Design of Dual-band Hollow Dielectric Antenna

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Abstract

A novel hollow dual-band hollow dielectric antenna is presented in this paper. The antenna operates in 2.4 GHz and 24 GHz bands with a frequency ratio of about 1:10. It consists of a dielectric resonator (DR) antenna (DRA) in the lower band and a Fabry-Perot resonator (FPR) antenna (FPRA) in the upper band by creating a hollow region through DRA. The antenna is excited by a vertical strip to DR at 2.4 GHz, and the upper frequency is fed by a rectangular waveguide. The proposed dual-band DRA-FPRA has -10dB bandwidths of 2.30-3.14 GHz (35%) and 23.60-24.82 GHz (5.1%), with maximum gains of 8.34 dBi (at 2.94 GHz) and 15.42 dBi (at 24.1 GHz), respectively. By integrating DRA with FPRA, the performance of DRA is not affected.

Keywords

Dielectric Resonator Antenna; Fabry–Perot Resonator Antenna; Dual-band Antenna.

1. Introduction

As a new kind of antenna, the dielectric resonator (DR) antenna (DRA) has developed rapidly in recent years. The earliest DRA was proposed and verified by Stuart A. Long et al in 1983[1]. DRs are characterized by wide bandwidth, lightweight, and high radiation efficiency. There are cylindrical, rectangular, and hemispherical shapes of this antenna[2]. DRA is fed in various ways, such as microstrip-slot feed, coaxial probe feed, microstrip line feed, microstrip slot coupled patch feed, coplanar waveguide feed[3-6], and other forms. Small size, low cost, lightweight, and easy integration of flat circuits make people study DR[7]. In recent years, many researchers have designed various types of antennas, which can be used in WLAN, mobile satellites, and other places, promoting the progress of science and technology[8].

With the rapid development of communication technology, the demand for high-gain, miniaturized and low-cost antennas is increasing. For some applications in aerospace and satellite fields, a high gain antenna is required. Fabry-Perot resonator (FPR) antenna is a new kind of high gain antenna (FPRA), because of its excellent characteristics such as high gain, it has attracted extensive attention. There are many ways to increase the gain of FPRA. In [9], a two layers dielectric plate is presented, and the gain of the antenna is increased by incorporating a tapered short horn into FPRA, but the horn antenna itself has a high gain. A method of wideband FPRA using a double-layer partial reflecting surface (PRS) is proposed[10]. The antenna is fed by a waveguide, and the gain of the antenna is improved by adjusting PRS to approach the ideal phase. However, the ideal phase is s not easy to control. A wideband FPRA is implemented in [11]. Five layers of a substrate composed of regions with different dielectric constants were selected as PRS. It is difficult to simulate and fabricate the antenna because of its complex structure.

Today, dual-band wireless communication system has been widely used and promoted the research of dual-band antenna. Dual-band antenna can be realized by changing feed[12], loading partial reflecting surface[13], loading folded transmission array[14], and other methods. By creating a

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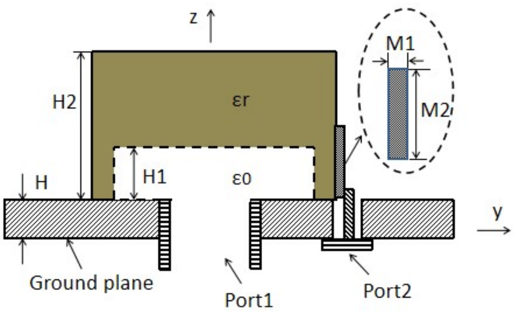
hollow cylindrical region, millimeter-wave FPRA and hollow cylindrical DRA in the microwave are formed[15]. The construction of an antenna is studied to achieve a dual-band with a large frequency ratio. The antenna has a simple construction and high integration. However, it is easy to cause material waste and increase production costs because the appearance of the medium material for DRA is usually rectangular. This paper presents a novel hollow dual-band resonator antenna. It consists of a DRA and an FPRA by creating a hollow rectangle region through DRA. The FPRA is fed by a WR-34 waveguide. A vertical strip connected by the probe excitation method with a feed stripe is employed to feed DRA. And the feed strip line is printed on the side of DRA.

