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COMPACT WIDEBAND RECTANGULAR DIELECTRIC RESONATOR ANTENNA WITH PARASITIC ELEMENTS AND AIR GAPS

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Abstract—A simple compact wideband aperture coupled rectangular dielectric resonator antenna (RDRA) loaded with similar parasitic dielectric elements separated by low dielectric spacers as air gap layers is designed. The bandwidths of the proposed RDRAs are significantly enhanced as compared with the bandwidth of the driven DRA without an air gap. The measurement results are verified experimentally for a one parasitic element case. A bandwidth of 18% and 27% with VSWR better than 2 is achieved for double and triple gaps, respectively. It is interesting to point out that radiation patterns are stable in the entire operation band.

1. INTRODUCTION

Dielectric resonator antennas (DRAs) have largely been emphasized in the past two decades because of several attractive features such as small size and light weight. Due to several advantages over microstrip antennas such as wide impedance bandwidth, high radiation efficiency and absence of surface waves [1], DRAs are introduced as vigorous candidates for wireless communications [2]. Although different shapes of DRAs, such as cylindrical, rectangular and hemispherical DRAs, have been investigated [3–5], rectangular shaped DRAs are attractive because of their independent tunable sizes, which make them possible to reach wide impedance bandwidth and easy fabrication [6].

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In order to achieve a wide impedance bandwidth in DRAs, many approaches have been investigated. One approach is to use special configurations for DRAs, but the geometries of these methods are not easy to construct [7, 8]. L- and T-shaped DR antennas have been reported, achieving impedance bandwidths of 30% and 60%, respectively [9, 10]. Using stacked DRAs is another method to improve the impedance bandwidth, but in this method, DRAs must be different in size and/or dielectric constants [10–14].

Antenna miniaturization is becoming significantly important, specially in low frequency applications. A rectangular dielectric resonator antenna with relative permittivity of 36 was used to reduce the size of the antenna and the resulting impedance bandwidth was found to be 2.7% [15]. If a wider bandwidth is required, a dielectric resonator with a lower dielectric constant can be used. However, the size of the antenna will be considerably increased for the same resonant frequency. From observations regarding the study of the air gap effects on the DRA performance, the bandwidth is increased due to the presence of the air gap [16, 17]. Other techniques are possible to reduce the size of the antenna [18]. However, these methods affect the radiation characteristics dramatically and the antenna is not suitable for phased arrays.

Here, two concepts are combined to achieve a simple, compact and yet a wideband aperture coupled dielectric resonator antenna. The first concept is related to reducing the size of the antenna using a high dielectric constant of $\varepsilon_r = 35.9$. To achieve a wide impedance bandwidth parasitic DRs and air gap layers are used as the case of stacked [19] and multisegment DRAs [20]. However, stacked DRAs are made of two resonators on top of each other, the bottom one is larger with a low dielectric constant and the top one has a higher permittivity and smaller size. Furthermore, multisegment DRAs are made of several layers of equal cross-sections of different dielectric constants. In the present work, the dimensions and dielectric constants of parasitic elements are quite similar to each other. The goal of this study is to improve bandwidth while maintaining a small size. For wide scanning range of an array, the distance between the elements must be small with broad beam radiation and at the same time the element size should allow that as well. This antenna would be a good candidate for phased array applications.

2. CONCEPT AND DESIGN

As a proof of concept a RDRA with high dielectric constant, $\varepsilon_r = 35.9$, a compact size of dimensions $a = b = 18\,\mathrm{mm}$ and $h = 8.9\,\mathrm{mm}$ is directly

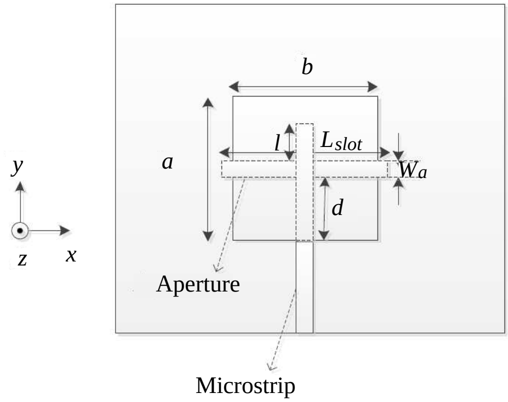


Figure 1. Geometry of the aperture coupled dielectric resonator.

