

High Gain and Wideband Multi-Stack Multilayer Anisotropic Dielectric Antenna

Farhad Moayyed, Hamid R. Dalili Oskouei, and Morteza Mohammadi Shirkolaei*

Abstract—A multi-stack anisotropic cylindrical dielectric resonator antenna with high gain and wide bandwidth is reported. This antenna is designed with three different stacks, and each stack consists of a multilayer dielectric structure to emulate uniaxial anisotropy. Multi-stack, multilayer structure is responsible for producing wide bandwidth and high gain. In addition, the antenna is surrounded by cylindrical metallic cavity to increase directivity in broadside direction. Similar simulated and measured results indicate a wide impedance bandwidth of 37% along with a maximum gain 9.25 dB.

1. INTRODUCTION

Nowadays, many researchers are interested in Dielectric Resonator Antennas (DRAs). This theme was introduced in 1983 [1], and they have been widely studied and used owing to their attractive properties like small size, low ohmic loss, light weight, ease of excitation, wide bandwidth, and very high radiation efficiency in compared with planner antenna [2–6]. They are used in both linearly and circularly polarized systems [7–11]. Several methods for gain and bandwidth enhancement of the DRAs have been reported such as: using electromagnetic bandgap structure [12], using DRA in its higher modes [13], employing short horn around DRA [14], and using non-transparent conducting sheet as superstrate [15]. Recently, much work has been done on cylindrical dielectric resonator antennas [16, 17]. In [18, 19] it is shown that uniaxial anisotropy can be emulated by using a multilayer dielectric structure. Utilizing uniaxial anisotropic materials in DRA structure increases gain and bandwidth of the antenna considerably [20–23].

This paper introduces a novel cylindrical DRA operating in HEM_{11} mode with enhanced gain and bandwidth. This is achieved using a multi-stack multilayer dielectric structure to emulate uniaxial anisotropy. The advantages of proposed multi-stack multilayer DRA in comparison with a traditional multilayer DRA are as follows: size reduction (normally 10% in compare with multilayer DRA), higher gain and bandwidth (20–30% compared with traditional DRA), and higher efficiency. Regarding the application due to its light weight and relatively high gain and bandwidth of the proposed antenna, it can be applied in variety of wireless applications such as mobile and military communication systems. In the proposed antenna, three different uniaxial anisotropic cylindrical structures with equal diameter are made, by placing two different dielectrics disks periodically on each DRA. The proposed antenna is made by stacking these structures and surrounding it by cylindrical metallic cavity. Use a slot aperture feeding to excite HEM_{11} mode to get radiation pattern in broadside direction. The simulation and measurement results proved the validity of proposed concept by achieving higher gain and wider bandwidth than previous works.

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* Corresponding author: Morteza Mohammadi Shirkolaei (m.mohammadi@ssau.ac.ir).

The authors are with the Department of Electrical Engineering, Shahid Sattari Aeronautical University of Science and Technology, Tehran, Iran.

2. ANTENNA DESIGN

Figure 1 shows the configuration of the proposed antenna, where the cylindrical DRA of radius a and height d is fed by a rectangular slot of width W_s and length l_s . A 50Ω microstrip line ($W_{ms} = 1.17 \text{ mm}$) is placed opposite to the slot face of a substrate of thickness 0.508 mm and dielectric constant of $\epsilon_r = 3.38$.

