INTENSITY NOISE REDUCTION USING A GAIN SATURATED SOA

KANAR ROSHEN TARIQ

UNIVERSITI TEKNOLOGI MALAYSIA

INTENSITY NOISE REDUCTION USING A GAIN SATURATED SOA

KANAR ROSHEN TARIQ

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineer (Electrical – Electronics & Telecommunications)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2014

In the name of ALLAH the Most Beneficial and the most Merciful
Specially dedicated to my beloved wife, Parents and Sisters.

ACKNOWLEDGEMENTS

In The Name Of Allah, Most Gracious, Most Merciful

First and foremost, I must be thankful to Allah for finishing the research and I would like to express my sincere thanks and appreciation to my supervisor DR.David Ian Forsyth, for his precious guidance, encouragement, constructive criticisms, advice, knowledge and motivation. Without his continual support and interest, this project report would not have been that same as presented here.

My gratitude also goes to my beloved and wonderful Wife (Riyam), thank you for the encouragement, for being my inspiration, for your endless love.

I would like to thank my Parents, Grandfather and both of my Sisters for their prayers and all their supports and encouragements. I 'm also grateful to my all friends, especially Osayd Kharraz, who never give up their support to me in all aspect of Study.

Kanar R. Tariq

ABSTRACT

Abstract— The Semiconductor optical amplifier (SOA) technology has a promising commercial value and viability in fiber optic communication systems. The SOA is usually employed as a booster or pre-amplifier in various optical communication networks. On the other hand, SOAs is also a strong option when operation as multi-functional elements in future all-optical networks is concerned. However with this in mind, the purpose of this project is to design a system employing SOAs as functional devices, for instance the noise reducer utilizing spectrum slicing source. The SOA is therefore modeled and simulated using the OptiSystem software. The SOA gain characteristic is also used to assist the design of the modeled SOA in order to prove a saturation gain case to reduce the Intensity noise. The performances of the systems are thus analyzed in terms of the Q-factor and bit-error-rate (BER) of the eye diagram, Relative intensity noise (RIN) and the optical signal-to-noise ratio (OSNR). The study of the SOA gain characteristics is in large agreement with the numerical simulation results by about 2.47% and therefore proves the means of the modeled SOA network used in this particular work. The SOA presents a promising option when operating as a functional device in all optical communication networks

ABSTRAK

Abstrak- Semiconductor penguat optik (SOA) teknologi mempunyai nilai komersial yang menjanjikan dan daya maju dalam sistem komunikasi gentian optik. SOA biasanya digunakan sebagai penggalak atau pra- penguat dalam pelbagai rangkaian komunikasi optik. Sebaliknya , SOAS juga pilihan yang kuat apabila operasi sebagai elemen-elemen pelbagai fungsi dalam rangkaian semua -optik masa depan berkenaan. Bagaimanapun, dengan ini dalam fikiran , tujuan projek ini adalah untuk mereka bentuk satu sistem menggunakan SOAS sebagai alat berfungsi, misalnya pengurang bunyi menggunakan sumber spektrum penghirisan. SOA Oleh itu, model dan simulasi menggunakan perisian OptiSystem itu. SOA keuntungan ciri ini juga digunakan untuk membantu reka bentuk SOA model untuk membuktikan keuntungan kes tepu untuk mengurangkan bunyi Intensiti . Prestasi sistem dengan itu dianalisis dari segi Q- faktor dan sedikit -kesilapan -kadar (BER) gambarajah mata, bunyi intensiti relatif (RIN) dan nisbah isyarat-kepada- hingar optik (OSNR). Kajian keuntungan ciri SOA dalam perjanjian besar dengan keputusan simulasi berangka oleh kira-kira 2.47% dan oleh itu membuktikan cara rangkaian SOA model yang digunakan dalam kerja-kerja khusus ini. SOA membentangkan pilihan yang menjanjikan apabila beroperasi sebagai alat berfungsi dalam semua rangkaian komunikasi optic.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APD	-	Avalanche Photodetector
AR	-	Anti Reflection
ASE	-	Amplified Spontaneous Emission
BER	-	Bit Error Rate
BPS	-	Band Pass Filter
CATV	-	Community Antenna Television
CIDF	-	Component Iteration Data Flow
CW	-	Continuous Wave
dB	-	Decibel
DBR	-	Distributed Bragg Reflector
DFB	-	Distributed Feedback
DVD	-	Digital Versatile Disk
EDFAs	-	Erbium Doped Fiber Amplifiers
EDWAs	-	Erbium Doped Wavelength Amplifiers
FFNR	-	Feed Forward Noise Reduction
FP-SOA	-	Fabre Perot SOA
FTTH	-	Fiber to the Home
FWM	-	Four - Wave - Mixing
GC-SOA	-	Gain Clamped SOA
GHz	-	Gigahertz
GUI	-	Graphical User Interface
Hz	-	Hertz
ISI	-	Inter Symbol Interference

