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Analytic model for the transmission and reflection in two cascaded stages of fibre Bragg grating

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Abstract

The fundamental issue limiting long-distance and high-speed optical fiber transmission is dispersion. Dispersion impairs system performance, the signal-to-noise ratio (SNR), and the bit error rate (BER). To address this, numerous dispersion modification techniques have been developed. The use of fiber Bragg grating (FBG) is one of the efficient strategies for dispersion compensation. The FBG is frequently used as a filter. The proposed model uses uniform fiber Bragg grating UFBG. Two cascaded FBGs with varying lengths, a constant grating period, and a constant spacing between FBGs are employed in the proposed thesis. The input signal for the stage that follows is the output signal from the previous stage. The best performance and many applications are considered while modeling, analyzing, and comparing this system. Transmission and reflection in two cascaded stages of fiber Bragg grating using first and second order are studied. The mathematical equations for the proposed model are simulated in MATLAB.

Keywords: Fiber Bragg grating (FBG), Dispersion compensation, two cascaded FBGs.

1. Introduction

The FBG of an optical fiber is a condensed region that includes planes with varied refractive indices. These planes are evenly dispersed in a uniform FGB, but chirped fiber Bragg gratings have asymmetrical distributions (CFBG) [1], [2]. The Bragg wavelength is the sole wavelength that is reflected by the planes in a uniform FGB, which pass all other wavelengths [3]. An ultraviolet laser beam can be used to create this profile by shining it on a photosensitive fiber. The FBG's usage as a filter is well recognized. More wavelengths are reflected in the case of CFBG from a variety of distant planes that are spaced out unevenly along the core [4], [5]. The FBG is frequently used as a filter. In such optical communication systems, when a variety of wavelengths are emitted from the light source, these wavelengths propagate along the optical fiber with differing velocities and arrive at the receiver at various times, resulting in dispersion [10-12]. Dispersion adversely affects bit rates, the signal-to-noise ratio, and system performance [13], [14]. Equation 1 determines the Bragg wavelength λB. Where neff is the real refractive index of the fiber core at the free space centre wavelength (ne $=\sqrt{n_2 * n_3}$) the distance between two adjacent grating planes is determined by the grating period of the fiber, where n2, n3 are the refractive indices of the two materials that make up the grating. When the Bragg condition is satisfied, the sum of all the reflected light forms a peak that faces backward and whose centre wavelength is provided by λB. Following the Bragg condition, the grating structure functions as a mirror, reflecting a portion of the wavelength λB and transmitting the remainder. If the requirement is not met, all of the grating plane reflections will be out of phase and cancel each other out, making it impossible to see any reflection.

$$\lambda_\beta = 2\, n_{eff}\, \Lambda \qquad (1)$$

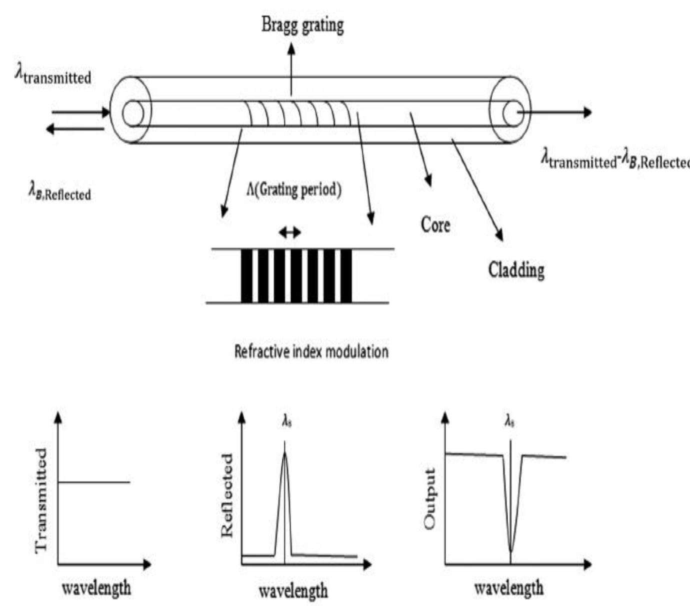

Fig. 1: Spectra of the transmitted, reflected, and output waves as well as the fiber Bragg grating structure.

