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Design and Analysis of Microstrip Patch Antenna Using Periodic EBG Structure for C-Band Applications

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Abstract
In this paper, an Electromagnetic Band Gap structured microstrip patch antenna is presented. The proposed antenna consists of a rectangular patch which is fed by way of 50 Ω microstrip line feed. This antenna occupies a totally very small area of $22\times22\times0.8$ mm^3 etched on FR4 substrate, making it suitable for C-Band applications. The substrate has relative permittivity of 4.4. The unit cells are etched on the dielectric substrate with 10 mm × 10 mm size. This antenna improves the gain and decreases the return losses. This proposed antenna has the improve gain of 8.5112 dB. The merits are miniaturized size and at comfortable structure.

Keywords EBG · Microstrip patch antenna · Surface wave

1 Introduction

In Recent years small size of antenna with high gain and wider bandwidth is required. So microstrip patch antenna plays a vital role in modern communication systems. Researchers revealed slot radiators/antennas are appropriate applicants for unobtrusive base stations and portable units of mobile communications systems and have been extensively studied due to their low profile, low-cost [1–5], compactness, light weight [1, 3–5] flush-mounting, easy structure and simplicity of fabrication [1]. Layout of antennas integrating multiple competencies like high gain over an extensive impedance bandwidth, directive beam forming, functionality have attracted excellent interest among researchers for the increasing needs of wireless communication.

Several strategies had been advanced until date for enhancing multiple parameters of an antenna and variety of them has been used for accomplishing diversity in antenna radiation or polarization [2]. Some of the techniques are stacking patches and introducing slots. While introducing the mentioned properties, it is very difficult to guide the plane waves

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between the conductor–dielectric boundry. During the electromagnetic propagation energy is confined over the medium. Part of the energy is radiated and remaining energy reflected at the edges are called as surface waves [6]. This surface wave produces deep nulls, ripples in radiation patterns, gain reduction and reduced polarization purity, because it is scattered over the surfaces. This surface wave can be minimized by employing high impedance periodic structure like Electromagnetic Band Gap structures (EBG). In recent years, there was developing interest in making use of EBG structures within the electromagnetic and antenna community [7].

EBG is a High-Impedance Surface (HIS) is able to suppressing the propagation of surface wave that passes via it with band gap function. With that, it allows all frequencies of surface wave to permit through it, except for the specific frequencies which are intended to be suppressed. Consequently, it can be used as a frequency selector, filter and used to reduce the mutual coupling hassle in antenna and microwave devices layout. EBG's capability in manipulating electromagnetic behavior affords extra flexibility in designing antenna and other microwave devices [3]. Attributable to the exclusive properties of surface wave suppression in a frequency band gap and zero-phase reflection coefficient for positive incident waves, EBGs have been extensively utilized in various antenna applications [8].

In current years, the EBG structures have attracted much attention and numerous varieties of them were confirmed. In generally, they can be categorized into three collections allowing to their geometric configuration: (1) 3D volumetric structures, (2) 2D planar surfaces and (3) 1D transmission lines. With the properties of low profile and simplicity of manufacturing, the two-dimensional surfaces are mostly utilized in EBG structure designing and antenna engineering [4]. EBG configuration is one of the keys which can be used to cope with degradation in antenna overall performance. EBG structures can be characterized into following classes: (1) EBG substrates and HIS used to lessen surface waves; (2) defect resonator antennas that create excessive directivity over a narrow bandwidth; (3) sources embedded in EBG substances which have high directivity due to the limited angular propagation allowed within the material. EBG resources were successfully used to improve the performance of antennas [9].

EBG arrangements without vias are called uniplanar compact electromagnetic bandgap (UC-EBG), which has attracted a main study due to the aids of adaptable with popular planar circuit technology [10]. Compact EBG structures at the moment are important requirements for applications in electromagnetic and antenna network [11]. Technique to reduce the surface-wave impact in microwave arrangements is the EBG technology. The two-dimensional (2-D) UC-EBG structure is a periodic metal array that can be used as a ground plane or on top of a conductor-backed substrate [12]. The ground plane is removed. The group of unit cells is located on a substrate [5].

Nowadays, the research on EBG structures remains on going and gaining greater interest owing to the advantages introduced with the aid of this structure [13]. Lately metal arrays printed on a grounded dielectric substrate are obtainable obtained [14]. Through in view of the induced currents in the slotted EBGs and then designing the format pattern of the EBGs, the mechanism of the gain enhancement concluded EBGs [15]. The patch antenna owns the advantage of smaller dimensions, so it's more suitable to construct antenna arrays when substrates with low dielectric constant are used [16]. Two techniques had been used to suppress surface wave propagation, specifically micromachining and periodic structures known as the EBG structures [17].

