Semicircular Aperture Coupled Hemispherical Dielectric Resonator Antenna

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Abstract. A compact, low profile semicircular aperture coupled hemispherical dielectric resonator antenna (HDRA) is presented in this paper. The HDRA is fed by a microstrip line through a semicircular aperture in the ground plane. The proposed antenna resonates at 3.7 GHz in TE_{111} mode with an impedance bandwidth of 10.8% (3.54ï 3.94 GHz), which can be effectively used for WiMAX applications. The maximum gain obtained is 5.4 dBi at 3.8 GHz. The experimental results show good agreement with the simulated results. A detailed parametric study has been conducted to realize the effects of slot radius, slot width and slot position to improve the coupling of the designed antenna.

Keywords: Aperture coupling, hemispherical dielectric resonator antenna, microstrip line, semicircular slot, WiMAX application.

1. Introduction

Over the past three decades, dielectric resonator antenna (DRA) has been extensively used due to their attractive features such as compact size, low loss, light weight, high power, low cost and wide bandwidth. Radiation properties of open dielectric resonators were realized by Ritchmyer in 1939 [1]. But the first theoretical and experimental analysis of a cylindrical DRA was carried out by Long et al. in 1983 [2], which created the foundation for future investigation of DRA. Different shapes of DRAs like rectangular [3], hemispherical [4], triangular [5], and so forth have been presented in the literature. DRAs operating in their fundamental modes radiate like a magnetic dipole, independent of their shapes. DRAs are easy to excite using different feeding mechanisms such as a coaxial probe, microstrip transmission line, aperture coupled microstrip, and coplanar waveguide. Among the various excitation schemes, aperture coupled DRA fed by a microstrip line is often used because of easy fabrication and compatibility with monolithic microwave integrated circuits (MMICs). Martin *et al.* have demonstrated the use of an aperture coupled source on a cylindrical DRA experimentally and the feasibility of this feed mechanism was confirmed [6]. DRAs are very efficient antennas at millimeter wave frequencies due to their lower ohmic losses in comparison with microstrip antennas. Compared to the microstrip antenna, DRA has much more impedance bandwidth. For applications that require much broader impedance bandwidth, further bandwidth enhancement is desired. Bandwidth enhancement can be achieved by stacking and using two segment structures [7, 8]. The aperture-coupled regular and irregular pentagon shaped dielectric resonator antennas providing wideband and multiband performance has been reported in [9]. The two-layered HDRA excited by an annular slot to increase the bandwidth is reported in [10]. However, this increases the overall size and cost of the structure. Different shapes such as stair-shaped [11], and bowtie-shaped [12] can significantly improve the bandwidth. But these DRAs are more complex and difficult to fabricate. A dual-band antenna using two rectangular slots was realized in [13]. Wideband operation is possible by using a wide slot in [14], but both of this method will increase cross polarization. The bandwidth obtained is quite large in probe coupling for tall DRAs compared to aperture coupling for low-profile DRAs in [15], which may be a disadvantage for applications that require low-profile antennas.

In this paper, a semicircular aperture coupled HDRA is proposed. The antenna consists of an HDRA placed on a semicircular slot etched on the ground plane which resonates at 3.7 GHz in TE_{111} mode with an impedance bandwidth of 10.8% (3.54ï 3.94 GHz). The effect of changing the slot radius, slot width, and slot position is also studied. Single, dual and wide band operations can be implemented by adjusting the position of the slot, without any additional structures.

2. Antenna configuration

The geometry of the proposed antenna configuration is shown in Figure 1. The proposed structure consists of HDRA made of alumina material (Al_2O_3) of radius 12.7 mm with dielectric constant 10. The hemispherical geometry offers an advantage over other shapes as the interface between air and dielectric is simpler.

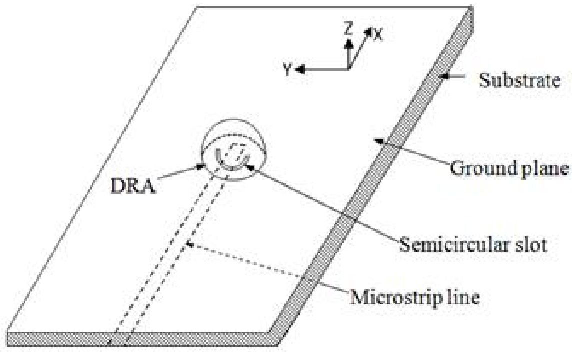


Fig.1. Configuration of semicircular aperture coupled HDRA.

