Software Simulation of Fiber Bragg Grating In WDM

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Received on :13/9/2005
Accepted on :4/5/2006

Abstract

WDM (wavelength division multiplexing) is a powerful technique available to meet the ever-increasing demand for communication bandwidth. Among the WDM techniques, the grating is widely used. Fiber gratings selectively reflect a narrow range of wavelengths; this becomes important in designing demultiplexers.

This paper presents a design idea to build a WDM demultiplexer component using Fiber Bragg Grating (FBG). The results obtained reveal that the suggested design is powerful in achieving accurate demultiplexer design. We aim to demonstrate the high level accuracy, the time and cost saving from using the latest state of art software. The performance was measured using quality factor (Q. Factor) and bit error rate (BER), available via visualizers Component Library, included in Optisystem simulator.

الخلاصة

تستخدم تقنية مزج الاطوال الموجية (WDM) لتلبية متطلبات تعريف المدى الترددي لشبكة الاتصالات الضوئية لغرض ارسال كمية كبيرة من المعلومات. باستخدام هذه التقنية يتم ارسال اكثر من قناة على نفس الكيبل الضوئي حيث يتم ترتيب العمل بينهم على اساس الطول الموجي حيث أن لكل قناة طول موجي خاص بها ، ويكون ترتيب العمل ما بين هذه القنوات على اساس الطول الموجي ، وهذا يتطلب تصميم المازج/المقسم الملائم لهذا الغرض.

يقدم هذا البحث فكرة بناء وحدة المقسم باستخدام (Fiber Bragg Grating) ، النتائج التي تم الحصول عليها تشير الى أن التصميم المقترح ذو كفاءة عالية للحصول على تصميم لموزع دقيق الفاعلية. كان الهدف الرئيسي في التصميم هو الحصول على أعلى درجات الدقة ، زمن الاستجابة وتقلل الكلفة باستخدام التقنيات البرمجية الحديثة . تم قياس الاداء من خلال قياس عامل الجودة (Quality Factor) اضافة الى معدل اخطأ (Bit error rate (BER)، المتوفرة في مكتبة حدة العرض المتضمنة في نظام المحاكاة المستخدم في هذا البحث .

Keywords

Fiber Bragg grating, Uniform fiber Bragg grating filter, Optical circulator, Ideal dispersion compensation.

1. Introduction

Recently, there has been growing interest in developing optical fiber networks to support the increasing band-width demands of multimedia applications, such as video conferencing and World Wide Web browsing. The demand for more bandwidth in telecommunication networks has rapidly expanded the development of new optical components and devices (especially Wavelength Division Multiplexers) characterized by small channel spacing and high bit rates, selective band pass filters are a key component [1].

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Consequently, the design possibilities offer a variety of unique WDM devices based on FBG. For wavelengths multiplexing (or separation), interference filters or gratings can be used. However, wavelength division multiplexers using interference filters cannot be used when the number of channels is too high or when the wavelengths are too close [2]. The main advantage of the fiber Bragg Grating is that it can reflect a predetermined narrow or broad range of wavelengths of light incident on the grating, while passing all other wavelengths of the light. So, the idea of this paper is based on designing a WDM demultiplexer by replacing any conventional filter in WDM multiplexer/ demultiplexer component by FBG. The design to be implemented and tested using CAD for photonics (Optisystem 3.0) software [3]. The suggested design depends on the idea of multi wavelength receivers for WDM systems described in [4]. The simulation design uses ideal dispersion compensation FBG. This choice has been made in order to compensate the dispersion both in reflection and transmission at wavelength uses to stop band [5].

2. WDM Multiplexer/Demultiplexer

The components multiplexer and demultiplexer are the essential components of a WDM. They can be classified into two broad categories [6]:

***i)* Diffraction–based Demultiplexer**

Grating–based Demultiplexer uses the phenomenon of Bragg diffraction from an optical grating to spread out a spectrum and pick a narrow range of wavelengths from that spectrum. A "Bragg Grating" is a periodic or aperiodic perturbation of the effective absorption coefficient and/or the effective refractive index of an optical waveguide [7]. More simply put, a Bragg Grating can reflect a predetermined narrow or broad range of wavelengths of light incident on the grating, while passing all other wavelengths of the light. This becomes important in demultiplexer design. Bragg gratings also are fibers, which is a mixed blessing. As fibers, Bragg gratings are easy to couple to other optical fibers. This makes it easy to get the transmitted light out of the Bragg grating, but the reflected light presents a problem, because of light reflected inside the fiber grating is reflected straight back toward the input fiber [8]. This reflected light has to be separated. To solve this problem by separating that light which is the job of a device inconspicuously called an optical circulator. In practice, the need for optical circulators is often considered a potential drawback of using fiber gratings [1].

