PERFORMANCE OF MULTICHANNEL FIBER OPTIC PARAMETRIC AMPLIFIER

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ABSTRACT

Optical networks have a significant role to play in the present and future global telecommunication networking scenario due to the increasing demand for larger transmission capacity. In fiber optic communication systems, Dense Wavelength Division Multiplexing (DWDM) is very popular in which multiple optical signals at various wavelengths are combined and transmitted through a single fiber. DWDM technology provides a cost effective deployment strategy. One of the key components in DWDM system is an optical amplifier. Fiber optical parametric amplifier (FOPA) can be used for several signal processing application including optical amplification, phase conjugate and wavelength conversion. FOPA operate based on a fiber nonlinearity known as four wave mixing (FWM). Fiber optical parametric amplifiers are based on the third-order susceptibility of the glasses making up the fiber core. It happens when at least two waves with the different frequencies co-propagate in the fiber. In this simulation is to show the ability of a single pump parametric amplifier in the eight channels DWDM transmission system and performance of FOPA in order to ensure higher level of amplification coped with less amplifier produced signal impairments. The simulation were done by software OptiSystem 13, the fiber optical amplifier is perform by simulation of 10 Gbit/s each channel. Furthermore NRZ encoding technique, intensity OOK modulation format has been used in this simulation. The frequencies of channel carrier was chooses in the region from 193.1 THz to 193.8 THz. Eight modulated signal are transmitter over 220 km span long single mode fiber. The single pump combination with four signal radio frequency, 180 MHz, 420 MHz, 1.087 GHz and 2.133 GHz are used to show higher level of amplification and mitigating the impact of simulated Brillouin scattering. As a result, the maximum 22.134 dB gain and lower noise figure 2.84 dB is achieved.

ABSTRAK

Rangkaian optik mempunyai peranan penting dalam senario rangkaian telekomunikasi global pada masa kini dan juga pada masa hadapan berikutan permintaan yang semakin meningkat untuk kapasiti penghantaran yang lebih besar. Dalam sistem komunikasi gentian optik, Dense Wavelength Division Multiplexing (DWDM) adalah sangat popular di mana pelbagai isyarat optik dalam berbagai panjang gelombang digabungkan dan dihantar melalui gentian tunggal. Teknologi DWDM menyediakan strategi perlaksaan yang lebih effektif. Salah satu komponen utama dalam teknologi DWDM ialah penguat optik. Gentian parametrik penguat optik (FOPA) boleh digunakan dalam beberapa aplikasi isyarat pemprosesan termasuk penguatan optik, fasa konjugate dan penukaran panjang gelombang. FOPA beroperasi berdasarkan gentian tidak linear yang dikenali sebagai *Four-wave Mixing*, (FWM). Serat penguat parametrik optik adalah berdasarkan kecenderungan ketiga-susunan kaca yang membentuk teras gentian. Ia berlaku apabila sekurang-kurangnya dua gelombang dengan frekuensi yang berbeza tersebar bersama di dalam gentian. Dalam proses simulasi ini menunjukkan keupayaan penguat pam parametrik tunggal dalam sistem penghantaran DWDM lapan saluran dan prestasi FOPA untuk memastikan tahap penguatan yang lebih tinggi diatasi dengan kurangnya penguat yang menghasilkan kecacatan pada isyarat. Proses simulasi ini dilakukan menggunakan perisisn OptiSystem 13, gentian penguat optik menghantar 10 Gbit/s setiap channel dianalisis. Tambahan pula, teknik NRZ dan format modulasi intesiti OOK telah digunakan dalam simulasi ini. Spectrum 193.1 THz hingga 193.8 THz telah dipilih untuk digunakan dalam simulasi ini. Lapan isyarat yang dimodulasi dihantar pada jarak 220 km melalui gentian tunggal. Kombinasi pump tunggal dengan bantuan empat isyarat frekuensi radio iaitu 180 MHz, 420 MHz, 1.087 GHz dan 2.133 GHz telah menunjukkan peningkat penguatan dan mengurangkan kesan *stimulated*

Brillouin scattering. Keputusan menunjukkan maksimum gain iaitu 22.134 dB dan noise figure yang rendah dapat dicapai.

