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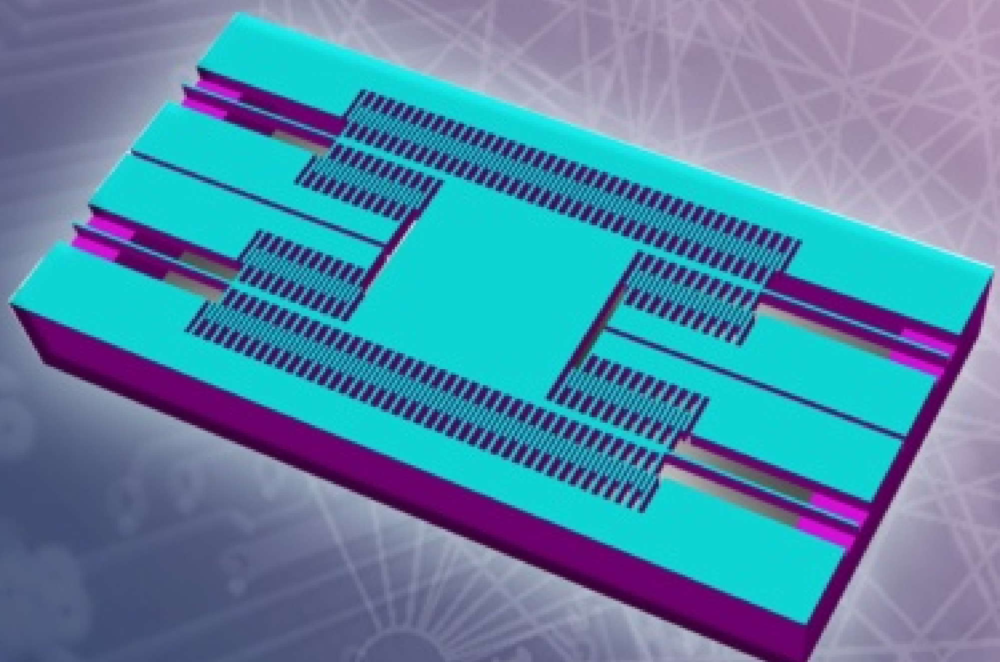

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Experimental Study on a Directional Cylindrical Dielectric Resonator Antenna (CDRA) At 5 to 6 GHz

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Abstract: In this paper an experimental study on a directional cylindrical dielectric resonator antenna (CDRA) at 5.8 GHz is discussed and presented. Dielectric resonator (DR) ceramic-base material is investigated in the design and it is found that it improves the antenna performance. The dielectric constant of dielectric resonator palette is 55 and it is fed with a 50 Ω microstrip transmission line. The aperture coupling technique is highlighted in order to improve the performance of the CDRA in terms of their tuning frequencies, impedance bandwidth, radiation pattern and gain. The CDRA measured results are compared with the simulation, by using the 3D microwave simulator, Computer Simulation Technology (CST). *Copyright © 2012 IFSA.*

Keywords: Dielectric resonator (DR), Dielectric resonator antenna (DRA), Microstrip, Frequency tuning.

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1. Introduction

Over the past three decades, the dielectric resonator antenna (DRA) has attracted the attention of antenna researchers due to its prospect of shrinking down the size of the antenna of wireless devices hence reducing the cost of manufacturing. Moreover it is also light weight and ease to be excited either from a probe or a microstrip line. With a proper impedance matching the DRA also able to present a reasonable bandwidth compared to other type of antennas. Since it is a dielectric material, there are no conductive and surface losses [1] occur. Another factor that attracts attention for many researchers are the frequency operation of DRA also can be tuned using defected ground structures (DGS) or electromagnetic band gap (EBG).

