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Wideband Vertical T-shaped Dielectric Resonator Antennas Fed by Coaxial Probe

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Abstract— Two vertical T-shaped dielectric resonator antennas (DRA) are designed and simulated using two 3D electromagnetic simulators: HFSS and CST MWS. The simulated results for these designs reach an impedance bandwidth of 70%. Moreover, in the second design the ground plane is sitting directly underneath the DRA; and a probe is passing through a circular aperture that is created in the ground plane at the top side of the substrate to excite the DRA. The simulated peak gain shows notable increment within the operating band and reaches 8 dBi with stable value. By using this feeding method, the cross polarization level is reduced within the operating band; and the overall size of the DRA is reduced by (16.2%). Moreover, both software show excellent agreement in the simulated results.

Keywords— Coaxial probe, Dielectric resonator antennas, Low cross polarization level, Size reduction, Wideband antenna.

I. INTRODUCTION

Dielectric resonator antenna (DRA) is fabricated from a high-relative permittivity (from about 6 to 100) low loss dielectric material [1]. Dielectric resonator antennas DRAs have several advantages which make them a good choice for wireless communication systems, especially if a small size antenna is required. Such advantages of the DRA as wider impedance bandwidth, higher gain, avoidance of surface waves and high radiation efficiency are more than those of the microstrip antennas [2]. Dielectric resonator antenna (DRA) can be excited by different excitation mechanisms. The applied feeding method and the position of the feeder with respect to the DRA will determine the coupling level to the DRA, resonant frequency, impedance bandwidth, gain and the radiation pattern [3]. Each feeding or excitation method has its advantages and disadvantages. The intended application will determine which one to apply. The most important factor when selecting the appropriate feeding method is the matching between both the feeder and the DRA. When a better matching is obtained, the reflection between the port and the feeder will be small. So, more effective power transfer to the DRA is achieved [3]. Coaxial feeder is the most common method for exciting the DRA. This method has the advantage that there is no need for matching network to match to 50-Ω system. The coupling level is determined by the probe position and height with respect to the DRA [4]. The probe position could be drilled in the DRA or at the side of the DRA. Also, the probe could be attached to a metallic strip to achieve higher bandwidth [5]. Many papers introduced different designs for DRA with a coaxial feeder. In [6], a rectangular DRA (RDRA) was designed. It was fed by a coaxial line, where the inner conductor of the coaxial cable was connected to the DRA through a trapezoidal shape metallic strip. The relative permittivity of the DRA was (ϵ_r=10.2); the operating frequency range was from (4.5-7) GHz, which is about 43.5% bandwidth. A P-shaped DRA was designed in [7] and fed by a coaxial probe drilled inside the DRA. The relative permittivity of the DRA was (ϵ_r=6.15). This design covers the

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frequency band from (4.5-9.3) GHz. The thickness of this P-shaped DRA was 10 mm. In [8], a high gain mushroom-shaped DRA was designed to cover the frequency band from (4.6-9.1) GHz, that is equivalent to 65% bandwidth. This design gave a very high gain which was up to 14 dBi. However, the size of this design was relatively large since the total height was 48 mm; and the substrate had a radius of 55 mm. A rectangular DRA (RDRA) that works as an ultra-wideband and narrowband was designed in [9]; this RDRA was fed by a two-port network. The first band covers (2.4-12) GHz. The other band for this design covers (2.3-4.5) GHz. The RDRA was designed using a relative permittivity material of (ϵ_r=10.2). The height of this RDRA design was 19.1 mm. In [10], a triangular DRA was designed. The proposed DRA was fed by a coaxial probe which was at the edge of the triangular DRA. This design gave 47.7% impedance bandwidth. The relative permittivity for the DRA in this design was (ϵ_r=10); and the height was 19 mm. In [11], an X-band RDRA was presented. The dimensions for this RDRA were (7×13×10.75) mm. This design had an impedance bandwidth of 57.8%.

