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# Analysis of Augmented Gain EDFA Systems using Single and Multi-wavelength Sources

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## ABSTRACT

The scope of this paper is to analyze the performance of augmented gain EDFA systems using Single and Multi-wavelength Input sources. The Performance of an Optical Communication system can be improved by the use of EDFAs as an Optical Amplifier. Erbium doped fiber amplifier (EDFA) is an important element in DWDM networks. We can achieve a flat gain spectrum by modeling the dynamic characteristics of an EDFA. This paper presents basic EDFA model operating on single (1550nm) and multi (1520-1610) nm wavelength operation with their simulation results. For the present work, we have used EDFA design software tool. It simulates various characteristics such as amplified spontaneous emission, gain, noise figure etc. in efficient manner. The working principle of this software provides accurate simulations and results. It confirms the excellent agreement between simulations and results obtained in real EDFA design. The proposed model consists of an input source, isolator, pump source, erbium fiber and WDM coupler. By changing the design parameters such as Input signal power and Pump Power, the different performance parameters (gain and noise figure) can be optimized. Without changing the values of isolator, erbium fiber length and WDM coupler and keeping the values of Input signal power -30dBm and Pump Power 80mW the obtained optimized gain is 34.45dB for single wavelength source and 32.924 dB for multi wavelength source.

## General Terms

Spectrum, Networks, Multiplexing.

## Keywords

EDFA, Pumping, Isolator, WDM, ASE, Optical Fiber Communications, Augmented

## 1. INTRODUCTION

Now a days, EDFAs have been an interesting and active research area in the field of Optical Fiber Communication Systems [1].EDFAs are reliable for transmitting data through Long distance because of their wide bandwidth and optimum bit error rate. The light signal passing through the optical fiber is attenuated due to fiber absorption and scattering losses. To avoid this problem, One of the most efficient and versatile optical amplifier is EDFA. The use of EDFA as a Booster and Pre-amplifier [2] in an OFCS have enhanced the capacity of light wave systems beyond 1Tb/s.Fig.1 is showing an optical fiber system using EDFA as a booster and Pre- amplifier. EDFAs deployed in WDM networks provide Multi channel amplification with no cross talks.WDM technology [3] employing EDFAs will play a dominant role for next generation high speed networks. The ability [4] to pump the devices at different wavelengths and low coupling losses are the main features of an EDFA.EDFAs used together [8] with the Raman amplifiers provide ultra-low NF combined amplifiers which are used in very high bit rate links. The main advantages of EDFA are [9] high gain and low noise figure. The performance of EDFA is highly affected by Concentration of Erbium ions and temperature.

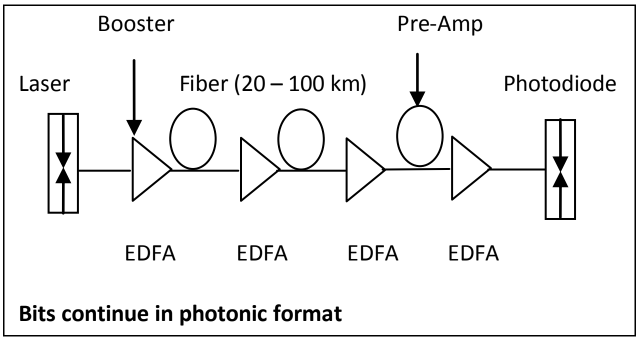

**Fig. 1: Optical Fiber system using EDFA**

### 1.1 Basic principle of EDFA

The basic principle [10] for Amplification in an Erbium doped fiber amplifier is stimulated emission. In stimulated emission process, the light wave signal itself acts a stimulator for the emission of light. The doping agent [14] used in EDFA for Silica fiber core is trivalent erbium ions. Erbium provides minimum attenuation because it possesses an active transition at 1550nm wavelength.