2. Design of Hollow Dual-band Resonator Antenna

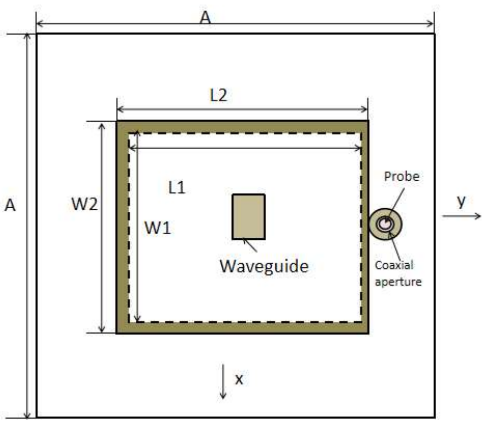
2.1 Antenna Configuration

Fig. 1 shows the configuration of our dual-band hollow dielectric antenna. The antenna is placed on a square ground with a length and width of A=130mm and a thickness of H=4mm. The substrate has a dielectric constant of 3.55. The hollow region is formed by creating a small rectangle DRA at the bottom of a large rectangle DRA. For the design in this study, DRs' parameters are chosen as L1=46mm, W1=30mm, H1=6.3mm, L2=48mm, W2=32mm, H2=19.4mm. The dielectric constant of the DRA is εr=7, and the dielectric constant of the hollow region without any medium is ε0=1. This hollow region is introduced to obtain the FP cavity used to form FPRA and the performance of the antenna does not change.

The FPRA is fed by a WR-34 waveguide at port 1 below the ground plane. A vertical strip connected by the probe excitation method with a feed stripe is employed to the low frequency of the antenna, and the feed strip line is printed on the side of DRA in Fig.1. The size of the stripe is the width of M1=2mm and the length of M2=13.5mm.



(a) Front view of the antenna



(b) Top view of the antenna

Fig. 1 The structure of the antenna

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2.2 Characteristic Analysis

ANSYS Electronics 2020 R1 electromagnetic simulation software is used for simulation optimization and analysis of dual-band DRA and FPRA. The hollow dual-band resonator antenna consists of a hollow DRA, coaxial probe, strip, and waveguide. By adjusting the length M2 of the strip and with or without the side wall of a hollow region formed by the rectangular cavity, the antenna reflection coefficients (S11) and gains are optimized.

A parametric study was done to study the reflection coefficients (S11) and gains. Fig. 2 and Fig. 3 show the reflection coefficients and gains for different strip lengths of M2 = 12.5, 13.5, 14.5, 15.5, 16.5, and 17.5 mm, respectively.

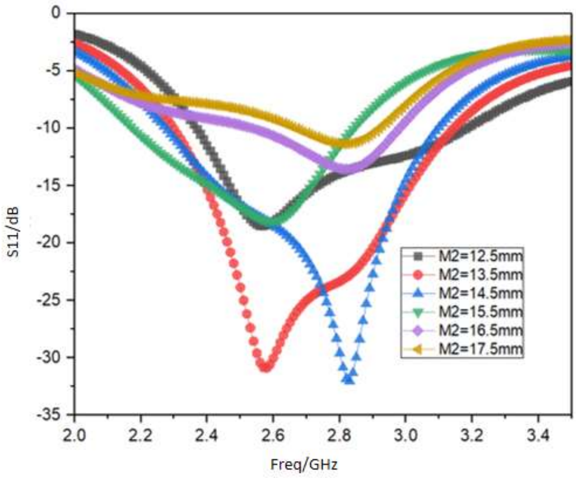

Fig. 2 reflection coefficients (S11) varied with parameter M2

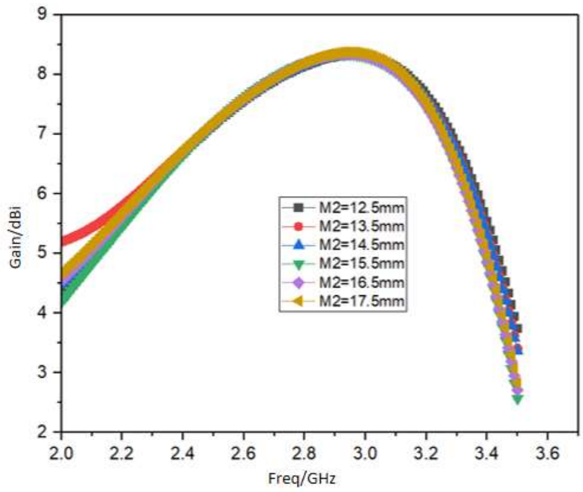

Fig. 3 gains varied with parameter M2

As can be seen from the inset, when strip length M2 increases from 12.5 to 17.5 mm, the impedance bandwidths of M2=12.5mm-15.5mm can cover 2.4GHz. Once the length M2 exceeds 15.5mm, the antenna impedance matching becomes worse. As parameter M2 varying the gains of antenna has little influence with almost no change in Fig. 3. Therefore, M2=13.5mm is selected to achieve a better match at 2.4GHz.

When other parameters remain unchanged, the influence of with or without the side wall on reflection coefficients (S11) and gains is shown in Fig. 4 and Fig. 5, respectively.