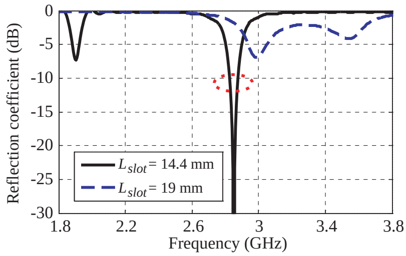
placed symmetrically over a narrow slot (Figure 1) etched on a 62 mil Rogers RT 5870 dielectric substrate with $\varepsilon_r = 2.33$ and $\tan\delta = 0.0027$. The slot is coupled to a $50\,\Omega$ microstrip, etched on the bottom side of the substrate. It should be mentioned that TE^{x}_{111} is the fundamental mode for the design. This mode provides a broadside radiation pattern. The resonant frequency of the RDRA can be easily determined using a dielectric waveguide model (DWM) [21].

In this structure, the antenna is different from the stacked one as we have very high dielectrics of the same value separated by spacers of $\varepsilon_r = 1$ to broaden the bandwidth and keep the size compact, but in the stacked structure they are made from two different dielectric materials with the bottom element from lower dielectric constant and larger in size. The proposed structure is different from multisegment structures, since here, we would like to achieve a compact size as well as a larger bandwidth. While, in a multisegment design, the main goal is to broaden the bandwidth without concern to the size.

Simulated reflection coefficients of homogeneous and non-homogeneous dielectric constants are shown in Table 1. According to [22], the slot length will be affected by the immediate dielectric constant materials that have sandwiched the slot. The slot length is inversely proportional to the effective dielectric constant of the surrounding materials. Hence, the proper length for the slot is used for each case. Table 1 provides the reflection coefficients and corresponding frequencies for six different cases. Table 2 provides the slot length and the corresponding bandwidths for each case. The results show that the bandwidth increases as the number of parasitic elements increases. Table 1 shows that for homogenized cases the resonant frequency is

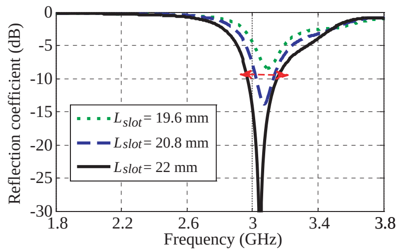
Table 1. Comparison between reflection coefficients of the high dielectric constant materials and proposed antennas.

Case 1

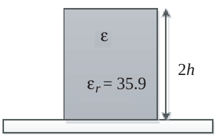


Computed reflection coefficients of case 1 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $l = 4$, and $\varepsilon_r = 35.9$.

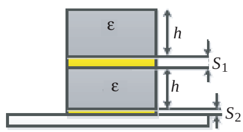
Case 2



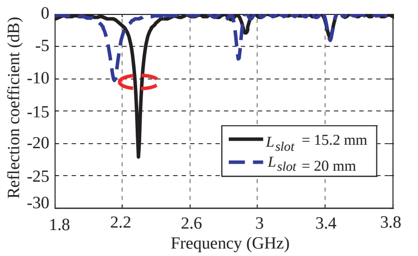
Computed reflection coefficients of case 2 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $l = 5.25$, $\varepsilon_r = 35.9$, and $S_1 = 1.4$.



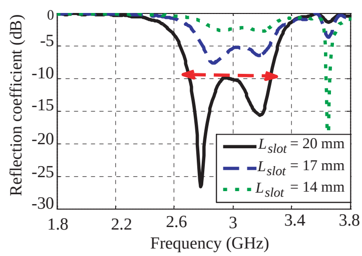
Case 3



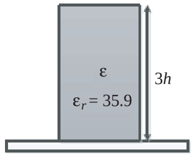
Case 4



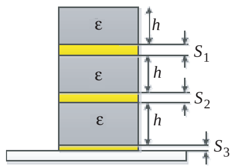
Computed reflection coefficients of case 3 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $d = 8$, $l = 4$, and $\varepsilon_r = 35.9$.