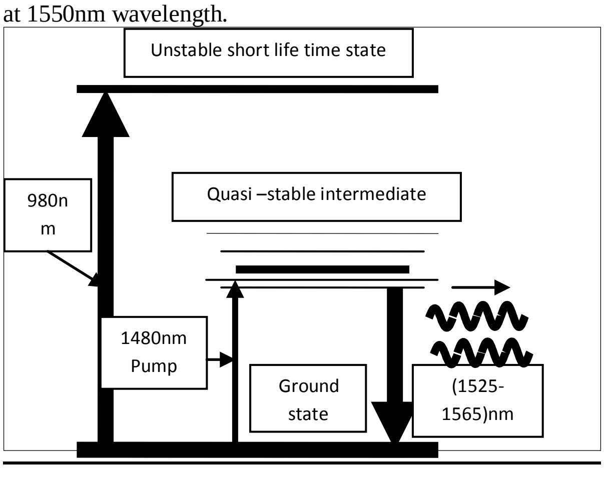

**Fig.2: Physical Principle of EDFA**

Wavelength Selective Coupler [10] is used to mix a high-powered beam of light of (either 980nm or 1480nm) from pumping source is mixed with the input signal. The mixed light is guided into a section of fiber with erbium ions included in the core. The Erbium ions are excited due to pumping source to a long lifetime intermediate state [13] as shown in Fig 2. When the photons belonging to the signal (at a different wavelength from the pump source) hit the excited erbium ions, the erbium ions give up some of their energy to the signal and return to their lower-energy state. A very important point is that erbium ions give up their energy in the form of photons of exactly same phase and direction as the input signal being amplified. Thus we can say, energy transfer will occur via the Erbium ions from the pump wavelength to the signal wavelength resulting in signal amplification[27] EDFAs can be designed to operate in forward –pumping configuration as well as backward –pumping configuration. In the forward pumping [5] configuration the input signal and the pump signal co-propagate with each other, while in the backward pumping they counter-propagate with each other. The gain and noise of an EDFA are greatly influenced by pump direction [15] because the pump direction changes the gain dynamics of amplifier. Pumping can be done at 660nm, 820nm [30], 980nm and 1480 nm etc.The most widely used wavelength are 980nm and 1480nm [20]. Choi Bo –Hun et al [20] proposed a new pump wavelength of 1540nm band for L-Band EDFA by cascading both 980nm and 1480nm pump wavelengths. When EDFAs are used in cascading structure, the two major issues must be considered for good performance [6].First issue is Non-linearity of amplifier gain and second is noise introduced by the amplifier.Fig.3 is showing the basic model consist of an input source, Pump source, WDM coupler and EDFA. Isolators [14] located before and after EDFA prevent pump signal from being transmitted along with the amplified signal.

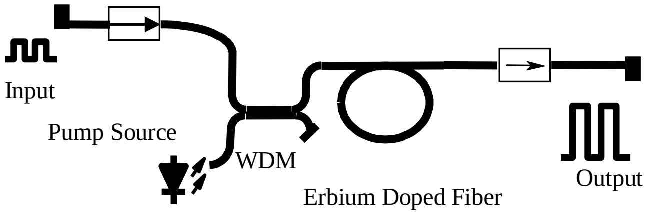

**Fig 3: Basic EDFA model with all components**

The principal source of noise in EDFAs is Amplified Spontaneous Emission (ASE) [3].It has a spectrum approximately the same as the gain spectrum [12] of the amplifier. The gain spectrum can be made extremely flat by optimizing the wavelength and pump power. Greater is the spontaneous emission, the greater will be the amplified spontaneous emission (ASE).As the nature of spontaneous emission [27] is incoherent, the amplified signal is noisier than the input signal. Kobayashi.M et al [29] proposed a new configuration for improving the noise figure of optical gain clamped fiber amplifier by mid-point band reject filter for lasing light. Erbium randomly emits photons between 1520 and 1570 nm. Spontaneous emission (SE) is not polarized or coherent and like any photon, SE stimulates emission of other photons. When there is no input signal, eventually all optical energy is consumed into amplified spontaneous emission (ASE) and contributes as a major source of noise in EDFA. Greater is the spontaneous emission, the greater will be the amplified spontaneous emission (ASE).