The DRA is kept at the center of the ground plane with a microstrip line of width 3 mm below it, separated by a substrate of thickness 1.6 mm. The substrate used is FR4 epoxy of dimension 140 mm x 100 mm. The size of the ground plane dimension is chosen such that it reduces backward radiation. A Large ground plane is selected to avoid backward radiation [16]. A semicircular aperture is etched on the ground plane to couple the field from the microstrip line to the DRA. The center of curvature of the aperture is displaced from the center of the DRA along the xï axis at a distance a, which is found to be the strong magnetic area of the DRA, so as to provide suitable coupling. The semicircular aperture has an inner radius, r_2 and width, w_s. The microstrip line has a stub length, l_s from the center of curvature of the slot to the end of the microstrip line as shown in Figure 2.

The slot and DRA resonances are merged by adjusting the different parameters like slot offset, slot width and slot inner radius to obtain single band operation. By changing the slot offset and keeping the other parameters constant, dual and wideband operations are obtained.

3. Simulation results and discussions

A thorough parametric study is conducted to obtain the optimum value of the parameters of the proposed structure using Ansoft HFSS. To achieve strong coupling, a magnetic current source (an aperture) is located in an area of a high magnetic field. The DRA centered over the slot ensures strong coupling to internal magnetic fields. Also by changing the position of the DRA from the slot center, some degree of impedance matching can be achieved. Figure 3 shows the simulated reflection coefficient of the antenna for different values of the slot offset a along x direction while keeping r_2 = 4.6 mm and w_s = 0.7 mm. Maximum coupling at the resonant frequency of the DRA is obtained for a = 0.4 mm.

The slot width plays a significant role in controlling the amount of power coupled to the DRA. Figure 4 shows the simulated reflection coefficient of the antenna for different values of slot width w_s, while keeping a = 0.4 mm and r_2 = 4.6 mm. For w_s = 0.7 mm, maximum coupling corresponding to DRA resonance is obtained. The inner radius of the slot also plays a significant role in controlling the amount of power coupled through the slot to the DRA. Figure 5 shows the simulated reflection coefficient of the antenna for different values of inner radius r_2, while keeping a = 0.4 mm and w_s = 0.7 mm. Maximum coupling corresponding to the DRA resonance is obtained for r_2 = 4.6 mm.

The rapid development of wireless communication has increased the demand for dual-band and wideband antennas. Dual and wide band operations are achieved by adjusting the slot position without introducing additional structures. The slot resonance and DRA resonance are separated, but close together to obtain wideband operation and are separated to obtain dual-band operation. The slot is rotated at 140° clockwise with respect to z axis and the centre of curvature of the slot is fixed at 2 mm from the centre of the origin along y direction and 3.9 mm from the origin along x direction to obtain dual-band operation. An offset of 1.7 mm along the negative x direction is applied while keeping the offset along y, same as in dual band operation to obtain wideband operation. Figure 6 shows the simulated reflection coefficient of wide band operation and dual band operation. The simulated wideband operation has an impedance bandwidth of 17% extending from 3.32 GHz to 3.95 GHz. The lower band impedance bandwidth of the dual band operation is 5% (from 3.12ï 3.3 GHz) and the upper band impedance bandwidth of the dual band operation is 7% (from 3.81ï 4.09 GHz).

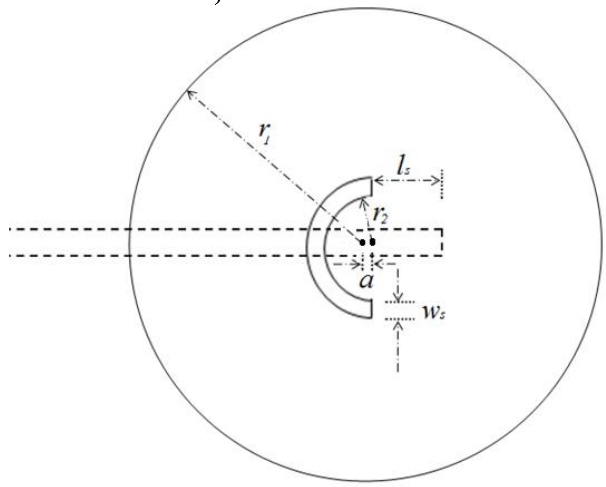


Fig.2. The enlarged view of slot and HDRA of Figure 1.

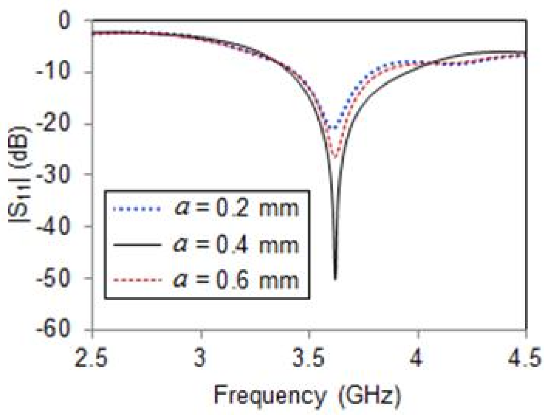


Fig.3. Simulated reflection coefficient as a function of slot offset, a with r_2 = 4.6 mm, w_s = 0.7 mm.

