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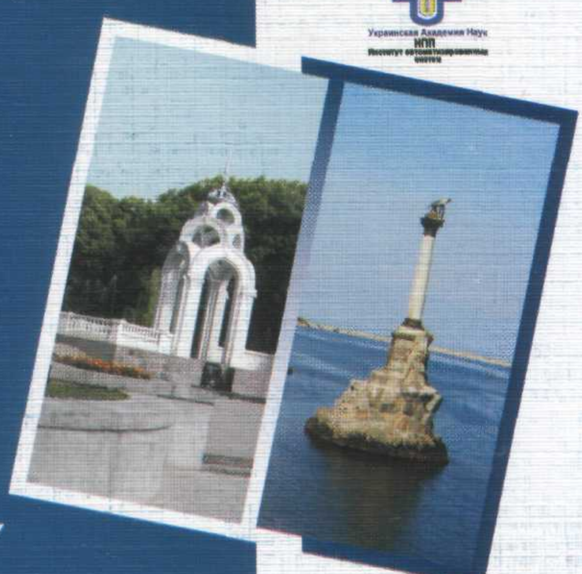

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DIGITAL ANALYSIS OF THE NON-LINEAR ULTRAWIDEBAND PROCESSES

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Abstract

The continuous wavelet transform, the analytical wavelet transform, the digital wavelet transform and the Wigner transform are proposed to apply for the digital analysis of the non-linear ultrawideband processes. The advantages and the disadvantages of each transform being significant during that application are discussed. As the convincing example, the results of the analysis of the Earth's magnetic field disturbances caused by the rocket "Proton" launch taken place 12 February 2000 at cosmodrome Baikonur (Kazakhstan) are considered.

Keywords: Signal processing, wavelet transforms, Wigner transform, ultrawideband processes, rocket launch, Earth's magnetic field disturbance.

1. INTRODUCTION

Non-linear oscillations and waves are well known to take on special significance in modern radio science [1 – 4].

Many physical processes accompanying by big energy extrication (power yield), for example, by earthquakes, eruptions, industrial explosions, rocket launches, magnetic storms etc., have essentially non-linear character near the source. However, the non-linear processes, in general, are not enough investigated and, thus, are not often used [5]. A lot of them have an ultra-wide Fourier spectrum. The application of integral transforms for the non-linear ultrawideband (NLUWB) process analysis is occurred to be perspective and actual. The purpose of this paper is to estimate the effectiveness of application of the continuous (CWT), analytical (AWT) and discrete (DWT) wavelet transforms as well as the Wigner transform for the NLUWB signal analysis.

2. ANALYSIS METHODES

Linear CWT and short-time (windowed) Fourier transform were successfully applied to the description of solitones and shock waves [6]. Analysis results in special convenient for the perception data format were shown. For each model process the set of numerical characteristics was calculated and the optimal wavelet basis with usage of the quality functional was chosen. In addition to CWT the AWT and DWT for the non-linear process analysis were applied.

The AWT is good addition to the CWT results as long as it allows obtaining not only the module of wavelet coefficients but the phase characteristics carrying the additional information about investigated process. The DWT permits to estimate the entropy of signal expansion in wavelet basis in discrete case. Using the minimum value of entropy, an optimal wavelet basis from the essentially large wavelet set can be chosen. The problem of NLUWB process reconstruction from the discrete expansion on the orthogonal wavelet basis with different expansion number usage was solved. The quality of reconstructed signal by the special functional is described.

Being non-linear, the Wigner transform (WiT) [7], as all transforms from Cohen's class were, has some advantages comparing with the linear transforms. The basic of them are well time-frequency resolution, the time, frequency and phase shift invariance, presents of marginal distributions. In addition, such transforms allowing to perform the non-linear signal processing are effective, for example, for the solving of problem of signal detection at background of the noise having non-linear distribution. The payment needed by obtained advantages is an appearance of cross-terms for multi-component signals. The WiT for the NLUWB process analysis was successfully applied. The obtained results with ones for the usage of traditional Fourier spectrogram were compared.

