In-phase Reflection and EM Wave Suppression Characteristics of Electromagnetic Band Gap Ground Planes

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1. Introduction

Electromagnetic band gap (EBG) materials have unique properties in controlling the propagation of electromagnetic waves, which enable them to be implemented in a number of applications. There are two major advantages of a EBG ground plane. First, such materials offer the possibility of creating a perfect magnetic conductor (PMC) because of their in-phase reflection features. This feature enables efficient radiation for antennas placed close to the EBG ground [1]. Second, by forbidding the propagation of EM waves in certain frequency bands, these materials can be used to block the propagation of waves and guide them in a desired direction [2-3]. This paper presents a study on these two characteristics of the EBG surfaces, and specifies the frequency regions of each of them for two typical EBG surfaces. The reflection phase of plane waves and the transmission coefficient of a suspended stripline over an EBG surface are used to model these two characteristics of the EBG ground planes.

2. Mushroom-like and uniplanar compact EBG

In this paper, two types of the EBG structures are analyzed and compared for in-phase reflection and EM wave suppression: the mushroom-like EBG [1], and uniplanar compact EBG (UC-EBG) [4]. The mushroom-like EBG consists of a ground plane, a dielectric substrate, metallic patches, and connecting vias as displayed in Fig. 1a. A unit cell of the UC-EBG consists of metallic patches with narrow inset lines on a dielectric ground as shown in Fig. 1b. Equal cell size and dielectric parameters are chosen so that a comparison can be made between these two structures. The relevant parameters of the two types of EBG structures are shown in Fig. 1.

3. FDTD models to investigate the in-phase reflection and EM wave suppression

3.1 In-phase reflection

One attractive feature of the EBG surfaces is their in-phase reflection in a certain band of frequencies. To search for this band, a FDTD model is established. A single cell of the EBG surface with periodic boundary conditions (PBC) on four sides is simulated to model an infinite surface. The perfectly matched layer (PML) is positioned a half-wavelength above the surface to absorb the reflected wave (Fig. 2a). Normal and oblique plane waves are launched to illuminate the structure. EBG surface is chosen as the phase reference plane, and the zero degree reflection phase defines the frequency of the in-phase reflection for each case. Results can be used to estimate the region in which the EBG surface behaves like a PMC.

Fig. 3 shows the reflection phase of normally incident plane wave on the EBG structures versus frequency. The zero degree reflection phase for a mushroom-like EBG occurs at 10.8GHz, while for the UC-EBG surface it is around 13.3GHz. This indicates that UC-EBG has higher resonant frequency than the mushroom-like EBG for the same cell size.

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Since the EBG surfaces are scalable, one can enlarge the UC-EBG cell size for the same resonant frequency with the mushroom-like EBG. However, this results in a larger UC-EBG ground plane than the mushroom-like EBG for the same number of cells.

3.2 EM wave suppression

An EBG surface forbids the propagation of EM waves in its band gap region. To model this behavior, a suspended stripline over an EBG ground plane is used as shown in Fig. 2b. The FDTD method is used to analyze the structure. The S21 is calculated by simulating the stripline connected from both sides to the two coaxial lines: one as an exciting source and the other as a matched load. It is expected that for frequencies within the band gap of the structure, the EBG ground plane will block the transmission of power along the strip [5]. The reduction of S21 at certain band of frequencies is due to this effect. In this paper, the band gap is defined as the frequency range within which S21 is less than -10 dB. As shown in Fig. 4, similarly to the in-phase reflection, the band gap for the UC-EBG is higher than that of mushroom-like EBG.

4. Relation between the region for in-phase reflection and EM wave suppression

In most works, the in-phase reflection phase of a normal plane wave is used to define the band gap region for EBG structures [1]. However, as shown in Fig. 3 and 4, the reduction of S21 for the mushroom-like EBG occurs at lower frequencies than the resonant frequency of a normally incident plane wave. For the UC-EBG, the frequency for in-phase reflection reasonably matches with the drop in S21. This indicates that the region for suppression of EM wave can be different from in-phase reflection for normal plane wave. This is because the suspended strip supports a quasi TEM mode with the dominant normal component of the electric field to the ground plane, while the normally incident plane wave is associated with the tangential component of electric field.