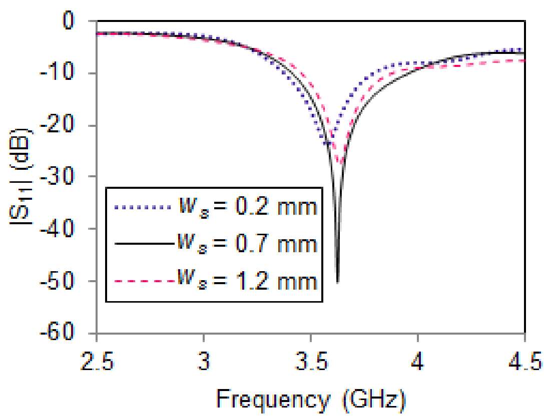


Fig.4. Simulated reflection coefficient for different values of slot width, w_s with a = 0.4 mm, r_2 = 4.6 mm.

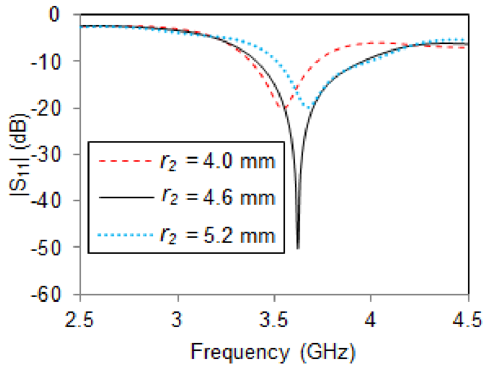


Fig.5. Simulated reflection coefficient for different values of inner radius of the slot, r_2 with a = 0.4 mm, w_s = 0.7 mm.

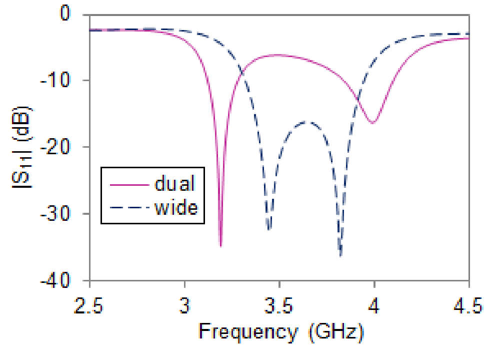


Fig.6. Simulated reflection coefficient of wide band and dual band operations

4. Measurement results

A semicircular aperture coupled HDRA is fabricated with optimized parameters. The optimum values of the parameters are: a = 0.4 mm, w_s = 0.7 mm, r_2 = 4.6 mm and l_s = 5.6 mm. The measurements were carried out using Rohde abd Swartz ZVL 13 Vector Network Analyzer.

Figure 7 shows the measured and simulated reflection coefficient of the antenna. The antenna resonates at 3.7 GHz with an impedance bandwidth of 10.8%. The measured resonant frequency, when compared with the simulated result, shows a 100 MHz upward shift. It is due to the presence of air gap that exists between the ground plane and DRA [17].

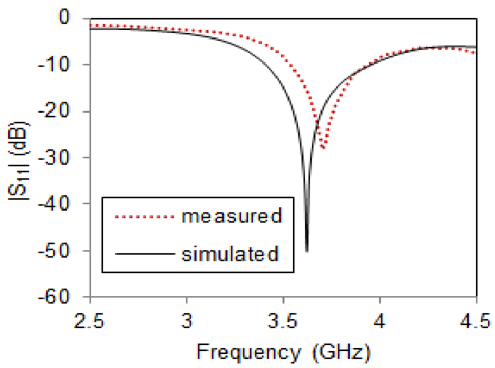
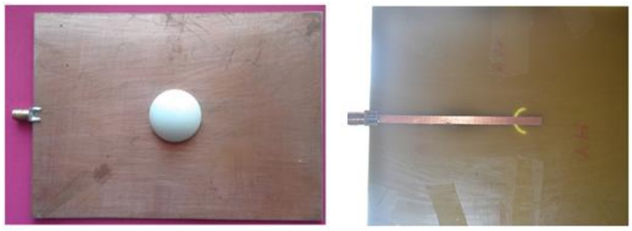


Fig.7. Simulated and measured reflection coefficient of semicircular aperture coupled hemispherical DRA with a = 0.4 mm, w_s = 0.7 mm, and r_2 =4.6 mm.

