CROSSTALK SUPPRESSION TECHNIQUES FOR MULTI-CHANNEL REGENERATION BASED ON FIBER OPTIC PARAMETRIC AMPLIFIER

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ABSTRACT

Optical transmission system is the best choice to transmit high capacity information over long distances. The progressive development in optical transmission technologies allows the growth of transmission speed and capacity.2R or 3R regeneration can refine the degraded signal and improve transmission performance. 2R stands for reamplifying and reshaping the signal, and 3R adds retiming of the signal. Conventionally, electrical repeaters are used for the regenerations. In this regeneration system, the signal is converted from optical to electrical, regenerated electrically and finally converted back to an optical. Besides the electrical repeater, all optical regenerator is an alternative to regenerate optical signal without the need of optical electrical optical signal conversions. All optical signal regeneration has been recognized as a potential enabler of future transparent long haul high bit rate systems. All optical regeneration is easily applicable to various modulations formats signals and can work ultrafast. Since fiber based all optical regeneration was introduced two decades ago, many excellent techniques to regenerate signals have been proposed was introduced in order to reduce nonlinear effect within the channel, two techniques approaches being polarization interleaving and polarization multiplexing. The purpose of the signal regeneration is therefore to remove these distortions and to restore the characteristics of the optical signal to a suitable level so that a high overall transmission quality is maintained. As a result, the improvement of Q factor of each regenerated channel can be more improved for each techniques. In this result, a WDM system with polarization based system is analyzed in order to mitigate the nonlinear effects within the fiber channel. Hence, the performance can be further improved by using concept of polarization modulation in the transmitter section WDM system.

ABSTRAK

Sistem penghantaran optik merupakan sistem yang terbaik untuk menghantar data kapasiti yang tinggi bagi jarak jauh.Pembangunan yang progresif dalam sistem penghantaran optik membolehkan kelajuan penghantaran dan kapasiti. 2R atau 3R merupakan pertumbuhan semula bagi menapis isyarat yang disorot dan meningkatkan prestasi penghantaran.2R bermaksud menguatkan dan membentuk semula isyarat dan 3R penambahan pengaturan masa. Lazimnya, elektrik adalah digunakan untuk penjanaan semula isyarat. Dalam sistem penjanaan semula, isyarat akan ditukarkan dari optik ke elektrik, elektrik akan dijana semula dan akhirnya ditukarkan kembali kepada optik. Selain pengulangan elektrik, semua penjana optik merupakan alternatif untuk menjana semula isyarat optik tanpa memerlukan penukaran isyarat elektrik optik. Semua penjana optik telah dikenali sebagai pemboleh potensi jarak jauh untuk sistem kadar bit yang tinggi bagi masa hadapan. Semua penjana optik adalah mudah diguna pakai untuk pelbagai isyarat format modulasi dan ia boleh beroperasi dengan kelajuan tinggi.Semenjak semua penjana optik diperkenalkan dua dekad yang lalu, pelbagai teknik di perkenalkan untuk menjana semula isyarat bagi mengurangkan kesan tidak linear dalam saluran, terdapat dua teknik yang digunakan bagi mengurangkan kesan tidak linear iaitu pengutuban sisipan saluran dan pengutuban banyak unsur saluran..Oleh itu tujuan penjanaan semula isyarat ini adalah untuk menghapuskan herotan dan mengembalikan ciri-ciri isyarat optik ke tahap yang sesuai supaya keseluruhan kualiti penghantaran yang tinggi dapat dikekalkan. Kesannya peningkatan faktor kualiti bagi setiap saluran menjadi lebih baik untuk setiap teknik. Didalam keputusan ini , sistem WDM menggunakan pengutuban dianalisi bagi mengurangkan kesan tidak linear dalam saluran.Oleh itu prestasi boleh dipertingkatkan lagi dengan menggunakan konsep pengutuban modulasi dalam sistem WDM dibahagian pemancar.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

CD	Chromatic dispersion
CW	Continuous wave
DMUX	De-multiplexer
DPSK	Differential phase shift keying
DSF	Dispersion shifted fiber
DWDM	Dense wavelength division multiplexed
EDFA	Erbium-doped fiber amplifier
FOPA	Fiber optical parametric amplifier
FRA	Fiber Raman amplifier
FWM	Four-wave mixing
HNLF	Highly Nonlinear Fiber
NRZ	Non Return Zero
PMD	Polarization mode dispersion
PRBS	Pseudo random binary sequence
SMF	Single Mode Fiber
SOP	State of Polarization
SPM	Self Phase Modulation
WDM	Wavelength Division Multiplexing
XPM	Cross Phase Modulation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

This project focuses on the investigation of crosstalk suppression techniques for multi-channel regeneration based on fibre optic parametric amplifier (FOPA). In this study we imply three crosstalk suppression methods including polarization multiplexing, interleaving and bidirectional transmission based dual-wavelength regeneration system. All optical regeneration, especially re-amplifying, reshaping and retiming is capable of improving the quality of degraded signals, resulting from fibre loss, dispersion, nonlinearity and amplified spontaneous emission (ASE) noise. The reshaping function can be realized using nonlinear effects, such as self-phase modulation (SPM) [1-3], cross phase modulation (XPM) [4], cross gain modulation (XGM) [5], four wave mixing (FWM) [6], saturated absorption [7] and nonlinear interferometer [8]. In wavelength-division-multiplexing (WDM) systems, multi channel regenerators are desired, instead of a regenerator per channel, to reduce cost [9]. However, the main issue is nonlinear the inter-channel crosstalk. In SPM-based 2R regeneration, polarization multiplexing [10], bidirectional transmission [11] and dispersion management [12] have been used to suppress the inter-channel crosstalk. By using polarization multiplexing and bidirectional transmission, four wavelength 3R regeneration based on a fibre optical parametric amplifier (FOPA) configuration will be demonstrated [13]. Furthermore the FWM-based dual-wavelength regeneration was also realized by using the time-interleaving technique [14,15]. In fact, compared with the SPM-based regeneration, the FWM-based regeneration has some unique advantages in wavelength conversion and 3R regeneration. FWM based regenerations can be classified as data-pump and high order cases [16-20], and the corresponding idler or high-order FWM products are regarded as the regenerated signals. Both schemes can improve the extinction radio (ER), when the input power is low and further suppress the amplitude fluctuations when the input power is high.

