A low profile wideband probe-fed dielectric resonator antenna

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Abstract Many approaches have been presented to broaden the impedance bandwidths of low profile dielectric resonator antennas (DRAs). However, few of them can achieve a balanced behaviour in terms of bandwidth, gain, radiation patterns, antenna size, etc. In this paper, a low profile wideband probe-fed DRA is proposed. By centrally placing a probe-fed strip DR in a 2×2 parasitic DR lattice, balanced antenna performance can be achieved. A DRA prototype was fabricated and tested for demonstration. Measured results show that the antenna can achieve an impedance bandwidth of 24%, a peak gain of 7.92 dBi with a compact DR size of 0.47×0.47×0.07λ₀³ (λ₀ is the wavelength of the center frequency). Besides, symmetrical and consistent radiation patterns can be maintained within the band.

Keywords: dielectric resonator antenna, low-profile, wideband, probe-fed
Classification: Microwave and millimeter-wave devices, circuits, and modules

1. Introduction

The dielectric resonator antenna (DRA) has been considered to be a good candidate for wireless communication systems due to its favourable characteristics, such as low loss, low cost and high design flexibility [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. Considering the market demand for skinny and lightness devices, antennas with compact size and low profile will usually be more attractive [16, 17, 18, 19]. Recently, some interesting low profile DRA designs, known as dense dielectric patch antennas [20, 21, 22] and planar dielectric antennas [23], are developed to solve the traditional DRAs' bulky and low gain issues. However, owing to that high permittivity dielectric materials are introduced for achieving low antenna profiles, the radiation Q-factors become so high, leading to limited impedance bandwidths (typically less than 5%) [22, 23].

Several approaches have been proposed to broaden the impedance bandwidth of low profile DRAs. In [24], the DRA mode and the feeding slot mode are skillfully combined to obtain a wide bandwidth of 10.49%. However, the antenna gain is low (<6.8dBi) due to the slot radiation. In [25], by enlarging the length-to-height ratio of the DRA, the higher-order mode can be shifted down to merge with the fundamental mode and a bandwidth of ~40% can be

Table I Performance comparison

DRA ref.	Excitation method	BW (%)	Gain (dBi)	Overall DR Size (λ ₀ ³)	Array Applications
[24]	Slot-coupling	10.49	6.75	0.5×0.5×0.04	Suitable
[25]	Slot-coupling	40	10.5	0.77×0.77×0.1	Limited
[26]	Slot-coupling	18.2	7.2	0.3×0.3×0.15	Suitable
[28]	Slot-coupling	12	7.6	1.6×0.2×0.2	Limited
This work	Probe-fed	24	7.92	0.47×0.47×0.07	Suitable

achieved. Nevertheless, the antenna has a large planar DR size ($> 0.77\lambda_0 \times 0.77\lambda_0$) that makes it unsuitable for many array applications. In [26], a stacked structure has been used to increase the antenna bandwidth to 18.2%, but at the cost of a higher antenna profile. In [27, 28], the parasitic elements are used to enhance the DRA bandwidths. For instance, the bandwidth of DRA is increased 4.5% by using two parasitic elements in [27]. However, in these cases, the excited DR and the parasitic DRs are all arranged in line, resulting in rectangular overall DR structures with high length-to-width ratios. Such asymmetric structure not only degrades the antenna's radiation performance (such as very different E-plane and H-plane beam widths) but also limits its applications in two-dimensional antenna array. It is also worth mentioning that the slot-coupling feed scheme is adopted by all of the designs. Note that although slot-coupling is beneficial for the realization of broadband, it brings strong backward radiation. The probe-feed technique can be used to avoid this problem, and it can also greatly facilitate the integration of antennas with other microwave circuits. Actually, the probe-feed is preferred in many applications, such as Antenna-in-Package [29], vehicle mounted antenna [30], etc.

In this paper, we present a low profile wideband probe-fed DRA. By using a main strip DR and four parasitic DRs, two resonant modes can be excited to form a wide operating bandwidth. In contrast to linear arrangement, the strip DR is centrally placed in the 2×2 parasitic DR lattice, with two parasitic DRs on each side. The overall DRA structure is, thus, square and symmetric, yielding symmetrical radiation patterns. Table I lists the comparison of the proposed antenna with some state-of-the-art low profile DRAs. It can be seen that this design has a wider impedance bandwidth and a higher gain than that of [19, 21] and [23]. Compared to [20], the proposed antenna has a much more compact DR size, making it more suitable for array applications.

