http://dx.doi.org/10.5755/j01.eee.19.2.3476 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 2, 2013

EDFA Application Research in WDM Communication Systems

V. Bobrovs[1], S. Berezins[1]
[1]*Institute of Telecommunications, Riga Technical University,*
Azenes St. 12, LV–1048 Riga, Latvia, phone: +371 29719208
sergejs.berezins@gmail.com

***Abstract*—Characteristics of Erbium-Doped Fiber Amplifier are researched in this article. Amplification, noise figure and its dependences on different EDFA parameters are simulated and measured in 2.5 Gbit/s one channel transmission system. Simulation allows using EDFA amplifier with a variable length of fiber which would be impossible to realize in the real world. EDFA operation is executed in OptSim software environment and in experimental working model. Almost identical results indicate on high accuracy of simulation.**

***Index Terms*—Optical fiber communication, wavelength division multiplexing, Erbium-Doped Fiber Amplifier,**

I. INTRODUCTION

The capacity of fiber optical communication systems has undergone enormous growth during the last few years in response to huge capacity demand for data transmission [1]. Because of signal absorption when transmitting optical signal at long distances it is necessary to use an optical amplifier. Choosing a signal amplification method for wavelength division multiplexing (WDM) systems, preference is given to one of amplifier class - Erbium-Doped Fiber Amplifier (EDFA). EDFA amplifiers insert small noises, they are almost insensitive to the polarization of signal and can be relatively simply realized [2]. Along with providing gain at 1550 nm, in the low-loss window of silica fiber, it can provide gain over a band that is more than 4000 GHz wide. With available WDM components, commercial systems transport more than 100 channels over a single fiber. Hence, installed systems can be upgraded many fold without adding new fiber, and new WDM systems can be built inexpensively with much greater capacity [3].

II. STRUCTURE OF ERBIUM-DOPED FIBRE AMPLIFIER

EDFAs consist of erbium-doped fibre having a silica glass host core doped with active Er ions as the gain medium [4].

Basic elements of an EDFA are shown schematically in Fig. 1. Erbium-doped fibre is usually pumped by semiconductor lasers at 980 nm or 1480 nm. Signal propagates along short span of a special fibre and is being amplified at that time [5].

Amplifier is pumped by a semiconductor laser, which is coupled by using a wavelength selective coupler, also known as WDM coupler, which combines the pump laser light with the signal light. The pump light propagates either in the same directions as the signal (co-propagation) or in the opposite direction (counters propagation). Optical isolators are used to prevent oscillations and excess noise due to unwanted reflections [6].

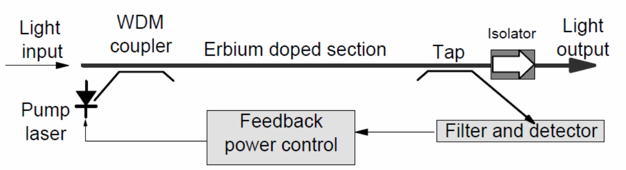

Fig. 1. Scheme of Erbium-Doped fibre amplifier [2].

To make the principle work, erbium atoms needed to be set in excited state. This is done by 980nm and/or 1480 nm lasers. The laser diode in the diagram generates a high-powered beam of light at a wavelength such that the erbium ions will absorb it and get to their excited state. Pumping laser power is usually being controlled via feedback [5].

III. REALIZATION OF EDFA SIMULATION SCHEME

Simulation of EDFA amplifier was done with the help of RSoft Design Group OptSim™ software. This software has two simulation cores: sample mode and block mode. For further work block mode was used since it allowed seeing and studying EDFA intrinsic processes: pump power and amplification propagation along fibre, Amplified Spontaneous Emission (ASE) noise creation and amplification [7], [8].

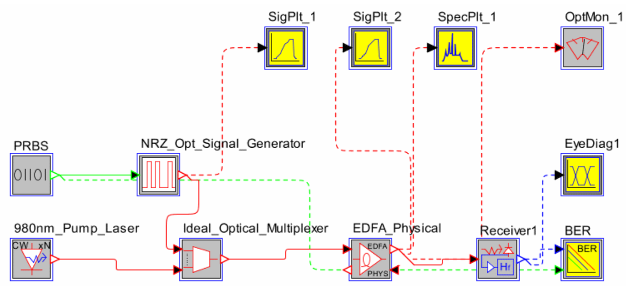

Fig. 2. Simplified optical system for EDFA amplifier parameter research.

