Hindawi
International Journal of Antennas and Propagation
Volume 2022, Article ID 1527674, 6 pages
https://doi.org/10.1155/2022/1527674

Research Article

New Choke Ring Design for Eliminating Multipath Effects in the GNSS System

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Received 1 July 2022; Accepted 30 September 2022; Published 11 October 2022

Academic Editor: Seong-Youp Suh

An anti-multipath antenna is an antenna that can effectively suppress multipath signals from the source of signal reception. There are many problems in the traditional choke design, such as excessive volume and low elevation gain damage. In this paper, the conventional choke ring is improved by using the complementary trapezoidal structure, and the detailed design process is given. The measured results show that the choke has good resistance to a multipath effect in the navigation frequency band (1.1–1.7 GHz) and can significantly improve the front-to-back ratio of the antenna.

1. Introduction

An anti-multipath antenna is an important kind of satellite navigation receiver antenna, especially for high-precision applications [1–3]. It can effectively suppress the multipath signal at the source of signal reception, which is beneficial to improving the final positioning accuracy. Therefore, the anti-multipath technology of an antenna is the key technology in GNSS antenna technology. At present, the anti-multipath technologies of an antenna include choke technology, electromagnetic bandgap technology, sawtooth structure, and surface wave suppression patch antenna. Choke ring technology is the most mature antenna anti-multipath technology. At present, choke coil technology is used in anti-multipath antennas of major antenna manufacturers.

The traditional choke ring is to set three to five equal height choke slots around the antenna, and the slot depth is about one quarter of the wavelength. At present, the choke ring used mainly has the following problems: first, the choke ring with the same depth only works in a narrow frequency range. For example, an early product by Filippov, its anti-multipath effect is very significant in the L2 band but not in the L1 band [4]. Ashjaee et al. proposed a dual frequency choke ring [5]. They set a filter diaphragm in the choke. The diaphragm is almost transparent to the electromagnetic wave in the L2 band but has a strong inhibitory effect on the electromagnetic wave in the L1 band. Second, the low elevation gain of the traditional choke is poor. In order to solve this problem, researchers proposed a 3D choke, which effectively improved the low elevation gain [6]. Third, choke antennas are generally expensive and have large volume with poor portability. They are generally only used for reference station antennas and scientific research [7]. The miniaturization of the choke has always been a difficulty. In order to solve this problem, Francesca and Makarov proposed a low profile choke structure, which reduces the choke height to 65% of the traditional choke. Allahgholi Pour and Shafai proposed a simple ring choke excited compact dual-mode circular waveguide feed for offset reflector antennas [8]. It will be very meaningful to improve the traditional choke and reduce its size while eliminating the multipath effect.

2. Choke Structure Design

According to different structures, common chokes can be roughly divided into single slot deep single frequency chokes, double slot deep double frequency chokes, and three-dimensional chokes. This paper adopts a three-dimensional choke structure. The choke is composed of a base, an inner core layer, and two layers of concentric circular grooves around. The height of the outer wall of the concentric circular groove is reduced from inside to outside, showing a three-dimensional effect as a whole. The design of two layers of concentric circular grooves can reduce the volume of the antenna.

The choke antenna is modeled and simulated by using HFSS software. In this paper, the L1 (1575 MHz) and L2 (1227 MHz) frequency points of the GPS will be used to characterize the influence of the choke on the performance of the antenna and the elimination of the multipath effect.

2.1. *Overall Design of the Choke with the Complementary Trapezoidal Structure.*

Generally, the surface wave consists of TE and TM modes. The surface of the plane floor is similar to the characteristics of PEC (perfect electric conductor), and its tangential electric field to E_*t* = 0; that is, a TE wave cannot propagate, but a TM wave can propagate on the surface of the plane floor. Similarly, for PMC (perfect magnetic conductor) surface, its tangential magnetic field H_*t* = 0, so a TM wave cannot propagate, but a TE wave can propagate on the PMC surface. The metal-corrugated surface structure with the cross arrangement of the PEC surface and equivalent PMC surface can neither transmit the TE wave nor TM wave when its depth is one quarter of the wavelength; that is, the propagation of a surface wave is restrained. When the depth d of the multipath choke satisfies the expression $\lambda/4 < d < \lambda/2$, there is no transmission of the surface wave on the metal-corrugated surface. Therefore, if the metal-corrugated surface structure is installed around the antenna floor, the propagation of the surface wave on the antenna ground plate can be effectively restrained so as to improve the back lobe of the antenna.

