

Analysis of cascaded chirp characteristics in fiber Bragg gratings for spectral sensor applications

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ABSTRACT

Chirped fiber Bragg gratings (CFBGs) offer broadened reflection bandwidths, making them attractive for wavelength-based spectral sensing applications. In this study, the spectral characteristics of a cascade CFBG system were analyzed using OptiGrating 4.2.2 and OptiSystem software with eight total chirp variations of 0.3, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 nm. The parameters analyzed included reflection bandwidth (FWHM), maximum reflectivity, spectral distribution, channel spacing, and output power. Simulation results indicate that increasing the total chirp significantly broadens the reflection bandwidth until 1.24 nm at a chirp value of 0.3 nm to 9.88 nm at 3.5 nm. Meanwhile, the maximum reflectivity tends to decrease from 100% to approximately 80% as the chirp value increases. The cascade configuration consisting of eight CFBGs successfully generated eight spectral channels within the wavelength range of 1550.4720 – 1556.0000 nm, producing a total spectral span of 5.5280 nm. The highest output power was 39.198 dBm at CFBG-2, while the lowest was 12.203 dBm at CFBG-5. These findings demonstrate that total chirp variation significantly influences the spectral characteristics of cascade CFBG systems and provides a basis for optimizing fiber-optic spectral sensor designs.

Keywords: Chirped fiber Bragg grating; FWHM; optical fiber; reflection bandwidth; spectral sensor

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INTRODUCTION

Fiber Bragg gratings (FBGs) are widely used in optical sensing for their compactness, electromagnetic immunity, and multiplexing capability [1]. Chirped FBGs (CFBGs) have a varying grating period, producing broader reflection bands governed by chirp, grating length, refractive-index modulation, and apodization [2].

CFBGs support temperature and strain sensing through changes in their spectral response [3]. Previous numerical and experimental studies demonstrated that grating design influences sensing performance [4]. In multichannel systems, bandwidth broadening must be balanced against channel spacing and spectral overlap to maintain distinguishable responses.

This study investigates eight CFBG designs with total chirp values ranging from 0.3 to 3.5 nm using OptiGrating 4.2.2 and OptiSystem. Reflection bandwidth, maximum reflectivity, spectral peak positions, channel spacing, and

output power are analyzed to assess the trade-off between spectral coverage and channel separation for spectral sensing applications.

LITERATURE REVIEW

Ouellette [5] investigated linearly chirped Bragg grating filters for dispersion cancellation, showing that chirp and taper design influence reflectivity and dispersion. Although developed for optical communications, this work provides a foundation for controlling CFBG spectral characteristics through grating design.

Tosi [6] compared peak-tracking techniques for FBG sensors, emphasizing how spectral sampling and noise affect wavelength estimation. Spectral sensing performance depends on grating characteristics and peak identification.

Werzinger et al. [7] developed a transfer-matrix approach to estimate FBG array positions and reflectivities. Their model includes multiple reflections and spectral shadowing, which can

introduce inter-grating crosstalk. Although their interrogation configuration differs from the present system, the study emphasizes accounting for interactions between sensing elements.

Together, these studies support evaluating chirp-dependent bandwidth, reflectivity, peak identification, and inter-grating interactions. This work applies these considerations to eight CFBG designs and their combined spectral response.

RESEARCH METHODS

CFBG Design and Simulation

Eight CFBG designs were simulated using OptiGrating 4.2.2 and OptiSystem. Each grating had a length of 20 mm, sinusoidal refractive-index modulation of 0.0005, uniform apodization, and linear period chirp. Total chirp values were 0.3, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 nm, with other parameters fixed. Reflection spectra were exported to OptiSystem to evaluate individual and combined responses.

System Configuration

The system comprised a continuous-wave laser, optical amplifier, 1×8 WDM demultiplexer, eight parallel CFBG branches, and an 8×1 WDM multiplexer (Figure 1). Optical spectrum analyzers and power meters monitored individual responses and the combined output.

Laser power and linewidth were 10 dBm and 10 MHz. Amplifier gain, saturation power, and noise figure were 20 dB, 20 dBm, and 4 dB, respectively. Each WDM component had a 3 dB insertion loss. Output spectra were recorded over 1540 – 1580 nm at 0.01 nm resolution.

