Mutual Coupling Reduction using High Impedance Surfaces

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Abstract: In the electromagnetic and antenna community, the utilization of electromagnetic band-gap (EBG) structures is becoming attractive. In this paper, a mushroom-like EBG structure is analysed and designed to demonstrate the mutual coupling reduction and surface wave suppression. The simulations are carried out using IE3D simulation tool. All structures are analysed, designed and fabricated using commercially available low cost FR4 material. In this paper, microstrip patch antennas are analysed and designed to operate at a frequency of 2.45GHz (operate at S and L band) for different substrate thicknesses and permittivity. Properties like radiation pattern, gain, mutual coupling are extracted to study the performance of antenna system. As a result, mutual coupling reduction of 8dB is obtained.

Keywords: Electromagnetic band-gap (EBG), Integral Equation Three- Dimensional (IE3D), mutual coupling, surface wave, microstrip patch antennas.

Introduction

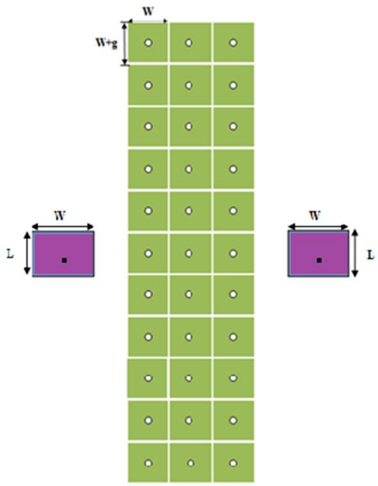


Figure 1. EBG structure integrated with microstrip patch antenna array to reduce mutual coupling

In present communication industry, utilization of electromagnetic band-gap (EBG) structures is gaining interest. The EBG terminology which is suggested in Ref. [1] has diverse forms Ref. [1] and [3], and recently new designs have been proposed like EBG structures integrated with active device Ref. [4] and multilayer EBG structures Ref. [5]. This paper mainly focuses on a mushroom like EBG structure, as shown in Fig. 1. There are many structures like dielectric rods and holes, but for communication antenna applications an important feature like compactness Ref. [6] and [7], is found in EBG structures. Electromagnetic band-gap features are: the surface-wave suppression and the in-phase reflection coefficient. The surface-wave suppression helps to improve antenna's performance such as reduction of back radiation and increasing the antenna gain Ref. [8]–[11]. To reduce the strong mutual coupling of the H-plane coupled microstrip antennas on a thick and high permittivity substrate, the mushroom-like EBG structure is inserted between antenna elements. In order to reduce the mutual coupling, the EBG parameters should be properly designed so that the pronounced surface waves are suppressed. In this work the mutual coupling of microstrip antennas is parametrically investigated.

This paper concentrates on the surface-wave suppression effect of the EBG structure and its application for the reduction of mutual coupling of microstrip antennas. The EBG structure is designed using commercially available FR4 material and simulated using the IE3D tool to investigate the surface wave suppression band. This band-gap study is closely associated with specific antenna applications such as microstrip antennas and arrays. To explore the surface-wave suppression effect, the propagating fields of microstrip patch antenna with and without the EBG structure are simulated and compared.

EBG Structure's Band Gap Characterization

The EBG structure was first proposed in Ref. [3]. It has four parts: connecting vias, metallic patches, a dielectric substrate and a ground plane. It exhibits a prominent stopband for propagation of surface waves. Its operation mechanism can be explained by an LC filter array: current flowing through the vias results in inductance L, and the gap between the adjacent patches results in capacitance C, as in Fig. 2. For an EBG structure with patch width W, gap width g, substrate thickness h and dielectric constant ε_r, the values of the inductor and the capacitor are determined by the formula Ref. [12].

Bandgap Analysis Using Simulation Tool

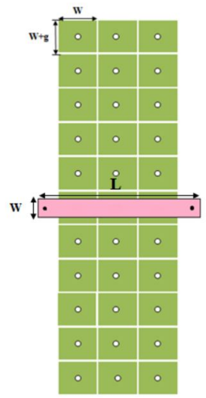


Figure 2. EBG simulation model

In this paper, to accurately identify the band-gap region and understand its properties comprehensively, the IE3D tool is used to analyze the band-gap features. A simple microstrip line is utilized to activate the structure in order to obtain a wide range of frequency responses. Fig. 2 shows the microstrip line source surrounded by the mushroom like EBG structure. The plot for the above structure is as shown in the Fig. 3. The EBG structure is designed to operate at 2.4GHz using FR-4 material has the following parameters: W = 30.3mm, g = 0.5mm, h = 1.6mm, ε_r = 4.3. The vias radius is 0.5mm. The ground plane size is kept to be 104.96mm * 208.20mm. A reference plane is positioned at 2.4mm distance away from the edge, where it is located outside the EBG structure, and the height of the reference plane is 0.8mm. The LC model [(5.1)-(5.4)] is used to analyze this mushroom- like EBG structure, and a band gap of 2.3 - 2.8 GHz is obtained. However, the EBG structure cannot successfully suppress surface waves outside its frequency band gap.

