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Optimization of Wide Band Circularly Polarized Microstrip Antenna for Satellite Communications Using Space Mapping

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Abstract　This work proposes a wide band circularly polarized multi-layer microstirp antenna. It consists of two circular patches with different radius, which serve as the radiating patches to obtain wide band. The two feeding points of the proposed antenna are connected with the two output ports of 3 dB directional coupler respectively. This way, the output signals at two ports of antenna are 90° out of phase, making the antenna realize the circular polarization. In order to improve efficiency, aggressive space mapping (SM) algorithm is used to optimize the proposed antenna. The optimization results of impedance bandwidth is from 0.87-2.55 GHz compared with the measurement results is from 0.88-2.55 GHz. And the axis bandwidth of simulation result is from 0.94-2.15 GHz which the measurement result is from 0.96-2.16 GHz. It can be seen that the measurement results are in good agreement with the optimization results. It can be seen that the measurement results are in good agreement with the optimization results. The results show that the aggressive space mapping algorithm is effective.

Key words　microstrip antenna; circular polarization; 3 dB directional coupler; aggressive space mapping

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0　Introduction

With the rapid development of society, the satellite navigation system is used more and more widely, thereby promoting the study of the satellite antennas. There are many different types of satellite antennas, including the cross dipole antenna, the four arm spiral antenna, microstrip antenna and helical antenna. Among them, four arm spiral antenna and microstrip antenna with excellent electrical properties are widely used in the satellites.

By cutting notches on the patch, an aperture-stacked microstrip antenna could be designed to realize dual frequency operation[1]. A wide band dual-polarized stacked patch antenna was described in[2,3]. Moreover, circularly polarized antenna is achieved by using the dual-feed or multiple-feeds network. For the dual-feed circularly polarized antenna in[4,5], the axial-ratio bandwidth is larger than 2%. The annular-ring patch antenna with two L-probe feeds[6] obtain circularly polarized characteristics.

The Chinese first generation of Beidou satellite navigation system uses a spiral antenna which has a large size. The second generation of the Beidou satellite uses a biased reflector antenna, which is smaller than the first generation. But they are still much larger than the EU's Galileo system and the GPS system used in the United States.

As an important component of the wireless communication systems, the antenna and its related research are being paid more and more attention today. Therefore, how to design and optimize the antenna efficiently in order to meet desired requirements are challenges for designers.

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The space mapping algorithm[8] is a new idea of optimization method that was proposed some years ago. It converts the complex and time-consuming optimization of the fine model into a simple and efficient optimization of the coarse model. By doing this way, the updates of the coarse model and prediction of the fine model are achieved by the mapping relations between the two models. The optimization is implemented through the coarse models, whereas the verification of design results is achieved through the fine model.

In this paper, we propose a novel wide band circularly polarized microstirp antenna to realizing low-profile and compact antenna. Due to the 90° phase difference characteristics of the microstrip directional coupler, we have achieved circular polarization characteristics of the antenna. Space mapping method is used to optimize the microstrip antenna, and a reduced number of full-wave evaluations are applied, leading to a reduced optimization time.

The remainder of the paper is organized as follows. The proposed wide band circularly polarized multi-layer microstirp antenna is proposed in detail in section 2; Optimization method in section 3 demonstrate the validity of the proposed method; The experiment verification is shown in section 4. Finally, a brief conclusion is given in section 5.

1 Antenna Layout

The proposed antenna consists of two circular copper patches, which attached on the two foam layers. The foam layers are ROHACELL A. Because the foam pore is opposite bigger, ROHACELL A particularly suited to the aerospace field, impregnation process with the temperature of 130 ℃, under the condition of 0.3 MPa vacuum infusion process. The lower patch is the main radiation element while the upper one is a parasitic patch, so that the bandwidth is broadened. The two microstrip lines are vertical orthogonal which are separated by the common ground plane, connected with the two output ports of 3 dB directional coupler respectively, so the signals at two microstrip lines are 90° out of phase. By this way the antenna can realize the circular polarization. The lower microstrip line's power is coupled to the circular patches via a cross-slot in the common ground plane. The geometry of proposed antenna is shown in Fig. 1. The two foam layers heightmm, mm and the two Rogers 5880 substrate layers height $h_1 = h_2 = 0.508$ mm. The width of 50 Ω and 100 Ω microstip line $W_{50} = 1.57$ mm, $W_{100} = 0.45$ mm respectively.