LAN	-	Local Area Network
LD	-	Laser Diode
LED	-	Light Emitting Diode
LIDAR	-	Light Detection and Ranging
LOA	-	Linear Optical Amplifier
NRZ	-	Non Return-to-Zero
NSR	-	Noise Suppression Ratio
OEIC	-	Optoelectronic Integrated Circuit
OEO	-	Optical - Electronic - Optical
OISL	-	Optical Inter Satellite Communication Link
OSNR	-	Optical Signal Noise Ratio
PD	-	Photodetector
PDL	-	Polarization Dependent Loss
PMD	-	Polarization Mode Dispersion
PON	-	Passive Optical Network
PRBS	-	Pseudo-Random-Bit-Sequence
Q	-	Quality Factor
QD-SOA	-	Quantum Dote SOA
RIN	-	Relative - Intensity - Noise
RZ	-	Return-to-Zero
SLC	-	Super Luminescent Diode
SNR	-	Signal Noise Ratio
SOA	-	Semiconductor Optical Amplifier
SPM	-	Self Phase Modulation
TW-SOA	-	Travelling Wave SOA
WDM	-	Wavelength Division Multiplexing
WL	-	Wetting Layer
XGM	-	Cross Gain Modulation
XPM	-	Cross Phase Modulation

CHAPTER 1

INTRODUCTION

1.1 Introduction

For over the past 20 years and more, ever since the unearthing of the laser and the advancement in low-loss optical fiber, fiber systems have turn out to be the core backbone of the information-conveying communications all around the world, owing to their superior capacity, high speed, minimal cost, and high security. There are three crucial parts required in an optical communication system, they are: a transmitter, a transmission medium, and a receiver. The laser forms the core of the transmitter, by means of its output beam being modulated by the input electric signal and which is then attached into an optical fiber, the optical fiber functions as the transmission medium to aid in conveying the signal to the receiving end of the link. A photo detector works as the nucleus of the optical receiver and it translates the optical signal back into an electrical signal.

The optical transmission system design [1 - 4] entails observing the diverse effects that may distort the signal all through modulation, transmission, and the detection processes. The transmission quality is realized via the received signal-to-noise ratio (SNR), the SNR is the ratio relating the signal power and the noise power at a specific point. The SNR is thus associated with the receiver sensitivity; the minimum received optical power desirable to maintain the SNR at the specified level. In digital optical communications, the bit-error rate (BER), described as the ratio of the bits in error to the whole number of transmitted bit at the certain point, it is normally used as a figure of value. In the same vein, the receiver sensitivity can be seen as the minimum needed received optical power which can keep the BER below a given value. There are three types of parameters important from the system engineering point of view, they consist of

1) Optical signal parameters which influences the signal level.
2) The optical noise parameters that influences the BER.
3) The impairment parameters that influences the power margin to be allocated to make up for their impact.

The optical signal parameters which define the signal level is made up of the optical transmitter output power, loss ratio, optical amplification gain, and the photodiode responsively. Additionally, the entire noise is a stochastic process that is composed of both the additive noise mechanism and the multiplicative (non-additive) noise mechanism. Therefore, There exist quite a number of impairments which weaken the signal quality all through transmission for instance fiber attenuation, chromatic dispersion, polarization mode dispersion (PMD), polarization-dependent loss (PDL), fiber nonlinearities, insertion loss, and frequency cheep; and so on.. A suitable design practice is made up of diverse phases to afford a pre-specified transmission system quality and also a sense of balance to different system parameters. The systems parameter can be therefore be related to power, time, wavelength, or a combination of them.

