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Performance Analysis of WDM Network Based On EDFA Amplifier with Different Pumping Techniques

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Abstract– A key mechanism for Wavelength Division Multiplexing (WDM) implementation in optical network systems is gain flatness of Erbium-Doped Fiber Amplifier (EDFA). The main intention of this paper is to correct the non-uniformity in the gain for every single channel so that the amplitude gain of the Wavelength Division Multiplexing (WDM) arrangement can be equalized.The software used in this paper is Optisystem 13 so as to accomplish gain flatness of EDFA. The gains are flattened inside 27dB from 1546nm to 1568nm group of wavelength with noise figure < 14dB and we have also seen the effect of various pumping techniques on gain and noise figure. A WDM system arrangement that includes an EDFA is modeled and obtained maximum uniformed gains.

Keywords: *EDFA, WDM, Pumping Techniques, Gain Flatness, Pump Power,Fiber length.*

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I. Introduction

Wavelength Division multiplexing (WDM) is method in that every single user's wants to work at desire electronic rate , that uses a huge number of optoelectronic bandwidth mismatch. Multiple WDM channels from distinct end users are multiplexed on similar fiber [1]. After multiple WDM channels coexist on a solitary fiber next we can use huge fiber bandwidth.

It is easier to apply each WDM mechanisms because all constituents in a WDM mechanism demand to work at electronic speed [3]. Therefore, multiple WDM mechanisms are obtainable in the marketplace today. EDFA is an optical amplifier in that a doped optical fiber is utilized as a gain medium to amplify an optical signal. The signal that is to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified across contact alongside the doping ions. EDFA additionally have huge gain bandwidth, that is normally tens of nanometers and it is more than enough to amplify data channels alongside the highest data rates lacking presence of gain narrowing [4]. EDFA is the most usually utilized optical amplifier due to low los optical window of silica fiber. EDFA gain-flattened is vital in long haul multichannel lightwave transmission system specially WDM. Implimentating a WDM system encompassing EDFA's is the tough part because the EDFA gain spectrum is wavelength dependent. The EDFA does not have to amplify the wavelength of the channels equally and oftentimes to have equalized gain spectra in order to attain uniform output powers and comparable signal-noise ratios (SNR). There are multiple methods in arranging a flat spectral gain EDFA such as by manipulating the doped fiber length and pump power by selecting of optical notch filter's characteristic, by employing an acousto-optic tunable filter and by retaining an in homogeneously widened gain medium [5]. In this paper we accomplish gain flatness of EDFA by manipulating the doped fiber length and pump power for a given input power of –26 dBm and desire output power of more than 8 dBm.

The remaining part of the paper is organized as follows. Section II gives basic Erbium Doped Fiber Amplifer design and working. Section III describes different pumping techniques. Section IV gives the gain and noise figure formulation. Section V gives the Schematics of different pumping techniques simulation results have been presented and discussed followed by conclusion.

II. Erbium Doped Fiber Amplifier

Erbium doped fiber is a standard silica fiber doped alongside active erbium ions as the gain medium. Erbium ions (Er^{3+}) are possessing the optical fluorescent properties that are suitable for the optical amplification [2]. There are usefully two wavelength widows C-Band (1530nm-1560nm) and L-Band (1560nm-1600nm). EDFA can amplify a expansive wavelength range (1500nm-1600nm) simultaneously, hence is extremely useful in wavelength division multiplexing for amplification. EDFA basic says after an optical signal such as 1550nm wavelength signal enters the EDFA from input, the signal is merged with a 980nm or 1480nm pump laser across a wavelength division multiplexer device [4]. The input signal and pump laser signal bypass across fiber doped alongside erbium ions. Here the 1550nm signal is amplified across contact alongside doped erbium ions. This can be well understood by the energy level diagram of Er3+ ions given in the figure 1. The three energy levels E1, E2, E3 are the ground, meta-stable and excited state levels respectively. The population of erbium ions in the three levels is denoted by N1, N2, N3 respectively. The population density is N1>N2>N3 in equilibrium state, after no pump signal is used. After pump or signal is present the population density of levels adjustments alongside the movement of ions between the levels, across the emission or absorption of photons at frequencies ambitious by the energy-level difference.

