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Metamaterial absorber and antenna ground plane

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Metamaterial absorber located near solid metal surface was investigated and antenna design was developed for receiving satellite navigation signals using absorptive ground plane comprises proposed material. The metamaterial structure has been developed, frequency characteristics have been analyzed by finite element method in frequency domain, operating dimensions of elements have been established. Modeling and analysis of radiation pattern for antenna with absorptive ground plane versus the antenna with the classic high impedance ground plane were carried out. Conclusions were drawn on the applicability of the proposed metamaterial structure.

Keywords: GNSS Antenna, metamaterial absorber, high impedance ground plane.

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Metamaterials are increasingly being used in antenna technology. In particular, with the use of artificial materials, shields of high-precision antennas are made to receive signals from global navigation satellite systems (GNSS) [1]. The technical implementation of the metamaterial is based on classical works [2,3], and in this case the metamaterial is a combination of open-loop matched ring resonators and closely spaced linear conductors. This medium makes it possible to simultaneously create negative magnetic and dielectric effective permeabilities and, which is interesting in the light of considering of this study, to work with an electromagnetic wave without significant reflections from the medium interface. The use of such an implementation in the form of a lattice of single elements in space, but with integrated absorbing elements, is possible and known [4]. However, the direct use of this option for operation as part of a GNSS antenna turned out to be impossible due to the need for the metamaterial to operate in close proximity to a metal shield with a type of polarization normal to the shield, which is subject to absorption with a small size of a single element of the metamaterial.

In the present work, the absorbing metamaterial is studied in order to improve the electrical characteristics of antennas when it is used as part of the shields of antenna structures.

To form special properties of GNSS antenna shields, it is also known to use Electromagnetic Bandgap (EBG) structures, including using the properties of metamaterials [5], however, this is associated with technological difficulties, consisting in the need for direct electrical contact between the structure and the metal shield .

The absorbing metamaterial developed based on the results of the study is made according to the type of metamaterials based on open ring resonators, however, it has features in the sense that it does not require direct contact of conductive elements with a metal shield and does not contain extended linear conductors in the topology of the structure.

As a result of the study, the effect was discovered, which consists in the fact that, with appropriate orientation of the single-ring resonator, there is a frequency region near the shield in which the considered periodic structure has the properties of metamaterial. In this case, the section of the conducting ring is oriented towards the shield , and the electromagnetic interaction of the ring structure is carried out with the field of the incident wave, the polarization of which is orthogonal to the shield. Load the cavity ring with a resistor allows the absorption of electromagnetic wave, while the properties of the metamaterial allow absorption in the absence of a significant level of signal reflection. The unit cell of the structure is shown in Fig. 1, *a*. Ring cavities can be made using printed technology by the common FR-4 dielectric material. As resistors, industrial thin-film surface-mount components can be used, the applicability of which is specified by the manufacturer for operation at frequencies of the order of units and tens of gigahertz [6].

The calculation of the reflection and absorption parameters is performed by analyzing the periodic structure through finite element simulation at fixed frequency points. The central working absorption frequency in the study was chosen to be 1575 MHz .It is the central frequency of one of the GNSS bands. Based on the diagrams of the *S*-parameters of the lattice cell model of the absorbing structure (Fig. 1, *b*), it can be argued that the periodic structure under study demonstrates the low level of the reflection coefficient and low level of the transmission coefficient near the resonant frequency, which is equivalent to high value of the absorption coefficient.

In the study, metamaterial parameters such as relative dielectric capacitance and magnetic inductive capacitance were calculated. To calculate these parameters, expressions from [7] were used. According to the calculation results, the equivalents of the real components at the central operating frequency were $\varepsilon = -1.6$, $\mu = -1.1$. The results of calculating the relative permeability parameters were

