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Embedded Dual-band Cylindrical Dielectric Resonator Antenna

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Abstract

A compact dual-band antenna made of high dielectric constant substrate is studied. Embedding a higher dielectric cylindrical inside the substrate host cylindrical enhances the dual-band behaviour. The first part displays the characteristics of single CRDA as return loss, bandwidth and radiation pattern, then, the second part describes the aim of using an antenna, composed by the arrangement of two cylindrical resonators in which the smallest is inserted in the largest, to lead dual-frequency behaviour, and achieve a dual-band antenna. The proposed antennas are investigated using Finite Element Method (FEM), the impedance matching dual-band definition and covers the Ultra High Frequency band (UHF).

1. Introduction

The dielectric resonator antennas (DRAs) have attracted wide attentions in various applications, as armored filters or oscillators [1,2], They offer several advantages in terms of high radiation efficiency and Q factor. Indeed, when a resonator is placed in a cavity, it presents a high quality factor, which allows the realization of a highly selective filter.

DRAs topologies as rectangular, cylindrical, hemispherical, circular, triangular etc. are possible with various feed techniques, for a single-mode excitation, the DRA's bandwidth doesn't exceed 15%. Recently, different shapes and embedded resonators have been proposed to enhance the bandwidth; these techniques are generally difficult to implement without increasing the size of the antenna. In another way the resonant frequency of the DRA is predominantly determined by its size, shape and material permittivity (ζ_r) [1,2].

In this present work, a novel DRA design is proposed, and a parametric study is carried out. In the first section, the proposed cylindrical dielectric resonator (CDR) antenna shown in **Figure 1** is made from ceramic ζ_{r1} = 36.7 mm, a_1 = 12.65 mm and d_1 = 9.6 mm and excited by a coaxial probe is investigated; the study next focuses on new way of designing a dual-band, symmetrical structure and low profile DRAs, in which a smaller size dielectric

resonator is embedded in a larger size "host" dielectric resonator with a lower dielectric constant as shown in **Figure 9**.

The operation principles of these embedded DRAs are similar to the stacked DRA but it has the advantage of being low-profile. Since the structure consists of same DRs with different dielectric constants, there are two resonant frequencies that can be made either close to each other to yield wideband behaviour, or sufficiently far apart to yield dual-band behaviour.

In order to design and optimize the proposed antenna, finite element method and Eigen mode solver are used. The measurement and simulation results are shown, followed by a discussion.

2. CDRA Theory

The preferable mode for the filter design is the mode $TE_{01\delta}$ because of its high Q factor performance, while for dual-band radiating purposes $TM_{01\delta}$ mode is chosen for its Omni-directional pattern and $HEM_{11\delta}$ mode is chosen for its broadside radiation [3,4]. The cylindrical resonator antenna under investigation have height and radius d and a, respectively. The ground plane, assumed to be of finite extent, supports the dielectric cylinder. The simple way of excitation of the lowest mode of the structure which is the HEM mode is using a coaxial probe, vertically orien-

tated with height equal to h and located at distance equal to ρ far from the centre of DRA on phi = 0°, the characteristics of the CDRA can be written as [1].

2.1. Resonant Frequency

The resonant frequency of the cylindrical DRA was calculated approximately with (1) described in [1]. This gives a frequency of 1.96 GHz for the single CDR (with ζ_{r1} = 36.7, diameter a_1 = 12.65 mm and high d_1 = 9.6 mm). In practical applications, we are interested in the fundamental (dominant) mode, which has the lowest resonant frequency.

The resonant frequency is given by dielectric constant ε_r, radius a, and height d on Equation (1) and the value are in **Table 1** [1,4],

$$f_0 = \frac{2.208 \times C}{2\pi \times d\sqrt{\zeta_r + 1}}\left[1 + 0.7013\left(\frac{a}{d}\right) - 0.002713\left(\frac{a}{d}\right)^2\right] \quad (1)$$

Equation (1) is used only when $0.4 \leq \left(\dfrac{a}{d}\right) \leq 6$ [1,2],

where c is the velocity of light in free space and ε_r is the relative dielectric constant of the cylinder.

2.2. Field Distributions

By viewing the field distribution within the DRA, one first may understand the mode in which the DRA is resonating, and secondly may be able to make adjustments to the DRA shape, size, and probe position to maximize operation in the required mode. Being able to view these fields also helps in understanding the expected radiation pattern and how modification to the structure will influence the pattern. To examine only those fields due to one resonant mode within the DRA, the excitation must be at one frequency only [1,5].

