Multi-scale Electromagnetic Band Gap Structures and Antenna Applications

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Abstract

Multi-scale rectangular mushroom structure, high impedance ground plane (HIGP), is designed to achieve large band gap. By suppressing surface waves, the structure becomes eligible for antenna applications. The HIGP's are composed of three different sized rectangular patch mushroom elements for different resonance frequencies. The characterizations of the three scaled HIGP with varying all dimensions are observed for GHz frequency range. Some antenna designs for free space application and the effect of the multi-scale HIGP on these antennas are also presented.

1. Introduction

Recently, increasing interest have been observed in artificial electromagnetic materials, such as photonic crystals, electromagnetic band-gap (EBG) structures, artificial magnetic conductor (AMC) and left handed meta-materials. These structures are generally composed of metallic thin films and dielectric substrates. Metamaterials which is not directly found in nature have unusual PMC-like electromagnetic properties [1-2]. They have been used in several applications, such as in antennas, filters and so on, for different frequencies. As it is well known, antennas have deep impact in the development of wireless communication that includes cell phones for GPS systems, laptops adapted with third generation mobile system. All these antenna systems require compact size, broad bandwidth and low profile properties. PEC plane is used as a ground plane in many antenna applications to manage backward radiation, improve the antenna gain, and preserve objects from the radiation [3-4]. The interval between antenna and ground plane is $\lambda/4$, and the radiation efficiency reduces below this restriction since out of phase reflection.

The HIGP is a periodic resonant structure used for reducing the surface waves for a desired frequency range and it is called a band gap structure. Surface waves occur in many antenna applications and they flow until reaching corners and edges, then perform as another source radiating into free space. Interference with main radiation pattern causes detrimental effect. Moreover, surface waves result in mutual coupling if radiators share the same ground plane. Each radiator cell in the HIGP array behaves as an isolated radiator with less interference with neighbours; hence inter-element coupling will be minimized. Different elements like triangular, square and circular are utilized in the mushroom structure of HIGPs [5]. Such mushroom patches are mostly identical in size and single periodicity [6]. In this investigation, optimization of rectangular mushrooms that consist of three different sized patches to achieve a combined large band gap is examined. Multi-scale rectangular patch HIGPs are used to further increase the band gap region for antenna application. After the optimization of the variables wy (the width of the rectangular patch through y direction), g (the gap distance between the patches), k (the width of the square patch antenna) type of antenna application results are illustrated.

2. Multiscale Rectangular HIGP Design

The frequency band gaps of the each HIGP structure designated by the transmission characteristics S_{21} of the two coaxial probe feeds. HIGPs are composed of rectangular-patch mushroom elements with three different sized rectangles and periodicities. The main idea is to design a multi-scale HIGP structure where the patch sizes are chosen to realize different band-gaps for each periodic subsection for the target frequency. The length of square patch antennas is assigned as $k \times k$ and the dimension of the rectangular shaped patches in mushroom are adjusted by arranging y direction, thus x dimension are adjusted automatically depending on y direction. The HIGP system is defined by 50.2 mm x 50.2 mm x 30 mm as a dimension of cubic free space and all the edges are assigned as radiation surface. The numerical analysis is solved for 1 - 20 GHz frequency range. Since the gaps may be represented by capacitive elements in a lumped circuit, each mushroom can be represented as LC resonant circuit and the increment of the inductive effect reduces the resonance frequency. The dielectric substrate between patches and metallic ground plane is Rogers R/T

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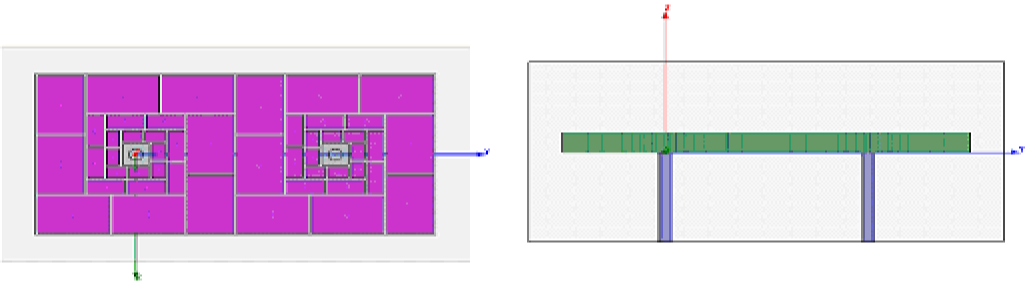
Duroid 5880 and all metallic components are assigned as PEC. The thickness of the substrate (3.175 mm) and metal (0.035 mm) are kept the same for all mushroom scenarios. Three different sized patches are positioned around the antennas to minimize ground plane surface waves for different band gaps and broad band frequency range.



