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MULTI-FEED DIELECTRIC RESONATOR ANTENNA WITH RECONFIGURABLE RADIATION PATTERN

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Abstract—This paper describes a steerable broadband dielectric antenna with 30% fractional bandwidth, operating at 11 GHz. The structure consists of a hollow cylindrical dielectric pellet of permittivity 6 fed by four probes. Two methods are described for beam forming: 1- Beam forming has been achieved by individually switching between excited probes. The switched excitation mechanism provides the antenna with a reconfigurable radiation beam that can be moved in the azimuth plane. 2- Variable phase excitation of several probes. Complete azimuth sweep was demonstrated by both methods, allowing any desired angle of beam directions. Simulation and experimental results are presented to illustrate the advantages of both designs.

1. INTRODUCTION

The commercial pressure of ever higher data rates and increases in user density are driving the antenna design for mobile wireless communicators to have wide-band response with spatial ability. Newer services, such as WiFi and ultra-wide band are moving into higher frequency bands to allow greater channel capacity. Furthermore isolation by spatial agility in the same frequency bands make them suitable candidates for MIMO (multiple input multiple output antennas) [1]. As the frequency increases, conductivity and surface wave losses in patch antennas increase [2–6]. Whereas dielectric antennas, off course, have no conductivity losses and dielectric losses. There are a range of low loss dielectric materials making them an alternative to conductive antennas.

Dielectric Resonator antennas have useful properties such as compact size [7], broad bandwidth [8, 9]; low profile [10], and high radiation efficiency [7–11]. DRAs with novel excitation mechanisms have been reported in literature to achieve wide bandwidths [12–16]. These describe antennas of dielectric material mounted on a ground plane with probes located either outside or inside the dielectric material itself. Air gaps cause changes in both resonant frequency and impedance levels; especially if the structure is designed for X-band frequencies or higher and the volume of the dielectric is small [17–20]. By using liquids; the authors in [16] avoid air gap losses. Air gaps usually have undesirable effects on the characteristic impedance of the antenna, and some techniques have been published to compensate those effects in [11].

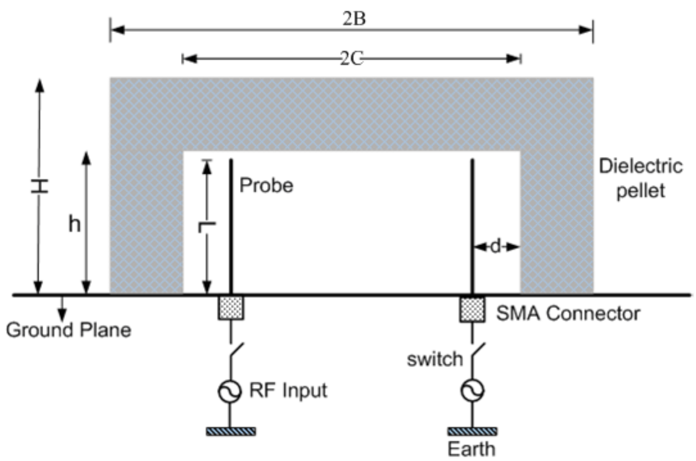
Beam-steering of a single antenna element can be achieved using several techniques such as: In [21], authors reported a novel patch antenna with switchable slot; switching between slots alter the current feed distribution in the antenna, thereby switching the beam. Authors in [22] designed a switched beam-planar fractal antenna. Simulated and measured results in this paper showed that a two switchable directional pattern can be achieved by changing the connection states of the switches within the antenna. Beam-steering of dielectric antennas was achieved by switching between probes within a dielectric [23, 24], however, [23] did not publish the radiation patterns. Researchers in [25, 26] have used two probes to produce circularly polarized radiation from cylindrical dielectric resonator antennas.

The concept of using several probes with the idea of using a hollow cylindrical dielectric pellet to increase the bandwidth reported in [27] is further developed in this paper. To the authors' knowledge there is no previously published work on this configuration of dielectric antennas. In the following sections, we will present the antenna configuration, measurement and simulation results using Ansoft HFSS package, followed by a discussion.