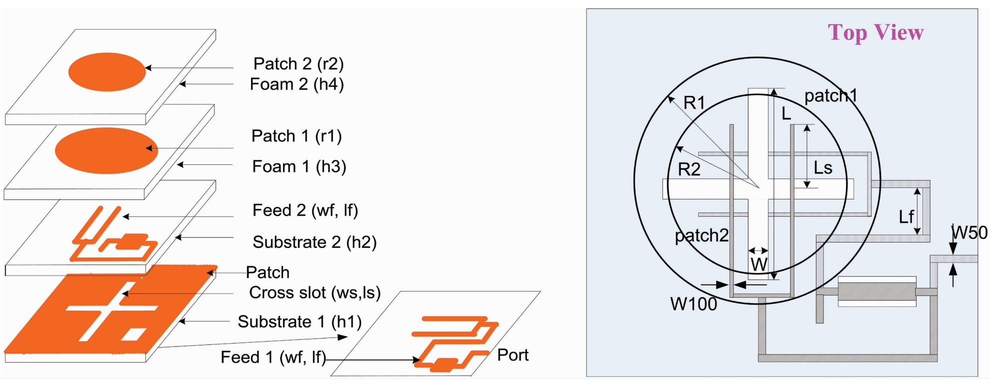

Fig. 1 The geometry of the proposed antenna

The 3 dB dual-layer microstrip directional coupler is shown in Fig. 2. The straight through port and coupling port connected with the two feeding points of the proposed antenna. The phase difference between the two feeding points of antenna is 90°, so the antenna can realized the circular polarization.

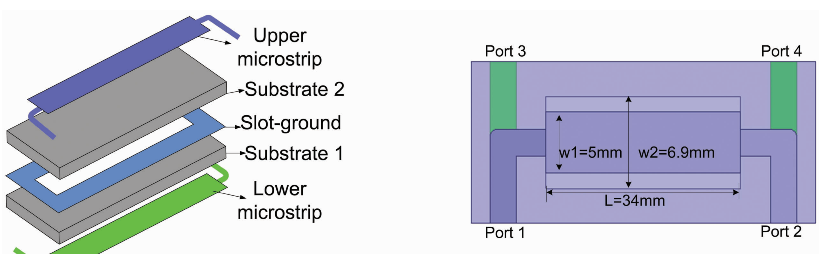

Fig. 2 The dual-layer microstrip directional coupler (a) is the geometry of directional coupler and (b) is the view of directional coupler

2　Optimization of Antenna Using SM

The space mapping algorithm is a new idea of optimization algorithm that put forward in recent years[8-10]. It could convert the complex and time-consuming optimization of fine model to the simple and fast optimization of coarse model. The space mapping algorithm updates coarse model and the prediction of fine model through the mapping relations between two models. Optimizations of the entire algorithm focus on coarse models, while the fine model is only responsible for the verification of design results. For the proposed antenna, the design goal is

$$\begin{cases} |S11| < -10\ \text{dB}, 1156\ \text{MHz} \leqslant f \leqslant 1595\ \text{MHz}, \\ AR < 3\ \text{dB}, 1156\ \text{MHz} \leqslant f \leqslant 1595\ \text{MHz}. \end{cases} \tag{1}$$

The variables need to be optimized

$$x = [W \quad R_1 \quad R_2 \quad L \quad L_f \quad L_s], \tag{2}$$

R_1 and R_2 is the radius of the two circle patches, W and L is the width and length of cross-shaped slot in the common ground plane. L_f is the distance between the two 100 Ω microstip lines. L_s is the length from the cross-shaped slot center to the end of the 100 Ω microstip line. These variables have been marked in Fig. 1.

Based on the aggressive space mapping algorithm[11], response surface approximation method[12,13] is used to construct the coarse model. The response surface method was proposed in the 1950 s, it is a method and mathematical statistics method with the combination of a kind of optimization algorithm. With an explicit analytic function to approximate the method of implicit function features known as the response surface method. Once the response surface form, the relationship between the input and output was set up, so that a given design variables and the corresponding response goes, don't need to simulation model. The response surface method has a lot of, such as Spline method based on Spline function, the polynomial approximation[12], neural network[13,14], kriging interpolation method, support vector regression method[15], etc. Kriging interpolation method is one of the most widely used in these methods, this paper will use this method.