The ideal radiation pattern (far-field pattern) of the mode $TM_{01\delta}$ looks like a pattern of a quarter-wavelength monopole above the ground plane. The radiation pattern of the $HEM_{11\delta}$ mode looks ideally like a pattern of the half-wave dipole parallel to the ground plane [1]. In practice, the feeding mechanism may excite more than one mode, so that the pattern will not look like the ideal one. Furthermore, the ground plane will be of finite extent, which will cause the pattern to depart from an ideal one and there will be some radiation to the lower half-space [4,5]. All these effects are taken into account in the numerical simulation.

3. Principles of Investigation

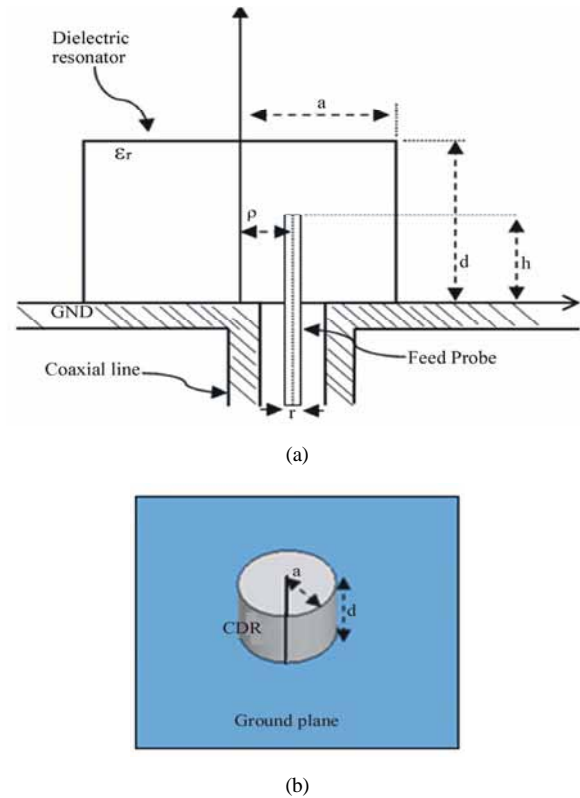The configuration of proposed DRA depicted in **Figure 1**.

(a)

(b)

Figure 1. DRA configuration. (a) Side view; (b) 3-D view.

Table 1. Frequencies of the two configurations.

Configuration antenna	Freq (eigen mode solver)	Permittivity (ζ_{r1} ; ζ_{r2})
Single DRA	1.94 GHz	36.7
DRA embedded	1.71 GHz	36.7 + 90

comprises a single CDR fabricated by using ceramic dielectric materials with relative permittivity ζ_{r1} = 36.7 with diameter a_1 = 12.65 mm and high d_1 = 9.6 mm. The DR is fed energy by a 50Ω Coaxial line of width r = 0.65 mm and length h = 5.6 mm at position ρ = 11.56 mm. "In all sections, the coaxial-probe line is localized in the edge near to the wall of CDR to maximize the excitation of the dominant mode".

The proposed structure in **Figure 1** is performed and the results are given by software based on finite elements method; the investigation is subdivided into three parts as following.

3.1. Antenna Composed by Single CDR

In this first part, **Figure 2** shows the proposed DRA configuration using one single cylindrical dielectric resonator fixed on finite ground plane with dimension mentioned above is lead to shows the adaptation in term of return loss and radian pattern.
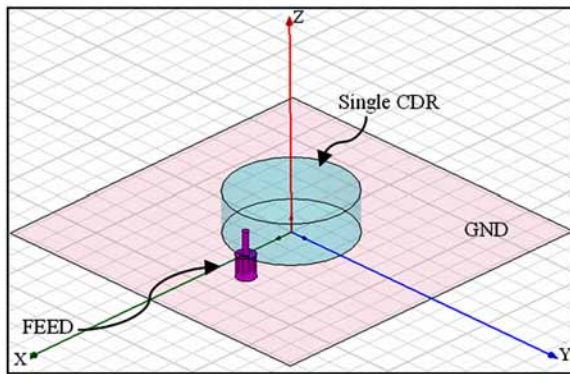
Figure 2. Geometry of the probe-fed cylindrical DR.

