Compensation of Dispersion with Fiber Bragg Grating in Optical Fiber Communication

Namreen Bashir[1], Mrs Vijeta[2]

[1,]PG SCHOLAR,DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING, R N COLLEGE OF ENGINEERING & TECHNOLOGY, MADLAUDA, PANIPAT
[2,]ASSISTANT PROFESSOR, DEPARTMENT ELECTRONICS AND COMMUNICATION ENGINEERING, R N COLLEGE OF ENGINEERING & TECHNOLOGY, MADLAUDA, PANIPAT
Email id :- namreenw23@gmail.com

Abstract

The Fiber Bragg Grating (FBG) is a periodic structure fabricated inside the core of the optical fiber. The periodicity could be mechanical like variation of the core diameter or it could be electrical like variation of the refractive index of the core. The optical fiber is always used in telecommunication system because of its characteristics which include small size or dimension, low loss and low interferences from outside environment. There are various types of optical fiber, the Fiber Bragg Grating (FBG) is commonly chosen as important components to compensate the dispersion in optical communication system. FBG is very simple, has low cost filter for wavelength selection and low insertion loss, it has also customized reflection spectrum and wide bandwidth. We have analyzed the dispersion compensation using Fiber Bragg Grating at different fiber lengths. The simulated transmission system will be analyzed on the basic of different parameters by using OptiSystem simulator.

Keywords:- FBG, Optical Fiber, Refractive index, Optisystem simulator.,

INTRODUCTION

Recently, increasing interest in worldwide industries towards the application of Fiber Bragg grating (FBG) in sensing technology has brought to the rapid development and deployment of optical sensors especially in the monitoring of temperature and strain. FBG has a number of advantages, such as relatively small size and long life span. Besides, it is also inexpensive to manufacture, lightweight, multiplexing ability, self-referencing with a linear response, ease of installation, durability and immune to electromagnetic interference (EMI) [1-4]. Moreover, a pressure quasi-distributed measure can be realized by multiplexing in one single optical fiber to provide multiple FBG sensing elements without the need of installing a huge amount of strain gauge [5]. Sensing process in extremely harsh environments such as explosive gas exposure setting, high-temperature combustion chamber, and environment which contains high electromagnetic interference is feasible by using FBG sensors due to its passive nature. Although naked FBG sensor is fragile, an approach to encapsulate the FBG sensor could solve the problem by adding carbon fiber for reinforcement and solidified by epoxy resin with encapsulation technique [6]. The encapsulation technology protects the fiber from the severe environment in mounting processing without influencing the transmission of the strain applied to the FBG [7, 8].

In recent years, various types of the FBG-based sensor [9, 10] has been developed. Vengel Rao Pachava et al. [11] used the longitudinal FBG deformation principle by the transverse deflection of a diaphragm which induced an axially stretched-strain along the length of the FBG thereby creating a red shift of Bragg wavelength with the increased pressure. However, according to Frantisek Urban et al. [12], a longitudinal FBG's deformation will result in bigger optical signal wavelength displacement (FBG central frequency moves from 10 to 30 nm). They also emphasized that, by using the method of pressing the FBG laterally to obtain an ellipsoidal fiber cross-section shape only, will generate a maximum of 300pm spectrum peak spread.

In 2008, Zhang et al. [13] has reported their new FBG pressure sensor based on a flat diaphragm with enhanced responsibility by using a single FBG and an L-shaped lever with a curve of Archimedes spiral. It achieved ultrahigh sensitivity, 244 pm/kPa and reduced temperature sensitivity of 2.8 pm/°C. The L-shaped lever is made up of quartz glass and laser machine. It requires high precision and the sensor design will be complicated compared to conventional diaphragm transducer. In the research works [13, 14] temperature was compensated because a temperature cross-sensitivity can lead to inaccurate measurement result [15, 16]. Zhao et al. [17] proposed a solution to compensate the temperature by adding a reference FBG. Sengupta et al. [18] solved this problem by utilized two FBG in different diameter fibers and the combination of FBG with the Fabry-Perot cavity is reported by Lin et al. [19].

A conventional pressure sensor based on strain gauge, vibration wire, mechanics, and etc. [20, 21] are unable to adapt to the harsh environments and also impossible to realize the online monitoring for long distance. Therefore, the FBG based pressure sensors become important in recent researches [22, 23]. Several studies have proposed improvement to the pressure measurement sensitivity, such as embedding FBG in the polymer, soldering metal-coated FBGs on a free elastic cylinder, and attaching the FBG to a diaphragm [5, 24].

In this research work, an FBG pressure transducer was designed and applied for pressure measurement by attaching FBG on the diaphragm. However, there are a lot of challenges to make the FBG based pressure transducer possible for a robust pressure measurement. For example, the issue of optic signal conversion to the voltage signal by using photodetector (PD); which shows the significant inconsistencies in output voltage [25]. This has led to huge variation in desired readings. To overcome the problem, a new arrangement of optical components has been proposed. In this configuration, additional FBG was added to the system which acts as reference FBG in order to eliminate the variation of voltage. The proposed pressure transducer, works under constant room temperature and the temperature cross-sensitivity is not being considered.

Working principles of FBG

FBG sensors are produced by creating periodic variations in the refractive index of the core of an optical fiber by using a high energy optical source and a phase mask [26]. Figure 1 shows the internal structure of an FBG sensor. Reflection of certain wavelength occurs when the light is traveling at the Bragg wavelength, which is a grating feature and appears missing in the transmission spectrum also shown in the diagram below when the grating structure only allows wavelengths of light [27].

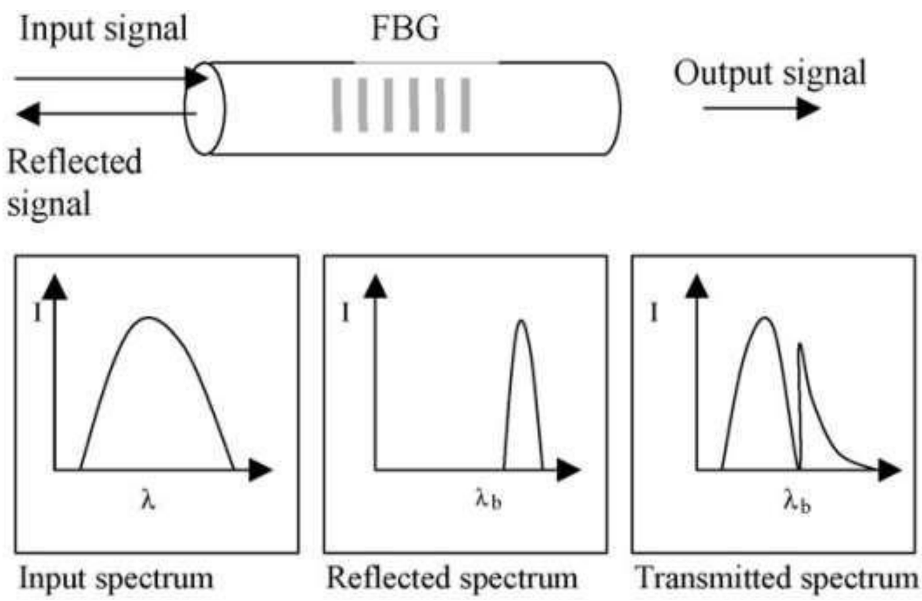

Figure 1. Transmission and reflection spectra from an FBG

Bragg wavelength is a narrowband spectral output or a peak reflected wavelength from the FBG sensor after being illuminated by broadband light source and the light interacts with the grating of an FBG. The detection of local strain from a deformation is done through the variation of grating period and the reflected wavelength via the Bragg equation. According to the Bragg condition, the Bragg wavelength can be expressed in a well-known formula.

$$h_{B}=n_{eff}fl$$

where λ_B is Bragg grating wavelength, Λ is grating periodic spacing, n_{ett} is the effective reflective index of the fiber core. This formula is established by Nobel Laureate Sir William Lawrence Bragg in 1915 about diffraction of X-Ray from crystals and he expressed it into a simple mathematical formula. The Bragg wavelength is sensitive to physical changes in the grating due to strain and temperature[30].

