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New Antenna Design for GNSS Application

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***Abstract* – A new radiating element design of the slot stripline leaky-wave antennas with right-hand circular polarization is proposed for high-accuracy positioning using Global satellite navigation signals (GNSS) GPS (L1/L2) and GLONASS (L1/L2/L3). Technical characteristics of the antenna with the new radiator have been studied. It is shown that the application of the new radiator decreases the axial ratio and improves the cross-polarization suppression and stability of the phase center, allowing one to increase the accuracy of GLONASS/GPS positioning.**

Keywords – slot stripline antenna, GLONASS/GPS antenna, circularly polarized antenna, high accuracy positioning by GNSS signals.

I. Introduction

Slot stripline leaky-wave antennas with right-hand circular polarization [1-3] due to their high phase center stability, low axial ratio, high cross-polarization suppression and a wide-angle radiation pattern have become widely used in high-accuracy GNNS receivers. A significant advantage of these antennas is their broad bandwidth allowing the reception of GNSS navigation signals in the frequency range from 1160 to 1615 (MHz) using a single radiating element.

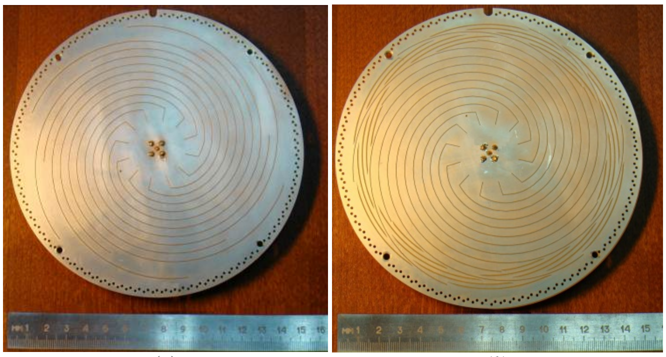
The radiating elements of these antennas are constantly being improved. For instance, in [4] an antenna is suggested with the radiator comprising «fractal slots» disposed at the radiator edges and coupled with the slots directed from the radiator central part. A more even distribution of the «fractal slots» across the antenna radiator surface allows improving the phase center stability, decreasing the axial ratio, and increasing the level of cross-polarization suppression.

In [5] a new method of improving technical characteristics of slot stripline leaky-wave circularly polarized antennas is proposed. This consists in creating a more uniform distribution of the microwave current density along the main slots of the antenna radiator. The peculiarity of the method lies in the fact that it can be applied for all the operating frequency bands of the antenna, in particular in L1, L2 and L3 [6]. The study of the antenna technical characteristics, with the slots disposed across the whole area of the radiator and implemented in the form of concentric arcs [7,8] or spirals [9], show that the application of the new radiators improves technical characteristics of the antena: decreases the axial ratio and improves the cross-polarization suppression and increases the phase center stability, allowing one to increase the accuracy of GLONASS/GPS positioning [10,11].

This paper presents new results of investigations of the antenna technical characteristics, with the additional slots performed in the form of concentric arcs located along the radiator edge.

II. AntennaDesign

Fig. 1 presents the radiator front side of the slot stripline leaky-wave right-hand polarized antenna, where (a) shows the radiator without additional slots, (b) – the radiator with additional slots in the form of concentric arcs which are disposed along the radiator edge.



(*a*) (*b*)

Fig. 1. The front and back sides of the slot stripline leaky-wave antenna with the right-hand circular polarization.

The radiators are fabricated using a dielectric substrate (1) with two-sided metallization. The substrate used was Rogers 4003C, with the permittivity ε_r= 3.66, height h_{sub}= 1.524 mm and diameter of 145 mm. The main slots are implemented in front-side metal of the dielectric substrate. They are performed in the form of spirals starting in the central part of the antenna and ending at its edge. The number of the main slots can be arbitrary. To receive a microwave signal the main slots are wrapped around the geometrical center of the radiator. The wrapping direction of the main slots is determined by the necessary type of the antenna circular polarization. For a smooth matching with a feeding microstrip line (ML) disposed at the back side of the radiator the main slots in the central part of the radiator can be rectilinear. The electrical lengths of the main slots are adjusted to the operating frequency band of GNSS: GPS/GLONASS/COMPASS/GALILEO etc.

The additional slots (4) are arranged between the main slots, as shown in Fig. 1 (b). The electrical length of the longest additional slots is smaller than the electrical length of the shortest main slots of the antenna radiator. Therefore, the additional slots hardly influence the matching of the main slots with the MSL feeding line in the antenna operating frequency band.

