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Fourier spectra of amplitude variations of the superposition of signals from navigation satellites near surfaces with different properties

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The experimentally recorded amplitude-time dependences of the interference superposition of signals from navigation satellites and their copies reflected by the boundaries of the "atmosphere-water" and "atmosphere-land" media are presented. Fourier spectra of these dependences are obtained. It was found that for different electrophysical properties of reflecting surfaces, noticeable features of the spectra appear.

Keywords: GNSS reflectometry, surface, interference, amplitude-time dependence, Fourier spectrum.

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Global navigation satellite systems (GNSS) are being actively used to solve various practical and scientific tasks [1]. In particular, continuously emitted signals of navigation satellites (NS) are used to obtain data about the characteristics of earth covers, which allows for contactless monitoring of surface parameters [2–6]. NS signals interact with earth cover surfaces, which results in an interference field formed by superposition of the direct signal and its copies reflected by media boundaries. NS motion causes the reflection area to move. In this natural way, surfaces in the antenna vicinity are „scanned". The GNSS signal receiver performs the type measurements and records the numeric values of amplitude-time dependencies (ATD) of interference superposition of processes at the reception point. Subsequent spectral analysis of ATD, applied by the authors, extends the possibilities of GNSS reflectometry of earth cover surfaces under study.

In this paper, ATD were recorded for NS signal propagation in the atmosphere, near water surfaces and soil covers. The recording conditions were identical to those in paper [6].

Fig. 1-3 show the experimentally recorded readouts of $x = x(n)$ ATD (a) and the calculated moduli of Fourier spectra, normalized to their maximum values: $X = |X(f)|/|X_{\max}(f)|$ (b). Curves *1* corresponds to the ATD obtained as a result of reception of GLONASS NS signals. Curves *2* were obtained at signal reception from GPS NS. Symbols *n* designate the time readouts with the interval of 1 s. Spectra $X(f)$ were obtained on the basis of a discrete Fourier transformation [7] of readouts $x(n)$.

The dependences shown in Fig. $1, a$ were recorded using an antenna with right-hand circular polarization, oriented to the upper hemisphere. The authors conventionally call these observation conditions the case the propagation in „free space", since the contribution of reflected signals, that form an interference superposition, is absent or small. This case is necessary as an „indicator" for absence of a reflecting surface.

The curves shown in Fig $2, a$ and $3, a$, have been recorded using a dipole antenna placed perpendicularly to the horizontal plane. This method is focused on accounting of the contribution of processes, reflected or dissipated by various surfaces, to the interference superposition. Fig. 2 corresponds to the case of reflection area passage along the soil cover and a segment of water surface. Fig. 3 corresponds to the case of ATD recording in the vicinity of a solely water surface.

As seen from Fig. 1, the recorded ATD and obtained Fourier spectra for the case of „free space" do not have peculiarities that arise in case of simultaneous presence of direct NS signals and NS signals reflected by a horizontal surface. It is due to the fact that atmospheric irregularities in the L1-band make rather a small contribution to the recorded ATD of the total interference process.

Fig. $2, 3$ show that the ATD and Fourier spectra have marked peculiarities that differ depending on surface type (soil, water). This is due to the fact the interference superposition contains a component of the signal reflected by the boundaries of atmosphere-water and atmosphere-land media. It can be seen from Fig. 1 that curve behavior is similar in case of ATD recording by signals of both systems. Moreover, it can be seen from the given figures (fragments a) that the values of all recorded ATD are within the interval $0 < x(n) < 500$. Thereat, values of normalized spectra for the case of „free space" (Fig. $1, b$) are approximately by an order less than in the case when a reflected signal is present (Fig. $2, b$ and $3, b$).

Thus, experimental amplitude-time dependences of interference superposition of NS signals, received in conditions of presence and absence of reflecting surfaces, have been obtained. The obtained Fourier spectra for the recorded dependences have visually distinguishable peculiarities that

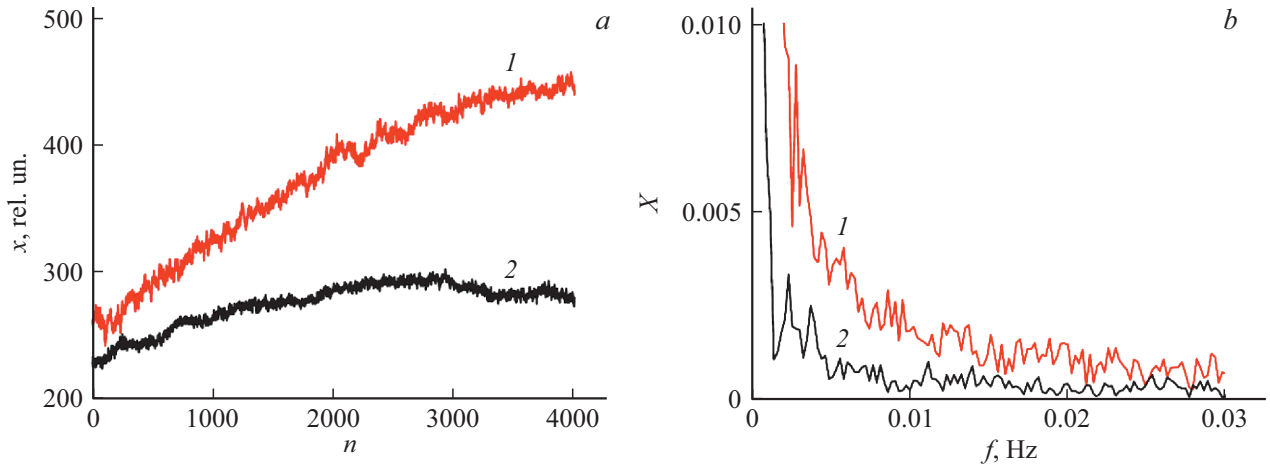

Figure 1. Amplitude-time dependences (*a*) and corresponding normalized Fourier spectra (*b*). The case of propagation in „free space“.

