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Optimized Gain of YDFA by Single and Double Stages of Different Lengths with an Influence of Pump Power

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Abstract: In this paper we have discussed the importance of YDFA and obtained optimized Gain and maintained Noise Figure in single stage and double stage YDFA (Ytterbium Doped Fiber Amplifier) with the help of simulation models of different Lengths (1m, 4m, 6m, 8m and 10m) using pumping wavelength 975nm and 910nm then the results are designed with an influence of various Pump power (0.25, 0.5, 0.75, 1 and 1.5) watt. The offered simulation model consists of input source with 90 channels ranging from (950-1150nm) with power of each channel 10^{-9} watt, WDM coupler, pumping source, Ytterbium doped fiber of various length and optical spectrum analyzer to measure output. It simulates maximum noise figure, minimum noise figure, maximum gain, minimum gain, mid-level gain etc. Simulation models given in this paper can be operated with high pump power levels and different parameters like (Gain and Noise Figure) can be optimized without changing values of YDF length, and input source. This paper is divided into six segments. In I segment Introduction of YDF (Ytterbium Doped Fibre), YDFA'S (Ytterbium Doped Fibre Amplifiers) is discussed. In II segment Background of YDFA work is understood and method for our work is discussed, whereas segment III & IV shows the Simulation model details and analysis of multistage YDFA models. Segment V presents the tables, results and discussions. Segment VI presents the conclusion of our simulation work. Lastly, in segment VII future scope of our work is discussed.

Keywords: YDFA (Ytterbium Doped Fiber Amplifier), EDFA (Erbium Doped Fiber Amplifier), ASE (Amplified Spontaneous Emission), YDF (Ytterbium Doped Fiber), OSA (Optical Spectrum Analyzer), NF(Noise Figure), λ_s (Signal wavelength), λ_p (Pump wavelength).

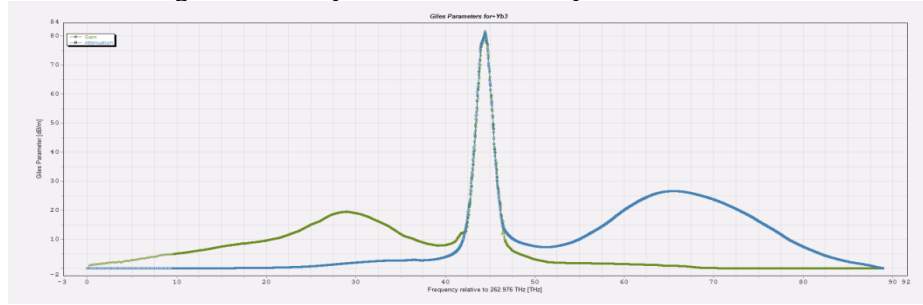
I. Introduction

In commercial applications EDFA (Erbium Doped Fiber Amplifier) is very important and much used amplifier in optical system [1], but the amplification of pulses at specific wavelength's and to provide a source of very high peak powers for telecommunications is no longer applicable in case of EDFA, so other doped amplifiers came into consideration. Ytterbium doped fiber amplifiers are best solution for it. YDFA'S provide amplification from 975nm to 1200nm and moreover absorption and emission spectra of Yb^{+3} ions is very broad shown in figure 1 [2], green curve specify absorption spectra and blue curve tells emission spectra, hence there is wide range of possible pump wavelengths around 860nm to 1064nm. Ytterbium doped fiber amplifiers (YDFA's) offer broad-gain bandwidth, high output power and excellent power conversion efficiency [3]. YDFA's provide power amplification at special wavelengths. YDFA gaining lots of interest in sensing applications, free-space laser communications, chirped-pulse amplification of ultra-short pulses, spectroscopic measurements, small-signal amplifiers, military applications, display, lithography, bio-medical applications and medicines etc. YDFA is an operative replacement of traditional optoelectronic regenerative repeaters. YDFA plays a substantial role in upgrading the performance of optical fiber systems [4].

