Comparative Gain Analysis of Erbium and Ytterbium Doped Optical Fibre Amplifiers

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ABSTRACT
In the present work, gain of EDFA (Erbium Doped Fibre Amplifier) and YDFA (Ytterbium Doped Fibre Amplifier) are analyzed based on their performance parameters. The effects of pump laser power, length of doped fibre that used for amplification and the wavelength of the input signal on the gains of the optical amplifiers is examined. EDFA exhibits maximum gain of 48db around 1550nm regions with pump wavelength of 980nm (pump power=10Watt, EDF length=30m), on the other hand YDFA exhibits maximum gain of 62db around 1030nm regions with pump wavelength of 975nm (pump power=5Watt, YDF length=8m). The ANALYSIS shows that the gain of YDFA is superior to that of EDFA for short fibre length.

Keywords
ytterbium-doped fibre (YDF), erbium-doped fibre (EDF), dense wavelength division multiplexing (DWDM), amplified spontaneous emission (ASE), optical fibre amplifiers (OFA).

1. INTRODUCTION
When an optical signal moves along an optical fibre over long distances and if the speed of data is high enough, it gets attenuated along the fibre and gets distorted due to dispersion respectively [1][2]. In order to counterbalance the attenuation losses in the optical fibre, optical fibre amplifiers OFA's came into existence. The development of optical amplifiers started in early 1980s and their use for long-haul communication systems became inescapable during late 1990s. Optical amplifier is a device or a component that amplifies an optical signal directly, without converting into electrical form. An optical amplifier may be assumed as a laser in which feedback from the cavity is suppressed, or a laser without an optical cavity. OFA's must be designed to amplify the signal along the fibre, the more the gain; the more span distance between amplifiers as long as the signal is not distorted due to high optical power. To make use of this great bandwidth, dense wavelength division multiplexing DWDM is used, but each type of optical fibre amplifier has different bandwidth, different range [3][4].

2. DOPED FIBRE AMPLIFIERS
The optical fibre can be doped with any rare earth element to provide large gain such as Erbium(Er), ytterbium (Yb), Neodymium(Nd) or Praseodymium(Pr). The host fibre material can be either silica or fluoride based glass. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fibre. The pump laser excites dopant ions present in the doped fiber to a higher energy level from where they decay to a lower energy state (level) by 3 methods. Firstly, the excited ions decay via stimulated emission of a photon at the signal wavelength, which is requirement of amplification. Secondly, the excited ions can also decay by spontaneous emission or thirdly by non-radiative (without light radiations) processes which involves interactions of phonons with the glass matrix which compete with stimulated emission reducing the overall efficiency of amplification of an amplifier. This spontaneous emission amplified along with signal when travels through doped fiber and becomes amplified spontaneous emission (ASE) which is major source of noise. The amplification window or operating regions of an optical amplifier is the range of optical wavelengths for which the amplifier provides a useful gain. The operating regions of an optical amplifier are determined by the spectroscopic properties of the dopant ions, the glass matrix of the optical fibre, power of the pump laser, and the wavelength of pump source [5]. The most popular material for long haul telecommunication applications is a silica fibre doped with Erbium and Ytterbium, which is known as EDFA and YDFA respectively. In Erbium Doped Fibre Amplifier (EDFA), core of a silica fibre is doped with trivalent Erbium ions and can be efficiently pumped with a laser at a wavelength of 980nm or 1480nm, and display gain in the 1500-1640nm regions and in Ytterbium Doped Fibre Amplifier (YDFA) core of a silica fibre is doped with trivalent Ytterbium ions and can be efficiently pumped with a laser at a wavelength of 910nm or 975nm, and display gain in the 1000-1150 nm regions.

