Int. J. Electron. Commun. (AEÜ) 69 (2015) 1755–1759

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

REGULAR PAPER

A novel half Hemispherical Dielectric Resonator Antenna with array of slots loaded with a circular metallic patch for wireless applications

Biswajeet Mukherjee*

Department of Electronics & Communication Engineering, PDPM Indian Institute of Information Technology, Design & Manufacturing, Dumna Airport Road, Jabalpur, India

ARTICLE INFO

Article history:
Received 6 May 2015
Accepted 29 August 2015

Keywords:
Circular patch
Dielectric resonator
Frequency
Modes
Resonance

ABSTRACT

In this paper, effect of loading of a circular metallic patch on a half Hemispherical Dielectric Resonator Antenna (HDRA) with array of slots is investigated. The half HDRA with array of slots operate from 5.3 GHz to 6.05 GHz. The circular patch controls the frequency tuning of the antenna geometry. The radius of the patch governs the resonant frequency and subsequently the bandwidth of operation. The patch also plays a role of reflector to improve the gain of the antenna. An optimized radius of patch of $r = 0.6$ cm on the proposed geometry offers 0.82 GHz of impedance bandwidth ($S_{11} < -10$ dB) at 4.55 GHz. The gain is significantly improved to 8.5 dBi at 5.05 GHz. A prototype is fabricated and the measured results are found to be in good agreement with the simulations. The resonant frequency is most suitable for standard wireless communications with wide band and high gain applications.

1. Introduction

The necessity of faster, efficient and voluminous data for communication has pushed the frequency range of operation of wireless communication systems toward a higher end. The erstwhile era has, thus been led by the growth in research and development of patch antennas and its planar counterparts. However, at escalated frequencies the ohmic losses of metallic antennas become non-linear.

Dielectric resonator antennas (DRA) due to its ease of fabrication, low loss and wide bandwidth has remained a topic of interest for researchers. Due to absence of any metallic components, it offers low losses at higher frequencies. Amongst the conventional shapes of the DRA like rectangular, cylindrical, etc., hemispherical geometry offers zero degree of freedom which lays a challenge in designing compact, wideband and high gain antenna designs [1,2].

HDRA can be excited by different feeding mechanisms like slot coupling [3], aperture coupling [4,5], etc., however, coaxial feeding at an offset to the HDRA is capable of exciting both TE and TM modes of the HDRA [6]. Many wideband techniques like air gap, multilayer dielectrics and multi-element stacking [1,2], parasitic slot on ground plane [7] have been inspected.

In addition to it, many novel variants of the shape of hemisphere have also been examined. This includes segmented HDRA [1,2], half HDRA [8], etc. In these modified geometries, apart from wideband offered, the modes excited are also altered. Like, in [8], the mode excited is TM_{101} like mode. The novel half HDRA with array of slots [8], is an attempt to design compact and wideband HDRA.

In this paper, investigation of a circular metallic patch on the half HDRA with array of slots is carried out. The effect of the circular patch results in frequency tuning of the DRA and offering high gain of up to 8.5 dBi at 5.05 GHz. The DRA with patch is still able to offer a wide bandwidth of 0.82 GHz for $S_{11} < -10$ dB, resonant at 4.55 GHz. The total efficiency of the proposed geometry is above 87.5% for the complete bandwidth of operation. Whereas HDRA suffers from zero degree of freedom, which constraints the radius of the hemisphere as the only physical parameter governing the volume, surface area and curved surface area, the proposed geometry not only significantly reduces the volume of the HDRA but also, controls frequency tuning by the metallic patch.

2. Antenna configuration

A dielectric material resting on a ground plane is capable of radiating when given an appropriate feed. The resonant frequency of the HDRA is governed by the following equation [1]:

$$f_r = \frac{4.775 \times 10^7 Re(K_a)}{\sqrt{(\varepsilon_r)}r} \quad (1)$$

* Tel.: +91 9425805501.
E-mail address: biswajeet.26@gmail.com

http://dx.doi.org/10.1016/j.aeue.2015.08.012
1434-8411/

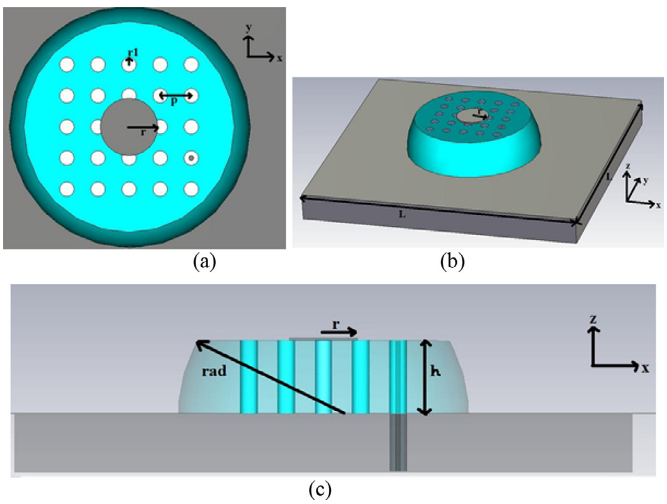

Fig. 1. The half HDRA with array of slots and circular metallic patch as viewed from different planes. (a) x–y plane. (b) Isometric view. (c) x–z plane. Here, 'L' is the dimension of the ground plane, 'r' is the radius of the circular patch, 'r_1' is the radius of the hole drilled in the hemisphere, 'p' is the periodicity of the holes, 'h' is the height of the DRA.