1.2 Problem Statement

Optical transmission system is the best choice to transmit high capacity information over long distance. The rapid progress of optical communication to full high data rates demands has been made possible by wavelength division multiplexing (WDM) technology. In WDM system, a number of channels at different wavelengths are simultaneously transmitted through one fibre. However, most of all optical regenerators studied only concern single channel operation. Thus, for the use in WDM systems, the number of regenerators required is proportional to the number of channel. For the multi-channel regeneration, interchannel nonlinear crosstalks in the nonlinear medium have to be avoided while efficient nonlinear effect is needed in the regeneration process. The nonlinear properties can be obtained by injecting sufficiently high light intensities material, such as fibre, semiconductor and silicon. Various types of nonlinear effects can, be used for fibre based signal regeneration such as FWM. High local dispersion can suppress interchannel FWM. In response to this situation, this proposed investigation of crosstalk suppression technique.

1.3 Aim

The investigation and implementation of crosstalk suppression technique for multichannel regeneration based on FOPA is the aims of this research study in order to improve performance between signal channels.

1.4 Objectives

- To design system polarization interleaving channels
- To design system polarization multiplexing channels
- To design system without polarization

- Evaluate the each performances of the crosstalk techniques by considering the following eye diagrams and optical spectra

1.5 Scope Of Project

The scopes of this project study is to investigate the performance of polarization interleaving and polarization multiplexing of crosstalk suppression technique for multichannel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This part describes the theoretical background of crosstalk suppression technique for multichannel based on FOPA and the observation by reviewing the previous project that related to this project study.

2.2 Fiber Optic Communication

Fiber optic communication system is just like every other communication system. An optical communication system is shown in Figure 2.1. The main parts of system are transmitter consisting of light source, a cable as a medium for protection from environmental effects and a receiver consisting of photo detector, amplifiers, regenerator.

The information source could be any physical quantity like sound, video, dat. This information is sent to electrical transmitter. Transmitter is usually a transducer, which converts a message signal into electrical signal. Usually we convert this electrical signal into digital form using ADC, because in fiber optics we are dealing with light and difficult to deal with analogue communication. Digital signal is sent through the fiber because it’s easy to deal with digital signal.

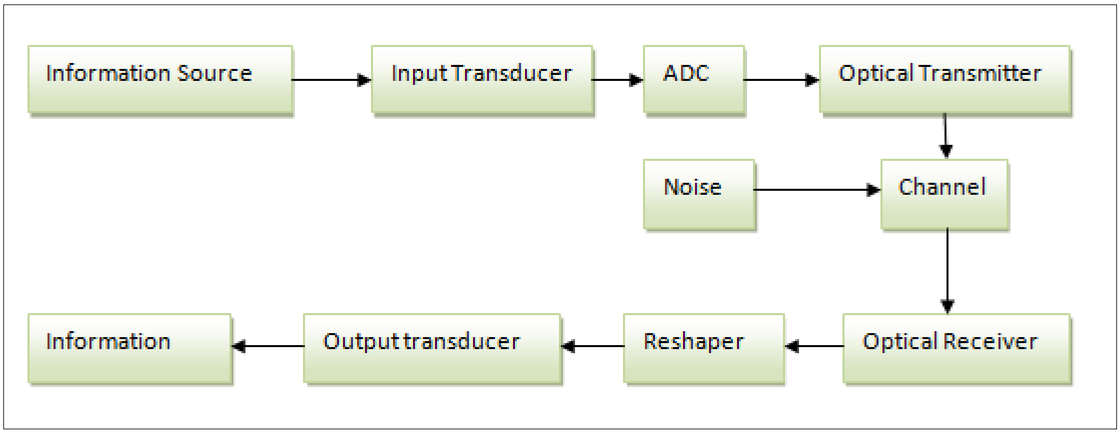

Figure 2.1: Optical Communication System

The Shannon-Hartley theorem states that, regardless of specific technology, the information carrying capacity is proportional to channel bandwidth, the range of frequencies within which the signals can be transmitted without substantial attenuation or mathematically:

$$C = W.\log_2(1 + \frac{S}{N}) \tag{2.1}$$

Where W is the bandwidth of a signal being transmitted over a noisy communications channel, S/N is the signal to noise ratio and C is the channel capacity, measured in bits per second. It is the frequency of the signal carrier that limits the channel bandwidth. The higher the carrier's frequency, the greater the channel bandwidth and the higher the information carrying capacity of the system. A copper wire can carry 1 MHz signal. A coax can carry a 100 MHz signal. A fiber optic transmission link can carry a 1000THz signal. Now, if bandwidth is say 10 % of the carrier, the bandwidth increases appreciatorily by from cooper to fiber optics. Consider these transmission media in terms of their capacity to carry, simultaneously, a specific number of one-way voice channels. A single coaxial cable can carry up to 13000 channels, a microwave terrestrial link up to 20000 channels and a satellite link up to 100000 channels. However, one ordinary fiber optic communication link, can carry 300000 two way voice channels simultaneously, which explain why fiber optic communication systems form the backbone of modern telecommunications and will most certainly shape its future. Table 2.0 summarizes the bandwidth relations:

Table 2.1: Summary of bandwidth and channels

	Carrier Frequency (Hz)	Bandwidth (Hz)	Channels
Copper wire	10^6	10^5	-
Coax	10^8	10^7	13000
Microwaves	10^{10}	10^9	20000
Fiber optic	10^{15}	10^{14}	300000

2.3 Basic Concepts of Optical Amplifiers

Optical amplifiers, which are the key enabling technology for WDM systems, can amplify multiple wavelength in the optical domain in the optical domain without requiring conversion to the electrical domain. Ever since EDFAs were successfully implemented as optical amplifiers, a lot of research has been done not only on the EDFA itself, but also on other types of optical amplifiers which use different material and working mechanisms.

2.4 Principle of Fibre Optic Parametric Amplifier (FOPA)

The fundamental principles of FOPAs have been known for more than twenty years, it is only recently that it has become possible to implement these in a practical way. The characteristics of FOPA are the high power, single-wavelength pump laser and a specifically tailored highly nonlinear, low dispersion optical fibre and FOPA is a new kind of amplifier which relies on the nonlinear process four-wave mixing. The parametric amplification occurs when FWM takes effect between a strong pump beam at ω_p and a weak signal beam ω_s propagating in a highly nonlinear fiber (HNLF). When the two beams are co-propagating in the fiber their frequencies are beating with each other due to Kerr effect. As a result the refractive index of the fiber is modulate with the frequency $\omega_p - \omega_s$. The modulated refractive index acts as a phase modulator for the pump beam and creates sidebands at $\omega_p - (\omega_p - \omega_s) = \omega_s$ and $\omega_p + (\omega_p - \omega_s) = \omega_{i.}$ Therefore the signal is amplified due to parametric gain, while a new wave, generally called idler, is generated simultaneously. FOPAs have important characteristics which make them have the potential to be used for a variety of applications. These properties are listed below:

- Large gain and bandwidth

  By using one or two pumps, FOPAs can provide relatively larger gain and bandwidth compared to EDFA .