A. YDFA

Amplifier is assumed as laser in which feedback is suppressed. In YDF host fiber material is silica based glass which is doped with ytterbium. Ytterbium doped fiber has two main energy levels one is $2F_{7/2}$ ground state (lower energy state) and other is $2F_{5/2}$ excited state (higher energy level). The pump source excites the dopant ions from lower energy state to higher energy state, from which they falls at ground energy state by stimulated emission, amplified spontaneous emission and by non-radiative method (means without radiations in form of heat). Only stimulated emission of photons from dopant ions in the doped fiber at signal wavelength help to achieve amplification and other two processes degrade the performance and become a major cause of noise [5]. Energy level diagram of YDF is very simple and energy gap between the lower energy level and excited-state is small and it results in extremely low quantum defects, many detrimental effects such as thermal effects, quenching and excited state absorption are evocatively reduced. Due to these tremendously small defects very high power efficiency is possible in YDFA and requirement of ytterbium doped fiber length is very small as compared with other doped fibers. Requirement of small doped fiber length is a major important issue and helps to decrease the overall cost of optical fiber transmission system for long haul applications and additionally small fiber length also helps to decrease fiber attenuation to a large extent [6][7].

Figure 1: Absorption and Emission Spectra of Yb³⁺ ions



II. Background

This paper [3] shows the variations in Gain at 1030nm signal input power with NA=0.2, Yb ions doping concentration 2000ppm, doped fiber length 1m, 2m and 6m for single pass amplifier configuration with a 910 and 975nm pump wavelength for 50,100 and 150mw pump power. It was shown that gain was increasing with rise in pump power and fiber length but up to certain extent after further increase in length gain starts deteriorating and reason for this, is already explained above. It was also observed that gain was more for 975nm pump wavelength as compared to 910nm, it was due to reason that the gain spectrum for 910nm pumping contains a high peak at 975nm, which give rise to strong amplified spontaneous emission (ASE) around 975nm which is major source of noise and which decreases the value of gain while gain spectrum for 975nm pumping does not contain the 975nm ASE peak, so more gain at 975nm pumping wavelength. This paper [8] shows the variation in gain of double pass configuration with the input signal power ranging from 1mw to 20mw for total pump power of 100, 200, 300 and 400mw with total ytterbium fiber length 10m, 15m, and 20m. It was observed that the gain was increasing with increase in pump power and by increasing total length of ytterbium doped fiber but on the other hand gain was decreasing with increase in input signal power, it was due to the reason that the for a fixed pump power YDF amplifier gets saturated at larger signal power.

A. Proposed Methodology

In our work, we offered the simulation models of multistage YDFA with combinations of forward and backward Pumping using wavelength 910nm and 975nm, pump power variation of 0.25W, 0.5W, 0.75W, 1W and 1.5W with different overall YDFA Lengths of 1m, 4m, 6m, 8m and 10m has been simulated using **VPI Photonics simulation software**. To understand the high capacity optical light wave transmission and optical networks wavelength-division multiplexing (WDM) method joined with Ytterbium doped fiber amplifier (YDFA) is analyzed here. Amplifier test meter and Optical Spectrum Analyzers are used to measure output.

III. Analysis of Multistage YDFA

Figure 2, 3 shows the simulated models of YDFA with Pumping wavelength 910nm and 975nm. It consists of Input Source ranging from 950nm to 1150nm with 96 channels and each channel has power of 10^{-9} watt, WDM (Wavelength division Multiplexer), test meter, Each YDFA of different length combinations and optical spectrum analyzer. OSA is used to plot for ASE, and gain with respect to signal wavelength. By running these models we have tabulated Values of simulation results that are Gain and ASE with different YDFA Length and different Pump powers as shown below. In TABLES for both stages of YDFA maximum value of gain and minimum value of Noise Figure are shown by **RED** color as they represents the best case. In double stage length of first YDFA is 40% of total and length of second YDFA is 60%, similarly total pump power is divided 1:1 between two pumps in double stage amplifier.

