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Uniform Fiber Bragg Grating FBG as a Filter

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Abstract:

This project demonstrates the simulation of the uniform fiber Bragg grating component in OptiSystem as a filter. This project has one project layouts. In the layout, a white light source is used. Since the frequency response of the FBG has very narrow pass band, it can be used as a narrow band filter. At 1550 nm wavelength a band width as narrow as 0.2 - 0.3nm can be achieved very easily. If a broad band or multi-wavelength signal is fed to the FBG, selectively a wavelength is reflected back without affecting the propagation of other wavelengths. Firstly, this project will state a theory on fabrication, structure, advantage and disadvantages, applications of optical fiber and then the simulation of the uniform FBG as a filter will be carried out using OptiSystem.

1.1 Introductions to Optical Fiber

Urging our current age, the increasing ability to transmit more information over longer distances more quickly has expanded the boundaries of our technological development in many areas such as data networks, wireless and satellite communications, cable operators, and broadcasters. All of this has become possible by the use of fiber optics, and as technology demands insist upon improved performance, fiber optics will continue to increase. Physicists Daniel Collodion and Jacques Babine reported in the 1840s that light could be directed along jets of water for fountain displays.

1.2 Optical Fiber Structure

Optical fiber consists of two concentric cylinders called the core, surrounded by another cylinder called the Cladding, then the protective cover (buffer coating) and the outer jacket of the cable (jacket).

Core: It is a thin (cylindrical) glass in which light transmits and is made of silica doped with germanium, for example, Ge-Silica.

Cladding: A material that surrounds the glass core (another surrounding cylinder) and works to preserve the light in the center of the optical fiber. It is made of silica, so that the refractive index of the core is greater than the refractive index of the shell, which is the required condition for the occurrence of the phenomenon of complete reflection, which is The basis of directing light in optical fibers, as the light is completely reflected and by repeating the reflection, the light spreads within the core of the optical fiber and reaches the other end of the fiber.

Buffer coating: A plastic cover that protects the optical fiber from moisture and protects it from damage and breakage.

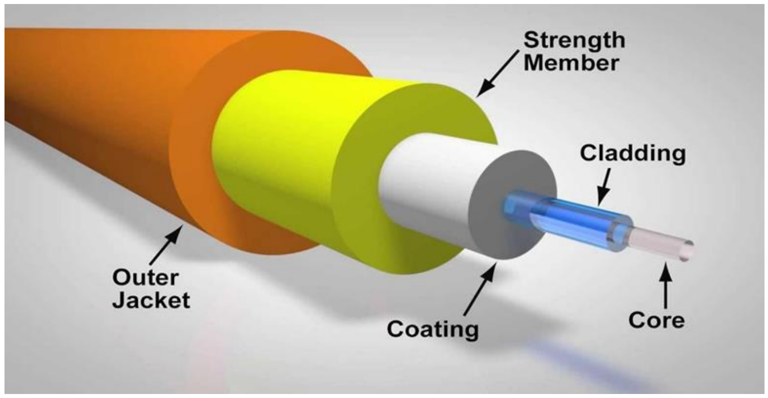
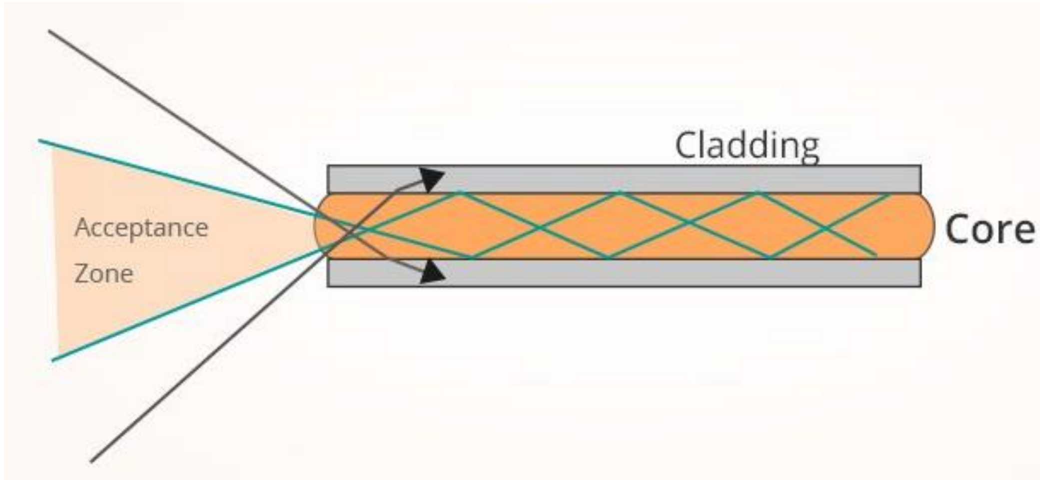


