

Research Article

A Series of Frequency Shift Antennas Based on Shape Blending

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Received 28 January 2021; Revised 30 March 2021; Accepted 22 April 2021; Published 3 May 2021

Academic Editor: Giovanni Andrea Casula

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In this paper, an automatic antenna design method based on the shape blending algorithm is proposed. The algorithm is used to construct the shape of the wide slot of a CPW-fed antenna. Firstly, two basic shapes are chosen as the initial shape and the target shape. The shape blending process is then applied on them to get a series of shapes, which are used as the geometry structure of the wide slot. In this way, a series of CPW-fed wide slot antennas are obtained. And they have similar but gradually changing characteristics. The bandwidth ranges are 8.00–9.24 GHz, 7.95–9.05 GHz, 7.05–8.55 GHz, 6.95–8.13 GHz, and 6.55–7.50 GHz, respectively. The overall size of the antenna is 26 mm * 20 mm * 0.6 mm. Experimental results show that the resonant frequencies vary (via translation) with the change of slot shape in a specific frequency band. The experiments also validate that the antennas have omnidirectional radiation characteristics. The radiation gains and aperture efficiencies of the antennas are about 3.8–5.5 dBi and 57.7–83.0% at their centre frequencies, respectively. The experiment results show that the proposed antennas could be used in C-band and X-band radar applications.

1. Introduction

In recent years, with the rapid development of new smart wireless communication systems and technologies, the requirements for wireless transmission are becoming more and more stringent. As an important part of wireless communication systems, antennas have an impact on the performance of the entire system [1]. The CPW structure feed-printing slot antenna adopts a coplanar waveguides transmission line structure for feeding; it has the advantages of ultra-wide bandwidth, small volume, and conformal design [2–4]. For antennas with CPW structure, there are two traditional design methods: one is to improve the impedance bandwidth or gain of the antenna by changing the geometry of the radiation patch, e.g., designing the radiation patch to be circular, square, diamond, or trapezoidal; the other is to improve the impedance bandwidth of the antenna via the geometry of the slot structure, e.g., rectangle [5], circle [6], and hexagon [7]. By embedding p-i-n diodes to the bow-tie arms, the electrical length of the antenna is changed and the resonance frequency is changed [8]. By controlling the feeding phase,

different resonance frequencies are generated [9]. And the resonant frequency is moved by adding different numbers of stubs [10].

However, these methods are all aimed at specific types of antennas and changing the antenna structure through experience to produce different resonance points or make the resonance points moving. The method proposed in this paper can be applied to many kinds of antennas. At the same time, this method does not need the designer's professional knowledge. And it can be widely popularized. This work breaks through the traditional design method and uses a shape blending algorithm to design and optimize the slot shape of the antenna to obtain a series of antennas whose resonant frequency varies with the shape of the slot geometry in a specific frequency band. This is of great significance to the design of antennas with specific resonant frequencies. Using this method, we designed and fabricated a series of antennas with dimensions: 26 mm * 20 mm * 0.6 mm. Test results show that with the change of the slot shape, the resonant points of these antennas shift in the characteristic frequency band; these antennas have stable gain and good directional radiation characteristics.

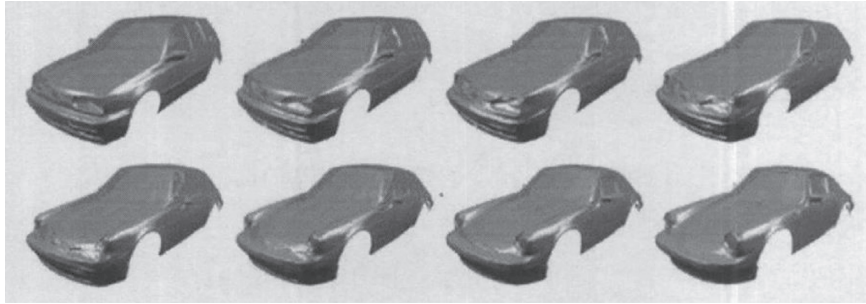


FIGURE 1: Contour fusion between a Volkswagen and a Porsche.

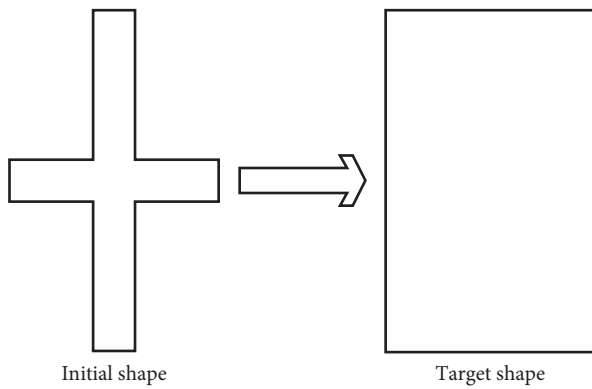


FIGURE 2: Initial shape and target shape.

