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Study of the characteristics of slot stripline antennas of high accuracy GLONASS/GPS positioning upon radiator miniaturization

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Abstract – **The main technical characteristics of active slot stripline leaky wave right-hand circular polarization antennas, with their radiator diameter being 145 and 70 (mm), have been investigated. The reduction of the radiator diameter is achieved by using dielectric substrates with increased dielectric permittivity. It is shown that with the radiator diameter reduction from 145 to 70 (mm) the root mean square deviation (RMSD) of the positioning error of an antenna relative to the other two antennas increases from 2.1 to 3.9 (mm) in the horizontal plane and from 1.7 to 3 (mm) in the vertical plane. The antennas are intended for high accuracy GLONASS/GPS positioning in three frequency bands: *L*1/*L*2/*L*3.**

Keywords ***– slot stripline antenna, GLONASS/GPS antenna, circular polarization, high accuracy GNSS positioning.***

I. INTRODUCTION

The reduction of the overall dimensions of active antennas for high accuracy positioning using the signals of Global navigation satellite systems (GNSS) GLONASS/GPS is necessary for the application of the given antennas in mobile high accuracy GNSS receivers. A slot stripline leaky wave antenna is one of the compact low-profile antennas [1,2]. The apparent advantages of the given antenna are broad bandwidth, wide radiation pattern with high signal enhancement at small elevation angles and common stable phase center coinciding with the geometrical center of the antenna. However, with all the obvious advantages the given antennas have a number of drawbacks, namely: a comparatively high axial ratio and low cross polarization suppression.

To eliminate these drawbacks, in [3] a new method is suggested for improving the technical characteristics of the slot stripline leaky wave circularly polarized antennas. The peculiarity of the method consists in its improving frequency [4], angular [5] and phase [6,7] characteristics of the antenna in all frequency bands including *L*1, *L*2 and *L*3. The method is to implement additional slots in the front side metal of the antenna radiator, with their electrical length being shorter than the electrical length of the main slots. The additional slots are implemented in a certain way: either in the form of concentric arcs around the antenna phase center or as spirals wrapped between the main radiating elements of the antenna. The electrical lengths of the main slots are alternately adjusted to the frequency bands *L*1 and *L*2 + *L*3. Owing to the given method it becomes possible to further miniaturize the antenna, retaining high technical characteristics in all the operating frequency bands.

The aim of the present study is to investigate the influence of the radiator miniaturization of the slot stripline leaky wave antennas on the main technical characteristics, and, finally, on the GLONASS/GPS positioning accuracy.

II. THE ANTENNA DESIGN AND EXPERIMENTAL TECHNIQUE

Fig. 1 shows the external view of the active tri-band antennas A145 (*a*) and A70 (*b*) and their radiators (*c*) and (*d*), respectively.

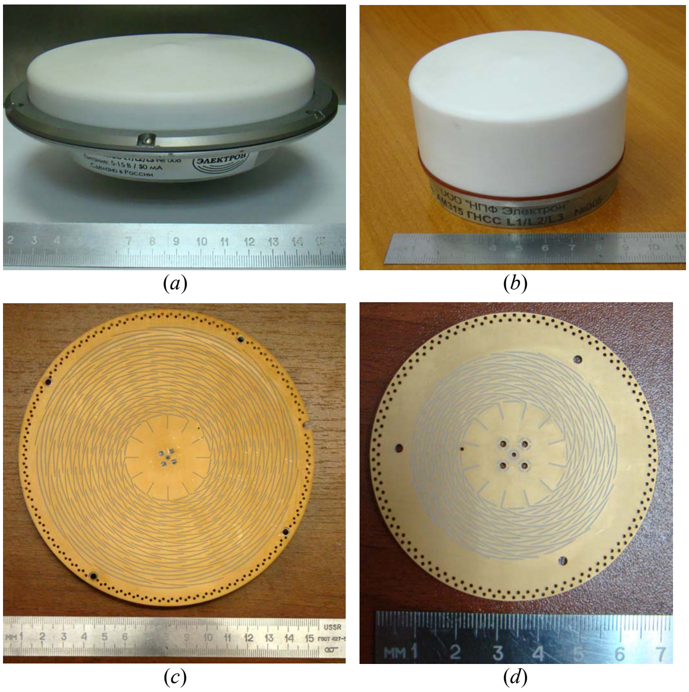
(*a*) (*b*)
(*c*) (*d*)

Fig. 1. External view of the active antennas (*a*, *b*) and front side of the antenna radiator (*c*, *d*).

