Patch Slot Leaky-Wave Right-Hand Circular Polarization Antenna with Additional Spiral Slots in the Radiator

Valery M. Vladimirov[1], Vladimir V. Markov[2], Vladimir N. Shepov[3]

Abstract – **A new design of the patch slot leaky-wave antenna with circular polarization has been suggested. The peculiarity of the present antenna is in using 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 of the radiator. The additional slots are implemented as spiral patches and located between the main spiral slots of the radiator. It is shown that the application of such additional slots allows microwave current lines to be more uniformly distributed along the main slots of the radiator, improving technical characteristics of the patch slot leaky-wave antennas with circular polarization.**

Keywords – **patch slot antenna, high accuracy positioning, receiving GNSS antenna, GLONASS/GPS antenna.**

I. Introduction

Patch slot leaky-wave antennas have widely been used for mobile multi-band multi-system receivers for the high-accuracy positioning using the signals of Global navigation satellite systems, including GLONASS, GPS and GALILEO [1]. The obvious advantages of these antennas are low profile, broad bandwidth, large radiation pattern with a high gain of the low-level signal and common phase centre coinciding with the geometrical centre of the antenna. However, in spite of all the apparent advantages the given antennas have a number of drawbacks, namely a comparatively high ellipticity and a low level of the cross-polarization suppression.

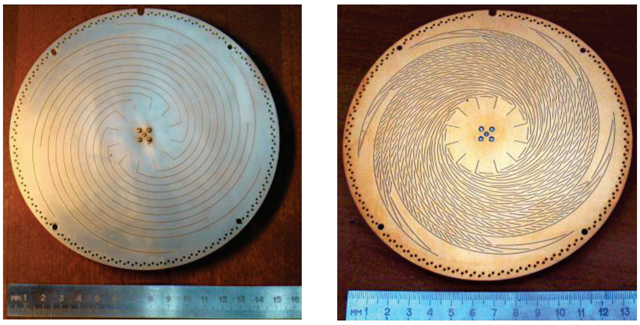
To eliminate these drawbacks a patch slot leaky-wave antenna with additional slots adjusted to one of the operating frequency bands of the antenna is suggested in [2]. The additional slots are located at the edge of the antenna and termed «fractal loops». A more uniform distribution of the additional slots over the antenna surface in this method results in improving the phase centre stability, decreasing the antenna ellipticity and increasing the level of the cross-polarization suppression. However, in such an antenna the additional slots referred to as «fractal loops», are adjusted to a single frequency band *L*1. Adjusted to other frequency bands (*L*2 and *L*3) are the slots located inside the antenna radiator. Therefore, the main technical characteristics of such an antenna, namely, the gain, ellipticity coefficient, cross-polarization suppression in the *L*2 and *L*3 frequency bands are two times lower than in the *L*1 band.

A new method to improve technical characteristics of the patch slot leaky-wave antennas with cross-polarization is suggested [3]. The peculiarity of the method consists in the antenna characteristics being improved in all the operating characteristics being improved in all the operating bands, including *L*1, *L*2 and *L*3. The method is to use 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 specific way: either in the form of concentric arcs around the phase centre of the antenna or as spiral patches and they are located between the main spiral slots of the antenna radiator. Here, all the main slots of the antenna radiator are implemented in the same (wave or half-wave) mode of the H-wave oscillations and adjusted alternatively to the frequency bands *L*1 and *L*2+*L*3.

The patch slot leaky-wave antenna with circular polarization with the additional slots in the form of concentric arcs around the phase centre of the antenna is considered in [3,4]. Studied in the present paper are the main technical characteristics of the patch slot leaky-wave antenna with the additional slots implemented as spiral patches located between the main spiral slots of the antenna radiator.

II. Antenna Design

Fig. 1 shows the front side of the radiators of the patch slot leaky-wave antenna with circular polarization, where (*a*) – the initial radiator of the antenna, (*b*) – the radiator with the additional slots in the form of spiral patches located between the main spiral slots.