***ii)* Interference-based Demultiplexer**

Using interference filters for WDM requires taking light out of the fiber and passing it through a set of filters that sorts the light out by wavelength. Typically a lens collimates or focuses the light emerging from the input fiber, which then passes through one or more filters. When the demultiplexing is finished, separate lenses collect the separated optical channels and focus them into individual output fibers [9]. The concept is simple and straightforward, but interference filters are not perfect. Although they reflect virtually all the incident light at other wavelengths, some is lost, and these losses add up after a series of reflections. Picking off one wavelength at a time works fine for 8 channels, but the losses could grow excessive using 16 channels. Interference filters are widely used for WDM and it's worth reviewing their advantages, but on the down side, you need roughly as many filters as you have optical channels—adding to costs, complexity, and optical losses [10].

3-Multiwavelength Receiver for WDM Systems

The Multiwavelength Receiver for WDM Systems that proposed by Frank Tong [4] is shown in Fig.1. The idea is to use fiber Bragg grating in WDM. It is known that fiber Bragg grating are formed by modulating the optical index periodically along the optical fiber, thus generating a distributed reflection at optical signals with wavelengths related to the period of the gratings.

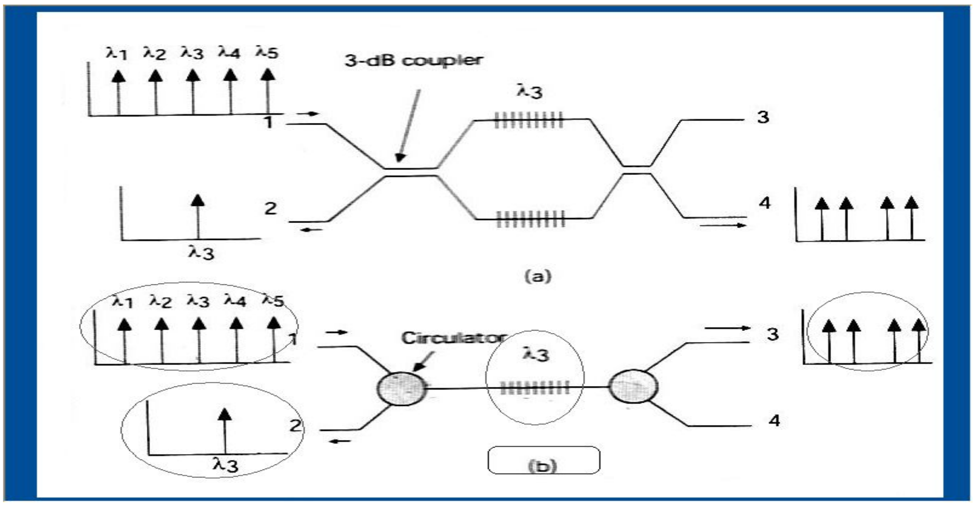

Fig. 1 Illustration of Multiwavelength Receiver

Using fiber Bragg grating similar to channel add-drop. The basic forms of wavelength demultiplexing using FBG are illustrated in Fig.1-b. In this figure, we see another single-stage demultiplexing scheme design with the FBG sandwiched between two circulators. Fiber 1 is the input, fiber 2 is for the dropped channel, and fiber 4 is for channel adding, and the remaining N-1 wavelength channels exit at fiber 3.

4. Reconstruction using Optisystem software

In order to implement the above idea described in Sec.3, the WDM multiplexer/ demultiplexer circuit experimentally constructed by using Optisystem 3.0 software. Fig.2 shows the main layout for 5 channels WDM Multiplexer/ demultiplexer, where no fiber has been used in this experiment. More than one technique available in Optisystem 3.0 can be used such as [3,5]:

- *Component library*: The Component Library is a library of all supported components in the Optisystem software, including system and user components. Components such as Fiber Bragg grating are available in the default component library have been used too.
- *Calculations*: At the beginning, several global parameters (such as bit rate, sequence length, and time window) relevant to the calculations should be setup.