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The antennas have a flat conductive ground plane. The diameter of antenna A145 ground plane is 175 mm, while that for A70 is 80 mm.

The antenna radiator A145 is implemented on a substrate with the thickness of 1.524 mm, dielectric permittivity 3.3 and diameter of 145 mm, the radiator A70 is implemented on a substrate with the thickness of 1.27 mm, dielectric permittivity 10.2 and diameter of 70 mm. Both antennas are intended for receiving navigation signals in the $L1$, $L2$ and $L3$ frequency bands.

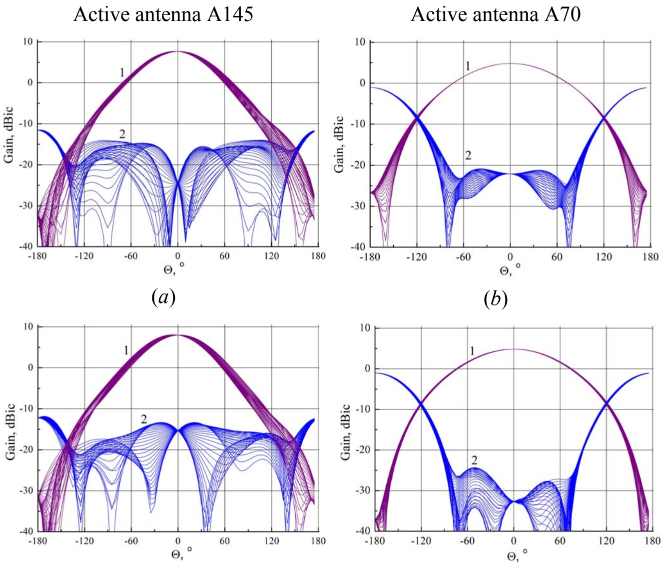
The topology of the front and back sides of the designed radiators of the slot stripline leaky wave right-hand circular polarization antenna is described in [4-6]. In both active antennas use is made of the same low noise amplifier (LNA) with the following characteristics: VSWR below 1.5, noise factor 1.2 dB, Δgroup-delay below 4 ns. The LNA gain in the active antenna A145 amounts to 30 ± 1 dB. The LNA gain in the active antenna A70 is increased up to 33 ± 1 dB to compensate the reduction of the miniaturized antenna gain. The LNA current consumption is not higher than 50 mA.

To test the active antennas the goniometric navigation equipment MRK-32 was used. Three antennas of each type were alternately connected to the MRK-32 phase modulator. The distance between the centers of three active antennas was equal to 0.7 m. The measurements of the positioning accuracy of an active antenna relative to the other two antennas in the horizontal and vertical planes as well as the measurements of the pitch, roll and azimuth angles were made in the $L1$ frequency band under static conditions using the combined GLONASS/GPS constellation. The data were accumulated within ≈ 10 hours. During the measurements the active antennas A145 and A70 were continuously receiving the GLONASS and GPS navigation signals in the upper hemisphere at the elevation angles higher than 4.8°.

III. RESULTS AND DISCUSSION

Fig. 2 presents the calculated amplitude radiation patterns in the vertical plane in the range of the azimuth angles φ from 0° to 360° at the GPS carrier frequency of 1575.4 MHz (*a*, *b*) and GLONASS frequency of 1602 MHz (*c*, *d*) of the $L1$ frequency band, where 1 – is the right-hand polarization, and 2 – is the left-hand one. It can be seen from Fig. 2 that both antennas are weakly directional ones. The gain decrease from the zenith to horizon in the A145 antenna was equal to about 12dB, while in the A70 antenna it was about 8 dB. Here, in the experiment both antennas were continuously receiving the GLONASS/GPS navigation signals in the $L1$ and $L2$ frequency bands in the range of operating angles of the antenna $\Theta = \pm 85°$, where $\Theta = 0$ – is the zenith radiation pattern of the antenna. However, the cross-polarization suppression in the lower hemisphere in the miniaturized antenna declined by more than 10 dB.