Since the simulation of fine model and coarse discrete model using the same electromagnetic simulation software, it is not necessary to extract the equivalent circuit model of the fine model, and there is no need to apply additional simulation software. This space mapping method is more convenient to operate.

For some structures such as antennas and waveguide filters that are difficult to find reliable rough models, such structures can be used in rough models. This greatly improves the ability of spatial mapping algorithm to be used in the optimization of complex structures. The whole optimization flow chart is shown in Fig. 3 and the optimization process is described as follows.

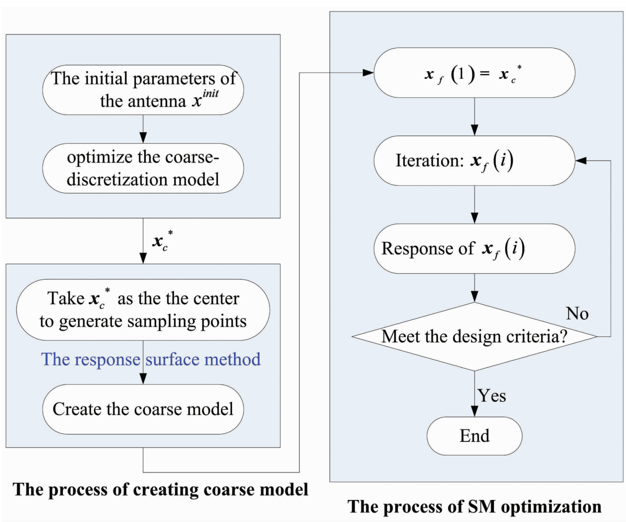

Fig. 3　The optimization flow chart

Firstly, the iterative precision of the coarse-discretization model is 0.2 in High Frequency Structure Simulator (HFSS). The built-in genetic algorithm (GA) is used to optimize the coarse-discretization model. In GA, the crossover probability is 0.8, the mutation probability is 0.05, the population size is 30, and the maximum number of iterations is 100.

Then obtained the optimal parameters are

$$x_c^* = [4.33 \quad 46.79 \quad 45.86 \quad 75.05 \quad 30.26 \quad 22.11]^T. \tag{3}$$

The 100 parameter samples are allocated in the vicinity of x_c^* of the size[±0.5,±5,±5,±5,±5,±3]. The responses of 100 samples can be obtained using the coarse-discretization model simulation. Using information of 100 samples and the corresponding responses, the approximate expression between the parameters and responses is obtained by Kriging interpolation technique[16]. The approximate expression is used as the coarse model.

The obtained parameters x_c^* are used to verify the response of a fine model, therefore the parameters of fine model are

$$x_f(1) = x_c^* = [4.33 \quad 46.79 \quad 45.86 \quad 75.05 \quad 30.26 \quad 22.11]^T. \tag{4}$$

The fine model is simulated using a commercial finite element full wave package (HFSS) and the simulated results of fine model are shown in Fig. 4.

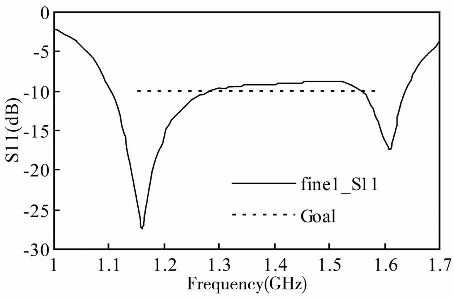

Fig. 4 The first simulation results of the fine model

The obtained responses of $x_f(1)$ are used as the new optimal goals. Upon a much faster Kriging coarse model optimization, we can extract a new set of parameters related to the coarse model as $x_c(1)$ below

$$x_c(1) = [4.62 \quad 45.90 \quad 45.07 \quad 74.36 \quad 30.39 \quad 21.31]^T. \tag{5}$$

Now the error between $x_c(1)$ and x^* is

$$f(1) = x_c(1) - x_c^* = [0.29 \quad 1.11 \quad -0.79 \quad -0.69 \quad 0.13 \quad -0.80]^T. \tag{6}$$

