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A high gain and simple-structured dielectric resonator antenna array with cylindrical rods and microstrip feeding

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Abstract. A novel microstrip-fed dielectric rod array antenna with high end-fire gain is proposed. It has simple structure, comprising a group of cylindrical dielectric rods and a microstrip corporate feeding network, and is low in cost. A prototype 4 × 4 array working at 8.0 GHz is designed, fabricated and measured. Simulation and measurement results show the antenna has encouraging performances, e.g. an impedance bandwidth ($|S_{11}| < -10$ dB) of 7.7%, an end-fire gain up to 20.3 dBi, side-lobes 13.5 dB below the main lobe, and linear polarization with the cross-polarization level less than −21 dB.

Keywords: Array antenna, dielectric rod, high gain, microstrip corporate feeding network

1. Introduction

In recent years, dielectric resonator antennas have become an attractive choice for many modern wireless communications systems due to their advantages such as small size [1–4], wide impedance bandwidth [5–9], high radiation efficiency [10–12], etc. But so far in the large numbers of previous researches, dielectric resonator antennas are commonly made of high permittivity materials [1–3] that are often expensive. In many antennas, dielectric rods that act as radiation elements are with tapered [7–9] or other more complicated configurations [4,5], which bring forth difficulties for antennas' design and fabrication. Some antennas are fed by a waveguide [3–5,8,10], an embedded probe [10], or a horn [13,14], which are not only difficult to be fabricated into modern devices but also may be bulky and expensive for a large array.

In this work, a novel dielectric rod array antenna is presented. This antenna is the combination of a group of dielectric rods with a microstrip corporate feeding network. The dielectric rods are of simple cylindrical configuration, act as the array antenna's radiation elements and fabricated by using Teflon, which is a low-cost material, moreover is low-loss at microwave frequency and has a stable dielectric permittivity over a wide range of frequency. Moreover, this array antenna is fed by a microstrip corporate feeding network, and thus able to make full use of the accurate and low cost planar print techniques.

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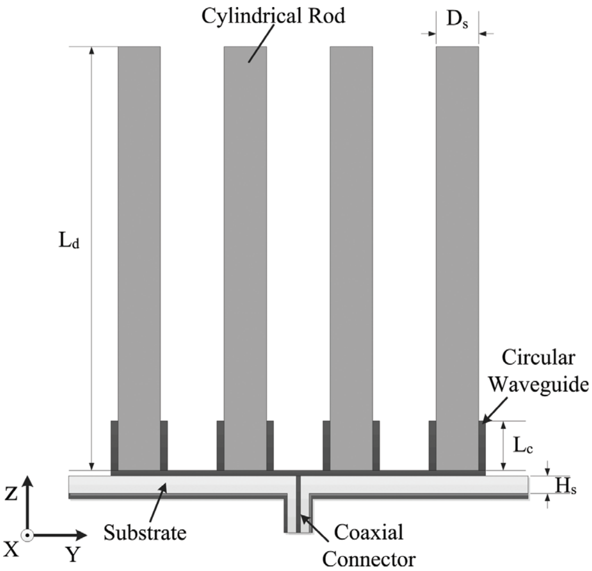


Fig. 1. The side view of proposed dielectric rod array antenna (D_s = 8.8 mm, L_c = 10.5 mm, L_d = 80 mm, H_s = 2 mm).