For studying EDFA parameters and its impact on a total signal amplification and ASE noise creation one channel optical link scheme was created (Fig. 2.). As shown in Fig. 2, EDFA research scheme consist of one channel and can be

Manuscript received February 17, 2012; accepted May 30, 2012.

divided into three main parts: transmitter, amplifier, and receiver section.

The transmitter section consists of binary data source and non-return to zero (NRZ) on/off keying optical signal source. Data source generate 2.5 Gbit/s data stream. NRZ was chosen because it is most popular code method in the fibre optical transmission systems and due to its simple realization [7]. Signal wavelength λ = 1535 nm corresponds to C-Band. Power of the optical signal was set as low as -30 dBm. This represented typical case when weak signal reaches amplifier. Amplifier part consists of EDFA physical model itself along with optical multiplexer and 980 nm co-propagating continuous wavelength pumping laser. No optical fibre was used in this solution. It was done to simplify simulation process and to accentuate on EDFA part. Other EDFA parameters: erbium doped fibre (EDF) length l =14 m, pumping laser power P = 40 mW.

Receiver section consists of PIN photodiode, preamplifier and Bessel filter grouped together in one receiver element [9]. Measurement elements were placed before and after amplifier to detect changes in signal propagation and its parameters [10].

IV. EDFA EXPERIMENTAL SCHEME

Simulation results are compared to those practically measured. For this purpose experimental EDFA scheme was built. This scheme also consists of transmitter, amplifier and receiver sections as shown in Fig. 3.

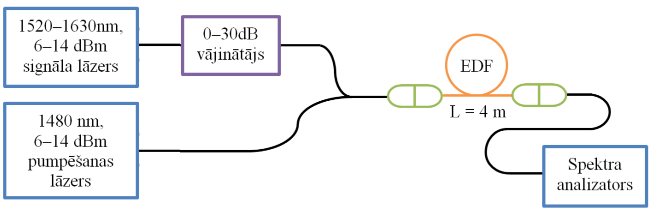

Fig. 3. Experimental EDFA measurement scheme.

For amplifier realization HWT-FIB-EDF-741 erbium doped fibre was used. It is intended for usage in C-Band. Scheme parameters are the same as in simulation. 1480 nm co-propagation laser with maximum 14 dBm output power was used to set the erbium ions in excited state. 0-30 dB signal attenuator was used to acquire low power amplified input signals. Output was sufficient to study EDFA parameters and to provide good erbium state inversion in 4 m long erbium doped fibre.

V. RESULTS AND DISCUSSION

During first simulation EDFA ability to amplify different level signals was studied. Amplified signal power was increased from -40 dBm to 0 dBm with 4 dB steps and following graphs were acquired: Fig. 3 and Fig. 4.

EDFA intrinsic process graphs with different input signal levels: -40 dBm, -20 dBm and 0 dBm were created to show the process in details (Fig. 6). In Fig. 6 can be seen that with input signal level increase while maintaining constant pumping laser power and EDF length, total Erbium inversion is decreasing.

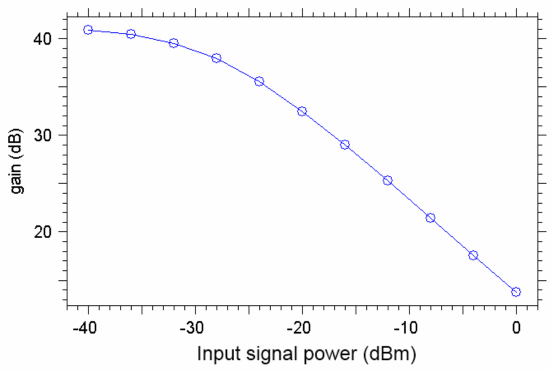

Fig. 4. Amplification's dependence from signal power.