Fig. 3 presents the measured values of the S_{11} for the antennas A145 – (1) and A70 – (2). One can see that the operating frequency range of the miniaturized antenna is slightly narrowed. Nevertheless, in all the operating frequency bands ($L1$, $L2$ and $L3$) VSWR of the antennas A145 and A70 is not lower than 1.5.



(*a*) (*b*)

(*c*) (*d*)

Fig. 2. Calculated amplitude radiation patterns in the vertical plane.

Fig. 4 presents the back-radiation patterns for the antennas A145 – (1, 2) and A70 – (3, 4), at the frequency of 1575.4 MHz (1, 3) and 1602 MHz (2, 4), where $\Theta = 0$ – is the zenith radiation pattern. One can see that the differences in the back-radiation patterns are insignificant.

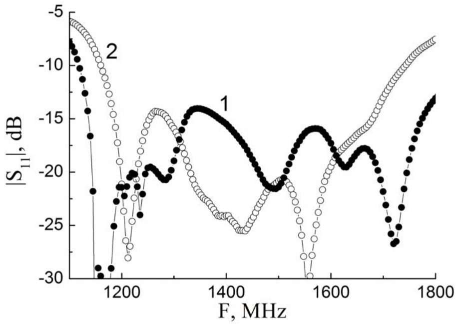


Fig. 3. Measured S_{11} of the antennas.

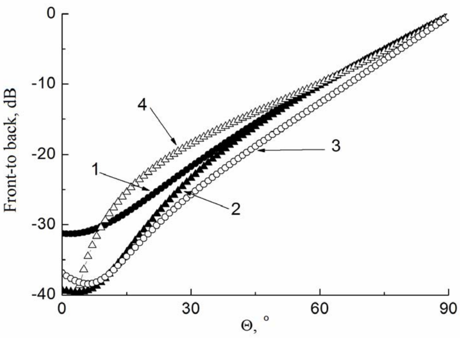
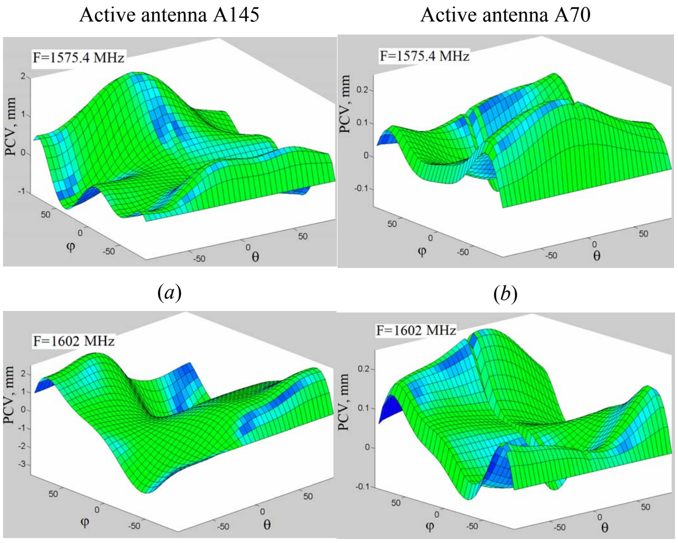


Fig. 4. Calculated back-radiation patterns.

Fig. 5 shows the calculated dependences of the change of the local phase centers (***PCV***) of the antennas A145 and A70 on the elevation angle (Θ) and azimuth angle φ at the frequency of 1575.4 MHz (*a*, *b*) and 1602 MHz (*c*, *d*). It can be seen from the figures that at both frequencies the antenna A70 has a more stable phase center. For example, at the frequency of 1575.4 MHz ***PCV*** in the miniaturized antenna A70 decreased from 3 to 0.4 (mm) as compared to the antenna A145, and at the frequency of 1602 MHz - from 5 to 0.3 (mm).