The bandwidth of DRA and patch antennas is usually less than 10 %. There are various approaches have been proposed to enhance the impedance bandwidth. For instance, the stacking approach has been proposed using two or more elements with different sizes with the same or different dielectric materials to improve coupling between feed line and antenna [2]. Different shapes of DRAs such as canonical, tetrahedron and triangular, also can be used to enhance the bandwidth [3]. Another approach such as co-planar parasitic DRAs also can be applied but this method has a drawback of increasing very much of the antenna size, then it was not suitable for the array antenna application. Then, the method of using the combination of different types of resonance from different structure to design a wideband hybrid structure has been by proposed by [4, 5]. This technique shows a good contribution in improving the antenna performance. However due to the technology demand that always moving ahead, the bandwidth obtained by previous studies is still considered small. In the recent years several techniques have been proposed which adopt different feeding structure for tuning the frequency of the DRA [6-10]. The concept of using DGS structure to reconfigure the frequency operation and impedance bandwidth of the DRA reported in [11-13] is further developed in this paper.

2. Antenna Design

A wide range of materials can be considered as ceramic dielectrics. Ceramic materials that can be used as resonators have dielectric constants ranging from 10 to 100 [14]. The resonance, radiation and Q factor will be affected by the ratio of the DR to a fixed dielectric constant. The additional of a DR allowing design flexibility. By selecting a dielectric material with low loss, radiation efficiency can be maintained, even at millimeter wave frequencies due to an absence of surface wave and conductor losses associated with DR. Since, a wide range of dielectric constant can be used in microwave application, allowing the designer to have additional factors to control the device through physical size and volume.

Several modes can be used to excite the DRA. Most of radiation pattern is similar to short electric or magnetic dipole, producing either broadside or omni-directional radiation pattern for different coverage requirements. Since DRAs can be suited to several feeding mechanisms including probes, slots, microstrip lines, dielectric image guides, and co-planar waveguide lines, it is easily fixed to the device making them amendable to integration with various technologies.

Based on impedance and resonant frequency in the Fig. 1, a DR is designed to resonate for $HE_{11\delta}$ mode. The size of the cylindrical DR is calculated and designed to operate at frequency of 5.5 GHz and a minimum fractional bandwidth of 5 %. The equations for the cylindrical DR to resonate and the Q-factor of $HE_{11\delta}$ mode are referred to [15] and [16]. The equations are based on extensive numerical solutions and curve fitting. As for the function of a/h with the selection of dielectric constant (ε_r), the parameter of $k_o a$ can be expressed as,

$$k_o a = \frac{6.324}{\sqrt{\varepsilon_r + 2}}\left\{0.27 + 0.36\frac{a}{2h} + 0.02\left(\frac{a}{2h}\right)^2\right\} \quad (1)$$

The *Q*-factor as a function of a/h for the selected ε_r is defined as,

$$Q = 0.01007\varepsilon_r^{1.3}\frac{a}{h}\left\{1+100e^{-2.05\left(\frac{a}{2h}-\frac{1}{80}\left(\frac{a}{h}\right)^2\right)}\right\} \quad (2)$$

The radiation Q-factor in equation (2) is used to estimate the fractional impedance bandwidth of the DRA and it is given by

$$BW = \frac{\Delta_f}{f_o} = \frac{s-1}{\sqrt{sQ}} \quad (3)$$

Furthermore the parameter of $k_o a$ is applied to determine the operating frequency of the design antenna and it is given by,

$$k_o a = \frac{f_{GHz} \bullet h_{cm} \bullet (a/h)}{4.7713} \quad (4)$$

Since the operating frequency is known to be 5.5 GHz, the equation (4) can be simplified and it is given by,

$$k_O a = 1.153 \bullet h_{cm} \bullet (a/h) \quad (5)$$

for $f_{GHz} = 5.5GHz$

Based from the equation (5) the graph for $k_o a$ versus a / h is plotted. For the $HE_{11\partial}$ mode and for a few values of h_{cm} the graph exhibits the results as depicted in Fig. 1. The intersection between h lines and the curve of $\varepsilon_r = 55$ will determine the value of a / h that requires resonating at 5.5 GHz. For the set of four heights chosen in this example, cylindrical DR with height of 0.2 cm or higher will resonate at 5.5 GHz at different a/h value. Each value of a / h, can be used to determine the Q-factor and the bandwidth. The graph for the Q-factor versus a / h and the results for the parameters of the dielectric resonator are depicted in the Fig. 2 and Table 1 respectively.

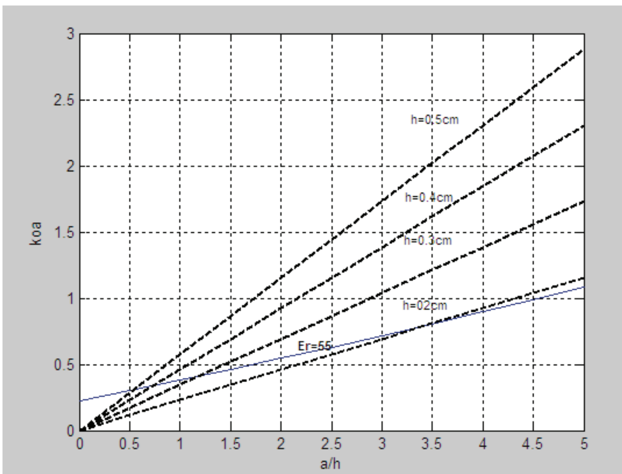

Fig. 1. Cylindrical DRA design to operate at 5.5 GHz with $\varepsilon_r = 55$.

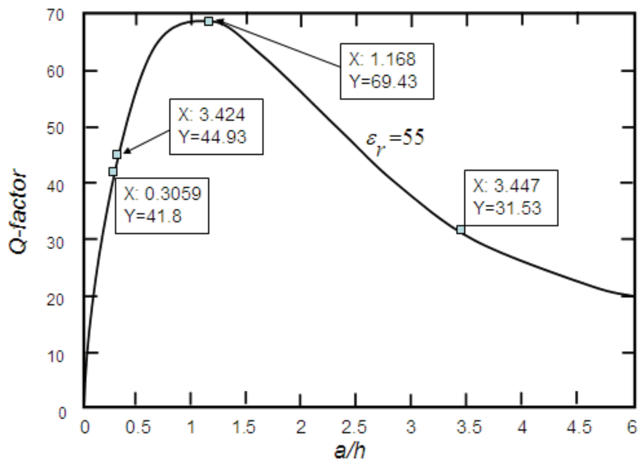

Fig. 2. Q-factor of the material with $\varepsilon_r = 55$.

Table 1. Parameters for the cylindrical dielectric resonator (CDR) for 5.5 GHz with $\varepsilon_r = 55$.

h_{cm}	$k_o a$	a/h	a_{cm}	d	Q	BW
0.2	0.795	3.44	0.688	1.376	31.5	3.0 %
0.3	0.404	1.169	0.350	0.700	68.4	1.0 %
0.4	0.742	0.342	0.140	0.280	44.9	1.5 %
0.5	0.520	0.300	0.150	0.300	41.8	1.7 %

Table 1 shows the possible size of the cylindrical DR computed from MATLAB software for frequency of 5.5 GHz. Generally, as the operating frequency becomes higher the size of the cylindrical DR becomes more compact and smaller and the bandwidth becomes narrow. The four DRAs can be fabricated in scale based from the results in Table 1. The geometry of the DR samples is depicted in Fig. 3. The DR dimension of $h_{cm} = 0.2$, and $d_{cm} = 1.376$ is selected for the design to achieve higher impedance bandwidth. For the simplicity, in the dielectric material fabrication, the DR diameter chosen is to be 1.4 cm.

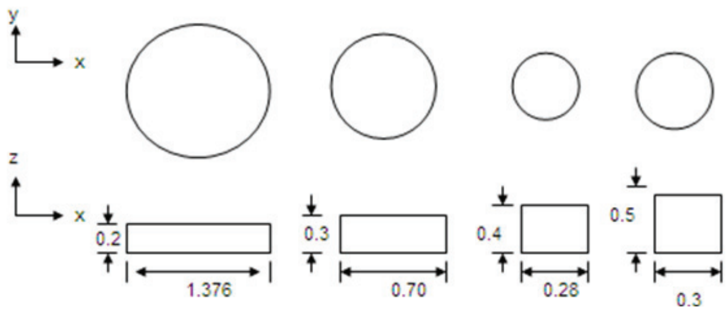

Fig. 3. Four samples of the DR geometry for 5.5 GHz with $\varepsilon_r = 55$.

Fig. 4 shows the proposed of a compact cylindrical dielectric resonator antenna (CDRA) with a slot on the ground plane. The antenna is printed on microwave substrate of thickness h_1 and relative permittivity ε_{r1} with overall ground plane size $(x \times y)$ of 50 mm × 40 mm. The cylinder DR has a radius of a, profile height of h_2 and relative permittivity ε_{r2}. The dimensions of the actual design of the CDRA based on the Fig. 4 (a) are summarized and tabulated in the Table 2.

The cylindrical DR is mounted on the ground plane of a RO4003C. The cylindrical DR is excited through aperture coupling fed from a microstrip line as shown in Fig. 4 (b). The slot has length of l_1 x w_1 and is embedded in the ground plane and it is placing perpendicular to the length of the 50 Ω microstrip transmission line, l_f x w_f. The distance of the narrow slot, s will be selected as an open stub so that it reactance will cancelled out that of slot aperture. The dimensions of the feeding structure are summarized and tabulated in Table 3.

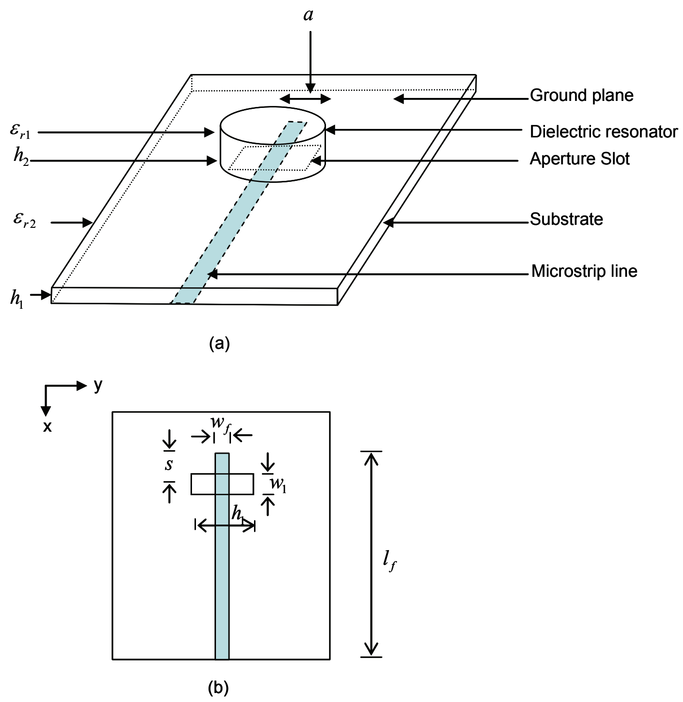

Fig. 4. The actual dimension of the proposed CDRA: (a) The CDRA side view, (b) The feeding structure.

Table 2. The geometry of dimension for the proposed CDRA.

x	y	h_1	ε_{r1}
50 mm	40 mm	0.813 mm	3.38
a	h_2	ε_{r2}	
14 mm	3 mm	55	

Table 3. The geometry of dimension for the feeding structure of proposed CDRA.

l_1	w_1	l_f	w_f	s
12 mm	2 mm	40 mm	1.9 mm	10 mm

The slot tuning technique also can be integrated with aperture couple DRA. With this technique the cylindrical pallet is place on the ground plane and it is excited by aperture coupled from microstrip line. The aperture slot is placed under the DR pallet with offset from the DR center in order to produce HE11δ mode resonant. The microstrip feed line feeder is placed at the bottom side of the circuit. The suitable size and position of rectangular slot tuning is used to reconfigure the frequency operation of the CDRA. Using aperture coupling technique, the amount of magnetic coupling from microstrip line to the DR will be lower as compared to direct microstrip line coupling as described in [16].

Fig. 5 shows the proposed structure of the antenna and including all important parameters. Using a material with a dielectric constant ε_r = 55 and height of h_{dr}=3 mm, the following DRA dimensions are chosen: rectangular tuning slot size w_{ts}= 14 mm and l_{ts}= 2 mm is placed at 12 mm from input port. The aperture slot with size of 14 mm x 2 mm is placed at 35 mm from input port. The microstrip line is printed on a substrate that has dielectric constant of ε_{sub} = 4.42 and thickness of 1.42 mm. The microstrip line length is 40 mm and the width is 1.95 mm.

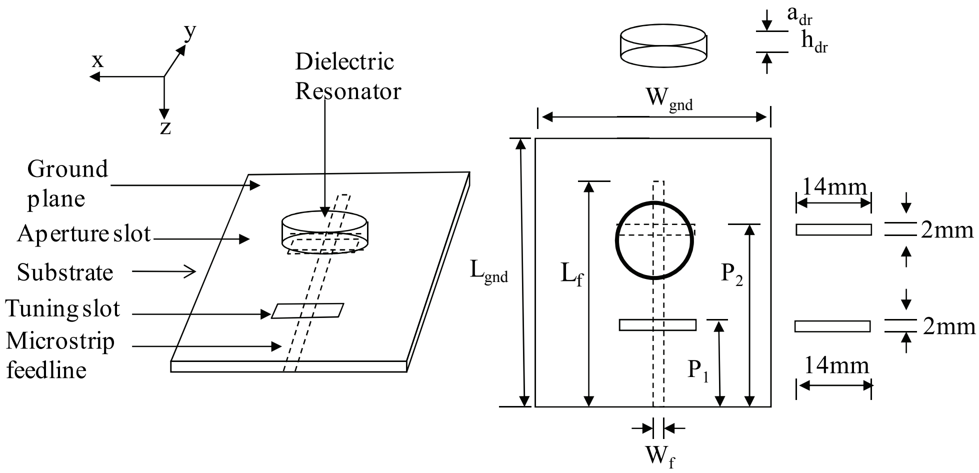

Fig. 5. The geometry of aperture couple DGS DRA.

3. Results and Discussion

Fig. 6 shows the simulated return loss for the proposed CDRA. The -10 dB bandwidth of return loss shows that the DRA resonated at the first three modes; HE_{111}, HE_{112} and HE_{113} with operating frequencies of 5.78 GHz, 5.99 GHz and 6.60 GHz, respectively. The impedance bandwidth recorded for these resonant frequencies are 1.9 %, 0.7 % and 0.7 %. For the measured return loss, HE_{111}, HE_{112} and HE_{113} operating frequencies recorded are 5.88 GHz, 6.09 GHz and 6.70 GHz respectively. It impedance bandwidth is slightly higher compared to simulated results with the different of 100 MHz. Both results show a good matching with return loss lower than – 10 dB.

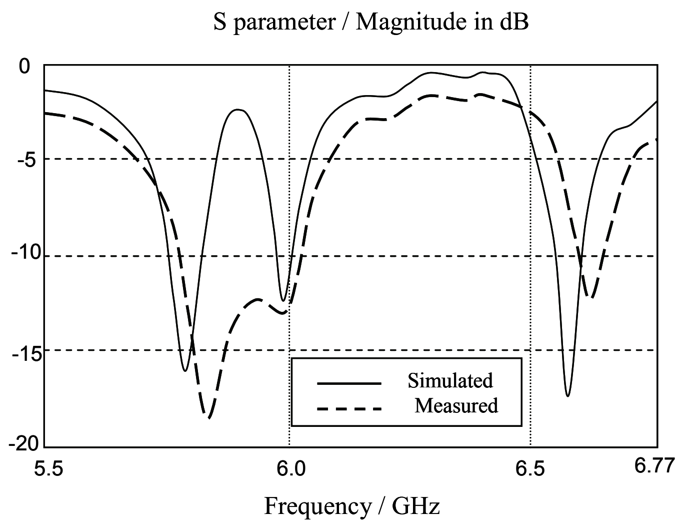

Fig. 6. The simulated and measured return loss for the proposed CDRA.

Fig. 7 shows the simulated and measured 2D-radiation patterns plotted in *yz* and *xz* planes. The 2D diagram is presented in two orthogonal planes perpendicular to the antenna plane. Generally the simulated results for both radiation patterns obtained are unidirectional type with small back lobes. For the 5.78 GHz operating frequency, the back lobe level is -9.6 dB with a broad beam but then it reduces to -18.3 dB with small beam at operating frequency of 6.60 GHz. The front to back lobe ratio is 15.38 dB for 5.78 GHz and increases to 23.9 dB when operating at frequency 6.60 GHz. The pattern shows that the back lobe level reduces when the operating frequency increases. However, the radiation pattern recorded for the *yz*-plane at 6.6 GHz is found to have slight tilt at the angle 150^o to 180^o, which result to broad radiation pattern in comparison to the lower operating frequencies. In comparison to the actual measurement, the radiation patterns recorded for 5.78 GHz, 6.0 GHz and 6.60 GHz are almost similar to the simulated results. However, the back lobes magnitude for all radiation patterns at the operating frequencies is slightly greater than the simulated one. This is due to the spillover affected by the small size of the ground plane.

The results for the proposed CDRA antenna gain are depicted in Fig. 8. For the simulated variation gain frequency, it is found that the gain more than 5.0 dBi is obtained between the frequencies 5.5 GHz to 6.3 GHz. This condition is also recorded at the frequency above 6.6 GHz. The highest and the lowest gains obtained from the proposed CDRA along the frequency range are 6.0 dBi and 4.2 dBi, respectively. Mean while the measured gains recorded are slightly higher, where the highest and lowest gains recorded are approximately 6.2 dBi and 4.7 dBi respectively. It is also can be seen that the gains are similar to the results obtained from the CDRA radiation patterns. The measured gain is recorded by using the gain absolute methods compared to a standard monopole antenna (5 dBi). It indicates that the proposed CDRA has a high efficiency with minimum loss due to the small conductor loss exists in the microstrip line feeder.

Moving the position of the tuning slot on the ground plane changes the input impedance level and resonance frequency of the aperture couple DGS DRA. The variable capacitance exists due to the difference position of the tuning slot that controlling the impedance matching and radiation loss of the antenna. Fig. 9 shows the effect of varying the tuning slot for different positions along the microstrip feed line. The DR palette is fixed at the middle of the ground plane which is about 25 mm from input port. At that location, the resonance frequencies were between 5.25 GHz to 5.95 GHz can be achieved when the tuning slot is positioned at 10 mm to 15 mm from the input port. When the tuning slot is placed close to the input port, the resonance frequency is down shifted to lower frequency. If the slot is moving away from input port, the frequency is shifted to higher frequency operation. It is also shown that aperture coupled DGS DRA are capable for tuning the frequencies operation in range of 5.0 GHz to 6 GHz.

The direct excitation by microstrip fed had advantage of producing a high gain radiation with a drawback of smaller bandwidth compared to the aperture feeding technique. The direct coupling technique provides high intensity of the signal to be coupled to the DR. Since the DR has high value of dielectric constant, then the effective Q-factor from the direct excitation is higher compared to the aperture technique. When the effective Q-factor is large, the bandwidth will become narrow. With aperture coupling technique, the intensity of coupling signal becomes lower and it will reduce the Q-factor and resulting of wider bandwidth.

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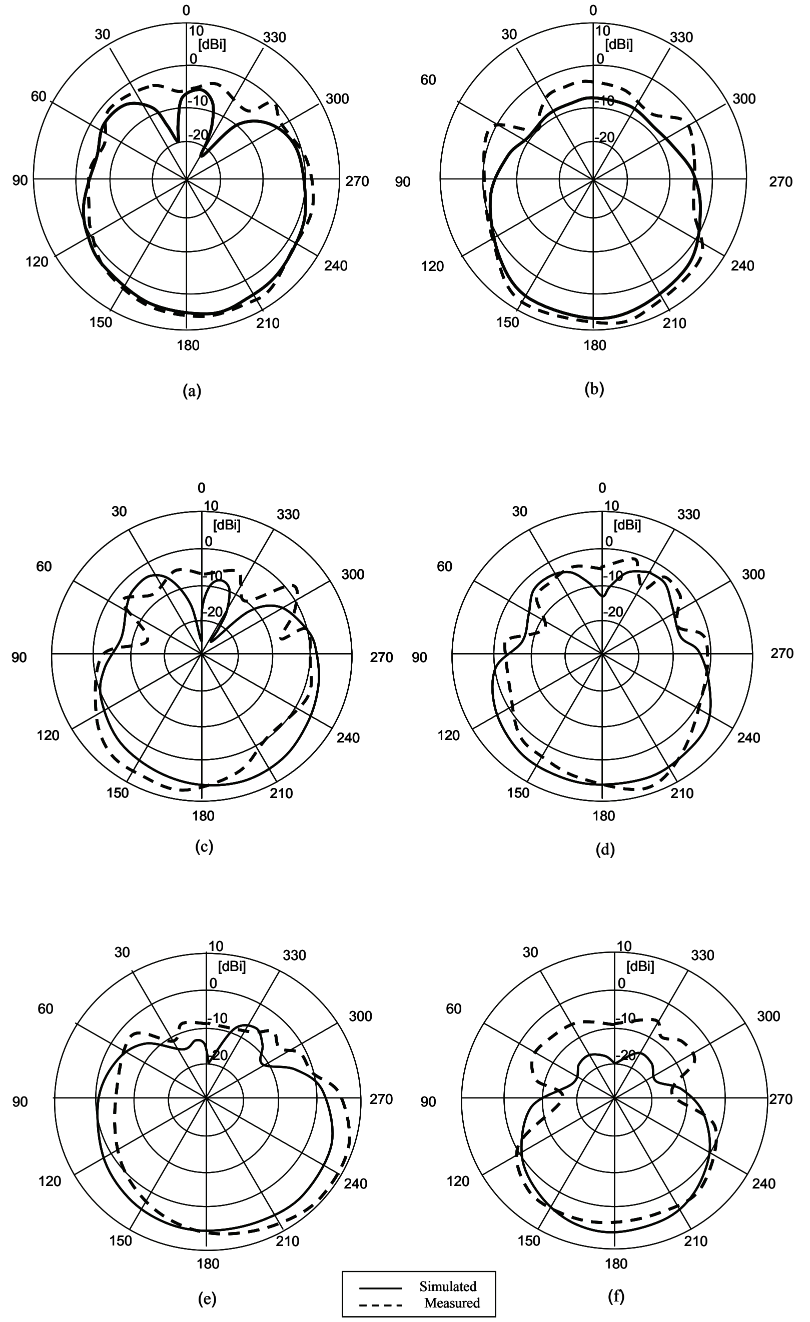

Fig. 7. 2D simulated results of the radiation patterns in *yz* plane and *xz* plane at operating frequencies, 5.78 GHz ((a), (b)), 6.0 GHz ((c), (d)) and 6.6 GHz ((e), (f)).

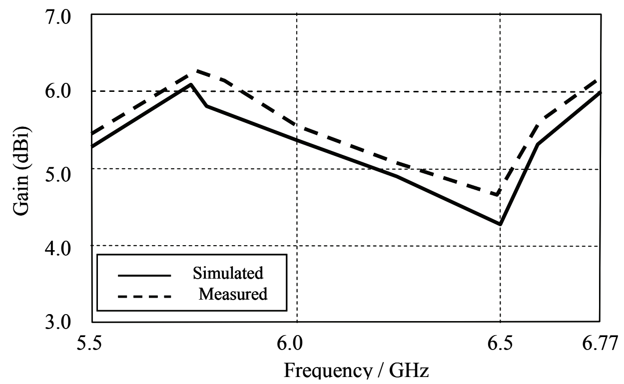

Fig. 8. The simulated and measured gain in dBi of proposed CDRA.

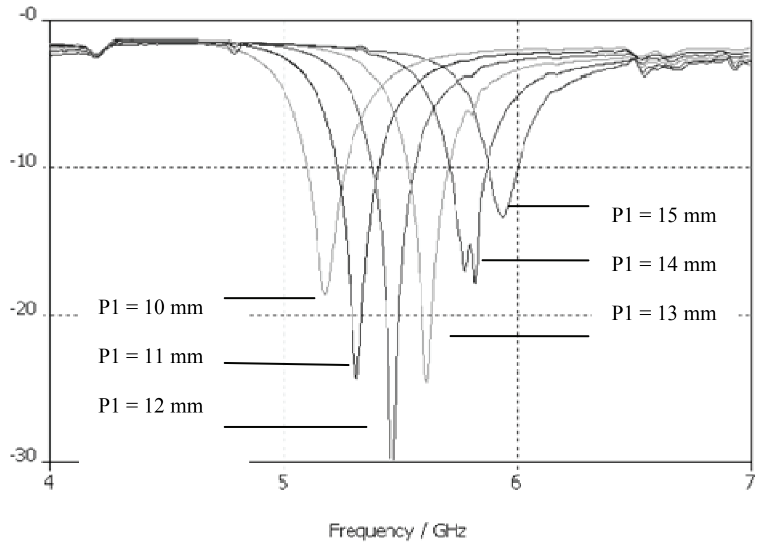

Fig. 9. Variation of resonance frequency of the aperture coupled DGS DRA due to different slot tuning position.

4. Conclusions

An experimental study on a directional cylindrical dielectric resonator antenna (CDRA) has been discussed and presented. Reasonable agreements between the simulated and measured results are observed in terms of their impedance bandwidth, radiation pattern and antenna gain. In the CDRA design the proposed aperture slot size is $l_1 = 12mm$ and $w_1 = 2mm$. Moreover, the slot size has a significant effect on higher resonant modes generated from the DR.

The signal that passes through an aperture is associated with slot size. It is observed that the passing signal through an aperture is proportional to the slot size. Likewise the condition allows the DR in receiving the high intensity fields and consequently permits higher resonant modes to the antenna. With a large size of the slot, the DRA is possible to be tuned at fundamental through high modes.

The frequency of the dielectric resonator can be tuned by modifying the design with the additional rectangular slot along the microstrip line feeder. It has been shown that from the experiments, the frequency of the CDRA can be tuned between 5.25 GHz to 5.95 GHz. Hence, additional slot provides wider frequency tuning for the CDRA. From the proposed CDRA design, it is clearly seen that, the antenna is suitable and appropriate for the application of WLAN.

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Guide for Contributors

Aims and Scope

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
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