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Analysis of microstrip patch integrated with electromagnetic band gap (ebg) structure

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Abstract
Novel artificial electromagnetic materials, such as photonic crystals, electromagnetic bandgap (EBG) structures and double negative (DNG) materials, have attracted increasing attention in the electromagnetics community. These structures are broadly classified as metamaterials and are typically realized by periodic dielectric substrates and metallization patterns. The artificial metamaterials can be classified into two groups: (1) three dimensional volumetric structures and (2) two dimensional surface designs. The latter possesses the advantages of low profile, light weight and low fabrication cost and hence is desirable in wireless communication system.

Keywords: Synthesis, Naphthalene

Introduction

During last two decades, there has been growing interest in utilizing electromagnetic band-gap (EBG) structures in the electromagnetic and antenna community. There are diverse forms of EBG structures [1, 2] and novel designs such as EBG structures integrated with active device [3] and multilayer EBG structures [4] have been proposed.

The artificial surfaces have been investigated over many years and representative examples include the frequency selective surface (FSSs) [5], artificial soft and hard surfaces [6], and micromachined substrates. Recently planner EBG surfaces [7] have been proposed which exhibit distinctive electromagnetic properties with respect to incident electromagnetic waves:

1. When the incident wave is a surface wave $\left(k_x^2 + k_y^2 \ge k_0^2\right)$, the analyzed structures show a frequency bandgap through which the surface wave cannot propagate for any incident angles and polarization states.
2. When the incident wave is a plane wave $\left(k_x^2 + k_y^2 \ge k_0^2\right)$ the reflection coefficient of the analyzed structures is +1 at a certain frequency, which resembles a perfect magnetic conductor (PMC) that does not exist in nature. Here k_x and k_y are the wavenumbers in the horizontal directions while k_0 is the free space wavenumber.

To date researchers have primarily focused on EBG development and their integration with antennas for surface wave suppression [8, 9]. The topic of low-profile linear antenna development has drawn some interest [10, 11]. A comparative overview of PBG, PMC and perfect electric conducting (PEC) structures was presented. Hansen [12] first introduced an analytical representation of the effects of a high impedance screen on a half - wavelength dipole antenna. He identified ± 45^0 as a useful range of reflection phase angles for efficient dipole operation. In [13] effects of a PBG structure on the performance of a planar inverted-F antenna have been studied. Further studies of the reflection phase characteristics of a mushroom type EBG structure have revealed that the EBG ground plane requires a reflection phase in the range of $90^0 \pm 45^0$ for a low profile wire antenna to obtain a good return loss. The overall height of the EBG structure in conjunction with the dipole antenna proposed was 0.06λ. The study presented in [14] considered determining the suitable reflection phase angles by varying the length of the dipole antenna and observing the antenna return loss characteristics.

Applications of microstrip patch on high dielectric constant substrates are of special interest due to their compact size and conformability with the monolithic microwave integrated circuit (MMIC). However, the utilization of a high dielectric constant substrate has some drawbacks. Among these are a narrower bandwidth and pronounced surface waves. The bandwidth can be recovered using a thick substrate, yet this excites severe surface waves. The generation of surface waves decreases the antenna efficiency and degrades the antenna pattern. Furthermore, it increases the mutual coupling of the antenna array which causes the blind angle of a scanning array. Several methods have been proposed to reduce the effects of surface waves. One approach suggested is the synthesized substrate that lowers the effective dielectric constant of the substrate either under or around the patch [15-17]. Another approach is to use a reduced surface wave patch antenna [18].

This paper deals with the surface wave suppression effect of the EBG structure and its application to reduce the mutual coupling of microstrip patch. To explore the said effect, the propagation fields of very small dipole source with and without the EBG structure are simulated.

Band gap feature of the EBG patch

In order to study the high impedance electromagnetic surfaces with forbidden frequency band, D. Sievenpiper et. al. firstly proposed the mushroom like EBG structure. This structure exhibits a distinct stop-band property in connection with surface wave propagation. The [main components are : a ground plane, a dielectric substrate, metallic patches and connecting bias.

The operation mechanism of the EBG structure can be explained by an LC filter array. The values of the inductance L and the capacitance C are obtained with the help of the formulae

$$L = \mu_0 h \qquad (1)$$

and

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

where

w = width of the EBG patch
g = gap width
h = substrate thickness
ε_r = dielectric constant
μ_0 = permeability of free space
and ε_0 = permittivity of free space

The frequency bandgap is predicted as

$$\omega = \frac{1}{\sqrt{LC}} \qquad (3)$$

$$Bw = \frac{\Delta\omega}{\omega} = \frac{1}{\eta}\sqrt{\frac{L}{c}} \qquad (4)$$

where η is the free space impedance with 120π.