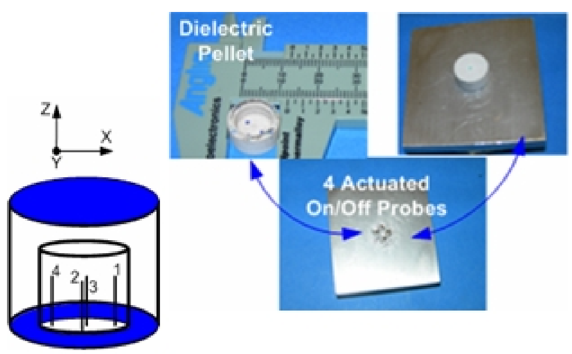
2. ANTENNA CONSTRUCTION

To avoid machining the dielectric material to accommodate the probes, authors in [16] used water as the dielectric medium. A liquid dielectric will eliminate any air gaps between the dielectric material and the inserted probes; however, liquid dielectrics are lossy at these frequencies. In this work, the authors introduce the concept of a cylindrical cup covering four probes in air to switch the beam. The azimuth radiation pattern of the antenna was manipulated by exciting different individual probes while leaving the other probes open-circuited.

The antenna presented comprises of hollow cylindrical dielectric resonator antenna fed by four orthogonally positioned probes. Figures 1(a) and 1(b) shows the side view and 3D view respectively of the proposed antenna. The dielectric pellet has a relative permittivity of 6, inner radius 'C' of 4.6 mm ($0.17\lambda_0$) and outer radius 'B' of 6.6 mm ($0.24\lambda_0$). The inner height 'h'' was 3.9 mm ($0.14\lambda_0$) and the outer height 'H' was 6.8 mm ($0.25\lambda_0$). Four gold electrodes of radius 0.653 mm and height 'L' 3.88 mm extended into the hollow cylinder to achieve 50 Ω matching impedance. The antenna was mounted on a 5.5 * 5.5 cm ground plane. The four probes were located on a radius of distance 'd', 1.6 mm, from the centre of the electrodes to the inner surface of the cylinder.



(a)



(b)

Figure 1. Schematic diagram and a snap shot of the proposed dielectric antenna. (a) Side-view of the proposed antenna. (b) 3D view of the antenna.

3. SIMULATION VERSUS EXPERIMENT

The design was modeled and optimized in Ansoft HFSS. To verify the simulated results, the physical antenna return loss was measured by an HP8720B vector network analyzer. The simulated results show good agreement with the measured results, Figure 2. The simulated 10 dB return loss bandwidth is 36% compared to the measured value of 32%. All results presented in this section are for one excited probe while the other probes were kept open-circuited.

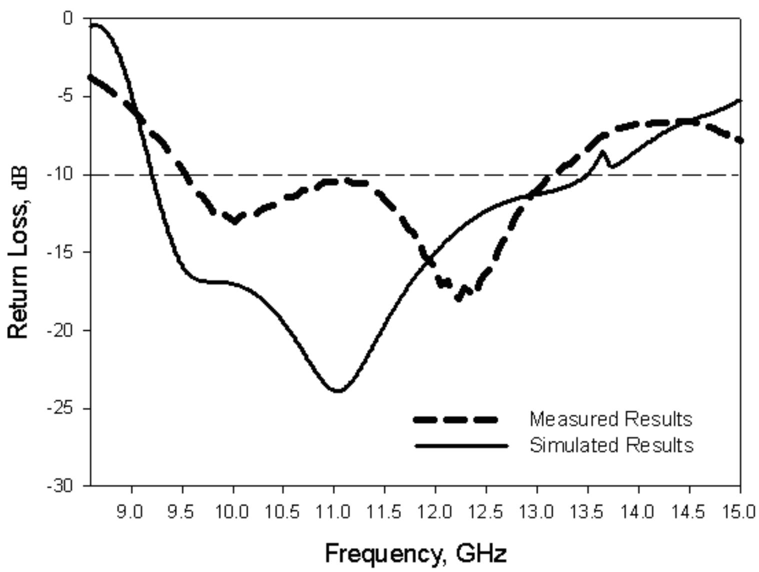


Figure 2. Measured versus Simulated Results when only one probe was excited, other probes are open circuit.

The difference between the measured and simulated results is not great. The mechanical stiffness of the ceramic material made tight tolerances difficult to achieve in manufacture; thus creating air gaps between the antenna and the ground plane. Air gaps reduce the effective dielectric constant of the whole structure; and thereby results in a higher resonant frequency; this is seen in the measured curve of Figure 2. Moreover the antenna resonance also depends on the length of the probe. Figure 3 shows the simulated return loss for different probes' dimensions. It is evident from this figure that small changes of the probe length can significantly affect the resonant frequency providing further explanation on the differences between measurement and simulation. Another study was undertaken to study the effect of the probe diameter on the return loss characteristics. However, Figure 4 shows that varying the diameter 's' of the excited probe has little effect on the fractional bandwidth of the antenna although there is a slight shift in resonant frequency of $\sim 750\,\mathrm{MHz}$.