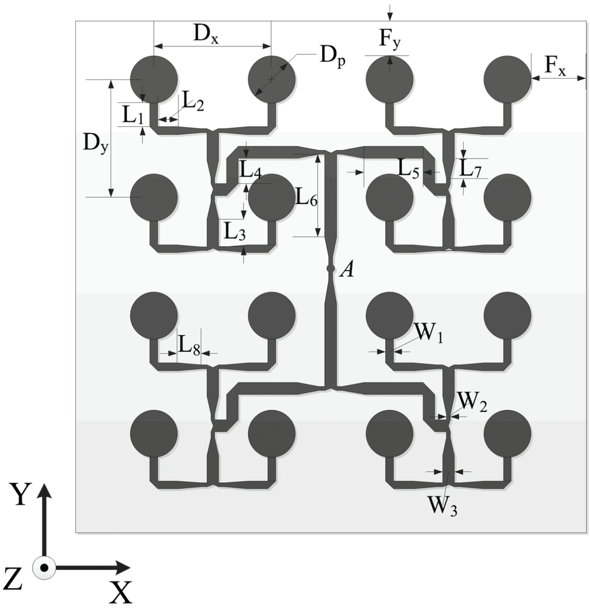


Fig. 2. The microstrip corporate feeding network (D_p = 11.8 mm, D_x = 17.4 mm, D_y =18.4 mm, L_1 = 2.6 mm, L_2 = 8.3 mm, L_3 = 5.6 mm, L_4 = 5.8 mm, L_5 = 15.9 mm, L_6 = 20.7 mm, L_7 = 6.2 mm, L_8 = 3.9 mm, W_1 = 1.4 mm, W_2 = 0.4 mm, W_3 = 2.0 mm, F_x = 8.7 mm and F_y = 7.2 mm).

2. Antenna design

2.1. Antenna configuration

In this work, a proposed dielectric rod array antenna is designed for high end-fire gain at the working frequency of 8.0 GHz. As illustrated in Fig. 1, this antenna comprises 4 $\times$ 4 cylindrical dielectric rods, which are fabricated by Teflon with relative permittivity 2.08. Each rod is inserted into a circular metallic waveguide with height L_c and mounted on a PCB (printed circuit board) with relative permittivity 2.65, size 121 mm $\times$ 117 mm and thickness 2 mm.

This antenna is fed from a 50 Ω coaxial connector, whose inner conductor penetrates the PCB and connects with the corporate feeding network at the point A. On the top side of the PCB, a microstrip corporate feeding network (see Fig. 2) is etched. Each branch lines of the feeding network is terminated by circular patches, on which is soldered a circular metallic waveguide and mounted a cylindrical dielectric rod, whose parameters are determined by the mode analysis and parameter sweep in the following sections.

The microstrip corporate feeding network is used to provide equal amplitude and in-phase excitation to all the cylindrical dielectric rods. To realize low return loss, corners of microstrip lines in the feeding network are blended. For the T-junctions of the deliver, the widths of microstrip lines W_2 and W_3 are set as 0.4 mm and 2 mm, which correspond to 100 Ω and 50 Ω characteristic impedance, respectively.

For this antenna, electromagnetic energy starts from the feeding point, flows to terminal circular patches through the corporate feeding network, enters the dielectric rods with the help of the circular

