

# Multi Parameter Gain Optimization of Raman Fiber Amplifier for Dense Wavelength Division Multiplexed Systems

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**Abstract:** In this paper, various parameters of the Raman Fiber Amplifier are optimized for DWDM system at 0.2 nm channel spacing. The various system parameters attained optimum value to give gain value targeted at 20dB for each of the 100 channels. The multi stage approach adopted in this work results in providing maximum gain (above 15dB) for the optimized system parameters i.e. for pump power nearly equal to 600mW, signal power lies between -4 to -5dBm, pump wavelength equals to 1460nm and Raman fiber length is approximately 25Km.

**Keywords:** Raman fiber amplifier (RFA), Multi parameter optimization (MPO), gain optimization, DWDM, Raman length.

## I. INTRODUCTION

Raman Fiber Amplifiers (RFAs) have been known for providing a simple single platform for long-haul Dense Wavelength Division Multiplexed (DWDM) systems [1]. Raman amplification mechanism in optical fibers is of great importance. In multiple wavelength telecom system, Raman amplification offers the ability to achieve gain flatness without inserting any wavelength-dependent lossy elements [2]. RFA comprises several advantages which have attracted much attention during the recent years [3]-6]. The key merits of Raman amplifiers along with flexibility of gain of amplifiers are: (i) Gain is non-resonant, i.e. gain is available over the entire transparency region of the fiber, (ii) Gain spectrum can be tailored by adjusting the pump wavelengths, (iii) the medium for propagation and amplification are the same, (iv) gain is independent of relative direction of a pump and a signal, (v) broad gain-bandwidth. One of these distinctive merit is the broad gain-bandwidth associated with RFAs which is an attraction for application to the DWDM systems [7]. A large number of research papers have been dedicated to the optimization of the RFA gain by considering multiple pumps. B. Neto et. al [3] used Hybrid Genetic Algorithm for gain optimization of a system covering entire C-band by optimizing pump powers. Farzin Emami et. al [4] employed Fuzzy Adaptive Modified Particle Swarm Optimization (FAMPSO) to obtain pump powers and pump wavelengths with minimum gain ripple for S-band. Junhe Zhou et. al [5] presented a Novel robust, compact and flexible neural network model for a Fiber Raman Amplifier to obtain optimal pump power and wavelength configuration to attain desired gain spectrum. Pencheng Xiao et. al [6] proposed a new optimal algorithm scheme based on neural networks model for multipump sources of distributed RFA. Zhi Tong et. al [8] analyzed broadband Distributed Raman Amplifier (DRA) for its OSNR and net gain and optimized a bi-directionally multi-wavelength pumped RA. B. Neto et. al [9] employed a Hybrid genetic algorithm in the gain optimization of multipump DRAs by efficiently combining Genetic algorithm with the Nelder-Mead method. According to the above reported work, RFAs have been analyzed and optimized for all the three bands (S, C and L-bands) [3], [8], [9] but most of the work has been done for Wavelength Division Multiplexed (WDM) systems with 5nm [4], 0.8nm (100 GHz) [5], [8] or even more channel spacing. Moreover, all the optimization criteria have been devoted towards pump power and wavelengths. There are also many other parameters for RFA which need to be optimized for improving the gain spectrum. Hence, multi-objective or multi-parameter optimization is required to be introduced. Recent work presented by [10-16], has deployed numerous numerical methods and analytical approaches. Junhe Zhou et. al [10] proposed an analytical design for RFAs with Time Division Multiplexed (TDM) pumps but for the channel spacing equal to 100 GHz (0.8nm). Hai Ming Jiang et. al [11] introduced Ant Colony Optimization (ACO) but having the system channel spacing equal to 1nm. Carmelo J. A. et. al [12] presented a Multi-objective Particle Swarm Optimizer (MOPSO) to define the number of pump lasers and their wavelengths and powers with a 40 WDM signal channels at 100 GHz of separation. Gustavo C. M. et. al [13] also used a Hybrid Genetic algorithm with Geometric Compensation Technique for simultaneous analysis of multiple parameters and multi-objective problem but few of the important parameters have been presented. Javeria Yasmin et. al [14] optimized RFA parameters like pump power and wavelength for WDM chaotic communication but presented the work for a channel spacing of 0.8nm only. Ferreira et. al [15] proposed a low complexity computational model for the gain of the RFA, to be used suitably with multiple pumps and a large number of signals, but used a tunable laser operating at 1mW instead of considering the whole broadband. Despite of a numerous work on the optimization of RFA, still there is a need to

take the following limitations into account: Firstly, much work has not been reported for optimization of RFA at 0.2nm channel spacing for DWDM systems [11-14]. Secondly, however the multiple pump sources have been optimized for their power, wavelength and also for the number of pumps [13], but almost no results have been presented for the limits on the optical power that can be transmitted on the wavelength channels of the optical fiber. Thirdly, to make the system cost effective, the Raman Fiber length also needs to be of optimum value.

