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Small-sized circular polarization antenna for satellite positioning, navigation and timing

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The paper presents a study of a new circularly polarized antenna less than $\lambda_0/8$ in size for satellite radio navigation systems. High reflection coefficients have been achieved in the operating frequency range of all the existing radio navigation systems. The directional properties and polarization characteristics of the proposed antenna have been analyzed.

Keywords: small-sized antenna, circular polarization, satellite radio navigation systems, reflection coefficient.

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At present, one of the tools performing such services as positioning, navigation and timing [1,2] are global navigation satellite systems (GLONASS). Using such systems, it is possible to obtain precise time data necessary for synchronizing various static infrastructure networks or, e. g., errorfree and stable positioning of autonomous vehicles [3].

Uninterruptable operation of the GLONASS services needs antennas or antenna systems allowing the useful signal spatial isolation and receiving without distortion and loss. The most promising approach is studying smallsized antennas that can act either as independent antenna systems or as part of a smallsized antenna array designed for the conditions of high interference (for example, unintentional interference occurring in dense urban areas).

Compact antennas for satellite radio navigation systems are currently widely used when microminiaturization is desired in developing functional electronic devices. However, solutions concerning antenna devices do not always provide the necessary characteristics on the one hand and small dimensions on the other hand. Paper [4] presents a printed dual frequency antenna whose small dimensions (about $0.35\lambda_0$) are ensured by shortcircuit loops arranged along the antenna perimeter. In addition, the antenna design involves a specially shaped hollow screen. The compact design of the printed antenna enables its operation in a wide range of elevation angles (above 130°) with a high axial ratio. Among disadvantages of this antenna there should be noted a narrow operating frequency range which allows reception of signals from only one of the GLONASS systems. This disadvantage is inherent to most known compact printed antennas, including those constructed on a substrate having high permittivity.

Known is a single layer design of a printed antenna on a suspended substrate, which involves lumped elements [5]. In this case, the dual frequency operating mode is achievable by exciting the resonators and slot emitter. Matching is ensured by a concentrated inductive element located in the slot emitter. The antenna advantages are the dual frequency operation mode, circular polarization in a wide angle sector of angles at the GLONASS frequencies and design simplicity; among its disadvantages there are large dimensions (about $0.5\lambda_0$). Large dimensions are typical also of circularly polarized spiral antennas [6]; this hinders their use in a number of compact applications. In addition to printed antennas, known are circularly polarized ones [7] composed of several monopoles and excitation circuit. Dimensions of these antennas do not exceed $0.5\lambda_0$, nevertheless, they are inapplicable in compact devices.

This study was devoted to the compact quadrupole antenna no less than $0.2\lambda_0$ in size. Small dimensions of this antenna are caused by the permittivity of the substrate. The proposed antenna is made of three layers of foiled material Wangling TP2500 with the permittivity of $\varepsilon = 25$, dielectric loss tangent of $\operatorname{tg}\delta = 0.003$, and single layer thickness of 6 mm (Fig. 1). The antenna element is a monopole created in the dielectric volume by metallizing the perforated holes (Fig. 1, *a*). The layers differ from each other in the number of holes. For instance, layer *1* contains one hole, layer *2* — three holes, layer *3* — five holes (Fig. 1, *b*). Metal loops on the dielectric layer surfaces connect together by metal coatings of all the holes thus providing electrical contact between the layers. At the base of the monopole there is a ground plane of antenna; the monopole base lies in the ground plane. To provide galvanic isolation, a slot is made in the ground plane along the monopole contour (see Fig. 1, *b*). To obtain circular polarization, the antenna is composed of four monopoles whose overall dimensions are $38 \times 38 \times 18$ mm. Size of ground plane (38×38 mm) is the same as that of the printed circuit boards. The distance between the monopoles is 13 mm (Fig. 1, *c*). In the antenna geometric center there may be installed a metal rod fixing the three layers without deterioration of the radiotechnical characteristics. The antenna feed network may be created

