right)$ in Equation (12) corresponds merely to a difference of F/2 between the phase characteristic of the prior art device and that of the symmetric FBG, which, being a constant, does not affect the dispersion; hence the dispersion characteristic of Equations (9) and (10) is equally applicable to the asymmetric case. However, it is immediately apparent from Equation (12) that the reflectivity spectrum of the prior-art FBG experiences an additional translation shift (detuning) of $\frac{F}{2L}$ as the chirp parameter F is varied; and a shift in the reflectivity spectrum has indeed been experimentally observed (B.J. Eggleton, *op. cit.*). That extra effect does not occur in the device of Fig. 2.

Although 2^{nd}-order dispersion can be compensated for by a linear chirp as outlined above, it is interesting to note that compensation of higher-order dispersions is a non-trivial problem. The quadratic phase function $\phi(z)$ can be represented mathematically as a complex Gaussian, which, when Fourier-transformed, yields another complex Gaussian, so that the phase characteristic is also quadratic close to the centre of the filter response. Taking the 2^{nd} differential of that filter phase response gives a constant; hence the uniform dispersion characteristic at the Bragg resonance, as shown in Fig. 4(b). However, a simple quadratic chirp will not compensate for a third-order dispersion, since the cubic phase function $\phi(z) = 4F\left(\frac{z}{L}\right)^3$ does not correspond to a Gaussian function and will not yield a function with the desired cubic phase characteristic at the centre of the filter response. It is expected that higher even-order dispersions can be compensated.

We have shown that a symmetrically chirped FBG can provide dynamic dispersion compensation with a reduced detuning as compared with prior art devices. Use of a weak-coupling scenario provides for a Fourier-transform-based treatment that is mathematically tractable. Symmetry arguments establish that the device analysis readily carries over to the strong-coupling case. Devices such as this may find application in future dynamic WDM networks.

Claims

1. A distributed grating comprising a chirped, arrangement of grating elements arranged along a line characterised in that the arrangement of the elements has reflection symmetry about a plane perpendicular to the line.

2. A distributed grating as claimed in claim 1, further comprises means for varying the grating chirp.

3. A distributed grating as claimed in claim 1 or claim 2, in which the grating is chirped such that, if a pulse of light were to be incident on the grating parallel to the line, a phase shift that varies quadratically with wavelength would be imparted to the light.

4. A distributed grating as claimed in claim 2 or claim 3, in which, in use, the varying means produces a variation in the chirp that shifts in wavelength the reflectivity power spectrum of the grating, the shift in wavelength being smaller than the shift of reflectivity power spectrum produced in an equivalent asymmetrically chirped grating by the same variation in the chirp.

5. A distributed grating as claimed in claim 2 or claim 3, in which, in use, the varying means produces a variation in the chirp that does not shift in wavelength the reflectivity power spectrum of the grating.

6. A distributed grating as claimed in any of claims 2 to 5, in which the phase shift imparted to the light after the chirp has been varied is a phase shift that varies quadratically with wavelength.

7. A distributed grating as claimed in any preceding claim, in which the grating is comprised in an optical fibre.

8. A distributed grating as claimed in claim 7, in which the line along which the grating elements are arranged is parallel to the longitudinal axis of the fibre.

9. A distributed grating as claimed in any preceding claim, in which the grating chirp results from differences in the refractive indices of the elements.

10. A distributed grating as claimed in any of claims 1 to claim 9, in which the grating chirp results from differences in the geometric lengths of the elements.

11. An distributed grating as claimed in any preceding claim, in which the grating elements are binary elements.

12. A distributed grating as claimed in claim 11, in which the grating has a refractive index profile that is substantially a rectangular wave.

13. A distributed grating as claimed in claim 12, in which adjacent corresponding scattering planes of the substantially rectangular wave are separated by a distance that varies linearly along the length of the grating.

14. A distributed grating as claimed in any of claims 2 to 13, in which the means for varying the grating chirp comprises thermal means.