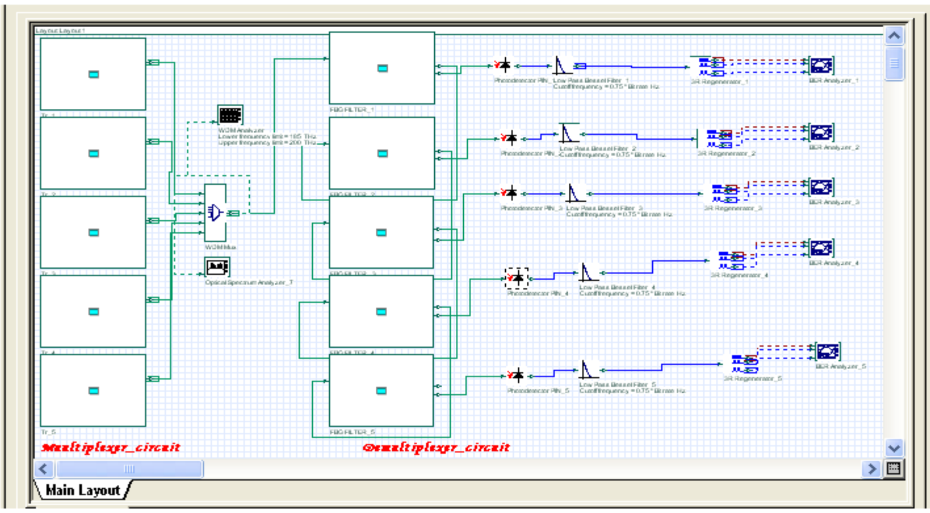

Fig. 2 Using FBG in the WDM multiplexer /demultiplexer

- *Subsystems*: A subsystem is like a component — it has an icon, parameters, and input and output ports. A Subsystem can be built using a group of components or other subsystems. It can easily be created by grouping selected components in the layout.
- *Uniform fiber Bragg grating*: Offer significant advantages over other parameters in the grating (grating period, grating modulation intensity are found by employing the information about maximum reflectivity and bandwidth). The result is a module for the calculation of the reflection and transmission spectra.
- *Ideal dispersion compensation fiber Bragg grating*: Plays important role to compensate the dispersion. Fiber gratings operating in the transmission mode can provide high dispersion at wavelengths close to the Bragg resonance. When multiple gratings are cascaded for wavelength division multiplexing (WDM) applications, the net dispersion between the stop bands of any two consecutive gratings is significantly modified.
- *Ideal optical circulator* Ideal optical isolator is built as subsystem in Opti-system3.0. It has 3 Input ports and 3 output ports.
- *Optical spectrum analyzer*: After running a simulation, the visualizers generate graphs and results based on the signal input. The graphs and results can be accessed from the *Project browser*, or by double-clicking a Visualize in the main layout.

5. Designing the proposed WDM demultiplexer

As described in Sec. 4 and Fig.2, the WDM system includes two main blocks:

1-Multiplexer circuit: Consists of five subsystems named (Tr_1 to Tr_5). Every subsystem includes non return to zero (NRZ) pulse generator, Mach-Zehnder Modulator (MZ), Continues Wave laser (CW) and pseudo random bit sequence generator, see Fig. 3.

The frequency of each CW laser in each subsystem has been configured, so that we have the following range of frequencies:193.1, 193.2, 193.3, 193.4 and 193.5 THz. The five signals from the subsystems are multiplexed using a Multiplexer as shown in Fig. 4.

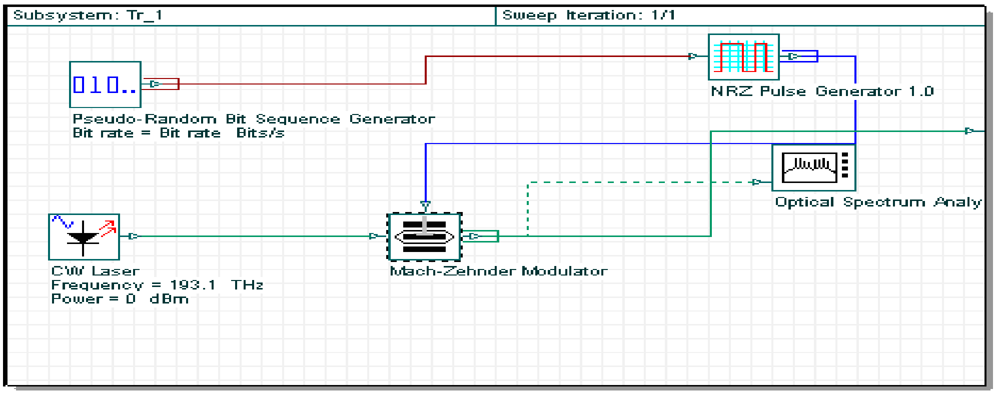

Fig. 3 Multiplexer subsystem (Tr_1)

