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MICROSTRIP-FED LOW PROFILE AND COMPACT DIELECTRIC RESONATOR ANTENNAS

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Abstract—This paper presents a novel broadband, low-profile dielectric resonator antenna using relatively low dielectric constant substrate material. The rectangular DRA is fed with a stepped microstrip feed to ensure efficient coupling. Bandwidths in excess of 17% are obtained. In addition, the paper investigates methods to miniaturize the antenna using metallic strips or patches. Substantial size reduction is demonstrated while maintaining a reasonable bandwidth. Simulations as well as experimental results are presented.

1. INTRODUCTION

In recent years, the demand for wireless mobile communications has led to the development of antennas that are low profile and small in size. In the last two decades, microstrip antennas [1–4] and dielectric resonator antennas (DRAs) [5–7] have been extensively investigated as suitable antennas for wireless applications. The DRA offers attractive features such as low ohmic loss, low profile, small size, wide impedance bandwidth as compared to the microstrip antenna. The DRA can be used at millimeter frequency bands and is compatible with existing excitation methods such as the coaxial probe, microstrip transmission line, co-planar waveguide feed or aperture coupling. DRAs are available in basic shapes such as rectangular, cylindrical, spherical and hemispherical geometries. Rectangular DRAs offer more design flexibility since two of the three of its dimensions can be varied independently for a fixed resonant frequency and known dielectric constant of the material [13]. Hence, we chose the rectangular DRAs for our investigations in this paper.

Feeding mechanisms that are generally used for DRAs include using microstrip lines [8], coaxial probes [6], co-planar waveguide feeds [10] and aperture coupling [6]. Coupling techniques that have appeared in the literature [6–10, 13] require the permittivity of the DRA to be high (usually $\gg 10$) to ensure efficient coupling. Even though high permittivity results in a small DRA, it also narrows the bandwidth. If efficient coupling for relatively low-permittivity, low-profile DRAs can be realized, much wider bandwidth can be obtained. Furthermore, inexpensive widely available microwave substrates can be used to make the DRA, rather than commonly used DRAs using high-permittivity ceramic resonators. This is precisely the focus of this research. In this paper, a novel, simple, and efficient coupling technique of low-permittivity, low-profile DRAs, resulting in very broadband performance is presented. Even though in [14] an aperture coupled DRA with a dielectric constant of 10.8 was used, no information whatsoever was given in that paper regarding the impedance bandwidth. We actually simulated the configuration investigated in that reference using Ansoft HFSS to find out what kind of bandwidth is obtainable, the bandwidth was very small (about 2%), far smaller than the bandwidth obtainable with the antenna proposed in this paper which exceeds 17%. Bandwidth enhancement techniques published in the literature for high dielectric constant DRAs include two or more stacked DRAs [15, 16], coplanar parasitic DRAs [17, 18], and inclusion of air gaps inside DRAs [19]. Such techniques require additional DRA elements increasing the size of the overall antenna or involve a more complicated geometry than the simple technique presented in this paper.

If desired, dielectric resonator antennas can be made more compact, at the expense of reduction in bandwidth, by placing a conducting strip or patch on the top of the DRA [11, 12, 20]. It was shown in [11] that by covering the top surface of the rectangular DRA with a metallic patch, the resonant frequency can be reduced by 10%. Furthermore, investigations carried out by [12] showed that by incorporating a metallic cap on the top surface of a cylindrical DRA, the resonant frequency of the DRA can be reduced by 30.6%. We also investigated reducing the size of our low-permittivity DRA by using this well known technique. The results of these investigations are also presented in this paper.

Section 1 of this paper presents the proposed geometry for the broadband, low-profile rectangular DRA. Section 2 presents the proposed geometry of the compact DRAs. In the second section, the low profile DRA is made compact by covering the top surface of the DRA with a square metallic sheet. By changing the size of the metallic sheet on the DRA surface, the effect on the resonant frequency and bandwidth is presented.

Full wave analysis of the antenna configurations were performed using commercially available software (Ansoft HFSS). Extensive simulations were carried out using the software in order to obtain optimal design parameters for the antenna. All the antenna configurations presented in this paper have been built and tested experimentally.