EXPERIMENTAL WORK

Attenuation along a fiber that is frequency dependent results in a dispersed signal. Visually, the effect on a pulse is a broadening of the pulse with respect to time. It is called intramodal dispersion, and it was discussed in chapter 2. Essentially, some modes take longer to travel the fiber than others. Thus, modes that are launched simultaneously do not arrive at the opposite side of the fiber at the same time.
It is normally necessary to measure relative propagation delays as a function of wavelength in order to determine the intramodal dispersion curve of an optical fiber or FBG. The broadening of the pulse is the basic principle underlying most intramodal dispersion measurement instruments used for characterizing fiber gratings or telecom fiber links.

Identiflcation of the measurement method

Analysis and accurate measurement of the group delay is essential in optimization of the performance of optical systems. We can apply various techniques to measure intramodal dispersion. It can include applications of Kramers-Kronig relations or a Hilbert transformation between the reflectivity and the phase of the components, low-coherence interferometry, and various pulse delay measurements and phase-shift techniques. The parameter that is typically measured is the group delay of the component as a function of the wavelength. Traditionally the group delay of an optical fiber has been an important characteristic to be measured. In practice, it is important to have knowledge of such parameters as the zero-dispersion wavelength, the dispersion slope and uniformity of the group delay of the device under test.
Accurate characterization of the dispersion of FBGs and fiber dispersion requires evaluation of the conventional methods to obtain reliable measurement results of their properties.
It is possible to measure dispersion using Hilbert-transform method, which the amplitude and phase response of an optical filter are related. To assure this relation is valid, the filter must fulfil a so-called minimum phase condition. This condition is fulflled by optical filters, such as uniform fiber Bragg gratings. For this component, the phase response and then the dispersion can be calculated directly from the measured amplitude response. However, the minimum phase condition does not hold for components as apodized or chirped fiber Bragg gratings. These components have a complex phase response that, in general, the reconstruction of the phase information from the measured amplitude response is not possible.
Measuring dispersion may also be done using interferometric method to obtain the group delay. In the interferometric method, the measurement setups are typically based on Michelson or Mach-Zehnder interferometers. Light from a broadband or a wavelength tunable light source is split in two paths one of which couples light into the component and the other is a reference path. The light transversing the component is combined with the light from the reference path and the resulting interferogram is detected. From this interferogram it is possible to calculate both the amplitude and the phase response of the component by means of a Fourier transform. The group delay of the component can be extracted from the phase of the interferogram.
A clear advantage of the interferometric method is its resolution. Very small dispersion values can be

measured accurately. However, interferometers often use freespace optics, which make them sensitive to variations in the environment. Also long components are difficult to be measured since the length of the reference arm needs to be approximately equal to the optical length of the device under measurement.

The light from a tunable laser is modulated with a sinusoidal signal. The modulation generates sidebands on the optical carrier. The sidebands will experience a phase shift when the modulated light passes through the device under test. The phase shift of the detected signal allows the group delay of the component to be determined. The basic setup and variations of it using different light sources have been utilized for measurements of the dispersion of an optical fiber for years. Several commercially available dispersion measurement systems rely on this measurement principle.

Measurement setup

The most commonly used and standardized technique is referred as the phase shift method, in which light is sinusoidal-intensity modulated. Phase variations related to wavelength are measured at a given high frequency. The reference signal, with respect to which phase shifts are measured, can come directly from an electronic oscillator or optical signal. The phase shift method can also be modifled to measure much smaller relative delays typical of most fiber-optic components when used with a tunable laser, an electric network analyzer, as well as modulation frequencies of up to many GHz.

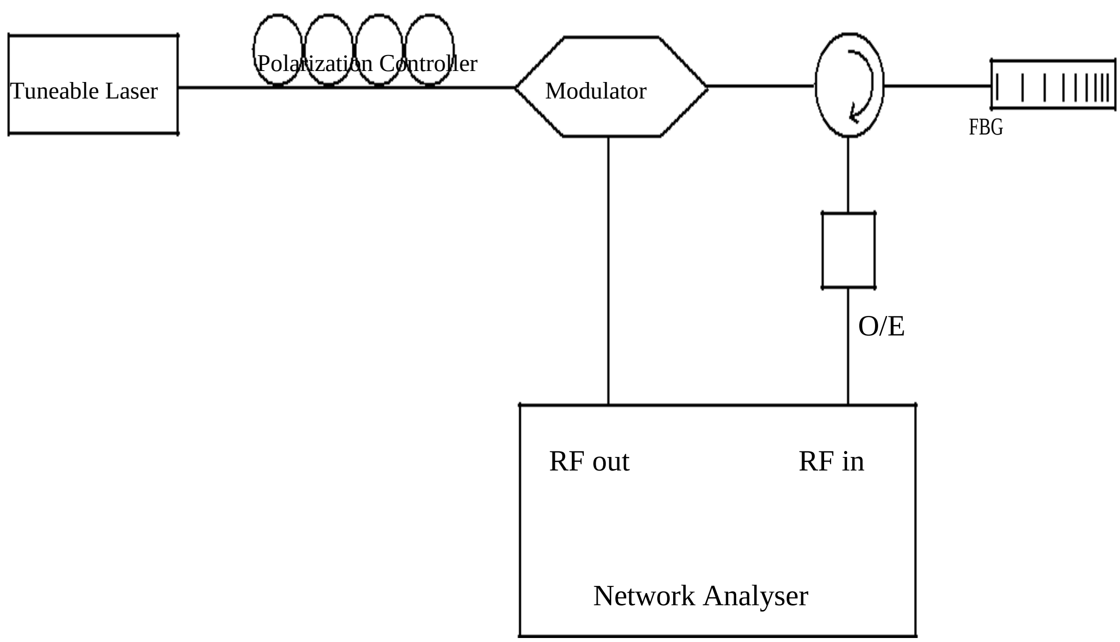

Figure 2: *Setup to measure group delay using the phase-shift method*

Laser Source

In order to measure the phase shift it necessary a continuous wave (CW) laser source, to work as carrier of the modulation signal. Due to the fact we wish to characterize the grating over a wide wavelength range, the laser must be tuneable and with high resolution.

The New Focus model 6427, has two control options, local and remote. Our main criterium for selecting this laser was his capability of being controlled remotely through a GPIB interface, making this model unique from all that INESC owns. This system provides high resolution between wavelengths. Although the standard resolution is 0.01 nm, the laser allows a resolution of 0.001 nm. This higher resolution will be the standard step resolution for our characterizating system.

