Analysis and Reduction of Stimulated Raman Scattering In DWDM Fibre Optic Communication System

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ABSTRACT

Stimulated Raman scattering effect is one of the Non linear effects in Dense wavelength Division Multiplexed (DWDM) Fibre Optic communication system. The effect of Stimulated Raman Scattering causes power to be transferred from lower wavelength channel to higher wavelength channel. In the long haul transmission system, Dense Wavelength Division Multiplexing is a possible technique to use. In addition, long haul transmission level power and optical amplifier are needed to be considered. Feeding the high power to the fiber can also activate the effect of nonlinearity like Stimulated Raman Scattering (SRS). SRS effects aredecrease the peak power, decrease the OSNR, andoptical crosstalk ~~and~~but increase bit errors is the main destructive phenomena in high data rate optical communication systems.This thesis analyses the effect of SRS in DWDM fibre optic communication system on the power distribution of 8x10Gbps and 16x10Gbpsafter propagates along 25 km, 50 km, 75 km and 100 km along single mode fibre optic cable. SRS effect is studied for various power levels of individual channels which are simulated using Optisystem 8.0 in order to obtainthe effect of SRS like optical spectrum after transmission through the fibre optic cable. SRS effect is reduced by using backward Raman amplifier. The performance results are evaluated in term of eye diagram and bit error rate BER) using a single pump with 1427 nm wavelength and different pump power. An 8 channel DWDM fibre optic communication system with below than 10mW input power and 25 km fibre optic length; and 8 channel has no effect of SRS.

ABSTRACT

Stimulated Raman Scattering merupakan salah satu kesan tidak linear dalam Dense Wavelength Division Multiplexed(DWDM) sistem komunikasi fiber optik. Kesan Stimulated Raman Scattering akan menyebabkan kuasa dipindahkan dari saluran gelombang yang lebih rendah saluran gelombang yang lebih tinggi. DWDM adalah teknik yang mungkin boleh digunakan dalam sistem penghantaran jarak jauh. Dalam penghantaran jarak jauh, aras kuasa dan penguat optik adalah antara perkara yang perlu diambil kira. Penggunakan kuasa masukan yang tinggi ke dalam gentian fiber juga boleh mengaktifkan kesan ketaklelurusan seperti SRS. Kesan SRS akan menyebabkan pengurangan kuasa, OSNR dan cakap silang, tetapi perubahan fenomena paling utama dalam penghantaran data yang tinggi ialah kesalahan bit. Tesis ini menganalisis kesan SRS dalam DWDM bagi sistem komunikasi fiber optik di mana pengagihan kuasa yang digunakan adalah 8x10Gbps dan 16x10Gbps selepas merambat di sepanjang 25 km, 50 km, 75 km dan 100 km menggunakan gentian optik tunggal. Kesan SRS dikaji pada pelbagai tahap kuasa bagi saluran individu dengan menggunakan Optisystem 8.0 untuk mendapatkan kesan SRS seperti spektrum optik selepas penghantaran melalui kabel gentian optik. Kesan SRS dikurangkan dengan menggunakan Backward Raman Amplifier.gambarajah mata dan Bit Error Rate (BER) digunakan untuk menganalisa keputusan yang diperolehi dimana pam tunggal dengan 1427 nm panjang gelombang dan kuasa pam yang berbeza digunakan. Kesan SRS boleh dikurangkan dengan menggunakan Backward Raman Amplifier. Sistem komunikasi fiber optic DWDM 8 saluran dengan kuasa masukan di bawah 10mW dan panjang kabel fiber optic 25 km tidak mempunyai kesan SRS

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CHAPTER 1

INTRODUCTION

Current trend is moving towards hands free or mobile where a lot of people have to access to mobile communicationfor services such asinternet, cloud services and video. We have to access to information at our finger tips when we need it, where we need it and in whatever format we need it. All these devices are network connected and demand for high-speed digital communication driven, stimulating the need for Dense Wavelength Division Multiplexing (DWDM) [1, 2]. Dense wavelength division multiplexing is a technique that uses in a long haul optical communication network to improve the performance, where DWDM allows information at various channel to be transmitted in different wavelength with huge channel capacity and link distance [3, 4]. DWDM system multiplex 32 or more wavelength in the 1550nm range, increase capacity on existing fibre and data rate transparent [5].

Long-haul transmission optical network commonly relies on high power laser to transmit optical pulse over long spans to overcome attenuation. Unfortunately,using high power and increasing number of optical channel, nonlinear effects become problematic factor in DWDM system. Fibre nonlinearities isa critical concern because it will limit the performance of optical fibre communication. This analog effect can be divided in two categories. The first category is refractive index phenomena, which cause phase modulation. This gives rise to nonlinearities such as self-phase modulation (SPM), whereby an optical signal alters its own phase; cross-phase modulation (XPM), where one signal affect the phase of all others optical signal and vice-versa; and four-wave mixing (FWM), whereby signal with different frequencies interfere to produce mixing sideband. The second category is scattering phenomena which lead to power loss. The scattering phenomenon isdivided into two types. It is stimulated Raman scattering (SRS), and stimulated Brilliouin scattering (SBS).

Fibre nonlinear effect such as stimulated Raman scattering (SRS), stimulated Brilliouin scattering, four wave mixing and self-and cross-phase modulation in a optical WDM communication has been long recognize butone of the major limitation of system performance is stimulated Raman scattering [2, 7, 8].

The Raman scattering effect is the inelastic scattering [10], when light is scattered from an atom or molecule, most photons are elastically scattered. Stimulated Raman scattering will cause power to be transferred from the lower-wavelength channel to the higher wavelength channel. This will reduced the signal to noise ratio for the high frequency channel or low frequency channel.

Stimulated Raman scattering effect can be reduced by using high pass filter [11], butthis proposal introduced a different method to reduced the Stimulated Raman scattering effect by using discrete Raman amplifier for long haul communication system.