2. ANTENNA DESIGN

The proposed geometry of the low profile DRA fed with a stepped microstrip line is shown in Fig. 1. Through simulations using a commercial full wave analysis software package (Ansoft HFSS), we observed that the width of a metallic strip under the DRA affects drastically its input impedance. A narrow strip width resulted in a high input impedance, much higher than 50 Ω, whereas a wide strip lowered the input impedance of the DRA; hence the proposed geometry. The wide strip in essence provides the necessary impedance matching, if its dimensions (width and length) are optimized. The DRA has a dielectric constant ε_r and dimensions of length l, width w and height h. The feed microstrip line has a 50 Ω characteristic impedance whereas the width and length of the stepped section are w_2 and l_2, respectively as shown in Fig. 2. The dielectric constants for both the DRA and the feed substrate are chosen to be the same. Actually, in the experimental verification part, the DRA was cut from the same substrate used for the feed line. As will be shown in Section 3, the proposed configuration produced an impedance bandwidth better than 17% experimentally.

In order to make the antenna more compact laterally, in addition to being low profile, we investigated the use of metallic sheet on the top surface of the DRA. The design parameters and the feed mechanism for the compact DRA configuration are the same as the low profile DRA. For the compact DRA configuration as shown in Fig. 3, the area of square metallic sheet ($a\,\text{mm}^2$) controls the level of miniaturization with a corresponding trade-off in bandwidth, a bigger sheet results in

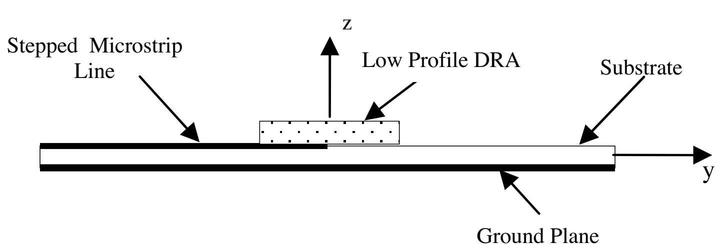


Figure 1. Low profile DRA with stepped microstrip feed.

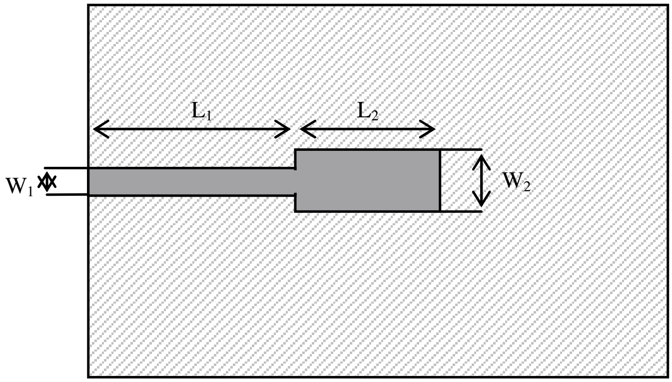


Figure 2. Top view of stepped microstrip feed line $W_1 = 1.2\,\text{mm}$, $W_2 = 3\,\text{mm}$, $L_1 + L_2 = 45\,\text{mm}$.

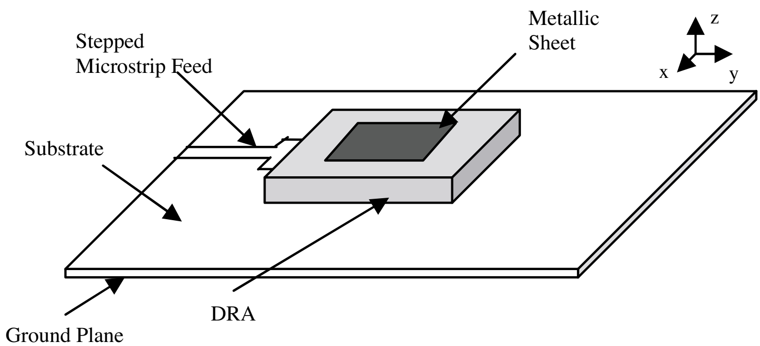


Figure 3. Geometry of compact DRA with small metallic sheet.

a more compact antenna with a narrower bandwidth than a smaller sheet. Section 3 presents the results for two cases: a small sheet covering a portion of the top surface of the DRA and a sheet that covers the entire top surface of the DRA as shown in Fig. 4.