The choke with a sawtooth structure is a relatively novel structure. It was seen in an article published by Liu et al. in 2017 [9], which showed a cross vibrator antenna with a sawtooth reflector. Although the sawtooth structure plays a great role in improving the anti-multipath ability of the antenna, the reflection cavity of the antenna can be regarded as a waveguide to "guide" the propagation of electromagnetic waves. A regular reflection cavity can make the electromagnetic field more likely to maintain the original polarization characteristics in the propagation process. A zigzag irregular structure may change the distribution characteristics of the electromagnetic field under some specific conditions, so it is easier to produce crosspolarization components. Therefore, it is necessary to further study and improve the structure. According to the anti-multipath principle of the sawtooth structure, the greater the degree of damaging the circumferential current at the top, the better the anti-multipath ability. The use of complementary trapezoidal structures may improve this situation.

Based on the above theoretical analysis and the theory of the frequency selective surface, a choke design method of a complementary trapezoidal structure is proposed in this paper, and the structure is deeply studied. Its specific structure is shown in Figure 1. Next, the specific design process is described.

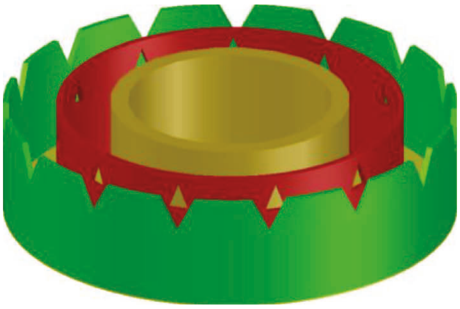

Figure 1: The new choke structure proposed in this paper.

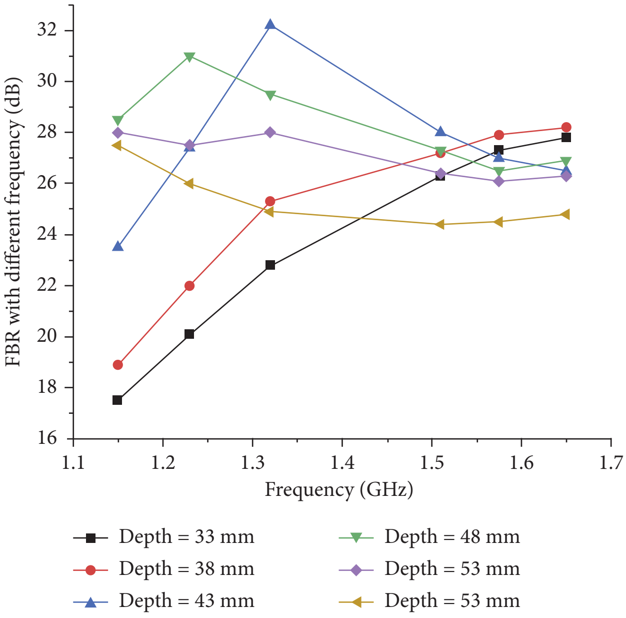

Figure 2: Effect of choke depth on the antenna front-to-rear ratio.

2.2. *Depth Selection of the Choke with the Complementary Trapezoidal Structure.*

The influence of the depth change of the choke ring on the antenna is studied by HFSS software, especially the influence of the depth change of the choke ring on the antenna front-to-back ratio. The specific influence results are shown in Figure 2.

It can be seen from Figure 2 that the choke has different effects on electromagnetic waves of different frequencies. At the frequency points near L1 and L2, the front-to-back ratio first increases and then decreases with the increase in depth, which proves that the suppression effect of multipath signals deteriorates with the increase in distance from the central working frequency point. According to the requirements of the navigation working frequency band, the choke depth selected is 48 mm.

