Mutual Coupling Reduction Between Two PIFA Using Uni-Planar Fractal Based EBG for MIMO Application

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Abstract*—Fractal Structures based on Electromagnetic bandgap (EBG) can contribute to the mutual coupling reduction between microstrip antennas due to its capability of suppressing surface waves propagation in a given frequency range. In this paper, a new arrangement of one layer Uni-Planar Fractal based on EBG (UPF-EBG) structure is analysed using the commercial finite element full wave solver High-Frequency Structure Simulation (HFSS version 17.0). The structure without any shorting pins or vias is based on a well-known fractal structure called Sierpinski carpet, within which two iterations have been applied as planner EBG between two PIFA for increase isolation issue. The total dimensions of the PIFA antenna are 40 mm × 68 mm × 1.6 mm and operate at 2.65 GHz approximately which is defined for wireless Long Term Evolution (LTE) MIMO application. Here a compact periodic lattice (2 × 3 EBG structures are joint to improve the mutual coupling) inserted between E-plane coupled PIFA array, and precise performance study is implemented to investigate the mutual coupling. As a result, significantly more than 30 dB mutual coupling reduction is noticed from the simulations.

***Keywords*—Fractal based on EBG; electromagnetic bandgap (EBG); Mutual coupling reduction; PIFA antenna; MIMO**

I. INTRODUCTION

Recently, developments in modern wireless communication systems have imposed additional challenges on microwave antenna and circuit designers to produce new designs that are miniaturized and multiband [18]. Up-to-Date efforts by researchers around the world to combine different fractal geometry with electromagnetic theory have led to a vast amount of new and innovative designs for mutual coupling reduction between antennas in MIMO environment [1]. With the rapid expansion of wireless MIMO communication systems, low profile, wide bandwidth, high isolation between antennas that maintain good performance is still in high demand. In recent years, several techniques have been employed to achieve these objectives [13]. The mutual coupling between nearly spaced antennas is caused by two sources:

Radiation Emission (RE, through electromagnetic coupling) and Conduction Emission (CE, through a common conductor such as the ground plane) [1].

Efforts have been directed to eliminate or decrease the effects of mutual coupling between PIFAs working in MIMO applications. Among the main techniques that have been extensively studied and discussed in the literature for mutual coupling reduction are the following: EBG structures [2], a defected ground plane [5], a neutralization technique [3], spatial and angular variations technique [7],[10], an addition of resonant slots [6], slots on the ground plane [8], Insertion of a small ground plane technique between the PIFA and the PCB [9], T-Shape as decoupling slot [4].

The use of fractal geometry is mainly a method to design multiband and low profile antennas, however, these fractal structures can be utilised for mutual coupling reduction in MIMO environment.

In this paper, we propose a new uni-planar fractal structure based on EBG (UPF-EBG) with a stopband centered approximately at 2.65 GHz. By inserting this structure between dual elements of PIFA antenna array to work in frequency range closer to UPF-EBG stop-band (for example in this paper we choose 2.65 GHz), the coupling reduction had been investigated. Despite the compact size, the inclusion of the proposed fractal based EBG improves the isolation and effectiveness of the MIMO design [2].

II. MIMO ANTENNA DESIGN AND CONFIGURATION

Fractal structures have been widely studied in the literature; it provides multi-band operation, performance enhancement and to meet the miniaturization requirements of the wireless equipment [15-17]. However, this paper focuses on mutual coupling reduction using these fractal structures rather than these previous functionalities.

A. Design Procedures of Proposed Antenna

The initial MIMO antenna configuration is shown in Fig. 1. It consists of two symmetrical planar inverted F-antenna (PIFA) elements, which are located on the same sides (Left and

Right) of the substrate FR4 epoxy (PCB of the mobile device with εr = 4.4 and (loss tangent=0.018) with a 50-ohm coaxial feed. As mobile terminals; such as handsets and PDAs; have become smaller, the design of smaller PIFAs is required, and thus, the dimension of a PIFA should be further reduced. To achieve this goal, the conventional PIFA structure is modified by replacing the shorting plate by a shorting pin (as shown in Fig. 1). The size of the radiating rectangular patches is 19 mm x 30 mm. The dimension of both ground and substrate is 40 mm×68 mm ×1.6 mm approximately as the mobile circuit board. The antenna radiating element is made up of copper sheet with a thickness of 0.1 mm.

