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Enhancement in the Gain of EDFA in Fibre Optic Communication

Vijaya Bhandari, Mohammad Yusuf

***Abstract:** With the evolvement ofhigh speed and long distance data communication systems, conventional band erbium-doped fiber amplifiers (C-EDFAs) are getting more attention in recent times. Major advantage of the C-band EDFA is that it provides the user to realize a system with wide bandwidth of 40 nm. But, from the reported works, it is evident that for Gain enhancement in C-band using EDFA is reported with the use of multiple stages, multiple pumps, Gain flattening filters etc. However, these techniques suffered from high cost, complex techniques and low performance.Here enhancement process was done through the narrowband Fiber Bragg Gratings (FBG) or fiber reflectors mirrors. In this work, a conventional band erbium doped fiber amplifier is proposed with high gain and less noise figure by incorporating the two fiber bragg gratings (FBGs) for amplified spontaneous noise reinjection. Maximum ASE is emerged at 1565 nmfor the at -55 dBm carrier powers. Maximum gain is found out to be 48.16 dB with noise figure of 5.29 dBm.*

***Keywords:** EDFA, WDM, FBG, ASE.*

I. INTRODUCTION

Information uprising implies that networks based on internet require high bandwidth for information exchange between multiple points. In recent times, fiber optic reliant systems are the only communication medium that providing such wide-bandwidth by means of offering very low signal degradations lossesin the transmission links [1]. In the beginning of the development of fiber optical systems, the amplitude degradation was very towering and typically deteriorate signal with the loss of up to 1000 dB/km as well as not incorporated in the industry based transmission systems [2].Later on, in the year 1970, the researchers at Corning Glass Works were flourishing in realizing anoptical fiber with attenuation 20 dB/km whichwas the breakthrough for this technology and in addition, made fiber optic very reliable to use.Further, as the work on enhancing the potential of fiber optic increased, the amplitude degrading value comes down to 0.2 dB/km and are easily available. Figure 1.1 depicts the basic transmission system using optical fiber strands.In the communication system reliant on fiber optic, there is deterioration in signal power of the pulses aslink length prolongs. By the incorporation of the optoelectronic repeater, the attenuation or losses emerged due to fiber optic length can be reduced [3].

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Working of these devices is simple that optical signal is first of all converted into electric signal and followed by amplification it is regenerated by sender/ transmitter. However, the aforementioned process becomes complex to a certain extent and also expensive for frequency division multiplexing or wavelength division multiplexed systems. Therefore, in order to accomplish the regeneration process with less losses and complexity, optical amplifiers are employed which in a straight line strengthen the transmitter optical signal by not including any O/E conversions.

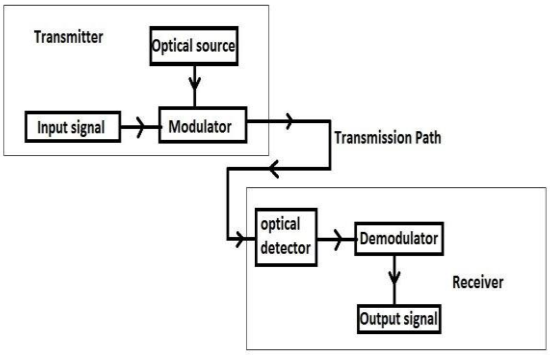

Figure 1.1: Block diagram of Optical fiber communication system [10]

The optical amplifiers are generally incorporated in the optical fiber system for amplification of entire array of wavelength division multiplexing system channels at the same time and this is termed as optical in-line amplification scheme [4].

1.1.1 Advantages of Optical Fiber Communication

Optical fiber cables provide the ultimate solution to the overall cost of the systems because they are cheaper in the cost as compared to co-axial and copper wires.Optical fibers are simple to install in the network for information sharing.Fiber optic cable networks can be easily upgraded without any complex efforts.In fiber optic based communication systems, there is an advantage to realize Bidirectional transmission. This is very prominent and an important property of the optical fiber systems and has potential to accommodate the full duplex communication with high Quality of service (QoS).A major performance limiting issue that exists in electrical medium was electromagnetic interference. On the other hand, in optical fibers there is non-presence of EMI interference.