Many researches were introduced recently in order to enhance the radiation patterns of the DRA. In [12], a rectangular DRA was wrapped by a conducting strip to improve the radiation characteristics for the rectangular DRA. By adding the strip, the cross-polarization level was reduced and the co-polarization radiation pattern was improved. The feeder for this design was a microstrip line. In [13], a linear array of DRA with dielectric image guide (DIG) feeder was designed. By adding a narrow metal strip around the DRA, the cross polarization level decreases by 20 dB.

In this paper, two vertical T-shaped DRAs will be designed and simulated. These designs are fed by a coaxial probe attached to a conducting strip. In the first design, the DRA is placed on the substrate. While, in the second design, the DRA is placed directly on a ground plane and fed by a probe passing through a circular aperture. By using this method, the gain is increased; and the cross polarization level is decreased with no change in the bandwidth. Although the slot aperture method was used in many researches, the interest was focused on the microstrip line feeder since it is widely used in array designs. However, little attention was given to the probe feeder.

II. HFSS AND CST MWS

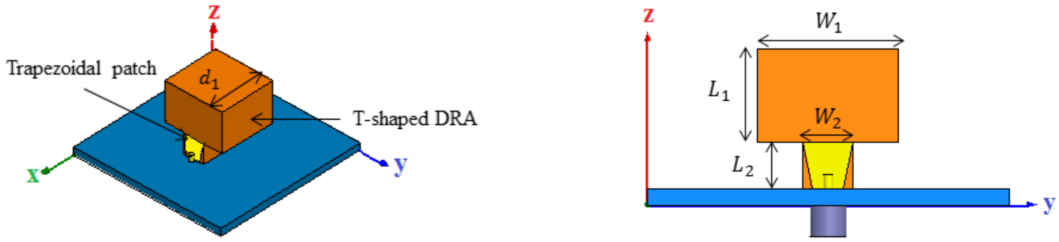
For the simulation, two software will be used to simulate the DRA designs: the high frequency structure simulator HFSS [14] and the CST MWS [15]. The HFSS is a 3D electromagnetic software that is widely used in simulating antennas. The HFSS is a commercial software based on Finite Element Method (FEM). The FEM is a method that depends on solving partial differential equations and subdividing the element into basic shapes. The solution leads to the fields of the element [16]. The first research that used the FEM was in 1968 [17]. The FEM works in the frequency domain. This means that it solves the equations at each assigned frequency. The HFSS is widely used now to simulate different types of antennas such as (patch, DRA, horn and other types). HFSS provides wide simulation results such as bandwidth, gain, VSWR, input impedance, radiation pattern and axial ratio. Many other results could be obtained from it. The CST microwave studio (CST MWS) is also a 3D electromagnetic simulator that is based on Finite Integration Technique (FIT) [16]. The CST offers the properties of using both time solver and frequency solver. The frequency solver works like the HFSS. The time domain solver calculates the broadband behavior of electromagnetic devices with an arbitrarily fine frequency resolution. In recent years, many researches started to use the CST due to its high accuracy and wide purpose usage.

III. Vertical T-Shaped DRA with Trapezoidal Feeder

In this design, a vertical T-shaped DRA is introduced. The DRA is attached to a trapezoidal strip patch which is centered at the lower part of the DRA as shown in Fig. 1.

A) Design Geometry

The FR-4 substrate has dimensions of (35×35×1.6) mm, relative permittivity of (ϵ_r =4.4) and dielectric loss tangent of (tanδ=0.02). The selected material for the DRA is Rogers 3010 with relative permittivity of (ϵ_r =10.2) and dielectric loss tangent of (tanδ= 0.0035). The dimensions for this design are shown in Table 1.