2.3. *Selection of the Number of Chokes with the Complementary Trapezoidal Structure.*

Considering the manufacturability of antenna processing, the complementary trapezoidal structure is selected at the top of the two reflection cavities. In this way, the optimization of a trapezoidal structure is mainly to optimize the number and height of trapezoids. The main inspection indexes are the gain front rear ratio and axial ratio (AR) of the antenna. The axial ratio is a variable in a large range, but it has no serious effect on the gain loss. Another important effect of a large axial ratio is that it will increase the multipath effect because a large axial ratio means strong reception capacity of left-handed circular polarization, and the energy contained in the multipath signal after one reflection is mainly a left-handed polarization wave, so it is still important to control the axial ratio.

Figures 3 and 4 show the variation curves of FBR and AR when the trapezoidal height = 15 mm and the trapezoidal number $n = 12$, 16, 20, 24, 28, 32, 36, and 40. It can be seen that with the increase in N, the FBR in the L1 band decreases slightly and the FBR in the L2 band increases slightly. AR decreases with the increase in N, indicating that the symmetry of the antenna improves with the increase in N, but as a parameter that is easy to change violently, the change can be considered to be very weak. In general, the change in the number of trapezoids has little impact on the antenna FBR and AR. When determining the number of sawtooth structures, we should focus on the manufacturability of the antenna, so the compromise is 16.

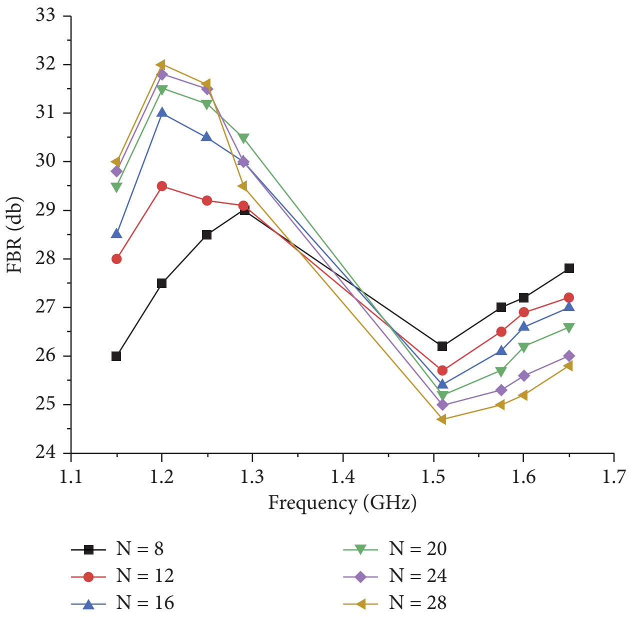

Figure 3: Influence of the trapezoidal number on the front-to-back ratio of the antenna.

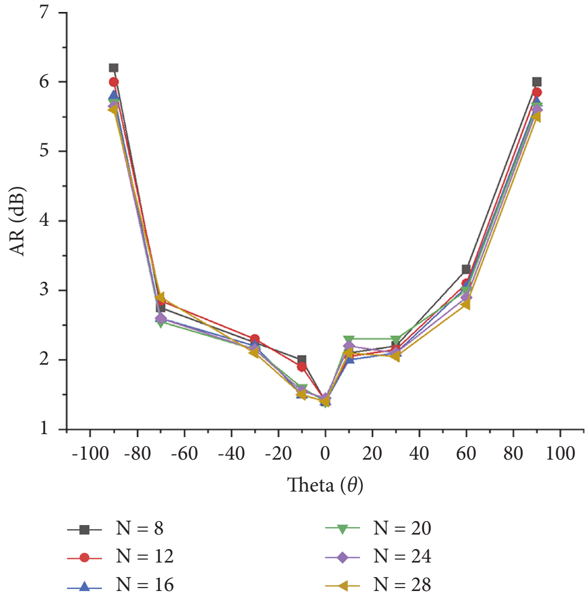

Figure 4: Influence of the trapezoidal number on the antenna axis ratio.

2.4. Trapezoidal Height Selection of the Choke with the Complementary Trapezoidal Structure. Figures 5 and 6 show the variation curves of FBR and AR when the trapezoidal number $n = 16$ and the trapezoidal height $t = 0$, 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm. It can be seen that with the increase in trapezoidal height, FBR changes about 7 dB near the L1 frequency band and 12–20 dB near L2 and L5 frequency bands. It can be seen that the trapezoidal height has a very significant impact on FBR in all navigation frequency bands, and the greater the sawtooth height, the greater the improvement of FBR. Therefore, in order to obtain better anti-multipath performance, the sawtooth height should be as large as possible.

