DIRECTIVE DIELECTRIC RESONATOR ANTENNA

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Abstract: Relatively directive, single element, linearly polarized, dielectric resonator antenna for the ISM band applications (5.8 GHz) is presented in the paper. Its operation is based on the excitation of higher order modes inside a cylindrical dielectric resonator antenna of low relative permittivity material (ε_r= 6.15) fed by an aperture coupled microstrip line. The behavior of the mode properties inside the resonator is studied and geometry providing maximum gain is determined. Measurement results are given and compared with simulations results obtained in CST Microwave Studio in order to confirm the correct operation of the antenna.

Keywords: dielectric resonator antennas, directive antennas, dielectrics, higher order modes

1. INTRODUCTION

Dielectric resonator antennas (DRA) have become very popular radiating elements in microwave frequency bands [1]. The most important advantages of DRAs are high radiation efficiency, compact size, ease of excitation and a relatively large impedance bandwidth when compared to other resonant antenna elements, e.g. microstrip antennas.

A cylindrical resonator, operating with the low-order hybrid electromagnetic mode $HEM_{11\delta}$ placed above a large ground plane (theoretically infinite), is the most frequently used DRA configuration [1-3]. This mode generates a broadside radiation pattern with linear polarization and a gain of about 5 dBi. Several approaches have been suggested to increase the gain of the DRAs. Arraying of single element DRAs [2] is probably the most versatile method in which the gain value can be directly controlled by the number of elements in the array. Nevertheless, increased size, complexity and costs of the resultant antenna are the main disadvantages.

Altering a single element DRA can be used in cases, where medium gains up to around 10 dBi are sufficient. In general, two tactics to increase the gain of the single element DRA exist. First strategy is to use additional structures in close vicinity of the resonator operating in the low-order mode. These can represent surface mounted short horns [4], electromagnetic bandgap (EBG) structures [5] or superstrates [6].

The second strategy utilizes higher-order radiating modes in a single dielectric resonator. This approach has already been adopted in both rectangular and cylindrical DRAs. Petosa and Thirakoune [7] showed that a DRA based on higher-order $TE_{\delta 13}$ and $TE_{\delta 15}$ modes in a rectangular resonator can achieve gains of 8.2 dBi and10.2 dBi, respectively. The structure operating in $TE_{\delta 15}$ mode [7] re- quired a maximum resonator dimension of about $1.1\lambda_0$ when built from dielectric material with rel- ative permittivity ε_r = 10, where λ_0 is the free space wavelength. Guha et al. [8] managed to excite higher-order $HEM_{12\delta}$ mode in a cylindrical resonator by introducing an air-filled cavity in the ground plane below the resonator. This way, peak gain of about 10 dBi was achieved but only in a relatively narrow impedance bandwidth.

In this paper, we use excitation of a higher-order hybrid electromagnetic HEM_{133} mode in a single cylindrical dielectric resonator with partial excitation of the nearby HEM_{123} mode to accomplish considerable gain enhancement. These modes require neither special feeding schemes nor ground plane modifications and can be excited similarly to the well-known $HEM_{11\delta}$ mode. The aperture coupling feed is selected and optimized to avoid excitation of unwanted TE/TM modes within the resonator. More detailed information on the topic can be found in [9].

The paper is organized as follows. Section II briefly describes the antenna concepts and the design process. The E-field distributions within the resonator are discussed. A simple parametric study and explanation of dimensions are given in Section III. Manufacturing of the prototype, final dimensions and a comparison between simulation and experimental results are summarized in Section IV. Finally, the paper is concluded by a short discussion in Section V.

2. CONCEPT OF THE PROPOSED ANTENNA

The antenna is composed of a single cylindrical dielectric resonator placed above the ground plane of a circular footprint. The resonator is excited through a rectangular slot in the ground plane of a microstrip line according to Fig. 1. An aperture coupling feeding mechanism was selected to minimize excitation of unwanted lower-order modes in the structure. Relative permittivity of the resonator in all simulations was 6.15. This value was simply selected due to availability of the material with the given ε_r. The substrate Arlon 25N with relative permittivity 3.38 was used in the feeding structure design.