To verify this, a TM wave incident at 80^0 from the normal is launched to illuminate both structures. As shown in Fig. 5, there is a major change in the location of resonant frequency for the mushroom-like EBG, while for the UC-EBG surface, this change is small. It is observed that for the mushroom like surface, the resonant frequency of the TM wave is closer to the drop in S21 than that of normal incident. This is because in the TM case, the dominant component of the incident field is nearly transverse to the plane of EBG, which more closely simulate the case of the stripline over an EBG structure. Therefore, an EBG surface may have different frequency bands for in-phase reflection of normally incident plane wave or transmission suppression for horizontal incident wave.

5. Conclusions

The reflection phases of incident plane waves on EBG surfaces are found and compared for mushroom-like EBG and UC-EBG structures. It is noticed that the in-phase reflection phase occurs at a lower frequency for mushroom-like than the UC-EBG for the same cell size. A suspended stripline over an EBG ground plane is used to model the EM wave suppression characteristics of EBG structures. The drop in S21 shows a clear band gap for EM wave suppression; however this region does not match with the resonant frequency of the normal incident for the mushroom like structure because of the dependence of resonant frequency on polarization and angle of the incident wave. It is found that the resonant frequency of an obliquely incident TM matches well with the band gap result of the suspended strip.

References

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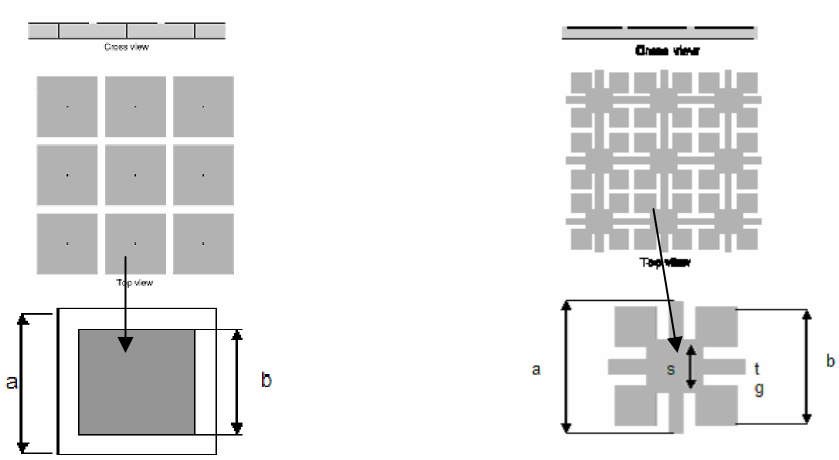
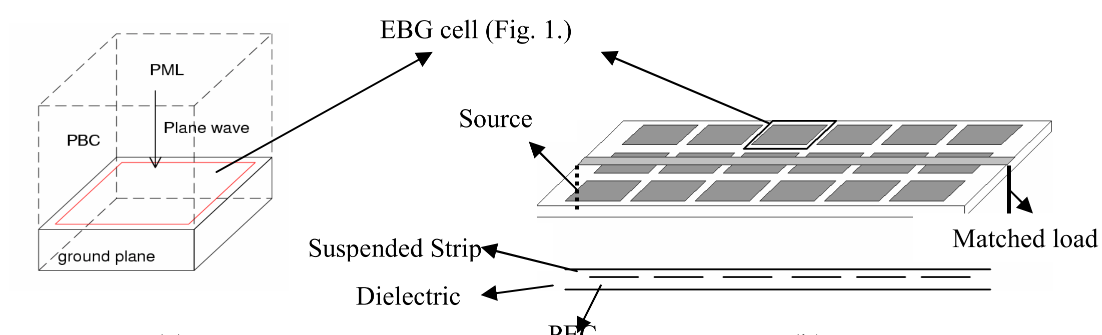


