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DESIGN AND DEVELOPMENT OF MICROSTRIP PATCH ANTENNA USING EBG STRUCTURES FOR S-BAND COMMUNICATION

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Abstract

In this paper, a new pattern of Electromagnetic Band Gap (EBG) structure is introduced on the substrate of microstrip patch antenna to enhance the gain and bandwidth. This proposed antenna works at the frequency of 2.3GHz which is for S band communication. The proposed antenna is designed on a FR-4 substrate which has the thickness of 1.6mm. The double L shaped EBG structures are introduced on the substrate in order to improve the gain and bandwidth of the conventional antenna. The proposed antenna is fabricated and its results are compared. It seems that the fabricated results have good agreement with the simulated one, also the gain and bandwidth are increased.

Keywords:

Double L Shape, Electromagnetic Band Gap Structures, Microstrip Patch Antenna

1. INTRODUCTION

Modern communication systems have need of antenna with maximum gain and broad bandwidth. Microstrip patch antennas are commonly preferred in order to electronic circuit miniaturization. Microstrip antennas are attractive due to their compactness, low cost, and it can easily be mounted in different structures. Even with all these pros, a patch antenna suffers from inbuilt disadvantages like low bandwidth (generally less than 5%), low gain, low efficiency, and etc [1]-[3]. Early effort to improve the performance of patch antenna is introducing “stacked” patches [4], [5], in which different sizes of patches are layered below one by one. Underlying layer will act as the effective ground, which may be excited directly or parasitically. However, the parasitic coupling was found to be much less effective in this orientation [5].

Introducing slots in patch and ground is another method to enhance the performance of the antenna. This approach tends to be empirical, therefore it is ill-equipped for systematic design [6]-[10]. The next method is designing planar antennas with frequency-dependent dispersive properties. In this approach multiple resonant band are achieved, but its radiation patterns are not resembling the fundamental mode for all radiating frequencies [5].

While introducing this property, the major problem is guiding of plane waves over the interface between conductor-dielectrics or dielectrics-dielectrics medium. When the electromagnetic waves are guided over the planar structures, the electromagnetic energy is confined between the interfaces. Part of the guided wave from this seized energy is radiated and part of the guided wave is reflected back at the edges of the substrate are called surface waves [11]. This surface wave causes deep nulls, ripples in radiation patterns, back radiation, gain drop and lower polarization purity, because it is scattered over the surfaces. The surface wave can be suppressed by incorporating high impedance periodic structure like Electromagnetic Band Gap structures (EBG). EBG is a class of metamaterials, when the period of metamaterial is smaller than the wavelength electromagnetic wave then it is named as EBG structures. Electromagnetic metamaterials are having homogenous structure with uncommon properties [12].

EBG structured materials that are designed to regulate the electromagnetic waves [13]. When the Electromagnetic plane waves are propagating inside EBG, its phase velocity will be in opposite direction. Hence, this LH materials are termed as “backward wave media” (BWM) [14]. When such media is integrated with conventional dielectrics, Snell’s Law is reversed and the incident plane wave with negative refraction is produced. So, it has negative permittivity and permeability simultaneously. The periodicity of EBG manages the macroscopic resonance or the Bragg resonance. The element characteristics manages the microscopic resonance [15]. When the two resonances accord, the structure will produce the band gap with maximum width. At this stop band, all electromagnetic wave will not be transmitted because this structure will act like a mirror.

By arranging number of unit cell in periodic structure. It has a variety of applications in antenna and propagation fields, EBG structure with multiple band-gaps can be designed. For example, EBG have been integrated with microstrip patch antennas to improve the performance due to the property of surface-wave suppression and in-phase reflection [16]-[18]. Electromagnetic Band Gap materials reduce these surface waves acting like stop band filter for them, hence the surface waves are mitigated and as a result the performance of the antenna is improved [14].

In this paper, the EBG structure is incorporated on the substrate to improve the performance of the conventional patch. The antenna operates in S-band (2.3GHz) and it produces high gain. The proposed high gain antenna has been fabricated and its results were measured to verify the design methodology.