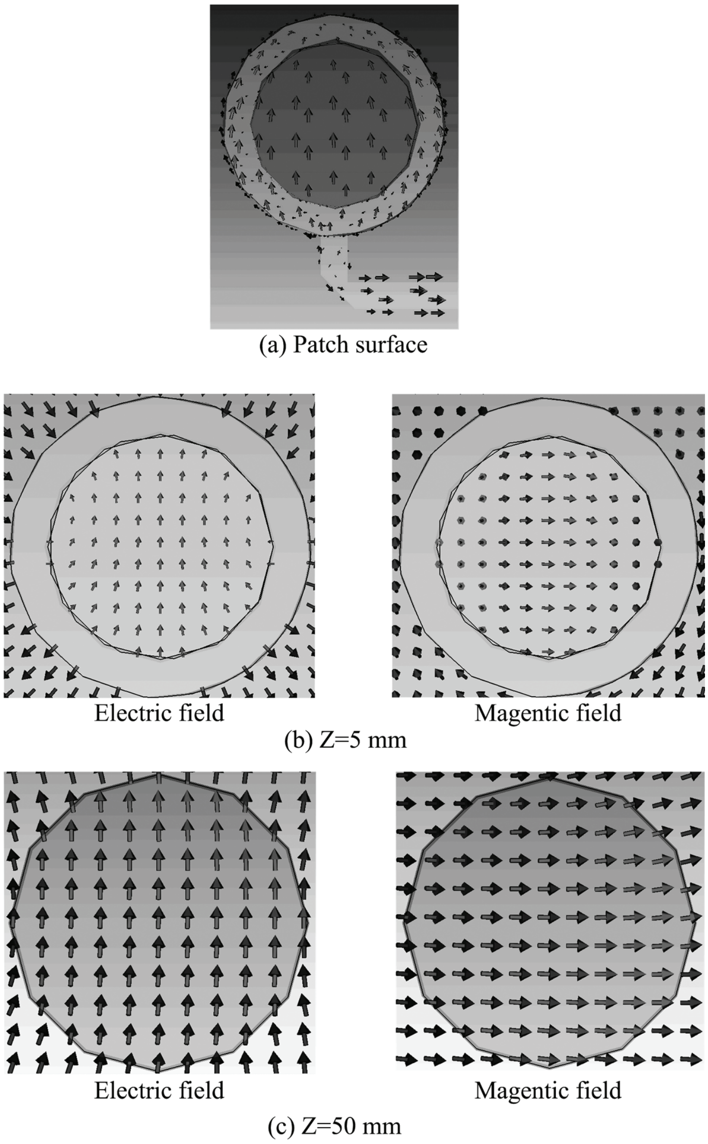


Fig. 3. Simulated surface current (a)/electric field distribution (b and c) on the cross-section of a circular patch (a), a circular metallic waveguide (b), and a dielectric rod (c).

metallic waveguides, and is progressively radiated from the rods to form a directional radiation pattern. The design objectives for the antenna are to achieve a good end-fire radiation pattern with the gain about 20 dBi, a good impedance match at the working frequency of 8.0 GHz, and a considerably wide impedance bandwidth more than 5%.

3. Mode analysis

Figure 3 depicts simulated surface current and electric/magnetic field distributions on the different cross-sections of the proposed antenna. Those simulation results are obtained by a popular commercial

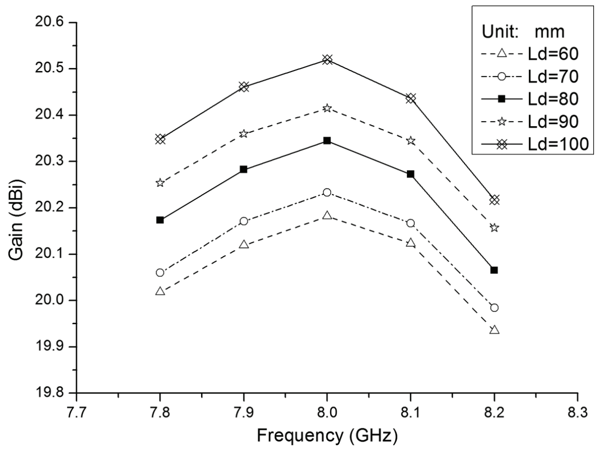


Fig. 4. Simulated gain for different values of L_d.

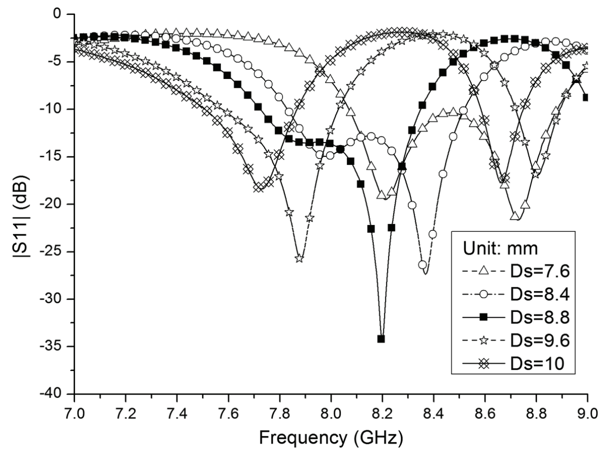


Fig. 5. Simulated $|S_{11}|$ for different values of D_s.

