Stacked dielectric patch resonator antenna with wide bandwidth and flat gain

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Abstract: A stacked dielectric patch resonator antenna with wide bandwidth and flat gain is proposed. For this design, two thin ceramic sheets with high permittivity are introduced to operate as approximate magnetic walls. Incorporated with another ground plane, two resonant modes can be excited to form a wide bandwidth, and a flat gain is also achieved within the band. Measured results demonstrate that the antenna obtains an impedance bandwidth of 18.2% and an average gain of 7.2 dBi.

1 Introduction

Dielectric resonator antenna (DRA) has been widely used in modern wireless communication systems, owing to its merits of low loss (especially in millimetre-wave applications) and high design flexibility in three-dimensional geometry and material permittivity [1, 2].

Recently, a kind of dense dielectric patch antenna (DDPA) has been presented in [3–5], which replaces the metallic patch of a microstrip antenna by a high-permittivity thin dielectric patch. The radiation mechanism of DDPA is similar to that of a metallic microstrip patch antenna. Hence, the DDPA shows a higher gain than the traditional DRA [6]. As development continues, a simplified theoretical model was further proposed to analyse such kind of planar dielectric antenna in [7], where the thin high-permittivity dielectric film was approximated to a perfect magnetic wall boundary.

Unsurprisingly, the DDPA, or DRAs with similar structures, usually have narrow bandwidths in low frequency due to its similarity with microstrip patch antennas. Only a few studies have been done to address this issue. In [4, 8], it is shown that the DDPA can exhibit much wider impedance bandwidths in millimetre-wave band than in the lower-frequency band. In [9], L-shaped probe feeding structures have been adopted to increase the impedance bandwidths of water DDPA. Meanwhile, a wideband DRA with a low profile and high-gain has been reported very recently [10]. By enlarging the planar dimension of the thin dielectric layer with high permittivity, two dielectric resonator (DR) modes can be excited to broaden the antenna’s bandwidth. However, the large antenna planar size makes it difficult to be arrayed.

In this paper, inspired by the classical stacked metallic patch antenna [11], a stacked dielectric patch resonator antenna (DPRA) with wide bandwidth and flat gain is presented. Within the stacked structure, two thin ceramic sheets with high permittivity are introduced and act as equivalent magnetic walls. Combined with another metallic ground plane (electric wall), a TE₁₁₁ mode that is located between the ground plane and high-permittivity ceramic layers, and the other TE₁₁₁ mode formed between the two high-permittivity ceramic sheets can be simultaneously excited, and thereby constitute a wide bandwidth. Meanwhile, the gain of the stacked DPRA is flat within the whole operating band and higher than that of the traditional DRA as the radiation is mainly contributed by the sidewalls rather than its top wall [6]. The stacked ceramic sheets are designed with the same planar size, which facilitates the alignment in the assemble process.

2 Antenna configuration and working principle

The antenna configuration is shown in Fig. 1. Two ceramic dielectric sheets (tan δ=8.5×10⁻⁴), having a high permittivity of ɛr₁ and thicknesses of h₁ and h₂, constitute two equivalent magnetic walls and another ceramic dielectric slab (tan δ=8.0×10⁻⁴) with a low permittivity of ɛr₂ and a height of h₃ is sandwiched. The three ceramic dielectric layers are cemented together using glue. Below them is a substrate layer of Rogers 5880 with a thickness of h₄, which serves as a supporting board between the stacked ceramic layers and feed structure. On the lowest is a microstrip-coupled slot feed structure. The microstrip line is etched on the bottom side of a substrate layer of Rogers 5880 with a thickness of h₅, while the feeding slot is fabricated on the top ground plane. The multilayer printed circuit board technology is used for the two Rogers substrate layers. The detailed dimensions of the antenna are listed in Table 1.

As previously mentioned, the ceramic slab with low permittivity (ɛr₂) is sandwiched between the other two ceramic sheets with high permittivity (ɛr₁). Since the permittivity contrast (ɛr₁/ɛr₂) is high enough, their interfaces in the x–y plane can be approximately treated as magnetic walls [7]. On the other side, the metallic ground plane can be considered as an electric wall. Accordingly,
the proposed stacked DPRA can be analysed by using a simplified equivalent model as demonstrated in Fig. 2. On the basis of the boundary conditions, it is shown that there exists a $\text{TE}_{111}^{(\text{half})}$ resonant mode between the magnetic wall and electric wall (resonating at low frequency), and the other $\text{TE}_{111}^{(\text{full})}$ resonant mode formed between the two magnetic walls (resonating at high frequency). The two resonant modes with slightly different resonant frequencies are simultaneously excited, constituting a wide operating bandwidth.

A parametric study has been implemented by Ansoft high-frequency structure simulator to verify the analysis. Fig. 3a shows the effect of varying the planar size of the lower high-permittivity ceramic sheet on the reflection coefficient of the antenna. It is observed that as the $L_1$ of this ceramic sheet increases, the lower resonant frequency shifts down while the higher resonant frequency remains unchanged. This is owing to that the lower resonant frequency is caused by the $\text{TE}_{111}^{(\text{half})}$ mode. Fig. 3b shows the effect of varying the height ($h_2$) of the sandwiched ceramic slab on the antenna’s reflection coefficient. It is found that the higher resonant frequency decreases when increasing $h_2$, while the lower resonance keeps stable. This means that the higher resonance is mainly contributed by the $\text{TE}_{111}^{(\text{full})}$ mode.

It is noted that as the thin ceramic sheets with high permittivity cannot be ideally equivalent to perfect magnetic walls, the dimensions of the three ceramic layers should be optimised in practice to achieve the desired performance.

### Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values, mm</th>
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<tbody>
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### 3 Experimental results

To validate the design principle, an antenna prototype with an overall size of $0.82\lambda_0 \times 0.82\lambda_0 \times 0.15\lambda_0$ was fabricated and measured. Fig. 4 shows the photograph of the antenna prototype. Fig. 5 shows the simulated and measured reflection coefficients and gains. The measured impedance bandwidth for $|S_{11}| < -10$ dB is 18.2%, ranging from 5 to 6 GHz. An average gain of about 7.2 dBi was obtained over the band. The simulated and measured radiation patterns were plotted in Fig. 6, for two resonant

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**Fig. 2** Simplified equivalent model for the proposed antenna

**Fig. 3** Simulated reflection coefficients for different parameters

- **a** Different side lengths ($L_1$) of the bottom dielectric layer
- **b** Different high ($h_2$) of the middle dielectric layer

**Fig. 4** Photograph of the fabricated stacked DPRA prototype

**Fig. 5** Simulated and measured reflection coefficients and gains of the proposed antenna

**Fig. 6** Simulated and measured radiation patterns of the proposed antenna

- **a** At 5.2 GHz, $E$-plane
- **b** At 5.2 GHz, $H$-plane
- **c** At 5.8 GHz, $E$-plane
- **d** At 5.8 GHz, $H$-plane

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frequencies of 5.2 GHz and 5.8 GHz. It is shown that the antenna radiates in a broadside direction and the cross-polarisation levels of lower than $-25$ dB are preserved within $\pm 45^\circ$ beam range.

4 Conclusion
In this paper, a stacked DPRA with wide bandwidth and flat gain has been designed and measured. Two resonant modes can be simultaneously excited and separately adjusted. The antenna prototype achieves a wide impedance bandwidth of 18.2% for $|S_{11}|< -10$ dB, and an average gain of 7.2 dBi. The antenna exhibits promising characteristics of wide bandwidth and flat gain, making it a suitable candidate for wideband wireless systems.

5 Acknowledgments
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6 References

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