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Dense Wavelength Division (De) Multiplexers Based on Fiber Bragg Gratings

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Abstract: This study is to measure the impact of demultiplexers based on Fiber Bragg Grating (FBG) filter on performance of DWDM system for optical access network. An optical transmission link has been established in which we have inserted a demultiplexer based on four different FBG filters. The first step will be the characterization of FBG's filters (i.e. uniform FBG, Gaussian apodized Grating, chirped FBG) to explain their behavior in the optical link. The simulations were conducted for different fiber's lengths, filter bandwidth and different received power to get the best system performance. This helped to assess their impact on the link performance in terms of Bit Error Rate (BER). *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Optical link, DWDM (de) multiplexer, Fiber Bragg grating, Optical filter.

1. Introduction

Over the last years the dense wavelength division multiplexing (DWDM) system is the state-of-the-art technology in optical communications. In order to increase the transmission capacity and transmission distance available with optical amplifiers, this technique has been developed to provide channel spacing as narrow as possible to the appropriate optical amplification band. This has led to the use of spacing 1.6 nm to 0.4 nm from (200-50 GHz) bandwidth of 1500-1600 nm (C and L bands) [1-4]. For applications in DWDM systems, optical filters ((de)multiplexers) require low insertion loss, a high selectivity, and should also exhibit near zero dispersion [1]. Fiber Bragg gratings (FBGs) have been rapidly considered as important components for many applications in telecommunications and sensing. FBGs are frequently used for DWDM system, because they are compact, present a low insertion loss and low crosstalk. The design of the apodization profile of the FBG can be tailored, so that the amplitude response is almost rectangular and the phase response is linear [4]. A linear phase response corresponds to a constant group delay and zero dispersion, leading to no system distortion. On the other hand the introduction of advanced modulation formats more resistant to fiber non linearity's and increased spectral efficiency [5]. These formats present different spectral widths resulting in different tolerance to amplitude and phase filtering. Consequently, novel FBG designs should be developed.

J. B. Jensen, N. Plougmann, and all [6, 7] have already proved that the a new technique allows the writing of advanced FBGs for DWDM applications with low-dispersion, but is limited by the design of the apodization profile, the beam quality of the UV-source and the nonlinear photo-sensitivity of the fiber used [6, 7].

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In this paper, we present the characterization of optical grating filter to obtain the best BER. The reflection spectrum, bandwidth and the reflectivity of side lobes were analyzed with different lengths and change in refractive index for each filter. A linearly chirped fiber Bragg grating with a Gaussian apodization function is proposed and numerically characterized; his reflection spectrum is steep edges, present high reflectivity and low side lobes. Furthermore, the measurements of BER for different fiber length, confirm the good dispersion of the grating.

2. Theoretical Study

Fiber Bragg gratings are spectral filters based on the principle of Bragg reflection. They typically reflect light over a narrow wavelength range and transmit all other wavelengths, as shown in Fig. 1. When the light waves transmit through the FBG, the light waves which accord with the Bragg condition will be reflected. For all other wavelengths the out of phase reflections end up cancelling each other, resulting in high transmission [1, 2, 8]. Bragg wavelength of FBG is described as [1, 9]:

$$\lambda_B = 2.n_{eff}.\Lambda, \qquad (1)$$

where λ_B is the central wavelength of FBG, n_{eff} is the valid refractive index, Λ is the optic cycle of the FBG or grating period.

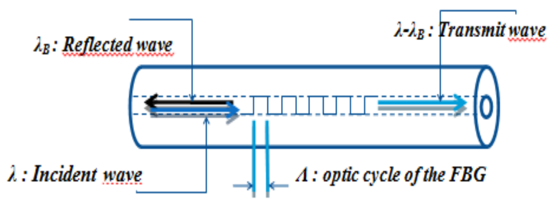

Fig. 1. Working principle of the FBG.

Fiber gratings are produced by exposing an optical fiber to a spatially varying pattern of ultraviolet intensity that creates a perturbation of the effective refractive index of the guided mode [1]. Many types can be classified by variation of this index change along the fiber axis, as uniform Bragg grating, apodized Bragg grating, chirped Bragg grating, etc.