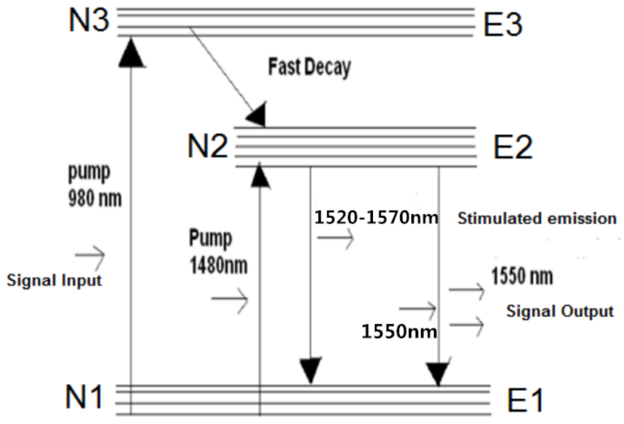

Fig 1: Energy level diagram of Er^{3+} ions

As shown in the Fig 1, two pump wavelengths can be utilized for EDFA i.e. 980nm and 1480nm. With 980nm pumping wavelength the Er3+ ions in the ground state (E1) are excited to the excited state (E3). The rate of transition from ground state to the excited state depends upon the pump power [2]. The ions in the excited state are not going to stay there for a long period and decays back to the meta-stable state and then plummet back to the ground state after 14 approximately 10ms and emits photon. This is called spontaneous emission. But photons generated in this spontaneous process are treated as noise as the photons are non-polarized and incoherent across time and space. But after the ions or photons that are in the metastable state event alongside light photons of suitable wavelength, they plummet back to the ground state emitting photons having same phase, frequency and polarization and travel in the same direction as the photons of the incident wave. This is called stimulated emission. In this procedure one photon gives two photons at the output. Hence multiplication of photons occurs and several number of photons subjected at the input generates huge number of photons at the output that increases the light intensity that we call gain and it amplifies the input signal. With 1480nm the ions in the ground state excited undeviatingly to the meta-stable state and the above procedure occurs. When the number of ions in the excited state or meta-stable state is greater than the ions in the ground state then the population inversion mechanism occurs.

A. BASIC EDFA DESIGN

EDFA consists of length of Erbium doped fiber, Laser diode utilized as pump and wavelength selective coupler to multiplex or combine the signal and pump wavelength together, so that they can propagate simultaneously in the fiber. The signal and pump can both propagate in the same direction or they can propagate in the opposite direction to every single supplementary in side the EDFA [5]. This paper briefly discusses about the types of pumping in the coming section. The length of the Erbium Doped Fiber depends upon the input signal power, pump power, Er3+ion density and the signal and pump wavelength.

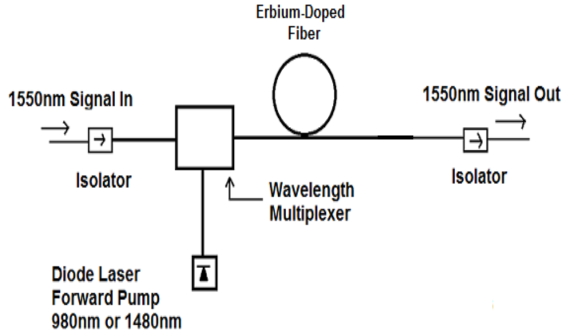

Fig 2: Basic Block diagram of an EDFA

Fig 2 shows the basic block diagram of EDFA amplifier co-pumped with a laser signal. The input signal here is a 1550nm wavelength optical light signal. The optical signal is next merged with diode laser through a wavelength multiplexer. The merged signal is then bypassed across EDF where the signal interacts with the Er3+ ions and gets amplified. At the output we get an amplified version of the input 1550nm signal.

III. PUMPING TECHNIQUES

There are three ways to pump the Er3+ ions from the ground state to the upper states [6].