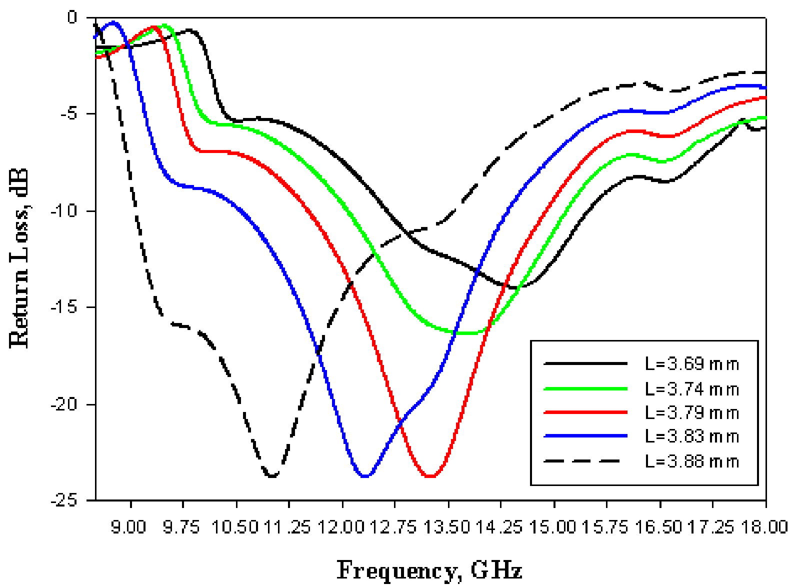


Figure 3. Simulated return loss characteristics versus different probe's length.

4. SWITCHING BETWEEN INDIVIDUAL EXCITED PROBES

For brevity we show the simulated results for far field radiation pattern in the H-plane at 9.53 GHz and 11.1 GHz. Figure 5 and Figure 6 shows that the far field radiation pattern change at two different frequencies (9.53 & 11.1 GHz) in the H-plane when probes 1 and then 2 were activated with the other probes open circuit.

Figure 7 and Figure 8 shows the simulated 3D far field radiation pattern when probes 4 and 2 were activated respectively while other probes were open-circuited, $f = 9.53\,\mathrm{GHz}$ & $f = 11.1\,\mathrm{GHz}$.

Figures 5–8 clearly demonstrates that beam steering is achievable by exciting different probes within a dielectric medium where other probes are open-circuited.

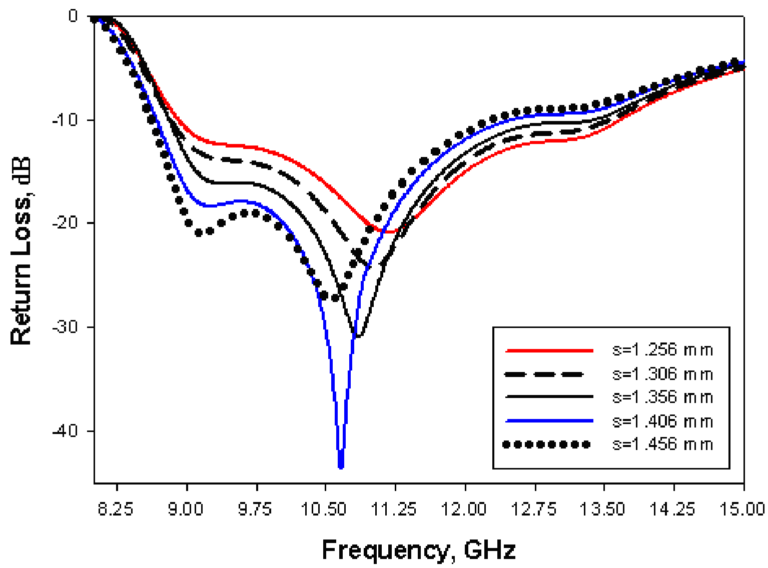


Figure 4. Simulated return loss characteristics versus different probe's diameter.

