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RESEARCH ARTICLE

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Analysis on two novel spherical helical antennas

Abstract Two novel spherical helical antennas are designed by projecting the planar equiangular spiral antenna onto hemisphere and partial sphere surfaces. Their radiation properties are analyzed by the moment method with curved basis and test function, and the curves of the voltage standing wave ratio (VSWR), gain, polarization and pattern that change with frequency are also given, respectively. It can be seen that the circular polarization band of the novel hemispherical helical antenna is broader. The gain curve of the partial spherical helical antenna is flatter and the structure is simpler.

Keywords spherical helical antenna, method of moment (MoM), curved basis function

1 Introduction

In mobile satellite communication systems, the radiation of antennas should cover a wide region so that the satellite can communicate with terminals on the ground. Thus, antennas with circular polarization and wide beam radiation are needed. Conventional long cylindrical helical antennas and microstrip antennas can produce circular polarization radiation but only within a small angular range in the axial direction and in a narrow frequency band. It was Riblet H B who proposed the spherical helical antenna in 1960 for the first time, and made lots of experiments later. After that, a kind of non-uniform spherical helical antenna was studied by Mei and Meyer [1] with theoretical analysis on far field radiation. The non-uniform spherical helical antenna was paid more attention to and studied in recent years though it was proposed early by Mei and Meyer. More detailed research on the antenna was made in Virginia University. The impedance and circular polarization were studied by Safaai-Jazi [2]. A hemispherical helical antenna was proposed by Hui [3,4]. It provides a more robust and low-profile structure.

It can be seen from references that the spherical helical antenna, which has been studied, are equal in the spaces between adjacent helixes. Detailed research on other types of windings on the spherical helical antennas was not carried out in the past decades. In this article, two kinds of spherical helical antennas were proposed by projecting the planar equiangular spiral antenna onto the surfaces of the sphere. Their radiation properties are analyzed by the moment method with curved basis and test function, and the curves of the voltage standing wave ratio (VSWR), gain, polarization and pattern vs. frequency are also given, respectively.

2 Structure of antennas

The planar equiangular spiral antenna, as shown in Fig. 1(a), is independent of frequency. It can provide good properties of impedance and radiation in a wide frequency region. A hemispherical helical antenna can be formed by projecting the planar equiangular spiral antenna onto the surfaces of the hemisphere whose diameter is the maximum of the planar equiangular spiral. Its structure is shown in Fig. 1(b). A partial sphere helical antenna can be formed by projecting the planar equiangular spiral antenna onto the surfaces of the hemisphere whose diameter is greater than the maximum diameter of the planar equiangular spiral. Its structure is shown in Fig. 1(c).

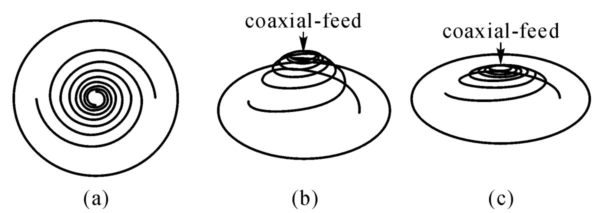

Fig. 1 Structure of antennas. (a) Planar equiangular; (b) hemispherical helical; (c) partial sphere helical

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The curved portion of one thin wire is described by the following equation in the polar coordinate system:

$$\begin{cases} r = a, \\ \theta = \cos^{-1}(1 - \sqrt{1 - e^{-2\varphi\tan\alpha}}), \end{cases} \quad 0 < \varphi < 2N\pi, \qquad (1)$$

where a is the radius of the sphere and N is the total number of turns of the helix. θ and φ represent elevation angle and azimuth respectively. α is the helical angle.