It is necessary to transform the FBG into a chirped structure for use in dispersion compensation. According to fig. 2, the CFBG has a non-uniform grating period. A series of gratings with varying periods that can reflect a variety of wavelengths make up the CFBG, giving each wavelength a unique time delay. The range of wavelengths that are reflected is provided by

$$\triangle\, \lambda_{chirp} = 2\, n_{eff}\, (\Lambda_L - \Lambda_S) = 2\, n_{eff} \triangle \Lambda_{chirp} \qquad (2)$$

Where λL is the longest wavelength, λS denotes the shortest wavelength, Δλ chirp denotes the difference between λL and λS, and ΛL and ΛS denote the longest and shortest grating periods, respectively. By allowing the fast wavelengths of the pulse to reflect from the shortest grating period in the chirp taking the longest time, a dispersion-broadened pulse can be recompressed. In contrast, as illustrated in figure 2, the slow wavelengths reflect from the longest one in the quickest manner.

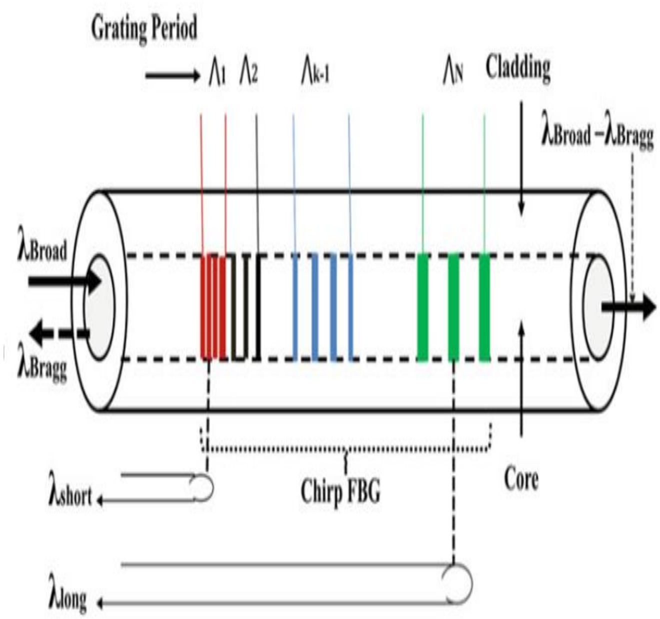

Fig. 2: A chirped FBG's configuration as a dispersion compensator.

According to eq. (3), each wavelength is reflected from a distinct area of the grating and is consequently delayed by a different amount of time. A CFBG's reflection time delay depends on its wavelength. The duration of the delay is given by

$$\tau(\lambda) = \frac{(\lambda-\lambda_s)}{(\lambda_L-\lambda_s)}\frac{2\,n_{eff}\;L_g}{c} \qquad \lambda_s \le \lambda \le \lambda_L \tag{3}$$

Where Lg is the length of the grating and c is the speed of light in space. To calculate the reflectivity achieved in FBG at each grating inside the fiber, Erdogen's coupled mode theory is employed. At each i' th grating, the reflectivity Ri (λ) is given as

$$R_i(\lambda) = \frac{\sinh^2\left(L_g\sqrt{k^2-\sigma_i^2}\right)}{\cosh^2\left(L_g\sqrt{k^2-\sigma_i^2}\right)-\frac{\sigma_i^2}{k^2}} \tag{4}$$

Where σi is the dc self-coupling coefficient that yields the dependency of wavelength for every grating and is provided in equation (4), k is the ac-coupling coefficient between the two modes, Lg is the length of the grating, and λ is the wavelength

$$\sigma_i = \delta + \sigma - \frac{1}{2}\frac{d\phi}{dz} \tag{5}$$

Where σ is the dc (period averaged) coupling coefficient, dϕ/dz is the change in grating chirp, and δ is given as

$$\delta = 2\pi n_{eff}\left(\frac{1}{\lambda}-\frac{1}{\lambda_D}\right) \tag{6}$$

For very weak gratings, λD is the design wavelength. eq. (7), where δneff is the magnitude of the refractive index modulation, is created when coupled mode theory is applied to the reflectivity equation:

$$\sigma_I(\lambda) = \frac{\pi}{\lambda}\delta n_{eff} + 2\pi\, n_{eff}\left(\frac{1}{\lambda}-\frac{1}{\lambda_{B,i}}\right) \tag{7}$$

