Progress In Electromagnetics Research Letters, Vol. 43, 155–163, 2013

A WIDEBAND HIGH-GAIN STACKED CYLINDRICAL DIELECTRIC RESONATOR ANTENNA

Yongfeng Wang[1, 2, *], Tayeb A. Denidni[2], Qingsheng Zeng[3], and Gao Wei[1]

[1]School of Electronics and Information, Northwestern Polytechnic University, Xi'an, Shaanxi 710129, China

[2]INRS-EMT, University of Quebec, Montreal, QC H5A 1K6, Canada

[3]Wireless Technologies Branch, Communications Research Centre Canada, Ottawa, Ontario K2H 8S2, Canada

Abstract—A new wideband and high-gain dielectric resonator antenna (DRA) is proposed. Three cylindrical dielectric resonators (DRs) with different materials and different sizes and a metallic cylinder are designed to obtain a wideband bandwidth and a high gain. The stacked structure provides a wideband bandwidth, and the cavity formed by the metallic cylinder provides a high gain. The measured results demonstrate that the proposed DRA has a wide bandwidth from 5.4 to 7.0 GHz with VSWR less than two and a gain around 11 dBi, covering the frequency range of 26%. The experimental and numerical results are discussed and compared with each other, showing a good agreement between them.

1. INTRODUCTION

The design flexibility offered by DRAs makes them suitable for many wireless applications. They can maintain high radiation efficiency, even at millimeter-wave frequencies due to low surface wave losses and minimal conductor losses [1]. Several methods have been proposed to enhance the gain of DRAs without considering arraying elements together using a feed network [2–6]. Stacking DRAs on top of each other can improve the directivity of the combined DRA with an enhancement of up to about 3 dB above that of a single DRA [2]. The use of a shallow pyramidal horn has been shown to increase the

Received 10 October 2013, Accepted 3 November 2013, Scheduled 5 November 2013
* Corresponding author: Yongfeng Wang (yongfeng.wang@emt.inrs.ca).

gain of a DRA to nearly 10 dBi [3]. Mushroom-like EBG structures are able to lead to a higher gain [4]. Recently, higher-modes methods are used for rectangular and ring DRAs, which have been proved to improve the gain of DRAs [5, 6]. However, most of these techniques lead to a narrow impedance and gain bandwidth.

In this paper, a new wideband, high-gain DRA design is proposed using a multi-layers DR and a cavity formed by a concentric metallic cylinder. Measured and simulated results are presented and compared with each other, showing a good agreement between them. The measured results demonstrate that the proposed DRA achieves a high gain (11 dBi) across bandwidth from 5.4 to 7.0 GHz, covering 26% frequency range.

2. ANTENNA DESIGN

The configuration of the proposed DRA is shown in Figure 1. It is prototyped on Rogers RO4350 substrate with dielectric permittivity of 3.66 and thickness of 0.762 mm. The feeding mechanism adopts a narrow slot (7.6×0.6 mm) centrally etched on a copper metallic ground with a size of 120×120 mm. The $50\,\Omega$ feeding microstrip line (width $W = 1.7$ mm) is etched at the center of the slot and terminated with an open stub of length $L_{\text{stub}} = 3.6$ mm.

Three dielectric discs are made of standard available dielectric substrate materials in our laboratory: Rogers RT/Duroid 6010 ($\varepsilon_1 = 10.2$) with thickness $h_1 = 7.5$ mm, Rogers RT/Duroid 6006 ($\varepsilon_2 = 6.15$) with thickness $h_2 = 10$ mm and Rogers RT/Duroid 5880 ($\varepsilon_3 = 2.2$) with thickness $h_3 = 16$ mm. Their radii are $r_1 = 5.5$ mm, $r_2 = 8$ mm, $r_3 = 13$ mm, respectively. A metallic cylinder with radius $r = 33$ mm and height $h = 13$ mm is placed concentric with the DRs. The distance between the metallic cylinder and the DR is almost $\lambda/2$, and the height of the metallic cylinder is about $\lambda/4$, where λ is the free space wavelength at the centre frequency of 6.5 GHz.

