Designing Ultra-thin Printed Dipole Arrays Based on EBG Reflection Phase Profile

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Abstract

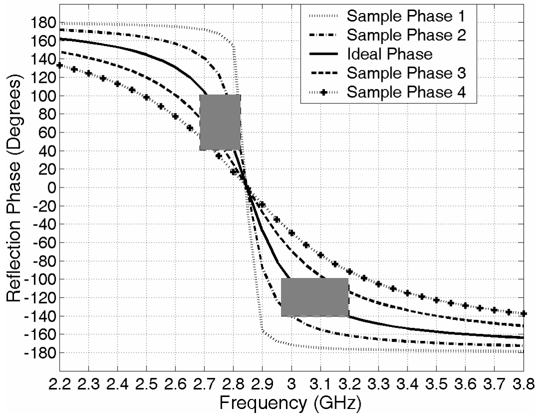
A study on the effects of the reflection phase profiles of EBG structure on the driving-point impedance of dipole antennas is presented. It is demonstrated that a specific range of phase angles is required to achieve good antenna performance. Finally, an actual EBG structure and a printed dipole antenna (0.03λ.height) are designed, fabricated and tested. The computed and measured results show that efficient printed dipoles on ultra-thin grounded dielectric substrates can be developed that will substantially reduce the sizes and weight of antenna arrays.

1. Introduction

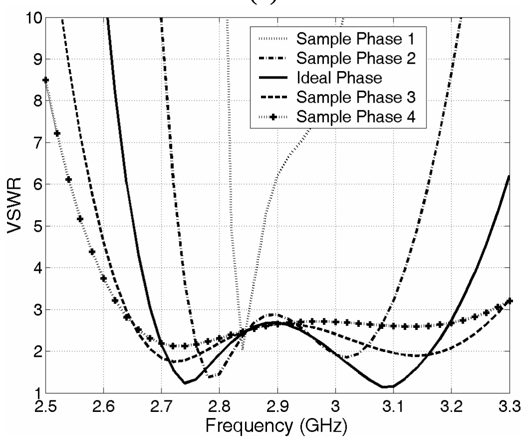
Low-profile printed dipole elements are widely used in arrays on ground-based, vehicular, air-borne, and shipboard applications. To achieve a unidirectional beam such elements are operated against a metallic ground plane, which degrades antenna performance mostly due to the radiating elements' close proximity to the metallic ground plane. Such a problem may be solved by employing engineered materials [1]. The topic of low-profile linear antenna development has drawn some interest recently [2]-[4]. Studies of the reflection phase characteristics of a mushroom type EBG structure were done and a thin dipole antenna of 0.06λ height was proposed in [4]. Reviewing the literature it is not clear whether it is sufficient to design an EBG with a specific stopband frequency and then integrate it with an antenna. The effect of the reflection phase of the EBG structure on the antenna driving-point impedance is also not known. The answers to these questions are essential if one intends to explore the possibility of designing and developing ultra-thin dipoles on a grounded dielectric substrate. In this paper the effect of the EBG reflection phase angle on the driving point impedance and consequently the bandwidth is studied. Useful phase angles are identified for a range of antenna heights considering hypothetical constant phases with frequency. Optimum EBG structures that can generate such phases were designed next. Finally a printed dipole antenna on an optimum 3D EBG structure was fabricated and tested.

2. Analytical Study

The influence of the EBG reflection phase on the antenna driving-point impedance was studied by considering a hypothetical EBG surface that can generate a constant reflection phase, θ with frequency. Based on this investigation, optimum reflection phase characteristic curves were generated for different heights by identifying the useful phase angles and their corresponding frequency bands [5]. Fig. 1(a) shows the reflection phase versus frequency curves of EBG structures with 5 different reflection phase profiles, which were generated by varying EBG design parameters. From Fig. 1(a) it is clear that all the curves have the same stopband frequency defined by the frequency corresponding to the 0^0 phase angle. The reflection phase curve indicated 'Ideal Phase' represents the useful phase angles required for efficient dual-band operation of a thin wire dipole at a height of 0.03λ from the ground plane. In contrast, the four adjacent curves contain only a small portion of the useful phase angles. The resulting VSWR characteristics that correspond to each reflection phase curve for the thin wire dipole in consideration are shown in Fig. 1(b). Clearly only the curve corresponding to the ideal phase shows a dual band response with bandwidths of 3.6% and 5.5% along the low and high frequency bands respectively. Thus just making the stopband frequency coincide with the antenna operating frequency is not enough to insure efficient operation.



