SYSTEM SPECTRAL ANALYSIS OF THE FRACTAL ULTRA-WIDEBAND SIGNALS

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The theoretical basis and practical peculiarities of the system spectral analysis are briefly considered. The necessity and the expediency of simultaneously application of different linear and non-linear integral transforms during the system spectral analysis performance are explained. The system spectral analysis usage for investigations of the time-frequency structure of the fractal ultra-wideband signals is shown to be effective and useful.

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INTRODUCTION

Last years the new types of the ultra-wideband (UWB) signals have been proposed. In particular, the fractal, the random, the direct-chaotic UWB signals, the UWB signals with changing mean frequency can be considered as the suitable examples of such new UWB signal types [1]. These new UWB signal types have been started to apply in many branches of science and engineering. Moreover, many natural and artificial processes in nature, in particular, in the complex open dynamical non-linear system called as the Earth-atmosphere-ionosphere-magnetosphere were appeared to be just the UWB processes, which can be classified as one of those new types [2].

The time-frequency structure of such UWB signals and processes is appeared to be more complex and miscellaneous than one of the traditional ultra-short UWB signals was. Therefore, for successful analysis and investigations of such signals and processes it is necessary to use, of course, a new analysis method.

One of the possible ways is the application of system spectral analysis. Actuality of this work is conditioned to these.

1. FRACTAL ULTRA-WIDEBAND SIGNAL MODELS

By the definition, a fractal UWB (FUWB) signal is a UWB signal with self-affine property and fractal dimension [1, 3].

Many different FUWB signal models as analytical, as numerical were proposed [1, 3]. In this paper, as an example, we consider the following model based on the Weierstrass function:

$$FUWB(t) = \left[1 - b^{2D-4}\right] \times \\ \times \frac{\sum_{n=0}^{M} b^{(D-2)n} \cos\left(2\pi s b^n t + \psi_n\right)}{1 - b^{(2D-4)(M+1)}};$$

where t is the time variable, b is the time scale parameter, s is the frequency scale parameter, D is the fractal dimension of the signal, $1 < D < 2$, ψ_n is the phase distributed randomly at the interval $\left[0, 2\pi\right]$, M is the harmonics number (if $M \to \infty$, a mathematical fractal is obtained).

2. SYSTEM SPECTRAL ANALYSIS BASES

One of the most effective modern signal analysis methods, called as the system spectral analysis, has been proposed in 2007 by the authors of the paper [4].

The system spectral analysis is based on the simultaneous application of set of linear and non-linear integral transforms [1, 4, 5]. In first group there are the continuous wavelet transform (CWT), the analytical wavelet transform (AWT), the Gabor transform (GT), the adaptive Fourier transform (AFT) and the short-time Fourier transform (STFT). Second group includes some members of the Cohen’s class of square non-linear integral transforms, namely the Fourier spectrogram (FS), the Wigner transform (WiT), the Choi-Williams transform (ChWT) and the Born-Jordan transform (BJT). In addition to the module of spectral density function (SDF), for every transform also the skeletons, energograms, dispersions of the SDF module for linear transforms and standard deviations of the SDF module for non-linear transforms are used.

The basic idea of the system spectral analysis is the compensation of disadvantages of the some transforms due to advantages of other ones.

A quantity and set of integral transforms, used in the systems spectral analysis, can change in the future.

For the system spectral analysis performing the system of computer mathematics MATLAB including packages Wavelet Toolbox, Time-Frequency Toolbox, Wave Laboratory and some original software for MATLAB created by authors were used.

3. ANALYSIS RESULTS

Considering the results of the system spectral analysis of model FUWB signal with the fractal dimension $D = 1.5$ (Fig. 1,a), lets demonstrate the validating of our transform choice.

The linear transform selection was based on the such reasons. The CWT SDF (Fig. 1,b) has a good time-frequency resolution, its basis is self-similar, there are many different wavelets allowing choosing the optimal one for each signal analyzed. The argument of the complex AWT SDF (Fig. 1,d) has more abilities for the analyzing of the signals with peculiarities than the CWT has. Therefore, AWT is appears to be very useful addition to the CWT. The GT SDF (Fig. 1,e) has the best time-frequency localization in the middle of all time-frequency transforms.

