Bandwidth Enhancement of Dielectric Resonator Reflectarray Antenna

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Abstract— **Aperture-coupled dielectric resonator antenna (DRA) is proposed using a novel reflectarray antenna unit-cell structure. It is shown that a bowtie shaped slot can enhance the bandwidth performance of a reflectarray antenna. The unit-cell's reflection phase response was verfified experimentally using the waveguide simulator (WGS) method. An array comprising of 256 elements was simulated using the finite integration technique (FIT) based on the proposed unit-cell. The array exhibits a 3-dB gain bandwidth of 28% and radiation efficiency of 43.8%. These results were validated using the transmission-line method (TLM).**

Index Terms—**Dielectric Resonator Antenna, Reflectarray Antenna, Bowtie shaped slot.**

I. Introduction

Reflectarray antenna essentially comprises of multiple isolated microstrip patch elements without any power division network that are located on a flat reflecting surface that are illuminated by a feed antenna [1]. To each element is attached a short segment of phase-adjusting transmission line to compensate for the phase delay over the path from the illuminating feed. The concept of reflectarray was first introduced by Berry in 1963 [2]. Although reflectarray antennas afford benefits such as high gain and compact size, however their main drawback is the narrow bandwidth.

A lot of work has been done to increase the bandwidth of the reflectarray antenna, which includes the use of certain geometrical shapes for the element [3] and use of true time delay lines [4]. Although the phase range of 360 degrees is sufficient for conventional reflectarray antenna designs, but as demonstrated in [5] the use of greater phase shift can result in better antenna performance in terms of bandwidth. Also as demonstrated in [6], the linear reflection phase curves exhibited by such antennas can provide a better bandwidth performance. From these studies it is clear that aperture coupled structure can enhance the performance of reflectarray antennas. In [7] it is shown that by using an hour glass shaped slot in the aperture coupled patch structure, a gain bandwidth of 24% is obtained. In this work the level of the sidelobes are about 10 dB lower than the main lobe, and the efficiency at the center frequency is 27%.

Recently the dielectric resonator antenna (DRA) has been used as a reflectarray antenna element [8]. This type of antenna exhibits improvements in the antenna's features, such as bandwidth, low loss and high radiation efficiency compared to conventional patch antennas. In 2000, Keller used DRA with variable dimensions as a reflectarray antenna element [9]. DRA loading with variable slot and strip were also studied in [10] and [11], respectively. In [12] by using DRA in the aperture coupled structure, a gain bandwidth of 18% is obtained.

In this paper we have shown that by using a bowtie shape for the slot element can significantly improve the dielectric resonator reflectarray antenna's gain bandwidth and radiation efficiency. The proposed antenna is composed of a rectangular DRA that is coupled to the stub loaded microstrip line through the bowtie slot in the ground-plane. The stub loaded microstrip line is curved on one end, and has a fixed and a variable part. Reflection phase curves of the DRA reflectarray were studied using Ansoft HFSS software, and its performance was validated experimentally. Finally, a 256 element reflectarray using the proposed DRA unit-cell was designed and verified. The reflectarray antenna's performance was compared with previously reported DRA reflectarrays, which show the proposed reflectarray structure provides improvement in the gain bandwidth, cross-polarization level and antenna radiation efficiency. Far-field was computed using both finite integration technique (FIT) and transmission line method (TLM) in CST software.

