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L Shaped via based Mushroom type High Impedance Structure

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***Abstract*—**High-impedance Electromagnetic Band-Gap structures (EBG) surfaces have the capability to forbid flow of EM waves in a given band which and therefore surface waves in case of planar antennas like mictostrip antenna can be minimized with this characteristics of EBG plane. Shape, size, symmetry, and material used in their construction defines their operating band. In this research, a novel compact EBG structure also called high impedance structure (HIS) is proposed. The design is achieved through incorporation of 'L' shaped via to conventional mushroom type EBG/HIS instead of straight vias. The design includes distribution of square patches over substrate material below which there exists a ground plane. Vias passing through the substrate connecting square patches and the ground plane are also part of its design It has been observed that operating frequency of L shaped via based EBG is much lower than that of conventional mushroom type EBG/HIS having straight vias. Alternatively, we can say that size reduction has been achieved through incorporation of L shaped via to the EBG/HIS resulting in 62.5 % of size reduction. All the designs and simulations are carried out in CST microwave studio.

***Keywords*—** Microstrip patch antenna, high impedance surface, substrate, bandwidth.

I. Introduction

One of emerging materials that has been engineered artificially is metamaterial. By definition these surfaces satisfy two conditions, i.e they are purely artificial and do not exist naturally, and secondly EM properties possessed by these structures is superior and different from their parent elements [1]. EM and optical characteristic offered by these artificial materials are very much unique as well as different from their constituents. This phenomenon is achieved through inclusion, discontinuities and pattern of host material due to which their EM fields interact differently resulting in modification of EM properties like of host materials permittivity (ε), permeability (μ), refractive index (n) etc of constituent materials. As these materials provides control over EM properties therefore some desired electromagnetic and optical performance can be achieved through them.

Since 1990s, rigorous analysis has been carried out for Single Negative (SNG) [2], Double Negative (DNG) metamaterials [3, 4] and planar Electromagnetic Band Gap (EBG) structures [5]. Sievenpiper in [6] introduced 2D mushroom type EBG surfaces that were structured through array of unit cells distributed in periodic manner. This unit cell is composed of square patch placed over dielectric substrate below which there exist ground plane. A conducting cylindrical pin connects the square patch with ground plane which is passing through the substrate hence forming mushroom like configuration. These periodic structures possess the ability of suppression of propagation of surface energy waves along with in-phase reflection in a given frequency band. In-phase reflection characteristics enable these structures to have image currents and antenna current both with same phase that results in constructive interference resulting in better antenna performance. If we look into the structural configuration of high impedance structure, we will see that its composition incudes two-dimensional lattice of resonating elements that form basic two dimensional stop band filter to forbid flow of surface currents.

As explained, high-impedance Electromagnetic Band-Gap structures (EBG) surfaces have the capability to forbid flow of EM waves in a given band which is another important feature. Surface waves in case of planar antennas like mictostrip antenna can be minimized with the help of EM wave suppression characteristics of EBG plane. An initial research on EBG structure at microwave frequencies was conducted by Prof. E. Yablanovitch and his research group in [7], which explained many of its properties (surface current suppression and zero reflection phase) using an effective surface impedance model. Since then, theory and practical applications of EBG structure has become an extensive research area due to its unusual properties and design flexibilities. Consequently, numerous of EBG structures have been successfully employed to realize novel high performance devices such as filters, waveguides, antennas, etc. [8], [9], [10].

Low profile wire antennas with EBG ground are studied in [11], [12], [13]. In [14] and [15], EBG structure is employed to on-body antennas to reduce sensitive absorption rate (SAR). Other applications of EBG structures such as Multi-band antenna, LTCC and bandwidth enhancement are introduced in [16], [17] and [18], respectively.

Another area of EBG structure research is focused on characteristics of its unique properties, providing simple and fast design approaches. [19] presents a study on in-phase reflection and wave suppression characteristics of EBG structure. In [20], a method of designing controlled bandwidth EBG structure is demonstrated. Spectral domain method is explained in [21] to prove that capacitive surfaces can perform perfect magnetic conductors in a relative low frequency range. Requirement for miniaturization exists in every design whether it is related to antenna, amplifiers, filters or some other RF components. Therefore, EBG structure with compact size is required in several applications. Several attempts have been carried out in different articles [22-24]. Edge located via based mushroom type EBG was presented in [25] for demonstrating reduction in size of the EBG. Another design introduced in [26] used helical shaped via in their design for size compactness of EBG plane.