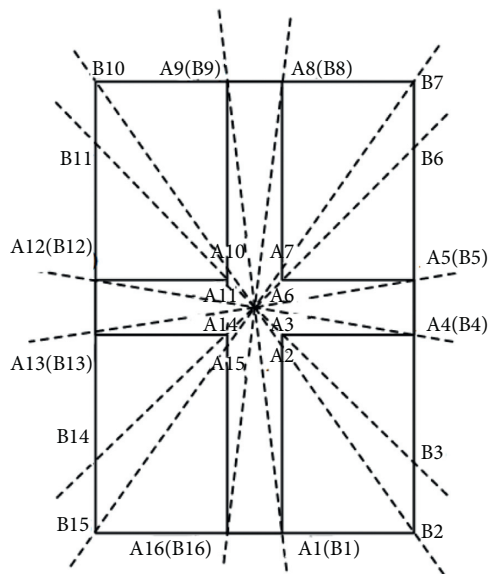


FIGURE 3: Schematic diagram of feature point selection.

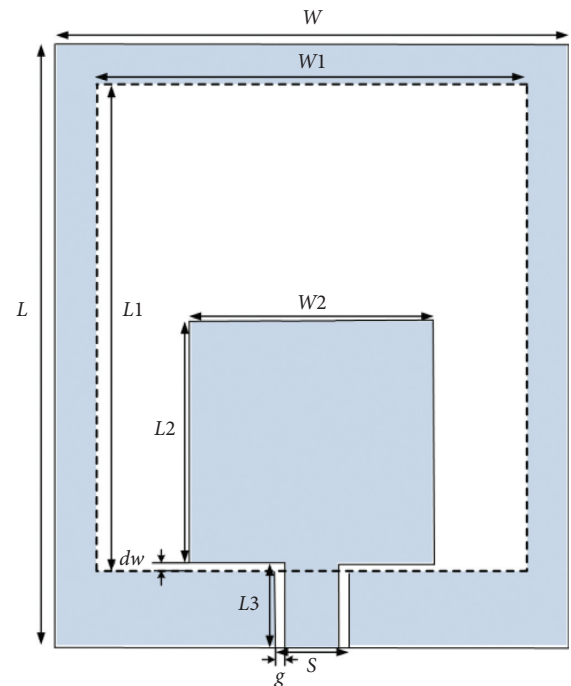


FIGURE 4: Schematic diagram of feature point selection.

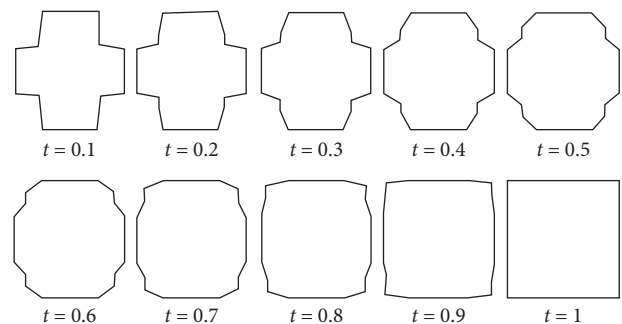


FIGURE 5: Shape blended graphics with different t values.

The second section of the paper describes the shape blending algorithm. The third section shows a series of antennas obtained by an algorithm that varies the resonant frequencies as the slot changes. In section four, the results of the antenna are presented and discussed. Finally, the work is summarized.

2. Shape Blending Algorithms

Shape blending is also called graphic deformation. As an application of computer vision, image deformation has attracted much attention in recent years. Its application scope has gradually expanded from the computer field to the