This paper proposes a multi-stage multi-parameter optimization for RFA gain with multiple input signals and single counter-pump laser. It intends to obtain optimal gain value with optimized pump power, Raman Fiber length, pump wavelength and signal power by using multi-stage approach. After the introduction, the remainder of the paper is described as follows. Section II introduces the RFA model and the theory of WDM limits on the launched optical power in the system. Section III presents the system setup and the results obtained. In section IV, the conclusions are drawn.

## II. RAMAN FIBER AMPLIFIER MODEL

Raman amplifiers utilize pumps to impart a transfer of energy from the pumps to the signals to be transmitted. This is achieved through the Raman effect mechanism [1]. Considering single continuous wave (CW) pump laser to amplify a continuous wave signal, the signal power across the Raman gain medium length  $L$  is given by [16]

$$P_s(L) = P_s(0) \exp\left(\frac{g_R}{\alpha_p} P_0 L_{eff} - \alpha_s L\right) \quad (1)$$

where  $L_{eff} = [1 - \exp(-\alpha_p L)] / \alpha_p$  is the effective length of the fiber amplifier which is less than the actual length.

$G_R$ - Raman gain coefficient,

$P_0$  -input pump power,

$\alpha_p$ - cross-sectional core area of the pump,

$P_s(0)$ - power of signal,

$\alpha_s$ - fiber loss at signal frequency.

To obtain the amplifier gain, signal-signal and pump-signal interactions are considered. Since, in this proposed method, a single pump laser is employed, so pump-pump interactions are absent.

Further, the limitations on the launched optical power in DWDM systems are essential to be considered. The broad bandwidth of RFA is useful for amplifying several channels simultaneously. Raman amplifiers work efficiently at any wavelength as long as pump wavelength is suitably chosen, thus RFA are quite promising for WDM systems [16]. As smaller and smaller channel spacings are becoming available, so the number of channels is not limited. However, optical non-linearities impose a limit on the optical power that can be transmitted on the wavelength channels of the optical fiber. Nonlinear effects such as self-phase modulation (SPM), cross-phase modulation (XPM), four-wave mixing (FWM) become important over long fiber lengths [17]. So, proper signal power and fiber length choice is of great importance. Moreover, the gain band shifts with the pump spectrum, and peak value of gain coefficient is inversely proportional to pump wavelength. Gain bandwidth is over 40THz wide, with a dominant peak near 13.2 THz (which corresponds to approximately 100nm) [1]. Hence, all these parameters of the RFA are optimally chosen to achieve an optimized gain profile over entire band in use.

A multi stage MPO has been used. It intends to optimize multiple (say two or more) parameters to achieve target gain value for DWDM system with 0.2 nm channel spacing. The resulting optimum parameters in the first stage are employed in second stage and further more parameters are optimized. Hence, adopting this multi stage approach, RFA gain is optimized.

## III. SIMULATION SETUP AND RESULTS

The setup consists of 100 DWDM channels spaced at 0.2nm in the wavelength region of 1560-1579.8nm. Each channel is carrying signals at a data rate of 10Gbps. The Raman Fiber Amplifier is provided with a single pump laser which is counter propagating. The basic simulation setup used is as shown in fig. 1.