The organization of the paper is as follows. In section 2, the related work is given. In section 3, the design of EBG structure is discussed. In section 4, the properties and parameters of proposed unit cell is analyzed. In section 5, the design of conventional patch antenna and the design of antenna with double L shaped EBG structure is given. The results are discussed in the in section 6. Finally, the conclusion is made in section 7.

2. RELATED WORKS

Aravind et al. [1] reported microstrip antenna with mushroom EBG ground plane. 27mm × 27mm patch was designed on FR4 substrate with the resonance frequency of 4.6GHz and 7.7GHz. Antenna parameters were analyzed the after introducing EBG on its ground with the size of 5mm × 5mm. It produced a return loss of -30dB and -25.51dB at the frequency of 4.6GHz and 7.7GHz, respectively. Peak gain as 4.1dB and bandwidth ratios as 10.75%, 25.6% were produced. This attempt is stated that slots improve the bandwidth at the cost of introduction of side lobes in the radiation pattern [1].

The dual-band microstrip patch antenna employed with metamaterial-based electromagnetic bandgap (MTM-EBG) was discussed by Smyth et al. [5] MTM-EBG was created to provide higher-frequency patch resonance. Patch with the size of 35.15mm × 43.32mm over the Roger material was used. Dual electromagnetic band gap centered at 3GHz and 5.5GHz had been introduced with the help of fractal EBG structures. Antenna had produced better return loss of -27.5dB and -13.7dB at the resonance frequency of 2.4GHz and 5GHz. [5].

Mittal et al. [11] discussed a method of employing both EBG and defected ground structure to improve the performance of the antenna. Antenna had a size of 21.5mm × 26.5mm was introduced on the FR4 substrate with the resonance frequency of 6.1GHz. Its performance was analyzed after introducing U slot on the patch and EBG with the size of 2.80mm. The above mentioned design produced the return loss of -31.54dB and peak gain as 4.77dB. Also the bandwidth ratio of 19.83% was achieved [11].

A GPS antenna in the size of 60mm × 60mm is incorporated with fractal EBG structure was introduced by Wang et al. [19], where the antenna produced a return loss of -17.5dB at 1.575GHz. Maximum gain and bandwidth were achieved as 4dBi and 31MHz respectively [19].

Reefat discussed method of improving the performance of antenna using circular and rectangular EBG structures. The following performance were obtained return loss -49.289dB, peak gain 6.59dB and bandwidth was 291.6MHz [20]. Han et al. were discussed the design of patch antenna with EBG structure with the size of 6.3mm × 5mm. The antenna resonated at 11.2GHz and produced the return loss above -30dB. Gain was increased by more than 3dB [21].

Abdul proposed a design of EBG structure with various shape to improve the antenna performance. They produced the maximum gain as 9.86dB and bandwidth as 233MHz while the EBG structure was incorporated in 4 columns [22]. However, while improving the performance of the antenna with the help of EBG structures the gain and bandwidth are a challenging factor. While transmitting the signal, a high-gain antenna permits more power towards the direction of the receiver, so, the received signal strength is increased. While receiving the signal, antenna with high gain captures more of the signal, again signal strength is increased.

Here, various EBG structure were introduced to enhance the antenna performance. Generally, the EBG structures were introduced over the ground. More over more number of EBG unit needed to get better performance. In this paper the radiating patch surrounded by EBG structure is introduced on FR4 dielectric material whose thickness is 1.6mm. The antenna has high gain at the resonant frequency. Also the antenna has wide bandwidth, but the antenna size is slightly increased.

3. DESIGN OF EBG STRUCTURES

The very promising way to eradicate the problems which are created by surface way is using EBG structures instead of ordinary dielectric antenna substrates. At the same time, it improves the performance of the antenna. This EBG unit cells are periodically loaded over the substrate, so that the surface waves cannot propagate along the substrate. Certain frequency bands are rejected by this EBG structures; thus electromagnetic band gaps are produced. In order to produce effective frequency selective surface, the EBG with following features is required. First, it must have the capacity to interact with parallel plate waveguide method. Second, in order to attain proper resonance frequency its parameters must be well known. Third, the EBG should be uniplanar and via less, for easy fabrication.