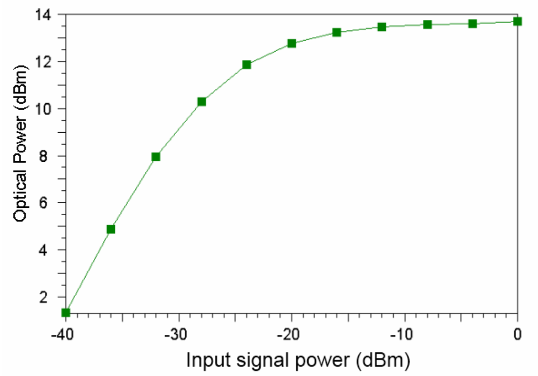

Fig. 5. Output signal's dependence from input.

Amplification has decreased because of insufficient erbium inversion.

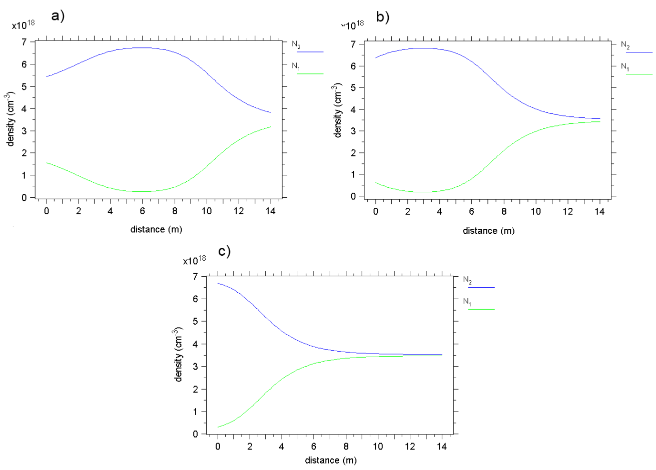

Fig. 6. Exciter erbium state densities at different input signal levels: -40 dBm (a), -20 dBm (b) and 0 dBm (c). (N2 – excited state, N1 – ground state).

Co- and counter-propagating ASE noise reduces almost in proportion to increasing input signal – more powerful signal uses more exited erbium to gain amplification and because of that less excited erbium remains for the amplification of a spontaneous emission. This can be seen in Fig. 7.

Experimental EDFA measurement scheme showed similar results. Because of different equipment setup simulation was re-simulated. Parameters for simulation scheme were chosen based on experimental EDFA amplifier model which was realized in Fibre Optics Transmission Systems Laboratory.

Highest amplification achieved with experimental EDFA scheme was only 5.7 dB as seen in Fig. 8. Result matches with simulation - 6.1 dB. This can be substantiated by 1480 nm low power pumping laser and short 4 meter EDF fibre span.

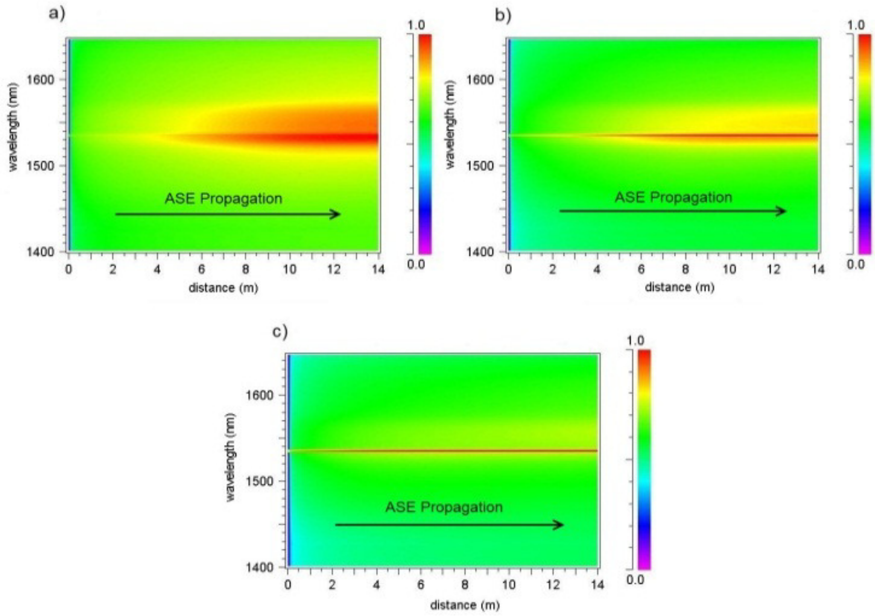

Fig. 7. Co-propagating ASE generation at different input signal levels: -40 dBm (a), -20 dBm (b) and 0 dBm (c).