## 1.2 Gain and Noise Figure in an EDFA

The most important feature of the EDFA is gain. The gain of EDFA can vary from amplifier to amplifier. It can vary over a wide range depending on the amplifier length [27]. The shape of gain spectrum is affected, considerably by the nature of erbium ions. When a WDM signal is amplified .Gain is the ratio of output to the input light power and is given by [28]

$$\mathbf{Gain = Pout/Pin} \qquad (1)$$

Where (Pout) is the output power and (Pin) is the input power. A fast increase in the value of gain occurs when an input power is decreased. The value of gain also increases with the pump power [14]. Novak Stephanie et al [22] developed an analytic model for gain modulation in EDFAs. They considered small modulation index and computed gain according to different parameters. Modulation index is the ratio of over modulation amplitude and mean pump level. An erbium doped amplifier can amplify light wavelength ranging [24] from 1500 nm to more than 1600 nm. Two such bands are in use today. One is the C-band (Conventional band) which occupies the spectrum from 1530 nm to 1560 nm and the second is L-band (Long wavelength band) which occupies the spectrum ranging from 1560 nm to 1610 nm. Most EDFA works in the C-band. Yeh Chein-Chung et al [16] developed an s-band (1480-1520 nm) gain clamped EDFA by using optical feedback method. Noise is the second most important characteristic of an optical amplifier. The optical noise in an EDFA is called as Amplified Spontaneous Emission (ASE).The noise performance of an optical amplifier is quantified through noise figure (Fn) parameter which is defined as [28]

$$\mathbf{Fn = (SNR)in/(SNR)out} \qquad \mathbf{(2)}$$

Where (SNR) in is the input signal to noise ratio and the (SNR) out is the output signal to noise ratio. Noise figure in an ideal EDFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 dB. Noise Figure can also be given by [28]

$$\mathbf{Fn = \left(1 + \frac{2Pase}{hv\Delta Vsp}\right) 1/G} \qquad \mathbf{(3)}$$

Where Fn is the noise figure, Pase is the ASE noise power, h denotes the planks constant, Vsp is the bandwidth of EDFA and G denotes gain. The two most important elements in order to produce high gain in L-band EDFA are the length of EDF, the pump power and the signal wavelength [31]. In this paper we have analyzed the effect of pump power and the input signal power.

This paper is organized into six sections. In section 2, Literature has been discussed, while section 3 presents the work methodology and the proposed work. Section 4, demonstrates the model Simulation details. Section 5 presents the results and discussions. Finally, the paper is concluded in section6 and Section 7, the paper lists all the references in section8.

## 2. LITERATURE REVIEW

EDFAs invention in late 80's has been a great achievement as it has given a new life to optical fiber communication systems Akhter Fowzia et al [1] Modeled and characterized all possible triple pass EDFA configurations. They determined optimum length and pump power ratio for each configuration and concluded that triple pass EDFA is the best for practical design. Chaugule Sachin et al [6] simulated WDM and Optical Amplifier. They recommended EDFA as a better option for optical amplifier due to its high gain and low noise. Naji W.A et al [7] proposed a new simulator which is capable of changing design parameters such as length, pump power and studies their effects on performance parameters. This paper [8] presented a quick review to the basic optical amplifier as technology and explains various configurations and models. Awaji Yoshinari et al [11] demonstrated various challenges towards burst mode EDFA.They optimized EDFA to suppress the transience intrinsically without any controlling such as AGC or Optical Feedback loop. Adolph Tamer et al [14] studied different features of the amplifier depending upon opto-geometric parameters and simulation results shows gain, power dependency on internal parameters.Tae Joon et al [17] proposed an All-Optical gain clamped Erbium-Doped Fiber Amplifier with improved noise Figure. It was based on reflecting amplified spontaneous emission (ASE) into EDFA.They experimentally demonstrated the scheme by using a coarse WDM Coupler at input fiber.Harun S.W et al[18] demonstrated a gain clamped L-Band EDFA with improved gain by incorporation of a broadband fiber brag grating(FBG).The Fiber Bragg Grating is a device which attenuates the backward propagating ASE.Subramaniam.T et al [19] presented the evaluation of design software capability in simulating any EDFA design and comparing the results with the experimental values.Izyani M.A[21] implemented a counter-propagating ring-laser cavity technique for gain clamped and flattened EDFA.They also compared the Gain and noise figure for with feedback and without feedback EDFA architectures. Hwang Seongtaek et al [24] demonstrated a broad-band EDFA with Double pass Configuration. They configured first stage for C-band and L-band amplification, while the second stage only amplifies the L-band signals.Kozak M.M [25] described EDFA_design and VPI Component Maker programs. A survey was made on commercially available software For EDFA design, Simulation and Optimization. It was concluded that such programs gave accurate results.Horiguchi Masaharu et al[30] suggested two different pumping wavelengths as 660nm and 820nm for the development of an efficient EDFA.The model with these pumping wavelengths experienced high gain and low noise Figure.

