A dipole antenna design incorporating both electromagnetic bandgap and zero-refractive index metamaterials

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Abstract

A dipole antenna incorporating both a planar electromagnetic bandgap (EBG) and a zero-refractive index (ZRI) metamaterial surface has been investigated. The combination of the EBG surface and the effective ZRI have been used to enhance both the bandwidth and the directivity of the dipole. The proposed dipole type antenna topology has a directivity in excess of 16 dBi with an s11< -10 dB bandwidth of 700 MHz at the operating frequency of 10.13 GHz. The total structure size is 45 × 45 × 29.3 mm^3, including the dipole antenna, the EBG and the ZRI.

1. Introduction

In the last decade various properties of waves propagating in artificial materials with negative permittivity or/and negative permeability have been published and numerous applications in antenna design have been explored [1-7]. In this paper the improvement of the antenna characteristics is demonstrated using a combination of an EBG effect and ZRI approach.

The fundamental property of an EBG is to suppress surface wave propagation in a specific frequency band and this is used to enhance the bandwidth of a low profile dipole over ground. Several publications based on EBG concepts have also demonstrated the improvement of the performances of antennas in aspects such as increasing the antenna efficiency and reducing side lobes using different EBG shapes [2-4]. Mushroom grounded patch are used here as the EBG unit cell.
In the case of ZRI materials, when the radiation is arriving at the interface from a zero-index medium the radiation will be refracted towards the interface normal. Due to this one of the most important applications for ZIM is in improving the directivity of antennas. [5-7]. Split rings structures in combination with wires are used to emulate a zero refractive index material which is placed in front of the antenna.

2. Design of EBG and ZRI surfaces

The basic configuration of the proposed dipole antenna placed above EBG surface with ZRI materials at the top is illustrated in Fig.1. It consists of three main parts: a dipole antenna in the middle, an EBG surface below antenna and a ZRI above antenna. The EBG array is composed of 7 x 7 mushroom-style elements (Fig. 1 left) printed on the top of a dielectric substrate and connected by vias to ground plane. The EBG was designed using h_s=0.508mm thick Rogers RO4003 substrate with a dielectric constant

of 3.55 and a loss tangent of 0.0027. The ZRI layers were realized using split ring resonators and cut wire metamaterials, shown in Fig. 1 right. Each of four ZRI layers, stacked one in top of each other at distance h_f, contain 10 x 10 unit cells. The ZRI design uses a 0.075 mm thick Kapton flexible substrate with relative permittivity ε_r=3.2 and dissipation factor equal to 0.0019. The ZRI metamaterial structure dimensions have been optimised to create a 'lens' to improve the directivity of antenna.
Initially the dipole antenna is designed to operate at the desired frequency of 10 GHz. Total length of antenna is 13.2 mm with a width of 0.5 mm. In the second step, the EBG and ZRI elements were optimized in order to operate at the same frequency as the antenna. The mushroom EBG is designed with square patch dimensions of 6.2 x 6.2 mm, a via radius of 0.25 mm and an element periodicity of 6.4 mm. The band gap properties can be calculated from the model using adjacent perfect electric and magnetic walls to estimate the reflection phase of the EBG cell under the normal incidence, Fig 2a. It can be seen that the zero phase point is at 9.95 GHz while the EBG bandwidth is about 4.4%. Similarly, the zero index of the refraction can be obtain from the model again using adjacent perfect electric and magnetic walls with the computed reflection and transmission characteristics of the ZRI cell are shown in Fig 2b. For split ring dimension is 3.95 x 3.95 mm with a gap of 0.4 mm, ring line width of 0.4 mm and wire element dimension of 0.7 x 4.15 mm. The zero phase point can be seen to be at 10.04 GHz. All simulations were performed using CST Microwave Studio.

3. Antenna results

After designing the individual unit cells dimensions, the whole structure combining dipole antenna, EBG and ZRI surfaces was analysed. Maximum directivity was obtained with the distance between EBG and first ZRI surfaces h_1 was set to 25 mm; the distances between ZRI layers h_2 was set to 1 mm; and the distance between dipole antenna and EBG surface is set to 0.5 mm. The simulation results are shown in Fig. 3 where the dipole with EBG, with and without ZRI layers is included for comparison.