TABLE I. DETAILED DIMENSIONS OF THE PROPOSED ANTENNA

Parameters	**Values**
Design frequency (f)	2.65GHz
Height of substrate (h)	1.6 mm
Ground length (LG)	40 mm
Ground width (WG)	68 mm
Patch length (L)	30 mm
Patch length (W)	19 mm
Distance (D)	5 mm
Space (S)	$0.35\lambda 0$ (Centre to Centre)
Shorting Pin	Radius=0.3mm,Height=1.6mm

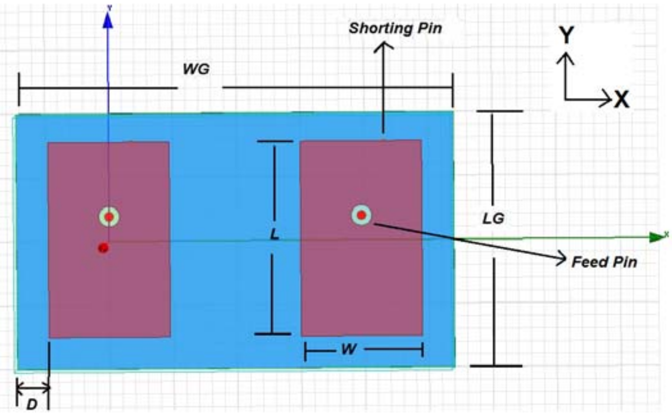

Fig. 1. Layout of the proposed antenna without EBG structure (Top view)

By taking into account of a small mobile terminal, the main radiating patch was designed to resonate at the LTE radio frequency (2.65 GHz) running MIMO applications.

B. Mutual Coupling Reduction

In the past, extensive research was done using fractal based EBG for mutual coupling reduction between two PIFA, Fractal structures are comprised of multiple smaller elements patterned after self-similar (with scaled down designs) to maximize the physical length of current paths or redistribute surface current density; These structure properties are more applicable when working with lower frequency bands in mobile applications.

For many reasons; we have chosen a well-known Fractal structure, which called Sierpinski carpet, within which two iterations (as shown in Fig. 2) have been applied as compact EBG structure between two PIFA antennas in order to have a lowest possible mutual coupling instead of the lattice mushroom-like EBG which occupied a large space between the antennas [12].

First; Fractal based EBG structure has a unique property of compactness with longer current paths that it could work in low-frequency range (due space filling feature). Additionally, these structures (due self-similarity features) are also found to be able to provide a band-stop effect for a particular frequency band due to the combination of inductance and capacitance [17], which can be applied to recent mobile MIMO antenna design to suppress harmonics, cross-polarization of a PIFA antenna, and to increase the isolation of dual-polarized PIFAs [14].

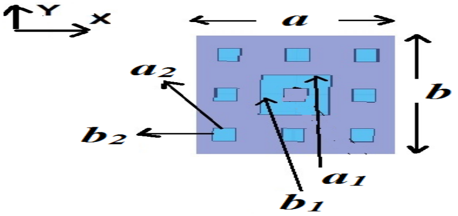

Fig. 2. Layout of the UPF-EBG unit cell

UPF-EBG was inserted between the two antennas to reduce mutual coupling, as shown in Fig. 3. it will suppress surface waves.

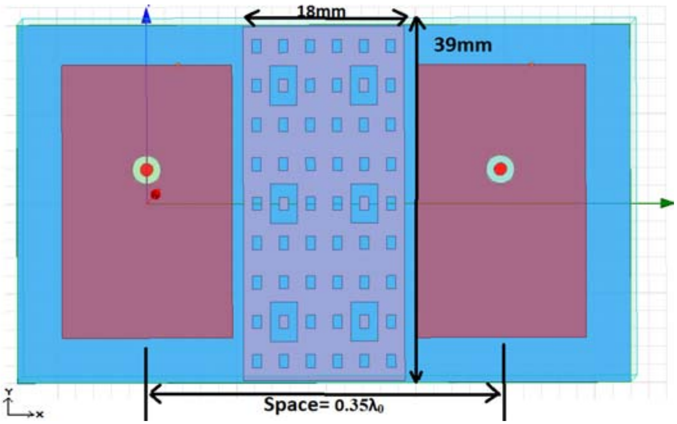

Fig. 3. The layout of the proposed antenna separated by the single layer UPF-EBG structure for a low mutual coupling (Top view).

