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Ku Band Annular Ring Antenna on Different PBG Substrates

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ABSTRACT: *In this paper, two types of PBG structures, one is the periodic lattice of air holes on the substrate and the other is a periodic lattice of air holes through the substrate and the ground plane, have been incorporated on the FR4 substrate to improve the performance of a simple annular ring antenna operating in the TM_{31} mode. For Ku band FR4 has higher loss which is reduced by integrating the air holes on the substrates. The effective dielectric constant of the substrates with two PBG structures are calculated theoretically using the Wheeler's Transform. There is a considerable increase in gain of annular ring antenna with these two different forms of PBG structures. The designed antenna structures are compared to find out an optimum design.*

Keywords: *Annular ring antenna, higher order mode, Ku band, Photonic Bandgap, Surface wave,*

I. INTRODUCTION

The Antenna technology for satellite applications is an interesting commercial market for the mobile satellite terminals. Ku band is very popular for different satellite communication services, because of small component size and less interference at higher frequencies [1]. The effective size of the antenna is less which is very useful for satellite communication where small size is a great requirement. Therefore, the frequency of 14.5 GHz (Ku band) is selected for an optimum antenna design for applications in satellite communications.

In general it has been found that the FR4 substrate has high loss tangent in higher communication frequencies, and hence it is supposed to be unsuitable for Ku band. But conversely, FR4 is a low cost substrate and is very easily available. Also, the FR4 substrate has a higher dielectric constant which results in a smaller antenna size. To design a Ku band antenna on FR4, the losses due to the substrate have to be minimized. To reduce the losses, PBG structures can be integrated with the antenna. In the present endeavor, the structures selected are having air holes in the substrate resulting in reduction of dielectric constant and hence reducing the dielectric losses.

The objective of the present paper is to design, simulate, fabricate and test an enhanced gain Ku band patch antenna on FR4 substrate using Photonic Bandgap technology.

Photonic Band-gap structures (PBG) are periodic structures in which propagation of certain bands of frequencies is prohibited [2]. PBG structures are readily scalable and applicable to wide range of frequencies, including microwaves and millimeter waves. Several types of PBG structures have been developed previously for wide range of applications [3]-[8]. Two different forms of PBG structures have been used in this paper. One is a periodic lattice of air holes drilled on the substrate with the ground plane intact and the other is periodic lattice of air holes drilled through the substrate and ground plane [9]. Simulations have been carried out using the an soft HFSS software.

In section II, antenna design will be discussed. The simulated and experimental results of gain and power pattern will be discussed in section III. The last section will be conclusion that will summarize the entire research findings.

II. ANTENNA DESIGN

1.1 Theoretical Considerations: A simple annular ring antenna is designed for operation in the TM_{31} mode. An annular ring antenna has an advantage over the rectangular or circular patch antenna of having higher radiation efficiency because of two radiating edges. The selection of higher order mode is done to obtain good matching so that the antenna could be fed directly using coaxial cables [10]. The antenna is designed on FR4 substrate of height 1.6mm, ε_r = 4.4 and loss tangent 0.03 [11-12]. The dimensions 'a' and 'b' are the inner and outer radii of the ring and are calculated as 3.9 mm. and 5.85 mm. for a design frequency of 14.5 GHz. Feed point is optimized for best matching at (x,y,z) = (28, 22, 1.6). Antenna with PBG structure has slightly different dimensions than the reference antenna, so that annular ring antenna with PBG structure resonates at the operating frequency f_0 of reference antenna. Period of the PBG structure is obtained using the following relation [13].

$$f_0 = \frac{c}{2S\sqrt{\varepsilon_{ef}}} \qquad (1)$$

Where f_0 operating frequency of the antenna, S = period of the structure, c= speed of the light in free space and ε_{ef} = effective dielectric constant [14]. Radius of the air holes of Figure 1 and Figure 2 are calculated as 0.25S, such that an optimized PBG structure is obtained [15].