(*a*) (*b*)

Fig. 1. The front side of the initial radiator of the antenna (*a*) and of the radiator with the additional slots (*b*)

The antenna radiator is fabricated from the dielectric substrate with two-sided metallization. The main slots are imple-

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mented in the front side metal of the dielectric substrate (Fig. 1*a*). They are performed in the form of spiral patches, starting in the central part of the antenna and ending at its edge. To receive a microwave signal with circular polarization the main slots are wrapped around the geometrical centre of the antenna. The wrapping direction is determined by the desired type of the antenna circular polarization. The front side of the radiator shown in Fig. 1 is designed for the antenna with the right-hand circular polarization. The antenna can be implemented based on the half-wave or wave mode of the H-wave oscillations. The electrical length of the main slots is adjusted to the operating frequency bands of the antenna: $L1/L2/L3$.

The additional slots are implemented between the main ones (Fig. 1*b*). They are made in the form of spiral patches. Since the additional slots are located between the main spiral slots and their electrical length is different: in the central part of the radiator they are shorter while at its edge they are longer. Nevertheless, 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 coupling of the main slots with the feeding microstrip line (MSL) in the operating band of the antenna.

Implemented in the back side metal of the antenna radiator is MSL which are inductively connected with the main slots on the front side of the radiator. MSL are made in the form of a spiral wrapped around the phase centre of the antenna. The direction of the spiral wrapping is also determined by the required type of the circular polarization of the signal received. To set a traveling wave mode MSL is loaded with the effective resistance, which is equal to its wave impedance.

The MSL coupling with the main slots is performed at the ends of the slots located in the central part of the antenna. To increase the inductive coupling coefficient of MSL with the main slots the spiral parameters are calculated in such a way that MSL should pass under each main slot twice. Moreover, to increase the inductive coupling coefficient between MSL and the main slots, microstrip conductors are performed in the back side metal of the substrate, which are connected to an external spiral turn of MSL and pass under the main slots at a certain distance. These conductors allow one to control the inductive MSL coupling with each main slot separately without changing the parameters of the entire MSL spiral. For a better MSL coupling with the main slots excited the MSL wave impedance can be different from 50 Ohm and correlate with the 50 – Ohm feeder using a balun located in the MSL input.

To suppress the back lobe of the antenna pattern and multipath interference in the given patch slot leaky-wave antenna a simple ground screen is used. Moreover, to suppress the multipath interference and feeding MSL radiation there is a microwave radiation absorber located between the ground screen and the antenna radiator.

III. The Main Technical Characteristics of the Antennas

Presented in Fig. 2 are the calculated radiation patterns of the antenna in the vertical plane, where (*a*) – is a pattern for the antenna without additional slots which is given in Fig. 1*a*, (*b*) – is a pattern of the antenna with additional slots which is given in Fig. 1*b*. The calculation is made at the frequency of 1575.4 MHz, where the azimuth angles φ range from 0 to 360°, with 1 – being the right-hand, and 2 – being the left-hand polarization. It can be seen that using additional slots in the antenna radiator, which are performed in the form of spiral patches and located between the main slots of the radiator, allows one to increase the suppression of the left-hand polarization in the range of the antenna elevation angles ($\Theta = \pm 85°$, where $\Theta = 0$ – is the zenith of the antenna radiation pattern).

