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Design of A Millimeter Wave Dielectric Resonator Antenna with Hollow Structure

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Abstract

In this paper, A dielectric resonator (DR) antenna operating in millimeter wave band is realized by using a cylindrical dielectric resonator (DR) with hollow structure. The circular polarization of the antenna is achieved by designing four irregular rectangular slots of the same size on the upper part of the cylindrical dielectric resonator. The simulation results of HFSS show that the bandwidth of the antenna is about 15.3% in the 3dB axial ratio, the S11 is less than -10dB in the 47.5-54.7GHz frequency band, and the antenna gain can reach 8.644dBi. The antenna, with two frequency bands and good impedance bandwidth, has a promising prospect of application in 5G base stations in the future.

Keywords

Dielectric Resonator Antenna; Millimeter Wave; Rectangular Groove; Hollow Structure Circular Polarization.

1. Introduction

In 1983, as researchers began to show that dielectric resonators (DR) could be used as radiators,dielectric resonator antenna (DRA) has gradually become a research hotspot [1]. In the 5th generation of wireless communication (5G) technology, dielectric resonator plays an important role by virtue of its advantages including low loss, high radiation efficiency, easy to feed and so on [2-4].

There are many shapes of dielectric resonator antennas,in which the most common ones are rectangular, hemispherical and cylindrical. In the process of designing cylindrical dielectric resonator antenna, the ratio between the height and radius of the dielectric resonator can be adjusted to make the antenna work in different frequency bands [5], thus increasing its flexibility. With the continuous exploration of researchers, the dielectric resonator antennas with various irregular shapes have been developed, such as cross-slot coupled dielectric resonator antennas [6], rectangular stepped dielectric resonator antennas [7], etc. The antenna performance can be optimized by changing its shape. For example, in [8], a stacked structure is used to perturb the antenna electric field, so that the antenna can achieve circular polarization. In [9], the circular polarization of dual-frequency antenna is realized by grooving on the cylindrical dielectric resonator.

In this paper, a cylindrical dielectric resonator with hollow structure will be used to excite the dielectric resonator by means of coaxial probe feed to make the antenna work in millimeter wave frequency band. Slotting is used in the upper part of the dielectric resonator to make the antenna achieve circular polarization in the millimeter wave band. The antenna has a gain of 8.644dBi and an axial ratio of less than 3dB in the 49.4-50.5GHz frequency band, with excellent performance.

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2. Antenna Design

2.1 Antenna Working Principle Analysis

Dielectric resonator antenna can be fed in many ways, such as microstrip line feed, slot feed and coaxial probe feed. In this paper, the antenna is fed by a coaxial probe, in which the probe is inserted into a cylindrical dielectric resonator, and the antenna is excited by adjusting the length and position of the probe to achieve better matched impedance. The advantage of this design is that the feeding position is on the floor side of the antenna, which can reduce the backward radiation and optimize the antenna radiation ratio.

By feeding the cylindrical dielectric resonator, it becomes a radiator. After the resonator is excited, the interface between it and the air is similar to an open road. At this time, the surface can be regarded as a magnetic wall in the radiation mode, so that electromagnetic waves can be radiated. By adjusting the three important parameters of the cylindrical dielectric resonator, namely height h, radius r and dielectric constant εr, the resonant frequency of the antenna can occur in different frequency bands, so as to find the desired resonant frequency.

When the proper feeding mode and size parameters are selected, four irregular rectangular slots of the same size are designed on the upper part of the cylindrical dielectric resonator to achieve circular polarization in the working frequency band of the designed antenna.

2.2 Antenna Concrete Structure Analysis

Fig. 1 shows the three-dimensional rendering of antenna simulation. They include a cylindrical dielectric resonator (CDR), an irregular rectangular groove, a hollow structure, a coaxial probe structure, a dielectric substrate, and a ground layer. Cyclic dielectric resonator (CDR) uses silicon-nitrate material, which belongs to ceramic materials. It has many advantages like lubricity, wear resistance and hardness. Its dielectric constant ε_{r1} =7; The dielectric substrate adopts pec material and its dielectric constant ε_{r2}=1.