In the literature, there are various techniques is employed to design the EBG resonator antennas (ERA) [18], compact antenna patch array [19], varactor integrated dipole-EBG array antenna [20], resonant cavity antennas [21], tunable double-layer EBG structures resonator antenna [22], dielectric resonator antennas [23], integrated uniplanar metamaterial-based EBGs [24], directive EBG antennas based on lattice modes [25], polarization rotation AMC structure [26], reconfigurable antenna [27], microstrip antenna using triple-band planar [28], dual-band antenna [29] and analyzing the parameters which includes return loss, gain and radiation pattern and it operated for numerous applications such as wideband footprint area [18], includes isolation enhancement [19], smart base station antennas [20], large directivity-bandwidth products [21], antenna isolation [22], MIMO systems [23], multi band [24], dual polarization [25], high-performance multi-polarized reconfigurable antennas [26], ISM band [27], gain enhancement and wideband radar cross section reduction (RCSR) [28] and mobile handset applications [29]. From the suggested papers, it's investigated that the antennas are bigger in size. With the intention to mitigate aforementioned issues, in this effort miniature primarily based microstrip patch antenna is designed by way of hexagonal shape unit cells. The sizes of each antenna are meant to operate at a frequency of resonance of 6.7 GHz. The antenna have been analyzed the manner of computer simulation and results have been analyzed.

The design calculation of patch is in brief defined in Sect. 2. The proposed microstrip patch antenna design is described in Sect. 3. The design of EBG unit cell is explained in Sect. 4. The EBG structured antenna design is given in Sect. 5. In Sect. 6 details of fabrication and measurements is explained. The experimental results and discussion is given in Sect. 6. Finally, the conclusion of this work is presents in Sect. 7.

2 Microstrip Patch Antenna Design

Design terms of proposed antenna, the length and width are most crucial parameters which are calculated as follows,

1. The Resonant frequency is selected by 6.7 GHz.
2. The substrate of the material is selected by FR4.
3. The dielectric constant of the substrate is 4.4.
4. The loss tangent of the substrate 0.02.
5. Width of the patch

$$\mathrm{W} = \frac{c}{2fr\sqrt{\frac{(\varepsilon_r+1)}{2}}} = 13.041\ \mathrm{mm}.$$

6. Actual length of patch

$$\mathrm{L} = \mathrm{L}_{\mathrm{eff}} - 2\Delta\mathrm{L} = 9.994\ \mathrm{mm}.$$

The geometrical view of microstrip patch antenna is shown in Fig. 1. The length and width of the substrate are 22 mm and 22 mm respectively. The rectangular patch fed by way of a microstrip line that has an impedance of 50 Ω and it resonates at a frequency of 6.7 GHz which has a width of 13.041 mm and length of 9.994 mm. The dielectric substrate has FR4 material with relative permittivity (ε_r) of 4.4 and loss tangent of 0.02 is considered. The height followed for the substrate become 0.8 mm. The length of the feed is 6.006 mm and the width of the feed is 0.5 mm. The structural parameters for the microstrip patch antenna are shown in Table 1.

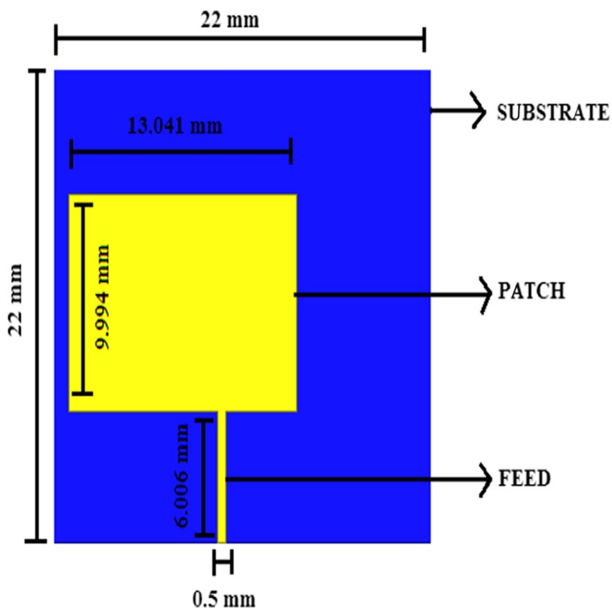


Fig. 1 Geometrical view of microstrip patch antenna

Table 1 Structural parameters of micro strip patch antenna

Parameters	Dimensions (mm)
Substrate length	22
Substrate width	22
Substrate height	0.8
Patch length	9.994
Path width	13.041
Feed length	6.006
Feed width	0.5

3 Design of EBG Unit Cell

The structure of the unit-cell contains a slotted rectangular cell of 10 mm length and 10 mm width, centered with hexagonal slots. Complementary split ring is produced on the ground plane, which consists of two concentric hexagonal split rings with the thickness 1.1 mm and the gap between the complementary rings is 0.9 mm. The schematic view of single unit cell structure is shown in Fig. 2. The parameters of unit cell are given in Table 2.