## 3. WORK METHODOLOGY

In this work, we proposed the simulation models of EDFA using Single and Multiple wavelength sources with Co-directional Pumping (980nm) scheme. The Pump power variation of 43mW, 65mW and 80mW along with signal power ranging from -30dBm,-20dBm,-10dBm and 0dBm have been simulated with WDM blocks and Isolators. We have presented a high Performance approach here that has not been used in this manner before for such design.

### 3.1 Applied Methodology

The applied methodology is based on Co-Propagating Pumping approach. All the blocks in the architecture have been tested and assembled together to compose the complete system. The resulting proposed model was simulated and the parameter values obtained were tabulated. For the present work, we have used an efficient EDFA design software tool to study simulation of basic EDFA model.Subramaniam. T et al [19] also simulated an EDFA system using EDFA_Design Software. The EDFA Design Software tool derives values for such as Gain, Noise Figure and ASE.Simulated results obtained are dependent on the options chosen and the parameters values set.

### 3.2 Proposed Work

Fig.4 shows the proposed model for simulation of EDFA with Pumping wavelength of 980nm using Co-directional (Forward) Pumping Scheme. The proposed model consist of either the single input Source (1550nm) or the Multiple Wavelength source with different channels (1520nm-1610nm) whose output is given to the isolator. An isolator [31] is a device which allows the propagation of light in only one direction with zero reflections. By using Co-directional pumping scheme, the output of an isolator is combined with the pump signal in a WDM Coupler. Wavelength Division Multiplexing (WDM) coupler used is the one that combines the input signal and the pump signal and it passes this combined signal to the EDFA.Ismail.N et al [26] presented 980nm pumped power variation effect on a Full Duplex Single EDF Bi-Directional Erbium Doped Fiber Amplifier. The proposed model consist of either the single input Source (1550nm) or the Multiple Wavelength source with different channels (1520nm-1610nm) whose output is given to the isolator.

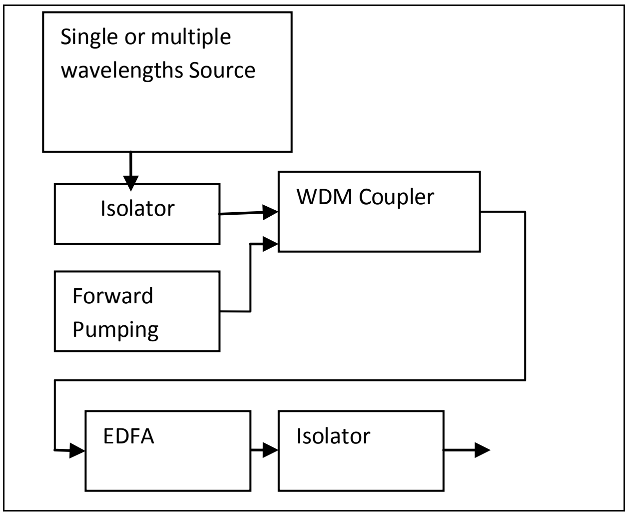

**Fig. 4: Block Diagram of Single /Multiple wavelength sources with Co directional Pumping Scheme**

An isolator [31] is a device which allows the propagation of light in only one direction with zero reflections. By using Co-directional pumping scheme, the output of an isolator is combined with the pump signal in a WDM Coupler. Wavelength Division Multiplexing (WDM) coupler used is the one that combines the input signal and the pump signal and it passes this combined signal to the EDFA_design software utilizes this model with all the components shown in the blocks. Parameters for the pump source (here used as 980nm), input signal source (single/multi wavelength) are varied so as to obtain optimized results. Graphs can be seen in the software itself for each changed value of parameters such as pump power and input signal power. The observations for required parameters such as gain, Noise figure and ASE can be carried out. Probe is used here between input and output to check overall gain and noise figure of the EDFA system.

## 4. PROPOSED MODEL SIMULATION

The proposed EDFA model with single wavelength source (1550nm) using Co-directional Pumping has been shown in the Fig.5.The wavelength for the pump source used is 980nm.The parameters Gain and Noise figure been measured with different pump powers 43mW, 65mW and 80mW and with EDF length of 10m. Firstly, the pump power is kept constant and input signal power is varied and secondly the input power is kept constant and Pump power is varied.Semmalar.S et al [2] simulated EDFA of different lengths with an influence of pump power for optimizing gain and noise Figure.