It is clearly noticed from **Figure 3** and **Figure 4**, that the resonant frequency of the HEM11d mode of a cylindrical dielectric is about 1.91 GHz with reflection coefficient S11 = –50 dB. The simulation results are obtained from Fidelity using a finite elements method and showing good agreement with calculated (in **Table 1**).

By incorporating a suitable feed position, and good probe lentgh ,the radiations patterns E-phi and E-theta over the two orthogonal planes (E-plane and H-plane) are having broadside direction and nearly ideal because some higher order modes with non-broadside radiation patterns are excited and disturb the radiation pattern axial symmetry [6,7].

3.2. Antenna Composed by Two DRA Delta = 0

Besides the single DRA, embedded DRAs can be of different shapes, such as cylindrical, square, or elliptical shapes [8-11]. For this purpose study, the geometry of embedded element is same as the host resonator as shown in **Figure 5**.

The additional cylindrical element has a radius $a_2 = 7.3$ mm, high $d_2 = 5.6$ mm, and permittivity $\zeta_{r2} = 90$. By using Eigen mode solver the frequency of the embedded antenna is 1.71 GHz as in **Table 1**.

Figure 3 and **Figure 6** show the simulated reflection coefficients of the single and embedded resonator respectively it is clearly found that no dual-band behaviour and also one frequency mode. So the new antenna looks like a single antenna characteristics.

The frequency is not proportionately to the permittivity which means that the first frequency mode of the embedded antenna is lowest then the single antenna.

Then we notice the apparition of the second mode but with low return loss value (< -10 dB) at $f_2 = 2.1$ GHz. It means that it should be possible to design the antenna either for wideband or for dual-band operations by varying the dielectric constants and geometry parameter to increase the second frequency f_2 [9].

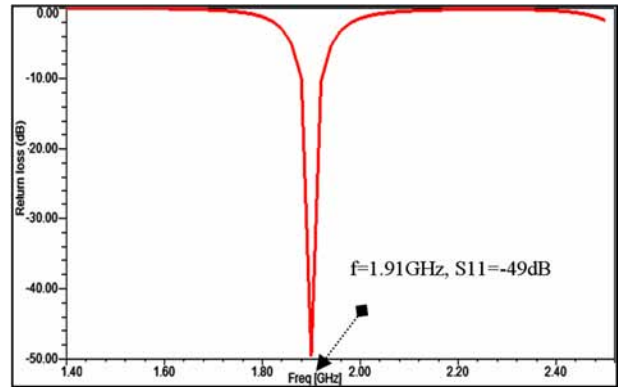The radiation pattern of the single DRA and embedded

Figure 3. Computed return losses of the DR antenna against frequency. a = 12.65 mm, d = 9.6 mm, ρ = 11.75 mm, h = 5.5 mm, r = 0.65 mm, GND = 75 × 75 mm.
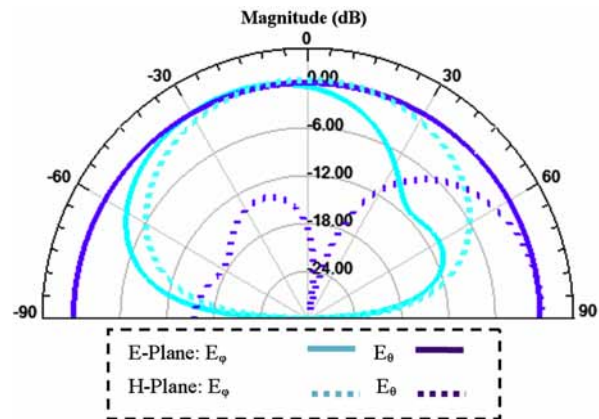

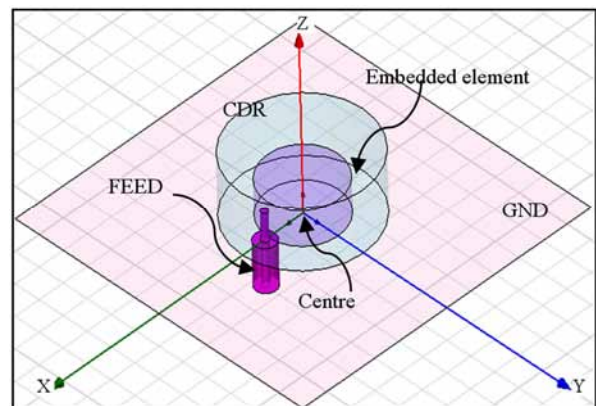**Figure 4. Simulated radiation patterns of the single cylindrical DRA.**

Figure 5. Geometry of the CDRA.