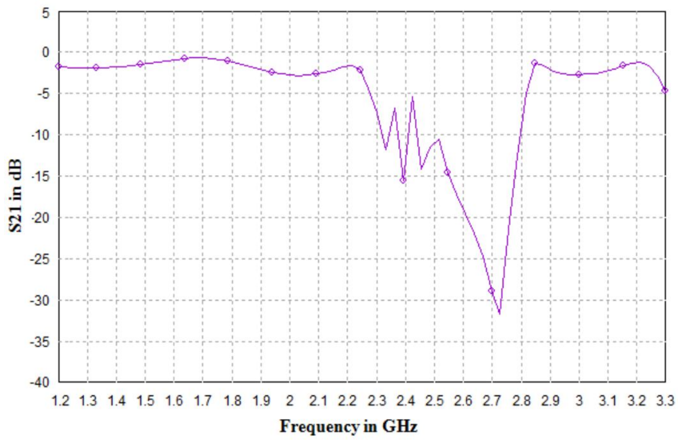
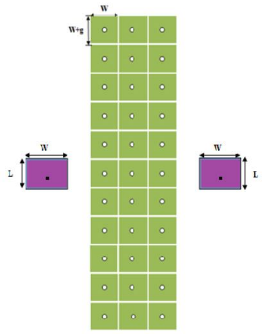


Figure 3. Band gap analysis of EBG

Mutual Coupling Reduction Using EBG structure

The microstrip antennas on a thick and high permittivity substrate which are H plane coupled exhibit very strong mutual coupling due to the pronounced surface waves. Since the EBG structure has already demonstrated its ability to suppress surface waves, three columns of EBG patches are inserted between the antennas to reduce the mutual coupling, as shown in Fig. 4. Fig. 5 shows IE3D simulated results of the H-plane coupled microstrip antennas on a dielectric substrate with h = 1.6mm and εr = 4.3. The antenna's size is 38mm*30mm, and the distance between the antennas is 140.32mm. The mushroom like EBG structure is inserted between the antennas to reduce the mutual coupling. Two different EBG cases are analyzed and their mushroom-like patch sizes are 30.3 and 25mm respectively.



The gap between mushroom-like patches is constant at 0.5 mm for all two cases. The mutual coupling results are shown in Fig. 6. Without the EBG structure, the antennas show a strong mutual coupling of -37.36 dB. If the EBG structures are employed, the mutual coupling level changes. When the 25mm EBG case is used, its band gap is higher than the resonant frequency 2.34GHz. Therefore, the mutual coupling is not reduced and a strong coupling of -45 dB is still noticed which is as shown in the Fig. 7.

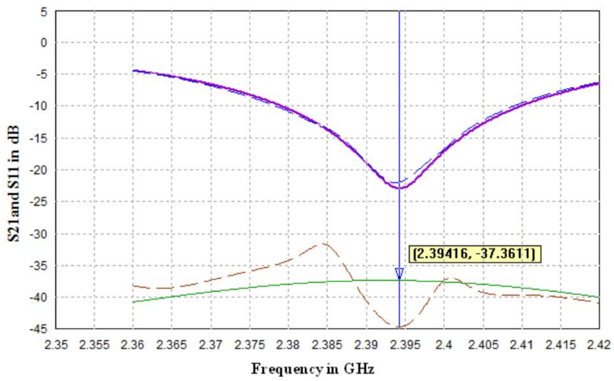


Figure 6. Measured results of microstrip antennas with and without the EBG structure.An 8dB mutual coupling reduction is observed at resonant frequency

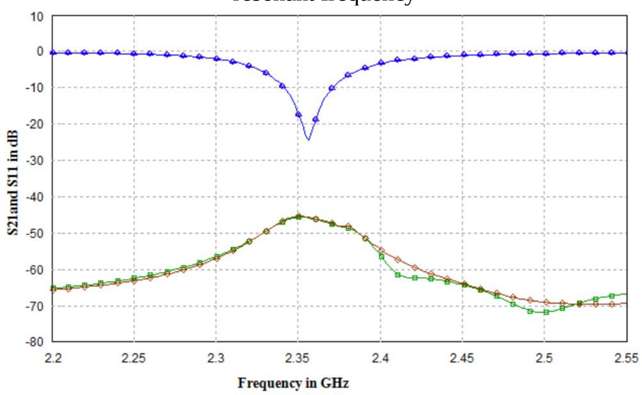


Figure7. H-plane coupled microstrip antennas separated by EBG structure with patch size 25mm

Conclusion

In this paper, a mushroom-like EBG structure is designed using low cost commercially available FR-4 material. The EBG structure is analyzed to investigate the bandgap using the IE3D simulator. The structure was designed to operate at center frequency of 2.45GHz. Simulation results clearly show the bandgap centered around 2.45GHz. Simulations were carried out to show the mutual coupling between microstrip antennas in the array using two element arrays. It is observed from the results that there is a strong mutual coupling between the antennas due to surface waves. The EBG structure is then inserted between the antenna elements to reduce the mutual coupling. There is an 8 dB mutual coupling reduction is observed at the resonant frequency. Compared to other approaches, 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. Mushroom like High Impedance Surface are applied for the noise reduction inside the shielded package. HIS based antennas are used for high data rate communications at frequencies around 40GHz. These find applications in flexible wireless systems and MIMO antenna systems.

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