15. A distributed grating as claimed in any of claims 2 to 13, in which the means for varying the grating chirp comprises electrical means.

16. A distributed grating as claimed in any of claims 2 to 13, in which the means for varying the grating chirp comprises mechanical means.

17. A distributed grating as claimed in claim 16, in which the mechanical means is a tensioning means.

18. A distributed grating as claimed in claim 16, in which the mechanical means is a compression means.

19. A distributed grating as claimed in claim 17 or 18, in which the mechanical means produces a symmetric strain along the grating.

20. A distributed grating as claimed in claim 19, in which the mechanical means produces a uniform strain along the grating.

21. A distributed grating as claimed in any preceding claim, in which the grating has a modulation depth that is apodised along the length of the grating.

22. A distributed grating as claimed in claim 21, in which the apodisation is a Gaussian variation in the modulation depth.

23. A distributed grating as claimed in any preceding claim, in which the reflectivity spectrum is substantially flat over the pass band of the grating.

24. A distributed grating as claimed in any preceding claim, in which the optical path lengths of adjacent elements are shorter at the centre of the grating than at the ends of the grating.

25. A distributed grating as claimed in any of claims 1 to 23, in which the optical path lengths of adjacent elements are longer at the centre of the grating than at the ends of the grating.

26. An optical device including a distributed grating as claimed in any of claims 1 to 25.

27. A telecommunications system including an interference grating as claimed in any of claims 1 to 25.

28. A telecommunications system as claimed in claim 27, in which the dispersion-compensation of the grating is dynamically adjustable in response to changes in the telecommunications system.

29. A method of dispersion compensation comprising: propagating a pulse of light in a direction parallel to a line so that the light is incident on a distributed grating comprising a chirped arrangement of grating elements arranged along the line, characterised in that the elements are arranged in an arrangement having reflection symmetry about a plane perpendicular to the line, the method including the step of varying the grating chirp and that variation resulting in a shift in wavelength of the reflectivity power spectrum of the grating, that shift being smaller than the shift of reflectivity power spectrum produced in an equivalent asymmetrically chirped grating by the same variation in the chirp.

30. A method as claimed in claim 29, in which the grating is used to cancel out temporal dispersion acquired by propagation through a telecommunications fibre.