1.1 Nonlinear effects in Optical fibres

Nonlinear effects in optical fibres occur due to change in the refractive index of the medium with optical intensity and inelastic scattering phenomenon. The intensity dependence of refractive index results in self-phase modulation (SPM), cross-phase modulation (XPM or CPM) and four-wave mixing (FWM). At high power level, the inelastic scattering phenomenon can induce stimulated effect such as Stimulated

Brillouin Scattering and Stimulated Raman Scattering. The intensity of scattered light grows exponentially if the incident power exceeds a certain threshold value.

1.2 Stimulated Raman Scattering

Stimulated Raman scattering (SRS) is the result of interaction between incident light and molecular vibration. Some portion of the incident light is downshifted in frequency by an amount equal to the molecular vibration frequency, which is generally called Stokes frequency. This in effect depletes the optical power of the incident light. When there is only a single light wave propagating along the optical fibre, Raman scattering results in the generation of spontaneous Raman Scattered light waves at lower frequency, the SRS light will amplify it and the higher wavelength channel will increase; Figure 1.1 illustrate this effect . Consequently, SRS can severely limit the performance of a multichannel optical communication system by transferring energy from short wavelength channels to neighboring higher wavelength channels. Power in WDM channels separate up to 16THz (125 nm) can be coupled through the SRS effect as shown in Figure 1.2.

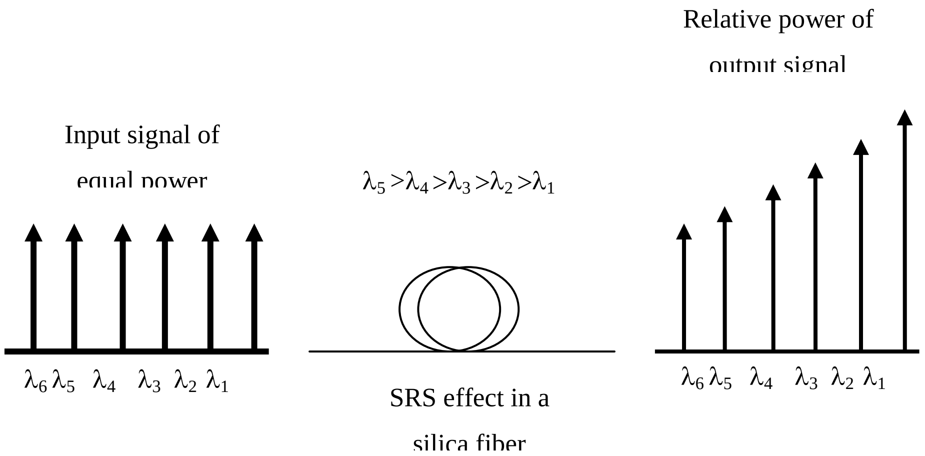

Figure 1.1: SRS transfer optical power from shorter wavelengths to longer wavelength [9]

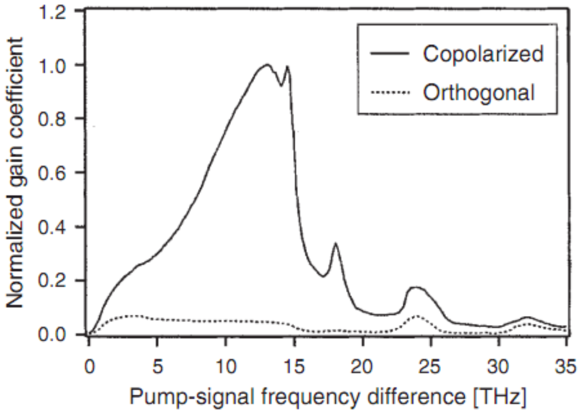

Figure 1.2: Raman-gain spectrum for fused silica at a pump wavelength λ p= 1 µm.The Raman gain scales inversely with λp.[23]

The effect of SRS can be estimated. Consider a WDM system with *N* equally spaced channel, 0, 1, 2, ……., (*N* – 1), with a channel spacing of $\Delta\lambda_s$. with the assumption that the same power is transmitted in all the channels, Raman gain increase linearly, and that there is o interaction between other channels, the fraction of power coupled from channel 0 to channel *i* is given approximately by

$$F(i) = g_R \frac{i\Delta\lambda s}{\Delta\lambda c}\frac{P_0\, L_{eff}}{2A_{eff}} \tag{1.1}$$

Where $g_R$the peak Raman gain coefficient, $\Delta\lambda c$is the total channel spacing, $\Delta\lambda s$ is channel spacing, $L_{eff}$is the effective length of the fibre, A_{eff} is the effective core and P_0 is the transmitted power per channel.

From the equation (1.1) we can calculate the total transmitted power P_{tot}as follows

$$P_{tot} = NP_0 = \frac{4F\Delta\lambda c A_{eff}}{g_R\Delta\lambda s L_{eff}(N-1)} \tag{1.2}$$

Where $P_o$is the transmitted power per channel, N is the equally spaced channel, $g_R$the peak Raman gain coefficient, $\Delta\lambda c$is the total channel spacing, $\Delta\lambda s$ is channel spacing, $L_{eff}$is the effective length of the fibre, A_{eff} is the effective core and F is the fraction of power.

1.3 Raman Threshold

In general, the criterion used to determine the level that can induced the scattering effect is the threshold power P_{th} defined as the input power level that can induced the scattering effect so that half of the power (3db power reduction) is lost at the output of an optical fibre. For single-channel light wave system, it has been shown that threshold power P_{th} is given by

$$Pth = \frac{16\mathrm{A_{eff}}}{\mathrm{g_R L_{eff}}} \tag{1.3}$$

Where $L_{eff}$the effective length of the fibre is, A_{eff}arethe effective core and $g_R$the peak Raman gain coefficient.

1.4 Forward Pumping

In forward pumping the input signal and the pump signal propagate in the same direction on the fibre, as shown in Figure 1.3. The input and the pump are combined using a pump combiner or wavelength division multiplexing.

Inside the fibre the pump energy is transferred to the input signal and the signal input is amplified at the output of the amplifier isolator are used in the scheme to make sure that the signal will travel only in one directional and no feedback of signal will occur.