Figure 1.1 optical fiber structures [1]

1.3 Optical Fiber Principle Work

Optical fibers typically work on the principle of total internal reflection of light. The term total internal reflection indicates that no part of the signal gets refracted or transmitted to the second medium, but instead, all of the signals is retained inside the fiber. The natural tendency of a ray of light, when it encounters a change in medium, is to slow down and get refracted. The change in the speed of the propagation of light before and after entering the medium can be represented easily with the help of the refractive index of the medium. The phenomenon of refraction of light is defined as the process of a slight bending of light at the interface of two different mediums having distinct values of refractive indexes. It should be noted that when the light travels from a medium of high refractive index towards a medium of low refractive index, the ray of light tends to get bend towards the interface. The bending of light towards the interface can be increased by increasing the refractive index of the second medium. This can be done easily by introducing dopants or selective impurities into the medium. If the refractive index of the medium is increased up to a value after which the refracted light does not go out, but instead, gets diverted towards the first medium, then one can say that total internal reflection of light has been achieved. The process of achieving the total internal reflection of light by increasing the refractive index of a medium is a tedious task. An alternate method of attaining TIR or total internal reflection is to increase the incident angle of light. The incidence angle at which the light gets reflected back inside the first medium is known as the critical angle. The signal incident at an angle greater than the critical angle tends to propagate from one end to the other by undergoing multiple reflections along the curved surface of the fiber.



Figurer 1.2 optical fiber principle work [2]

1.4 Advantages and Disadvantages of Optical Fiber

Advantages:

1. More capable of carrying information. Because optical fibers are thinner than regular wires, a large number of them can be placed within one bundle, which increases the number of telephone lines or the number of television broadcasting channels in one cord. It is enough to know that the bandwidth of optical fibers is up to 50THZ, while the largest bandwidth needed by television broadcasting does not exceed 6Mhz.
2. Less in size, as its radius is less than the radius of traditional copper wires. For example, a copper wire with a diameter of 7.62 cm can be replaced by another fiber optic whose diameter does not exceed 0.635 cm. This is especially important when laying underground wires.
3. Lighter in weight, copper wires weighing 94.5 kg can be replaced by fiber optics weighing only 3.6 kg.
4. Less loss of transmitted signals.
5. The signals transmitted through adjacent fibers cannot overlap in a single cord, which ensures the clarity of the transmitted signal, whether it is a telephone conversation or a TV broadcast. It is also not exposed to electromagnetic interference, which makes the signal transmitted in complete secrecy, which is of particular importance in military purposes.
6. Non-flammable, which reduces the risk of fires.
7. You need less power in the generators because the losses during the connection process are small.

Disadvantages:

1. The Installation of these cables is cost-effective. They are not as robust as the wires. Special test equipment is often required to the optical fiber
2. Fiber optic cables are compact and highly vulnerable while fitting
3. These cables are more delicate than copper wires.
4. Special devices are needed to check the transmission of fiber cable.