Figure 8 shows the photograph of the top and bottom view of the fabricated structure. Figure 9 shows the radiation pattern measured at 3.7 GHz. Both the E- and H-plane field patterns are symmetrical about the broadside direction. The lowest order transverse electric mode, TE_{111} is being excited here, which has a broadside peak[18]. It creates a far field radiation pattern similar to a short horizontal magnetic dipole. The measured gain versus frequency plot is shown in Figure 10. The measured maximum gain is obtained 5.4 dBi at 3.8 GHz. The gain of the antenna increases as the frequency increases and reaches its maximum value at the resonant frequency and decreases as the frequency increases again. The simulated radiation efficiency is shown in Figure 11. The maximum radiation efficiency obtained is 92.6%, which is at the resonant frequency.



(a) (b)

Fig.8. Photograph of the fabricated structure (a) Top view and (b) bottom view

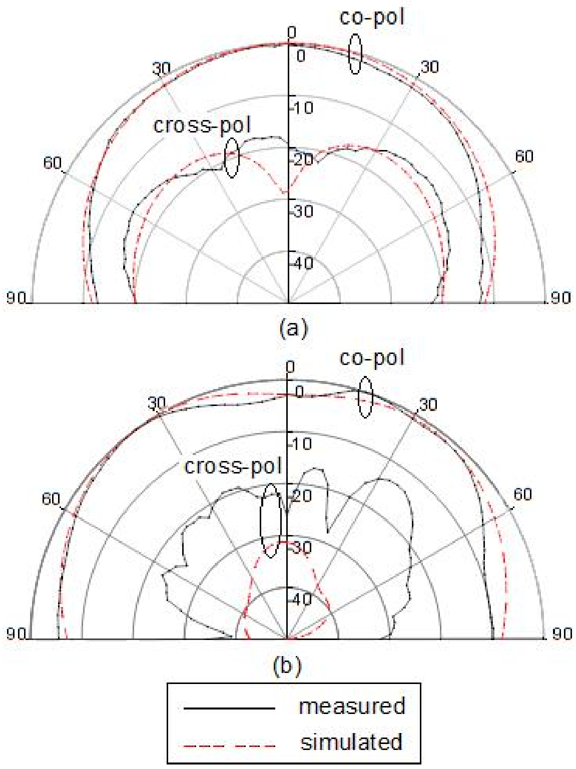


Fig.9. Measured and simulated radiation patterns at 3.7 GHz (a) H-Plane (b) E-Plane.

5. Conclusion

A semicircular aperture coupled HDRA for WiMAX application is developed. The proposed antenna resonates at

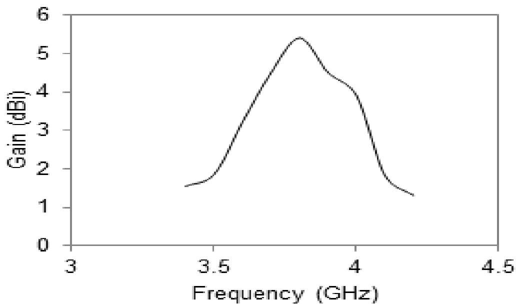


Fig.10. Measured gain of the proposed antenna.

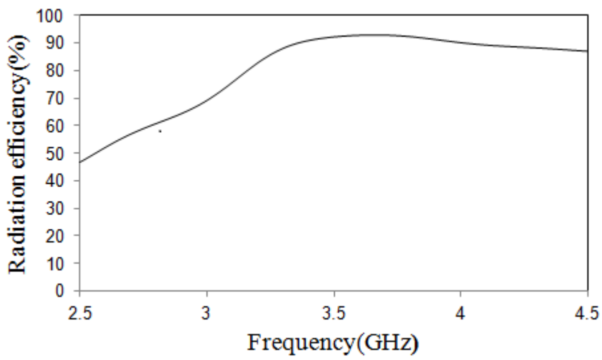


Fig.11. Simulated radiation efficiency of the proposed antenna with optimized parameters

3.7 GHz in TE_{111} mode with an impedance bandwidth of 10.8% (3.54 GHz ï 3.94 GHz). The maximum gain obtained is 5.4 dBi at 3.8 GHz. The radiation patterns are symmetrical about the broadside direction.The experimental results show good agreement with the simulated results. Dual as well as wide band operation is obtained by adjusting the slot position. The simulated wideband DRA has an impedance bandwidth of 17% extending from 3.32 GHz to 3.95 GHz. The lower band impedance bandwidth of the simulated dual band operation is 5% (from 3.12 GHz ï 3.3 GHz) and the upper band impedance bandwidth of the simulated dual band operation is 7% (from 3.81 GHz ï 4.09 GHz).

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