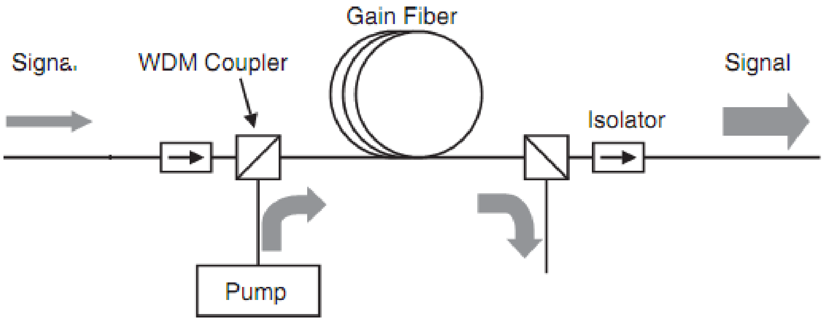

Figure 1.3: Single-stage Forward Raman Amplifier [23]

1.5 Backward Pumping

In backward pumping the input signal and the pump propagate in the opposite direction to each other inside the fibre, as shown in Figure 1.4. For amplification the direction of input and pump signal is not essential. The signal from transmitter Tx will propagate to the receiver Rx and the pump travelling in the opposite direction of the signal is called the counter- or backwardpump.

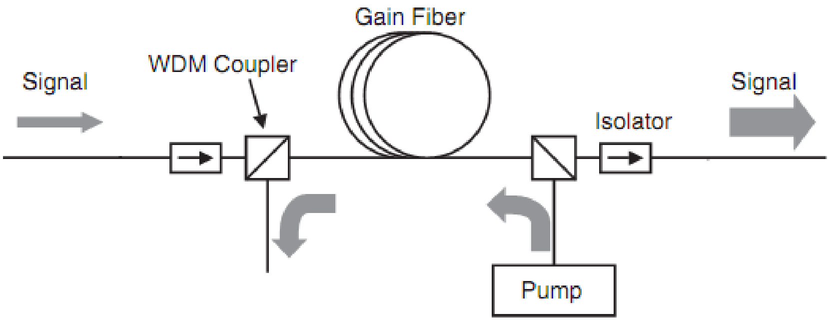

Figure 1.4: Single-stage Backward Raman Amplifier, [23]

1.6 Problem statement

In the long haul transmission system, Dense Wavelength Division Multiplexing is a possible technique to use. In addition, long haul transmission level power and optical amplifier are needed to be considered. Feeding the high power to the fiber can also activate the effect of nonlinearity like Stimulated Raman Scattering (SRS). SRS effects aredecrease the peak power, decrease the OSNR, andoptical crosstalk ~~and~~but increase bit errors is the main destructive phenomena in high data rate optical communication systems.

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1.7 Objective:

There are several objectives that have been outline to complete this analysis and reduction of stimulated Raman scattering in DWDM fibre optic communication system.

1. To design 8 and 16 channel Dense Wavelength Multiplexing (DWDM) system in fiber optic communication using Optisystem.
2. To analysis the effect of Stimulated Raman Scattering (SRS) on performance of Dense Wavelength multiplexing technique.
3. To determine the performance of backward Raman amplifier in term of Bit Error rate (BER) and eye diagram.

1.8 Scope of project

1. To study the effect of stimulated Raman scattering (SRS) in DWDM fiber optic communication system.
2. The approach is using Optisystem version 8.0 software.
3. The input power, wavelength of the CW laser and the length is change to study the effect of SRS in an 8 and 16 channel.
4. Backward Raman amplifier is used to reduced the Stimulated Raman Scattering.
5. The performance parameter to evaluate the system is in term of Bit Error Rate (BER) and eye diagram.

1.9 Thesis Outline

This thesis comprises of six chapters and is organize as follows:

Chapter 1 is the introductory part of this thesis which consists of introduction of the project, problem statement, objective, scope of workand thesis outline.

Chapter 2 presents the literature review of thisthesis which is review the last paper journal from others writer

Chapter 3 presents the methodology of this thesis which is explaining some basic theory of in term of DWDM design in fibre optic communication by using optisystem software version 8.0 Orthogonal. This chapter consists of introduction and design methodology.

Chapter 4 discussesthe simulation result andanalysis of Stimulated Raman Scattering (SRS) in 8 x 10gbps and 16 x 10gbps DWDM fibre optic communication system.Optisytem 8.0 software is used to model and implement the system. In this chapter the proposed 8 channel and 16 channel of DWDM fibre optic communication systemto observed a SRS effect.

Chapter 5 discusses the simulation result and analysis of the simulation of 8 x 10gbps and 16 x 10gbps dwdm system based on backward raman amplifier**.**Optisytem 10.0 software is used to model and implement the system. In this chapter the proposed 8 channel and 16 channel of DWDM fibre optic communication system to observed the effect of SRS were reduced by using a Backward Raman Amplifier.

Chapter 6 provides the conclusion for the whole project and also provides the recommendation of future works for developing and modifications of the system presented in this thesis.

CHAPTER 2

LITERIATURE REVIEW

Valliammai Muthuraman and Sivananatharaja [9] described that the impact of SRS on the power distribution of a 4 and 32 channels multiplex after 10km transmission over a single mode fibre. The unwanted power tilt is increase when the input optical power in the individual channel is increased.

Manoj Kumar Dutta, Karthik B.S.N, Srinivas R and V.K. Chaubey [2] described that the nonlinear due to stimulated Raman scattering is having a negative consequence on the optical WDM network and need to be accounted for in designing network and choosing the parameter since it affects the bit error rate that determine system evaluation and budget.

Fang Juanni [12] described that the effect of SNR in the context of number and spacing of channel. Among fibre nonlinearities, SRS effect the power of high frequency channel is transferred to low frequency channel. In designing a small fibre optic communication systems several factor have to considered such as the input optic power must be properly selected, it must be smaller than 1mw and the space of channel is no to big and smaller than 100GHz.

V.Yu. Golyshev, E.A. Zhukov, I.E. Samartsev and D.G. Slepov [15] in theiropinion that a 2-channel long distance fibre optic communication line with Wavelength Division Multiplexing system with a Fibre Raman amplifier (FRA) pump, SRS will be negligible.