Laser Characteristics	Min		max
Wavelength Range (nm)	1520	-	1570
Wavelength step resolution		1 pm	
Power (dBm)	-3	-	6.9
Time to warm up		45 min	

Table 1: *Laser main characteristics [14].*

Modulator

The LiNbO3 based device is a optical modulator witch uses high performance travelling-wave electrodes. It has the following features:

- Low insertion loss
- Low driving voltage
- Wide-band
- Polarization Maintaining input port
- the structure of the electrode is optimized to reduce unwanted electrical reflection

To input the modulator signal in the optical modulator we have two possible SMA connectors. Each one are associated to an individual electrode.

In order to optimize optical output wave-form it is necessary to adjust the Bias voltage. From our experimental analysis of the modulator it was possible to flnd out that the modulated optical output was minimum at 0.4 V and 4.5 V, this conflrms the last inspection sheet [19] about the driving voltage, table 4.2. The central value would be 2,45 V, this is the Bias voltage that we will set. Knowing this last value we can say that the NA peak-to-peak voltage can be half of the driving voltage, to ensure that it is working in a linear zone of the modulator. But we decided to use an even more strict gap, not $V_{ppNA} = 2{:}05V$ but $V_{ppNA} = 1V$Having these parameters set, it is just necessary to calculate the NA output power:

$$PNA = \frac{V_{rmsNA}^2}{R} \qquad (1)$$

Modulator Characteristics	Min		max
Driving voltage V... (V)	-	4.1	-
Insertion loss (dB)	-	5.5	-
Maximum input optical power (dBm)	-	10	-
Bias DC voltage (V)	-	2.45	-

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Network Analyzer

Network analyzers measure the reflection and transmission characteristics of devices and networks by applying a known swept signal and measuring the responses of the test device. The signal transmitted through the device or reflected from its input is compared with the incident signal generated by a swept RF source. The signals are applied to a receiver for measurement, signal processing, and display. A network analyzer system consists of a source, signal separation devices, a receiver, and a display.

The *HP* 8753*A* produces a sept RF signal in the range of 300 kHz to 3.0 GHz. A portion of the transmitted signal is routed to the R (reference) input of the receiver, and transmitted and reflected signals are applied to the A and/ot B inputs. The *HP* 85046*A* S-parameter test set contains the hardware required to make simultaneoustransmission and reflection measurements in both the forward and reverse directions. The reflectivity of the FBG corresponds to the forward gain of the NA. In figure 4.1 the block that is identified as the network analyzer in reality it is the combination of the *HP* 8753*A* and *HP* 85046*A*, being RF_{out} the Port 1, and RF_{in} the Port 2 of the *HP* 85046*A*.

S-parameters (scattering parameters) are a convention used to characterize the way a device modifies signal °ow. S-parameters are always a ratio of two complex (magnitude and phase) quantities, its notation uses the numbering convention where the first number refers to the port where the signal is emerging and the second number is the port where the signal is incident. For example, the S-parameter S21 identifies the measurement as the complex ratio of the signal emerging at Port 2 to the signal incident at Port 1, forward direction.

a 1 S21 b_2

S_{11} S22

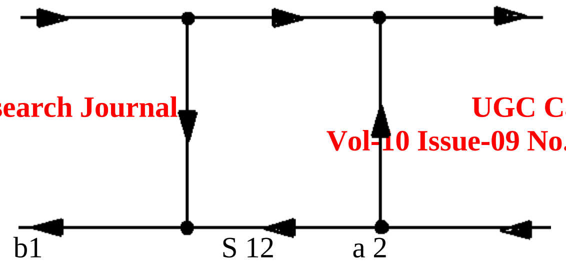


Figure 3: *S-parameters of a two-port device.*

In the table 2 it is possible to consult all possible minimum values for the sweep time. When preset is done, in the Network Analyzer, the default value for the IF Bandwidth is 3000 Hz, and the developed software does not allow modifications. This means that the only values of the minimum sweep time we must take into consideration are the ones associated to the IF of 3000 Hz.
This instrument has limited resolution for the phase measurement, being its mini-mum phase resolution $0{:}1^{o}$. In the table 6.4 it is possible to see the time resolution of the phase method, for all different modulation frequencies given.

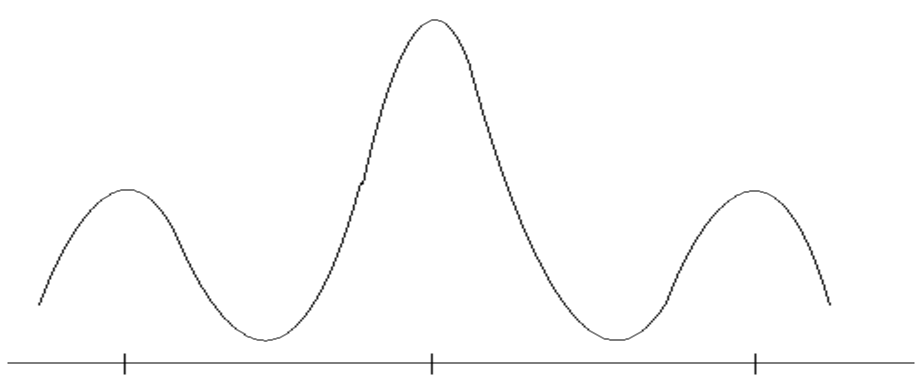
Number	IF Bandwidth			
of Points	3000 Hz	1000 Hz	300 Hz	10 Hz
11	0.0055	0.012	0.036	1.14
51	0.0255	0.06	0.166	5.3
101	0.0505	0.12	0.328	10.5
201	0.1005	0.239	0.653	20.9
401	0.2005	0.476	1.303	41.7
801	0.4005	0.951	2.603	83.3

Table 2: *Network Analyzer minimum sweep time [9].*

Modulation Frequency (MHz)	Group delay resolution for 0.1^o (ps)
100	2.78
250	1.11
500	0.56
1000	0.28
1500	0.19

Table 3: *Group delay resolution.*

As it is possible to see, the increase of the modulation frequency improves the delay resolution. But this increase of the frequency has a con: it makes the optical signal spectrum larger. This enlargement of the optical signal is due to the modulator characteristics. Normal modulators output signal has the carrier, and two sidebands. The spectral resolution is given directly by the width of the signal, the distance between the two sidebands, as it is possible to imagine based on figure 4
For 1GHz modulation frequency (¢ ”), and the laser set to 1550 nm, the spectral resolution on this optical system is given by 2 £ ¢, = 16*pm*.
Thus, we have lower spectral resolution for higher frequencies.
So, it is clear that the group delay resolution resolution is improved with the increase of the modulation frequency, but in the other hand, the increase in frequency will increase the spectral width of the optical signal, decreasing spectral resolution.
Therefore it is necessary to settle a frequency considering a compromise between this two factors.
A good value is 1 GHz, allowing a group delay resolution of 0.28 ps and a spectral resolution of 16 pm.



fc-
fm
F
c
fc+fm

Figure 4: *Modulated signal.*

System Control

In this section we will briefly explain the control of the whole setup. But first we will emphasize the function of each individual machine in the process of characterizing an FBG.