1.1.2Optical fiber communication

Transmitter: It is basically the first and foremost part of the communication that consists of various components such as light source, a pulse provider modulation, an intensity modulator and binary data generator.

Channel: In fiber optic systems, the channel is of glass fibers or waveguide that play a role to pass the optical pulses from the transmitter to receiver. As far as security is concerned for sensitive information such as in military, optical fiber is more secure than the electrical mediums. Principle for the transmission in the optical fiber is total internal reflection and due to this phenomenon the size of the core and clad is too small.

Receivers: In order to get the information signal in the electrical form, photodetectors are needed and these are comprised inside the receiver In general detectors are of two types [5] such as P-i-N and avalanche photodetector.

1.2 Wavelength Division Multiplexing (WDM): To carry the different number of wavelengths through one medium is termed as the Wavelength Division Multiplexing. However, there is one condition that wavelength should be different for each channels. As a result, more bandwidth and time saving is in this case.Incorporating WDM, the bit streams can be augmented or enhanced to several terabits.To supplementary get better the entire capacity of the systems, more number of channels should be accommodated in the strand of single fiber optic which can be attained by employing WDM or Dense WDM (DWDM).

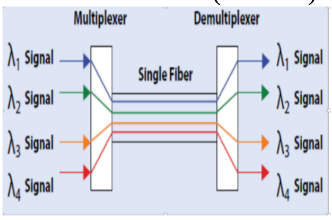

Figure 1.4: Block diagram of Wavelength division multiplexing [8]

However, the signal amplitude degradation and pulse width broadening along with the non-linear impairments turn out to be worse in densely spaced DWDM networks. Polarization mode dispersion and pulse broadening (dispersion) are referred as the linear impairments. On the other hand, incident power and refractive index variation reliant special effects comprise XGM, XPM (Cross-Gain and phase Modulation), FWM (Four-Wave Mixing) and SPM (Self-Phase Modulation).

1.3 Fiber optic nonlinear effects

This is a performance degrading issue and moreover, it also bound the total bit rate, connection distance end to end and channels spacing selection freedom in the system [9]. Figure 1.6 depicts the a variety of special effects in the optical fiber cable. These comprises linear effects such as attenuation, dispersion as well as nonlinear effects.

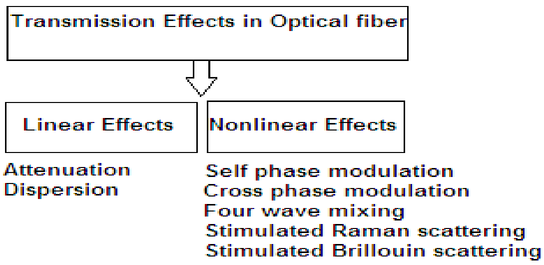

Figure 1.6:Linear and Non Linear effects in optical fiber [9]

1.4 Introduction of Optical amplifiers

The signal degradations in the fiber optic such aspower loss (attenuation) because of a range of effects like bending take place when communication of signal accomplished. As a result, there is trouble to access system with high quality at the reception side. For realizing the long link length communication, there is strong need to overcome these aforementioned effects. First step for designing the communication link is the laser intensity that is required to modulate data. To overcome attenuation, regenerators are inserted in the system. Conversion of O/E and E/O is required for this operation . As there is more than one conversion, system becomes costly. At the present time to overcome this limitation, optical amplifiers are required that are capable to boost signal without conversions. This growth of optical systems has offered breakthrough in the fiber prolonged link length transmission

1.4.1 Principle of optical amplifier

Principle of amplification in optical is simple that there is existence of the atoms and have discrete state of energy. There are discrete energy states in the process of absorption to achieve higher energy states and also a process of loosing energy for coming back to ground state. The difference in the two states of emission and absorption is equal to the difference in ground state and excited state. For the process of storing energy by the atom for going to excited state takes place when light or photon strikes on it . After reaching the higher energy state, atoms does not be steady and at all times tend to go to ground state by generating a photon . This is termed as the phenomenon of spontaneous emission in the energy states [4]. Optical fiber amplification experiences this phenomenon of stimulated emission and it is widely incorporated. Aforementioned method is accomplished at the time when incident photon with energy $E = hc/\lambda$ [11] act togetherwith electron in high energy or excited energy state. This provides the potential to the atom for emerge on meta stable state by losing some fraction of total energy. Meta stable state is near to the excited state and just below to this level. After this state, by losing high amount of energy atoms return to ground by generating an additional photon .For the attainment of the amplification,number of atoms in high energy states should be greater than the lower energy state in order to get population inversion $N1 < N2$, where N1, N2 are population densities of lower and upperstate.

