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DESIGN AND ANALYSIS OF META-MATERIAL BASED WLAN ANTENNA

Muhammad Aamir Afridi , Sadiq Ullah*

Department of Telecommunication Engineering , UET Peshawar Mardan Campus Pakistan

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*Corresponding author
sadiqullah@uetpeshawar.edu.pk

Abstract

In this paper, a 2.42 GHz micro-strip patch antenna is designed and analyzed using a conventional and a metamaterial (artificial) based Electromagnetic Bandgap (EBG) ground planes. The directivity, return loss and VSWR of the conventional 2.42 GHz patch antenna were found to be 5.23dB, -13.2dB, and 1.5 respectively. The proposed antenna then being mounted on a Mushroom-type EBG structures (artificial ground plane) produced better far-field performance as compared to conventional counterpart i.e. the return loss, directivity and VSWR were improved by 80.3%, 58.5% and 24.6%. The WLAN antenna was designed and tested on a miniaturized slotted EBG structure. The slotted EBG was 11.4 % compact as compared to the mushroom structure. The directivity, return loss and VSWR of the antenna using the slotted EBG are improved by be 51%, 31.8%, 15.4% respectively as compared to the patch conventional WLAN patch antenna. The antenna can be used for WLAN applications.

Keywords: Mushroom type; metamaterial, bandgap; unit cell

1.0 INTRODUCTION

There is a rapid growth in the field of wireless systems and the demand for new wireless applications such as Wireless Local Area Network (WLAN) [13, 14]. Therefore, it is very important to design antennas with high gains and broadband to cover wide range of frequencies. In applications like mobile radio, missiles, aircraft, Satellite and other wireless communications low profile, small weight and size, low cost of fabrication, ease of installation are the important constraints. In order to fulfill the above mentioned requirements, Micro-strip patch antennas are the best choice. Micro-strip Patch antennas have some other advantages over other antennas such as they support both circular and liner polarizations and have low cast of fabrication. On the other hand, they have some disadvantages like narrow bandwidth, surface wave excitation etc. But the problem of narrow bandwidth can be improved by making certain changes like by increasing the height of the substrate (ϵ_r) and to use antenna array [2]. Bandwidth can also be increased by making a U-Slot in the patch antenna [1].

In order to improve the radiation performance of the antenna, Electromagnetic Bandgap (EBG) structures are used. These are periodic or non-periodic meta-material structures that assist or prohibit the propagation of EM waves in certain band of frequencies [3]. The properties of in-phase reflection (reflection phase bandwidth) and surface wave suppression (surface wave bandgap) are exhibited by EBG's. EBG can be used to increase the performance of the antenna in terms of gain, bandwidth and efficiency [4, 5]. The reflection phase of meta-material is of great importance. At the reflecting surface it is normalized to the phase of the incident electric field. The PMC has a phase reflection of 0° while the PEC has a refection phase of 180°. The EBG in certain frequency band can satisfy the PMC like condition [6, 7]. From 180° to -180°, the reflection phase of EBG varies continuously versus frequency. There is an effective bandgap of surface-wave propagation for mushroom like structures which improves the gain and efficiency of the designed antenna [4, 5].

In this paper, a 2.42 GHz patch antenna is designed and excited using an inset feed 50 ohms microstrip line. Mushroom-type EBG structure will be used in order to improve the performance of the antenna in terms of return loss, VSWR and directivity.

The rest of the paper is organized as follows: Section 2 describes the design methodology of traditional and EBG based 2.42 GHz patch antennas. The reflection phase and unit-cell designs of the EBG ground planes are also discussed in this section. Results are compared and analyzed in section 3 while the paper is concluded in section 4.

2.0 DESIGN METHODOLOGY OF PATCH ANTENNA

2.1 Traditional Ground Plane Approach

The following parameters are necessary for designing a micro-strip patch antenna.

(a) Resonant frequency (f_r)
(b) Width or height of substrate (h)
(c) The dielectric constant (ε_r)

In order to design a micro-strip patch antenna, certain dimensions are needed to be calculated using the well-known microstrip antenna theory [11].

2.1.1 Width Of Patch (W)

The width of a patch can be calculated using,

$$W = \frac{c_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

where c_o is the speed of light (3x10^8 m/sec) and f_r is the resonant frequency in Hertz.

