Software for analysis of parameters and characteristics of Semiconductor Optical Amplifier

E R Kozhanova¹, V V Belyaev², I M Tkachenko², H Yazbeck²
¹Yuri Gagarin State Technical University of Saratov, Saratov, Russia
²RUDN University (Peoples’ Friendship University of Russia), Moscow, Russia

E-mail: tkachenko_im@rudn.university

Abstract. The article discusses the prospects of modernization of the author’s software «labpraktikum_osnov_wavelet» for studying and analyzing the parameters and characteristics of a semiconductor optical amplifier (SOA) by expanding the list of wavelet analysis types in order to select the most informative type of wavelet analysis and wavelet function to interpret the results.

1. Introduction

Nowadays there are a lot of works on theoretical and practical application of wavelet analysis in various fields of science and technology, which is explained by the presence of libraries and functions of wavelet analysis in mathematical packages and programming languages, implementing various transformations (continuous, discrete and other) and offering a certain list of wavelet - functions for its realization [1, 2].

The group of authors created the software "labpraktikum_osnov_wavelet" [3] for training signal processing specialists. User application is written in GUIDE MATLAB [4, 5]. This application includes six interrelated software modules and a signal base (Fig. 1) that teach how to recognize the characteristics of a given signal [6]. The structure of the program "labpraktikum_osnov_wavelet" (Fig. 2) is based on the modular principle, which allows us to change, add or remove one or more program modules independently of the other program modules, therefore, each program module can be considered as a separate software product [7]:

- Main module - the module controls the work of the program "labpraktikum_osnov_wavelet" and performs transition from one program module to another.
- Software modules - user programs that perform a certain computational task. They can be extended or adjusted for a specific task.
- Work modules - programs that perform functions of libraries and subprograms. In our case, two libraries: signal library and library of author's and additional wavelets - functions that extend the list of wavelets - functions of MATLAB library.
- MATLAB library.
In the process of approbation and use of this software in educational and scientific work the ways of modernization were defined. Primarily, they are related to the expansion of the list of wavelet analysis types in order to select the most informative wavelet analysis type and wavelet functions for a specific task.

2. Parameters and characteristics of semiconductor optical amplifier SOA - as an object of research

Semiconductor Optical Amplifier (SOA) is an optoelectronic device that, under appropriate operating conditions, can amplify the incoming light signal and is widely used as a linear optical amplifier and intensity modulator in Wavelength Division Multiplexing (WDM) networks [8]. In addition to SOA, there are other versions of SOA: quantum well SOA (QW-SOA) and quantum dot SOA (QD-SOA), which have significant improvements over conventional SOA: lower noise levels, low threshold current, high power output and temperature stability [9]. Recently, QD-SOA has
sparked research interest, primarily due to its joint development with a QD laser. They are used as intensity modulators (IM), multichannel amplifiers and wavelength converters [10].

The characteristics of semiconductor optical amplifiers (SOA) [10] include:
- SOA amplification is an important working parameter calculated as the ratio of output power to input power. The spectrum of SOA amplification depends on its structure, material, retention factor, SOA length, losses and operational parameters.
- Saturation output power.
- Noise factor (F) is used as an indicator of the quality of the optical amplifier and is defined as the ratio between the signal-to-noise ratio (SNR) at the input and (SNR) at the output of the amplifier.
- Non-linearity. Nonlinearities SOA are mainly due to changes in electron density caused by the input signals of the amplifier. The main types of non-linearities are self-gain modulation (SGM), cross gain modulation (XGM), cross-phase modulation (XPM), self-phase modulation (SPM), four-wave mixing (FWM) and cross-polarization modulation (XPoLM).

The article [10] describes the theoretical and numerical research of the models of intensity modulators of different versions of SOA, including the model of multielectrode mass semiconductor optical amplifier (ME-SOA) and multi-electrode quantum-dot semiconductor optical amplifier (ME-QDSOA), which increase the bandwidth of optical access networks. As a result of modeling obtained:
1) System bandwidth dependence on the transmission distance (fig. 3, 4).

![Figure 3. System bandwidth compared to transmission distance for 1E-SOA, 2E-SOA and 3E-SOA for input optical power 0 dBm and bias current 300 mA [10]](image1)

![Figure 4. System bandwidth compared to the transmission distance for 1E-QDSOA, 2E-QDOSOA, 3E-QDSOA, for input optical power 10 dBm and bias current 300 mA [10]](image2)

2) System contour graphics (fig. 5).

![Figure 5. System productivity for 3E-SOA (a) and 3E-QDOSOA (b) [10]](image3)

Parameters and characteristics of all semiconductor optical amplifiers (SOA) depend on its structure and material, which allows us to consider the possibility of using wavelet analysis to recognize the chemical composition [10, 11].
The analysis of the results shows that the parameters and characteristics of the semiconductor optical amplifier (SOA) can be investigated by wavelet analysis, both in terms of signal analysis (system productivity) and recognition.

3. Development of new software modules

Consider the initial composition of the modules "labpraktikum_osnov_wavelet" [7], which allows to consistently study the classical spectral analysis and continuous wavelet transformation (CWT):

1. Construction of approximating Fourier row for the selected signal - lab01 (Fig. 6a). The approximating Fourier row of the selected signal with a given number of harmonics, a graph of the difference between the obtained Fourier row and the selected signal and the spectra of amplitudes and phases for further statistical data processing are plotted.

2. Construction of spectrogram and periodogram of signal - lab02 (Fig. 6b). The above graphs with different window functions are plotted.

