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Performance Analysis of Micro Strip Patch Antenna at 2.4 GHz using Metamaterial

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Abstract— In this article, rectangular shape Micro strip Patch Antenna (MPA) with cut edges is proposed at 2.4 GHz for ISM and Wi-Fi application. The proposed antenna is designed on fr-4 material having standard thickness of (h=1.6mm), relative permittivity (εr= 4.3) and loss tangent 0.02. PEC is used as a conducting element for radiating patch and ground plane. The volume of proposed antenna is 58 x 58 x 1.6 mm3. The proposed antenna resonates at 2.4 GHz having return loss -21dB, gain 3.14dB and efficiency 41%. For achieving good performance of antenna 4 x 4 Electromagnetic Bandgap (EBG) structure is used. By utilizing EBG structure as a ground plane a discernible improvement occur in the performance of proposed antenna. Proposed antenna with EBG structure gives gain up to 68.14dB, return loss -32dB and efficiency 85%. The antenna and mushroom type EBG is designed and simulate in CST microwave studio.

Keywords— Micro strip antenna, EBG (metamaterial), in-phase reflection, surface waves suppression.

I. INTRODUCTION

In the advancement of wireless communication, use of planer Micro strip patch antenna (MPA) in various wireless application become increases due to certain advantages like, low profile, low weight, less costly and easily integration with other devices and compact size. However, MPA has drawbacks like low radiation efficiency, limited bandwidth, less directive gain and unstable radiations. The use of metamaterial can lessen these drawbacks.

Metamaterials are firstly used by Bose [1] where he introduced the use of metamaterial with chiral structure. Afterwards, the use of metamaterial was put in practise in the field of radio frequency and system design.

According to Veselago [2], metamaterials are unnatural uniform material which doesn't exist in natural world. Mostly attributes of meta material are described by electric permittivity and magnetic permeability [3]. Air is the thinnest material in nature having permittivity εo and permeability μo. The relative permittivity and permeability is expressed as $\varepsilon r = \varepsilon / \varepsilon o$ and $\mu r = \mu / \mu o$ [35]. Naturally most of the materials have permittivity and permeability greater than εo. Although metamaterial exhibits either ε or μ or both of them negative [4].

Metamaterial structure acts as high-impedance surface (HIS) in specific frequency band and is known as band gap of the (HIS). Electromagnetic bandgap structure (EBG) has two characteristics which offer [5]. i) It suppresses the surface waves, minimize back radiations which results in improvement in gain and radiation efficiency. ii) It also gives in-phase reflection. These surfaces have also the property of protecting human body from intensive radiation and reduce the specific absorption rate (SAR) and reduction in impedance match when antenna operates nears the body for wearable applications [6].

In literature, dual band MPA is modelled using fr-4 substrate as a dielectric material which is applicable for WI-MAX, W-LAN and WIFI [7]. A wearable planer E-shaped single band antenna for rescue operations, while single band circular shape having T-shape slot operating at 2.45GHz are studied in [8-9]. In [10] metamaterials are utilized in the designing of low profile antenna for compact portable electronic devices. Slots are taken in Mushroom-type EBG increase capacitance thereby reducing in-phase frequency and size reduction [11].

In study, Metamaterial EBG structure is designed with no cylindrical vias; due to which surface wave propagate on the surface of EBG metamaterial [12]. Reduction in the length of antenna is achieved, by increasing the relative permittivity of dielectric material in [13]. By using EBG surface as ground improvement in the behaviour of antenna can be achieved [14]. Novel EBG is designed by creating slots in the conventional EBG to improve the return loss is studied in [15].

A single band Micro strip patch antenna having FR-4 substrate as a dielectric material, operating at 2.4GHz is presented in this paper. To enhance the performances of antenna i.e. (gain, directivity, efficiency, beamwidth) by employing the antenna with Mushroom-like EBG, which is created through taking small rectangular slots at the top and bottom of EBG unit cell to provide in-phase reflection at 2.4GHz. A good improvement occurs in gain and directivity by using EBG (metamaterial) surface as a ground plane. The optimization of EBG structure gives surface wave band gap at 2.4GHz, which suppress the surface waves providing the better gain and efficiency.

This article is organized as: Section II describes the antenna designing theory and results of proposed fracture antenna without metamaterial. The design of mushroom-like EBG to provide in-phase reflection and surface wave band gap is covered in Section III. while Section IV present the integration of proposed fracture antenna with mushroom-like EBG, and comparison of results with and without EBG. Conclusion is derived in Section V.