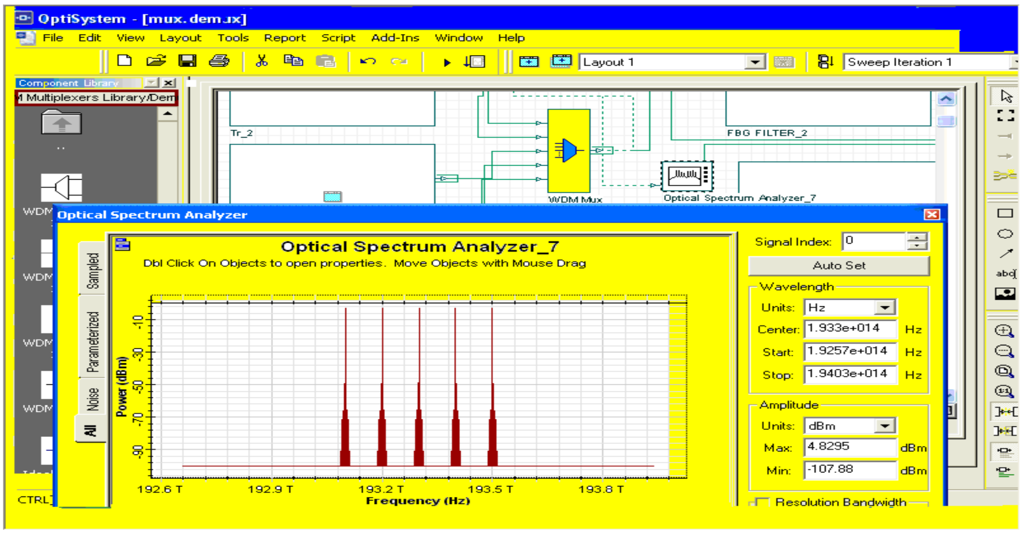

Fig. 4 Optical spectrum analyzer of WDM multiplexer

*2-Demultiplexer circuit:*The demultiplexer circuit consists of five subsystems which named (FBG FILTER_1 to FBG FILTER-5). Every subsystem consists of optical circulator, uniform FBG filter as shown in Fig.5.

The five channels that are out from WDM multiplexer are entered into the first subsystem of demultiplexer via its input port, and then the signal is received by ideal optical circulator, and then transmitted to the first uniform FBG filter by first out port of this optical circulator. The UFBG has been set so that the reflectivity is 0.99 and its condition is equal 193.1THz. This channel is reflected and at the same time this reflected channel is entered into the second UFBG filter, while the remaining four channels are transmitted to the second subsystem. This design faced the dispersion problem where the reflected channel appears again with the transmitted channels as shown in Figures 6 and 7.