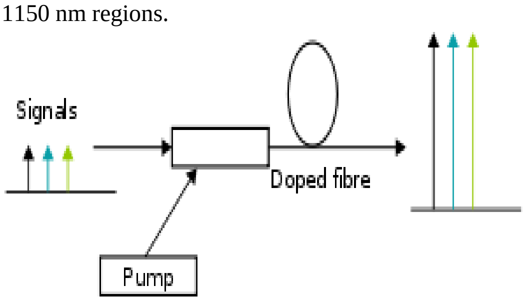

Fig 1: simple doped fibre

2.1 YDFA System
Figure 2 Shows the absorption and emission cross-sections of Yb^{3+} in a silica glass. There are two absorption peaks at 910nm and 975nm wavelengths and two emission peaks at 975nm and 1030nm wavelengths. For the superlative pursuance of an amplifier the pump wavelength should be positioned in the range of absorption peak and the

amplification wavelength should be in the range of emission peaks. Hence by applying pumping wavelength around 910nm a very high gain can be achieved at 975nm signal wavelength. But, the amplification bandwidth around 975nm is narrow which limits the many potential applications. Second possibility is to achieve amplification from 1000 to 1150nm signal wavelength (which is broad bandwidth) with a pumping wavelength around 910nm. Yb ions effectively excited by 910nm pumping, providing inversion close to 97% for high pump powers. As a result very high gains can be achieved in very short fibre length. However, 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. This ASE diminishes the inversion and reduces the gain as the fibre length increases, which could reduce the overall proficiency significantly. The advantage of using 975nm pumping wavelength is that it does not contain the 975nm ASE peak, because the absorption and emission cross-sections at 975nm are nearly the same. The 975nm pumps excite Yb ions by providing inversion close to 50% which leads to smaller gains for short fibres as compared with 910nm pumping. However, the 975nm pumped YDF have no problem of 975nm ASE which is a major problem, it means that the maximum gain is limited only by ASE around 1030nm. Hence as the fibre length is increased higher gains can be achieved [6].

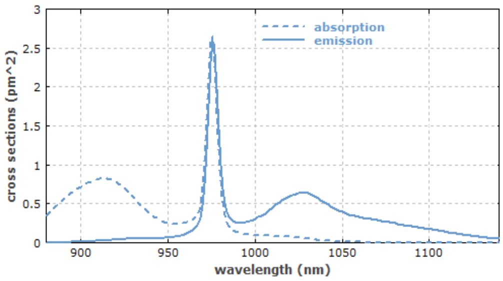

Fig 2: Absorption and emission cross-sections of Yb^{3+}

2.2 EDFA System

EDFAs have two commonly-used pumping bands – 980nm and 1480nm. Absorption cross-section at 980nm band is higher and is generally used where low-noise performance is required. As the absorption band is relatively narrow hence wavelength stabilized laser sources are needed. But absorption cross-section for the 1480nm band is lower and broader so it is generally used for higher power amplifiers. A combination of 980nm and 1480nm pumping is generally best blend in amplifiers. EDFA provide high gain in 1530-1560nm wavelength band region, here erbium ions emitted band energy is greater than the energy absorbed and in this range gain bandwidth is narrower. The emission and absorption of the energy EDF according to Figure 3 of the spectrum, where the highest gain peak of EDFA near 1550nm, hence the gain obtained clears that the operating wavelength is 1550nm [7][8][9].

