DESIGN AND CHARACTERIZATION OF HIGH PERFORMANCE C AND L BAND ERBIUM DOPED FIBER AMPLIFIERS (C,L-EDFAs)

Ahmet Altuncu Arif Başgümüş Burçin Uzunca Ekim Haznedaroğlu
e-mail: altuncu@dumlupinar.edu.tr e-mail: basgumus@dumlupinar.edu.tr
e-mail: burcinuz@yahoo.com e-mail: ekimhaz@yahoo.com
Dumlupınar University, Faculty of Engineering, Department of Electrical & Electronics Engineering, 43100, Tavşanlı Yolu 12.km, Kütahya, Turkey

Key words: Erbium doped fiber, EDFA, fiber optical communications, WDM

ABSTRACT

The design and experimental characterization of high performance C and L band EDFAs pumped at 980 nm are presented. The spectral gain and noise figure performance of EDFAs analysed through simulations have shown strong dependence to EDF length. Highly optimized C and L band EDFAs are realised and experimentally characterized by gain and noise figure measurements. A small signal gain as high as 32.4 dB with a noise figure as low as 3.7 dB were obtained in our C band EDFA. In a L band EDFA, gain enhancement provided through C band signal injection is experimentally demonstrated. In this design, the backward ASE noise at the amplifier input is suppressed by an injected 1550 nm seed signal increasing PCE. This has resulted in a gain as high as 18.3 dB and a moderate noise figure of 7.1 dB obtained in our L band EDFA.

I. INTRODUCTION

Erbium doped fiber amplifiers which have been initially developed for optical signal amplification in the conventional band (C band, 1525-1565 nm)[1] are now being utilized to cover the long wavelength band (L-band, 1565-1620 nm) with an inherent flat gain spectrum [2]. A combined C and L bands offer a much wider transmission window for the dense WDM systems. The lower EDFA gain in L band relative to the C band can in principle be increased by using longer lengths and more heavily doped active fibers. Several different amplification methods have been proposed in order to improve the relatively low pump conversion efficiency (PCE) and thus enable a higher gain per unit fiber length in the L-band EDFA (L-EDFA). Specifically, a significant gain enhancement was achieved through external C-band (1550-1560 nm) seed signal injection [3-7], re-reflection of the unused backward ASE to amplifier using fiber reflectors [7], circulators [8] or fiber Bragg gratings [9], the use of external ASE sources as a secondary pump source [10], the use of signal double-pass configuration [11] and using 1540 nm band pumping [12]. In this paper, firstly, the fiber length dependence of the spectral gain and noise figure performance in C and L band EDFAs are analysed through the simulations. Then, a C band EDFA pumped forward at 980 nm with optimized gain and noise characteristics was constructed and its experimental characteristics are given. Finally, gain enhancement provided in an L-band EDFA pumped bidirectionally at 980 nm through C band signal injection is experimentally demonstrated.

II. SIMULATION RESULTS

The simulations are performed in order to analyse the length dependence of spectral gain and noise figure performance in C and L band EDFAs using Optiwave OptiAmplifer 4.0 simulation program. The important parameters of erbium doped fiber (Metro-12 EDF of Fibercore) used in both the simulations and the experiments are shown in Table 1.

Table 1. Metro-12 EDF parameters.

NA	0.21
Cutoff Wavelength	960 nm
Ion Concentration	1.6e25 iyon/m^3
Core radius	1.75 µm
Background Loss	8 dB/km @ 1310 nm
Absorption Loss	10.46 dB/m @ 980 nm 17.70 dB/m @ 1530 nm
Emission Loss	16.59 dB/m @ 1530 nm