These formulations are very simple; however, their results are not very accurate. For example, this model does not consider the vias radius information. An accurate but complex model using the theory of transmission lines and periodic circuits can be found in [19].

The computational code developed in UCLA is based on a Cartesian grid cell with perfectly matched layer (PML) boundary condition. A uniform 0.02 λ_6 GHz (λ_6 GHz is the free space wavelength at 6 GHz) discretization is used. An infinitesimal dipole source with laussian pulse waveform is utilized to activate the structure order to obtain a wide range of frequency responses.

Fig.-1(a) The infinitesimal dipole source surrounded by the mushroom-like EBG structure. The dipole is chosen to be vertically polarized because the E field in microstrip antenna applications is vartical to the ground plane. As an example, two rows of EBG patches are plotted here. The EBG structure analyses has the following parameters:

$$W = 0.12\ 26\ \lambda_6\ \text{GHz},\ g = 0.02\ 26\ \text{GHz}$$
$$h = 0.04\ \lambda_6\ \text{GHz},\ \varepsilon_r. = 2.20. \qquad (5)$$

The vias radius is 0.005 λ_6 GHz. The ground plane size is kept to be 2.84 λ_6 GHz × 2.84λ_6 GHz. A reference plane is positioned at 0.12 λ_6 GHz distance away from the edge, where it is located outside the EBG structure, and the height of the reference plane is 0.04 λ_6 GHz. For the sake of comparison, a conventional case is also analyzed. This conventional case consists of a perfect electric conductor (PEC) ground plane and a dielectric substrate with the same thickness and permittivity as the EBG case.

The basic idea is to calculate and compare the E field at the reference plane. Since the EBG structure can suppress the surface waves in a certain band gap, the E field outside the EBG structure should be weaker than that of the conventional case. To quantify the surface-wave suppression effect, an average $[\tilde{E}]^2$ is calculated according to the following equation:

$$[\bar{E}]^2 = \frac{1}{S}\iint_s |E|^2\, ds \qquad (6)$$

where S is the vertical reference plane whose boundary is plotted by the dashed line in Fig. 1(a).

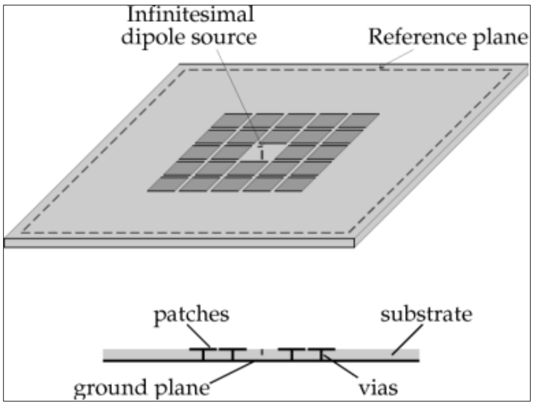

Fig 1(a): The vertical reference plane whose boundary is plotted by the dashed line

Fig.- 1(b) plots the $[\bar{E}]^2$ of various EBG cases and they are normalized to the $[\bar{E}]^2$ of the conventional case. A parametric study analyzing the number of EBG rows is carried out varying the number of rows from two to eight. It is observed that when less rows of EBG patches are used, the band-gap effect is not significant.

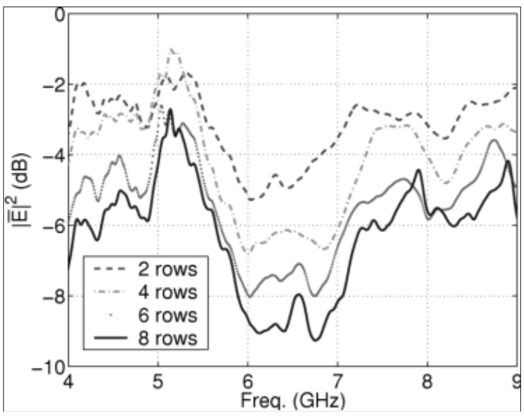

Fig 1(b): plots the $[\bar{E}]^2$ of various EBG cases and they are normalized to the $[\bar{E}]^2$ of the conventional case.

when the number of rows is increased, a clear band gap can be noticed. Inside this band gap, the average E field in the EBG case is much lower than that in the conventional case. To determine the band-gap region, a criteria is used that the average E field magnitude with the EBG is less than half of that without the EBG. This is equivalent to the –6 dB (10 $\log_{10}[\bar{E}]^2$) level in Fig. 1(b) thus a band gap from 5.8-7.0 GHz can be identified with a minimum of four rows of EBG patches.