1.5 The Application of Optical Fibers

1. Medical industry

Because of its extremely thin and flexible nature, it is used in various instruments to view internal body parts by inserting into hollow spaces in the body. It is used as lasers during surgeries, endoscopy, microscopy and biomedical research.

2. Communications

In the communication system, telecommunication has major uses of optical fiber cables for transmitting and receiving purposes. It is used in various networking fields and even increases the speed and accuracy of the transmission data. Compared to copper wires, fiber optics cables are lighter, more flexible and carry more data.

3. Defense purposes

Fiber optics is used for data transmission in high-level data security fields of military and aerospace applications. These are used in wirings in aircraft, hydrophones for SONARs and Seismics applications.

4. Industries

These fibers are used for imaging in hard-to-reach places such as they are used for safety measures and lighting purposes in automobiles both in the interior and exterior. They transmit information at lightning speed and are used in airbags and traction control. They are also used for research and testing purposes in industries.

5. Broadcasting

These cables are used to transmit high-definition television signals which have greater bandwidth and speed. Optical Fiber is cheaper compared to the same quantity of copper wires. Broadcasting companies use optical fibers for wiring HDTV, CATV, video-on-demand and many applications.

6. Optical fiber as filters

Fiber optic filters are designed to connect into a fiber optic system. They pass specific wavelengths and reject others. Fiber optic filters can be either low-pass or high-pass filters. A low-pass fiber optic filter allows only shorter wavelengths of light to pass through the filter, while a high-pass fiber optic filter allows only the longer wavelengths to pass through. Fiber optics filters can be fine-tuned to select very narrow wavelength ranges. Fiber optic filters are used extensively in optical telecommunications networks and aerospace applications.

2.1 Introduction

A fiber Bragg grating is a periodic or aperiodic perturbation of the effective refractive index in the core of an optical fiber as shown in Figure 2.1. Typically, the perturbation is approximately periodic over a certain length of e.g. a few millimeters or centimeters, and the period is of the order of hundreds of nanometers, or much longer than that for long-period fiber gratings. For short periods of the index modulation, the refractive index perturbation leads to the reflection of light (propagating along the fiber) in a narrow range of wavelengths, for which a Bragg condition is satisfied