In the simulations, the total bidirectionally applied pump power was 2x150 mW and the signal input power was -30 dBm for each channel assuming 100 WDM channels in total from 1520 nm to 1635 nm. Figure 1 shows the gain spectrum of bidirectionally pumped EDFA with different fiber lengths varying from 5 m to 100 m. For short fiber lengths (5-10 m), the EDFA operates completely in C band. When the EDF length increases to longer than 30 m, The gain spectrum of the EDFA shifts to longer wavelength band (L band) and gives almost no gain in C band. The gain spectrum shift is nearly proportional to EDF length although the net gain decreases for longer lengths than 75 m due to insufficient pumping conditions. Flat gain values except the gain peaks observed at 1535 nm and 1560 nm are around 37 dB for C band and around 33 dB for L band. 20 dB gain bandwidth for 50 m EDF was 69 nm between 1554-1623 nm, for 75 m EDF was 75 nm between 1559-1634 nm.

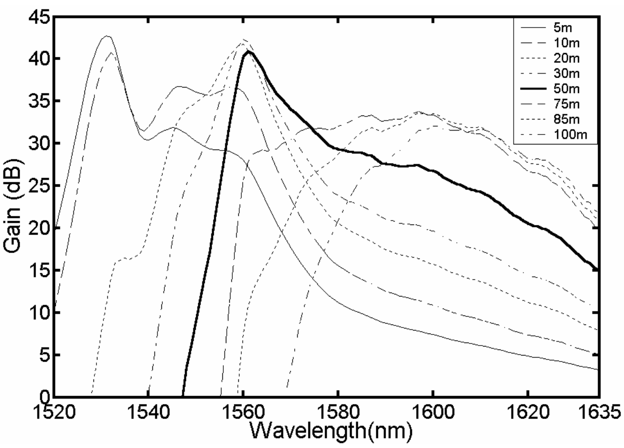

Figure 1. Gain spectrum of bidirectionally pumped EDFA with different fiber lengths. Total pump power = 2x150 mW, Signal input power = -30 dBm X 100 channels.

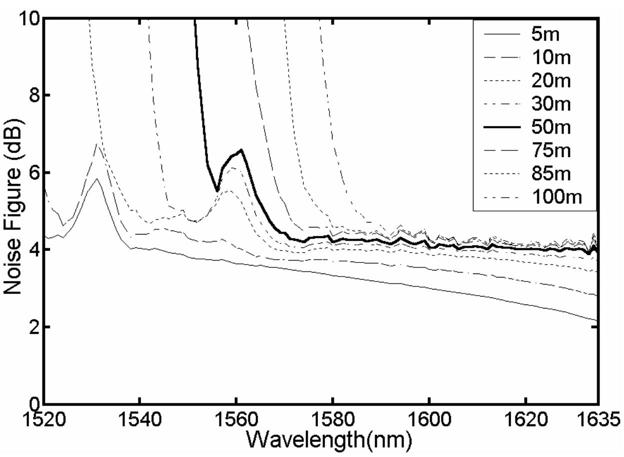

Figure 2. Noise figure spectrum of bidirectionally pumped EDFA with different fiber lengths. Total pump power = 2x150 mW, Signal input power = -30 dBm X 100 channels.

Figure 2 shows the noise figure spectrum of bidirectionally pumped EDFA with different fiber lengths varying from 5 m to 100 m. As shown in the figure, for short fiber lengths (5-10 m), the noise figure of the EDFA is as low as 4 dB due to high gain of the C band EDFA. On the other hand, the low noise region of the amplifier shifts to longer wavelength region for longer lengths. The threshold wavelengths at which the NF reduces under 5 dB is 1567 nm for 50 m EDF and 1571 nm for 75 m EDF. According to these results, the usable 20 dB bandwidth of the EDFA is 56 nm for 50 m EDF and 63 nm for 75 m EDF lengths.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental setups of a forward pumped C band EDFA and a bidirectionally pumped L band EDFA are shown in figures 3 and 4. In both configurations, a tunable laser source (TLS) with a variable optical attenuator was used as a C+L band signal source and 980 nm pump lasers were used as high power pump sources. In L band EDFA (Figure 4), TLS output signal and C-band injection signal at 1550 nm are combined via a 90/10 coupler and this combined signal is applied to the L band EDFA pumped bidirectionally at 980 nm. Erbium doped fiber lengths used in C and L band EDFAs were 6 m and 50 m, respectively. The amplified signals at the EDFA outputs are observed with an Anritsu MS9710B optical spectrum analyser, and gain and noise figure measurements performed systematically for 0.1 nm resolution. The maximum pump power applied in C-EDFA was 92.5 mW in forward direction and in L-EDFA was 205.6 mW with 114.8 mW in forward and 90.8 mW in backward directions giving a forward/total pumping ratio of 0.56.

