Wideband P-Shaped Dielectric Resonator Antenna

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Abstract. *A novel P-shaped dielectric resonator antenna (DRA) is presented and investigated for wideband wireless application. By using P-shaped resonator, a wideband impedance bandwidth of 80 % from 3.5 to 8.2 GHz is achieved. The antenna covers all of wireless systems like C-band, 5.2, 5.5 & 5.8 GHz-WLAN & WiMAX. The proposed antenna has a low profile and the thickness of the resonator is only 5.12 mm, which is 0.06-0.14 free space wavelength. A parametric study is presented. The proposed DRA is built and the characteristics of the antenna are measured. Very good agreement between numerical and measured results is obtained.*

Keywords

Dielectric resonator antenna (DRA), wideband, P-shaped, Q-factor.

1. Introduction

Recently, antennas using high-permittivity dielectric ceramic materials as radiation elements have received much attention due to several features like high radiation efficiency, low temperature coefficient, low profile and suitable scale in microwave band [1]. Since dielectric resonators have very low loss, higher efficiency without any conductor loss is ensued. Therefore, DRAs own much lower loss and are a very good candidate to design the antenna for microwave bands. Moreover, by choosing a suitable dielectric constant to fabricate an antenna, a reasonable size can be achieved. In addition, variety types of feedings can be utilized to excite DRAs like using a coaxial probe [2], a microstrip feed-line [3], an aperture-coupled source [4], a coplanar waveguide (CPW) [5]. Also, different radiation patterns are obtained by exciting different modes. Over the last decade, investigations have been focused on the bandwidth enhancement and thus, various techniques have been developed for wideband DRAs. These techniques use special composite dielectric resonator (DR) structures [6]-[11], such as embedded DRs [7] or other DR configurations including tetrahedron and triangular [8], L-shaped [9], T-shaped [10], stair-shaped [11], trapezoidal [12], H-shaped [13], and so on. By using these methods, operation bandwidth ranges from 30 % to 62 % have been achieved. In this paper a new shape of dielectric resonator antenna has been investigated. The P shape of DRA produces a significant improvement of bandwidth which is 80 % from 3.5 up to 8.2 GHz. In the following sections, the design of the proposed antenna is described. Simulation and measurement results are presented and discussed.

2. Antenna Configuration and Design

In order to illustrate the design procedure of the proposed design, a simple rectangular resonator is considered as a preliminary shape (Fig. 1-a). The initial dimensions of DRA are determined using the equations developed for the magnetic wall waveguide model with the dielectric slab in the transverse plane (x-z) of the waveguide at 4.5 GHz by considering $m = n = 1$ [14]. Enforcing the magnetic wall boundary condition at the side wall surfaces of the resonator, the following equations are obtained for the wave-numbers:

$$k_x = \frac{m\pi}{a}, \tag{1}$$

$$k_y = \frac{n\pi}{b}, \tag{2}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{3}$$

where k_x, k_y, and k_z denote the wave-numbers along the x, y, and z directions, respectively, inside the DR also should satisfy:

$$k_z \tan\left(\frac{k_z h}{2}\right) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2} \tag{4}$$

where k_0 denotes the wave-number in the free space.

Firstly, a rectangular part of the DR is removed (Fig. 1-b; no-hole P-shaped resonator) to decrease the Q factor of the resonator and hence a wider bandwidth can be achieved. By simulating this new design, the return loss is evaluated in comparison to the simple shape rectangular resonator. It is apparent from Fig. 2; 2.5 GHz bandwidth enhancement is achieved.

In the second step of the design, as illustrated in Fig. 1-c, a hole with dimensions of $q \times p$ is drilled inside the structure of DR to obtain wider bandwidth. It is noted that this hole is effective on the improvement of the impedance matching.

To show the improvement of the operation of the proposed antenna, volume and simulated bandwidth results of all three structures; rectangular DRA, no-hole P-shaped DRA, and P-shaped DRA are illustrated in Tab. 1.

