Design of a High Gain Low Profile Dipole Antenna Using EBG Ground Plane as a Reflector

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Abstract. In this paper, design and development of a low profile, high gain dipole antenna using EBG ground plane as a reflector is presented. A broadband dipole antenna is designed and realized in planar form on an FR4 substrate. The feed gap of dipole antenna is modified to have broadband characteristics and low cross-polarization levels in radiation patterns. The mushroom- like Electromagnetic Band Gap (EBG) cell has been modified to get wideband electrical characteristics. For this, the cell via is shifted diagonally from center to increase its frequency band of operation. The dipole antenna is backed with EBG reflector to make it directional. Parametric studies for dipole, EBG cell and antenna with reflector are carried out. The parametric studies and optimized results are presented. The working frequency range of this antenna is 3.9–6.1 GHz. Antenna height is 0.05λ at lowest frequency of operation. This height is only 4% compared to height of antenna with conventional (PEC) reflector.

Keywords: Antenna · Dipole · EBG · Mushroom- like · Reflector · PEC

1 Introduction

In modern communication systems; high data rates, long rage, low latency are some of the very important requirements. These requirements can be fulfilled with wideband high gain antennas. Dipole and its variants are the antennas having omnidirectional radiation characteristics with low cross-polarization levels. The main drawbacks of these antennas are narrow bandwidth and low gain. One of the methods to increase the bandwidth of these antennas is the design of radiating antenna elements with lesser λ/D ratio, where λ is the wavelength of operation and D is the diameter of radiating elements [1]. In this method, antenna dimensions and cross-polarization levels in radiation patterns are increased. In this proposed design, the antenna bandwidth is improved with feed gap modification without decreasing the λ/D ratio. The omnidirectional antenna can be transformed into directional antenna by backing it with metallic reflector [2]. In this case, the required spacing between antenna and reflector is of the order of λ/4. This requirement, not only makes antenna bulky but antenna becomes narrow band due to λ dependent spacing. The solution for this problem lies in metamaterial ground planes. Antenna can be placed very close to reflector consisting of metamaterial ground plane.

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The antenna gain can also be improved using metamaterial properties. Metamaterial ground plane consisting of Mushroom-like EBG cells is a most common and widely used meta surface for antenna applications [3]. In this paper, this cell is modified in form of displacement of via from its central position to get wider bandwidth. This paper is organized in three sections: (a) Design of EBG ground plane (b) Design of printed dipole antenna and (c) Design of antenna with EBG ground plane as a reflector.

2 Antenna Design

2.1 Design of EBG Ground Plane

The in-phase reflection characteristics of EBG ground plane allow the antenna placement very near to it when it is used as a reflector. This in-phase reflection, reinforce the radiation in favored direction owing to vector addition of direct and reflected waves. The EBG ground plane consists of N × N No. of cells placed on a grounded substrate. The mushroom-like cell is a metallic square patch on grounded substrate with a via connecting patch and ground plane. The in-phase reflection properties of this cell are evaluated with simulation tools. A plane wave is launched at the cell surface and phases of incident and reflected waves are compared at an observation point. If this reflection phase lies within ± 90° it is satisfactory for antenna applications [4]. In mushroom-like cell design, the required patch dimensions are 0.12λ x 0.12λ and cell to cell spacing of 0.024λ with via at center. A mushroom-like cell with size of 15 mm × 15 mm and periodicity of 18 mm is used in this design. An FR4 substrate of height 1.6 mm, permittivity 4.4 and loss tangent 0.02 is used in cell configuration. As per these dimensions of the cell, the design frequency is 2.4 GHz. This cell is modeled in an FDTD based simulation tool and simulated for its reflection phase characteristics with periodic boundary conditions. The dimensional details and simulation model for this cell are shown in Fig. 1(a) and 1(b) respectively.

