The GNSS Helix Antenna for High Precision Application

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***Abstract*—The investigation of four-way cylindrical helix antenna for applications in high-precision field of global navigation satellite systems (GNSS) was presented in the article. A comparison of the proposed antenna with the classical approach of reducing multipath in the form of choke ring structure was produced. It is shown that it is possible to use the antenna in high-precision measurements without the bulky and heavy choke ring structures. The conclusions about the application of the antenna in navigation area were made.**

Keywords—helix antenna, multipath interference, choke ring antenna

I. INTRODUCTION

At the present time one of the GNSS important problem is the high level reception of reflected signal along with the direct signal from the navigation satellite. As a rule, antennas with multipath protection have in their design a broadband antenna element as Dorne&Margolin antenna or dual four-point-feed patch antenna [1] (by Trimble) or compact circularly polarized antenna (by Topcon positioning) [2] or other quadrupole antenna [3]. Such broadband antenna element is surrounded by a multipath suppression structure as a choke ring [1]. However, when there is the high multipath level, such structures are not always effective. As a result the low positioning accuracy is observed. There are investigations in which the improvement of such antennas is produced [4] by adding ground plane and radio frequency absorbing foam.

It should be noted that all modern GNSS antennas with multipath protection due to a choke ring structures have big weight and size. Below, the helix antenna without a multipath suppression structure but with better electrodynamic characteristics than classical choke ring solutions will be presented.

II. PROBLEM DEFINITION

The characteristics of a navigation receiver depend on quality of signal received by antenna. The relationship between the quality of the received signal and the antenna parameters is not unambiguous. However, it is possible to determine requirements for «ideal» antenna in terms of absence of a multipath signal.

The amplitude pattern of «ideal» antenna must has directivity in the upper hemisphere for the right hand circular polarization (RHCP) equal to 1 and the directivity tend to zero for the left hand circular polarization (LHCP) in entire sphere. It is supposed that such antenna receives only direct signals from navigation satellites («1» in Fig. 1) and it does not receives signals reflected from the ground and some objects («2» and «3» in Fig. 1). That is a receiver with «ideal» antenna has resistance to multipath interference. The reflected signals «2» and «3» are eliminated by «ideal» antenna because the RHCP signal inverts the phase and it becomes a LHCP after reflection. However, this is ideal case. It is impossible to eliminate cross-polarization in the entire sphere.

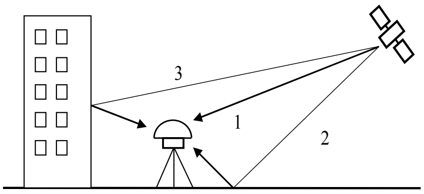

Fig. 1. GNSS antenna reception of direct (1) and reflected (2, 3) signals.

In addition, the phase of reflected signal (from flat metal ground plane) is inverted by 180°. In fact, the signal «3» can pass to the input of receiver despite on the antenna receives only RHCP in upper hemisphere. Therefore, an exact match between the characteristics of real and «ideal» antenna is impossible due to physical reasons. The derivative (the slope) of the amplitude pattern is equal to infinity at angle $\theta = 90°$ from the zenith (Fig. 2).

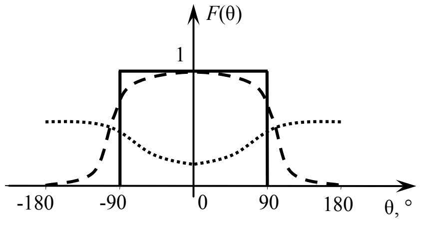

Fig. 2. Radiation pattern of «ideal» multipath resistance antenna (RHCP – solid, LHCP – line on the θ axis) and real antenna (RHCP – dashed, LHCP – dotted line).

It is known that the maximum slope of amplitude pattern at sliding angles ($\theta = 80°–100°$) is limited by physical dimensions of antenna. The slope cannot be high for small size antennas (about wavelength). Because of this limit, the ideal form of amplitude pattern is not reachable. Nevertheless, it is interesting to investigate how to obtain the maximum slope at sliding angles. Next, we will propose special construction based on using special helix antenna design.

