UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF REMOTELY PUMPED ERBIUM DOPED FIBER AMPLIFIER TRANSMISSION SYSTEM

MOHD SHAHNAN BIN ZAINAL ABIDIN

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By

MOHD SHAHNAN BIN ZAINAL ABIDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

December 2004

DEDICATION

To

My Mother;
SitiKhadijah Bt. Kila

My Father;
Zainal Abidin Bin Yahaya

Brothers and Sister;
Mohd Faizal, Mohd Haris, Mohd Rafie, Siti Nurathirah

Relatives, Friends, Teachers and Neighbours

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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December 2004

Chairman: Associate Professor Mohd Adzir Mahdi, Ph.D.

Faculty: Engineering

Erbium Doped Fiber Amplifier (EDFA) has been deployed extensively in optical communication systems especially for a long haul transmission link. Basically, EDFA requires a local pump laser for its optical amplification. This design will encounter problem if the amplifier is located at the middle of transmission line where power supply for the pump laser is unavailable. Therefore, remotely pumped amplifier can overcome the problem by injecting the pump light from either side of the transmission ends; transmitter or receiver.

This dissertation reveals a new technique of designing a repeaterless transmission system using a remotely pumped EDFA. By varying the length of transmission fiber before and after EDFA, its location can be optimized for a specific pump power. A bit error rate is used as the main performance parameter and its threshold value is set at better than 10^{-10}. The optimized location of EDFA will lead to the maximum transmission distance where it is found that the location of EDFA is closer to the receiver side.

In conclusion, the EDFA location on transmission line using remotely pumped technique gives major impact to the system's performance.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK DAN PEMBANGUNAN SISTEM TRANSMISI PENGUAT GENTIAN TERDOP ERBIUM DIPAM SECARA JAUH

Oleh

MOHD SHAHNAN BIN ZAINAL ABIDIN

Disember 2004

Pengerusi: **Profesor Madya Mohd Adzir Mahdi, Ph.D.**

Fakulti: **Kejuruteraan**

Penguat Gentian Terdop Erbium (EDFA) telah digunakan secara meluas di dalam sistem komunikasi optikal terutamanya untuk sistem talian transmisi panjang. Secara dasarnya, EDFA memerlukan laser pam setempat untuk penguatan optiknya. Rekabentuk ini akan menghadapi masalah jika penguat itu diletakkan di tengah talian transmisi di mana bekalan kuasa untuk laser pam tidak dapat diperolehi. Oleh itu, penguat dipam secara jauh mampu mengatasi masalah ini dengan menyuntik cahaya pam daripada mana-mana belah hujung transmisi; penghantar atau penerima.

Tesis ini mendedahkan suatu teknik baru dalam merekabentuk sistem transmisi tanpa ulangan menggunakan EDFA yang dipam secara jauh. Dengan mengubah panjang gentian transmisi sebelum dan selepas EDFA, lokasinya boleh dioptimumkan bagi kuasa pam yang spesifik. Kadar kesilapan bit diguna sebagai parameter prestasi dan nilai ambang ditetapkan kepada lebih baik daripada 10^{-10}. Lokasi EDFA yang optimum akan membawa kepada jarak transmisi maksimum yang mana didapati bahawa lokasi EDFA tersebut adalah lebih dekat kepada sebelah penerima.

Kesimpulannya, lokasi EDFA pada talian transmisi menggunakan teknik pam secara jauh memberi kesan yang besar kepada prestasi sistem.

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I certify that an Examination Committee met on 30th December 2004 to conduct the final examination of Mohd Shahnan bin Zainal Abidin on his Master of Science thesis entitled "Design and Development of Remotely Pumped Erbium Doped Fiber Amplifier Transmission System" 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:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of Supervisory Committee are as follows:

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DECLARATION

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

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MOHD SHAHNAN BIN ZAINAL ABIDIN

Date:

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LIST OF ABBREVIATIONS

ASE	-	Amplified Spontaneous Emission
BER	-	Bit Error Rate
BERT	-	Bit Error Rate Tester
DCF	-	Dispersion Compensating Fiber
DUT	-	Device Under Test
EDF	-	Erbium Doped Fiber
EDFA	-	Erbium Doped Fiber Amplifier
FEC	-	Forward Error Correction
G	-	Gain
GCE	-	Gain Conversion Efficiency
LD	-	Laser Diode
NA	-	Numerical Aperture
OSA	-	Optical Spectrum Analyzer
OSNR	-	Optical Signal to Noise Ratio
PRBS	-	Pseudo-Random Bit Sequence
PCE	-	Power Conversion Efficiency
PPM	-	Part Per Million
SOA	-	Semiconductor Optical Amplifier
TLS	-	Tunable Laser Source
VOA	-	Variable Optical Attenuator
WDM	-	Wavelength Division Multiplexing
WSC	-	Wavelength Selective Coupler