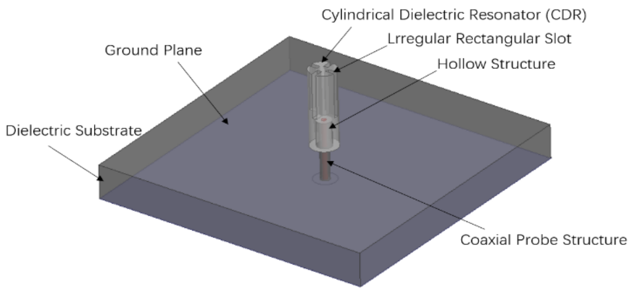

Figure 1. 3D rendering of antenna simulation

The side view of the antenna is shown in Figure 2, where r1 is the radius of the cylindrical dielectric resonator; h_1 is the height of the cylindrical dielectric resonator; r_2 is the radius of the hollow structure; h_2 is the height of the hollow structure; h3 is the height of the medium substrate, l_1 is the length of the medium substrate; l_c is the length of the irregular rectangular groove in the vertical plane; l is the probe length.

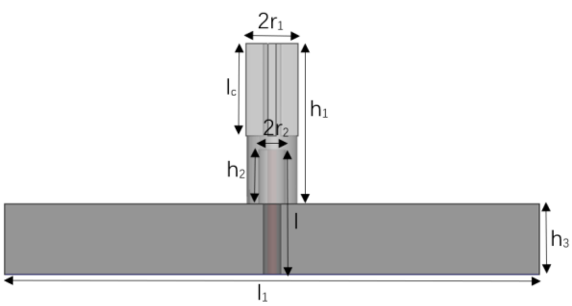

Figure 2. Antenna side view

ISSN: 2414-1895
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Fig. 3 shows a top view of a cylindrical dielectric resonator (CDR), where r_3 is the radius of the feeding probe;r_4 is the radius of the defect structure, which is also the distance between the four irregular rectangular slots and the center O of the CDR.l_b is the width of the irregular rectangular groove in the horizontal direction.

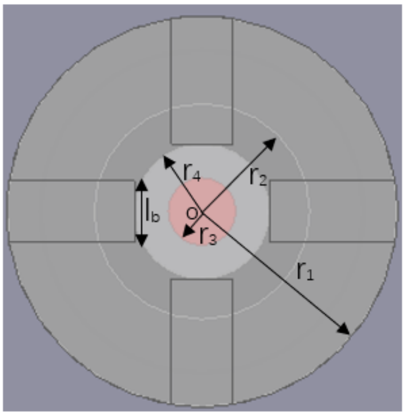

Figure 3. Top view of a cylindrical dielectric resonator (CDR)

3. Antenna Parameter Analysis and Optimization

In the antenna design process, every parameter have an impact on its performance. The antenna designed in this paper adopts a variety of optimization methods, such as hollow structure, irregular rectangular groove structure, coaxial probe structure, etc. The following are the analysis of the parameters that greatly affect the performance of the antenna.

3.1 Size Optimization of Hhollow Structure

The radius r_2 of the hollow structure is the influence on the return loss S_{11} of the antenna, as shown in Fig. 4. When r_2 =0.6mm, the antenna's return loss S_{11} parameter is poor; When the frequency of S_{11} is higher than -10dB in the working frequency band, the impedance bandwidth is relatively poor; When r_2=0.7mm, the antenna return loss S_{11} has two resonant points at 47.7GHz and 52.9GHz respectively, and the minimum loss reaches -38.45dB and -35.54dB, respectively. The impedance bandwidth of the antenna (S_{11}<-10dB) is 16%; When r_2 =0.8mm, the minimum loss of the antenna at the resonant point increases, and the impedance bandwidth (S_{11}<-10dB) is 14%. Compared with r_2 =0.7mm, the performance of the antenna becomes worse at this time. Therefore, r_2 =0.7mm is chosen for the antenna designed in this paper.