Amplifier types:There are different types of amplifiers in optical as given below:
1) Semiconductor optical amplifier
2) Erbium Doped Fiber Amplifier
3) Raman amplifier

1.4.3Semiconductor Optical Amplifier

Laser diodes are the end mirrors less having optical fibers connected to both ends are termed as Semiconductor optical amplifiers (SOAs). Anti reflection coatings are the alternate to the end mirrors in this amplifier.These coatings are used as a dialectical coating to sides of the fiber optic in order to diminish the reflectivity within a particular range of wavelengths.Semiconductor optical amplifier boosts the wide range of the wavelengths that are fed to one end and emerged to another end.

Population inversion in SOA amplifiers is different from other amplifiers.As this is a semiconductor material thus the population inversion is of electrons and holes irrespective of the ions [13]. Figure 1.8 shows the diagram of semiconductor optical amplifier [14].

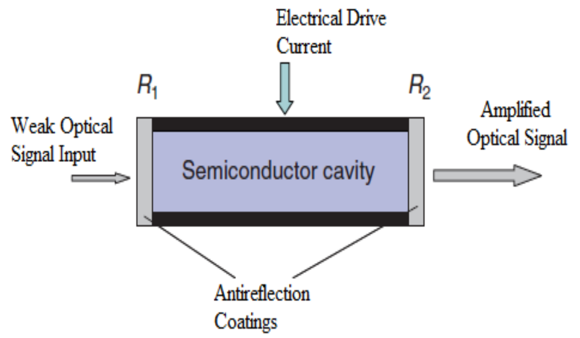

Figure 1.7: Basic diagram of Semiconductor Optical Amplifier (SOA) [14]

1.4.4 Erbium Doped Fiber Amplifier

Rare-earth elements like erbium, ytterbium and thallium can be doped into optical fibers to create fiber amplifiers function in diverse wavelengths from 0.5 µm to 3.5 µm. In erbium doped fiber amplifier, for the most part two pump wavelengths are required for work to boost the signal. Basically EDFA supported regions such as C and L band. Most of the work has been reported for the C-band with the pump wavelengths of 980 nm and 1480 nm. Energy states and erbium doped amplifier represented in Figure 1.8.

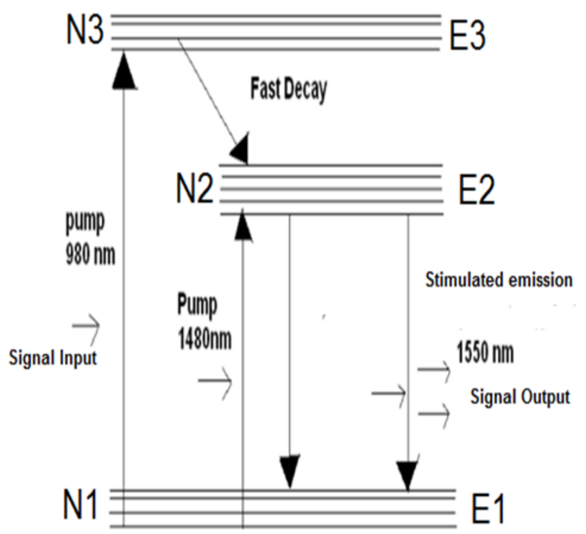

Figure 1.9:Three level energy diagram of Er3+ ions [15]

However, due to the ever-increasing demands, L band also needs to be incorporated in the WDM systems. But the problem in L-band that exists in the systems, this band experiences the uneven gain. Lower gain is experienced by L band as compared to higher gain of C band.