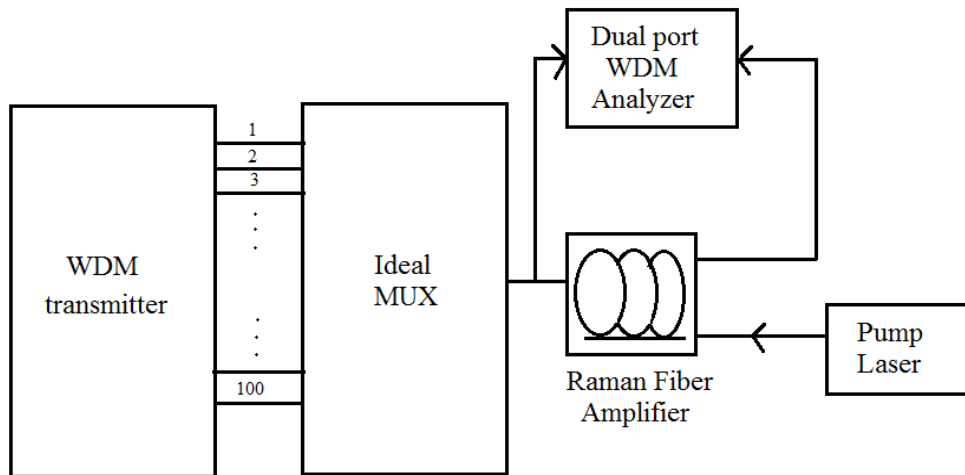


Fig. 1 Basic simulation setup

Multi-target optimization (MPO) tool available in Optisystem 7.0 has been used here. Goal Attainment optimization based on a nonlinear least-squares (LSQ) implementation is used. This type of optimization minimizes the sum of squares of the results by varying one or more parameters within the defined range starting from an initial guess. Stage I: At the initial stage, the counter propagating pump wavelength is set to be 1410nm. Each of the 100 signal channels are launched with -15dBm of optical power. The MPO is performed for Raman fiber Length and pump power with a target gain of 20 dB for each channel. The resultant gain profile is as shown in fig. 2.

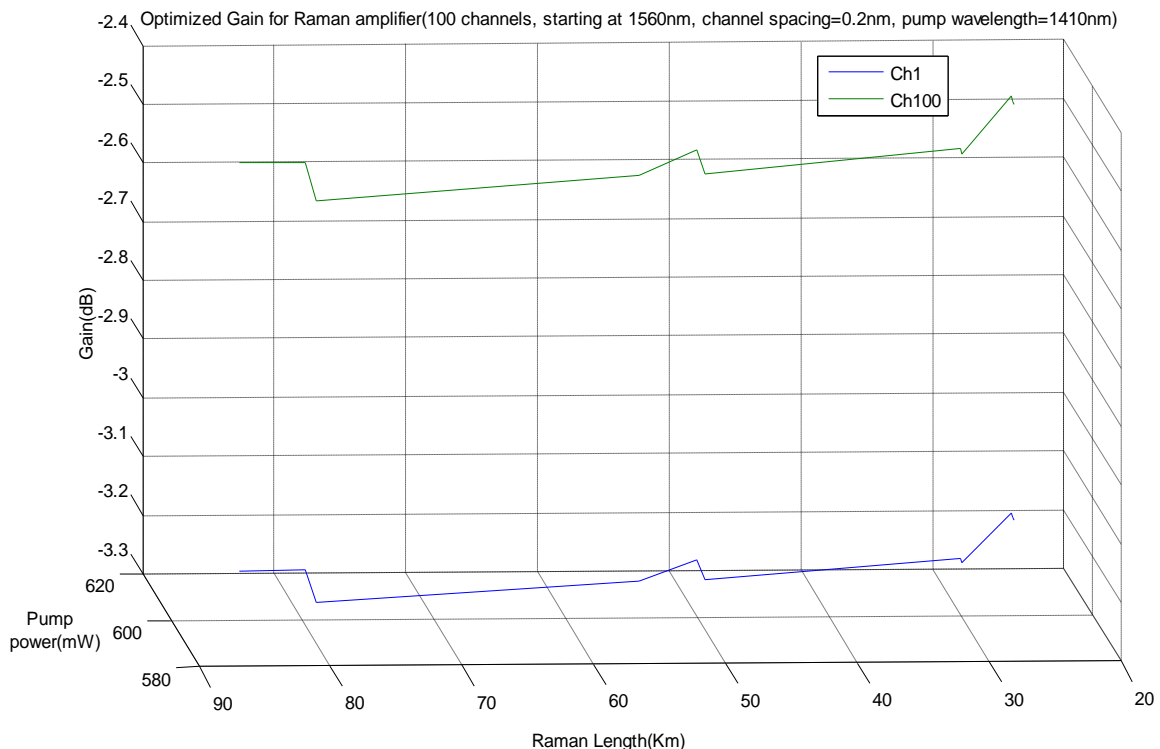


Fig. 2 Optimized Gain for RFA with optimum pump power and Raman length

From fig. 2, it is observed that the optimized gain is achieved at Raman length nearly equal to 25 Km and pump power approximately 600mW.