In [5] it is shown that when via is shifted in x or y-directions from its central position, the cell becomes polarization dependent EBG cell and the polarization of the wave may change depending upon the reflection phase of x-polarized and y- polarized waves. In order to avoid this polarization dependency, via is placed at 45° having equal distance

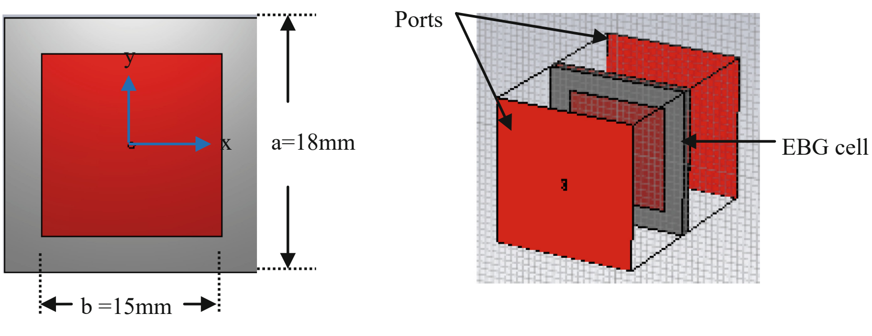

Fig. 1. The **(a)**. Dimensional details of ushroom –like EBG cell; **(b)**. Reflection phase simulation model

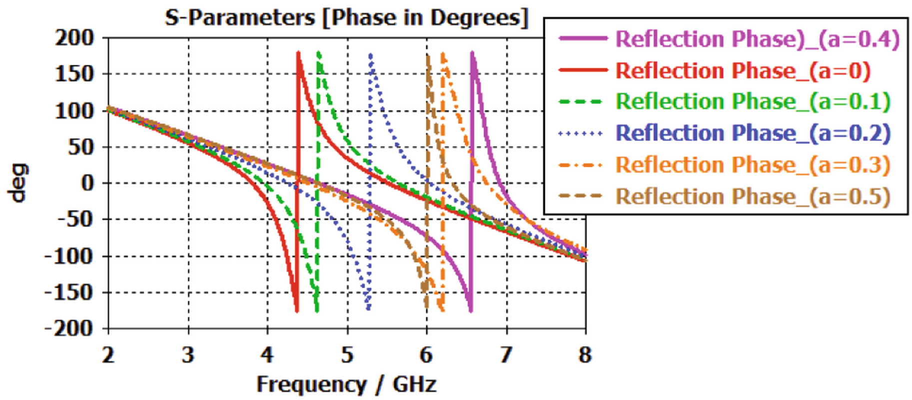

Fig. 2. Variation of reflection phase of the cell as a function of via distance (d).

from x and y axes. For study, this via is moved diagonally from center. A parametric study is carried out for variation of reflection phase with via distance from center of the cell. This distance is varied in terms of patch width (W = b). For this, a constant a is defined as a parameter such as diagonal distance, $d = a \times W$. The reflection phase simulations are carried out for a = 0 to 0.5 with a step of 0.1. Here, a = 0 corresponds to original mushroom-like EBG cell with via at centeral position (d = 0) while a = 0.5 corresponds to via at corner of the cell (d = 7.5 mm). Simulated reflection phase study as a function of d is shown in Fig. 2.

As evident from these plots, the bandwidth of the cell for reflection phase of $\pm$ 90° is minimum for central position (d = a = 0) of via. This bandwidth is improving as via is shifted from its central position. This trend continues up to a = 0.4 (d = 6 mm) after this value, bandwidth is getting reduced. The optimum value of d for maximum bandwidth is 0.4W. Bandwidth for original cell is 60.7% while bandwidth for via shifted cell is 105.8%. An improvement of bandwidth of 74.3% is achieved in this proposed design compared to original mushroom-like EBG cell. The bandwidth of operation for this cell is 2.38–6.2 GHz.The overlay of reflection phases of original mushroom- like cell and its derivative with optimized via spacing is shown in Fig. 3. The achieved bandwidth is indicated with dotted rectangular box.