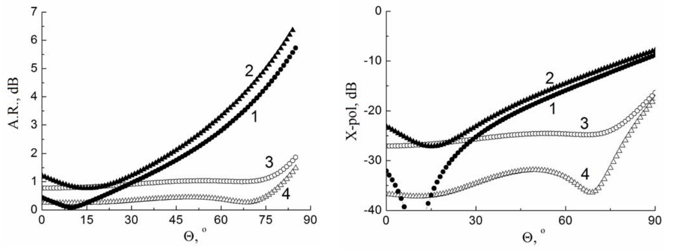


(*a*) (*b*)

(*c*) (*d*)

Fig. 5. Graphical view of the stability of the antenna phase centers.

Fig. 6 presents the dependences of the antenna axial ratio (A.R.) (*a*) and cross-polarization (X-pol) (*b*) on the elevation angle Θ for the antennas A145 (1, 2) and A70 (3, 4), where Θ = 0 – is the zenith radiation pattern of the antenna. The calculations were made at a frequency of 1575,4 MHz (1, 3) and 1602 MHz (2, 4). One can see from Fig. 6 that at both frequencies the antenna A70 has the axial ratio and cross-polarization level which are comparable with those of the antenna A145 in the zenith radiation pattern and the better ones near the horizon.

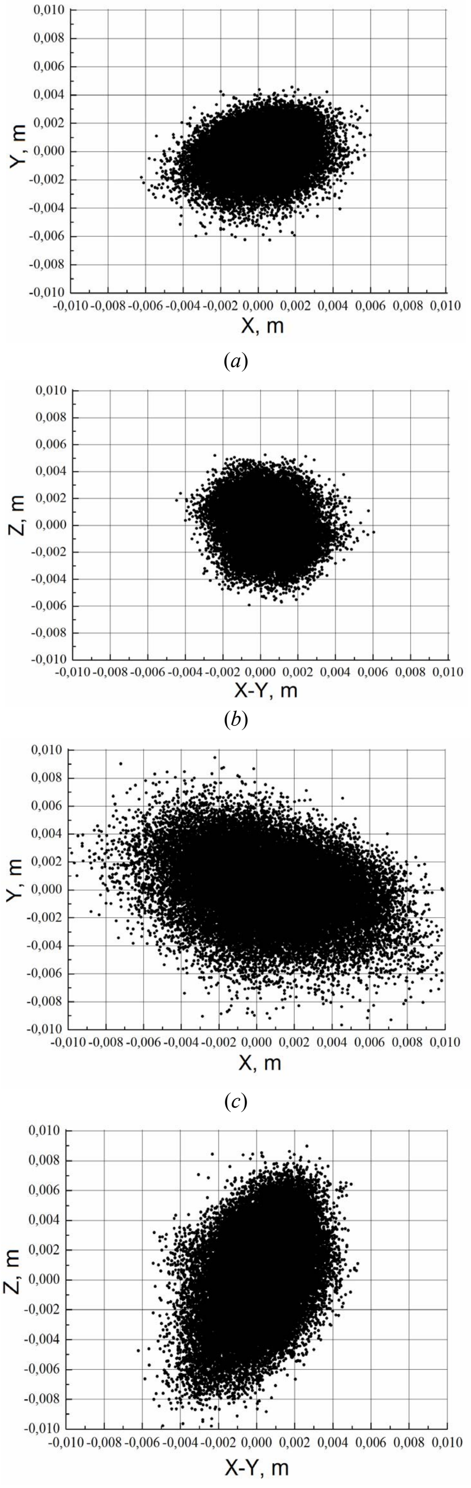


(*a*) (*b*)

Fig. 6. Dependences of the antenna axial ratio (*a*) and cross-polarization (*b*) on the angle Θ.

Fig. 7 shows the measurement results of the GLONASS/GPS positioning accuracy of an active antenna relative the other two antennas in the horizontal (A145 – a, A70 - c) and vertical (A145 – b, A70 - d) planes.