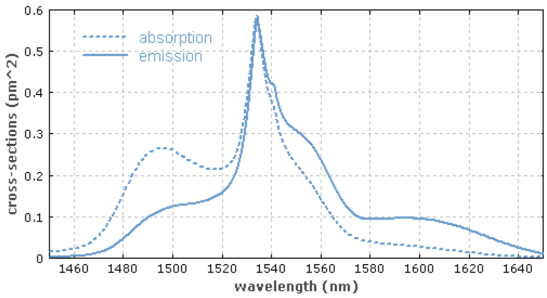

Fig 3: Absorption and emission cross-sections of Er^{3+}

3. ANALYSIS OF EDFA

In this section, VPI simulation program is used to prepare model for Figure 4(a) and figure 5(a). For EDFA assembly single stage WDM signal source ranges from (1500-1640nm) with constant signal power, pump source of 980nm with different pump power (1W,10W etc.), erbium doped fibre of variable length (8m,10m,20m,30m,50m etc.) is considered. Test set amplifier and optical spectrum analyzer are used to measure output power, gain and optical spectrum. In EDFA system (working with band 1500nm and 1640 nm) when the analysis is done according to EDFA assembly as shown in Figure 4(a) gain start increasing till 1550nm and then flattened and after that near 1550nm gain rapidly begins to fall as shown in figure 4(b). In Table1: max value of gain for different length of EDF and different pump power is given.

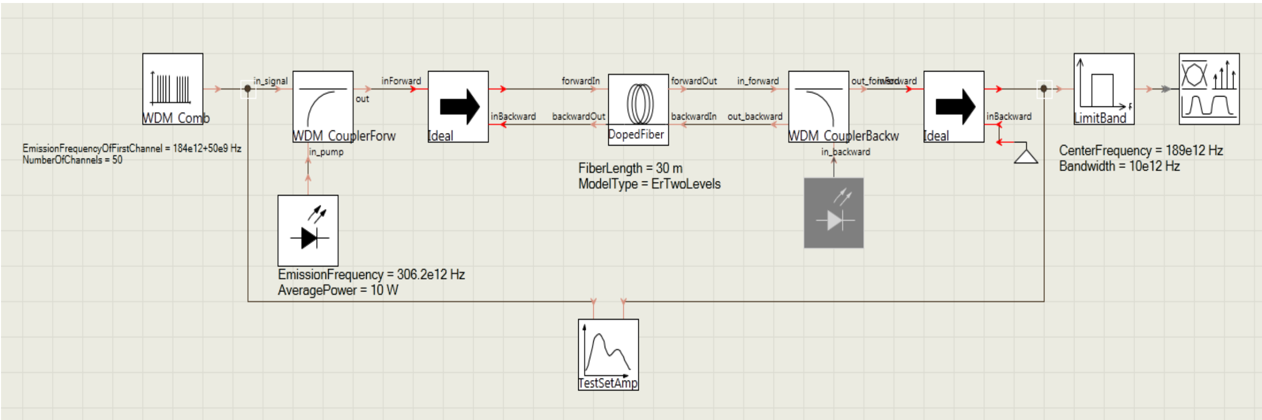

Fig 4(a): EDFA assembly

Table1: Analysis of EDF gain with single stage

Signal Wavelength(nm)	Gain (db)	Length of Doped Fibre (m)	Pump Power (Watt)
1550	33	50	10
1550	28	8	10
1550	41	20	1
1550 (Best Case)	**48**	**30**	**10**