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III. ANTENNA CONFIGURATION

At first, we consider the classical approach of multipath resistance antennas then move to the proposed helix antenna.

A. *Broadband Antenna with Impedance Ground Plane*

In recent years, many developers of GNSS antennas use multipath suppression structures of large electric size. An antenna with big size structure allows improving the positioning accuracy by reducing the undesirable multipath signal. On the other hand, there are significant disadvantages when using such an antenna system. Often, antenna with large electrical dimensions (tens of wavelengths) is used as base station antennas. Such high-impedance structures have 2-3 meters in diameter at GNSS frequencies. It based on choke ring technology or pin-type structures and it has a profile height about λ/4 and it must be constructed of metal [5].

Consequently, the weight of such antennas will be very large. In addition, the manufacture of such antennas will require significant resources, and their transportation for mobile applications is not possible.

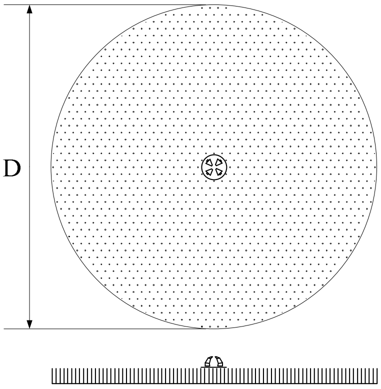

Fig. 3. An impedance ground plane of large electrical size with antenna.

The example of antenna with multipath suppression is shown in Fig. 3. The antenna system has a diameter D and it consists of the broadband antenna element [3] located in the center of the structure and λ/4 pins impedance surface. The slope of amplitude pattern depends on the diameter D of the impedance surface. However, this dependence is not linear.

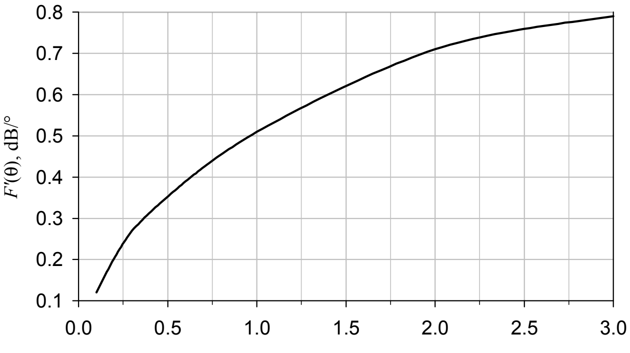

Fig. 4. The slope versus diameter D of impedance ground plane at 1.6 GHz.

With the help of modern CAD software (CST Microwave Studio), the slope of amplitude pattern was calculated at sliding angles. Fig. 4 shows the dependence of slope (*F'*(θ)) versus D. The study was conducted at frequency 1.6 GHz. The figure shows that the dependence is quadratic. Therefore, a significant increasing of diameter of the high-impedance ground plane does not provide increasing of the amplitude pattern slope. Thus, large ground planes for GNSS antennas can provide a slope about 0.8 dB/° or less.

B. *Four Fed Helix Antenna*

By means of using a special design of the helix antenna (Fig. 5), it is possible to avoid the heavy and bulky high impedance structure as choke ring, which has used for a long time in GNSS antennas.

The helix antenna model with a hemispherical shape of radiation pattern for RHCP is presented below.

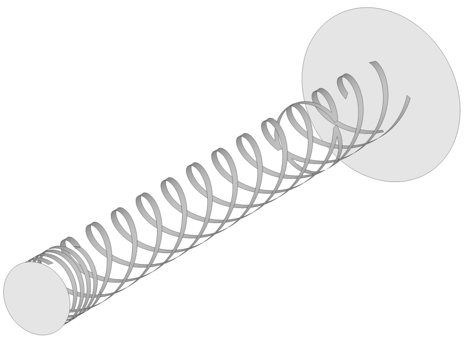

Fig. 5. The model of proposed helix antenna.