1. Forward Pumping or Co-directional Pumping
2. Backward Pumping or Counter-directional Pumping
3. Bi-directional Pumping

1. FORWARD PUMPING

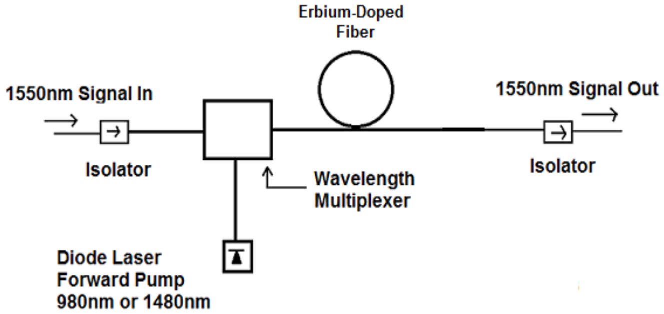

Fig 3: Forward Pumping or Co-directional Pumping

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Fig 3 shows forward pumping method or technique in which the input signal and the pump signal propagate in the same direction inside the fibre [6]. The input signal and pump are merged by using a pump combiner or wavelength division multiplexer. Inside the fiber the pump energy is transferred to the input signal and the signal is amplified at the output of the amplifier. Isolators are utilized in the scheme to make sure that the signal will travel only in one direction and no feedback of signal will occur.

2. BACKWARD PUMPING

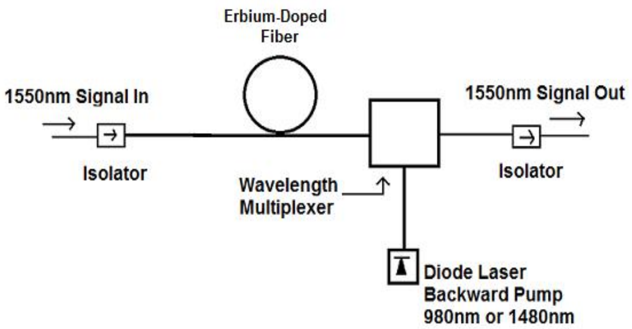

Fig 4: Backward Pumping or Counter-directional pumping

Fig 4 shows Backward pumping technique in which the input signal and the pump signal propagate in the opposite direction to every single supplementary inside the fibre [7]. For amplification the direction of input and pump signal is not essential. They can travel in any direction.

C. BIDIRECTIONAL PUMPING

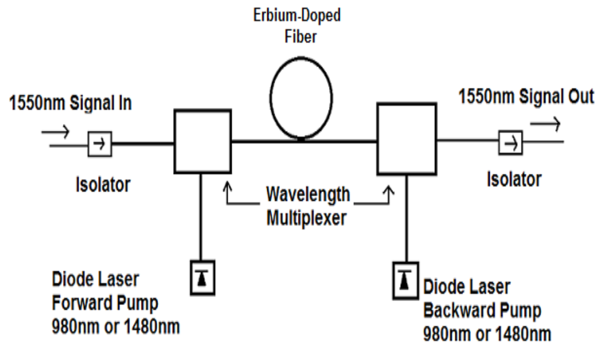

Fig 5: Bi-directional Pumping

Fig 5 shows Bi-directional pumping technique in which the input signal travels in one direct ion. But the there are two pump signals that travel inside the fibre [6]. One pump signal travels in the opposite direction as the input signal and the other pump signal travels in the same direction to that of the input signal.

IV. GAIN AND NOISE FIGURE

Gain of an erbium-doped fiber alongside a length of L is the ratio of the signal power at the fiber Output to the signal power injected at the fiber input as:

$$G = P_s(L) / P_s(0) \quad (1)$$

Where is the signal power at length L

And $P_s(0)$ is the signal power at the input of the EDFA.

ASE noise generated across amplification procedure is added to the signal leading to decrease in signal to noise ratio (SNR) at the amplifier output. SNR reduction ratio from input to output of the amplifier is describes as Noise Figure (NF), which is utilized for electronic Amplifiers:

$$NF = (SNR_{in}) / (SNR_{out}) \quad (2)$$

Noise Figure can also be expressed in terms of gain and spontaneous emission factor (or population inversion factor)

$$N = 2*n_{sp}*((G-1)/G) = 2* n_{sp} \quad (3)$$

V. SCHEMATICS

Fig 6 shows the schematic design of EDFA in WDM system. The system consists of 32 input channels (signals), pump laser, two isolators, ideal MUX, DEMUX, Photo detector PIN, Erbium doped fiber, 3R generator and low pass bessal filter with the following Specifications:

