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An estimation of the spatial-polarization selectivity of GNSS antennas based on analysis of the multipath error from two reflected signals

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Received March 28, 2023
Revised April 26, 2023
Accepted April 26, 2023

In this paper, we have estimated the error introduced by the multipath effect in global navigation satellite systems (GNSS) for a stationary user. Based on the mathematical model of the radio path of direct and two reflected signals (multipath model), the results of the multipath error for various types of high-precision positioning antennas are obtained.

Keywords: Antenna, GNSS, multipath error, interference, radiation pattern, multipath error envelope.

DOI: 10.61011/TPL.2023.06.56383.19569

A high positioning accuracy is one of the essential needs of the end user of global navigation satellite systems. The key component of the error of measurement of navigation parameters is known as multipath interference (multipath effect). If specialized techniques for controlling them are not applied, positioning errors related to the multipath effect may reach a considerable magnitude and exceed all the other error components [1–3]. The positioning accuracy may degrade from several centimeters to several meters (or even tens of meters) under an adverse influence of the multipath effect.

This effect emerges when both the direct (desired) signal from a satellite and parasitic reflected signals arrive at the receiver position. These parasitic signals form due to reflection both from various obstacles on the propagation path of the direct signal (buildings, facilities, etc.) and from the underlying terrain. Reflected signals arrive with varying delays, energies, and phases.

The multipath error envelope has been estimated earlier in [4] based on the two-path model of radio signal propagation. In the present study, a multipath model of a radio link with account for both sub- and above-horizon reflected signals is considered. This model should provide a more accurate estimate of multipath interference in a complex interference environment.

Let us consider multipath signal propagation and its influence on the estimation of radio navigation parameters (specifically, the pseudo-range measurement by a receiver of navigation signals). The following simple but helpful model is proposed to be used for estimation: reception of two reflected signals by a stationary user (Fig. 1). Signal 1 is reflected from a vertical screen of a finite size located at a certain distance from a receiving antenna, and signal 2 is reflected from the horizontal surface on which a mast of height H with a receiving antenna is mounted.

Reflected signal 1 propagates over additional distance $\Delta R_1 = S_1 + S_2$ to antenna phase center P. Reflected signal 2 has to propagate over additional distance ΔR_2 to point P.

Several ways to mitigate the multipath effect have already been proposed [1,3–7]. The most notable one consists in using an antenna with a special radiation pattern (RP) suppressing the influence of reflected signals arriving from low angles. Three antennas with different RPs [4] were examined in the context of mitigation of multipath signal propagation with spatial characteristics. An estimate of their efficiency based on the results of simulation of the error of determination of radio navigation parameters for two reflected signals is presented below.

In modeling, direct and reflected signals may be regarded as a composite multipath signal characterized by the following relations [1]:

$$I_k = A_{IQ,k}\cos(\delta\Phi_k) + n_I\sigma_{IQ,k},$$

$$Q_k = -A_{IQ,k}\sin(\delta\Phi_k) + n_Q\sigma_{IQ,k},$$

$$A_{IQ,k} = \frac{A_k L}{2}\operatorname{sinc}\left(\frac{(\omega_{d,k} - \tilde{\omega}_{d,k})T}{2}\right)\rho(\tau_k - \tilde{\tau}_k),$$

$$\sigma^2_{IQ,k} = \sigma^2_{n,k}L/2,$$

$$\delta\Phi_k = \operatorname{mod}\left(\frac{(\omega_{d,k} - \tilde{\omega}_{d,k})T}{2} + \phi_k + \theta_k\pi, 2\pi\right),$$

where A_k is the amplitude of the navigation signal at the input of an analog-to-digital converter (ADC); $\sigma^2_{n,k}$ is the noise dispersion at the ADC input; L is the number of ADC cycles involved in accumulation in the correlator; τ_k, $\tilde{\tau}_k$ are the delays of the ranging code of a satellite signal and a reference signal of the correlator, respectively; $\omega_{d,k}$, $\tilde{\omega}_{d,k}$ are the angular frequency of a satellite signal and a reference signal of the correlator, respectively; ϕ_k is the initial phase of a navigation signal at interval k; $\rho(x)$ is the correlation function of the ranging code; n_I, n_Q are