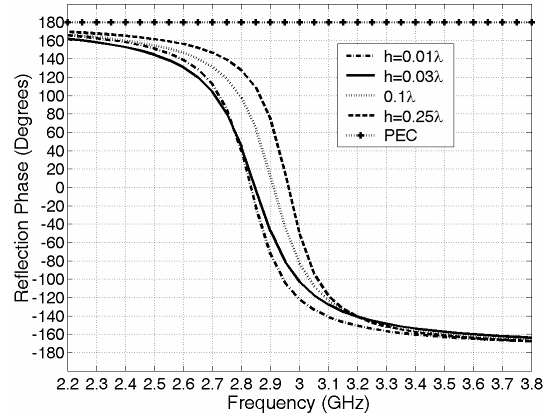
(a)



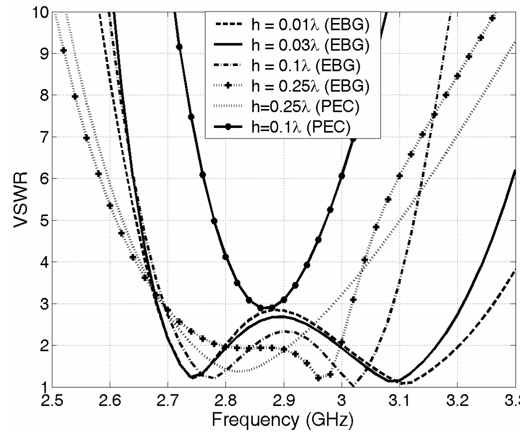
(b)

Figure 1. (a) Identifying the optimum reflection phase profile of an EBG structure and (b) the corresponding VSWR of a thin wire dipole (antenna height of 0.03λ).

Similarly, the thin wire dipole was further studied for other antenna heights. For each height, an optimum reflection phase curve was generated based on our knowledge of the useful phase angles. In other words, the reflection phase curve for an EBG was generated in such a manner that for a specific height of the dipole the useful range of reflection phase angles were mapped to their corresponding frequency bands by varying the EBG design parameters [6]. The optimum reflection phase curves for different dipole heights are shown in Fig. 2(a). The corresponding VSWR data are shown in Fig. 2(b). It is clear that within the frequency range of interest the optimized reflection phase curves ensure efficient dual-band operation for the dipoles. In contrast, for the dipole placed at a height of 0.1λ from a PEC results in higher VSWR. However, this problem is solved when the antenna height is increased to 0.25λ, which makes the whole structure very thick and bulky.



(a)



(b)

Figure 2. (a) Reflection phase profiles of different EBG structures designed based on dipole height. (b) Corresponding VSWR data of the thin-wire dipole.

3. EBG Structure Design

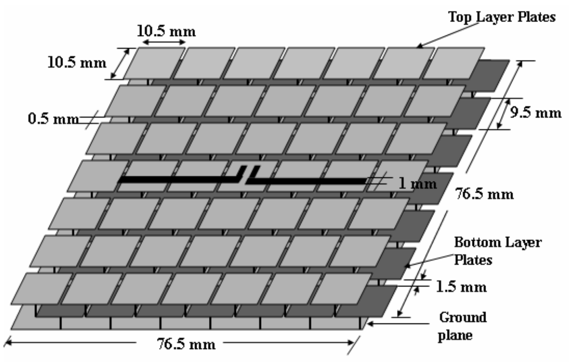
Based on the analytical study presented, one can easily determine the optimum values of design parameters for an EBG structure, which in turn predicts the inductance (*L*) and capacitance (*C*) given by [1]:

$$L = \mu t \ldots\ldots\ldots\ldots\ldots (1)$$

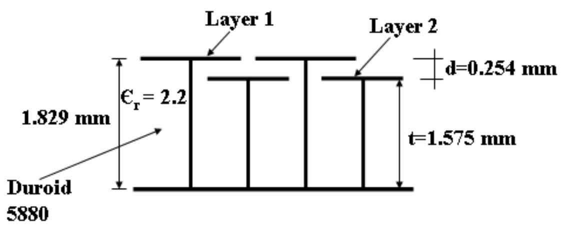
$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \ldots\ldots\ldots\ldots\ldots (2)$$

where t, d and A represent the height of layer-2 from the ground plane, gap between layer-1 and layer-2 [see Fig. 3(b)] and overlapping area between the 2 layers of metal plates [see Fig. 3(c)] respectively.

The steps involved in designing an EBG structure for a thin dipole antenna include the



(a)



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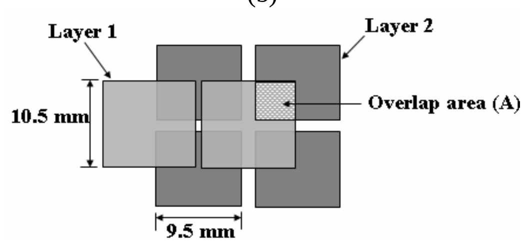


(c)

Figure 3. (a) Schematic diagram, (b) Side view, and (c) Top view of a 3-Layer EBG structure.

following. First, identify the useful range of phase angles and the corresponding frequency bands for a printed dipole of specific height considering a hypothetical EBG structure inserted between the antenna and the ground plane. Second, based on the data found in the previous step generate an optimum EBG reflection phase profile that satisfies the required phase angles. Third, calculate the sheet inductance, *L* and capacitance, *C* values from the optimum EBG design parameters. Finally, design and develop an actual EBG structure that conforms to our reflection phase requirements by evaluating the values of *t*, *d* and *A* from *L* and *C*.

Considering an antenna height of 0.03λ and based on the optimum EBG design parameter values a 3-layer structure was designed, which is shown in Fig. 3. The vias connecting the metal plates with the ground plane provide the necessary inductance and the overlapping areas between the 2-layers of metal plates provide the capacitance. The 1st and 2nd layers of metal plates (see Fig. 3) are placed at heights of 1.83 mm and 1.575 mm, respectively from the ground plane. RT/Duroid 5880 (ε_r=2.2) was used for both layers. A thin (strip width=1 mm) dipole antenna of length 45 mm was designed to operate at 2.9 GHz. The antenna was printed on a 0.5 mm thick RT/Duroid 5880 substrate. A spacing layer (Rohacell Foam) of thickness 0.5 mm was inserted in between the EBG structure and the dipole. So the total thickness of the whole structure containing the dipole was 2.8 mm.

4. Simulated and Measured Results

Before fabrication, the printed dipole placed on the proposed EBG structure was analyzed using IE3D, a full-wave Method of Moments (MoM) solver. Computed return-loss (S_{11}) versus frequency data are shown in Fig. 4, wherefrom it is clear that the

