High Gain, Low NF EYDFA with Distributed Pumping

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ABSTRACT
Optical amplifiers are an indispensable part of today's network and face increasingly stringent demands on their performance in terms of peak gain, noise figure, cost, compactness, etc with growing transmission rates, increasing link lengths, wavelength division multiplexing and the continual improvisation of technology. Erbium-Ytterbium co-doped fiber amplifier (EYDFA) an improvement of Erbium doped fiber amplifier (EDFA), helps overcome the limitation of increase in the concentration of excited erbium ions by countering the pairs quenching phenomenon. This paper investigates the role of optical pumping in dual stage single pass EYDFA and the strong dependence of gain on the pump power till a stage of saturation is reached is observed. Further, an amplifier with high gain of 40-46 dB at 1550nm with low noise figure is simulated for very short lengths of active fiber.

General Terms
Compact in-line amplifier, dual stage configuration, high gain, low noise figure, optical amplifier

Keywords
Distributed pumping, EYDFA

1. INTRODUCTION
Consumer products like smartphones, tablets combined with multiple AirPlay devices are stimulating demand globally. Market research has accepted that these devices are further exposing existing bottlenecks in telecom networks. As a consequence there are further investments in fibre optic networks and fierce global competition on who delivers more, better, faster and cheaper. Thus, stringent demands are placed on the performance of these networks. Any incremental improvisation in technology helps in cost savings and performance improvement in a large scale. Optical amplifiers in particular erbium doped fiber amplifiers (EDFA) form an integral part of today's optical network [1] as they are in general bit rate transparent and can amplify signals at different wavelengths simultaneously. The goal is to achieve maximum gain with acceptable noise figure thereby enabling high capacity repeaterless transmission [2-4]. The gain profile of an EDFA is a function of the Erbium concentration, length of the Erbium doped Fiber, Pump Power and Input Signal power amongst other variables [5,6]. EYDFA which is an advancement of EDFA, overcomes the limitation of increase in the concentration of excited erbium ions by countering the pairs quenching phenomenon [7] also shows similar correspondence. It is demonstrated here that optical pump power for an EYDFA is a variable which can influence the performance of an optical amplifier and lead to cost savings.

2. PRINCIPLE OF EYDFA
A well known technique to minimize the effects of pair induced quenching is to co-dope fiber with Yb^{3+}. sensitizer [8-9]. Ytterbium ions absorb most of the pump power, and subsequently transfer the absorbed energy to adjacent erbium ions through a cross relaxation mechanism.

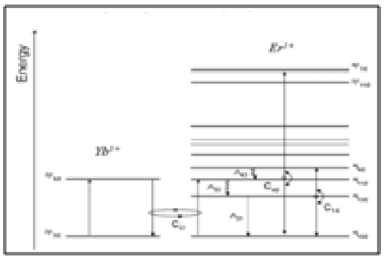

Figure 1: Energy Level for Er-Yb System

The energy level for Er-Yb system is shown in Figure1. Depending on the pump wavelength, pump energy can be absorbed by both the Er ions in the $_4I^{15/2}$ and by the Yb^{3+} ions in the $_2F^{\ 7/2}$ ground levels. Ytterbium ions excited to the $_2F^{\ 5/2}$ level transfer their energy to neighboring Erbium ions in the $_4I^{15/2}$ ground level, exciting them to the $_4I^{\ 11/2}$ pump level from where they rapidly relax to the metastable $_4I^{\ 13/2}$ level. Ytterbium ions absorb most of the pump power, and subsequently transfer the absorbed energy to adjacent erbium ions through a cross relaxation mechanism. Higher power levels can be achieved by increasing the available pump power as evident in the following simulations.

Various configuration of EDFA/EYDFA [10-16] such as single stage, single stage double pass, conventional dual stage, dual stage with partial double pass, dual stage double pass, quadruple pass have been reported. Also, various combinations of hybrid amplifiers targeting higher broadband gain low noise figure are reported. Here this particular configuration leads to a gain of above 46 dbm at 1550 nm with noise figure in the range 3 to 4. The salient feature of the proposed setup is achieving high gain and low noise figure using smaller length of active fiber and a single pump laser i.e. a compact overall setup. For pumping, distributed pumping from single pump laser as reported in [17] has been employed.

3. SIMULATION SETUP
The characteristics and design parameters for EDFA, the use of interstage elements, and various digital transmissions systems applications for multi-stage amplifiers have been reviewed [19]. The schematic layout of the proposed dual stage EYDFA is presented in Figure 2.