31. A method of dispersion compensation using a distributed grating as claimed in any of claims 1 to 25.

32. A distributed grating substantially as herein described with reference to the accompanying drawings.

Fig. 1

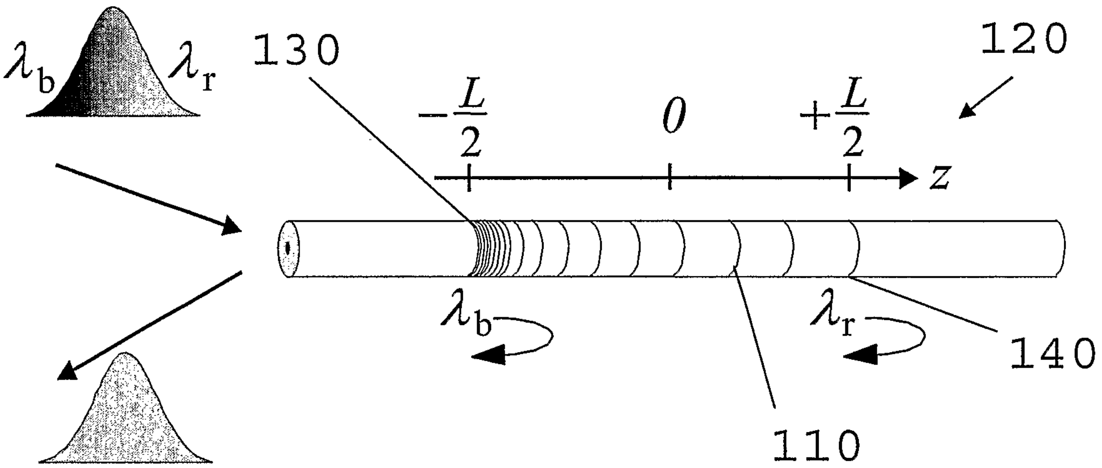

λb
λr
130
120
−L/2
0
+L/2
z
λb