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2. Antenna configuration and working principle

The geometry of the proposed antenna is shown in Fig. 1. The radiation unit on the top consists of a main strip DR and four parasitic DRs. Specifically, the strip DR is centrally placed in the 2×2 parasitic DR lattice. All of the DRs are made of high permittivity ceramic materials but with ϵ_{r1} for the strip DR and ϵ_{r2} for the parasitic ones. Below them is Substrate 1 (RO4003C, $\epsilon_r = 3.38$, $\tan \delta = 0.0027$) which serves as a supporting board. Note that four small L-shaped metal strips are etched on the upper surface to facilitate the parasitic DRs' positioning and alignment. They can also, to some extent, help to suppress some spurious DR modes. On the bottom is a feeding microstrip line. It is printed on the back side of Substrate 2 (RO4003C), and connected to the feeding pad through a via.

The basic idea of this design is clear. The strip DR mode is excited firstly by the feed probe, and the 2×2 DR lattice is then parasitically coupled to the driven strip DR, producing additional mode for widening the bandwidth. The simulated E-field distributions at the two resonant frequencies are depicted in Fig. 2. It is found that, at a higher frequency, most of the E-fields are located in the parasitic DRs (TE₁₁₁ mode is excited for each parasitic DR), indicating that they are strongly coupled to the strip DR in this case. The resonance is then mostly influenced by the parasitic DRs. On the other hand, the lower frequency resonance is found to be mainly

contributed by the strip DR as the E-fields are concentrated in the strip DR (TE₁₁₁ mode is excited). In Fig. 3, a comparative study of two antennas with different configurations has been done to further demonstrate the working principle. It can be found that even half of the parasitic DR lattice is removed, the coupling between strip DR and parasitic DRs still exists but with the gain degraded in high frequency band due to the reduced radiation aperture. Finally, it is worth noting that the radiation from the gaps between the DR blocks decreases the radiation Q factor of the DRA, which can further facilitating the bandwidth enhancement.

Parametric studies have been carried out to characterize the design. Fig. 4 shows the reflection coefficients for different heights (h_s) of the strip DR and lengths (p) of the parasitic DRs. It can be observed that as h_s increases, the lower

Fig. 2 E-field distributions of the DRA at two resonant frequencies. (a) At 9.4 GHz, (b) at 10.6 GHz

Fig. 1 Configuration of the proposed DRA ($G_W = 32\text{mm}$, $h_1 = 0.813\text{mm}$, $h_2 = 0.305\text{mm}$, $\epsilon_{r1} = 69$, $p = 6.7\text{mm}$, $g = 0.6\text{mm}$, $w = 5.3\text{mm}$, $h = 1\text{mm}$, $\epsilon_{r2} = 45$, $L_s = 7\text{mm}$, $W_s = 2.2\text{mm}$, $h_s = 1\text{mm}$, $t = 0.6\text{mm}$, $L_1 = 2.25\text{mm}$, $W_1 = 1\text{mm}$, $D_{via} = 1.2\text{mm}$, $L_m = 12.63\text{mm}$, $W_m = 0.65\text{mm}$, $L_p = 1.65\text{mm}$, $W_p = 1.8\text{mm}$)

DRA I: with 2×2 parasitic DR lattice

DRA II: with 2×1 parasitic DR lattice

(a)

Fig. 3 A comparative study of two kinds of antennas. (a) Two antenna configurations: DRA I and DRA II, (b) simulated results of the two antennas

Fig. 4 Simulated $|S_{11}|$ for different parameters. (a) Height (h_s) of the strip DR, (b) length (p) of the parasitic DRs

resonant frequency shifts down, while the higher resonant frequency stays unchanged. When increasing p , the higher resonant frequency decreases while the lower resonant frequency remains relatively stable. These results verify that the lower frequency resonance is mainly contributed by the strip DR, while the higher one is caused by the parasitic DR lattice.

3. Experimental results

To validate the design concepts, an antenna prototype was fabricated and measured. The simulated and measured reflection coefficients and gains of the antenna are shown in Fig. 5. The measured impedance bandwidth for $|S_{11}| < -10$ dB is 24%, from 8.99 GHz to 11.43 GHz. A measured peak gain of 7.92 dBi is achieved at 10.7 GHz. Fig. 6 depicts the radiation patterns at two resonant frequencies of 9.4 and 10.6 GHz. It is found that the antenna radiates in a broadside direction with symmetrical radiation patterns and consistent E-plane and H-plane beam widths.

4. Conclusion

In this paper, a technique to design a low profile wideband probe-fed DRA has been presented. The dual-mode op-

Fig. 5 Simulated and measured $|S_{11}|$ and gains of the antenna

Fig. 6 Simulated and measured radiation patterns of the antenna. (a) At 9.6 GHz, E-plane, (b) at 9.6 GHz, H-plane, (c) at 10.4 GHz, E-plane, (d) at 10.4 GHz, H-plane

erating principle is studied firstly followed by a parametric analysis. Compared to the state-of-the-art low profile DRAs, the antenna combines some valuable features of wide bandwidth, high gain, compact size, symmetrical and consistent radiation patterns, making it an attractive candidate for future wireless communication system applications.

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