2.2 Design of Printed Dipole Antenna

A dipole antenna is modeled on FR4 substrate with substrate height 1.6mm, $\epsilon_r = 4.4$ and $\tan\delta = 0.02$. The dipole width is kept only 8mm to keep cross-polarization levels low. This corresponds to 0.1λ at 3.7 GHz. A printed microstrip tapered balun is designed for balance to unbalance transformation. The dipole arms are printed on opposite sides of the substrate to facilitate direct connection between respective antenna elements with balun arms. Antenna performance is simulated with uniform, tapered and stepped feed gaps for various antenna lengths (L). Due to limited width of antenna element the return loss for first two cases was poor. For stepped feed gap, it is found that antenna bandwidth was very sensitive for step position (m) and step height (n). The antenna simulation model and dimensional details for stepped feed gap are shown in Fig. 4.

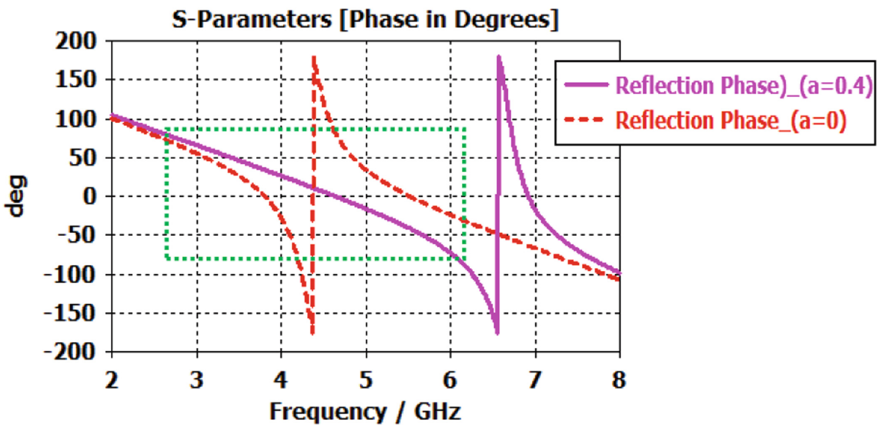

Fig. 3. Reflection phase overlay of original and its derivative. EBG cells with indicated bandwidth

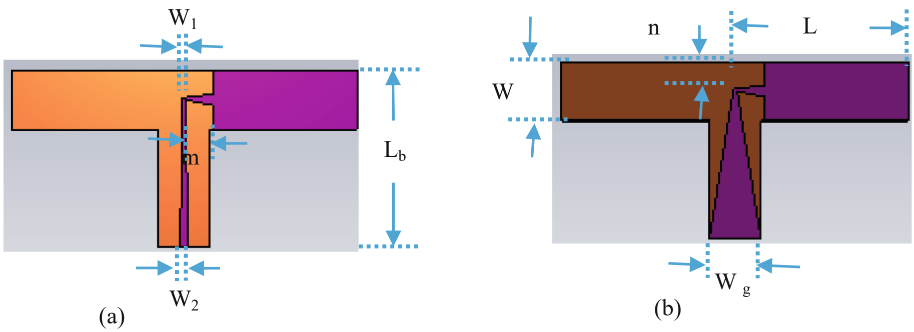

Fig. 4. Simulation model of dipole antenna with dimensions (a) Top view (b) Bottom view

The simulation studies are carried out for electrical performance of antenna by varying its various parameters. These parameters include, antenna length (2L), antenna width (W), balun length (L_b), microstrip line widths (W_1 & W_2), microstrip ground plane width (Wg) and step parameters (m & n).For optimized values of various antenna parameters, antenna return loss is $\geq$ 10 dB from 3.7 GHz to 10 GHz. The optimized values for dipole antenna are given in Table 1.