3. RESULTS AND DISCUSSION

3.1. Simulated Results of the Proposed Antenna

The proposed DRA was optimised by using HFSS. The simulated impedance bandwidth curve of the DRA is shown in Figure 2. The simulated bandwidth covers the range from 5.4 to 7.5 GHz for VSWR < 2, viz, 32.5% of the total frequency range. The wideband design of the proposed DRA adopts stacked DRs with different resonant frequencies, and it mainly depends on the lower two discs. The modes

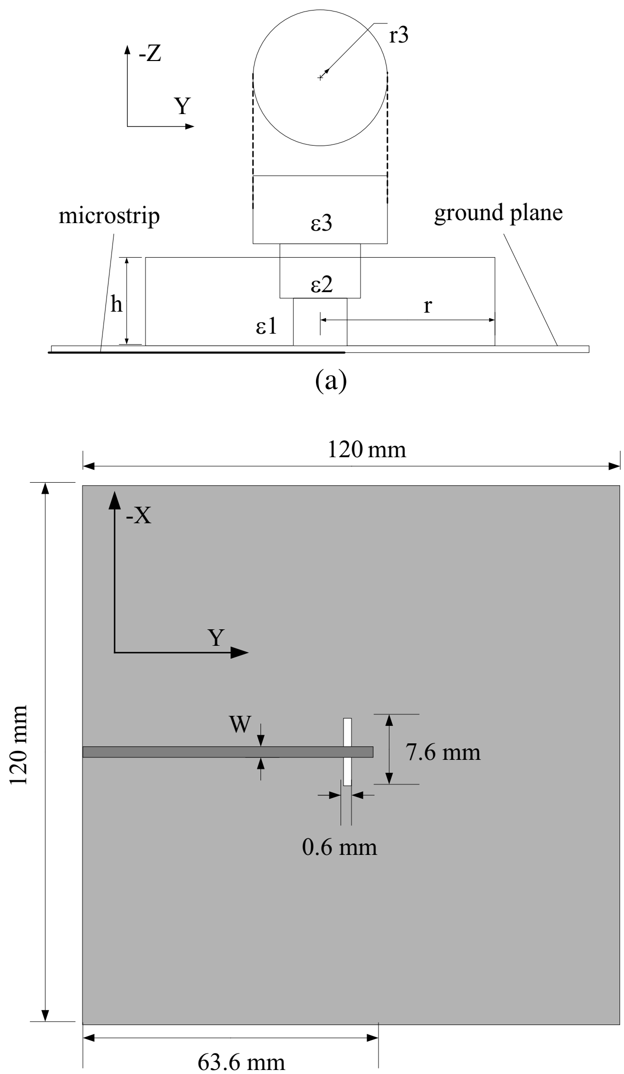

Figure 1. Geometry of the proposed DRA. (a) Side-view. (b) Back-view.

$\mathrm{HEM}_{11\delta}$ are excited in the DRs. The resonator frequency of the excited $\mathrm{HEM}_{11\delta}$ mode of the proposed DRA is calculated by [1]

$$f_{\mathrm{HEM}11\delta} = \frac{6.324}{\sqrt{\varepsilon_r + 2}} \left(0.27 + 0.36 \frac{r}{h} + 0.02 \left(\frac{r}{2h} \right)^2 \right) \frac{4.7713}{r} \qquad (1)$$

where r and h is the radius and the height of the cylindrical DRA, respectively. The length of the feeding slot is designed by [7]

$$f = \frac{c}{2L}\sqrt{\frac{2}{\varepsilon_{r1} + \varepsilon_{r2}}} \tag{2}$$

where c is the speed of light in vacuum, L the length of slot, and ε_{r1} and ε_{r2} are the relative permittivity of the substrate and the DR, respectively. The width and position of the slot and the length of the feeding microstrip line are optimized by HFSS. The calculated resonant frequencies of the lower two DRs are 6.36 GHz and 5.56 GHz, respectively.

Figure 3 shows the simulated peak gain of the DRA. The high-gain design uses a stacked structure together with the cavity formed between a metallic cylinder and the DRs. To validate the accuracy of the simulation by HFSS, a simulation by CST was implemented, and a good agreement between the two simulations was achieved.