(a) (b)

Fig 1: a) Top view of the rectangular patch HIGP, b) Side view with two coaxial cable feeds

Firstly, the results for the variation of wy dimension are observed for k =4 mm and g =0.5 mm. Distinctive S_{21} results depicted in Figure 2. There is no clear band gap for wy =1 mm and two band gap occurred for wy =3 mm. Suitable and clear results attained for wy =2.5 mm. An exciting observation is the optimization of the dimension directly related with wavelength and due to usage of multi scale. In this case, the number of the band gap is increased.

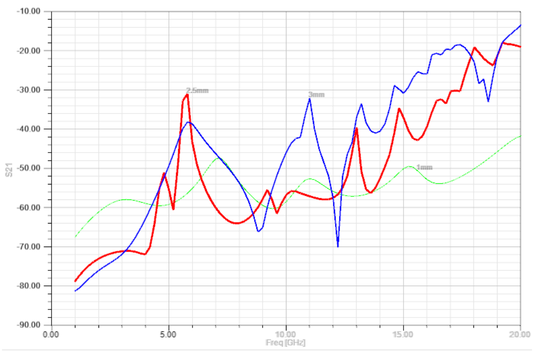


Figure 2: S_{21} for different values of wy in HIGP structure.

The other parameter that affects the band gap frequency region and range is the gap between patches. As g varies between 0.3-0.5 mm, wy =2.5 mm and k =4 mm are fixed. Small gaps 15-18 GHz have been observed for g =0.3 mm and 0.4 mm above 15 GHz. But the gap depth have to be further than 10 dB otherwise it is not clear and useful. Therefore they could be neglected. g =0.5 is not clear to use either and the band gaps between 5.2-12.8 GHz, and 12.8-15 GHz for g =0.4 mm is suitable which can be seen in Figure 3.

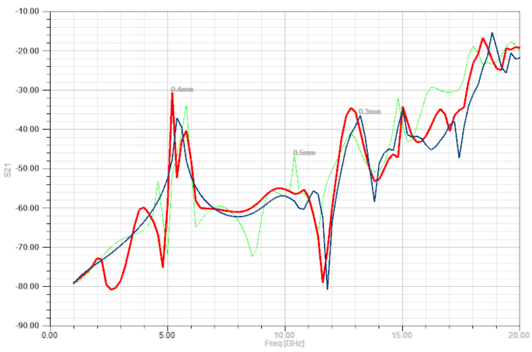


Figure 3: S_{21} for different values of g in HIGP structure.

Square sized length on the coax (k) is also another parameter to be optimized in EBG. There is no actual EBG to use for k =3 mm and 5 mm. Eligible result for k =4 mm is depicted in Figure 4. All these scenarios allow to design the reduction in broadband surface wave and to have more than one EBG between 1-20 GHz.

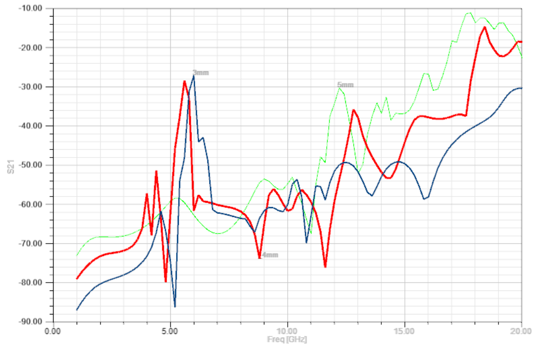


Figure 4: S_{21} for different values of k in HIGP structure.

Optimization of these dimensions of mushroom provides three EBG for k=4mm, g=0,4mm, wy_1=2mm, wy_2=2,5mm wy_3=7mm and all the other parameters and substrate properties are the same with previous simulations. The first gap is between 3.8-12.8 GHz that is the broadest band gap. The second one is between 12.8-16.6 GHz and the last one is between 16.6-17.8 GHz. Three different band gaps are depicted for three different rectangular patch sizes which can be seen in Figure 5.

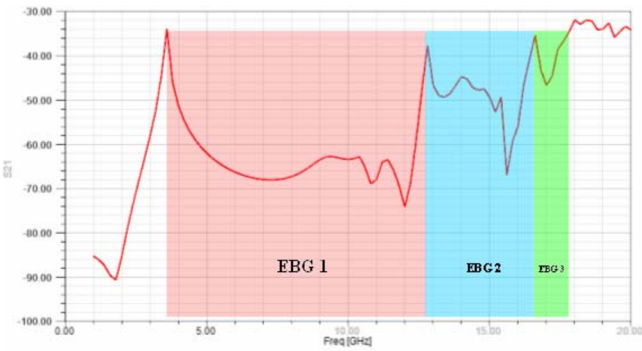


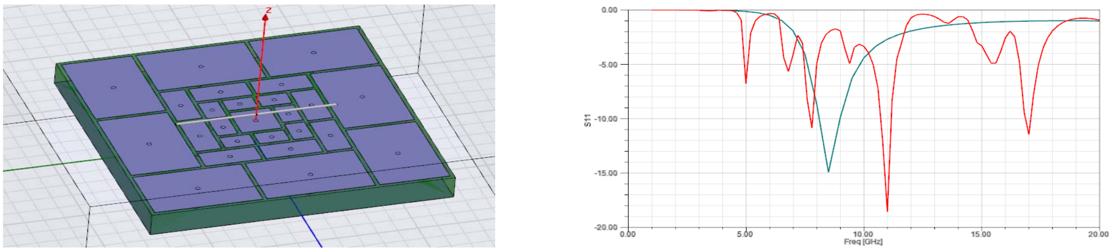
Figure 5: Different regions, three different EBG.