1. For WDM Transmitter:
   - Input power = -25 dBm
   - Frequency = 1545 nm
   - Modulation Type = NRZ
   - Frequency spacing = 0.7972 nm
2. Erbium Doped Fiber Length = 5 m
3. Pump Laser:
   - Frequency = 980 nm
   - Power = 50 mW
4. Low Pass Bessel Filter:
   - Cutoff frequency = 0.75*Bit Rate Hz

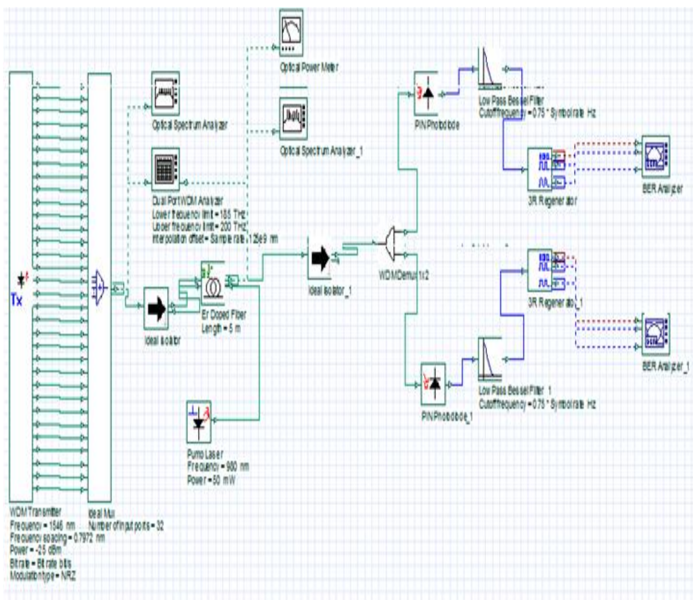

Fig 6: Schematic Design of EDFA in WDM System

1. FORWARD PUMPING

Fig 7 shows the schematic design of EDFA in WDM system for forward pumping technique.

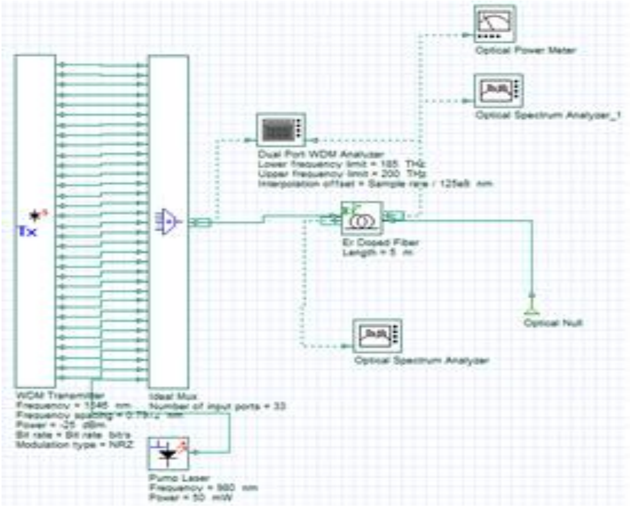

Fig 7: Schematic Design for forward pumping

2. BACKWARD PUMPING

Fig 8 shows the schematic design of EDFA in WDM system for backward pumping technique.

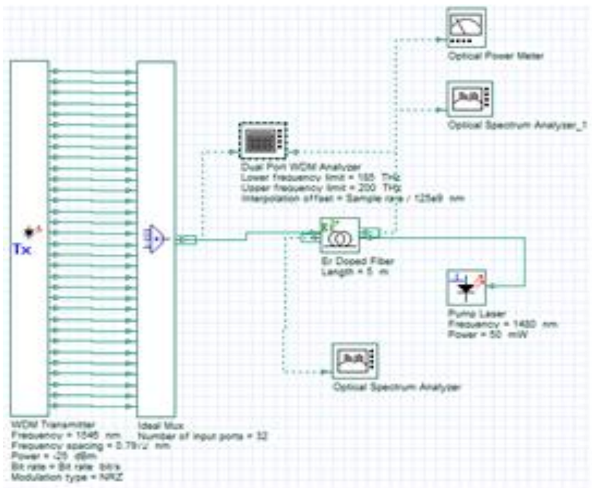

Fig 8: Schematic Design for Backward pumping

3. BIDIRECTIONAL PUMPING

Fig 9 shows the schematic design of EDFA in WDM system for bidirectional pumping technique.