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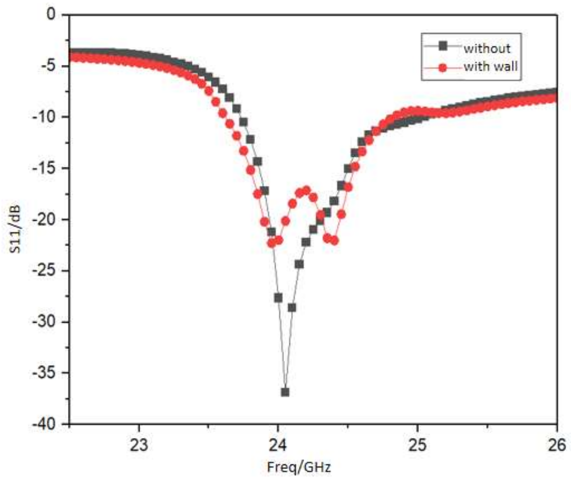

Fig. 4 reflection coefficients (S11) varied with and without side wall

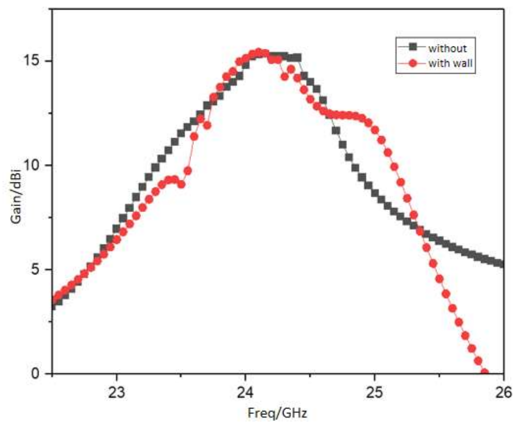

Fig. 5 gains varied with and without side wall

Concerning the figure, the side wall has little influence on the reflection coefficients (S11) and gains of the antenna. Therefore, the antenna with a side wall with wide impedance bandwidths is selected as the designed antenna. And the antenna with the side wall is fed to low frequencies conveniently.

3. Simulation Results

After optimized parameters, the simulated impedance bandwidths, gains, and E-plane and H-plane radiation patterns at 2.4GHz and 24GHz are presented in Fig.6, Fig.7, and Fig.8.