In this research, a novel compact EBG structure is proposed. The design is achieved through incorporation of 'L' shaped via to conventional mushroom type EBG instead of straight vias. The design includes distribution of square patches over substrate material below which there exists a ground plane. Vias passing through the substrate connecting square patches and the ground plane are also part of its design. Geometrical shape of via can vary response of the EBG. In our case straight via is modified and transformed into L shaped via. This modification is carried out by moving both ends of straight via over square patches in opposite direction. Band gap response and parametric study of the newly designed L shaped based EBG is studied. A comparison between conventional mushroom type EBG & L shaped EBG is also carried out in order to analyze the benefit of L shaped EBG.

Sequence of the paper is as following. Section II mainly deals design parameters of HIS. Section III presents design of L shaped via base mushroom type HIS alongwith discussion of results. At the end conclusion of the research work is presented.

II. HIGH IMPEDANCE SURFACE

Square patch EBG structures is the conventional design which is also termed as high impedance structures (HIS) that was proposed by Sievenpiper [27-31] which finds application in variety of low profile efficient antennas. Rahmat Samii [32] describes EBG as a periodic or a periodic configuration of multi dimension having power to stop or enhance the transmission of electromagnetic waves in a certain frequency range with no conditional limit of incident angel and polarization. Bandgap is the frequency range in which the surface waves are suppressed. Substrate thickness and dimensions of the EBG unit-cell affect the band gap characteristic. The unit cell may be either square or rectangular in shape. The mushroom, loop, or spiral may be the resonating element. Rahmat-Samii [33] and Sievenpiper [34] designed several kinds of EBG and HIS configuration which were further used and find its application in a variety of low profile linear and circularly polarized antennas. HIS design by Sievenpiper is shown below in Figure 1 and 2.

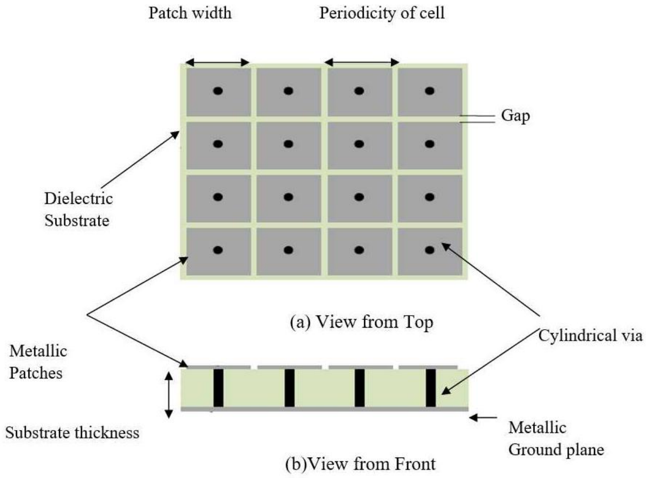


Figure 1. High impedance Surface (Sievenpiper) (a) Top-View (b) Front-View

Planar structures give in-phase reflection and suppress surface propagation in a particular frequency band. Additionally, the antenna currents are in-phase with the image currents, therefore both constructively interfere and provide better antenna performance[35].

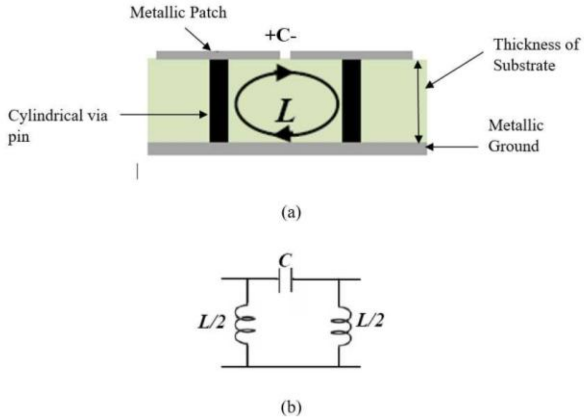


Figure 2. Equivalent circuit (LC) model (a) Front-View (b) Equivalent resonant circuit (LC)

To explain operation of HIS, consider Figure 4. It can be seen that HIS behavior is just parallel resonant circuit. The charge distribution among neighboring cells correspondent to capacitance C while the current flow through metallic via from top and bottom results to inductance L.

Following formula determines L and C values [33].

$$C = \frac{W(\varepsilon_0 + \varepsilon_r)}{\pi} \cosh^{-1}\left(\frac{2W + g}{g}\right)$$

$$L = \mu h$$

Here

W = Width of the patch
g = Gap between two adjacent patches

ε_r = EBG substrate relative permittivity
h= Thickness of the substrate used
μ= Medium permeability

Following equation expressed resonant frequency f_r

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

From above equation the Frequency Band Gap (BW) can be come near to as

$$BW = \frac{\Delta\omega_0}{\omega_0} = \frac{1}{\eta}\sqrt{\frac{L}{C}}$$

Here **η** is the intrinsic impedance of free-space = 120π

By suppressing surface waves, these assemblies are very co-operative just in case of planer antennas resulting in directivity, efficiency of the antenna and achieving high gain [36-37]. EBGs can also be utilized for GPS applications [38-39]. It has been observed that when EM wave strike Perfect Electric Conductor or planner EBGs, sense of polarization reverses resulting in mismatching in polarization. In order to side-step this kind of mismatch, PDEBGs (Polarization dependent EBGs) in several applications are introduced [40-41].

III. Results and Discussions

This section represents the design of mushroom type EBG with L shaped vias. The design includes distribution of square patches over substrate material below which there exists a ground plane. Vias passing through the substrate connecting square patches and the ground plane are also part of its design. Geometrical shape of via can vary response of the EBG. In our case straight via is modified and transformed into L shaped via. This modification is carried out by moving both ends of straight via over square patches in opposite direction. Figure 3 shows this transformation.

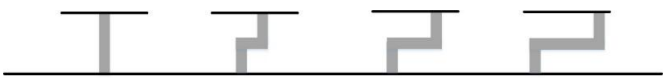


Figure 3. Transformation of Straight Vias to L shaped Vias

Structural configuration of designed mushroom type EBG with L shaped vias is given in figure 4.

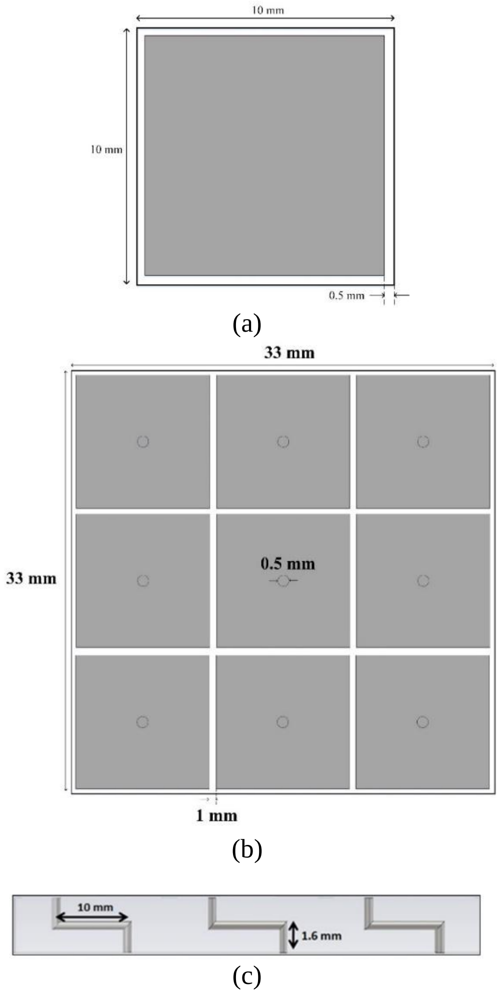
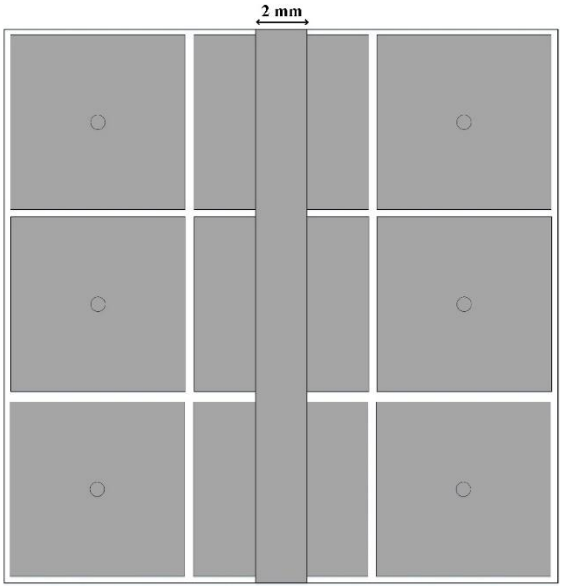


Figure 4. Mushroom type EBG with L shaped Vias (a) Unit Cell Model (b) Top view of 3x3 EBG plane (c) Side View of 3x3 EBG plane

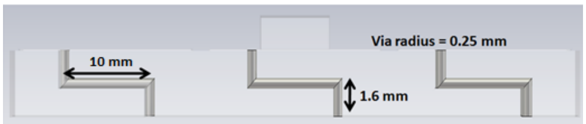
Here FR-4 substrate is used for the design of EBG having dielectric constant of 4.3 with thickness of 3.2 mm. Dimension of square patch is 10 mm x 10 mm and a total of nine patches are taken for the design. Gap between square patches is 1 mm and radius of connecting vias is taken to be 0.25 mm. Overall dimension of 3 x 3 patch mushroom type EBG is 33 mm x 33 mm.