1.2 System Descriptions

More often than not, for long-haul communications, the optical fiber communication. System shown in Fig 1.1 is used [5]. The fundamental constituents of such an optical communication systems are the transmitter, the medium of transmission and the photo receiver. There is also an optical encoder, by means of which the electrical information signal is enhanced to an optical Signal via modulating the optical emission from the optical transmitter. This optical transmitter is frequently a light emitting diode or a laser diode together with a germane modulating and driving circuits. Afterward, the optical signal is then transmitted via a medium that affords a suitable propagating condition for the carrier signals. This transmission medium is by and large an optical fiber with optical amplifiers and repeaters which depends on the length. Lastly, at the photoreciever, the optical signal is converted back into an electrical signal.

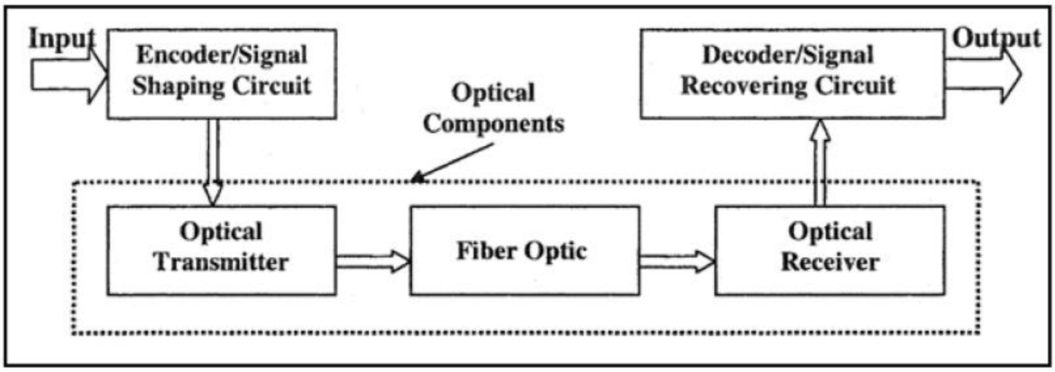

Figure 1.1 Schematic representation of an optical fiber communication system[5].

The chief advantages of the optical telecommunication systems are their enormous bandwidth owing to the high frequency of the optical carriers (100 GHz), low signal attenuation and low dispersion, these can be realized by a selecting a suitable laser wavelength and optical fiber. Optical signals are protected to minimize crosstalk and thus several communication links can be supported by the signal fiber. They signals are also protected from the interference from inductive coupling and they provide a more secure communication.

Conventional fiber is made up of silica which is composed of a core which has a higher refractive index than its cladding. These obvious changes in the refractive index result in a total internal reflection of the propagating signal, as a consequence allowing for the signal to propagate over a long distance. A Single mode fiber may be preferred as a transmission channel over multimode fiber due to the fact that it could be optimized for low dispersion and attenuation for a particular wavelength. The key mechanism of attenuation in the single mode fibers is the impurity scattering.

With the current quantity of impurity control in the manufacturing of single mode fibers, the present day commercial fibers are precisely close to the theoretical attenuation limit of about 0.15dB/km at a wavelength (λ) of 1.55μm.The Zero dispersion in the commercial fibers can also be achieved at 1.3μm. This therefore implies that the resulting shape of the signal at this specific wavelength does not change as it propagates from end to end the fiber. Based on the system requirement, either 1.3μm or 1.55μm can be utilized as a carrier wavelength.

1.3 Basic Principles

In principle optical fiber communication systems are used both in analog and digital modes of modulation. The Analog optical fiber communication systems are typically restricted to short distance and low bandwidth applications, for example the cable TV. As in the situation with wire line systems, analog systems are often less efficient in contrast to digital systems due to their superior signal-to-noise ratio requirement. Besides, the high linearity that is essential for analog signal recuperation circuits is not simply accomplished in semiconductor optoelectronic components. These complete extra requirements make the digital format of modulation an enhanced choice for the communication systems. In addition, with the development of a superior quality of digital television, merging of television, telephone and internet traffic will bolster the switch to digital optical communication systems.

Consequently, Optical fiber telecommunication systems are utilized both for short and long-haul communications. In short-haul applications, there exists a normal separation sandwiched between the source and the receiver which is between 30 to

80 km, according to the speed of transmission and the existing application. Generally, in such systems, no extra signal amplification or phase correction is necessary along the haul. In long-haul applications, where a usual separation between the source and the receiver can be a few thousand kilometers, for instance in sub-marine applications, signal regeneration is necessary at more or less every 100km.