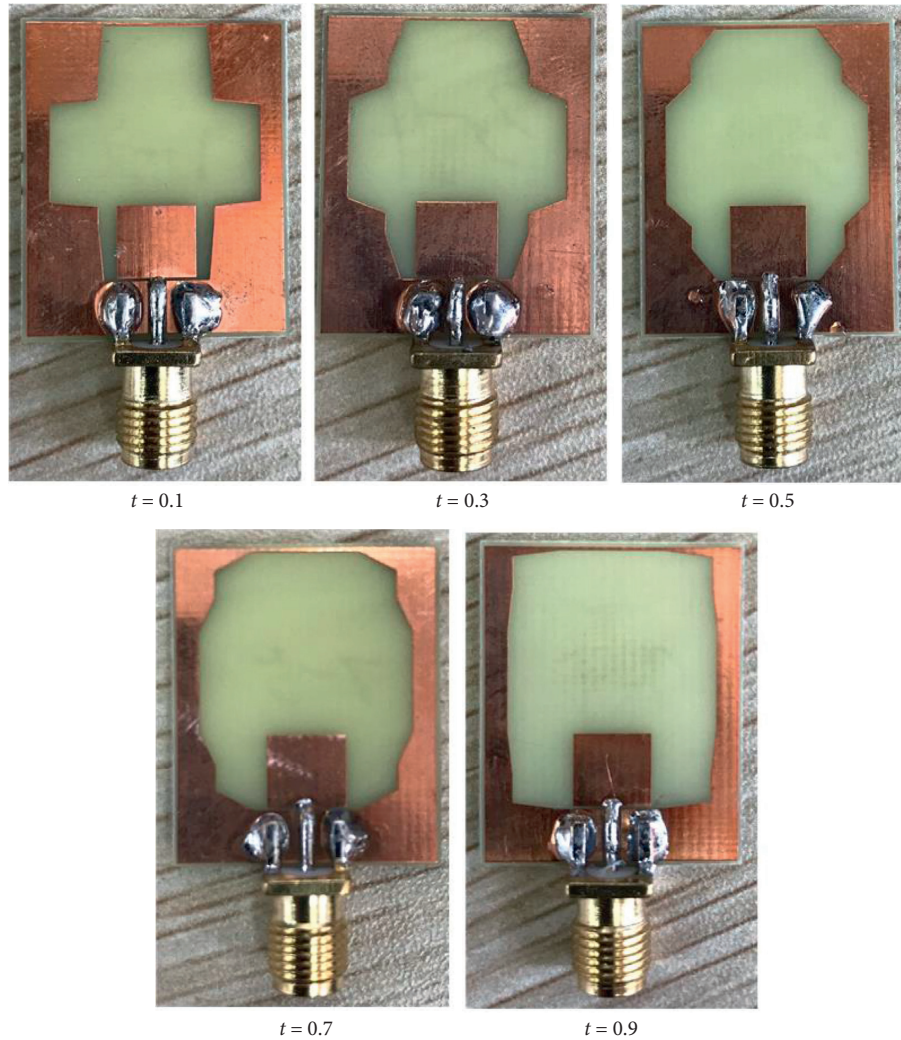


FIGURE 6: Photographs of antennas with different t values.

industrial field [11]. Shape fusion is the fusion of initial shape and target shape to produce a series of shapes. The resulting shape has the characteristics of both the initial shape and the target shape. As shown in Figure 1 [12], it shows the contour fusion process from a Volkswagen to a Porsche. Several blended contour shapes are obtained during the fusion process.

There are two key steps in the shape blending algorithm.

The first step is to establish the corresponding relationship between the initial shape and the target shape. This relationship is established on the elements of two shapes (such as vertices and edges). It is called the corresponding problem.

The second step is to determine the trajectory of the corresponding elements, which is called the trajectory problem. In this paper, the shape blending algorithm is used to optimize the slot shape of the antenna. The cross shape is selected as the initial shape, and the rectangle is taken as the target shape, which is shown in Figure 2. The selection of feature points is especially important after determining the initial and target shapes. The feature points are selected and paired by the Ray firing method. The cross and the square are placed in the same

coordinate system so that their centres coincide at the origin. 16 feature points A_1 – A_{16} are selected on the cross shape, and then 16 rays are, respectively, formed by connecting with the origin, and the 16 rays and the square generate 16 intersection points B_1 – B_{16} as feature points of the square. The selection of feature points in this paper is shown in Figure 3.

