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ПРОЕКТИРОВАНИЕ МНОГОСЛОЙНОЙ СТРУКТУРЫ БИФИЛЯРНОЙ СПИРАЛЬНОЙ АНТЕННЫ

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DESIGN OF A MULTI-LAYER STRUCTURE OF A BIFILAR HELICAL ANTENNA

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Основываясь на опыте проектирования традиционной спиральной антенны и многослойной печатной платы, в данной статье предлагается многослойная бифилярная спиральная антенна на печатной плате, работающая в диапазоне С. Антенна состоит из нескольких симметричных металлических дуг, которые распределены по разным слоям и соединяются сквозными отверстиями. Результаты показывают, что антенна имеет низкопрофильное излучение с круговой поляризацией и лучшее согласование импедансов, обеспечивая новое решение для проектирования структуры многослойной антенны.

Ключевые слова: *низкий профиль*, *бифилярная спиральная антенна*, *многослойная печатная плата*, *круговая поляризация*.

Based on the design experience of traditional helical antenna and multi-layer PCB structure, a multi-layer PCB bifilar helical antenna that works in C band is proposed in this paper. The antenna is composed of several symmetrical metal arcs, which are distributed on different layers and connected by plated via-holes. Meanwhile, the design and the simulation results are given in the paper. The results show that the antenna has low profile, circularly polarized radiation and better impedance matching, providing a novel solution for the design of multi-layer structure antenna.

Keywords: *low profile*, *bifilar helical antenna*, *multi-layer PCB*, *circular polarization.*

Introduction

As a common circularly polarized antenna, helical antenna can suppress the multipath reflection, avoid the polarization mismatch, and support a flexible alignment for the receiving and transmitting antennas. It also has high gain and wide bandwidth. So the helical antenna is very needed for airborne and space tracking applications [1].

However, common axial mode helical antenna often requires more than 3 turns of helical coils and pitch angles between 12° and 14°, which leads to the large axial sizes. So it is not suitable for surface-mounted and space-constrained application [2]. To reduce the size of the helical antenna, some scholars have found that a helical antenna with a small number of turns and a small pitch angle is also capable of radiating circularly polarized waves [3]. However, short helical antenna is still of three-dimensional structure and requires high precision in machining.

Multilayer structures are commonly used in the design of metamaterials. Such structures have a low profile, and are easier to be implemented using the printed circuit board technology. Some scholars have combined the printed circuit board technology with helical antennas to make planar helical antennas by using printed strips that are straight-edge connected by plated through holes [4]. The antenna has a simple structure, a low profile and excellent CP performance with end-fire radiation.

According to the theory of helical antennas, the gain of a single-arm helical antenna is 2 dB lower than that of a bifilar helical antenna [5]. In this paper, a new bifilar helix antenna operating at 5.2 GHz based on multi-layer PCB technology is described. The radiation pattern and circular polarization performance are optimized. The proposed antenna emits mainly along the axis of the helix, in contrast to the previously considered bifilar helical antenna [6], [7]. The radiation from the former antenna is directed mainly perpendicular to the axis of the helix. The thickness of the antenna is only 7.2 mm and the design reduces the height and volume compared with traditional helix antenna. Also, the structure is simple and low cost. It can be easily fabricated using the printed circuit board technology.

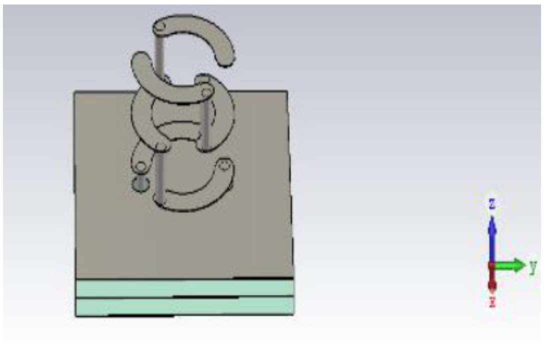
1 Antenna structure

The antenna model was built in Computer Simulation Technology (CST) Microwave Studio and the simulation was completed.

The configuration of the proposed planar multi-layer bifilar helical antenna is shown in Figure 1.1. The dielectric plate of the antenna part is hidden to make the antenna structure more intuitive to see.