The reflection spectrum of uniform Bragg grating presents a series of side lobes at adjacent wavelengths, which are quite disadvantageous when the filter is used in DWDM system. It is very important to minimize the reflectivity of these side lobes, or apodize the reflection spectrum of the grating [3]. However, the chirped Bragg grating is a grating that has a varying grating period.

The induced perturbation of the refractive index of the FBG is given by [1, 9, 10]:

$$n(z) = n_{eff} + \delta n(z) * \left[1 + v * \cos\left(\frac{2\pi}{\Lambda} z\right) + \phi(z)\right], \qquad (2)$$

where n_{eff} is the refractive index, ν is the fringe visibility, $\delta n(z) = \delta n * f(z)$, δn is the peak value of the “ac” effective index change, f(z) is the apodization function, φ(z) describes the grating chirp and Λ is the grating period defined by [10]:

$$\Lambda = \Lambda_0 (1 + c_0 z), \qquad (3)$$

where Λ_0 is the initial grating period and c_0 is the linearly chirped modulus. The apodization function can be Gaussian, Hyperbolic tangent, raised cosine, etc. We note that a Gaussian apodization profile with zero dc index change is chosen for this work. It can be written as [1]:

$$f(z) = \exp\left[-4.\ln(2).\left(\frac{z - \frac{L}{2}}{\alpha \frac{L}{3}}\right)^2\right], \qquad (4)$$

where α is the apodization factor and L is the grating length.

3. Simulation Setup

An optical transmission link consists of three stages i.e. transmitter, optical fiber and receiver as shown in Fig. 2. Eight channels (T_x) with different center frequencies i.e. 193.1 THz, 193.15 THz, 193.20 THz, 193.25 THz, 193.30 THz, 193.35 THz, 193.40 THz and 193.45 THz are fed to the input multiplexer’s ports. Each transmitter is composed of data source, NRZ rectangular driver, laser source, optical Mach Zehnder modulator. Data source generates a binary sequence of data stream. Laser block shows simplified continuous wave (CW). The model has eight center emission frequencies, 4 dBm power and 10 MHz FWHM line width. The output from the driver and laser source is passed to the optical amplitude modulator. Modulation driver here generates data format of the type NRZ. The pulses are then modulated using MZ modulator at 10 Gb/s bit rate. The transmitters are followed by a fiber link of 50 km and an Optical (de)multiplexer in the circuit which has FBG filter, each receiver is composed of PIN photodiode and low-pass Bessel filter. BER analyzers are used to observe change in performance. PIN photodiode is used to detect the optical signal, i.e. conversion into electrical signal. Its parameters are 193.1 THz/1552.52 nm reference frequency, 0.7981 quantum efficiency, 1 A/W responsivity, and zero dark current. Electrical filter at the receiver side is implemented by low-pass Bessel filter. The filter has bandwidth 8 GHz. BER analyzers as the measurement component is used to obtain the eye diagram. From the eye diagram, the values of Q-factor, BER, can be analyzed.

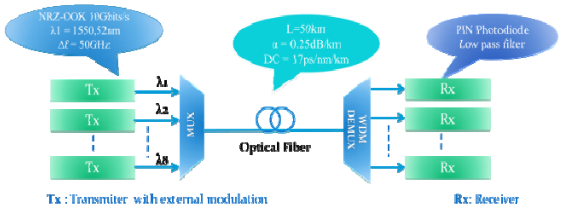

Fig. 2. Block diagram of the simulation system.

First, we present the characterization of optical grating filter. The spectral reflectivity response from each filter (Uniform FBG, Gaussian apodized FBG, Lineary chirped FBG, Lineary chirped Gaussian apodized FBG) is represented for different parameter this step the filter will be introduced in the as grating length, refractive index change, apodization parameter, etc., after optical link.