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LIST OF ABBREVIATIONS

EDFA	- Erbium Doped Fiber Amplifier
WDM	- Wavelength Division Multiplexer
DWDM	- Dense wavelength division multiplexing
C-band	- Convensional Band
L-band	- Long Length Wideband
OSA	- Optical Isolator Analyzer
ASE	- Amplifier Spontaneous Emission
SNR	- Signal Noise Ratio
BER	- Bit Error Rate
CW	- Continuous Wave
DCF	- Dispersion compensating fiber
DeMux	- Demultiplexer
DSF	- Dispersion shifted fiber
FOPA	- Fiber optical parametric amplifier
FWM	- Four Wave Mixing
HNLF	- Highly Nonlinear Fiber
MZM	- Mach Zehnder Modulator
NF	- Noise Figure
NRZ	- Nonreturn-to-Zero
O/E/O	- Optical electrical optical
OOK	- On-off keying
OF	- Optical Fiber
PMD	- Polarization mode dispersion

PRBS	- Pseudo random binary sequence
RZ	- Return-to-zero
SBS	- Stimulated Brillouin scattering
SMF	- Single mode Fiber
SPM	- Self-phase modulation
SRS	- Stimulated Raman scattering
SSMF	- Standard Single Mode Fiber
XPM	- Cross-phase Modulation
ZDW	- Zero-dispersion wavelength

CHAPTER 1

Introduction

1.1 Background of study

Optical fiber communication systems have attracted remarkable attention in the past two decades, as they are up to now the most promosing technology in response to the exponentially growing demand for higher transmission capacity. This is due to the technique feature of optical fibers, which is their relatively low attenuation over a wide frequency range in third telecommunication window around 1550 nm. This telecommunication window offers a bandwidth of a few tens of THz. However, most of the installed fiber optic communication systems are only using a fraction of this huge available bandwidth.

The technique of multiplex several signals at different wavelengths and transmit them in a single fiber, which is called wavelength division multiplexing (WDM) can used to fully utilize the available bandwidth of optical fibers. [1]. By increasing the number of wavelengths, the transmission capacity will be enhanced using this technology. WDM became possible only with the emergence of the erbium-doped fiber amplifier (EDFA) [2], which provided amplification of multiple wavelengths simultaneously due to its relatively large bandwidth and low crosstalk [2]. The EDFA uses fiber doped with erbium as a gain medium to amplify an optical signal. Amplification is a result of stimulated emission of photons from Erbium ions in the fiber. The dopant ions are pumped (usually at 980 nm or 1480 nm) to a higher energy state from where they can release their energy by stimulated emission of a photon which has the same wavelength as the input signal. This release energy will bring the excited ions back to the lower energy level and meanwhile will amplify the input optical signal.

Another, the fiber Raman amplifier (FRA) also one of optical amplifiers based on fiber nonlinearities. FRA can utilizes a nonlinear phenomenon in fibers known as the stimulated Raman scattering (SRS) for amplification [3,4]. In SRS the incident pump photon gives up its energy to create another photon with a lower energy at a lower frequency, while the remaining energy is absorbed by the medium in the form of molecular vibration. When the pump and signal beams are injected into the fiber, energy is transferred from the pump to signal through SRS, which gives rise to Raman gain. The Raman gain can be distributed in the transmission fiber which usually reduces the noise.

Fiber optical parametric amplifier (FOPA) operated based on another fiber nonlinearity known as four wave mixing (FWM). These amplifiers used as another possible solution on fiber nonlinearities. Lately these amplifiers are investigated by many researches. FWM arises from the third order nonlinearity in a fiber and occurs when at least two waves with different frequencies co-propagate in the fiber. A refractive index modulation occurs at the difference frequency of the input waves, which creates an additional frequency component. FOPA can operate at any arbitrary wavelength. In the meantime, the FOPA gain is approximately twice as high as that of the FRA of the same parameter [5]. The higher gain makes FOPA more suitable for lumped amplification and all-optical signal processing applications. An important, the generation of an idler in the parametric process can be used for wavelength conversion [6]. FOPA are uni-directional amplifiers which makes them less sensitive to saturation effects arising from the generated internal amplified spontaneous emission (ASE) [7].