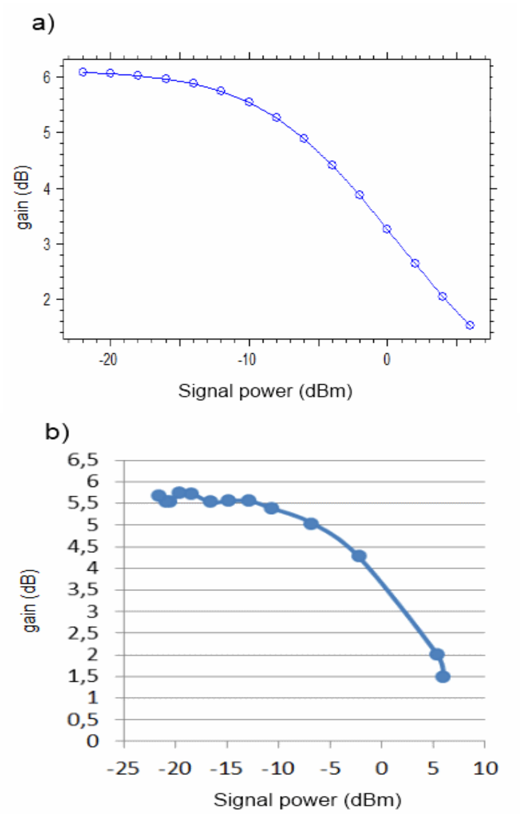

Fig. 8. Amplification's dependence on input signal power: simulation (a), experimental measurement (b).

Fig. 9 shows power spectra from simulation and experimental scheme. Can be seen that pump power is almost constant when input signal power is increased, but total ASE noise power reduces (red line). ASE peak at 1530 nm cannot be seen in Fig. 9, (b) and Fig. 9, (d). This means that excited erbium which was used for ASE amplification in Fig. 9, (a) and Fig. 9, (c) started to amplify stronger input signal.

EDFA amplifies weaker signals more than stronger ones - amplification can achieve 40dB or more. However, in this case EDFA will cause a large amount of ASE noise - up to 30 dB more than if amplifying signal with 0 dBm level. If optical transmission line contains only one amplifier, then everything is normal. A weak signal will be amplified and, together with relatively low noise level will reach receiver. However if there are many amplifiers in the line, extra care should be taken on incoming signal level. If it is less than -20 dBm, EDFA will add additional ASE noise of relatively high power and it will spread further along with the signal. The next EDFA will amplify ASE noise in the signal spectrum together with the signal and will also create additional ASE noise - signal-to-noise ratio will decrease rapidly.

Second experiment was devoted to get amplification and noise dependence on EDF length while keeping other parameters constant. EDF length was changed from 5 m to 30 m with 5 m steps. Simulation result can be seen in Fig. 10.

Maximum amplification with chosen parameters was achieved with EDF length of 15 m. Noise Figure (NF) – relation of signal-to-noise ratio before and after the implication only increased with increasing erbium-doped fiber length.