The laser source has an important function in the setup. His beam is modulated and travels all the setup including the device under test (DUT), sufiering the

dispersiveeffect and attenuation that we wish to characterize. Since we want to characterize the DUT under a wide wavelength bandwidth, this laser source must be variable, that is the reason we used the New Focus model 6427. With this laser it is possible to have a wavelength resolution of 1 pm, which is a generous step size for characterize a FBG. It is possible to remotely control the laser source by two different ways. One possibility is to define the start and stop wavelength and the step size. With this option, as the measurement is running we send the command to increase one more step to the actual wavelength. The other possibility is, for each step of measurement, we send acommand defining the following wavelength. We choose to control the laser by this last process, mainly because with this way we have full control of the laser wavelength. Case something unexpected changed the laser wavelength, for instance if we are controlling the laser remotely and the user changes it manually, the step control wouldn't be any useful. For this important reason we choose to set individually all wavelength.

After the laser, it is plugged the polarization controller, his function is to maximize the modulated signal. It was also told that it can be replaced by a PM fiber. Even so, we will explain how to work with it. In order to operate the polarization controller it is necessary with the NA to read the output after the modulator. So that we can see if, when we change the paddle, there is any change of the modulated signal.

In order to measure the relative propagation delay we will use the most standardized method, the phase-shift method. This method has a great advantage for improving resolution. It is possible to increase group delay resolution while decreasing spectral resolution, or the other way around, just by adjusting the modulating frequency.

The brain of this setup, besides the computer with our software, is the NA. This machine control is critical. Our goal is to reach the best performance possible with the most reliable data

Number of points	Data °ow timings (seconds)
101	0
201	1

401	3
801	8
1601	15

Table 4: *Time for the data °ow from NA to PC.*

SOFTWARE IMPLEMENTATION

Optisystem Software

OptiSystem is a comprehensive software design suite that enables users to plan, test, and simulate optical links in the transmission layer of modern optical networks. It is a system level simulator based on the realistic modeling of fiber-optic communication systems. A comprehensive Graphical User Interface (GUI) controls the optical component layout and netlist, component models, and presentation graphics OptiSystem allows for the design automation of virtually any type of optical link in the physical layer, and the analysis of a broad spectrum of optical networks, from Long-Haul Networks, Metropolitan Area Networks (MANs) and Local Area Networks (LANs). OptiSystem includes an extensive library of sample optical design (.osd) files that can be used as templates for optical design projects or for learning and demonstration purposes. OptiSystem capabilities can be extended with the addition of user components, and can be seamlessly interact with a wide range of tools.

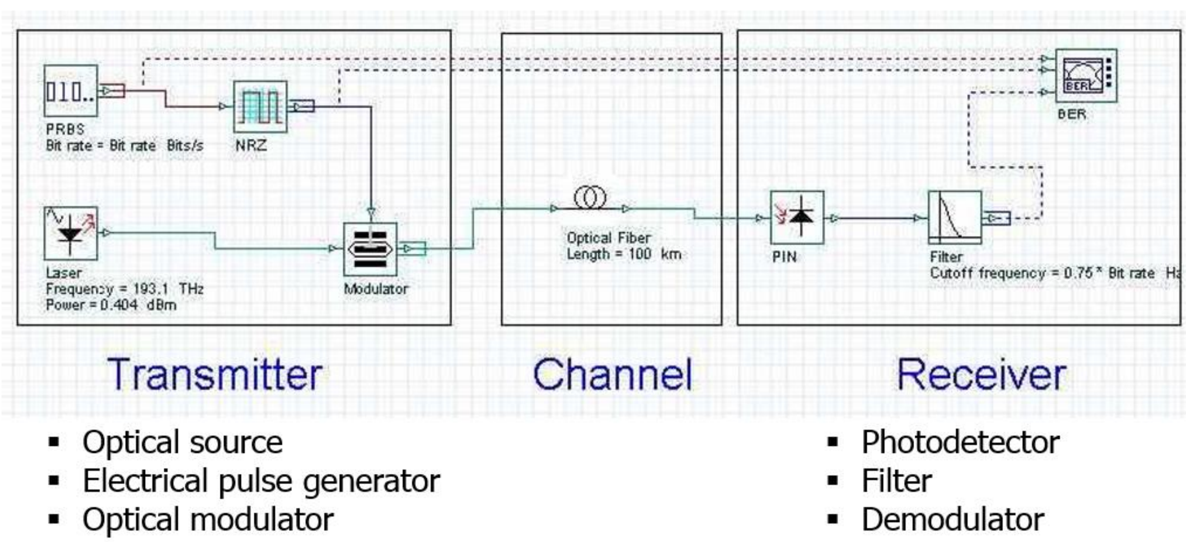
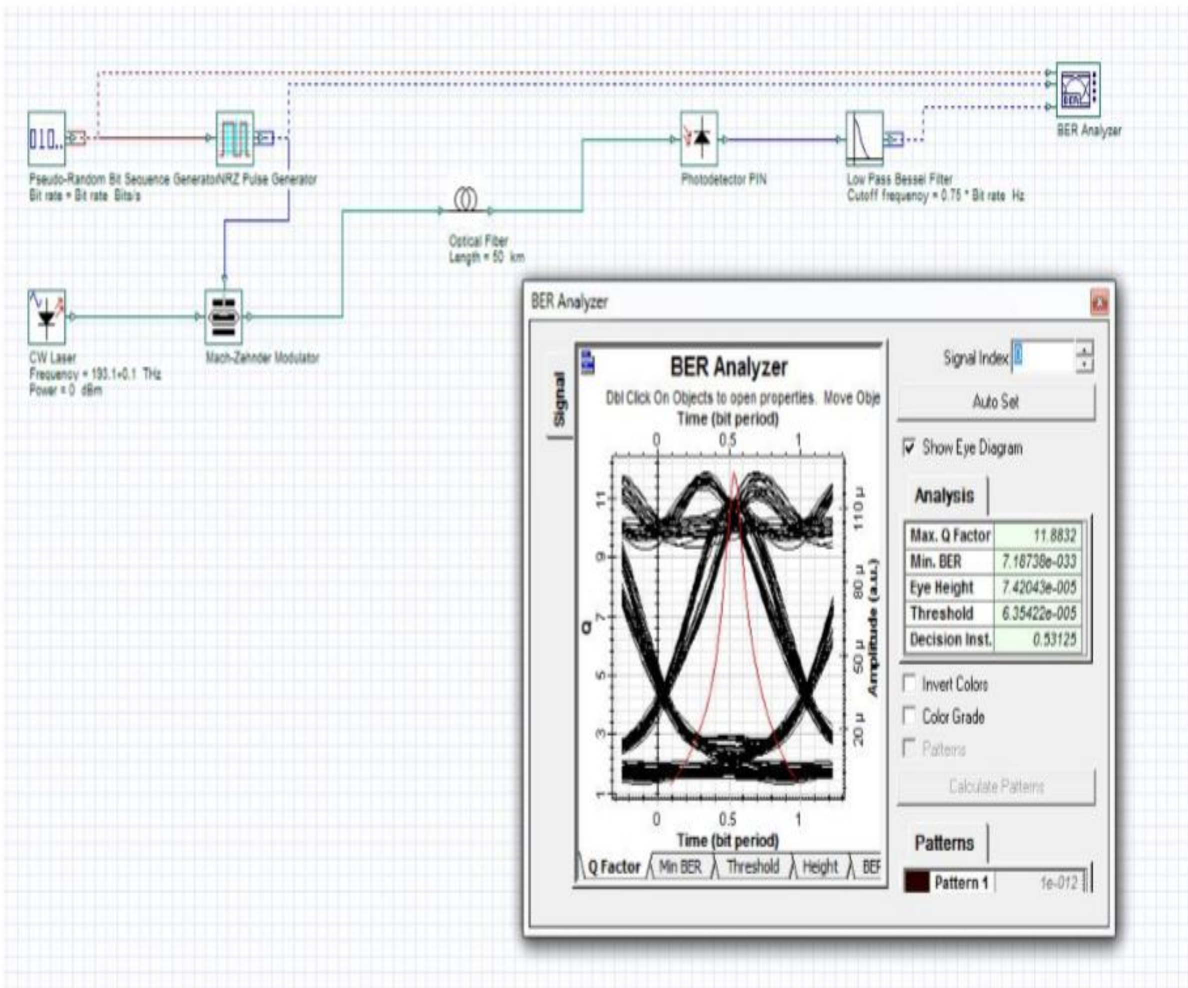