2.3 Design and Realization of Dipole with EBG Reflector

A 5 $\times$ 5 cells of designed EBG cells are used to form the broadband EBG ground plane. This is modeled and realized on an FR4 substrate of height 1.6mm, $\epsilon_r = 4.4$ and tanδ = 0.02. This EBG ground plane is used as a reflector for designed dipole antenna. The spacing between these two is used as a parameter to study the electrical performance of the antenna. The simulation model and corresponding photograph of proposed antenna are shown in Fig. 5.

Variation of magnitude of S_{11} as a function of spacing is shown in Fig. 6. As evident from these plots the return loss bandwidth is more for spacing, S = 1mm. For this spacing

Table 1. Optimized parameters of dipole antenna

Sl. No.	Parameter	Value	Description
1	h	1.6 mm	Substrate height
2	L	24.5 mm	Length of radiating Element
3	W	8 mm	Width of Radiating Element
4	L_b	20 mm	Balun length
5	W_g	7 mm	Width of Ground Plane
6	W_1	0.5 mm	Upper width of Microstrip line
7	W_2	1.0 mm	Lower width of Microstrip line
8	m	4 mm	Step distance
9	n	3.2 mm	Step Height
10	t	0.035 mm	Thickness of Printed Copper layer

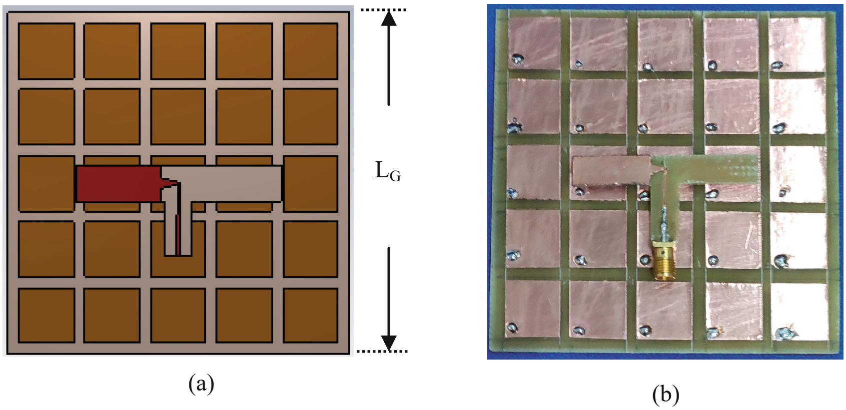

Fig. 5. Dipole antenna over EBG reflector (a) Simulation model (b) Photograph

the bandwidth is 44% with lower and higher frequencies of operations 3.9 GHz and 6.1 GHz respectively. In terms of lower frequency of operation the various dimensions are: $L = 0.64\lambda_L$, $L_G = 1.2\lambda_L$, $S = 0.01\lambda_L$, $L_b = 0.64\lambda_L$ and $W = 0.1\lambda_L$. Simulated and measured return loss plots are compared in Fig. 7. A marginal improvement in measured return loss is observed and measured result is in good agreement with simulated.

With these optimized parameters the antenna is also evaluated with metallic (PEC) reflector. Comparison of magnitude of S_{11} of antenna for EBG, PEC ground planes and antenna without ground plane are shown in Fig. 8. From these plots it is clear that when antenna is in free space, the broadband response is obtained. Antenna with PEC reflector shows very poor return loss due to short circuiting effect of PEC reflector. It is because the spacing requirement for PEC reflector is $S = 0.25\lambda_L$. The obvious advantage of the