The proposed MIMO antenna has better performances, higher isolation, and the smaller size.

C. UPF-EBG Characterization

The proposed UPF-EBG structure as shown in Fig. 3. consists of 2×3 unit cell of fractal structures are joint to form a compact periodic lattice with dimensions 39mm×18mm and inserted between the coupled PIFA array to improve the mutual coupling. Eigen mode analysis was performed using the full-wave 3-D simulation tool HFSS ver. 17 to demonstrate the filtering characteristics of the proposed structure.

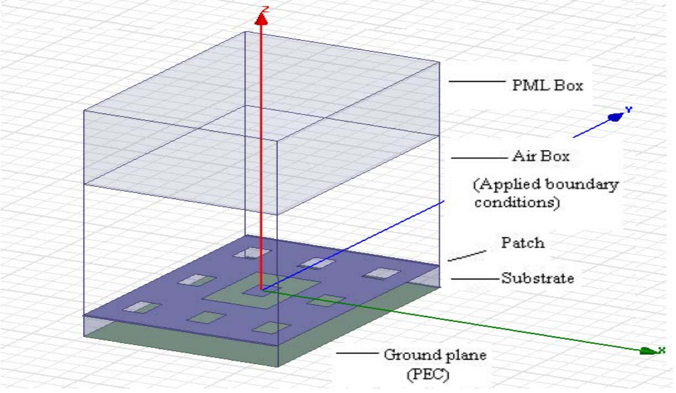

Fig. 4 (a) Unit cell with PML boundary

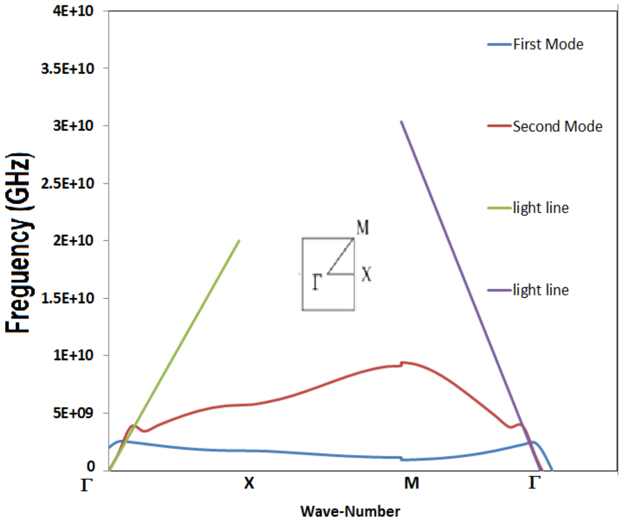

Fig. 4. (b) Dispersion diagrams of the EBG structure.

The stop band of the EBG structure is verified using more computationally efficient unit cell Eigen-Mode model which has only one single periodic cell of the EBG lattice as illustrates in Fig. 4(a) with Perfect Electric Conductor (PEC) layers assigned on the top (which behave as the patch antenna on top) and the two pairs of side walls (+X/-X) & (+Y/-Y) to which linked periodic boundary conditions [11].

The full-wave numerical simulator Ansoft HFSS 17.0 based on finite element method is used to analyze the 2-D propagation on the irreducible Brillouin zone. Figure 4(b) shows the simulated dispersion diagram. A complete band gap between first mode and the second mode, approximately from frequency 2.5 GHz to 2.7 GHz can be seen (the bandgap is centered at 2.6 GHz).

The optimized dimensions for unit-cell used in this work are $a = 9\ mm$, $b = 13.2\ mm$, $a_1 = 1/3 \times a$, $b_1 = 1/3 \times b$, $a_2 = 1/3 \times a_1$, $b_2 = 1/3 \times b$, scaling down with no. of iterations by a particular factor (1/3) (see Fig. 2). The inclusions are etched on an FR4 dielectric substrate ($\varepsilon_r = 4.4$) with a thickness of 1.6 mm. The dimensions of the structure unit cells were precisely optimized to obtain a rejection band from 2.5 to 2.7 GHz approximately.

III. RESULTS AND DISCUSSION

A. S Parameters

Fig. 5. Illustrates the return loss of adding UPF-EBG and antennas without the structure. It was observed that the antennas without UPF-EBG structure resonate around 2.64 GHz while the resonant frequency of the MIMO antennas with the single layer UPF-EBG structure slightly shifts higher from 2.64 GHz to 2.66 GHz. This due to the effects on the input matching of the antennas; however, the antennas still have a return loss better than -10 dB.

