National Conference on Science, Engineering and Technology (NCSET – 2016)
Volume: 4 Issue: 6

ISSN: 2321-8169
24 - 28

All Optical Networks

EDFA Transients –Effects, Measurements & Control

Varun Seshadri
Vellore Institute Of Technology, Chennai Campus
SENSE
(M.Tech) Communication Engineering
e-mail: varunseshadri1992@gmail.com

Sangeetha R.G*
Vellore Institute Of Technology, Chennai Campus
SENSE
(M.Tech) Communication Engineering
e-mail:sangeetha,rg@vit.ac.in

Abstract— An all optical network is a network where the user network interface is optical ant the data does not undergo opto-electronic conversion. They are attractive because they provide high rates, flexible switching & broad application support. This paper investigates fault surveillance and fault identification mechanisms & open fibre management protocols for all optical network. To achieve population inversion an EDFA uses stimulated emission process where incident photon and emitted photon have same phase. But, alongwith the stimulated emission that creates gain, spontaneous emission is also produced by the gain medium, which gives rise to the amplified spontaneous emission (ASE) spectrum of the amplifier . In this paper we have considered the setup to measure amplified spontaneous emission in an in-line EDFA. ASE spectrum is observed with increased number of fiber spans. It has been observed that the ASE power increases with increase in pump power and EDFA length. It is further observed that increasing the doping radius reduces ASE power. The ASE spectrum peak is found to shift to longer wavelengths with increased number of fiber spans. The simulation has been done using OptSim software.

Keywords- AONs, EDFA Gain Competition, OXC, Service disruption, QOS, Vulnerability, WDM, Pre-amplifier, Booster Amplifier, OSNR, Amplified Spontaneous Emission *(*ASE), Ring laser & Lasing signal.

*****

I. INTRODUCTION *(HEADING 1)*

Although AON offer high data rate for communications, there are new challenges in terms of network security that do not exist in traditional communication networks. In particular AON components have different accessibility & vulnerabilities as compared to electronic components. For example it is quite easy to tap or jam signals at a specific wavelength by bending an optical fibre slightly & either radiating light out of it or coupling light into it. Besides, the optical transmission technology allows for different attack opportunities. For instance the cross-talk level in switches may be sufficiently low for normal operations but may not be low enough to prevent an eavesdropping attack. In addition, the transparency features allows an intruder that has gained access to one component to simply pass a signal right through all the components that handle the associated light path. This means that the signal can be injected into the network at a remote location & by attentive choice of wavelength affect various parts of network. This widespread attack is hard to realise in conventional networks because signals are regenerated at every node & therefore a malicious physical signal can be trapped at the ends of the link. Finally, the high data rates employed in the AONs make them very sensitive to communication failures because large amounts of data can be affected even with failures of very short duration [1].

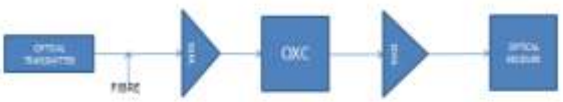

Fig. 1. AON architecture.

The key technologies applied to AONs fall into four categories: all-optical switching technology, optical cross-connection technology (OXC), wavelength division multiplexing (WDM) & optical amplifier technology.

Edfa mainly boosts the intensities of optical signals being carried through the optical fibre. An optical fibre is doped with a rare earth element erbium so that the glass fibre can absorb light at one frequency & emit light at another frequency. It is used as the line amplifier as it can directly amplify the optical signal transmitted in the line which is the optical fibre. In AONs it is used as both booster as well as for pre-amplification. When used as the booster amplifier, Edfa is deployed at the output of an optical transmitter to improve the output power of the multi-wavelength signal having been multiplexed. In this way distances of optical communication transmission can be extended. In this application Edfa requires higher output power. Edfa improves the sensitivity of the optical receiver when deployed as pre-amplifier at the input of the receiver [3].

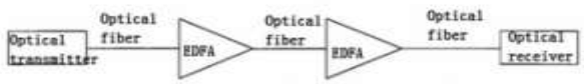

Fig. 2. EDFA as line amplifier.