Spectral Analysis

Reflection bandwidth was calculated using the Equation (1):

$$FWHM = \lambda_R - \lambda_L \quad (1)$$

where λ_L and λ_R are the half-maximum wavelengths, equivalent to approximately 3.01 dB be-

low peak reflectivity. Adjacent-channel spacing was calculated from ascending peak wavelengths using Equation (2):

$$\Delta\lambda_i = \lambda_{i+1} - \lambda_i \quad (2)$$

Maximum reflectivity, peak-to-peak spectral span, and output power were evaluated. Channel spacing and bandwidths indicated potential spectral overlap without quantifying crosstalk. Integrated and wavelength-resolved peak powers were analyzed separately.

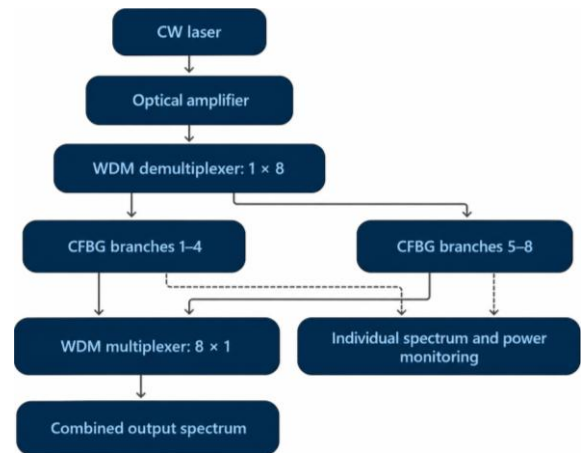


Figure 1. Configuration of the eight-branch WDM-based CFBG simulation system.

RESULTS AND DISCUSSION

Effect of Chirp on Bandwidth and Reflectivity

Increasing total chirp from 0.3 to 3.5 nm broadened the FWHM from 1.24 to 9.88 nm (see Figure 2). Greater period variation allows different grating sections to reflect a wider wavelength range (see Table 1). This highlights the importance of jointly considering chirp, reflectivity, and apodization in CFBG design [8].

Maximum reflectivity decreased from approximately 100% to 73.53% as chirp increased (see Figure 3), indicating a trade-off between bandwidth and peak reflectivity. Theoretical bandwidths followed a similar trend, but differences reached 42.53% and 24.14% at the two lowest chirp values. These discrepancies require consistent interpretation of the analytical model and software chirp definition before validation.

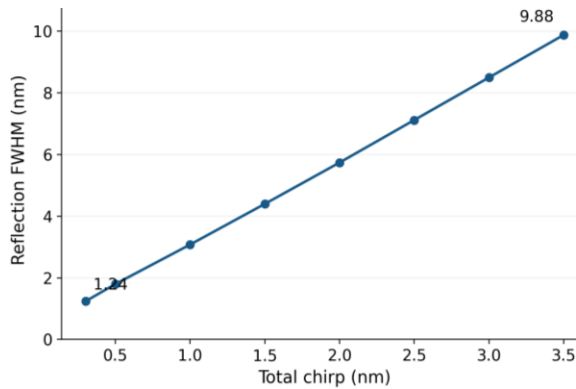


Figure 2. CFBG reflection FWHM.

Table 1. Bandwidth and maximum reflectivity of the CFBG designs.

CFBG	Total chirp (nm)	FWHM (nm)	Maximum reflectivity (%)
1	0.3	1.24	100.00
2	0.5	1.80	100.00
3	1.0	3.08	99.90
4	1.5	4.40	94.64
5	2.0	5.74	89.43
6	2.5	7.12	83.81
7	3.0	8.50	78.00
8	3.5	9.88	73.53

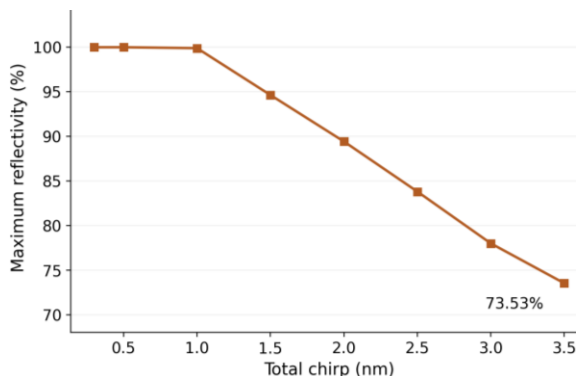


Figure 3. CFBG maximum reflectivity.