Fig 5: optical system components

Full Design



RESULTS AND DISCUSSIONS

It is important to say that all measurements were done using Optisystem 8 software. The process was quite interactive, with many changes in the system code. This procedure was adopted in order to improve the program efficiency and to improve its implementation. This process had a consequent, the first measurements were not very accurate.

Types of fiber optic cables

Multimode fiber and single-mode fiber are the two primary types of fiber optic cable. Single-mode fiber is used for longer distances due to the smaller diameter of the glass fiber core, which lessens the possibility for attenuation -- the reduction in signal strength. The smaller opening isolates the light into a single beam, which offers a more direct route and allows the signal to travel a longer distance. Single-mode fiber also has a considerably higher bandwidth than multimode fiber. The light source used for single-mode fiber is typically a laser. Single-mode fiber is usually more expensive since it requires precise calculations to produce the laser light in a smaller opening.

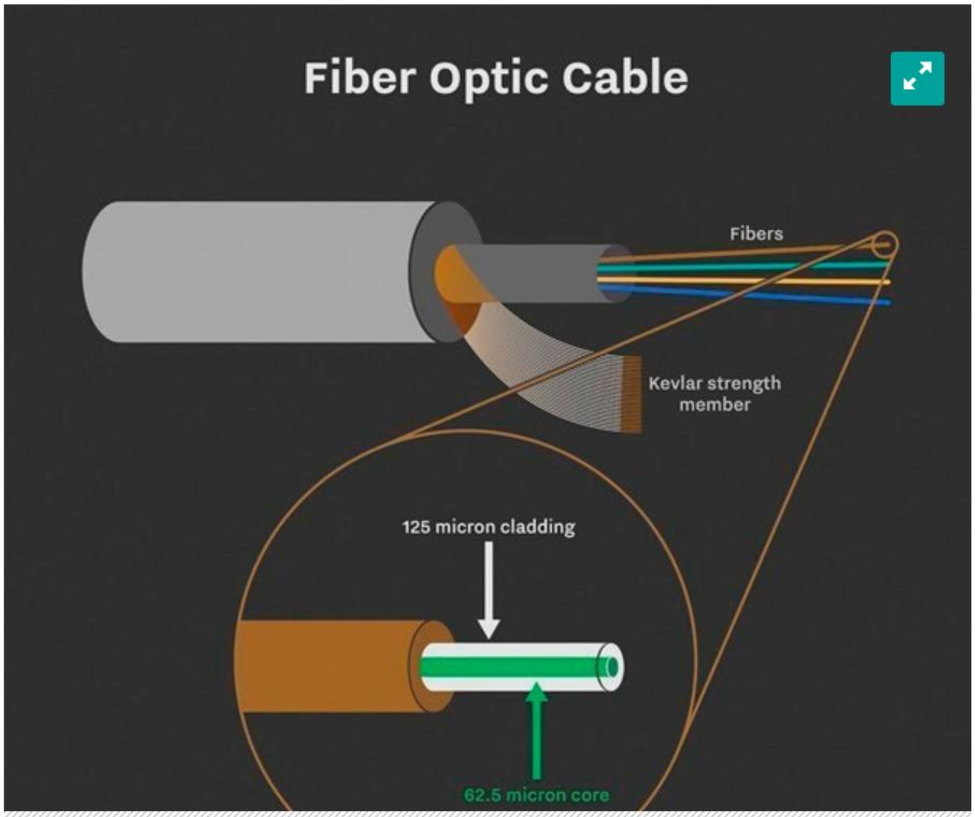


Fig 6: fiber optic cable

Multimode fiber is used for shorter distances because the larger core opening allows light signals to bounce and reflect more along the way. The larger diameter permits multiple light pulses to be sent through the cable at one time, which results in more data transmission. This also means that there is more possibility for signal loss, reduction or interference, however. Multimode fiber optics typically use an LED to create the light pulse.While copper wire cables were the traditional choice for telecommunication, networking and cable connections for years, fiber optics has become a common alternative. Most telephone company long-distance lines are now made of fiber optic cables.

Optical fiber carries more information than conventional copper wire, due to its higher bandwidth and faster speeds. Because glass does not conduct electricity, fiber optics is not subject to electromagnetic interference, and signal losses are minimized.