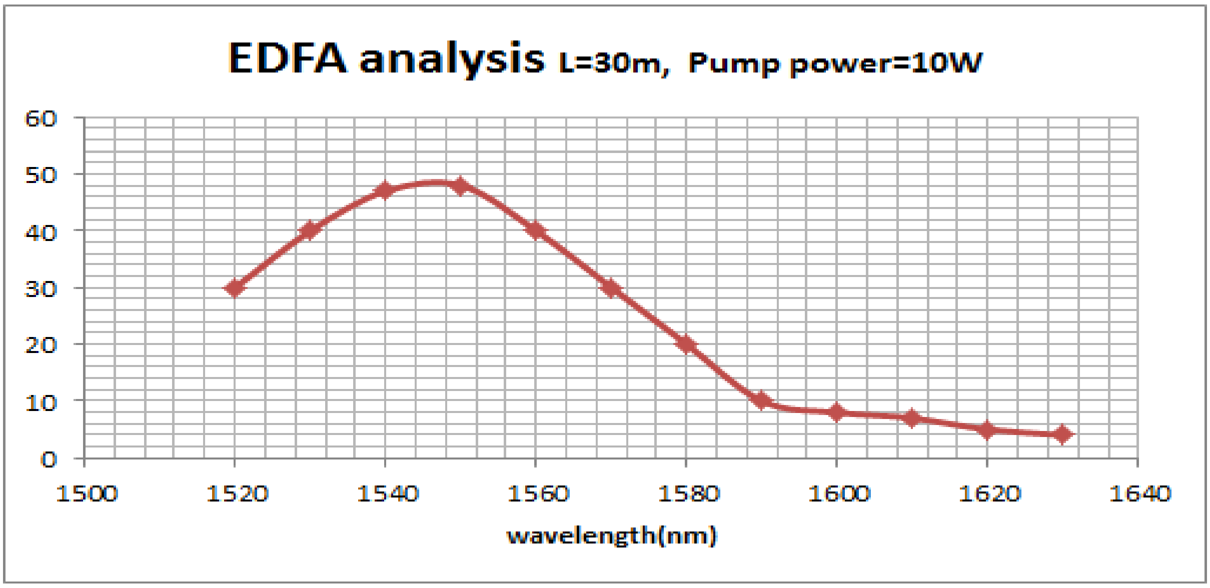

Fig 4(b): Variation in gain (db) of EDFA.

4. ANALYSIS OF YDFA

For YDFA assembly single stage WDM signal source ranges from 1000nm to 1140nm with constant signal power, pump source of 975nm with different pump power (1W,5W etc.), Ytterbium doped fibre of variable length (6m,8m,10m etc.) is considered. Test set amplifier and optical spectrum analyzer are used to measure gain, output power and optical spectrum.

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In YDFA system (working with band 1000 nm and 1140 nm) when the analysis is done according to YDFA assembly as shown in Fig 5(a) gain start increasing firstly till 1030nm and then after gain rapidly begins to fall quickly as shown in figure 5(b). In Table2: max value of gain for different length of YDF, and different pump power is given.

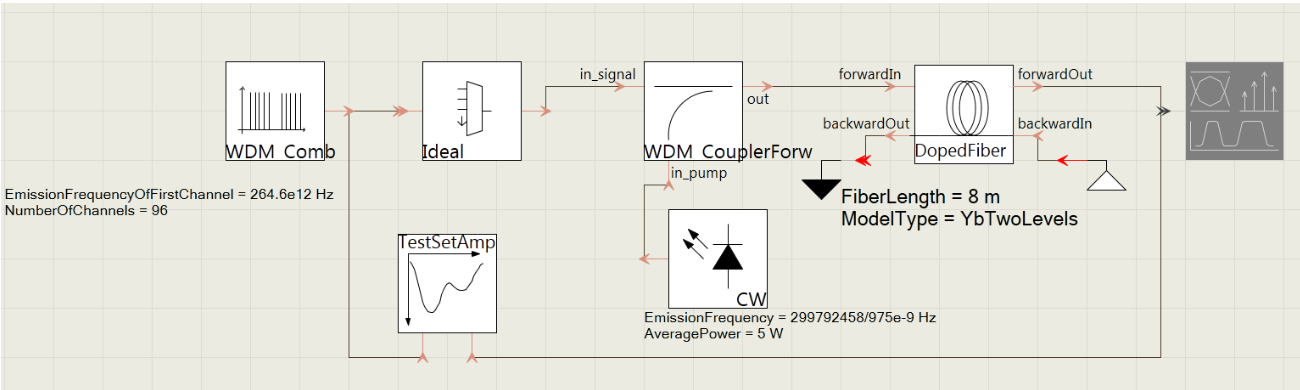

Fig 5(a): YDFA assembly

Table2: Analysis of YDF gain with single stage

Signal Wavelength(nm)	Gain (db)	Length of Doped Fibre (m)	Pump Power (Watt)
1030	52	8	1
1030	50	10	1
1030	55	6	5
1030 (Best Case)	**62**	**8**	**5**

