11

Expansion of the operating frequency range of compact trailing-wave slot strip antennas with circular polarization for high-precision positioning GLONASS, GPS, Galileo, and Beidou signals-based

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A new approach aimed at expanding the operating frequency range of compact trailing-wave slot antennas with circular polarization designed to receive signals from global navigation satellite systems (GNSS) such as GLONASS, GPS, Galileo, and Beidou, is described. It is showed that the effect of increasing the antenna's operational bandwidth exceeded 85%.

Keywords: broadband slot strip antenna, high-precision GNSS signal-based positioning, compact GNSS receive antenna.

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Trailing-wave slot strip antennas have a stable phase center, a high axial ratio for receiving signals with right-hand circular polarization in the upper hemisphere, a high level of cross-polarization isolation, a steep radiation pattern (RP) roll-off near zero elevation angles for suppression of multipathing, and a gain sufficient for reliable reception of signals of global navigation satellite systems (GNSSs). Therefore, they are used successfully for high-precision positioning by the phase of the carrier frequency of GLONASS and GPS signals. The undoubted advantages of these antennas are their low profile, relatively low cost, manufacturability, and small dimensions and weight. A small-sized conductive screen is used to suppress the back RP lobe in compact slot strip antennas.

A special feature of the design of these antennas is the use of a microwave absorber. It is made in the form of a ring and is located between the antenna radiator and the screen. The microwave absorber suppresses re-reflected navigation signals that have changed right-hand circular polarization to left-hand circular one. This enhances the resistance of these antennas to multipathing, which, as is known, produces a decisive contribution to the error of high-precision positioning by GNSS signals. However, this also reduces the gain for useful navigation signals with right-hand circular polarization. Therefore, it is important to maintain high gain without an absorber when one expands the antenna bandwidth, so that a wider absorber, which suppresses re-reflected signals with left-hand circular polarization as much as possible, could be used in the future.

Classical trailing-wave slot strip antennas have a relatively narrow bandwidth. This is attributable to the fact that a single H-wave oscillation mode (the lowest half-wave one) is used to receive GNSS signals. Therefore, in order to receive GLONASS and GPS signals within frequency ranges $L1$ and $L2$, short and long slots are alternated to tune the resonant frequencies of the half-wave mode of H-wave oscillations within the ranges of 1563–1610 MHz and 1215–1254 MHz, respectively [1,2].

With the introduction of the $L3$ (GLONASS) and $L5$ (GPS) frequency ranges and the Galileo and Beidou navigation systems, a need arose to expand the bandwidth of slot strip antennas within one of the ranges to 1164–1300 MHz for reception of GLONASS $L2/L3$, GPS $L2/L5$, Galileo $E5a/E5b/E6$, and Beidou $B2/B3$ signals. It becomes difficult to ensure the reception of GNSS signals in this extended operating frequency band with one mode and half the number of slots while maintaining the stability of the key technical parameters of the antenna.

Additional slots connected to fourteen main slots and called fractal loops were used in [3] to expand the bandwidth of circular-polarization slot strip antennas. A trailing-wave slot strip antenna with twelve slots and their fundamental mode of H-wave oscillations tuned to the frequency range from 1.14 to 1.67 GHz was designed in [4]. However, microwave absorber was removed from the antenna structure to increase the gain, which results in weaker suppression of left-hand circular polarization and should translate into a lower accuracy of measurements using GNSS signals.

In the present study, a new approach to expanding the bandwidth of receiving slot strip antennas while maintaining their gain is discussed: it is proposed to receive navigation signals within the frequency range of 1164−1300 MHz (GLONASS $L2$, $L3$; GPS $L2$, $L5$; Galileo $E5a$, $E5b$, $E6$; and Beidou $B2$, $B3$) with the half-wave mode of H-wave oscillations of all slots and use the wave mode within the 1559−1610 MHz range (GLONASS $L1$, GPS $L1$, Galileo $E1$, and Beidou $B1$). To achieve this, all slots of the antenna radiator are fabricated with jumps in wave resistance at the node of the high-frequency electric field of the wave mode