Peak Distribution and Channel Separation

Output peaks ranged from 1550.4720 to 1556.0000 nm, spanning 5.5280 nm (Figure 4). Adjacent spacing varied from 0.1155 to 2.1430 nm (Figure 5), indicating potential overlap relative to individual grating bandwidths.

Although overlapping CFBG spectra can support power-based demodulation [9], independent channel identification requires suitable filtering. Bandwidth and peak spacing alone cannot quantify crosstalk because WDM filtering also influences the output.

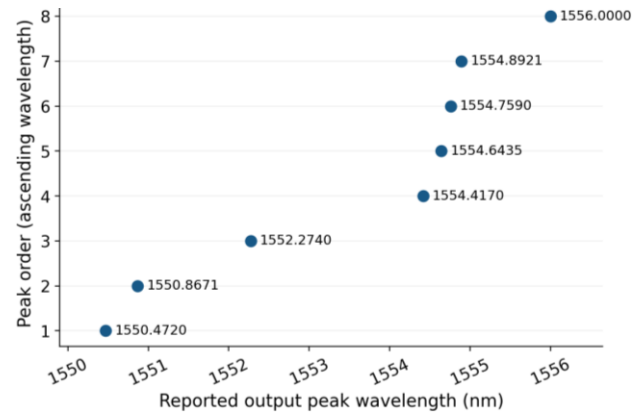


Figure 4. CFBG output peak positions.

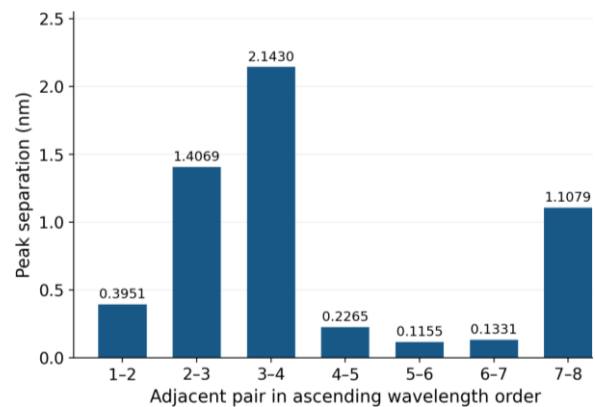


Figure 5. CFBG adjacent-peak spacing.

Output Power and Design Implications

Reported power readings ranged from 12.203 to 39.198 dBm. The maximum corresponds to approximately 8.31 W and requires verification against the source and amplifier settings before identifying an optimum channel.

The system uses parallel WDM-connected CFBG branches. Multiple-reflection crosstalk reported for serial arrays [10] therefore cannot be directly assumed here. Channel isolation requires evaluating full spectra and WDM characteristics.

Overall, increasing chirp broadened bandwidth while lowering reflectivity. Optimal design balances spectral coverage, channel separation, filtering, and optical power. Temperature and strain sensitivity need further investigation.

CONCLUSION

Increasing chirp from 0.3 to 3.5 nm broadened CFBG bandwidth from 1.24 to 9.88 nm while reducing reflectivity from 100% to

73.53%. The output peaks spanned 5.5280 nm, with potential spectral overlap. Optimal design requires balancing bandwidth, reflectivity, and channel separation, alongside verification of optical power and channel isolation.

AUTHOR CONTRIBUTIONS

Liva Delvi: Simulation, analysis, visualization, original draft. Saktioto Saktioto: Conceptualization, methodology, supervision, review and editing. Awitdrus Awitdrus: Validation, review and editing. Zulfa Zulfa: Analysis, validation. Tengku Emrinaldi: Resources, methodology. Defrianto Defrianto: Supervision, review and editing. All authors approved the manuscript.

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DECLARATION OF AI USE

The authors declare that no AI tools were used to prepare this manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All supporting data are included in this article. No additional datasets are available.

ETHICAL APPROVAL

Ethical approval was unnecessary, as no humans or animals were involved.

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