Furthermore, FOPA are used for amplification of WDM communication signals is that nonlinearity of the amplifying medium may lead to detrimental inter-channel crosstalk [8], which arises from spurious FWM and cross-gain modulation (XGM) due to pump depletion [9]. FOPA have characteristic which make them have the potential to be used for a variety of applications [5]. In additional to being an amplifier, due to the generation of a new wave, FOPA can simultaneously be used as a wavelength converter [10,11] which is required for wavelength routing in optical works. The intrinsic spectrum inversion of idlers in FOPA can be used for dispersion compensation in long haul transmission system. Due to the requirement of higher network capacity, the data bit rate and channel number of WDM system have been rapidly increasing.

The performance of Fiber Optical Parametric Amplification (FOPA) today has been significantly improved by the advances in both highly nonlinear fiber (HNLF), which acts as the gain medium, as well as improved pump sources offering high coherence and high power. FOPA are an innovative type of amplifiers with many promising amplification [1]. In FOPA there is several factor effected for their performances, which is polarization dependence of the gain, stimulated Brillion scattering, transferred from the pump to the amplified optical signal and related intensity noise (RIN) [2]. Fiber optic parametric amplifiers (FOPA), based on four-wave mixing (FWM) occurring inside optical fibers, are attracting considerable attention because they can provide signal for the entire wavelength band used in optical communication system and generation of phase conjugated idler harmonics that can be used for wavelength conversion [3]. There has several key of components in FOPA, it is high power, single wavelength pump laser and a specifically tailored highly nonlinear and low dispersion optical fiber [4]. The maximum gain can be achieved by using single-pumped in FOPA. Furthermore, for low-penalty amplification improvement of DWDM signal by means of FOPA is achieved by reducing signal-signal FWM crosstalk using short highly nonlinear fiber (HNLF) in conjunction with a high power pump.

1.2 Problem statement

DWDM system required rapidly demand in internet traffic due to emerging multimedia application. In order to fulfill such required system, FOPA can be useful for communication system because it is offering prospect for amplification over large bandwidth outside the EDFA band. However the nonlinearity of the amplifying medium and good phase matching are necessary for parametric amplification which is occur deleterious nonlinear crosstalk in DWDM system. Since of these issues, the crosstalk can be reduced by using highly uniform fibers, low signal power, polarization multiplexing and one pump FOPA. By using single pump of FOPA can provide higher gain and also can reduces crosstalk.

1.3 Objectives

Most of this project is focused on the fiber optical parametric amplifier (FOPA) in a DWDM transmission. An objective of this project is

i) To design and simulate the setup of FOPA.

ii) To exhibit the performance with higher gain and lower noise figure in FOPA.

iii) To evaluate the length of HNLF, pump power and input power signal by single pump of FOPA.

1.4 Scope of project

i) Using non return zero encoding technique with phase modulation format

ii) Optimization the pump power to get highest gain and better bit error rate BER to get better quality in data transmission.

iii) Channel spacing is set at 100 GHz to separates eight signals channel multiplex.

CHAPTER 2

Literature Review

2.1 Theoretical Background

This part will describe about theoretical background of fiber optical parametric amplifier performance by reviewing the previous project related to this research.

2.2 Optical communication system

In optical communication system, the data is transported into optical fiber by light signals that travel through suitable channel that used. This provides transmission of data over long distances with higher speed and bandwidth as compared to the other media used for telecommunications. A electrical signal is modulated onto a carrier light such as the light from continuous wave laser using opto-electronic modulator (Mach Zehnder modulator). The light wave carrying signal then travels in the optical fiber and then received at the other end by a light wave receiver such as photo detector which then converts the light back to the electrical signal [12]. In order to utilize the capacity of an optical fiber to the maximum extent, several electrical channels are multiplexed onto a signal fiber channel using either wavelength division multiplexing (WDM) or optical time division multiplexing (OTDM).