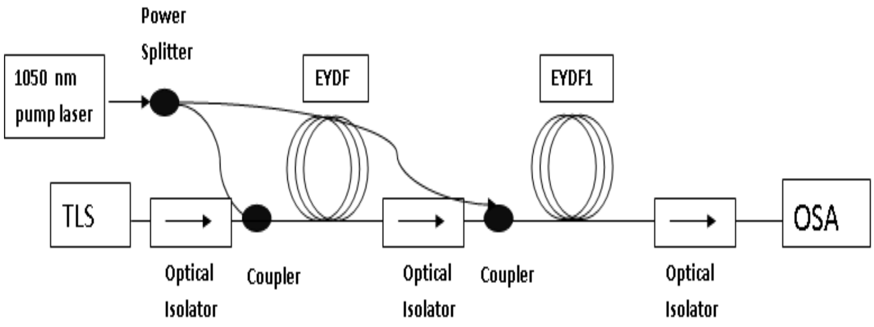

Figure: 2 Schematic layout of proposed dual stage EYDFA with distributed pumping

For simulations, the EYDF is initially taken as 3.3m long for both stages and input signal power is kept fixed.To eliminate any backward propagating amplified spontaneous emission (ASE), an optical isolator is incorporated between the stages. The EYDF is pumped with 1050 nm laser diode by using a forward pumping scheme and output from a single laser source is coupled to both active fibres i.e. distributed pumping is employed. The pump power is varied and results recorded for input signal power -20 dBm and -40dBm and signal wavelength 1535nm and 1550nm. Isolators were incorporated at input and output ends to block any spurious backreflections Results of the simulations are discussed below.

4. RESULTS AND DISCUSSION

Results of output signal power for varying pump power at input signal power -20 and -40 dBm at wavelengths 1535nm and 1550nm are tabulated in Table 1. We infer greater pump power is required for optical pumping to increase gain. Details of input pump power and residual pump power at the first and then, second stages respectively are analysed. These results corroborates with above inference. These results are graphically illustrated in Figure 3. Initially, at low pump powers, the Er^{3+} is not inverted and most of the signal is absorbed. Hence, the signal obtained at the output is even weaker than the input. Increasing the pump power gradually increases the population inversion of Erbium and amplification results.

Table 1:Results of gain for varying pump power at input signal power -20 and -40 dBm at wavelengths 1535nm and 1550nm

S. No	Pump power	A	B	C	D
1	100	-57.15	-119.53	-57.05	-119.3
2	120	-45.57	-102.49	-45.41	-102.18
3	140	-34.63	-86.422	-34.40	-85.91
4	160	-24.48	-71.503	-24.14	-70.62
5	180	-14.98	-57.507	-14.47	-56.08
6	200	-6.04	-44.33	-5.28	-42.14
7	220	2.32	-32.00	3.45	-28.81
8	240	9.97	-20.70	11.52	-16.39
9	260	-	-	18.75	-5.177
10	280	-	-	25.02	4.765
11	300	-	-	30.20	13.36
12	320	-	-	34.39	20.76

A. Output power (dB) for input signal power -40 at 1550nm
B. Output power (dB) for input signal power -40 at 1535nm
C. Output power (dB) for input signal power -20 at 1550nm
D. Output power (dB) for input signal power -20 at 1535nm

It is to be noted here the dependence of gain on pump power under general conditions is being investigated. Optimising other fiber amplifier parameters viz. erbium concentration, ytterbium concentration, core diameter, eydf length will definitely result in higher gains.

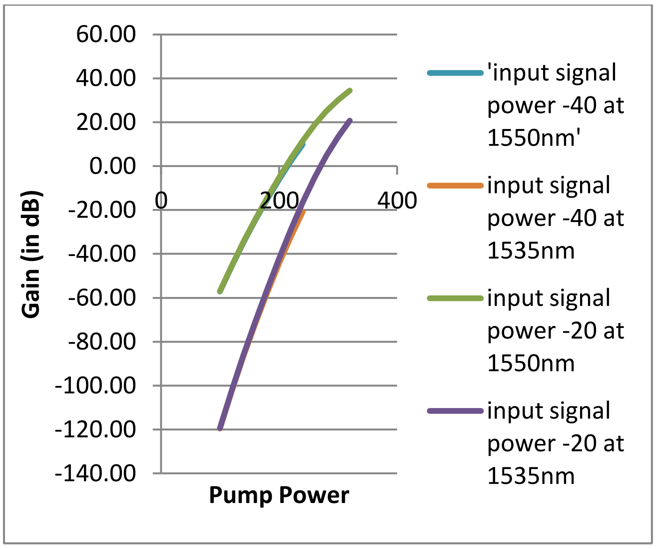

Figure 3: Gain versus the input pump power at 1535/1550nm

The above simulation is repeated with EYDF lengths as 3.3 and 2.0 m. The input signal is fixed at wavelength 1550nm and -20db power. The results are shown in Table-2 for varying pump power.