3. NUMERICAL AND EXPERIMENTAL RESULTS

3.1. Low Profile DRA

The low profile DRA is analyzed first. The dimensions of the low profile DRA are $l = w = 10\,\text{mm}$ and $h = 2.5\,\text{mm}$. The prototype DRA is made of widely available Rogers RT®/Duroid 3010 substrates that have dielectric constant $\varepsilon_r = 10.2$. The same substrate material is used

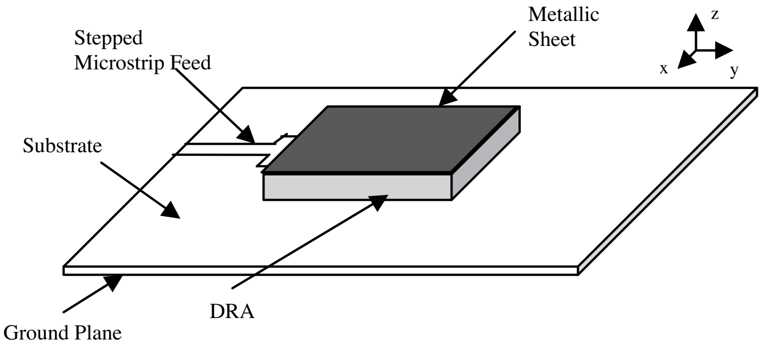


Figure 4. Compact DRA with metallic sheet covering the entire top surface.

for both the feed line substrate as well as the DRA. The thickness of the substrate used is $t = 1.27$ mm. The width of the feed microstrip line is $w_1 = 1.2$ mm (resulting in $50\,\Omega$ characteristic impedance) and the width and length of wide strip are $w_2 = 3$ mm and $l_2 = 11$ mm. In the simulations, a finite substrate was used (finite ground plane) with dimensions 90 mm $\times$ 90 mm. The DRA is placed on the substrate such that the wider edge of the microstrip line coincides with the DRA's center. Theoretical results for the antenna were obtained using Ansoft HFSS. The prototype antenna was also built and tested using a HP 8719A microwave network analyzer.

Input impedance and return loss: The computed input impedance versus frequency is shown in Fig. 5. The figure shows good impedance matching is achieved using the stepped microstrip line feed. The computed and measured results of return loss versus frequency of the low profile DRA are shown in Fig. 6. The computed return loss is less than -10 dB over a frequency bandwidth of 13% whereas the measured -10 dB return loss bandwidth is even better, at about 17%. The prototype was constructed using a milling machine that is not very precise resulting in the difference between simulation and measurement.

Radiation patterns: The radiation patterns are computed at 8.3 GHz, 8.8 GHz and 9.1 GHz respectively as shown in the Fig. 7, to verify the stability of the radiation pattern over the entire bandwidth. It is seen from the radiation patterns that the antenna is linearly polarized with broadside radiation. The radiation patterns show the there is some scalloping due to the diffraction from the edges of the finite ground plane. The cross polarization levels are less than at least -20 dB at 8.3 GHz, 8.8 GHz and 9.1 GHz.