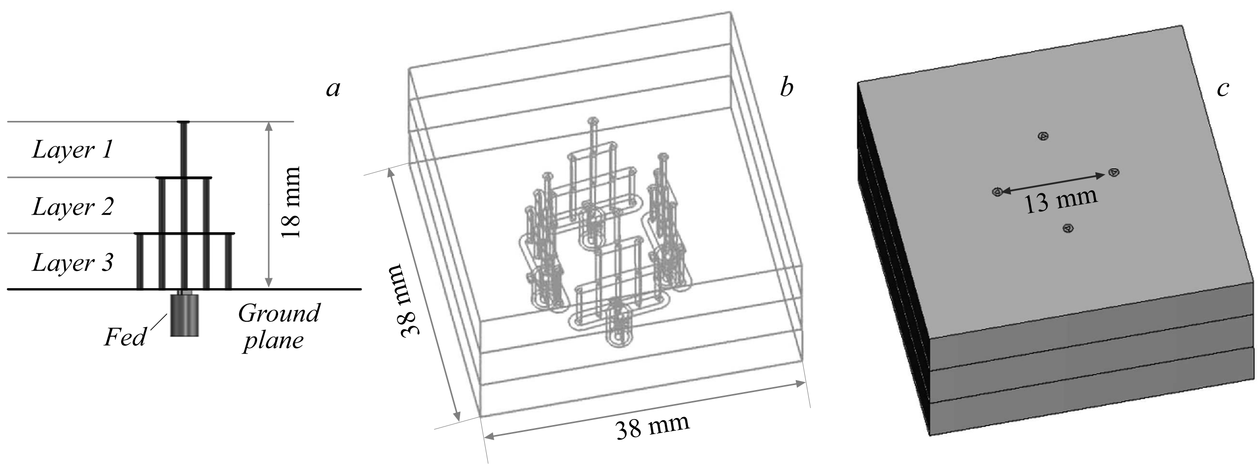

Figure 1. *a* — antenna element of the „monopole above the screen"type; *b* — quadrupole antenna consisting of four monopoles; *c* — quadrupole antenna in dielectric volume Wangling TP2500.

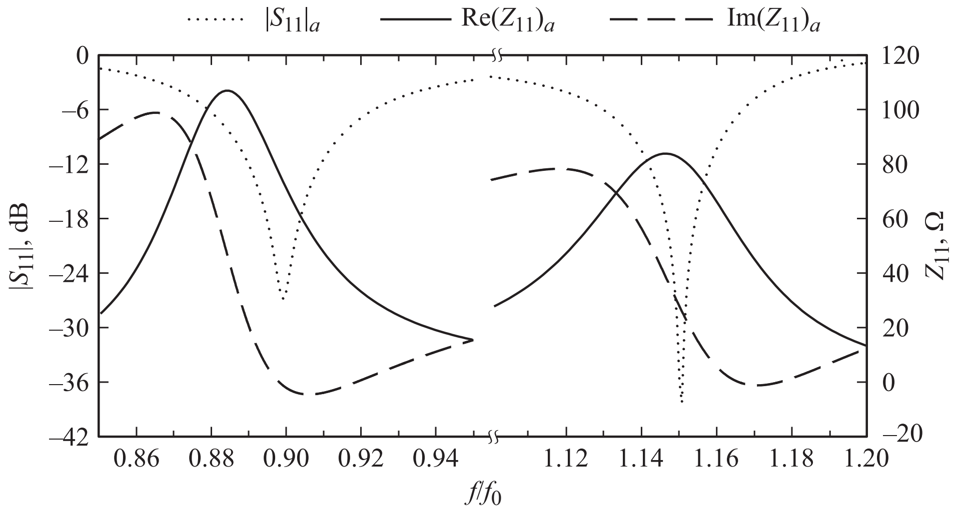

Figure 2. Frequency dependence of the total reflection coefficient and total input impedance.

by using the known solutions for quadrature bridges with the total insertion losses not exceeding 0.5 dB.

In analyzing the proposed compact quadrupole antenna, its matching characteristics and directional properties were calculated. Fig. 2 presents the frequency dependence of the total input impedance and total reflection coefficient modulus under equal amplitude excitation of four monopoles with the phase incursion of 90°. Given frequency $f_0 = 1.4$ GHz is the frequency averaged over the GLONASS frequency ranges. Apparently, the input impedance has a resonant character with the reactive part close to zero at the frequencies of the satellite navigation systems. This makes it possible to ensure the reflection coefficient of no more than -10 dB in the GLONASS operating frequency range. The dual frequency operating mode is possible due to realizing the monopole in the dielectric volume with high permittivity; this means that both the monopoles and dielectric resonator of the proposed antenna are excited. This effect is not valid for the antenna of the „monopole-in-air"type which typically exhibits broadband matching [7].

Fig. 3 shows the amplitude directional patterns and axial ratio for the upper and lower GLONASS frequencies. The antenna gain factor is 5 to 6 dBi at different GLONASS frequencies, while the directional pattern maximum is concentrated at the zenith $(\theta = 0°)$ but is not distributed over the azimuth $(\theta = 90°)$ because triangular monopoles are used. Due to the small antenna size, the axial ratio is at least 0.7 in angular range $\theta = [-80°; 80°]$. The antenna efficiency in the operating frequency range is not lower than 80 % according to the reflection coefficient criterion of not higher than -10 dB. Dissipative losses in the dielectric material are ~ 10 %; they may be reduced by using dielectric substrates made of ceramic materials.

