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Gain and Noise Figure Analysis of Erbium Doped Fiber Amplifier by Four Stage Enhancement and Analysis

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Abstract- The aim of this paper is to analyze the performance of Erbium Doped Fiber Amplifier (EDFA) system by comparing the gains and noise figures of different commonly available EDFAs. The four stage enhancement circuit has been designed and simulation studies for different types of EDFAs are compared by replacing different EDFAs in the four-stage enhancement circuitry of EDFA in WDM configuration. Further, for the EDFA with comparatively better gain and noise figure spectrum, the pump powers are varied and a comparison of gain and noise figure with respect to wavelength is carried out. Finally, the Eye Diagram and Min BER has been generated for the best Pump Power performance.

Index Terms- EDFA, Four Stage, Gain, Noise Figure, Stage Enhancement.

I. Introduction

Optical fiber communication is seen as one of the most reliable, fastest and secure telecommunication technologies to achieve consumer needs for present and future application. Optical Fiber communication has grown in importance exponentially in the present modern era. It is reliable in handling and transmitting data through hundreds of kilometers with an acceptable bit error rate. The Wavelength Division Multiplexing (WDM) technique is the preferred way to increase the information transmission capacities of a fiber system. An erbium doped fiber amplifier is a suitable component for optical fiber networks serving as a wide range of applications from WDM network repeaters to a CATV power amplifier and an inline amplifier.
The main attraction of EDFAs is their large gain bandwidth while simultaneously amplifying a large number of channels at different wavelengths within the spectrum without narrowing the gain. The gain flattened EDFA is a key component in a long-haul multichannel light wave transmission system.
But even now in optical fiber communication losses such as fiber loss, splice loss still occur. Thus in order to prevent signal degradation over long distance communication we need an optical amplifier with good gain and flat gain bandwidth. Thus Erbium Doped Fiber Amplifiers come into play. EDFA's have the major advantage of being optical amplifiers, with no conversion of the optical signal into electrical signal.

II. SOFTWARE USED

Here, two softwares are used

- Gainmaster ™
- Optisystem 7.0

There are six pre-defined fibers in Gainmaster Software. Gainmaster is used to compare the gain and noise figures of the six different fibers and choose the fiber with better gain and noise figure characteristics.
Once the fiber is chosen in Gainmaster, the same fiber is designed in Optisystem software and implemented in a communication system. Optisystem is a more-customizable software and further parameters can be customized to design the required communication system.

III. EDFA WORKING PRINCIPLE

By considering a three-level atomic system, the working of EDFA can be explained. As shown in the fig1. the ground state is denoted by 1, an intermediate state is denoted by 3 and a state with longer lifetime is denoted by 2 (also called metastable state). The populations of the levels are labeled Ni, N2, and N3. To obtain amplification, we need a population inversion between states 1 and 2. Since state 1 is also the ground state, at least half of the total population of erbium ions needs to be excited to level 2 to have population inversion. The major advantage of EDFA is that light fields are confined in a core of very small dimensions. Hence Population Inversion is achieved with smaller pump powers.

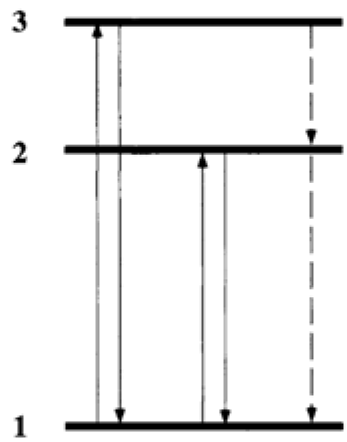

Figure 1 : Three- level system for amplifier model

- The transition from level 2 to 1 can be used as the laser transition for amplifying light in the 1.5-µm wavelength region, which is often used for optical fiber communications. The used pump light often has a wavelength near 980 nm. This actually pumps ions from the ground state (level 1) into level 3. From there, ions in the fiber glass quickly decay to level 2.
- The upper laser level (level 2) is quite long-lived, with an upper-state lifetime of the order of 10 ms..
- As the non-radiative transition 3 → 2 is rather fast, the level scheme used in a model can often be simplified. One assumes that the mentioned transition takes no time at all – with the consequence that at any time an ion can only be in level 2 or level 1.

IV. EDFA DESIGN

Initially, a four-stage EDFA circuitry is designed by connecting four EDFAs in cascade in Gainmaster software. Now, there are six different EDFAs available in Gainmaster where each EDFA have different properties like Saturation Parameter, Background Loss. Using replace tool in Gainmaster, the various fibers are implemented in the four-stage circuit. The Gain and Noise Figure for each and every Fiber circuitry is plotted and compared.