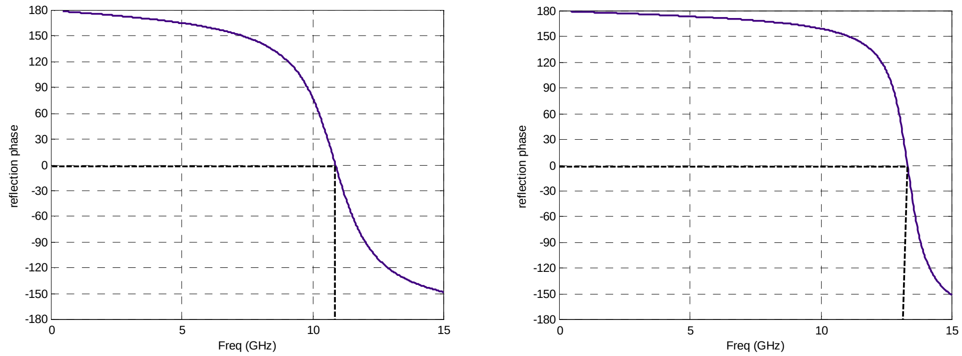
(a) (b)

Figure 1: EBG structures: a) Mushroom-like b) UC-EBG (s=0.14λ, t=g=0.04λ). For both structures, a=0.30λ, b=0.26λ, dielectric thickness=0.04λ, permittivity=2.2.
λ is the free space wavelength at 12GHz



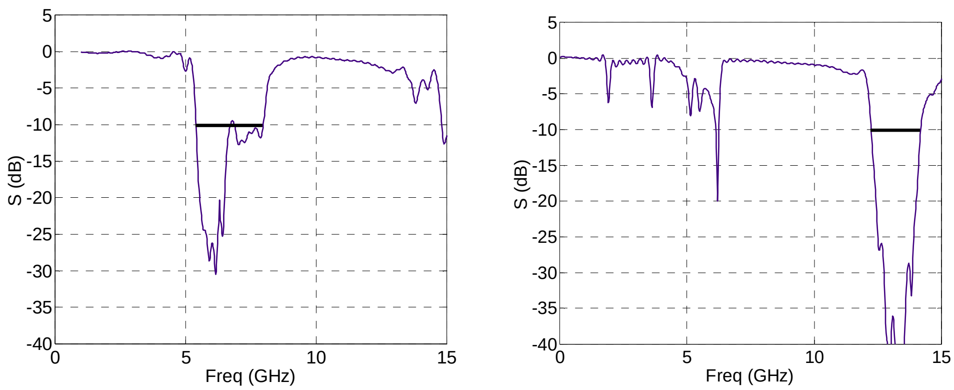
(a) (b)

Figure 2: FDTD models: a) plane wave incident to the one cell of EBG structures b) suspended stripline over EBG ground plane (Strip height over EBG surface=0.02λ).



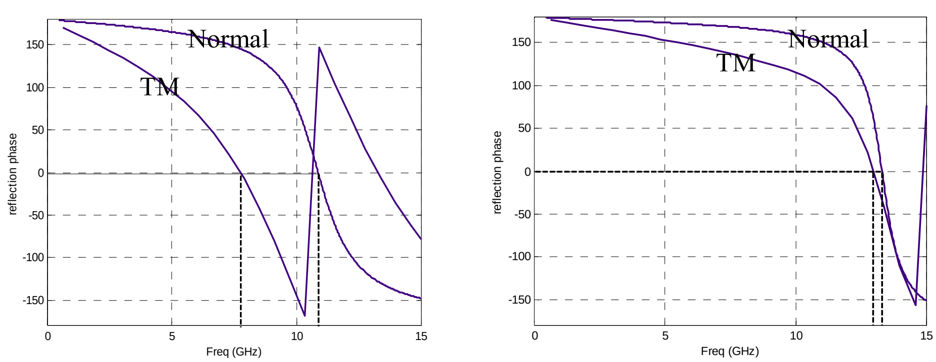
(a) (b)

Figure 3: Reflection phase of a normally incident plane wave on the EBG surface:
(a) Mushroom-like, and (b) UC-EBG.



(a) (b)

Figure 4: The S21 of the suspended strip over EBG ground plane:
(a) Mushroom-like, and (b) UC-EBG.



(a) (b)

Figure 5: The incident TM_{80} wave on the EBG surface:
(a) Mushroom-like, and (b) UC-EBG