Mir Muhammad Lodro and Muhammad Ali Joyo [13], described that in between two amplifier theyuse a 32 channel DWDM system, Raman pump out performed than EDFA for long distance fibre optic communication. However the performance of EDFA pump is still good in the short distance up to 60km, but when the channel length is increase the performance reduce. Figure 2.1 shows the DWDM transmission section.

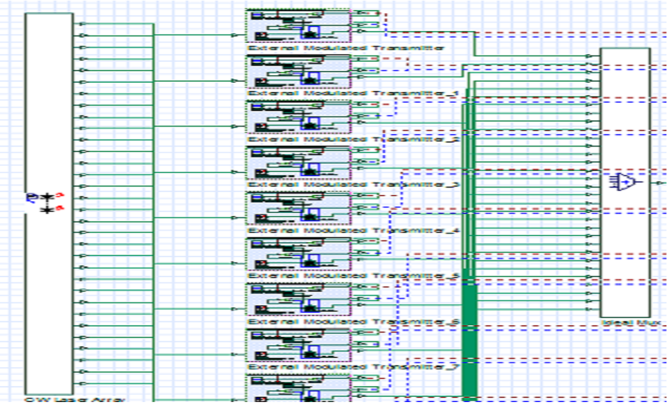


Figure 2.1 DWDM Transmission Sections [13]

Christoper M. McIntosh, Alexandra G. Grandpierre, Demetrios N. Christodoulides, Jean Toulouse, Jean-Marc P. Delavaux [7], emphasized that by inserting a High Pass Filters (HPFs) into the fibre network it can be effectively suppressed the SRS power flow from the WDM channel to lower frequency noise component.

Xiang Yang and Yang Hechao [14] use the Optisystem software to design the fibre optic communication system and stimulated the result in order to overcome the traditional shortcoming of the experiment in optical fibre communication. Figure 2.1 shows the design for WDM by using a Optisystem software.

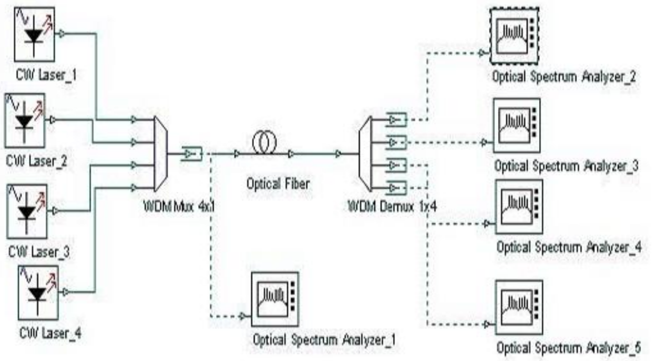


Figure 2.2 OptiSystem WDM system diagrams [14]

Gurmeet Kaur, M.L. Singh and M.S. Patterh [17], emphasized that inter-amplifier separation has opposite effects on noise generated due to the fibre non-linear effects. SRS and FWM will be increase by decreasing the amplifier spacing as shown in Figure 2.3.

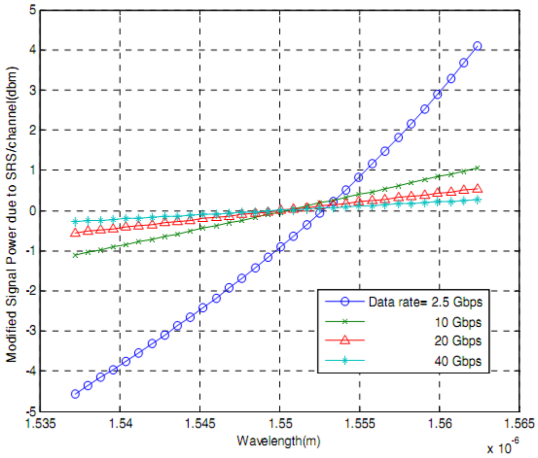


Figure 2.3: Modified Signal Power due to SRS/channel (dbm) Vs.Wavelength(m)including pulse walk off effect in the DWDM transmission system with centrewavelength=1.55x10-6m, Fiber attenuation coefficient at 1.55 µm = 0.205 dB/km,Effective Area of the optical fibre= 5.3x10-7cm2, Fiber chromatic dispersioncoefficient at 1.55 µm =3.0 ps/nm-km [17]

It has been conclude from the study of the literature that in designing fibre optic communication system stimulated Raman scattering have been recognized. SRS effect can be reduced or suppressed by using a filter and amplifier. In this research, the effect of SRS in a long haul DWDM fibre optic communication system will be analyze and the Raman amplifier forward pump and backward pump will used to reduce the SRS effect. The analysis of SRS will be investigating using Optisystem 8.0 software.

Table 2.1: List of the research

No.	Title of Journal	Software	DWDM	Length of fibre	Amplifier	Performance measure
			No. of channel			
1	Analysis of stimulated Raman Scattering on DWDM *system* *Author: Valliammai Muthuraman and Sivananatharaja*	OPTISIM	4 and 32	10Km (Single mode)	×	
2	32-channel DWDM system design and simulation by using EDFA with DCF and Raman *Author: Mir Muhammad Lodro and Muhammad Ali Joyo*	OPTISYSTEM	32		EDFA &Raman 60Km & 120Km	BER Eye diagram
3	Analysis and reduction of stimulated Raman scattering in DWDM fibre optic communication system *Author: T.Sabaphati, S.Sundaravadivelu and G.Prabhu*	OPTISIM	4, 8, 16, 32 and 64		×	Reduced SRS effect using high pass filter
4	Analysis and reduction of stimulated Raman scattering in DWDM fibre optic communication system	OPTISYSTEM	8 and 16	100km	Backward and forward Raman amplifier	Reduced SRS effect using Backward and forward Raman amplifier

CHAPTER 3

METHODOLOGY

1.1 Introduction

There are different method carrying out research in the field of optical system, like experiment and simulation. The building of a design and the testing of it in practical experiment is an expensive and time-consuming method. In orderto minimize time and cost, this research focus on simulation experiment based on OptiSystem software in order to investigate the performance of signal transmission in Dense Wavelength Division Multiplexing (DWDM) fibre optic communication system. The major aspect during methodology stage is simulation process. The main objective of simulation is to find the best configuration of the system that can operate at optimum performance to be implemented it on the application systems.