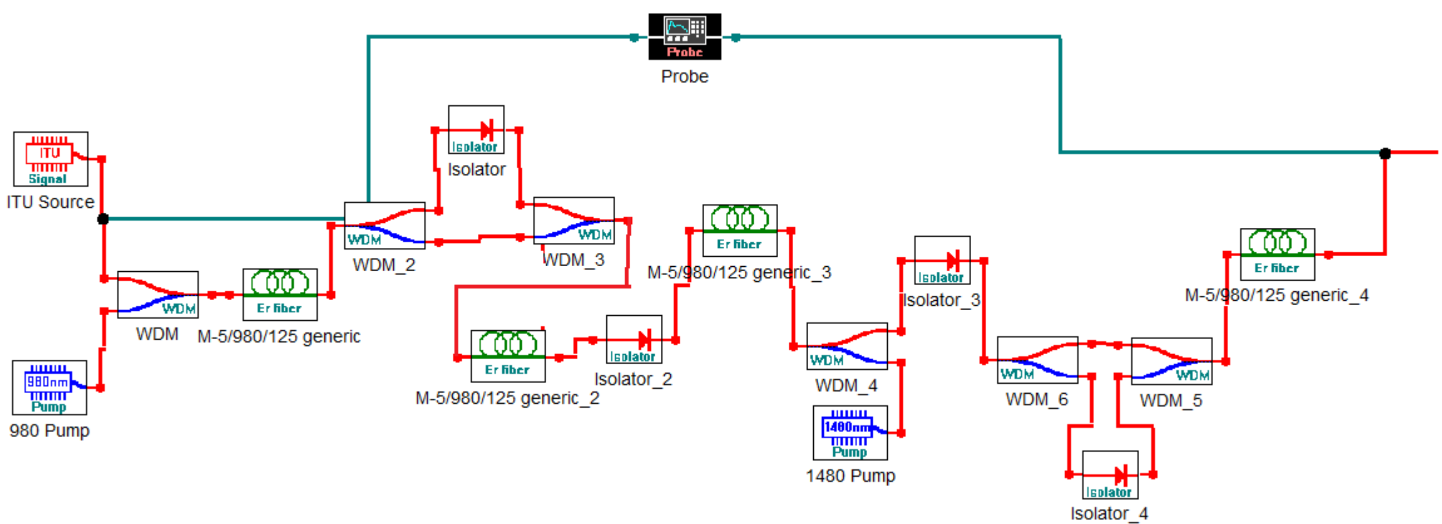

Figure 2 : Four- Stage EDFA Circuitry

An ITU-T laser source operates with 200GHz channel spacing. The source transmitting 23 signal channels and transmitting the power of each channel is a −30dBm/channel. Isolator is used to provide unidirectional propagation and restricting back reflection. It has isolation of 20dB, insertion loss −0.2dB and input and output return loss −60dB and 55dB, respectively. A wavelength selective coupler (WDM) has been fixed with an of insertion loss 0.2dB and pump and signal isolation of 20dB and 30dB, respectively. The length of the fiber used is 5m. A probe is a device used to measure the gain spectrum and noise figure spectrum between any two points in the circuit. Four Er Fibers are used to achieve the required four-stage enhancement.

Here, in the place of Er Fiber, we replace the circuit with the different available Fibers and the circuit is executed for every change and the required graphs are generated using Gainmaster Software. The different Er Fibers available in the software are DHB 1500, I-4, I-6, I-25, M-5 and M-25.

Following are the various graphs generated :