3. Low Profile Antenna Applications

The surface wave band gap of HIGP does not exactly guarantee to enhance radiation of low profile antennas. Therefore, the effect of the HIGP to the antenna radiation could only be evaluated by using HIGP with antenna application. S_{21} represents EM band gap, S_{11} represents return loss. In order to enable the operational frequency band, the operation frequency of the antenna has to be inside the frequency range of the band gap. Antennas have been used to define the characterization of the HIGP structure. In this application, HIGP's effect over the antenna designs is examined. Dipole antenna, bow-tie antenna and log periodic antenna are positioned one by one nearby the EBG surface to observe the effect of the HIGP. Application results are depicted in the following figures (Figure 6, Figure 7, and Figure 8), respectively.Dipole antenna in free space has the radiation of 15 dB at 8.5 GHz, After the application, the main radiation has been increased to 18 dB and the radiation frequency shifts to 11 GHz, as it is depicted in Figure 6. Bow-tie antenna in free space has the radiation of 18 dB at 9.5 GHz. After the application, the magnitude of the radiation remains the same. But, two main radiation frequencies occur approximately at 8.5 GHz and 17 GHz, as can be seen in Figure 7. Figure 8 shows the results for the log periodic antenna. Log periodic antenna in free space has a radiation of 14 dB at 3.5 GHz. After the application, the main radiation increases to 21 dB and there is no shift.

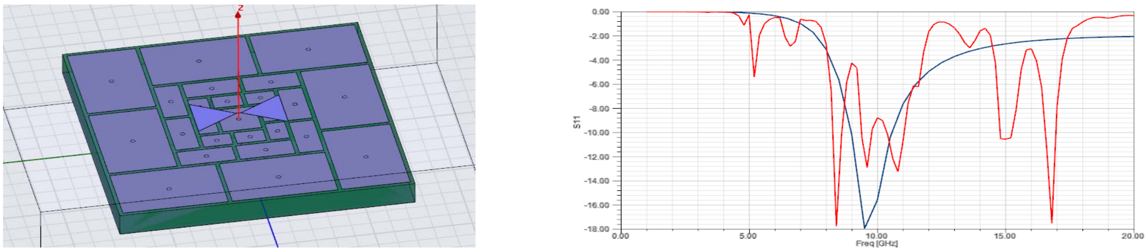
4. Conclusions

A multi-scale HIGP with three different dimensioned rectangular patch mushroom structures has been investigated as a ground plane to enhance in phase reflection and reduce surface waves. Three different EBG have been observed at different frequency range and wide band gaps have been demonstrated for some values. The radiation improvement of the dipole, bow tie, log periodic antenna with HIGP and additional resonance frequencies has been indicated.



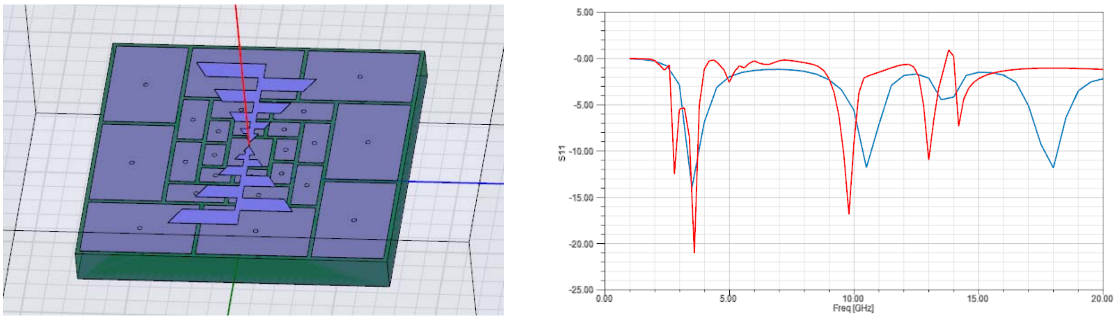
(a) (b)

Figure 6: a) Dipole with HIGP structure, b) Dipole antenna free space (blue) and dipole antenna with HIGP structure (red)



(a) (b)

Figure 7: a) Bow-tie with HIGP structure, b) Bow-tie antenna free space (blue) and bow-tie with HIGP structure (red)



(a) (b)

Figure 8: a) Log periodic antenna with HIGP b) Log periodic antenna free space (blue) and log periodic antenna with HIGP (red)

5. References

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