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A novel Hemispherical Dielectric Resonator Antenna on an Electromagnetic Band Gap substrate for broadband and high gain systems

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ABSTRACT

In this paper we propose and investigate the application of Electromagnetic Band Gap (EBG) substrate for improving the performance of Hemispherical Dielectric Resonator Antenna (HDRA). Our designed EBG shows a band gap in the frequency range of 1.75–2.25 GHz and the HDRA is resonant at 2 GHz which falls within the bandgap of the EBG. When combined with the EBG substrate the −10 dB bandwidth shows an improvement from 11.25% to 30%. On engineering the height of the HDRA on EBG substrate the gain is improved from 6.13 dBi to 9 dBi. To validate the results, simulations are carried out on CST Microwave Studio and HFSS.

1. Introduction

Dielectric Resonators, which have found different applications as microwave circuit elements, can also be useful as radiators if the shapes, permittivity and feed mechanisms are chosen appropriately. Several geometries have been analyzed for generating efficient, high gain Dielectric Resonator Antennas (DRA) [1–3]. The various shapes are cylindrical, hemispherical, etc. However, a DRA compared to a microstrip antenna have lower gain and directivity. DRAs have no metal inclusion; hence, absence of copper losses decreases the overall losses of the DRA. On the other hand, they offer a wide bandwidth of operation. Several analyses have also been carried out to demonstrate gain enhancement by using different feeding techniques in the antenna. The novel feed techniques used for investigation of DRAs include aperture coupled feed [4], microstrip feeding [5] and dielectric image line [6]. Further, bandwidth and gain enhancement of Hemispherical Dielectric Resonator Antenna (HDRA) are also possible using Air Gap, Multi Layer techniques and modification in shapes [7,19].

Electromagnetic Band Gap (EBG) structures, on the other hand, are periodic rod or hole type structures that inhibits propagation of Electromagnetic (EM) wave over a range of frequency called Band Gap. EBG because of the property of sharp rejection have found various applications in antennas and filter components to work on various frequency levels and on different geometries like square lattice, hexagonal lattice on microstrips, CPWs, etc. [8–12]. In antennas, it has been used for gain and directivity enhancement. This investigation has been carried out on many different MIC based antennas [13–16]. In filters [17,20], it aids in the improvement of the roll off factor in pass band and stop band by minimizing the effect of the surface waves and also lower the radiation losses.

In this paper, an HDRA embedded in an EBG substrate for its bandwidth and gain enhancement has been proposed. A simple HDRA and EBG have been well known, however, no such investigation by combining the effects of an EBG and HDRA or any DRA so far, has been investigated. The simulations have been done on CST Microwave Studio (Finite Integration in Time method) and HFSS (Finite Element based) to validate the results. To the best of our knowledge, such an investigation has not been made so far and so this is an attempt to understand how the two distinct features effects the performance of the HDRA cumulatively.

2. Configuration of the antenna and EBG

The antenna configuration is as shown below in Fig. 1. Hemisphere of radius 2.54 cm (1″) is designed from a dielectric material with relative permittivity $\varepsilon_r = 8.9$. A feed probe of diameter 0.15 cm and length 1.52 cm penetrates the hemisphere at a distance 0.8 cm

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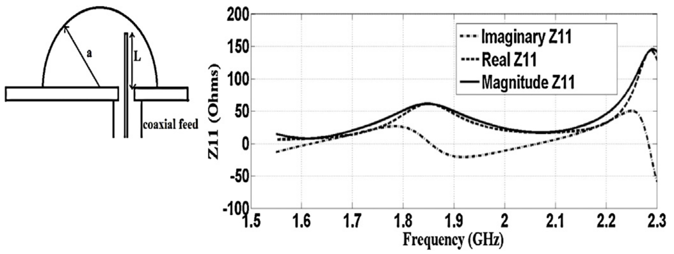

Fig. 1. The HDRA and plot of the real, imaginary and magnitudes of the impedance Z11 at input port in CST Microwave as compared to Ref. [3].

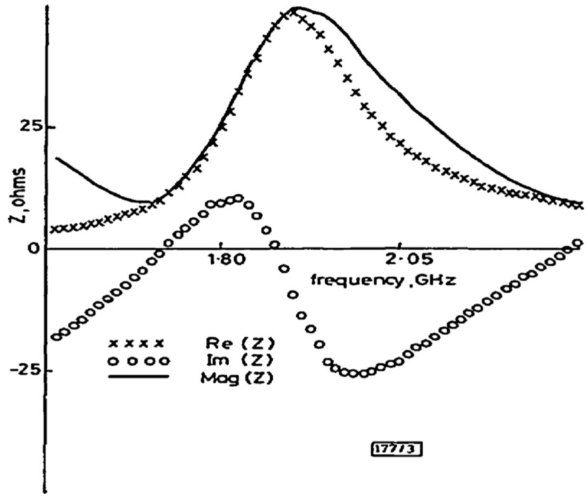

Fig. 2. The real, imaginary and magnitude of the impedance Z11 at input port as shown in Ref. [3].

from the edge. The resonant frequency (f_r) of the HDRA is calculated by the following formula [3]:

$$f_r = \frac{4.775 \times 10^7\, Re(K_a)}{\sqrt{(\varepsilon_r)}a} \tag{1}$$

where f_r is the resonant frequency, ε_r is the dielectric constant of the DRA, a is the radius of the hemisphere in cm and K_a is the wave number in the dielectric.