1.4.5 **Raman amplifier**

For the cost effective way out, the single mode fiber by itself can be incorporated as a medium of gain, termed as Raman amplifier, for boosting the signal under high pump power phenomena devoid of by means of expensive doped ions [19Distributed configuration systems that use fiber optic, two types of pumping are used. When the pump is used near the transmitter or in the direction of the signal then it is referred as the co-pumping. On the contrary, when the pump is used in the reverse direction of the propagation of the signal then it is called as the counter pumping.This gain depends upon the pump power and wavelength.

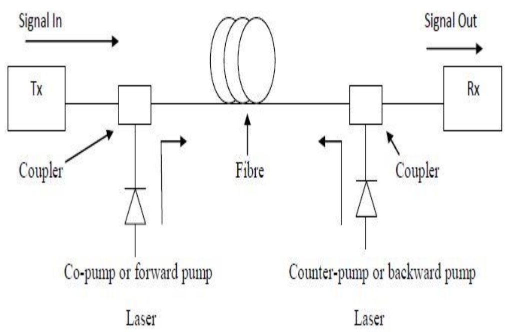

Figure 1.10: basic block diagram of Raman Amplifier

Raman is capable of amplifying all the wavelengths ranging from 1280 to 1650 nm. The amplification is based on Raman scattering which is a nonlinear effect in which a signal is captivated as well as at once emitted backphotons, thus amplifying the signal.

II RELATED WORKS

In 2017, Belloui Bouzid *et al.* [27] presented the qualified investigation of the design experiment, programing and simulations analysis of EDFA of double pass using three distinct categories. Experiment, Optisys and Matlab types were required to investigate and analyses the gain and noise figure of EDFA double pass. Two EDFAs and two pumps were used to get the maximum Gain of 41 dB at input power of -40 dBm.

In 2014 S Sugumaran *et al.* [38] presented the wavelength division multiplexed system by taking the simulation software optiwave optisystem. Work demonstrated was looked to the effects of the channel spacing in the WDM system and their effects along with the nonlinear effect such as four wave missing..

In 2010 R. S. Kaler *et a.l* [39] proposed a single mode fiber-28 based system that was made to carry bit rate of 10 Gbps. Different phase shift keying with return to zero was incorporated in the system because of their features to tolerate dispersion effects. It was perceived that at the lower data rates such as 10 Gbps, there were less performance deteriorating effects due to dispersion and self phase modulation**In 2005 Lee *et al.* [35]** proposed the diverse arrangements ofhybrid optical amplifiers in terms of the total gain achieved and emergence of noise figure. Proposed HOA was realized through the use of erbium fiber and Raman fiber. Where, the dispersion compensation fiber in the system was used as the Raman fiber to amplify the signals. .**In 2004 Zimmerman *et al.* [34]** presented and elaborated the theoretical study of diverse gain flattening techniques and in addition to this, compared these methods. A range of configurations of amplifiers are studied such as hybrid Al-co-doped with Al/P- co-doped EDFAs, Raman-EDFA HOA. Also they have reviewed the GFFs (gain flatting filters) for best gain and even power to every WDM channels.

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III PROPOSED TECHNIQUE

To complete the proposed work, use of a commercial simulation package Optiwave Optisystem^{TM} is taken into use. This package permits us to realize the proposed system, to test and to analyze in modern optical transmission layer. To fulfill these demands, optical amplifiers are required. EDFA is perfect candidate to use in C-band wavelength window based communication. However it suffers from low Gain and high cost. To overcome this issue, C-band EDFA amplifier is proposed with high gain and less noise figure by incorporating the two fiber bragg gratings (FBGs) for amplified spontaneous noise reinjection. Maximum ASE is emerged at 1565 nm at -55 dBmcarrier powers. Maximum gain is found out to be 48.16 dB with noise figure of 5.29 dBm at optimal physical parameters of the EDF, pump wavelength pump power and input power. Only single stage EDFA amplifier and single pump is employs to get maximum Gain.In C band EDFA, prominent and premier technique of amplified spontaneous noise was used by utilizing forward and backward ASE to get the improved gain and less noise figure. This process was done through the narrowband Fiber Bragg Gratings (FBG) or fiber reflectors mirrors.