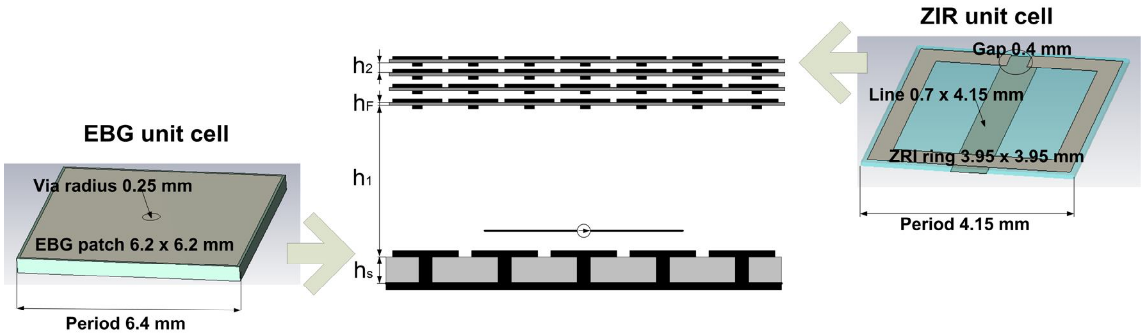
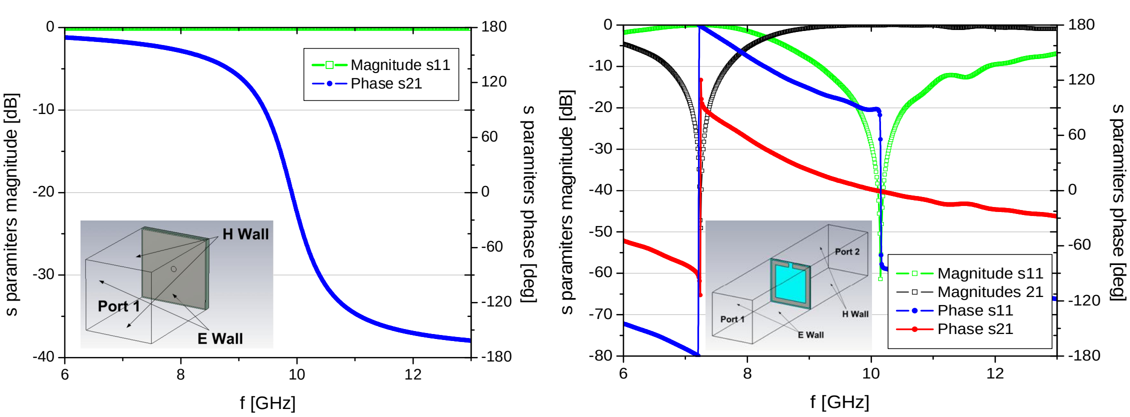
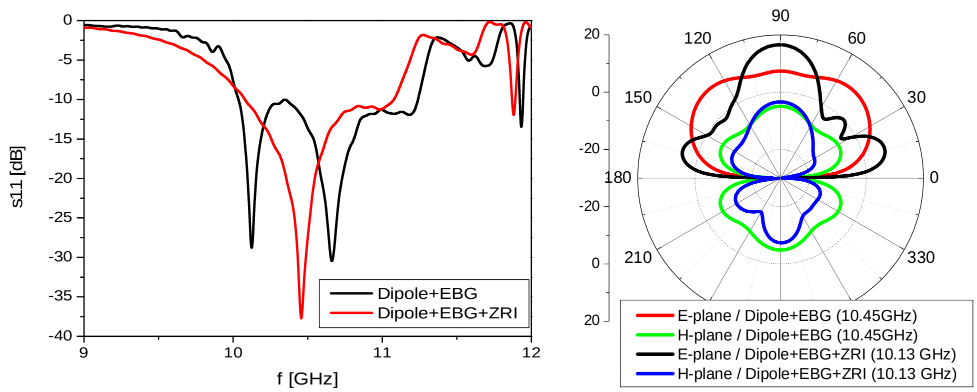


Fig. 1. Configuration of the proposed antenna.



a) b)

Fig. 2. a) Reflection phase for a normal incident plane wave on the EBG unit cell.
b) Reflection and transmission characteristics of the ZRI unit cell.



a) b)

Fig. 3. Comparison of the simulation result for dipole above EBG with and without ZRI layers: a) Return losses, b) Radiation patterns in E- and H-plane at resonances.

It can be seen that placing a ZRI layer over the EBG structure results in an increase of the antenna gain, from 9.1 to 16.5 dBi. Combining the antenna with the reactive surfaces causes a small shift in the resonant frequency that is more prevalent without the ZRI surface. The outside dimensions of antenna including EBG and ZRI are $45 \times 45 \times 29.3$ mm^3. The simulation results show that the bandwidth and directivity of the antenna with EBG and ZRI is significantly improved.

4. Conclusion

In this paper the application of metamaterial surfaces for simultaneous bandwidth and directivity improvement of a dipole antenna is investigated. The mushroom EBG surface under the antenna adds bandwidth and provides for a gain of 9.1dBi, while adding four ZRI layers at the top delivers an additional 7.4dBi of directivity at the operating frequency of 10.13 GHz. The proposed results show that combination of EBG and ZRI surfaces is a useful topology, and that these structures offer substantial directivity enhancement.

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