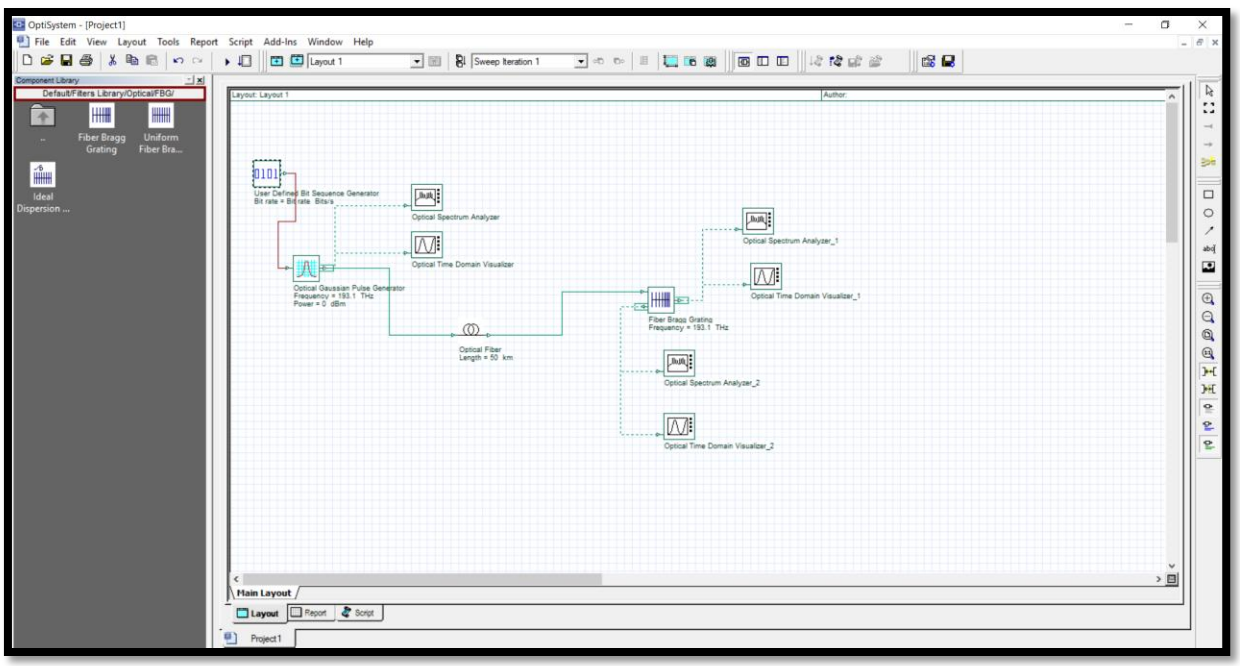
Visualizer

1. Optical Power Meter: An optical power meter (or laser powermeter) is an instrument for the measurement of the optical power (the delivered energy per unit time) in a light beam, for example a laser beam. Typically, it allows for power measurements only with a relatively low bandwidth, and will e.g. display only the average power when receiving a pulse train with a high pulse repetition rate, e.g. from a Q-switched or mode-locked laser. For measuring pulse energies, there are other instruments, called optical energy meters.

Most power meters are suitable only for light beams with a quite limited beam radius, not e.g. for diffuse light, but there are e.g. special sensor heads with an integrating sphere, which can accept and precisely measure even highly divergent input beams, for example from light emitting diodes. Normally, an optical power meter comes with a sensor head (see Figure 1) containing the power sensor, which is typically mounted with a post for receiving a horizontal input light beam in a certain height above the optical table.

A sensor head may be equipped with additional optical attenuators for extending the measurement range; these are particularly offered for photodiode-based devices.
The sensor head may be connected to a stand-alone display instrument, containing an analog or digital display for the laser power. Frequently, it allows the user to choose between different power ranges, and possibly to do other settings, for example concerning the speed of response (slow or fast mode) or the laser wavelength. Devices for telecom applications may also display powers in dBm, meaning decibels relative to 1 mW. Some instruments have an analog electrical output, delivering a voltage signal which is proportional to the received light power, and/or a digital interface (e.g. USB, GPIB, RS-232, WLAN or Bluetooth) for connection to a computer.
Display instruments can often be combined with different sensor heads – even with sensor heads of different type, e.g. pyroelectric and photodiode-based types. Some instruments can also work as optical energy meters.
There are also “meterless” sensor heads, which can be directly connected to a computer, typically with a USB interface. They contain only little electronics, in particular an analog-to-digital converter in addition to the digital interface, and those electronics may be integrated either into the sensor head itself or into a compact device at the USB connector or somewhere along the cable. One uses a software coming with the device for displaying values, changing measurement ranges, possibly also for data logging and similar purposes, going beyond the functionality of a typical stand-alone power meter. Such devices save the cost for an extra display and may also be quite convenient, for example for an engineer traveling with a notebook and only a minimum of extra instruments to carry. Also, such power sensors may be connected to more complex systems, for example to laser marking machines.

Optical Spectrum Analyzer
An Optical Spectrum Analyzer (or OSA) is a precision instrument designed to measure and display the distribution of power of an optical source over aspecified wavelength span. An OSA trace displays power in the vertical scale and the wavelength in the horizontal scale.



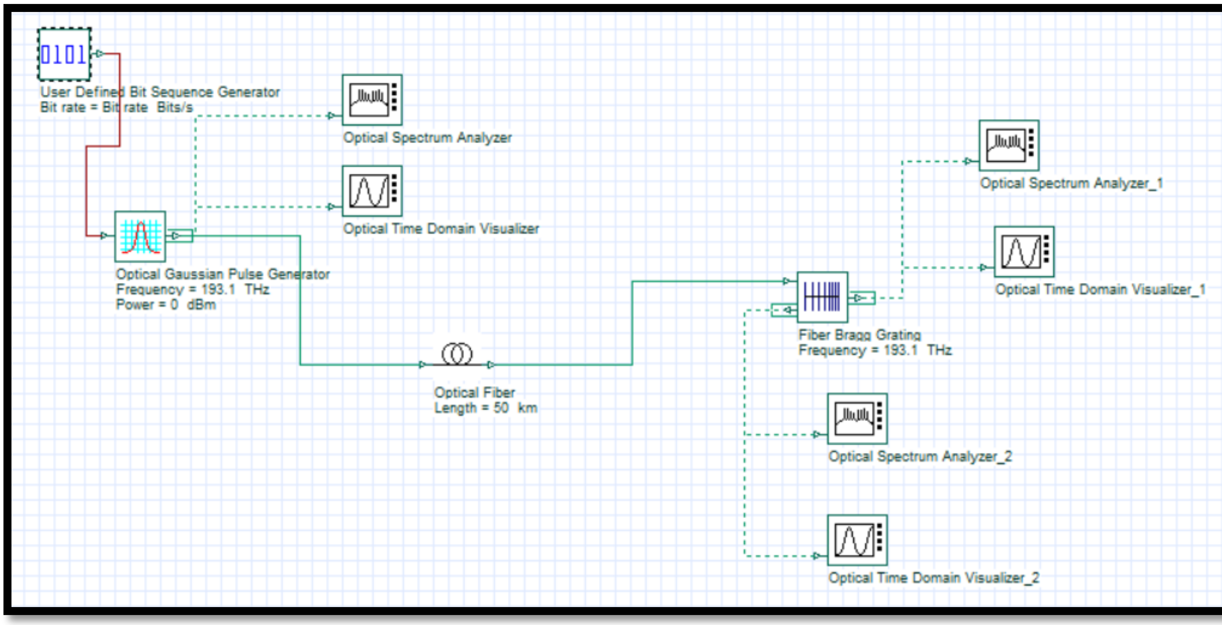


Figure 7: Project Layout for dispersion compensation with Fiber Bragg grating component in OptiSystem

Because of this different velocity of propagation of different spectral components, the pulse spreads. If we create fiber grating with period linearly reducing along the grating, because the higher frequencies will reflect after longer propagation in the grating a time delay between lower and higher frequency components will appear which is just opposite to this created in the SMF.

Therefore propagating and reflecting our pulse in this device will allow to compensate the dispersion broadening of our pulse.