II. EDFA WORKING PRINCIPLE

To achieve optical amplification, population inversion is a necessity, which means the population of upper energy level has to be greater than that of lower energy level, i.e. N2> N1, where N1, N2 is population density of lower and upper state. So to achieve the above criteria the electrons are excited into a higher energy level by external source called pumping. When incident photon having energy E= hc/λ interacts with electron in upper energy state to cause it return to lower state with creation of second photon(h is Plank constant, c is velocity of light and λ is the wavelength of light), stimulated emission occurs . When incident photon and emitted photon are in same phase and release two more photons, light amplification occurs and continuation of process effectively creates avalanche

ISSN: 2321-8169
24 - 28

multiplication. Operating near 980 and 1480 nm wavelengths. EDFAs can be designed to operate in such a way that the pump and signal beams propagate in opposite directions (backward pumping) or same direction (forward pumping). In bidirectional configuration the amplifier is pumped in both the directions simultaneously by using lasers at two ends of fiber. Therefore amplified coherent emission is obtained [1].

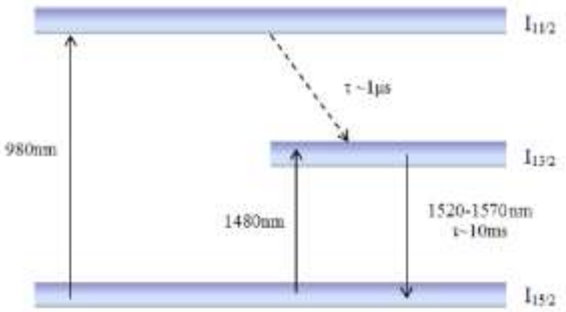

Fig. 3. Schematic of Er ion energy levels & spontaneous lifetimes of the excited levels.

III. MODEL

In this scheme the amplifier is pumped by a semiconductor laser which is complemented by a WDM Coupler, which combines the pump laser light with signal light. The pump light propagates either in the same direction or in both ways. The optical isolator is used to prevent oscillations & excessive noise due to unwanted reflections. The excitation is performed by a powerful pumping laser with a corresponding radiation wavelength of 980nm or 1480nm or 1550nm. The corresponding model is described in detail & is done through OptSim software. The simulation model is completely shown below. This describes the basic methodology of the simulation.

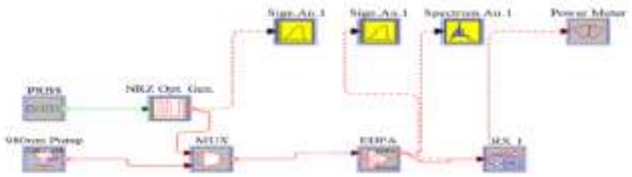

Fig. 4. Simplified optical network for studying EDFA parameters.

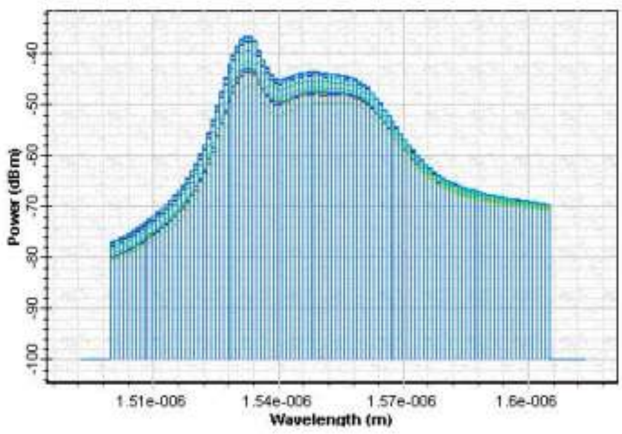

Fig. 5. Graph of noise power vs wavelrngth for a peak power of 1milli & 0.5milli watts.