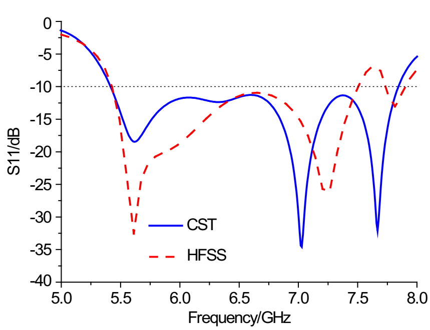

Figure 2. Simulated reflection coefficients of the proposed DRA.

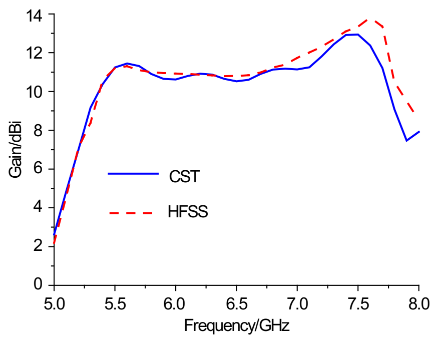

Figure 3. Simulated peak gains of the proposed DRA.

3.2. Simulated Results of the Reference Antennas

To better understand the bandwidth and gain enhancement of the proposed DRA, two reference antennas were discussed. Reference Antenna 1 was built by placing a single cylindrical DRA made of Rogers RT/Duroid 6010 ($\varepsilon_1 = 10.2$) with thickness $H = 10$ mm, and radius $a = 6$ mm on the center of feeding substrate shown in Figure 1(b). Reference Antenna 2 was formed by removing the metallic cylinder of the proposed antenna. Using CST, the simulated results of the Reference Antennas are plotted in Figures 4 and 5, which illustrate that the stacked structure can broaden the bandwidth and improve the directivity of the combined DRA with an enhancement of up to about 3.5 dB above that of a single DRA. Furthermore, it can be seen that introducing the cavity can elevate the gain with another 2 dB and broaden the bandwidth further.

To better understand the DRA bandwidth and gain enhancement by using the top-layer material (Rogers RT/Duroid 5880), an optimized selection for h_3 was performed, which is usually very useful for practical antenna design. Figure 6 shows the simulated reflection coefficients of the proposed DRA with different values of h_3. It is clearly observed that by introducing the low-permittivity material, the Q factor is reduced, which enhances the impedance bandwidth. Figure 7 shows the effect of h_3 on the DRA gain. When h_3 is equal to 16 mm, the

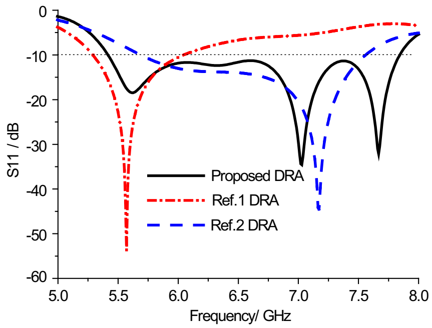

Figure 4. Reflection coefficients of the proposed DRA and two reference DRAs.

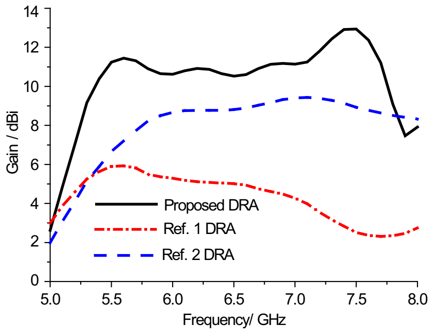

Figure 5. Gains of the proposed DRA and two reference DRAs.

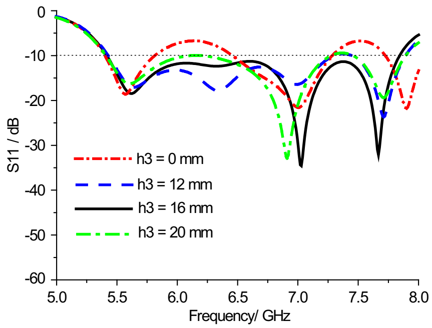

Figure 6. Reflection coefficients of the proposed DRA for different values of h_3.