After the feature points are determined, the trajectory problem is solved by using the simple linear interpolation method to get the fused shape C , which is expressed as the following equation:

$$\begin{aligned}
 C(t) &= t * A + (1 - t) * B \\
 &= [t * A_1 + (1 - t) * B_1, \dots, t * A_n + (1 - t) * B_n] \quad (1) \\
 &= [C_1(t), \dots, C_2(t)].
 \end{aligned}$$

3. Antenna Design

In this work, only the slot shape of the antenna is fused, while the other parameters are identical. The basic geometric structure of these antennas is shown in Figure 4. The shape

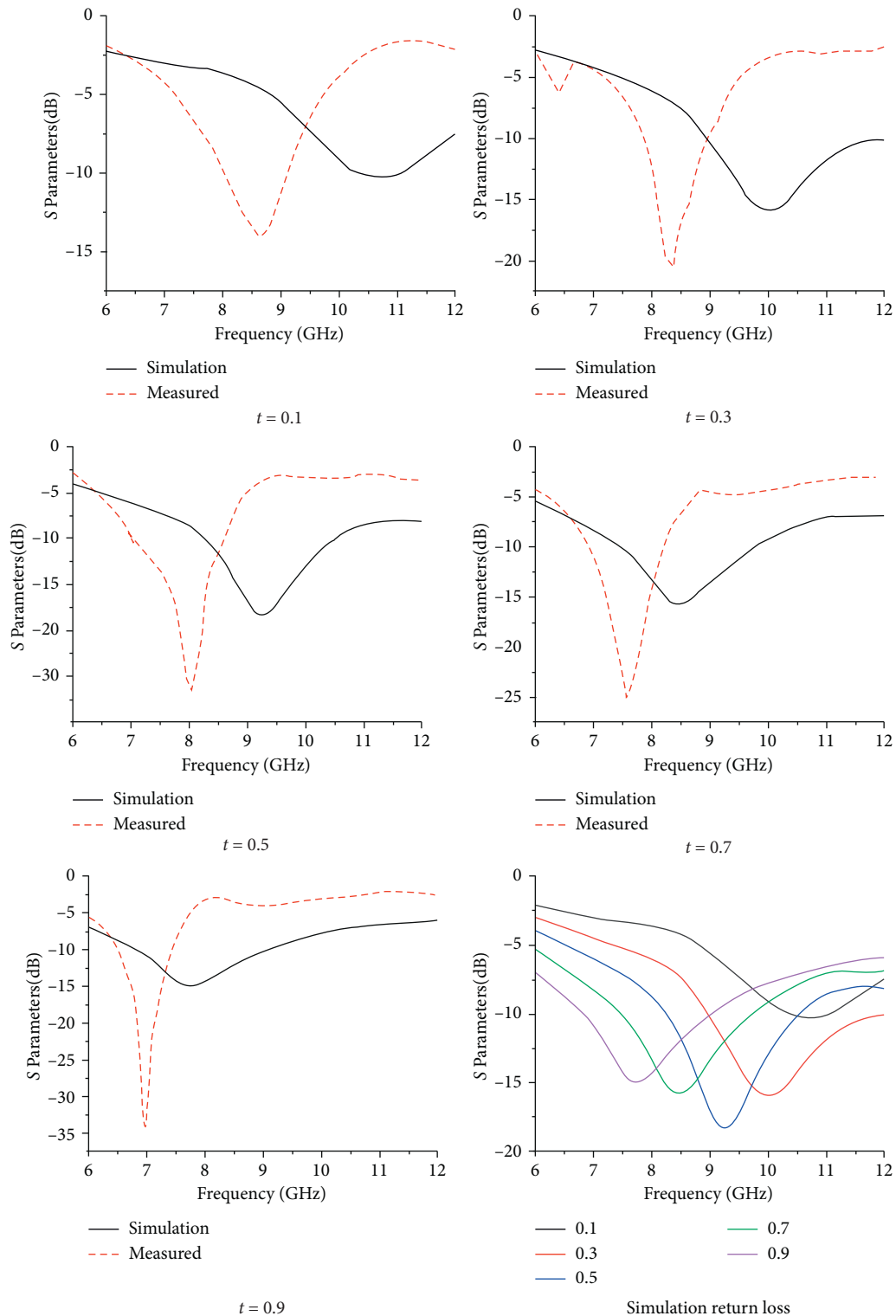


FIGURE 7: The results of return loss.

of the slot is represented by a frame with dimensions determined by a shape blending algorithm. The substrate thickness of the antenna is 0.6 mm, the relative dielectric constant is 4.4, the loss tangent is 0.02, and the overall antenna size is $W * L$. The antenna is fed via a CPW structure such that the feed line width s is 1 mm and the

gap between the feed line and the ground is 0.2 mm. The specific dimensions are as follows: $W = 20$ mm, $W1 = 16$ mm, $W2 = 6$ mm, $S = 1$ mm, $L = 26$ mm, $L1 = 21$ mm, $L2 = 6$ mm, $L3 = 4.7$ mm, $dw = 0.2$ mm, and $g = 0.2$ mm. During the shape blending process, the shape of the gap is produced by varying the t parameter, as shown