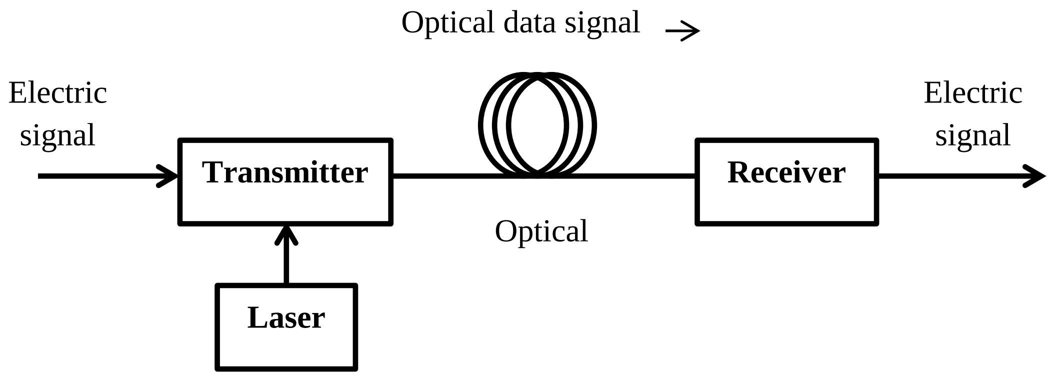

Figure 2.1: Schematic basic of optical transmission

Over long spans of optical fiber channel, the optical signal attenuates due to dispersion, bending losses, fiber imperfection and polarization mode. Amplifier is used to regenerate the signal after a certain distance [13]. Figure 2.1 depicts the schematic of the basic optical communication system.

2.3 Fiber Optic Parametric Amplifier Theory

Optical Parametric Amplifier relay on the third order nonlinearity of the fiber material and it can in principle be operated at an arbitrary center wavelength, corresponding to the zero-dispersion wavelength of the fiber. Their bandwidth depends on pump power, fiber nonlinearity and fiber dispersion. The presence of a frequency-shifted idler indicates that such devices can also be used as broadband wavelength converters, possibly exhibiting high conversion efficiency. The effect of dispersion fluctuation on noise properties of FOPA's with use of highly non-linear dispersion shift fiber (HNLDSF), it was found that zero dispersion wavelengths (ZDWL) variation became very significant with high gain of more than 25 dB [14]. When the input signal power equals a power called the saturation power, the parametric gain will amplify the signal and idler waves equally. The idler wave is produced in all parametric amplifiers (PA) with a frequency less than the pump by an amount equals exactly the frequency shift between the signal and that of the pump as shown in Figure 2.2

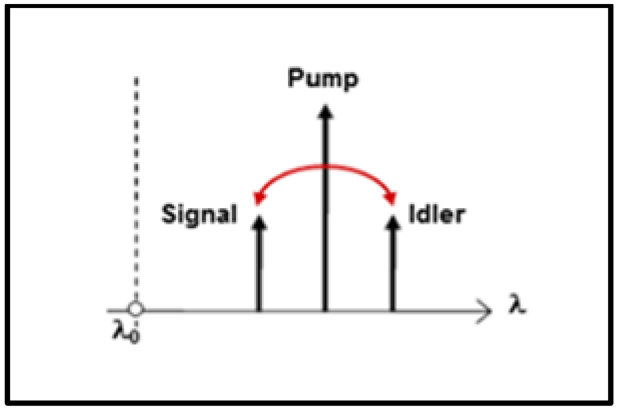

Figure 2.2: Amplifier and idler signal after HNLF

2.4 Fiber Nonlinearities

The response of any dielectric (silica) to light becomes nonlinear for intense electromagnetic fields, and optical fibers are no exception. On a fundamental level, the origin of nonlinear response is related to a harmonic motion of bound electrons under the influence of an applied field. When an electric field is applied to a dielectric material, which contains negative (electrons) and positive (nuclei) charges, it drives these charges and polarizes atoms in the dielectric material. For intense electric field (high power) applied, a harmonic motion of the electrons is observable. As a result the total polarization P induced by electric dipoles is not linear in the electric field E, but satisfies the more general relation in a Taylor expansion as [15].

$$\mathbf{P} = \varepsilon_0\chi^{(1)} \cdot \mathbf{E} + \varepsilon_0\chi^{(2)} : \mathbf{EE} + \varepsilon_0\chi^{(3)} \vdots \mathbf{EEE} + \ldots , \qquad (2.0)$$

Where ε_o is the vacuum permittivity and $\chi^{(j)}$ is jth order susceptibility. In general, $\chi^{(j)}$ is a tensor of rank $j+1$. The linear susceptibility $\chi^{(1)}$ represent dominant contribution to P. the second order susceptibility $\chi^{(2)}$ is responsible for such nonlinear effects as second-harmonic generation and sum frequency generation. However, it is nonzero only for media that lack of inversion symmetry at the molecular level. As SiO_2 is a symmetric molecule, $\chi^{(2)}$vanish for silica glasses. As a result, optical fiber do not normally exhibit second order nonlinear effects. Nonetheless, the electrical-quadrupole and magnetic-dipole moments can generate weak second order nonlinear effects.