3. Base functions of wavelets and their characteristics - lab03 (Fig. 7). This module performs the construction of psi- and phi-functions of the wavelet selected from the proposed list. Depending on the type of the wavelet, only the psi - function (Gaussian wavelets, Morlet wavelet) (Fig. 7a) or psi- and phi-functions (Dobeshi wavelets, Haara wavelet) can be constructed (Fig. 7b).

4. Different types of visualization of continuous wavelet - transformation- lab04 (Fig. 8.). In continuous wavelet transform (NWT) signal the matrix of wavelet coefficients is obtained. The most common types of visualization in MATLAB are wavelet surface coefficients, four types of visualization of wavelet spectrograms (lvl, glb, abslvl, absglb) and contour graph of wavelet surface.
coefficients. This module introduces various types of visualization and allows to recognize the features of signals.

**Figure 8.** Example of work of the program - lab04

5. *Value of wavelet coefficients at scales 1 and 9 at different wavelet steps - transformations - lab05* (Fig. 9a.) This module tests the equality of wavelet coefficients - coefficients of equal levels of CWT at different steps of CW (Fig. 9b).

6. *Comparison of Fourier transform and continuous wavelet - transformations for different signals.* The last module constructs two figures - the first one shows the wavelet spectrograms of the selected signal and the approximating Fourier row with different number of harmonics (Fig. 10a) and the second one shows correlation coefficients of the relevant levels of different wavelets - spectrograms and their t - significance criteria (Fig. 7b).

**Figure 9.** Example of work of the program - lab05 (a) and result of work (b)

**Figure 10.** Results of work of the program - lab06

Approbation and analysis of the above mentioned modules allowed to formulate the directions of development of new modules:

1) First four modules remain. The second module expands the selection of window functions by offering the MATLAB library. These modules introduce with classical spectral analysis basics, with
the list of wavelet functions and types of visualization of continuous wavelet transforms, which are represented by the mathematical package MATLAB.

2) The fifth and sixth modules are proposed to be deleted and replaced by new modules:
   - the fifth module - discrete wavelet transform (DWT) (Fig. 11) [7].

![Figure 11. Signal (Graph 1) and its DWT: up to level 1 (Graph 2), up to level 2 (Graph 3), up to level 3 (Graph 4) and up to level 5 (Graph 5)](image)

- The sixth and seventh modules - signal recognition through the calculation of statistical and stochastic characteristics. For these modules it is necessary to set two or more signals, one of which is considered to be a reference. For example, a rectangular impulse with different duration (Fig. 12a) and statistical methods of wavelet recognition - coefficients for these signals (Fig. 12b – 12d) are specified [11].

![Figure 12. Main window of the module (a) and the modules with the results implementing the methods: calculation of the arithmetic mean (b), dispersion (c) and deviation (d)](image)

One of the most used stochastic characteristics is the Hearst index (Hearst coefficient, Hearst degree index).

3) It is necessary to provide both reference signals and downloading signals from files.

4) Possibility to save the results of the calculation in MS Excel for further processing or creation of an archive of experimental data.
5) Develop accompanying documentation in the form of a study guide for the upgraded software product.

6) Software tool - GUIDE MATLAB. The selection is based on the presence of wavelet libraries and a wide range of visualization tools.

4. Conclusion
The software modules "labpraktikum_osnov_wavelet" have been created for the analysis of the parameters and characteristics of the semiconductor optical amplifier. They allow to select the most informative type of wavelet analysis and wavelet functions by comparing the results of research in order to provide high quality analysis of local features of signals.

5. Acknowledgement
The paper is prepared under partial support of Russian Foundation for Basic Researches (RFBR) (project No. 19-07-00602_a).

References
[1] Malla S 2005 Wavelets in signal processing: English translation. - Moscow: Mir, 671.
[2] Blatter K, 2006 Wavelet, analysis. Fundamentals of the theory. - M: Technosphere, 272.
[3] Kozhanova E R, Zakharov A A, Tkachenko I M. labpraktikum osnov wavelet: Certificate of State Registration of Computer Software No 2011611250 dated February 07, 2011.
[4] Chen K. 2001 MATLAB in Mathematical Research/K. Chen, P. Jiblin, A. Irving; English translation - M.: Mir, 346.
[5] Smolentsev N K 2008 Fundamentals of Wavelet Theory. Wavelets in MATLAB/N.K. Smolentsev. - Moscow: DMK Press, 448.
[6] Zakharov A A, Kozhanova E R, Tkachenko I M. 2012 Comparative Characteristics of Application of Classical Fourier Transform and Continuous Wavelet Transform For Signal Analysis: Study Guide for students in Specialty Electronic Instruments and Devices (210105.65), Majors Electronics and Nanoelectronics (Bachelors – 21010062, Masters - 2110068). Ministry of Education and Science of the Russian Federation, Yuri Gagarin State Technical University of Saratov, Saratov. 132.
[7] Zakharov A A, Kozhanova E R, Tkachenko I M 2015 Study Guide. Saratov: Wright Expo Publishing House, 56.
[8] Schubert C, Ludwig R, Weber H, 2004 Opt. Fiber Communication, 171.
[9] Norman J C, Jang D, Wan Y, Bowers J E, 2018 APL photonics 3 (3) 1.
[10] Hussein A, Yazbeck H, Belyaev V V Physical and Electronic Model of Semiconductor Optical Amplifier SOA and Quantum-dot Semiconductor Optical Amplifier QD-SOA
[11] Tkachenko I M, Kozhanova E R, Belyaev V V, Yazbeck H. 2019 J Phys Conf. Ser. DOI:10.1088/1742-6596/1309/1/012020.