2. System Description

The proposed model of two cascaded UFBGs is shown in figure 3. It is composed of two-cascaded FBGs regions with different lengths. Each FBG region has a uniform period. The separation between FBGs is also uniform. The input signal for the stage that follows is the output signal from the previous stage. Table 1 provides an illustration of the control parameters for the two uniform cascaded FBGs. With the use of MATLAB, the suggested model's mathematical equations are simulated in order to account for the influence of dispersion.

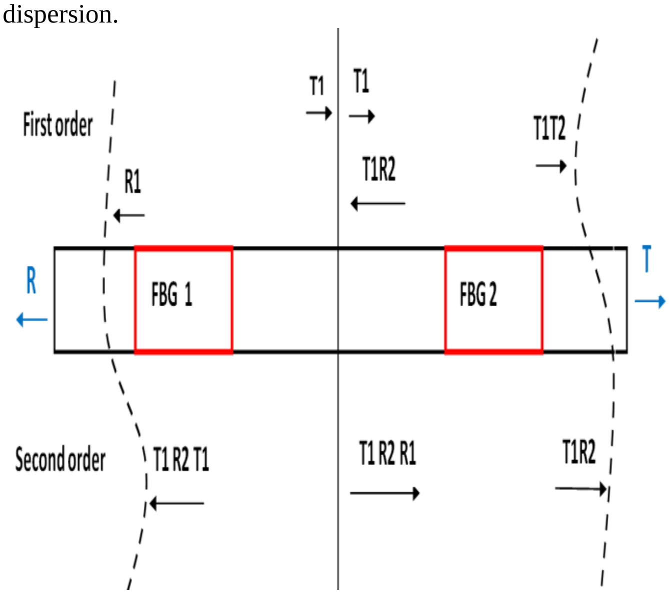

Fig 3: Two cascaded uniform FBGs.

3. Simulation results and performance analysis

Transmission and reflection in two cascaded stages of fiber Bragg grating using first and second order are studied. The performance of the system is impacted by several parameters are listed in table1.

Table 1: control parameters for two cascaded UFBGs.

Parameter	Value
ʌ	490 nm, 493.6 nm
n1,n2	1.4496,1.7
Ne	1.57
dne	1e-4
K	1e-5
N	1000

FBG length	0.49 mm, 0.493 mm

Where Λ is the Grating period, n1 and n2 is the refractive index of one material of the grating, refractive index of the other material of the grating respectively, ne is the effective refractive index of the core (ne $=\sqrt{n2 * n3}$), dne is the magnitude of refractive index modulation, Lg is the length of the fiber grating = N*A, N is the number of grating period, K is the coupling coefficients between the two modes. Transmission and reflection using first order are shown in figures 4, 5.

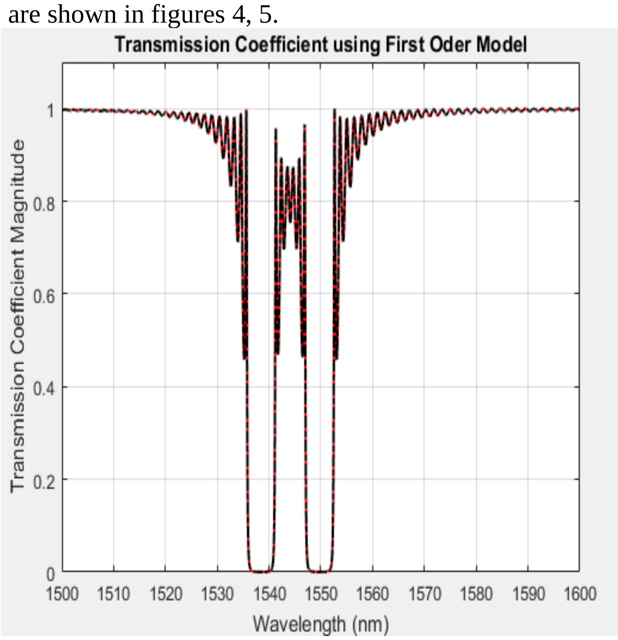

Fig 4: Transmission coefficient using first order model.