2.1.2 Effective Refractive Constant (ε_{reff})

Some waves from the patch travels directly into the substrate while some through the air. As a result effective dielectric constant (ε_{reff}) is introduced to account for fringing. Therefore, the value of ε_{reff} is needed to be calculated using,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{w}]^{\frac{-1}{2}} \quad (2)$$

The value of the effective dielectric constant (ε_{reff}) is between 1<ε_{reff}<ε_r. If the value of ε_r is much higher than unity, then ε_{reff} is very close to the actual value of ε_r.

2.1.3 Length (L) of The Patch

Due to fringing, electrically the size of the patch is increased by an amount of ΔL. The amount of extension is a function of width-to-height (W/h) ratio and effective dielectric constant (ε_{reff}). The gain of the antenna has an inverse relation with the value of dielectric constant [4]. The amount of extension (ΔL) is calculated using;

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (3)$$

After finding the value of ΔL, the length of patch (L) can be calculated by:

$$L = \frac{c_o}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

2.1.4 Width (W_g) and Length (L_g) of Ground Plane

The dimensions of the ground plane and the substrate are to be calculated using [11]. The width of ground (W_g) and length of the ground (L_g) are same for the substrate.

$$W_g = 6h + W \quad (5)$$

$$L_g = 6h + L \quad (6)$$

Using the above mentioned formulae (1, 2, 3, 4, 5, 6) [11] the dimensions of the patch antenna are calculated (Table 1) for a resonant frequency of 2.42 GHz using a FR-4 ($\varepsilon_r = 4.3$) as a dielectric substrate having thickness of the substrate (h) as 1.6 mm.

Table 1 Summary of antenna dimensions

Parameters	Dimensions (mm)
Length of patch (L)	28.4
Width of patch (W)	37.02
Height of substrate (h)	1.6
Length of ground (L_g)	38
Width of ground (W_g)	46.6
Width of the strip-line feed	2.5
Thickness of patch and ground	0.035

2.2 Artificial (EBG) Ground Plane Approach

The fundamental theory of mushroom-type [7] EBG structure is used to design an artificial ground plane. The mushroom EBG structure gives an in-phase reflection in the desired frequency band [9, 10]. The resonant frequency of the EBG structure is found using:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (7)$$

where, 'C' is the capacitance value of the EBG, caused by fringing between the unit cells of the structure. The capacitance depends on unit cell dimensions {gap (*g*) and width (*x=W*)} [7]:

$$C = \frac{W\varepsilon_o(1+\varepsilon_r)}{\pi}cosh^{-1}(\frac{x+g}{g}) \quad (8)$$

And '*L*' is the inductance of the surface, evaluated using:

$$L = \mu t \quad (9)$$

where, $\mu = \mu_o\mu_r$ is permeabaility of the medium (substrate).

2.2.1 Mushroom Type EBG

A mushroom EBG structure is designed at a resonant frequency of 2.42 GHz using Vias at the center of each unit cell (Figure 1). The material used as a substrate for designing of a unit cell is Rogers RT5880 (loss free) with 2.2 dielectric constant (ε_r). The width (*W*) of the patch of a unit cell is found to be 34.6 mm and gap (*g*) as 0.3 mm using [7]. Metal Vias are used of radius 0.5 mm which connects the center patch of the unit cell with the bottom of metallic ground.

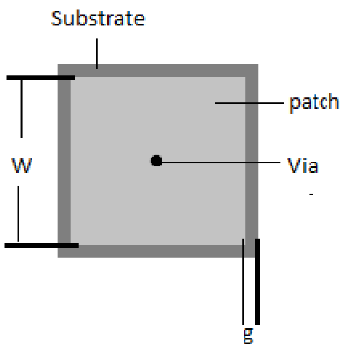


Figure 1 Unit Cell of mushroom type EBG with via

It is worth mentioning that the EBG surface gives 0^0 reflection phase at 2.42 GHz (Figure 2).