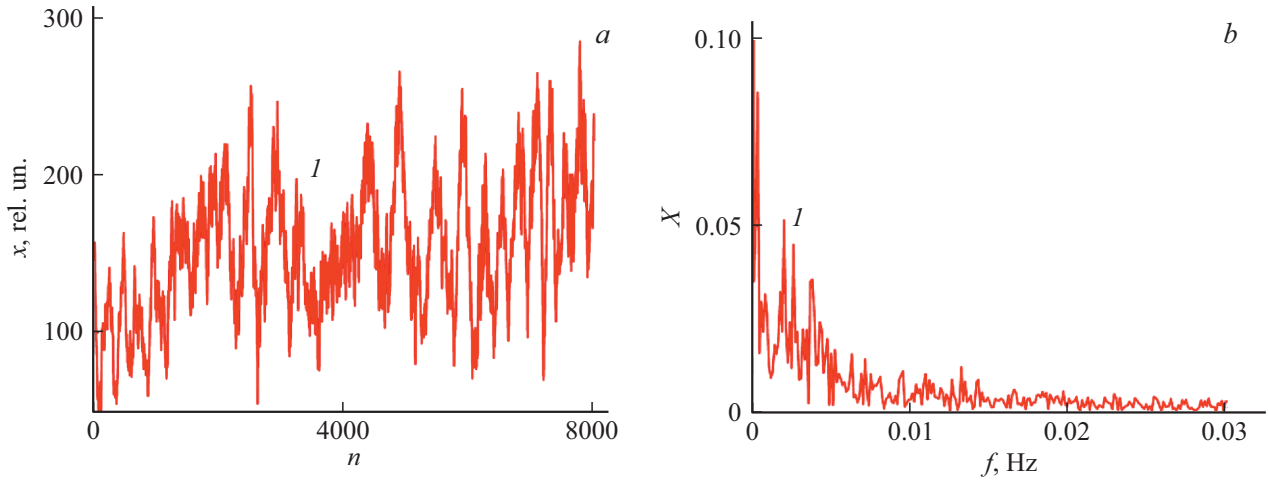

Figure 2. Amplitude-time dependence (*a*) and the corresponding normalized Fourier spectrum (*b*). Chiefly the soil cover and a segment of water surface.

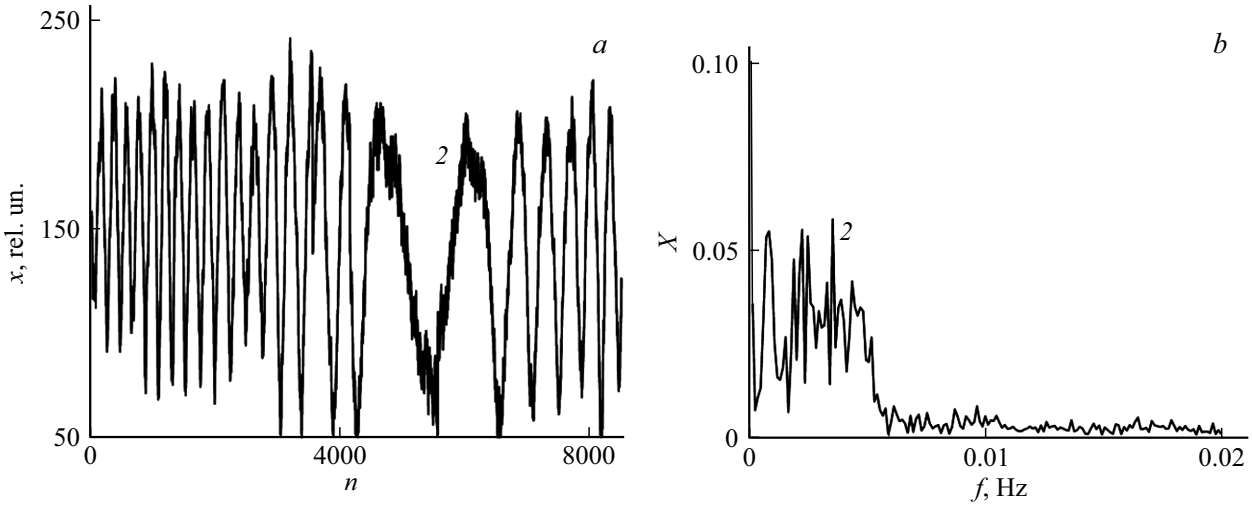

Figure 3. Amplitude-time dependence (*a*) and the corresponding normalized Fourier spectrum (*b*). Water surface.

vary for different signal reception conditions. It has been shown that, when considering ATD for the case of NS signal propagation in the atmosphere, Fourier spectra have a monotonously decreasing behavior with some „surges“ at the initial section. It has been found that when NS signals are received in the vicinity of reflecting surfaces, visible changes are observed in ATD spectra. The spectra acquire multiple „bursts“ and „dips“, become „extended“ and occupy a larger frequency band as compared to NS signal propagation only in the atmosphere. The said extension is particularly noticeable in case of NS signal reception near a water surface: the recorded ATD and their spectra are respectively similar to time and spectral diagrams of signals having intrapulse frequency modulation. The authors' examples demonstrate that the Fourier spectra for ATD of interference superposition of NS signals are an in-demand tool for increasing the efficiency and extending the capabilities of GNSS reflectometry when studying properties of various surfaces.

Conflict of interest

The authors declare that they have no conflict of interest.

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