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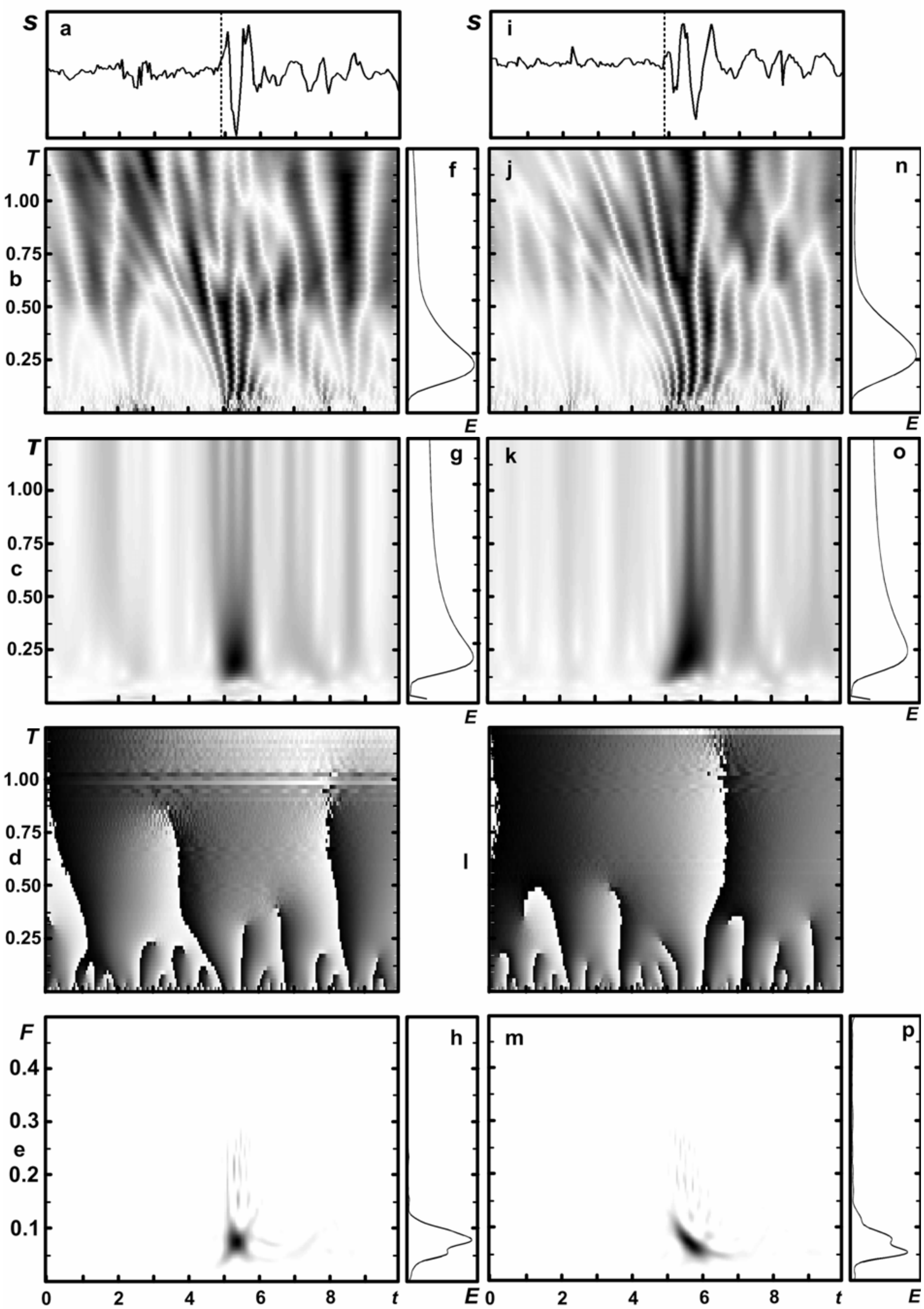

Fig. 1. The results of the analysis of the Earth's magnetic field disturbances caused by the rocket "Proton" launch taken place 12 February 2000 at cosmodrome Baikonur (Kazakhstan).