(a) (b)

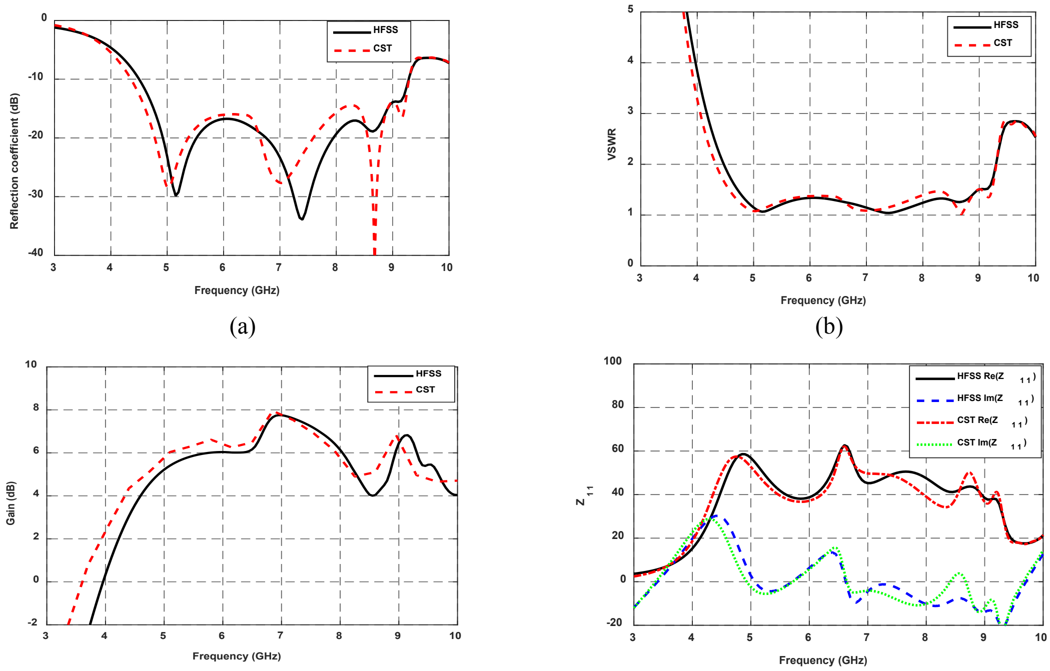
Fig. 1. Geometry of the vertical T-shaped DRA: a) 3D view, b) front view

TABLE 1
DIMENSIONS OF THE VERTICAL T-SHAPED DRA IN (MM)

Parameter	Value	Parameter	Value	Parameter	Value
L_1	9	W_1	13.65	d_1	12.8
L_2	4.5	W_2	4.8	DRA height	13.5

B) Simulated Results

The simulated -10 dB reflection coefficient (or the VSWR value under 2) is achieved for a frequency band from (4.5-9.3) GHz, which is about (70%) impedance bandwidth. A good matching is achieved since more than (85%) of the operating band is under -15 dB reflection coefficient as depicted in Fig. 2a and 2b. Fig. 2c shows the simulated peak realized gain of the proposed vertical T-shaped DRA, which is between (4-8) dBi. The input impedance is plotted in Fig. 2d.

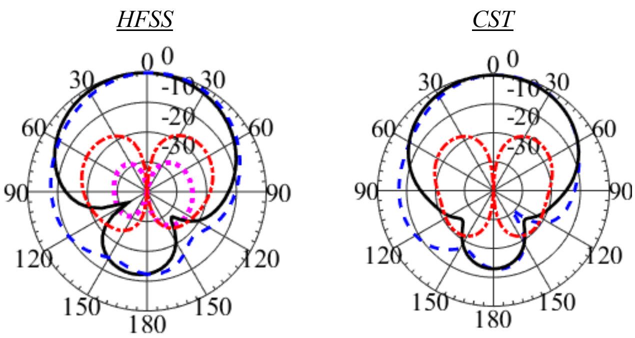


(a) (b) (c) (d)

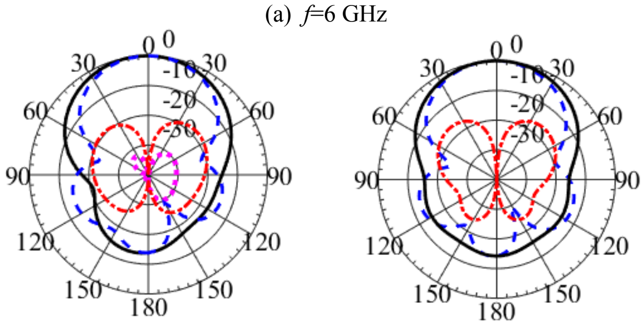
Fig. 2. Simulated results of the vertical T-shaped DRA: a) reflection coefficient, b) VSWR, c) peak gain, d) input impedance