To evaluate band gap behavior of the EBG, suspended microstrip line technique is utilized. For this purpose, a microstrip line is placed over the EBG ground plane and excited on both of its port thus forming a to port network. Coupling between the two port of transmission line i.e S21or S12 will show the band gap response of the EBG. As surface impedance of EBG plane is very high, therefore propagation of EM waves will be blocked in side band gap and similarly EM wave transmission will be high in rest of the band. Hence reduction if S21 will be observed within bandgap.

To analyzer bandgap response of the mushroom type EBG with L shaped, a microstrip line having length of 33 mm and width of 2 mm is placed over 3 x 3 patch mushroom type EBG with L shaped vias and excited. The configuration of design is given in figure 5.



(a)



(b)

Figure 5. Suspended transmission line over Mushroom type EBG with L shaped Vias (a) Top View (b) Side View

Frequencies, having S21 less than -10 dB, are defined as the band gap normally. Simulated S21 of mushroom type EBG with L shaped vias is presented in figure 6. This can be seen that value of S21 decreases to –40 dB near 1.3 GHz having -10 dB stop band of 112 MHz ranging from 1.253 GHz to 1.366 GHz.

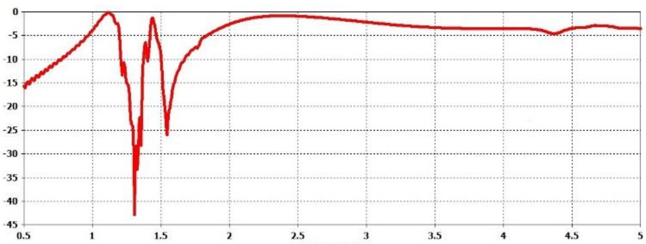


Figure 6. S21/Band gap for Mushroom Type EBG with L shaped Vias

Afterwards conventional mushroom type EBG having straight vias is also designed. In this case all the parameters are kept same as that of mushroom type HIS with L shaped via except configuration of the via. It was observed that its operating frequency band is centered at 2.1135 GHz having -10 dB stop band of 310 MHz ranging from 1.9559 GHz to 2.2659 GHz as depicted in figure 7.

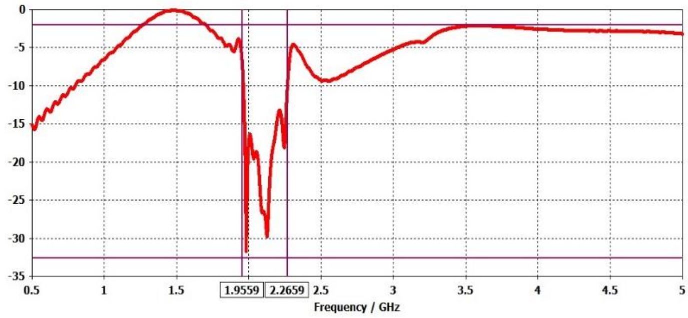


Figure 7. S21/Band gap for Mushroom Type EBG with Straight Vias

From these results we can clearly see that operating frequency of L shaped via based EBG is much lower than that of conventional mushroom type EBG. Alternatively, we can say that size reduction has been achieved through incorporation of L shaped via to the EBG resulting in 62.5 % of size reduction.

CONCUSLION

This article discusses miniaturization of conventional mushroom type EBG/HIS. Desired response is achieved through modification of via configuration of HIS. For this puspose the straight vias of HIS plane is replaced with L shaped vias. It has been observed that band gap of conventional mushroom type HIS with straight via is centred at 2.1135 GHz having -10 dB stop band of 310 MHz ranging from 1.9559 GHz to 2.2659 GHz. Wheras band gap of mushroom type HIS with L shaped vias was centred at 1.3 GHz having -10 dB stop band of 112 MHz ranging from 1.253 GHz to 1.366 GHz. Hence 62.5 % reduction is operating band of mushroom type HIS was observed through incorporation of L shaped vias i.e 62.5 % size reduction is achieved.

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