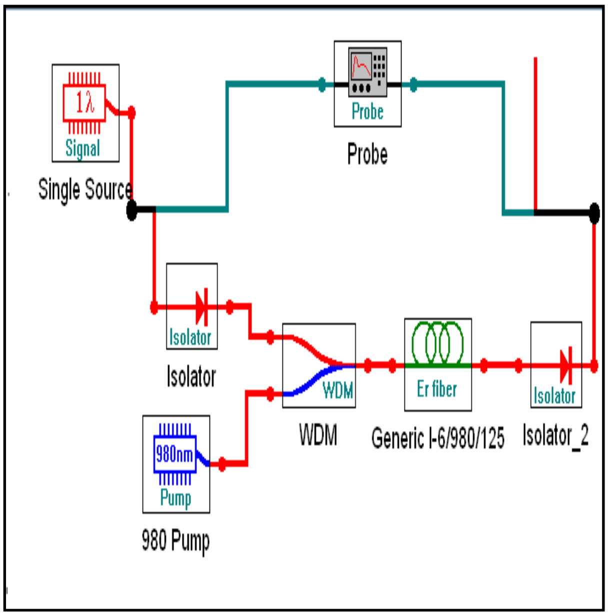

**Fig.5: Simulated model of single wavelength source (1550nm) with co-directional pumping scheme.**

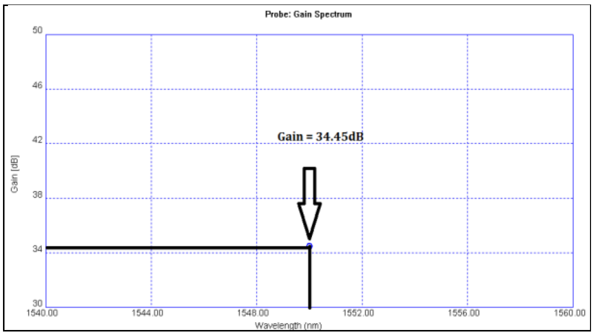

**Fig.6.Simulated Gain spectrum for Single channel EDFA of length=10m with Input Signal Power=-30 dB and Pumping power=80mW for Co-directional pumping.**

The simulator was used for the implementation of single stage Erbium Doped Fiber Amplifier (EDFA) such as single pass (SP), double pass (DP) and triple-pass EDFA. Below Fig.6 is showing the Gain spectrum of single channel source EDFA of wavelength=1550 nm with input signal power of -30 dB. Pumping source used here is 980 nm, Insertion loss for isolator is 0.3dB and the gain measured is 34.450dB. Fig.7 is showing the Noise Figure spectrum of simulated model with single wavelength source. Parameters like pump power and the input signal power [31] have an influence on the gain spectrum and as well as the noise Figure spectrum.

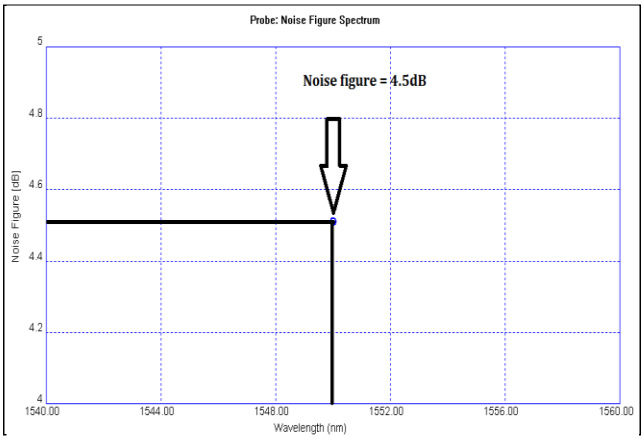

**Fig.7: Simulated Noise spectrum for EDFA of length=10m with pumping power=80mW for Co-directional pumping Scheme.**

The gain spectrum and the noise figure spectrum of EDFAs can vary from amplifier to amplifier even with the same core composition. The reason for this variation is dependency of gain spectrum on length of EDFA [31].Fig.8 is showing the simulated model of Multi-wavelength source over the wavelength ranging from (1520nm-1610nm) including C-band and L-band. Optimized Pump power used here is 65mWand Input Signal power is -30 dBm. Insertion loss for isolator is 0.3 dB. The maximum gain measured is 31.646 dB and the Noise Figure measured is 4.0dB. S.Semmalar [3] simulated an EDFA with optimized gain using Tri-Counter Directional Pumping scheme. It was justified that gain increases with increasing the pumping stages.