II. Design procedure

A. Reflectarray Unit-Cell Design

In this paper a square cross-sectional DRA using an aperture coupled structure with bowtie shaped slot is proposed as a new reflectarray element. The antenna's reflection phase can be varied by varing the length of the stub loaded microstrip line. The DRA unit-cell is shown in Fig. 1. To experimentally study the behavior of the unit-cell element, four unit-cells of different microstrip line lengths were fabricated. The measurements were done here with the waveguide simulator (WGS) method. In this method, one or more unit-cell elements were placed inside a rectangular waveguide, and the waveguide's conductive walls simulate infinite array behavior for a specific angle of incidence [13], [14]. In order to make measurements using this method, we placed two unit-cells on the waveguide aperture. Fabricated unit-cell elements are shown in Fig. 2. The unit-cells were also simulated using Ansoft HFSS software. The parameters of the structure were optimized to realize the best results, i.e., in terms of impedance matching, linear and greater reflected phase variation. The optimized parameters are shown in Table I. Fig. 3 shows the comparsion of the simulated and measured reflection phase curves as a function of stub loaded microstrip line length. These results show that there is almost a linear relationship between the reflected phase and line length. The simulated and measured

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results are in good agreement and any difference can be attributed to the fabrication tolerance and defects.

In the next stage, the dimensions of the DRA unit-cell was increased to increase the range of the reflected phase, which was done without changing other parameters of the structure. The new dimensions are: 17 mm × 17 mm. In Fig. 4, the reflection phase curves are shown at around 10 GHz. As can be seen from this figure, the reflected phase curves are almost linear over the 21.5% bandwidth, and the reflected phase range obtained is greater than 400 degrees. These results are better in comparison than the previous work reported in e.g. [10], [11].

In general, the phase of the reflection coefficients depends not only on the unit-cell element size but also on the incidence angle of the plane wave [2]. The reflected phase curves for three different incidence angles are shown in Figure 5. As can be seen from this figure that for incidence angles between 0 and 40 degrees, result in reflected phase variation of about 90 degrees.

B. *Reflectarray Antenna Design*

To study the far-field performance of the proposed element, a 256 element reflectarray antenna was designed. The diameter of the aperture was 27.2 cm. The reflected phase curves presented in Fig. 4 were used to determine appropriate values of the stub loaded microstrip line length used in the reflectarray unit-cell element. The antenna was fed by a pyramidal horn that was located 34.55 cm from the reflectarray. The dimensions of the horn aperture were 4.94 cm × 7.32 cm, and its incidence angle was 90 degree. The corresponding f/D ratio was equal to 1.27, and it was selected to find the best trade-off between feed blockage, spillover and aperture efficiency [15]. The reflectarray DRA is shown in Fig. 6. The far-field calculations were carried out with FIT. Relative power of the E-plane and H-plane patterns at the center frequency of 10.65 GHz are shown in Fig. 7. To validate the results, calculations were also carried out using TLM. In Fig. 8 shows the relative power of the E-plane patterns. As can be seen, good agreement between two results exists. The antenna's gain versus frequency are shown in Fig. 9. This figure shows the 3-dB bandwidth of 28% is obtained, which is larger than that reported in [7], [9]-[12], [16]-[18]. Salient results are compared with some recent papers in Table II.

III. Conclusion

In this paper a new reflectarray DRA unit-cell element is proposed, that was fabricated and analyzed. Measurements were done using the WGS method in WR90. DRA's reflected phase response is shown to be almost linear and the reflected phase range is greater than 400 degrees. Far-field calculations were carried out with FIT and TLM. The DRA reflectarray has a 3-dB gain-bandwidth and radiation efficiency of 28% and 43.8%, respectively. Using this new DRA unit-cell element in the reflectarray antenna design, antenna characteristics are improved in comparison with previous designs.

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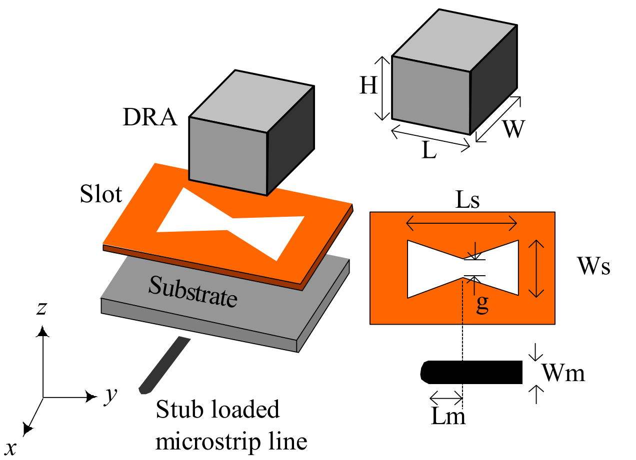


Fig 1. Proposed reflectarray DRA unit-cell structure.