The material used in the system is FR-4, the dielectric constant is 4.4. The substrate size is 20 mm × 20 mm.

In Figure 1.1, the antenna is composed of several symmetrical metal arcs, which are distributed on different layers and connected by plated via-holes. The circular arcs and columnar through holes are used to generate horizontal and vertical electric fields, respectively. In order to ensure the connection of the upper and lower metal arms, pads are added around the two via holes of the metal arm. The antenna is fed at the bottom using a differential port feed. Separation of the feeding arm and the helical arm of the antenna with the metal plate, not only realizes the differential feeding of the ports required by the helical antenna, but also avoids mutual interference between the helical portion of the antenna and the lower feeding network.



(a) 3D antenna structure (media board is hidden)


(b) Helical arms on each layers.

Figure1.1 – Antenna model in CST Microwave Studio

Traditional helical antenna usually needs to consider parameters such as the number of turns *N*, the radius of the helix *R*, the pitch of the helix *S*, the cutting angle of the helix α, the height from the ground *H*, and the width of the line *W*. Therefore, similar parameters should be considered.

In this design, the radiation of the bifilar helical antenna can be considered as the synthesis of the radiation fields of multiple arcs and the radiation fields of multiple short dipoles.

The short dipole's radiation field has only a vertical component:

$$E_\theta = j\frac{60\pi I}{r}\sin\theta\cdot\frac{S}{\lambda}.$$

The radiation field of the arcs has only the horizontal component:

$$E_\phi = \frac{120\pi^2 I}{r}\sin\theta\cdot\frac{A}{\lambda^2}.$$

A is the area of the small rings. D is the diameter of the rings $A = \pi D^2/4$.

When $|E_\theta| = |E_\phi|$, a circularly polarized wave is generated. At this time, the following relationship should be satisfied between the parameters of the helical antenna: $\pi D = \sqrt{2S\lambda}$.

If the radiated wave propagates along the helix axis, that is the OZ axis, then this wave is created only by circular arcs. Vertical holes do not contribute to the radiated wave in this case. Then the circular polarization of the radiated wave can be obtained under the condition, which is often used for helical antennas:

$$\frac{\lambda}{\sqrt{\varepsilon}} \approx S + \pi D.$$

This formula means that the wavelength is approximately equal to the length of the helix turn. In this case, the wavelength is calculated taking into account the dielectric constant of the material surrounding the helix.

In this design, the thickness of the PCB board is fixed, so the parameter *S* is fixed, and the diameter of the arcs can be calculated. A multi-layer structure helical antenna operating in the C-band is designed. The relevant parameters are shown in Table 1.1.

Table 1.1 – The parameters of the antenna

R	Radius of helix	4.262 mm
*H*1	Pitch	3.6 mm
W	Helical arm width	2 mm
*H*2	Height from the ground	1.2 mm
α	helical arm curvature	120°
Rs	radius of pads	0.9 mm
Rvia	radius of via-holes	0.5 mm
N	Number of helix	1

2 Simulated performance and parameter study

Simulated performance

The *S*-parameters and radiation directivity obtained from the time-domain analysis using Computer Simulation Technology (CST) Microwave Studio are shown in Figure 2.1. As can be seen, the impedance bandwidth for |*S*11| <= −10 dB is from 4.9 GHz to 5.5 GHz.