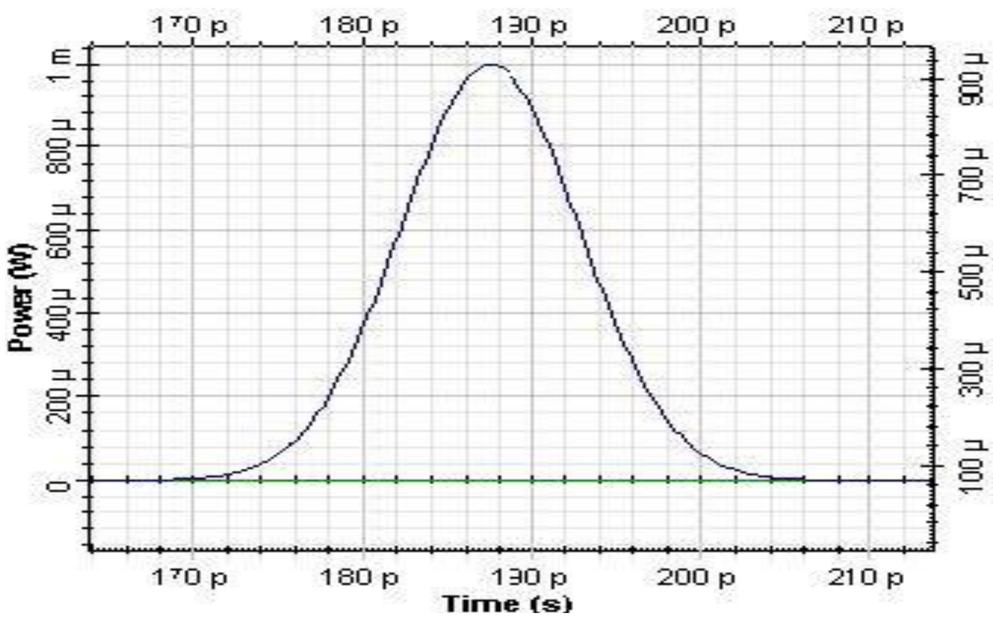


Figure 8: Initial Gaussian pulse

The pulse was launched in 10 km SMF. As a result of this propagation, the width of the pulse increases approximately four times.

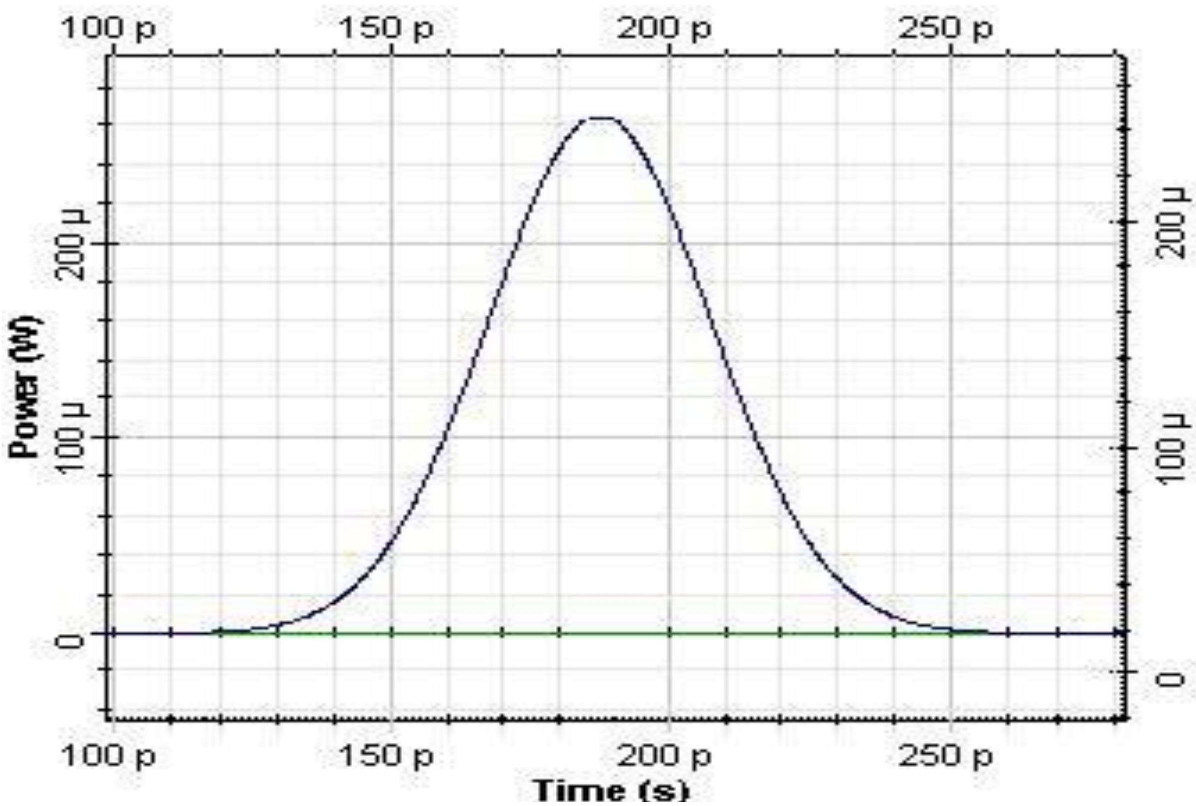


Figure 9: Gaussian pulse after 10 km propagation in SMF

Fiber Bragg Grating with following properties has been used: frequency 193.1 THz, effective index =1.45, length = 6 mm, apodization uniform, index of modulation 0.0001, linear chirp with a linear parameter 0.0001, number of segments 101 and maximum number of spectral points 1000.

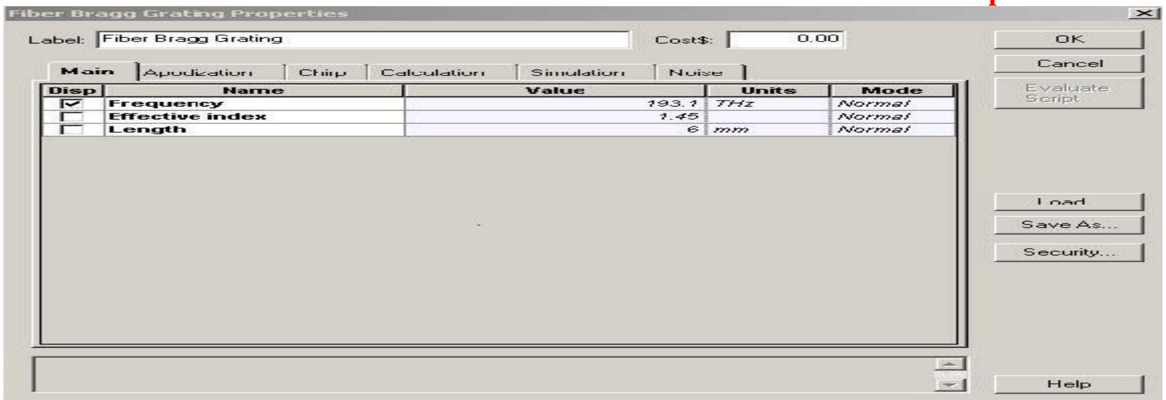


Figure 10: Parameters of uniform, apodized, linear chirped Fiber Bragg Grating

The result of dispersion compensation performed from this fiber grating component is obtaining of a pulse with approximately 20 ps width.