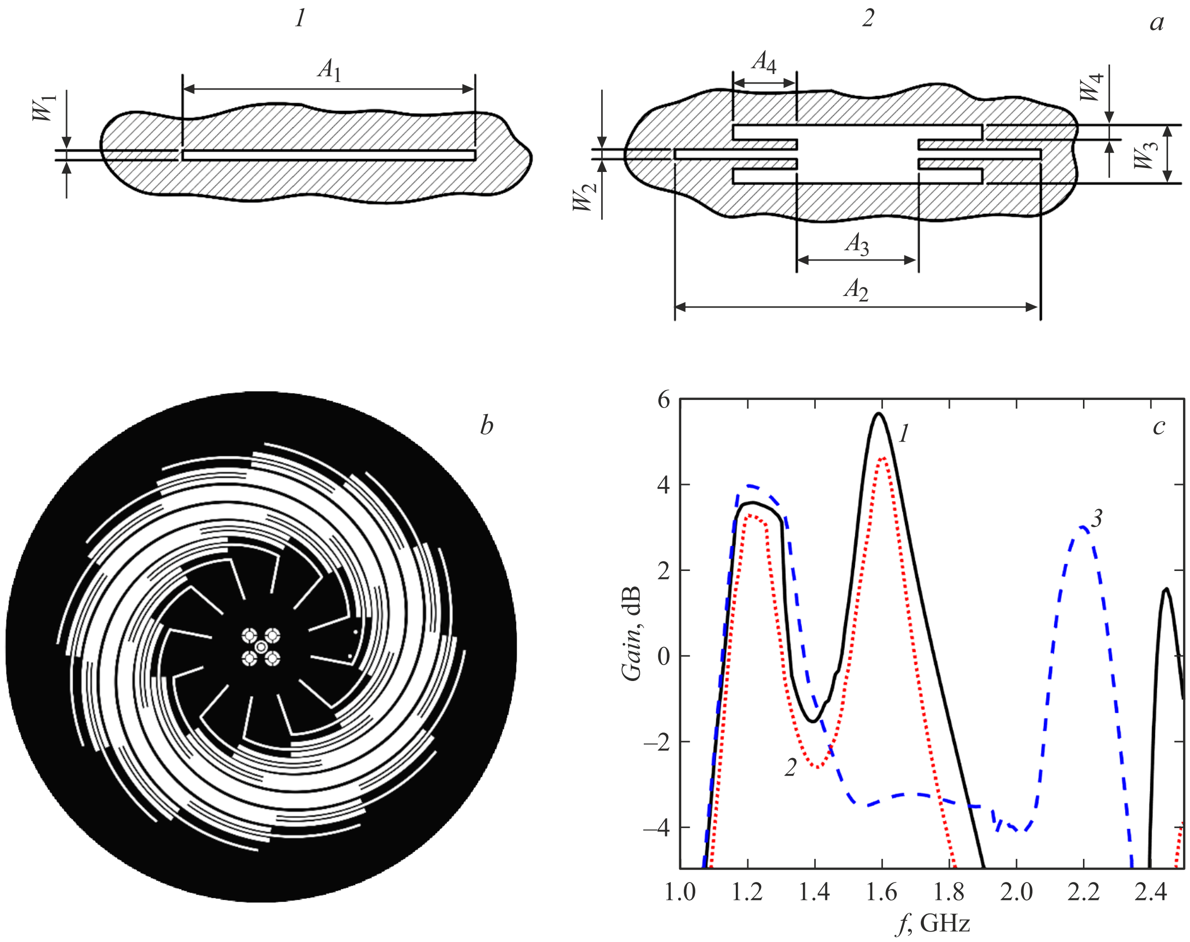

Figure 1. *a* — regular slot strip resonator (*1*) and slot strip resonator with slot width jumps (*2*); *b* — upper side of the radiator of the 3D antenna model; and *c* — calculated antenna bandwidths: *1* — for the half-wave and wave modes of H-wave oscillations of slot resonators with slot width jumps; *2* — antenna with all slots made without width jumps, the half-wave mode of half of the slots tuned to one frequency sub-range, and the half-wave mode of the second half tuned to another sub-range; and *3* — antenna with all slots made without width jumps and having the same length.

of H-wave oscillations, which are induced by jumps in their width [5].

Figure 1, *a* shows a regular slot strip resonator (*1*) and a resonator with slot width jumps (*2*) made to reduce the frequency of the wave mode of H-wave oscillations. Owing to the increase in wave resistance of a slot at the node of the high-frequency electric field of the wave mode of H-wave oscillations, the resonant frequency of the wave mode decreases. The length of the wide slot section (A_3) is adjusted for maximum convergence of frequencies of the half-wave and wave oscillation modes. However, a regular jump in slot width (W_3) is insufficient to tune the resonant frequencies of the slot wave mode to the required antenna bandwidth, since W_3 is limited by the adjacent slots of the antenna radiator. Therefore, additional jumps with length A_4 and width W_4 are introduced.