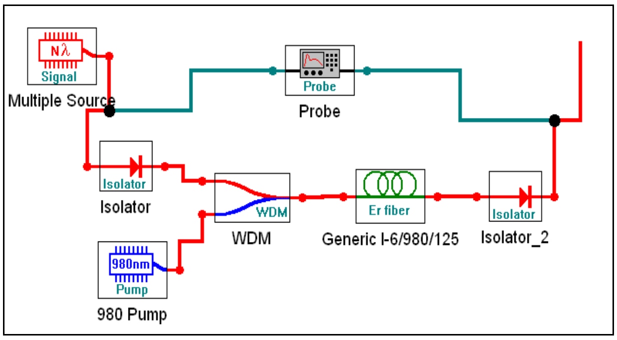

**Fig.8: Simulated model of Multi- wavelength source with co-directional pumping scheme**

Fig.9 is showing the gain spectrum for multi-channel EDFA with length=10m. The absorption and emission cross sections having different spectral characteristics affect the gain spectrum [27]. Novak Stephanie [23] developed a simulink model using MATLAB for EDFA dynamics applied to gain modulation. This Simulink model used two wavelengths, one or the pump and another for the signal.

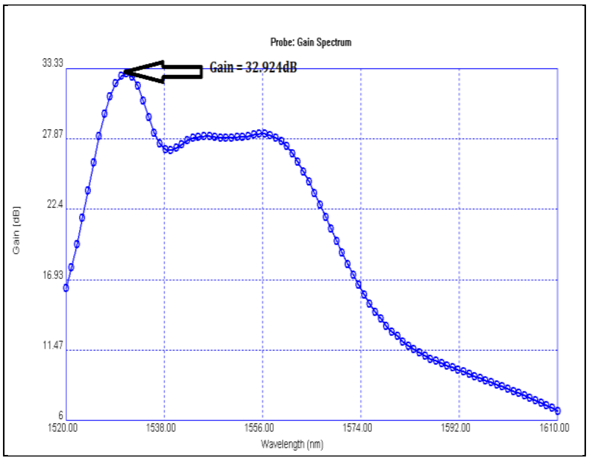

**Fig. 9: Simulated Gain spectrum for Multi-channel EDFA of length=10m with Input Signal Power=-30 dB and Pumping power=80mW for Co-directional pumping.**

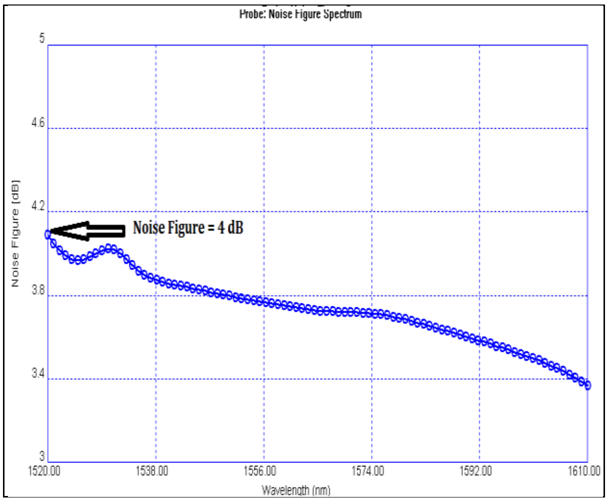

**Fig.10: Simulated Noise spectrum for EDFA of length=10m with pumping power=80mW for Co-directional pumping.**

Fig.10 is showing the noise spectrum for EDFA of length 10m with pumping power of 80mW using Co-directional Pumping Scheme.WDM technology will play a dominant role for the development of the next generation high-speed networks [5].

## 5. RESULTS & DISCUSSIONS

The proposed model simulation results for both gain and noise figure shows change in their peak values. The simulation results have been shown for (1550nm) for single wavelength source and for (1520nm-1610nm) for multi-wavelength source. The plotted values are tabulated with different pump power and input signal power in Table 1.

