Investigation of four wave mixing & cross gain modulation in photonic transmission system

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This project titled Investigation of Four Wave Mixing and Cross Gain Modulation in Photonic Transmission System was prepared and submitted by Noor Faridah Binti Mat Isa (1330110934) and has been found satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the Master of Science Microelectronic Engineering in Universiti Malaysia Perlis (UniMAP).

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ABBREVIATIONS

ASE	Amplified Spontaneous Emission
BER	Bit Error Rate
CW	Continuous Wave
DCF	Dispersion Compensating Fiber
DWDM	Dense Wavelength Division Multiplexing
DRZ	Duobinary Return-to-Zero
EDFA	Erbium Doped Fiber Amplifier
FBG	Fiber Bragg Grating
FWM	Four Wave Mixing
MUX	Multiplexer
DEMUX	Demultiplexer
MZM	Mach-Zehnder Modulator
NRZ	Non Return to Zero
OOK	On-Off Keying
OSA	Optical Spectrum Analyzer
PC	Polarization Controller
PRBS	Pseudo-Random Bit Sequence
RZ	Return-to-Zero
SBS	Stimulated Brillouin Scattering
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SPM	Self-Phase Modulation

XGM	Cross Gain Modulation
XPM	Cross-Phase Modulation
WC	Wavelength Converter
WDM	Wavelength Division Multiplexing

Penyiasatan Mengenai Pencampuran Empat Gelombang Dan Pemodulatan Gandaan Silang Di Dalam Sistem Penghantaran Fotonik DWDM

ABSTRAK

Tesis ini menfokuskan kepada kajian mengenai dua jenis ketidaklelurusan di dalam optik iaitu, pencampuran empat gelombang (FWM) dan pemodulatan gandaan silang (XGM) di dalam sistem penghantaran data dan aplikasinya. Kajian bermula dengan menganalisis prestasi untuk kedua-dua kesan tak linear di dalam sistem penghantaran data pelbagai saluran (WDM). Ia juga merangkumi aspek berkaitan dengan sistem penghantaran optik untuk penghantaran jarak jauh. Model untuk penghantaran data jarak jauh melebihi 1680 km bagi 16 saluran RZ dan NRZ mencapai isyarat yang baik berdasarkan nisbah bunyi. Faktor-Q berkurangan apabila jumlah saluran bertambah untuk kedua-dua format NRZ dan RZ.Kajian ini juga menilai beberapa format modulasi dalam sistem DWDM seperti RZ, NRZ, CSRZ dan duobinary. Keputusan menunjukkan bahawa nilai Q berkurang dengan lebih perlahan bagi RZ berbanding dengan NRZ dan duobinary merupakan format yang paling berkesan merujuk kepada kelinearan dan had kekukuhannya berbanding format modulasi lain seperti RZ dan NRZ. Dalam pemerhatian ini, kesan FWM dan XGM mengurangkan prestasi penghantaran isyarat optik di dalam sistem penghantaran data dengan ketara. Ini boleh dikaitkan dengan pelancaran kuasa yang lebih tinggi ke dalam satu saluran yang membawa kepada kesan tak linear. Kerja-kerja ini direka untuk mengoptimumkan prestasi peranti bagi sistem DWDM memandangkan had yang dikenakan oleh kesan tak linear. Pada peringkat awal, peranti penguat dan pengulang dalam gentian optik digunakan untuk meningkatkan prestasi sistem. Pendekatan lain yang dikenali sebagai kaedah penggunaan jarak yang berbeza bagi setiap saluran pada transmitter pelbagai saluran digunakan untuk mengatasi had yang disebabkan oleh FWM dan XGM. Pemerhatian menunjukkan bahawa kaedah penggunaan jarak yang berbeza bagi setiap saluran meningkatkan prestasi faktor Q bagi sistem ini berbanding berbanding kaedah jarak yang sama bagi setiap saluran. Ia juga jelas diperhatikan bahawa penggunaan modulasi duobinary mengurangkan kesan FWM dalam sistem DWDM. Tahap produk FWM dikurangkan sekitar 12 dB yang menjadi penyumbang utama kepada peningkatan prestasi sistem.