IV. Simulation Models

Figure 2: Single Stage YDF optical amplifier design

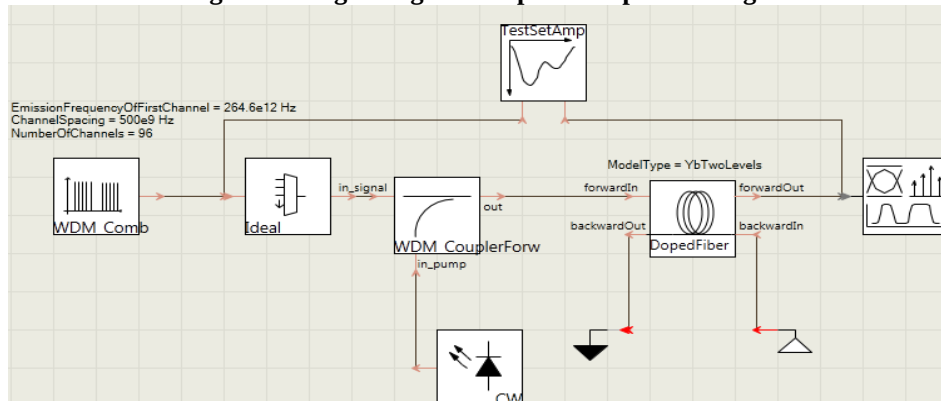
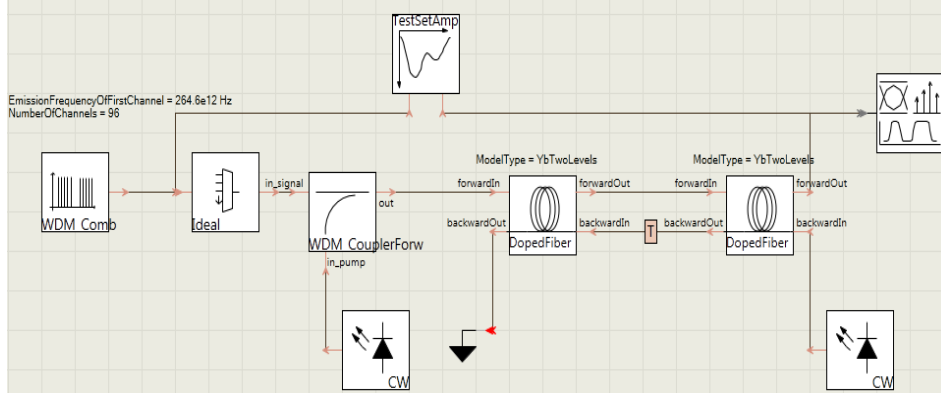


Figure 3: Double Stage YDF optical amplifier design



V. Results and discussions

Table I: Result of Gain and Noise Figure of single stage YDFA with 975nm PUMPING MODEL

S.no	length of YDFA	Pumping power ▼	Gain(dB) at 975nm Pump wavelength λ_p			Noise Figure (dB) at 975nm λ_p	
Signal wavelength (λ_s) →			Gain Value at 1027-1030nm	Gain Value at 1130-1135nm	Gain Value at 975-977nm	Min Value	Max Value
1.	1m	0.25w	6	1	12.5	-1	5
2.	1m	0.5w	7	1	12.7	-1.33	3
3.	1m	0.75w	8	1	13	-1	2.5
4.	1m	1w	9	2	13.81	-1	3
5.	4m	0.25w	34	4	-7.4	1	7
6.	4m	0.5w	35	4	-7	1	7
7.	4m	0.75w	36	4	-7	.7	6
8.	4m	1w	37	4	-7	1	6.5
9.	6m	0.25w	47	5	-52	1	6
10.	6m	0.5w	51	5	-25	1.3	7
11.	6m	0.75w	52	5	-17	2.5	7.5
12.	6m	1w	52	5	-15	3	8
13.	8m	0.25w	45	5	-100	-4	10
14.	8m	0.5w	50	5	0	-4	5
15.	8m	0.75w	52	4	-100	-3	6
16.	8m	1w	54	5	-100	1	10

TABLE II: Result of Gain and Noise Figure of single stage YDFA with 910nm PUMPING MODEL

S.no	length of YDFA	Pumping power ▼	Gain(dB) at 910nm Pump wavelength λ_p			Noise Figure (dB) at 910nm λ_p	
Signal wavelength (λ_s) →			Gain Value at 1027-1030nm	Gain Value at 1130-1135nm	Gain Value at 975-977nm	Min Value	Max Value
1.	1m	0.25w	16	1	49	-1	3
2.	1m	0.5w	16	1	52	-1	4
3.	1m	0.75w	16	1	54	-1	4
4.	1m	1w	16	2	56	-1	5
5.	4m	0.25w	39	3.5	42	1	6
6.	4m	0.5w	40	3.7	43	1	7
7.	4m	0.75w	41	4	44	1	6
8.	4m	1w	42	4	46	1	6.5
9.	6m	0.25w	42	4	-80	-4	20
10.	6m	0.5w	43	4.5	-75	-3	15
11.	6m	0.75w	44	5	-65	-2	10
12.	6m	1w	45	5	-55	-1.5	8
13.	8m	0.25w	41	5	-100	-8	12
14.	8m	0.5w	42	5	-100	-6	5
15.	8m	0.75w	43	5	-100	-7	10
16.	8m	1w	44	5	-100	-6	15

In Single Stage YDFA using pumping model of 975nm we have obtained maximum optimized gain of 51dB at signal wavelength ranging 1027-1030nm with Doped Fiber length of 6m, pump power .5watt. We found minimum Noise figure of -1dB and maximum Noise figure of 2.5dB with Doped Fiber length of 1m, pump

power 0.75watt. Similarly when YDF Single Stage Amplifier model of pump wavelength 910nm operated we obtained maximum optimized gain of 56B at signal wavelength ranging 975-977nm with Doped Fiber length of 1m, pump power 1watt. We also found minimum Noise figure of -1dB and maximum Noise figure of 2dB with Doped Fiber length of 1m, pump power 0.25watt.

