

# Performance Enhancement of Hemispherical Dielectric Resonator Antenna by Using Artificial Materials

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**Abstract**—This paper investigates the use of artificial materials (electromagnetic band-gap structure) for the performance enhancement of hemispherical dielectric resonator antenna. It is shown that reduction of surface waves improves the performance of the dielectric resonator antenna considerably. Conversion of surface waves into the radiated waves is achieved by the electromagnetic band-gap structure. The electromagnetic band-gap substrate is made of two periodic structures. One periodic structure consists of circular rings and the other periodic structure is made of metallic vias which are placed radially and circularly. These vias connect the circular rings to the ground. HFSS software is used to optimize the periods of two periodic structures. The integration of hemispherical DRA and an electromagnetic band-gap substrate improves the antenna performance. It is observed that the EBG structure enhances the antenna gain and antenna bandwidth by 2.6 dB and 35 MHz respectively. The dielectric resonator antenna structure is simulated by the simulator HFSS.

**Keywords**—Hemispherical Dielectric Resonator Antenna (HDRA), Dielectric resonator, Cylindrical electromagnetic band-gap structure.

## I. INTRODUCTION

Dielectric resonator antennas (DRAs) offer various advantages over microstrip antennas and these can be considered as impeccable contenders for antenna applications. DRAs offer negligible loss due to the absence of conducting parts. But at various places, there is requirement of high antenna gain. Many researchers have tried to enhance the gain of dielectric resonator antenna. A dielectric resonator antenna using stacked dielectric resonators (DRs), with an air gap, between a patch and the DRA has been reported [1]. A DRA based on offset dual-disk DR is investigated in [2]. However, the size and cost of the DRA may be increased by

these techniques. One more technique for DRA gain enhancement is to lessen the surface wave loss, which is responsible for the generation of ripples in the radiation pattern. Surface waves are undesired waves and these are confined along the substrate. The antenna performance is reduced considerably because of this confined electromagnetic energy. A great volume of energy is confined in the substrate, which results in undesired surface wave loss. The DRA performance can be enhanced by conquering these surface waves. Various researchers have applied different techniques to suppress the surface waves [3]-[8]. One method is the synthesized substrate, which lowers the effective dielectric constant of the substrate either under or around the patch [3], [4]. Other approaches are to use parasitic elements [5] or to use a reduced surface-wave antenna [6]-[8]. Electromagnetic band-gap (EBG) substrates have been vastly used for the performance enhancement of the antenna [9]-[16]. The surface waves can be curbed by creating EBG structures in the substrate. These structures are capable of opening a band-gap, in which the electromagnetic wave propagation is prohibited. The surface waves get suppressed by the EBG substrate, but the performance improvement is also because of the coupling in-between the EBG substrate and the DRA. EBG structures significantly improve the antenna aperture efficiency without increasing the antenna size. Various researches have demonstrated that electromagnetic band-gap substrates, when combined with DRAs or patch antennas, considerably improve its performance in terms of directionality, gain, bandwidth, return loss and reduction of size etc. [17]. The resonant artificial materials (EBGs) help the surface-waves to get radiated by the antenna and add up the gain of antenna. Within the band-gap, around the resonant frequency of the antenna, it does not allow surface-waves to propagate in the substrate. Hence the radiations go up in the vertical direction and improve the gain. In all antennas making use of electromagnetic band-gap substrates, the antenna is designed with its resonant frequency lying in the band-gap of EBG

substrate. During past few years, numerous microstrip patch antennas as well as DRAs have been designed by the researchers with EBG substrates for the performance improvement.

The paper is organized as follows. Section II demonstrates the design and simulation of conventional HDRA. In section III, the design and simulation of HDRA with cylindrical EBG substrate has been demonstrated. Section IV illustrates and compares the simulation results of the conventional HDRA and HDRA with EBG structure. Section V concludes the paper.