The impedance bandwidth (S11 < - 10 dB) is 2.6% for both cases (without and with UPF-EBG). Inserting UPF-EBG structure may shift the resonant frequency a little higher than before (about 2% from 2.64 GHz to 2.66GHz.) as shown in Fig. 5. (which is acceptable)

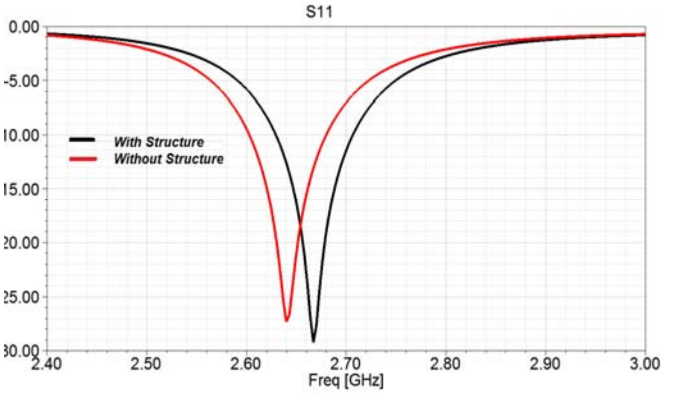

Fig. 5. Simulation S11 of the proposed MIMO antennas

The isolation between antennas or mutual coupling reduction results is shown in Fig. 6. It is clear: without the UPF-EBG structure, the antennas show a strong mutual coupling of –27 dB While when the UPF-EBG structure is employed, the mutual coupling level is significantly reduced (-58 dB).

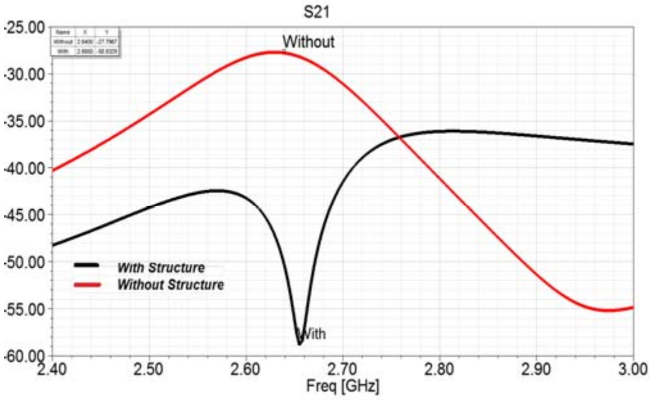

Fig. 6. Simulation S21 of the proposed MIMO antennas.

B. Radiation Performance

This section presents the study performed on the effect of far-field radiation patterns as a comparison between both cases (with and without the structure). The E-plane and H-plane patterns of the antenna with absence and presence of EBG are demonstrated in Fig. 7(a) and (b) at 2.65GHz.