In this work, a conventional band erbium doped fiber amplifier is proposed with high gain and less noise figure by incorporating the two fiber bragg gratings (FBGs) for amplified spontaneous noise reinjection. Maximum ASE is emerged at 1565 nmfor the at -55 dBm carrier powers. Maximum gain is found out to be 48.16 dB with noise figure of 5.29 dBm at optimal physical parameters of the EDF, pump wavelength pump power and input power. Only single stage EDFA amplifier and single pump is employs to getmaximum Gain.In this work, a single pumped C band erbium doped fiber amplifiers is proposed using two fiber bragg gratings with amplified spontaneous reinjection as depicted in Figure 4.1. Speed of the operation is fixed to 10 Gbps from binary data bits generator. A continuous wave laser at -55 dBm power is incorporated in the system which is acting as C-band source. Laser signal is passed through optical isolator to prevent optical source from the back flowing optical intensity due to ASE. Laser signal fed to optical co-propagating pump coupler at 1490 nm wavelength is also coupled to this module. Here, FBG 1 is acting as the reflector of backscattered ASE signal at 1565 nm and combined with pump . We have chosen the 1565 nm wavelength to be reflected because of maximum intensity at this point. An erbium doped fiber with 200 ms metastable lifetime is taken. Various physical parameters are varied such as input power, and pump power. Simulation parameters are shown in Table 4.1 to clear the factors that are considered for the proposed work. FBG 2 is employed to reflect the forward scattered amplified spontaneous noise. Finally signal passed through the isolator and gain of signal is accessed by dual port WDM analyzer.

Table1:Simulation parameters of the demonstrated work

Parameters	Values
Laser	Tunable laser source
Input power	-55 dBm
Data speed	10 Gbps
Number of FBGs to reinject ASE	2
Length of EDF fiber	30 m
Core radius of EDF	1.9 um
Pump wavelength and power	1490 nm and power varied from 1 mW to 1000 mW

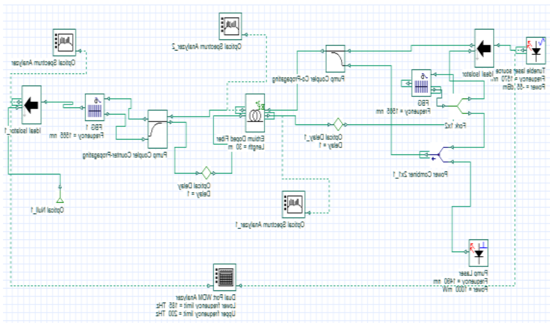

Figure 3.1: Simulation setup of proposed EDFA with ASE reinjection

IV RESULTS AND DISCUSSIONS

Results are discussed in following steps:

1 Effect of different physical parameters of EDF on C-band EDFA

In this research work, we emphasised on the Gain enhancement of the C band erbium doped amplifier with the use of amplified spontaneous emission reinjection through FBGs. To accomplish the work, Optiwave optisystem is considered which provide extensive library and good simulation environment. Effect of various physical parameters of erbium doped fiber such as length of the EDF fiber, launched power, pump power, forward/backward ASE power emergence are investigated in terms of Gain, noise figure. Optical spectrum analyzer is a depicter which is incorporated in the system to represents carriers and their power with respect to frequency or wavelength. OSA is important to check faults, carrier power and noise power. Figure 1(a) represents the OSA diagram after laser source and Figure1 (b) shows the OSA diagram after optical amplifier in the final output at -55 dBm. Similarly Figure 1 (c) and Figure 1 (d) shows the OSA diagram after optical amplifier in the final output at -20 dBm and 0 dBm respectively.

Fig 4.1(a)

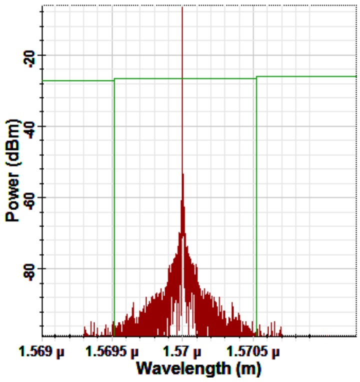

Fig 4.1(b)

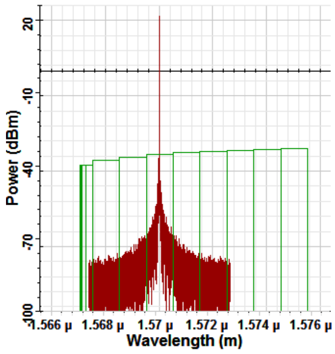

Fig 4.1(c)

