Study on raised-cosine sampled chirped fiber Bragg grating for dispersion compensation applications

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Abstract: In this paper, raised-cosine sampled chirped fiber Bragg grating (SCFG) has been studied. A linear chirp is varying the optical period of this grating. To reduce ripples and side lobes, a raised-cosine apodization is applied. SCFG is proposed for the purpose of dispersion compensation in wavelength division multiplexing systems. Simulation results show that SCFG presents five channels in a bandwidth of 0.6 nm and with a dispersion of -1400 ps/nm. The wavelength spacing between two neighboring channels is 0.8 nm.

Key-Words: Sampled chirped fiber grating, dispersion compensation, wavelength division multiplexing.

1 Introduction
A key technique for enabling high capacity optical transmission systems is the management of fiber dispersion. The chirped fiber grating (CFG) has been successfully used to provide the necessary dispersion compensation in dispersed managed systems. However, in a wavelength division multiplexing (WDM) system, each channel must have its own CFG for dispersion compensation. The sampled chirped fiber grating (SCFG) [1] has brought forward. Comparing with CFG, it has the same length, but can compensate several WDM channels simultaneously. SCFG has a great prospect for dispersion compensation.

2 Theoretical Study on Sampled Chirped Fiber Gratings
It’s very important to analyze the design of SCFG theoretically to obtain characteristics including the reflectivity, the dispersion, the number of channels, wavelength spacing between channels and their bandwidth. These characteristics are modeled by the coupled mode theory. The basic idea of the coupled mode theory is that the electrical field of the waveguide with a perturbation can be represented by a linear combination of the modes of the field distribution without perturbations. The fiber is perturbed by changing the refractive index of its core. The refractive index modulation is represented by [2]

\[ n = n_0 + \delta n \cos \left( \frac{2\pi}{\Lambda} z + \phi(z) \right) \]  (1)

Where \( n_0 \) is the average refractive index, \( \delta n \) is the modulation of the refractive index, \( \Lambda \) is the Bragg period and \( \phi(z) \) is the grating phase.

An amount of incident light is reflected at each periodic refractive index change. The entire reflected waves are combined into one large reflection at the Bragg wavelength \( \lambda_B \) [2].

Fig. 1 shows a sampled fiber Bragg. Where \( L_A \) is the sampling period and \( L_B \) is the range that was exposed by UV light. The range \( L_A-L_B \) between two grating sections can be represented by the phase shift matrix.

The duty cycle is defined as the ratio, \( R=L_B/L_A \) [3]. The phase shift is given by [3]

\[ \phi = \frac{4\pi n_{eff} \Delta z}{\lambda} \]  (2)

Where \( \Delta z=L_A-L_B \) is the separation between two grating sections.

The sampled fiber is chirped by varying the optical period of the grating. The linear chirp is represented by the phase equation [3]

\[ \frac{d\phi}{db} = \frac{8\pi n_{eff} b d\lambda_D}{\lambda_D^2} \]  (3)

Where \( d\phi/db \) is the chirp variable and \( \lambda_D \) is the design wavelength. The chirp of each section is changing from
zero to the variable \( b \). The grating has a negative variation of its optical period because the chirp variable takes a negative value.

To eliminate the ripples in time delay, and to reduce the reflectivity of side lobes, we should make an apodization of the grating. The coupling coefficient is represented by

\[
k(z) = \frac{\pi}{\lambda} \delta \eta(z) g(z)
\]

In our simulations \( g(z) \) is a raised-cosine apodization function, it equals to

\[
g(z) = a \left[ 1 + \cos \left( \pi \frac{z - L}{L} \right) \right]
\]

Where \( a \) is the raised-cosine parameter and \( L \) is the total length of SCFG. The apodization function is plotted on Fig. 2.

2.1 Characteristics of sampled fiber gratings

The spectral response is simulated by multiplying the total transfer and the phase shift matrixes. The frequency spacing between two adjacent channels can be written as

\[
\Delta f = \frac{c}{2n_{off} L_A}
\]

Corresponding to the standard frequency spacing of transmission system of 100 GHz (\( \Delta \lambda = 0.8 \) nm), the sampling period \( L_A \) must be 1 mm. The channel number of the SCFG can be described as

\[
m = \frac{2}{R} - 1
\]

Fig. 3 shows the different channel number with \( R = 0.2 \), the other SCFG parameters are given in Table 1. When the duty cycle, \( R \), is taken equal to 0.2 we will have nine theoretical channels. However, Channels which are at the two sides of the spectrum are avoided because they present bad values of the reflectivity. We note that the design wavelength is 1551.2 nm.

The power reflectivity presents five channels centered on 1552.34 nm, 1551.52 nm, 1550.7 nm, 1549.88 nm and 1549.05 nm. The reflectivity peak of each channel is about 0.8~0.9 and the wavelength spacing is 0.82 nm.

Among the five channels, the difference of dispersion is small, showing a good consistence. Numerical results are listed in Table 2.
3 Conclusion

In this paper, the raised-cosine chirped sampled fiber Bragg grating is simulated. The coupled mode theory is a suitable tool to analyze this optical filter. Reflectivity and dispersion spectrum of SCFG with different parameter values (coupling coefficient, raised-cosine parameter, linear chirp, length of SCFG, sampling period and duty cycle) is simulated and discussed. A raised-cosine apodization is made to reduce ripples and side lobes, resulting in an, approximately, equal reflectivity and bandwidth of each channel.

SCFG gives five channels spaced by 0.8 nm, with a reflectivity peak of 90% and with a dispersion of -1400 ps/nm, in a bandwidth of 0.6 nm. All these characteristics allow using this component in dense wavelength division multiplexing (DWDM) transmission systems as a dispersion compensation module.

References: