Investigation of DGS CDRA for High Gain Applications

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Abstract A single element rectangular aperture coupled cylindrical dielectric resonator antenna (CDRA) with a plane reflector is proposed. A plane reflector is integrated at the back of the proposed CDRA to provide unidirectional radiation pattern with the improvement in gain and sidelobe level. The gain of the DRA is improved by reducing the back radiation caused by the aperture coupling. The peak gain of the antenna has been enhanced about 4.3 dB from 4.7 to 9.0 dBi at 5.18 GHz. The measured impedance bandwidth achieved for the proposed DRA is 0.2 GHz for S11 < −10 dB from 5.17 to 5.37 GHz. The radiation pattern with broadside radiation and low back radiation has been obtained. The experimental and measured results show that the antenna is high gain, small in size and satisfies the basic requirements of WLAN 802.11a.

Keywords Cylindrical Dielectric Resonator Antenna (CDRA) · Defected Ground Structure (DGS) · Plane reflector · High gain

1 Introduction

The extensive, fast and explosive expansion in wireless communication technology and communication systems has prompted the broad use of high gain, low profile, easy to manufacture and low cost antennas. Although, microstrip patch antennas provide the solution to the modern requirement of the wireless communication, but the performance of the microstrip patch antennas decreases at the higher frequencies such as millimeter wave frequencies. However, the dielectric resonator antenna

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(DRA), compared with microstrip patch antennas has lower conductor and surface wave losses at millimeter wave frequencies [1, 2].

Dielectric resonator antenna has several advantages which include its small size, light weight, low loss, ease of fabrication, low production cost, high radiation efficiency (>98 %) and high dielectric constant. Furthermore, the benefits of DRA also include that it is available in various sizes and shapes and the resonance frequency of DRA is the function of its size and shape. The size and bandwidth of DRA can be controlled by permittivity value. For compact size, high permittivity is used while for wide bandwidth low permittivity is used [3–7]. DRA can be excited by different feeding techniques such as probes [8–10], slot [11–13], microstrip lines [14–16], dielectric image guides [17, 18], and co-planar waveguides [19, 20].

Different feeding techniques have different advantages and disadvantages. Aperture coupled antenna provides design advantages that can be favorable in wireless communication. The main advantage of aperture coupling is that it provides feed network under the ground plane which isolates the radiating aperture from useless coupling or spurious radiation from the feed [3]. However, the drawback of this method is that a large amount of radiation is produced by the aperture, which causes large amount of back radiation [21].

Generally, a single element dielectric resonator antenna exhibit gain of about 5 dBi [22]. Therefore, various gain enhancement techniques for DRA have been presented in literature. A nine element array of DR excited by a microstrip feeder with an aperture slot was designed to enhance the gain of DRA to 10 dBi at 5.84 GHz [23]. A gain of 12.31 dBi at 10.5 GHz has also been achieved using 15 elements DRA array by feeding DRA array with dielectric image guide [24]. In some cases multi-segment is also used to enhance the gain of DRA [25, 26]. Other efforts to enhance the gain of DRA include; integrating DRA with a surface mounted short horn [27] and using dielectric image line (DIL) as feed [28]. In case of DRA array, the array must have a specific phase and amplitude distribution in order to maximize the gain or to reduce the sidelobe levels. A good gain was achieved in the above cases by using very large number of elements. The fabrication of such large number of elements is difficult and the calculations of phase and amplitude for such a large number of elements are complicated. The DIL technique is an effective solution in obtaining high gain with reduced losses but its design structure is complicated.

In this paper a rectangular aperture coupled cylindrical dielectric resonator antenna (CDRA) with plane reflector has been presented. A plane reflector beneath the CDRA is introduced to reduce the back radiation caused by the aperture coupling and to improve the directivity of DRA. The reflector is placed 4.0 mm away from the CDRA to achieve maximum directivity and low back lobe level. The simulation of the antenna is carried out using 3D CST microwave studio. From an experiment, analyses of a reflector size and its distance to the DGS CDRA are observed and recorded. The performance of the DGS CDRA with a reflector is then compared with the reference unit (stand-alone unit). The simulation is furthered conducted to DGS CDRA with reflector unit to validate the results. Subsequently, the design structure is fabricated and later followed by the testing and measurement process. The improvement to the forward radiation results of the DGS CDRA is then analyzed in term of the forward gain and back lobes level. Thus by observing the resonant frequencies, impedance bandwidth, gain and radiation pattern the proposed DGS CDRA can be thoroughly investigated.

2 Antenna Description and Design Geometry

In this section, the enhancement of radiation characteristics for the aperture coupling technique is presented by employing a perfect electrical conductor (PEC) reflector plate attached to the antenna circuit. The antenna circuit is designed by applying single dielectric pellet. This dielectric pellet is excited through an aperture slot. In addition the antenna circuit uses another slot for tuning purposes as illustrated in Fig. 1. The reflector is applied in this design and it is attached to the ground plane of the CDRA. The plane reflector is placed at a distance of 4.0 mm from the ground plane of the CDRA to reflect the back lobe radiations from both aperture coupling and tuning slots. The reflector is designed with a copper layer of 0.05 mm thickness, dielectric constant of 3.38 and substrate thickness of

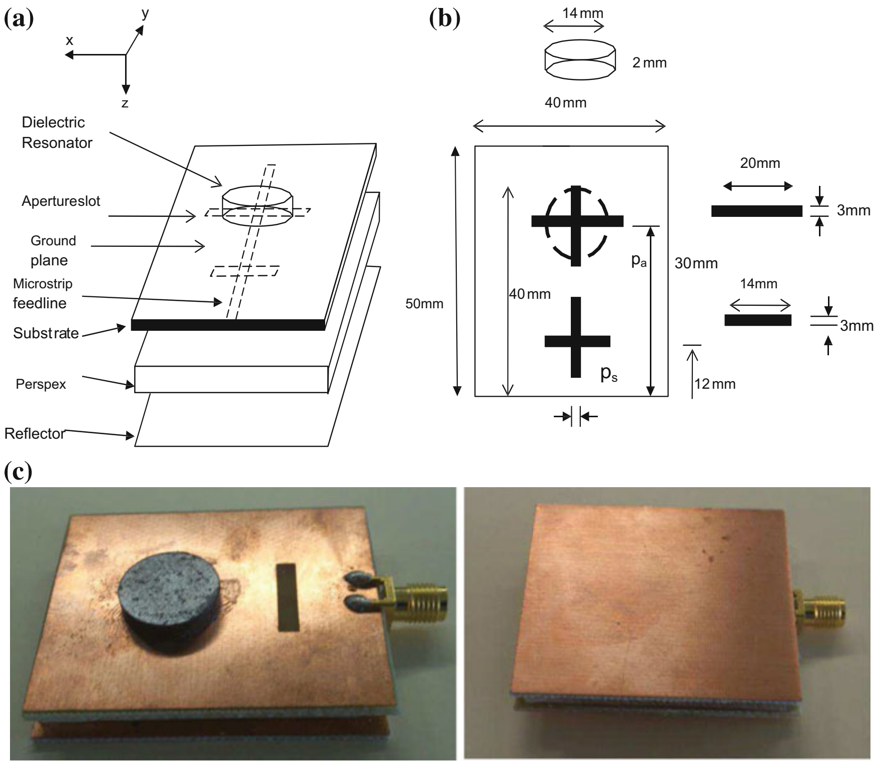

Fig. 1 DGS CDRA with reflector. **a** Perspective view, **b** design layout, **c** actual fabricated unit

0.813 mm. The dimensions for both aperture coupling and tuning slots are 3.0 mm × 20.0 mm and 3.0 mm × 14.0 mm, respectively. Furthermore the position for both aperture coupling and tuning slots are 30.0 mm and 12.0 mm (from the input port) respectively. The microstrip line for the design is assumed to be 40.0 mm. In the design the ground plane that being used is 50.0 mm × 40.0 mm. By reducing the ground plane size, it able to increase the magnitude of the antenna gain. With smaller ground plane the magnetic field from the dielectric pellet is concentrated on the ground plane, thus resulting to an increment of the magnetic field intensity. As a result the magnitude of the main beam radiation is increased. Thus affects the antenna gain to be increased.

3 Results and Discussions

The simulated results for the resonant frequency are illustrated in Fig. 2. The resonant frequency for the standard design of the CDRA and the design with reflector is compared. The DGS CDRA design without reflector produces a resonant frequency of 5.18 GHz while, by applying the reflector to the design, the resonant frequency is shifted to 5.28 GHz. It is observed that the implementation of the reflector shifts the peak resonance about 0.1 GHz and produces an impedance bandwidth of 0.033 GHz. It is found that the reflector affects the impedance characteristic of RLC circuit. By applying the reflector, it varies the value of effective reactance value (L and C) with a small increment to resistance value (R). As a result the return loss plot shows that center of resonant frequency is upward shifted from frequency of 5.18–5.28 GHz and the return loss level is improved from −12.0 to −13.0 dB.

The measured result shows that the center of the resonant frequency occurs at 5.292 GHz with the impedance bandwidth of 0.20 GHz. The resonant frequency shows small deviation of 0.0012 GHz (0.02 %) as compared to simulated results. The measured results produce higher impedance bandwidth with deviation of 83 %. Larger deviation of impedance bandwidth is caused by the existence of an air gap between aperture slot and ground plane surface during the fabrication process. Thus reduces the effective dielectric constant of the dielectric pellet and as a result the impedance bandwidth become wider.

Figure 3a and b shows the simulated radiation patterns for both antennas without and with the reflector. The results of the *yz*-plane describe the forward and backward radiation patterns of the antenna. It is depicted that without applying the reflector the radiation patterns emerge at forward and backward directions with an average gain magnitude 4.5 dBi as depicted in Fig. 3a.

The main lobe radiation at maximum gain is 4.7 dBi during of angle 145° direction. Thus without the reflector it is found that the antenna's radiation pattern is more to bi-directional. However the antenna's radiation patterns by applying the reflector exhibits large beam width for the forward direction. Consequently the reflector reduces the antenna's back lobes as depicted in Fig. 3b. The main beam

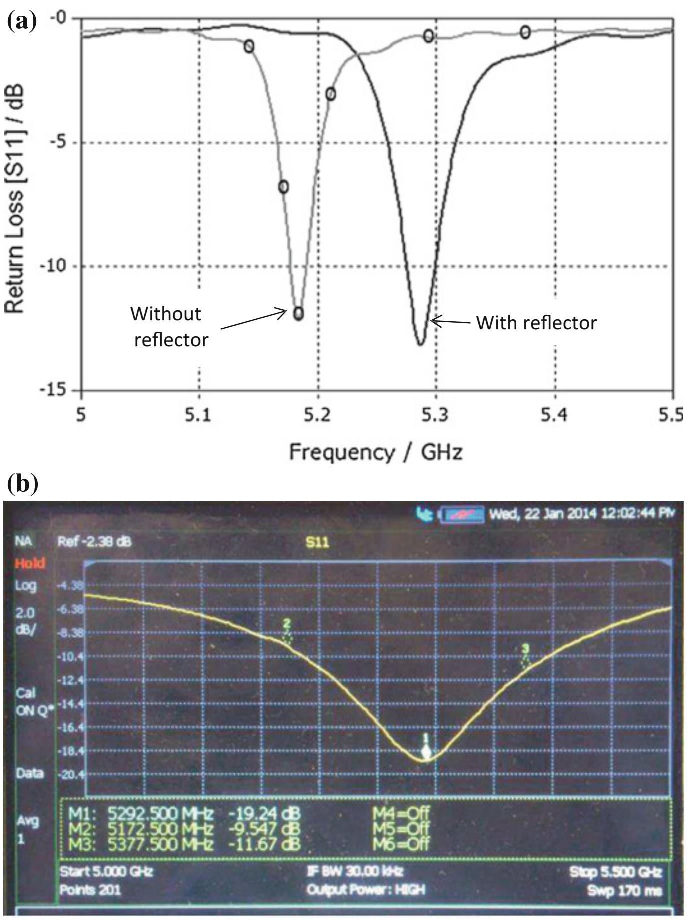

Fig. 2 Results of the return loss **a** simulated, **b** measured

occurs at 150° direction with magnitude of 9.0 dBi. The magnitude of the main lobe (forward direction gain) improves from 4.7 to 9.0 dBi by applying the reflector to the antenna. It is observed that the antenna with reflector produces two back lobes at 30° and 330° directions. The maximum magnitude of the back lobes is approximately 4.3 dBi. It is seen that the reflector reduces the magnitude of the back lobes from 4.5 to 4.3 dBi. This is due to the reflection of the back lobes simultaneously improves the magnitude of the forward gain.

The variations of the directivity gain (maximum gain) from simulations are observed for the frequency range 4.0–6.0 GHz is depicted in Fig. 4. The gain variations of the antenna by applying the reflector and without reflector are compared. It is shown that the antenna with reflector achieves directivity gain more than 7 dBi for the frequency range 4.0–5.8 GHz. Furthermore at frequency range 5.05–5.6 GHz the antenna recorded above 8 dBi of its directivity gain. However

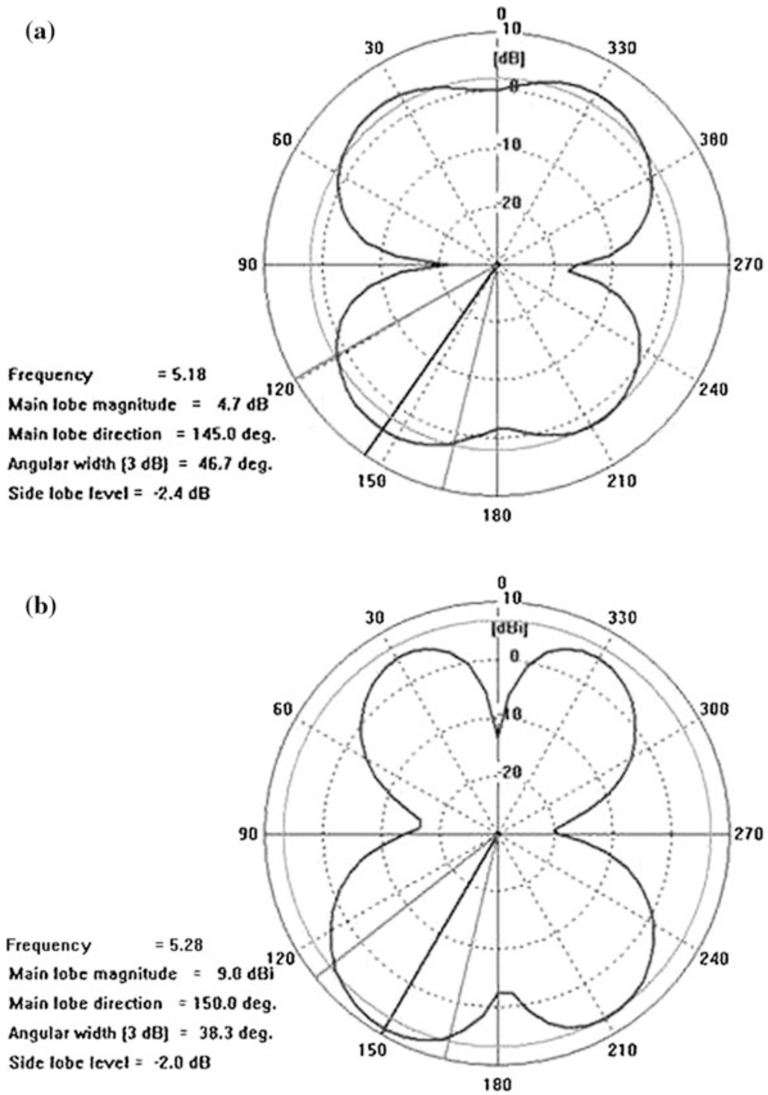

Fig. 3 Radiation pattern of *yz*-plane for the CDRA **a** without reflector, **b** with reflector

without reflector, the antenna directivity gain is somewhat low. Thus it is seen that by applying the reflector it improves the directivity gain magnitude to all frequency range sweep from 4.0 to 6.0 GHz.

From the antenna design, it is realized that the radiation patterns are created from the dielectric pellet and the aperture coupling slots. The dielectric pellet produces a main beam (forward direction) excited by the aperture coupling technique of the slot. Both aperture coupling slots contribute in developing the back lobes radiation

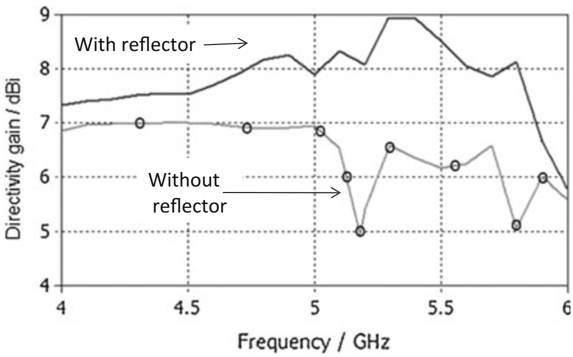

Fig. 4 Comparison of the antenna's directivity gain with and without the reflector

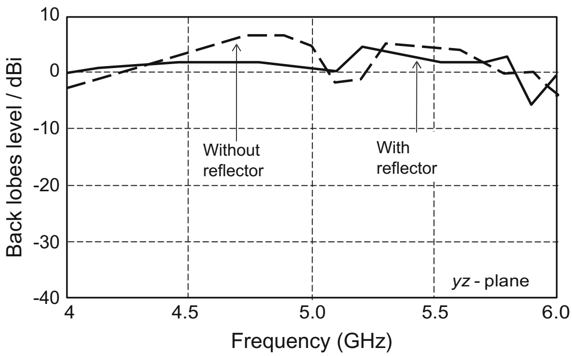

Fig. 5 Back lobes magnitude of *yz*-planes with and without the reflector

pattern. Figure 5 shows the antenna's simulation results of the back lobes level on yz-plane for frequency range 4.0–6.0 GHz. It is seen that the back lobes magnitude of the antenna is improved with the reflector application. The antenna's back lobes without the reflector clearly shown that, high level in magnitude due to the backward radiation are not being reflected.

3.1 Effect of Reflector Size on Forward Directivity Gain and Backlobes

Reflector size plays an important role in reflecting the back lobes radiated signal thus improving main lobe's magnitude of the antenna. Figure 6 shows the effect of the reflector size on forward directivity gain. The reflector is placed at distance of 4.0 mm with antenna board ($0.07\lambda_o$). The size of the reflectors is assumed to be 50.0 mm × 40.0 mm, 50.0 mm × 60.0 mm and 60.0 mm × 70.0 mm. It is shown that the reflector size of 60.0 mm × 70.0 mm produces higher improvement to the forward directivity gain of the antenna. It produces gain of above 8 dBi from 4.0 to 6.0 GHz. Furthermore magnitude of the forward directivity gain is increased

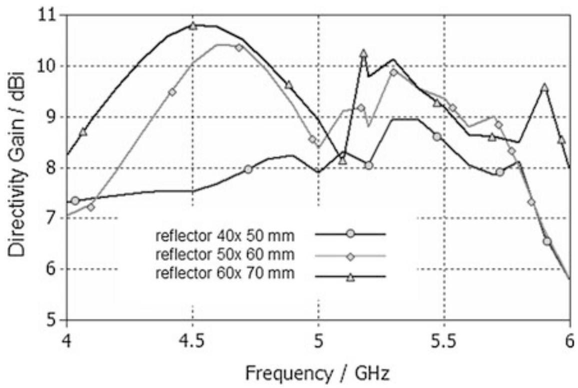

Fig. 6 The effects of the reflector size on forward directivity gain

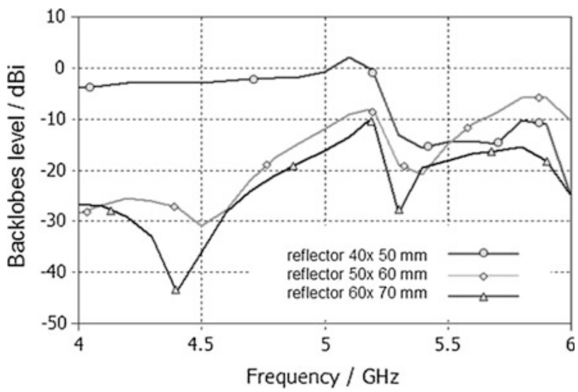

Fig. 7 The effects of the reflector size on back lobes

from 9 to 10.2 dBi at the resonant frequency of 5.3 GHz. The reflector of 50.0 mm × 60.0 mm shows almost similar trend but slightly low improvement. With the similar specifications of the reflector the simulation also investigates the effect on back lobes radiated signal. The simulation results are plotted and depicted in Fig. 7. It is shown that larger reflector produces low magnitude of the back lobes. Furthermore reflector size of 50.0 mm × 60.0 mm and 60.0 mm × 70.0 mm produces signification reduction to the back lobes for frequency range 4–5.2 GHz. As such it is found that the magnitude of the back lobes decreases with an increment of the reflector size. Therefore it can be said that reflector's size is an important parameter to be considered in the antenna design to achieve greater forward directivity gain.

4 Conclusion

A single element rectangular slot aperture coupled dielectric resonator antenna with plane reflector has been presented. The measured results for return loss have been found to be convincingly in good agreement with simulated results. Effects of introduction of plane reflector have been discussed. It has been demonstrated that the gain of the single element CDRA can be enhanced by placing a plane reflector beneath the CDRA. The improvement in the backlobe level of the antenna after the incorporation of reflector antenna has also been observed. The effect of changing the size of the reflector has been observed. From the parametric study it is concluded that increasing the size of the reflector increases the directivity and reduces the back lobe level. The fabricated antenna covers 5.17–5.37 GHz band and is suitable for IEEE 802.11a WLAN applications.

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