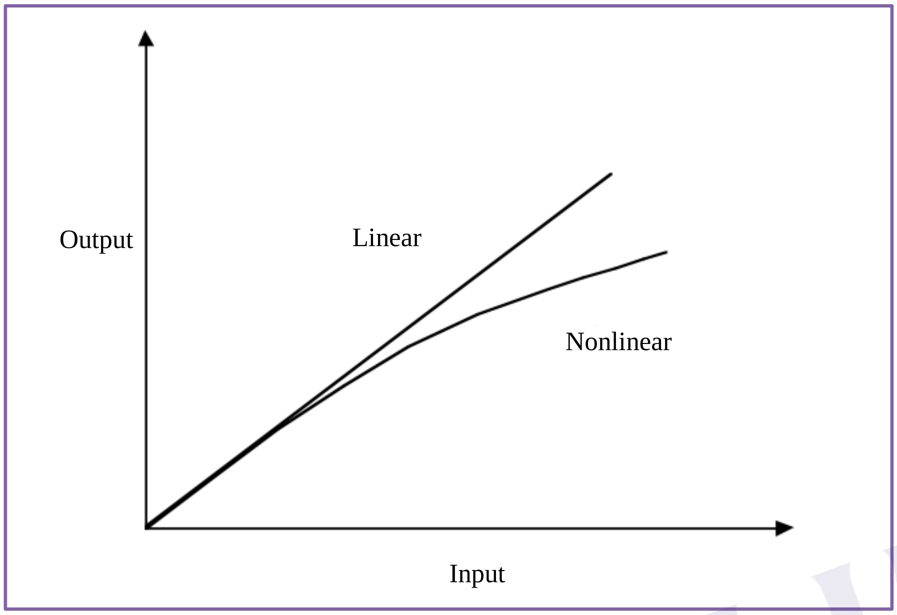

Figure 2.3 : Linear and nonlinear interaction

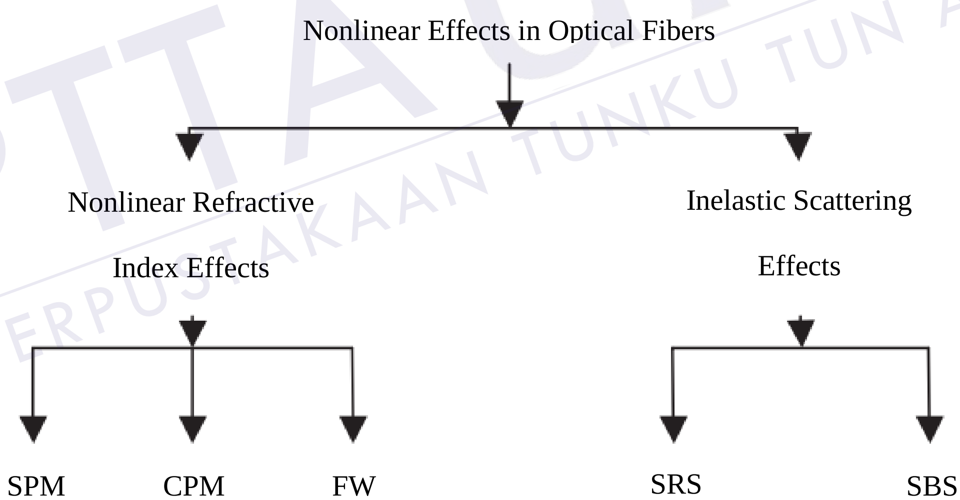

Figure 2.4: Nonlinear effect in optical fiber

2.5 Nonlinear Refractive Index Effect

2.5.1 Four Wave Mixing

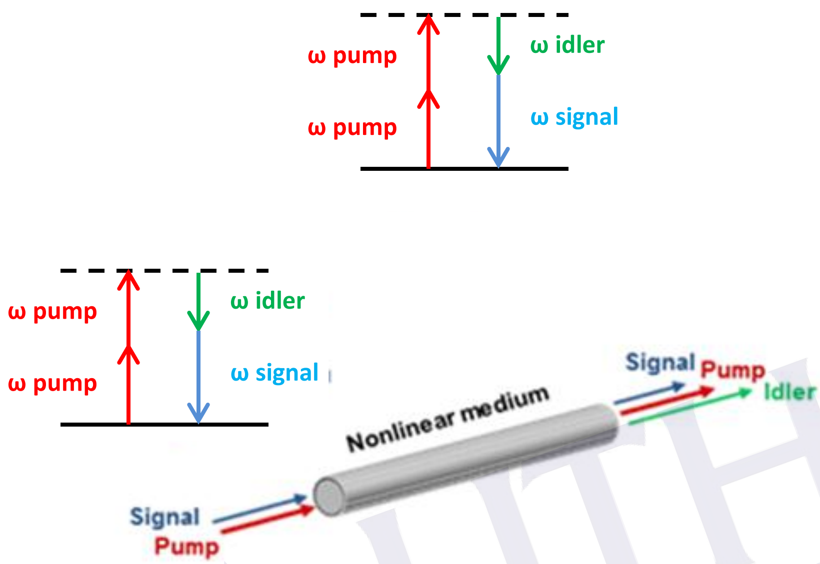

Figure 2.5: Four wave mixing in a waveguide to generate a new colour of light

Four-wave mixing (FWM) also called four photon mixing is one of the major in limiting factor in WDM optical fiber communication system that use the low dispersion fiber or narrow channel spacing. FWM is very harmful for a multichannel fibers optics transmission system such as wavelength division multiplexing (WDM). Normally, multiple optical channels passing through the same fiber interact with each other very weakly. However, these weak of interaction in glass become significant over long fiber-transmission distance. The most important is FWM in which three wavelength interact to generate fourth [16].

The term of four-wave mixing is usually reserved for the interaction of four spatially or spectrally distinct fields. FWM reduces to the previously discussed processes when two or more of the frequencies are degenerate. FWM may be used to probe either one photon resonances or two photon resonances in a material by measuring the resonant enhancement as one or more of the frequencies are tuned. By tuning the frequencies to multiple resonances in the material, excited state cross sections, lifetimes, and linewidth may be measured. [17]