Initial dimensions of the resonator (height *h* and diameter *d* according to Fig. 4) were found by the magnetic wall method using CST Eigenmode solver. All the walls were perfect magnetic conductors and the resonator dimensions were obtained so that the resonant frequency of both the target modes HEM_{133}, and HEM_{123} lied close to the desired frequency 5.8 GHz. Since the magnetic wall method does not take radiation losses of the resonator into account, considerably large inaccuracy is a result for low permittivity dielectrics. Nevertheless, the method provided a reasonable initial approximation of dimensions that needed to be tuned and optimized afterwards. Full-wave transient solver of CST Microwave Studio was used for this purpose.

Figure 2 depicts the simulated E-field and H-field distributions of the desired modes in several planes (see Fig. 1) of the resonator as obtained from the modal analysis and as excited within the designed DRA at target frequency 5.8 GHz. The comparison clearly shows the presence of the modes inside the DRA. Moreover, the modes are excited with quadrature phase shift which simplifies their identification. The E-field oscillates predominantly in the *x*-axis and thus the radiation is linearly polarized in the broadside direction (the direction along the *z*-axis).

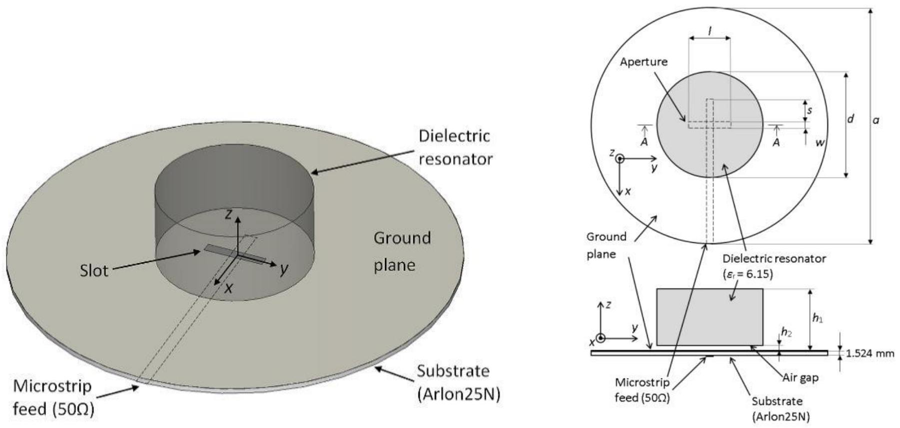

Figure 1: Geometry of the aperture-fed cylindrical (left) and its dimensions explained (right).

An aperture coupling excitation scheme is selected to excite both the desired modes in the DRA. This solution is preferred since the desired modes are of higher order and e.g. a probe feed would give rise to the excitation of unwanted TE/TM modes, deteriorating the near field distribution. The aperture is fed by a 50 Ω microstrip line placed on the other side of the ground plane according to

Fig. 4. By placing the aperture symmetrically below the DRA and tuning its dimensions, we can excite both the de- sired modes with a single feed. Correct values of parameters *l*, *w* and *s* have to be found. The length of the slot *l* is selected, so that the resonances of the slot are avoided. The optimum dimensions of the feed were found to be *l* = 17.73 mm, *w* = 3.49 mm with the stub length *s* = 10.94 mm.

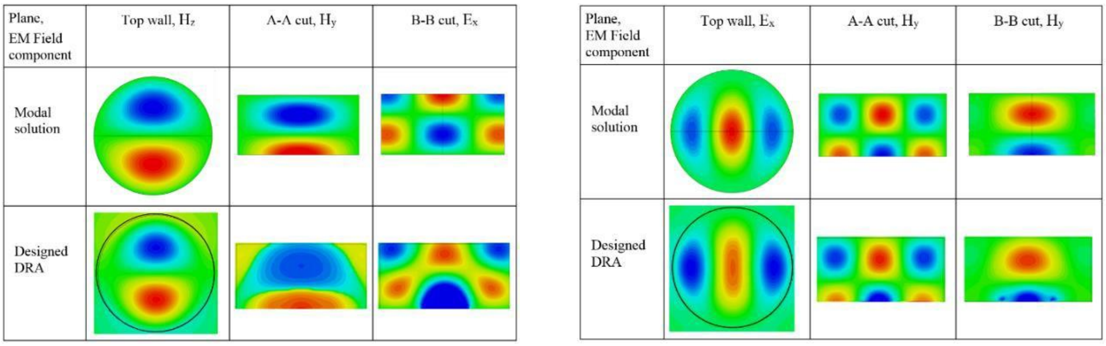

Figure 2: E-field and H-field distributions of the HEM_{133} mode (left) and HEM_{123} mode (right) as obtained by modal analysis and the same field components as excited in our cylindrical DRA at 5.8 GHz. The phase difference between the visualized E and H-field is 180°. For plane cuts see Fig. 1.