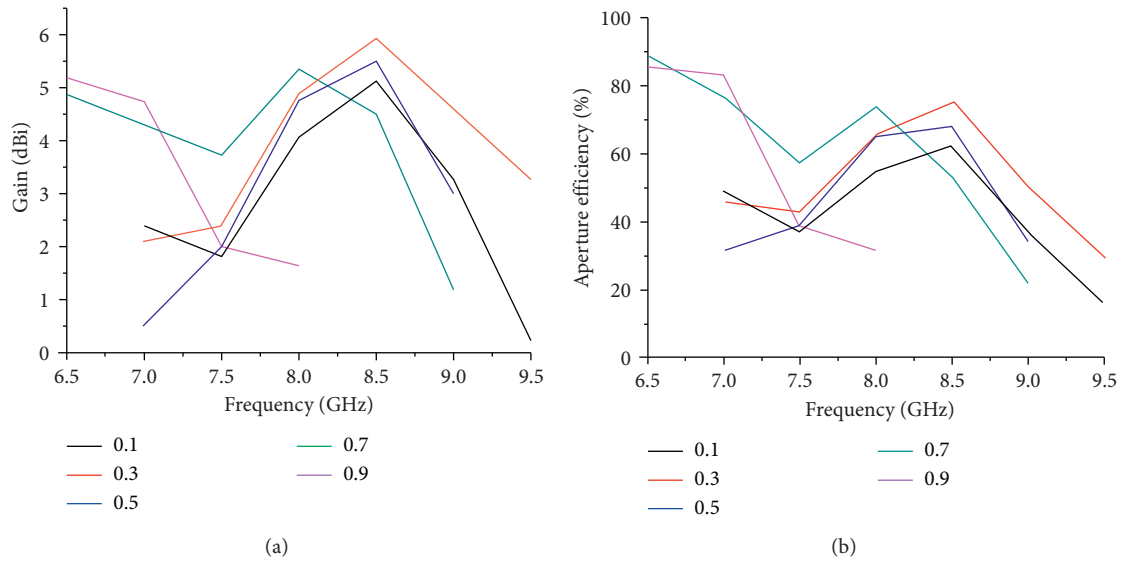


FIGURE 8: The measured results of (a) antenna gain and (b) aperture efficiency.

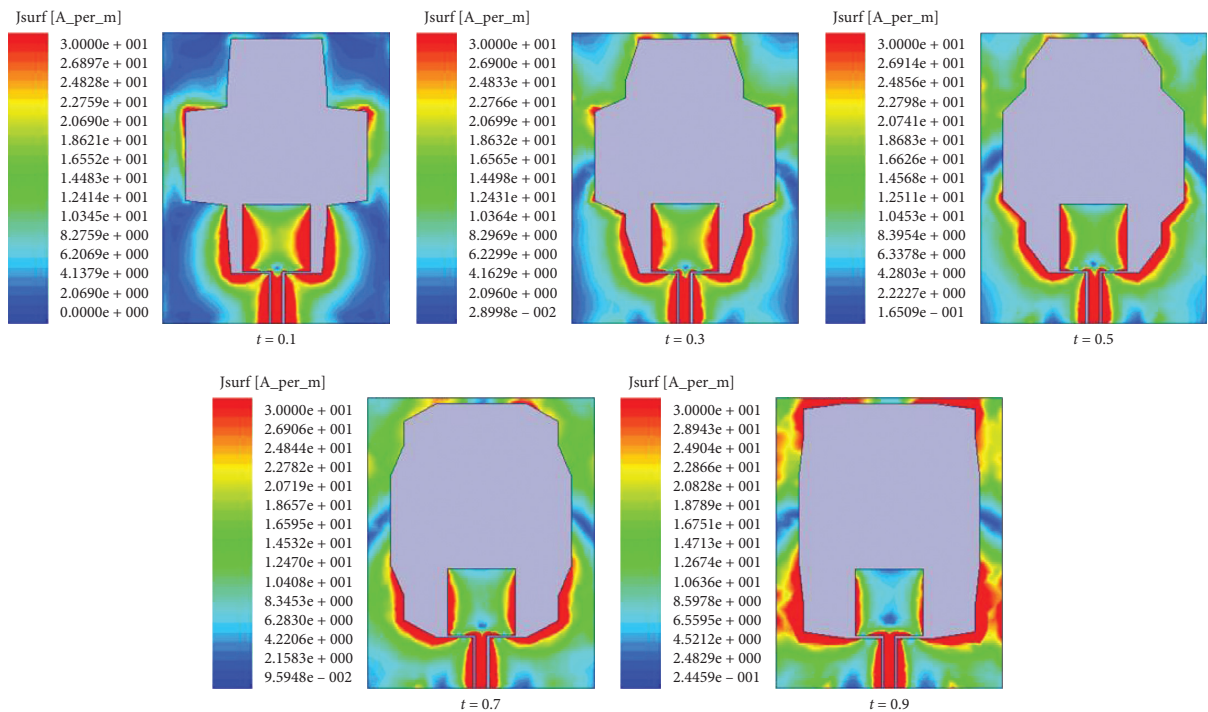


FIGURE 9: Current distribution map.