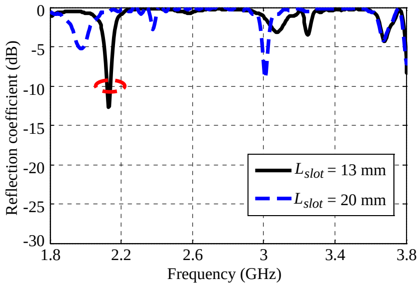
Computed reflection coefficients of case 4 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $d = 8$, $l = 5.25$, $\varepsilon_r = 35.9$, $S_1 = 3$, and $S_2 = 1$.



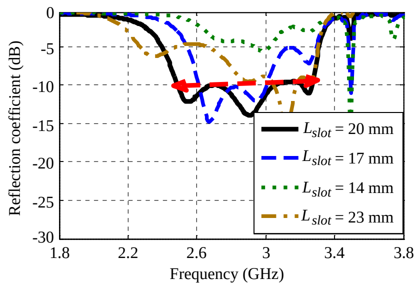
Case 5



Case 6



Computed reflection coefficients of case 5 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $d = 8$, $l = 8.5$, and $\varepsilon_r = 35.9$.



Computed reflection coefficients of case 6 with $a = 18$, $b = 18$, $h = 8.9$, $w_a = 2$, $d = 8$, $l = 6.6$, $\varepsilon_r = 35.9$, $S_1 = 3.15$ $S_2 = 1.2$, and $S_3 = 0.6$.

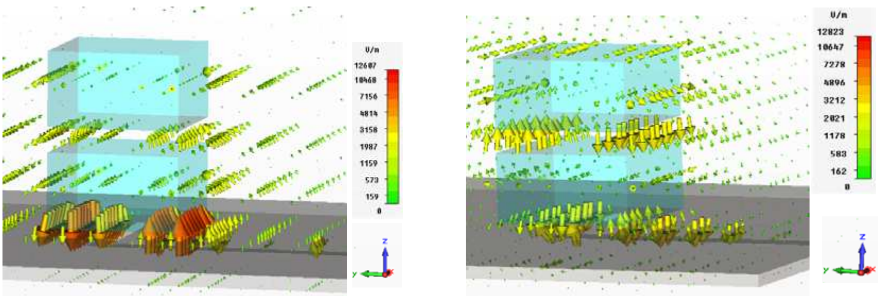
Table 2. Bandwidths of different cases.

Case	Material ($\varepsilon_r = 35.9$)	Length of the slot (mm)	Frequency range ($S_{11} < -10\,\text{dB}$) (GHz)	Bandwidth (%)
1	Homogeneous	14.4	2.82–2.87	1.7
2	One gap	22	2.97–3.15	5.8
3	Homogeneous	15.2	2.27–2.32	1.03
4	Two gaps	20	2.7–3.25	18
5	Homogeneous	13	2.12–2.14	0.93
6	Three gaps	20	2.48–3.27	27

inversely proportional to the DR height. However, the number of resonances increases as the number of parasitic elements increases. It should be also observed that if we keep the height of the antenna with gaps about the same as the antenna without gaps, the first resonant frequency increases followed by other frequencies. If one would like to reduce the frequency, most likely longer DR structures with gaps should be used. As the number of elements increases, the frequency of the lower end of the band decreases. Also, from the variations of reflection coefficients within the bandwidth, one can observe that the number of resonant frequencies is the same as the number of dielectric resonators.

3. DETAILED STUDY OF THE ANTENNA WITH ONE PARASITIC ELEMENT

It is interesting to point out that electric fields in air gaps tend to be normal to the surface and as such the electric field strength is stronger than that in dielectric resonators in the same direction. From the continuity of normal component of electric flux density at the bottom surface of the dielectric, the normal electric field will be 35.9 stronger in the gap than in the dielectric. The graphs are illustrated in Figure 2.



(a) (b)

Figure 2. Electric field distribution of the proposed antenna. (a) 2.8 GHz. (b) 3.2 GHz.

