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# Microstrip Antennas Integrated with Electromagnetic Band-Gap (EBG) Structures for Array Applications

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**Abstract:** In this paper, a mushroom-like EBG structure is analyzed using the finite-difference time-domain (FDTD) method. Utilization of electromagnetic band-gap (EBG) structures is becoming attractive in the electromagnetic and antenna community. Its band-gap feature of surface-wave suppression is demonstrated by exhibiting the near field distributions of the electromagnetic waves. The mutual coupling of microstrip antennas is parametrically investigated, including the E and H coupling directions, different substrate thickness, and various dielectric constants. It is observed that the E-plane coupled microstrip antenna array on a thick and high permittivity substrate has a strong mutual coupling due to the pronounced surface waves. Therefore, an EBG structure is inserted between array elements to reduce the mutual coupling. This idea has been verified by both the FDTD simulations and experimental results.

**Keywords:** Electromagnetic band-gap (EBG), finite-difference time-domain (FDTD) method, microstrip antennas, mutual coupling, surface wave.

## I. INTRODUCTION

The electromagnetic band-gap (EBG) structure in the electromagnetic and antenna community is based on the photonic band-gap (PBG) phenomena in optics that are realized by periodical structures. This paper focuses on a mushroom-like EBG structure, as shown in Fig. 1. Compared to other EBG structures such as dielectric rods and holes, this structure has a winning feature of compactness, which is important in communication antenna applications. Its band-gap features are revealed in two ways: the suppression of surface-wave propagation, and the in-phase reflection coefficient. The feature of surface-wave suppression helps to improve antenna's performance such as increasing the antenna gain and reducing back radiation. Meanwhile, the in-phase reflection feature leads to low profile antenna designs.

This paper concentrates on the surface-wave suppression effect of the EBG structure and its application to reduce the mutual coupling of microstrip antennas, as shown in Fig. 1. To explore the surface-wave suppression effect, the propagating fields of an infinitesimal dipole source with and without the EBG structure are simulated and compared using the finite difference time-domain (FDTD) method, and a frequency stop band for the field propagation is identified.

Applications of microstrip antennas on high dielectric constant substrates are of special interest due to their compact size and conformability with the monolithic microwave integrated circuit (MMIC). However, the utilization of a high dielectric constant substrate has some drawbacks. Among these are narrower bandwidths and pronounced surface waves. The bandwidth can be recovered using a thick substrate, yet this excites severe surface waves. The generation of surface waves decreases the antenna efficiency and degrades the antenna pattern. Furthermore, it increases the mutual coupling of the antenna array which causes the blind angle of a scanning array.

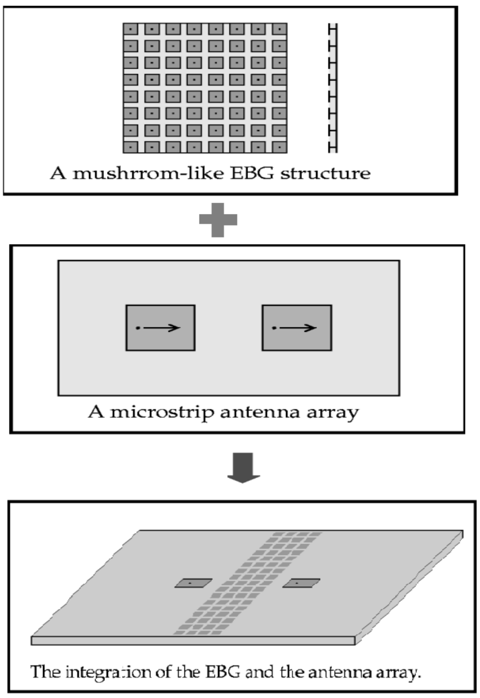


Fig.1. Integration of the EBG structure with MSA array

## II. MUTUAL COUPLING COMPARISON OF VARIIOUS MICROSTRIP ANTENNA ARRAYS

A. FDTD Method for Mutual Coupling Simulation:
The FDTD method is used to analyze the mutual coupling of microstrip antennas. The mutual coupling of antennas fed by microstrip lines has been solved using the FDTD method and the probe fed antenna case is discussed herein. Fig. 5 plots an FDTD model to calculate the mutual coupling of two probe fed patch antennas. The reflection coefficients are defined as

$$\begin{bmatrix} b1 \\ b2 \end{bmatrix} = \begin{bmatrix} S11 & S12 \\ S21 & S22 \end{bmatrix} \begin{bmatrix} a1 \\ a2 \end{bmatrix}$$

Where, a1, a2, b1 and b2 are the normalized voltage waves. The incident wave and reflected waves are mixed together during the FDTD simulation, and the voltages and currents are recorded at the ports.
A Gaussian pulse type of voltage source is used to excite the structure. For simplicity, only port one is activated during the simulation and port two is matched to 50. Therefore, the incident wave at port two is zero;
$b_1 = S_{11}\, a_1$
$b_2 = S_{21}\, a_1$