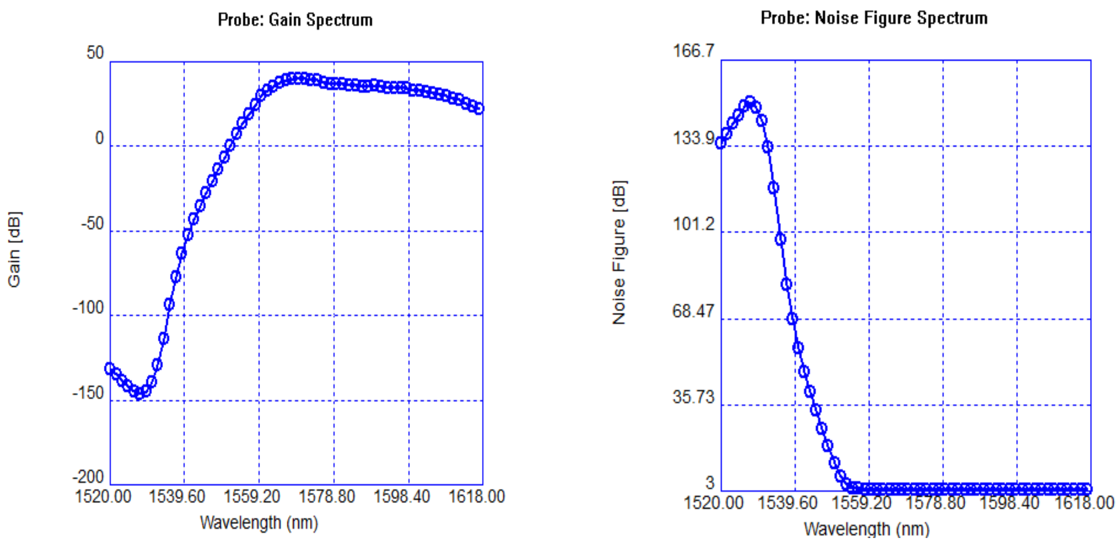

Figure 3 : Gain Spectrum and Noise Figure Spectrum of DHB 1500

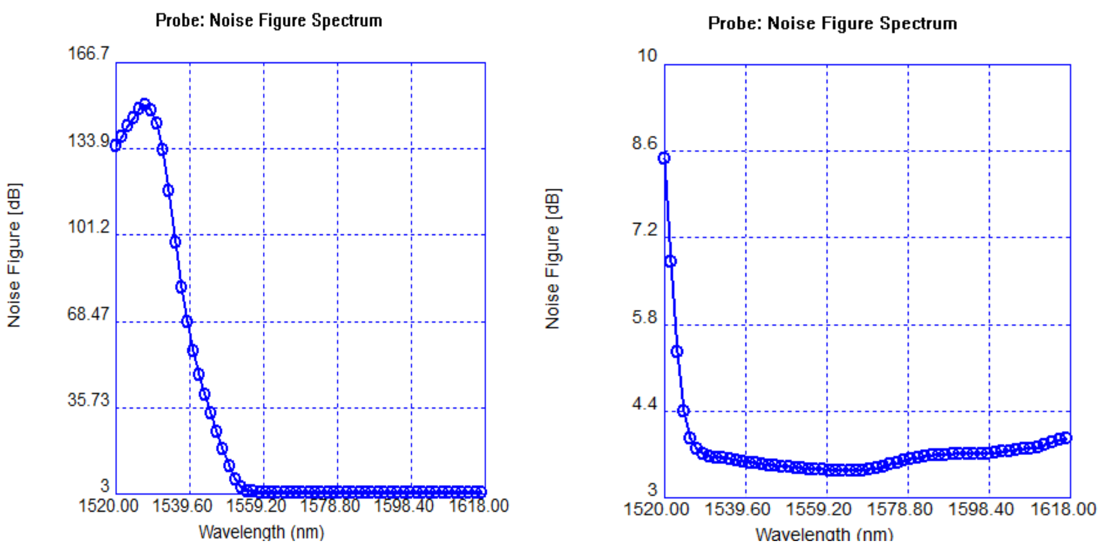

Figure 4 : Gain Spectrum and Noise Figure Spectrum of I-4

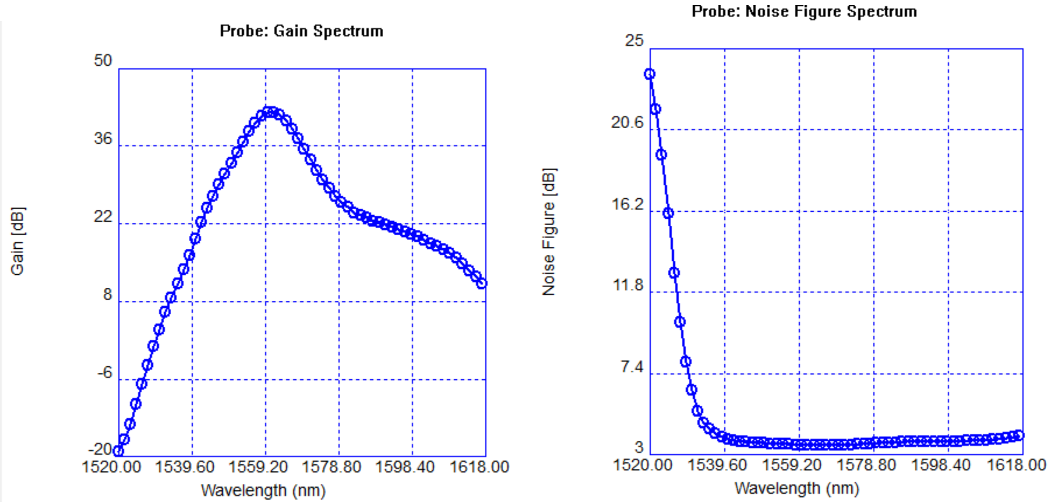

Figure 5 : Gain Spectrum and Noise Figure Spectrum of I-6

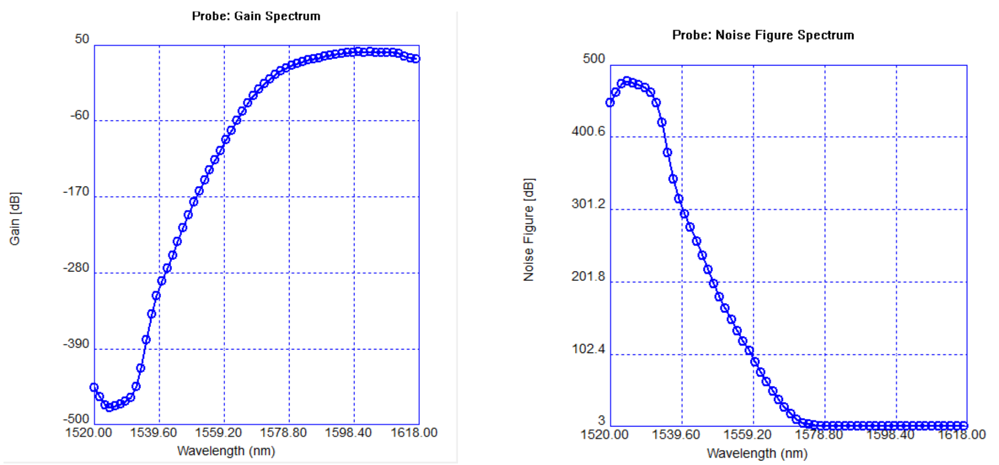

Figure 6 : Gain Spectrum and Noise Figure Spectrum of I-25

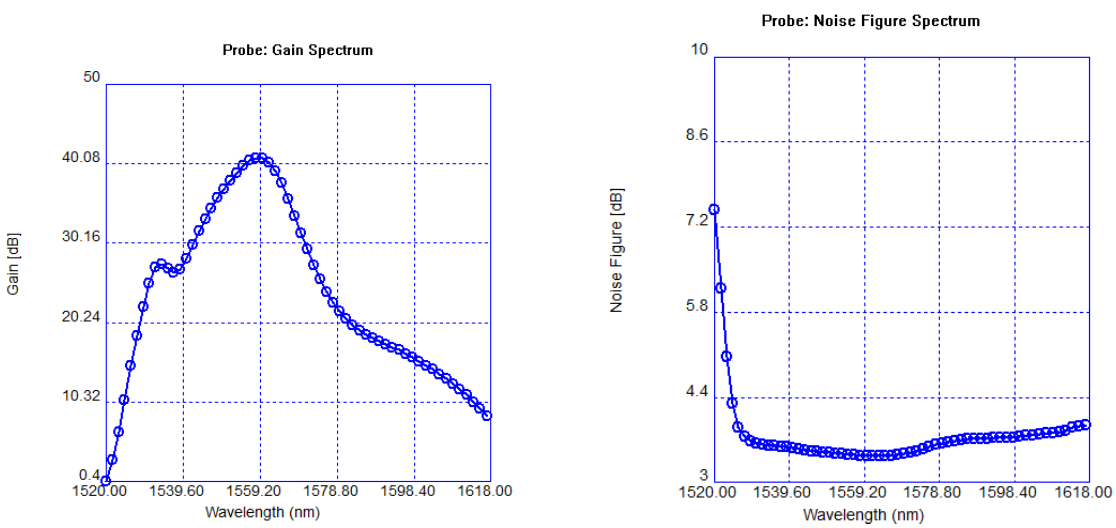