in Figure 5. Physical photographs of some of the antennas in this series are shown in Figure 6.

And the design idea of this paper is as follows. Firstly, the classical antenna is selected. And the patch shape and slot shape have the greatest impact on the antenna performance. By using shape fusion algorithm to change the slot shape, the function of antenna resonance point is realized. At the same time, the advantages of this design method are as follows: (1) to a certain extent, no longer rely on the experience of engineers so that everyone can realize the movement of the resonance point of the antenna

through this method; (2) this method can be applied to many types of antennas and has great advantages compared with the method which can only be used for a single type of antenna.

4. Results and Discussion of Antenna Parameter

Antennas with different slot shapes can be obtained by changing the value of t . As t changes, the resonant frequency of the antenna also changes. We have also made prototypes of several antennas and tested them. Several

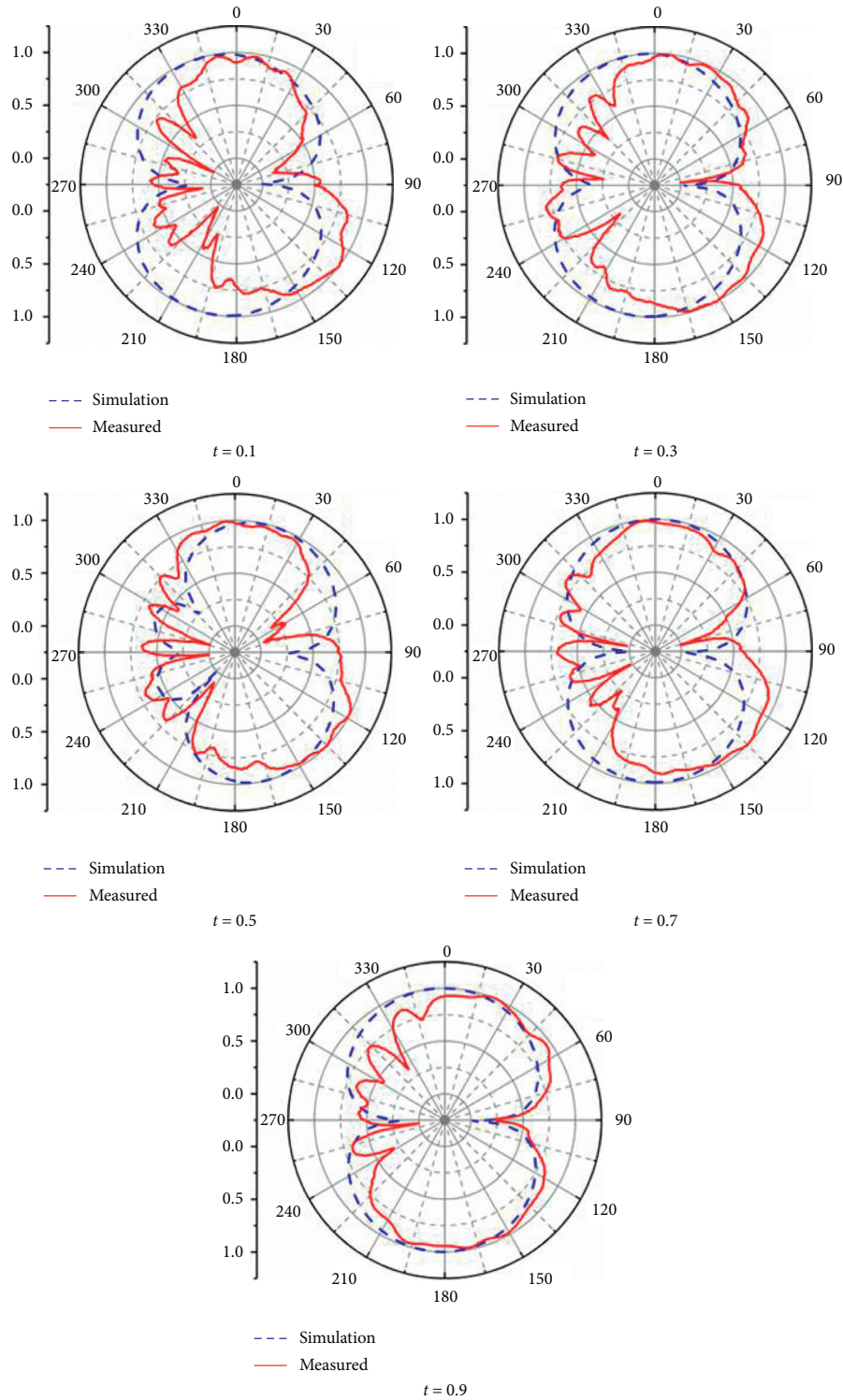


FIGURE 10: E-plane pattern with different t values.

antennas in this series are selected, and their measured return losses are shown in Figure 7 comparing with the simulation return loss. And we can see that the test results and the simulation results have the same change trend. As the t parameter increases, the resonant frequency of the antenna decreases. As shown in Figure 7, as t increases, the measured return loss improves. Similarly, the resonant

frequencies are getting closer to the simulation results. The antenna gains and aperture efficiencies of the series of antennas in their respective effective frequency band are shown in Figures 8(a) and 8(b). Although these antennas are omnidirectional antennas, it can be seen from the results shown that the gain of these antennas is mostly maintained above 2 dBi, with a maximum gain of 5.96 dBi.