Such EBG is proposed with double L shape and it is designed on the FR-4 substrate. The band gap position and size can be determined by the shape and loading of the EBG unit cell. As it is shown in Fig.1(a) and Fig.1(b), when the periodicity is smaller than its operating wavelength, the EBGs can be drawn as a parallel LC equivalent circuit in order to find its resonant frequency. The capacitance C is determined by the fringing capacitance between neighbouring metal patches. A periodic structure can be designed by the following parameters:

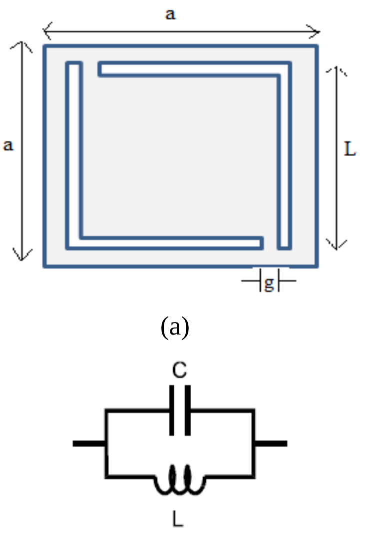
- Shape of individual patches.
- Filling factor ratio between size of the patches and the periodicity of unit cell (a/P).

where, the dimension of the patch is ‘a’ and periodicity is ‘P’. For a suitable performance, the filling factor ratio must be greater than 0.65 ($0.65<a/P<0.75$). The proposed EBG structure is designed on the FR4 substrate which has the thickness of 1.6mm. The Fig.1 depicts the geometrical structure of proposed EBG unit cell. The proposed EBG unit cell has patch size of 12mm × 8mm, slot length as 11mm and the gap between the adjacent unit cells as 0.04mm. Each unit cell is periodically arranged to behave as a microwave resonant circuit. The inductance “L’ and capacitance ‘C’ of equivalent circuit are given by the following equations [23]:

$$L=\mu_0\mu_r h \tag{1}$$

$$C=\frac{a\xi_0(1+\xi_r)}{\pi}\cosh^{-1}\left(\frac{2a+d}{d}\right) \tag{2}$$

where, μ_0, ξ_0, and d are the permeability, permittivity of free space and gap between neighbouring cells respectively. From the Eq.(1) and Eq.(2), the inductance and the capacitance of the EBG unit cell are calculated as 2ηH and 2.3ρF, respectively. From the Eq.(1) and Eq.(2), it is noticed that the inductance formed by plate is unchanged, once the substrate is defined. The capacitance is made by the adjacent unit cells which could be altered by varying the size of the unit cell. When the unit cell size increases, the gap (d) will reduce and the capacitance will increase. The high value of capacitance will try to move the band gap towards the lower frequency. According to the equivalent LC circuit of the EBGs, the surface impedance is equal to the impedance of the LC circuit.



(a)

(b)

Fig.1. Proposed EBG Unit cell (a) Geometrical view, (b) Equivalent LC circuit

The resonance frequency of the EBG structure is calculated as following [23]:

$$Z=\frac{j\omega L}{1-\omega^2 LC} \tag{3}$$

$$f_r=\frac{1}{2\pi\sqrt{LC}} \tag{4}$$

From Eq.(3) and Eq.(4), the high impedance could be obtained at the resonance frequency and the EBGs do not allow any surface waves around the resonance frequency, resulting in a frequency band gap. The variation in capacitance with respect to different gap is listed in Table.1. When the gap increases, the capacitance reduces.

Table.1. Variation in Capacitance w.r.t different Gap and L=2ηH

Gap (d) (mm)	Capacitance (ρF)	Resonant Frequency (GHz)
0.01	2.7	2.1
0.04	2.3	2.3
0.07	2.1	2.4

Hence, the EBG structure with high capacitance is having the band gap over the lower frequency. The periodic arrangement of these LC resonant elements is parameterized to significantly block surface wave's propagation in the antenna within a predetermined frequency band gap [24]. The L and C values can be tuned finely in order to get the desired band gap.

