# Uncluttered Gain Roll Out In Erbium Doped Fiber Amplifier

Mariya Garba Mustapha, Mohammed Ajiya, and Dahiru Sani Shuaibu

**Abstract**— The gain flattening of Erbium – doped fiber amplifiers (EDFA) has been a research issue in recent years with the development of high capacity wavelength division multiplexing (WDM) optical communication systems. As the number of channel increases, in the WDM systems, transmission problems arises such as reduced effective transmission bandwidth and system performance degradation because a conventional EDFA has intrinsic non uniform gain. The gain of EDFA depends on large number of parameters such as erbium-ions concentration, erbium-doped fiber length, pump power and core radius. We achieved average gain of 23dB, gain flatness of 0.299 dB, noise figure <6 dB and output signal power of about 8mW for 16 channels simultaneous amplification in a single stage EDFA by controlling the fiber length and pump power. The gains are flattened over 12 nm from 1546 nm to 1558 nm. The system is simulated using OPTISYSTEM software

*Keywords*— EDFA, gain flatness, gain uniformity, gain optimization, fiber length, pump power, WDM.

### I. INTRODUCTION

ERBIUM doped fiber amplifier (EDFA) is an optical amplifier that consists of length of fiber that has been specially doped with erbium ions. The optical signal which is to be amplified and the pump laser that is used in exciting the erbium ions are multiplexed into the doped fiber and the signal is amplified through interaction of erbium doped ions [1]. EDFAs have extensive applications in present optical communication systems because of their high gain, low noise and high speed response. They also exhibit large gain bandwidth where a single EDFA can amplify large amount of data without any gain narrowing effects [2, 3]. In WDM systems, a stream of wavelength channels particularly in C and L-band regimes can be simultaneously amplified to a desired power level where the amplification of any particular channel is dependent on the signal wavelength, the number of signals present in the system, the input signal powers and its absorption and emission cross-sections [4].

In WDM transmission systems and their related optical networks, one key of the technological issue is the achievement of broad and flat gain bandwidth for EDFA [5].

Uniformity of gain involves two aspects, gain equalization and gain flattening. Gain equalization means achieving identical gains for optical channel while gain flattening means achieving a spectrally uniform gain bandwidth. Several methods in designing a flat spectral gain EDFA have been reported. These include controlling the doped fiber length and the pump power [6], by employing Mach-Zehnder interferometer [7], by employing long period fiber Bragg grating [8-12], and by using an acousto-optic tunable filter [13, 14]. However most of the previously reported work employed structures that rather increased the complexity of their setups.

In this paper, we report 12 nm gain flattened EDFA by controlling the length of the erbium doped fiber and the pump power. The gains are flattened from 1546 nm to 1558 nm. For 16 channels simultaneous amplification in a single stage EDFA, we achieved average gain of 23dB, gain flatness of 0.299 dB, noise figure <6 dB and output signal power of about 8mW. We utilized Optisystem software for the design of the EDFA in the WDM system.

#### II. METHODOLOGY

The WDM system consists a transmitter, an ideal multiplexer, a pump laser, erbium doped fiber, dual port analyzer, output spectrum analyzer and an output power meter as shown in Fig 1. The input to the system is 16 equalized wavelength multiplexed signals from the WDM transmitter which encapsulates different components and allows selection of different modulation formats and schemes for multiple channels. The signals are in the wavelength region of 12nm (1546-1558) with 0.8nm channels spacing and power of each channel at -23.5dBm. The pump laser generates optical parameterized signals to be used for optical amplifier pumping at 980nm which is used to excite the doped erbium ions to higher energy level. The Dual Port WDM analyzer is utilized to detects, calculates and displays the optical power, noise, OSNR, gain, noise figure, frequency and wavelength for each WDM channel at the visualized inputs. It is also used to measure the desired gain and the gain flatness. The optical spectrum analyzer calculates and displays optical signals in the frequency domain. It was used to monitor the signal intensity. Optical power meter is used to calculate and displays the average power of optical signals. The software Optisystem was used to simulate the set-up.

The pump has a maximum power of 160mW. 100mW was chosen as initial value of the pump power while 4m was chosen as the initial erbium doped fiber length. The system was then optimized at 24 passes. An average gain of

Mariya Garba Mustapha is with the Department of Electrical/Electronic Engineering, School of Technology, Kano State Polytechnic, Kano, Nigeria. (e-mail: umg780@ymail.com).

Mohammed Ajiya, is with the Department of Electrical Engineering, Faculty of Engineering, Bayero University, PMB 3011, Kano, Nigeria (Phone: +2348139418201; e-mail: majiya.ele@buk.edu.ng).

Dahiru Sani Shuaibu is with the Department of Electrical Engineering, Faculty of Engineering, Bayero University, PMB 3011, Kano, Nigeria (email: dsshuaibu.ele@buk.edu.ng).