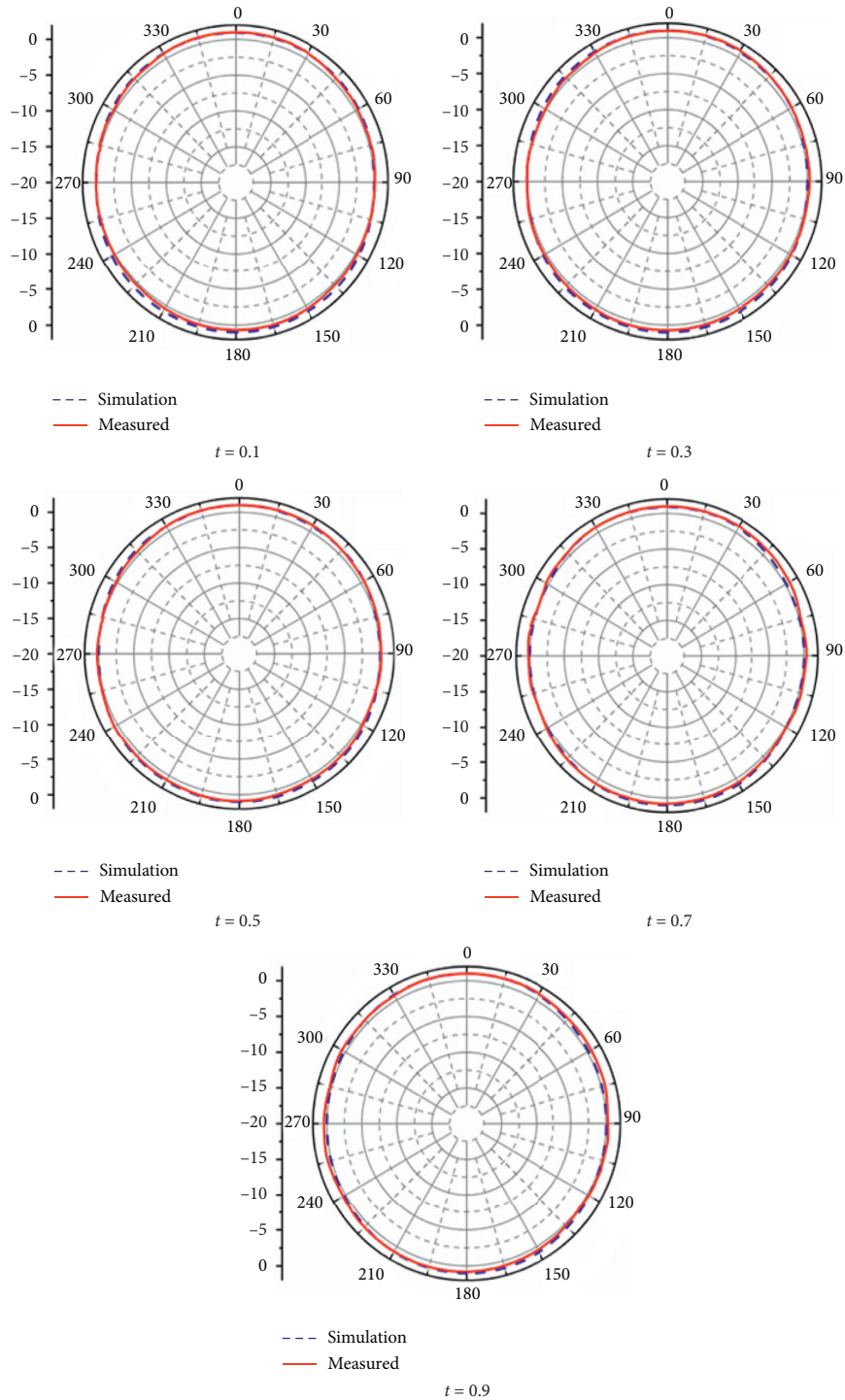


FIGURE 11: H-plane pattern with different t values.

The aperture efficiencies of the 5 antennas span from 16% to 89% over the whole frequency band. Figure 9 shows the current distribution of the antenna. The image shows the current direction and distribution of these antennas in a more intuitive manner. The gain is relatively stable along a particular frequency bands. The E-plane and H-plane antenna patterns of these antennas are shown in Figures 10 and 11, respectively. The FR4 material is not suitable for

high-frequency signals, processing technology, or the test environments, among other factors; therefore, the measured data and the simulated data of the return loss at high frequencies are quite different. As the t changes, the resonant frequency of the antenna decreases; the measured data and the simulation data gap becomes smaller as a result. The measured and simulated patterns of these antennas are similar, as shown in Figures 10 and 11.

TABLE 1: Comparison between the proposed antennas with the recent works.

Reference	Novelty	Antenna design	The resonant frequency	Gain
Li et al. [8]	By embedding p-i-n diodes over the bow-tie arms, leading to an electrically tunable operating band	Dependent on antenna theory	2.4 GHz	0.02 dBi
			3.5 GHz	2.34 dBi
			5.5 GHz	2.8 dBi
Altamirano et al. [9]	The frequency reconfiguration occurs by controlling the feeding phase	Dependent on antenna theory	850 MHz	No relevant data available
			1.7 GHz	No relevant data available
Yasir and Savi [10]	Increasing the number of stubs causing an increase in the frequency shift	Dependent on antenna theory	4.49 GHz	0.5 dBi
			4.64 GHz	No relevant data available
			4.99 GHz	5 dBi
Alibakhshikenari et al. [13]	Broadband antennas loaded with split ring resonators (SRRs)	Dependent on antenna theory	~4 GHz	2.4 dBi
			~6 GHz	3.4 dBi