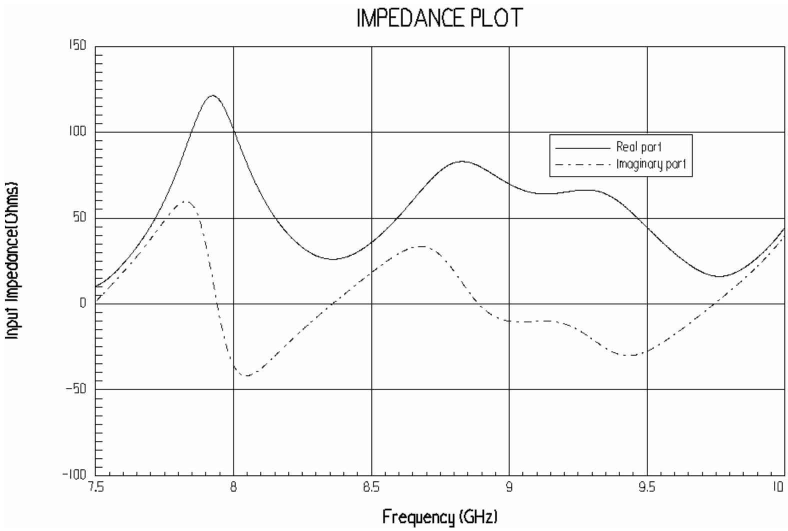


Figure 5. Computed input impedance, real and imaginary parts, vs. frequency.

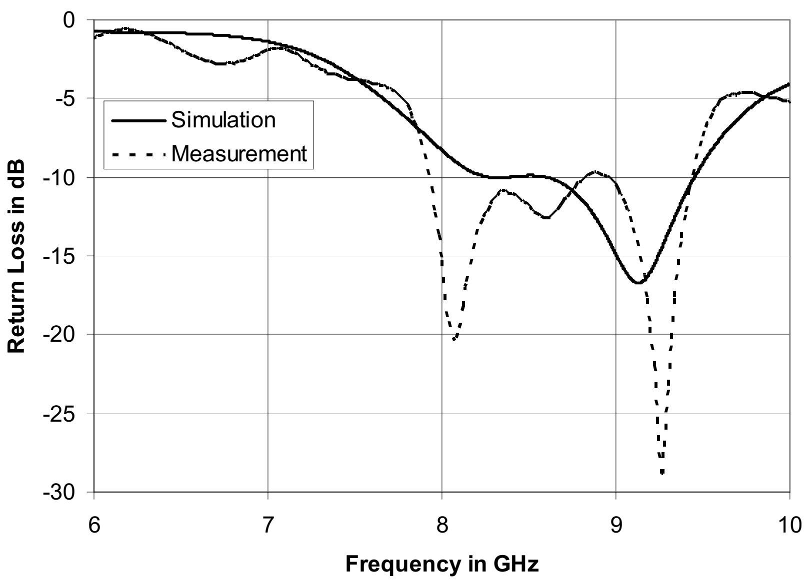
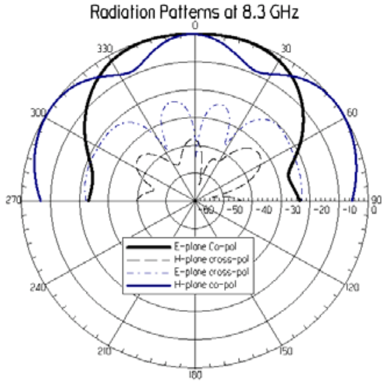
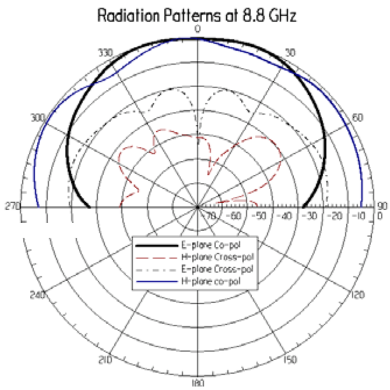


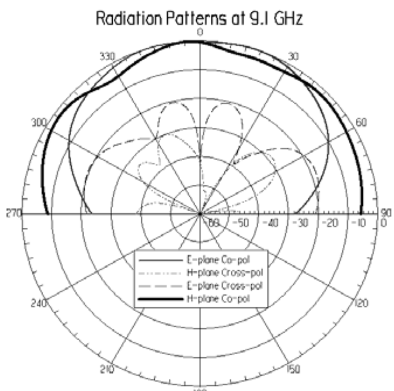
Figure 6. Computed and measured return loss vs. frequency for low profile DRA.