The trapezoidal height also has a very obvious impact on AR, and the greater the height, the more serious the deterioration of AR. Therefore, in order to ensure better polarization characteristics, the height of the trapezoid should be as small as possible. Therefore, FBR and AR should be considered when selecting the trapezoidal height. According to the application scenario of the GNSS antenna, it should be considered to increase the FBR as much as possible under the condition that the AR should meet the standard. A common measurement standard is that the axis ratio is no more than 3 dB in the 20° elevation direction, which is better than the performance requirements of the BeiDou/global satellite navigation system (GNSS) measuring antenna and the index of no more than 4 dB in the test method. Therefore, taking 3 dB as the standard, a trapezoidal height of 15 mm is selected.

3. Results and Discussion

According to the theory obtained from the above simulation results, the choke is preliminarily fabricated. First, the model of the choke is printed by using a 3D printer, and copper foil is pasted on its surface. Then, the antenna is placed and fixed above to test the antenna performance. By observing its impact on the antenna performance, the ability of the choke to eliminate the multipath effect can be measured. Figure 7 shows the fabrication of the antenna.

Figure 8 shows the pattern when the choke is not used, and Figure 9 shows the pattern when the developed choke is used. It can be seen from the test diagram that the choke improves the front-to-rear ratio of the antenna, and the axial ratio of the antenna is still good, indicating that the antenna has strong ability to resist the multipath effect.

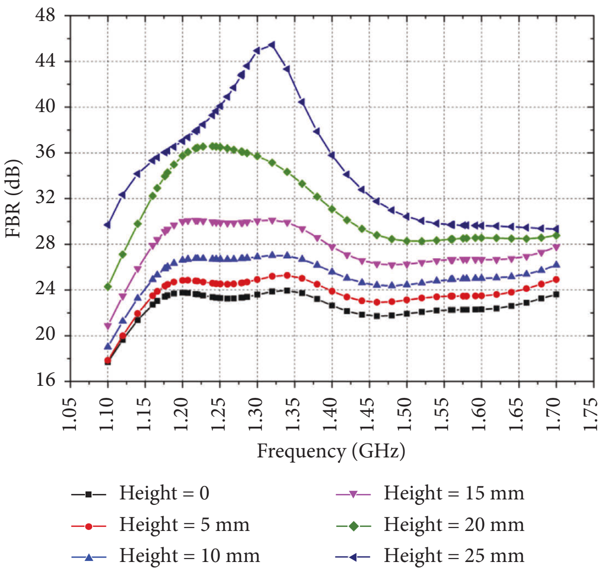

Figure 5: FBR changes with trapezoidal height.

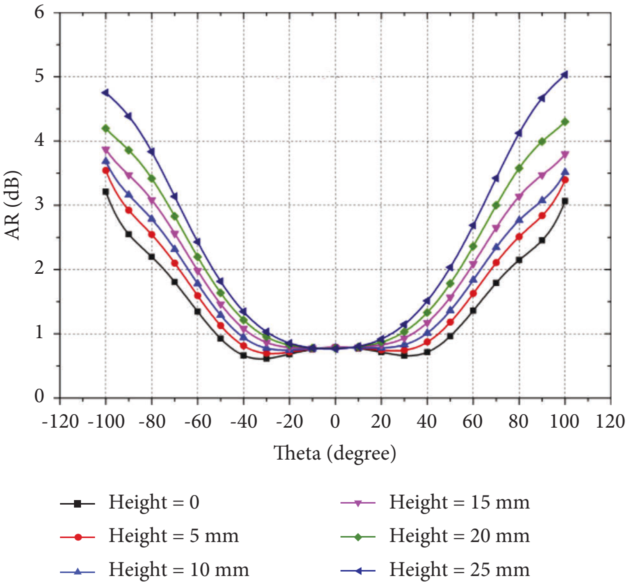

Figure 6: Change in AR with trapezoidal height.