The above designed antenna is analyzed in time domain using CST Microwave Studio and HFSS. The resonance as per the experimental verification confirms at 1.9 GHz [3] whereas our simulation result is in close agreement at 1.85 GHz as can be observed in Fig. 1. Fig. 2 shows the results of Ref. [3] for a better comparison with our simulated results. The return loss calculated from the simulation is −12.087 dB and a wide impedance bandwidth of 11.25%. The simulated result measures a gain of 6.13 dBi. The simulator set up in time domain solver of CST consists of 25 mesh cells per unit wavelength for finer meshing and accurate results, imposed with open boundary condition along all sides to perfectly emulate the real time environment. The simulator set up has been kept invariant throughout the process. Similar set up has been used in HFSS as well for validation of the results.

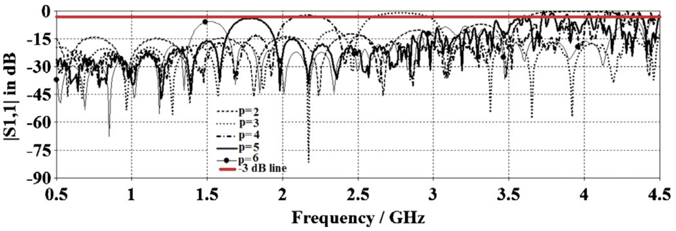

Fig. 3. The parametric sweep of S11 of the periodicity of the holes drilled in the dielectric.

In order to design a simple EBG structure, two constraints are important namely the contrast between the dielectric materials (contrast of permittivity of the dielectric material and the material of the drilled holes) and array size of the number of holes drilled. Higher the contrast of permittivity of the dielectrics and bigger the size of the array of the number of holes drilled, better is the band gap response of EBG. The HDRA resonates at 1.816 GHz and hence the design of the EBG is also centred at around this frequency. The critical parameters of the EBG include the radius of the hole '*r*' and the periodicity of the holes '*p*'. Further, the bandgap is formed due to effective cancellation of the reflected waves from the holes, which are positioned at approximately $\lambda/4$ distance to each other. The design of the EBG used for the purpose of analysis is a hexagonal lattice arrangement of air holes in a dielectric slab of dieletric constant $\varepsilon_r = 2.81$. Hexagonal lattice is chosen since the HDRA can be placed at its centre with a closer approximation than the square lattice based EBG. The optimization of the hole parameters begin with the periodicity in which the holes are to be placed. The S_{11} and S_{21} of the results of the parametric analysis are as shown in Figs. 3 and 4 respectively. Initially, the radius of the hole is chosen as 1 cm. It can be seen that as the periocity is increased from $p = 2$ cm to $p = 6$ cm, there is a shift in the band gap. Also, the span of the bandgap also increases. The span of the band gap, in our case has been depicted by −3 dB line, which shows the start and the stop frequencies of the band gap. This may be accounted to the fact that increasing periodicity, causes a better cancellation of the EM waves over a wider range of frequencies. The shift in the bandgap and the increase of bandwidth is also observed in the S_{21} response of Fig. 4 with increasing periodicity. The figures also suggest that the expected bandgap can be achieved between $p = 4$ cm and $p = 5$ cm. The optimized periodicity is, thus, reached at 4.5 cm

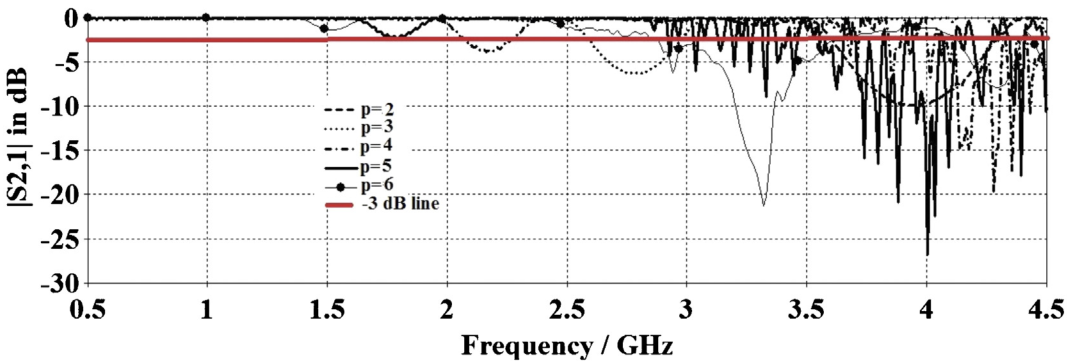

Fig. 4. The parametric sweep of S21 of the periodicity of the holes drilled in the dielectric.