One can see the increase in RMSD of the positioning error upon the antenna miniaturization. In the horizontal plane RMSD increased from 2.1 to 3.9 (mm), and in the vertical plane - from 1.7 to 3 (mm).



(*a*)

(*b*)

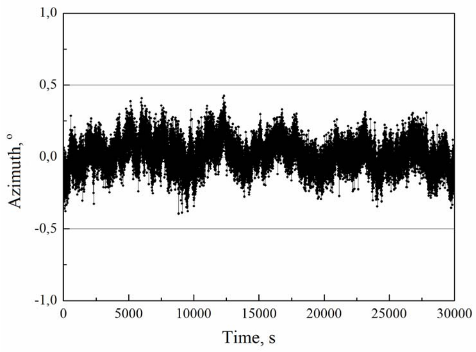
(*c*)

(*d*)

Fig. 7. Positioning accuracy of an antenna relative to the two antennas in the horizontal and vertical planes.

Fig. 8 presents the azimuth measurement results obtained using GLONASS/GPS signals.

Active antenna A145



Active antenna A70

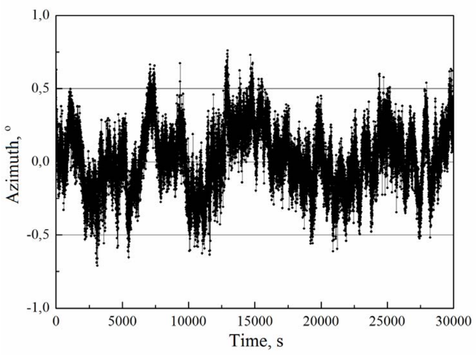


Fig. 8. Positioning accuracy of one antenna relative to the two with regard to the roll, pitch and azimuth angles.

One can see from Fig. 8 that in the miniaturized antenna RMSD of the positioning error with regard to the angular measurements also increased. Here, as noted above, the miniaturized antenna A70 has a more stable phase center than the antenna A145, VSWR which is comparable with that of the antenna A145 in the operating frequency bands, and the comparable axial ratio and cross-polarization suppression in the zenith, with these parameters being better when approaching the horizon. Consequently, the inherent characteristics of the antennas A145 and A70 are quite high in the upper hemisphere and no longer influence the resulting positioning error. In the lower hemisphere, with the ground plane dimensions decreasing, the cross-polarizations suppression level of the antenna A70 increases. Therefore, the reflected signals changing the polarization upon reflection make a decisive contribution into the positioning error of the considered antennas.

IV. CONCLUSION

To summarize, the studies of the technical characteristics of the active slot stripline leaky wave right-hand circular polarization antennas with the radiator diameters 145 mm and 70 mm show that the miniaturized antenna has a more stable phase center, better axial ratio and higher cross-polarization suppression in the upper hemisphere of the received navigation signals. However, the increase of the cross-polarization level in the lower hemisphere, with the antenna ground plane diameter decreased, makes the miniaturized antenna less protected from multipath interference which is the main source of errors in high accuracy positioning.

It has been found that with the radiator diameter decreasing from 145 mm to 70 mm, RMSD of the positioning error of an antenna relative to the other two antennas in the horizontal plane increases from 2.1 to 3.9 (mm), and in the vertical plane - from 1.7 to 3 (mm). RMSD of the positioning accuracy with regard to the azimuth angle increases from 6.12 to 12.5 (angular minutes), roll angle - from 9.4 to 15.6 (angular minutes), and pitch angle - from 6.85 to 19.5 (angular minutes), with the distance between the centers of the three antennas being 0.7m.

It should be noted that the given results have been obtained for the active antennas with the small-size flat conductive ground planes. Such antennas are intended for the antenna arrays of mobile high accuracy GLONASS/GPS receivers. Therefore, to solve the multipath problem main attention in the considered antennas has been paid to the characteristics of the antennas themselves: radiation pattern shape, axial ratio, cross-polarization level and phase center stability. To apply the given antennas in stationary GLONASS/GPS base stations it is possible to further suppress multipath interference using ground planes of special design, for example, using conventional choke ring ground planes and low profile impedance ground planes with a varying impedance profile.

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