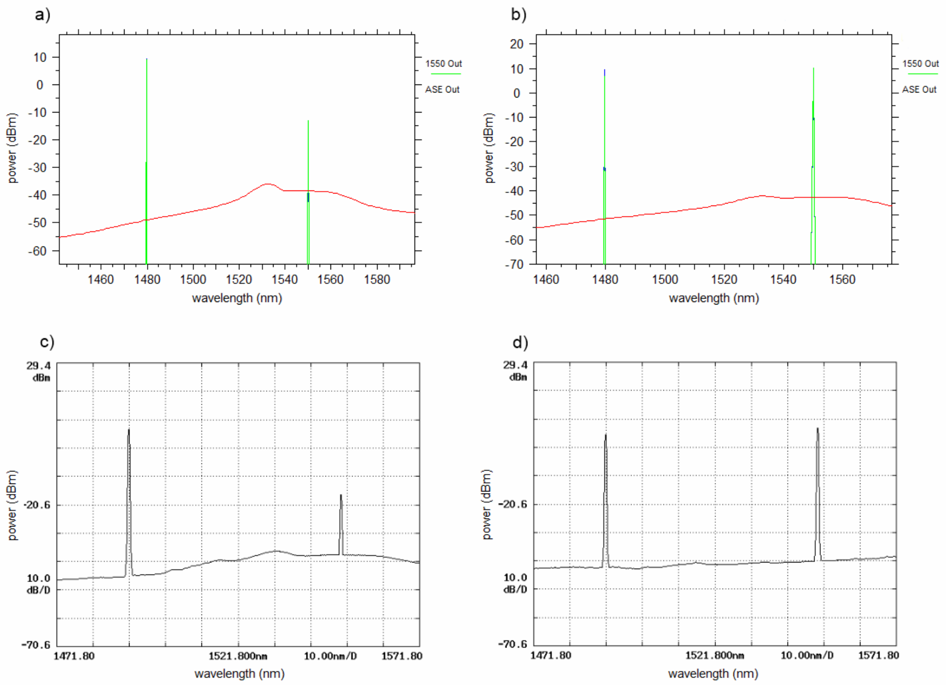

Fig. 9. EDFA power spectrum at amplifier's output. Simulation – input signal power -22 dBm (a), 6 dBm (b); measurement – input signal power -21.66 dBm (c), 6 dBm (d).

To explore dependences shown on Fig. 10 EDFA internal erbium density state graphs were created. It can be seen in Fig. 11.

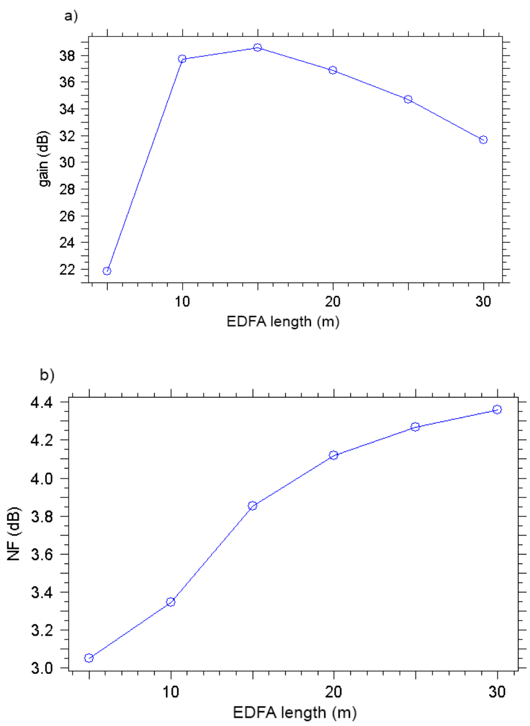

Fig. 10. a) Amplification's dependence on EDFA length, b) Noise Figure's dependence on EDFA length.

At 5 m EDF length (Fig. 11, (a)), all of erbium is in excited state. Signal obtains only half of the maximum possible gain in this short fibre span. ASE noise level is quite low. Amplifier is operating in saturation mode, with almost 100% inversion and amplification is homogeneous throughout all the EDF fibre length.

By increasing the length to 20 meters, the situation changes completely (Fig. 11, (b)). At the fibre length of 15 m signal amplification achieves its maximum and exited erbium ion count is approaching base state erbium count - at this point EDFA doesn't amplify the signal. Counter-propagating ASE also leads to the decrease of inversion at the beginning (first 0-5 m) of the EDF fibre.

In the case of 30 meter long EDF fibre (Fig. 11, (c)) starting from 15 meters and till amplifier's end, erbium inversion became lower than 50% - signal absorption takes place. EDF absorbs the signal together with ASE noise.

During the third simulation a research on different pumping laser configuration was performed. While other simulation parameters were kept constant, laser power, direction and wavelength were changed. Aggregated information is placed in Table I.

1480 nm laser requires longer EDF fibre, than 980 nm laser to create same amount of amplification. In 980 nm laser usage case, erbium excite to higher energy state requires less energy than in the case of 1480 nm laser, and at the same laser power, the use of 980 nm wavelength g will lead to greater gain then with 1480 nm. However, by using 1480 nm lasers, higher laser power can be applied and even greater output signal level can be achieved. Combined laser pumping, as was expected, gave the largest signal amplification since it provided larger erbium inversion along the EDF fibre length.