IV. NOISE IN EDFA

Erbium Doped Fiber Amplifiers are used as in-line amplifiers to compensate for power losses caused by fiber attenuation, connections, and signal distribution in networks. So the main requirement of this type of amplifier is stability over entire WDM bandwidth. Noise should be at the minimal level for an in-line amplifier. The fact that noise is inherent in all amplification systems based on atomic population inversion can be understood by the physical picture of amplified spontaneous emission. Besides the stimulated emission that creates gain, the gain medium also produces spontaneous emission, which gives rise to the amplified spontaneous emission (ASE) spectrum of the amplifier [4]. In EDFA, ASE is the dominant noise source. This spontaneous emission reduces the amplifier gain by consuming the photons that would otherwise be used for stimulated emission of the input signal. This ASE noise limits the optical signal-to-noise ratio (SNR) of a cascade of amplifiers and is quantified in the amplifier's noise figure (NF). This can be denoted as NF =2 nsp/ ni in which nsp= N2 / (N2-N1) is the inversion parameter of the amplifier (i.e., the degree of population inversion, with N1 and N2 the fractional number of erbium atoms or carriers in the ground and excited states, respectively), and this is the input coupling loss. Both well-designed EDFAs and SOAs have inversion factors close to unity, but the fiber-chip coupling loss of the SOA puts it at a disadvantage. EDFA noise figures typically are 4–6 dB, while SOA noise figures are usually 6–8 dB [4].

V. REALIZATION OF EDFA & EXPERIMENTAL MEASUREMENT SCHEME

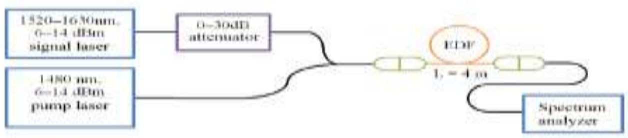

Fig. 6. Experimental scheme of Edfa measurements.

The simulation setup to measure the ASE in an in-line EDFA is shown in fig 1.1. The data source is a PRBS generator with a bit rate of 10Gbps and baud rate of 10Gbps and 7 degrees pseudorandom sequence. Electrical generator is on-off ramp type with NRZ modulation format. It has rise and fall times of 40e-12 and ring filter type configuration. CW laser1 has a peak power of 1mW and operates at wavelength=1550nm in single mode with random intensity noise of -150dB/Hz. External modulator1 is MZ type with on-off ratio=30dB and normalized average power output of -40dBm. CW laser2 has a pump power of 0.1W and wavelength of 1480nm. It operates in single mode with random intensity noise (RIN) = -150dB/Hz. The Write-Once/Read-Many model is a special model that is used in cases where connection branches into a repetition loop. The input signal is cached inside the model and is read as many times as requested inside the loop. The model has no parameters [11]. A repetition loop is used to change the number of fiber spans. An optical MUX is used to combine the signals from CW laser and input signal through repetition loop. The MUX operates in multiband mode and has no losses. The EDFA is unidirectional with meta-stable life of 10ms and 1550nm wavelength. A nonlinear fiber with 81km length and

0.25dB/km loss is used as transmission medium. The optical filter has Gaussian shape with 1550nm center wavelength. The receiver employs an APD with a quantum efficiency of 0.8. Measurements are done with the help of spectrum analyzer, eye diagram analyzer and property map.

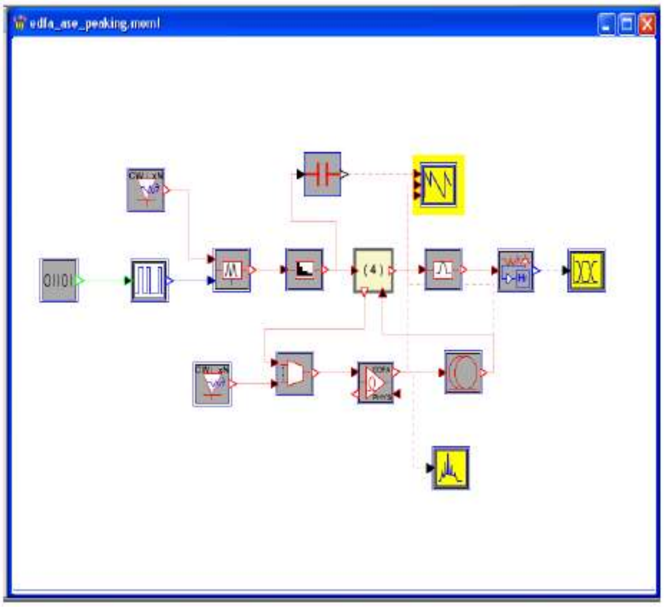

Fig. 7. Simulation set-up for EDFA ASE measurement.