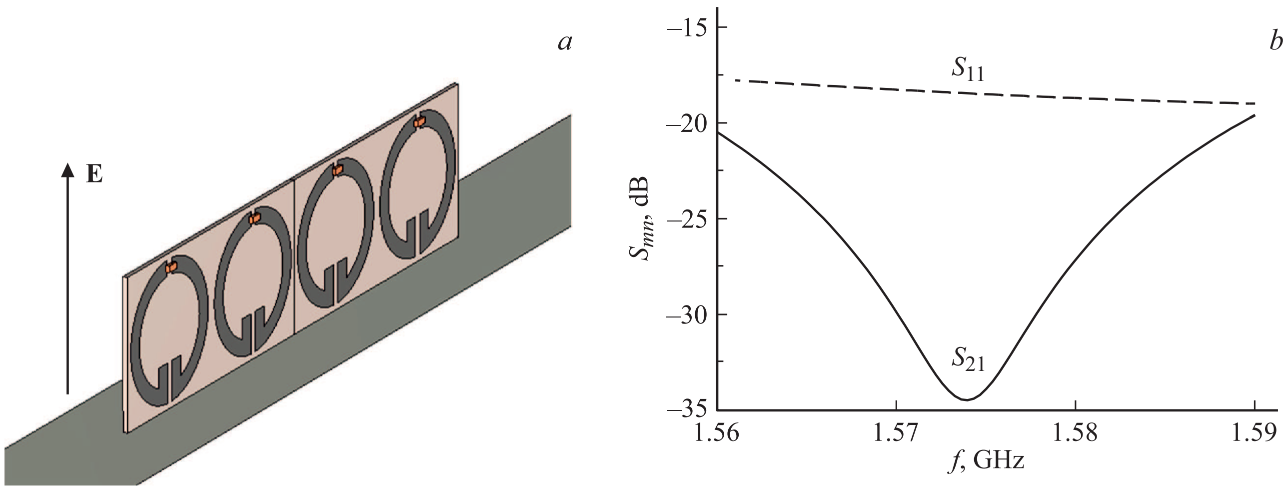

Figure 1. *a* is the lattice cell for calculating the electromagnetic properties of the structure. *b* is the frequency dependence of the *S*-parameters of the lattice cell model of the studied metamaterial.

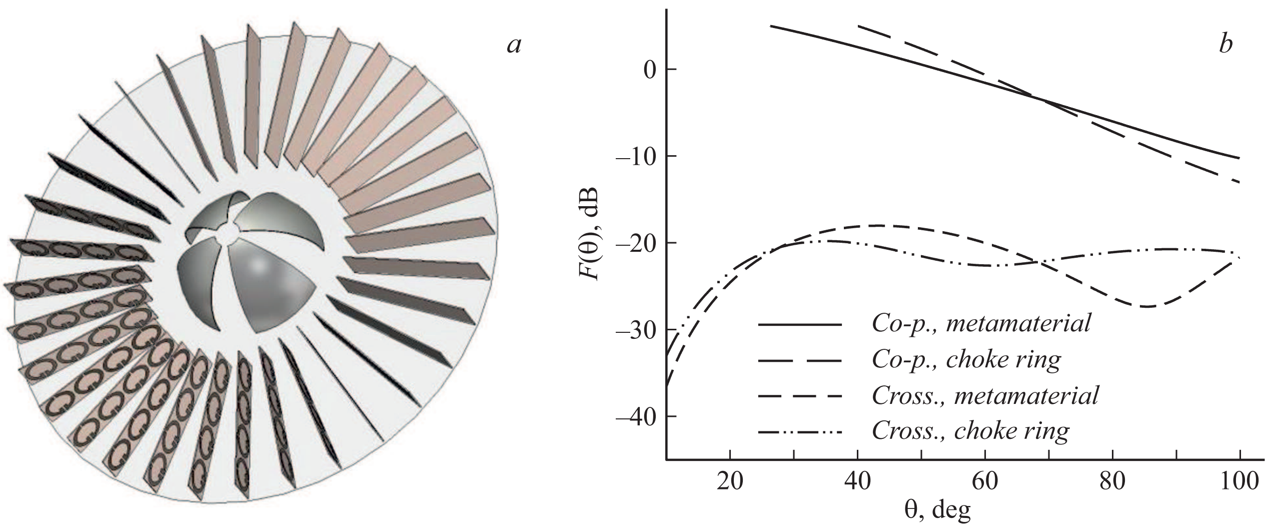

Figure 2. *a* — isometric view of the antenna for receiving GNSS signals with absorbing shield based on the studied metamaterial. *b* — Antenna directional pattern (DP) in the sector of operating angles. *Co-p.* is main polarization, *Cross.* is cross-polarization.

verified through the analysis of the cell model in the same boundary conditions, and consisting of solid material filled volume with given permeability values.