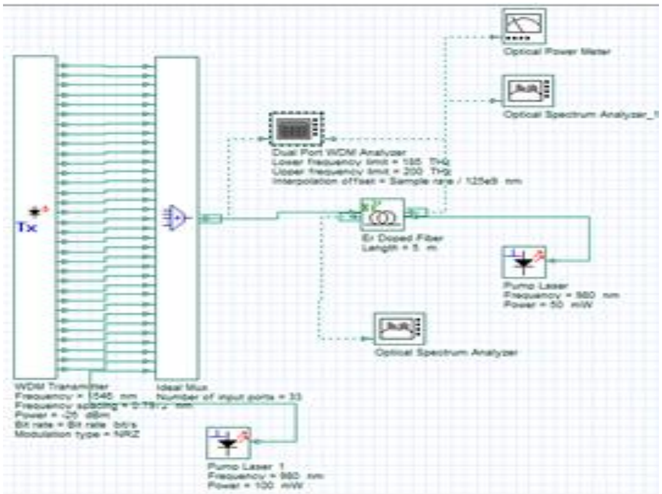

Fig 9: Schematic Design for Bidirectional pumping

VI. RESULTS AND DISCUSSION

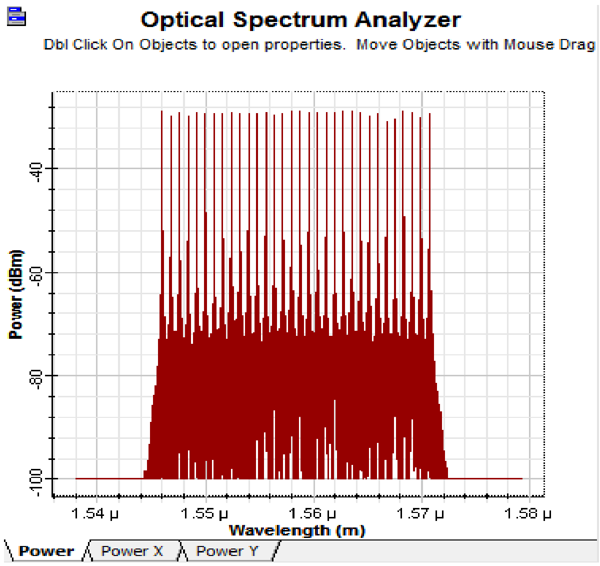

Fig 10: 32 x 1 Multiplexer Output Power

Fig 10 shows the input signal spectrum. It is the output of the WDM MUX and shows the power for different channels of the MUX. It displayed a clear view of the power for different wavelength 1546 to 1570nm. It is a plot of power(dBm) versus the wavelength(m).It is the 32-channel MUX with output power of -25dBm.

Fig 11 shows the higher pump power will furnish higher gain but inversely in terms of noise figure.The green wave in the consequence is representing the noise which shows that the noise is decreasing when the pump power is increasing while the red symbol in the graph represent the sample wavelength. The maximum gain can be attained in the journal at the maximum pump power of 40mW is 28dB with the lowest noise figure of 5dB.

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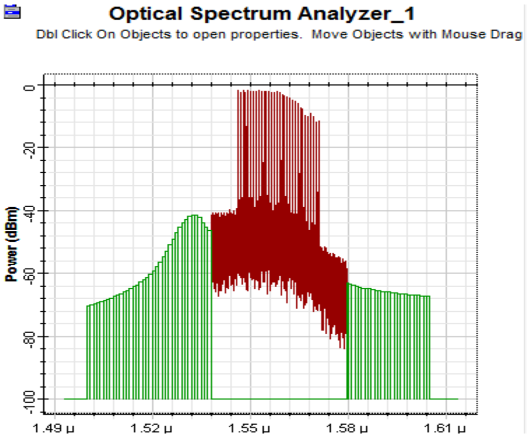

Fig 11: EDFA output

For every pump power, the output power increases and decreases after reaching a maximum value. As the fiber length increases, Er3+ ions available to excite increases and output power increases [5]. After a certain length, when all pump power is exhausted, the unexcited Er3+ ions results is the decreased of output power.