(a)



(b)



(c)

Figure 7. Computed radiation patterns at (a) 8.3 GHz, (b) 8.8 GHz and (c) 9.1 GHz for low profile DRA.

3.2. Compact DRA

The placement of a metallic sheet or patch on the top surface of the DRA lowers the center frequency of operation. The magnitude of this shift is an indication of the compactness or size reduction that can be obtained. Our investigations concluded that the bigger the metallic sheet (the more surface area of the DRA it covers), the larger is the shift, and hence the bigger is the size reduction that can be obtained. However, there is also a corresponding reduction in bandwidth. We present two examples in this paper, a small patch partially covering the surface of the DRA and a larger patch covering the surface of DRA entirely. The area of the small patch is $32.5\,\mathrm{mm}^2$ and the area of the larger patch is $100\,\mathrm{mm}^2$. The following presents results for the return loss, bandwidth, and radiation patterns of both cases.

Return loss/bandwidth: The computed and experimental return loss versus frequency is shown in Fig. 8 for the DRA with the small metallic patch. This antenna achieves a computed return loss of $-28\,\mathrm{dB}$ at a frequency of 6.3 GHz and gives a 10-dB return loss bandwidth of 4%. Experimentally, the measured return loss as shown in Fig. 8 is $-25\,\mathrm{dB}$ at a frequency of 7 GHz and the 10-dB return loss

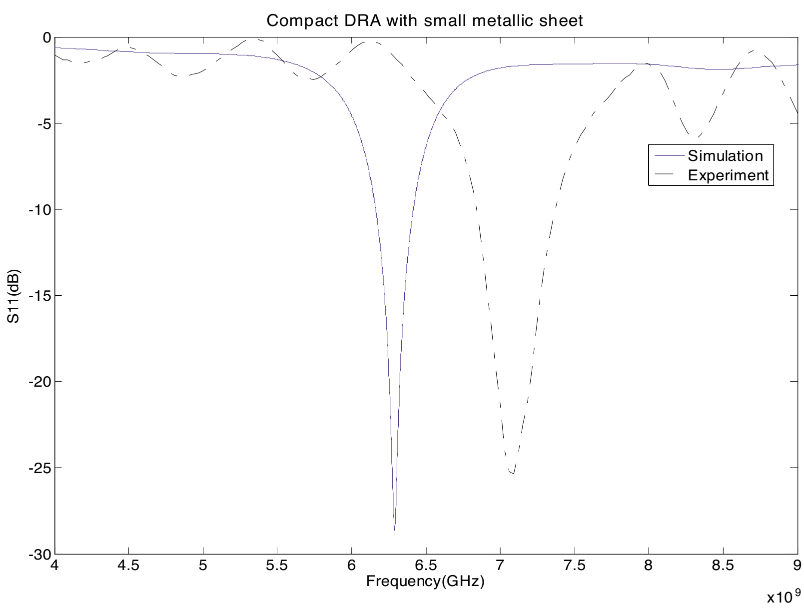


Figure 8. Computed and measured return loss vs. frequency for compact DRA with small metallic sheet.

bandwidth is nearly 7.8%. The addition of the small patch resulted in 22% downward shift in the center frequency.

The computed and measured return losses for the DRA with larger metallic patch are shown in Fig. 9, which shows center frequencies of 5.15 GHz and 5.5 GHz, respectively. The downward percentage shift in the measured center frequencies, relative to the uncovered low-profile DRA is 39%. The 10-dB measured return loss bandwidth was 5%. Even this bandwidth is still much better than that of a standard microstrip patch antenna built on an identical substrate, which is no more than 1–2%.

Radiation patterns: The radiation patterns, computed at 6.3 GHz for the DRA with the small metallic patch, and at 5.1 GHz for the DRA with the large metallic patch, are shown in Fig. 10 and Fig. 11, respectively. The figures show linear polarization with cross polarization levels below −30 dB in the E and H planes, for both antennas.