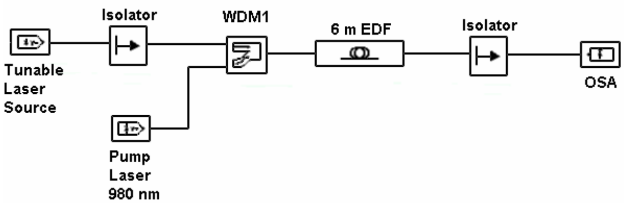

Figure 3. Forward pumped C band EDFA.

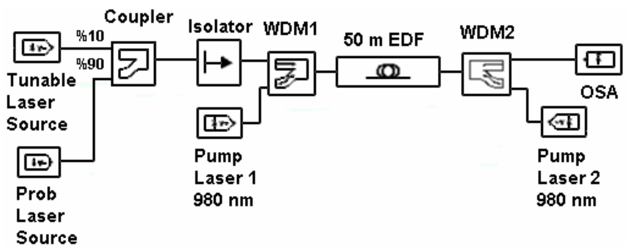

Figure 4. Bidirectionally pumped L band EDFA.

C BAND EDFA

Fig.5 shows the measured gain and noise figure variation of C band EDFA as a function of pump power. The input signal power was -30 dBm and the signal wavelength was 1550 nm in this setup. As expected, the gain increases and NF decreases with increasing pump power and start to saturate at 30-40 mW pump power. For the maximum pump power applied (92.5 mW), the gain and NF values were 32.4 dB and 3.7 dB, respectively. The NF value is slightly higher at 92.5 mW pump power with respect to the lowest level at 25 mW pump power because of strong saturation effects for high pumping powers.

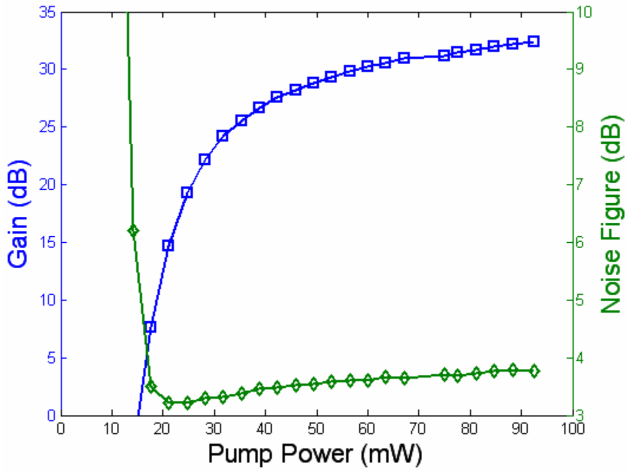

Figure 5. Gain and noise figure characteristics of a 6 m long C band EDFA as a function of pump power. Psig $_{in}$ = -30 dBm, Signal wavelength = 1550 nm.