5. BEAM FORMING BY CONTROLLING THE PHASE OF THE EXCITED PROBES

The second method to reconfigure the radiation was achieved by feeding power to all (4) excitation probes shown in Figures 1(a) and (b). Beaming steering was achieved by controlling the relative phase between the excited probes. This technique was reported in [28] to steer the radiation pattern of microstrip antennas; however, to the authors knowledge, no previously published work has been reported on applying the same technique on dielectric antennas. In this work diametrically opposite probes are driven in phase opposition. Changing the relative phase between the drive pairs generates the principle radiation controlled by that phase difference. Plan view of the antenna and the probes located number is shown in Figure 1(b).

Figure 9 shows the return loss of the antenna when four probes were excited. Simulation using Ansoft HFSS has been carried out to verify that the antenna pattern can be manipulated using the concept of phase switching.

Table 1 shows beam direction of the antenna versus the phase switching scheme that has been used for each port. Figure 10 demonstrates some of the simulated radiation pattern of different case

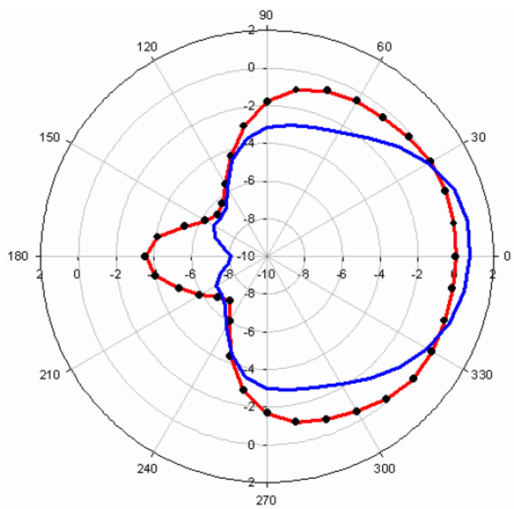


Figure 5. Far field radiation pattern in the H-plane when probe 1 is activated; blue solid line represents the far filed at $f = 9.53\,\mathrm{GHz}$; red scatter line represent the far filed at 11.1 GHz.

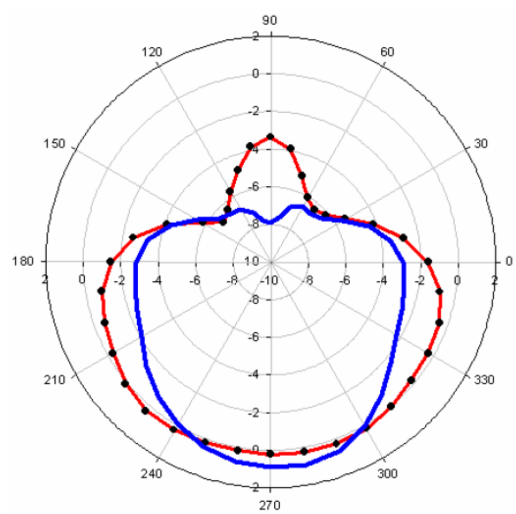


Figure 6. Far field radiation pattern in the H-plane when probe 2 is activated; blue solid line represents the far filed at $f = 9.53\,\mathrm{GHz}$; red scatter line represent the far filed at 11.1 GHz.

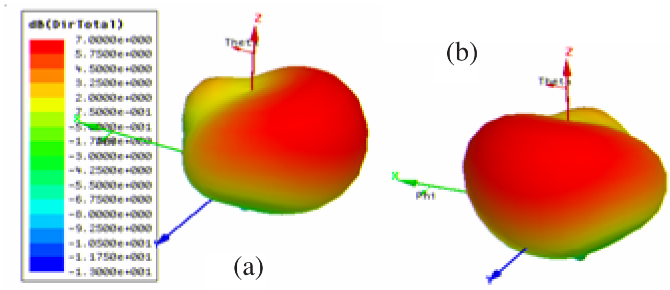


Figure 7. 3D-far field radiation plot for two different activated probes ($f = 9.53\,\mathrm{GHz}$); (a) probe 4 is being activated; (b) probe 2 is being activated.