Investigation Of Four Wave Mixing & Cross Gain Modulation In Photonic Transmission System

ABSTRACT

This thesis focuses on investigation of two nonlinear effects, four wave mixing (FWM) and cross gain modulation (XGM) in photonic transmission system. The work begins with analyzing the performance for both nonlinear effects in multiple channels of wavelength division multiplexing (WDM) transmission system. It addresses the optical transmission system for long haul transmission. The long haul model of 16 channels RZ and NRZ over 1680 km achieved a good signal to noise ratio. The Q-factor decreases with the growth number of channels for both NRZ and RZ format. This study also examined several modulation formats in DWDM system such as RZ, NRZ and duobinary. It is observed that the Q factor degrades slower for RZ in comparison to NRZ. The duobinary has shown the most efficient format due to its nonlinear and band limitation robustness than traditional modulation formats, such as RZ and NRZ. In the observation, FWM and XGM crosstalk degrades the optical signal transmission characteristic of multiplexing signals system significantly. This could be attributed to the higher power launched into the individual channel that led to the nonlinear effects. The work is designed to optimize the performance for the DWDM system considering the limitation imposed by the nonlinear effects. Preliminarily, in-line optical amplifiers and repeaters are noticed to enhance the system. Other approach known as unequal spacing channel allocation in multichannel transmitter is employed to overcome limitation imposes by FWM and XGM. The observation reveals out that unequal channel spacing advances the Q-factor for the system as compared to equal channel spacing. It is also clearly observed that the adoption of duobinary modulation scheme reduces the impact of FWM in DWDM system. The levels of FWM products are reduced by around 12 dB which offer a prominent performance benefit for the system.

CHAPTER 1

INTRODUCTION

1.1 Thesis Background

The field of fiber optics developed rapidly during the 1960s, mainly for the purpose of image transmission through a bundle of glass fibers. These early fibers were extremely loss (loss >1000 dB/km) from the modern standard fibers. However, the situation changed drastically in 1970 whereby losses of silica fibers were reduced to below 20 dB/km (Govind P.Agrawal, 2007). Further progress in fabrication technology resulted by 1979 in a loss of only 0.2 dB/km in the 1.55 μm wavelength region, a loss level limited mainly by the fundamental process of Rayleigh scattering.

Keigo IIzuka (2002) mentioned that the availability of low loss silica fibers led not only to a revolution in the field of optical fiber communications but also to the advent of the new field of nonlinear optics. Stimulated Raman and Brillouin scattering processes in optical fibers were studied as early as 1972. This work stimulated the study of other nonlinear phenomena such as optically induced birefringence, parametric four wave mixing and self-phase modulation. The decade of 1980s saw the development of pulse compression and optical switching techniques that exploited the nonlinear effects in fibers (Govind P.Agrawal, 2001).

The field of nonlinear optic continued to grow during the decade of the 1990s. A new dimension was added when optical fibers were doped with rare earth elements and used to make amplifiers and lasers. The terms linear and nonlinear in optics, mean intensity independent and intensity dependent phenomena respectively. Nonlinear effects in optical fibers occur due to change in the refractive index of the medium with optical intensity and, inelastic scattering phenomenon. The power dependence of the refractive index is responsible for the Kerr-effect. Depending upon the type of input signal, the Kerr-nonlinearity manifests itself in three different effects such as Self-Phase Modulation (SPM), Cross-Phase Modulation (CPM) and Four-Wave Mixing (FWM). At high power level, the inelastic scattering phenomenon can induce stimulated effects such as Stimulated Brillouin-Scattering (SBS) (S.P. Singh and N. Singh, 2007). After 2000, two nonlinear effects occurring inside optical fibers, namely stimulated Raman scattering and four wave mixing, were employed to develop new types of fiber optic amplifiers. Fiber optic parametric amplifiers based on four wave mixing are also attractive because of their potential for ultrafast signal processing.