A full wave simulation based on Finite Element Method is carried out to analyse the properties such as permittivity, permeability, S-parameter and Surface impedance of the proposed unit cell, and it is given as follows:

Fig. 2 Schematic of single unit cell structure

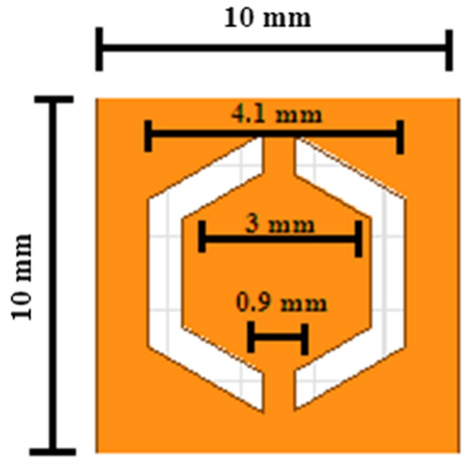


Table 2 Parameters of unit cell

Parameters	Dimensions (mm)
Rectangular cell length	10
Rectangular cell width	10
Hexagon outer radius	4.1
Hexagon inner radius	3
Gap between the hexagons	0.9

3.1 Permittivity and Permeability

Permittivity is a measure of the resistance in forming an electric field through a medium. It is important electric parameters of the materials, especially in the case of insulators. Permeability is a measure of a material's ability to form magnetic fields within it. It is an important property when considering the magnetic properties of a material. The permittivity and permeability of unit cell is shown in Fig. 3. It seems that the effect of permittivity and permeability while differing the frequency. It appears that the proposed SRR accord negative permittivity which is fundamental to guarantee the alluring execution. This hexagonal shaped unit cell produces negative permittivity and negative permeability at the same time.

3.2 Transmission Co-efficient

A transmission co-efficient describes the amplitude intensity or total power of a transmitted wave relative to an incident wave. The transmission co-efficient of unit cell is shown in Fig. 4.

It is noticed that the hexagonal EBG structure is centered at 6.7 GHz. It produces a bandgap about 400 MHz from 6.5 to 6.9 GHz ($S12 < -10$ dB). No surface wave can propagate inside this frequency band gap.

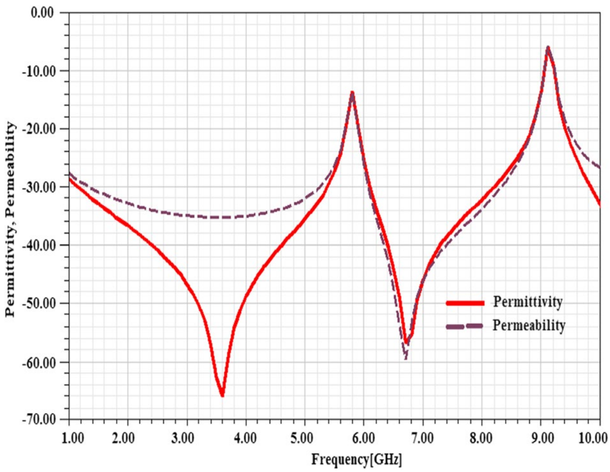


Fig. 3 Permittivity and permeability of unit cell

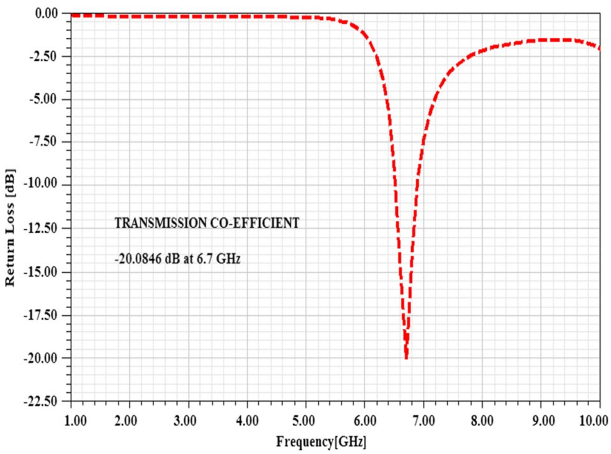


Fig. 4 Transmission co-efficient of unit cell

3.3 Surface Impedance

Normally the surface impedance and the impedance of the parallel resonant circuit is equal to each other. It depends on the capacitance and inductance of the EBG unit cell. The EBG supports TM surface waves at low frequencies and TE surface waves at high frequencies. Between these two bands near the resonance frequency, the imaginary part of the surface impedance of the EBG structure becomes very large, where both TE and TM surface waves are suppressed (i.e. the surface does not support bound surface waves), resulting in an electromagnetic surface wave band gap. The variation of the surface impedance with respect to frequency is shown in Fig. 5. It is observed that the surface has inductive impedance for low frequencies and over the high frequencies the surface impedance is capacitive. At the resonant frequency 6.7 GHz crosses through infinity.

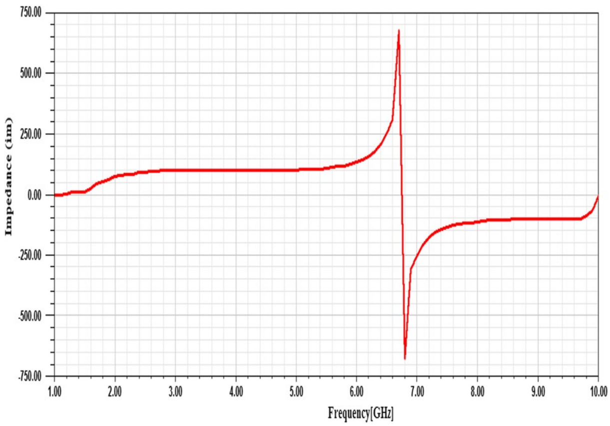


Fig. 5 Surface impedance of unit cell

4 Design of EBG Antenna

A periodic structure of the EBG unit cell having 10×10 mm^2 arrays is modeled to create electromagnetic fields back of substrate that are favored for the improvement of proposed antenna. EBG array structure is shown in Fig. 6.