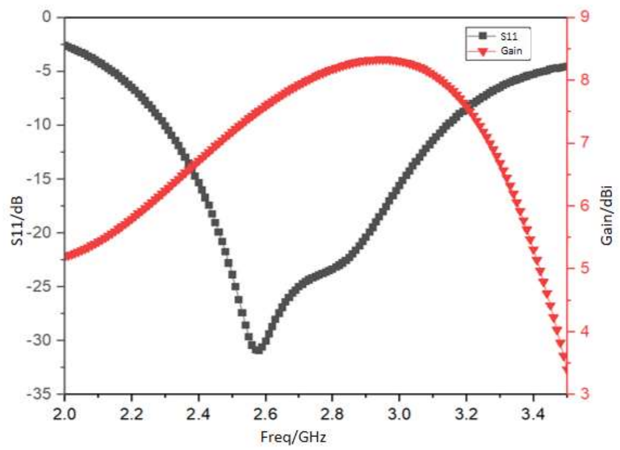

Fig. 6 simulated reflection coefficients and gains of and DRA

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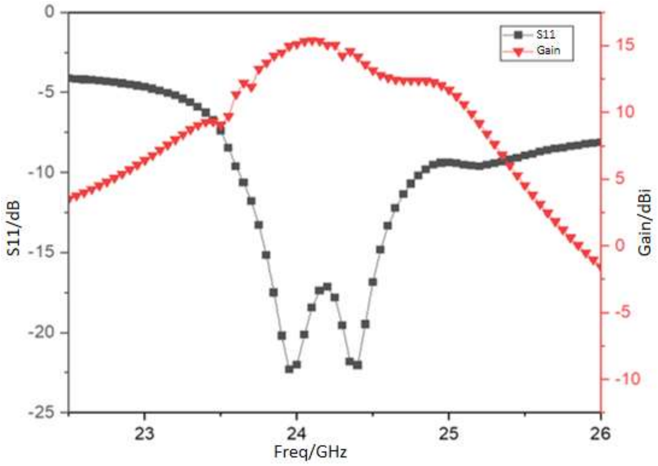
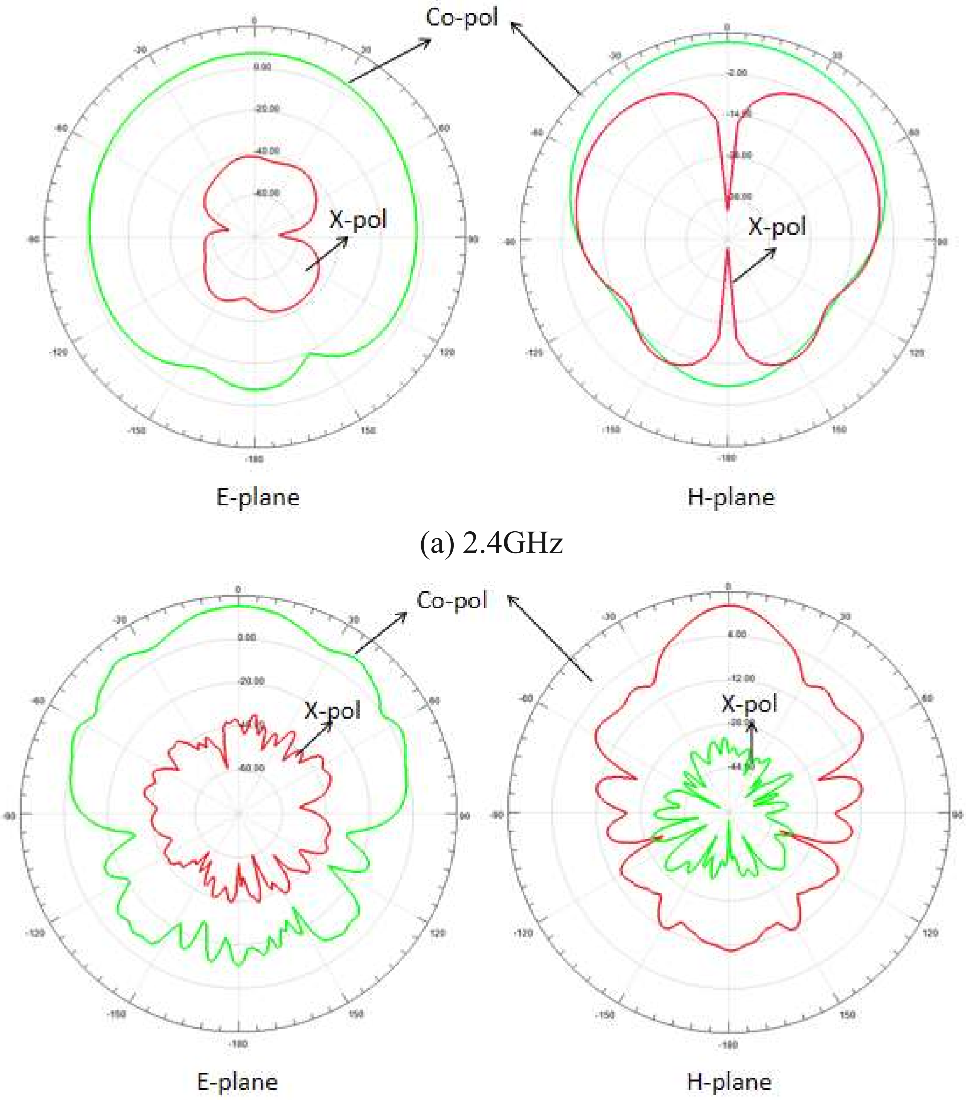


Fig. 7 simulated reflection coefficients and gains of FPRA



(a) 2.4GHz

(b) 24GHz

Fig. 8 simulated radiation patterns of DRA and FPRA

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Regarding the inset, simulated the lower frequency DRA 10-dB impedance bandwidths (|S11| < −10 dB) and maximum gain are 35% (2.30–3.14 GHz) and 8.34dBi (at 2.94GHz), respectively. And simulated the upper frequency FPRA 10-dB impedance bandwidths (|S11| < −10 dB) and maximum gain are 5.1% (23.6–24.82 GHz) and 15.42dBi (at 24.1GHz), respectively. In Fig.8, it can also be observed the dual-band antenna has good symmetry in the boresight direction (θ = 0°) radiation pattern of 2.4GHz and 24GHz. Because of the feed structure in the y-o-z plane, the cross-polarization of the low-frequency E-plane field is weak. The cross-polarization of E and H planes of high-frequency FPRA at 24GHz is very small, and the simulated co-polarization field is more than 30dB stronger than the cross-polarization field in the boresight direction.

4. Conclusion

A novel hollow dual-band resonator antenna has been investigated. By creating a small rectangle DRA at the bottom of a large rectangle DRA the hollow region is formed. The impedance bandwidth and antenna gain are given by 35%, 8.34dBi (at 2.94GHz), and 5.1%, 15.42dBi (at 24.1GHz), respectively. Because of the advantages such as its compact structure and ease of fabrication, our dual-band antenna should be useful for modern wireless communication systems.

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