Figure 7 : Gain Spectrum and Noise Figure Spectrum of M-5

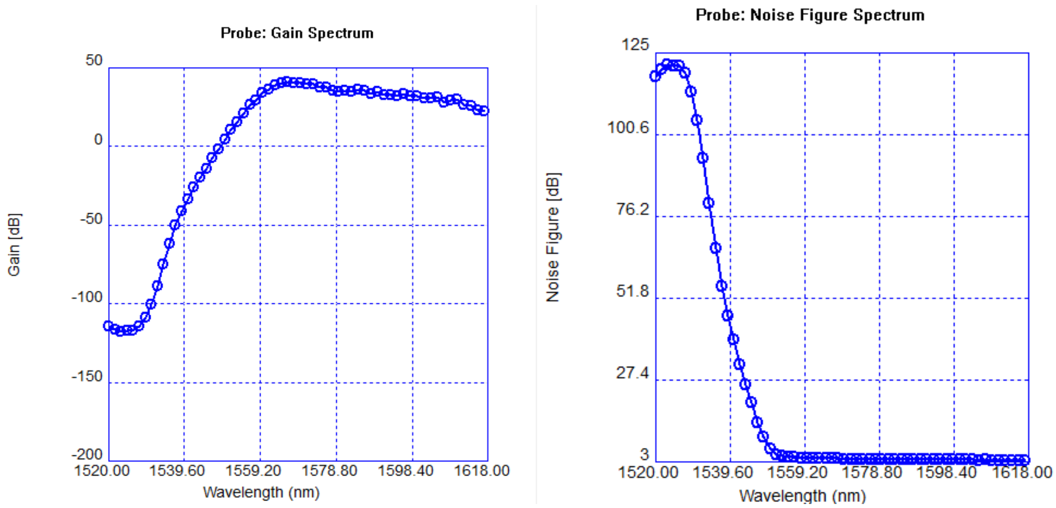

Figure 8 : Gain Spectrum and Noise Figure Spectrum of M-25

From the graph, it is concluded that M-5 Fiber is the most suitable EDFA that can be used to implement four-stage enhancement of the required EDFA Design. The properties and parameters of the M-5 Fiber are noted and the same is implemented in Optisystem Software.