DRA are the same and present broadside looks as shown in **Figure 7**; finally the two antennas behave the same characteristics.

3.3. Antenna Composed by Two DRA Delta $\neq$ 0

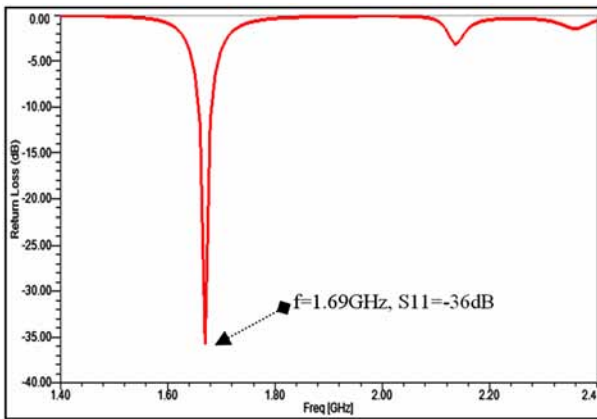In this section, we provide some insight into dual-band

Figure 6. Computed return losses of the CDR antenna against frequency. a_1 = 12.65 mm, a_2 = 7, 3 mm, d_1 = 9.6mm, d_2 = 5.6 mm, ρ = 11.75 mm, h = 3 mm.
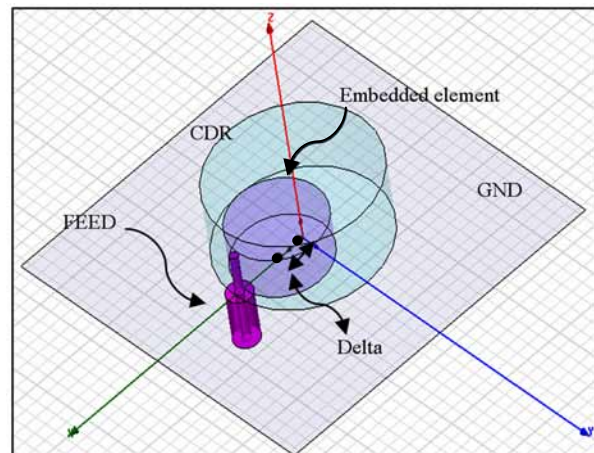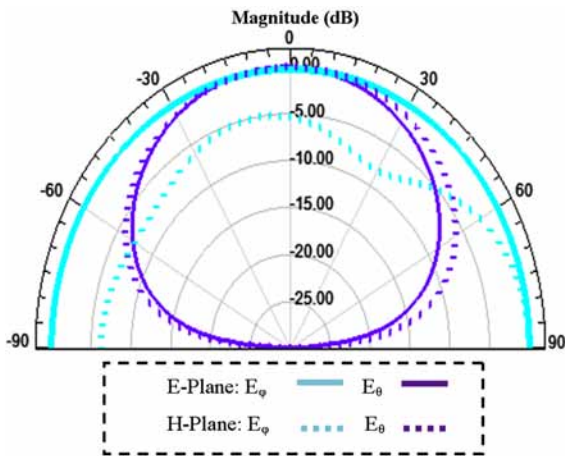

Figure 8. Geometry of the CDRA.

behaviour. For this purpose, two cases are studied [8-10].

First, see the impact of varying only the distance "Delta" between the two cylindrical centre is varied from 1 mm to 5.35 mm (a_1-a_2) as shows in **Figure 8**, In the second case we keep the same configuration and the permittivity of the host cylindrical DR is fixed (ζ_{r1} = 36.7) while that ζ_{r2} of the embedded element is varied from 30 to 90 with step equal to 10.