3.2 Design Methodology

Dense Wavelength division Multiplexing (DWDM) is a technique that couples multiples optical carrier signals onto a single optical fibre using different laser wavelength. A DWDM system employs several lasers at different wavelength to simultaneously transmit separate streams of data along a single optical fibre. At the receiving end, the different wavelength are optically separated and individually detected.

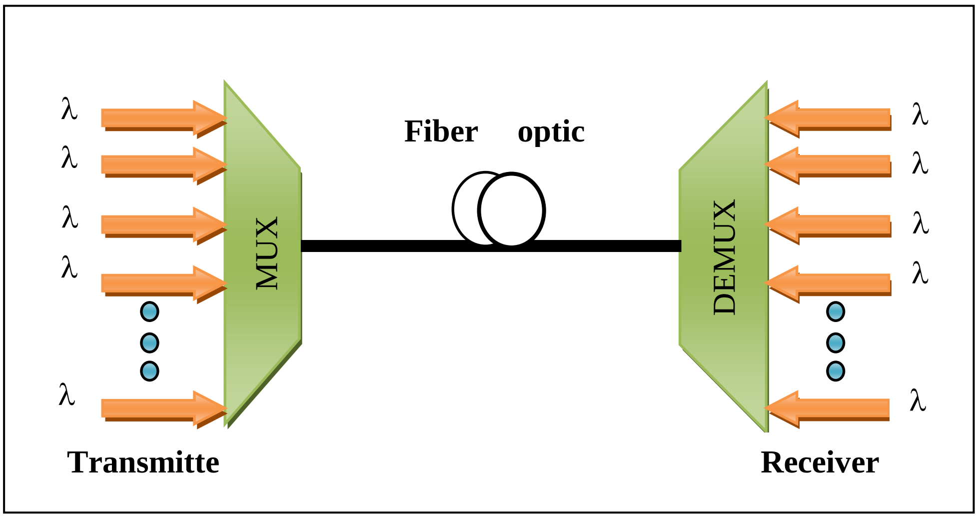


Figure 3.1: DWDM system[31]

Figure 3.1, shown the proposed system for the DWDM consists of three sections, namely the transmitter, fibre and the receiver.

3.2.1 Transmitter

Optical transmitter is the core equipment of fibre optic transmission system. The role of optical transmitter is to convert the electrical signal into optical form. It consists of optical source, electrical pulse generator, optical modulator and multiplexer.

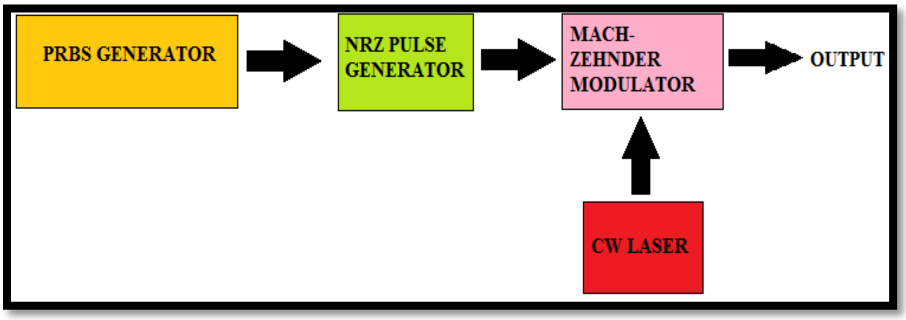


Figure 3.2: transmitter

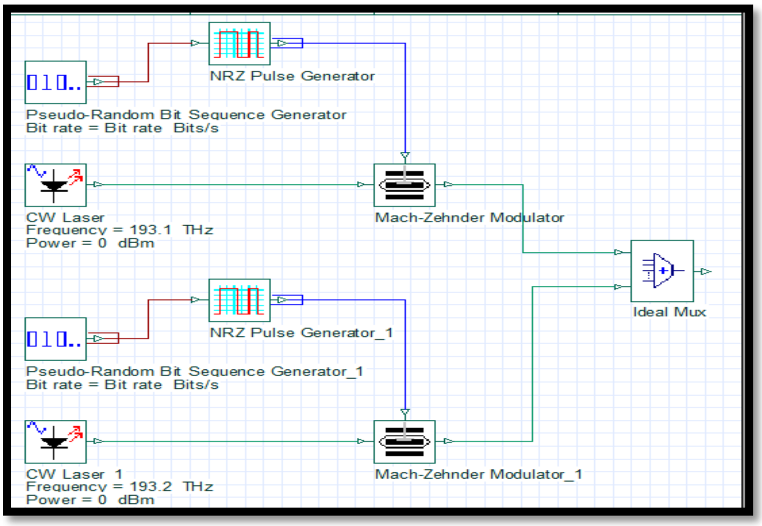


Figure 3.3: Transmitter simulation design using OptiSystem version 8.0

3.2.2. Pseudo-Random Bit Generator

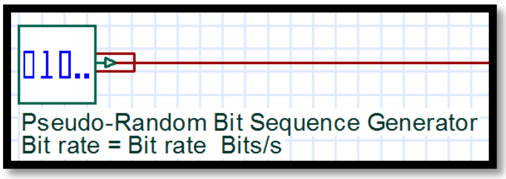


Figure 3.4: Symbol of component Pseudo- Random Bit Sequence Generator using OptiSystem version 8.0

A pseudorandom bit generator (PRBG), also known as a Deterministic Random Bit Generator (DRBG), is an algorithm for generating a sequence of numbers that approximates the properties of random numbers. The sequence is not truly random in that it is completely determined by a relatively small set of initial values, called the PRBG's *state*, which includes a truly random. Although sequences that are closer to truly random can be generated using hardware random number generators, *pseudorandom* bit are important in practice for their speed in bit generation and their reproducibility, and they are thus central in applications such as simulations (e.g., of physical systems with the Monte Carlo method), in cryptography, and in procedural.