VI. Simulation Results

In this section we present the results of simulations carried out using optsim software. We have studied the variation of ASE power with increasing EDFA length at different pump powers and doping radius [10]. The variation in ASE power with EDFA length for different pump powers at pump wavelength of 1480 nm, is shown. It is observed that, as the EDFA length is varied from 1m to 10m there is an increase in ASE power. It is further noticed that at higher pump powers the value of ASE power is high. At pump power value of 1mW, maximum value ASE is observed to be -158dBm/Hz, at pump value of 10mW maximum value of ASE is -118dBm/Hz, at pump value of 100mW maximum value of ASE is - 100dBm/Hz. Sufficient pump power is supplied to the amplifier in order to achieve population inversion & to minimize ASE . Further the variation of ASE power with doping radius of amplifier is studied. The doping radius is varied from 0.5μm to 4μm. It is observed that ASE power decreases with increase in doping radius [11]. Although, it is desirable to have large doping radius for decreasing the ASE power, but at the same time signal gain increases as doping radius decreases, because the light signal does not suffer from additional absorption [10]. That is, the Er(3+) ions do not exist in the area where the pump power is small. So there is a trade-off between high gain and low ASE while deciding on the doping radius. Further, the ASE spectrum is observed by increasing the number of spans of nonlinear fiber (and amplifier). It is observed that initially the ASE spectrum is most strongly peaked near 1530 nm, but as the number of spans increases, spectral peak gradually shifts to longer wavelengths or shorter frequencies. The ASE spectra peak is at 1532nm after first span, after fourth span ASE is peaked at 1533nm, ASE spectra peak after eighth span is 1558nm and that after the twelfth span the ASE peak is at is 1560nm. This shift in ASE spectra peak towards longer wavelengths with increased number of fiber spans is depicted in figure below shows the ASE spectra. So the particular graph is shown as given below. The test measurements are observed by keeping a particular value of the given component constant.

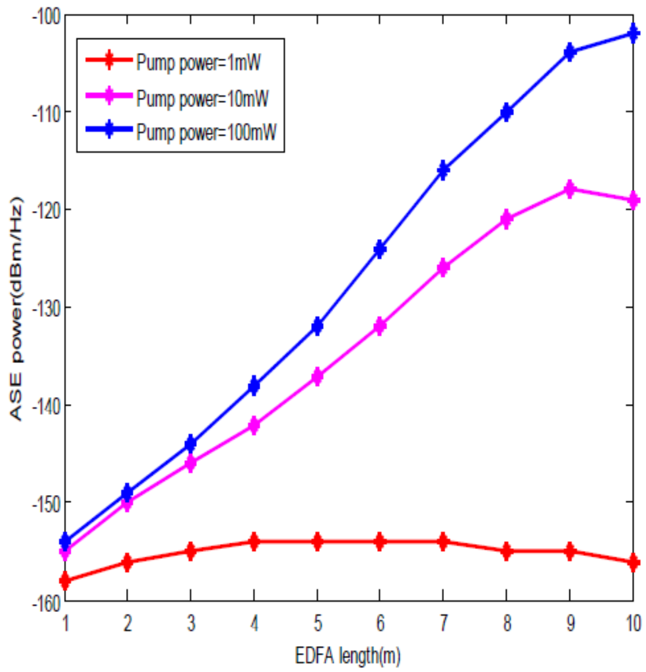

Fig. 8. ASE power Vs EDFA length.