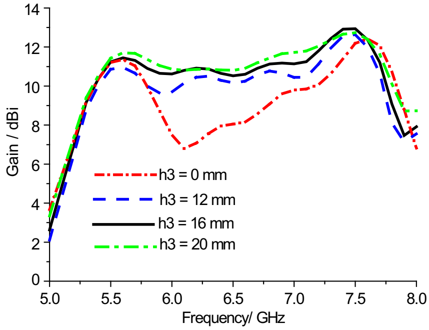

Figure 7. Gains of the proposed DRA for different values of h_3.

maximum gain bandwidth covers the whole operation band (5.4 to 7.5 GHz). The results indicate that the optimized height of the top-layer is about $\lambda_g/2$, where λ_g is the waveguide wavelength at the centre frequency of 6.5 GHz.

3.3. Fabrication and Measurement

A prototype DRA associated with the given parameters was fabricated and measured. The antenna performances in terms of bandwidth and radiation pattern were investigated numerically and experimentally. Because of the difficulties in fabrication, we changed the upper cylindrical disc to a square one with its edge length equal to the diameter (26 mm). This leads to little change to the DRA impedance and gain bandwidth. Figure 8 is the photograph of the fabricated DRA. Figure 9 plots the measured and simulated impedance bandwidth curves of the fabricated DRA. The measured bandwidth covers the range from 5.4 to 7.0 GHz for VSWR < 2, and a mismatch between the simulated and measured results is seen due to the fabrication imperfections, i.e., layer stacking and machining of microwave laminates.

The fabricated DRA was also measured in a far-field anechoic chamber. Figure 10 illustrates the measured and simulated peak gains of the proposed antenna. It is seen that the peak gain is stable and has an enhancement of up to 6 dB above that of a single DRA across the operating frequency range. Figures 11 and 12 show the measured radiation patterns in the yz-plane (E-plane) and the xz-plane (H-plane) at 6 and 7 GHz. It is clear from Figures 11 and 12 that the cross polarization levels are less than -40 dB in the direction of maximum radiation ($-Z$ axis) and lower than -20 dB in the main lobes (120° to 240°) and all the other directions, in spite of the spurious

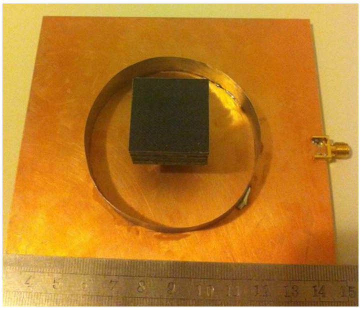

Figure 8. Photograph of the fabricated prototype.

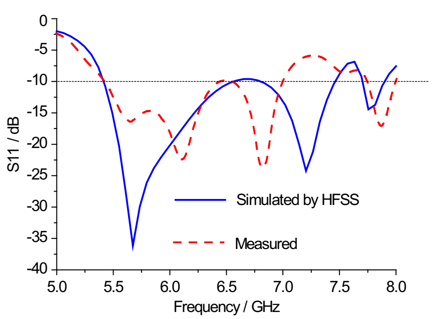

Figure 9. Simulated and measured reflection coefficients of the fabricated antenna.

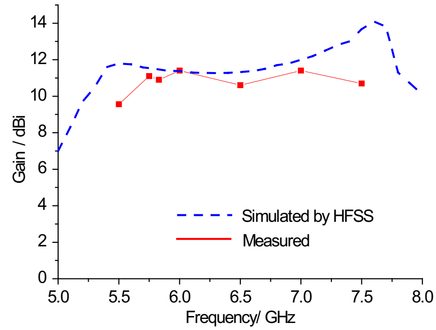

Figure 10. Simulated and measured peak gains of the fabricated antenna.