There are four arrays are arranged in periodic structures. EBG arrays are mounted on the 22×22 mm^2 FR4 substrate. The gap between the unit cells are 1 mm.

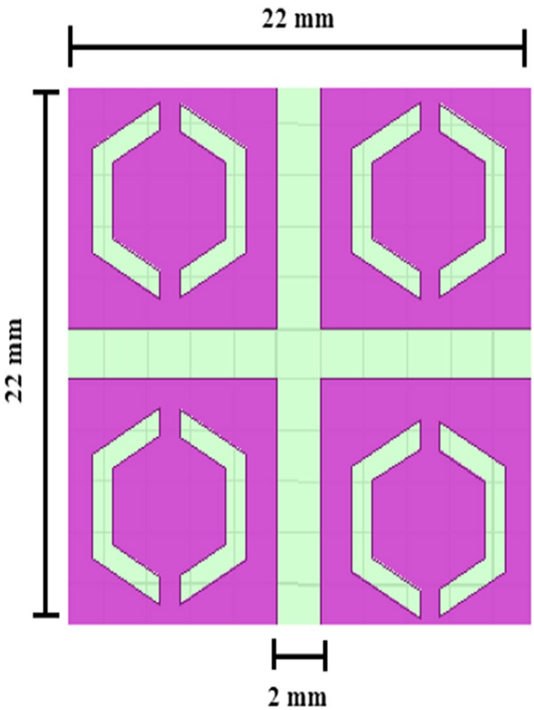


Fig. 6 Schematic of EBG array structure

Figure 7 shows the proposed microstrip patch antenna using EBG structure. The aim of enhancing the performance of the proposed antenna had been introduced unit cells within the substrate. By varying the thickness and the gap between the concentric rings of the hexagonal split ring the performance of proposed antenna is analyzed.

5 Results and Discussions

5.1 Patch Antenna

The conventional as well as the EBG antenna are simulated, fabricated and measured followed by the design procedure. From the return loss shown in Fig. 8a, it is noticed that the better return loss of −10 dB is achieved from 6.5 to 6.8 GHz and from 8.6 to 8.8 GHz. At resonant frequency of 6.7 GHz the conventional antenna produces return loss of −12.73 dB. The VSWR of the conventional patch antenna is shown in Fig. 8b. It is observed that the VSWR of 1.6 is achieved at 6.7 GHz. The radiation pattern graph at 6.7 GHz, the gain and the directivity of the conventional patch is shown in Fig. 8c–e, respectively. The gain and the directivity are 3.26 dB and 5.32 dB respectively.

5.2 EBG Antenna

The parameters of the EBG antenna are shown in Fig. 9. From the return loss shown in Fig. 9a, it is observed that the return loss of −32.24 dB is achieved at 6.5 GHz. The proposed antenna without EBG surface produces return loss of −12.73 dB at the resonant frequency of 6.7 GHz. The return loss is enhanced about −32.24 dB at 6.5 GHz, after using EBG structure on the substrate. It is observed that EBG structures on the substrate reduce surface wave radiation hence; the return loss is reduced as −32.24 dB from −12.73 dB. The VSWR of the

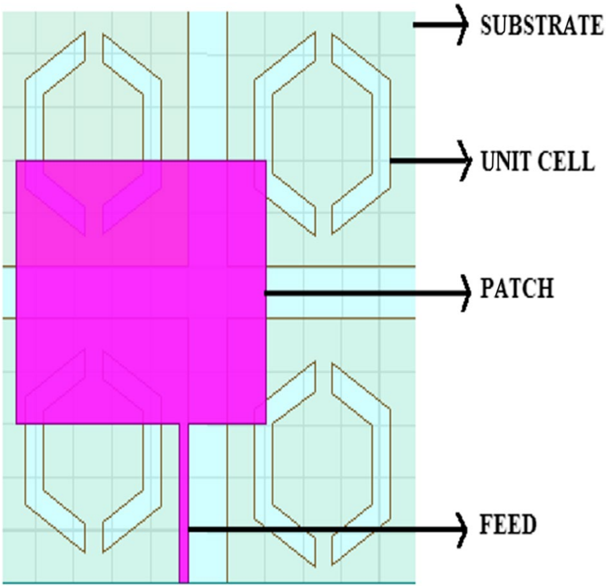


Fig. 7 Proposed microstrip patch antenna using EBG structure

Fig. 8 Parameters for the antenna **a** return loss, **b** VSWR, **c** radiation pattern, **d** gain, and **e** directivity