In this research, integrating unequal channel spacing with duobinary modulation format which has been used in many researches as a good alternative of RZ, NRZ and DRZ is studied.

The work reported in this thesis evaluates the performance of nonlinear effects in photonic transmission system. Performance studies have been carried out for four wave mixing (FWM) and cross gain modulation (XGM).

Performance of this nonlinear effect in multiple channels of WDM transmission system has been analyzed. Bit error rate test (BERT) has been considered as the performance index in all analysis. The analysis has been carried out with simulation studies using Optisystem.

1.2 Problem statement

The present transport networks are based on the electronic devices such as electronic repeaters, switches and drop multiplexer. These devices put limit on the optical fiber bandwidth as these devices cannot sustain high data rate. There have been numerous proposals to implement light switching between optical fibers such as semiconductor amplifiers, liquid crystal and tiny mirrors (N. Sharma, 2012). Optical switches are the subject of research in past few years and some of these switches are available commercially.

The long haul simultaneously requires high data rates and long distances. This is the condition under which fiber nonlinearities, dispersion and crosstalk induced by optical switches are the limiting factors. Crosstalk can be intraband or interband. Intraband crosstalk degrades the performance of network more than as compare to interband. Intraband is considered in this research.

Four wave mixing and cross gain modulation crosstalk degrades the optical signal transmission characteristic of wavelength division multiplexing (WDM) system significantly.

Over the years, various method and techniques were developed to suppress these nonlinear effects. Unequally spaced (US) channel allocation methods are reported, but application of those are limited to prime number, many solutions are found for specific value of channel number and channel spacing. The problem has been formulated algebraically that reduces time complexity and minimizes the total optical bandwidth requirement. Sharma & Kaur (2013), proposed a method but better result than that can be found at the cost of bandwidth.

In 2003, Zhang, J.G and Sharma, through their journal proposed another method but better result than that can be found at the cost of bandwidth. Randhawa proposed two methods which have the same limitations (Forghieri, Tkach, & Chraplyvy, 1995). A method for finding the solutions to the unequal spaced spaced channel allocation problem has been reported by A. Rouf and M.S Islam in 2012. The problem has been formulated algebraically reduces time complexity and minimizes the total optical bandwidth requirement.

1.3 Thesis Objectives

The main purpose of the study is to investigate the nonlinear effects four wave mixing (FWM) and cross gain modulation (XGM) in wavelength division multiplexing (WDM) system. In addition, the study contributed the methods which are used to examine the impact of these effects on a transmission system consisting erbium doped fiber amplifiers (EDFAs) and a multiplex of coherent channels.

Generally, this work is divided into two major parts. First, the investigation of FWM and XGM effects in transmission system. It also includes several modulation formats of DWDM system for return to zero (RZ), non return to zero (NRZ), and duobinary modulation format (DRZ). The second major objective is to reduce both of the nonlinear effects XGM and FWM in DWDM optical transmission system. The simulations are executed to optimize the device performance for the WDM system considering the limitation imposed by the nonlinear effects in multiwavelength systems with in line optical amplifiers and repeaters. Unequal channel spacing in multichannel transmitter and duobinary modulation technique is proposed in this research to overcome this limitation

1.4 Methodology

An improved architecture of nonlinear effects FWM and cross gain modulation is presented in this thesis. Performance of the nonlinear effect in multiple channels of WDM transmission system is analyzed.

Fig. 1.1 shows the flow chart in designing XGM and FWM. The works start with the investigation of XGM and FWM and understanding of these two effects. XGM and FWM are designed in the background of the Optisystem. The project circuits include of several parts and each part consists the combination of more than one component. The main part of this circuit is transmitter, receiver and channel parts.