The gain reaches to 8 dBi at *f*=7 GHz, which is considered a very high gain value for a single element. The input impedance Z_{11}, which satisfies input matching through the operating band, is also shown in Fig. 2d, which shows that the real part is around 50-Ω; and the imaginary part is around 0-Ω. In this design, a very good agreement in the simulated results between both HFSS and CST MWS is obtained as the results show.

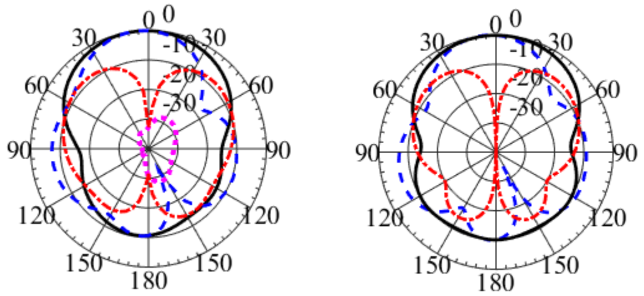
In Fig. 3, the simulated radiation patterns show a low level of cross polarization at the lower frequency band, but it is high at *f*=8 GHz and 8.5 GHz, because of the higher order modes. The cross polarization level at the H-plane is too small in the CST MWS to be visible. But, it is 30 dB less than the co-polarized H-plane according to HFSS which is also a very small value. The radiation patterns show more than 10 dB front to back radiation ratios.



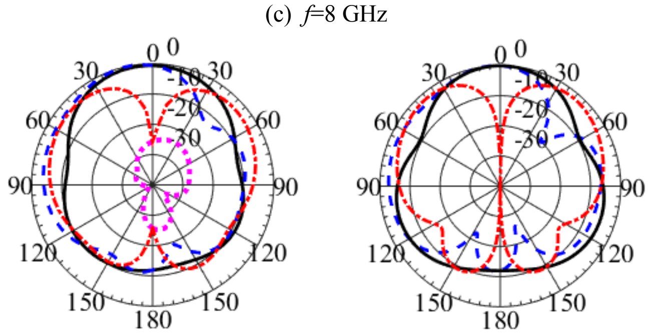
(a) *f*=6 GHz



(b) *f*=7 GHz



(c) *f*=8 GHz



(d) *f*=8.5 GHz

Fig. 3. Simulated radiation patterns for the vertical T-shaped DRA at different frequencies

IV. Vertical T-Shaped DRA Fed by Trapezoidal Strip Mounted Directly on the Ground Plane

In this design, the ground plane is directly underneath the T-shaped DRA, and on the top side of the substrate. The probe is then attached to a trapezoidal patch through a circular aperture which is created in the ground plane as shown in Fig. 4a and 4b. On the back side of the substrate, another circular ground plane is around the probe as shown in Fig. 4c.