3. PARAMETRIC STUDY

The influence of two main design parameters of the designed DRA on antenna performance was studied. Namely the resonator diameter *d* and the ground plane diameter *a* were varied and the resonant frequency, impedance bandwidth and maximum gain were observed. Due to the restrictions of the antenna fabrication method, the height *h* must be an integral multiple of 1.575 mm only, which was the height of the Arlon substrate used for manufacturing (for details, see Section 4). The optimum height *h* was found to be 22.05 mm corresponding to 14 layers of the Arlon substrate. The desired resonant frequency was 5.8 GHz with the band of interest covering the frequency range 5.725-5.875 GHz. The band of interest corresponds to the relative bandwidth of 2.6 %. Throughout the parametric study, the dimensions of the feeding structure (i.e. the slot width *w*, its length *l* and the stub length *s*) were kept constant as well as the height *h* of the resonator.

The resonant frequency of the DRA and its impedance bandwidth were determined mostly by the dimensions of the resonator whereas its gain was in addition quite strongly influenced by the diameter of the ground plane. Fig. 3 shows the frequency response of the reflection coefficient for several *d* values (the reference impedance 50 Ω) with the ground plane size *a* = 132.5 mm. The height of the resonator *h* was fixed to the value 22.05 mm in all of the plots. Fig. 3 depicts the frequency response of reflection coefficient magnitude and frequency response of realized gain for several diameters of the resonator.

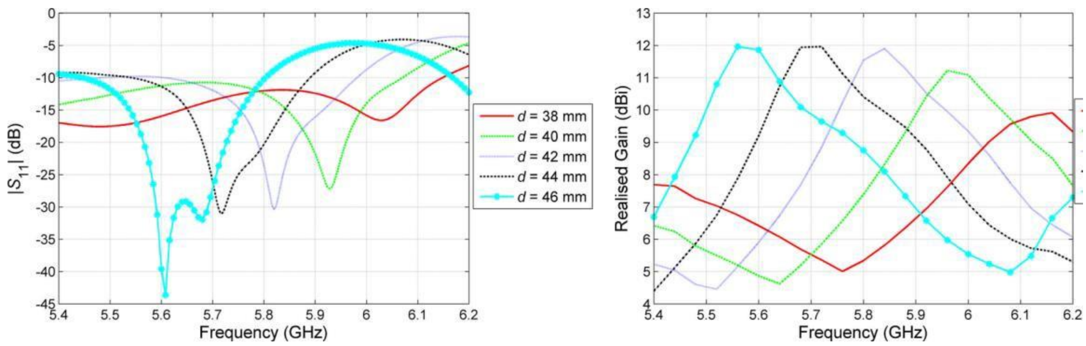

Figure 3: Reflection coefficient vs. frequency for several diameters of the resonator (left) and realized peak gain in the broadside direction vs. frequency for several diameters of the resonator (right).

4. PROTOTYPES AND RESULTS

The antenna was built by stacking up layers of a completely etched Arlon 600 substrate with ε_r = 6.15, loss tangent tan δ = 0.0015 and thickness 1.575 mm. The layers were held together by double sided duct tape of 65 μm thickness and relative permittivity 3, approximately. The resonant frequency had to be slightly tuned by altering the resonator diameter to compensate the effect of 14 layers of the duct tape in between the dielectric layers. The final dimensions of the resonator were h = 22.75 mm corresponding to 14 layers of Arlon 600 substrate interleaved with 14 layers of duct tape. The diameter of the resonator was 44.1 mm and the diameter of the ground plane a = 132.5 mm.

The comparison between the simulated and measured magnitude of the reflection coefficient is depicted in Fig. 4; reasonable agreement can be observed. Simulations were conducted in the transient solver CST Microwave Studio and measurement was done using a vector network analyzer.