II. ANTENNA DESIGN THEORY AND RESULTS

A. *Antenna Designing theory:*

A single band micro strip patch fracture antenna operating at frequency 2.4 GHz is modelled in CST microwave studio. FR-4 material is used as substrate, having relative permittivity 4.3 and loss tangent 0.02 respectively. The thickness of the substrate is chosen as standard thickness which is (h=1.6mm). Total volume of proposed antenna is ls×ws×h (58×58×1.6mm3). Where ls is length of the substrate, Ws is width of substrate and h is the height of substrate.

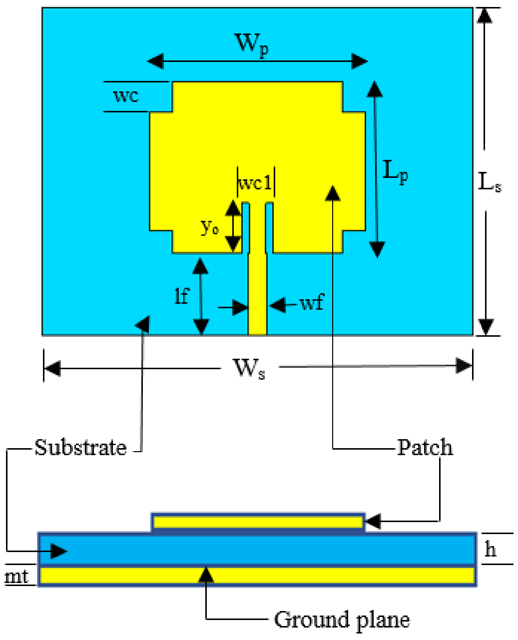


Fig.1. Proposed Antenna Geometry (top and side views) of patch antenna

PEC is used as conducting material for radiating patch and ground plane. Fig.1. shows the geometry of prosed fracture antenna. At all side of rectangular patch (wc=3×2mm) cuts are etched in the patch. The antenna is fed through 50 (ohm) micro strip feed line. The dimension of the proposed antenna is calculated form transmission line theory [16].

The width of the antenna (wp) is determined from the equation:

$$W=\frac{c}{fr}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

Where ε_r is dielectric constant, c is the speed of light, f_r is resonating frequency.

The effective dielectric constant ε_r is determined from equation 2.

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\times\sqrt{(1+(\frac{12h}{w}))} \tag{2}$$

H represents the thickness of dielectric material.

Length (l_P) of the antenna is determined from equation 3.

$$L_{eff}=\frac{c}{2fr\sqrt{\varepsilon_{reff}}} \tag{3}$$

Where ΔL represent difference between original and electrical lengths.

$$\Delta L=0.412\times h\times\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.26)}{(\varepsilon_{reff}+0.253)(\frac{w}{h}+0.8)} \tag{4}$$

Therefore, the effective resonant length of the radiating patch is:

$$L=L_{eff}-2\Delta L \tag{5}$$

The optimized parameter of proposed antenna is given in table.1.

TABLE I. DIMENSIONS OF FRACTURE ANTENNA

parameters	Description	values(mm)
L_S	Substrate length	58
W_S	substrate width	58
L_P	patch length	30.4
W_P	patch width	38
W_F	Feed line width	3.2
L_F	Feed line length	14.5
Y_O	Feed cut	8.85
WC	Length and width of rectangular cut	3×2
WC1	width of feed cut	5.6
h	Substrate thickness	1.6
mt	Patch thickness	0.035

B. *Proposed Antenna: Results*

S_{11}, vswr, polar plots of (Gain and directivity) simple ground surface is given below.

a) *S_{11} (Reflection coefficient)*

S11 of proposed Micro strip antenna is -25dB at 2.4GHz, while 60MHz bandwidth is achieved at resonance frequency. S11 of investigated antenna with full ground plane is given in fig.2.