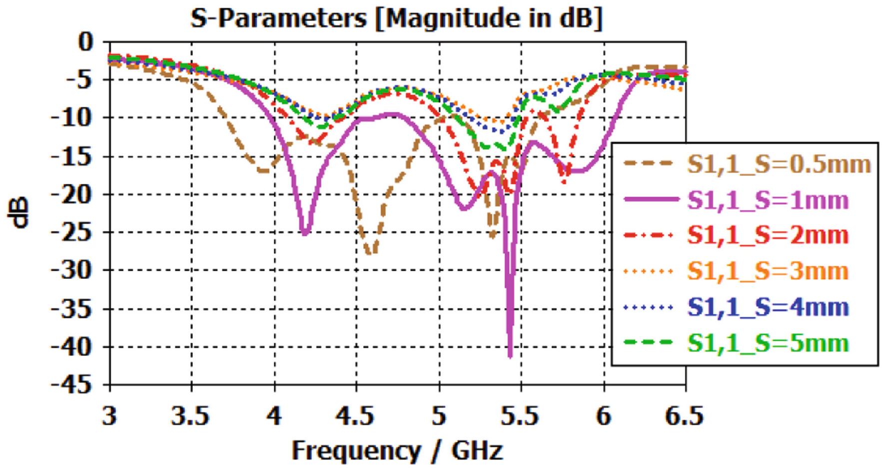

Fig. 6. Variation of return loss as a function of spacing between antenna and EBG reflector.

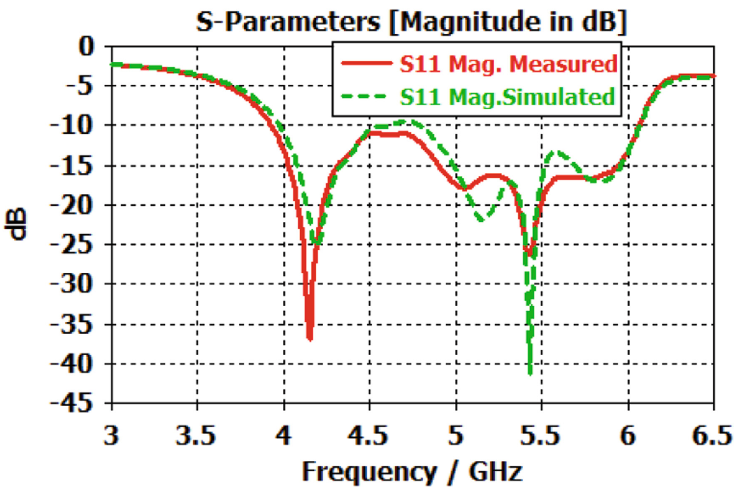

Fig. 7. Comparison of measured and simulated return losses.

EBG reflector can be seen in terms of return loss. In the working frequency range of EBG ground plane, return loss is improved compared to other two cases.

The antenna was evaluated for its radiation characteristics. The radiation patterns are plotted in two orthogonal planes ($\phi = 0°$ and $\phi = 90°$). These radiation patterns are shown in Fig. 9. The radiation patterns are shown in overlay form in two cuts, E-plane ($\phi = 0°$) and H-plane ($\phi = 90°$) for lowest and highest frequencies of operation. The antenna gain varies from 4 to 8.5dBi over the band. Overlay of simulated and measured gain plots is shown in Fig. 10. The measured gain is better due to lesser back lobes resulting from unavoidable mounting plate in antenna pattern measurement system.