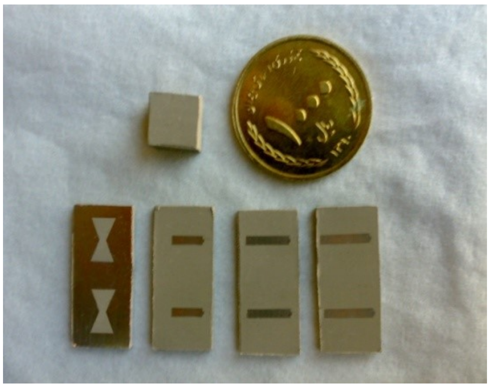


Fig. 2. Fabricated reflectarray unit-cell elements.

Table I. Optimal size of the reflectarray unit-cell elements.

	Width (mm)	Length (mm)	Height (mm)	ε_r
Substrate	10.16	11.43	1.5	10.2
Stub loaded microstrip line	Wm = 1.4	Lm = 3.1 Lm = 4.0 Lm = 6.7	0.175	-
Slot	Ws = 5 g = 3.1	Ls = 10	0.175	-

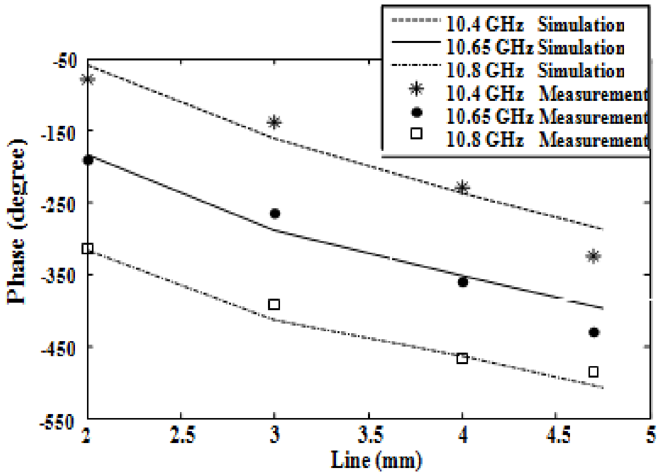


Fig. 3 Measured and simulated reflected phase of the proposed unit-cell as a function of the stub loaded microstrip line length at frequencies close to 10.65 GHz.

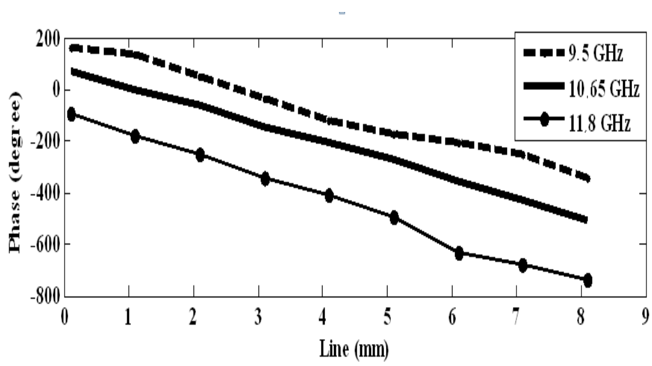


Fig. 4 Reflection phase curve of the proposed unit-cell as a function of the stub loaded microstrip line length between 9.5-11.8 GHz.