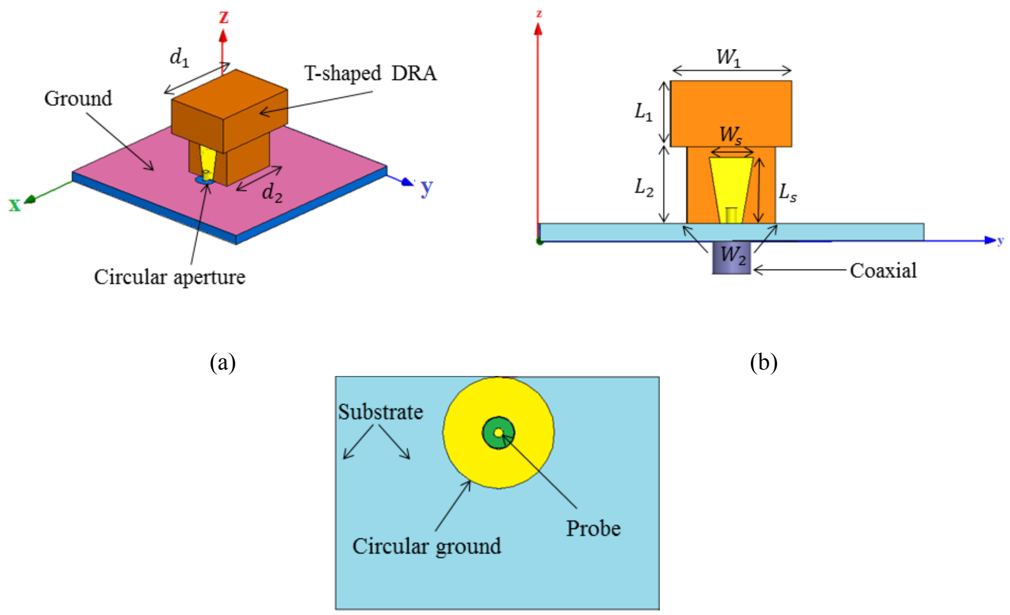
A) Design Geometry

In Fig. 4, the DRA is centered at the FR-4 substrate with dimensions of (35×35×1.6) mm. The DRA is positioned directly above the ground plane, while a circular ground plane is at the back side of the substrate, with 6 mm radius.

The selected material for the DRA is Rogers 3010 with relative permittivity of (ϵ_r =10.2) like in the first design. Table 2 describes the dimensions of the vertical T-shaped DRA which is mounted directly on the ground plane.

TABLE 2
DIMENSIONS OF VERTICAL T-SHAPED DRA MOUNTED ON THE GROUND PLANE IN (MM)

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
L_1	6	W_1	11	Ground radius	6	d_1	15
L_2	7	W_2	8	aperture radius	1.65	W_s	4
L_s	6	d_2	10	DRA height	13	----	----



(a) (b)

(c)

Fig. 4. Geometry of the T-shaped DRA mounted directly on the ground plane: a) 3D view, b) front view, c) bottom view

B) Simulated Results

The simulated -10 dB reflection coefficient is achieved in a frequency band (4.6-9.6) GHz, which is about (70%) bandwidth as shown in Fig. 5a. This is equivalent to the obtained bandwidth in the previous T-shaped DRA. Also, the VSWR is plotted in Fig. 5b. Fig. 5c shows the simulated peak realized gain of the proposed design, which is between 5 and 8 dBi in the operating band. Gain values show increment at certain frequency values within the operating band compared with the previous design.

The input impedance Z_{11}, which satisfies the input matching through the operating band, is also shown in Fig. 5d.

The simulated radiation patterns show a low level of cross polarization within the band as shown in Fig. 6. Unlike the previous vertical T-shaped DRA, this design has a low cross polarization level even at *f*=8 GHz and 8.5 GHz. Radiation patterns show more than 10 dB front to back radiation ratios.

Table 3 compares the proposed DRAs in this paper with previous designs of the DRA that used the coaxial probe to excite the DRA. The proposed designs achieved a wideband compared with other designs. Also, the proposed designs gave higher peak realized gain values. Another important parameter is the low cross polarization level. Moreover, the total size of the second design was only 1550 mm^3, while it was 1848.9 mm^3 for the first design where a size reduction of (16.2%) was achieved. If the DRA is designed to work at the lower frequency range, then the size of the DRA should be larger or the relative permittivity of the DRA should be higher [18]. But, in this paper, the material of the DRA is kept the same in the two designs; and the size was reduced while the frequency range remained the same. Also, the radiation patterns were enhanced at the end of the band.