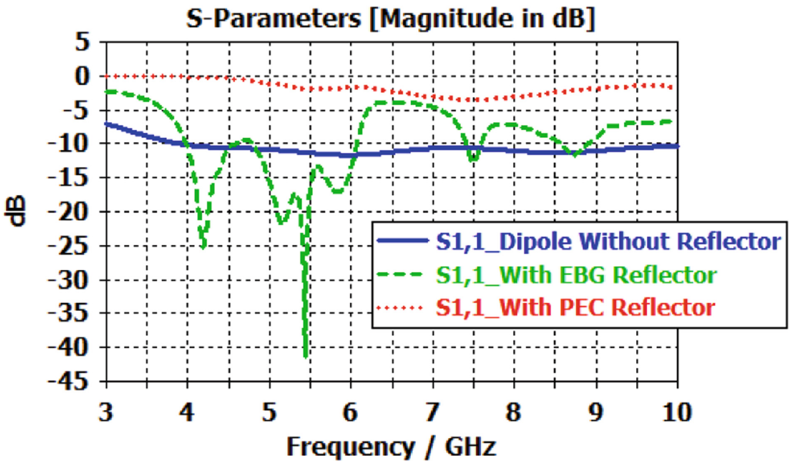

Fig. 8. Return loss comparison for dipole without and with PEC & EBG reflectors.

Antenna gain is decreasing after certain frequency as the electrical spacing between antenna and reflector is increasing at higher frequencies.

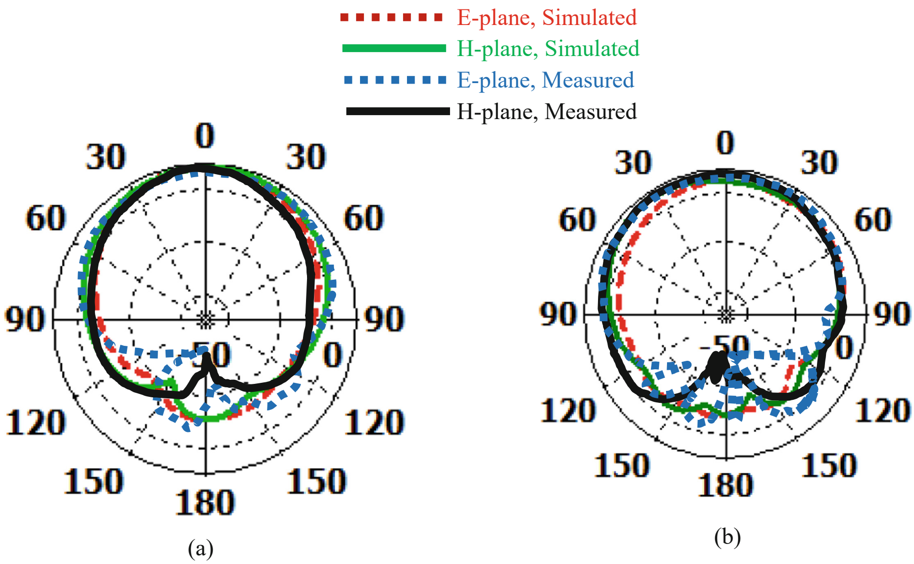

Fig. 9. Radiation patterns of proposed antenna at (a) 3.9 GHz and (b) 6.1 GHz

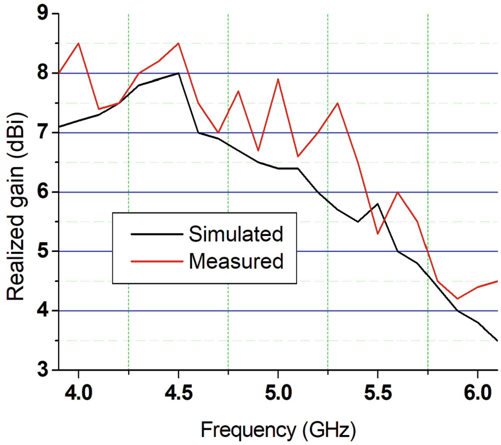

Fig. 10. Overlay of simulated and measured gain plots.

3 Conclusion

A broadband EBG cell has been designed using mushroom-like EBG cell. This cell has more bandwidth compared to its original. An EBG ground plane is configured using array of this cell. This ground plane is used as a reflector for dipole antenna. A dipole antenna is designed and its bandwidth is improved with feed gap shaping. The AMC (artificial magnetic conductor) property of EBG reflector is used to reduce the antenna height and to achieve improvement in gain. The antenna height is only 4% compared to the antenna with PEC reflector.

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