The distance connecting the repeaters is decided by a mixture of the requisite bit rate, carrier wavelength (1.3μm or 1.55μm), attenuation and dispersion in the fiber. One way to categorize optical communication systems is to take into account the distance over which they function. At one edge of the spectrum are the long-haul systems, related to the information transported across the greatest possible distances.

Hence, a silica based optical fiber is a more apt transport means over a vast distance with very low propagation loss, thus attaining a high capacity which occurs at the operating wavelengths in the region of 1.55μm. Nevertheless, when the distance traveled is less critical, a number of other factors come into play, they are the costs associated with the endpoints, networking topologies and the principles and compatibility with legacy systems. The High costs of photo detector and optoelectronic integrated circuits (OEICs), which exclude their utilization in short distance applications for example local area networks, fiber to the home, and optical interconnects on print circuit boards and between boards. Meanwhile the High volumes of low cost OEICs will be needed also for optical buses in cars and in optical storage system akin to CD-ROM and digital versatile disk (DVD).

1.4 Background of Project

There has been an approximately exponential growth in the deployment and capacity of optical fiber communication networks over the past twenty-five years, made possible primarily by the new development of optoelectronic technologies utilized to develop the enormous bandwidth of optical fiber [6]. Systems and networks operating at bit rates well in excess of 100 Gb/s had been demonstrated [7]. All-optical technology is the leading carrier of worldwide information, and is also central to the realization of future all-optical networks that will have the capabilities demanded by a growing society. In communication systems, the need for high bandwidth interconnects and efficient sharing of large amounts of almost any kind of data from one destination to another is highly essential. Many of the advances in optical communication networks have been made possible by the semiconductor optical amplifier (SOA).

The semiconductor optical amplifier is an optoelectronic device used for many applications in advanced optical fiber communication systems. As the incredible new growth in data speeds is largely certified to new photonics technologies that enable the enormous capacity of optical fiber to be exploited, next generation optical networks will require advanced photonic devices/subsystems for high speed all-optical signal processing of narrow (picoseconds) optical pulses to allow for very large increases in data rates (100s Gigabit/s to Terabit/s). The SOA has become a candidate device, due to its various attractive properties; such as fast switching speed, low power consumption and the ability to be cascaded [8]. SOAs are also compact, highly compatible devices which are easily installed into a communications link. SOAs are ever more becoming devices of interest, not only as basic amplifiers, but as more capable elements in optical communication networks qualified of providing all-optical signal processing; such as high speed optical switching [9 – 10], optical gating [11]. These functions, whereby there is no modify of optical signals into the electrical domain, will be necessary in future transparent optical networks. SOA based subsystems have been recognized to have the capability of implementing many all optical signal functions, and the technology has therefore been showing to the world due to its huge commercial value and future high ability in fiber optic communication systems.

1.5 Problem Statement

Most of the project has been focused on noise reduction, the SOA is a key section that used here to reducing the intensity noise, and the basic parameters used to characterize the SOA are: input power, relative high gain, output saturation power 5-10 dBm.

One of the major disadvantages of the SOA is its nonlinearity, due to the very short lifetime of the injected carriers [12]. However, this disadvantage can be functional when it comes to wavelength conversion, noise reduction and switching. In this thesis, applications of SOAs, such as amplification and noise reduction are modeled using OptiSystem software, and performances of the system are analyzed. Results are also compared with previous reported work.

1.6 Objectives

This project linked of several applications of SOAs for future all optical networks. Based on above mentioned problem statement, the objective can be specified as:-

1. To model, simulate and analyze the Semiconductor Optical Amplifier for amplification function, particularly for gain saturation.
2. Using Semiconductor Optical Amplifier to reduce Intensity Noise in saturated gain case of SOA.
3. Optimization of optical system by reducing the intensity noise of a spectrum-sliced incoherent light source to get best quality factor of the system.

1.7 Scope of the Project

In order to complete these project objectives, the matching works to be carried out in this project are:

- Evaluation of the application concepts of the SOA for future all-optical networks, including factors which influence the performance, characteristics and design structure.
- Modeling the SOA using OptiSystem software, and analyzing the system in order to obtain the most advantageous amplification concert.
- Modeling, simulating and analyzing a gain saturated SOA in order to check the intensity noise from a spectrum-sliced source.