27.90818dB, noise figure of 4.1044863dB, and gain flatness of 1.716952 dB were achieved at pump power and fiber length of 65.61mW and 4.18076m respectively. An output power of 14.10447dBm was obtained. The OSA displays the signal and noise spectrum of the first optimization amplifier output signal as seen in Fig 2.



**III. RESULTS AND DISCUSSIONS** 





Referring to Fig. 2, The pump power of 100mW yields irregular gain spectrum with sharp peak around 1530nm at position A and a 3dB bandwidth of 12nm(1539-1551) from positions B to C. The uneven gain profile causes significant problems in multiwavelength system over a long transmission span and large accumulation of ASE at the peak of the gain profile, which can eventually saturate the amplifier.

Second optimization was then performed at 24 passes, an average gain of 25.93325 dB, noise figure of 4.47882dB and gain flatness of 1.51276 dB were achieved at optimum pump power and fiber length of 42.1918mW and 4.3071m respectively. The spectrum is shown in Fig. 3



## Fig 3 Signal and Noise Spectrum of Second EDFA Gain Optimization

At the third optimization with 15 passes, an average gain of 22.99458 dB, noise figure of 5.6325763 dB and gain flatness of 0.289288 dB were achieved at optimum pump power and fiber length of 24.9567mW and 4.73625m respectively. An output power of 8.798339dBm was obtained which is more than 8.5dBm and the average gain and gain flatness are approximately equal to the desired values. The OSA displays the signal and noise spectrum of the third optimization amplifier output signal as seen in fig 4



## Fig 4 Signal and Noise Spectrum of Third EDFA Gain Optimization

The best case for the gain flatness (0.299dB) is at 24.9567 mW which shows a uniform flattened gain spectrum where the peak of the gain profile at position A is reduced from -33dB to -42dB hence increasing the 3dB bandwidth to 21nm (1538-1559nm) and most equalized gains of 23dB within the channels are represented by the parameterized signal as seen in Fig 5.The reduction in ASE improves the gain flatness and gain uniformity.



## Fig 5 Signal and Noise spectrum of Optimized EDFA

The optical gain and noise figure (NF) for multi-channels amplification were measured for different pump powers, Fig 6 shows the gain and noise figure variation of -26dBm/channel amplification for different pump powers.





The pump power of 100mW has the lowest noise figure and high gain. It yields the highest gain flatness of 2.24dB.This shows that the pump power at 100mW does not offer good performance for the system since the objective is to achieve gain flatness of 0.5dB and the most equalized gain for the channels. The best gain flatness was found at optimum pump power of 24.96mW and fiber length of 4.73625m with a low gain flatness of 0.29dB and equalized gain of 23dB through the 16 channel as shown in Fig. 7. As the pump power decreases, the gain flatness decreases along with the decrease in pump power. For each pump power, the output power increases and decreases after reaching a maximum value. As the fibre length increases,  $Er3^+$  ions available to excite increases and output power increases. After a certain length, when all pump power is exhausted, the unexcited  $\text{Er3}^+$  ions results in the decreased output power. It is observed that the optimum fiber length is 4.73625m with an output power of 8.798339dBm.



Fig 7 Flattened gain spectrum for saturated condition

In the small signal regime (unsaturated condition), backward ASE power is large, so the amplifier is saturated by larger ASE powers and the noise figure becomes higher. As backward input signal increases, backward ASE power gradually decreases as gain also decreases due to signal saturation. It is clear that the equalized gain profile remains uniform even when the amplifier gain shows the gain spectrum which makes it ideal for WDM applications as shown in Fig. 7. At the average inversion of erbium ions with desired gain flatness, it was found that the pump power is a linear function of the output signal power and input signal power.



#### (a) Pump power Vs output signal power (b) pump power Vs input signal power

Fig 8 EDFA operated at average inversion

# IV. CONCLUSION

A simple method for EDFA gain optimization has been proposed and examined in an effort to obtain a flat gain value by controlling the erbium doped fiber length and pump power for a given input power and desired output power using OptiSystem Software. The optimization analysis that relates the EDFA performance parameters has been presented by considering the pump power, pump wave length, Erbiumdoped fiber length, and input signal levels and their spectral range. Short EDFA length and low pump power are desirable for practical and affordable purposes and it was shown that average gain of 23dB and gain flatness of 0.299dB were obtained at the shortest optimum fibre length of 4.73625m of and lowest optimum pump power of 24.9567mW for 16-channel simultaneous amplification. The gain flatness of 12 nm (from 1546nm to 1558nm) bandwidth was demonstrated. The output power of 8.798339dBm and an average noise figure of 6.5dB were obtained from the simulation.