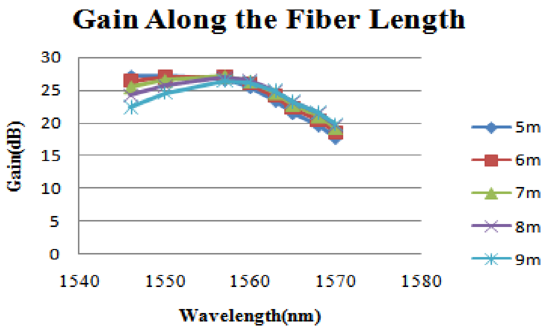

Fig 12: Gain Vs Wavelength For Different Lengths

The pump power is 50 mW while the fiberlength is attached between 5 and 9 m. The Gain and Noise Figure are measured by fluctuating fiber length at a steady input power of–25 dBmas shown in Figure 11. The Gain and Noise Figure changes as the fiber length changes. For a given pump power, Gain and Noise Figure increases in initial stage and inclines to decrease after the fiber length was optimized [5]. It is observed that the optimum value of fiber length is between 4 m to 6 m due to the minimum losses.

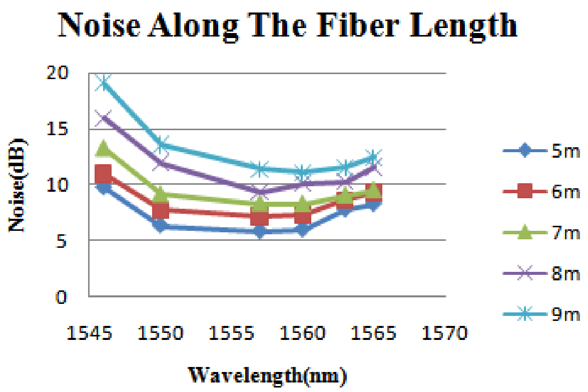

Fig 13 : Noise Figure vs wavelength for different length

The variation of gain and noise figure for distinct EDFA length is shown for a 32-channel transmitter in fig 13. Here we can observe that for smaller wavelength the gain is low and it increases with the higher wavelength and again falls down [5].

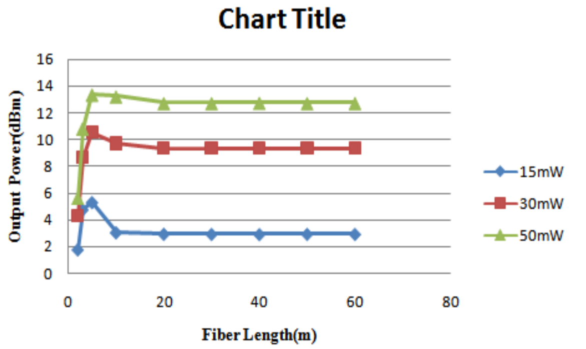

Fig 14: Effect on output power for different lengths for constant pump power

Fig 14 shows that the effect of the increasing of pump power to the output power at disparate length of amplifier. The increasing of pump power will increase the output power at every single meter of the length. This is because when the length of the amplifier is increase, there will be more power utilized to transmit the signal in the system.

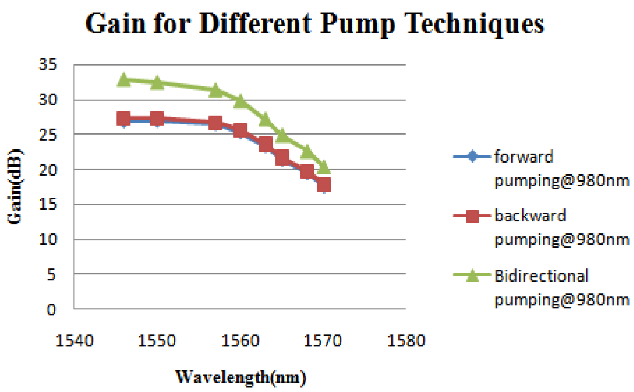

Fig 15: Gain for pumping techniques at constant wavelength

Fig 15 shows the analogy between different pumping techniques and the result of variation of gain as we vary the wavelength for disparate pumping techniques. For forward and backward pumping gain is almost same and for bi-directional pumping the gain is high.