Now, Optisystem 7.0 is used to design a circuit to test the gain and noise figure of the EDFA using M-5 fiber Erbium Doped Fiber. A four stage Erbium Doped Amplifier circuit is implemented. From prior analysis in the Gainmaster software it had been found out that M-5 had the best performance levels for C and L bands. So the following characteristics have been set in optisystem:-

i. Bit Rate: 10^{10} Bits/sec
ii. Sequence Length: 128 Bits
iii. Samples per bit: 64
iv. Number of samples: 8192

Now inside the EDFA we set the following parameters in order to simulate M-25 Erbium Doped fiber:-
i. Length of fiber: 5m
ii. Er Metastable lifetime: 10ms
iii. Saturation Parameter: $4.4*10^{15}$
iv. Er Ion Density: 10^{25} m^{-3}
v. Numerical Aperture: 0.24

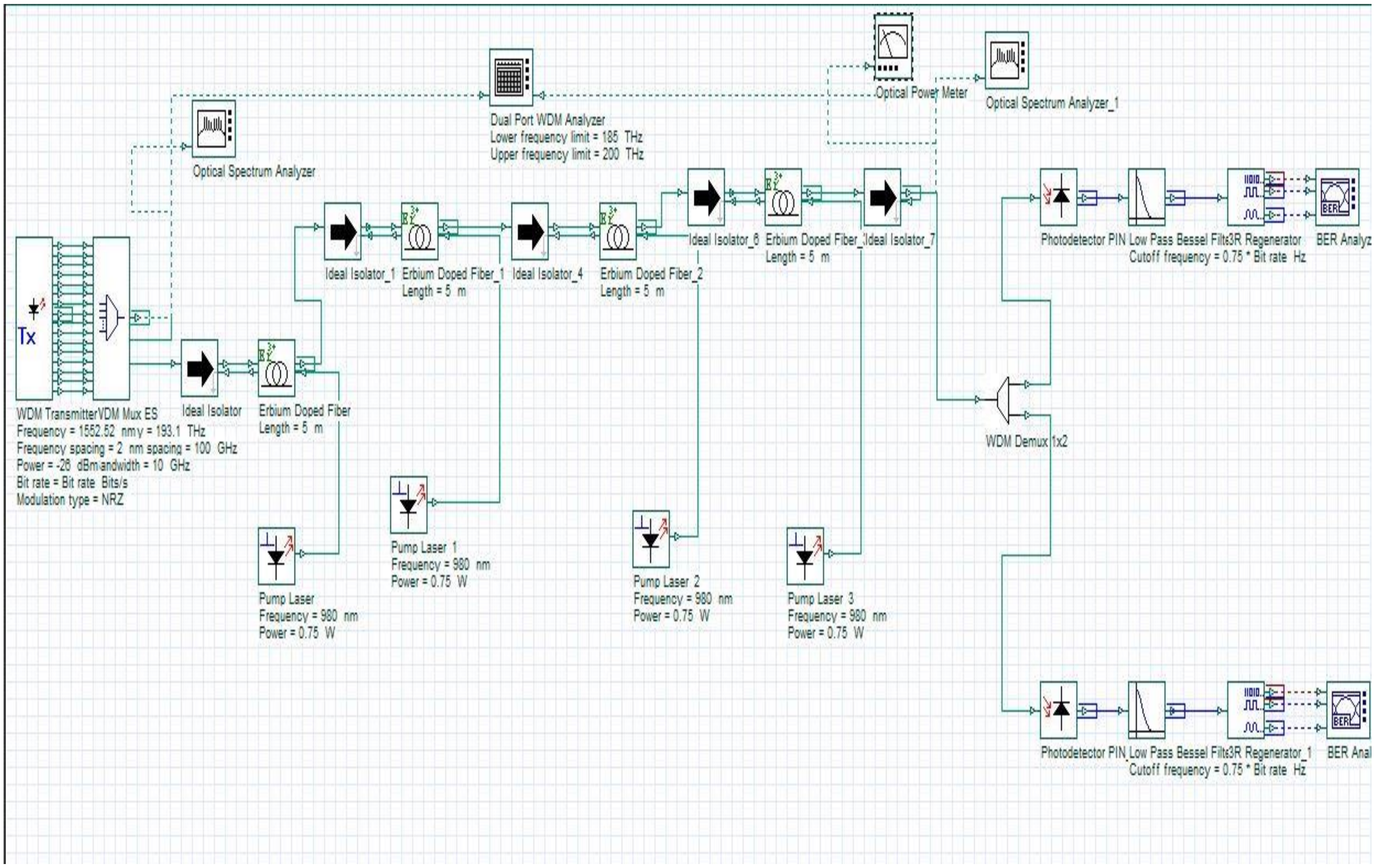

Figure 9 : Four-stage implementation in Optisystem

A WDM Transmitter has been used with center frequency 1552.52 nm, frequency spacing 2 nm and input power -26 dBm. The input signal can be visualized by attaching an Optical Spectrum Analyzer to the output of the WDM transmitter. The input signal is as follows:-