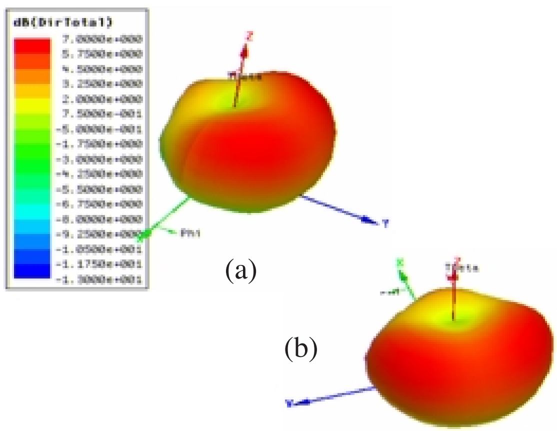


Figure 8. 3D-far field radiation plot for two different activated probes ($f = 11.1\,\mathrm{GHz}$); (a) probe 2 is being activated; (b) probe 4 is being activated.

studies presented in Table 1. The operating frequency was set to 10 GHz when the data in Table 1 and Fig. 10 was collected.

It is clearly seen from Table 1 and from Figure 10 that the main beam of the antenna can be manipulated by controlling the phase of several ports fed into the dielectric pellet.

Another study was undertaken to study the effect of changing the phase on the radiation pattern but with different operating frequency, $f = 12\,\mathrm{GHz}$. Table 2 illustrates the different case studies. Figure 11 demonstrates the simulated radiation pattern for the case studies presented n Table 2.

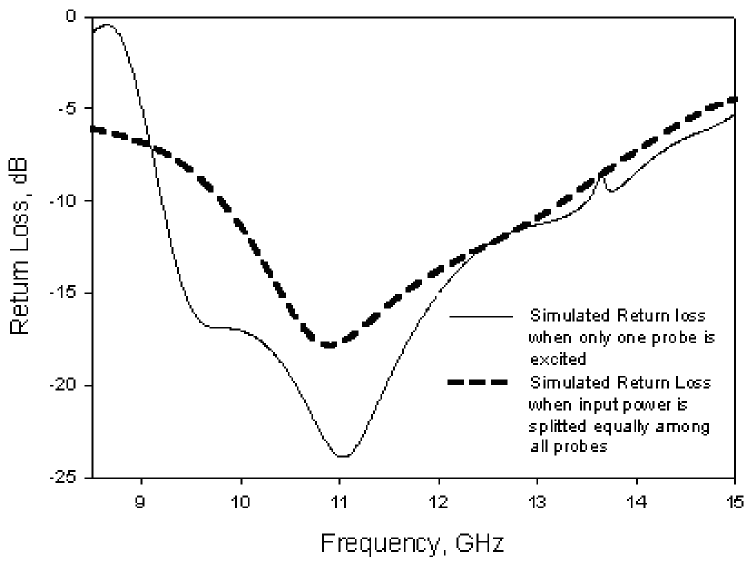


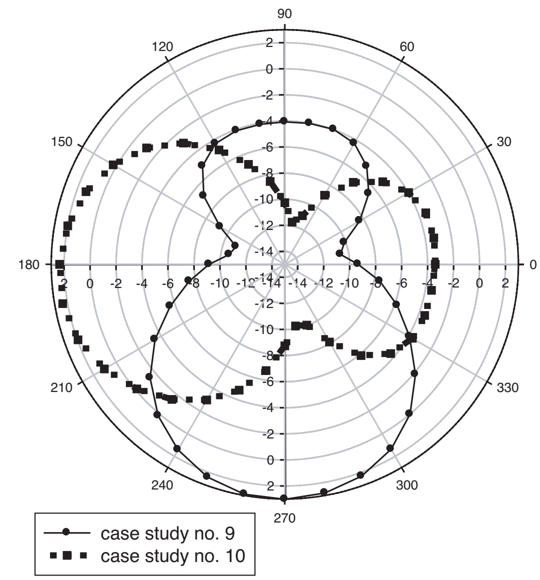
Figure 9. Simulated return loss of the antenna when 4 probes were excited versus the simulated return loss when only one probe was excited.

6. DISCUSSION

Removal the central part of a low permittivity ceramic pellet is the main contributor to the wide bandwidth of this antenna. Removing the central part reduces the effective dielectric constant of the structure which results in lowering the quality factor of the antenna, thus increasing its bandwidth. (The quality factor of dielectric antennas is an important figure for the performance of these types of antennas. It is defined as the ratio of the oscillating power over dissipated power. For a dielectric antenna, the dissipated power is the sum of the radiated power, power dissipated in dielectric losses, in addition to the power dissipated in the metal electrodes [29]).