Use $B(1)h(1) = -f(1)$, we can obtained the modified vector $h(1)$. Where $B(1)$ is the identity matrix $B \in \mathbf{R}^{n\times n}$ (is the number of optimized parameters). So the modified vector is obtained as

$$h(1). = [-0.29 \quad -1.11 \quad 0.79 \quad 0.69 \quad -0.13 \quad 0.80]^T. \tag{7}$$

With $h(1)$, the next set of values of the fine model can be updated as

$$x_f(2) = x_f(1) + h(1) = [4.04 \quad 43.68 \quad 46.65 \quad 75.74 \quad 30.13 \quad 22.91]^T. \tag{8}$$

The optimization includes three iterations and four fine model simulations. After three iterations, the second norm of $\| f(3) \|_2 = 0.0057$ becomes less than the specified error and the iteration converges. The optimal variables of the fine model are

$$x_f^* = [4.00 \quad 48.02 \quad 44.00 \quad 75.00 \quad 28.29 \quad 22.03]. \tag{9}$$

The obtained model parameters of fine model of each iteration are listed in Table 1.

Table 1 The data of fine model. Unit/mm

Fine model	W	$R1$	$R2$	L	Lf	Ls
$x_f(1)$	4.33	44.79	45.86	75.05	30.26	22.11
$x_f(2)$	4.04	43.68	46.65	75.74	30.13	22.91
$x_f(3)$	4.06	47.71	43.94	76.86	30.17	22.82
$x_f(4)$	4.00	48.02	44.00	75.00	28.24	22.03

Table 2 The optimization costs

Algorithm Component	Number	Time
Optimization of the coarse discretization model	100	100×2 min=200 min
Simulation coarse discretization model	50	50×2 min=100 min
Fine model simulation	4	4×18 min=72 min
Parameter extraction	3	3×1.5 min=4.5 min
Total	N/A	376.5 min

Using space mapping method to optimize the microstrip antenna, can lead to a reduced optimization time. Optimization costs are summarized in Table 2. The return loss of the proposed antenna before and after optimization are shown in Fig. 5. Before optimization, the return loss of antenna was greater than-10 dB between 1.41 GHz and 1.56 GHz, which did not meet the design specifications. Using the aggressive space mapping algorithm, the performance of the antenna reaches the design specifications after three iterations and four fine model simulations.

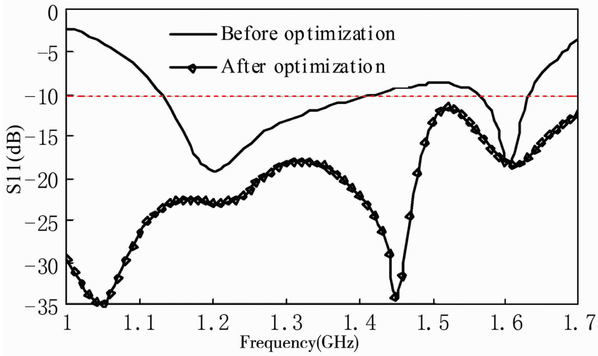

Fig. 5　The return loss before and after optimization

3　Experiment Verification

The photograph of the antenna is shown in Fig. 6. A universal test fixture (Anritsu 3680 V) is used to clamp the antenna, which is measured with network analyzer Agilent N5 244A. The simulation results and measurement results of return loss are compared in Fig. 7.

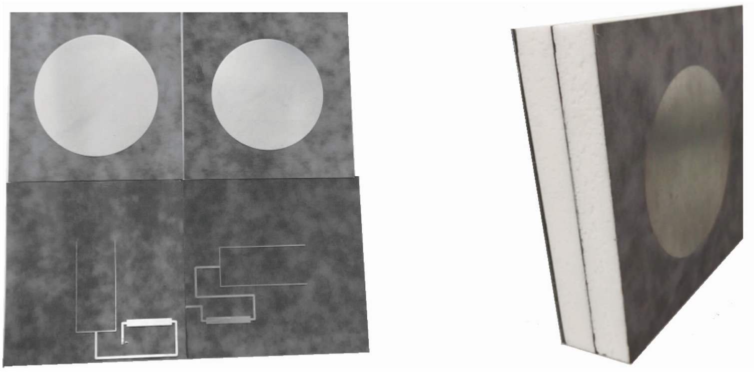

Fig. 6　Photographs of the fabricated antenna: (a) each later structure of the antenna and (b) the overall structure of the antenna