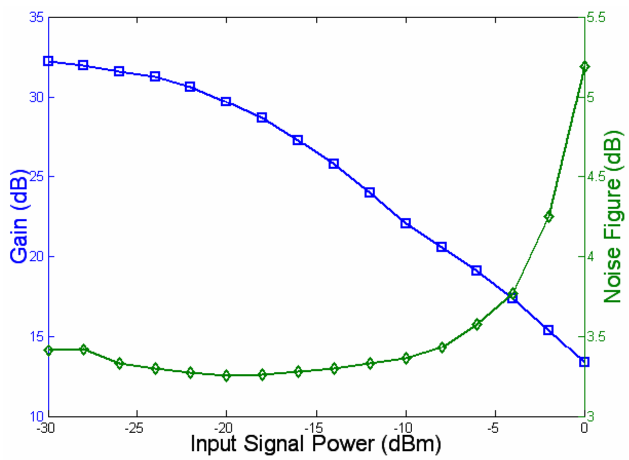

Figure 6. Gain and noise figure characteristics of a 6 m long C band EDFA as a function of input signal power. Ppump $_{in}$ = 92.5 mW, Signal wavelength = 1550 nm.

Fig.6 shows gain and noise figure variations as a function of input signal power for C band EDFA. The forward pumping power applied in this experiment was 92.5 mW, the signal wavelength was 1550 nm. As seen in the figure, gain saturation occurs from -20 dBm input signal power (-3 dB point). At a saturating signal level of 0 dBm, the EDFA gain reduces to 13.4 dB and NF increases to 5.2 dB. However, the NF remains under 4 dB up to the input signal power of -4 dBm.

Fig.7 shows the measured gain and noise figure spectra of C band EDFA between 1525-1570 nm. The pump power and signal input power used here were 92.5 mW and -30 dBm, respectively. It can be seen from the figure that the gain bandwidth for a 30 dB gain limit is about 38 nm between 1526 nm and 1564 nm which corresponds to approximately 100 ITU channels (100 GHz separation) for WDM transmission. On the other hand, NF spectrum is slightly wavelength dependent giving a NF difference of 3.1 dB within the 30 dB gain band. This difference is expected to be significantly reduced when a multi channel amplification scheme with small signals or a single channel with a saturating single power is employed.

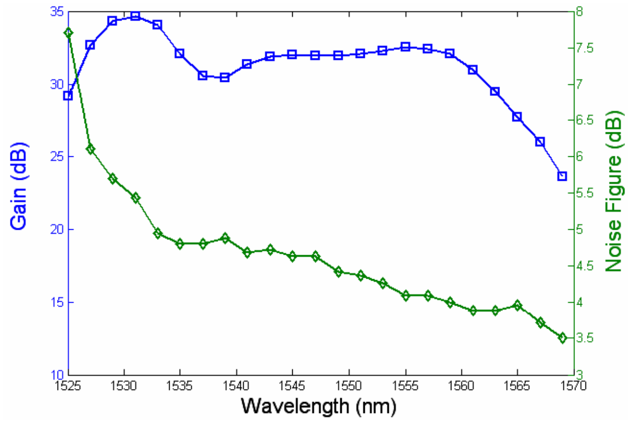

Figure 7. Gain and noise figure spectra of a 6 m long C band EDFA. Ppump $_{in}$ = 92.5 mW and Psig $_{in}$ = -30 dBm.

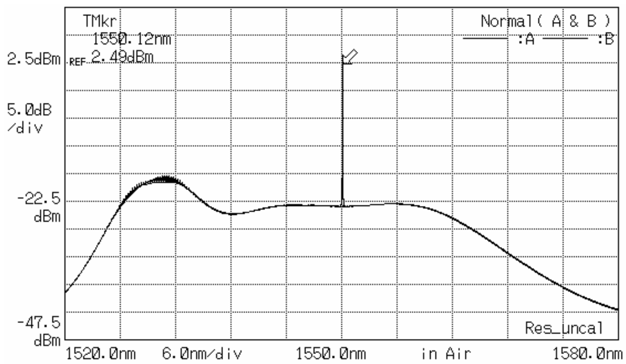

Figure 8. Output spectrum of C band EDFA. Ppump $_{in}$ = 92.5 mW and Psig $_{in}$ = -30 dBm.

Fig.8 shows the output signal and ASE spectrum of C band EDFA between 1520-1580 nm observed on OSA for a small signal level of -30 dBm at 1550 nm and 92.5 mW pump power. Since two isolators were used at the input and output of the EDFA there is no lasing oscillations observed on the spectrum. This has resulted in a stable operation along a wide wavelength range in C band.