CHAPTER 1

INTRODUCTION

Telecommunication industries evolve rapidly since past years influenced by hungry demanding competition among manufacturers. Various telecommunication technologies have been created and innovated in order to achieve manufactures need for a reliable telecommunication quality more than just voice services. Higher bandwidths are required to satisfy a real time video on demand, live telecast and interactive applications. An optical communication is seen as one of the enabling technologies and being one of the key factors for the present and future applications. This chapter will explain briefly about optical communication systems and its development up to date. Later, optical amplifiers will be highlighted by focusing to rare-earth doped fiber amplifier. Statement of related problem and scope of the research to be conducted are discussed in details as well as its objectives to achieve.

1.1 Background

Optical fiber communication systems can fulfill the bandwidth need for a practical long haul transmission distance. It is reliable in handling and transmitting data over hundreds of kilometers with an acceptable bit error rate. Worldwide researchers continuously update the technology to improve the system's performance.

Typically, a link of optical fiber communication can be hundreds of kilometers and some could be extended up to several thousands of kilometers with an additional amplifiers and repeaters [1]. Data speed of each optical fiber transmission channel could reach up to 40 Gb/s [2] and it is limited by polarization-mode and chromatic dispersions, attenuation, and nonlinearity of the fiber [3]. Some schemes included into the system to improve the transmission distance and bit rate further such as Forward Error Correction (FEC), new remote pumping schemes and utilization of dispersion compensating fibers [4]. Optical fiber communication growths impressively with over 600 millions kilometers of fiber optics have been installed worldwide [5] with USD 1.2 billion amounted only for equipment of optical transport for the year of 2000 only [6].

1.2 Optical Communication System

Basically an optical communication system consists of a link of fiber optic as a transmission medium between a transmitter and a receiver. Information is converted from electrical to optical domain, modulated and multiplexed before injecting into the fiber optic. Optical fiber carries the information by guiding the laser beam in its core utilizing a total internal reflection requirement. At the receiver end, the signal is converted back into an electrical domain by a photodetector, amplified and demodulated to produce the original signal.

Between two transmission ends, an amplifier could be added to extend the link. Previously, electrical amplifiers were utilized by converting optical signal into electrical domain before it was amplified. Electrical amplifiers require external power supply to operate and this would become a big problem if a submarine transmission link is going to be deployed. The optical amplifier overcomes this barrier since the system uses light to amplify the information signals all optically and light can be send from a distance.

1.3 Optical Amplifiers

Traditionally, an electrical amplifier converts optical signal into electrical domain first before converts back again into optical signal after amplifying it. The state of signal changes several times as there are several stages of electrical amplifiers. This would add more delay in transmission and would affect the overall system bit error rates.

Every transmission medium introduces some signal losses of its signal power. The signal is attenuated along the medium as it travels from transmitter to receiver end. In an optical fiber communication, the attenuation causes the launched signal power level to decrease mainly due to signal absorption by the fiber itself.

Optical amplifiers are designed in such a way that the weakened signal is boosted to a specific power level for the next transmission sequent. As its name implies, optical amplifiers operate in optical domain and maintain signal's state along fiber within the transmission distance. They eliminate a need for signal interconversion of photons to electrons. Moreover, they offer a simple setup of a single in line components arrangement which is practical for any kind of modulations and transparent to any transmission speeds [7]. Multiple optical wavelengths can be easily amplified over a certain bandwidth that is limited by the operating range of optical amplifiers.

There are two main techniques to achieve optical amplification. Semiconductor Optical Amplifier (SOA) uses a fundamental of stimulated emission to amplify an optical information signal. The information signal is amplified in a semiconductor's active region where the injection current is applied to deliver the external energy to pump electron at the conduction band. The signal stimulates the electron transition and emits photons with the same energy and wavelength as the input's [8]. SOA can be used in both nonlinear and linear modes of operation [9, 10]. But on the other hand, the SOA is unsuitable to be utilized in a repeaterless transmission system due to its operation requirement for an inline electrical source.

The second type of optical amplification is the use of rare-earth doping material inside the fiber. Essentially it is a spliced active fiber connected to a pump laser within a transmission line [11]. It works on the principle of stimulated emission; the pump laser is used to provide energy and to excite ions in a special doped fiber to an upper energy level. Then, the ions are stimulated by photons of the information signal and fall down to lower level of energy; subsequently, emits photon energy exactly at the same wavelength of the signal.