The antenna is performed by a four-way helix with variable step (Fig. 6). The top of the antenna ends with upper ground plane with radius R1 = 20mm. The radius R1 should not exceed the radius of the helix antenna. Otherwise, it leads to distortion of amplitude pattern in the reference direction (at the zenith, θ = 0°). The antenna begins with a small step spiral S1 (1 turn, height 30mm, winding angle 13.5°) and it ends with the spiral S2 with a large step (3 turns, height 330mm, winding angle 41°). Counterclockwise rotation of the helix is realized not far from the end of the antenna to reduce the cross-polarization field. Total length of the helix antenna is L = 365 mm. To reduce the LHCP level in lower hemisphere the bottom ground plane with radius R2 = 50mm is applied. However, it should be noted that the size of bottom ground plane has not significant effect on the side lobe level and it may be reduced. The model of the proposed antenna was obtained using the optimization algorithms of CAD.

The feeding of such antenna is provided by a coaxial cable located on the axis of helix from lower ground plane R2 to the upper R1 (it is not shown). There are no distortions of the radiation pattern when the coaxial cable is located on the antenna axis. The microstrips of the helix antenna are fed with equal amplitude, but it has different phases (0°, 90°, 180° and 270°) to obtain the RHCP. In the presented CAD model, the discrete ports with strict values of amplitudes and phases were used.

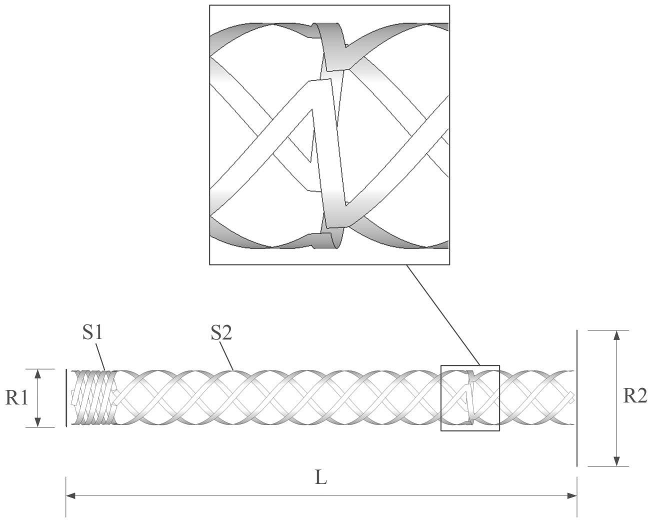

Fig. 6. The dimensions of proposed helix antenna.

The real divider has to provide strict values of phases and amplitudes at the outputs. Otherwise, there will be a significant increasing of backward radiation (LHCP level). In the presented article, the simulation of the real divider (feeder) was not conducted. Only the directional pattern of the helix antenna were investigated. However, it is should be added that the best solution is implementation of divider at the top of helix antenna on ground plane R1. The divider should be compact and broadband to cover all GNSS frequency bands.

IV. FIELD ANALYSIS

As noted above, the CAD simulation at frequency domain was used to calculate and analyze the electrodynamic characteristics only. Therefore, here is no presented VSWR. Fig. 7–8 shows the radiation patterns at 1.2GHz and 1.6GHz, respectively. The amplitude pattern of helix antenna is symmetric, so the patterns are presented at angles θ = [0°; 180°] (where θ = 0° – zenith, θ = 90° – horizon).