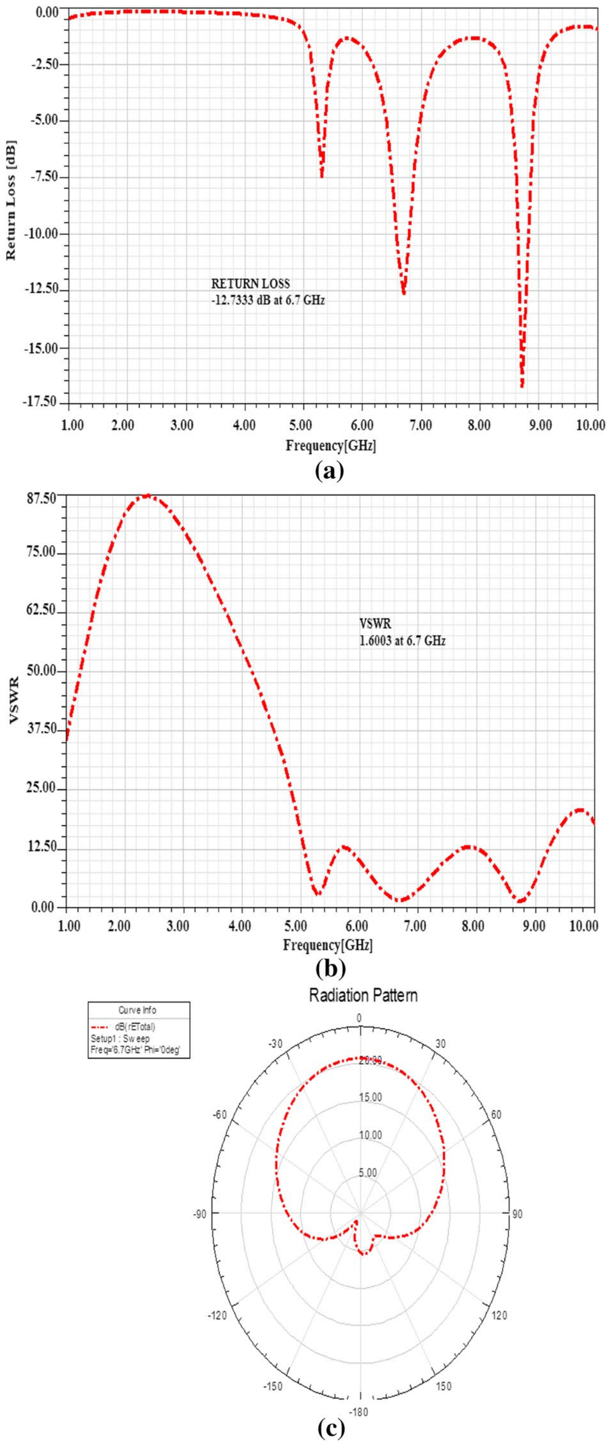
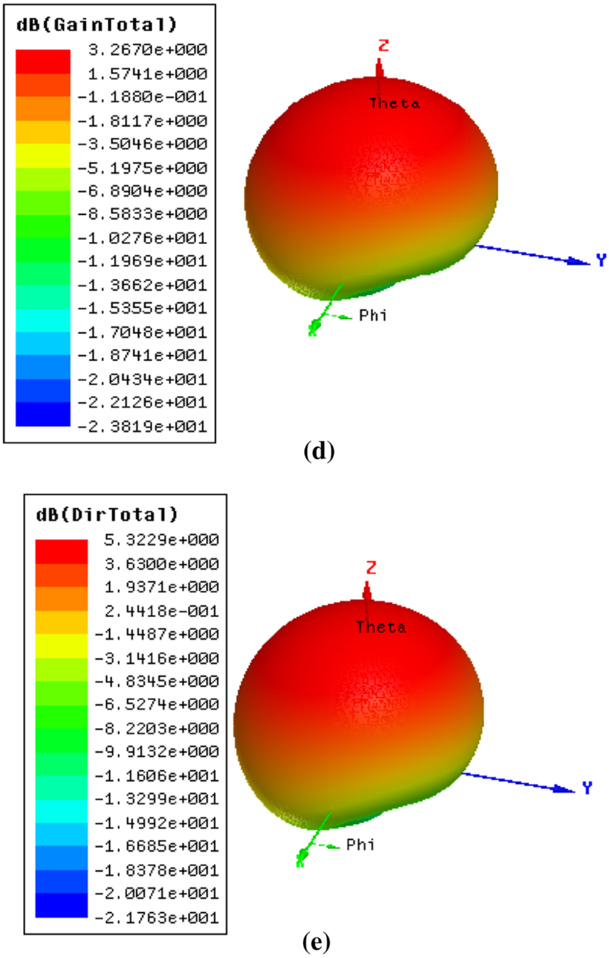


Fig. 8 (continued)

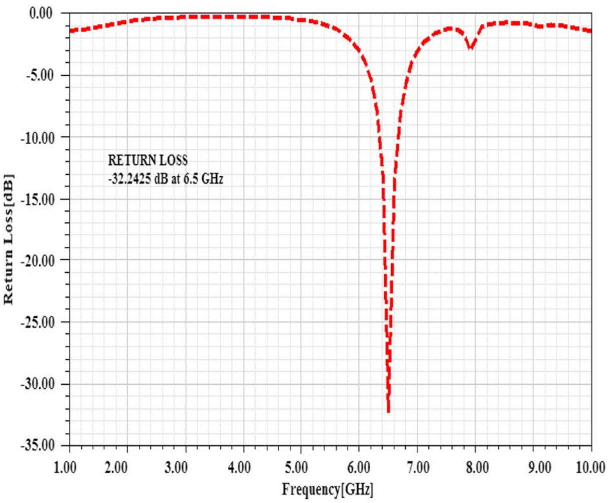


EBG antenna is shown in Fig. 9b. It is noticed that the VSWR is reduced as 1 form 1.6 after employing the EBG structures. The radiation pattern graph at 6.5 GHz, the gain and the directivity of the conventional patch is shown in Fig. 9c–e, respectively. The gain and the directivity are 4.94 dB and 1.94 dB respectively.