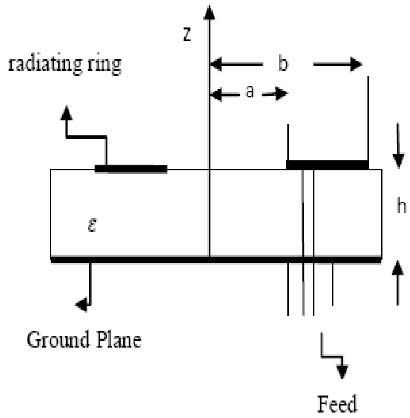

Fig.1 Geometry of **a**nnular ring antenna without PBG

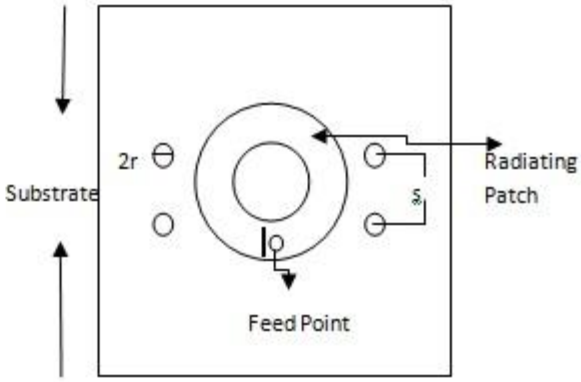

Fig.2 Annular ring antenna with periodic lattice of air holes drilled only on substrate (antenna1)

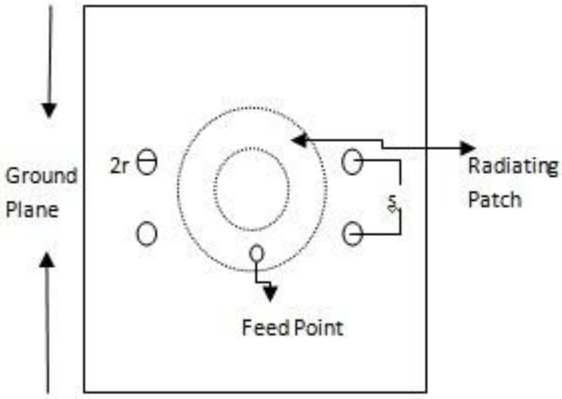

Fig.3 Annular ring antenna with periodic lattice of air holes drilled through substrate and ground plane (antenna2)

III. Fabricated Antenna

The antennas are fabricated using photolithography and chemical etching. For antenna 1, the ground plane is added after the holes are drilled (Fig.4) and for antenna 2 the holes are drilled through the substrate and the ground plane (Fig.5).

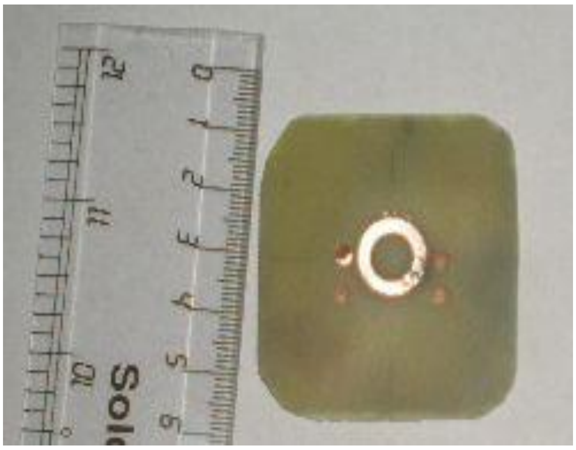

Fig.4. Top view of the fabricated annular ring antenna with periodic lattice of air holes drilled only on substrate (antenna1).