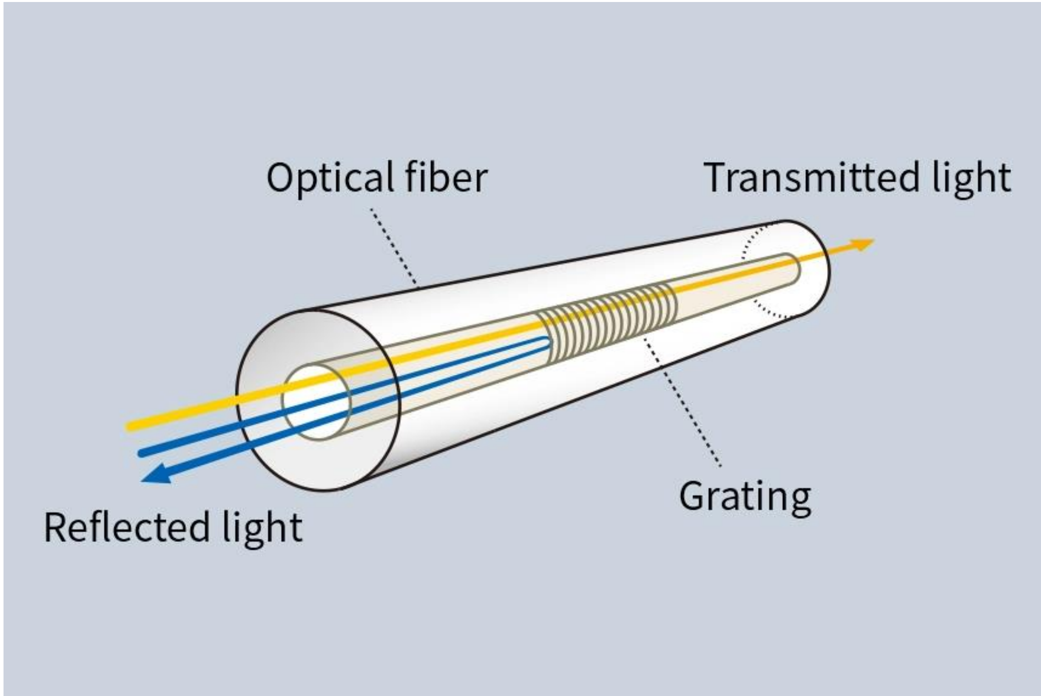


Figure 2.1 FBG optical fiber [1]

$$\frac{2\pi}{\Lambda} = 2 \cdot \frac{2\pi n_{\mathrm{eff}}}{\lambda} \quad \Rightarrow \quad \lambda = 2 n_{\mathrm{eff}} \Lambda \tag{2.1}$$

where Λ is the grating period, λ is the vacuum wavelength, and n_{eff} is the effective refractive index of light in the fiber. Essentially, the condition means that the wavenumber of the grating matches the difference of the (opposite) wave vectors of the incident and reflected waves. In that case, the complex amplitudes corresponding to reflected field contributions from different parts of the grating are all in phase so that they can add up constructively; this is a kind of phase matching.

2.2 FBG Fabrication

The fabrication of fiber Bragg gratings typically involves the illumination of the core material with ultraviolet laser light (e.g. from a KrF or ArF excimer laser or other type of ultraviolet laser), which induces some structural changes and thus a permanent modification of the refractive index. The photosensitivity of the core glass is strongly dependent on the chemical composition and the UV wavelength: silica glass (as is often used for the cladding) has a very weak photosensitivity, whereas germanosilicate glass exhibits a much stronger effect, making possible a refractive index contrast up to ≈ 10−3. A significant further increase in photosensitivity is possible by loading the fiber with hydrogen (hydrogenated fibers). For that purpose, the fiber is kept in a high-pressure hydrogen atmosphere for some time. Phosphate glasses are normally regarded as unsuitable for FBG fabrication, but special methods make this possible [5].

The first fiber Bragg gratings [3] were fabricated with a visible laser beam propagating along the fiber core, but in 1989 a more versatile technique was demonstrated by [3], using the interferometric superposition of ultraviolet beams which come from the side of the fiber (transverse holographic technique). The angle between the ultraviolet beams determines the period of the light pattern in the fiber core and thus the Bragg wavelength. The two ultraviolet beams are often generated by exposing a periodic phase mask (photomask) with a single UV beam [6] (phase mask technique), using the two first-order diffracted beams. Non-periodic phase masks can be used to obtain more complicated patterns. Another technique is the point-by-point technique [8], where the regions with increased refractive index are written point by point with a small focused laser beam. This is an appropriate (and very flexible) technique particularly for long-period Bragg gratings (see above), although extra propagation loss may occur at shorter wavelengths.

Instead of ultraviolet light, infrared light in the form of intense femtosecond pulses can also be used for writing Bragg gratings [2] in various kinds of glasses. In that case, two-photon absorption occurs near the focus of the laser beam, but not in regions outside the focus. It is even possible to write such gratings through the polymer coating of a fiber [4], since the intensity in the coating is much lower when the beam is focused to the fiber core. A totally different method also using infrared light is the fabrication of long-period FBGs in photonic crystal fibers by irradiation with a CO_2 laser beam.