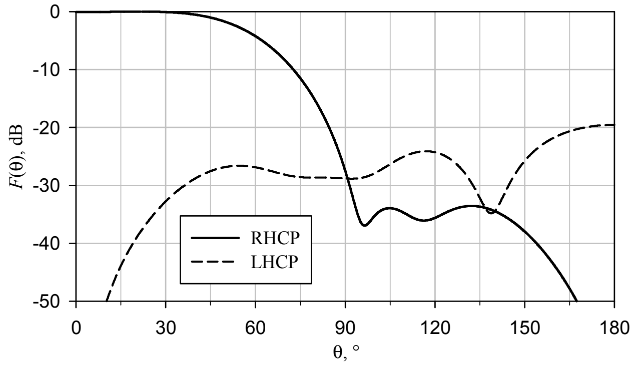

Fig. 7. The radiation pattern of proposed helix antenna at 1.2 GHz.

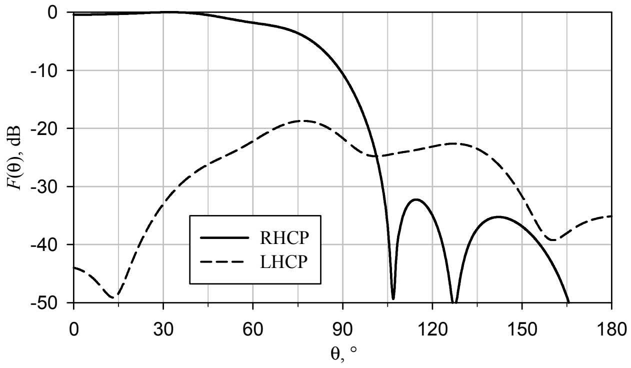

Fig. 8. The radiation pattern of proposed helix antenna at 1.6 GHz.

As can be seen from figures, at sliding angles the radiation patterns have high slope and low level of cross polarization in the upper hemisphere [θ = -90°; 90°]. In the lower hemisphere [θ = 90°; -90°], there is low signal reception level of RHCP and LHCP less than -20 dB. Moreover, the low level of LHCP is also observed in the upper hemisphere. Consequently, the antenna has high axial ratio.

The most interesting is the analysis of radiation pattern at angles θ = 80° – 100° because multipath propagation is critical there. The frequency response of the RHCP slope for these angles θ is presented on Fig. 9. As is seen the *F*'(θ) is changed significantly, therefore the angular range is divided by two ([θ = 80°; 90°] and [θ = 90°; 100°]) for the easiest analysis. It can be seen that *F*'(θ) is 0.8 – 1.4 dB/°. Typically, the slope increases when moving from θ = 80° to θ = 100°. At frequencies near 1.2 GHz for angles 90° – 100°, the slope is seems high because there is first RHCP pattern minimum at θ ≈ 95°. The typical *F*'(θ) of choke ring antennas with D = 0,35m is about 0.3 – 0.35 dB/°.

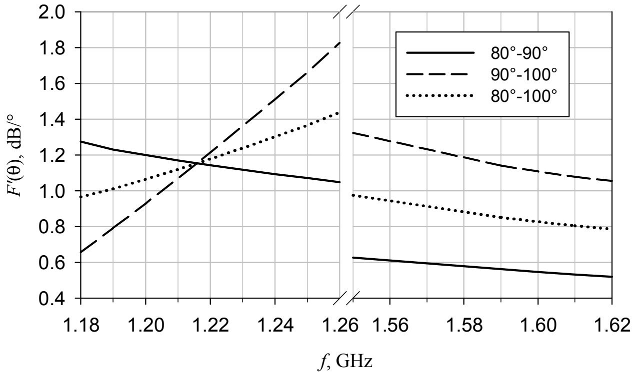

Fig. 9. The frequency response of RHCP pattern slope at sliding angles.

The frequency response of the gain at θ = 90° (roll-off gain) is shown in Fig. 10. The radiation pattern of the presented antenna does not have a constant width even in the GNSS frequency band (is about 35%). Therefore, roll-off gain is about -25 dB at low frequencies and -10 dB at high GNSS frequencies. The different widths of the radiation pattern on upper and lower frequencies are a disadvantage of the antenna and it can be investigated in more detail with the proposal of a new antenna design.