## II. DESIGN AND SIMULATION OF CONVENTIONAL HEMISPHERICAL DRA

In this section, an HDRA is designed by using HFSS simulator. The HDRA is designed to operate at an arbitrary chosen frequency. Then in the next section, the cylindrical electromagnetic band-gap structure is designed for the performance improvement of designed HDRA at its operating frequency. The geometry of the reference antenna is shown in Fig. 1, which consists of a hemispherical dielectric resonator (HDR) placed on a grounded substrate.

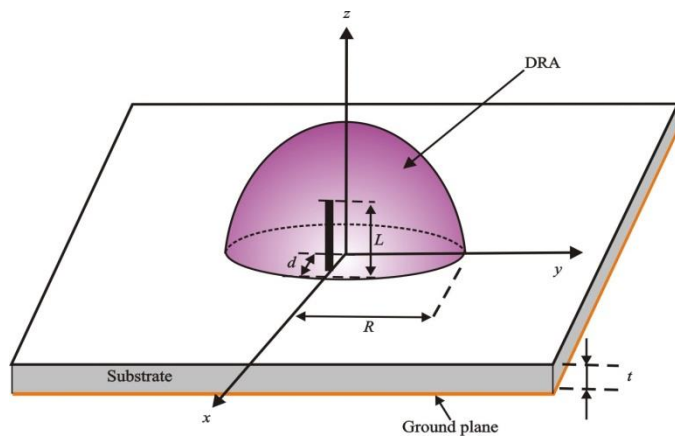


Fig. 1: Geometry of Hemispherical DRA

The material used for the HDRA is GaAs. The HDRA has radius,  $R=16$  mm and dielectric constant  $\epsilon_{dra} = 12.94$ . It is placed on substrate (RT Duroid 5880) of permittivity,  $\epsilon_r = 2.2$  and a thickness,  $t = 2$  mm. The excitation is achieved through a coaxial probe of length,  $L = 5$  mm placed at a distance,  $d = 4.6$  mm from the centre of HDRA. The size of the substrate is  $200 \text{ mm} \times 200 \text{ mm}$ .

TABLE 1

Parametric Values of Hemispherical DRA

| Parameter   | Value  |
|---|--------|
| Permittivity of DR (GaAs), $\epsilon_{dra}$                       | 12.94  |
| Radius of DR, $R$   | 16 mm  |
| Permittivity of grounded substrate (RT Duroid 5880), $\epsilon_r$ | 2.2    |
| Thickness of grounded substrate, $t$                              | 2 mm   |
| Length of coaxial probe, $L$                                      | 5 mm   |
| Distance of coaxial probe from the centre of HDRA, $d$            | 4.6 mm |

Table 1 shows the parametric values of HDRA. The feed location is optimized to give good impedance matching. Remaining parametric values are either constant values, or are taken arbitrarily. While designing EBG substrate in the next section, the parametric values of HDRA are kept same as in this section. The resonant frequency is expected to be dependent on the dimensions of the HDRA and the substrate. The designed HDRA resonates at 4.3 GHz and the maximum gain of the antenna is around 7.1 dBi. The antenna performance is improved using an EBG structure, which is discussed in the next section.

## III. DESIGN AND SIMULATION OF HDRA WITH CYLINDRICAL EBG STRUCTURE

The design of the cylindrical EBG substrate is described in this section. Fig. 2 shows the geometry of the HDR surrounded by an EBG structure consisting of metal rings and grounding vias. The concentric rings of the metal strips are printed on the grounded substrate (RT Duroid 5880), with the distance  $g$  between two successive strips. These rings are connected to the ground through metal vias.  $P_1$  is the radial period of circular rings. The grounding vias have radial period  $P_2$ , transversal period  $P_t$  and radius  $r$ . The vias' position is based on the procedure demonstrated in [14], where the transversal period is constant for all layers. It is shown in [14] that the gain enhancement of DRA is maximum, when the radial period of rings ( $P_1$ ) and the radial period of grounding

vias ( $P_2$ ) are different but close to  $\frac{\lambda_0}{4}$ . The value of gap between two successive rings ( $g$ ) is taken as double the radius of vias ( $r$ ). The value of  $r$  is taken arbitrarily as 1.2 mm. Hence, the value of  $g$ , which is double the value of  $r$ , is taken as 2.4 mm. The initial values of  $P_1$  and  $P_2$  are calculated from following relations [20]:

$$P_2 \approx \frac{\lambda_0}{4} \quad (1)$$

Where  $\lambda_0$  is free space wavelength.