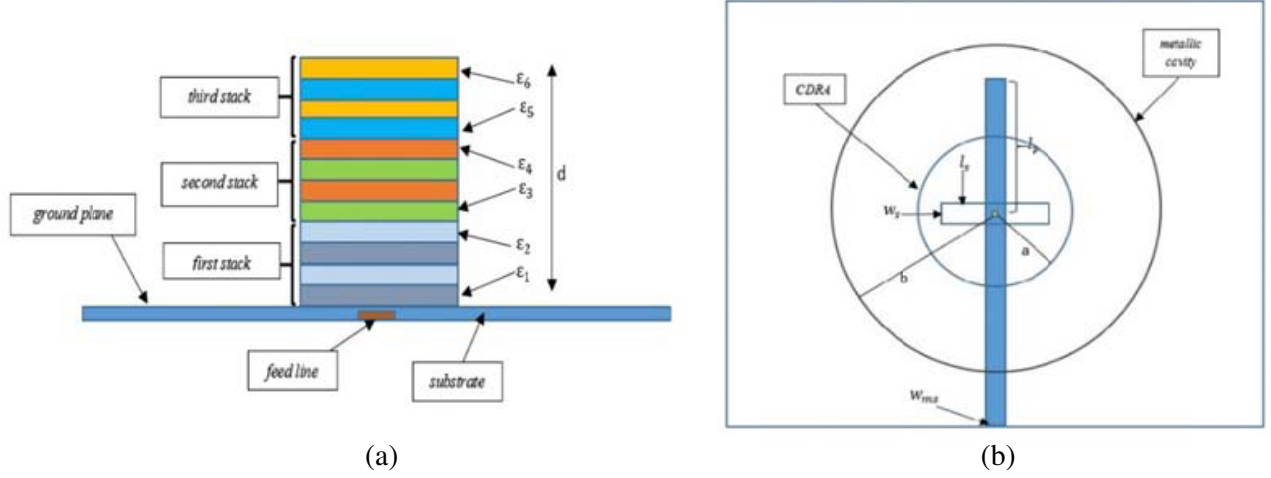


Figure 1. Configuration of proposed uniaxial anisotropic CDRA. (a) Front view. (b) Bottom view.

The CDRA is coupled to a microstrip-fed slot in the ground plane. The ground plane size is $100 \text{ mm} \times 100 \text{ mm}$. The anisotropic antenna is designed by three main stacks. The first stack consists of 2 layers of substrate 1 ($\epsilon_1 = 12.2$) and 2 layers of substrate 2 ($\epsilon_2 = 4.5$) that are periodically stacked. Other two stacks have same configurations but with substrate 3 ($\epsilon_3 = 10.2$) and substrate 4 ($\epsilon_4 = 3.27$) for the second stack and substrate 5 ($\epsilon_5 = 9.8$) and substrate 6 ($\epsilon_6 = 2.2$) for third stack. The thickness of all different dielectric layers is equal to 1.9 mm . laminates properties, used in each stack, are listed in Table 1. The cylindrical metallic cavity is placed concentric with antenna with 21 mm height and 31 mm distance apart from the side wall of antenna.

Table 1. Properties of the used laminates in fabricated antenna.

	Dielectric constant	laminate model	Thickness (mm)	Layer No.
First stack	$\epsilon_1 = 12.2$	Rogers TMM13i	1.905	1, 3
	$\epsilon_2 = 4.5$	Rogers TMM4	1.905	2, 4
Second stack	$\epsilon_3 = 10.2$	Rogers RT/duroid 6006	1.905	5, 7
	$\epsilon_4 = 3.27$	Rogers TMM3	1.905	6, 8
Third second	$\epsilon_5 = 9.8$	Rogers TMM10i	1.905	9, 11
	$\epsilon_6 = 2.2$	Rogers RT/duroid 5880	1.905	10, 12

Considering that individual laminate thickness is much smaller than wavelength, the overall structure of each stack behaves like a homogeneous anisotropic medium with the equivalent homogenized permittivity tensor [17, 18]. Calculated permittivity tensor indicates that the ratio of $\frac{\epsilon_{zz}}{\epsilon_{xx}}$ is less than 1 in each stack which guarantees that its effective contribution in overall gain and bandwidth increase. The calculated effective permittivities of the first, second, and third stacks using Eq. (1) are 6.19, 4.95 and 3.59, respectively

$$\epsilon_{eff} = \frac{h_{eff}}{h_1/\epsilon_1 + h_2/\epsilon_2}, \quad h_{eff} = h_1 + h_2 \quad (1)$$

where ε_1 , h_1 and ε_2 , h_2 are used to denote constant permittivity and height of different substrates used in each stack [24]. By knowing the effective permittivity and equal height of the each stack, now we can assume the combination of the first and second stacks as an individual uniaxial anisotropic medium, and its effective permittivity and equal height are 5.5 mm and 15.2 mm, respectively. By considering the combination of the first and second stacks with the third stack as an individual uniaxial anisotropic medium and using Eq. (1), the overall height and effective permittivity of antenna are 22.8 mm and 4.57, respectively. Finally, the antenna radius (a) calculated from Eq. (2) is 12.3 mm.

$$f_r = \frac{6.324c}{2\pi a \sqrt{2 + \varepsilon_{eff}}} \left[0.27 + 0.02 \left(\frac{a}{2h_{eff}} \right)^2 + 0.36 \left(\frac{a}{2h_{eff}} \right) \right] \quad (2)$$

where c is the speed of light in free space, ε_{eff} the total permittivity of the DRA (obtained by Eq. (1)), a the radius, and h_{eff} the height of the DRA (obtained by Eq. (1)) [24].

It should be noted that the proposed design concept and procedure can be used in designing uniaxial anisotropic DRA with any fixed-size cross-section shape.

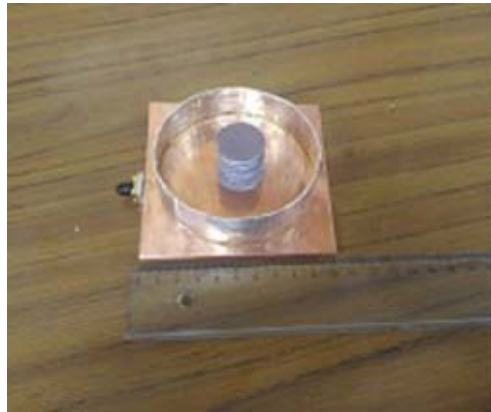


Figure 2. The fabricated prototype of the proposed antenna.