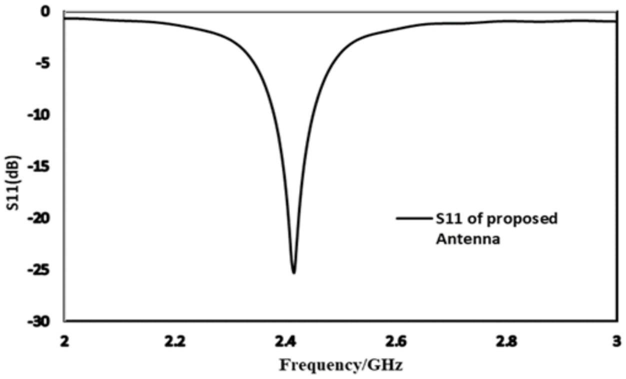


Figure.2. S_{11} of proposed antenna simple ground

b) *VSWR (Voltage standing wave ratio)*

For good matching the vswr should be nearly equal to one at the resonance frequency. The value of vswr at 2.4GHz is 1.3 respectively. Fig.3. shows good matching of proposed antenna.

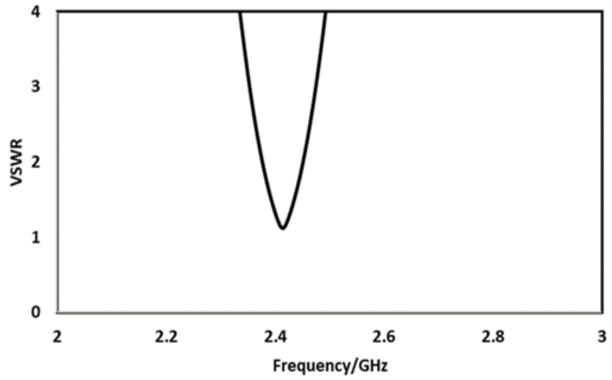
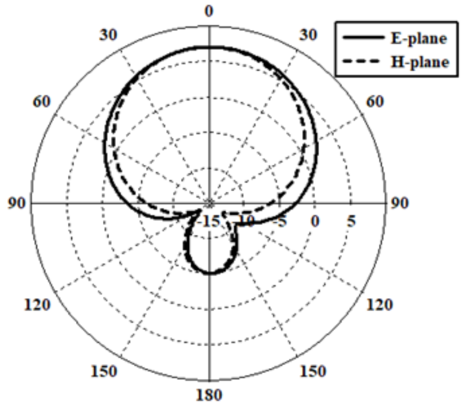


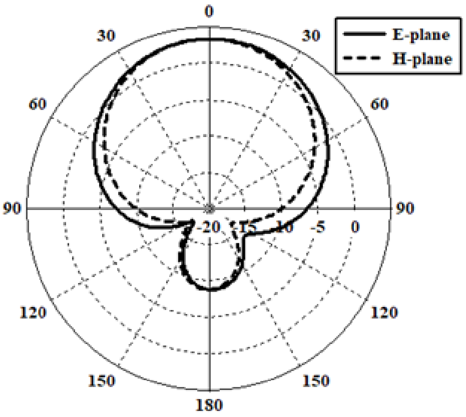
Figure.3. VSWR of proposed antenna without EBG

c) *Radiation patterns*

Directivity and Gain polar plots at 2.4GHz are presented in fig.4. E-plane is taken ta (yz plane at phi=900) while h-plane is taken at (xz plane at phi=00). From the figure.4 it is observed that proposed antenna is linearly vertical polarized.



(a)



(b)

Figure.4. polar plots at 2.4GHz (a) Directivity (b) Gain

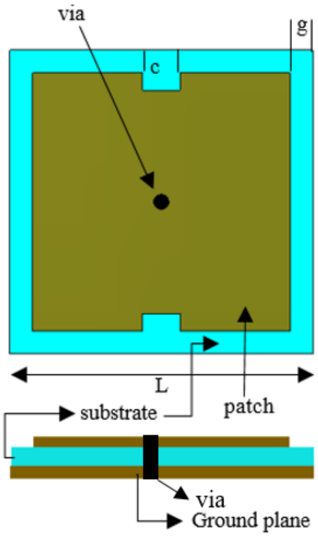
III. DESIGN OF MUSHROOM-TYPE EBG

This portion covers design and analysis of mushroom type EBG structure using cst micro wave studio.

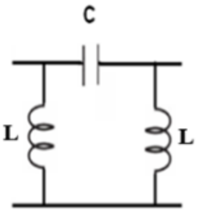
a) *Design of single band EBG unit cell*

To layout Mushroom EBG structure which give in phase reflection and also have the attribute of suppression of the surface waves. These structures illustrate the property of high impedance surface (HIS) which provides the surface wave suppression in certain frequency band gap [17]. These surfaces are being employed in antennas to reduce backscatter radiation and to enhance the characteristics parameter like gain and radiation efficiency along the main lobe position.