There are two main resonances of the antenna, Figure 2 (measured results, $f1 = 10\,\mathrm{GHz}$ and $f2 = 12.3\,\mathrm{GHz}$). This may be explained because the structure looks like two different DRAs stacked on top of each other. The inner cavity has a low dielectric constant of 1 upon which is stacked another dielectric of permittivity 6. The higher resonance results from the air cavity where the dielectric constant is lower, and the lower resonance results from the dielectric pellet itself.

The use of switched excitation probes coupled with the field concentration in the nearby dielectric gives the ability to change the



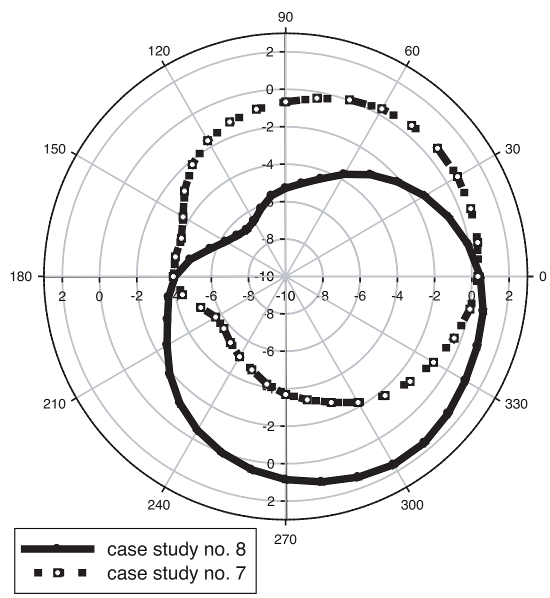


Figure 10. Simulated radiation pattern in the H-plane due to different case studies presented in Table 1.

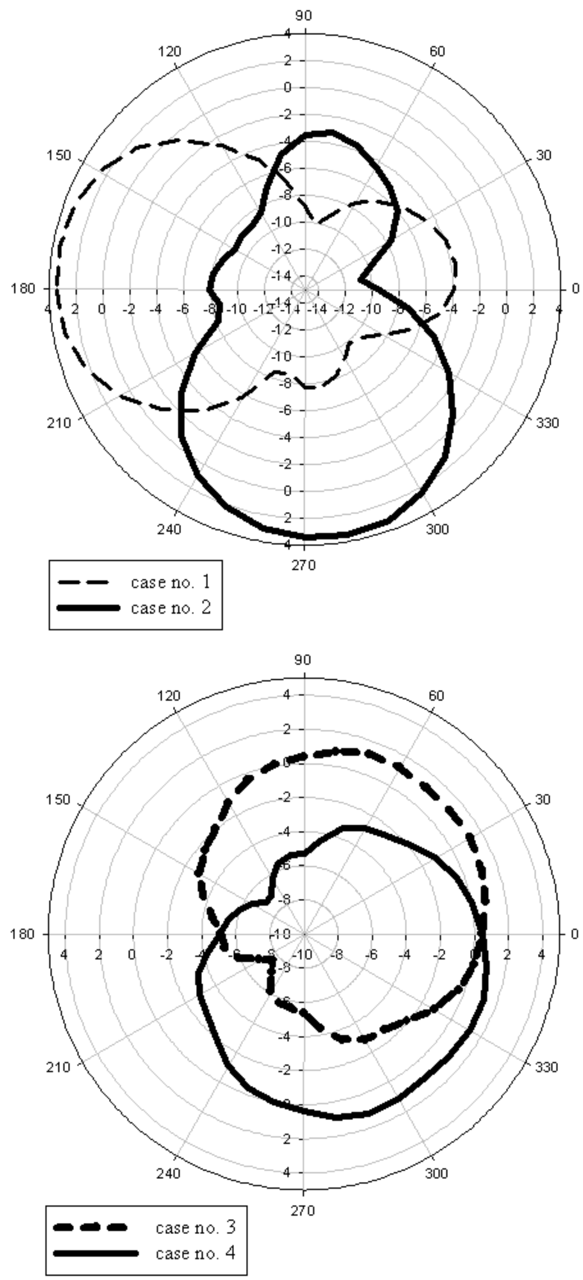


Figure 11. Simulated radiation pattern in the H-plane for the case studies presented in Table 2.

Table 1. Beam direction versus different feed phases; $f = 10\,\mathrm{GHz}$.