- Arbitrary centre wavelength

  The centre wavelength , λ_c of the gain region in FOPAs can be any arbitrary wavelength. However it should be noted that the zero dispersion wavelength (ZDW) of the fiber should be close to λ_c.

- Wavelength conversion

  Besides amplifying the input signal, a new wavelength component is generated by the FOPA. This feature can be used for creating new wavelengths for wavelength routing in optical networks. The signal to idler conversion efficiency can be high as the signal gain, therefore leading to large conversion efficiencies which cannot be obtained with other conversion techniques. Dual pump FOPAs can produce multiple idlers at the same time.

- Spectral inversion

  In FOPAs the idler spectrum is symmetric to the signal spectrum with respect to the central frequency. This feature can be used for dispersion compensation in communication systems.

- Phase conjugation

  The idler's phase is opposite to that of the original signal. Some nonlinear effects such as cross phase modulation which affect the phase of the waves can be counteracted using this idler property.

- High speed optical signal processing

  The ultrafast nature of the nonlinear response of FOPAs is useful for many applications. Generally high speed modulation of the pump will result in modulation of the signal and idler which can be used for applications such as pulse generations, regeneration of signal pulses and all optical sampling.

- Low noise figure

  FOPAs can theoretically have a noise figure of 0 dB while operating in phase sensitive mode.

- Unidirectional gain

  Unlike EDFA, in FOPA only the signal waves which propagate the pump get amplified. Therefore, it doesn't provide gain for the reflections from the end of the amplifier.

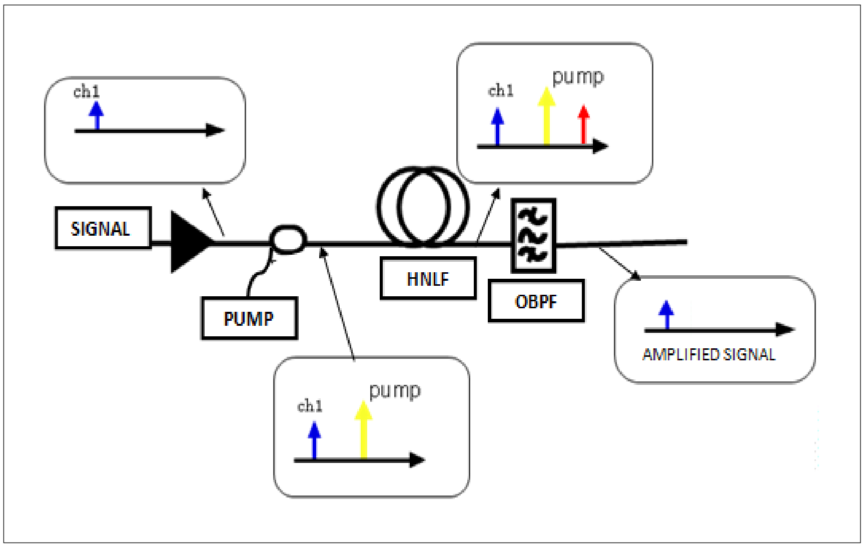

Figure 2.2 : Single pump FOPA configuration. HNLF: High Nonlinear Fiber; OBPF: Optical Band Pass filter

The FOPA is unique in many ways when comparing with other amplifiers, example having a gain spectrum almost entirely dictated by the dispersion properties of the fibre and the possibility of reaching a quantum limited noise figure of 0dB. It provides unidirectional and single-polarization amplification and can have high pump-to-signal conversion efficiency as well as very high gain [21].Since FOPAs react almost instantaneously, they have several potential applications besides amplification including wavelength conversion [22], tunable filter [23], tunable delays [24], tunable lasers [25], pulse generation [26] and signal regeneration [27].

2.5 Multi-Channel Regeneration

In multi channel system, a signal channel suffers from FWM, which generates various combinations of different channel frequencies and cause crosstalk degradation [28].The rapid progress of optical communication to full fill the high data rates demand has been made possible by wavelength division multiplexing (WDM) technology. In WDM system, a number of channels at different wavelengths are simultaneously transmitted through one fibre.

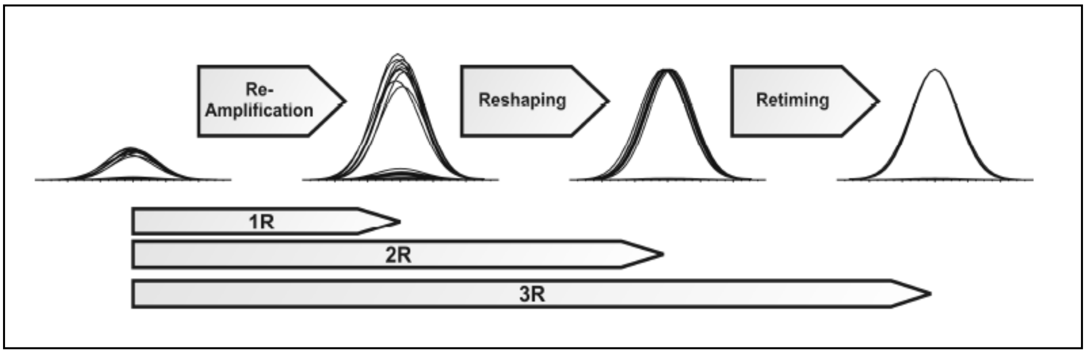

Figure 2.3 : Signal regenerator scheme illustrating the re-amplification, reshaping and retiming operations on a input signal. Note that the order of reshaping and retiming can be independently exchanged for 3R regeneration schemes.

For the multi-channel regeneration, interchannel nonlinear crosstalks in the nonlinear medium have to be avoided while efficient nonlinear effect is needed in the regeneration process. Some technique for fibre based multi-channel regeneration have been proposed. Most of the studies use dispersion management to suppress interchannel crosstalk [29]. High local dispersion can suppress interchannel FWM and XPM. In reference of [30], polarization orthogonalization between adjacent channels is used in addition to fibre dispersion management for suppression of the XPM effect. For references [31] applies the periodic group delay devices as the dispersion compensators to ensure fast bit walk off between different channels, and the suppress the interchannel XPM as well as FWM. Other study proposed bidirectional configuration to avoid interchannel crosstalk, but the number of channels is limited [32]. Interchannel crosstalk mitigation by properly time-interleaved channels is another method introduced in references [33]. Multi-channel regeneration is conceivable because their short gain response time in the order of 100 ps to 1 ps leads to negligible patterning effects and spatial isolation of quantum dots leads to spectrally localized effects.