$$P_1 = \text{slightly less than } \frac{\lambda_0}{4} \quad (2)$$

The initial value of  $P_1$  is considered arbitrarily. After getting the initial values of  $P_1$  and  $P_2$  from Eq. (1) and Eq. (2), these two parametric values are optimized along with  $P_t$ , to give the maximum gain at its resonance frequency. After optimization, the maximum antenna gain is obtained at the resonance frequency 4.42 GHz with  $P_1$ ,  $P_2$  and  $P_t$  values as 21 mm, 23 mm and 9 mm respectively. The first circular ring starts at the radius  $R + g$ , whereas the  $n^{\text{th}}$  metal ring starts at

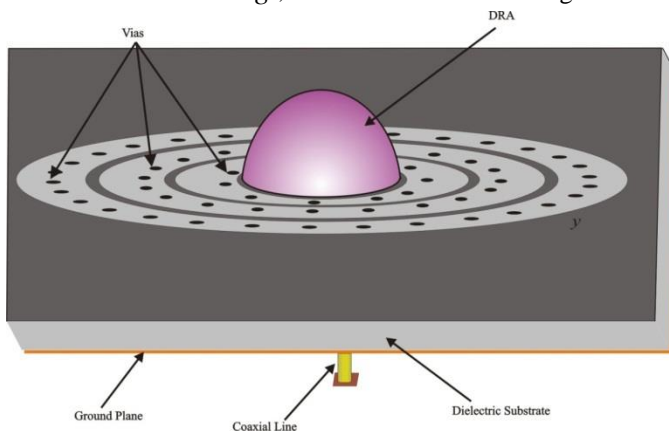


Fig. 2: HDRA surrounded by cylindrical EBG configuration

radius  $R + g + (n-1)P_1$ .

Table 2 depicts the final parametric values of electromagnetic band-gap substrate. All the parametric values are taken arbitrarily except the three parameters (radial period of metallic rings  $P_1$ , radial period of metal vias  $P_2$  and transversal

period of vias  $P_t$ ) which optimized using HFSS. The parametric values of HDRA are kept same, as used in previous section while designing conventional HDRA.

TABLE 2  
Parametric Values of Cylindrical EBG structure

| Parameter                                   |        |
|---|--------|
| Radius of vias, $r$                         | 1.2 mm |
| Radial period of vias, $P_1$                | 21 mm  |
| Transversal period of grounding vias, $P_t$ | 9 mm   |
| Radial period of metal rings, $P_2$         | 23 mm  |
| Gap between two successive metal rings, $g$ | 2.4 mm |

#### IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The impedance matching of HDRA is negligibly affected by the EBG substrate. Return loss of the conventional HDRA and HDRA with EBG substrate is -24 dB and -32 dB respectively. Fig. 3 and Fig. 4 show the simulated radiation pattern in E-Plane and H-plane respectively for the two antennas, with and without EBG substrate. The EBG substrate increases the HDRA gain around the resonance frequency. The gain achieved 7.1 dB and 9.7 dB for conventional HDRA and for HDRA with EBG substrate respectively. Corresponding bandwidth is approximately 280 MHz at the centre frequency of 4.3 GHz and approximately 315 MHz at the centre frequency of 4.42 GHz for conventional HDRA and for HDRA with EBG substrate respectively. Hence, the EBG substrate improves the HDRA gain by 2.6 dB due to suppression of surface waves. However, the coupling in-between the HDRA and the EBG substrate also contributes in HDRA gain enhancement.