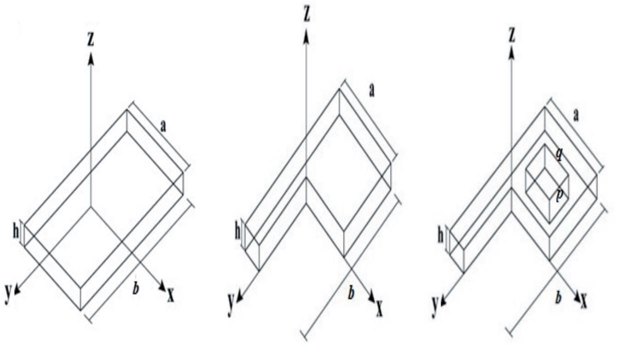

Fig. 1. (a) The rectangular resonator, (b) the no-hole P-shaped resonator, (c) the P-shaped resonator.

Parameters	Volume (mm^3)	Bandwidth
Rectangular DRA	819.20	4 to 5.91 GHz (38%)
No hole P-shaped DRA	603.92	3.6 to 7.27 GHz (67%)
P-shaped DRA	522	3.6 to 8.1 GHz (77%)

Tab. 1. Comparison between the rectangular, no hole P-shaped, and P-shaped DRA.

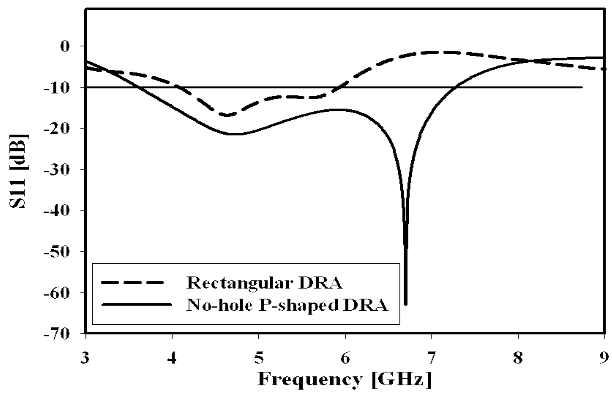

Fig. 2. Comparison of the simulated S_{11} between rectangular and no-hole P-shaped DRA.

Fig. 3 shows the top, side and 3D views of the proposed antenna, which consists of a DR, the microstrip feed line and a substrate with the dimensions of 17×35 mm^2. The P-shaped DRA is made of Rogers-RO3010 with the relative permittivity of $\varepsilon_r = 10.2$ and with a thickness $h = 5.12$ mm, and it is supported by the substrate with a dielectric constant of 4.6, loss tangent, $\tan \delta = 0.019$ and a substrate thickness of 1.6 mm. The DR is designed with P-shaped cross, which is characterized by the dimensional parameters *a, b, c,* and *d* as shown in Fig. 3. The width of the microstrip-feed line is 3 mm to have an input impedance of 50 ohm. The microstrip-feed line is placed on the top side of the substrate while the ground plane is on the bottom side of the substrate.

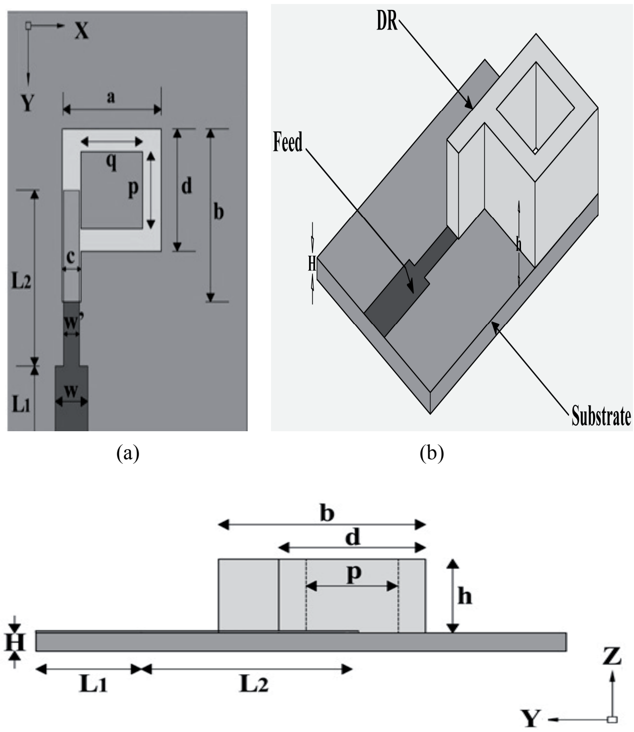

Fig. 3. (a) Top and (b) 3D (c) side views of the proposed antenna.