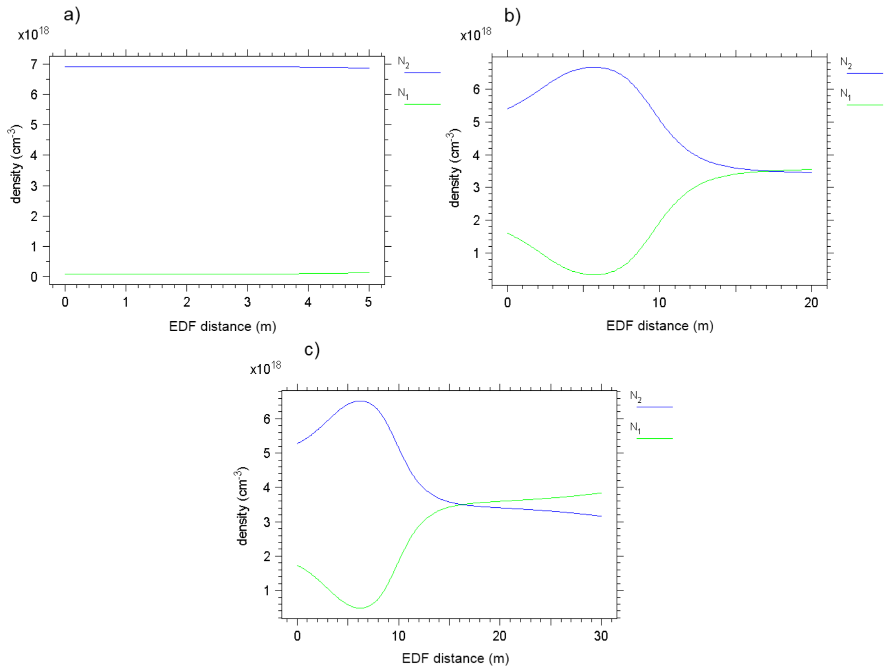

Fig. 11. Densities of erbium ion states. EDF length: 5 m (a), 20 m (b) and 30 m (c). (N_2 – excited state, N_1 – ground state).

TABLE I. SIMULATION RESULTS.

Pumping laser setup	Laser power, mW	Output signal, dBm	Co-prop. ASE, dBm	Counter-prop. ASE, dBm	Co-prop. ASE at 1535nm dBm
Co-prop. 980nm laser	10	-0.65	-3	2	-15
	40	9.1	6	10	-6
	80	12.7	10	13	-2
Counter-prop 980nm laser	10	-0.65	-2	2.5	-10
	40	9.4	9.4	7	-4
	80	13	12	11	0
Co-prop. 1480nm laser	10	-7.2	0	4	-18
	40	6.8	9	11	-5
	80	11	12	15	-1
Counter-prop 1480nm laser	10	-7.3	4	0	-12
	40	6.9	11	10	-2
	80	11.1	14	12.5	1
Co-prop. 980nm and Counter-prop 1480nm	10	1.68	5	7	-11
	40	11.1	11	15	-2
	80	14.7	14.5	18	2
Co-prop. 1480nm and Counter-prop 1480nm laser	10	1.74	7	5	-8
	40	11.2	14	12.5	0
	80	14.9	15.5	15	4

VI. CONCLUSIONS

In this article we have investigated EDFA optical amplifier's operating parameters and its effects on the resulting gain and noise.

In summary, it can be concluded that increase in input signal power reduced EDFA gain and ASE noise. According to our observations the most effective way to decrease ASE noise created by the amplifier is not to have a too weak signal to be amplified at EDFA input.

There is always an optimum EDFA length depending on the pumping laser power. If the fiber is too short then the whole potential of the amplifier won't be realized. Some laser energy will remain unused. If the EDFA fiber is longer than the optimal value then erbium inversion level at the end of the EDF will be less than 50 % and fiber will start to absorb the signal.

The second key component of the EDFA besides erbium-doped fiber is pumping laser. All simulation results showed the advantage of 980 nm co-directional laser usage in amplifier setup. Compared to 1480 nm laser, higher gain and lower noise values are possible to achieve in this setup by using the same pumping power.

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