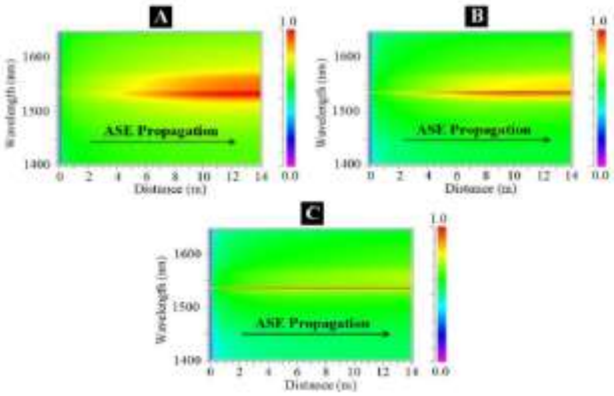

Fig. 9. ASE at input signal levels- -40,-20 & 0dBm.

The above shows the graph of various noise spectra as measured for different levels & range. So it is relevant that such amplified spontaneous emission noise proves to be hazardous for the network.

The noise gets accumulated & amplified at every stage of the network making the transfer of light through the fibre difficult.If the noise is neglected as it is too little to be considered at the initial stage.

So to avoid such situation a method to control such problem has been proposed in the further section of this paper. The model & functioning has also been explained for reference using simulation.

ISSN: 2321-8169
24 - 28

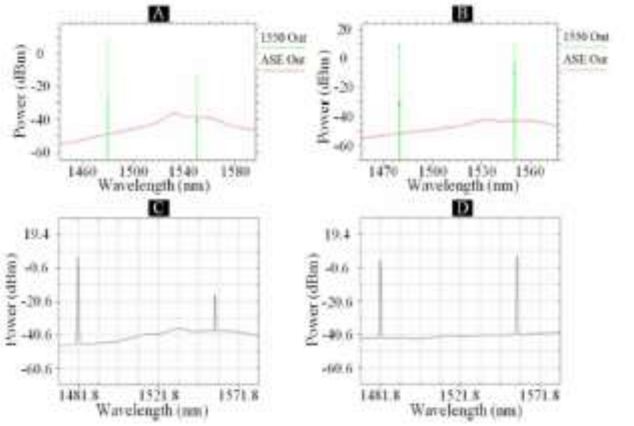

Fig. 10. Power spectra at EDFA output for input signal levels- -22, 6, -21.66 & 6dBm.

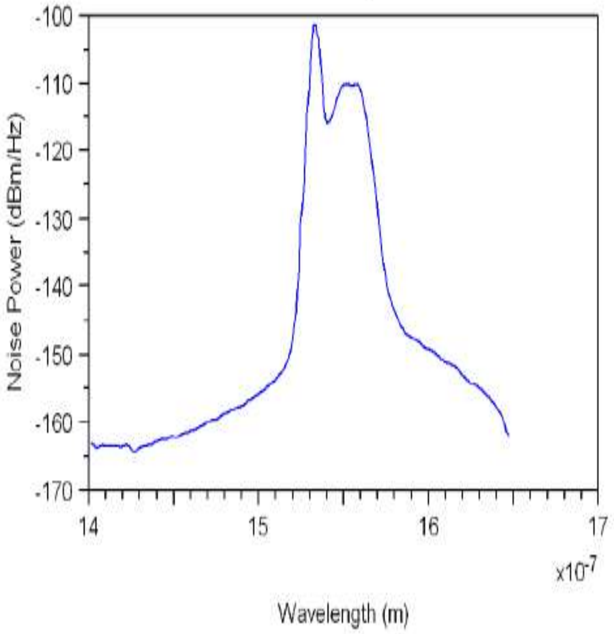

Fig. 11. ASE noise spectra.