software CST MICROWAVE STUDIO (MWS) based on the finite integration technique (FIT). Figure 3(a) clearly reveals the circular patches are excited in the TM_{11} mode, which then is converted into the TE_{11} mode power propagating along circular metallic waveguides (see Fig. 3(b)), and finally as shown in Fig. 3(c), the HE_{11} mode becomes the dominant mode inside the dielectric rods. Hence the circular patches, circular metallic waveguides and dielectric rods are not only flowing routes of electromagnetic energy, but also mode converters.

For dielectric rod antennas, they are commonly designed to have single-mode propagation and the HE_{11} mode is used most often [4,5,7–10,14]. Some researches pointed out, when dielectric rod antennas work under the HE_{11} mode, low side-lobe and end-fire radiation can be obtained [8–15]. To guarantee the dominant mode inside the rod is HE_{11}, the following condition should be satisfied [16].

$$\frac{D_s}{\lambda_0} < \frac{0.626}{\sqrt{\varepsilon_r}} \tag{1}$$

where D_s is the diameter of the rod, λ_0 is the free-space wavelength, and ε_r is the relative permittivity of the dielectric rod. Thus, for the proposed antenna with the working frequency of 8.0 GHz, its rod diameter D_s should be less than 16 mm to guarantee the HE_{11} mode operation. Meanwhile, the HE_{11} mode in the dielectric rods implies the proposed antenna will radiate a linearly polarized EM field.

3.1. Parameter analysis

By making use of simulation results, this section analyzes the impact of some important parameters, such as the length and diameter of dielectric rods and metallic waveguides as well as the distances between dielectric rods, on the performances of the proposed antenna.

As a dielectric resonator antenna, the length of the dielectric rods is the main determinant of the gain, which follows Zucker's design rules [16] and could be expressed as

$$G \cong \frac{ML_d}{\lambda_0} \tag{2}$$

where G and L_d are the dielectric rods' gain and length respectively; λ_0 is the free-space wavelength; and M is a proportionality factor, which slowly decreases with the dielectric rods' length. For example,

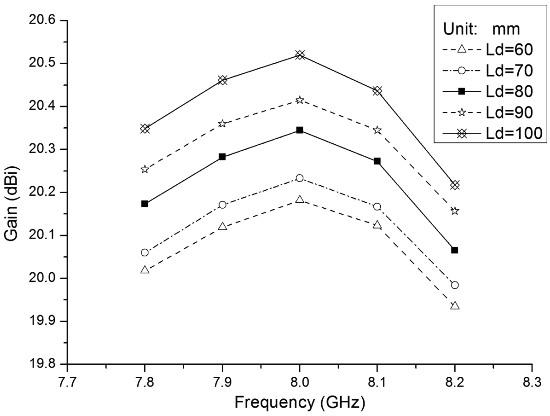
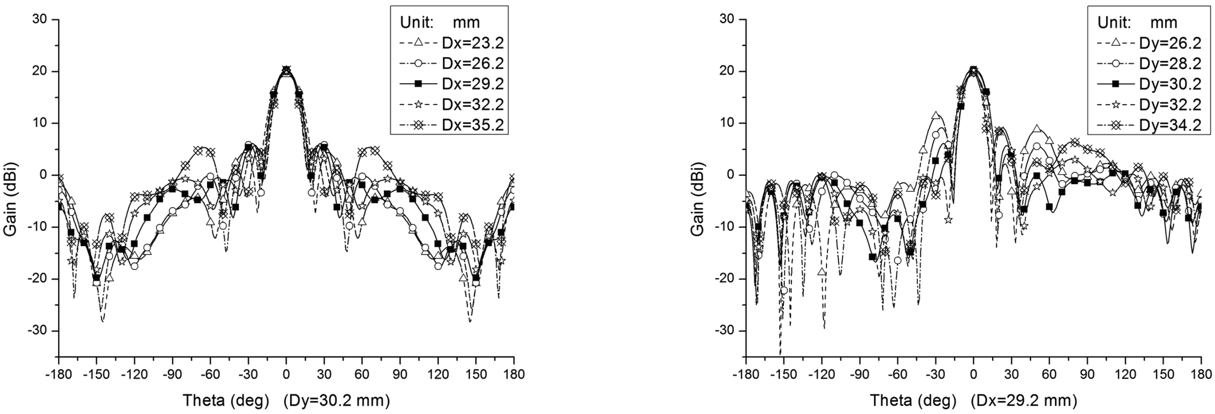