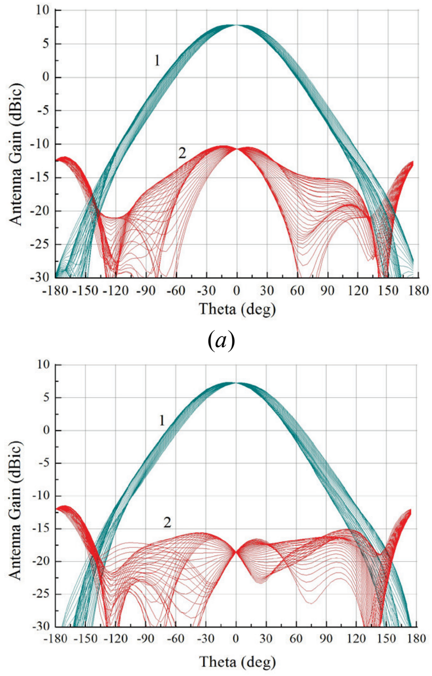


Fig. 2. The calculated amplitude radiation patterns in the vertical plane at the frequency of 1575.4 MHz

Fig. 3 shows the calculated values of the voltage standing-wave ratio (VSWR) for the antenna without additional slots (1), with the additional slots (2) and the calculated VSWR values for the antenna with the additional slots in the radiator (3). One can see in Fig. 3 that performing additional slots with shorter electrical length than the electrical length of the main slots hardly influences the coupling of the main slots of the antenna radiator with MSL. Here, the calculated VSWR values do not exceed 1.5 in the frequency range of 1190 – 1615 (MHz), and a good agreement of the calculation (1,2) with the experiment (3) is observed.

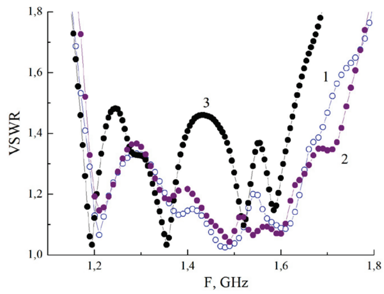
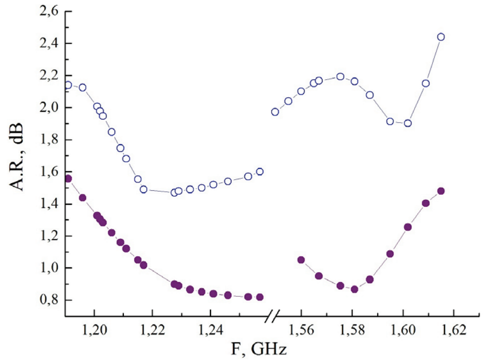
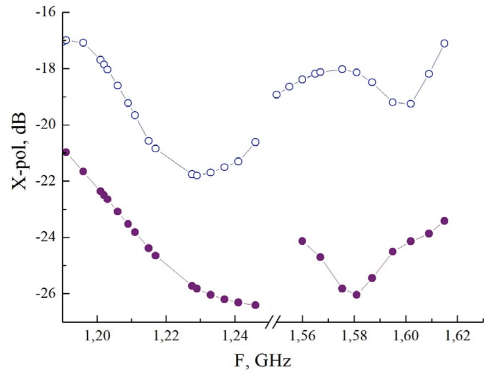


Fig. 3. The calculated and measured VSWR of the antennas

Fig. 4 presents the calculated frequency dependences of the ellipticity coefficients (A.R.) (*a*) and cross-polarization levels (X-pol) (*b*) in the zenith of the antenna pattern without additional slots (empty circles) and that with the additional slots performed as spiral patches (points). One can see from Fig. 4 that using additional slots in the antenna radiator in the form of spiral patches which are located between the main slots of the antenna radiator allows one to decrease the ellipticity and to increase the cross-polarization suppression in all the operating bands of the antenna (*L*1, *L*2 and *L*3).