1.8 Research Methodology

This project begins with literature studies in order to give a good understanding of the SOA applications for future optical communication networks, based on the systems procedure and design considerations. Then, the gains characteristics of SOA are studied by simulate the system based on OptiSystem software from Optiwave ® due to its flexibility.

The SOA parameters used in this project are chosen from a previous work [13]. The work then proceeds by modeling the SOA for amplification principle. The system is analyzed in terms of the Q-factor in order to reach the optimum amplification performance. The next point will be on the application of a SOA as an intensity noise reducer in a spectrum-sliced incoherent light system. The SOA is modeled based on gain saturation in an SOA in order to obtain maximum reduction in the intensity noise, and thus achieving clean switching besides amplifying.

REFERENCES

[1] Cvijetic M. (2004). Optical transmission systems engineering. Artech House, Boston, MA.

[2] Ramaswami R, Sivarajan K. (2002). Optical networks: a practical perspective, 2nd edn. Morgan Kaufman, San Fransisco, CA.

[3] Agrawal GP. (2002). Fiber-optic communication systems, 3rd edn. Wiley, New York.

[4] Agrawal GP. (2004). Lightwave technology: components and devices. Wiley, New York.

[5] SENIOR, J. M. (1992).Optical Fiber Communications,2 ed. New York: Prentice Hall.

[6] Connelly M.J. (2003). Semiconductor Amplifiers and Their Applications (Invited paper). 3rd Spanish Meeting of Optoelectronics. OPTOEL'03. Madrid. Spain.

[7] Leuthold J., Joyner C.H., Mikkelsen B., Raybon G., Pleumeekers J.L., Miller B.I., Dreyer K., and Burrus C.A. (2000). 100Gbit/s all-optical wavelength conversion with integrated SOA delayed-interference configuration. Electronics Letters. Vol. 36, No. 13: 1129-1130.

[8] Huang D. (2002). Semiconductor Optical Amplifiers and Related Applications. Proceeding of the SPIE (Invited paper). Vol. 4833.

[9] Aw E.T., Lin T., Wonfor A., Penty R.V., and White I.H. (2007). Multi-Stage SOA Switch Fabrics: 4x40Gb/s Packet Switching and Fault Tolerance. Optical Fiber Communication and the National Fiber Optic Engineers Conference.

[10] Pleros N., Kanellos G.T., Bintjas C., Hatziefremidis A., and Avramopoulos H. (2004). Optical Power Limiter Using a Saturated

SOA-Based Interferometric Switch. IEEE Photonics Technology Letters. Vol. 16, No. 10: 2350-2352.

[11] Guo L.Q. and Connelly M.J. (2005). All-Optical AND Gate Using Nonlinear Polarization Rotation in a Bulk Semiconductor Optical Amplifier. Optical Amplifiers and Their Applications Topical Meeting on CD-ROM (The Optical Society of America, Washington, DC, 2005). SuB9. ISBN: 1-55752-790-3.

[12] Stubkjaer K.E., Mikkelsen B., Durhuus T., Storkfelt N., Joergensen C., Jepsen K., Nielsen T.N. and Gliese U. (1992). Recent advances in semiconductor optical amplifiers and their applications. Fourth International Conference on Indium Phosphide and Related Materials. pp. 242 – 245.

[13] Aziz A.A.El., Ng W.P., Ghassemlooy Z., Aly M.H., Ngah. R. and Chiang M. F. (2008). Characterization of the semiconductor optical amplifier for amplification and photonic switching employing the segmentation model. International Conference on Transparent Optical Networks "Mediterranean Winter".

[14] Seeds A.J. (1998). Broadband Fibre-Radio Access Networks. Proceedings of the International Topical Meeting on Microwave Photonics, MWP, Technical Digest.

[15] Jager D. (1999). Recent Developments in Microwave Photonics Devices. EUMC’99 Workshop.

[16] Tangdiongga E., Crijns J.J.J., Spiekman L.H., Van den Hoven G.N. and De Waardt H. (2002). Performance Analysis of Linear Optical Amplifiers in Dynamic WDM Systems. IEEE Photonics Technology Letters. Vol. 14, No.8: 1196-1198.

[17] Gallep C.M. and Conforti E. (2002). Reduction of Semiconductor Optical Amplifier Switching Times by Preimpulse Step-Injected Current Technique. IEEE Photonics Technology Letter. Vol. 14, No. 7: 902-904.