Next, radiation patterns and gain of the designed antenna were measured in an anechoic chamber. First, the realized gain frequency response was measured in the broadside direction; a maximum gain of 11.59 dBi was obtained at the frequency 5.82 GHz (Fig. 4). Radiation patterns in two orthogonal principal planes (*xz*, *yz* in Fig. 1) were measured at the frequency of maximum gain 5.82 GHz for co- and cross-polarization components (Fig. 5). The co-polarization component corresponded to the *x* axis and the cross-polarization to the *y* axis according to Fig. 1.

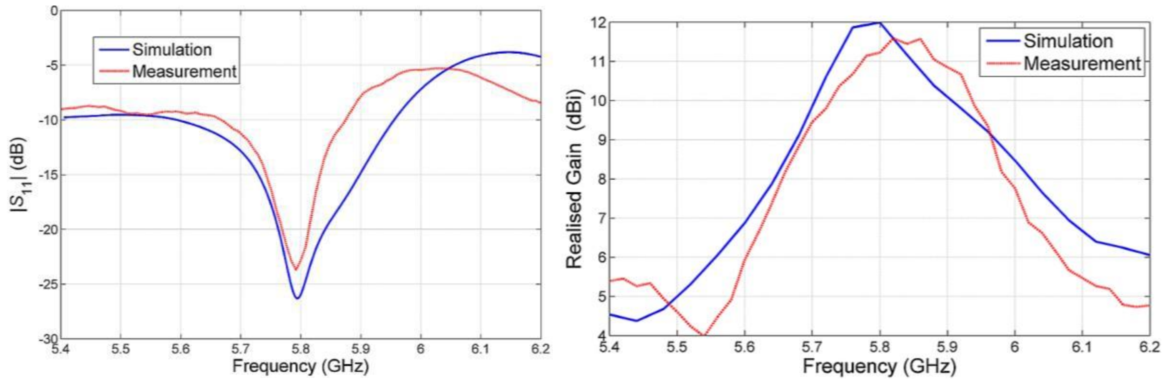

Figure 4: Comparison between simulated and measured magnitude of the reflection coefficient (left) and frequency response of the realized gain (right).

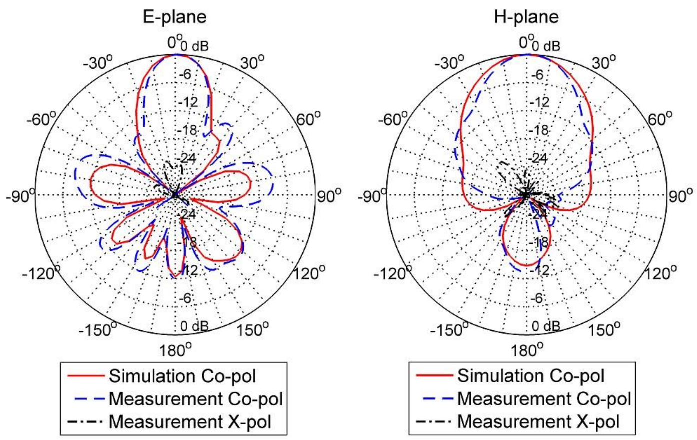

Figure 5: Simulated and measured radiation patterns at 5.82 GHz, E-plane corresponds to *xz* plane and H-plane to *yz* plane.

5. CONCLUSION

A concept of a dielectric resonator antenna based on the combination of higher-order modes in a simple cylindrical dielectric resonator was presented and experimentally verified. Good agreement between simulation and measurement was achieved. A directive radiation pattern with a high gain of 11.59 dBi was measured and impedance bandwidth was sufficient to cover the whole 5.8 GHz ISM band. Relatively high side lobe levels in the E-plane (8dB below the gain in the broadside direction) are the main disadvantage. The implementation of the antenna might be more convenient at higher frequencies where dimensions are less crucial. Since the structure operates with higher-order modes, the electrical size is increased when compared to the operation of low-order modes.

The proposed antenna concept might find application in all the areas of wireless communication where directive elements are required and where the bandwidth is not crucial, e.g. radio relay links. More complex shapes of the resonator might provide larger bandwidths and thus broaden the application range of this antenna element.

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