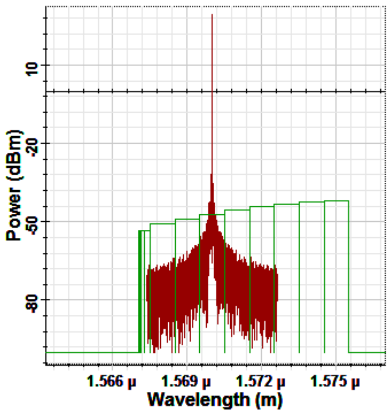

Fig 4.1(d)

Forward and backward optical spectrum of ASE noise is shown in Figure 4.1 (e) and (f) respectively. Amplified spontaneous emission noise is a prominent power degrading issue in the erbium doped fiber amplifiers. However, in this work, the use of ASE has been done to enhance the Gain through the FBGs. This is done by re-injecting the ASE in the EDF fiber with the combined power of pump. It is seen that there are two type of ASEs in the system. One is forward ASE and second is backward ASE. Figure1 (e) (f) represents the output of optical spectrum analyzer to depict the backward/forward ASE. It is percived from Figure 4.1 (f) that maximum backward ASE is emerged at the wavelength of 1565 nm and in Figure 4.1 (e), again the maximum forward noted ASE is near about 1565 nm. Thus, in proposed work, ASE at 1565 nm is reinjected through the two FBGs in the EDF fiber.

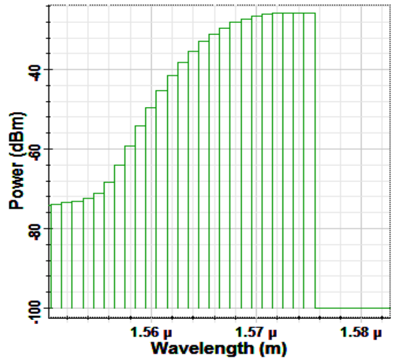

Fig 4.1 (e)

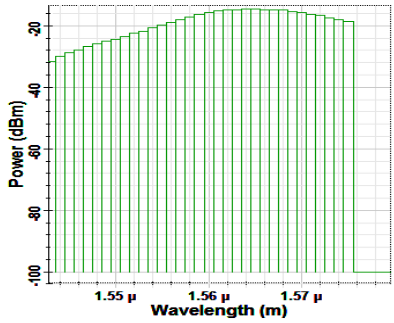

Fig 4.1 (f)

First and foremost, effect of pump power is analysed on C-band EDFA. A tunable laser at wavelength 1570 nm andpump wavelength of 1490 nm is incorporated in the system with 10 MHz laser linewidth. Pump power is varied from 200 mW to 100 mW and iterated in the EDF fiber which connected with single pumping. Results are analyzed in terms of output power and readings are noted from wavelength division multiplexed analyzer. Figure 2 depicts the performance of the system at varied levels of pump power in terms of Gain at different input power levels. Results revealed that there is increase in output power (Gain) with the increase in pump power. While input power is also changed for three different levels one by one such as -55 dBm, -20 dBm and 0 dBm. It is observed that lower input power levels and high pump power is optimal for getting high Gain in the system. Highest Gain value of 48.16 dB is achieved at input power level of -55 dBm with noise figure of 5.29 dB as shown in Table 5.1. So, it is recommended to use -55 dBm due to highest Gain.

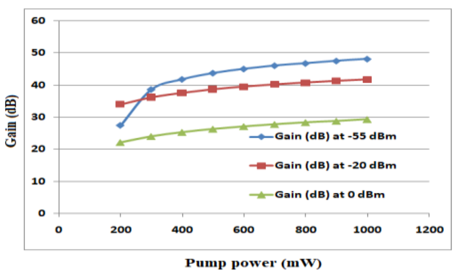

Fig 4.2: Variation of Gain with different pump power of proposed C-band EDFA with respect to three different input powers.