λr
140
110

Fig. 2

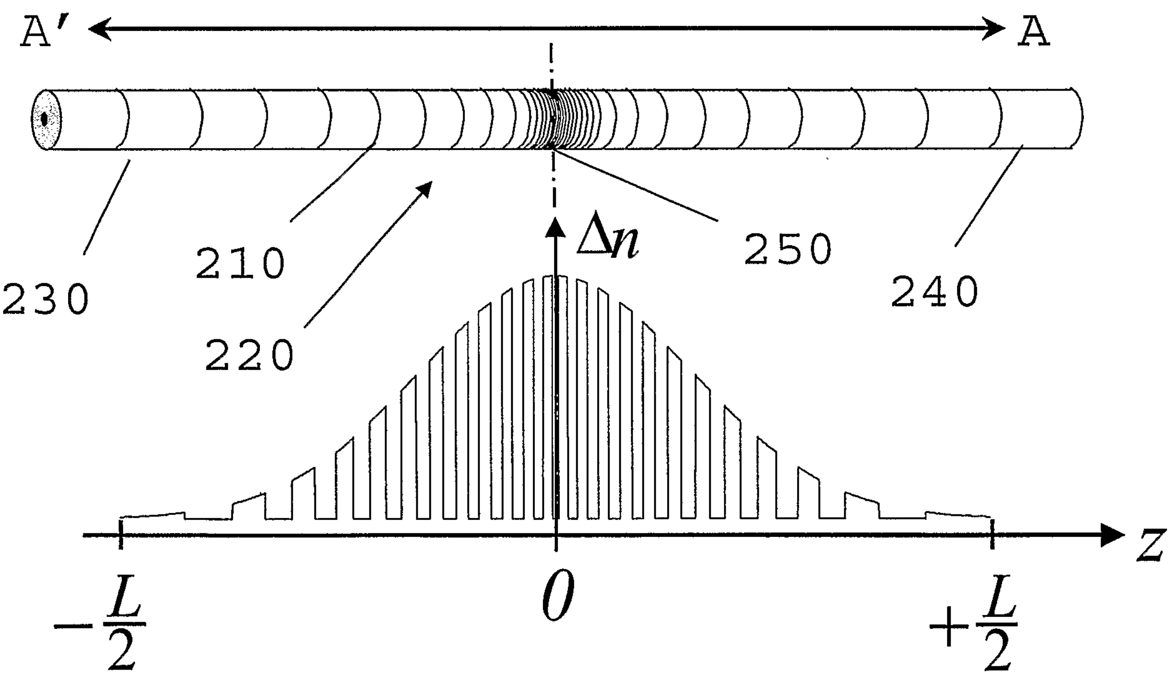

A′
A
230
210
220
Δn
250
240
z
−L/2
0
+L/2

Fig. 3

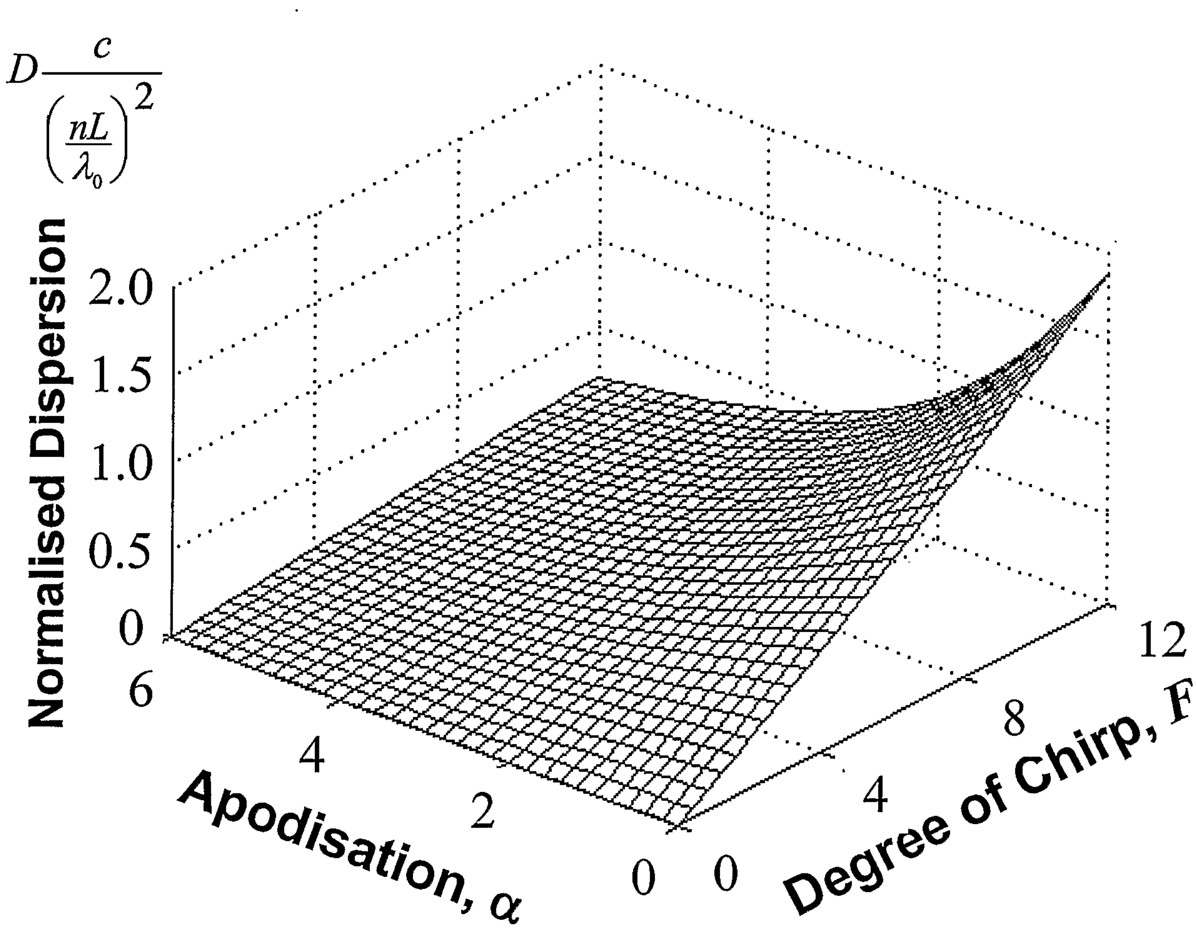
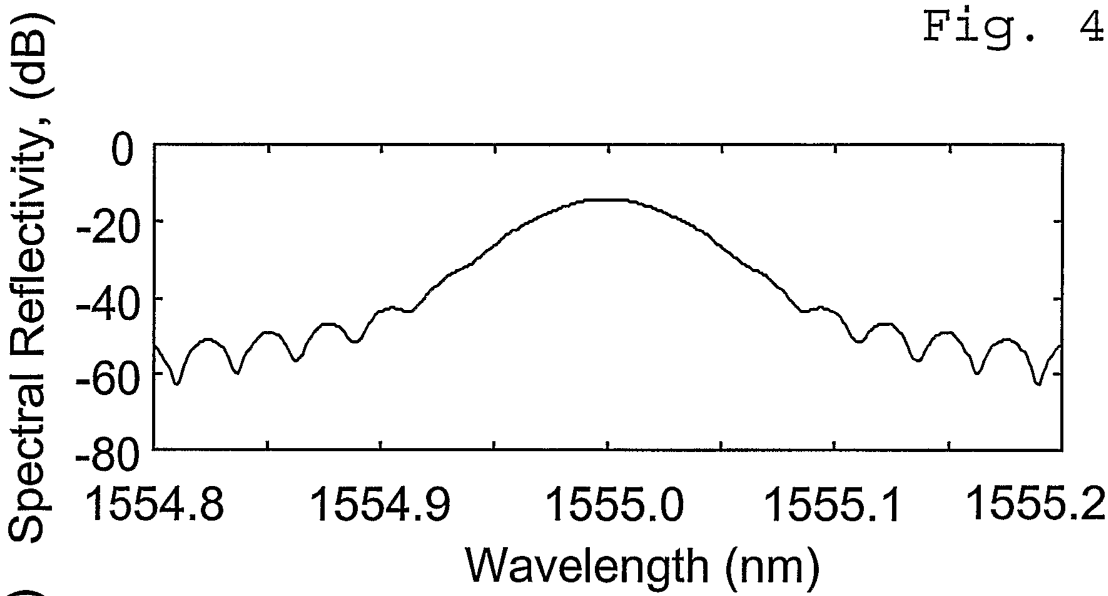
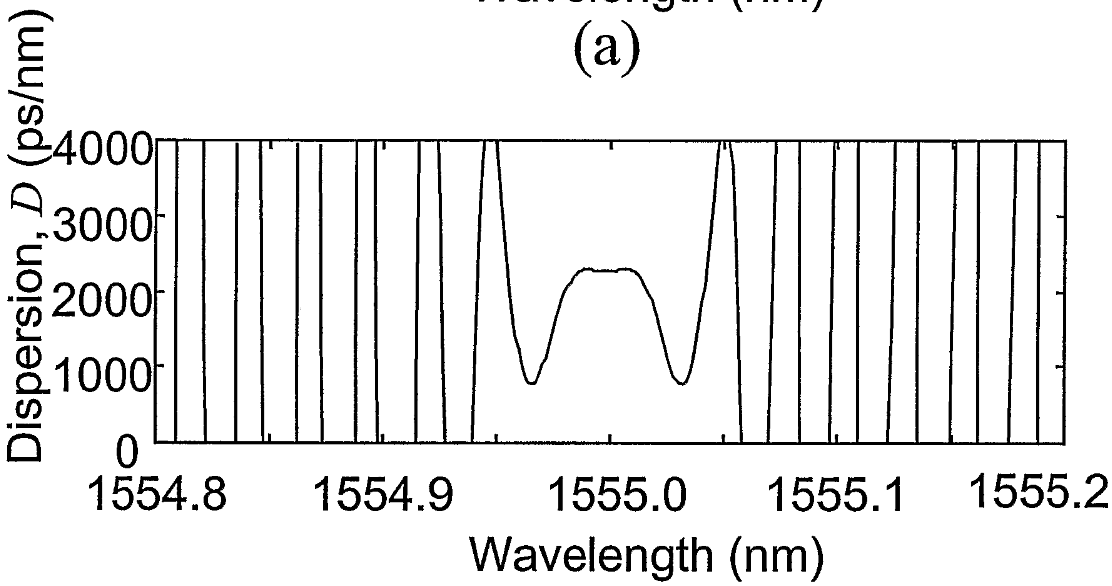

$D\frac{c}{\left(\frac{nL}{\lambda_0}\right)^2}$
Normalised Dispersion
2.0
1.5
1.0
0.5
0
6
4
2
0
Apodisation, α
0
4
8
12
Degree of Chirp, F

Fig. 4


Spectral Reflectivity, (dB)
0
-20
-40
-60
-80
1554.8
1554.9
1555.0
1555.1
1555.2
Wavelength (nm)

(a)


Dispersion, D (ps/nm)
4000
3000
2000
1000
0
1554.8
1554.9
1555.0
1555.1
1555.2
Wavelength (nm)

(b)