Other than fiber nonlinearity, nonlinearity in semiconductor optical amplifiers (SOAs) is also available for all regeneration. However, only a few SOA based regeneration have been proposed for multi-channel regeneration because of high interchannel cross gain modulation (XGM) interaction [34]. Quantum dot SOAs have been studied to handle multiple WDM channels [35,36]. Multi-channel regeneration is conceivable because their short gain response time (in the order of 100ps to 1ps) leads to negligible patterning effects, and spatial isolation of quantum dots leads to spectrally localized effects. However, very little experimental demonstration has been reported to date in support of the encouraging numerical predictions as quantum dot devices with very low XGM have not been implemented yet. Interchannel crosstalk mitigation by time interleaving channels has also been proposed in SOA based regenerator.

2.6 Concept of Polarization

Polarization is a property of electromagnetic radiation describing the shape and the orientation of the electric field vector as a function of time, at a given point of the space.

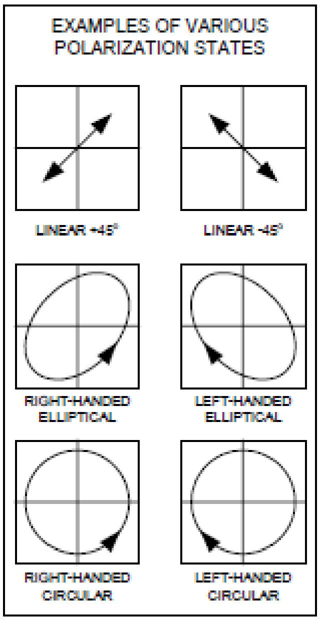

Figure 2.4: Example of different polarization states, which depend upon relative magnitude and phase between the two principle polarization

Optical communication has greatly influenced the communications environment towards the advanced information society. Innovations in optical fiber technology are enabling transmission of high-speed signals over transcontinental distances without the need for electronic regeneration. It has thus given thrust to networks with higher capacities and a lower costs. Wavelength Division Multiplexing (WDM) is one of the solutions to increase the capacity of the optical using fiber a different method from traditional Time Division Multiplexing (TDM). In order to utilize the maximum bandwidth, trend is towards DWDM systems with the more number of channels with less wavelength spacing and large transmission distances.

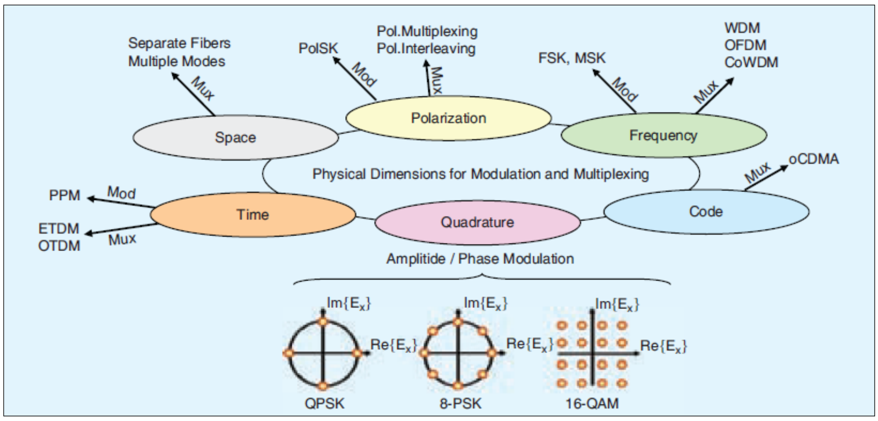

Figure 2.5 : Physical dimension for modulation and multiplexing

In WDM system, non-linear effects degrade the performance of the system, As the optical signal propagates through the fiber they undergo power fluctuations and crosstalk between the channels in WDM system. The dominant degradation effect of Cross Phase Modulation causes a nonlinear polarization dependent phase shift between the signal propagating through the same optical fiber. This leads to polarization rotations even in the absence of polarization mode dispersion. Due constant phase shift and polarization rotations produced by XPM additional spectral components are generated in the optical spectra leading to polarization scattering which depolarized the two polarization components and causes crosstalk between the X and Y polarization components.

In this paper is reduce the nonlinear impairment due to cross polarization by introducing the concept of polarization interleaving and polarization multiplexing into the WDM system. Sending signals in disjoint frequency bins on different optical carrier frequencies is called wavelength division multiplexing. Such signals are orthogonal and individual bit streams can be recovered using optical band pass filter or electronic filter following a coherent receiver front-end. If signals leak energy into neighbouring frequency bins, orthogonality is degraded and perfect reconstruction is no longer possible (WDM crosstalk). A possible counter-measure ,which has been used, is alternating the polarization of adjacent channels to re-establish orthogonality in the polarization dimension (polarization interleaving).The second approach being polarization division multiplexing in which one sends two independent signals on both orthogonal polarizations supported by a single mode optical fiber. In order to recover these polarization-multiplexed bit streams, either a polarization beam splitter whose axes are constantly kept aligned with signal polarization (polarization control) can be used, or the detection of two arbitrary orthogonal polarization (polarization diversity) using coherent detection can be employed.

2.7 Nonlinearities Fiber

The operation mechanism of all-optical signal regeneration relies on optical non-linearity. Optical fiber, which has low loss and high confinement, is a promising nonlinear medium. When pulsed light is confined in a relative small area over long interaction lengths in optical fibers, nonlinear effects can easily be observed. Typically optical fibers has nonlinear coefficient y-1/W/km , which is too small to be used as a nonlinear medium for signal processing. Since 1990, silica-based highly nonlinear fibers (HNLFs) have been developed . The value of HNLF, which is inversely proportional to fibers effective mode area A_{eff}, can be enhanced by reducing the core parameter and controlling the amount of dopants in the fiber. Nowdays HNLFs with y-20/W/km are available. Efforts toward producing and using fibers having much higher nonlinearity with different glass material and micro structured compositions. The nonlinearities in fibers are reviewed particularly regeneration based on FWM.

Optical nonlinearities arise from nonlinear response of dielectric to light. When an electric field is applied to a dielectric material, which contains negative and positive charges, it drives these charges and polarize atoms in the dielectric material. For intense electric field applied, a harmonic motion of the electrons is observable. For nonlinear phenomena that involve generation, such as FWM , phase matching has to be satisfied for them to occur. Most of nonlinear effects in optical fibers therefore originate from nonlinear refraction, a phenomenon referring to the intensity dependence of the refractive index (Kerr effect). For the intensity dependence of refractive index is responsible for important nonlinear effects discussed below:

2.8 Optical Kerr Effect

The optical Kerr effect or AC kerr effect is the case in which the electric field is due to the light itself. This cause a variation in index of refraction which is proportional to the local irradiance of the light. This refractive index variation is responsible for the nonlinear optical effects of self focusing and self phase modulation. This effect only becomes significant with very intense beams such as those from lasers. In fact, phase modulation due to intensity dependent refractive index various nonlinear effects, namely, self phase modulation (SPM), cross phase modulation (XPM) and four wave mixing (FWM).