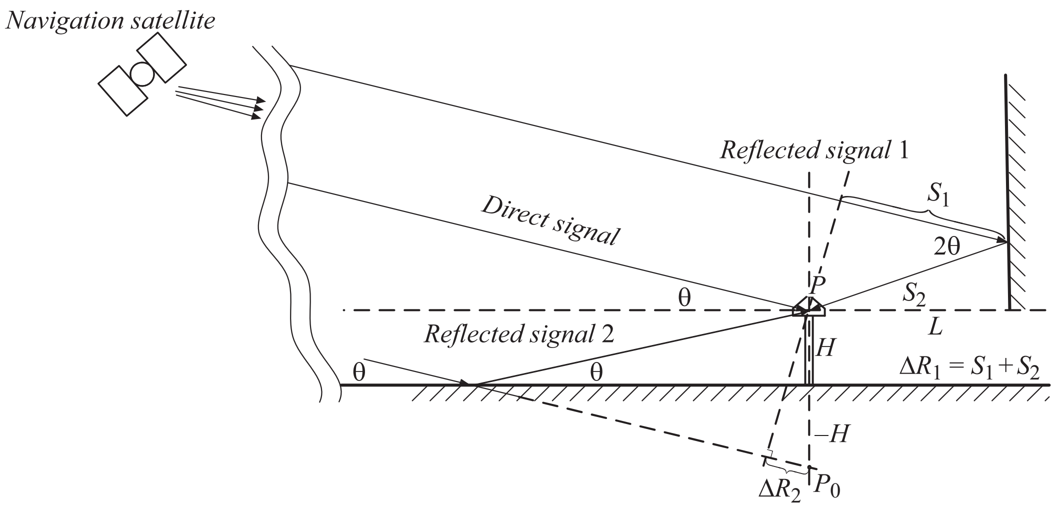

Figure 1. Diagram of propagation of two reflected signals.

uncorrelated white Gaussian noises; $\delta\Phi_k$ is the phase at the ADC input; θ_k is the digital character value (-1 or 1); and T is the accumulation time.

The signal at the correlator output for the direct signal and two reflected signals may then be characterized by expressions

$$I_k = A_{IQ,k}\Big[\cos(\delta\Phi_k) + K_{MP1,k}\cos(\delta\Phi_k + \Delta\Phi_{R1,k}) + K_{MP2,k}\cos(\delta\Phi_k + \Delta\Phi_{R2,k})\Big] + n_I\sigma_{IQ,k},$$

$$Q_k = -A_{IQ,k}\Big[\sin(\delta\Phi_k) + K_{MP1,k}\sin(\delta\Phi_k + \Delta\Phi_{R1,k}) + K_{MP2,k}\sin(\delta\Phi_k + \Delta\Phi_{R2,k})\Big] + n_Q\sigma_{IQ,k}, \quad (1)$$

where $K_{MP1,k}$ is the coefficient of attenuation of the reflected signal relative to the direct one at the correlator output and $\Delta\Phi_{R1,k}$ is the phase difference between direct and reflected signals; indices 1 and 2 correspond to the first and the second reflected beams.

The simplest option for error estimation (coherent discriminator) [1,2] was used in modeling of (1).

which was performed in several stages.

First stage. Almanac data were used to calculate the predicted position of GLONASS navigation satellites (NSs) within an interval of seven days for an antenna mounted at the following coordinates: 56°N, 92°4′E, and an elevation of 200 m above sea level (approximate coordinates of the Institute of Engineering Physics and Radio Electronics, Siberian Federal University, Krasnoyarsk).

Second stage. The NS visibility (with account for positioning at a distance of 1.5 m from a screen 10 m in height) and the geometry of direct and reflected signals were determined for each NS.

Third stage. The power and phase of direct and reflected signals were calculated for given receiving antennas. An ideal antenna featuring an RP with an instantaneous gain change from 0 to -25 dB in passing over the horizon and with zero distortion of the phase of the received signal was also estimated [4]. Concrete (for the signal reflected from a wall) and asphalt (for the signal reflected from the ground) were used as reflecting surfaces [3]. According to [3], the reflection (attenuation) coefficient for concrete under normal incidence at frequency L1 is 0.404 (-7.87 dB), and the corresponding values for asphalt are 0.121 (-18.3 dB).

Fourth stage. Correlation processing of a combination of the direct signal and two reflected signals was performed, and the pseudo-range estimation error was determined.

The simulated dependence of the pseudo-range estimation error on the elevation angle is presented in Fig. 2. The elevation angle was determined in accordance with Fig. 1, where $\theta = 0°$ is the horizon direction. The used antenna RPs were taken from [4]. The trajectory of GLONASS NSs was modeled within an interval of 7 days, 23 hours, 27 minutes, and 28 seconds in order to cover all NS flight paths with respect to the user [6]. The results are presented for elevation angles up to 70° (due to the paucity of signals reflected from a wall for NSs at the indicated elevation angle).