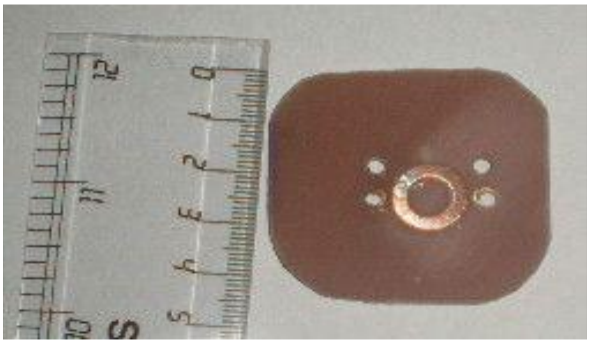

Fig.**5** Top view of the annular ring antenna with periodic lattice of air holes drilled through substrate and ground plane (antenna2).

IV. THEORETICAL CALCULATION OF EFFECTIVE DIELECTRIC CONSTANT

Effective dielectric constant of the substrate plays an important role in PBG concept. In antenna1 and antenna 2 due to introduction of air holes effective dielectric constant of the substrate reduces and hence increases the gain of antenna. Using Wheeler transform effective dielectric constant is calculated [16, 17]. The effective dielectric constant, ε_{ef} is calculated from the following equation [18].

$$\varepsilon_{ef} = \frac{\varepsilon_0 \varepsilon_1}{\varepsilon_0(1-q) + q\varepsilon_1} \qquad (2)$$

Where q is the filling factor and is calculated as

$$q = \frac{area\ of\ the\ four\ air\ hole\ cylinders}{Total\ area\ of\ the\ rectangle} \qquad (3)$$

ε_0 and ε_1 are dielectric constants of air and substrate respectively.

V. EXPERIMENTAL AND SIMULATION RESULTS

The reflection loss, S_{11} of the fabricated antenna is measured with the help of the Vector Network Analyzer and Radiation patterns are obtained using Spectrum Analyzer and Signal Generator. Reference patch antenna resonates at 14.5 GHz showing good agreement between experimental and simulated results. Figure 6 shows comparative experimental and simulated reflection loss of the reference antenna and antenna 1, Figure 7 shows the comparative experimental and simulated reflection loss of reference antenna and antenna 2, and Figure 8 shows the comparative experimental and simulated results of antenna 1 and antenna 2 for comparison.

Figure 10 and figure 11 shows experimental and simulated Power Pattern (dB10 normalized) at resonance for the antenna 1 and antenna 2.

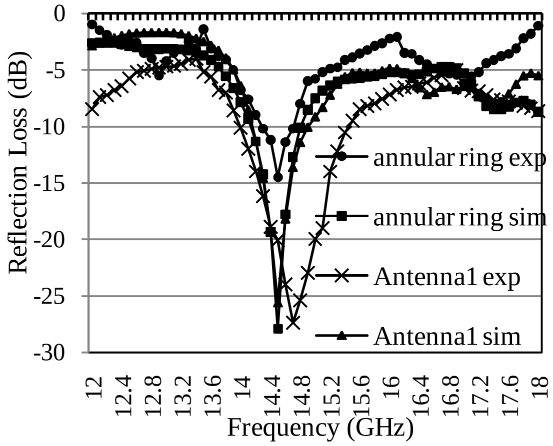

Fig. 6 Experimental and simulated reflection loss for the reference antenna and antenna 1.

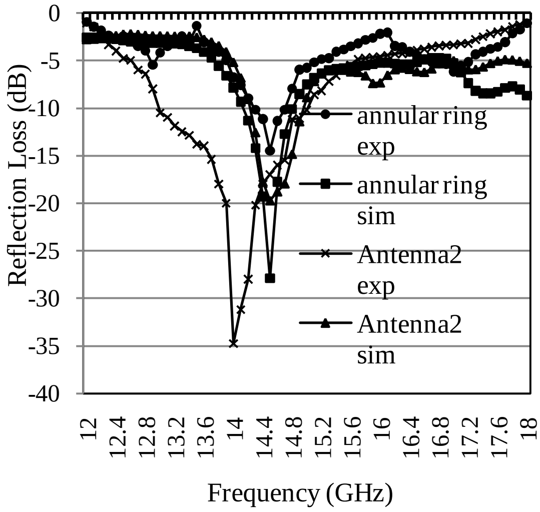

Fig.7 Experimental and simulated reflection loss for the reference antenna and antenna 2.