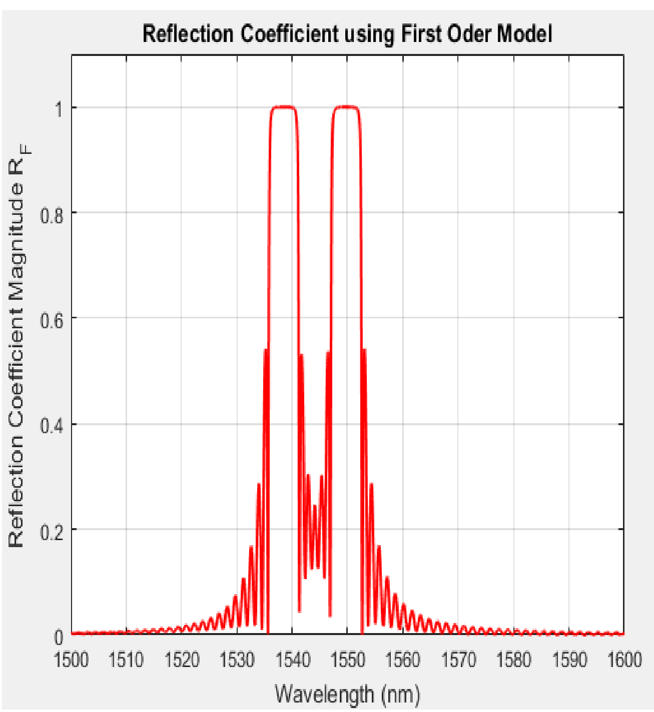

Fig 5: Reflection coefficient using first order model.

Transmission and reflection in two cascaded stages of fiber Bragg grating using second order model are shown in figures 6, 7.

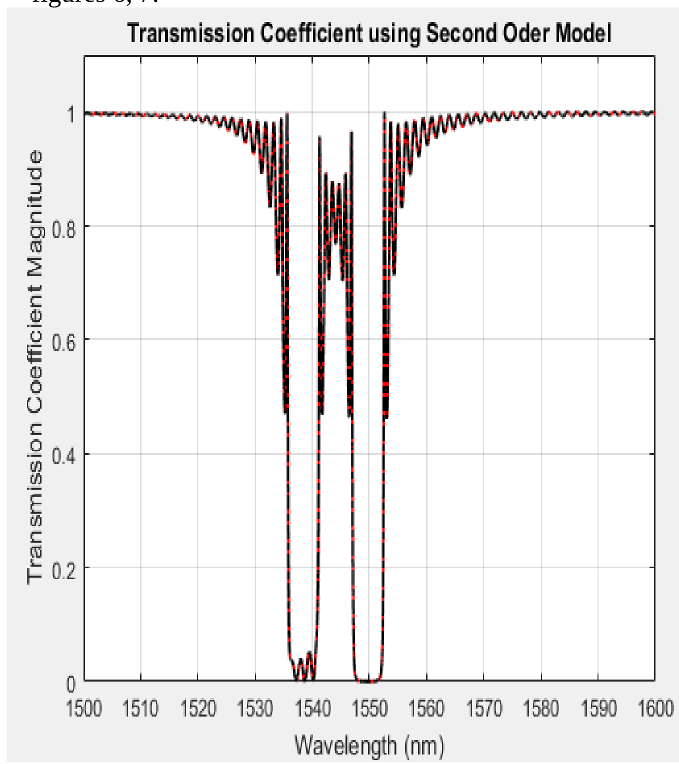

Fig 6: Transmission coefficient using second order model.