Thus, the paper presents a compact antenna designed for the GLONASS systems. Due to its small dimensions of about $0.2\lambda_0$ and simplicity of the design based on the

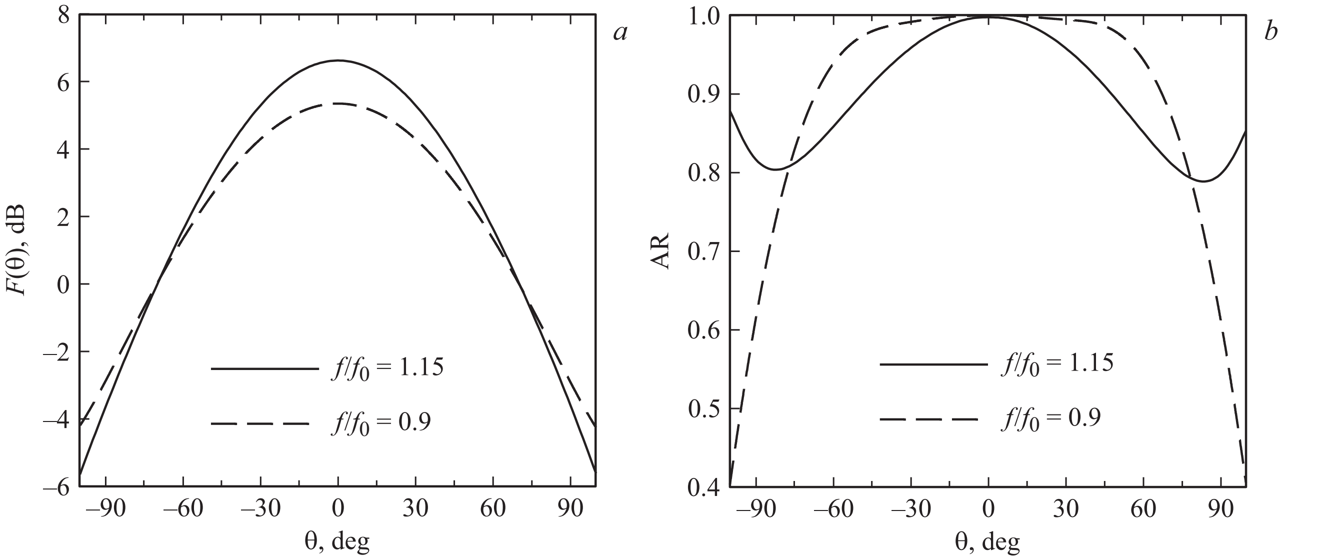

Figure 3. Amplitude directional pattern (a) and axial ratio (b).

printing technology, the proposed antenna may be used both as part of a compact antenna array and as an independent antenna. Advantages of the compact quadrupole antenna over printed antennas of the same dimensions are a lower quality factor and, hence, possibility of operating in a wider frequency range covering frequencies of all the known GLONASS systems.

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Conflict of interests

The authors declare that they have no conflict of interests.

References

[1] T. Hadas, K. Kazmierski, I. Kudłacik, G. Marut, IEEE Geosci. Remote Sensing Lett., **21**, 8000905 (2024). DOI: 10.1109/LGRS.2024.3354293

[2] I.T. McMichael, E. Lundberg, D. Hanna, in *2017 IEEE Int. Symp. on Antennas and Propagation & USNC/URSI National Radio Science Meeting* (IEEE, 2017), p. 2495. DOI: 10.1109/APUSNCURSINRSM.2017.8073290

[3] S.R. Ganti, Y. Kim, in *2015 IEEE 12th Int. Conf. on Information Technology — New Generations* (IEEE, 2015), p. 273–279. DOI: 10.1109/ITNG.2015.50

[4] Z.-P. Zhong, G.-L. Huang, W. He, X.-C. Chen, in *2019 IEEE Int. Conf. on Microwave and Millimeter Wave Technology (ICMMT)* (IEEE, 2019), p. 1–3. DOI: 10.1109/ICMMT45702.2019.8992469

[5] S. Lee, Y. Yang, K.-Y. Lee, K.C. Hwang, IEEE Trans. Anten. Propag., **68** (12), 8197 (2020). DOI: 10.1109/TAP.2020.2997990

[6] A.A. Erokhin, E.R. Gafarov, Y.P. Salomatov, S.V. Polenga, A.M. Aleksandrin, in *2024 IEEE 25th Int. Conf. of Young Professionals in Electron Devices and Materials (EDM)* (IEEE, 2024), p. 380–383. DOI: 10.1109/EDM61683.2024.10615086

[7] E.R. Gafarov, A.A. Erokhin, Y.P. Salomatov, in *2017 IEEE Int. Siberian Conf. on Control and Communications* (SIBCON) (IEEE, 2017), p. 1–4. DOI: 10.1109/SIBCON.2017.7998468

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