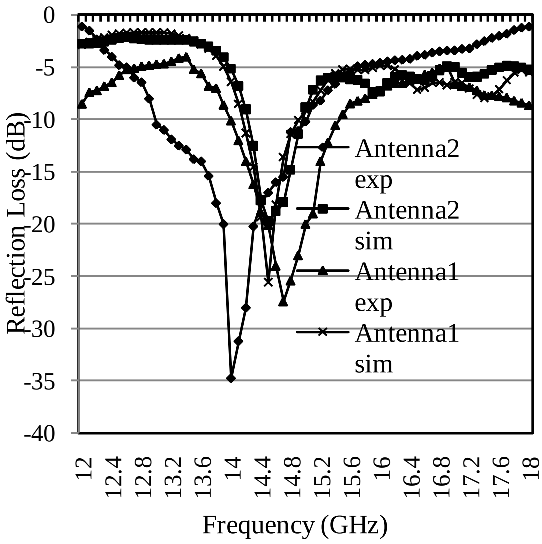

Fig. 8 Experimental and simulated reflection loss for the antenna 1 and antenna 2.

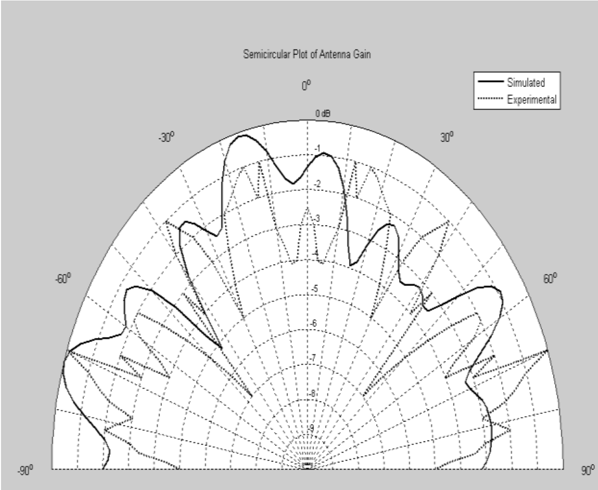

Fig.9 Experimental and simulated Radiation Pattern for reference antenna

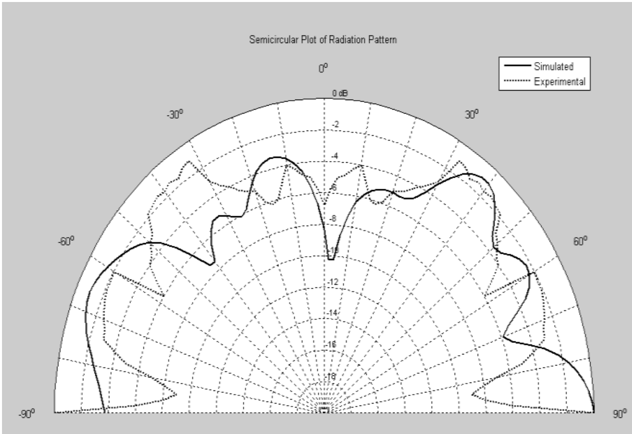

Fig. 10 Experimental and simulated Radiation Pattern for antenna1

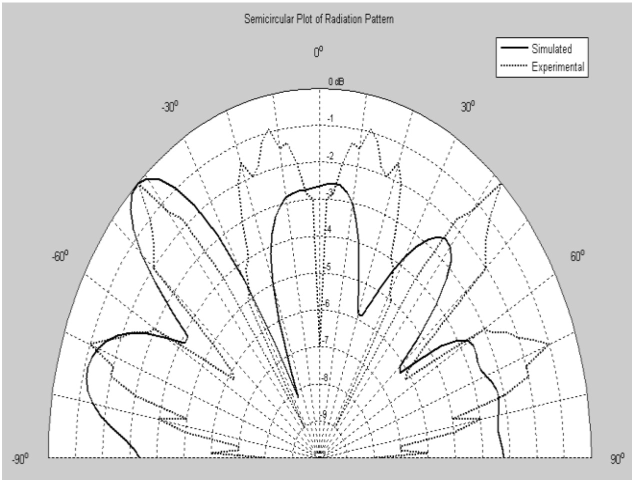

Fig. 11 Experimental and simulated Radiation Pattern for antenna2

VI. Discussions

Figure 6 shows comparative experimental and simulated reflection loss of reference antenna and annular ring antenna with periodic lattice of air holes on the substrate (antenna1). From this figure it is clear that antenna1 resonates at the operating frequency of reference antenna. Reference antenna resonates at 14.5 GHz with experimental and simulated reflection loss of -14.4 dB and -27.9dB respectively and antenna1 resonates at 14.5 GHz with simulated reflection loss of -25.5 dB and experimentally resonates at 14.7 GHz with reflection loss of -27.41 dB. The Matching improves with the PBG structure but there is a slight shift in the resonant frequency. Bandwidth of antenna1 has increased by three times of the reference antenna. Bandwidth of reference antenna is 2.75% and bandwidth of antenna1 is 9.52%. Figure 7 shows comparative experimental and simulated reflection loss for antenna 2 which resonates at 14.5 GHz with simulated reflection loss of –19 dB and experimentally it resonates at 14.0 GHz with reflection loss of -34.75 dB. The slight shift in the resonance frequency of experimental results of both the antennas can be attributed to little bit of fabrication inaccuracy.

Bandwidth is also increased in antenna 2, it again increases more than three times than the reference antenna. Bandwidth of antenna 2 is 10%. Figure 8 shows comparative experimental and simulated reflection loss for antenna1 and antenna 2 which emphasizes on the fact that antenna 2 gives the best