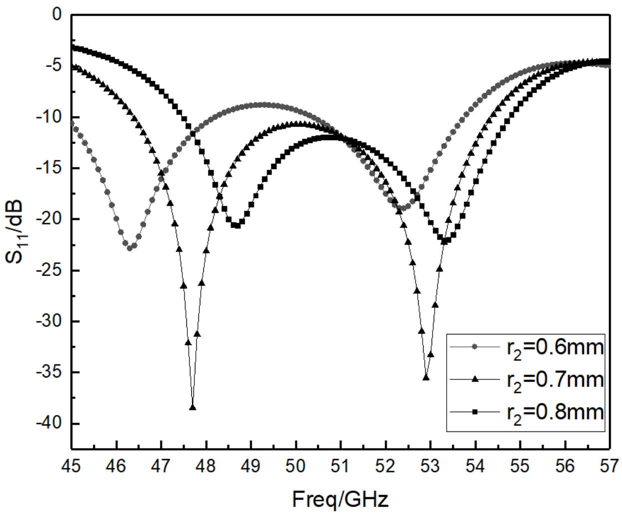

Figure 4. Influence curve of r_2 on antenna return loss S_{11}

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The influence of the height h_2 of the hollow structure on the return loss S_{11} of the antenna is shown in Fig. 5. As can be seen from the figure, when h_2=3mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 12%; When h_2=3.1mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 15%, and the minimum return loss S_{11} is -47.3GHz; When h_2 =3.2mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is still 15%, but the minimum value of return loss S_{11} is -23.6GHz, and the antenna performance is reduced. Therefore, the antenna performance is better when h_2 =3.1mm.

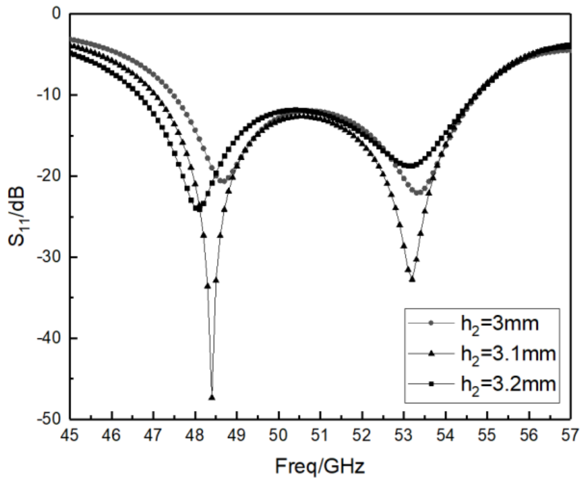

Figure 5. Influence curve of h_2 on antenna return loss S_{11}

3.2 Optimization of The Size of Irregular Rectangular Slot

Fig. 6 shows the influence of the direction width lb parameter of the horizontal square of the irregular rectangular slot on the return loss S_{11} of the antenna. As can be seen from the figure, when l_b =0.45mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 13%; When l_b =0.55mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 16%, and the minimum return loss is -37.7dB; When l_b =0.65mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 16%, but the minimum return loss can only reach -28.9dB, Therefore, the antenna performance is better when l_b =0.55mm.

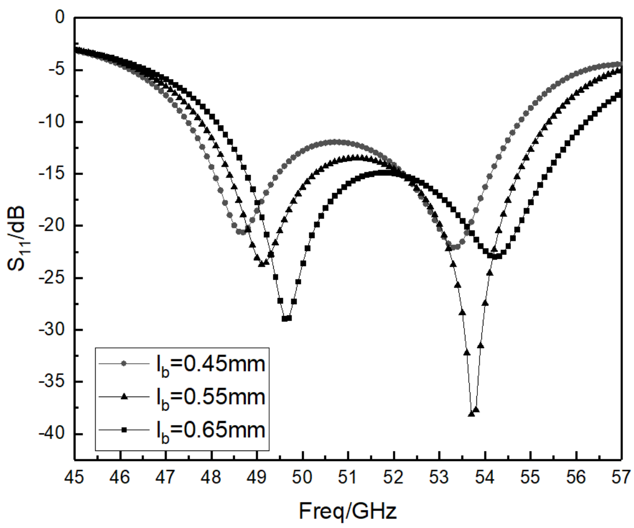

Figure 6. Influence curve of l_b on antenna return loss S_{11}

Fig. 7 shows the influence of the length l_c of the irregular rectangular slot in the vertical plane on the return loss S_{11} of the antenna. As can be seen from the figure, the operating frequency band of the antenna will gradually become higher with the continuous decrease of l_c parameter. However, when

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l_c =-7.2mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is 15%; When l_c =-6.2mm, the impedance bandwidth of the antenna (S_{11}<-10dB) is also 15%, but its minimum return loss is reduced, which can reach -25.9dB; When l_c=-5.2mm, the overall performance of the antenna decreases, and the impedance bandwidth (S_{11}<-10dB) is 14%, and the minimum return loss is -20.6dB, Therefore, the antenna performance is better when l_c =-6.2mm.