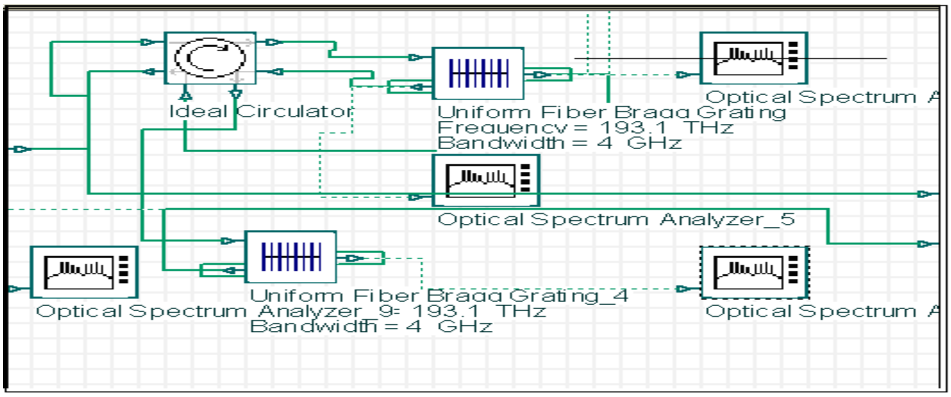

Fig. 5 One of the demultiplexer subsystems before solving dispersion problem

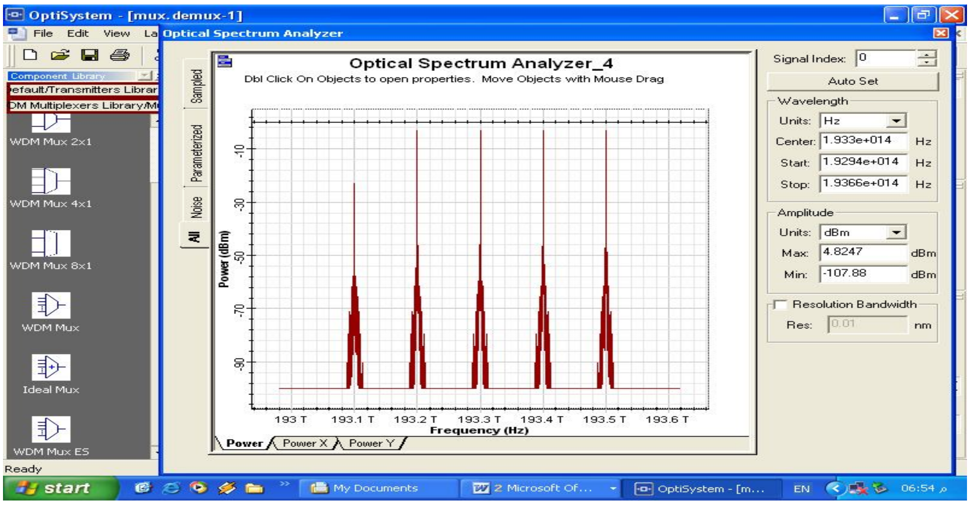

Fig. 6 The effect of dispersion in transmitted channels

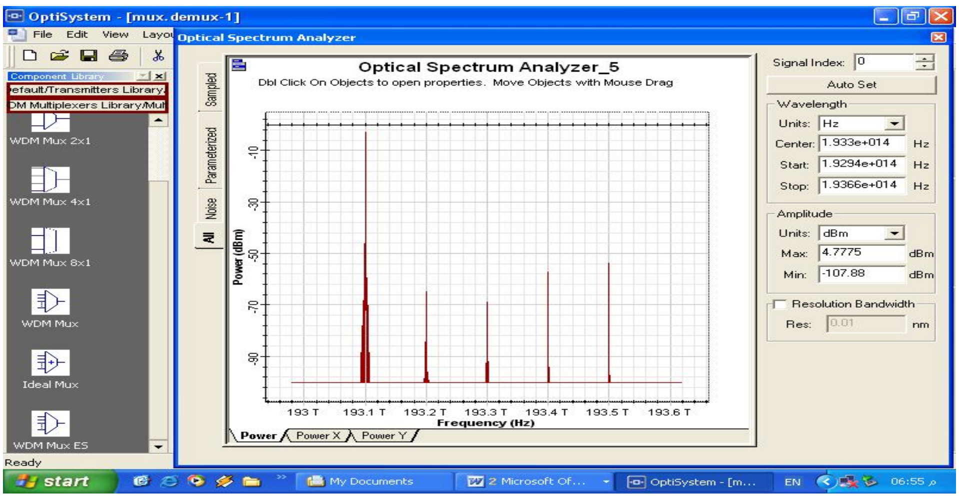

Fig.7 The effect of dispersion in reflected channel

Table 1 shows the results of the optical spectrum analyzer results for all demultiplexer subsystems transmitted and reflected.

After the dispersion problem has been discovered, which affects the transmitted channels and reflected channel, the design of the demultiplexer subsystems had been changed by adding ideal dispersion compensation FBG, as shown in Fig. 8. In other words, to compensate the dispersion in the WDM, ideal dispersion compensation FBG should be used in such transmission channels and in the reflected channels, where the first channel is reflected only and the remaining four channels are transmitted to the second subsystem of the demultiplexer circuit. The corrected results are shown in Figures 9 and 10.