[18] Zhou J., Chrostowski J. and Myslinkski P. (1997). Measurements of Very Low Bit- Error Rates of Optical Switches Based on Semiconductor Optical Amplifiers. IEEE Photonics Technology Letters. Vol. 9, No.8: 1131-1133.

[19] Sharaiha A. (2004). Semiconductor Optical Amplifiers for future optical networks. Proceedings - 2004 International Conference on Information and Communication Technologies: From Theory to Applications, ICTTA. Pp.165-166.

[20] Bogoni A., Poti L., Porzi C., Scaffardi M., Ghelfi P. and Ponzini F. (2004). Modeling and Measurement of Noisy SOA Dynamics for Ultrafast Applications. IEEE Journal on Selected Topics in Quantum Electronics. Vol.10, No. 1: 197-205.

[21] Connelly M.J. (2002). Semiconductor Optical Amplifier. Kluwer Academic Publishers, New York.

[22] Forsyth D.I., Evans, I. and Connelly M.J. (2005). Spectrum-sliced source noise reduction using a semiconductor optical amplifier. Proceeding of the Fifth IASTED International Multi-conference.

[23] Bernard, J. and Renaud, M. (2001). Semiconductor optical amplifiers. SPIE’s OE Magazine, vol. 1, no. 9, pp. 36-38.

[24] Saitoh, T. and Mukai, T. (1990). Gain saturation characteristics of Traveling-Wave semiconductor optical amplifiers in short optical pulse amplification. IEEE Journal of Quantum Electronics, vol.26, no. 12.

[25] Maio, I. (1991). Gain saturation in Traveling-wave ridge waveguide semiconductor optical amplifier. IEEE Photonics Technology Letters, vol. 3, no. 7.

[26] Mohammed, K.A., Shaker, M.M. and Azawe, M.I. (2009). Dynamics simulations of semiconductor optical amplifier by analytical solution of Traveling-Wave equation. Al-Rafidain Engineering, vol.17, no. 1.

[27] Masumi, S., M. B, Mitsuru, T. and Yoshiaki, N. (2000). Wavelength conversion using Fabry-Perot type semiconductor optical amplifier IEIC Technical Report (Institute of Electronics, Information and Communication Engineers), vol. 99, no. 542, pp. 31-36.

[28] Bauer, B., Henry, F. and Schimpe, R. (1994). Gain stabilization of a semiconductor optical amplifier by distributed feedback. IEEE Photon. Technol. Lett., vol. 6, pp. 182-185.

[29] Tiemeijer, L.F., Van den Hoven, G.N., Thijs, P.J.A., Van Dongen, T., Binsma, J.J.M. and Jansen, E.J. (1996). 1310 nm DBR type MQW

gain clamped SOAs with AM-CATV grade linearity. IEEE Photon. Technol. Lett., vol. 8, pp. 1543-1455.

[30] Sum, J., Morthier, G. and Baets, R. (1997). Numerical and theoretical study of the crosstalk in gain clamped semiconductor optical amplifiers. IEEE J. Sel. Topics in Quantum Electron., vol. 3, pp. 1162-1167.

[31] Schaafsma, D.T. and Bradley, E.M. (1999). Cross-gain modulation and frequency conversion crosstalk effects in 1550-nm gain-clamped semiconductor optical amplifiers. IEEE Photon. Technol. Lett., vol. 11, pp. 727-729.

[32] Last R. Unpublished. Semiconductor optical amplifier design and applications. Available at http://files.robertlast.com/SOA. pdf.

[33] Lu Z. G., Liu, J.R., Raymond, S., Poole, P.J., Barrios, P.J., Pakulski, G., Poitras, D., Sun, F.G., Taebi, S. and Hall, T. (2007). Ultra-broadband quantum-dot semiconductor optical amplifier and its applications. Optical Soceity of America.

[34] Kim T.Y., Kim S.J. and Park C.S. (2007). Gain-saturated SOA-based optical power booster for spectrum-sliced incoherent light. Microwave and Optical Technology Letters. Vol. 49, No. 12: 3038–3040.

[35] Wei J.L., Hugues-Salas E., Giddings R.P., Jin X.Q., Zheng X., Mansoor S., and Tang J.M. (2010). Wavelength reused bidirectional transmission of adaptively modulated optical OFDM signals in WDM-PONs incorporating SOA and RSOA intensity modulators. Optics Express. Vol. 18, No.10: 9791- 9808.