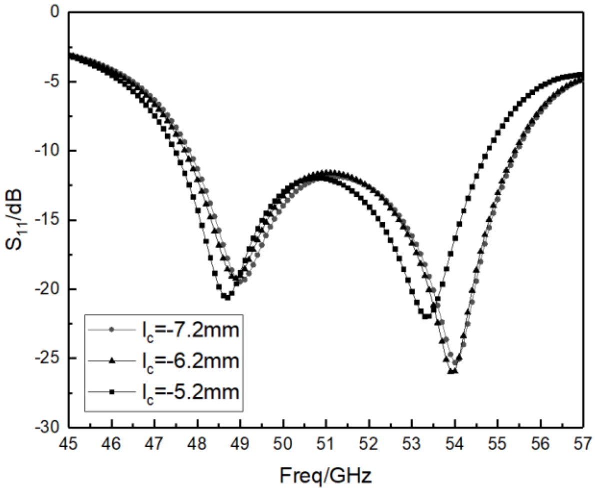

Figure 7. Influence curve of lc on antenna return loss S11

3.3 Optimization of Probe Length

The influence of probe length l on the return loss S_{11} of the antenna is shown in Fig. 8. Due to hollow structure, the maximum value of l parameter is 7mm. As can be seen from the figure, when the value is 6mm and 6.5mm, the performance of the antenna is poor, while when the value of l is 7mm, the antenna shows a good S parameter performance, and the impedance bandwidth (S_{11}<-10dB) is 14%, so the length of the probe is chosen as 7mm.

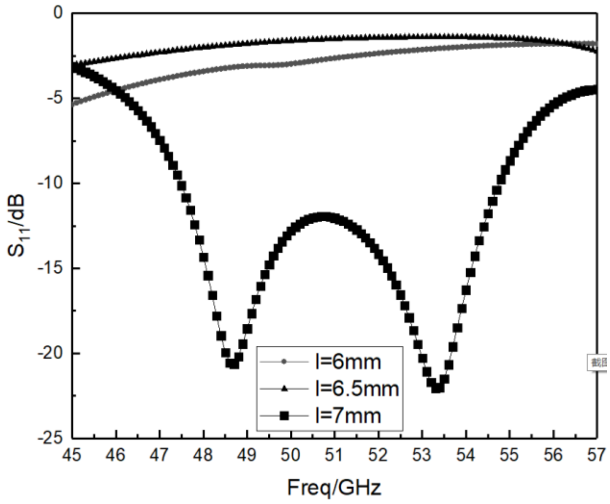

Figure 8. Influence curve of l on antenna return loss S_{11}

4. The Simulation Results

In order to optimize the performance of the antenna, the size parameters of the antenna were comprehensively selected during the design process. After optimization and simulation, the antenna structure size was finally obtained as shown in Table 1.

Volume 7 Issue 9, 2021
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Table 1. The final optimized antenna structure parameters

Pparameter	r_1	r_2	r_3	r_4	h_1	h_2	h_3	l	l_1	l_c	l_b
Value (mm)	1.45	0.7	0.25	1.2	9	3.1	4	7	30	-6.2	0.55

Fig. 9 shows the simulation results of the return loss (S_{11}) of the antenna. As can be seen from the figure, the antenna designed in this paper has two resonant points, whose operating frequency range is 47.5-54.7GHz, the relative impedance bandwidth is 14.1%, the center frequency is 51.1GHz, and the return loss S_{11} reaches the lowest of -22GHz, which indicates that the antenna has a good impedance bandwidth and a small return loss in the operating frequency range.

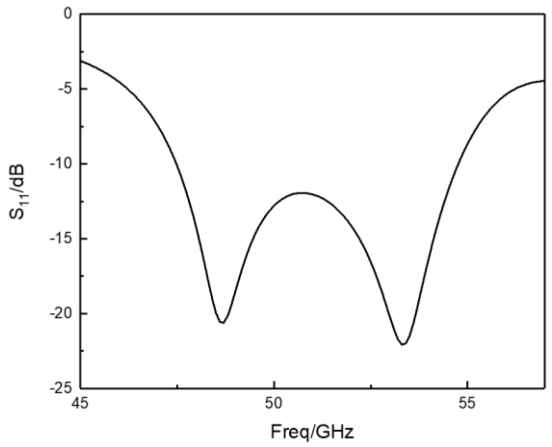

Figure 9. Return loss (S11) curve of antenna

Fig. 10 shows the simulation results of the axial ratio curve of the antenna. In Figure 9, the internal axis ratio of the antenna between 49.4-50.5GHz is less than 3dB, indicating that the antenna has good circular polarization characteristics in this frequency band.