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Input power (dBm)	Gain (dB) at -55 dBm	Gain (dB) at -20 dBm	Gain (dB) at 0 dBm
200	27.37	34	22.10
300	38.6	36.2	24.01
400	41.8	37.6	25.3
500	43.75	38.71	26.30
600	45.06	39.54	27.1
700	46.09	40.22	27.78
800	46.8	40.80	28.37
900	47.56	41.31	28.8
1000	48.16	41.76	29.33

Table 2: Observed values of Gain at different input powers and pump powers

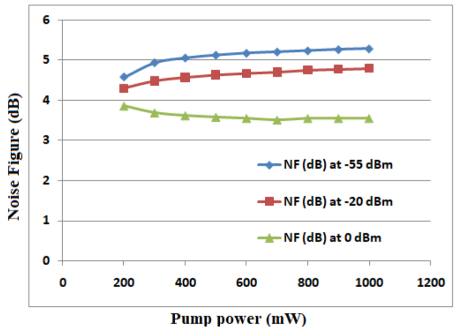

Fig 4. 3: Variation of NF with different pump power of proposed C-band EDFA with respect to three different input powers.

Results revealed that there is increase in noise power with the increase in input power. Input power is changed for three different levels one by one such as -55 dBm, -20 dBm and 0 dBm. It is observed that lower input power levels and high pump power is optimal for getting low noise figure in the system. Lowest NF value of 3.55 dB is achieved at input power level of 0dBmas shown in Table 3.So, it is recommended to use -55 dBm due to lowest level of noise figure. Moreover, in case of noise figure, the power of the noise is following the opposite trend as Gain at all pump power levels but with very less power level. However, a -55 dBm noise power is 5.29 dB which is also less and we can choose this power optimal due to minimum Gain at this point.

Table 3: Observed values of NF at different input powers and pump powers

Input power (dBm)	Gain (dB) at -55 dBm	Gain (dB) at -20 dBm	Gain (dB) at 0 dBm
200	27.37	34	22.10
300	38.6	36.2	24.01
400	41.8	37.6	25.3
500	43.75	38.71	26.30
600	45.06	39.54	27.1
700	46.09	40.22	27.78
800	46.8	40.80	28.37
900	47.56	41.31	28.8
1000	48.16	41.76	29.33

Further, a wavelength division multiplexer analyzer is used in the system to check the total Gain of the system. This analyzer calculates the Gain of the output signal by taking reference of input signals.In this work, C-band EDFA with ASE reinjection is proposed by incorporating an extra FBG for the Gain enhancement purpose. Figure 4.4 represents the values of the Gain at each frequency and also the maximum ratio difference between them. It is perceived that the maximum Gain is 48.16 dB. As a result of this, the Gain achieved is highest to the best of author's knowledge.

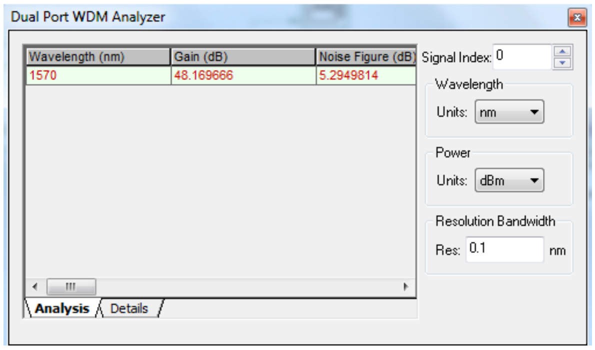

Figure 4.4: Representation of WDM analyzer's output in terms of Gain and noise figure.

V CONCLUSION

In this study, the effect of different physical parameters of the erbium doped fiber amplifier on the conventional band wavelength has been studied by incorporating the amplified spontaneous emission noise re-injection through the cost effective fiber bragg gratings. With the incorporation of the two FBGs in the system, there is significant increase in the values of the Gain. Maximum Gain is achieved at the input power level of -55 dBm and the maximum ASE is emerged (both forward and backward) at 1565 nm. Further, pump power, input power is varied to examine their effects on the Gain of the system. It is perceived that the input power of -55 dBm, pump power of 1000 mW and EDF length of 30 m provides the maximum Gain of 48.16 dB with the noise figure of 5.29 dB and thus, is considered as the optimal parameters.

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