2.8.1 Self Phase Modulation (SPM)

Phase modulation of an optical signal by itself is known as self phase modulation (SPM). SPM is primarily due to the self modulation of the pulses. Generally, SPM occurs in single-wavelength systems. However at high bit rates bit rates, SPM tends to cancel dispersion. However, consideration must be given to receiver saturation and to nonlinear effects such as SPM, which occurs with high signal levels. SPM results in phase shift and a nonlinear pulse spread. As the pulses spread, they tend to overlap and are no longer distinguishable by the receiver. The acceptable norm in system design to counter the SPM effect is to take into account a power penalty that can be assumed equal to the negative effect posed by XPM. By the SPM –impact new spectral components are generated in the optical signal spectrum resulting in a spectral broadening.

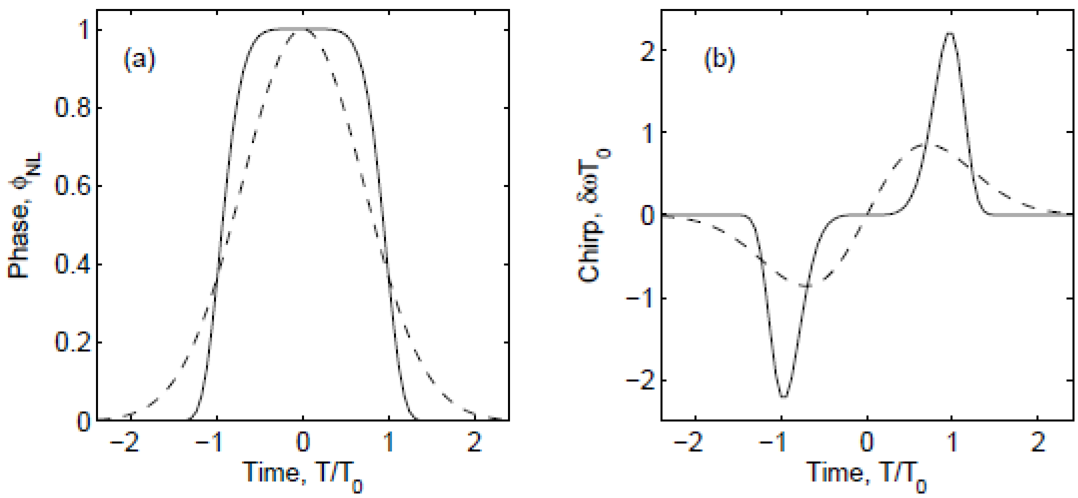

Figure 2.6 : Temporal variation of SPM induced (a) phase shift (b) frequency chirp for a Gaussian pulse.

The phase shift undergone by each temporal part of an optical pulse is different because the intensity is not constant during the pulse duration. The peak has maximum phase shift due to the highest intensity as shown in figure 2.6(a). Since the frequency is time derivative of the phase, the differential phase shift can change the frequency spectrum of optical pulse travelling along a fiber. Figure 2.6(b) show the time-dependent of SPM induced frequency chirp, where chirp occurs at two values of T. These two points represent two waves at the same frequency but different phases that can interfere constructively or destructively depending on their relative phase difference. If the pulse is initially unchirped or up-chirped (the lower and higher frequencies are in the leading and the trailing edges, respectively). SPM leads to spectral broadening .Whereas, spectral compression can result if the initial pulse is down chirped. SPM itself does not change the pulse shape in the time-domain, but affects it in operation with chromatic dispersion. In regions of normal dispersion, a lower frequency component in the pulse have a higher velocity than the latter, broadening the pulse shape in time. In regions of anomalous dispersion on the other hand, the opposite is true, and the pulse is temporally compressed and become shorter. This effect can be exploited to produce an ultra short pulse. When a pulse has appropriate intensity, the spectral broadening due to SPM can balance with the temporal compression due to anomalous dispersion, resulting in an equilibrium state. The resultant pulse is called an optical solution.

2.8.2 Cross Phase Modulation (XPM)

Cross phase modulation (XPM) is a nonlinear effect that limits system performance in wavelength division multiplexed (WDM) system. (XPM) is the phase modulation of a signal caused by an adjacent signal within the same fiber. XPM is related to the combination (dispersion/effective area). XPM results from the different carrier frequencies of independent channels, including the associated phase shifts on one another. The induced phase shift is due to the walkover effect, whereby two pulses at different bit rates or with different group velocity walk across each other. As a result the slower pulse sees the walkover and induces a phase shift. The total phase shift depends on the net power of all the channels and on the bit output of the channels. Maximum phase shift is produced when bits belonging to high powered adjacent channels walk across each other. However, when pulses in each channel travel at different group velocities due to dispersion, the pulse slide past each other (walk off) and the XPM effect is reduced. XPM effect is also reduced when the two waves are not identically polarized along the same axis.

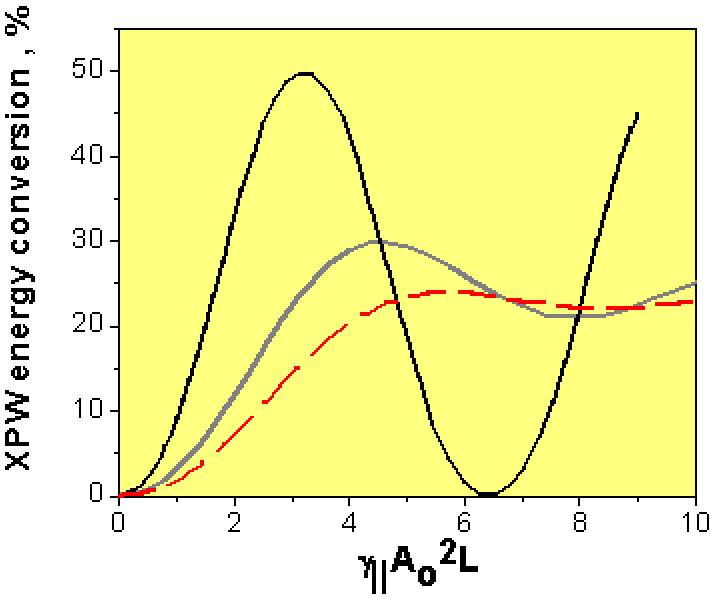

Figure 2.7 : Dependences of the efficiency of XPM generation for three different time and spatial profiles