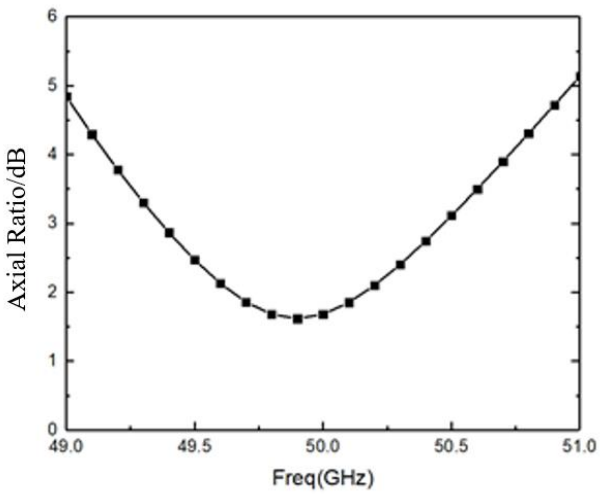

Figure 10. Axial ratio curve of antenna

Fig. 11 shows the three-dimensional orientation of the antenna. As can be seen from Figure 10, the maximum gain of the antenna is 8.644dBi, indicating that the antenna has good gain and strong radiation directivity.

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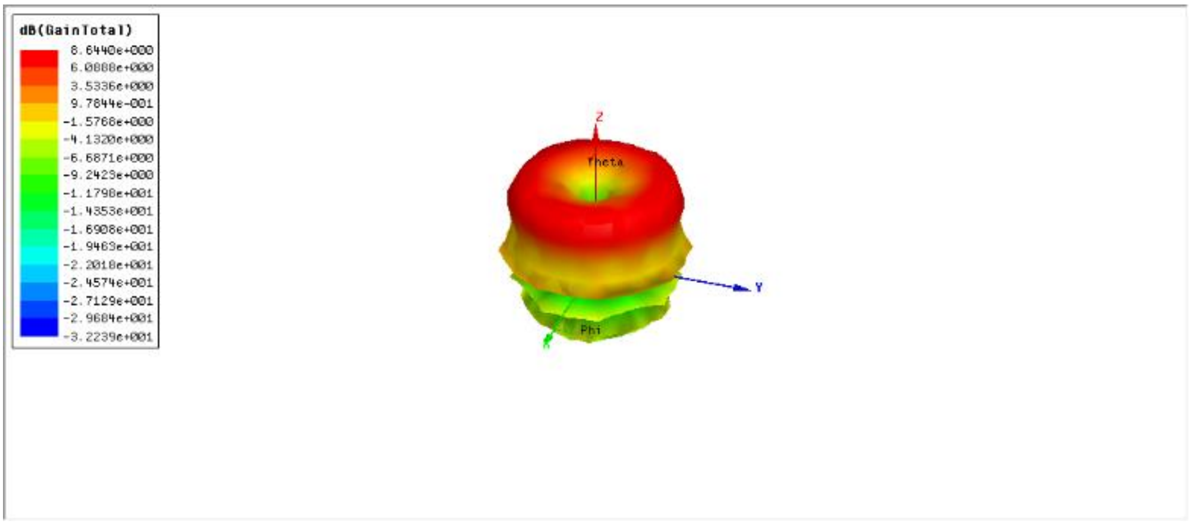

Figure 11. 3D orientation of the antenna

5. Conclusion

In this paper, a millimeter wave dielectric resonator antenna with hollow structure is designed, which has circular polarization performance in the working frequency band and good impedance bandwidth. The antenna is fed by coaxial probe, and the performance can be optimized by adjusting the size of hollow structure, the size of irregular rectangular slot and the length of probe. The 3dB axial ratio bandwidth of the antenna is about 15.3%, the S_{11} is less than -10dB in the 47.5-54.7GHz frequency band, the relative impedance bandwidth is 14,1%, and the antenna gain is 8.644dBi. The antenna has good performance parameters and has a prospect of application in the development of 5G (6G) base station antenna.

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