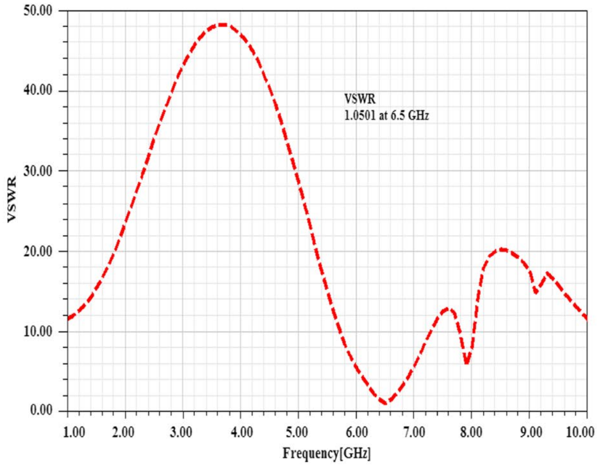
6 Fabrication and Measurements

The antenna integrated with EBG structure in ground surface is fabricated and the results are measured. Figure 10 shows the view of fabricated antenna. The measurement is taken to compare the simulated results with the measured ones.

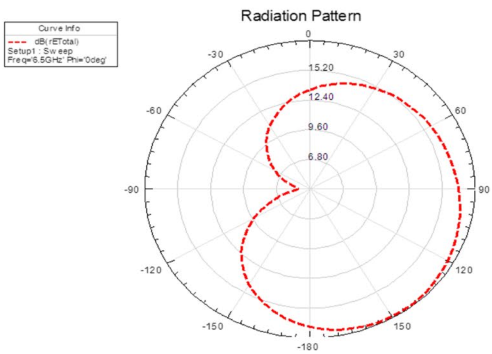
Fig. 9 Antenna parameters of proposed EBG antenna **a** return loss, **b** VSWR, **c** radiation pattern, **d** gain, and **e** directivity



(a)

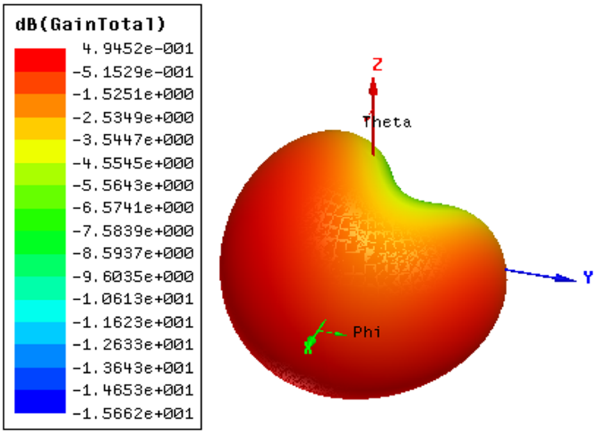


(b)

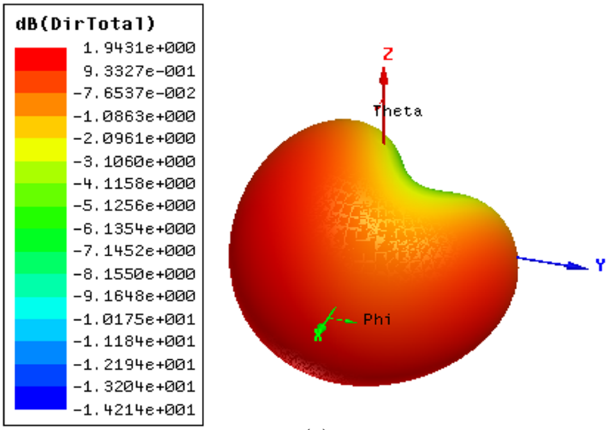


(c)

Fig. 9 (continued)



(d)



(e)

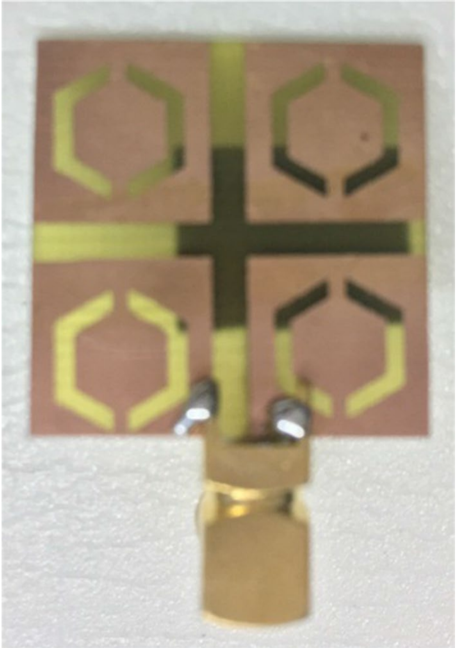
6.1 Return Loss

Figure 11 is Vector network analyzer (VNA) is used to measure the return loss. The simulated and measured return loss result of fabricated antenna. The simulated frequency variety is found at −32.24 dB at 6.5 GHz, whereas the measured equivalent result is −42.45 GHz at 6.479 GHz respectively.