Table 2: Results of gain, noise figure and output OSNR for input signal at wavelength 1550nm and -20db power

S. No.	Pump power (mW)	Gain (dB)	Noise Figure (dB)	Output OSNR (dB)
1	240	20.95661	16.91	12.7249

2	260	25.36761	13.50	16.1363
3	280	29.57954	10.31	19.3258
4	300	33.45049	7.64	21.9935
5	320	36.89886	5.68	23.9541
6	340	39.71921	4.47	25.1709
7	360	41.84293	3.83	25.8102
8	380	43.31974	3.54	26.1004
9	400	44.29975	3.43	26.2123
10	420	45.0014	3.40	26.2411
11	440	45.5054	3.41	26.2321
12	460	45.93425	3.43	26.2062
13	480	46.29648	3.46	26.1728
14	500	46.6123	3.50	26.1363
15	520	46.89388	3.54	26.0988

For input signal at 1550 nm and input power-40dBm, the pump power is absorbed. This behaviour is observed approximately up to 130 Mw and thereafter, gain is observed. This gain increases sharply with increase in pump power. This behaviour is a result of the increased optical pumping resulting in higher population inversion and hence higher gain. The corresponding value is 200 mW for 1535 nm wave length. Gain of the order of 40 dB is observed for 340 mW power and 46dB when the simulation is repeated for optimized length of active fibre, viz. 3.3 m and 2.0 m respectively. The gain, noise figure and output OSNR is plotted against the input pump power in figure Figure 4. It is observed, that after 340 mW pump power, the increase in gain is not so sharp but the noise figure and OSNR are consistent.

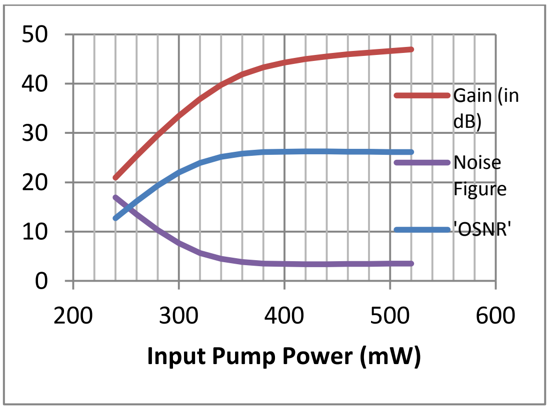

Figure 4: Gain, noise figure and output OSNR versus the input pump power

5. CONCLUSIONS &FUTURE ASPECTS

To summarize, we have simulated the EYDFA model with distributed pumping with relatively short length of active fibre 3.3 m and 2.0 m respectively and a single pump source. In the current scenario, short active fiber length and a single pump source will lead to miniaturization and economy.

A peak gain of 46 dB with noise figure of the order of 3 to 4 is observed at high pump power. The spectral variation of gain with these parameters can be explored and if need be flattening can be incorporated. Even incremental advancement in fibre amplifier performance reduces the cost of regeneration and thus the overall system cost.

6. REFERENCES

[1] http://www.corning.com/opticalfiber/innovation/futureof fiber/connection/index.aspx

[2] J.R. Fernandes de Oliveira, U.C.de Moura et al., “Hybrid EDFA/Raman Amplification Topology for Repeaterless 4.48 Tb/s (40 x 112 Gb/s DP-QPSK) Transmission Over 302 Km of G.652 Standard Single Mode Fiber”, Journal of light wave technology, vol. 31, no. 16, August 15, 2013 ,2799.