[36] Wang J., Meloni G., Berrettini G., Pot`I L., and Bogoni A. (2010). All-Optical Clocked Flip-Flops and Binary Counting Operation Using SOA-Based SR Latch and Logic Gates. IEEE Journal of Selected Topics in Quantum Electronics. Vol. 16, No. 5: 1486-1494.

[37] Dong J., Zhang X., Zhang. Y. and Huang D. (2008). Optical UWB doublet pulse generation using multiple nonlinearities of single SOA. Electronics Letters. Vol. 44, No. 18: 1083-1085.

[38] Mulvad H.C.H., Tangdiongga E., Raz O., Herrera J., de Waardt H., and Dorren H.J.S. (2008). 640 Gbit/s OTDM Lab-Transmission and

320 Gbit/s Field- Transmission with SOA-based Clock Recovery. Conference on Optical Fiber Communication/National Fiber Optic Engineers Conference.

[39] Fernandez A., Chao Lu., and Chi J.W.D. (2008). Dispersion-Managed Ring Laser Using SOA and Dispersion-Compensating Fiber for Pulse Reshaping and Clock Recovery. Proceedings of the 6th International Symposium Communication Systems, Networks and Digital Signal Processing. pp. 479- 482.

[40] Mahad F.D., Supa'at A.S.M., Idrus S.M., and Forsyth D. (2010). Modeling of Semiconductor Optical Amplifier gain characteristics for amplification and switching. Proceeding of the Nanotech Malaysia 2010: International Conference on Enabling Science and Nanotechnology.

[41] Gutierrez-Castrejon R., Dolores-Calzadilla V. and Duelk M. (2009). Gain-controlled semiconductor optical preamplifier for the 100 Gbit/s 40 km Ethernet receiver. Applied Optics, Vol. 48, No. 25: F82-F89.

[42] De Souza E.A., Nuss M.C., Zirngibl M., Joyner C.H. (1995). Spectrally slices WDM using a single femtosecond source. OFC'95 Tech. Dig., Paper: PD16-1.

[43] Keating A.J., Holloway W.T., Sampson D.D. (1995). Feedforward noise reduction of incoherent light for spectrum sliced transmission at 2.5 Gb/s. IEEE Photonics Technology Letters. Vol. 7, No. 12: 1513-1515.

[44] Kim S.J., Han J.H., Lee J.S., Park C.S. (1999). Intensity noise suppression in spectrum-sliced incoherent light communication systems using a gain saturated semiconductor optical amplifier. IEEE Photonics Technology Letters. Vol. 11, No. 8: 1042-1044.

[45] McCoy A.D., Thomsen B.C., Ibsen M., Richardson D.J. (2004). Filtering effects in a spectrum-sliced WDM system using SOA-based noise reduction. IEEE Photonics Technology Letters. Vol. 16, No. 2: 680-682.

[46] McCoy A.D., Horak P., Thomsen B.C., Ibsen M., Richardson D.J. (2005). Noise suppression of incoherent light using a gain-saturated

SOA: Implications for spectrum-sliced WDM systems. IEEE Photonics Technology Letters. Vol. 23, No. 8: 2399-2409.

[47] Mahad F.D., Supa'at A.S.M., Idrus S.M., and Forsyth D. (2012). Simulation on Semiconductor optical amplifier Intensity Noise reduction for future spectrum sliced optical network. International journal for light and electron optics.Vol.123, No.2:95-99.

[48] Zhao M., Morthier G., Baets R. (2002). Analysis and optimization of intensity noise reduction in spectrum-sliced WDM systems using a saturated semiconductor optical amplifier. IEEE Photonics Technology Letters. Vol. 14, No. 3: 390-392.

[49] Dutta N.K. and Wang Q. (2006). Semiconductor Optical Amplifiers. Hackensacks. NJ: World Scientific Publishing Company.

[50] Rana F. (2011). Semiconductor Optical Amplifier. Semiconductor Optoelectronics chapter 9. Cornell University.

[51] J. Kani, K. Iwatsuki and T. Imai. (2006). "Optical Multiplexing Technologies for Access-Area Applications", IEEE J. Sel. Topics in Quantum Electron. vol. 12, no. 4, pp. 661-668.

[52] Woerner B. D., Besieris I. M. and Wongpaibool V. (1998). Effect of Dispersion on Spectrum-Sliced WDM Systems. Virginia: Blacksburg. Available at http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.10.8908