Sadeghzadeh et al. [14]	Metamaterial-based antenna using the concept of composite right-left-handed transmission lines	Dependent on antenna theory	450 MHz	All below 4.5 dBi
			725 MHz	
			1150 MHz	
			1670 MHz	
			1900 MHz	
This paper	Shape blending algorithm for frequency reconfigurable	Independent of antenna theory	8.62 GHz	4.8 dBi
			8.38 GHz	5.5 dBi
			8 GHz	4.8 dBi
			7.6 GHz	3.8 dBi
			7 GHz	4.7 dBi

Before concluding the paper, the proposed design has been compared with the existing technology. The specific results are shown in Table 1.

5. Conclusions

A shape blending algorithm, which can be used to steadily change the resonance point of antenna, is proposed in this paper. Compared with the conventional design method, the proposed design method does not require much on the expertise of the antenna designers. Another advantage is that a series of antennas could be obtained with just one design process. To verify the proposed method, five prototypes have been designed, fabricated, and tested. The experiment results show that by changing the blending coefficient value t , the resonant points vary accordingly, which are 8.62 GHz, 8.38 GHz, 8 GHz, 7.6 GHz, and 7 GHz, respectively, while keeping the absolute bandwidth fixed, around 1.2 GHz. The overall size of the antennas is all 26 mm * 20 mm * 0.6 mm. The antennas also demonstrate stable gain and omnidirectional radiation characteristics. The radiation gains and aperture efficiencies of the antennas are 3.8–5.5 dBi and 57.7–83.0% at their centre frequencies, respectively. Therefore, the proposed antennas could be applicable for C-band and X-band, offering good gains and efficiencies through the working frequency bandwidths.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (grant nos. 61501153 and 61801153), State Key Laboratory of Millimeter Waves (grant no. K202012), and Natural Science Foundation of Zhejiang Province (grant no. LQY20F010001).

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