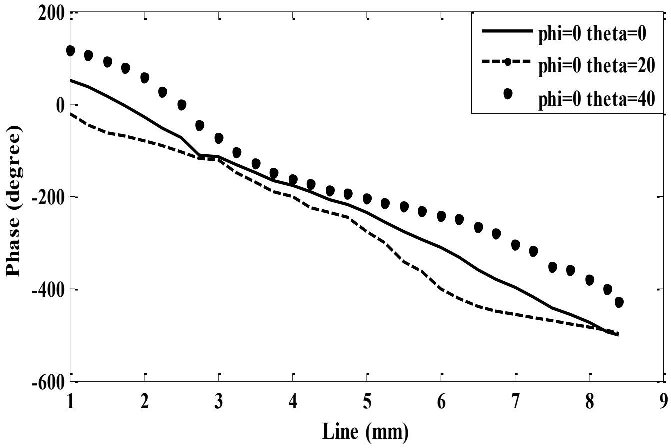


Fig. 5 Reflection phase curve of the proposed unit-cell as a function of the coupled base microstrip line length and at various illumination angles by the linearly-polarized pyramidal horn antenna in E-plane.

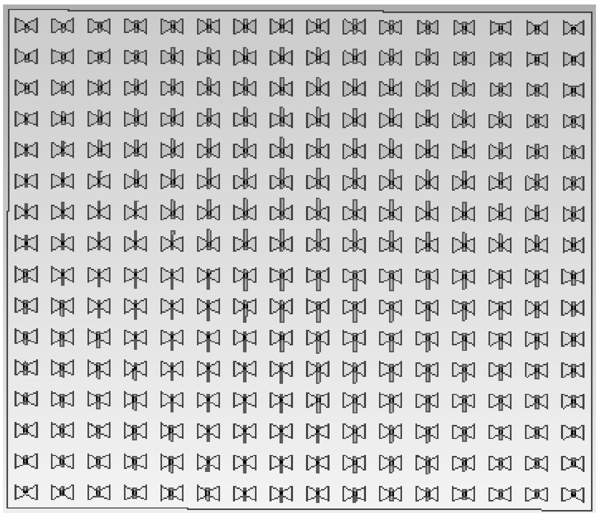
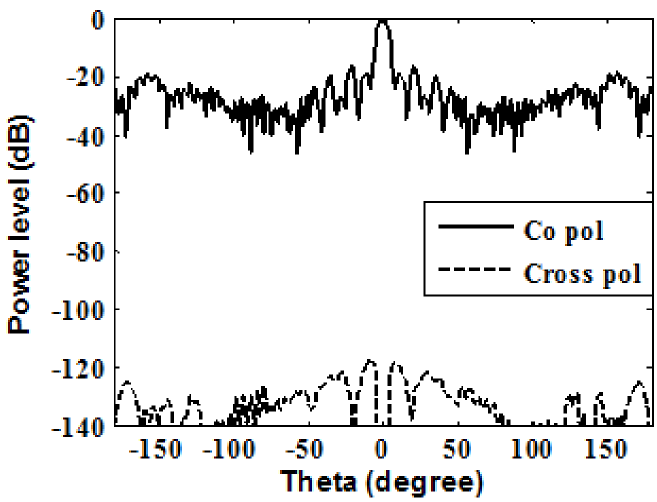
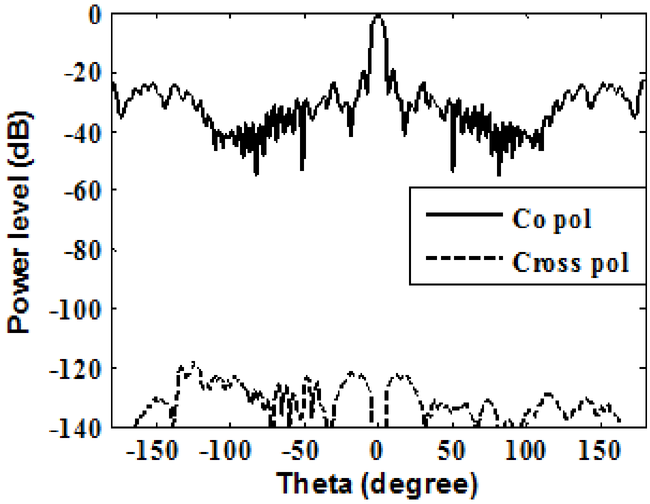


Fig. 6 The reflectarray antenna structure.