A helical antenna yields the best results in terms of estimated multipath error within the [7°; 33°] angle range (the root mean square (RMS) value does not exceed 0.3 m), where the influence of multipath interference is the most significant [8]. This is attributable to the fact that the radiation pattern of a helical antenna has a steep slope [4] in transition to the non-working angle range. The classical solution to the problem of multipath interference, a choke ring antenna with a longitudinal dimension of approximately 2λ, was the least efficient (with an RMS of about 0.45 m) in the [3°; 33°] angle range. Although its RP slope is shallow [4], a helical-slot antenna has just a slightly greater RMS than a

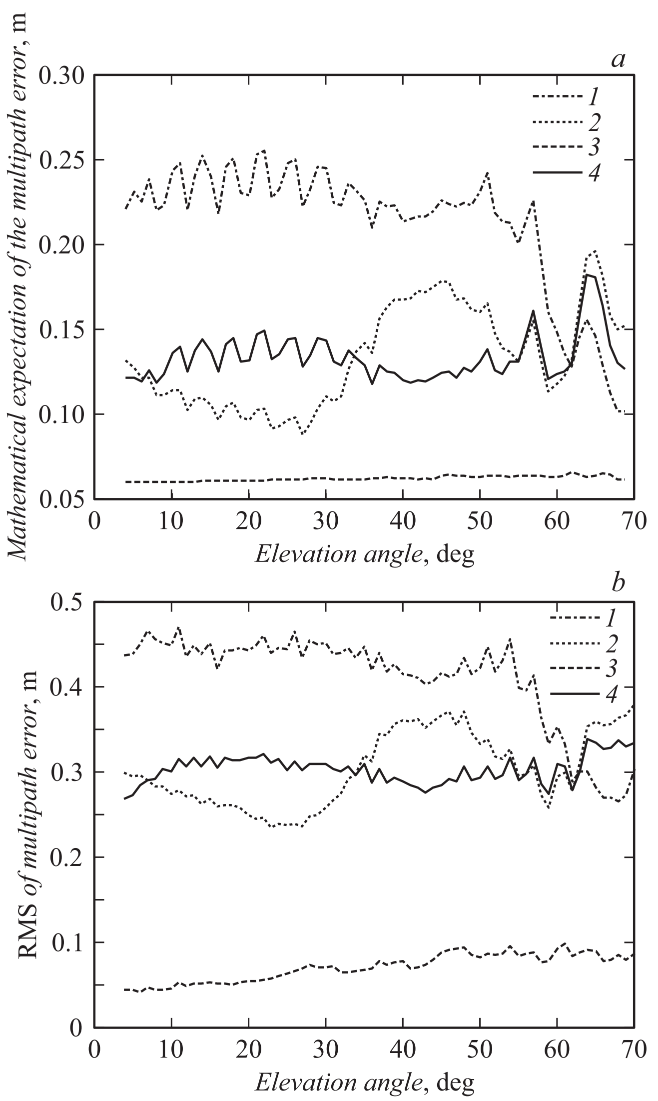

Figure 2. Estimation of the influence of multipath propagation of navigation signals. *a* — Mathematical expectation of the pseudo-range estimation error, *b* — RMS of the pseudo-range estimation error. *1* — Choke ring antenna, *2* — helical antenna, *3* — ideal antenna, and *4* — helical-slot antenna.

helical antenna. Therefore, a helical-slot antenna may serve as a fine polarization filter; as is known [9], polarization selection also allows one to achieve a strong suppression of the multipath effect.

Thus, the results of examination of a multipath model revealed that a helical antenna is the least susceptible to multipath interference. Therefore, the use of antennas with a steep RP slope is preferable in the context of enhancing the accuracy of radio navigation systems. In addition, a helical antenna is small and lightweight compared to a choke ring one.

The obtained results correlate well with the data reported in our previous paper [4]. Our plans for future research include conducting an experiment under such conditions that correspond roughly to the ones modeled in the present study.

Funding

This study was supported financially by the Krasnoyarsk Regional Science Foundation as part of scientific project No. 2022102108922 „High-Accuracy Antenna System of the GLONASS Ground Segment for Application in the Arctic".

Conflict of interest

The authors declare that they have no conflict of interest.

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Translated by D.Safin