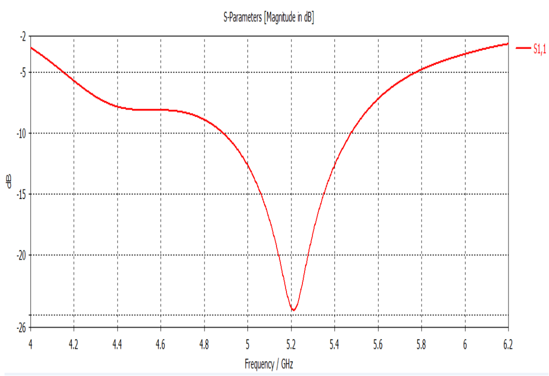
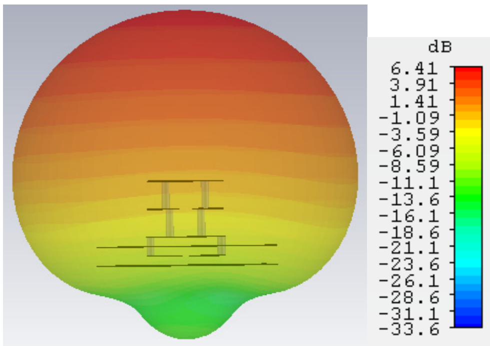
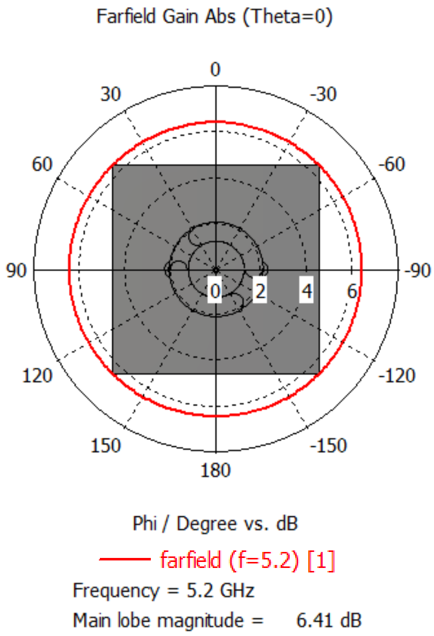


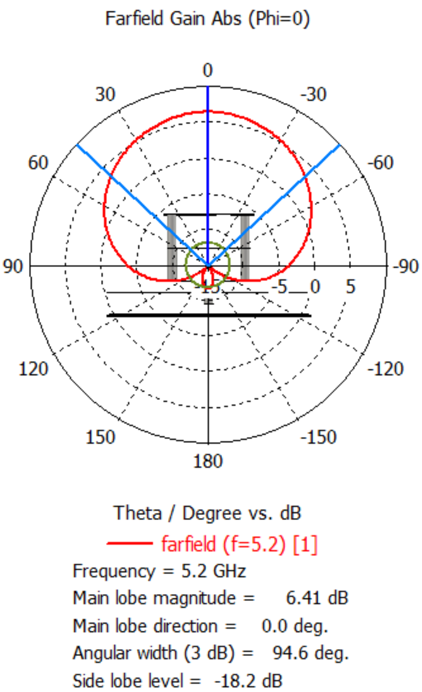
Figure 2.1 – *S*11-parameter



(a) 3D radiation pattern at 5.2 GHz



(b) YOZ direction



(c) XOZ direction

Figure 2.2 – Radiation pattern of the antenna at 5.2 GHz

It can be seen in Figure 2.2 that the antenna has good omnidirectional radiation characteristics at a resonant frequency of 5.2 GHz with a gain of approximately 6.5 dB. As it is shown in Figure 2.3, the axial ratio at 5.2 GHz of the antenna is less than 5 dB. The results are: the designed antenna has good circular polarization and can achieve similar radiation characteristics of the traditional helical antenna.

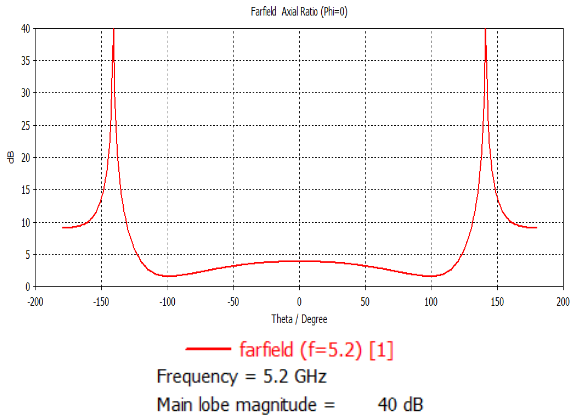


Figure 2.3 – Axial Ratio

As is shown in Figure 2.4, the electric currents along the spiral arm and the through hole are almost equal. According to the introduction in Chapter 2, circularly polarized radiation can be realized.

However, the through holes between each layer are relatively small compared with the helical arms, so the electric field in the horizontal direction is stronger than the vertical direction, which makes the axial ratio of the planar helical structure worse than the traditional helical structure.