Pumping laser	Laser power, mW	Output signal, dBm	Co-prop. ASE, dBm	Counter-prop. ASE, dBm	Co-prop. ASE at 1535 nm dBm	Noise figure, dB
Co-prop. 980 nm laser	10	-0.65	-3	2	-15	3.779
	40	9.1	6	10	-6	3.776
	80	12.7	10	13	-2	3.733
Counter-prop 980 nm laser	10	-0.65	-2	2.5	-10	6.9
	40	9.4	9.4	7	-4	6.2
	80	13	12	11	0	5.6
Co-prop. 1480 nm laser	10	-7.2	0	4	-18	6.79
	40	6.8	9	11	-5	6.72
	80	11	12	15	-1	6.57
Counter-prop 1480 nm laser	10	-7.3	4	0	-12	13.5
	40	6.9	11	10	-2	9.1
	80	11.1	14	12.5	1	8.3
Co-prop. 980 nm and Counter-prop 1480 nm	10	1.68	5	7	-11	5.235
	40	11.1	11	15	-2	5.300
	80	14.7	14.5	18	2	5.205
Co-prop. 1480 nm and Counter-prop 1480 nm laser	10	1.74	7	5	-8	7.57
	40	11.2	14	12.5	0	7.24
	80	14.9	15.5	15	4	7.06

Table. Simulation results for -30dBm 1535nm signal as EDFA input

VII. CONTROL MECHANISM

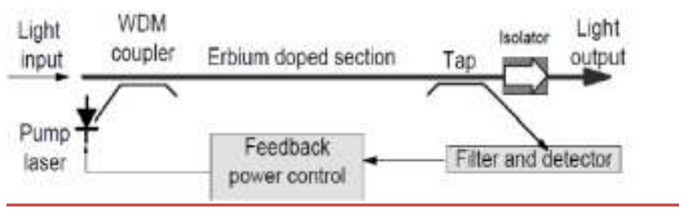

Fig. 12. Controlling mechanism using feedback loop.

A portion of ASE is coupled at the output of the amplifier, filtered at a selected wavelength, attenuated & then finally re-injected at the input. The amplifier thus forms a ring laser configuration. Lasing conditions are controlled by tuning the selected wavelength & varying the attenuation in the feedback loop. This can be used to suppress ase [12].

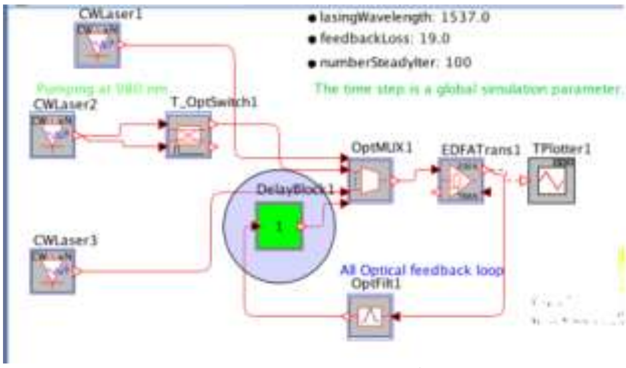

Fig. 13. OptSim simulation of the model.

The feedback loop forms a ring laser with the edfa providing the necessary gain. The lasing wavelength is selected by the optical filter in the loop. The operating point of the ring laser can be controlled by changing the overall gain. The switch simulates the adding & dropping of the channels [12]. Lasing is required for stimulated emission [11]. Ring lasers are composed of two beams of light of the same polarization traveling in opposite directions ("counter-rotating") in a closed loop. This is effective for operating wavelength selection.