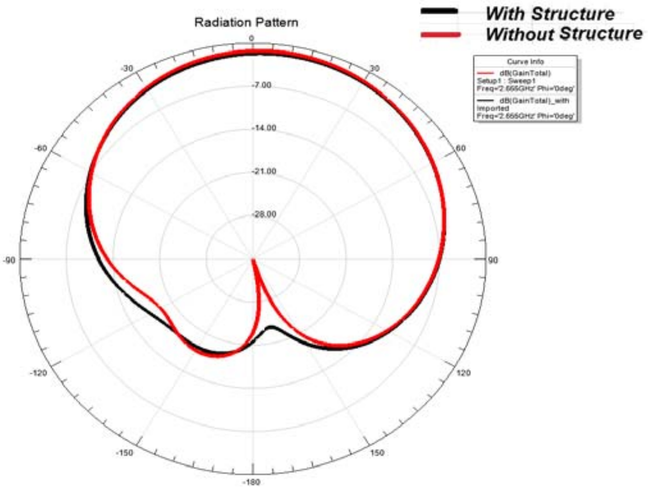

Fig. 7 (a) E-plane

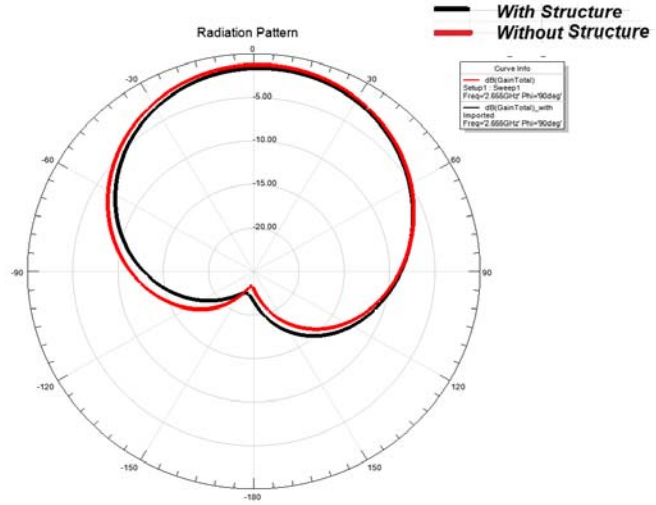

Fig. 7 (b) H-plane.

Fig. 9. Simulated Radiation patterns of the two-PIFA array with and without structure at 2.65 GHz. (a) E-plane, (b) H-plane.

As shown in Fig. 7. the EBG structure does not affect antenna pattern (nearly still directional at interested band 2.65GHz and do not significantly degrade the patterns in the principal plane) and does not show a significant difference between the main lobes patterns; it is seen that aside from minor changes at the back-lobe of the patterns which are not more than 5 dB (in the E-plane only), these all plots are taken out when the first antenna is excited, and the other antenna is matched terminated.

C. Surface Wave Distribution and Current Density

It is also good to better understand its mechanism by investigating both the surface wave distribution and the surface current density. We have performed this by plotting the surface wave distribution within the dielectric substrate. As shown in Fig. 8(a) and (b), respectively:-

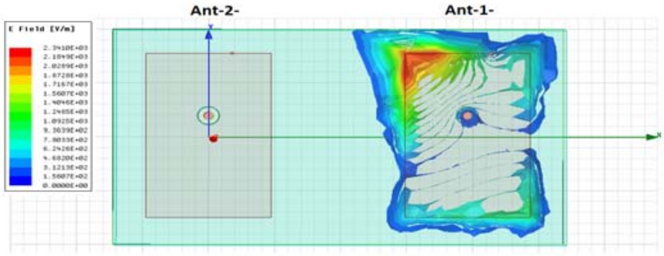

Fig. 8. (a) Without case

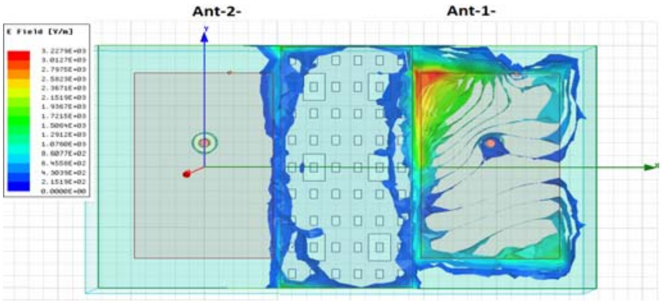

Fig. 8. (b) With case

Fig. 8. Simulated surface waves within the dielectric at 2.65 GHz of the antenna array (top view) when the first antenna is excited and the second one is terminated to a 50 load. (a) Without case and (b) With case

It is observed that strong surface waves which are excited by the first antenna, are concentrated around the corners of the structure (circulate) and do not affect the second antenna. From Fig. 8(a) and (b), It is clearly seen that the structure function as an effective wave-trap, that is blocking antenna's near-field radiation between the two antennas. That can explain the improved isolation obtained for the proposed design with the presence of the structure.

The effect of the structure is also clearly noticed in the surface current density plots as shown in Fig. 8(c) and (d), respectively. In without structure a large amount of surface current is coupled from Antenna-1- to Antenna-2- through common substrate and ground. This surface current flow between two ports is reduced to a great extent by structure at mentioned frequency and also the effect is same when Antenna-2- is excited and antenna1 is matched terminated.