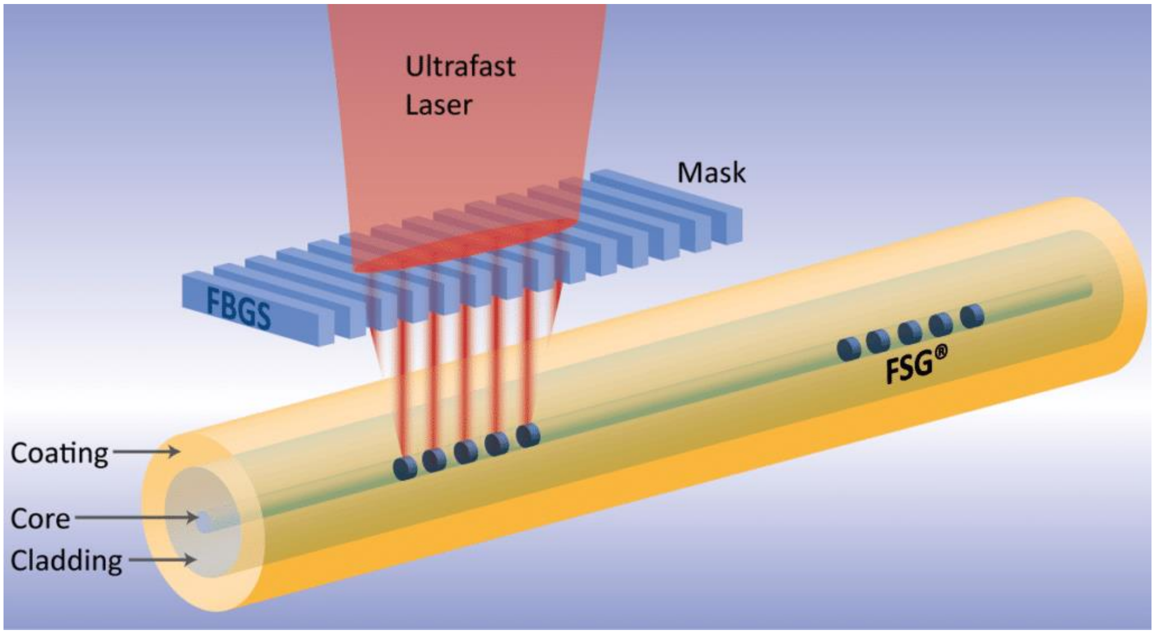


Figure 2.2 FBG fabrication process [2]

2.3 FBG Principle of Work

Fiber Bragg Gratings are made by laterally exposing the core of a single-mode fiber to a periodic pattern of intense laser light. The exposure produces a permanent increase in the refractive index of the fiber's core, creating a fixed index modulation according to the exposure pattern. This fixed index modulation is called a grating. At each periodic refraction change a small amount of light is reflected. All the reflected light signals combine coherently to one large reflection at a particular wavelength when the grating period is approximately half the input light's wavelength. This is referred to as the Bragg condition, and the wavelength at which this reflection occurs is called the Bragg wavelength. Light signals at wavelengths other than the Bragg wavelength, which are not phase matched, are essentially transparent. This principle is shown in Figure 2.3. Therefore, light propagates through the grating with negligible attenuation or signal variation. Only those wavelengths that satisfy the Bragg condition are affected and strongly back-reflected. The ability to accurately preset and maintain the grating wavelength is a fundamental feature and advantage of fiber Bragg gratings.