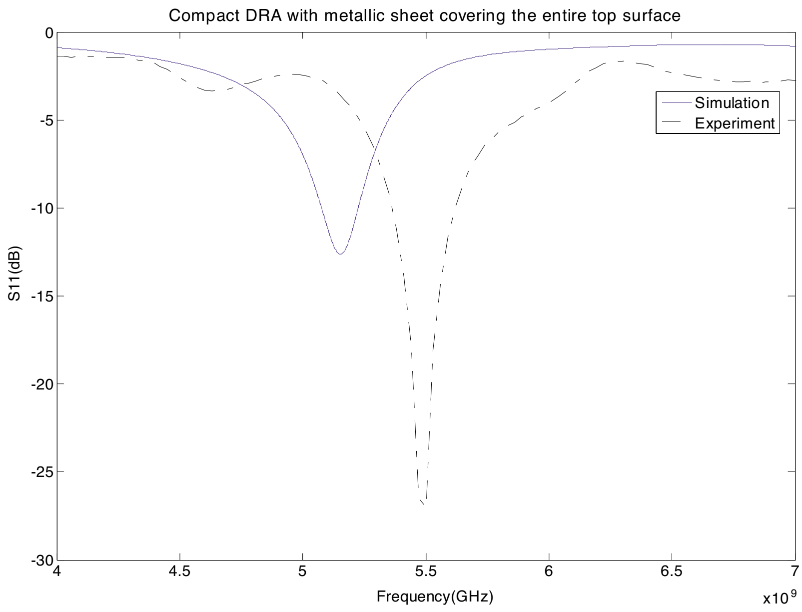


Figure 9. Computed and measured return loss vs. frequency for compact DRA with large metallic sheet.

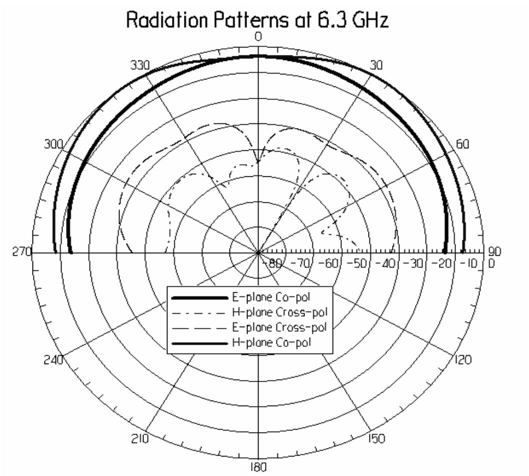


Figure 10. Computed radiation pattern at 6.3 GHz for compact DRA with small metallic sheet.

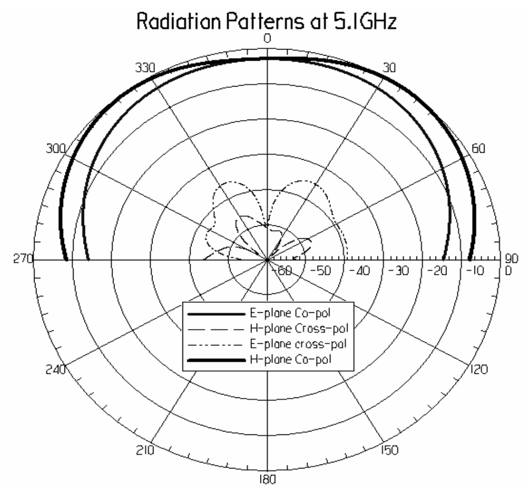


Figure 11. Computed radiation pattern at 5.1 GHz for compact DRA with large metallic sheet.

4. CONCLUSION

This paper presented a broadband low profile dielectric resonator antenna that uses a relatively low dielectric constant substrate. A stepped microstrip feeding mechanism was developed to achieve efficient coupling over a wide bandwidth. The DRA was made from inexpensive widely available substrate material. Bandwidth of about 17% was obtained experimentally for the low-profile DRA. Furthermore, methods for size reduction of the proposed antenna using metallic patches were investigated. As expected, there is a tradeoff between bandwidth and size reduction. Experimental results presented in the paper demonstrated that a patch totally covering the top surface of the DRA resulted in downward shift of the resonance frequency of about 39%, relative to the uncovered DRA, and a bandwidth of about 5%.

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