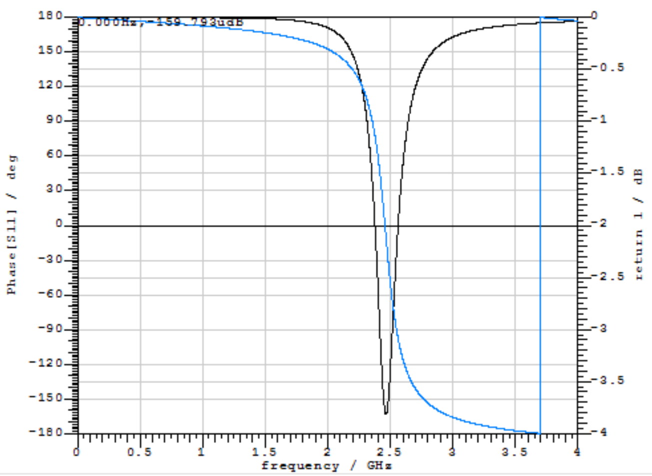


Figure 2 Reflection Phase of Mushroom Type EBG

2.2.2 Novel EBG

A novel EBG unit cell is designed to reduce the size of the unit cell using CST Microwave Studio software. The unit cell is designed with same material of the substrate (Roger RT5880). The dimensions of the unit cell as 31 x 31mm and via diameter as 0.5 mm. The width of the patch is 30.3 x 30.3 mm and g=0.3 mm. Four rectangular cuts are introduced in patch as shown in the Figure 3 with *a*=2 mm and *b*=20 mm. The cell size is reduced by 4 mm as compared to the unit cell of Figure 1.

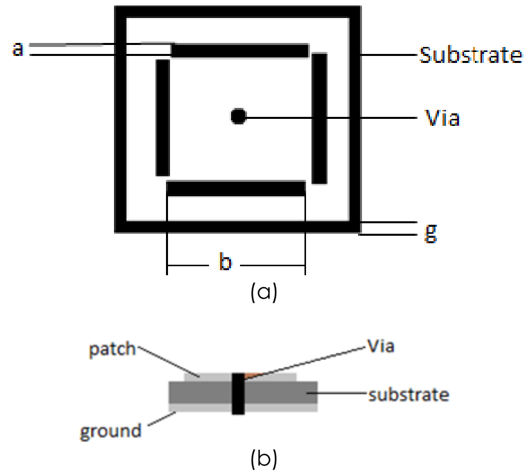


Figure 3 Unit Cell of Novel EBG (a) Front view (b) Side view

The reflection phase of this Novel unit cell is zero degrees at 2.42 GHz (Figure 4).

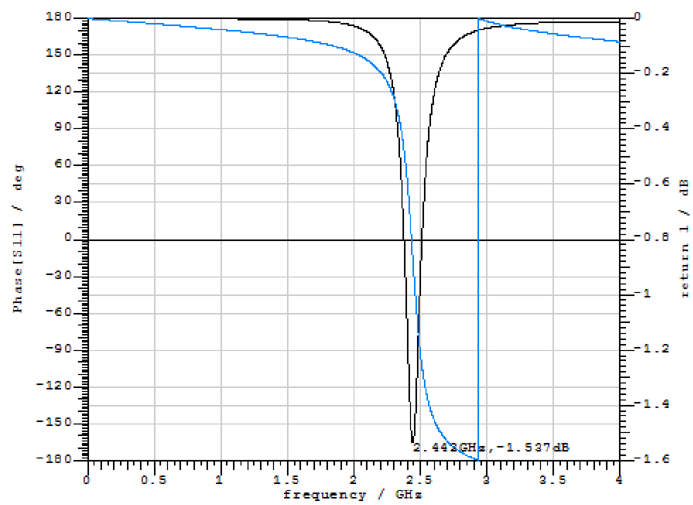


Figure-4 Phase Reflection of novel EBG

3.0 RESULTS

The Return loss of the proposed antenna without EBG (traditional Patch antenna), and with EBG (Mushroom, Novel) are compared in Figure 5.

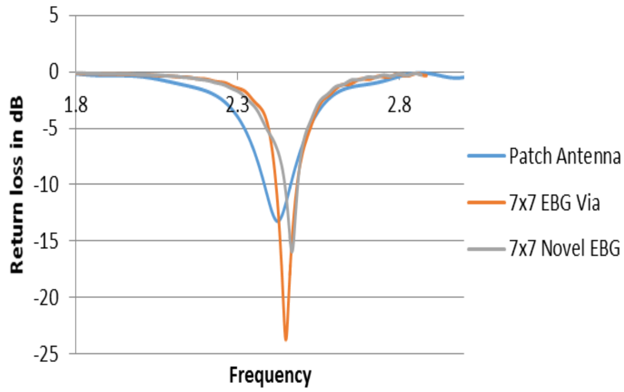
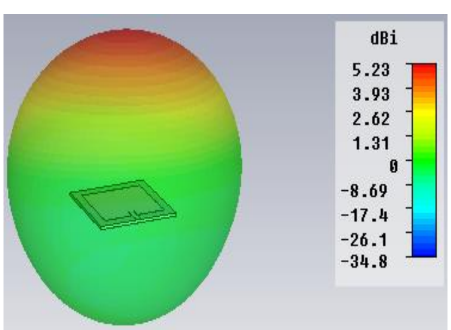