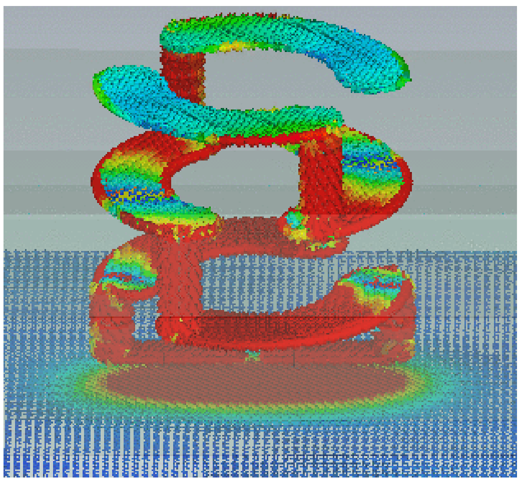


Figure 2.4 – Surface current at 5.2GHz

Parametric study

Because the number of PCB antenna layers should not be too large, the design is similar to a short spiral unit.

The traditional helix antenna has some important parameters, such as: the helical diameter, pitch, pitch angle, number of turns and axial length.

The multi-layer bifilar helix antenna has the similar parameters.

A parametric study is conducted in order to examine the effects of the key parameters on the radiation performance and it helps to optimize the performance of the antenna.

Helical diameter. In the design of helical antenna, the resonant frequency is closely related to the helical diameter. A parametric sweep analysis of the effect of changes in the diameter of the designed helical antenna on the resonant frequency of the entire antenna system is shown in Figure 2.5.

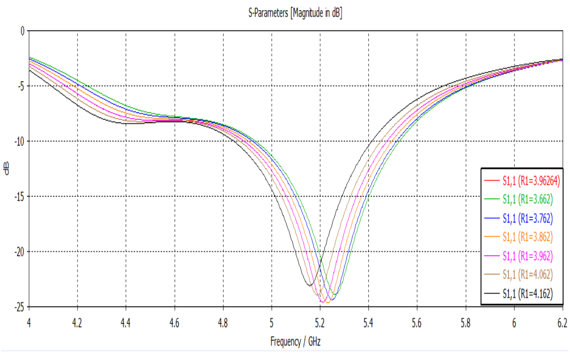


Figure 2.5 – Effect of spiral diameter on resonant frequency

It can be seen from the results that as the diameter of the helical antenna increases, the resonant frequency of the antenna gradually decreases, which is consistent with the theory of the classical helical antenna. This shows that the designed planar helical antenna has similar properties to the traditional helical antenna.

Size of the ground.

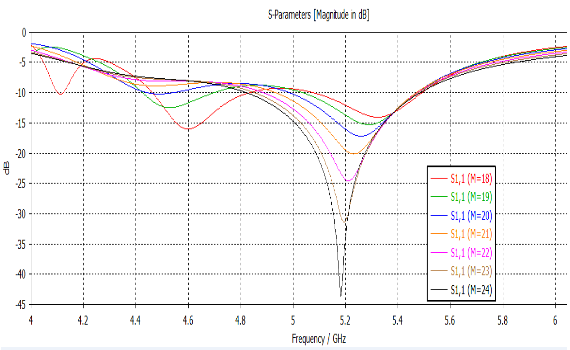


Figure 2.6 – Effect of size of the ground on resonant frequency

It can be seen that as the floor changes, the resonant frequency is almost constant, but the *S*-parameter increases and the gain of the antenna is reduced to about 2dB.

Conclusion

In this paper, a multi-layer structure helical antenna is realized by symmetrical metal arcs connected by plated through holes. According to the designed antenna structure and the principle of circular polarization, the relevant parameters of the antenna that works in C-band are calculated. To simulate the antenna we use CST Microwave Studio. The simulation results show that the designed antenna can realize circularly polarized radiation from 4.9 GHz to 5.5 GHz, and analyze the influence of key parameters on the performance of the antenna. The results show that the designed antenna has similar characteristics to the traditional helical antenna. In addition, the proposed planar helical antenna is fabricated using an FR4 dielectric substrate, so it has a low profile, high stability and low cost, and can be easily extended to an array configuration. Besides, quadrifilar helix antenna requires the feeding phases to be 0°, 90°, 180°, 270°. So the bifilar helical is easier to implement.

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