Table 1 Optical spectrum analyzer results

Channels or Subsystem (Tr)	optical spectrum analyzer of the transmitted	optical spectrum analyzer of the reflected
Tr_1, frequency=193.1	193.08-193.12	Only 193.1
Tr_2, frequency=193.2	193.18-193.22	Only 193.2
Tr_3, frequency=193.3	193.28-193.32	Only 193.3
Tr_4, frequency=193.4	193.38-193.42	Only 193.4
Tr_5, frequency=193.5	193.48-193.52	Only 193.5

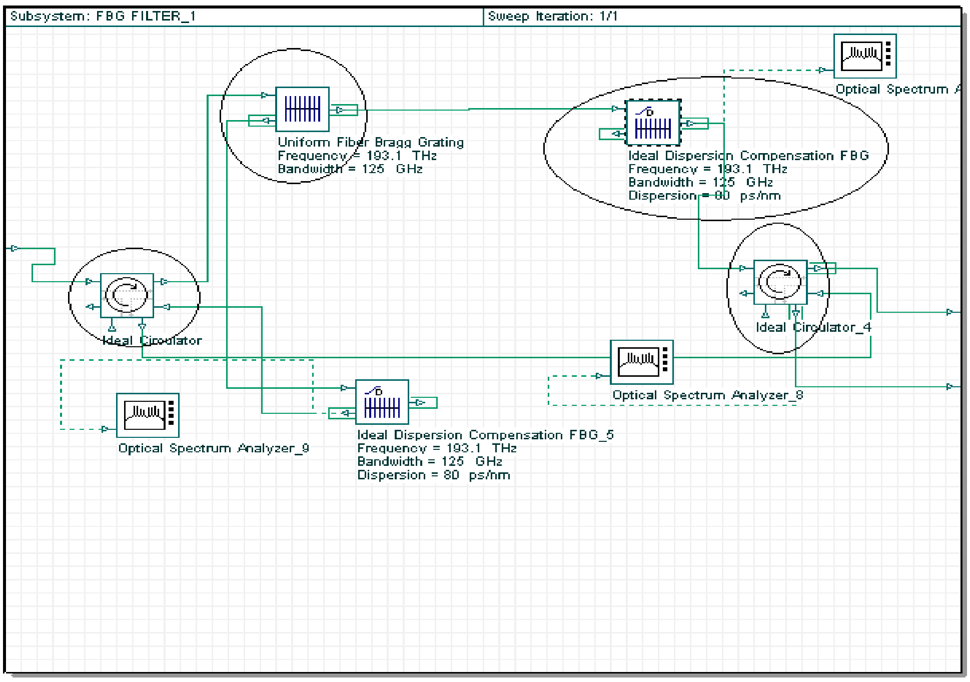

Fig.8 Demultiplexer subsystem after solving the dispersion problem

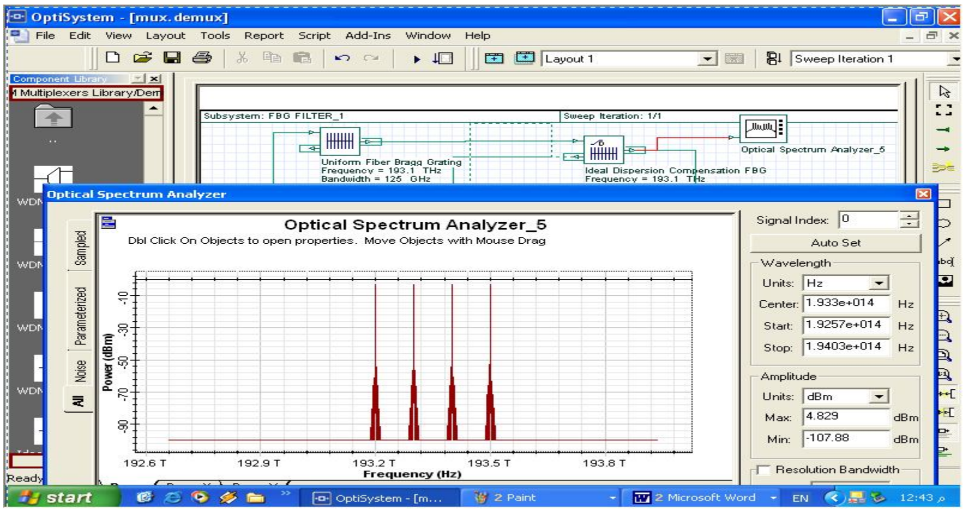

Fig.9 The OSA of the transmitted channels of the ideal dispersion compensation FBG for the first demultiplexer subsystems.