TABLE III: Result of Gain and Noise Figure of Double stage YDFA with 975nm PUMPING MODEL

S.no	Total length of YDFA	Total Pumping power ↓	Gain(dB) at 975nm Pump wavelength λ_p			Noise Figure (dB) at 975nm λ_p	
Signal wavelength (λ_s) →			Gain Value at 1027-1030nm	Gain Value at 1130-1135nm	Gain Value at 975-977nm	Min Value	Max Value
1.	1m	1w	9	0.9	-2	-2	4
2.	1m	1.5w	9	1	-2	-1	4
3.	6m	1w	52	5	-12	-13	9
4.	6m	1.5w	53	5	-12	-15	12
5.	8m	1w	58	5	-100	-15	11
6.	8m	1.5w	61	5	-90	-9	9
7.	10m	1w	55	5	-100	-22	10
8.	10m	1.5w	59	5	-100	-22	8

TABLE IV: Result of Gain and Noise Figure of Double stage YDFA with 910nm PUMPING MODEL

S.no	Total length of YDFA	Total Pumping power ↓	Gain(dB) at 910nm Pump wavelength λ_p			Noise Figure (dB) at 910nm λ_p	
Signal wavelength (λ_s) →			Gain Value at 1027-1030nm	Gain Value at 1130-1135nm	Gain Value at 975-977nm	Min Value	Max Value
1.	1m	0.5w	1.7	0.9	57	-1	4
2.	1m	1w	12	1	57	-2	5
3.	1m	1.5w	17	5	60	-2	5
4.	4m	1w	43	4	58	1	6
5.	6m	0.5w	52	5	-17	-3	8
6.	6m	1w	54	5	-2	-5	9
7.	6m	1.5w	57	5	0	-5	10

In Double Stage YDFA using pumping model of 975nm we have obtained maximum optimized gain of 61dB at signal wavelength ranging 1027-1030nm with Doped Fiber length of 8m, pump power 1.5watt. We found minimum Noise figure of -1dB and maximum Noise figure of 4dB with Doped Fiber length of 1m, pump power 1.5watt. Similarly when YDF Double Stage Amplifier model of pump wavelength 910nm operated we obtained maximum optimized gain of 60B at signal wavelength ranging 975-977nm with Doped Fiber length of 1m, pump power 1.5watt. We also found minimum Noise figure of -1dB and maximum Noise figure of 4dB with Doped Fiber length of 1m, pump power 0.5watt.

VI. Conclusion

- Best results of Gain found with double stage YDFA. By using 975nm pumping model, maximum gain value of 61db measured at 1030nm signal wavelength and with 910nm pumping model maximum gain value of 60db measured at 975nm signal wavelength.
- Best results of Noise Figure found with single stage YDFA. By using 975nm pumping model, minimum noise figure value of -1db and maximum NF of 2.5db measured and with 910nm pumping model minimum noise figure value of -1db and maximum NF of 3db measured with 1m YDF length.
- Optimized gain increase with increase in pumping power.
- Noise figure increase with increase in YDF length of amplifier and with increase in pumping power.
- By using 975nm pumping model gain increase with increase in YDF length of amplifier near 1027nm to 1030nm signal wavelength.
- By using 975nm pumping model gain Decrease with increase in YDF length of amplifier near 975nm to 977nm signal wavelength. High value of gains is obtained at short YDF length.

VII. Future Scope

In this paper we have taken stage enhancement up to two levels only, which can go up to 5 stages. Gain obtained is high but range of signal wavelength for that high value is too small i.e. Bandwidth is too small, which can be increased. Gain can be flattened by using gain equalizing filters, thin film filters. Many Hybrid connections of

amplifiers like RAMAN+YDFA, EDFA+RAMAN, RAMAN+YDFA+SOA, SOA+YDFA etc. can be considered, which will provide not only longer range amplifier but may also give increased and flattened gain.

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