UNIVERSITI PUTRA MALAYSIA

DESIGN AND ANALYSIS OF A HIGHLY SENSITIVE HYBRID DISPERSION-COMPENSATED ERBIUM-DOPED FIBER AMPLIFIER

MD ZAINI BIN JAMALUDIN

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MD ZAINI BIN JAMALUDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

June 2007

DEDICATION

To

My Loving Parents:
Saudah Binti Md Yatim
And
My Late Father:
Jamaludin Bin Ibrahim

My Wife:
Norashikin Binti Abdul Kadir

My Children:
Muhammad Hafiz, Hani Izzati, Ahmad Syafiq and Nurhanani Amni

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DESIGN AND ANALYSIS OF A HIGHLY SENSITIVE HYBRID DISPERSION-COMPENSATED ERBIUM-DOPED FIBER AMPLIFIER

By

MD ZAINI BIN JAMALUDIN

June 2007

Chairman: Professor Mohamad Khazani bin Abdullah, PhD

Faculty: Engineering

Optical amplifiers have a great impact on optical communications due to their ability to amplify light along the optical path. Thus optical amplifiers have become indispensable components in high-performance optical communication links. However, while optical amplifiers are effective in mitigating link power loss problems, they are conventionally unusable and irrelevant for another major fiber optic transmission which is dispersion. Compensation of dispersion is a necessity in high speed and/or long distance links. This is separately achieved by use of a dispersion compensator which is either of fiber optics based or fiber Bragg grating based. Thus there is clear need for an integrated system which can achieve both important functions at the same time.

New designs have been envisaged and achieved in this thesis. It has shown a great enhancement in performing simultaneous function in amplifying the power as well as compensating the dispersion of the signal (Hybrid). The double-pass erbium-doped fiber amplifier (EDFA) with embedded chirped fiber Brag grating and as well as other filtering technique (optical Bragg grating) have been demonstrated and investigated. It is shown through simulations and by the hardware implementation that the new design is significantly better than that of existing double pass amplifier and double pass amplifier with tunable filter.

There are two levels of tests carried out in this study; device level and system (transmission) level. At the device level, the performance parameters of the new configurations are thoroughly characterized showing improvement in gain, noise figure, and the output power, considering the effects of pump power, input signal level, and input signal wavelength. The device configuration is based on double-pass amplification with a Bragg grating employed as the reflector. The grating also serves as a filter suppressing the Amplified Spontaneous Noise from the signal. At the system level, the performance parameters investigated are power sensitivity, power penalty, signal-to-noise ratio (SNR), eye amplitude, eye opening and jitter which all see a level of improvements, based on Wavelength Division Multiplexing (WDM) system.

A gain as high as 53.4dB, a noise figure of as low as 5.36dB, and sensitivity of -40dBm have been achieved at the BER of 10^{-12} for the transmission speed of 2.5Gbps. The new hybrid amplifier provides power gain improvement of 12.5 dB and 8.4 dB for single and multi channel system. The power penalty incurred by the new hybrid amplifier for single and multi channel system are 3.5 dB and 3.2 dB respectively. Comparisons are made against the conventional double pass amplifiers and back-to-back connection.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MEREKABENTUK DAN MENGANALISA SEBUAH PEMBESAR HYBRID SENSITIF PAMPASAN SEBARAN FIBER TERDOPAN ERBIUM

Oleh

MD ZAINI BIN JAMALUDIN

Jun 2007

Pengerusi: **Profesor Mohamad Khazani Abdullah, PhD**

Fakulti: **Kejuruteraan**

Pembesar optik mempunyai satu kesan besar di dalam komunikasi optik disebabkan oleh keupayaannya untuk membesarkan cahaya sepanjang lintasan optic. Oleh itu pembesar optik telah menjadi sebahagian daripada komponen-komponen penting di dalam talian komunikasi optik berprestasi tinggi. Walaupun optik amplifier dapat memberi kesan yang efektif dalam menangani kehilangan kuasa dalam gentian optik, tetapi secara konvensional tidak berkesan untuk memgatasi masalah utama dalam fibre transmisi optik iaitu kesan sebaran. Pampasan sebaran adalah satu keperluan dalam talian yang berkelajuan tinggi dan/atau rangkaian jarak jauh. Ini selalu nya diperolehi secara berasingan dengan menggunakan penyebaran pemampas yang berdasarkan optik fibre atau berdasarkan fibre Bragg parutan. Oleh itu terdapat

satu keperluan yang jelas dan penting untuk mengujudkan satu sistem bersepadu yang boleh menghasilkan kedua-dua fungsi pada masa yang sama.