4. Results and Discussion

4.1. Uniform Bragg Grating Filter

Fig. 3 shows a result of simulations assuming a uniform Bragg grating of 1 cm length and different index of refraction changes. For the first grating with δn = 0.0001 the reflectivity is 100 % and the bandwidth is approximately 20 GHz. When we change the refractive index the reflectivity decreases to 58 % and the filter bandwidth become narrower.

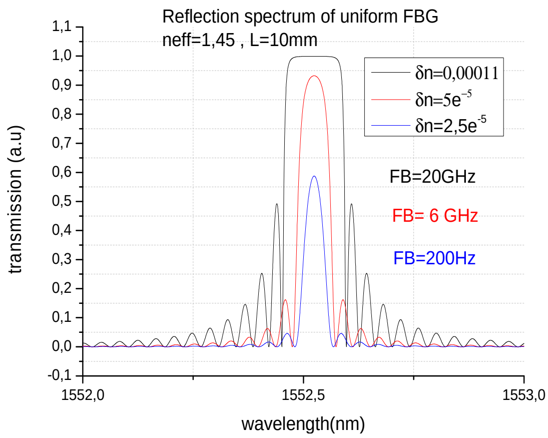

Fig. 3. Spectral reflectivity response for uniform Bragg gratings. The various spectrums correspond to different refractive indices.

The three spectrums represented in Fig. 4 demonstrate that the bandwidth of the gratings decreases with increasing grating length, but the reflectivity increases. On the other hand the level of side lobes in spectral reflectivity curve increases with increase of grating length as indicated in Fig. 4.

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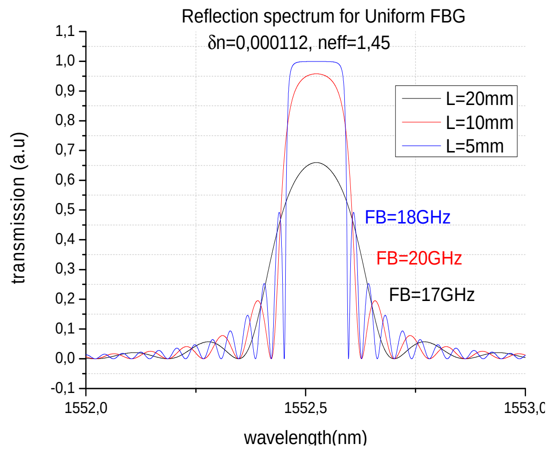

Fig. 4. Spectral reflectivity response for uniform Bragg gratings. The various spectrums correspond to different grating length.

4.2. Gaussian Apodized Bragg Grating Filter

Fig. 5 shows that the apodization can effectively minimize the reflectivity of the side lobes and eliminate it for α = 0.75 which allows to increase the isolation of adjacent channels which is very useful in the design of (de)multiplexers.

The Gaussian apodized grating of 1 cm length, refractive index of 1.45 and different apodization factor (α) changes. For the first grating with α=0.75 the reflectivity is 94 % and a bandwidth of 20 GHz.

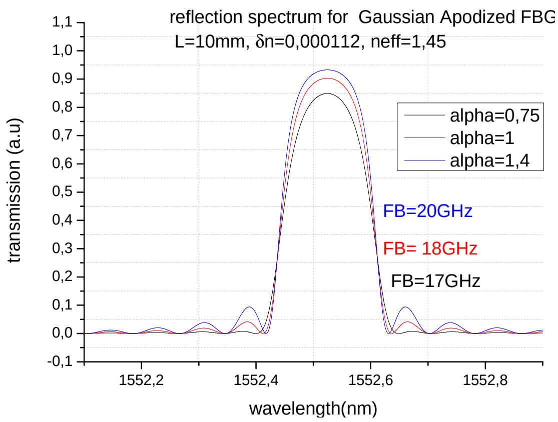

Fig. 5. Spectral reflectivity response for Gaussian apodized FBG. The various spectrums correspond to different apodization factor.

4.3. Linear Chirped Bragg Grating Filter

Strength of side lobes in reflection spectrum curves increases with decrease of the linearly chirped modulus as indicated in Fig. 6. The filter bandwidth is almost constant after c_0=5e^{-5}.