The **Figure 9** and **Figure 10** show the return losses for these two cases. In case 1, as shown in **Figure 9**, when the cylindrical resonators are offset by Delta ≠ 0, it appears more resonance peaks. This phenomenon seems to prove that this configuration of dielectric resonators behaves either as an equivalent resonator "Delta = 0", but as two different singles resonators.
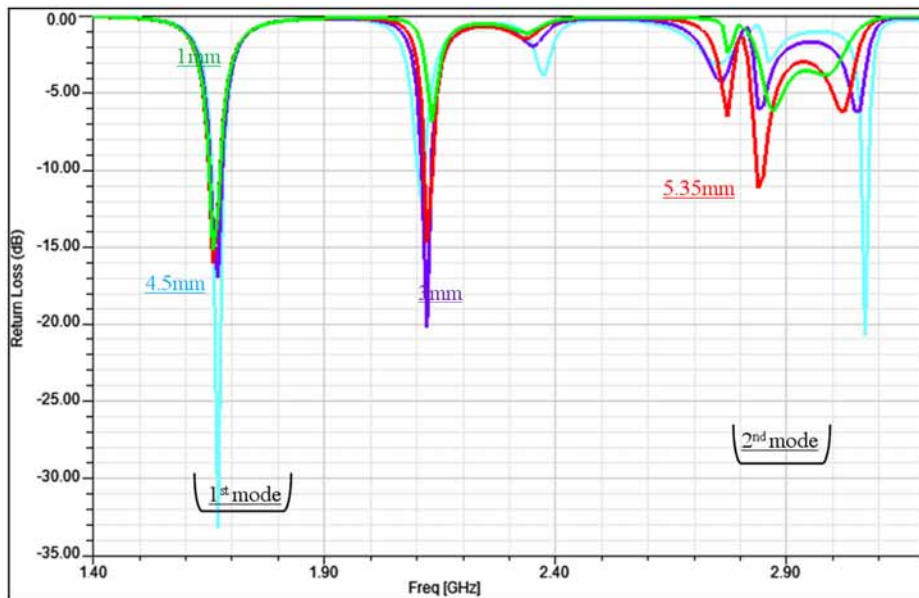

Figure 7. Simulated radiation patterns of the double CDRA.

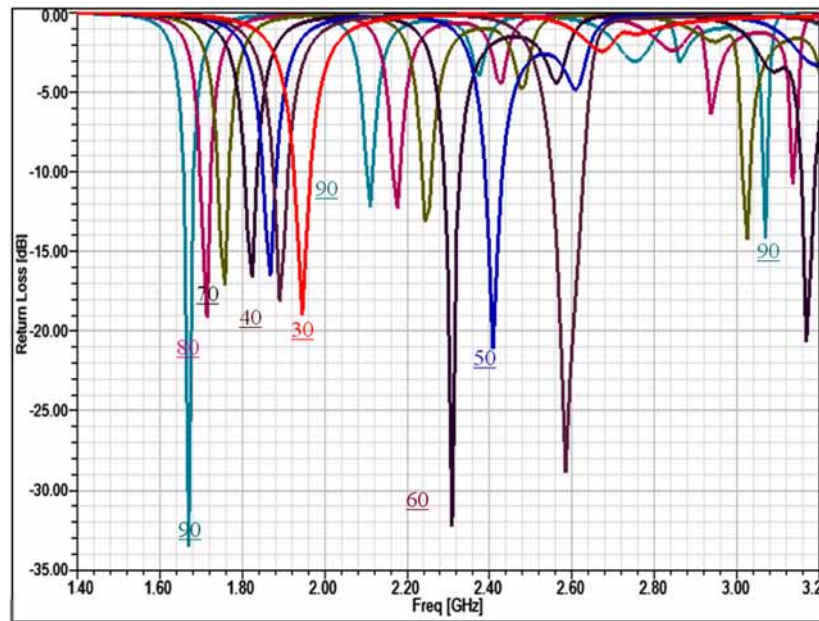**Figure 9. Effect of varying Delta from 1 mm to 5.35 mm.**

Figure 10. Effect of varying embedded element permittivity (ζ_{r2}) from 30 to 90.
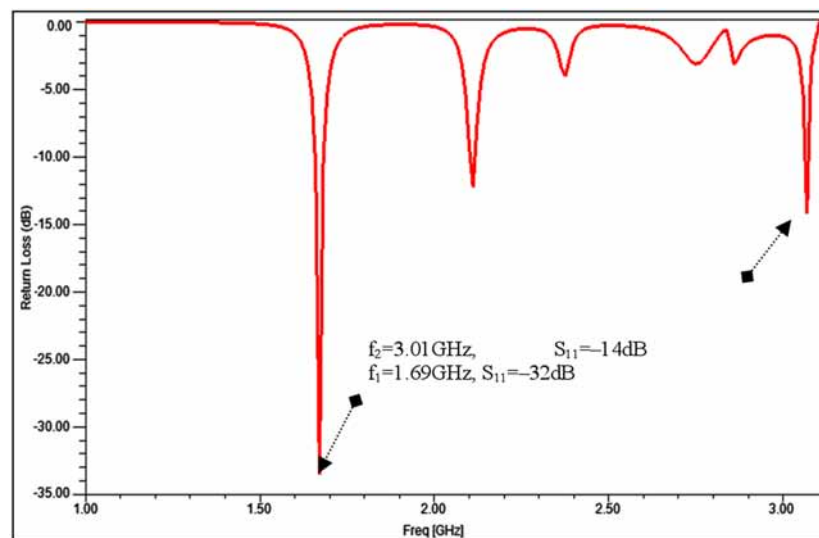