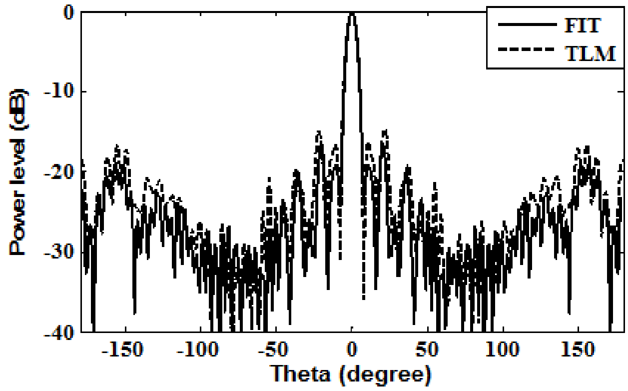


(a)



(b)

Fig. 7 Co-pol and Cross-pol patterns at 10.65 GHz, (a) E-plane, and (b) H-plane.



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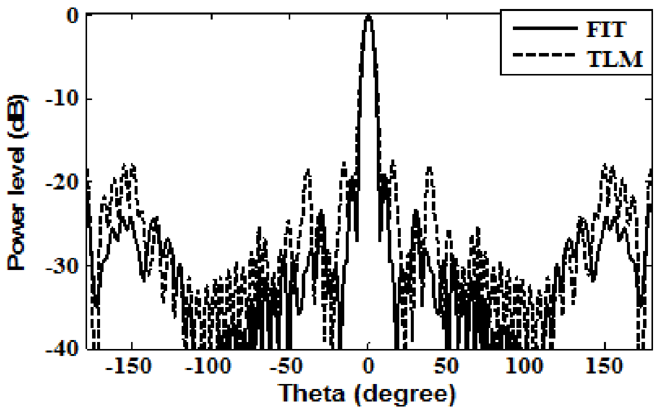

(b)

Fig. 8 Co-pol pattern by FIT and TLM, (a) E-plane, and (b) H-plane.

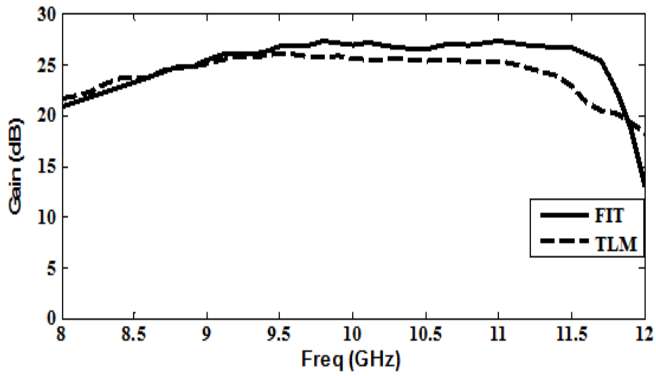

Fig. 9 Gain versus frequency obtained using FIT and TLM.

Table II. Performance comparison with previous works

	Efficiency at center frequency	Sidelobe level (dB)	Cross Pol (dB)	Bandwidth (%)
Proposed element	43.8%	-16	-120	28%
DRA [12]	71 %	-15	Not specified	18%
DRA [16]	Not specified	-15	-50	15%
DRA [17]	55%	-20	-24	13.6%
DRA [18]	29%	-15	-22	14%
Patch [7]	27 %	-10	Not specified	23.7%