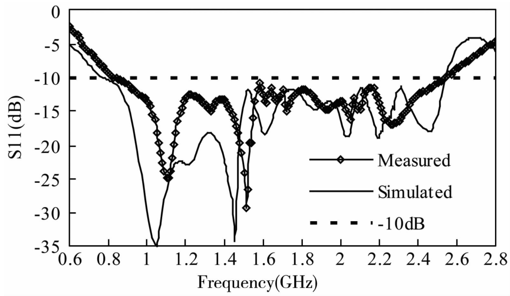

Fig. 7　Comparison of simulation and measurement results of the return loss

It can be observed that the impedance bandwidth of simulation result is from 0.87-2.55 GHz compared with the measurement results is from 0.88-2.55 GHz. Deviation is observed between simulation and measurement results. This could be explained that the measured S11 is extremely sensitive to calibration errors and fabrication errors could also contribute to this deviation.

The comparison of simulation and measurement results of the axial ratio is shown in Fig. 8. It is observed that the simulation 3 dB AR bandwidth is from 0.94-2.15 GHz which the measurement results is from 0.96-2.16 GHz. The measurement results show that the axis ratio of the antenna is larger than 3 dB near 1.76 MHz. Fig. 9 shows that the measured gain is between 7.58 dB and 9 dB from 0.8-1.6 GHz. The gain of traditional microstrip antenna is from 6 dB to 8 dB. Fig. 9 shows that the measured gain is between 7.58 dB and 9 dB from 0.8-1.6 GHz. It is can be seen that the gain of the antenna mentioned in this paper is slightly improved.

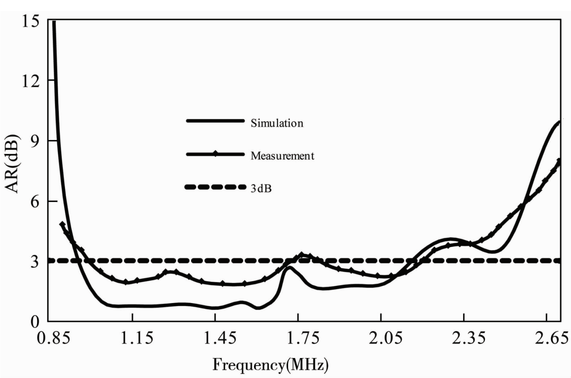

Fig. 8　Comparison of simulation and measurement

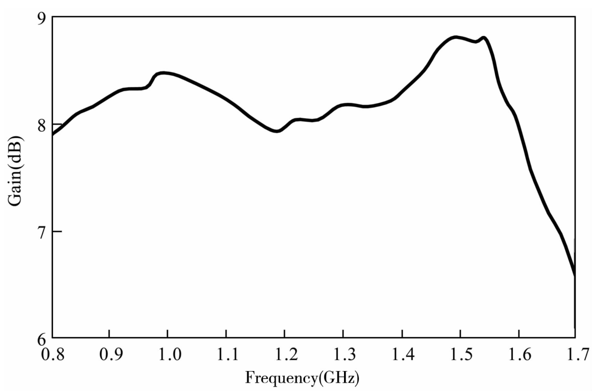

Fig. 9　Measured gain of the proposed antenna

4 Conclusion

A wide band circular polarization microstrip antenna was proposed, which has good performance of impedance and axial ratio bandwidth. ASM was used to optimize the antenna and achieved high design efficiency. The coarse model was constructed from the response of the coarse-mesh electromagnetic model of the antenna, using Kriging interpolation technique. In this letter, the optimized design was obtained at the low computational cost compared with a few full-wave electromagnetic simulations of the proposed antenna. Through this method, a circular polarized microstrip antenna was designed. The optimization results of impedance bandwidth is from 0. 87-2. 55 GHz compared with the measurement results is from 0. 88-2. 55 GHz. And the axis bandwidth of simulation result is from 0. 94-2. 15 GHz which the measurement result is from 0. 96-2. 16 GHz. It can be seen that the measurement results are in good agreement with the optimization results. The proposed antenna can be used for terminal systems of satellite navigation communications.

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