Figure 5 Comparision of return loss

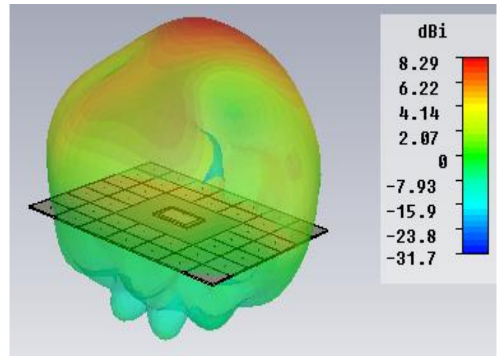
The return loss of the proposed conventional antenna is -13.2 dB at 2.42 GHz. A 7x7 mushroom-type EBG structure is designed in CST Microwave Studio. The length x breath of this EBG is 245 mm x245 mm. The proposed 2.42 GHz patch antenna backed by this EBG, gives a reduced return loss of -23.8 dB. Finally the same antenna is mounted on a 7x7 Novel EBG structure. The unit cell of the Novel EBG was reduced by 4 mm, therefore the overall dimensions of this structure is 217 mm x 217 mm which is 28 mm x 28 mm reduced than the mushroom EBG. The return loss of the antenna backed by this novel EBG structure is reduced to -17.4 dB (Figure 5). There is a slight deviation in resonant frequency (shifted towards the right), when the antenna is mounted on the EBG surfaces (mushroom and Novel). The reasons behind the band shifting are the variations in the capacitive and inductive effects [12] of the novel surface.

The three-dimensional plot of directivity of the traditional and EBG backed 2.42 GHz patch antenna is demonstrated in Figure 6. The peak directivity of the patch antenna at 2.42 GHz is 5.23 dBi, 8.29 dBi and 7.9 dBi using traditional, mushroom type and novel EBG ground plane backing respectively.

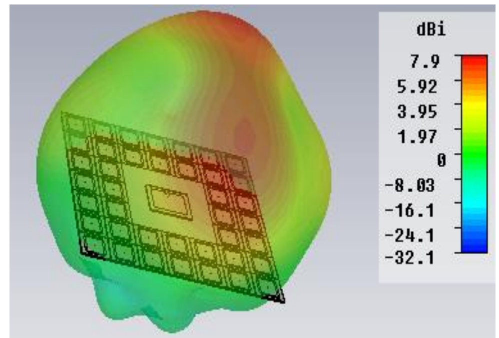
It is also worth mentioning that the level of the back lobe radiations is reduced due to the high-impedance nature of the proposed EBG surfaces. The Voltage Standing Wave Ratio (VSWR) of the proposed 2.42 GHz patch antenna is 1.5, 1.13 and 1.3, using traditional, mushroom and novel EBG ground plane approaches respectively.



(a) Conventional patch antenna



(b) Mushroom type EBG backed patch antenna



(c) Novel EBG backed patch antenna

Figure 6 Directivity of 2.42 GHz patch antenna (a) Traditional ground backing (b) Mushroom type EBG backed (c) Novel EBG backed

4.0 CONCLUSION

A micro-strip patch antenna has been designed at a resonant frequency of 2.42 GHz using traditional as well as EBG approaches. The performance of the antenna is enhanced in terms of return loss, directivity and VSWR using Mushroom type EBG structures. The return loss and VSWR of the antenna is reduced by 80.3% and 24.6% using the proposed EBG ground planes. The directivity is enhanced up to 58.5% using the mushroom type EBG approach. Furthermore, the size of the mushroom-type EBG was reduced by an amount of 11.4% per unit cell using Novel EBG approach. This antenna can be used for efficient and portable WLAN applications.

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