Arranged in the back side metal of the antenna radiator is MSL inductively coupled with the main slots disposed at the front side of the radiator. MSL is implemented in the form of a spiral wrapped around the antenna phase center. The wrapping direction of the MSL spiral is also determined by the required type of the received signal circular polarization. To establish a leaky-wave mode, MSL is loaded with effective resistance (resistive impedance) which is equal to its wave impedance. For better MSL matching with the main slots being excited, the MSL wave impedance can be different from 50 Ohm and match with a 50 Ohm feeder using a balun disposed at the MSL input. To suppress the back lobe of the radiation pattern and multipath interference a simple small-size low-profile ground plane is used. The ground plane is chosen depending on the antenna application in the antenna array.

III. RESULTS AND DISCUSSION

Fig. 2 presents the calculated radiation patterns in the vertical plane at 1227 MHz: (a) – the antenna without additional slots in the radiator, (b) the antenna with additional slots in the radiator, (1) – right-hand, (2) – left-hand circular polarization. Fig. 2 shows that the additional slots implemented in a certain configuration in the radiator which are not connected with the main slots allow one to increase suppression of the left-hand circular polarization in the range of operating elevation angles (±85° from zenith) at 1227 MHz. At other operating frequencies of the antenna the effect of applying additional slots is similar.

Fig. 3 shows the values of the voltage standing wave ratio (VSWR) (1) calculated for the antenna without additional slots in the radiator; (2) calculated and measured (3) values for the antennas with additional slots in the radiator. It can be seen in Fig. 3 that the use of the additional slots of a certain configuration in the antenna radiator hardly influences the matching of the main slots with MSL. The VSWR values measured do not exceed 1.5 in the frequency range of 1150 – 1650 (MHz). A good agreement of the calculated values with the experiment is observed.

Fig. 4 presents the simulated frequency dependences of the axial ratios (a) and levels of the cross-polarization suppression (b) in the zenith of radiation pattern of the antenna without additional slots in the radiator (1) and with the additional slots in the radiator (2).

One can see in Fig. 4 that the application of the new radiator allows one to decrease the axial ratio and improve cross-polarization suppression in all the operating bands of the antenna.

Fig. 5 shows a graphic representation of the calculated variations of the local phase center of the antenna without (a) and with the additional slots (b) in the radiator at a frequency of 1575.4 MHz. One can see that the application of additional slots allows one to reduce the variations of the antenna local phase center from 4,5 mm to 3 mm. In other operating bands of the antenna the effect of the additional slot influence is similar.

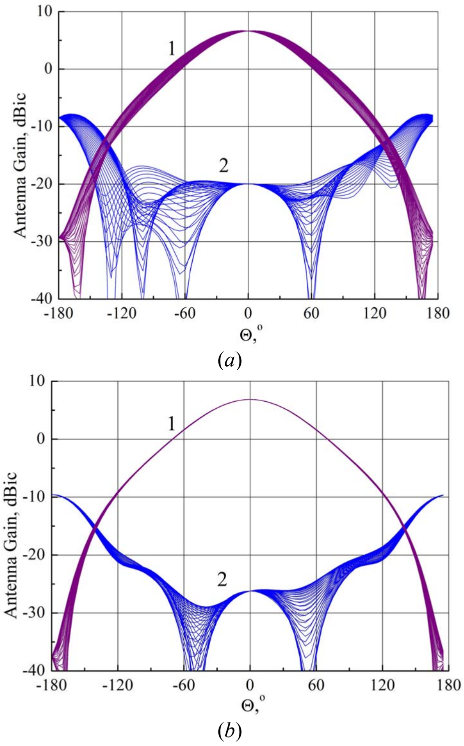


Fig. 2. The calculated antenna patterns in the vertical plane at 1227 MGz: (*a*) – the pattern without the aditional slots in the radiator, (*b*) – the pattern with additional slots in the radiator, (1) – right-hand circular and (2) – left-hand circular polarization.