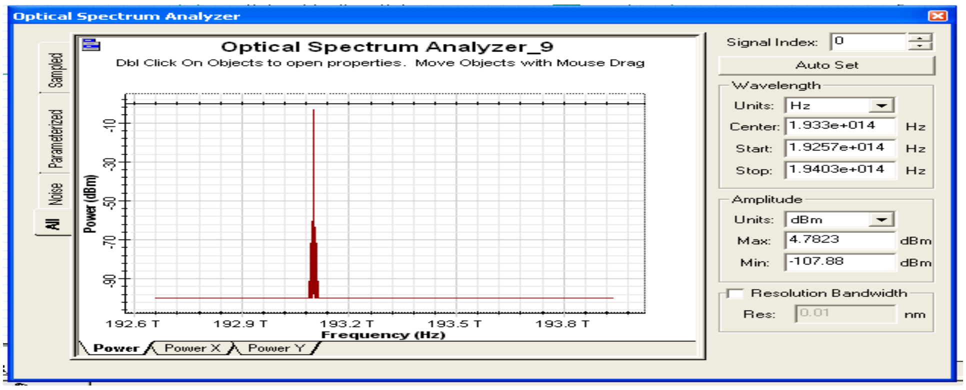

Fig.10 The OSA of the reflected channel of the ideal dispersion compensation FBG for the first demultiplexer subsystems.

After that, every reflected channel in these subsystems is connected to the PIN Photo Detector, in order to convert the optical signals back into electrical pulses form. Every PIN detector is connected to a low pass Bessel filter. Because of the analog nature of transmission, even for digital data, optical signals undergo degradation as they travel through optical fiber due to dispersion, loss, crosstalk, and nonlinearities associated with fiber and optical components. These signals require regeneration periodically. There are 1R Regeneration, 2R Regeneration and 3R Regeneration. Using 3R Regeneration in this design will assure Amplification, Reshaping and Re-timing (signal size increases, limited to give distinct "0" and "1" levels, and the signal's timing information is restored). Currently 3R Regeneration requires converting the optical signal to electrical, performing the required clock extraction and retiming function, and then converting the signal back to optical [7].

6. Experimental result

The performance of the designed component is measured using bit rate error (BER) analyzer and optical signal to noise ratio (OSNR). Figure 11 shows the WDM Analyzer property which has the OSNR equals to 96.96041. The results are shown in Fig.12, where Q-factor and BER values are achieved in agreement with the ITU standard [11], so that Q>6 and BER <10^{-12} [7].

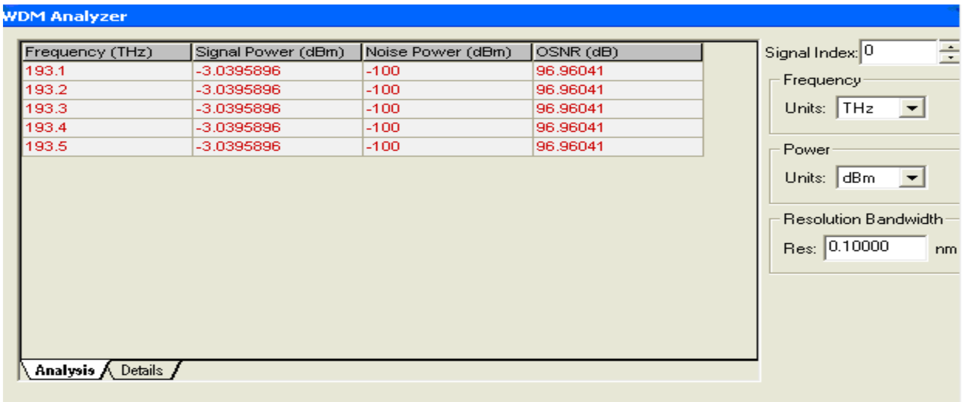

Fig.11 Properties of the WDM analyzer of the five channels

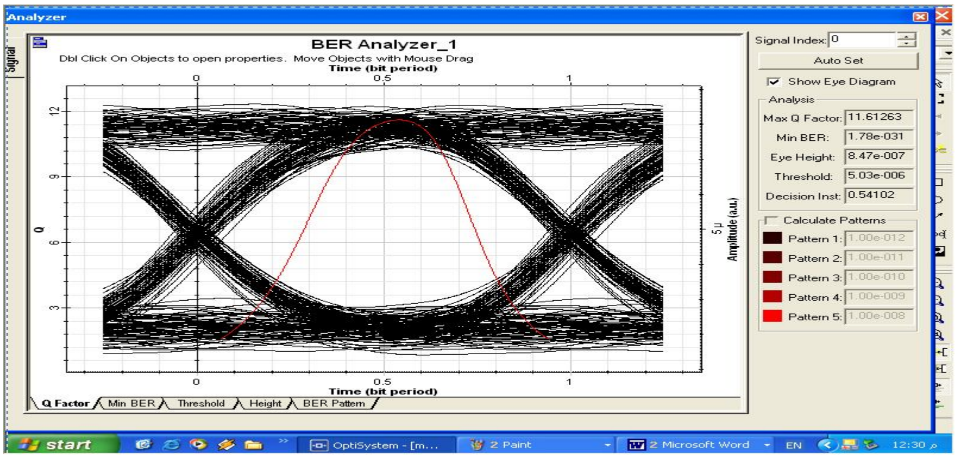

Fig.12 Q- Factor and BER of the first demultiplexed signal (BER-1)