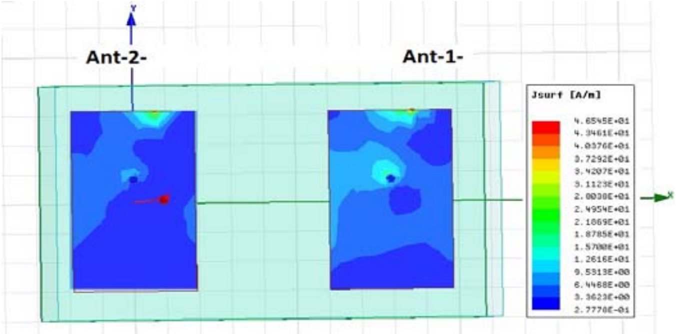

Fig. 8. (c) Without case

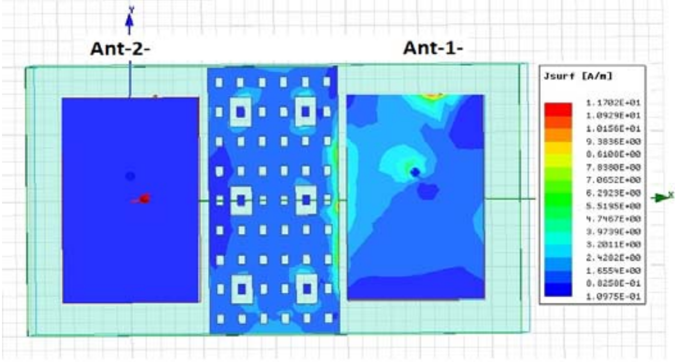

Fig. 8. (d) With case

Fig. 8. Simulated surface current density at 2.65 GHz of the antenna array (top view) when the first antenna is excited and the second one is terminated to a 50 load. (c) without case and (d) With case.

From the Figs. 8(c) and (d), respectively, it is clearly shown that very less amount of surface current is flowing towards second antenna and maximum amount are reflected from the structure and travel towards the first antenna instead of being flows towards the second antenna. So the structure can significantly increase the isolation of MIMO antenna system. This demonstrates that current flows from one side of the design to the other side are substantially reduced, and this effectively helps to reduce mutual coupling between the two PIFAs. So the structure can significantly increase the isolation of MIMO antenna system.

IV. COMPARISON WITH OTHER APPROACHES

As mentioned before, some other approaches such as EBG structures, slotted ground plane, neutralization technique, spatial and angular variations technique, insertion of a resonator in between method are applied to reduce the mutual coupling between antenna elements; several attempts have been made to mitigate this situation through the following summary:-

TABLE II. PERFORMANCE COMPARISON OF PLANAR MULTIPLE ANTENNAS

Ref	**BW (GHz) S11< -10dB**	**Isolation (dB)**	**Space (mm)**	**Size (mm^2) / volume (mm^3)**
[7]	2.4-2.6 GHz	8 dB	0.4λ0	75×65×5mm3
[2]	2.37-2.53GHz	9.12 dB	0.12λ0	0.8λ0 × 0.4λ0
[8]	1.8-2.1 GHz	9 dB	0.5λ0	100×40mm^2
[9]	2.45-2.55GHz	14 dB	0.17λ0	100×40×5mm3
[10]	2.45-2.5 GHz	10 dB	0.42λ0	105×55mm^2
[6]	2.4-2.48 GHz	20 dB	0.15λ0	100×40mm^2
[3]	1.92-2.17GHz	22 dB	0.11λ0	100×40×5mm3
Proposed	2.61-2.68GHz	30 dB	0.35λ0	68×40×1.6mm3

The proposed antenna shows the highest mutual coupling reduction compared to previous related works and other approaches for narrow-band applications.

V. CONCLUSIONS

A novel high isolation MIMO antenna has been proposed and studied in this paper, A new Uni-Planar Fractal based EBG (UPF-EBG) structure has been proposed for mutual coupling reduction between two PIFA antennas for MIMO applications (resonates at LTE radio frequency 2.65 GHz). All the simulations are analysed by Ansys HFSS 17.0 (High-Frequency Simulator Structure).

The fractal structure is shown to be useful in achieving more isolation and compactness at the lower frequency band. The new structure has been investigated for mutual coupling reduction of an E-plane coupled PIFA antenna array that operates within the stop band of the fractal-EBG.

Strong rejection characteristics are observed for the structure, where the band-gap zone is clearly seen within the designed frequency range. More than 30 dB reduction of mutual coupling is obtained from simulation process.

A performance study such as impedance B.W and isolation and radiation pattern and both surface wave distribution and current density was performed to identify the significance of the structure in term of coupling level. These results clearly show that fractal-based EBG design can be used to improve isolation between microstrip MIMO antennas.

As future work, practical implementation of the design and simultaneous optimization using standard optimization procedures will be considered.

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