Mutual Coupling Reduction in Patch Antenna Arrays Using a Planar Compact EBG Structure

Z. Karami* and A. Attari

Department of Electrical Engineering, Ferdowsi University of Mashhad, Iran

*Corresponding author: zahra67karami@gmail.com

ABSTRACT—An important issue in antenna array design is reduction of mutual coupling. In microstrip antennas this reduction can be achieved by using electromagnetic band-gap (EBG) structures. These structures prevent the propagation of surface waves on the substrate of a microstrip antenna array. This paper presents a new configuration of a planar compact electromagnetic bandgap structure to reduce mutual coupling between array elements. First, the bandgap feature of the EBG structure is studied by obtaining the dispersion diagram. Next, the EBG structure is placed between two antennas to reduce the mutual coupling level. Simulation results show that a significant value of mutual coupling reduction, more than 22 dB, can be obtained by using the proposed structure.

KEYWORDS: Dispersion diagram, electromagnetic bandgap structures, microstrip antenna arrays, mutual coupling, surface wave.

I. INTRODUCTION

Mutual coupling in arrays is considered to be very important problem for antenna design engineers. In arrays of microstrip antennas, this coupling is especially critical. This coupling can be due to radiated waves or due to surface waves [1]. Surface waves can become dominant if high dielectric constant substrates are used [2]. When the antenna is operating in the fundamental mode \((\text{TM}_{10})\) for rectangular patches), surface waves are strongly excited in E-plane. In this mode, the field distribution can excite the \(\text{TM}_0\) mode of the surface waves E-plane [1]. A commonly used method for reduction of mutual coupling effect is using EBG structures between two adjacent antenna elements [1-4]. Different forms of EBG structures such as mushroom-like EBG structure or dielectric rods and holes have been introduced [5]. Later on, several other novel EBG structures were presented such as planar compact EBG (UC-EBG) [6] and fork-like EBG [2]. Due to the capability of these structures for reducing the surface waves, they can improve the antenna performance. This improvement can be achieved in reduction of back-lobe radiation, increasing the antenna gain and increasing the antenna efficiency [7].

In this paper we propose a new, compact and easy to fabricate, EBG structure, based on totally planar layout without via. Bandgap feature of the EBG structure is studied using dispersion diagram and performance of two mutually coupled patch antennas, separated by the EBG structures is also tested.

II. EBG STRUCTURE CONFIGURATION

When periodicity of structure is small compared to the operating wavelength, the operation mechanism of EBG structure can be...
described using an equivalent LC circuit model [8]. The inductor $L$, results from the current flowing along adjacent patches through narrow lines and the capacitor $C$ is used to model the gap effect between the patches. The surface impedance equals to the impedance of a parallel resonant circuit and the central frequency of the bandgap is calculated as below [8]:

$$z = \frac{j\omega L}{1 - \omega^2 LC}$$  

(1)

$$\omega_0 = \frac{1}{\sqrt{LC}}$$  

(2)

From (2), it is obvious that increasing the equivalent capacitance or inductance results in decreasing the resonant frequency and hence a compact structure can be achieved.

Here, we propose a novel planar compact EBG structure, which is realized with metal pads etched in the substrate connected by narrow lines to form a LC network. The schematic of the unit cell of proposed EBG structure is shown in Fig. 1. Pink parts in this figure represent the metallic periodic structure which is etched on a dielectric substrate.

In the case at hand, the antenna resonant frequency is selected at 10 GHz. The parameters of the EBG structure are designed in a way that the desired frequency bandgap can accommodate the resonant frequency of the antenna. These periodic cells are printed on a dielectric slab with permittivity $\varepsilon_r = 10.2$ and thickness 1mm (Roger RT/ Duroid 6010), which could provide an equivalently miniaturized design. For the novel EBG structure, the element parameters are chosen as follows: the periodic spacing is $w=2\text{mm}$, the gap between neighboring elements is $g=0.3\text{mm}$, the $p$ parameter that describe in Fig. 1 is $p=1.62\text{mm}$, the radius of truncated circle is $r = p/2+m$, the width of conductor lines is $m=0.1\text{mm}$.