2.8.3 Four Wave Mixing (FWM)

Another nonlinear effect that is relevant in optical fibers is FWM. FWM is parametric process occurs when lights at frequencies $f_{i,}f_j$ and f_k $(i, j \neq k)$ interact in the fiber, and generate a new light at frequency. FWM is the nonlinear effect in which two more wavelength are produced by the interaction of two different wavelength. Let λ_a, λ_b and λ_c be the three different wavelengths, which on combining together, produces nine other wavelength λabc, mathematically

$$\lambda_{abc} = \lambda_a \pm \lambda_b \pm \lambda_c \tag{2.2}$$

The worst combination wavelength resulting in degradation of WDM system is

$$\lambda_{abc} = \lambda_a - \lambda_b + \lambda_c \tag{2.3}$$

When λ_{abc} is known as crosstalk products. For instance, let $\lambda_1 = 1548nm,$ $\lambda_2 = 1549nm \; and \; \lambda_3 = 1550nm$ be the given optical wavelength, upon combining together, crosstalk signal wavelength is produced as $\lambda_4 = \lambda_1 + \lambda_2 - \lambda_3 = 1549nm.$ So, $\lambda_4$acts as noise in original spectrum λ_2. The same phenomenon has also been depicted in Figure 2.8

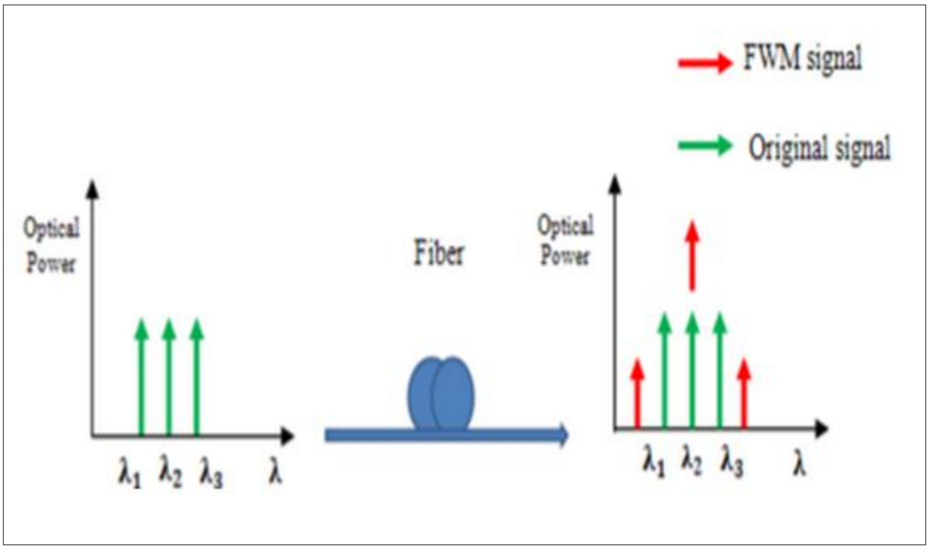

Figure 2.8 : Spectrum before and after fibre optic

To intuitively describe the FWM process, we consider the non- degenerate FWM, we consider the non-degenerate FWM ($i \neq j$) case shown in Figure 2.9

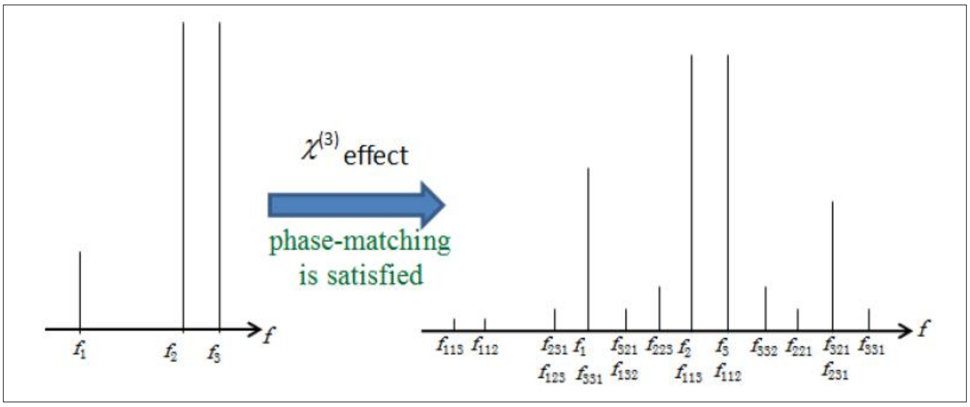

Figure 2.9 : Generation of new frequency component via FWM

The process start when two waves at frequencies f_1 and $f_2$copropagate together through a fiber. As they propagate, they continuously beat with each other. The intensity modulated beat note at frequency f_2 - f_1 modulates the intensity dependent refractive index n of the fiber. Then, a third wave at frequency f3 is phase-modulated with the frequency$f_2 - f_1$, due to the modulated n. As a result, the wave at f3 creates sidebands at frequencies $f_3 \pm (f_2 - f_1)$ The amplitude of the sidebands are proportional to the amplitude of the wave at f_3. In the same way, f_3 beats with f_1, and f_2 becomes phase modulated. Consequently, the wave at f_2 generates sidebands at $f_2 \pm (f_3 - f_1)$, where f_2+($f_3 - f_1$) coincides with f_3+($f_2 - f_1$)Nine new frequencies can be generated in the FWM process from three incident, as shown in figure 2.8. It also shows that some FWM products overlap with the signal frequency at f1, which turns to be cross phase modulation. The remaining weaker frequency component are usually neglected except a stronger one (idler), which is determined by phase-matching. In the degenerated case with one pump, f_2 and f_3 coincide and light energy is only transferred to the signal and idler frequencies.

2.9 Techniques to Reduce the effects of Crosstalk

Some well-known methods are using to reduce the FWM :

- Dispersion Management
- Polarization Allocation
- Unequal Chanel Spacing

Using all above method can reduce the crosstalk. In dispersion management will introduce dispersion in our system, this way FWM products suffer from more losses which reduces its power. Changing the polarization of input channels alternate to horizontal and vertical can also reduce FWM, method is known as polarization. By using unequal channel spacing we can reduce FWM, channel spacing between every two channels to be different then spacing between other channels. All the above methods require some major changing in optical system to reduce FWM. In this project will analysis by using concept of polarization.

Regarding from the some related work done by others, the theoretical work has proved that to suppress the crosstalk by using multi technique. There are several techniques that can be applied in order to suppressed the crosstalk and reduce the effects such as:

i. Multistage optical amplifier that are multi, demultiplexer and delay line.
ii. Polarization Interleaving
iii. Polarization Multiplexing
iv. Bidirectional transmission.
v. Wavelength regeneration

In this project study, the polarization interleaving and polarization multiplexing method will be used in order to reduce nonlinear effects within the channel. All this method is done by using Optisystem software.