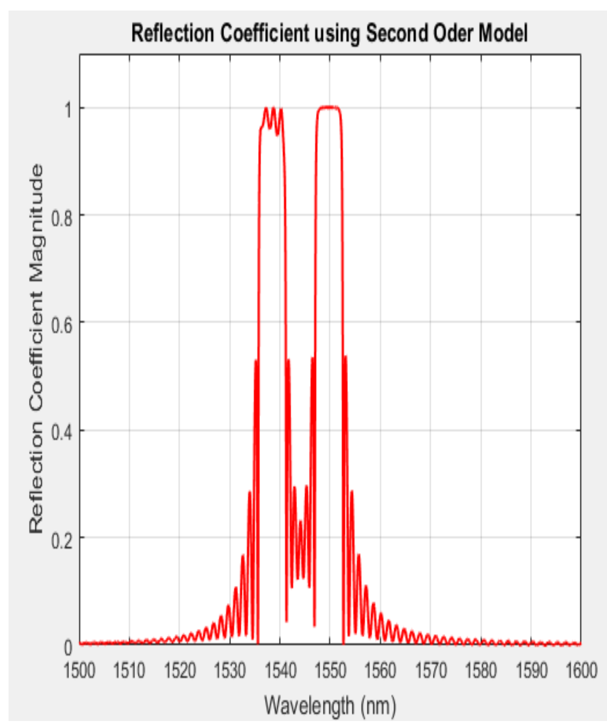

Fig 7: Reflection coefficient using second order model.

Error in transmission coefficient between second and first order models is shown in figure 8.

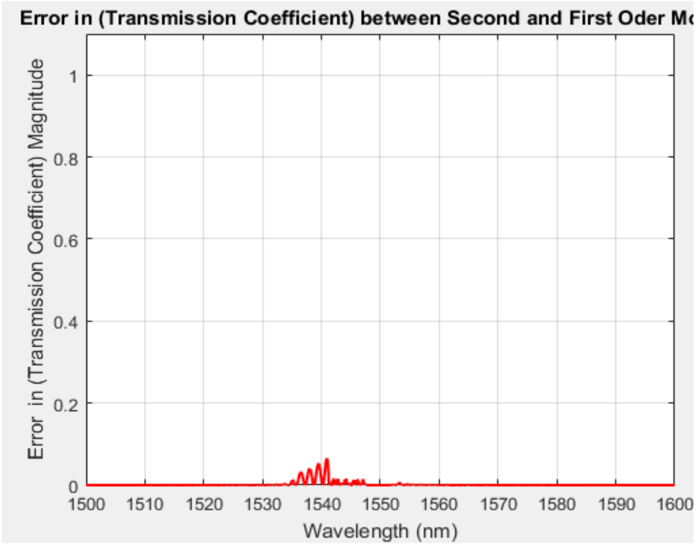

Fig 8: Error in transmission coefficient between second and first order model.

The error in transmission coefficient between second and first order model is very small. Error in reflection coefficient between second and first order models is shown in figure 9.

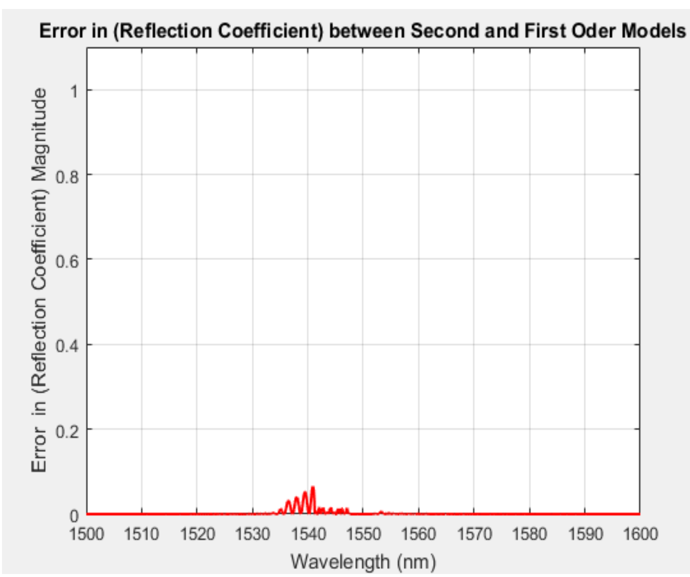

Fig 9: Error in reflection coefficient between second and first order model.

The error in reflection coefficient between second and first order model is very small. Since the error between the second and first order is so minimal, the third order can be disregarded based on the prior Data

4. Conclusions

The FBG is frequently used as a filter. Transmission and reflection in two cascaded stages of fiber Bragg grating using first and second order are studied. The error in reflection and transmission coefficient between second and first order model is very small. Since the error between the second and first order is so minimal, the third order can be disregarded.

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