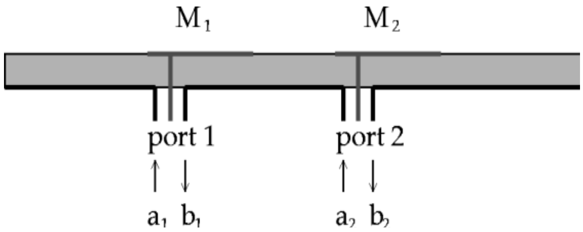


Fig.2. FDTD model to calculate the mutual coupling of probe fed MSA

B. Mutual Coupling Comparison:
The developed FDTD method is next used to analyze the mutual coupling features of microstrip antennas at different thicknesses and permittivity. Both the E-plane and H-plane couplings are investigated, and four patch antennas are compared as follows:

1) Patch antennas on a thin and low dielectric constant substrate: $€_r$=2.20, h=1 mm, and the patch size is 16 mm X 9 mm;
2) Patch antennas on a thick and low dielectric constant substrate: $€_r$=2.20, h=2 mm, and the patch size is 15.5 mm X 12 mm;
3) Patch antennas on a thin and high dielectric constant substrate: $€_r$=10.20, h=1 mm, and the patch size is 7.5 mm X 5 mm;
4) Patch antennas on a thick and high dielectric constant substrate: $€_r$=10.20, h=2 mm, and the patch size is 7 mm X 4 mm.

It can be observed that the bandwidth increases with increasing thickness and decreases while the permittivity increases. It's worthwhile to point out that the bandwidth of case 4 is even larger than that of case 1, which means the bandwidth of microstrip antennas on a high permittivity substrate can be recovered by increasing the substrate thickness. Similar observations were also made, which emphasized on a single element's performance, especially on the improvement of radiation patterns. The first case has the lowest mutual coupling level, while the last case shows the strongest. This is because the microstrip antenna on a high permittivity and thick substrate activate the most severe surface waves. The mutual coupling of all cases decreases as the antenna distance increases. It is observed that both increasing the substrate thickness and permittivity will increase the mutual coupling level.
In contrast to the E-plane coupled results, the strongest mutual coupling occurs at the second case, which has a low dielectric constant and a thick substrate thickness, and the weakest mutual coupling happens at the third case, which has a high dielectric constant and a thin substrate thickness. It is observed that increasing the substrate thickness still increases the mutual coupling, while increasing the permittivity decreases it.

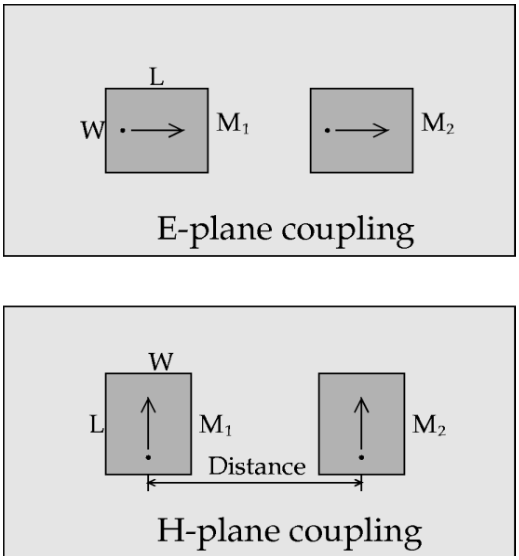


Fig.3. E and H-plane coupled probe fed microstrip antennas.

## III. MUTUAL COUPLING REDUCTION USING THE EBG STRUCTURE

From the above comparison, it is found that the E-plane coupled microstrip antennas on a thick and high permittivity substrate exhibit very strong mutual coupling due to the pronounced surface waves. Since the EBG structure has already demonstrated its ability to suppress surface waves, four columns of EBG patches are inserted between the antennas to reduce the mutual coupling,

The mushroom-like EBG structure is inserted between the antennas to reduce the mutual coupling. Three different EBG cases are analyzed and their mushroom-like patch sizes are 2, 3, and 4 mm, respectively. The gap between mushroom-like patches is constant at 0.5 mm for all three cases. It is observed that all the antennas resonate around 5.8 GHz. Although the existence of the EBG structure has

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some effects on the input matches of the antennas, all the antennas still have better than -10 dB matches.