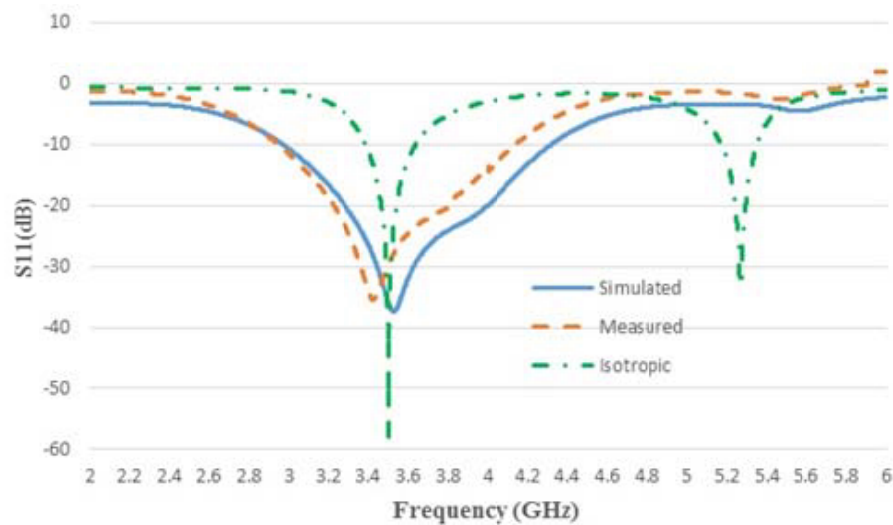


Figure 3. Simulated and measured reflection coefficient of proposed antenna and isotropic DRA ($\varepsilon_r = 12.2$).

3. RESULTS AND DISCUSSION

Figure 2 shows a photograph of the proposed antenna. The measured and simulated reflection coefficients (S_{11}) of proposed antenna and isotropic DRA ($\epsilon_r = 12.2$) are shown in Fig. 3, which shows a wide impedance bandwidth of 37% (2.97–4.31 GHz). The multi-stack multilayer CDRA is fabricated by placing 12 dielectric layers onto each other and pressing them mechanically. In order to fix the structure, some glue is applied to the edges. Inevitably, some air gaps exist between dielectric layers and also between bottom layer and ground plane which cause discrepancy between measured and simulated results. Fig. 4 shows the measured and simulated radiation patterns of proposed antenna at 3.5 GHz in both the XZ and YZ planes.

The measured and simulated results exhibit high gains of 9 dB and 9.25 dB, respectively. It should be noted that in the absence of metallic cylindrical cavity, the structure has 7.9 dB gain which is