6.2 VSWR

Figure 12 shows the VSWR of fabricated antenna. The simulated frequency variety is found at 1.05 at 6.5 GHz, whereas the measured counterpart is 1.01 GHz at 6.4 GHz.

Fig. 10 View of fabricated antenna



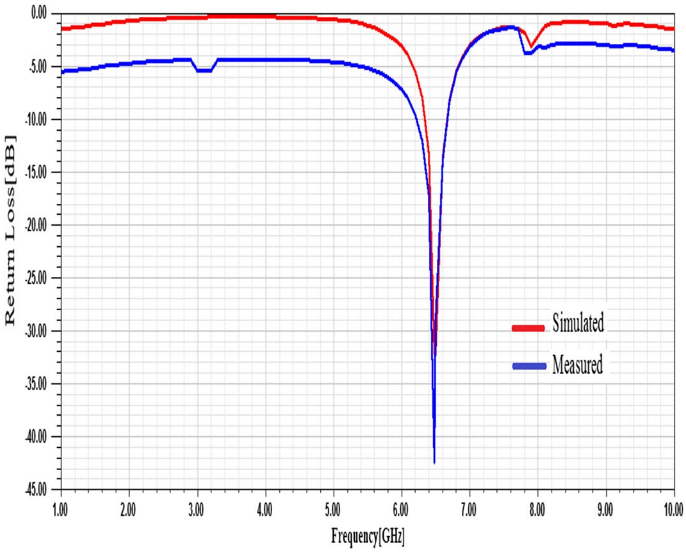


Fig. 11 Return loss of fabricated antenna

7 Parametric Analysis

The proposed antenna of the EBG structure are designed at an operating frequency of 6.7 GHz while varying the radius of the hexagon and varying the gap that are simulated

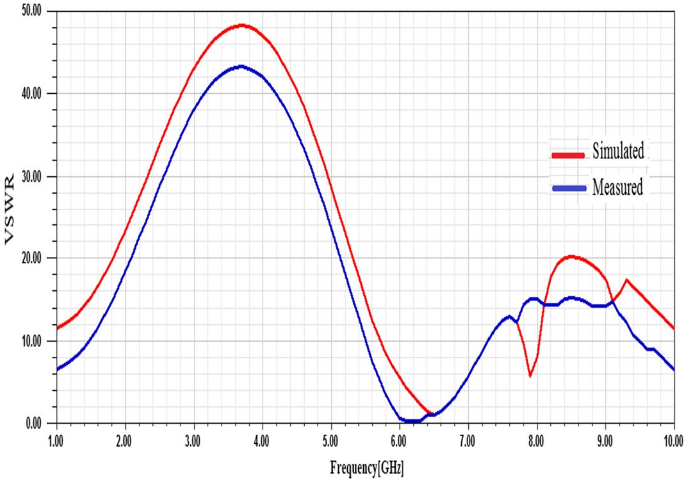


Fig. 12 VSWR of fabricated antenna

using the software. The solution technique generates the field variations for S-parameter determination. The thickness of the hexagonal complementary ring is varied as 0.9 mm, 1 mm and 1.1 mm. By way of varying the space between the concentric hexagons are 0.7 mm, 0.8 mm and 0.9 mm. The structural details of proposed microstrip patch antenna and the varieties of configurations are given in Table 3.

Figure 13 shows the return loss for the thickness of hexagonal ring is 0.9 mm (Conf. I). It is observed that the minimum return loss of −22.08 dB at 6.5 GHz, −21.40 dB at 6.5 GHz and −23.23 dB at 6.6 GHz are achieved when the gap between the concentric hexagons are 0.7 mm, 0.8 mm and 0.9 mm respectively.

The return loss for the Conf. II (hexagonal ring with the thickness of 1.0 mm) is shown in Fig. 13. It is observed that when the thickness of the hexagonal ring increases the return loss is slightly reduced. The return loss produced by the thickness of 1.0 mm are

Table 3 Types of configurations

Configurations	Thickness of the hexagonal ring (mm)	Gap (mm)
Unit cell length is 10 mm and width is 10 mm		
Conf. I		
Conf. I (a)	0.9	0.7
Conf. I (b)		0.8
Conf. I (c)		0.9
Conf. II		
Conf. II (a)	1.0	0.7
Conf. II (b)		0.8
Conf. II (c)		0.9
Conf. III		
Conf. III (a)	1.1	0.7
Conf. III (b)		0.8
Conf. III (c)		0.9