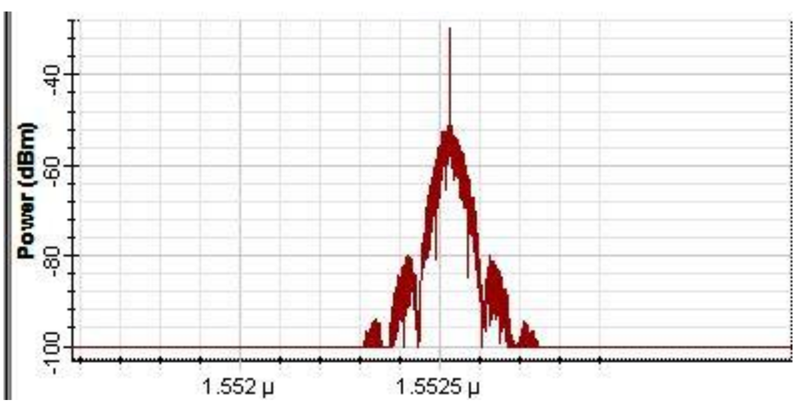

Figure 10 : Input Signal

In order to ensure flow of power in one direction only and not in the reverse direction isolators have been used. Contra-directional pumping has been used in all four EDFs. The pump frequency has been set at 980 nm. The pump power has been varied. The three values of pump power that has been used are 0.1 W, 0.15 W, 0.75 W. The Gain Spectrum, Noise Spectrum and the output signal have been found out for each of the respective pump powers.

The Dual port WDM analyzer is used to find out the gain and the noise figure for the operational bandwidth. The BER analyzer has been used to find the min BER and the eye diagram.

Table I : Gain Spectrum for different pump powers

Wavelength(nm)	Gain(dBm)		
	0.1 W Pump Power	0.15 W Pump Power	0.75 W Pump Power
1582.52	29.941368	30.573338	32.940168
1580.52	30.937892	31.610414	34.129228
1578.52	32.149755	32.870812	35.571123
1576.52	33.673193	34.453605	37.376305
1574.52	35.829664	36.68915	39.907931
1572.52	38.080989	39.028459	42.576794
1570.52	40.792572	41.847149	45.79654
1568.52	43.383366	44.551482	48.926112
1566.52	46.179726	47.478812	52.343909
1564.52	48.842566	50.280179	55.664067
1562.52	50.777812	52.347165	58.224423
1560.52	52.260644	53.961806	60.332688
1558.52	52.479255	54.283944	61.042541
1556.52	51.712619	53.599858	60.667601
1554.52	50.418389	52.381326	59.732559
1552.52	48.677173		58.310645