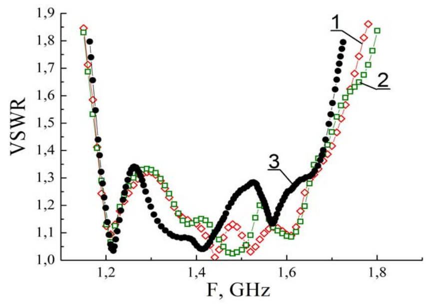
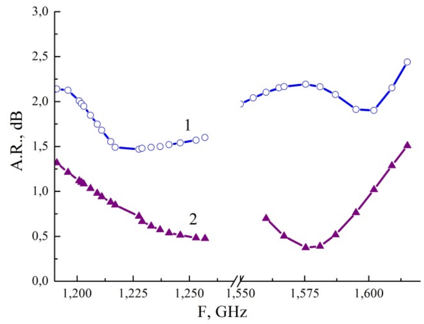
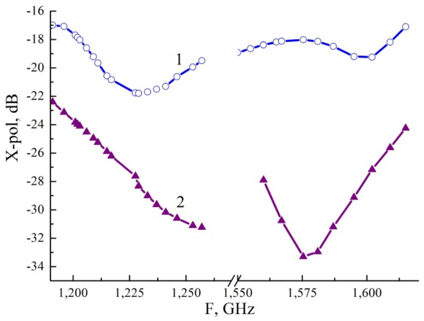


Fig. 3. The antenna VSWR: calculated for the anenna without additional slots (1), the calculated (2) and measured (3) values for the antenna with additional slots in the radiator.

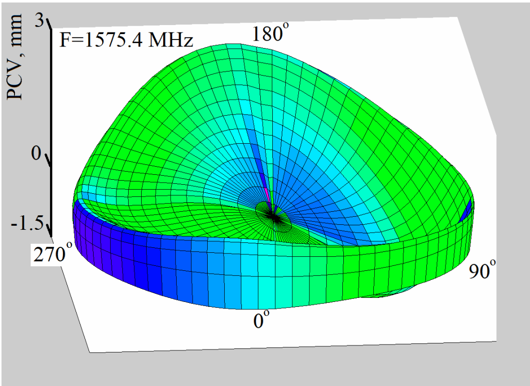


(*a*)



(*b*)

Fig. 4. The calculated frequency dependences of the axial ratios (*a*) and cross-polarization levels (*b*) in the zenith of the antenna pattern without additional slots (1) and with the additional slots (2) in the radiator.



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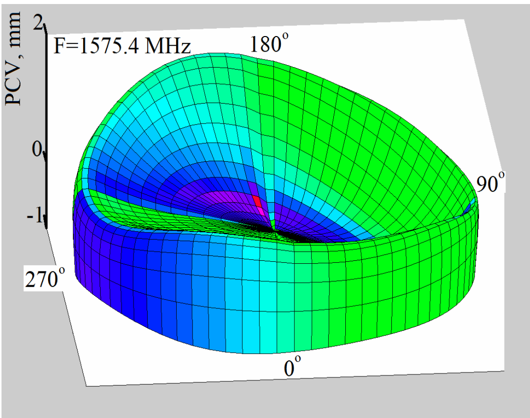
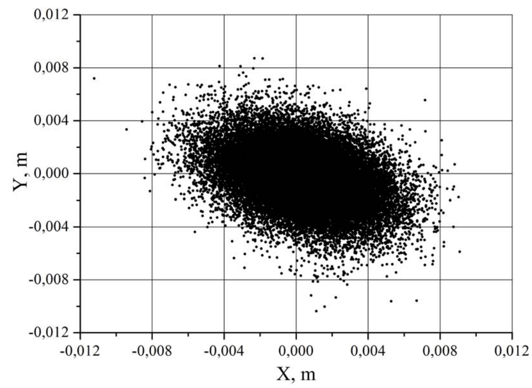


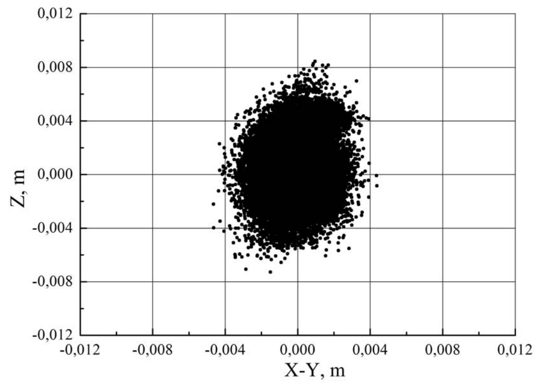
(*b*)

Fig. 5. Graphic representation of the calculated variations of the local phase center of the antenna without (*a*) and with the additional slots (*b*) in the radiator at a frequency of 1575.4 MHz.