Figure 1, *b* shows the upper side of the antenna radiator designed in accordance with the proposed approach. The radiator is made of a dielectric substrate with metallization on either side that is 1.524 mm in thickness, 112 mm in diameter, and has permittivity $\varepsilon = 3.38$. Slots in the metal on the upper side of the substrate are twisted in a spiral around the center of the radiator for reception of signals with right-hand circular polarization. A microstrip traveling-wave resonator similar to the one discussed in [6] is formed on the lower side of the substrate for transmission of navigation signals received by the slots to the radio path. A C-RAM MT-30 microwave absorber with an insertion attenuation of 16 dB/cm at a frequency of 1 GHz forms a ring between the radiator and the flat conductive screen.

The results of electrodynamic analysis of the frequency dependences of gain of the 3D trailing-wave slot strip antenna model are presented in Fig. 1, *c*. Curve *1* in this figure corresponds to an antenna designed in accordance with the proposed approach: all its slots have such jumps in wave impedance that the half-wave mode of H-wave oscillations of all slots is tuned to the 1164–1300 MHz frequency range, while the wave mode is tuned to

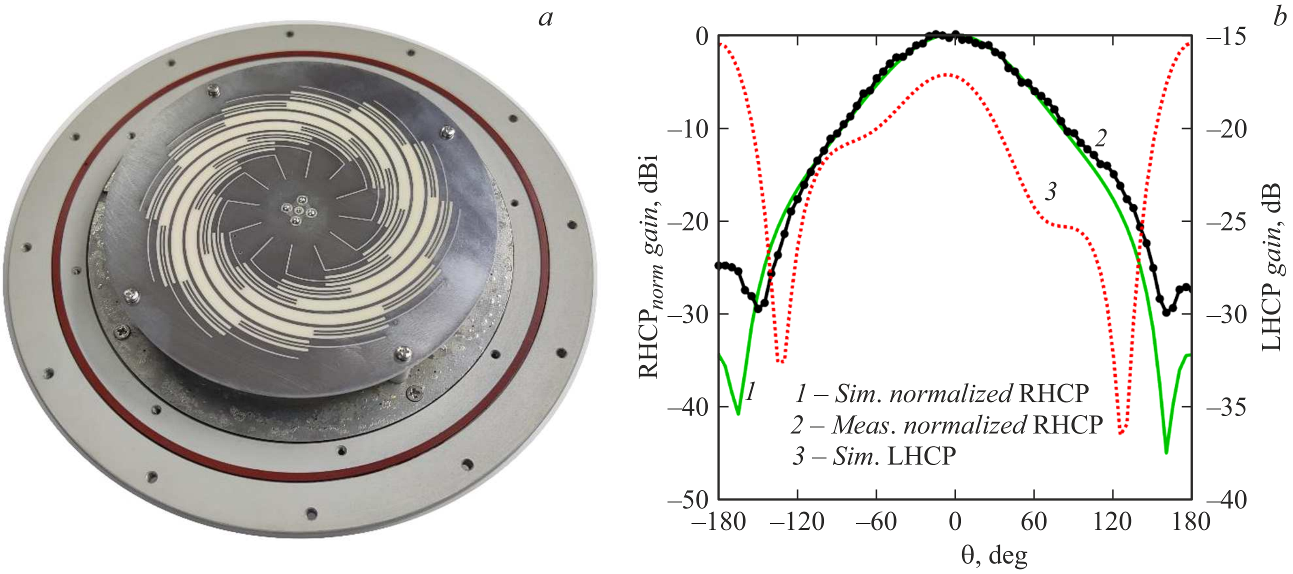

Figure 2. *a* — Photographic image of the antenna with the cover removed; *b* — calculated (*1*) and measured (*2*) normalized radiation patterns for right-hand circular polarization and calculated radiation pattern for left-hand circular polarization (*3*) at a frequency of 1300 MHz.