2.10 Regeneration Scheme

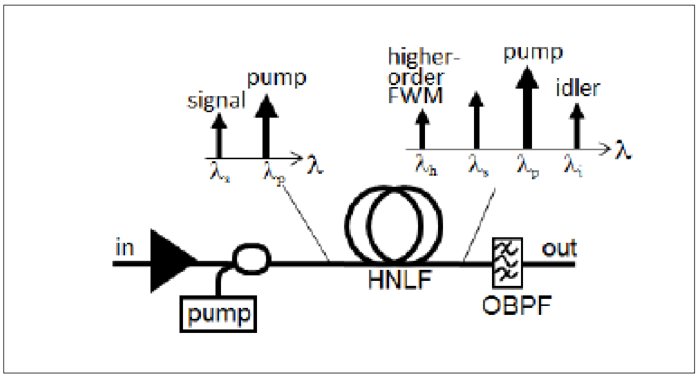

Figure 2.10: Regeneration based on fiber-optic parametric amplifier.

The regeneration uses the second-order FWM product generated at a frequency $f_s+f_p-f_i$ where f_s, f_p and f_i are the signal, pump and idler frequencies, respectively. The FWM product at this frequency is called second-order here because it appears only after the idler is generated from the pump and the signal through the fundamental parametric process of $p_i = 2f_p - f_s$. As phase matching is not satisfied for the second order FWM generation when input signal power is very small, space level noise is suppressed. In the higher-order parametric interaction, the light energy from the pump and the signal is transferred to the idler and the second order FWM product. The generated average power is proportional to $p_s p_p p_i$ where p_s, p_p and p_i are average input powers of the signal, pump, and idler respectively.

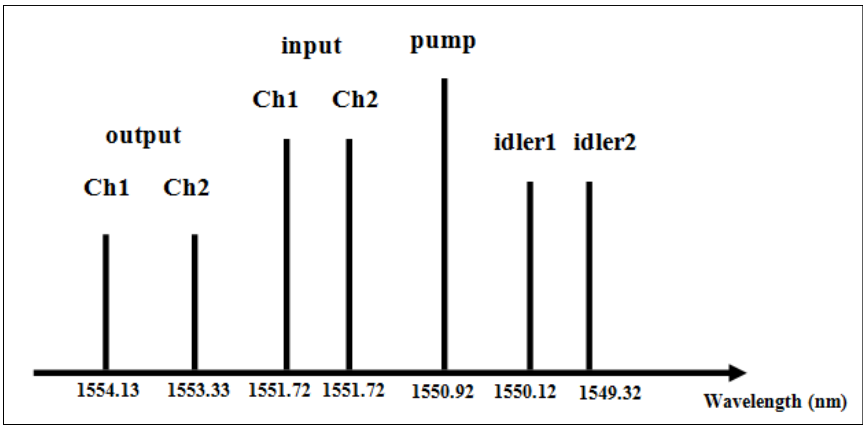

Figure 2.11: Wavelength of the light components involved in the FWM interaction.

For multi-channel regeneration, channel should be properly interleaved before entering the regenerator to avoid nonlinear interchannel crosstalk. Consequently, pump depletion associated with gain saturation is caused by different signal channels simultaneously. When pulses of adjacent temporally overlap, undesired FWM product are additionally generated.

However to get the effective regeneration, the polarization of multi-wavelength channels and the continuous wave pump should be aligned before entering the HNLF. After the FWM interaction between the pump and signals takes place in the HNLF, the second order product are extracted at the output via an optical bandpass filter (OBPS).

2.11 Parametric Analysis

All the simulation are performed on above mentioned attributes by exploiting optisys simulator on 10Gbps WDM system with the undermentioned simulation specifications:

Any DWDM system is consists of input, mux, demux and fiber cable. Optical pulses spread in time domain when they travel through fiber. To control spreading of pulse we had to use Dispersion Compensation Fiber (DCF). And we used optical amplifier (Erbium Doped Fiber Amplifier) to boost signals at output.

2.11.1 Dispersion Compensating Fiber

A special kind of fiber has been developed to compensate dispersion.DCF has been the most successful method of compensating of fiber due its wide operating band. DCF does not just has negative dispersion, it also has negative dispersion slope. Usually DCF has dispersion of -80ps/nm/km to -100ps/nm/km, so a small DCF can compensate much longer fiber cable. DCF can either be placed at one place or it can be distributed along fiber. Setting chromatic dispersion above zero helps in reduction of crosstalk.

2.11.2 Optical Amplifier

These days our optical communication system is completed based on optical devices. Optical amplifiers were developed to operate in optical domain so we don’t have to convert signal electric form and amplify it. We use OA as preamplifier so the degradation of signal noise ration caused by thermal noise in receiver electronics can be suppressed. The most popular silica doped fiber amplifier is Erbium Doped Fiber Amplifier. In some cases Yb is added to increase the efficiency of amplifier. Operating region of EDFA is 1530nm to 1560nm.

2.11.3 High Nonlinear Fiber (HNLF)

A segment of HNLF of 1.01km is placed for FWM process. The characteristics of the HNLF is shown in table 2.2

Table 2.2: The parameter of HNLF

Parameter	**Values**
Length L	1.01km
Attenuation coefficient ∝	0.9dB/km
Dispersion	-0.1 ps/nm/km
Dispersion Slope	0.0168 ps/nm^2/km
Effective Area	10um^2

2.11.4 Polarization Combiner and Splitter

This model can combine and split two input signals to one output port, it can stand very high power with low insertion loss. This polarization will select the appropriate polarization component of each signals at the input ports and adds the selected polarizations components. Figure 2.12 and 2.13 show that this model is implemented. There are a linear polarizer at each input port. The angle of 90° is added to the device angle of the polarize at input port 2.