The LC model is also used to analyze this mush room-like EBG structure, and a band gap of 6.378.78 GHz is obtained. It has some overlap with the band gap calculated which means this model can be used to get an initial engineering estimation.

To visualize the band-gap feature of surface-wave suppression, the near field distributions of the eight row EBG case and the conventional case are calculated.

Mutual coupling return loss with EBG structure

This section depicts the return loss of both EBG cases as well as the antenna without the EBG substrate. Also the mutual coupling study is made. It is found that the E-plane coupled microstrip antennas on a thick and high permittivity substrate exhibit very strong mutual coupling due o the pronounced surface waves. Since the EBG structure demonstrates its ability to suppress surface waves, four columns of EBG patches are inserted between the antennas to reduce the mutual coupling, as shown in Fig. 2.

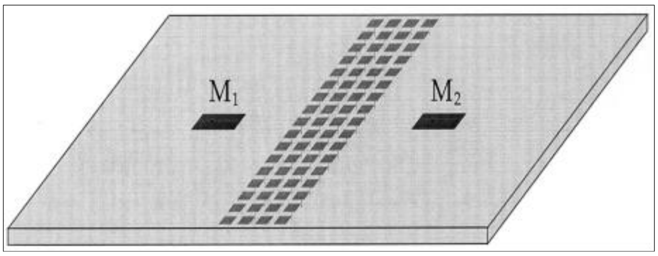

Fig 2(a): The antennas to reduce the mutual coupling

Fig. 3(a) shows the return loss of three EBG cases, as well as the antennas without the EBG structure. It is observed that all the antennas resonate around 5.8 GHz. Although the existence of the EBG structure has some effects on the input matches of the antennas, all the antennas still have better than - 10 dB matches.

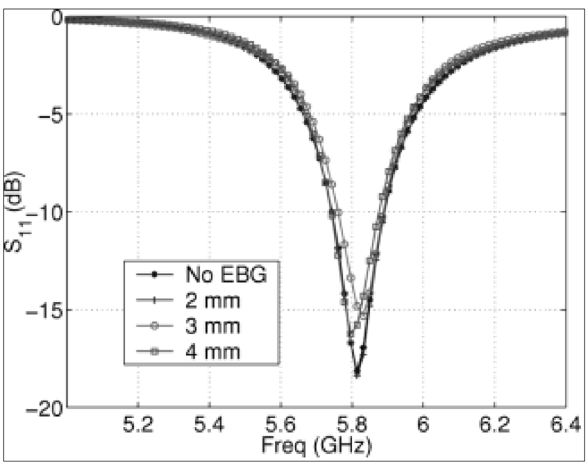

Fig 2(b): The return loss of three EBG cases.

The mutual coupling results are shown in Fig.- 2(b). Without the EBG structure, strong mutual coupling of - 16.15 dB.

Fig 2(b)

If the EBG structures are employed, the mutual coupling level changes. When the 2 mm EBG case is used, its band gap is higher than the resonant frequency 5.8 GHz. Therefore, the mutual coupling is not reduced and a strong coupling of 15.85 dB is still noticed. For the 3 mm EBG case, the resonant frequency 5.8 GHz falls inside the EBG band gap so that the surface waves are suppressed. As a result, the mutual coupling is greatly reduced: only –25.03 dB at the resonant frequency. It is worthwhile to point out that the bandwidth of the EBG structure is much wider than the antenna bandwidth so that it can cover the operational band of the antenna. When the size of the mushroom-like patch is increased to 4 mm, its band gap decreases, and is now lower than the resonant frequency. Therefore, the mutual coupling is not improved and is still as strong as - 16.27 dB.

Conclusion

The band gap feature of surface wave suppression has been shown by near field distributions of the electromagnetic wave. The strong mutual coupling caused by the thick and high permittivity substrate has been analyzed to reduce it. Also it has been compared the mutual coupling of microstrip patch with various thickness and permittivities substrates. The strongest mutual coupling happens in E-plane coupled antennas. The EBG- structure is then inserted between the antenna elements to reduce the mutual coupling compared to other approaches such as cavity back structure, the EBG structure demonstrates a better performance to improve the mutual coupling. This mutual coupling reduction technique can be used in various antenna array applications.

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