#### REFERENCES

- E. Desurvire, D. Bayart, B. Desthieux, and S. Bigo, *Erbium-Doped Fiber Amplifiers: Device and System Developments*. New York: John Wiley and sons, Inc., 2002.
- [2] Y. Sun, A. K. Srivastava, J. Zhou, and J. W. Sulhoff, "Optical fiber amplifiers for WDM optical networks," *Bell Labs Technical Journal*, vol. 4, pp. 187-206, 1999. http://dx.doi.org/10.1002/bltj.2153
- [3] P. C. Becker, N. A. Olsson, and J. R. Simpson, *Erbium-doped fiber amplifiers: fundamentals and technology* vol. 1. New York: Academic Press, 1999.
- [4] H. Ono, M. Yamada, T. Kanamori, S. Sudo, and Y. Ohishi, "1.58-\ mum Band Gain-Flattened Erbium-Doped Fiber Amplifiers for WDM Transmission Systems," *journal of lightwave technology*, vol. 17, p. 490, 1999.
- [5] G. Levesque and V. Oliver, *Guide to WDM Technology and Testing*. Canada: Electro-optical Engineering Inc., 2000.
- [6] S. Park, H. Kim, C. Park, and S. Y. Shin, "Doped fibre length and pump power of gain-flattened EDFAs," *Electronics Letters*, vol. 32, pp. 2161-2162, 1996.

http://dx.doi.org/10.1049/el:19961436

- [7] W. Imajuku and A. Takada, "Gain characteristics of coherent optical amplifiers using aMach-Zehnder interferometer with Kerr media," *IEEE Journal of Quantum Electronics*, vol. 35, pp. 1657-1665, 1999. http://dx.doi.org/10.1109/3.798089
- [8] J. C. Dung, S. Chi, and S. Wen, "Gain flattening of erbium-doped fibre amplifier using fibre Bragg gratings," *Electronics Letters*, vol. 34, pp. 555-556, 1998. http://dx.doi.org/10.1049/el:19980446
- [9] P. F. Wysocki, J. B. Judkins, R. P. Espindola, M. Andrejco, and A. M. Vengsarkar, "Broad-band erbium-doped fiber amplifier flattened beyond 40 nm using long-period grating filter," *Photonics Technology Letters, IEEE*, vol. 9, pp. 1343-1345, 1997. http://dx.doi.org/10.1109/68.623257
- [10] M. Rochette, M. Guy, S. LaRochelle, J. Lauzon, and F. Trepanier, "Gain equalization of EDFA's with Bragg gratings," *Photonics Technology Letters, IEEE*, vol. 11, pp. 536-538, 1999. http://dx.doi.org/10.1109/68.759390
- [11] I. B. Sohn, J. G. Baek, N. K. Lee, H. W. Kwon, and J. W. Song, "Gain flattened and improved EDFA using microbending long-period fibre gratings," *Electronics Letters*, vol. 38, pp. 1324-1325, 2002. http://dx.doi.org/10.1049/el:20020915
- [12] I. B. Sohn and J. W. Song, "Gain flattened and improved double-pass two-stage EDFA using microbending long-period fiber gratings," *Optics Communications*, vol. 236, pp. 141-144, 2004. http://dx.doi.org/10.1016/j.optcom.2004.03.063
- [13] S. Su, R. Olshansky, D. Smith, and J. Baran, "Flattening of erbiumdoped fibre amplifier gain spectrum using an acousto-optic tunable filter," *Electronics Letters*, vol. 29, pp. 477-478, 1993. http://dx.doi.org/10.1049/el:19930319
- [14] S. H. Yun, B. W. Lee, H. K. Kim, and B. Y. Kim, "Dynamic erbiumdoped fiber amplifier based on active gain flattening with fiber acoustooptic tunable filters," *Photonics Technology Letters, IEEE*, vol. 11, pp. 1229-1231, 1999. http://dx.doi.org/10.1109/68.789700

Mariya Garba Mustapha was born in Kano. She obtained her Bachelor of Engineering and Master of Engineering degrees in Electrical Engineering from Bayero University. She is currently a lecturer at the Department of Electrical/Electronic Engineering, School of Technology, Kano State Polytechnic, Kano, Nigeria.

**Mohammed Ajiya** (M'08) was born in Misau, Bauchi State, Nigeria. He obtained both his Bachelor and Master's degrees in Electrical Engineering from Bayero University, Kano, Nigeria. He obtained PhD degree in optical communication engineering from University Putra Malaysia. He is currently a Senior Lecturer in the department of Electrical Engineering, Bayero University, Kano. His research interest include, nonlinear optics, optical amplification and fiber based lasers.

**Dahiru Sani Shuaibu** was born in Rurum town, Kano State. He obtained both his Bachelor and Master's degrees in Electrical Engineering from Bayero University, Kano, Nigeria. He obtained PhD degree in wireless communication from University Technology Malaysia. He is currently a Senior Lecturer in the department of Electrical Engineering, Bayero University, Kano.