The design consists of radiating patch, cylindrical via having radius 0.8mm in the middle of unit cell connecting patch and ground plane. Single band unit cell is design consist on fr-4 substrate having length and width L=W=32.6mm. The radius of the R is 0.8mm while the gap between the adjacent unit cell g=2.5mm respectively. A rectangular shape cuts are etched in the patch of the dimensions 2×4mm. fig.5(a) shows the proposed single band unit cell design.



(a)



(b)

Figure.5. Geometry of unit cell (a) proposed Geometrical model (b) LC-resonant circuit.

The parameters of Mushroom type EBG unit cell are determined from the sieve piper's design equation [18].

The unit cell surface behaves like parallel LC-resonant circuit, where inductance and capacitance are the main elements of the circuit. The In-phase reflection and the resonance frequency depend upon inductance L where capacitance depends on dimensions and the geometry of EBG unit cell [19]. The resonance frequency of the unit cell is given by:

$$f_r = \frac{1}{2\pi\sqrt{lc}} \qquad (6)$$

Where, C is the capacitance due to the surrounding effect of the neighbour cells, is given by:

$$C=\frac{w\varepsilon_o(1+\varepsilon_r)}{\pi}cosh^{-1}\left(\frac{w+g}{g}\right) \qquad (7)$$

Where, ε_o is free space permittivity, w, is the width of unit cell and g is gap between the adjacent unit cell. The inductance L is dependent on thickness of substrate t or radius of metal cylindrical via.

$$L=\mu_o\mu_r t \qquad (8)$$

The periodicity of unit cell a=L+g=32.5+2. 5=35mm.The optimized parameter of single band unit cell is listed in table 2.

TABLE 2. CHARACTERISTIC PARAMETER OF UNIT CELL

Parameter	Description	Value(mm)
L=W	Length and width of substrate	32.5
Lp=Wp	Length and width of patch	30
r	Radius of via	0.8
c	Length and width of cut in the patch	2×4
g	Gap between adjacent cells	2.5

b) *Results of Mushroom-type EBG unit cell*

1) *In-phase reflection*

The simulated scattering parameter and reflection phase of mushroom-type EBG is shown in fig.6. The EBG unit cell surface provides in-phase zero reflection at 2.4GHz and act like a perfect Magnetic Conductor (PMC) at the required frequency. The simulated reflection phase changes from +900 to -900 within the band from 2.3GHz to 2.45GHz and also in this band of frequency the surface act as an Artificial Magnetic Conductor (AMC). The behaviour of in-phase reflection is need full in the design of low profile and compact size antennas.

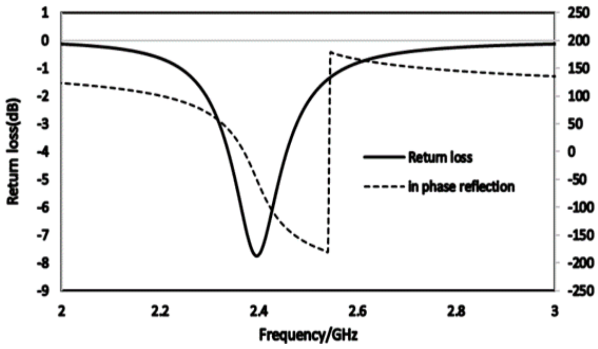
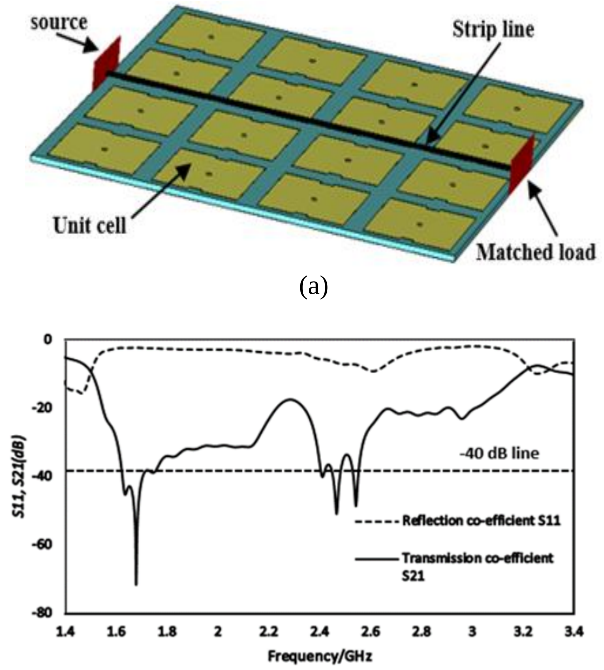