4. PROPERTIES OF PROPOSED EBG UNIT CELL

To analyze the wave propagation properties such as S-parameter, Surface impedance and Reflection phase angle of the proposed unit cell, a full wave simulation based on Finite Element Method is carried out and it is given as follows:

5. S-PARAMETERS ANALYSIS

The unit cell is positioned inside a fictitious waveguide to achieve a continuous repetition along the change axis of the electric field on the Y-direction. The two ports of TEM-like modes are applied to the side faces of the waveguide. The top and bottom sides are assigned as Perfect Electrical Conductors (PECs), while, the other two phases are assigned as Perfect Magnetic Conductors (PMCs) to mimic the behaviour of infinite arrays of the unit cell. The Fig.2 shows the transmission coefficient of the proposed unit cell. It appears that the band gap is centered at 2.3GHz and 4.6GHz. The electromagnetic band gap is achieved from 2.1GHz to 2.5GHz and from 4.5GHz to 4.75GHz (S_{12}<-10dB).

5.1 SURFACE IMPEDANCE

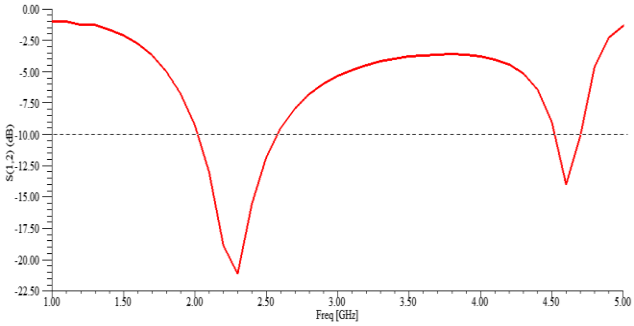


Fig.2. Transmission coefficient of proposed EBG unit cell

Normally the surface impedance is equal to the impedance of the parallel resonant circuit and it depends on the capacitance and inductance which are produced by the EBG unit cell. The surface impedance with respect to each frequency can be calculated by using the Eq.(3). The variation of the surface impedance with respect to frequency is shown in Fig.3. It is observed that at low frequencies the impedance is inductive and it is capacitive over the high frequencies. The impedance crosses through infinity at the resonance frequency.

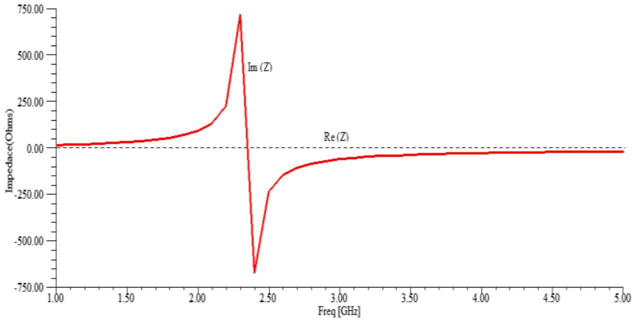


Fig.3.Surface Impedance of proposed EBG unit cell

6. DESIGN OF EBG ANTENNA

The conventional microstrip antenna is designed on FR4 dielectric material.

6.1 GEOMETRICAL PARAMETRS OF EBG ANTENNA

The conventional microstrip antenna structural parameters are calculated with the predefined values as follows:

$$W = \frac{C}{2f_0\sqrt{\frac{(\xi_r+1)}{2}}} \tag{5}$$

$$\xi_{reff} = \frac{(\xi_r+1)}{2} + \frac{(\xi_r-1)}{2}\left(1+12\frac{h}{w}\right)^{\frac{1}{2}} \tag{6}$$

$$\Delta L = 0.412h\frac{(\xi_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\xi_{reff}-0.264)\left(\frac{w}{h}+0.8\right)} \tag{7}$$

$$L_{eff} = \frac{C}{2f_0\sqrt{\xi_{reff}}}; L_{eff} = L+2\Delta L \tag{8}$$

$$L_g = 6h+L; W_g = 6h+W \tag{9}$$

From the Eq.(5)-Eq.(9) the parameters are calculated for the resonant frequency of 2.3GHz and those values are listed in Table.2.