(*a*)

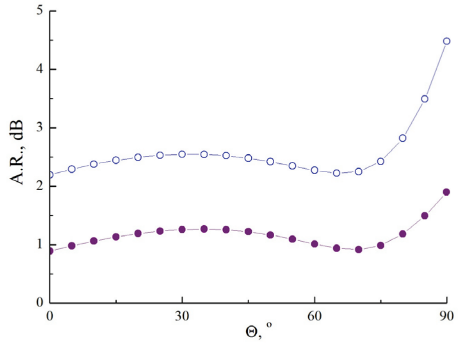


(*b*)

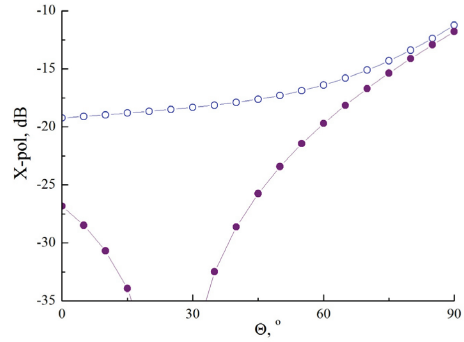
Fig. 4. The frequency dependencies of the ellipticity coefficients (*a*) and cross-polarization (*b*) in the zenith of the antenna

Fig. 5 shows the calculated dependences of the ellipticity coefficients (*a*) and cross-polarization levels (*b*) on the angle Θ at the frequency of 1602 MHz for the antenna without additional slots (empty circles) and for that with the additional slots in the form of spiral patches (dots). As is seen from Fig. 5 the use of additional slots in the antenna radiator performed in the form of spiral patches located between the main slots of the radiator allows one to decrease the ellipticity and to increase the cross-polarization suppression in all the operating elevation angles of the antenna (Θ = ±85°, where Θ = 0 is the zenith of the antenna pattern).

Fig. 6 presents the calculated local phase center variation (PCV) of the antenna without additional slots (*a*, *c*, *e*) and of the antenna with the additional slots (*b*, *d*, *f*) for the case when the phase centers are determined separately for each frequency band: *L*1, *L*2 and *L*3. One can see from Fig. 6 that using additional slots allows decreasing the local phase center variation of the antenna in the range of the operating angles (Θ = ± 85° and φ = ±180°). For example, at the frequency of 1575.4 MHz PCV decreases from 4 mm to 2.8 mm, at the frequency of 1227.6 MHz it decreases from 1.4 mm to 1.1 mm, and at the frequency of 1202 MHz from 1.5 mm to 0.8 mm.

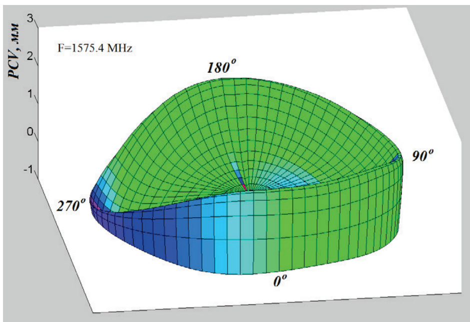


(*a*)

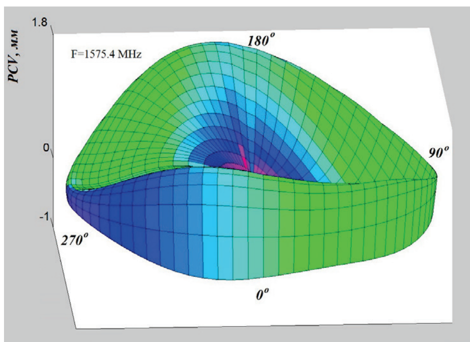


(*b*)

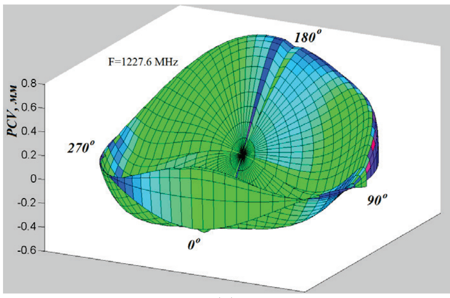
Fig. 5. The angle dependencies of the ellipticity coefficients (*a*) and cross-polarization levels (*b*) at the frequency of 1602 MHz