Figure.6. In-phase reflection of Mushroom-type EBG

2) *Band Gap of EBG Structure*

The Expanse of EBG unit cell is High Impedance Surface (HIS) which have the property of surface wave suppression and can be achieved by different means, i.e. by dispersion diagram or transmission line method. In this article, suspend transmission line method is used. In this procedure a conducting metal strip is mounted 3mm above the EBG surface and excited in a way that one port act as source and the other act as matched load. The setup for surface wave suppression is shown in Fig.7(a).

The simulated result shows that transmission coefficient (S21) is minimum (< -40dB) within the range of 2.38 to 2.6GHz. Within this specific band the transmission of surface wave is limited minimum low level. In this band the surface acts like high impedance surface to suppress the surface waves, is known as surface wave band gap of mushroom-type EBG. The Fig.7(b) shows the band gap of EBG.



(a)

(b)

Figure.7. 4×4 EBG array (a) Suspend line model of EBG (b) Simulated (S11, S21) of EBG array

IV. INTEGRATION OF PROPOSED ANTENNA WITH EBG (METAMATERIAL SURFACE)

In this section, the proposed antenna has been integrated with 4×4 single band mushroom-like EBG as shown in Fig.8.

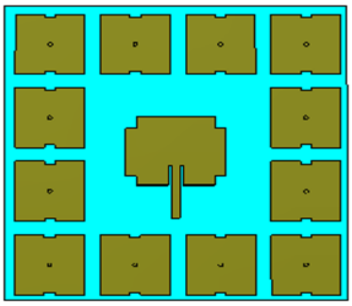


Figure.8. Antenna integration with 4*4 EBG

a) *Return loss*

Return loss of proposed antenna with and without Mushroom-like EBG is given below in Fig.9. A Good improvement occurs in the return loss up to -32dB when the antenna is employed with EBG.

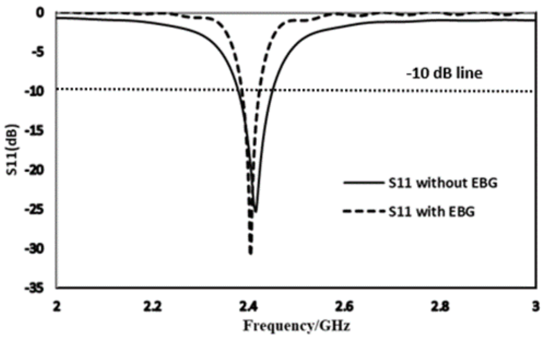


Figure.9. S_{11} comparison of proposed antenna with and without EBG

b) *Voltage standing wave ratio (VSWR)*

VSWR is given in Fig.10 also it is observed from the graph the vswr is nearly equal to 1 at 2.4GHZ with the value of 1.12.

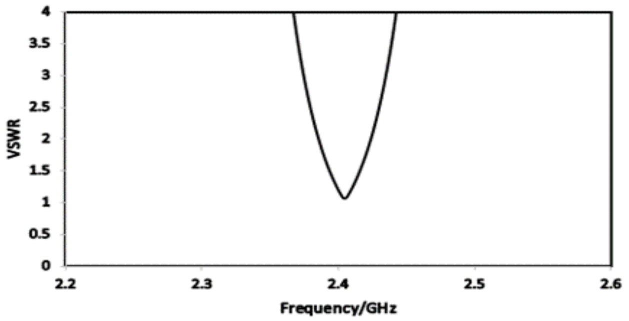


Figure.10. VSWR of Antenna with EBG

c) *Surface currents*

At 2.4GHz surface currents are dense and linearly distributed over rectangular patch which enhances the radiation at the resonance frequency.