Figure 11. Computed return losses of the CDR antenna against frequency. a_1 = 12.65 mm, a_2 = 7, 3 mm, d_1 = 9.6 mm, d_2 = 5.6 mm, ρ = 11.75 mm, h = 3 mm, r = 0.65 mm, GND = 75 × 75 mm.

In effect, by increasing Delta and feed the internal resonator the fields' lines are forced not to behave a display as a single resonator.

This structure has now two frequencies modes with a maximum radiation diagram in the axis ($\theta = 0°$) of which the first frequency is lower than the external resonator and the second is greater than that embedded resonator. In addition to this second mode, it aparts a mode whose caused a hollow in axis ($\theta = 0°$) of radiation pattern at f_2 = 2.1 GHz [9].

When Delta increases the second mode becomes more adapt, and the radiation diagram over the two planes becomes dissymetrical. So it is important to choose the medium delta to keep the ideal performance.

For Delta = 4.5 mm the CDRA embedded present a good adaptation (low S_{11}) at resonate frequency (**Table 1**) the 1st mode is at 1.69 GHz and 2nd mode at 3.07 GHz.

Second, **Figure 10** shows that when the dielectric constant of the embedded element decreases, the two resonance frequencies are increased at different rates. The

optimized wideband performance is obtained with ζ_{r2} = 90, where two resonances are close to each other. It is noted that the two bands are further apart as ζ_{r2} become small so the gap between the 1st mode and the second become large; it means that the permittivity of the embedded element should be chosen according to the requirement application and the dual resonances can be achieved by adjusting the feed dimensions and delta length and the permittivity of the antenna.

In short, the arrangement of two resonators in which the smallest is inserted in the largest leads to a dual-frequency behavior; the geometrical characteristics of the antenna control performance. Thus, distance between the centers of the resonators affects the adaptation, the permittivity mainly affect the resonant frequencies; Indeed, in some configurations, radiation patterns are significantly altered. In addition, a compromise must always be defined between the simultaneous adaptation of both bands and the spacing between the bands and the purity of radiation patterns [7-9].

Finally the **Figure 11** and **Figure 12** shown the return loss and radiation pattern respectively of the embedded CDRA whit Delta = 4.5 mm and ζ_{r2} = 90.
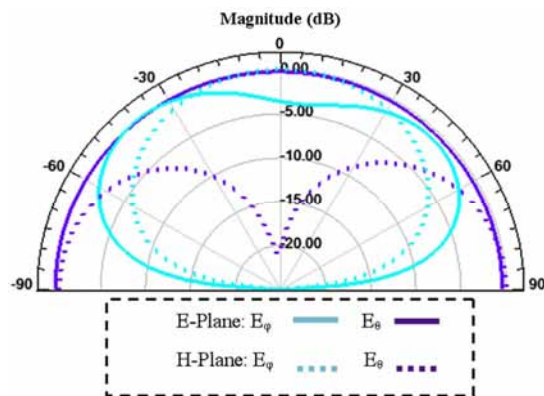

Figure 12. Simulated radiation patterns of the single CDRA.

4. Conclusions

A new dielectric resonator antenna has been proposed in this work; parametric studies have been realized to see the impact on the resonance frequencies. The results have shown that by embedded the dielectric antenna resonance frequencies have been reduced compared to the single DR antenna. Otherwise good performances have been obtained. The embedded structure was achieved using coaxial probe feeding comprise two resonators inserted one into the other revealed dual-band behavior.

The proposed antenna can be used for UHF and/or DCS 1900 applications with a wide bandwidth and a good efficiency.

5. References

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