A PRBG can be started from an arbitrary starting state using a seed state. It will always produce the same sequence thereafter when initialized with that state. The period of a PRBG is defined as the maximum over all starting states of the length of the repetition-free prefix of the sequence. The period is bounded by the size of the state, measured in bits. However, since the length of the period potentially doubles with each bit of 'state' added, it is easy to build PRBGs with periods long enough for many practical applications.

Most pseudorandom generator algorithms produce sequences which are uniformly distributed by any of several tests. It is an open question, and one central to the theory and practice of cryptography, whether there is any way to distinguish the output of a high-quality PRBG from a truly random sequence without knowing the algorithms used and the state with which it was initialized.

Pseudo Random bit sequence generator is used whose output in turn is given to a pulse generator to generate NRZ pulse. The Non Return-to-Zero (NRZ) format is commonly used because the signal bandwidth is about 50% smaller for it compared with that of the Return-to-zero (RZ) format [19]. RZ is better when the average power into the fibre is constant and NRZ is a better choice for a system with a large number of channels.

Prabhjett Singh, Narwant Singh and Amandeep Singh [20], from their opinion that NRZ will provide better result for DWDM system.

3.2.3 NRZ Pulse Generator

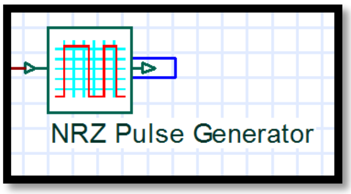


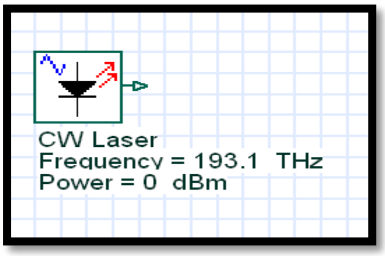
Figure 3.5: Symbol of component NRZ pulse generator using OptiSystem version 8.0

RZ pulse signalling is increasingly being used in ultra-long-haul systems because its robust bit-error rate (BER) performance allows longer span lengths between the last optical amplifier in the chain and the receiver. It also provides significant advantages in the cost-sensitive metro networking market because it can now be implemented in a single, surface-mount module that performs **non-return-to-zero (NRZ)** to return-to-zero (RZ) conversion electronically rather than optically. In addition to the savings achieved by the highly-integrated module, the use of RZ in metro systems eliminates the need for a midspan dispersion compensation.

In contrast, using NRZ pulse signalling in ultra-long-haul optical communications systems (beyond 2000 km) can be hampered by several technical issues. For instance, mismatch in dispersion compensation modules for lengthy spans produces a higher probability of error for NRZ signals as compared to RZ signals due to the additive properties of modulation chirp of the optical signal. In addition, the additive signal-to-noise ratio of cascaded erbium-doped fibre amplifiers (EDFAs) also contributes to the BER problem of NRZ signals. Most optical communication systems deployed today use an NRZ modulation format. This means that the logic level stays high when a string of "1"s occurs. Conversely, in an RZ coding format, when a "1" occurs, the logic level stays high for only half the bit period 50% duty cycle, and then returns low no light.

The temporal pulse width for an isolated “1” for the RZ coding format is only half as long as that for the NRZ coding format, so the RZ coding format will require twice the frequency spectrum of NRZ coding. However, in an optical system, if the average optical power is a constant, the RZ coding format will have twice the peak power of the NRZ coding format for the bit period.

3.2.4 CW laser



CW Laser
Frequency = 193.1 THz
Power = 0 dBm

Figure 3.6: Symbol of CW laser using OptiSystem version 8.0

Continuous-wave (CW) operation of a laser means that the laser is continuously pumped and continuously emits light. The emission can occur in a single resonator mode (→ single-frequency operation) or on multiple modes.

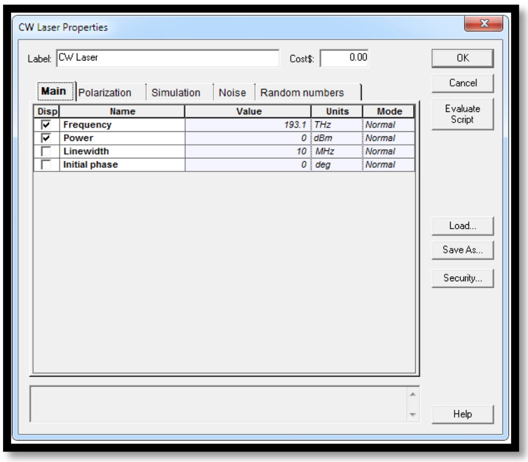
The first continuous-wave laser was a helium–neon laser operating at 1153 nm. A version working with the now common emission wavelength of 632.8 nm was demonstrated soon after that. Later on, many other types of lasers were developed which can also be operated continuously: other gas lasers, many types of solid-state lasers including semiconductor lasers, and dye lasers.

For many lasers with low-gain laser transitions, continuous-wave operation is difficult to achieve, while operation with pulsed pumping is easy to obtain. In some cases, continuous-wave operation is only possible with fibre lasers, but not with bulk lasers, as the fibre geometry greatly increases the gain efficiency. Some so-called self-terminating laser transitions are not suitable at all for continuous-wave operation.

In continuous-wave operation, some lasers exhibit too strong heating of the gain medium. The heating can then be reduced by quasi-continuous-wave operation, where the pump power is only switched on for limited time intervals.

CW laser were choose as an optical input rather than LED because LED was not suitable for long distance wideband transmission. The fundamental difference between LED light output and LASER light output is that the led output is incoherent whereas the laser output is coherent. The laser light is highly directional and of the same frequency and phase. It is this characteristic of lasers which has allowed for the development of many of today's optical applications.

Several type of laser manufacturer by different company is shown in the Table 2. By referring to this table we can set the power of the CW laser in optisystem from 10mw to 40mw.