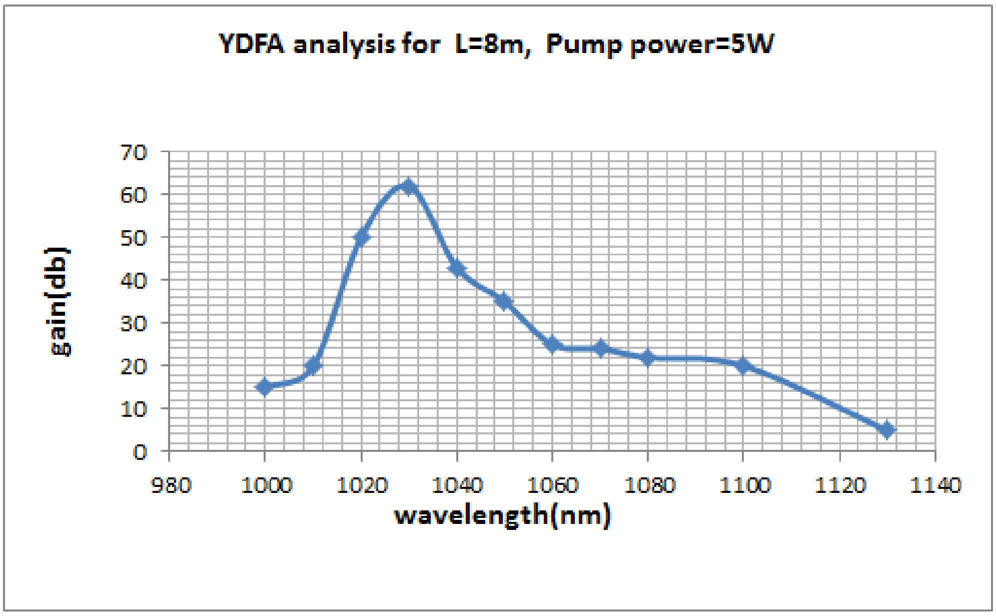

Fig 5(b): Variation in gain (db) of YDFA.

5. CONCLUSION

Optical amplifiers are very important module in long distance optical communication. In this paper gain characters of EDFA (Erbium Doped Fibre Amplifier) and YDFA (Ytterbium Doped Fibre Amplifier) examined with constant/fixed signal power. EDFA maximum gain 48db with 30m length of fibre around 1550nm signal wavelength and pump power of 10watt while in YDFA 62db gain is achieved with only 8m fibre length and pump power of 5watt around 1030nm signal wavelength. Hence YDFA is better than EDFA. Length of doped fibre required in case of YDFA is less as compared to EDFA. It is due to the reason that Ytterbium doped fibre has two main energy levels involved in the light amplification and gain media arise from the fact that only one excited state is involved in the laser transition [10]. The comparatively small energy gap between the lower energy level and excited-state results in extremely low quantum defects, consequently high power efficiency is possible, and many detrimental effects such as thermal effects, quenching and excited state absorption are meaningfully condensed [11]. But Erbium-doped fibre has three main energy levels involved in the light amplification [12] and in EDFA excited state absorption and concentration quenching phenomenon is present at large extent, So YDFA can emit high output power only using a small fibre lengths.

6. FUTURE SCOPE

In this paper only single pass assembly of EDFA and YDFA is considered but in future double pass, triple pass and higher configuration can be examined which may exhibits large gain around 90db. Moreover we can see gain of YDFA and EDFA is not flat. To flatten the gain many techniques can be implemented and gain equalizing filters can be used. To increase the input signal range many amplifiers like RAMAN+YDFA, EDFA+RAMAN, RAMAN+YDFA+RAMAN, SOA+YDFA etc. hybrid connection can be considered, which will provide not only longer range amplifier but may also give increased and flattened gain.

7. REFERENCES

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