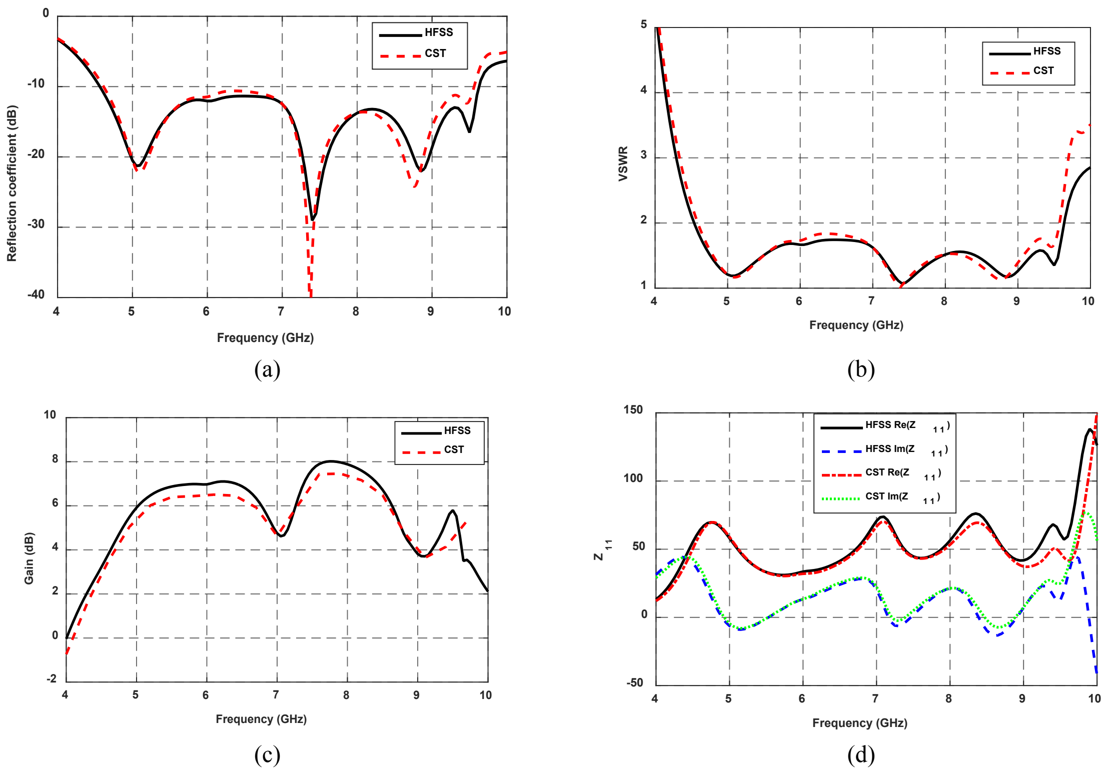


Fig. 5. Simulated results of the vertical T-shaped DRA mounted on the ground plane: a) reflection coefficient, b) VSWR, c) peak gain, d) input impedance