Fig. 6. Simulated $|S_{11}|$ for different values of L_c (a); Simulated radiation patterns for different heights of the circular waveguide (b) XZ (H plane), (c) YZ (E plane).



(a) (b)

Fig. 7. Simulated radiation patterns for different spacing values. (a) XZ (H plane); (b) YZ (E plane).

if an antenna with one rod is considered, M is about 10 for a length L_d between $3\lambda_0$ and $8\lambda_0$, and about 7 for $L_d \gg \lambda_0$. This rule is useful to predict a dielectric rod antenna's gain.

Figure 4 gives the simulated gain over a frequency band centered at 8.0 GHz against the dielectric rods' length L_d. It is evidence that longer rods result in higher gain. Considering the gain for the proposed antenna is required to be about 20 dBi at the working frequency of 8.0 GHz, we selected the length of rods L_d to be 80 mm.

The effect of cylindrical dielectric rods' diameter D_s on the antenna's return loss is simulated and depicted in Fig. 5, which clearly shown D_s determines the working frequency of the antenna. Taking both the value of $|S_{11}|$ at 8.0 GHz and the impedance bandwidth into account, D_s is chosen to be 8.8 mm for the proposed antenna.

Figure 6 shows the return loss and simulated radiation pattern for different values of the circular metallic waveguides height L_c. From the figure, it can be observed that height L_c considerably affects the antenna's impedance match and the side-lobe level of the radiation pattern, and meanwhile has small impact on the antenna's gain. When L_c is less than 10.5 mm, as L_c increases, the antenna's gain slightly rises but the side-level drops. However once L_c is larger than 10.5 mm, a further increase of

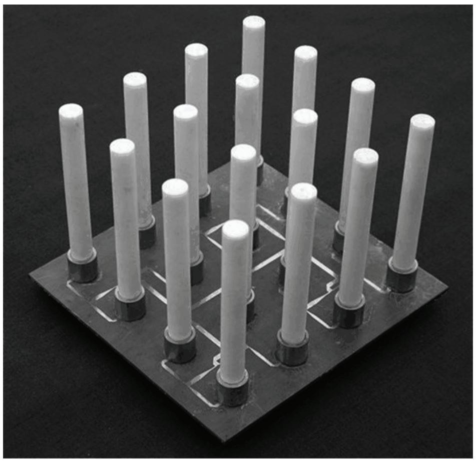


Fig. 8. The fabricated dielectric rod array antenna.