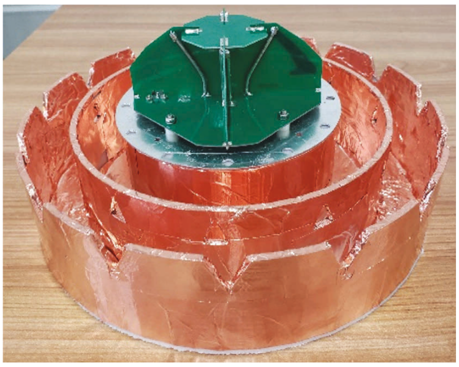

Figure 7: The antenna actually made.

It is found that in the range of an elevation angle greater than 70°, the measured front-to-back ratio of nine groups is between 25–35 dB and the simulated front-to-back ratio is 28 dB, which are basically consistent. In terms of the axial ratio, the simulation and measured results are highly consistent in the trend, and the symmetry of the measured axial ratio is less than that of the simulation data, which is related to the symmetry of antenna fabrication. Specifically, for the axial ratio at 20° elevation, the measured value is 0.5–1 dB larger, which means that the LHCP gain of the antenna itself is very low, the received LHCP signal is very weak, and the noise in the measured environment will greatly affect the reception of LHCP waves. Thus, the measured LHCP gain is too large, so is the shaft ratio.

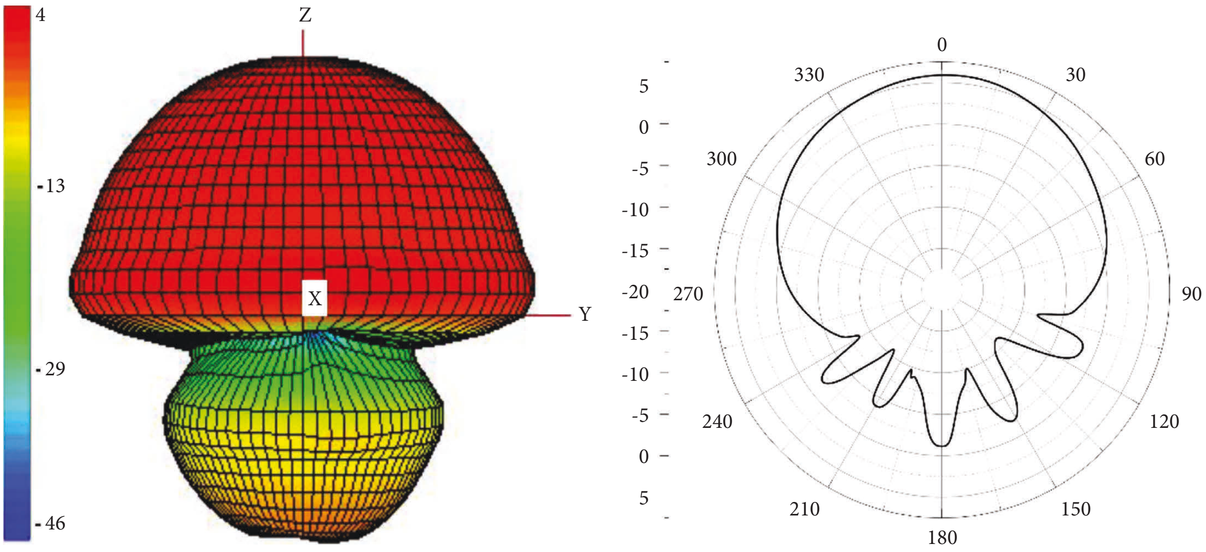

Figure 8: The pattern when the choke is not used (simulated and measured results).