Fig. 6 presents the results of the positioning accuracy of an antenna as related to the other two antennas in the horizontal (a) and vertical (b) planes for the antennas with the additional slots in the radiator as well as the comparison of the results measuring the azimuth (c), roll (d) and pitch (e) angles of the antennas without additional slots (empty circles) and with the additional slots (solid circles) in the radiator, with the distance between the centers of three active antennas being 2 m. The measurements were taken with regard to the navigation signal phase in the L1 frequency band using GLONASS/GPS constellation. The root-mean-square deviation (RMSD) of the positioning accuracy of an antenna relative to the other two was equal to 2.4 mm in the horizontal plane, and to 1.8 mm in the vertical plane. For the azimuth angle RMSD of the positioning accuracy of an antenna relative to the other two decreased from 2.87 to 2.15, for the roll angle from 3.74 to 3.17, and for the pitch from 4.18 to 2.83 (angular minutes).



(*a*)



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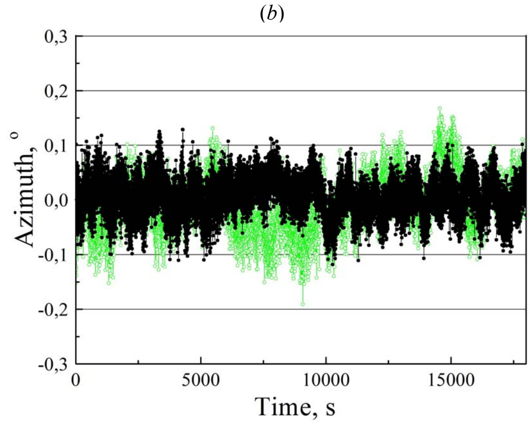
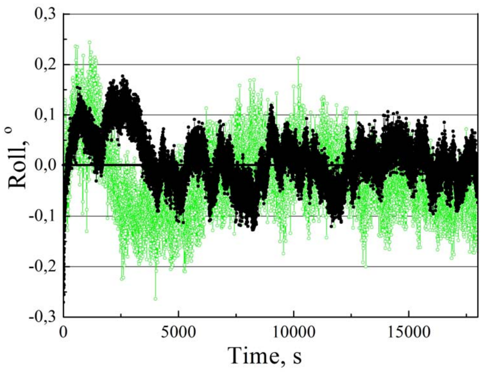
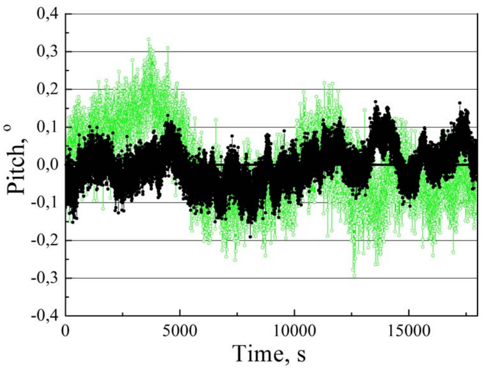


(*c*)



(*d*)



(*e*)

Fig. 6. The positioning accuracy of an antenna relative to the other two in the horizontal (*a*) and vertical (*b*) planes for the antennas with the additional slots in the radiator and the comparison of the results of measuring the azimuth (*c*), roll (*d*) and pitch (*e*) angles of the antennas without additional slots (empty circles) and with the additional slots (solid circles) in the radiator, with the distance between the centers of three active antennas being 2 m.

IV. Conclusion

To summarize, the study of technical characteristics of the antenna with the new design of the radiating element with the additional slots implemented in the form of concentric arcs arranged along the edge of the radiator shows that the new design of the radiating element decreases the axial ratio, increases the level of cross-polarization suppression and improves the phase center stability of the antenna in the L1/L2/L3 bands of GLONASS and L1/L2 bands of GPS< allowing one to increase the GLONASS/GPS positioning accuracy.

It should be noted that the results presented in this paper were obtained for the antennas with a flat small-size ground plane. These antennas are intended for the small-size few-element antenna arrays of mobile noise-resistant GLONASS/GPS receivers. Therefore, to suppress multipath special attention in the considered antennas has been paid to the characteristics of the antennas themselves: the desired radiation pattern, reduction of the axial ratio, increase of the cross-polarization suppression and stability of the phase center. To apply these antennas in stationary base stations GPS/GLONASS/COMPASS/GALILEO it is possible to further suppress multipath interference using ground planes of special design, for example, the widely known «choke ring» ground planes [12,13] or low-profile impedance ground planes with a varying impedance profile [14].

Acknowledgments

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