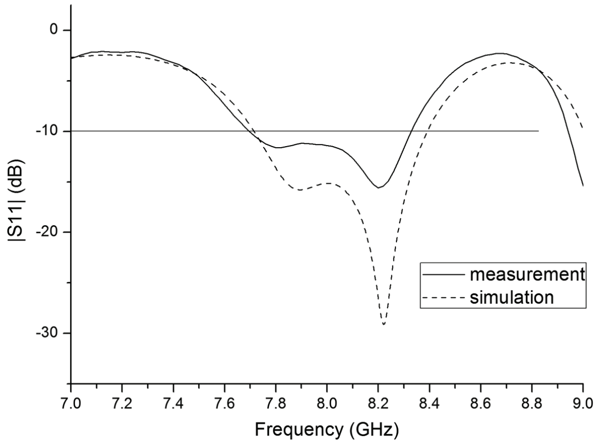
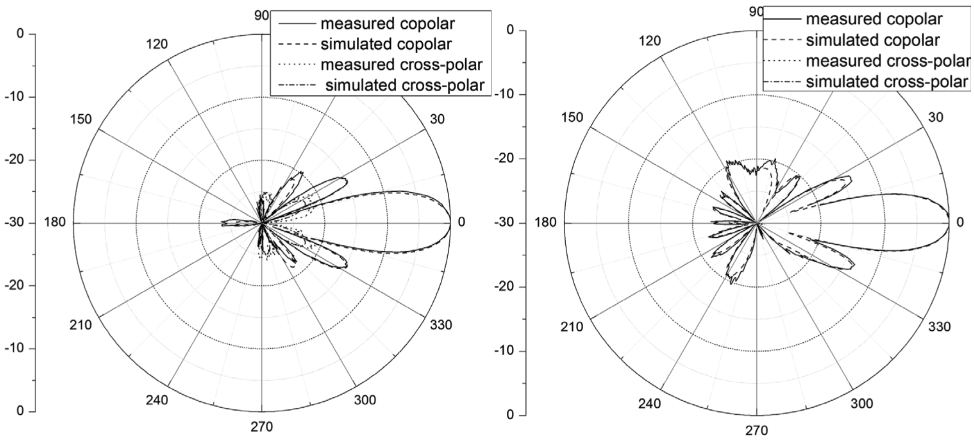


Fig. 9. The measured and simulated return loss of the prototype antenna.



(a) (b)

Fig. 10. Measured and simulated radiation patterns on the XZ Plane and YZ plane.

L_c will reduce both gain and the side-lobe level. To make a good compromise on those aforementioned performances, L_c is set to be 10.5 mm.

Figure 7 shows the simulated radiation pattern for different values of vertical and horizontal center-to-center distances between two neighboring rods D_x and D_y respectively. From the figure, one can observe that D_x and D_y have impact on the antenna's gain and side-lobe level. To make a good compromise between the gain and the side-lobe level, we select $D_x = 29.2$ mm and $D_y = 30.2$ mm.

4. Results and analysis

A prototype antenna as shown in Fig. 8 has been fabricated and measured. Its length, width and height are 121 mm, 117 mm, and 82 mm respectively.

Figure 9 compares the measured and simulated return loss of the prototype antenna. It can observe that the measured bandwidth is about 7.7% (from 7.70 GHz to 8.32 GHz). At the working frequency of 8 GHz, this antenna has an input return loss of -11.4 dB, which is approximately 4 dB greater than the simulation. The discrepancy between the simulated and measured results owes to the fabrication error and the inaccurate permittivity of the Teflon.

Measured and simulated radiation patterns on the XZ plane and YZ plane at the working frequency of 8 GHz are illustrated in Fig. 10. It's obvious that the measured and simulated radiation patterns agree very well. The gain at 8 GHz is up to 20.3 dBi. The measured side-lobes are approximately 13.5 dB below the main lobe. As shown in Fig. 3, the direction of the electric field on the cross-section of the dielectric rod is consistently along the Y-axis, which implies the antenna radiates in linear polarization with good cross-polar performance, which is verified by the simulation and measurement results that this antenna possesses a low cross-polarization level of less than -21 dB.

5. Conclusions

A novel microstrip-fed dielectric rod array antenna with high gain is presented. The dielectric array antenna is composed of cylindrical dielectric rods, which are made of Teflon. The microstrip corporate feeding network has been chosen to provide matched phase and electromagnetic energy to all the dielectric rod elements. A prototype antenna was fabricated and measured. The measured results agree with the simulated results well and show that the antenna achieves a high radiation gain up to 20.3 dBi at its working frequency of 8 GHz. Future work will focus on the design and fabrication of significantly larger arrays of profiled dielectric rods and raise the working frequency of the antenna.

Acknowledgment

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