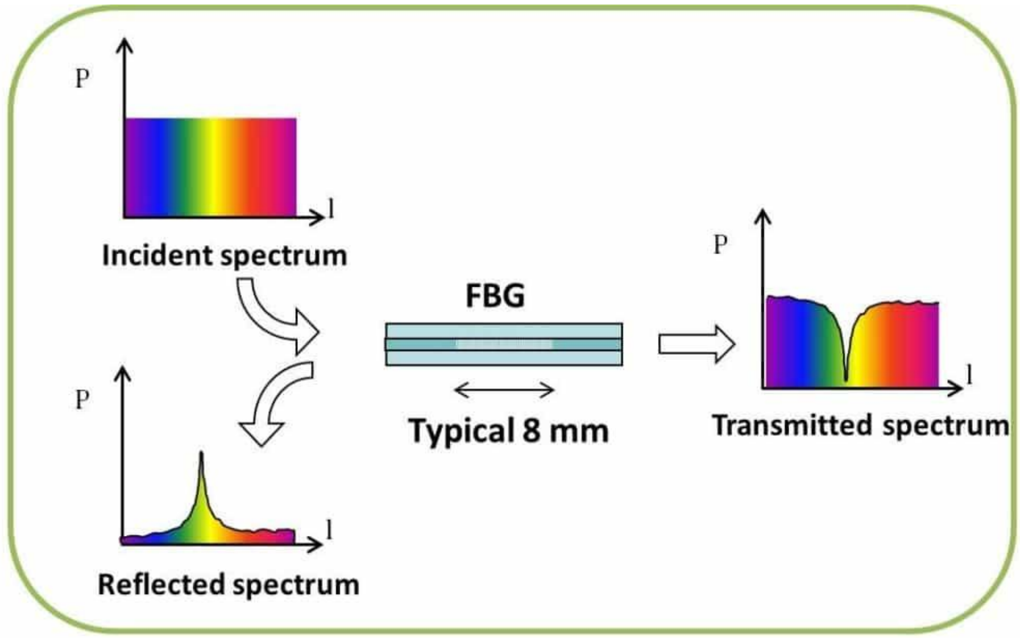


Figure 2.3 work principle of FBG [5]

A fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by creating a periodic variation in the refractive index of the fiber core, which generates a wavelength-specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector. Raysung is capable of manufacturing various FBGs, including Uniform FBG, Apodized FBG, Double-Clad FBG as well as Chirped FBG.

3.1 Simulation Layout of Uniform FBG as a Filter

The following system was created using the Optisystem 7 program. The system shown in figure 3.1 which illusteats the component used in this project. A wight ligth source with input power equal to -130 dBm. Then a uniform FBG filter was used. The input and output signals were recorded and inserted in this project by using optical spctrum analyzer befor and after the FBG. Besides, the transmission and reflection spectrum were recorded. According to simulation parameters, table 3.1 shows these paramerters.

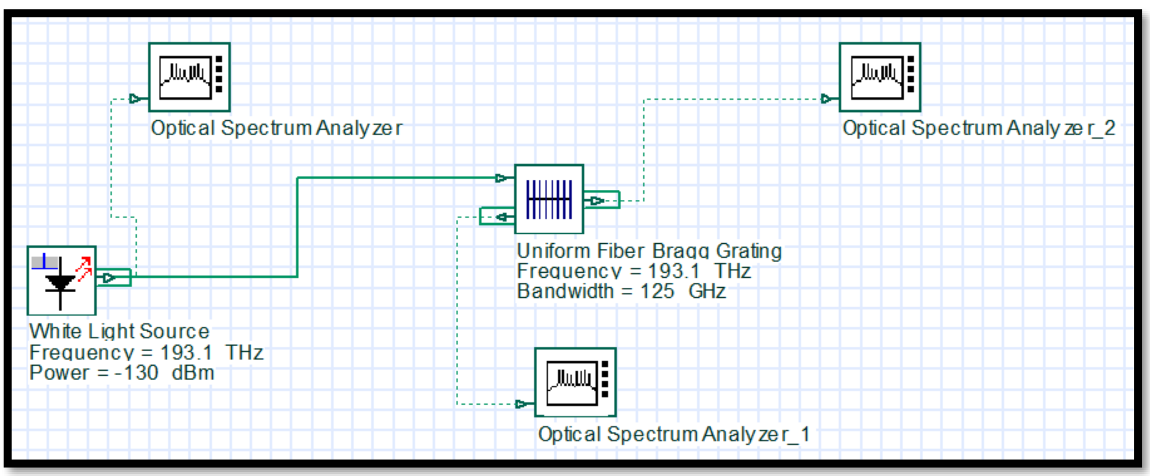


Figure 3.1 Uniform FBG layout using Optisystem 7.