Simulation Results indicate that Gain and noise figures are affected by pump power and the Input Signal power variations.ASE is the Amplified Spontaneous which also varies with the changed parameters as indicated by the present results. Here we have observed only backward ASE.

**TABLE 1 Results of comparison of Gain, Noise figure and ASE for different pump power and EDFA length=10m with forward Pumping scheme.**

| Pump Power | Signal Input power (dBm) | Gain(dB) | NF(dB) | Backward SE(dBm) |
|---|---|---|---|---|
| 43mW | -30 | 32.193 | 4.5 | 0.16 |
| | -20 | 29.765 | 4.2 | -2 |
| | -10 | 22.649 | 3.8 | -10 |
| | 0 | 13.351 | 4.41 | -23 |
| 65mW | -30 | 33.73 | 4.5 | 2.5 |
| | -20 | 31.537 | 4.2 | 0.333 |
| | -10 | 24.58 | 3.7 | -8 |
| | 0 | 15.24 | 4.1 | -20 |
| 80mW | -30 | 34.45 | 4.5 | 4 |
| | -20 | 32.378 | 4.2 | 1.429 |
| | -10 | 25.532 | 3.7 | -8 |
| | 0 | 16.175 | 4.1 | -20 |

Table 1 shows the Results of comparison of Gain, ASE and noise figure for different pump power and EDFA length=10m with Co-directional Pumping scheme.

Following points can be summarized from the results shown in the table for Single wavelength source:

i. Keeping the pump power constant when signal power is decreased there is an increase in gain, 0.2db change in N.F and ASE power gets increased.
ii. Proposed results clearly show that pump power is proportional to gain as well as ASE. By fair choice of the signal input power and pump power we can optimize Gain, N.F, ASE.
iii. 80mw pump power with signal energy =-10dBm shows lowest N.F of 3.7dB with average gain =25.532dB.Also compared to other values ASE is minimized so, it can be considered as an Optimized value.
iv. Lowest value of ASE is accounted for increased signal power and that can also be decreased by decreasing pump power.

As we see in the proposed results Pump power has a significant effect on both gain and noise figure. The direction of pump also affects the value of gain and noise figure.

Table 2 results shows that for a multi-wavelength source the optimized values can be taken at Pump Power 80mW and Input Signal Power of -30dBm where the gain comes out to be maximum that is 32.924 dB and the Noise Figure is minimum that is 4 dB.

**TABLE 2 Results of comparison of Gain, ASE and noise figure for different pump power and EDFA length 10m with Forward Pumping scheme**

| Pump Power | Signal Input power (dBm) | Gain(dB) | NF(dB) | Backward ASE(dBm) |
|---|---|---|---|---|
| 43mW | -30 | 28.947 | 4.3 | -8 |
| | -20 | 18.116 | 5.8 | -19 |
| | -10 | 8.589 | 12.06 | -30 |
| | 0 | 2.489 | 23 | -37 |
| 65mW | -30 | 31.646 | 4 | -5 |
| | -20 | 19.91 | 5.1 | -16 |
| | -10 | 10.5 | 11 | -29 |
| | 0 | 2.98 | 23 | -36 |
| 80mW | -30 | 32.924 | 4 | -4 |
| | -20 | 20.761 | 4.9 | -15 |
| | -10 | 11.457 | 10 | -28 |
| | 0 | 3.3767 | 21 | -35 |

Following points can be summarized from the above results for Multi-wavelength source:

i. Gain of 32.924db is obtained for a higher pump power without changing any other parameters shows an efficient technique.
ii. Here both L,C –Bands are used as source wavelength Other than these wavelengths ,for any desired window results shows improvement over gain and noise figure as with limited range stimulated emission show better progression.
iii. To reduce ASE we can vary signal power down below to 0db without changing pump power.
iv. -30dBm signal power value for any pump power shows maximum values of gain and comparatively the lowest values of noise figure.

J.A Carmelo et al [15] proposed the pump direction influence on EDFA. They used both co-propagating and counter-propagating schemes with optical feedback. The pump power values used for co-propagating scheme were 43mw, 65mw and 75mw.The input signal power used was -30dBm.They considered feedback attenuator losses in the range 0 to 50 dB. The gains and noise figure obtained were 28dB and 7dB.