Table.2. Structural Parameters of Proposed Patch Antenna

Parameters	Dimension (mm)
Length of Patch (L)	29.44
Width of Patch (W)	33.03
Length of Substrate (L_g)	40
Width of Substrate (W_g)	60
Thickness of Substrate (h)	1.6
Length of Feed	12
Width of Feed	4

6.2 DESIGN OF ANTENNA WITH EBG

A proposed microstrip antenna has a size of 29.44 × 33.03mm^2 is designed on a Flame Retardant 4 (FR-4) substrate has size of 40 × 50 × 1.6mm^3, the relative permittivity of 4.4 and loss tangent is 0.02. The proposed design has inset feed with 50Ω matched impedance. The feed length and width are 12mm and 4mm respectively. The parameters of unit cell are as follows: square patch size (a) is 12mm, the gap (d) between neighboring cells is 0.04mm, therefore the periodicity (p) is $a+d$ = 12.04mm. EBG is proposed in 1×3 structure over the length of the substrate. The geometrical view of the antenna with EBG structure on the substrate is shown in Fig.4. The proposed antenna is fabricated on FR-4 dielectric substrate with the thickness of 1.6mm. Front and bottom view of the fabricated antenna is shown in Fig.5.(a) and Fig.5.(b), respectively. The fabricated antenna is fed through the SMA connector.

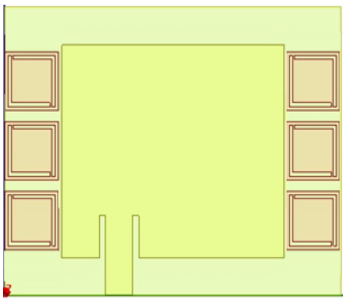
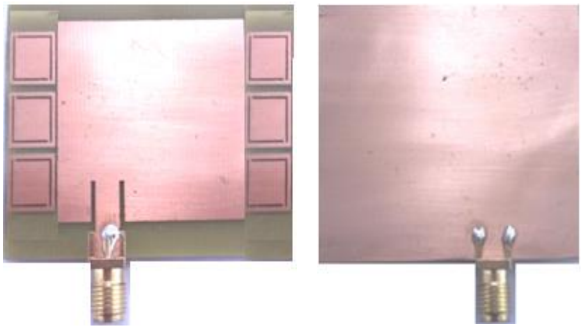


Fig.4. Geometrical view of Proposed EBG antenna



(a) (b)

Fig.5. Fabricated antenna (a) top view and (b) bottom view

7. RESULTS AND DISCUSSION

Following the design procedure, the conventional as well as the EBG antenna are simulated, fabricated and measured. From the return loss shown in Fig.6, it is noticed that the EBG antenna is producing return loss better than 10dB over the frequency range of 2GHz - 2.5GHz. The proposed antenna without EBG surface produces return loss of -24.08dB at the resonant frequency of 2.3GHz. After employing EBG structure on the substrate the return loss is enhanced about -26.02dB at 2.3GHz. It is observed that EBG structures on the substrate reduce surface wave radiation hence; the return loss is reduced as -26.02dB from -24.08dB. The return loss of proposed antenna before and after incorporating EBG structures is shown in Fig.6. It is observed that the results of the fabricated antenna are closer to the simulated results. The fabricated antenna has a return loss of -24.48dB at a frequency of 2.2GHz. The fabricated antenna has -10dB and below -10dB of return loss ranging from 2GHz - 2.4GHz which represents 0.4GHz of bandwidth. From Table.3, it is noticed that there is a minor change in performance parameters owing to SMA connector. The gain of the proposed EBG antenna is raised as 9.07dB from 6.91dB. The Bandwidth is also improved as 400MHz from 230MHz.

The simulated far field radiation pattern in E plane with Φ=90 and H plane with Φ=0 of the proposed antenna at 2.3GHz is shown in Fig.7.(a) and Fig.7.(b), respectively. The simulated and the measured radiation patterns are having good agreement. It is noticed that the antenna has high gain at resonant frequency as 9.07dB. Also, it dictates that the EBG on the substrate reduces the back lobe, hence it will effectively suppress the back wave radiation. One major disagreement is seen in the radiation pattern of the H plane. Here radiation intensity of the measured back lobe is significantly more than the conventional pattern. Due to the continued presence of unbalance current, the EBG antenna exhibits this behaviour. However, the measured and simulated values confirm that the EBG antenna produces the pattern which are similar to conventional patch antennas. So, it observes that the proposed EBG structure on both its transmission and band gap region does not affect the radiation pattern of the conventional one.