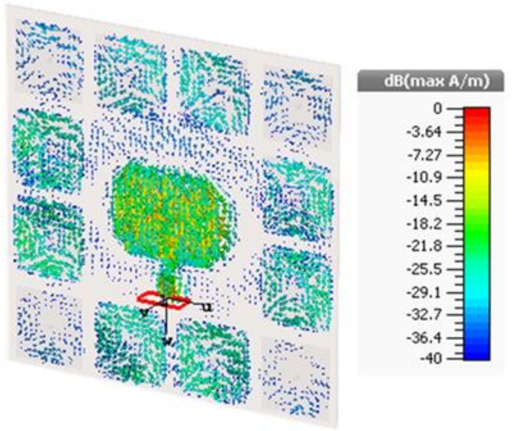
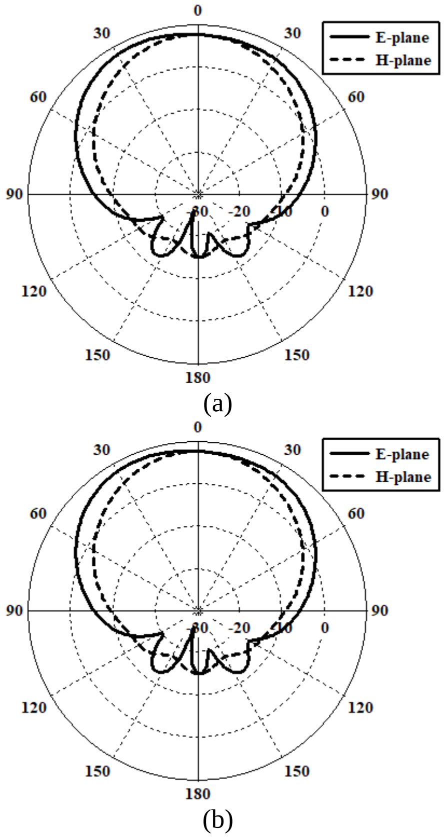


Figure.11. Surface currents of Antenna with EBG

d) *Polar plots and 3D-Radiation pattern*

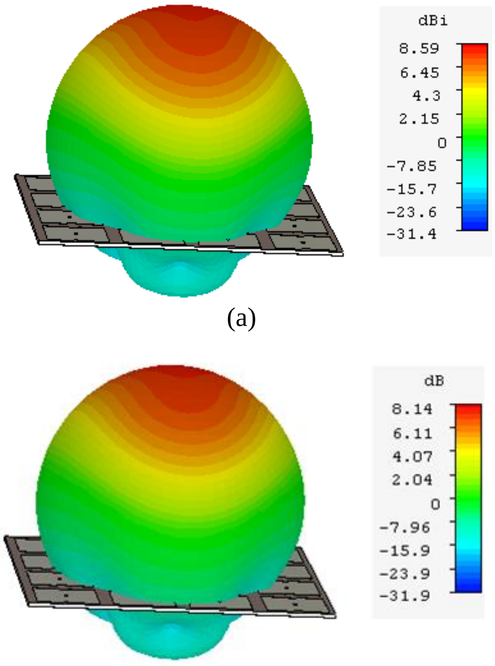
Directivity and Gain polar plots are shown in Fig.12 (a,b). A major improvement occurs in the Beamwidth, Directivity and Gain.



(a)

(b)

Figure.12.Polar plots at 2.4 GHz (a) Directivity (b) Gain



(a)

(b)

Figure.13. 3D-Radiation pattern of Antenna with EBG (a) Directivity (b) Gain.

TABLE 3. SUMMARY OF RESULTS WITH AND WITHOUT EBG

Parameters	Without EBG	With EBG
Frequency (GHz)	2.41	2.40
Return loss (dB)	-25	-32
Directivity (dBi)	6.97	8.59
Gain (dB)	3.42	8.14
Beam width (deg)	78.9	94
Efficiency (%)	50	85
VSWR	1.3	1.12

CONCLUSIONS

In this article, A single band patch antenna is modelled at 2.4GHz by using simple and EBG surface as a ground plane which is discussed and compared in (Table 3). The proposed fracture antenna is designed on FR-4 substrate. A ponderable enhancement occurs in gain, directivity and beam width. It is observed that Antenna with simple ground plane exhibits less efficiency (50%) and maximum efficiency (80%) when EBG surface is used as ground plane. In this work, the EBG ground plane lead to better enhancement in the performance of the proposed antenna. The EBG based antenna will be fabricated in future to valid the simulation results. The proposed antenna finds its applications in WIFI and ISM band.

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