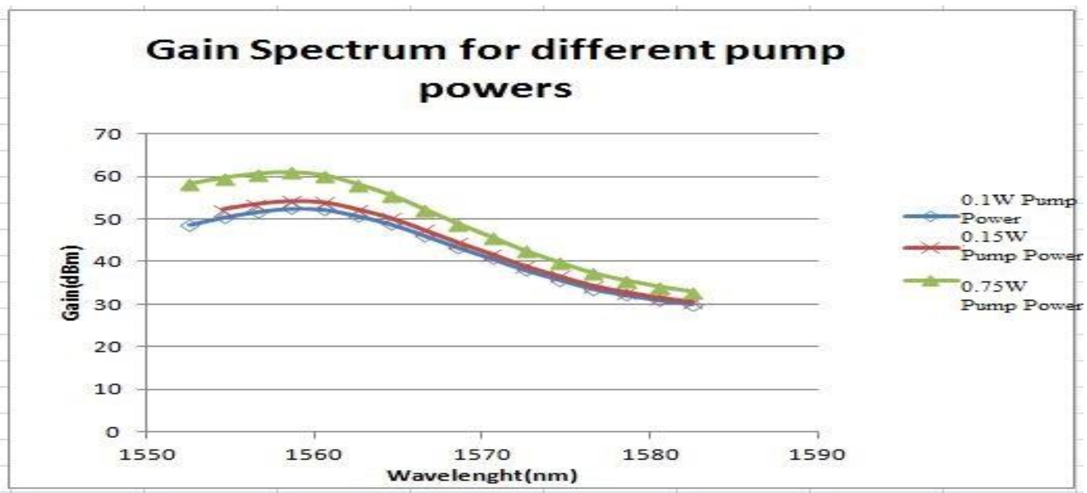

Figure 11 : Gain Spectrum for different pump powers

Table II : Noise Figure Spectrum for different pump powers

Wavelength(nm)	Noise Figure(dBm)		
	0.1W Pump Power	0.15W Pump Power	0.75W Pump Power
1582.52	4.14188	4.09725	3.95146
1580.52	4.11827	4.07032	3.9126
1578.52	4.27781	4.23095	4.07721
1576.52	4.43252	4.38669	4.2359
1574.52	4.54593	4.50027	4.34862
1572.52	4.76622	4.72297	4.57848
1570.52	4.80651	4.76054	4.60425
1568.52	5.16881	5.12878	4.99193
1566.52	5.20459	5.16034	5.00571
1564.52	5.17937	5.12944	4.95193
1562.52	5.24155	5.18717	4.99242
1560.52	4.96933	4.8996	4.6481
1558.52	4.94241	4.8651	4.58584
1556.52	4.86874	4.78166	4.46719
1554.52	4.90561	4.81095	4.46913
1552.52	5.02467		4.57485

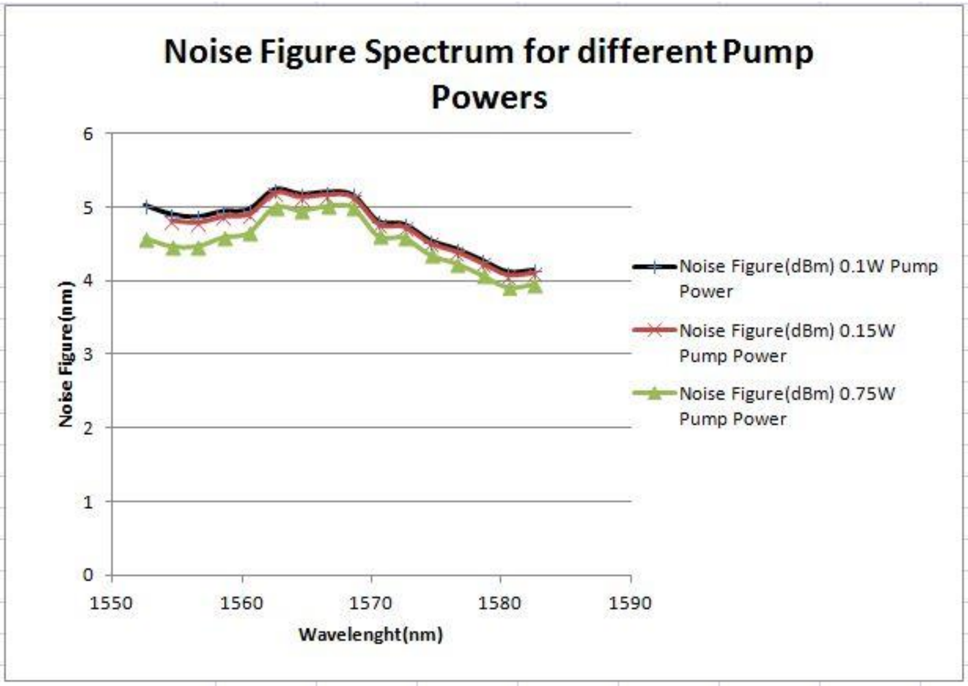

Figure 12 : Noise Figure Spectrum for different pump powers

After comparing the Gain and Noise figure for pump powers 0.1W, 0.15W and 0.75W it has been found that, for pump power 0.75W the best simulation results are obtained. After this the Eye Diagram, min BER and the output spectrum has been obtained for the 4 stage EDFA configuration for pump power 0.75W.

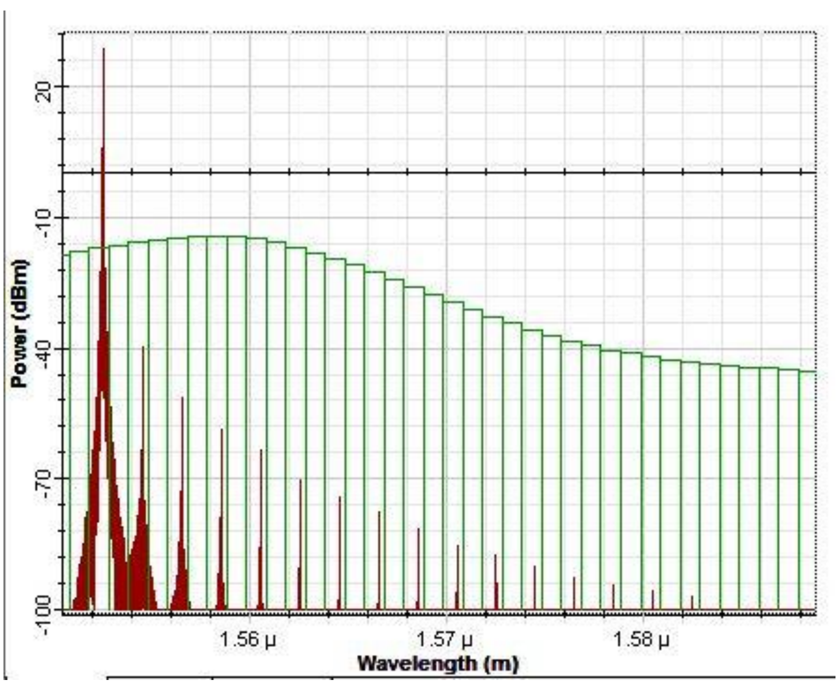

Figure 13 : Output Signal at 0.75 W Pump Power.