In the case under consideration, in order to increase the axial ratio of the antenna pattern when operating at angles close to the horizon, it is assumed that the polarization component perpendicular to the plane of the antenna shield is absorbed like to how classical GNSS antennas with corrugated flange (choke ring) suppress the propagation of the *E* component of incident electromagnetic wave [8].

Rows of resonant absorbing elements (32 plates) of the metamaterial, spaced along the metal shield of the quadrupole antenna, make up an absorbing screen, which is designed to absorb the antenna field component with the polarization normal to the shield. Isometric view of the antenna for receiving GNSS signals with absorbing shield is shown in Fig. 2, *a*.

Directional patterns (DPs) of the main and cross-polarizing components for circular polarization of the antenna, the shield of which is made in the form of corrugated metal flange, and the antenna with the studied absorbing metamaterial are generally similar (Fig. 2, *b*). Great difference is observed beyond the operating angles, near the 180° direction, where the antenna with the absorbing shield has a much higher (~ -10 dBi) level of reception of the cross-polarized component. However, this fact predictably will not bring deterioration in the accuracy of determining the coordinates when receiving GNSS signals in geodetic applications.

It is more informative to compare the dependences of the axial ratio for antennas with screens of various types, which

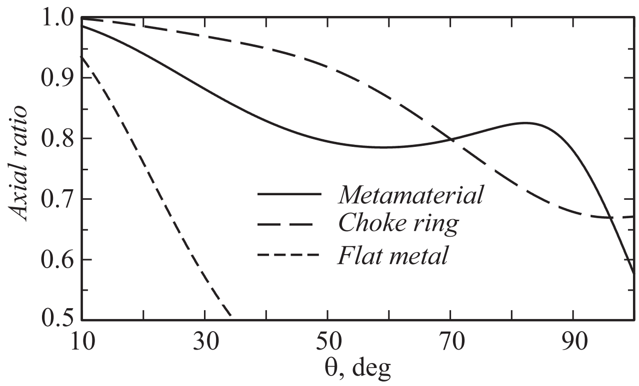

Figure 3. Dependences of the axial ratio for antennas with different types of shields.

are shown in Fig. 3 (including for an antenna with a simple solid metal screen — flat metal).

It is known that when considering the operation of high-precision antennas for receiving GNSS signals, the most critical problem is multipath propagation [9] and receiving suppression of reflected signals. In the most critical range of angles, the antenna model with the proposed absorbing shield demonstrates some advantage: the ellipticity coefficient for DP angles near 90° is about 0.78, while for the antenna with metal corrugated flange (three rings), it is equal to 0.68.

The antenna with the proposed type of absorbing shield is smaller in size: the height of the shield of the proposed type is 19 mm, in the case of the antenna with corrugated flange is 48 mm. The height of the antenna with the shield of the proposed type is determined by the height of the radiator and in the model is 40 mm, the height of the antenna with the flange is determined by the sum of the heights of the radiator and the flange and in the model is 88 mm. The antenna shield diameters were chosen pretty much alike to ensure the correctness of the comparison (270 and 280 mm for the antenna with metamaterial and for the antenna with flange, respectively).

Thus, studies show that the implementation of the antenna shield for receiving GNSS signals using the developed absorbing metamaterial is competitive and allows, at a high level of electrical characteristics, at any rate to improve the weight and size parameters of such antennas. Also, this version of the absorbing shield is economically feasible due to the use of common and inexpensive dielectric material FR-4 and printed circuit board manufacturing technology.

The presented study has prospects in terms of expanding the working frequency band of the metamaterial (or the formation of the separate second band) due to the use of the second side of the dielectric material, on which the similar structure can be placed with parameters ensuring its operation at distant frequency. In addition, it is possible to consider variations of preparing technology using conductive ink instead of the copper layer and resistors, which will allow the use of such structures at substantially higher frequencies [10].

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Conflict of interest

The authors declare that they have no conflict of interest.

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