Rekaan terbaru telah berjaya menepati jangkaan dan pencapaian dalam tesis ini. Ia telah berjaya membuktikan satu peningkatan dalam menjalankan secara serentak fungsi memperbaiki serakan (compensation) dan juga mengandakan isyarat secara kacukan (hybrid). Pembesar kacukan terdopan Erbium laluan berganda (DP-EDFA) bersama-sama dengan tertaman parutan chirped Bragg berserta dengan teknik penapisan yang lain (pemboleh ubah parutan optik Bragg) telah didemonstrasikan dan disiasat. Siasat telah di jalankan secara simulasi dan juga secara ujilari komponen di dalam makmal.

Terdapat dua jenis ujian yang telah dijalankan dalam kajian ini; tahap alatan dan tahap sistem (transmisi). Di tahap ujian alat, parameter prestasi tatarajah baru adalah dengan sempurna menggambarkan sifat menunjukkan pembaikan dalam keuntungan, angka hingar, dan kuasa keluaran, dengan mengambil kira kesan-kesan kuasa pam , aras isyarat masukan, dan isyarat jarak gelombang masukan. Konfigurasi alat berdasarkan kepada pembesar dua kali-laluan dengan satu Bragg parutan yang bertindak sebagai pemantul isyarat. Parutan juga berkhidmat sebagai satu penuras mengurangkan ataupun menghalang kesan Dikuatkan Bunyi Spontan (ASE) daripada isyarat. Di peringkat sistem, parameter prestasi disiasat adalah kuasa kepekaan, mendayai penalti, nisbah

isyarat dengan hingar (SNR), amplitud mata, keterbukaan mata dan ketaran dimana terdapat suatu peningkatan yang ketara, ujian berdasarkan sistem Bahagian Jarak Gelombang Multipleksan (WDM). Satu keuntungan setinggi 53.4dB telah didapati, satu bunyi bising angka serendah 5.36dB, dan kepekaan -40dBm telah tercapai di BER 10^{-12} untuk kelajuan penghantaran 2.5Gbps. Rekaan terbaru kacukan (hybrid) pembesar ini telah bejaya menambahbaikan gandaan kuasa se banyak 12.5 dB dan 8.4 dB masing-maing bagi system satu saluran dan pelbagai saluran. Ia juga dikenakan kuasa penalti sebanyak 3.5 dB and 3.2 dB masing-masing bagi system satu dan pelbagai saluran. Perbandingan-perbandingan ini dibuat terhadap gandan pembesar konvensional dan sambungan tanpa gentian fiber.

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I certify that an Examination Committee has met on 26 June 2007 to conduct the final examination of Md Zaini Jamaludin on his Doctor of Philosophy thesis entitled "Design and Analysis of a Highly Sensitive Hybrid Dispersion-Compensated Erbium Doped Fiber Amplifier" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Wan Mahmood Mat Yunus, PhD
Professor
Faculty of Sains
Universiti Putra Malaysia
(Chairman)

Syed Javaid Iqba, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sabira Khatun, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sahbudin Shaari, PhD
Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(Independent Examiner)

____

HASANAH MOHD. GHAZALI, PhD.
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Khazani Abdullah, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Adzir Mahdi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Faidz Abdul Rahman, PhD
Associate Professor
Faculty of Engineering
Multimedia University
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 15 November 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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MD ZAINI BIN JAMALUDIN

Date:

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASE	Amplified spontaneous emission
BER	Bit-error rate
BERT	Bit-error rate tester
BPF	Band-pass filter
CD	Chromatic dispersion
CFBG	Chirp Fiber Bragg grating
DCA	Digital communication analyzer
DCF	Dispersion compensation fiber
DFB	Distributed feedback laser
DP-EDFA	Double-pass - Erbium-doped fiber amplifier
DPC-$EDFA_I$	Double-pass CFBG- Erbium-doped fiber amplifier internal
DPC-$EDFA_E$	Double-pass CFBG- Erbium-doped fiber amplifier external
DPF-$EDFA_I$	Double-pass VOBG- Erbium-doped fiber amplifier internal
DPF-$EDFA_E$	Double-pass VOBG- Erbium-doped fiber amplifier external
DSF	Dispersion shifted fiber
EDF	Erbium-doped fiber
EDFA	Erbium-doped fiber amplifier
EMI	Electromagnetic interference