Figure 3(a) shows the reflection coefficients of the antenna with one parasitic element (double air gaps) as a function of frequency for different air gaps between the driven DR and the ground plane, S_1. It is observed that the upper resonant frequency shifts up as the air gap thickness increases widening the bandwidth. The effect of the thickness of the air gap between the two DRs, S_2, on the reflection coefficient of the DR antenna is shown in Figure 3(b). This figure shows that S_2 is tuning the resonant frequency close to the lower end of the band without affecting the upper resonant frequency. It is also affecting the bandwidth from the lower end.

In view of the above investigations, the matching bandwidth for the non-homogenized DRA with one parasitic element (double air gap) is enhanced. The final dimensions for air gaps are $S_1 = 3\,\text{mm}$ and $S_2 = 1\,\text{mm}$. The computed bandwidth is around 18% for reflection coefficients less than $-10\,\text{dB}$ (Case 4 in Table 1). Similarly, an optimized wideband non-homogenized DRA with two parasitic elements (triple air gaps) is obtained. The dimensions for air gaps are $S_1 = 3.15$, $S_2 = 1.2$ and $S_3 = 0.6\,\text{mm}$. The computed bandwidth is around 27% for the reflection coefficients less than $-10\,\text{dB}$ (Case 6 in Table 1).

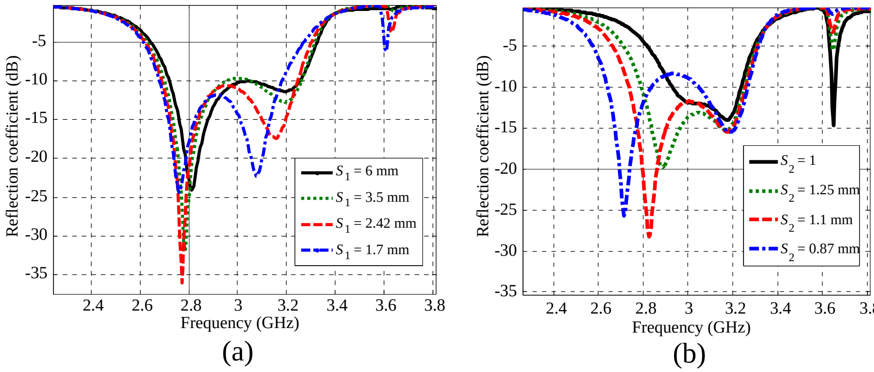


Figure 3. Computed reflection coefficient of the proposed antenna with one parasitic element ($a = 18$, $b = 18$, $h = 8.9$, $L_{slot} = 20$, $w_a = 2$, $d = 8$, $l = 5.25$, $\varepsilon_r = 35.9$). (a) Different S_1 lengths when $S_2 = 1\,\text{mm}$. (b) Different S_2 lengths when $S_1 = 3\,\text{mm}$.

4. MEASUREMENTS FOR THE ONE PARASITIC ELEMENT

The antenna with one parasitic element and two spacers is built as shown in Figure 4. DR and other systems are attached by using an adhesive. The reflection coefficients were measured by a HP 8720 C network analyzer. The computed and measured reflection coefficients are illustrated in Figure 5 showing good agreement. The measured matching bandwidth for reflection coefficients below $-10\,\text{dB}$ is 18%

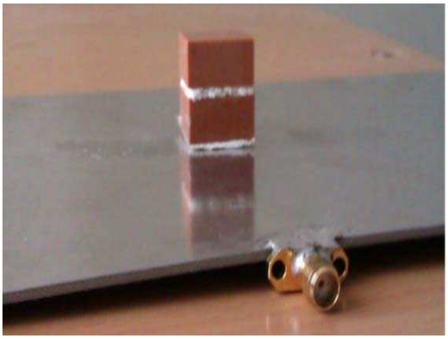


Figure 4. Photograph of the fabricated antenna with one parasitic element.