Stage II: During the second stage, the optimized set of values from the previous stage is introduced to optimize pump wavelength by considering pump power variation. The Raman fiber length is set to be 25Km. The resultant gain profile is as shown in fig. 3.

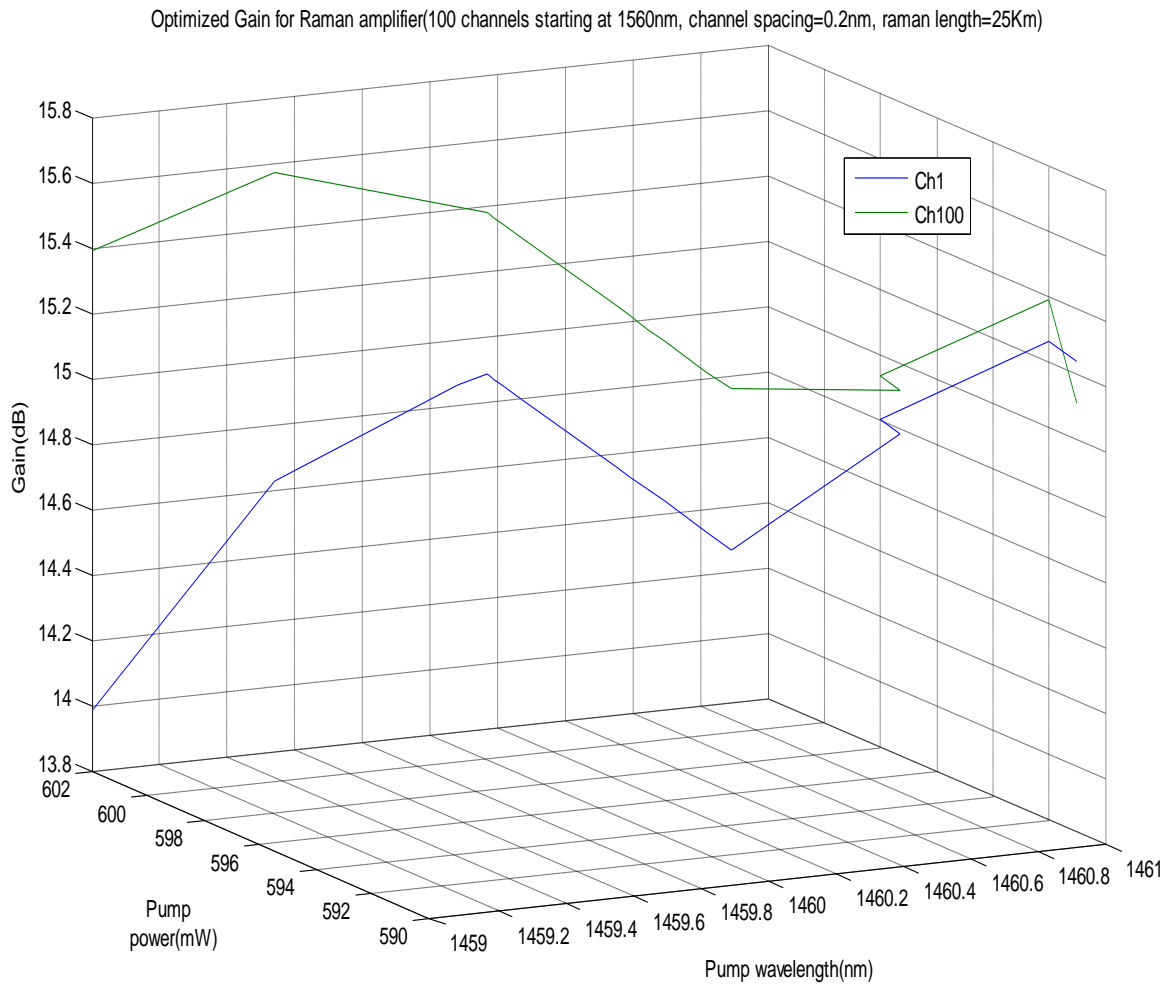


Fig. 3 Optimized gain for RFA with optimum pump wavelength and pump power

Fig. 3 shows that the maximum gain is achieved at Pump wavelength nearly equal to 1460nm and pump power approximately 600mW which is in agreement with previous stage.