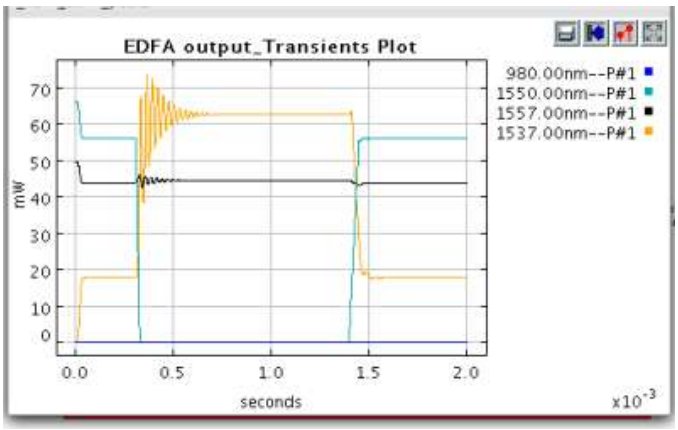

Fig. 14. Simulation result of the gain control model

ISSN: 2321-8169
24 - 28

VIII. CONCLUSION

From the above discussion it is concluded that, the ASE power in an EDFA increases with increase in pump power. So the pump power provided to an EDFA should be just enough to ensure population inversion. Further, ASE power decreases with increase in doping radius, but at the same time increase in doping radius gain decreases so there is a trade-off between increasing gain and decreasing ASE while deciding upon doping radius. It is also observed that as the number of fiber spans increases in an optical link the ASE spectrum peak shifts to longer wavelengths or shorter frequencies.In conclusion, an effective gain control scheme for EDFAs using a simple, passive, all-optical feedback loop has been demonstrated. Theoretically it is verified, that the feedback loop eliminates slow gain dynamics due to signal input power variations almost completely. Practically, the feedback loop should be adjusted just above lasing threshold when all signal channels are turned on.

REFERENCES

[1] Amor Lazzez, " All-Optical Networks: Security Issues Analysis,'' *J. Opt. Commun. Netw.*/Vol. 7, No. 3/March 2015.

[2] R. Rejeb, M. S.Leeson & R.J.Green, "Fault & attack management in all-optical networks,''*IEEE Comun. Mag.*, vol.44, no. 11, pp. 79-86, Nov. 2006.

[3] Lin Chu-shan, Deng Da-peng, Liao Xiao-min & Zhang Bin, " Research on Validity of EDFA Gain Competition Attack in Optical Networks," *International Conference on Industrial Control and Electronics Engineering*, 2012.

[4] J.-S.Yeom, O. Tonguz & G. Castanon, "Security in all-optical networks: Self-Organization & Attak Avoidance,''*IEEE Int. Conf. on Communications*, Glasgow, Scotland, June 2008.

[5] Tao Deng & S Subramaniam, " An analysis on optical amplifier gain competition attack in a point-to-point WDM Link,'' *Opticomm*, 2002.

[6] Jin Qi & Zhao Feng, " Research on Detection of Attack & Failure over Physical Layer of Transparent Optical Network,'' *Optical Communication Technology*, pp. 11-16, Dec. 2005.

[7] J. C. R. F de Oliveira, A. C. Bordonalli & J. B. Rosolem, " All-Optical Gain Controlled EDFA: Design & System Impact," Lecture Notes in Computer Science, vol. LNCS 3134, pp. 727-734, 2004.

[8] Eiichi Yamada and Masataka Nakazawa, " Reduction of ASE from a transmitted soliton signal using a nonlinear amplifying loop mirror & a nonlinear optical loop mirror," *IEEE JOURNAL OF QUANTUM ELECTRONICS*, VOL. 30, NO. 8, AUGUST 1994.

[9] G.Ivanovs, V.Bobrovs, S.Olonkins, A.Alsevska, L.Gegere, R.Parts, P.Gavars & G.Lauks, " Application of EDFA in WDM Transmission Systems,"*International Journal of Physical Sciences*, 2014.

[10] Amandeep kaur, Jagtar Singh, " M easurement of ASE in an in-line EDFA," *International Journal of Advanced Research in Computer Science and Electronics Engineering (IJARCSEE)*, Volume 1, Issue 7, September 2012.

[11] Y. Ben-Ezra, M. Haridim, and B. I. Lembrikov, "All-Optical AGC of EDFA Based on SOA," *IEEE JOURNAL OF QUANTUM ELECTRONICS*, VOL. 42, NO. 12, DECEMBER 2006.

[12] M.Zimbigl, "Gain Control in EDFA by All-Optical Feedback Loop," *Electron. Lett.*, vol. 27, pp. 560–561, 1991.