Table 3.1 Simulation parameters for first case.

Parameters	values
White light source frequency	193.1 THz
White light source Power	-130 dBm
FBG bandwidth	125 GHz
FBG frequency	193.1 THz
Central FBG wavelength	1552.6 nm

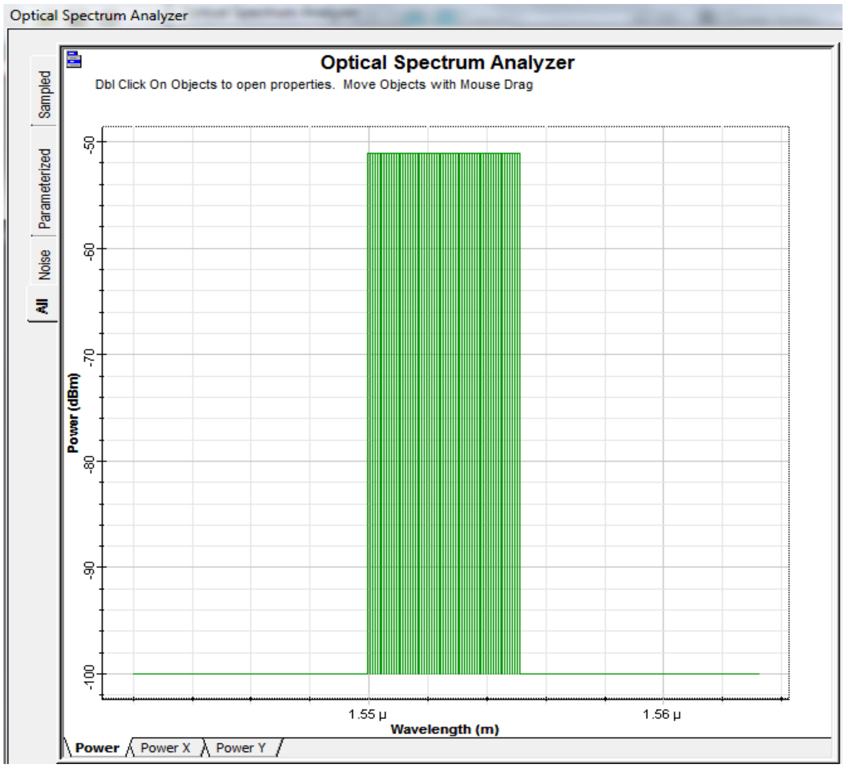


Figure 3.2 the input signal from the light source.

3.2 Reflection and Transmission Spectrum of The FBG

Figure 3.2 shows the input signal of the light source which is clear that the signal is complete and has no separation. After passing this signal through the FBG filter, the signal was reflected and transmitted with a central Bragg wavelength equal to 1552.6 nm as shown in figures 3.3 and 3.4 respectively. It is reordered by monitoring the optical spectrum analyzer. However, this proves that the FBG works as a filter that passes the wavelength of a central peak1552.6 nm.