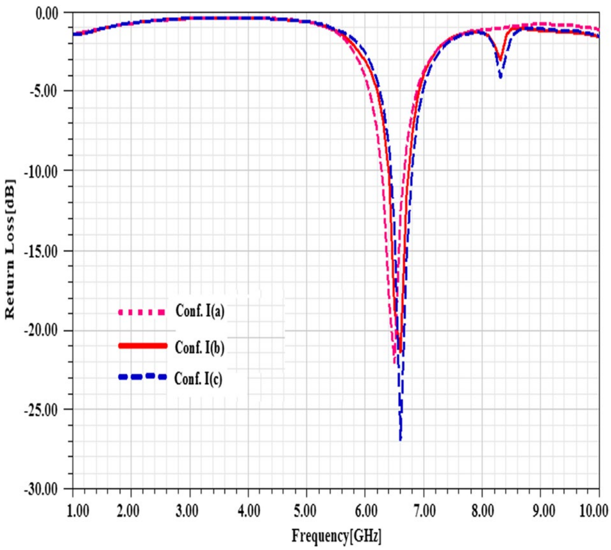


Fig. 13 Impact of return loss for Conf. I

−22.00 dB at 6.4 GHz, −31.99 dB at 6.5 GHz and −19.79 dB at 6.6 GHz when the gap between the concentric hexagons are 0.7 mm, 0.8 mm and 0.9 mm respectively (Fig. 14).

Figure 15 shows the return loss for the thickness of hexagonal ring is 1.1 mm (Conf. III). It is noticed that compared to conf. I and Conf. II the return loss is reduced still more. The minimum return loss of −32.24 dB at 6.5 GHz when the gap between the concentric hexagons is 0.9 mm. Also return loss of −22.58 dB at 6.4 GHz, −21.36 dB at 6.5 GHz and are achieved when the gap between the concentric hexagons are 0.7 mm, 0.8 mm and 0.9 mm respectively.

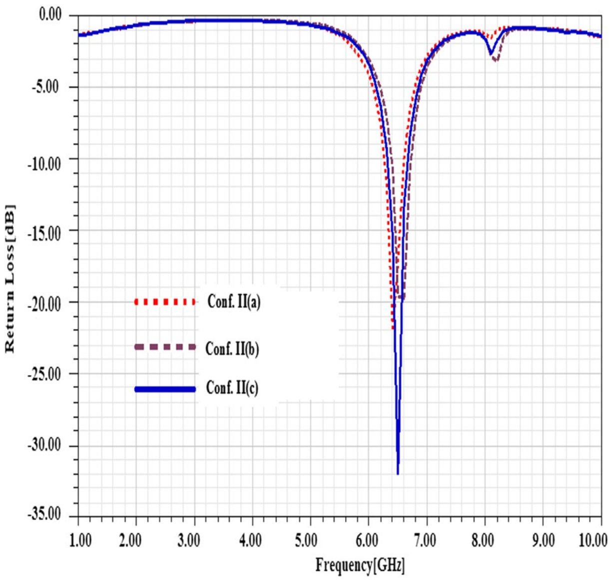


Fig. 14 Impact of return loss for Conf. II

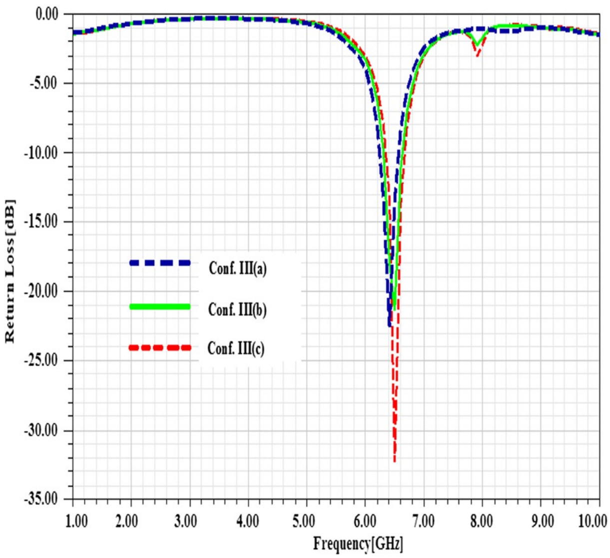


Fig. 15 Impact of return loss for Conf. III

Table 4 Comparison result of parameters for EBG antenna

Configurations (C)	Return loss (dB)	VSWR	Gain (dB)	Directivity (dB)
Conf. I				
(a)	−22.08	1.17	5.52	1.75
(b)	−21.40	1.18	8.51	2.16
(c)	−23.23	1.14	7.13	2.00
Conf. II				
(a)	−22.00	1.17	2.56	1.78
(b)	−31.99	1.05	5.92	2.00
(c)	−19.79	1.22	5.01	1.87
= Conf. III				
(a)	−22.58	1.16	4.05	1.96
(b)	−21.36	1.18	7.75	2.14
(c)	−32.24	1.05	4.94	1.94

The comparison results of antenna parameters such as return loss, gain, directivity regarding to the variation of outer radius and gap with the respective frequency is shown in Table 4.

8 Conclusion

A compact hexagonal shaped EBG antenna is proposed, designed and fabricated on FR 4 substrate with the substrate thickness 0.8 mm. Electromagnetic band gap is obtained from 6.5 GHz to 6.9 GHz after introducing EBG structure on ground plane as the high surface impedance. The proposed antenna produces the return loss of −32.24 dB at the resonant frequency of 6.5 GHz. Also, the antenna produces maximum gain of 8.51 dB. This proposed antenna has been fabricated and the results were measured. This antenna has good antenna parameters, miniaturized size and at comfortable structure.

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