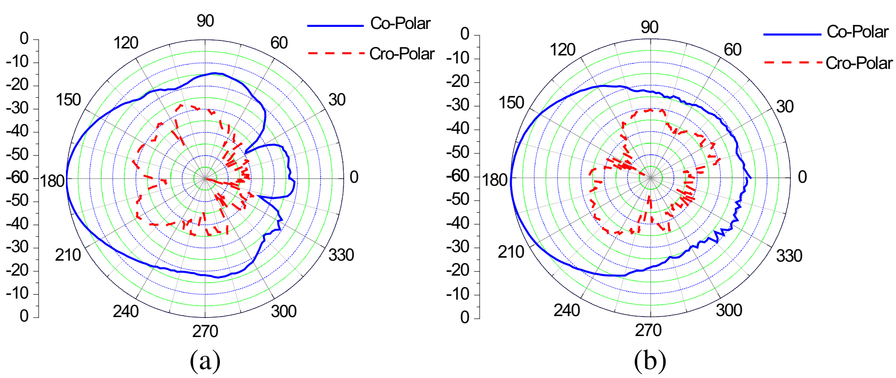

Figure 11. Measured radiation patterns at 6 GHz. (a) *E*-plane, (b) *H*-plane.

reflection from the SMA connector and cables. Thus, Figures 9–12 show that the designed high-gain antenna is suitable for practical wireless applications.

3.4. Discussion of Proposed Wideband High-gain Antenna and Comparison with Recently Published Antenna Designs

The high-gain DRAs published in [2–6] were very successful. Among these antennas, the one presented in [3] is the most similar to the proposed DRA in this study. Both antennas enhance the gain and bandwidth, and have a cavity formed in their structures. Other high-gain DRAs previously presented have one narrower impedance

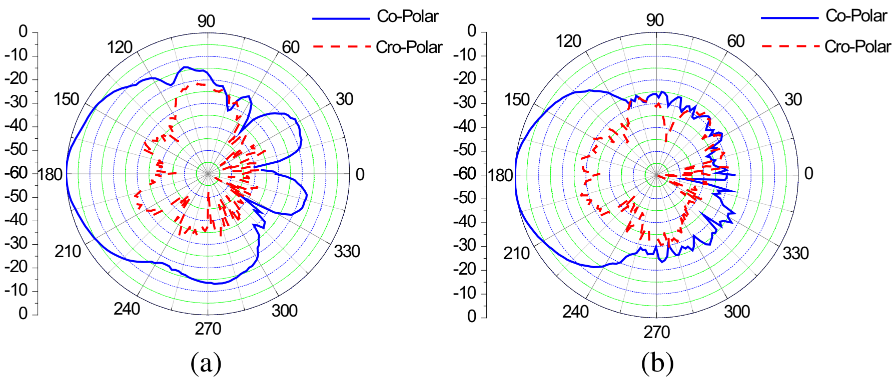

Figure 12. Measured radiation patterns at 7 GHz. (a) *E*-plane, (b) *H*-plane.

Table 1. Compare the proposed DRA design with other recent DRA designs in terms of bandwidth and gain.

	This work	Ref. [2]	Ref. [3]	Ref. [4]	Ref. [5]	Ref. [6]
Sim. bandwidth	32.5%	NaN	26%	8%	15%	NaN
Mea. bandwidth	26%	37%	21.3%	6%	15%	6.5%
Sim. Gain (dBi)	12	NaN	10	9.5	12	NaN
Mea. Gain (dBi)	11	6.5	10	8.5	12	9.5

or gain bandwidth. Table 1 shows that both antennas have better performances than most of other existing DRAs when considering the bandwidth and gain simultaneously. In addition, the proposed DRA has a stable high gain across the operating band, but needs more different types of materials in comparison with the majority of other designs.

4. CONCLUSION

A new wideband and high-gain DRA design has been proposed and implemented. By using a stacked dielectric structure and a cavity formed by a metallic cylinder, the proposed DRA achieves a high gain (11 dBi) and a wide bandwidth from 5.4 to 7.0 GHz, covering 26% frequency range. In addition, this antenna provides a stable radiation pattern and low cross-polarization levels in the operating frequencies. Accordingly, the proposed antenna can be a good candidate for wireless applications.

ACKNOWLEDGMENT

The authors would like to thank Rogers Corporation for providing the microwave substrate materials through the University Program. This work is supported by China Scholarship Council (CSC) (201206290106).

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