3 Moment method based on curved functions

The analysis method employed in this article is the method of moment [5]. Partition the helical wire into $M+1$ helical segments (where M is odd number) and suppose that the length of each segment is d in the axial direction, then spread the expression of the current of the antenna by the subsection triangle basis function shown in Fig. 2(a) as follows:

$$I(z) = \sum_{n=1}^{M} I_n A_n(z), \qquad (2)$$

where

$$A_n(z) = \begin{cases} (d - |z - z_n|)/d, & z_{n-1} \leqslant z \leqslant z_n, \\ 0, & \text{others}. \end{cases} \qquad (3)$$

Put Eqs. (2) and (3) into the electric field integral equation (EFIE) and choose the pulse basis function shown in Fig. 2(b) as the test function, then

$$w_m(z) = \begin{cases} 1, & z \in (z_{m-}, z_{m+}), \\ 0, & \text{others}. \end{cases} \qquad (4)$$

As the test function, the matrix function can be gained by the expression:

$$[Z_{mn}][I_n] = [V_m]. \qquad (5)$$

In this way, the number of the unknown matrix to calculate is reduced significantly, which can accelerate the computing speed and save much time [6,7].

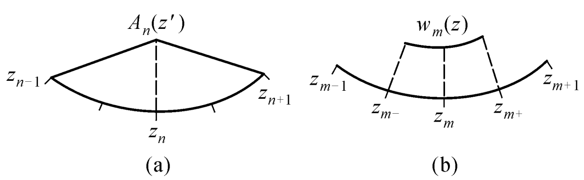

Fig. 2 Curved basis function and test function

4 Analysis of antennas

As regards to the hemisphere helical antenna studied in this article, the radius of the hemisphere is 70 mm, the diameter of the spiral wire is 0.1 mm and the turns number N is 4. As regards to the partial sphere helical antenna, its radius is also 70 mm and the height is 35 mm, which is half of the hemisphere helical antenna. Besides, a reflection plate with a diameter of 200 mm is added to increase the radiation, and the distance between the plate and the hemisphere is 2 mm.

The results calculated by the moment method are shown in Figs. 3–8.

Figure 3 shows the curves of VSWR vs. C/λ (where C is the circumference of the sphere and λ is the wavelength). It can be seen that the VSWR is less than 3 while C/λ is greater than 1.8 from $C/\lambda = 1.7$ to $C/\lambda = 5.8$. The two curves are basically the same as the frequency varies. The variations of the gain with C/λ are shown in Fig. 4. As regards the hemisphere helical antenna, the gain varies rapidly in the whole frequency band. The 3 dB bandwidth of the gain are only in the ranges of $1.1 < C/\lambda < 2.7$ and $4 < C/\lambda < 5.5$. In the partial sphere helical antenna, the variations of the gain with C/λ are little from $C/\lambda = 1.1$ to $C/\lambda = 5.6$, which shows a wide gain bandwidth.

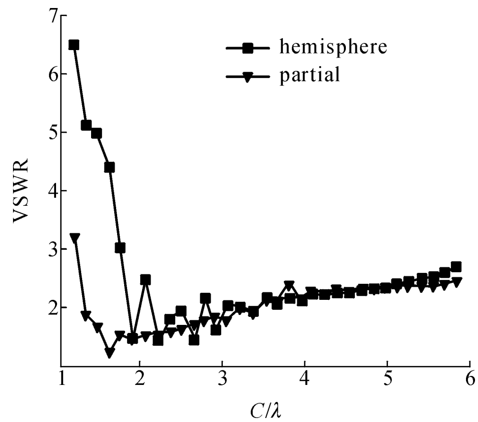

Fig. 3 VSWR curves

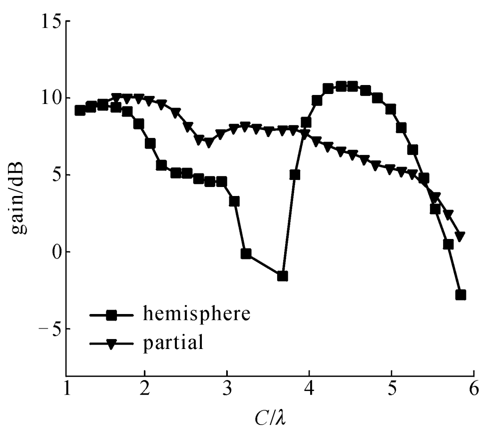

Fig. 4 Gain curves

Figure 5 shows the curves of axial ratio vs. C/λ. It can be seen that the axial ratio is less than 3 dB while C/λ is greater than 1.5 for the hemisphere helical antenna, and the axial ratio is less than 3 dB while C/λ is greater than 2.7 for the partial helical antenna, showing that the hemisphere helical antenna has a wider circular polarization bandwidth.