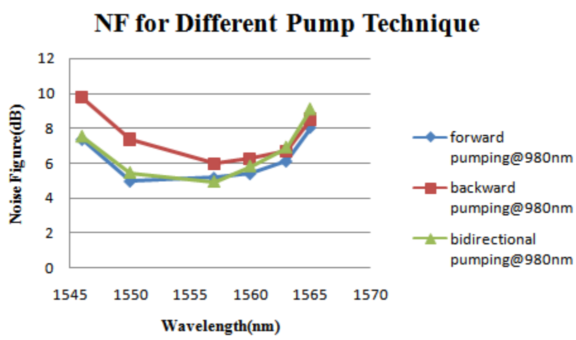

Fig 16: Noise Figure for Pumping techniques at constant wavelength

Fig 16 shows the analogy between disparate pumping techniques and the effect of variation of noise figure as we vary the wavelength for disparate pumping techniques. Noise Figure for Counter pumping is high than the other pumping techniques. Noise figure for bidirectional pumping and co-pumping is same

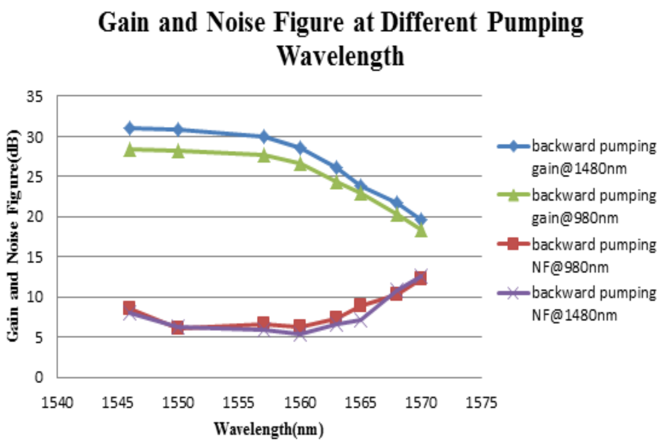

Fig 17:Gain and noise figure for different pumping wavelength

Fig 17 shows, the variation of gain and noise figure for disparate pumping wavelength. Backward pumping is utilized for 32-channel WDM network. The input power per channel is –25 dBm. EDFA length is 5 m, pumping power is 100 m Watt. The wavelength range is 1546 nm to 1570 nm with 0.8 nm wavelength spacing. It was observed that gain for 1480 nm is higher than 980 nm and noise figure at 1480 nm is less than 980 nm pumping wavelength.

The performance of the system was analyzed using BER analyzer as shown in Fig 18. The eye diagram for Channel 1 gives a large opening that way that the intersymbol interference (ISI) is low As the width of the opening indicated the period above that sampling for detection is performed. The optimum sampling period corresponding to the maximum eye opening, compliant the biggest protection opposing noise

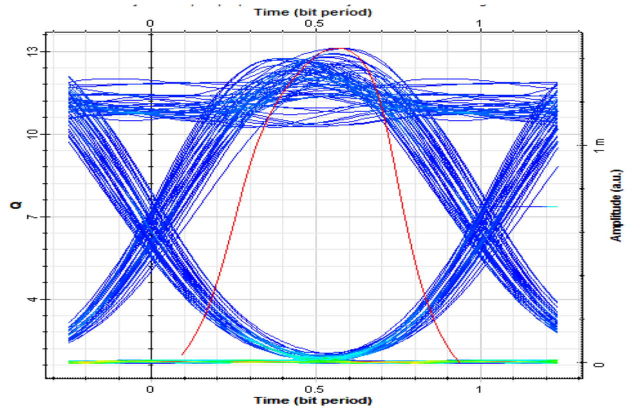

Fig 18:Eye Diagram

VI.CONCLUSION

Gain Flatness is attained from 1546nm to 1570nm. The output power of 13.363dBm and an average noise figure of 6dB and Gain 27.39dB were obtained from the simulation.For given pump power, Gain and Noise Figure increases primarily and next decreases. Gain is Low for smaller wavelength and it increases alongside higher wavelength and once more plummet down. Forward and Backward pumping Gain are nearly Same and Bi-directional pumping Gain is High. Noise Figure for backward pumping is High and it is same for Forward and Bi-directional pumping.

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