Stage III: Final stage uses the results from the second stage to obtain the optimal values for pump power and signal power. Using Raman fiber length of 25 Km, the pump wavelength at 1460nm, the target gain value of 20dB, third stage of optimization is achieved to get appropriate signal power value. Fig. 4 shows the results obtained during the third stage.

Optimized Gain for Raman amplifier(100 channels starting at 1560nm, channel spacing=0.2nm,Raman length=25Km)

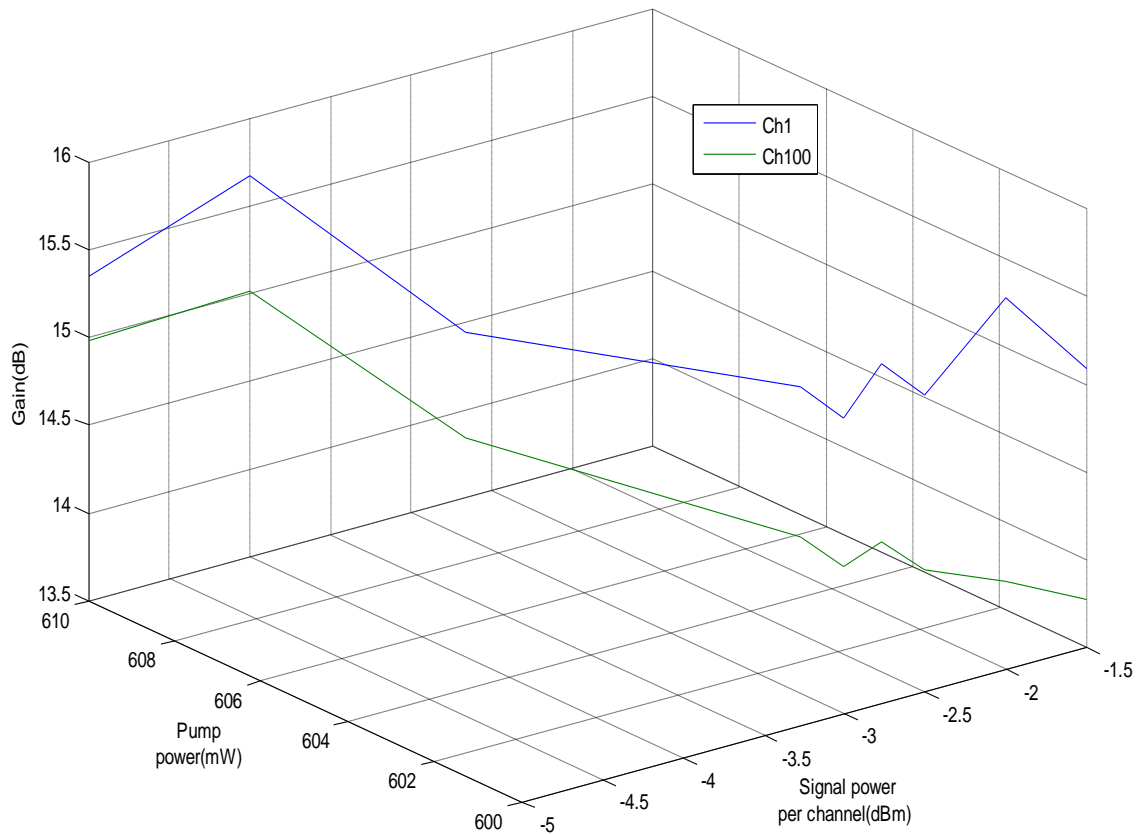


Fig. 4 Optimized gain for RFA with optimum signal power and pump power

From fig. 4, it can be deduced that the appropriate signal power to be launched per channel is nearly -5 to -4dBm as it shows a maximum gain for RFA for this range. High gain is also observed near -2dBm power per channel, but for all the channels, the maximum gain is not observed at this value. Hence, the optimized set of parameters for RFA is attained with a gain (of single channel) approximately 15 to 16 dB.