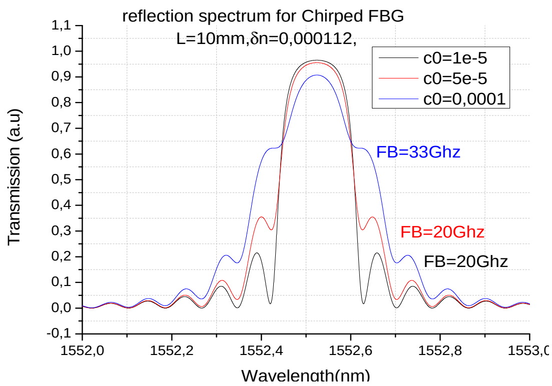

Fig. 6. Spectral reflectivity response for chirped FBG. The various spectrums correspond to different linearly chirped modulus.

4.4. Linear Chirped Gaussian Apodized Bragg Grating Filter

Fig. 7 shows that the last filter configuration present high reflectivity approximately 95 %, the lowest side lobes and his reflection spectrum is steep edges.

4.5. Impact of Filter Bandwidth « FB » on the Received Signal Quality

This study concerns the impact of the filter's bandwidth on the received signal quality for the four (de)multiplexers configuration the first being based on Uniform FBG filter (UFBG), the second based on Gaussian apodized FBG (GA FBG) filter, the third based on linear chirped FBG filter and the last based on linear chirped apodized FBG filter (CGA FBG).The BER curve as a function of filter bandwidth for a fiber's length about 50 km, shows that the uniform FBG filter presents poor performance compared to other filters, as indicated in Fig. 8. The best bit error rate (BER) is obtained for the filter bandwidth of 20 GHz, exception of the chirped FBG filter for which a bandwidth of 10 GHz, and more appropriate.

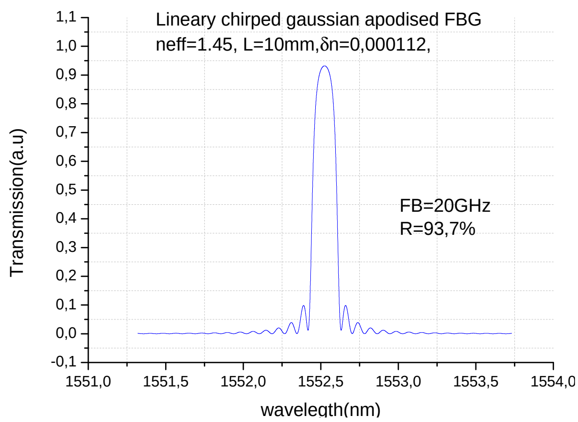

Fig. 7. Spectral reflectivity response for FBG.