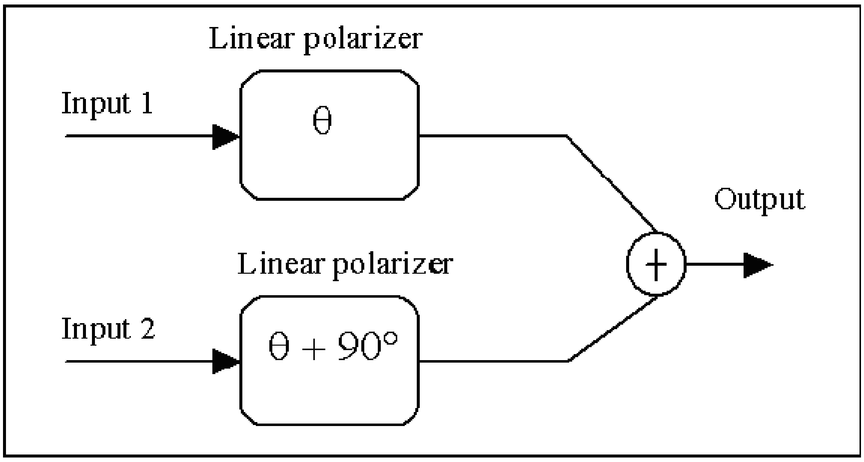

Figure 2.12: Polarizer Combiner

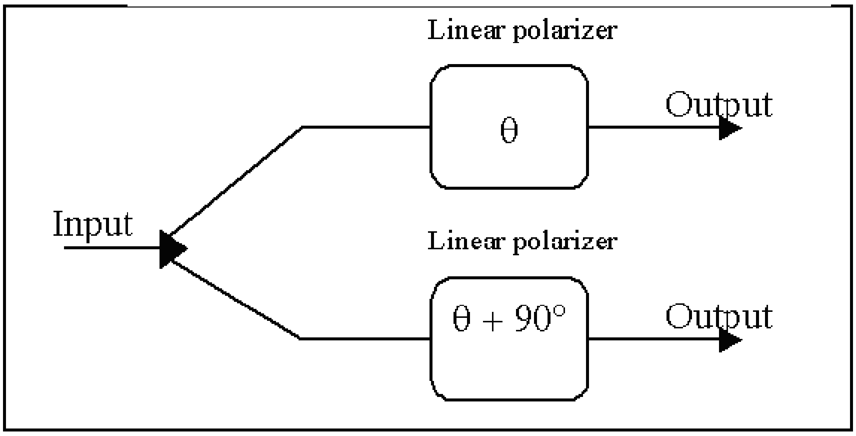

Figure 2.13: Polarizer Splitter

2.13 Linear Effects

For the linear effects, that leads to system degradation in optical communication, where the main focus will be on the effects that somehow change the input polarization (ISOP)

2.13.1 Chromatic Dispersion

Chromatic dispersion is a variation in the velocity of light according to wavelength. This variation cause the pulse of a modulated laser source to broaden when travelling through the fiber up to a point where pulses overlap and bit error rate increases. Mathematically, the effects of chromatic dispersion are accounted for by expanding the mode constant. From equation (2.4) in a Taylor series about frequency ω_0 at which the pulse spectrum in centred.

$$\beta(\omega) = \eta(\omega)\frac{\omega}{c} = \beta o(\omega o) + \beta 1(\omega - \omega o) + \frac{1}{2}\ \beta 2(\omega - \omega o)^2 + \frac{1}{6}\beta 3(\omega - \omega o)^{\ 3} \quad (2.4)$$

Where

$$\beta m = (\frac{d^m}{d\omega^m})\omega = \omega o \text{ where m=0,1,2...} \quad (2.5)$$

The parameters $\beta 1$ and $\beta 2$ are related to the refractive index η and its refractive index through the relations

$$\beta 1 = \frac{1}{vg} = \frac{ng}{c} = \frac{1}{c}(\text{n}+\omega\frac{dn}{d\omega}) \quad (2.6)$$

$$\beta 2 = \frac{1}{c}(2\frac{dn}{dw} + \omega\frac{d^2n}{dw^2}) \quad (2.7)$$

Where n_g is the group index and v_g is the group velocity. A pulse envelope move at the group velocity $v_g = 1/\beta 1$ while $\beta 2$ represents dispersion of the group velocity and it corresponds to pulse broadening due to frequency dependent group velocity. This is known as group-velocity dispersion (GVD) $\beta 3$ account for the third order dispersion (TOD) which distort ultrashort pulses.

The more commonly used dispersion parameter is given by

$$\text{D} = \frac{d\beta 1}{d\lambda} = -\frac{2\pi c}{\lambda^2}\beta 2 \approx \frac{\lambda}{c}\frac{d^2}{d\lambda^2}(\frac{ps}{nmkm}) \quad (2.8)$$

For standard single mode fibre D=0 near 1.3μm. Above 1.3 , where D>0 ($\beta 2$<0) is called anomalous dispersion while the region where D<0 is called normal dispersion. The third order dispersion parameter can be expressed as

$$\beta 3 = \frac{\lambda 4}{(2\pi c)^2}(\frac{dD}{d\lambda} + \frac{2}{\lambda}\ D) \quad (2.9)$$

And can be neglected except very close to the wavelength where D=0

2.13.2 Polarization Mode dispersion

A pulse can broaden even in the case of no chromatic dispersion. Polarization mode dispersion (PMD) is a problem associated with different arrival time of light in different polarization. Today's fiber exhibits PMD that can be smaller by orders of magnitude than older, currently laid out fiber, which is mostly due to a much improved manufacturing process. Replacing old fiber, however is very costly. Therefore understanding and compensating PMD is of great importance.

The asymmetries in circular geometry and stresses in the fiber core lead to a polarization dependent refractive index n, and propagation constant . This propagation different between the LPo modes corresponds to the birefringence, which varies randomly along the fiber and leads to pulse spreading.

In a short section of fiber the birefringence can be considered uniform. The different between the propagation constants of the fast and slow modes can defined :

$$\Delta\beta_x\omega_o = \beta_{0x}(\omega_o) - \beta_{0y}(\omega_o) = \frac{\omega o n_s}{c} - \frac{\omega o n_f}{c} = \frac{\omega o \Delta_n}{c} \qquad (2.10)$$

Where $\Delta_n = n_s$-n_f is the differential effective refractive index between the slow and fast axis mode where LPo_x is chosen as the slow mode and LPo_y as the fast mode. When a linearly polarized input wave is launched 45° to the birefringence axis into a short fiber, the SOP evolves in cyclic fashion as the light propagate down the fiber to a linear state orthogonal to the launch state. In Stokes space this means that if e.g an average input stokes vector lies along the S_2 axis,$\hat{s}$ =(0, 1,0)$^{\mathrm{T}}$ (as is the case for a PDM scheme with two orthogonal input stokes vector $\hat{s}A$ =(1, 0,0)$^{\mathrm{T}}$ and $\hat{s}B$ =(-1, 0,0)$^{\mathrm{T}}$ and is 90° opposed to the birefringent axe which lies along the S_1 axis, the polarization will evolve through the circular polarizations and the orthogonal polarization $\hat{s}$ =(0,-1,0)$^{\mathrm{T}}$.

Analogous, for fixed input SOP, if the frequency is varied, the output SOP will cycle in the same way through the various states. The frequency domain picture of PMS is shown in Figure 2.14, for a launch state near the birefringent axis. The output polarization traces out acircle on the surface of the Poincaré sphere. This cycle trace corresponds to the beat length $L_b = \frac{\lambda}{\Delta_n}$ or the propagation distance for which a $2\frac{1}{4}$ phase different accumulates between the two LP_0 modes.

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