1559–1610 MHz. Curve *2* is an antenna with all slots made without width jumps, the half-wave mode of half of the slots tuned to one frequency sub-range, and the half-wave mode of the second half tuned to another sub-range, and curve *3* represents an antenna with all slots made without width jumps and having the same length. It can be seen from Fig. 1, *c* that the 0.5 dB bandwidth of the antenna designed in accordance with the proposed approach (curve *1*), which is formed by half-wave modes of twelve slots, was 158 MHz at KY = 3.5 dB, while the classical antenna (curve *2*) had a bandwidth of 85 MHz at KY = 3.1 dB. Thus, the magnitude of the effect of expanding the antenna bandwidth to 1164–1300 MHz was over 85 % with a gain on the order of 3 dB. This effect is induced by a two-fold increase in the number of resonances of *H*-wave oscillation modes within the antenna bandwidth (relative to traditional slot strip antennas). The corresponding slot parameters were $A_1 = 105.64$ mm, $A_2 = 122.99$ mm, $A_3 = 40.22$ mm, $A_4 = 19.78$ mm, $W_1 = 0.3$ mm, $W_2 = 0.3$ mm, $W_3 = 3.1$ mm, and $W_4 = 0.75$ mm; the microwave absorber height and width were 12.3 and 9 mm, respectively. In the case where all the slots are made without jumps in wave resistance, are of the same length, and have their half-wave mode of the *H*-wave tuned to the 1164–1300 MHz frequency range, the wave mode is positioned in the region of 2.2 GHz (curve *3*).

Since the antenna bandwidth that is to be formed by the wave mode of *H*-wave oscillations is narrower (1559–1610 MHz), the gain here is higher. Therefore, the microwave absorber width is optimized within the frequency range of 1164–1300 MHz to achieve a gain on the order of 3.5 dB. It should be noted that the gain

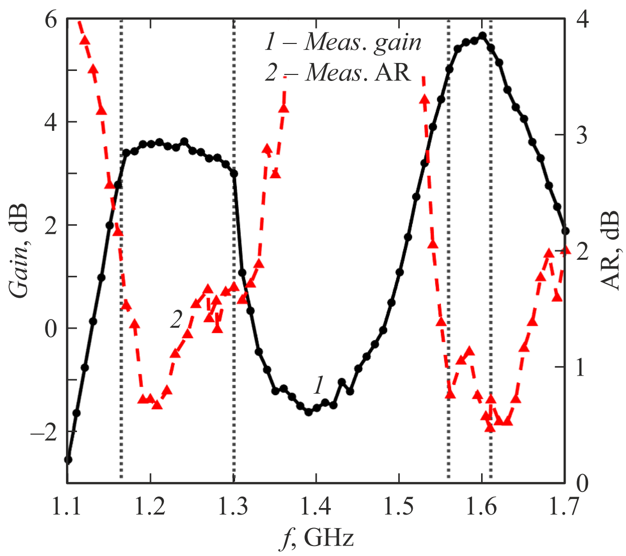

Figure 3. Measured frequency dependences of gain (*1*) and axial ratio (*2*).

within this frequency range increases to 6.5 dB without the microwave absorber, but the level of left-hand circular polarization at the zenith of the antenna RP also rises from −18 to −13 dB.

Figure 2, *a* shows the photographic image of the antenna without a cover. The antenna screen diameter is 146 mm, and the distance between the radiator and the screen is 12.3 mm. The calculated (curve *1*) and measured (curve *2*) normalized antenna RPs at a frequency of 1300 MHz are shown in Fig. 2, *b*. It can be seen that they agree fairly well within the range of elevation angles $\theta \pm 85°$ from the zenith.

The antenna gain reduction from the zenith to the horizon is close to 12 dB. The measured back lobe level decreases due to insufficient shielding of the antenna housing in the nonreflecting room. The calculated worst-case suppression of left-hand circular polarization was −18 dB at the zenith of the antenna RP (curve *3*).

The measured frequency dependences of gain (curve *1*) and axial ratio (curve *2*) are shown in Fig. 3. With a microwave absorber height of 12.3 mm and a width of 9 mm, the measured antenna gain was 3 dB (with 0.5 dB ripple) within the frequency range of 1164−1300 MHz and 5 dB (with 0.5 dB ripple) at 1559−1610 MHz. The worst-case axial ratio was 1.8 and 1.2 dB within the frequency range of 1164−1300 and 1559−1610 MHz, respectively. The standing wave ratio was no worse than 1.7 within both ranges.

Thus, a method for expanding the bandwidth of trailing-wave circular-polarization slot strip antennas was proposed. It was demonstrated that the utilization of all slots within each range of operating frequencies (1164−1300 and 1559−1610 MHz) allows for a two-fold increase in the number of their resonances (in comparison with classical slot strip GNSS antennas), which provides an opportunity to maintain a high antenna gain with an expanded bandwidth. Therefore, it becomes possible to use a microwave absorber in broadband slot strip GLONASS, GPS, Galileo, and Beidou antennas (in contrast to foreign counterparts), which is beneficial for cross-polarization isolation that is needed to suppress multipathing.

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Conflict of interest

The authors declare that they have no conflict of interest.

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