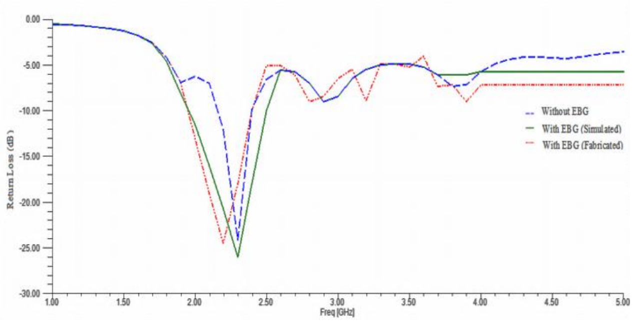
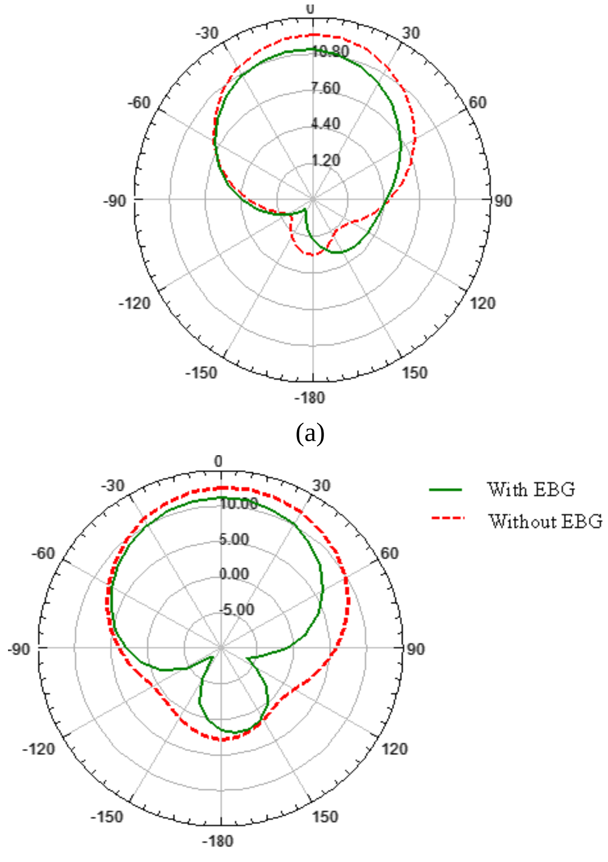


Fig.6. Return loss of proposed antenna with EBG



(a)

(b)

Fig.7. Radiation pattern of proposed antenna (a) E Plane (Φ=90) (b) H Plane (Φ = 0)

Normally, the voltage is high at the end of the patch and a half-wavelength distanced from the start of the patch. The voltage current has equal magnitude but out of phase. So, the vector current density at the edges of the patch is minimum. The surface current distribution is shown in Fig.8. It looks that the patch has minimum current distribution of 0.49A/m at its ends.

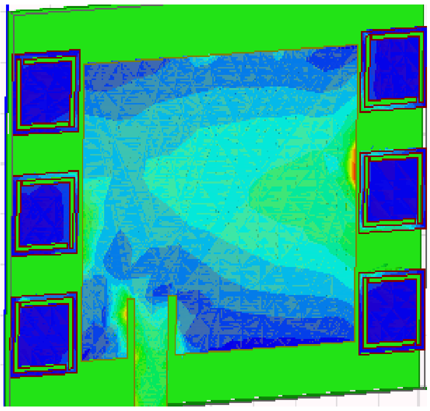


Fig.8. Current distribution of proposed antenna

8. CONCLUSIONS

A compact patch antenna loaded with double *L* shaped EBG structure is proposed, designed and fabricated on FR 4 substrate with the substrate thickness 1.6mm. After incorporating the high surface impedance two electromagnetic band gaps are obtained between 2.1GHz - 2.5GHz and 4.5GHz - 4.75GHz. The proposed antenna produces the return loss of -26.02dB at the resonant frequency of 2.3GHz. Also, the antenna produces peak gain of 9.07dB at the resonant frequency. The measured impedance bandwidth for 10dB is 21.73% from 2GHz to 2.5GHz because of the reduction of back wave radiation over the substrate. So, the proposed antenna could be used S band (2GHz - 4GHz) with enhanced gain.

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