The dimensions *a, b, c, d* of the proposed DRA are 10 mm, 16 mm, 3 mm and 10 mm, respectively. The feed line is shown by two different widths *W* and *W'* and different lengths L_1 and L_2, respectively. By changing the width of the microstrip-fed line, from $W = 3$ mm to $W' = 1.4$ mm, and choosing $L_1 = 9$ mm and $L_2 = 13.5$ mm, the optimum matching is achieved.

The design presented in [16] has been enhanced and experimental results are introduced to verify the simulated results. In the present design a lower dielectric constant is used that is cheaper and easier to machine. In the next section, the effective parameters are studied and the measured results are also presented and compared in the last section.

3. Parametric Study and Discussion

For a better understanding of the proposed P-shaped DRA impedance bandwidth with the variation of some parameters, a parametric study is performed to see the effect on the reflection coefficients, which is usually helpful for practical antenna design. The CST Microwave Studio software 2011 [17], based on the finite integral technique, was used for the parametric analysis.

First, the shape of DRA is studied. As Fig. 1(c) shows, there is a hole with dimensions ($q \times p$) inside the structure of DR which is very effective on the improvement of the impedance matching. By creating the hole inside the DR, the effective permittivity of the whole volume is reduced and consequently the radiation Q-factor of DR is decreased, and hence it increases the impedance bandwidth of the proposed DRA. The best values of the length p and width q of the hole are quite important to achieve good impedance matching. By tuning these values, it is found that the best values of both p and q are 4 mm.

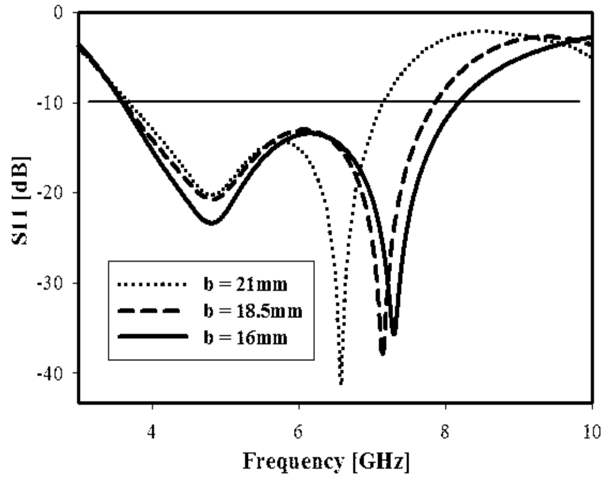

Fig. 4. Simulated S_{11} of the antenna with different values of b.

Fig. 4 shows that by decreasing b the impedance matching is improved especially at high frequencies so the proper value of b is achieved when b = 16 mm.

Although the simple P-shaped DRA without hole has an acceptable wide bandwidth enough to cover different wireless communication frequency bands, by creating the hole inside the P-shaped DRA the impedance matching is further enhanced by about 1 GHz as shown in Fig. 5.

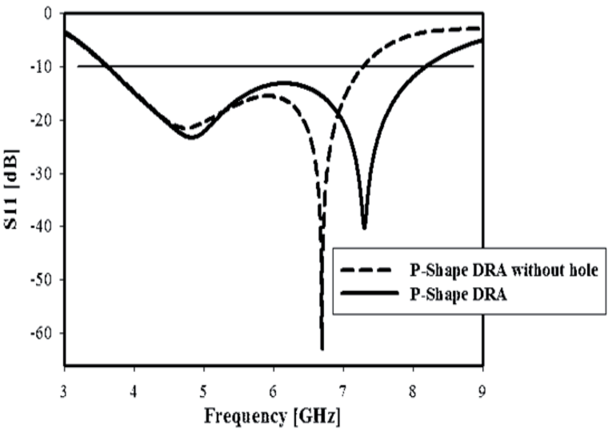

Fig. 5. Comparison between simulated S_{11} of the antenna with and without hole inside P-shaped DRA.

In addition, another important factor of enhancing the bandwidth is the efficient coupling between the DR and the feed. The feed line width and length overlapping with the DR are important parameters to achieve matching over wide bandwidth. Figs. 6 and 7 show the effect of these parameters on the matching for the proposed DRA. The impedance matching is sensitive to the length L_1 and L_2 and width of the matching transformer W' (see Fig. 3), especially at higher frequencies.