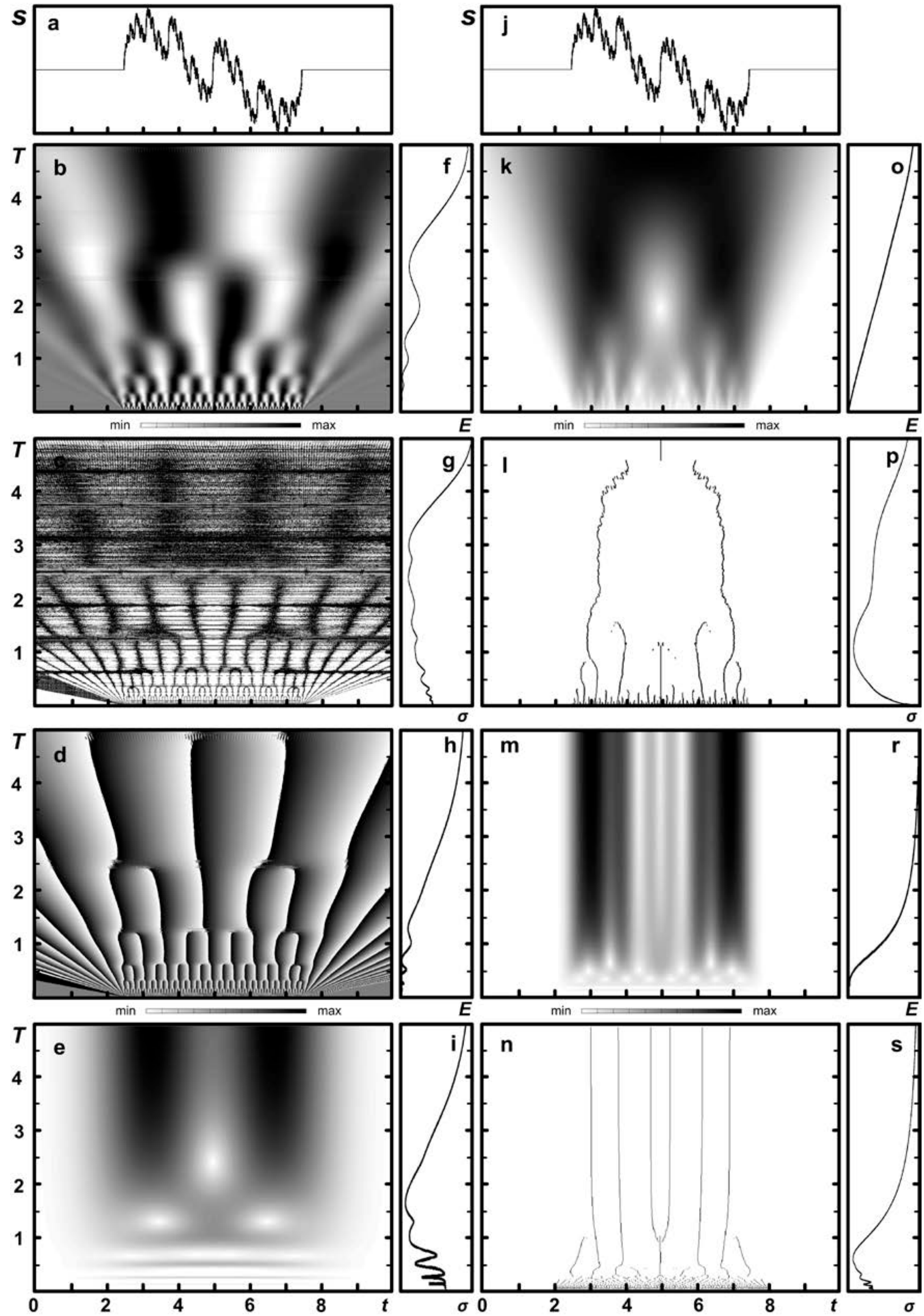

Fig. 1. The analysis results of model FUWB signal: a, j – signal in time domain; b – CWT SDF with Morlet wavelet; c – CWT SDF skeleton; d – phase of complex coefficients of AWT with cgau1 wavelet; e – GT SDF module; f – CWT SDF energogram; g – dispersion of CWT SDF coefficients; h – GT SDF energogram; i – dispersion of GT SDF module; k – AFT SDF module; l – AFT SDF skeleton; m – STFT SDF module; n – STFT SDF skeleton; o – AFT SDF energogram; p – dispersion of AFT SDF module; r – STFT SDF energogram; s – dispersion of AFT SDF module