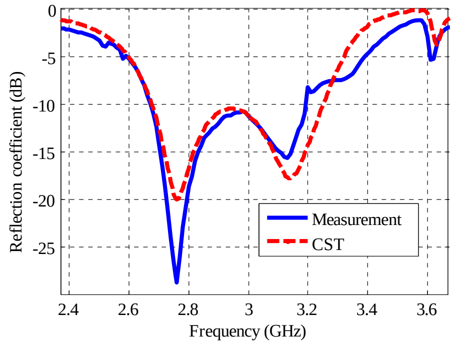


Figure 5. Reflection coefficient of the proposed antenna. ($a = 18$, $b = 18$, $h = 8.9$, $L_{slot} = 20$, $w_a = 2$, $l = 5.25$, $\varepsilon_r = 35.9$).

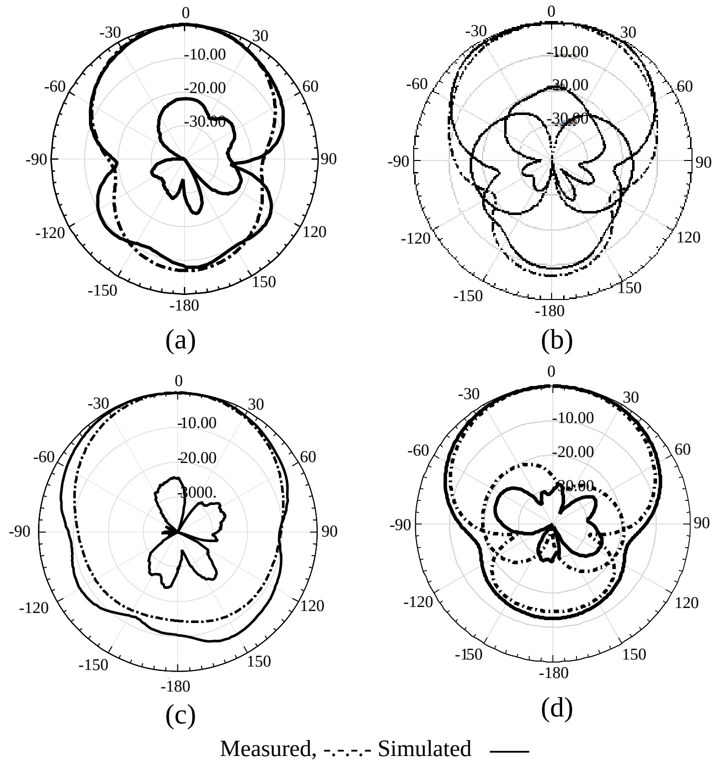


Figure 6. Measured and simulated radiation patterns: (a) E-plane (2.8 GHz). (b) H-plane (2.8 GHz). (c) E-plane (3.2 GHz). (d) H plane (3.2 GHz).

where the microstrip stub length is 5.25 mm. It should be pointed out that the antenna size at 3 GHz is $0.18 \times 0.18 \times 0.21\lambda_0^3$.

Figure 6 shows the measured co-polar and cross-polar radiation patterns in E-plane and H-plane, at 2.8 and 3.2 GHz. These radiation patterns are stable across the impedance matching bandwidth and calculation of the gain after accounting for free space loss and comparing to a standard horn resulted in total gains of 7.5 and 5.5 dBi at 2.8 and 3.2 GHz, respectively. It should be mentioned that the computed cross polarizations in E-plane are too small to be visible in Figure 6. The gain of the antenna is measured as shown in Table 3. The measured gains are the peak values of the co-polarization fields.

Table 3. Measured gain and radiation efficiency of the antenna.

Frequency (GHz)	2.7	2.8	3	3.2
Gain$_{meas}$ (dBi)	7.45	7.5	7	5.5
η_{sim} (%)	82	99	87	94

5. CONCLUSION AND FUTURE WORK

A compact wideband rectangular dielectric resonator antenna was introduced. In this antenna, a wide impedance bandwidth was obtained using parasitic dielectric resonators separated by thin dielectric spacers close to be air gap layers. All high dielectric materials were of the same size. The effects of the air gaps thicknesses on the return loss and the bandwidth were studied and found that each parasitic dielectric adds a resonance that tends towards the lower end of the frequency band. The measurement results were verified experimentally for the case of two elements with two spacers. A study for this antenna as an element in a phased array can be studied. This study shows that for wide scanning range of an array, the distance between the elements must be small with broad beam radiation and at the same time the element size should allow that as well. This antenna would be a good candidate for phased array applications.

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