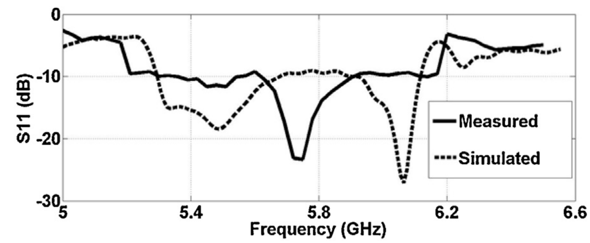

Fig. 2. The plot of the simulated and measured S_{11} for the half HDRA with array of slots.

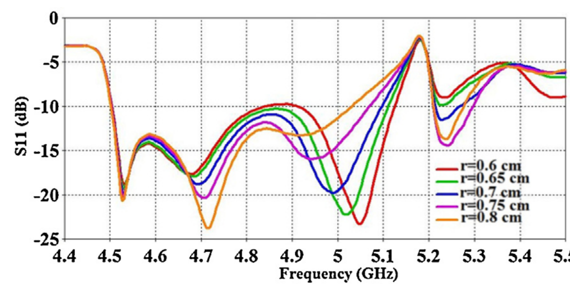

Fig. 3. The parametric study of the radius of the circular metallic patch 'r' placed on the proposed half HDRA with slots. The maximum bandwidth is observed for radius of $r = 0.6$ cm.

where 'f_r' is the resonant frequency, 'ε_r' is the dielectric constant of the HDRA, 'r' is the radius of the hemisphere (in cm) and 'K_a' is the wave number in the dielectric.

The dielectric material used for simulation is Rogers TMM10 which is a ceramic thermoset polymer composite material of the Rogers high frequency laminates with $\varepsilon_r = 9.2$. An HDRA of 9.2 dielectric constant and a radius of 2.54 cm (1″) will resonate at 1.816 GHz. The impedance bandwidth offered by the HDRA is 10.4% ($S_{11} < -10$ dB). The feed location is kept at $x = 1.74$ cm, $y = z = 0$ cm. Thus, the offset in the x direction excites the TE_{111} mode which resonates at 1.816 GHz [8]. This basic hemispherical geometry is modified to derive the half HDRA with array of slots. In order to design the base geometry, first, the height of the HDRA is reduced, the radius of the holes and the pitch (center to center distance of each hole) is optimized and then, the number of holes i.e. the array size of the holes drilled is optimized. This is achieved through parametric analysis in CST Microwave studio [8]. The proposed structure with the circular metallic patch is as shown in Fig. 1. Fig. 1(a) is the x–y plane projection, (b) is the isometric view and (c) is the x–z plane projection. The ground plane is of the dimension 10 cm × 10 cm. The optimized parameters for the half HDRA with array of slots from [8] is rad = 2.54 cm, $r_1 = 0.15$ cm, $p = 0.65$ cm, h = rad/2. The array size of the cylindrical slots is 5 × 5, which is the maximum number of slots that can be drilled in the DRA. The slots are drilled with an aim to lower down the Quality factor and thus improve the bandwidth as given in the following equation:

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}} \tag{2}$$

The feed location is $x = 1.3$ cm and $y = -0.65$ cm from the central hole. The feed location is chosen for best impedance matching and excites all the modes of the DRA. With the optimized parameters, the DRA is resonant at 5.3 GHz with a bandwidth of 0.96 GHz and a peak gain of 7.2 dBi at 6.02 GHz [8]. The S_{11} plot of the structure is as shown in Fig. 2, taken from Ref. [8].

On this existing geometry a circular metallic patch is placed. The effect of changing the radius of the patch on the S_{11} plot is as shown in Fig. 3. The shift in the resonant frequency is clearly visible due to the loading of the patch on the DRA. Whereas the half HDRA with slots has the first resonant point at 5.3 GHz, on placing the metallic patch the resonant frequency shifts to 4.55 GHz. As the radius of the patch increases, the first resonant point remains fixed however, the other resonant points start shifting. As 'r' changes from 0.6 cm to 0.75 cm, the second resonant point shifts from 4.68 GHz to 4.7 GHz. Similarly, the third resonant point shows a shift from 5.05 GHz to 4.95 GHz. The frequency tuning is attributed to the fact that as the radius of the patch increases, the patch itself starts acting as a circular patch antenna based on the current induced by the fields on the DRA and hence, alters the resonant frequency of the DRA.

It is also worth observing that as the radius 'r' increases, the bandwidth of the DRA decreases. This is because of metal loading on the DRA which increases the losses and impedance mismatch, thus, the reduction in bandwidth is observed [1,2]. The widest bandwidth of operation of 0.82 GHz is observed for $r = 0.6$ cm which is the optimized value. The impedance bandwidth (%) is measured by the following equation:

$$\mathrm{BW} = \frac{\Delta f}{f_0} \times 100 \tag{3}$$

and

$$\Delta f = f_u - f_l \tag{4}$$

where BW is bandwidth, f_0 is the resonant frequency (GHz), Δf is the difference between the upper (f_u) and the lower frequency (f_l) along the −10 dB S_{11} plot, measured in GHz.

It is interesting to note that despite adding the circular metal plate the bandwidth is considerably high. This is evident based on the following equation [9]:

$$Q = 2\omega_0 \frac{StoredEnergy}{RadiatedEnergy} \propto 2\omega_0 (\varepsilon_r)^p \left(\frac{Volume}{Surface}\right)^t \tag{5}$$

Where $p > t \geq 1$, ω_0 is the resonant frequency and ε_r is the dielectric constant. Because the holes drilled in the proposed structure lowers down the Q factor, hence offering a wide bandwidth of operation.

3. Results and discussions

The simulations of the antenna are carried out on Computer Simulation Tool (CST) Microwave Studio, which is based on the Finite Integration in Time (FIT) computational technique. The meshing in