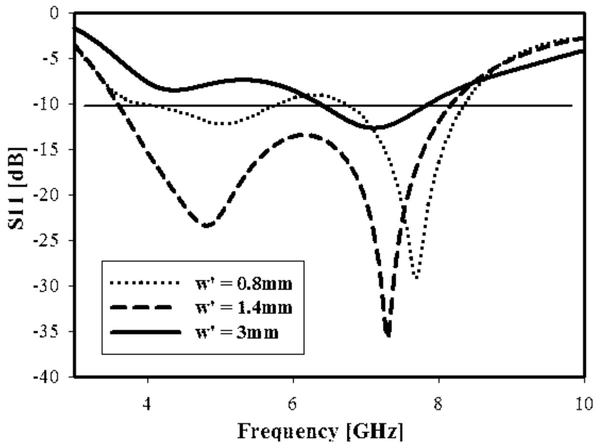

Fig. 6. Simulated S_{11} of the antenna with different values of W'.

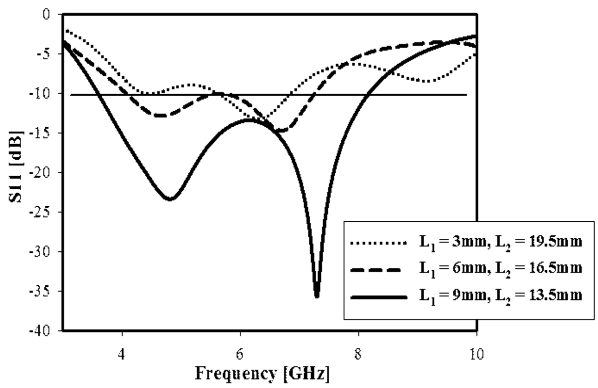

Fig. 7. Simulated S_{11} of the antenna with different values of L_1 and L_2 (W' = 1.4 mm).

4. Measurement Results

Fig. 8 shows the fabricated P-shaped dielectric resonator antenna. Considering the simple manufacturing facilities in our lab to fabricate the DRA and the fact that the DRA is made of small pieces and multiple thin dielectric layers, the structure is successfully constructed and measured. The measured and simulated S_{11} of the proposed antenna are simultaneously illustrated in Fig. 9. It is clearly seen that the measured and computed S_{11} are in excellent agreement with each. Such an excellent agreement between measured and simulated results indicates the high tolerance of this antenna in terms of dimensions and materials. It is noted that TE_{110} and TE_{120} are excited in the structure.

Simulated results show that the proposed P-shaped DRA achieved more than 95 % antenna efficiency within most of the band. It is noted that the measured gain values of the antenna are always greater than 3.5 dB from 3.5 to 8.2 GHz.

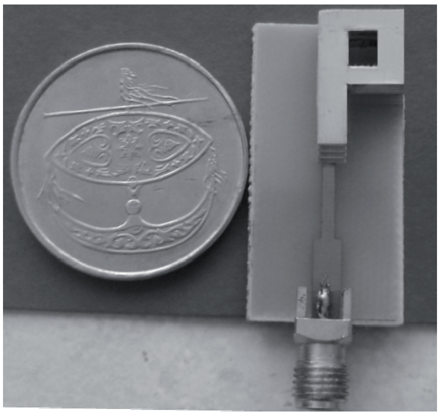

Fig. 8. Photograph of the realized P-shaped dielectric antenna.

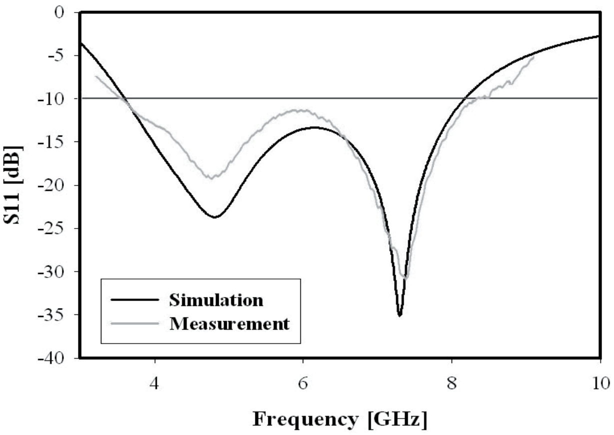

Fig. 9. Measured and simulated S_{11} of the P-shape DR antenna.