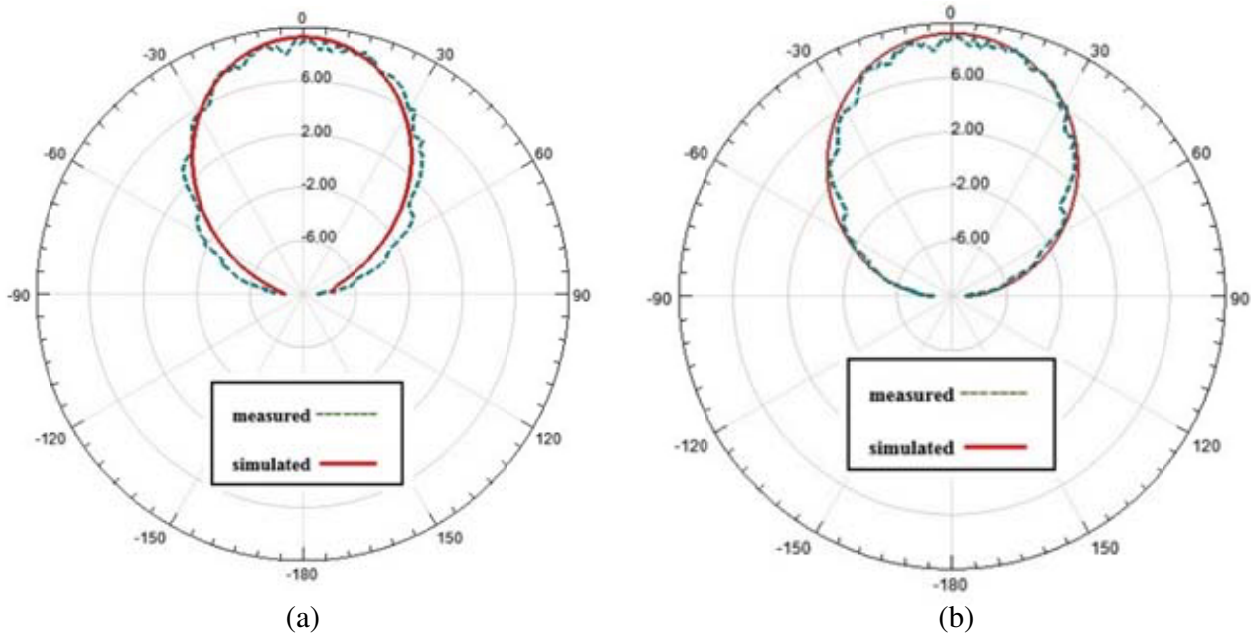


Figure 4. Measured and simulated radiation patterns of proposed CDRA at 3.5 GHz (a) XZ -plane, (b) YZ -plane.

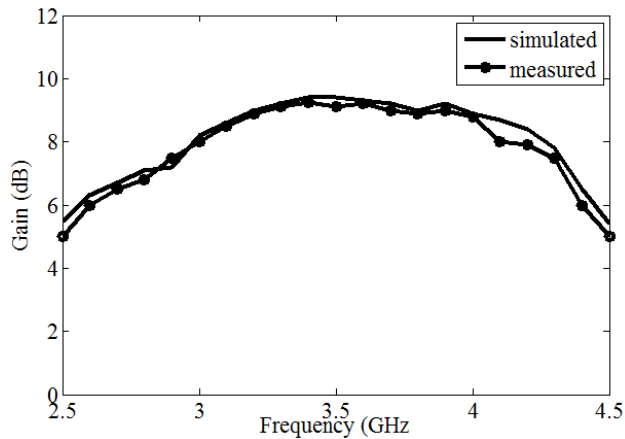


Figure 5. Simulated and measured gains of the proposed antenna.

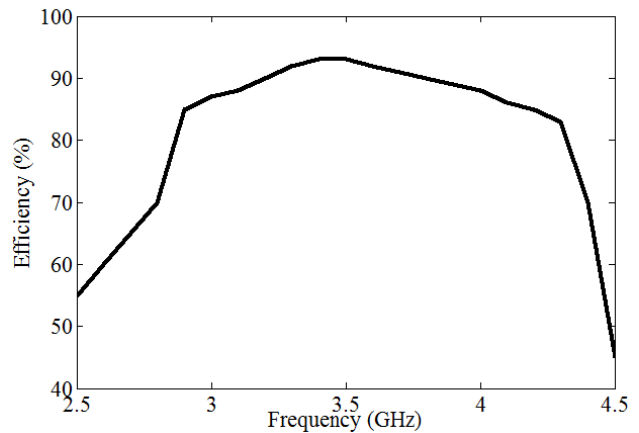


Figure 6. Measured radiation efficiency of the proposed antenna.

higher than the achieved gain in [23]. The discrepancies between simulated and measured results are attributed to fabrication tolerances, especially the air gap between layers. Finally, a comparison between the present work and earlier work in [23] is conducted. In [23], a CDRA is designed based on isotropy concept then filled with a multilayer dielectric structure to emulate uniaxial anisotropy, but in the present work the proposed CDRA is designed based on anisotropy concept by staking three uniaxial anisotropic mediums. Consequently, the impedance bandwidth shows 10% enhancement and size reduction in antenna radius (14.5 mm to 12.3 mm). The proposed antenna as the result of multi-stack multilayer structure and surrounding cavity has higher gain about 1.5 dB at 3.5 GHz.

The simulated and measured gains of the proposed DRA are shown in Fig. 5. The peak gain is 9.25 dB, and the 2-dB gain bandwidth is 2.9–4.3 GHz. As shown in Fig. 6, the measured radiation efficiency is from 85% to 93% by calculation in this bandwidth.

A comparison of the proposed antenna with other wideband DRAs is tabulated in Table 2, which shows that the proposed antenna has a higher gain and lower size than previous works. As a result, the proposed DRA has high efficiency.

Table 2. Comparison of the proposed antenna with the previous works.

references	Peak gain (dBi)	Bandwidth	Overall antenna size (λ_0) ³
[23]	8	29%	$3.14 \times 0.17^2 \times 0.27$
[25]	7	59.7%	$1.07 \times 1.07 \times 0.31$
[26]	6.2	56%	$1.2 \times 1.2 \times 0.18$
This work	9.25	37%	$3.14 \times 0.15^2 \times 0.27$

4. CONCLUSION

A cylindrical uniaxial dielectric DRA is realized by stacking three different multilayer uniaxial anisotropic mediums. This CDRA is fed by a rectangular slot aperture to excite HEM_{11} mode in DRA and generating radiation pattern in broadside direction. Bandwidth and gain enhancement in addition to size reduction are obtained due to the multi-stack multilayer structure of CDRA.

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