The performance of the unit cell is studied by Ansoft HFSS. Periodic boundaries are added on four sides such that an infinite periodic structure could be modeled. The simulated dispersion diagram of the infinite structure is shown in Fig. 2. The band-gap of this structure is 17.21% that is not very wide. The reason is that it has been designed in such a way that we have a very compact structure; the capacitance of structure is much larger than that of the conventional structures.

![Unit Cell Schematic](image)

Fig. 1 Top view of the proposed unit-cell.

![Dispersion Diagram](image)

Fig. 2 Dispersion diagram of novel EBG structure

### III. BANDGAP CHARACTERIZATION

The dispersion is an effective tool for studying bandgap characterization of the EBG structures [9].

### IV. REDUCTION OF MUTUAL COUPLING BETWEEN MICROSTRIP ANTENNA

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. Mutual coupling brings crosstalk between different received signals. It has been proved that the E-plane coupled microstrip antennas exhibit much stronger mutual coupling than the H-plane coupled ones due to surface waves [10].

An antenna array operating at 10 GHz is designed on the substrate. The thickness of the substrate is 1 mm and the relative permittivity is 10.2. To obtain the resonant frequency at 10 GHz, the rectangular patch’s size was 3.77mm ×5.3mm and the distance between the centers of the antennas is 22.5 mm (0.75λ). The microstrip antennas are excited by a coaxial probe and the feed point is located at the distance 0.7mm away from the edge of the patches.

The return loss and mutual coupling of antenna array are simulated. As shown in Fig. 3 without the EBG structure, the antennas show a strong mutual coupling of 16.2 dB. The radiation pattern in E-plane and H-plane of array are also presented in Fig. 4.

Due to the EBG’s capability to suppress surface waves, five columns of novel EBG patches are inserted between the E-plane coupled antennas, as shown in Fig. 5, to reduce the mutual coupling. With EBG, the distance between the patch has not changed (0.75λ).

The dimensions of EBG patches are same which that mentioned in section III. The resonant frequency 10 GHz falls inside the EBG bandgap so that the surface waves are suppressed. The simulated mutual coupling results are shown in Fig. 6.
Fig. 6 Comparison of return loss and mutual coupling for two E-plane coupled patch antennas separated or not by novel EBG structure. (a) return loss, (b) mutual coupling.

As expected, the propagation characteristics of the antennas incorporated with EBG structures have been improved compared to the one without EBG structures. Without the EBG structure, the antennas show a strong mutual coupling of 16.2 dB. When the EBG structure is employed, a significant 22.9 dB mutual coupling reduction is achieved at 10 GHz, which proves that the surface waves are suppressed. Also as shown in Fig. 7, the side and back radiation for microstrip antenna array with EBG structure is reduced.

To show the performance of novel structure, we compare the compaction and amount of coupling reduction of this novel structure and some other planar EBG structures that previously presented in literatures. As is clear from the Table 1, this novel EBG structure has a better performance than the previous structures.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Frequency (GHz)</th>
<th>Period of unit cell (mm)</th>
<th>$\frac{w}{\lambda}$</th>
<th>Amount of coupling reduction (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[11]</td>
<td>10.2</td>
<td>3.048</td>
<td>0.104</td>
<td>17 (dual layer EBG)</td>
</tr>
<tr>
<td>[12]</td>
<td>5.45</td>
<td>15.5</td>
<td>0.28</td>
<td>13.5</td>
</tr>
<tr>
<td>[13]</td>
<td>3.9</td>
<td>15.748</td>
<td>0.204</td>
<td></td>
</tr>
<tr>
<td>This paper</td>
<td>10</td>
<td>2.3</td>
<td>0.076</td>
<td>22.9</td>
</tr>
</tbody>
</table>

Table 1 comparison on new EBG and other structures
V. CONCLUSION

We have presented novel EBG design that offer several distinct and quite appealing features: easy fabrication, entirely planar configuration, absence of vias, compaction, making them electrically smaller, about 0.076 of the wavelength. This novel design inserted between the E-plane coupled antennas and a significant 22.9 dB reduction in mutual coupling is achieved at operation frequency.

REFERENCES