7. Discussion

To assure measuring a high quality of the simulated design, three parameters have been used (Q-factor, BER analyzer, and Optical signal to noise ratio OSNR). This design is arranged on two circuits; multiplexer circuit and demultiplexer circuit based on the idea of (Multi wavelength receivers for WDM systems) experimental method published in IEEE and it is operated at bit rates equal to 2.5Gbits/s and 10Gbits/s. The result obtained before putting the ideal dispersion compensation FBG is shown in the Table 2.

When this design is operated at 2.5Gbits/s and after putting **ideal dispersion compensation FBG** the results obtained reveal that the suggested design is powerful in achieving accurate demulti-plexer design as shown in Table 3 which gives the Q- factor and BER. On the other hand, the design demonstrated increase in signal to noise ratio (OSNR), measured using WDM analyzer. The OSNR is equal to 96.95041, which falls within the predefined limit.

When changing the bit rate of this design to 10Gbits/s, the results that are obtained are very good as shown in Table 4 and the OSNR equal 73.864114.

Table 2 Simulation results of the first design operating at 2.5Gbits/s before putting ideal dispersion compensation FBG.

Channels	Max Q Factor	Min BER	Eye HIGHT	Threshold	Decision ins
Ch 1	9.55664	6.03e-022	6.91e-005	4.84e-oo4	0.60156
Ch 2	9.57382	5.11e-022	6.93e-005	4.84e-oo4	0.60156
Ch 3	9.52131	8.47e-022	6.90e-005	4.84e-oo4	0.60547
Ch 4	9.51820	8.72e-022	6.90e-005	4.84e-oo4	0.60547
Ch 5	9.52320	9.72e-022	6.91e-005	4.84e-oo4	0.60547

Table 3 Simulation results of the first design operating at 2.5Gbits/s

Channels	Max Q Factor	Min BER	Eye Height
Ch 1	11.61263	1.78e^{-031}	8.47e^{-007}
Ch 2	11.54232	4.04e^{-031}	8.45e^{-oo7}
Ch 3	11.27359	8.86e^{-030}	8.11e^{-007}
Ch 4	11.05874	9.94e^{-029}	7.89e^{-007}
Ch 5	10.25480	5.62e^{-025}	7.56e^{-007}

Table 4 Simulation results of the first design operating at 10 Gbits/s

Channels	Max Q Factor	Min BER	Eye Height
Ch 1	11.73713	3.68e^{-032}	5.50e^{-006}
Ch 2	11.57651	2.43e^{-031}	5.47e^{-006}
Ch 3	11.42472	1.40e^{-030}	5.41e^{-006}
Ch 4	11.73391	3.83e^{-032}	5.46e^{-006}
Ch 5	11.14830	3.20e^{-029}	5.36e^{-006}

Conclusions

This paper summarizes the significant contributions made to design and implementation of a WDM multiplexer/demultiplexer, where UFBG filter is used inside the demultiplexer to replace the conventionally used filters. The proposed WDM multiplexer/demultiplexer was designed using the Bragg wavelengths of every FBG. In this design, UFBG was experimentally implemented. By properly choosing the Bragg wavelengths of the UFBG and tuning the filter frequency responses with different side lobe levels according to that demonstrated in [12]. There was a problem that faced this design, which is grating dispersion that affects the performance of a WDM network incorporating cascaded gratings as shown in the first design (i.e., before adding ideal dispersion compensation FBG). Two UFBG filter were used, the bandwidth of these filters is 4 GHz where the transmitted channel may be distorted due to dispersion. This problem was solved by using ideal compensator to compensate dispersion, as shown in the results. After adding ideal dispersion compensation FBG in both transmission and reflection, the bandwidth becomes 125 GHz.

Finally, the results of this work may be also important in designing of recently proposed multiple-grating fiber structures for WDM multiplexer / demultiplexer.

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