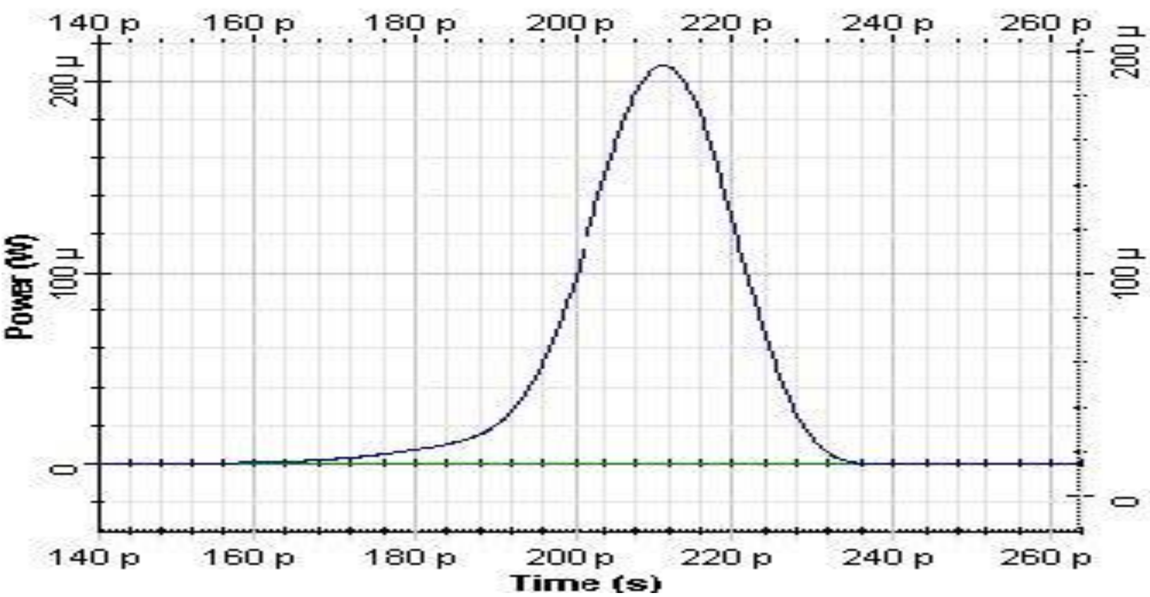


Figure 11: Pulse after dispersion compensation with fiber grating with uniform apodization and linear chirp.

Conclusion And Future Scope

This paper demonstrate a very important concept. If a FBG can be easily characterized in order to its rectivity and transmissivity with a white light source, a circulator and a Optical Spectrum Analyzer, the group delay cannot be measured this way. For the group delay there is the phase-shift setup, and, with our system, the measurement of the group delay is automated. Besides that, we believe that this method has greater accuracy in the calculus of the rectivity and transmissivity, because there is no risk of losing linearity due the white light source. Also, the method used by the setup that we developed is useful not only to characterize the group delay of FBG, but as well as the group delay of others optical devices.

Working in this project, i acquired greater sensibility in matters as optical transmission in single-mode fibers, in the subject of attenuation and dispersion, and methods to compensate these problems. More precisely, the use of chirped FBG for dispersion compensation, allowed to further understand this method and all effects produced, and above all, the importance of the characterization of these devices.
With my system accomplishing most of requested tasks, it was possible, in early stages of development, to test it with other projects in development. This interaction allowed us to be more sensitive to the actual/future user requests to further improve our system for an higher satisfaction level. It also allowed us to invest all knowledge already acquired in the process of development of this project.
As this setup allows modification of several parameters that condition the measurement, it gives to user full control of the method application. With a user-
friendly interface user may define wavelength range, frequency of modulation, number of samples, sweep time and laser source power. These parameters directly influences measurement accuracy, processing time, spectral resolution and group delay resolution.
Finishing a project like this, after five months of work, there is always space to implement other features in order to improve the characterization setup in future work. This project may grow and, for example, a web interface may be developed. Labview language supports this feature. This portal may be hosted in an already existing web server owned by INESC. Measurements may be effectuated remotely. The setup may be calibrated locally, but all measurements which not need new calibration may be ordered remotely. Allowing a file upload, several measurements may be ordered at the same time, and the software may coordinate all measurements and send results to an also specified e-mail address, for example. This new feature should be welcomed by INESC but also by foreign researches.
This web interface may be a new impulse to future work that will complement the project here described. Like this idea, others related to this subject should be useful in order to make this setup even more robust and functional.

Future Work

- In future, different modulation formats can be used to enhance the effect of dispersion in the optical fiber system.
- We can use highly efficient amplifiers to strengthen the signal while transmitting through optical fiber cables.
- Material chosen should have optimum refractive index to support efficient transmission with minimum loss.

REFRENCES

[1] Agilent Technologies, Inc., *10 Hints for Making Better Network Analyzer Mea-surements,* 2001
[2] Agilent Technologies, Inc., *Agilent 11896A Polarization Controller - OperatingManual*
[3] Anderson, D., *Living with Dispersion in Fiber Optic Systems*, http://www.commsdesign.com/csdmag/sections/feature article/showArticle.jhtml ?articleID=16503594, 01 November 2001.
[4] Asano, R., *Generated Learning Software: MultiMediaModule Optical Waveguide*, http://it.tud.uni-essen.de, December 2002.
[5] Department of Physics and Astronomy (Georgia State University), *HyperPhysics:Dispersion*, http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/dispersion.html,2003.

[6] [6] Force, Incorporated, *The Effects of Dispersion on High-speed Fiber Optic Data Transmission: Fiber Bandwidth isn't Infinite*, http://www.fiberoptics.info/articles/dispersion.htm, 2004.
[7] Giozza, W. et al. *Fibras Opticas: Tecnologias e Projectos de Sistemas*, McGraw-Hill, 1991.
[8] Gowar, J., *Optical Communication Systems*, 2^{nd} ed., Prentice Hall, 1993.
[9] Hewlett Packard, *HP 8753A Network Analyzer - Operating and Programming Ref-erence*
[10] K.D. M˜uller-Glaser, "Systems and Software Engineering" *http://www-itiv.etec.uni-karlsruhe.de/opencms/opencms/en/study/lectures/sse/index.html*,Universit˜at Karlsruh .
[11] Keiser, G., *Optical Fiber Communications*, 3^{rd} ed., McGraw-Hill, 2000.
Lauzon, J. et al.,"Implementation and Characterization of fiber Bragg gratings linearly chirped by a temperature gradient" *Optics Letters, Vol. 19, No. 23,* De-cember 1994McAdams, L., *IP over DWDM*, http://www.nanog.org/mtg-9905/ppt/mcadams/, 20 May 1999.
[12]New Focus, Inc., *6427 Vidia-Discrete laser - Operating Manual*
Mendes, S. et al., *Web based FBG Reflection Spectrum and Dispersion Measure-ment*VER DATA E A CONFERENCIA
[13] P.S.Andre, "Componentes Optoelectronicos para Redes Fotonicas de Alto Debito", University of Aveiro, Ph.D. Thesis, 2002
[14] Ribeiro, J., *Comunica»c~oes Opticas*, Editora Erica, 2003.
[15] Senior, J. M. *Optical Fiber Communications: Principlis and Practice*, 2^{nd} ed., Prentice Hall, 1992.
[16] Sumitomo Osaka Cement Co., LTD *LiNbO3 Optical Modulators - Inspection PassSheet*, December 2001
[17] Sumitomo Osaka Cement Co., LTD *LiNbO3 Optical Modulators - Operating Man-ual*, PSNTDE01-02, 2000
[18] Volanthen, M. et al.,"Low coherence technique to characterise reflectivity and time delays as a function of wavelength within a long fiber grating" *Electronics Letters,Vol. 32, No. 8,* 11th April 1996
[19] Williams, J.A.R. et al.,"Fiber Bragg Grating Fabrication for Dispersion Compen-sation" *IEEE Photonics Technology Letters, Vol. 8, No. 9,* september 1996
[20] METER MANUAL DO