The values of pump power used in our proposed work are 43mw, 65mw and 80mw which are similar as used by J.A Carmelo [15].The simulation results obtained shows that the gain obtained at -30 dBm input power for single wavelength source is 34.45 dB and for multi-wavelength source is 32.924dB. The values obtained for noise figure are 4.5dB for single wavelength source and 4dB for multi-wavelength source. If our proposed results are compared with the paper [15], we find that our results are better in terms of gain and noise figure.

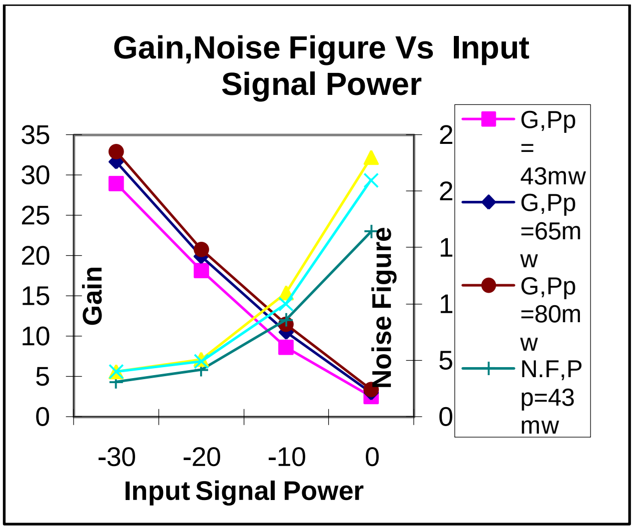

**Fig.11: Gain and Noise Figure as a Function of Input Signal Power for single wavelength source usiing codirectional Pumping**

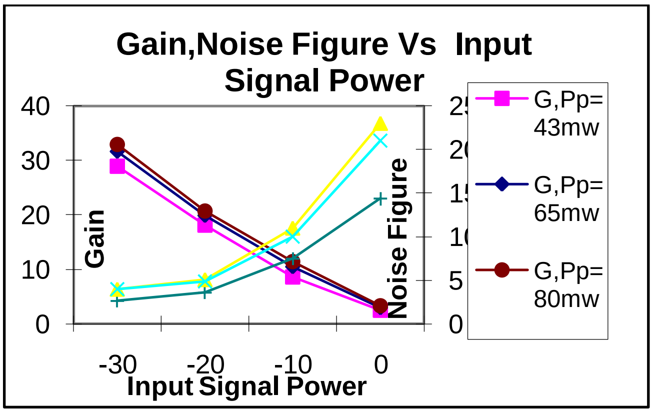

**Fig.12: Gain and Noise Figure as a Function of Input Signal Power for Multiwavelength source using Codirectional Pumping.**

Fig 11 & 12 are showing the comparison graphs for gain and noise figure using single and multiple wavelength sources. Result observations show a mapping between pump power and input signal power over noise figure, ASE and gain. If any of the parameter has a limitation to be changed, other can be utilized to perform the same operation. Comparison graphs show that gain increases with increase in pump power. The reason is that gain depends on both the absorption and emission cross sections [27].

## 6. CONCLUSION AND FUTURE ASPECTS

We have proposed and simulated the EDFA model with single and multi-wavelength sources using pumping source of 980 nm wavelength. The various results were also compared. It is important to understand the desired range of wavelength used in EDFA which provides efficient results. Along with source wavelength if other parameters like length, pump power, signal power are changed , than optimized values of gain and noise figure are obtained. Thus, we have shown that the proposed model of an EDFA utilizing both single and multi-wavelength sources was successfully simulated using WDM.

For each pump power signal power is changed and we observed the changes in gain and noise figure. We have also shown the impact of change on ASE i.e. the major noise component in EDFA systems. Any of the desired condition of maximum gain and low noise or minimum ASE can be achieved using the values shown in the proposed results and also without changing each and every component. It may be observed that the Gain is optimized and Noise Figure initially decreases with increase in Pump Power and then attains the same value.

In future work, the model can be modified in different ways. Firstly, we can take this model and go with another parameter i.e. length of fiber and the Concentration of erbium ions using 1480 nm pumping. Secondly, cascaded model employing two EDFA's can be used with same parameters to have better results. Thirdly with the addition of new wavelengths the proposed model can be used network re-configuration. And the last is optical feedback method and circulators can be deployed on proposed model.

## 7. ACKNOWLEDGMENTS

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