L BAND EDFA

Figure 9 shows the output ASE spectrum of L band EDFA between 1520-1620 nm for an input signal power of -30 dBm at 1585 nm and a total pump power of 205.6 mW. The trace (a) in the figure corresponds to the output ASE spectrum of L-EDFA with applying a -1.4 dBm C band seed signal at 1550 nm and the trace (b) is without applying the seed signal. As seen in the spectrum, a significant increase in L band ASE signal and also in gain occurs when the C band seed signal is applied. Observing no reduction in forward C band ASE when the seed signal is applied indicates that the unused backward ASE energy generated at the fiber input is transferred to forward propagating C band seed signal and this is further used to pump L band forward propagating signal. The reason for a higher gain in this design of L band EDFA can be explained by the fact that the combined L band signal and the injected C band seed signal are strongly amplified at the input section of the EDF. The backward ASE generated at the input end of the EDF is significantly suppressed due to the heavily amplified C band seed signal. The amplified C band seed signal is then used to further pump L band forward propagating signal. Backward ASE suppression and secondary pumping effects provided at the fiber input section result in enhanced PCE and a significantly higher gain achievable in L band EDFA.

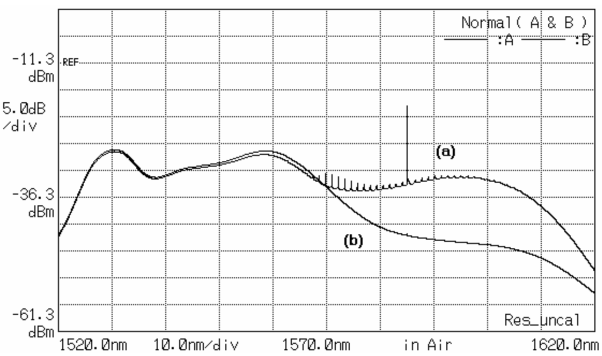

Figure 9. The output spectrum of bidirectionally pumped L band EDFA. Ppump $_{tot}$ = 205 mW and Psig $_{in}$ = -30 dBm. (a) with the seed signal (b) without the seed signal.

Fig.10 shows the measured gain and noise figure spectra of L-EDFA between 1565-1585 nm. The spectral gain and NF measurements were limited to 1585 nm at L band due to unavailability of the TLS operation beyond this wavelength. It can be seen on the figure that the L-EDFA gain increases with increasing wavelength up to 1585 nm. Although the gain and NF performance of L-EDFA at 1565-1570 nm is worse (4.7 dB gain and 31.3 dB noise figure at 1565 nm), they become moderate at 1585 nm as 18.3 dB and 7.1 dB, respectively. These results include two FC/PC-FC/APC connector converter losses used at the EDFA input and output. From the output ASE spectrum of L-EDFA observed on OSA, the L-EDFA design is estimated to provide an approximately 40 nm gain bandwidth between 1570-1610 nm for saturating signal powers.

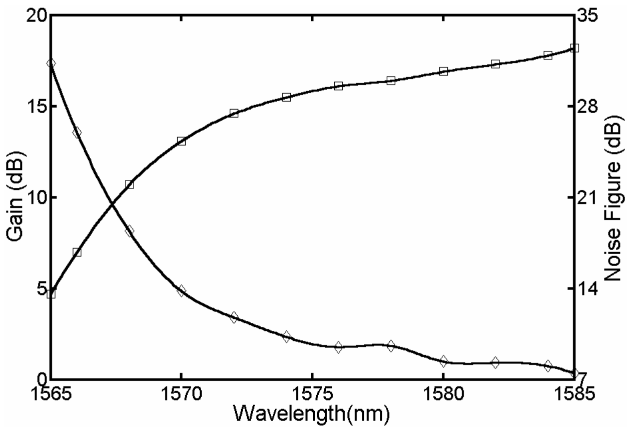

Figure 10. Gain and noise figure spectra of a 50 m long L band EDFA. Ppump $_{tot}$ = 205 mW and Psig $_{in}$ = -30 dBm.