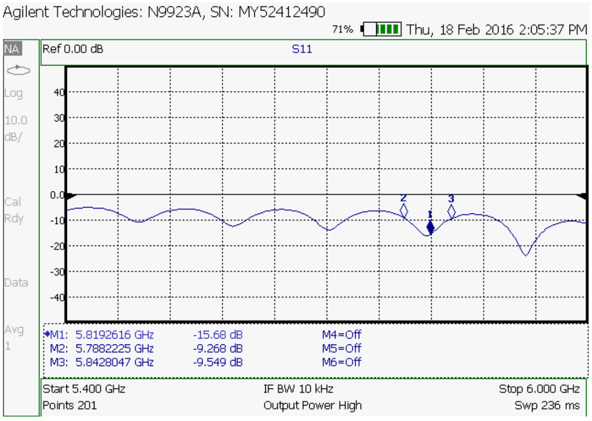

Fig.4. Return loss without EBG

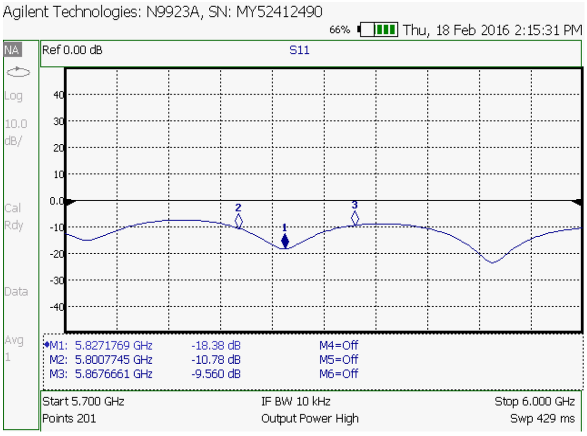

Fig.5. Return loss with EBG

Without the EBG structure, the antennas show a strong mutual coupling of -15.60 dB. If the EBG structures are employed, the mutual coupling level changes. When the 2mm EBG case is used, its band gap is higher than the resonant frequency 5.8 GHz. Therefore, the mutual coupling is not reduced and a strong coupling of -18.38 dB is still noticed.

B. Comparison of the EBG Structure With Other Approaches:
It is instructive to compare the EBG structure with other structures also used to reduce the mutual coupling. Fig. 14(a) plots four E-plane coupled antenna structures to be compared:
1) Normal microstrip antennas,
2) The substrate between antennas are removed,
3) Cavity back microstrip antennas, and
4) Microstrip antennas with the EBG structure in between.

During the comparison, the antenna size, substrate properties, and antenna distance in all the structures are kept the same as in the EBG case. In structure 2), a 13.5 mm width substrate is removed between the patch antennas. This width is chosen to be the same as the total width of four rows of the EBG patches.

When the cavity structure is used, the distance between the adjacent PEC walls is also selected to be 13.5 mm. The normal microstrip antennas show the highest mutual coupling. The substrate removal case and the cavity back case have some effects on reducing the mutual coupling. A 1.5 dB mutual coupling reduction is noticed for the former case and a 2 dB reduction is observed for the latter case. The lowest mutual coupling is obtained in the EBG case as an 8.8 dB reduction is achieved. This comparison demonstrates the unique capability of the EBG structure to reduce the mutual coupling.

## IV. FABRICATION AND DEMONSTRATION

To design a rectangular micro strip patch antenna following parameters such as dielectric constant (Ɛr), resonant frequency (fr), and height (h) are considered for calculating the length and the width of the patch.
The antennas size is 11.4mm 14 mm, and the distance between the antennas is 30 mm. Fig. 4 & 5 shows the return loss and the coupling coefficient of the antenna array with and without the EBG structures. It is observed that the antenna resonate around 5.8 GHz. The fabricated antenna structure with EBG and Without EBG structure between microstrip patch antenna arrays is shown in Fig.6. This is feed using coaxial feeding technique at the center of the patch.

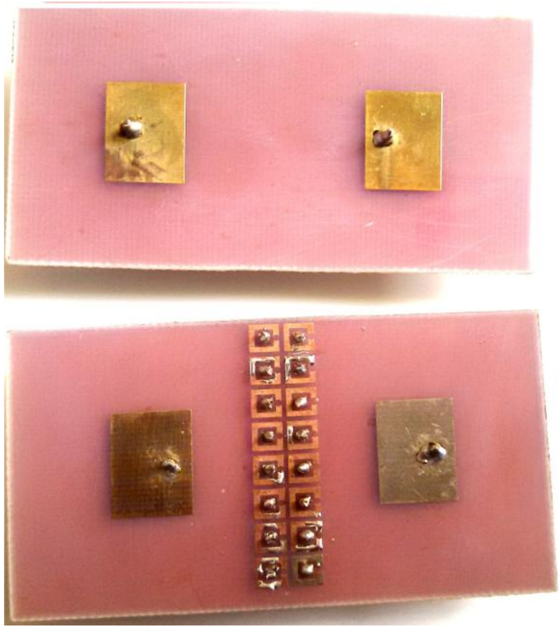
Fig.7. Fabrication of designed antenna

## V. CONCLUSION

In this paper, mushroom-like EBG structure for array miniaturization with reduced mutual coupling has been introduced. EBG structure is analyzed using the Ansoft HFSS. The final results show a -18.38dB reduction in mutual coupling and a reduction in compared to general antenna array structure. EBG structures for an operating frequency of 5.8GHz have been presented and several


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useful properties of the structure have been investigated, like the in-phase band gap reflection coefficient and S-parameters. These properties make the proposed EBG structure a good candidate to enable the design of flow profile antennas, and the surface wave suppression band gap property which improves the antenna performance.

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