[3] Jianqiang Li, Magnus Karlsson, Peter A. Andrekson, and Kun Xu, “Transmission of 1.936 Tb/s (11 × 176 Gb/s) DP-16QAM superchannel signals over 640 km SSMF with EDFA only and 300 Ghz WSSChannel” Optics Express, Vol. 20, Issue 26, pp. B223-B231 (2012) http://dx.doi.org/10.1364/OE.20.00B223

[4] Raja Ahmad, Martin Rochette, and Stephane Chatigny, “Spectrally wide and high-power Er-Yb fiber amplifier for 40 Gb/s telecommunications Applications,” OSA / CLEO/QELS 2010 of Nonlinear Optical Physics & Materials,Vol. 21, No. 1 (2012)

[5] Strohhofer, C.; Polman, A., "Relationship between gain and Yb3+ concentration in Er3+–Yb3+ doped waveguide amplifiers," Journal of Applied Physics , vol.90, no.9, pp.4314,4320, Nov 2001 doi: 10.1063/1.1406550

[6] B. A. Hamida,, X. S. Cheng et al., “Optical amplifier with flat-gain and wideband operation utilizing highly concentrated erbium-doped fibers,” Journal of Nonlinear Optical Physics & Materials, Vol. 20, No. 4 (2011) pp.443–451

[7] Townsend, J. E.; Barnes, W.L.; Jedrzejewski, K.P.; Grubb, S.G., "Yb^{3+} sensitised Er^{3+} doped silica optical fibre with ultrahigh transfer efficiency and gain," Electronics Letters , vol.27, no.21, pp.1958,1959, 10 Oct. 1991 doi: 10.1049/el:19911214

[8] R¨udiger Paschotta, Johan Nilsson, Anne C. Tropper, and David C. Hanna, “Ytterbium-Doped Fiber Amplifiers,” IEEE Journal Of Quantum Electronics, VOL. 33, NO. 7, JULY 1997 Masaru

[9] Shooshtari A., Touam T., Najafi S.I., Safavi-Naeini S., Hatami-Hanza H., Yb3+ sensitized Er3+-doped waveguide amplifiers: a theoretical approach, Optical and Quantum Electronics 30(4), 1998, pp. 249–64

[10] J.M. P Delavaux, Senior Member, IEEE, and J. A. Nagel, “Multi-Stage Erbium-Doped Fiber Amplifier Designs,” Journal Of Lightwave Technology, VOL. 13, NO. 5, MAY 1995 , SCrgio Milo, Rui F. Souza, Marcia B. C. Silva, Evandro Conforti, and Aldario C. Bordonalli, “An EDFA Theoretical Analysis Considering Different Configurations and Pumping Wavelengths” International Journal of Engineering & Technology IJET-IJENS Vol:12 No:04 August 2012

[11] IM.A.Othman , M.M. Ismail , M.H.Misran ,M.A.M.Said and H.A.Sulaiman, “Erbium Doped Fiber Amplifier (EDFA) for C-Band Optical Communication System” International Journal of Engineering & Technology IJET-IJENS Vol:12 No:04

[12] Ramgopal Gangwar , S.P.Singh,NarSingh, “ Gain optimization of an erbium-doped fiberamplifier and two-

stage gain-flattened EDFA with 45nm flat bandwidth in the L-band" Optik - International Journal for Light and Electron Optics, Volume 121, Issue 1, January 2010, Pages 77–79

[13] Desurvire, E.; Zyskind, J.L.; Giles, C.R., "Design optimization for efficient erbium-doped fiber amplifiers,"Lightwave Technology, Journal of , vol.8, no.11, pp.1730,1741, Nov 1990 doi: 10.1109/50.60573

[14] S.Z. Muhd-Yassin, M.S. Khairul Anuar, M.I. Zulkifli, S.W. Harun, H.A. Abdul-Rashid, M.K. Abd-Rahman, "56 dB Gain EYDFA with improved noise figure with dual-stage partial double pass configuration" Optik - International Journal for Light and Electron Optics, Volume 123, Issue 20, October 2012, Pages 1884–1887

[15] N Md Samsuri et al, "Comparison of performances between partial double-pass and full double-pass systems in two-stage L-band EDFA" 2004 Laser Phys. Lett.1 610

[16] Rajneesh Kaler and R.S. Kaler, "Gain and Noise figure performance of erbium doped fiber amplifiers (EDFAs) and Compact EDFAs," Elsevier, Optik - International Journal for Light and Electron Optics, Volume 122, Issue 5, March 2011, Pages 440-443

[17] Dual-stage L-band erbium-doped fiber amplifier with distributed pumping from single pump laser, N.Md. Yusoff , A.F. Abas , S. Hitam, M.A. Mahdi, Optics Communications 285 (2012) 1383–1386 doi:10.1016/j.optcom.2011.11.086

[18] Masaru Fukushima and Jutaro Miura, "Recent Progress of Erbium-Doped Fiber Amplifiers and their Components" Furukawa Electric Ding, W. and Marchionini, G. 1997 A Study on Video Browsing Strategies. Technical Report. University of Maryland at College Park.