3. Analysis results and discussion

As the example, the results of the analysis of the Earth's magnetic field disturbances caused by the rocket "Proton" launching taken place 12 February 2000 at cosmodrome Baikonur (Kazakhstan) [8] are considered.

This NLUWB process having the artificial origin is the reaction of the near-to-Earth space caused by powerful effect of the rocker launch. The D- and H-components of the geomagnetic field were recorded separately. The geomagnetic effect at the distance equal approximately 800 km south from the site of "Proton" start was registered [8].

The results of performed analysis of both D- and H-components of the intensity of terrestrial magnetism are presented at the Fig.1. That registrations in time domain at Fig.1,a and Fig.1,i correspondingly and are shown. The wavelet spectrum obtained with CWT using the Daubechies wavelet of fourth order (db4) for both magnetic field components at Fig.1,b and Fig.1,j are displayed. The Fig.1,c and Fig.1,k present the module of the spectral density function (SDF) of the short-time Fourier transform (STFT) for both components correspondingly. At the Fig.1,d and Fig.1,l the phase component of the complex wavelet spectrum obtained with the AWT and the Gauss complex wavelet of first order (cgau1) are shown. Fig.1,e and Fig.1,m are containing the SDF of the Wigner transform.

Other figures present the energograms of used transforms. The energogram of chosen transform is given by the relation

$$E_P f(T) = \int_{-\infty}^{\infty} |P_l f(T,\tau)|^2 d\tau$$

for the linear transforms and by the relation

$$E_P f(F) = \int_{-\infty}^{\infty} P_n f(F,\tau) d\tau$$

for the non-linear transforms, where $E_P f(T)$ and $E_P f(F)$ are the energograms, $P_l f(T,\tau)$ and $P_n f(F,\tau)$ are the SDF for the linear and non-linear transforms correspondingly, T is the non-dimensional period variable, F is the non-dimensional frequency variable. The distribution of the energy of the analyzed signal or process $f(t)$ along the period or frequency variable is given exactly by the energogram.

The CWT energograms for both magnetic field components at the Fig.1,f and Fig.1,n are shown. The Fig.1,g and Fig.1,o contain the STFT energograms. Finally, the Fig.1,h and Fig.1,p are related to the WiT energograms. Vertical dashed line at Fig.1,a and Fig.1,i corresponds to the time moment of rocket start.

The unit segment along the horizontal time axis at the Fig.1,a-e, and Fig.1,i-m is equal to 300 seconds. The unit segment along the vertical period axis at the Fig.1,b-d, Fig.1,f-g, Fig.1,j-l and Fig.1,n-o is equal to 1080 seconds. The unit segment along the vertical frequency axis at the Fig.1,e, Fig.1,h, Fig.1, m and Fig.1,p is equal to $5 \cdot 10^{-2}$ Hz.

The performed analysis of the response of the near-to-Earth space caused by the rocker launch allows obtaining such interesting results. The reaction of the magnetosphere is appeared to be practically symmetric in time domain ultrawideband process with the wideband index $\mu \sim 1,3 - 1,5$ for D-component of the intensity of terrestrial magnetism and to be non-symmetric in time domain ultrawideband process with the wideband index varied in time. The last results by the SDF of the Wigner transform are good demonstrated.

Thus, the simultaneous application of the linear transforms, such as the CWT, the AWT, the DWT and the STFT, and the non-linear transforms, such as the WiT, for the NLUWB process analysis are demonstrated to be useful and perspective.

Conclusions

- The CWT, the AWT, the DWT, the STFT and the WiT for the NLUWB process analysis were successfully applied.
- A lot of information about the reaction of the near-to-Earth space caused by powerful effect of the rocker launch is shown to given with the simultaneous application of the CWT, the AWT, the DWT, the STFT and the WiT.

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