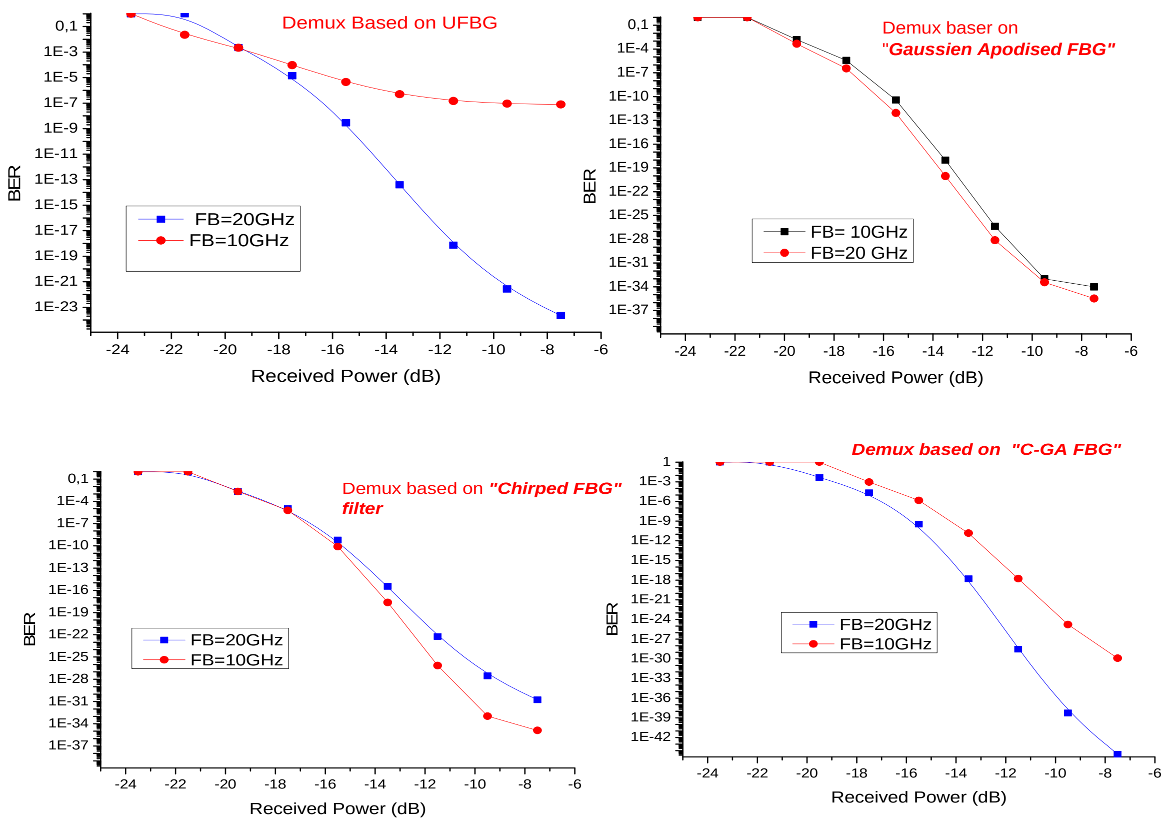

Fig. 8. BER as a function of filter bandwidth FB.

4.6. Effect of Varying the Fiber's Length on the Received Signal Quality

The last step is to see the effect of varying the fiber's length on the signal quality. The simulations are performed at a rate of 10 Gb/s and for fixed bandwidth of 20 GHz. The fiber length ranges from 10-90 km in 10 km. Fig. 9 shows that we can maintain a BER less than 10^{-9} for a fiber length not exceeding 80 km. The (de)multiplexer based on Chirped Gaussian apodized FBG filter offers the best performance in terms of BER, but beyond 80 km the signal degrades for the four types of filter without exception. The measurements of BER for different fiber length, confirm the good dispersion of the chirped Gaussian apodized FBG.

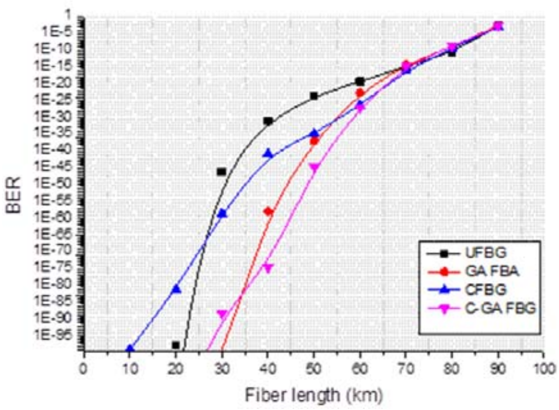

Fig. 9. BER as function of the received power for different fiber's lengths.

5. Conclusions

The various simulations on an optimized point-to-point DWDM transmission system with 8*10 Gbit /s, and a channel spacing of 50 GHz, to characterize the (de)multiplexer, have allowed as to study the different characteristics of FBG filters numerically, with various grating filter (Uniform FBG, Gaussian apodized FBG and Chirped FBG, etc.). We found that the reflectivity increases with increase in grating length as well as index difference. A linearly chirped fiber Bragg grating with a Gaussian apodization function present high reflectivity and low side lobes. Furthermore, the measurements of BER for different fiber length, confirm the good dispersion of this grating.

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