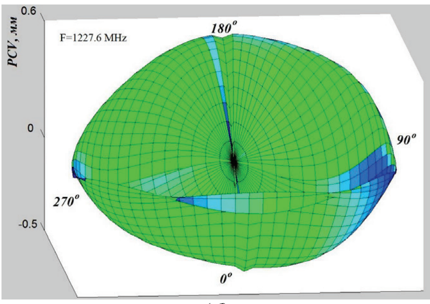
(*a*)



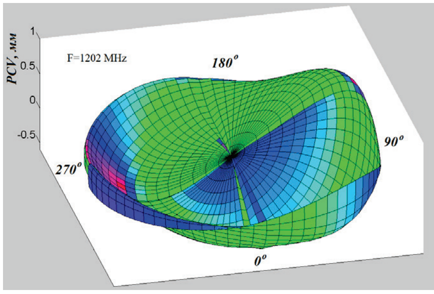
(*b*)



(*c*)



(*d*)



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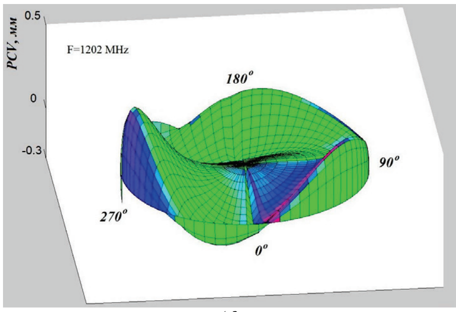
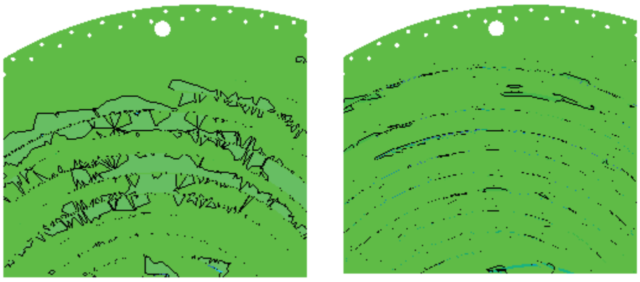


(*f*)

Fig. 6. The calculated local phase center variation (PCV) of the antenna without additional slots (*a*, *c*, *e*) and that of the antenna with the additional slots (*b*, *d*, *f*)

The observed improvement of the technical characteristics of the patch slot leaky-wave antenna with the additional slots in the antenna radiator is assumed to be due to the decrease of the microwave magnetic field ellipticity of H-wave propagating in the patch slot radiators. Without additional slots the microwave magnetic field in the main slots is elliptically polarized. This results in the deviation of the microwave current power lines from the slot direction. However, the additional slots located between the main spiral slots of the radiator which are performed as the spiral patches allow the longitudinal component of the microwave magnetic field to be decreased. Owing to this, the microwave current lines are more uniformly distributed along the main slots of the antenna.

This above assumption is evidenced by Fig. 7, showing the antenna section with the current distribution over its surface, where *a* – is the antenna without additional slots, *b* – is the antenna with the additional slots. One can see from the figure that using the additional slots performed in a certain form allows a more uniform distribution of the microwave current lines along the main slots of the antenna. Therefore, the ellipticity of the signal with the right-hand polarization is improved and the level of the cross-polarization suppression is increased.



(*a*) (*b*)

Fig. 7. The antenna section with the microwave current distribution over the main slots of the radiator: (*a*) – the antenna without additional slots, (*b*) – the antenna with the additional slots

IV. Conclusion

To sum up, a new design of the patch slot leaky-wave antenna with circular polarization with the additional slots in the antenna radiator has been studied in the present paper. The additional slots are performed in the form of spiral patches located between the main wrapped slots of the radiator. It has been shown that using such additional slots enables one to improve the main technical characteristics of the antenna, in particular, to decrease the ellipticity, increase the cross-polarization suppression and improve the stability of the local phase centers of the antenna, allowing to increase the resistance of the given antennas to the multipath interference.

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