Label: CW Laser

Cost$: 0.00

Disp	Name	Value	Units	Mode
☑	Frequency	193.1	THz	Normal
☑	Power	0	dBm	Normal
☐	Linewidth	10	MHz	Normal
☐	Initial phase	0	deg	Normal

Figure 3.7: Setting the CW laser layout

The parameter of the CW laser is setup at the CW laser properties as shown in Figure 3.7. The frequency is chosen byreferring to the ITU-T grid for C-band DWDM and the power is chosen by referring to the manufacturer datasheet.

Table 3.1: Type of laser from different manufacturing

Type of laser	Power	Company	Description / Application
DWDM CW DFB Laser Module	High optical output power up to 40mW	Fitel	DFB laser module is designed for long haul DWDM applications with external intensity modulator
1772 DWDM High Power CW Source Laser	40 mW, 50 mW, and 63 mW	Emcore	for use as a CW optical source in CATV and DWDM networks
Full band tunable DFBB laser module	10/20mW	Furukawa Electric	Full band tunable, 50G ITU grid 88ch, Locker, RoHS6
20mW CW DWDM laser with integrated wavelength monitor	20mW	JDS Uniphase	Series laser specially developed for DWDM system, where it is in combination with external modulator such as a $LiNbO_3$-based Mach-Zehnder modulator
CW Tunable Laser – Butterfly Package	High, flexibly adjustable output power, from 9 to 13 dBm	Finisar	Using in DWDM transmission systems and Tunable DWDM transponders and transceivers

3.2.5 Mach-Zehnder External Modulator

Keang-Po Ho and Joseph M. Kahn [18], in theiropinion that in between direct modulation, electro absorption modulator and Mach-Zehnder modulator (MZM), MZM is the best modulator that provide superior signal quality and widely use in DWDM system.

MZM yield smaller chirp, providing a narrow signal spectrum and resulting in a larger tolerance to uncompensated chromatic dispersion

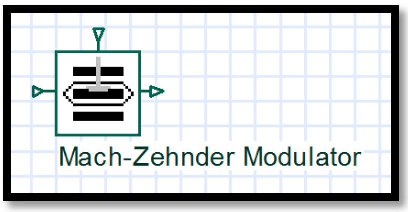


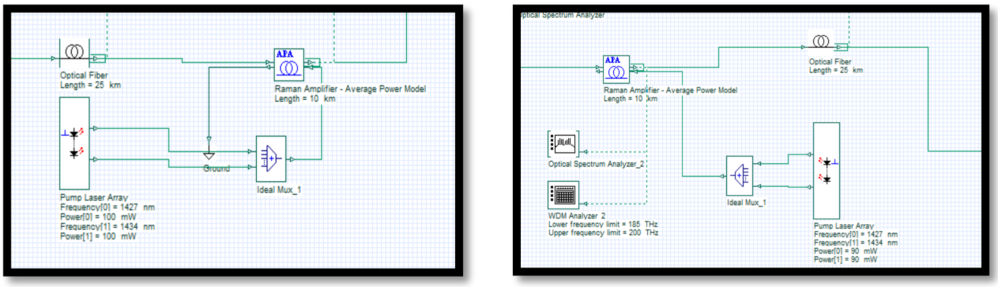
Figure 3.8: Mach-Zehnder Modulator block in OptiSystem version 8.0

The Mach–Zehnder Modulator is a device used to determine the relative phase shift between two collimated beams from a coherent light source. The interferometer has been used, amongst other things, to measure small phase shifts in one of the two beams caused by a small sample or the change in length of one of the paths. The Michelson interferometer is a Mach–Zehnder modulator that has been folded back upon it. The principal difference is that in the Michelson interferometer, the beam splitting optic is also used to recombine the beams.

3.2.6 Raman Amplifier

Optical amplifier is used to boost an optical signal to compensate for power loss or attenuation, caused by propagation over long distance. Raman fiber amplifiers can be divided into two main categories, namely *discrete* and *distributed*. The term distributed amplification refers to the method of cancellation of the intrinsic fiber loss. When the fiber being pumped is the actual transmission span that links two points, this setup is referred to as a distributed Raman amplifier. For the distributed raman amplifier application, optical power from one or more raman pump laser is inserted into end of the transmission fibre toward the end transmitting end. Discrete Raman amplifiers are also commonly referred as lump Raman amplifiers since these devices are used as a lumped element inserted into the transmission line to provide the gain. Typically distributed Raman amplifiers have lengths along several kilometers of fiber whereas discrete Raman amplifiers have lengths around 5km [23].

In an optical communication system the signal propagates from the transmitter (Tx) to the Reciver (Rx). The pump traveling in the same direction as the signal is called the *co- or forward pump*, and the pump traveling in the opposite direction of the signal is called the *counter- or backward pump*. Most important is the co- or forward-pumped amplifier configuration, in which the pump and signal propagate in the same direction. The implementation of this configuration offers an improved noise performance over a counter-pumped distributed Raman amplifier [24].



(a) (b)

Figure 3.9: Raman amplifier (a) Backward Amplifier (b) Forward Amplifer

3.2.7 Optical Fibre

Single Mode fibre (SMF) is a small core (1-16mm) optical fibre, widely use in transport and access network for long distance. This fibre obtains beneficial properties like low attenuation, large wavelength area and high bandwidth over distance [21]. Compared to multi mode fibre (MMF), SMF is obtains lower loss and eliminates intermodal dispersion. The parameter of the single mode fibre can be setup at the optical fibre properties.

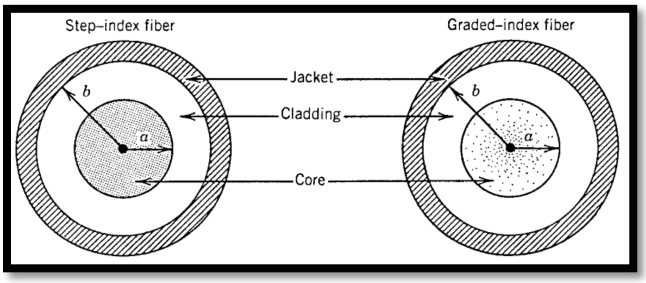


Figure 3.10: Single Mode Fibre[19]

REFERENCES

1. Lexington, Massachusetts, “Dense Wavelength Division Multiplexing (DWDM) Market Opportunities, Strategies, and Forecasts, 2006 to 2012”, WinterGreen Research, Inc.