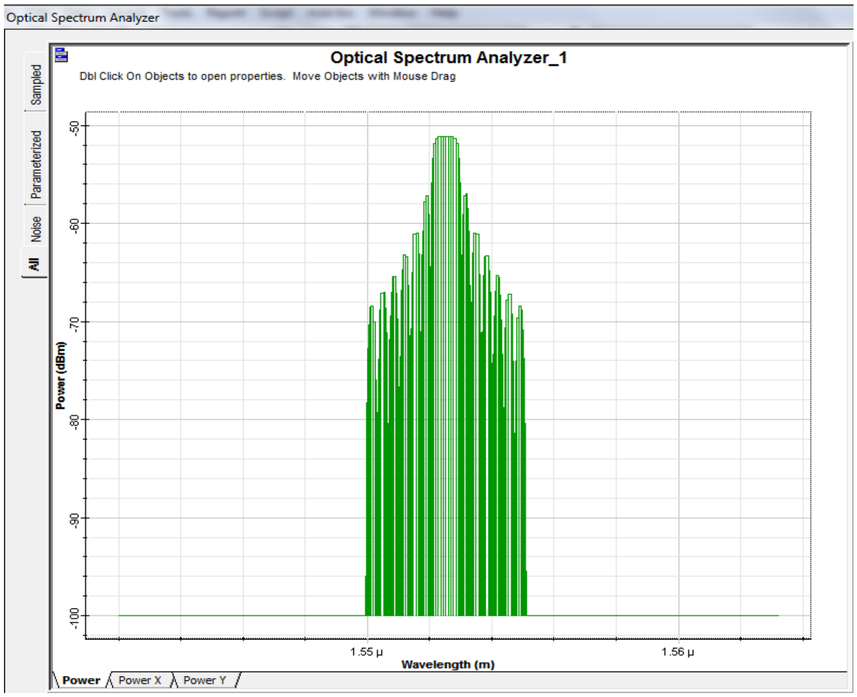


Figure 3.3 the reflection spectrum of the FBG

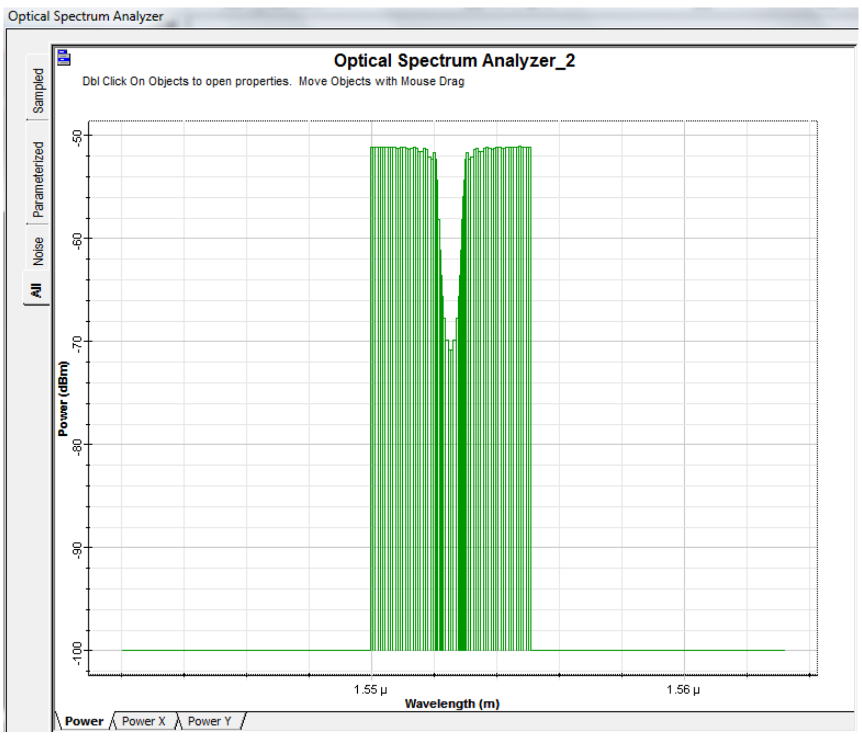


Figure 3.4 the transmission spectrum of the FBG

3.3 Discussion and Future Work

The aim of this work was to simulate the FBG as a filter using the Optisystem software. However, the results show how the FBG works in this system. After passing this signal through the FBG filter, the signal was reflected and transmitted with a central Bragg wavelength equal to 1552.6 nm. The future work may be will consider working on the system in laboratory taking into account the surrounding factors that affect the readings and measurements.

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