1.3.1 Rare-Earth Doped Fiber Amplifier

Currently research works are concentrating more on the erbium dopant, particularly in silica based fibers. This is due to the emission of Er^{3+} ion lying within a set of wavelength around 1550 nm where the silica fiber exhibits the minimum attenuation of the information signal. Erbium doped fiber amplifiers (EDFA) could provide gains as high as 40 dB associated with low noise, as successfully demonstrated within a pump power range of 50 to 100 mW [12-14].

The first rare earth doped material of Neodymium (Nd^{3+}) used into a single mode fiber was demonstrated in 1983 by Bell Telephone Laboratories [15, 16]. Since then, rare-earth doped fibers were fabricated in a variety of methods to suit the different designs of amplifiers. The amount of dopant inside the fiber core ranging from 100 to 2000 parts per million (ppm) up to as high as 5000 ppm [17]. Various methods used to provide a low loss optical fiber communication with an introduction of new composition to improve the performance of amplifier, as well as uniformity of doping along the longitudinal and transverse fiber axes [18-22].

1.3.2 Optical Amplifier Classification

Optical fiber amplifiers generally can be classified and categorized based on its position in transmission lines which in turn shows their respective applications. There are three basic types of amplifier; post, inline and preamplifiers.

1.3.2.1 Post-amplifier

Known as a booster and power amplifier, a post amplifier is located just after a transmitter (Tx) before the launched signal goes down to fiber as depicted by Figure 1.1(a). As its location is near to the transmitter, the post amplifier handles relatively high power signals compared to other types of optical amplifiers. Mainly the post amplifier's function is to boost the signal power to the highest level hence maximizes the transmission distance. It differs than a normal amplifier as it relieves a need for a transmitter to produce a maximum optical power.

1.3.2.2 Inline Amplifier

An inline amplifier as shown by Figure 1.1(b) is usually located in the middle of a transmission span. It functions to compensate the power losses along the fiber link and could be cascaded to extend the transmission length. As it amplifies the signal several times in the case of cascaded system, the noise level is to be kept at a minimal level. For a WDM system, its stability to produce a uniform gain among wavelengths becomes its main goal.

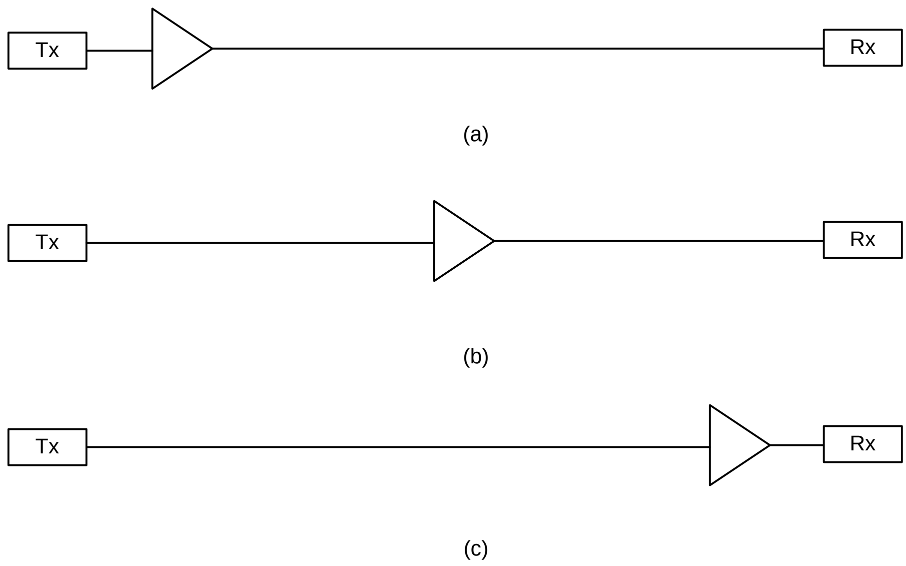

Figure 1.1: Optical fiber amplifier classification; (a) Post amplifier (b) Inline amplifier (c) Preamplifier

1.3.2.3 Preamplifier

Preamplifier amplifies the incoming signal before entering a receiver (Rx) at the end of the transmission as illustrated by Figure 1.1(c). Located just before the receiver, a preamplifier increases a weak signal to an acceptable level for detection. Hence the preamplifier is designed to have a good sensitivity, high gain and low noise level. Receiver's performance is not only limited by its own noise but also contributed by the noise from preamplifier [23].