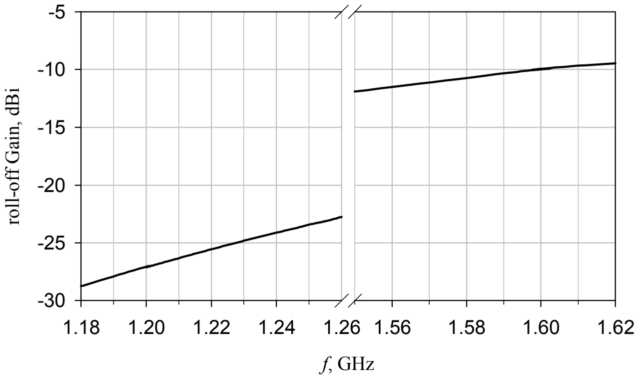

Fig. 10. The frequency response of RHCP roll off gain at θ=90°.

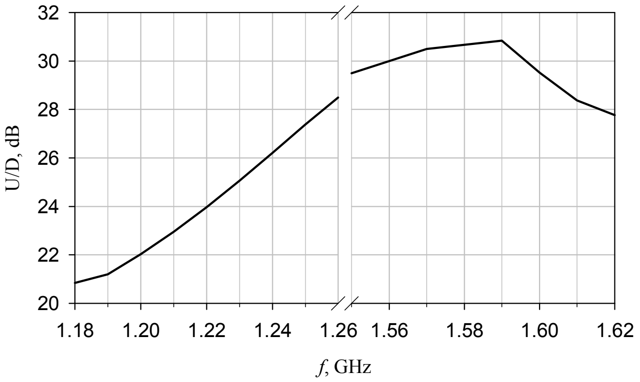

Fig. 11. The frequency response of up-down ratio of proposed helix antenna.

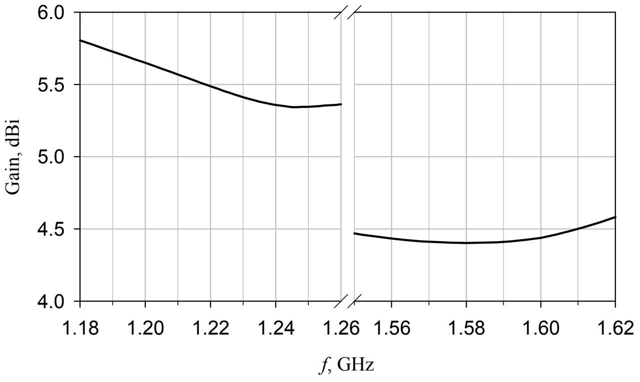

Fig. 12. The frequency response of the gain of proposed helix antenna.

The up-down ratio (U/D) of the helix antenna is shown in Fig. 11. The low U/D is observed in the lower frequency range. At the edge of the lower frequency range, the fields created by two orthogonal turns of helix are summarized with a phase unequal to 180°. As a result, there is increased level of radiation pattern at backward direction. Nevertheless, it is clear that unidirectional radiation is observed at GNSS frequencies. The Gain of proposed antenna versus frequency is presented in Fig. 12. The gain is about 5.5 dB at low frequencies and 4.4 dB at high GNSS frequencies.

V. CONCLUSION

Modelling of four-way helix antenna for using in the high-precision area of satellite radio navigation was performed. It is shown that the proposed antenna can replace the classic choke ring antenna solutions. It is possible due to a synthesized radiation pattern with high slope at sliding angles and a low level of back lobe. Also it is noted that antenna has a low level of LHCP in the upper hemisphere and high axial ratio, respectively. With the help of the large width of the radiation pattern the improved reception of navigation satellites located near θ = 90° is possible. The dimensions of the proposed helix antenna are much smaller than the one of classical antennas with impedance ground plane. This advantage makes helix antenna perspective for using at GNSS. A disadvantage of the proposed antenna is the implementation of compact divider.

At present there are feeding network solutions which have high losses (about 1.5 dB). Further, the modeling of compact broadband feeding network with low losses will be carried out.

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