IV. CONCLUSION

Erbium doped fiber length dependent spectral gain and noise figure characteristics of EDFAs were analysed through simulations. Using optimized fiber length and pumping conditions, high gain (32.4 dB) and low noise figure (3.7 dB) values were obtained in C band EDFA. Due to low gain efficiency in L band, a substantial gain enhancement was achieved in an L band EDFA by using a longer EDF and a C band seed signal. The significant C band backward ASE suppression occurring due to C band signal injection was observed through output ASE measurements. This has yielded the pump conversion efficiency to increase and providing a higher gain in L band region. As a result, a high gain (18.3 dB) and a moderate noise figure (7.1 dB) values were obtained in the small signal regime. In general, with its relatively high NF values, this type of L-EDFA can be used as a booster amplifier not requiring very low noise figures.

Acknowledgements: This project was funded by State Planning Organization (DPT) in Turkey with Project number 2003K120380.

REFERENCES

1. E. Desurvire, “Erbium doped fiber amplifiers: principles and applications”, John Wiley and Sons, New York 1994.
2. F.A. Flood, “L-band erbium doped fiber amplifiers”, Tech. Digest’ OAA99, 1999.
3. M.A. Mahdi, F.R.M. Adikan, P. Poopalan, S. Selvakennedy, W.Y. Chan, H. Ahmad, “Long wavelength EDFA gain enhancement through 1550 nm band signal injection”, Optics Comm., vol.176, pp. 125-129, March 2000.
4. Y. Zhang, X. Liu, J. Peng, X. Feng, W. Zhang, “Wavelength and power dependence of injected C-band laser on pump conversion efficiency of L-band EDFA”, IEEE Photon. Technol. Lett., vol.14, pp. 290-292, March 2002.

5. C.Jiang, W. Hu, Q. Zeng, S. Xiao, “Novel split-band erbium doped fiber amplifier”, Optics and Laser Technol., vol.35, pp. 251-256, 2003.
6. H. Chen, M. Leblanc, G.W. Schinn, “Gain enhanced L-band optical fiber amplifiers and tunable fiber lasers with erbium doped fibers”, Optics Comm., vol. 216, pp. 119-125, 2003.
7. A.Altuncu, A.Başgümüş, M.A. Ebeoğlu, “Gain enhancement in L band loop EDFA through C band signal injection”, accepted to be published in IEEE Photon. Technol. Letters. 2005.
8. M.A. Mahdi, H. Ahmad, “Gain enhanced L-band Er^{3+} doped fiber amplifier utilizing unwanted backward ASE”, IEEE Photon. Technol. Lett., vol. 13, pp. 1067-1069, Oct.2001.
9. S.W. Harun, N. Tamchek, P. Poopalan, H. Ahmad, “Gain clamping in two-stage L-band EDFA using a broadband FBG”, IEEE Photon. Technol. Lett., vol. 16, pp. 422-424, Feb. 2004.
10. F.R.M. Adikan, A.S.M. Noor, M.A. Mahdi, “Optimum pumping configuration for L-band EDFA incorporating ASE pump source”, IEEE Photon. Technol. Lett., vol. 16, pp. 1465-1467, June 2004.
11. L.L.Yi, L. Zhan, J.H. Ji, Q.H. Ye, Y.X. Xia, “Improvement of gain and noise figure in double-pass L-band EDFA by incorporating a fiber bragg grating”, IEEE Photon. Technol. Lett., vol. 16, pp. 1005-1007, April 2004.
12. B.H. Choi, H.H. Park, M. Chu, S.K. Kim, “High gain coefficient long wavelength band erbium doped fiber amplifier using 1530 nm band pump”, IEEE J. of Quantum Electronics, vol.39, pp. 1272-1280, Oct.2003.