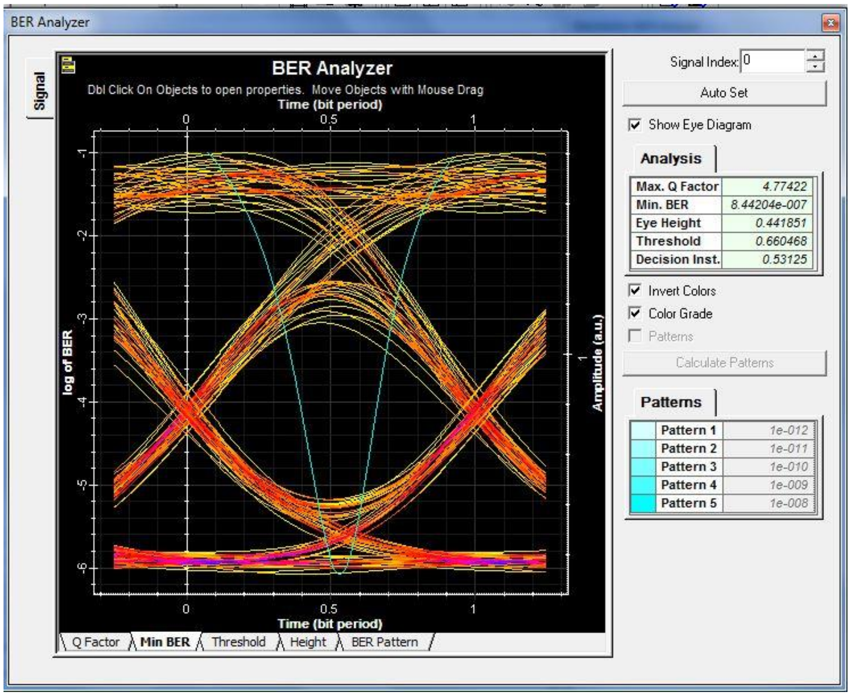

Figure 14 : BER analysis and Eye Pattern

The min Bit Error Rate(BER) is recorded to be 8.442e-7. Also the Eye Height is recorded to be 0.441851 which is significantly better than the other pump powers.

CONCLUSION

From the Gainmaster results, it is concluded that M-5 fiber is the most suitable fiber for the four-stage implementation of EDFA. The same EDFA has been implemented in Optisystem with further customizable parameters. The pump power was varied. Different Pump Powers like 0.1W, 0.15W and 0.75W were used. Analyzing the gain and noise figure spectrum for the EDFA under different pump powers, it was concluded that the pump power of 0.75 W gives better results. Further, the Output Spectrum, Q-Factor, Eye Diagram were generated for the 0.75 W Pump Power case . Therefore, a four-stage EDFA in WDM Configuration with high and relatively flattened gain with low noise figure has been designed. This EDFA design can be used in booster applications. A maximum gain of 61.04 dBm has been recorded.

REFERENCE

[1] Ricky Antony, "Performance analysis of different erbium doped fiber based codirectionally pumped wdmsystems operating in optical wide-band" in International Journal of Engineering Science and Technology (IJEST), Vol. 4 No.02 February 2012

[2] Sunil Kumar Panjeta, "Gain Optimization of of EDF Amplifier by stage enhancement and variation in pump power" in International Journal of Scientific and Research Publications, Volume 2, Issue 11, November 2012

[3] Mousami Biswas, "Modeling of Wide-Band Optical Signal Amplification in an EDFA Network" in PHOTONICS LETTERS OF POLAND, VOL. 4 (4), 158-160 (2012)

[4] Somnath Pain , "Gain Flattening and Noise Figure Analysis of EDFA WDM Configuration for L-band Optical Communication using Wavelength Selective Attenuator" in PHOTONICS LETTERS OF POLAND, VOL. 5 (3), 106-108 (2013)

[5] M A Mahdi, "Saturation parameters of erbium doped fibre amplifiers" in ICSE'98 Proc., Nov. 1998, Bangi, Malaysia

[6] Usman J Sindhi " Performance analysis of 32-channel WDM System using EDFA" in IJEETC vol.2 no 2, April 2013

[7] Farah Diana Binti, "Gain Optimization for WDM System" in Elektrika vol II no I , 2009.

[8] Erbium Doped Fiber Amplifiers - Fundamentals and Technology by PC Becker

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