2. Manoj Kumar Dutta, Karthik B.S.N, Srinivas R, V.K. Chaubey (2011), “Stimulated Raman Scattering Induced Power Penalty Analysis for Optical WDM Network”, IEEE.

3. Amir R. Sharifi Pur Shirazi, Mohsen Kazemian, Masoud Jabbari (2010) “Simulation and Analysis the Performance of 3970 Km DWDM Transmission Link Employing Optimized Semiconductor Optical Amplifiers” 1st International Conference Communication Engineering: University of Sistan and Baluchestan, Dicember 22 – 24 2010, pp. 155-160

4. Gurmeet Kaur, M.S Patterh, M.L. Singh (2009) “Impact of pulse walk off effect on stimulated raman scattering in a DWDM transmission system” International Conference on Emerging Trends in Electronic and Photonic Devices & System (ELECTRO-2009), 2009, pp. 556- 558.

5. Regis J. “Bud” Bates (2001),”Optical Switching and Networking Handbook”, McGraw Hill.

6. Fang Juanni (2010) “The effect of SRS to DWDM optical system” International Conference on Electrical and Control Engineering, 2010, pp. 2340-2342.

7. Christoper M. McIntosh, Alexandra G. Grandpierre, Demetrios N. Christodoulides, Jean Toulouse, Jean-Marc P. Delavaux (2001), “Eliminating SRS Channel Depletion in Massive WDM system via Optical Filtering Techniques”, IEEE Photonic technology Letter, Vol.13, No.4.

8. D.N Christodoulides, R.B. Jander (1996), “Evolution of Stimulated Raman Crosstalk in Wavelength Division Multiplex Systems”, IEEE Photonic technology Letter, Vol.8, No.12.

9. Valliammai Muthuraman, Sivananatharaja (2011), “Analysis of stimulated Raman Scattering on DWDM system”, Optics: phenomena, Materials, Devices and characterization AIP Conf. Proc. 1391, pp.400 – 402.

10. Boyd, R.W (1992) ,”Nonlinear Optics”, Academic Press, SanDiego, CA.

11. T. Sabpathi, S. sundaravadivelu, G. Prabha (2010), “Analysis and Reduction of Stimulated Raman Scattering in DWDM Fibre Optic Communication System”, Proceeding of the international conference

12. Fang Juanni (2010), “The effect of SRS to DWDM Optical System”, International Conference on Electrical and Control Engineering

13. Mir Muhammad Lodro and Muhammad Ali Joyo (2012), “32-channel DWDM system design and simulation by using EDFA with DCF and Raman”, International Conference on Information and Computer Network (ICICN 2012). IPCSIT vol. 27 (2012) © (2012) IACSIT Press, Singapore

14. Xiang Yang, Yang Hechao (2010), “The Application of OptiSystem in Optical Fibre Communication Experiment”, Proceeding of the Third International Symposium on Computer Science and Computational Technology (ISCSCT ’10)

15. V.Yu. Golyshev, E.A. Zhukov, I.E. Samartsev, D.G. Slepov (2004), “Stimulated Raman Scattering in Fibre-Optic Communication Lines”, Technical Physic, Vol.49, No.1, pp. 135 – 137

16. Jena Pierre Laude (2002), “DWDM Fundamentals, Component, and Applications”, Artech House, Inc, pp.128

17. Gurmeet Kaur, M.L. Singh and M.S. Patterh (2009), “Simulation of 10 GBPS DWDM Transmission System in the Presence of Fibre Nonlinerities, International Conference on Optic and Photonic (ICOP)

18. Keang-Po Ho and Joseph M. Kahn (2004), “Spectrum of external modulated optical signal”, Journal of Lightwave Technology, Vol.22 No.2, pp. 658 – 663

19. Govind P. Agrawal (2002), “Fibre-Optic Communication System, 3rd Edition”, John Wiley & Sons, Inc, pp.411

20. Prabhjett Singh, Narwant Singh and Amandeep Singh (2012), “Investigation of DWDM system for Different Modulation Formats”, IOSR Journal of Engineering (IOSRJEN), vol.2 Issue 1, pp. 111 - 117

21. Roberto Gaudino, Daniel Cardenas, Martial Bellec, Benoit Charbonnier, Noella Evanno, Philippe Guignard, Sylvain Meyer, Anna Pizzinat, Ingo Mollers and

Dieter Jager (2009), " Future Internet in Home Area Networks: Towards Optical solutions?", G. Tselentis et al. (Eds), IOS press.

22. John Crisp and Barry Elliott 3rd Edition (2005),"Introduction to Fibre", Elsevier Newnes.
23. Govind P. Agrawal anad Clifford Headly (2005), "Raman Amplificationin Fibre OpticalCommunication Systems", Elsevier Academic Press.
24. Paul L. Kelley, Ivan P. Kaminow and Govind P. Agrawal 3rd Edition (2001), "Nonlinear Fibre Optics", Academic Press.
25. S.P.Singh, R.Gangwar and N.Singh (2007), "Nonlinear Scattering Effect in Optical Fibers", Progress In Electromagnettics Research, PIER 74, pp. 379 – 405
26. R.P Khare (2004), "Fiber Optics and Optoelectronics", Oxford University Press.
27. Joseph C. Palais 4th Edition (2004), "Fiber Optic Communications", Pearson Prentice hall.
28. Gerd Keiser 4th Edition (2010), "Optical Fiber Communications", McGraw Hill International Edition.
29. Arwa. H. Bashar, Moustafa H. Aly and A.K. Aboulseoud (2011), "Different Pump Configuration For Discrete Raman Amplifier", International Journal of Scientific & engineering Research Volume 2.
30. Gerald P. Ryan (1997), "Dense Wavelength Division Multiplexing", CIENA Coprporation.