value of S_{11}. The reference annular ring antenna has experimental and simulated maximum gain of 5.105 dB and 8.81 dB respectively. Antenna1 has experimental and simulated gain 9.168 dB and 13.48 dB respectively. Antenna2 has experimental and simulated gain 10.45 dB and 14.37dB respectively. The normalized power pattern of the antennas is shown in Fig. 9-11. The experimental and simulated results of the radiated power with angle are in good agreement for all the three antennas. The shift in radiation maxima is seen in all the cases which are a result of higher mode excitation [19].Table 1 shows the comparative results of all fabricated antennas.

VII. CONCLUSION

In this research article annular ring antenna with two different forms of PBG structures is presented. From the Theoretical calculation of effective dielectric constant, simulated and experimental results it is observed that the annular ring antenna with PBG structures have the advantage of gain enhancement. Annular ring antenna with periodic lattice of air holes drilled through the substrate and ground plane exhibits better gain enhancement than annular ring antenna with periodic lattice of air hole drilled only on the substrate. Objective of my research work is also fulfilled as gain of antenna2 is just doubled than simple annular ring antenna on FR4 and using Photonic Bandgap technology, a high gain, highly cost effective Ku band annular ring antenna is successfully designed. Improved antenna performances with this design make it useful for wide range of applications for higher frequencies.

TABLE I
COMPARISON TABLE

Para-meter		Simple annular ring antenna (Reference Patch antenna)	Antenna1	Antenna2
S11 dB	Simulated	-27.9dB (14.5 GHz)	-25.5 dB (14.5 GHz)	-19dB (14.5 GHz)
	Experimental	-14.4dB(14.5 GHz)	-27.41 dB(14.7GHz)	-34.75 dB(14.0 GHz)
Gain dB	Simulated	8.81 dB	13.48 dB	14.37 dB
	Experimental	5.105 dB	9.168 dB	B

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