Figures 6–8 show the radiation patterns while C/λ is 2.7, 4.5 and 5.5 respectively. It can be seen that both antennas have the properties of axial radiation and wider beam.

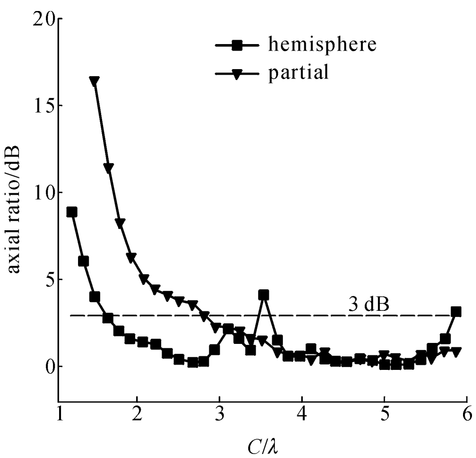

Fig. 5 Axial ratio curves

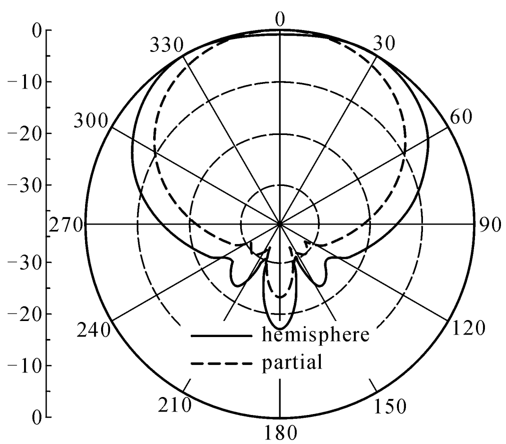

Fig. 6 Radiation pattern while $C/\lambda = 2.7$

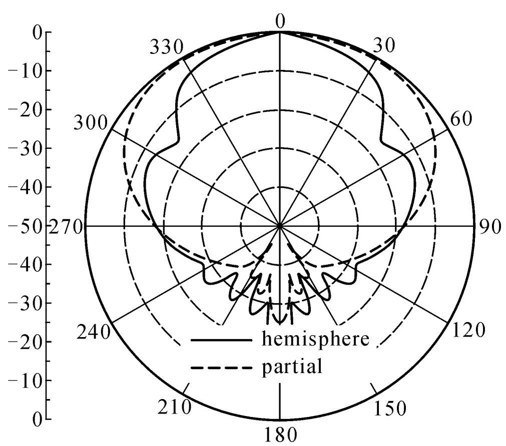

Fig. 7 Radiation pattern while $C/\lambda = 4.5$

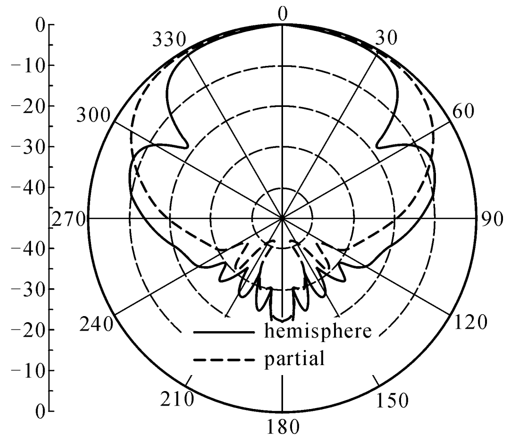

Fig. 8 Radiation pattern while $C/\lambda = 5.5$

5 Conclusions

Two novel spherical helical antennas are designed by projecting the planar equiangular spiral antenna onto hemisphere and partial sphere surfaces. Their radiation properties are analyzed by the moment method with curved basis and test function. It can be seen that the circular polarization band of the novel hemispherical helical antenna is broader. The gain curve of the partial spherical helical antenna is flatter and the structure is simpler.

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