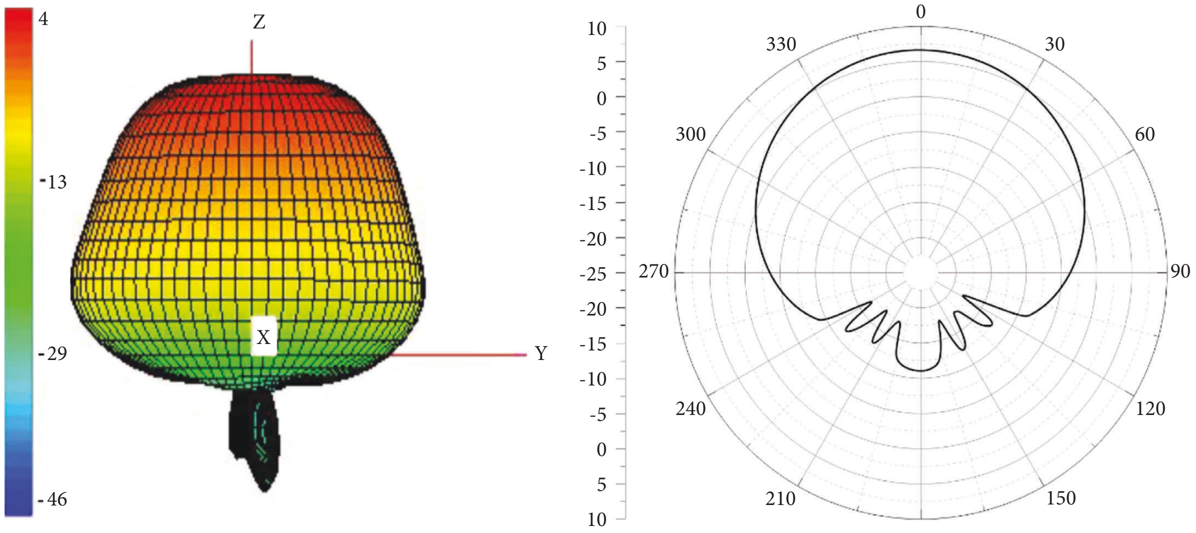

Figure 9: The pattern when the choke is used (simulated and measured results).

4. Conclusion

Through simulation and comprehensive measurement, the effects of different complementary trapezoidal structure parameters on the antenna pattern, FBR, and AR are found. By making and testing the choke, the results show that the choke meets the requirements of high-precision measurement of the GNSS antenna for anti-multipath ability and maintains good axial ratio performance.

Data Availability

The measurement data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported in part by the Research on Key Technologies of Accurate Positioning of BINGTUAN Transportation Key Vehicles and Infrastructure Based on BeiDou under Grant 2108AB028 and the Project of Young YuYou of the North China University of Technology, 2018.

References

[1] E. Taghdisi, M. S. Ghaffarian, and R. Mirzavand, "Low-profile substrate integrated choke rings for GNSS multipath mitigation," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 3, pp. 1706–1718, 2022.

[2] M. K. Emara, J. Hautcoeur, G. Panther, J. S. Wight, and S. Gupta, "Surface impedance engineered low-profile dual-band grooved-dielectric choke ring for GNSS applications," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 2008–2011, 2019.

[3] D. J. Sawyer, S. Das, N. Diamanti, A. Peter Annan, and A. K. Iyer, “Choke rings for pattern shaping of a GPR dipole antenna,” *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 12, pp. 6781–6790, 2018.

[4] V. Filippov, D. Tatarnicov, J. Ashjaee, A. Astakhov, and I. Sutiagin, “The first dual-depth dual-frequency choke ring,” *International Technical Meeting of Satellite Division of the Us Institute of Navigation*, pp. 1035–1040, 1998.

[5] J. Ashjaee, V. S. Fillippov, D. V. Tatarnikov, A. V. Astakhov, and I. V. Sutjagin, “Dual-Frequency Choke-Ring Ground Plane,” US. Patent, NO. 6278407B1, 2001.

[6] M. K. Emara, K. Madhoun, R. Madhoun, and S. Gupta, “A low-cost light-weight 3D-printed choke ring for multipath mitigation for GNSS antennas,” in *Proceedings of the IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, pp. 721-722, Atlanta, GA, USA, July 2019.

[7] A. V. Boriskin, M. Zhadobov, C. Person, and R. Sauleau, “Focusing choke ring antenna for a short-range millimeter-wave exposure system,” in *Proceedings of the European Microwave Conference*, pp. 365–368, Nuremberg, Germany, October 2013.

[8] Z. Allahgholi Pour and L. Shafai, “A ring choke excited compact dual-mode circular waveguide feed for offset reflector antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 6, pp. 3011–3015, 2012.

[9] S. Liu, D. Li, B. Li, and F. Wang, “A compact high-precision GNSS antenna with a miniaturized choke ring,” *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2465–2468, 2017.