The process of FWM is when two intense pump waves at frequencies ω_1 and ω_2 co-propagate inside a silica fiber, electrons, which only have a tiny mass, can be driven almost instantaneously at any frequency stemming from the mixing of these waves. Even though the potential provided by silica molecules confines electrons top their original atom, electrons respond to the applied electromagnetic field by emitting secondary waves not only at the original frequencies ω_1 and ω_2 (linear response), but also at two new frequency components denoted as ω_3 and ω_4 (third order nonlinear response). Physically, two photons at the original frequencies are scattered elastically into two new photons at frequencies ω_3 and ω_4. In the absence of absorption, the total energy and momentum is conserved during FWM.

In practice, the efficiency of the FWM process is enhanced by seeding it. Seeding is accomplished by lunching a signal wave at the frequency ω_3. The probability of creating photons at the frequency ω_4 depends on how many photons at ω_3 already exist inside the fiber. As a result, the FWM process is stimulated and new photons at ω_3 and ω_4 are created with an exponential growth rate provided the phase matching condition is nearly satisfied. The fourth wave at the frequency ω_4 is commonly referred as the idler wave following the terminology used in the microwave literature [18].

The process of four-wave mixing is when photon at frequencies ω_1 and ω_2 are annihilated and create two photons at frequencies ω_3 and ω_4 such that

$$\omega_3 + \omega_4 = \omega_1 + \omega_2 \tag{2.1}$$

The FWM process can be described by Eq.(2.1) relies on a phase matching condition given by

$$\Delta\kappa = \kappa 3 + \kappa 4 - \kappa 1 - \kappa 2 = 0 \tag{2.2}$$

Condition (2.2) is easily satisfied in optical fibers for the partially degenerate case when $\omega_1 = \omega_2$. The FWM effect is used in many important fiber applications,

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