Fig. 10 shows the simulated antenna efficiency with the measured gain of the antenna versus frequency for the proposed DRA Fig. 11 indicates the measured and simulated H (x-z) & E (x-y) planes radiation patterns at two selected frequencies, 4.8 and 7.2 GHz. The cross-polarized fields in both E & H planes are sufficiently low compared to the co-polarized peak level.

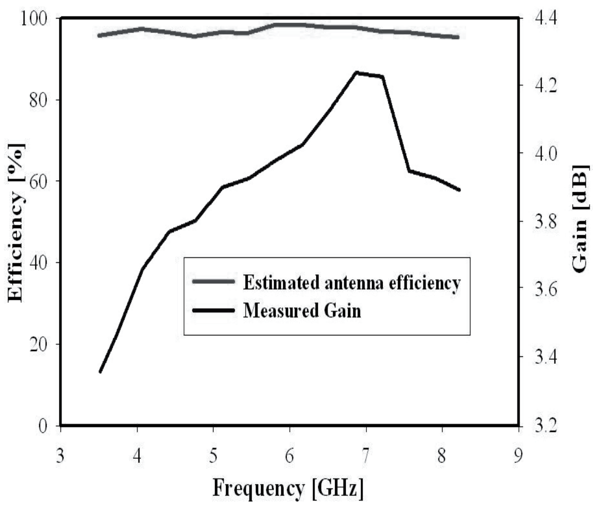

Fig. 10. Estimated antenna efficiency and the measured gain of the antenna versus frequency.

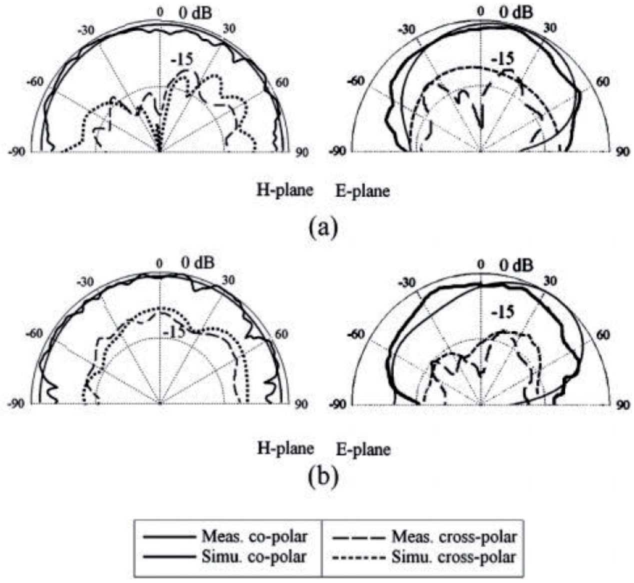

Fig. 11. Measured and simulated H (x-z) & E (x-y) planes radiation patterns of the realized antenna in normalized form, at: (a) 4.8 GHz and (b) 7.2 GHz.

As mentioned earlier in the introduction, different shapes of DR antennas are investigated for wideband application. To determine the validity of this particular design, a comparison with the some available designs in the literature is presented in Tab. 2. The comparison shows not only that the proposed antenna achieves wider bandwidth, but also its volume is considerably less than other DRAs.

Parameters	Volume (mm^3)	Height (mm)	Bandwidth
Proposed design	522	5.12	3.5 to 8.2 GHz (80%)
L-shaped DRA[9]	44732	24	1.71 to 2.51 GHz (38%)
T-shaped DRA[10]	26970	30	1.6 to 3.1 GHz (60%)
Stair-shaped DRA[11]	666	5.89	7.68 to 13.4 GHz (54.3%)
Trapezoidal DRA [12]	704	12	6.8 to13 GHz (62%)

Tab. 2. Comparison between the proposed antenna and other designs.

5. Conclusion

A novel P-shaped dielectric resonator antenna is presented to support the wideband operation. In this design, P-shaped DR with low volume mounted on the microstrip feed line to get wideband impedance bandwidth is studied. The total thickness of the antenna was only 6.72 mm including the FR4 substrate and DR thickness. By using this novel design several wireless systems between 3.5 and 8.20 GHz such as WLAN, WiMax, Wi-Fi and C-band are supported, simultaneously. A good agreement between the measured and simulated results is achieved. In addition, suitable radiation patterns and gain characteristics over the covered frequency range are obtained. As a result, the proposed antenna is attractive and can be of practical use for various wireless communication systems.

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