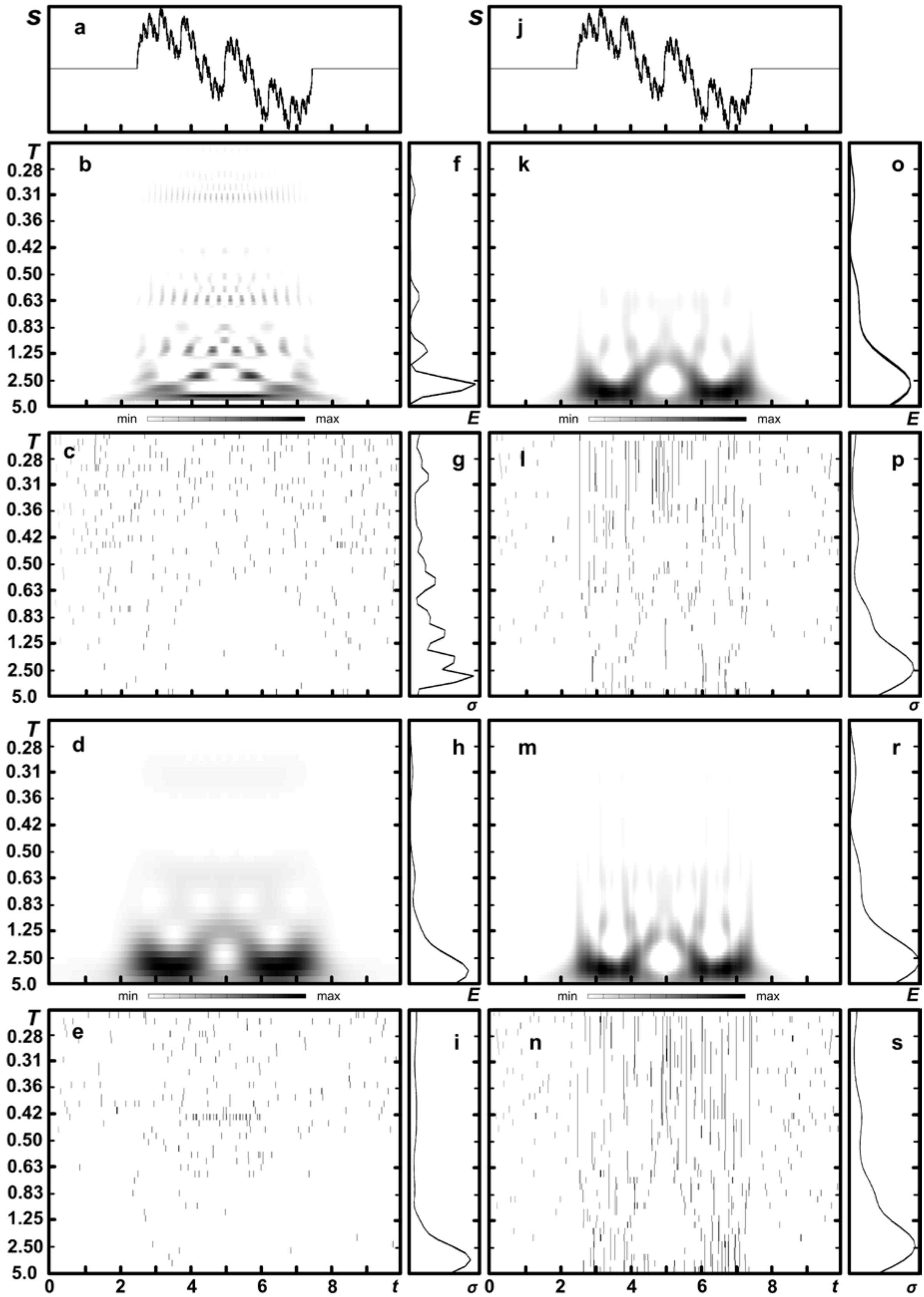

Fig. 2. The analysis results of model FUWB signal: a, j – signal in time domain; b – WiT SDF; c – WiT SDF skeleton; d – FS SDF; e – FS SDF skeleton; f – WiT SDF energogram; g – dispersion of WiT SDF coefficients; h – FS SDF energogram; i – dispersion of FS SDF module; k – ChWT SDF module; l – ChWT SDF skeleton; m – BJT SDF module; n – BJT SDF skeleton; o – ChWT SDF energogram; p – dispersion of ChWT SDF module; r – BJT SDF energogram; s – dispersion of BJT SDF module

The AFT SDF (Fig. 1,k) is appeared to be another useful look at the signal time-frequency structure. Sometimes, the AFT comes to the AWT, but in a number of cases it has an independent sense, in particular, when the non-symmetrical window functions have been used. The STFT SDF (Fig. 1,m) is appeared to be a good addition to the other ones. It is useful especially for the narrow-band signal analysis.