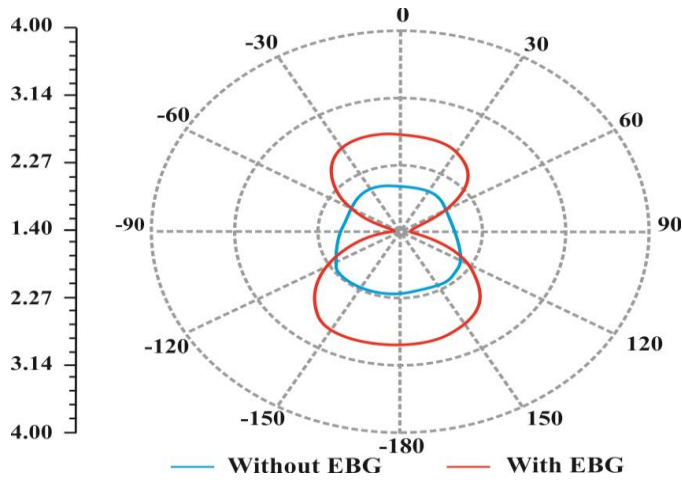


Fig. 3: Radiation Pattern (E-Plane) of HDRA

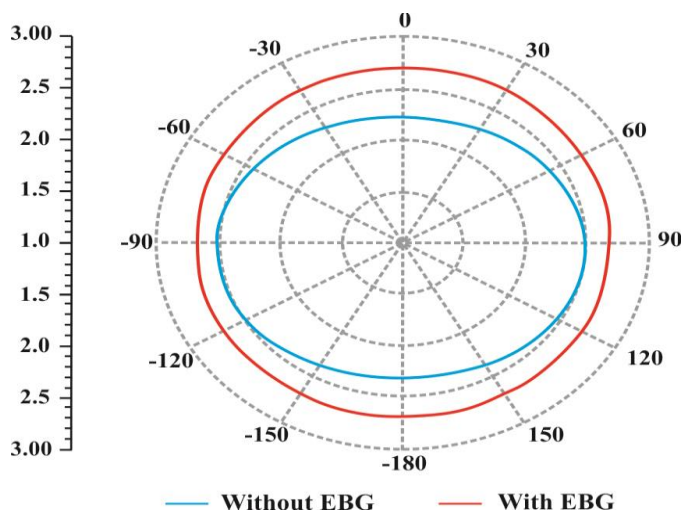


Fig. 4: Radiation Pattern (H-Plane) of HDRA

The simulated results for the conventional HDRA and HDRA with EBG substrate are shown in Table 3.

TABLE 3

Simulated results comparison for conventional HDRA and HDRA with EBG structure

|                             | CONVENTIONAL HDRA | HDRA WITH EBG STRUCTURE |
|-----------------------------|-------------------|-------------------------|
| <b>RESONATING FREQUENCY</b> | 4.3 GHz           | 4.42 GHz                |
| <b>BANDWIDTH</b>            | 280 MHz           | 315 MHz                 |
| <b>RETURN LOSS</b>          | -24dB             | -32dB                   |
| <b>GAIN</b>                 | 7.1 dBi           | 9.7dBi                  |

### V. CONCLUSION

A technique for performance enhancement of HDRA has been proposed in this paper. A cylindrical EBG substrate consisting of three circular metal rings and a periodic structure of metallic vias has been used for HDRA gain improvement. It is shown that the performance of the HDRA can be considerably improved by confining the surface waves. The conversion of surface waves into the radiated ones by the EBG substrate results in the HDRA performance improvement. It has been demonstrated that because of incorporation of the EBG structure, HDRA gain is enhanced by 2.6 dB and its bandwidth is slightly enhanced by 35 MHz. The designed antenna finds applications in C band based communication systems.

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