#### IV. CONCLUSION

A multi-stage MPO method has been employed for optimizing multiple parameters of a counter-pumped RFA. The optimized gain value is about 15-16dB with four parameter optimization. Since, the single pump laser source is considered, so pump-pump interactions are not present. Thus, the method has resulted in an optimal gain value for 100 channel DWDM system with 0.2nm channel spacing.

#### REFERENCES

- [1] Mohammed N. Islam, *Raman Amplifiers for Telecommunications-1 Physical Principles*, Springer: New York, pp. 10-30, 2004.
- [2] C. Headley and G.P. Agrawal, *Raman Amplification in Fiber Optical Communication Systems*, Elsevier Academic Press: California, pp. 11-13, 2005.
- [3] B. Neto, C. Reis, A. Teixeira, P. S. Andre and N. Wada, "Gain equalization technique for Raman amplification systems based on the hybrid optimization algorithm", IEEE Microwave and Optoelectronics Conference, pp. 687-689, 2009.
- [4] Farzin Emami and Majid Akhlaghi, "Gain Ripple Decrement of S-Band Raman Amplifiers", IEEE Photon. Technol. Lett., vol. 24, no.15, pp. 1349-1351, 2012.
- [5] Junhe Zhou, Jianping Chen, Xinwan Li, Guiling Wu, Yiping Wang, and Wenning Jiang, "Robust, Compact, and Flexible Neural Model for a Fiber Raman Amplifier", J. Of Lightw. Technol., vol. 24, no. 6, pp. 2362-2367, 2006.
- [6] Pengcheng Xiao, Qingji Zeng, Jun Huang and Jimin Liu, "A New Optimal Algorithm for Multipump Sources of Distributed Fiber Raman Amplifier", IEEE Photon. Technol. Lett., vol. 15, no.2, pp. 206-208, 2003.
- [7] John M. Senior, *Optical Fiber Communications- Principles and Practice*, Dorling Kindersley: India, pp. 528-530, 2010.
- [8] Zhi Tong, Huai Wei and Shuisheng Jian, "Theoretical investigation and optimization of bi-directionally pumped broadband fiber Raman amplifiers", Opt. Comm., pp. 401-413, 2003.
- [9] B. Neto, A. L. J Teixeira, N. Wada and P. S. Andre, "Efficient use of hybrid Genetic Algorithms in the gain optimization of distributed Raman amplifiers", Optics Express, vol. 15, no. 26, pp. 17520-17528, 2007.

- [10] Junhe Zhou and Philippe Gallion, "Analytical Design, Analysis, and Optimization of Raman Fiber Amplifiers with TDM Pumps", *J. Of Quant. Elect.*, vol. 46, no. 11, pp. 1597-1604, 2010.
- [11] Hai Ming Jiang, Kang Xie and Ya Fei Wang, "Novel Design of Flat Gain Spectrum Raman Fiber Amplifiers Based on Ant Colony Optimization", *IEEE Photon. Technol. Lett.*, vol. 23, no. 23, pp. 1823-1825, 2011.
- [12] Carmelo J. A. Bastos-Filho, Joaquim F. Martins-Filho and Marcelo E. V. Segatto, "Simple Design of Raman Fiber Amplifiers using a Multi-objective Optimizer", 11th International Conference on Intelligent Systems Design and Applications, pp. 1128-1133, 2011.
- [13] Gustavo C. M. Ferreira, S. P. N. Cani, M. J. Pontes and M. E. V. Segatto, "Optimization of Distributed Raman Amplifiers Using a Hybrid Genetic Algorithm With Geometric Compensation Technique", *IEEE Photon. J.*, vol. 3, no. 3, pp. 390-399, 2011.
- [14] Javeria Yasmin and M. K. Atiq, "Optimization of Raman Amplifier Parameters to Achieve Flat Gain for WDM Chaotic Communication", International Conference on Emerging Technologies (ICET), pp. 1-4, 2012.
- [15] J. M. Ferreira, R. Nogueira, Paulo monteiro and A. N. Pinto, "Weighted Undepleted Pump Model For Broadband Counter-Pumped Raman Fiber Amplifiers", *J. Opt. Comm. Netw.*, vol. 4, no. 8, pp. 595-602, 2012.
- [16] G.P. Agrawal, *Fiber-Optic Communication Systems*, Wiley India: New Delhi, pp. 243-250, 2009.
- [17] Jean-Pierre Laude, *DWDM Fundamentals, Components and Applications*, Artech House: Norwood, pp. 221-230, 2002.