The non-linear transform selection was based on such reasons. The WiT SDF (Fig. 2,b) has good time-frequency resolution which is better than one for linear transforms. The ChWT SDF (Fig. 2,k) has the parameter allowing to control by level of the cross-terms appearing in the WiT SDF in case of the multi-component signal analysis. Another way of the cross-term influence reduction is given by the BJT SDF (Fig. 2,m) application. The FS SDF (Fig. 2,d) has the worst time-frequency resolution, but it has no interference structures for multi-component signals. Being the limit result of the WiT averaging in time- and frequency domains, the FS allows effectively selecting the really existent signals and the cross-terms during the WiT interpretation process. Moreover, all non-linear transforms are appeared to be useful for the analysis of the signals in case of the non-Gaussian noise presence.

Some words about other numerical characteristics.

The skeleton is defined as the set of the local maxima lines of the SDF module. Some experts believe that in skeleton there is all possible information about signal investigated.

The distribution of the energy of the analyzed signal along the period or frequency variable is given exactly by the energogram. Some another view is given by the dispersion of module of the SDF coefficients for linear transforms and the mean-square deviation of module of the SDF coefficients for non-linear ones.

The time-frequency structure of the model FUWB signal was found to be fractal. This is demonstrated particularly bright by the SDFs and skeletons of the linear integral transforms, namely the CWT and the AWT. The non-linear transforms results are appeared to be slightly worse.

CONCLUSIONS

- The system spectral analysis as a new integrated signal analysis method based on the simultaneous application of linear and non-linear integral transforms got further development.
- The system spectral analysis was shown to be able to perform a complex research of a signal, compensating the disadvantages of some used integral transforms by advantages other ones.
- On the example of study of the model FUWB signal the efficiency of the system spectral analysis as a new signal analysis method was shown.

REFERENCES

1. O.V. Lazorenko, L.F. Chernogor. *Ultrawideband Signals and Processes: Monograph.* Kharkov: V.N. Karazin Kharkiv National University, 2009.
2. L.F. Chernogor. *About Nonlinearity in Nature and Science: Monograph.* Kharkov: V.N. Karazin Kharkiv National University, 2008.
3. O.V. Lazorenko, A.A Potapov, L.F. Chernogor. Fractal Ultrawideband Signals // *Informational security: the encryption methods* / Ed.-in-ch. E.M. Suharev. Moscow: “Radiotechnika”, 2011.
4. O.V. Lazorenko, L.F. Chernogor. System Spectral Analysis of Signals: Theoretical Bases and Practical Applications // *Radio Physics and Radio Astronomy (12).* 2007, № 2, p. 162-181.
5. L.F. Chernogor, O.V. Lazorenko. System Spectral Analysis of Model Ultra-Wideband Signals // *Proc. Ultrawideband and Ultrashort Impulse Signals.* Sevastopol, Ukraine, 2012, p. 243-245.

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СИСТЕМНЫЙ СПЕКТРАЛЬНЫЙ АНАЛИЗ ФРАКТАЛЬНЫХ СВЕРХШИРОКОПОЛОСНЫХ СИГНАЛОВ

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Кратко рассмотрены теоретические основы и практические особенности системного спектрального анализа. Разъяснена необходимость и целесообразность одновременного применения различных линейных и нелинейных интегральных преобразований для проведения системного спектрального анализа. Показано, что использование системного спектрального анализа для исследования время-частотной структуры фрактальных сверхширокополосных сигналов является полезным и эффективным.

СИСТЕМНИЙ СПЕКТРАЛЬНИЙ АНАЛІЗ ФРАКТАЛЬНИХ НАДШИРОКОСМУГОВИХ СИГНАЛІВ

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Стисло розглянуто теоретичні засади та практичні особливості системного спектрального аналізу. Роз’яснено необхідність і доцільність одночасного використання різних лінійних і нелінійних інтегральних перетворень для проведення системного спектрального аналізу. Продемонстровано, що застосування системного спектрального аналізу для дослідження часо-частотної структури фрактальних надширокосмугових сигналів є корисним та ефективним.