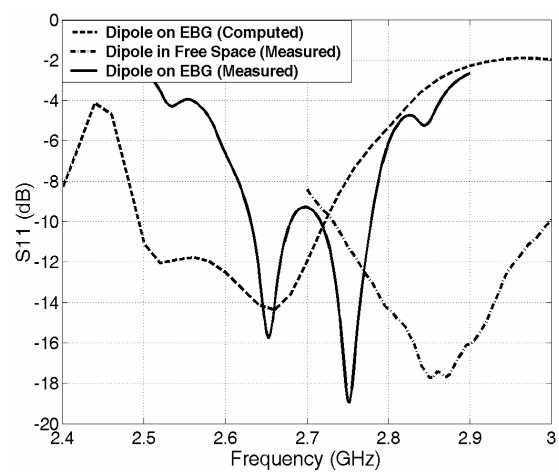
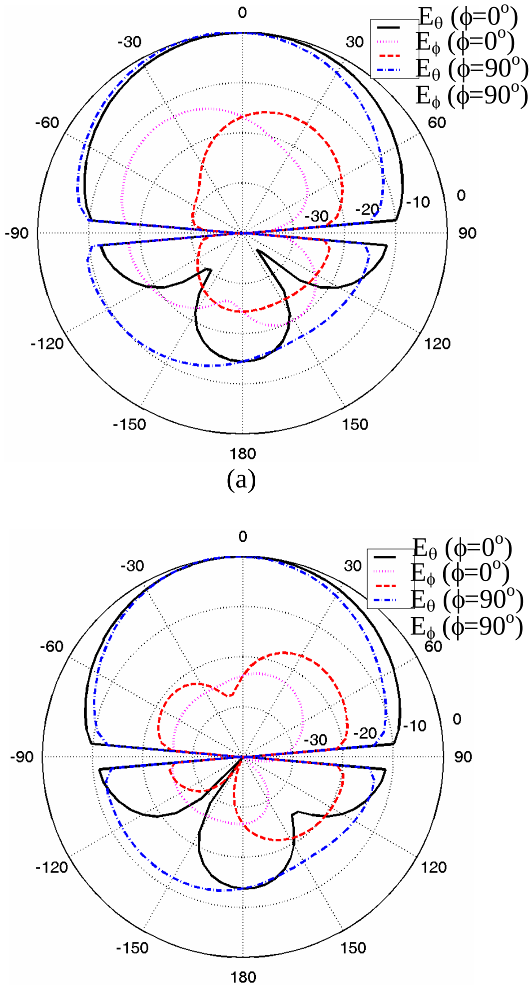


Figure 4. S_{11} Data of a 1 mm strip-width dipole.

dipole has distinct dual-band characteristics. The bandwidth of the antenna is 9%. Measured return-loss versus frequency data for the dipole on top of the EBG structure are also plotted in Fig. 4, which clearly show the presence of dual-band performance with bandwidth of 6%. The antenna on the EBG is far more superior in performance when compared with a similar antenna printed on a grounded dielectric substrate with same thickness. For the latter case the antenna has no bandwidth and negative gain. The antenna on the EBG structure has 6% bandwidth and 7 dBi gain.



(a)

(b)

Figure 5: Computed radiation pattern data of the dipole at (a) 2.55 GHz and (b) 2.65 GHz.

Computed normalized radiation patterns of the dipole on the proposed 3-layer EBG at 2.55 GHz and 2.65 GHz are shown in Fig. 5. According to Fig. 5, the E_θ component in the $\varphi = 0^0$ plane and the E_φ component in the $\varphi = 90^0$ plane are the primary components for both the frequencies. Both the E_φ component in the $\varphi = 0^0$ plane and E_θ component in the $\varphi = 90^0$ plane are below 15 dB of that of their respective primary components. The radiation pattern peaks at both the frequencies are along 0^0. The peak gain of the dipole antenna at 2.55 and 2.65 GHz are 7.0 and 7.2 dBi respectively. The front to back (F/B) ratio for both the frequencies is around 15 dB. The substrate size was 76.5 by 76.5 mm^2. Increasing the substrate size to 99 by 99 mm^2 resulted in an F/B ratio of 25 dB.

5. Conclusion

A study on the effects of the reflection phase profiles of EBG structures on dipole antennas is presented. The study includes the characterization of the dipole driving-point impedance as function of various reflection phase profiles that vary with frequency, yet have the same reflection phase stop-band. It is clarified that although many different reflection phase profiles can be generated that satisfy the same stop-band frequency, it is the profile that satisfies some specific phase angles is required to achieve good performance. Finally, an EBG structure was designed, fabricated and tested along with a printed dipole antenna. The overall antenna height for this case was 0.03λ. The measured results show that significant improvement in bandwidth and radiation pattern can be obtained by utilizing EBG structures over conventional antennas on grounded dielectric substrates.

6. References

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