Case Study no.	Port no.1 Feed phase (in degrees)	Port no.2 Feed phase (in degrees)	Port no.3 Feed phase (in degrees)	Port no.4 Feed phase (in degrees)	Beam direction
1	0	0	0	0	Omni-directional
2	0	180	0	0	270
3	0	0	180	0	90
4	0	0	0	180	0
5	180	0	0	0	180
6	45	45	0	0	225
7	0	0	45	45	45
8	0	45	0	45	315
9	0	180	45	0	270
10	180	0	0	45	180
11	0	220	0	0	90 and 270

Table 2. Beam direction versus different feed phases; $f = 12\,\mathrm{GHz}$.

Case Study no.	Port no.1 Feed phase (in degrees)	Port no.2 Feed phase (in degrees)	Port no.3 Feed phase (in degrees)	Port no.4 Feed phase (in degrees)	Beam direction
1	180	0	45	0	180
2	0	180	0	45	270
3	0	0	45	45	45
4	0	45	0	45	315

current field distribution pattern, thereby steering the main beam of the antenna. By viewing the field distribution inside the dielectric pellet one can qualitatively predict the radiation pattern. A snap shot of the magnetic field intensity was taken in a cut through the dielectric pellet, Figure 12. The cut was placed across the dielectric pellet but above the exciting probes by 1 mm. Figure 12 reveals the H-field vector distribution when probe 4 was activated; $f = 9.53\,\mathrm{GHz}$. This shows that by activating different probes individually, one can manipulate the field distribution. The shift in electric field caused by actuating a probe in a different quadrant allows the radiation pattern to rotate

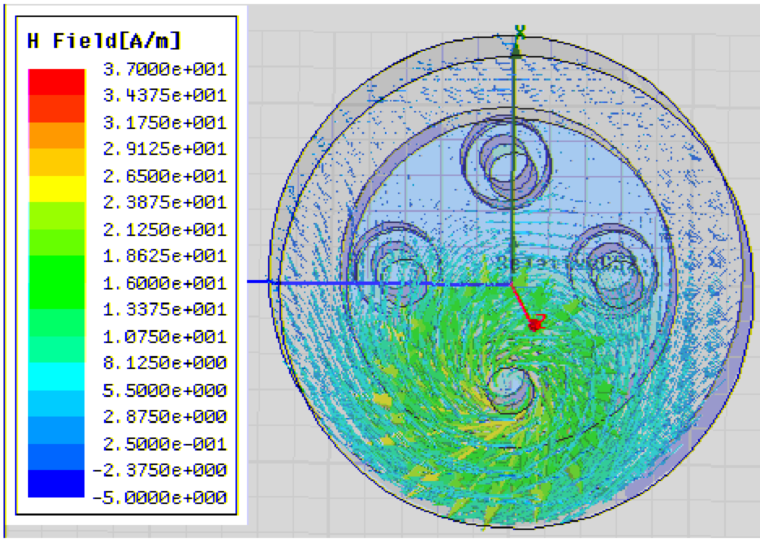


Figure 12. H-field vector distribution in the dielectric pellet, $f = 9.53\,\mathrm{GHz}$ (single probe was excited).

through 360° in the azimuth plane.

Figures 10 and 11 clearly demonstrated that a reconfigurable pattern can be achieved by phase switching. Changing the phase of excited ports alters the current field distribution in the dielectric material, thereby beam steering. Advantages of using both techniques is the ability to manipulate the radiation beam of a dielectric antenna using only one dielectric element. Both techniques are efficient; however, the first method is more practical than the second one. The second approach requires the involvement of more electronic circuits; furthermore, it has a higher insertion loss than the first one since the input power passes through power dividers and phase shifters. Moreover; because the antenna is broadband and the excitation of each probe is varied with operating frequencies, this could affect the radiation pattern and its directivity, see Figures 10 and 11. The radiation pattern in the second technique is frequency/phase dependent. Therefore, the first approach is more likely to be used in practical applications.

Though the antenna described in this paper has been shown as a cup-dielectric structure, however, the antenna may have any other cross sections, such as circular or square.

7. CONCLUSION

A new pattern reconfigurable dielectric antenna is presented to demonstrate the capability of beam steering by either switching between individual probes, or by controlling the phase of the excited probes. Simulated results show that the two techniques are capable of steering the far field radiation pattern in the azimuth plane through 360 degrees. The paper has shown that beam agility and wide-bandwidth are achievable in one antenna design. Future work will focus on designing phase switching circuits to control the phase of the excited probes, and on measuring the radiation pattern of both designs.

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