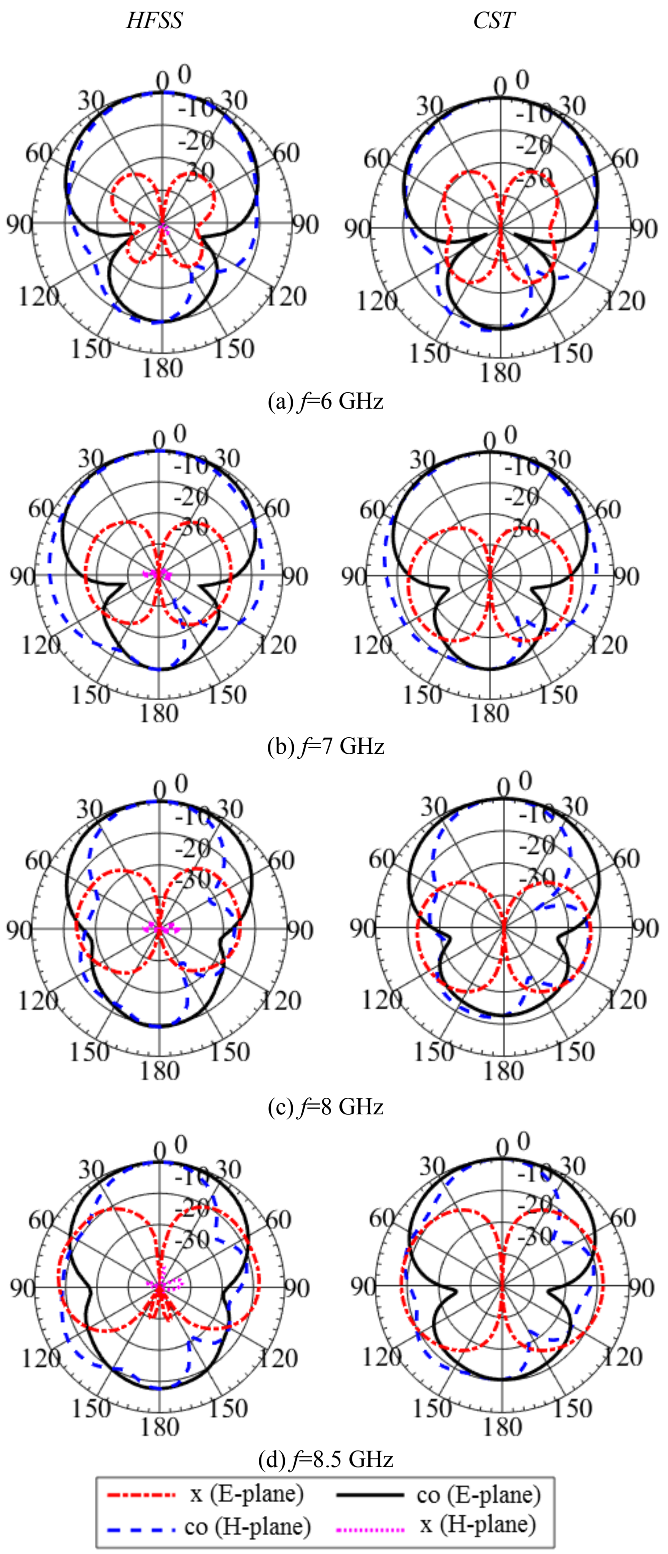


Fig. 6. Simulated radiation patterns for the vertical T-shaped DRA mounted directly on the ground plane at different frequencies

TABLE 3
COMPARISON BETWEEN THE PROPOSED DRAS DESIGNS AND PREVIOUS DESIGNS

Ref #	DRA Shape	DRA (ϵ_r)	Substrate Dimensions, mm^2	DRA Height, mm	Frequency Range, GHz	BW%	Gain, dBi
6	Rectangular	10.2	30×30	18.3	4.5-7	43.5	Not mentioned
7	P-shape	6.15	16×18	10	4.5-9.3	65	2.4
8	Mushroom	3 & 4	110 mm (diameter)	48	4.6-9.1	65	10-16
9	Rectangular	10.2	150×150	19.1	2.3-4.5 2.4-12	64.7 133.3	6 4-7
10	Triangular	10.2	140×140	19	4.33-7.02	47.7	4-7
11	Rectangular	9.8	7×13	10	8-14.5	57.8	3.4-7.7
1st design	T-shape	10.2	35×35	13.5	4.5-9.3	70	4-8
2nd design	T-shape	10.2	35×35	13	4.6-9.6	70	5-8

V. CONCLUSIONS

In this paper, two DRAs fed by coaxial probe were designed and simulated by two 3D electromagnetic simulators. The proposed designs achieved a wide bandwidth and stable gain value with a low cross polarization level compared to other DRA designs that use the probe as a feeder. The first vertical T-shaped DRA design covered 70% impedance bandwidth; and the ground was at the bottom side of the substrate. Another T-shaped DRA was then designed; and the ground plane was assigned directly underneath the DRA. A small circular ground plane was assigned at the bottom side of the substrate and around the coaxial itself. By using this feeding method on the vertical T-shape, the gain value was increased; and a reduction in the cross polarization level was achieved. Also, a notable reduction in the DRA size was achieved. A good agreement between HFSS and CST MWS was obtained in the simulated results.

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