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Miniaturized Double-layer EBG Structures for Broadband Mutual Coupling Reduction between UWB monopoles

Qian Li, *Member IEEE*, Alexandros P. Feresidis, *Senior Member IEEE*, Marina Mavridou and Peter S. Hall, *Fellow, IEEE*

***Abstract*— Novel miniaturized two-layer Electromagnetic Band Gap (EBG) structures are presented for reducing the electromagnetic coupling between closely spaced UWB planar monopoles on a common ground. The proposed EBG structures employ two closely coupled arrays, one comprising linear conducting patches and the other comprising apertures (slits) in the ground plane. The two arrays are printed on either side of a very thin dielectric layer (55μm) with a rotation of 90^0 between the elements to produce maximum coupling for miniaturizing. A microstrip line excitation is initially used for the efficient analysis and design of the slit-patch EBG structures, which are subsequently employed between two UWB printed monopoles. The proposed EBG structure has a small footprint and produces a significant reduction of the mutual coupling across the wide operating band of the UWB antennas. Simulated results as well as measurements of fabricated prototypes are presented.**

***Index Terms*— Electromagnetic band gap, Mutual coupling, miniaturization, MIMO antennas.**

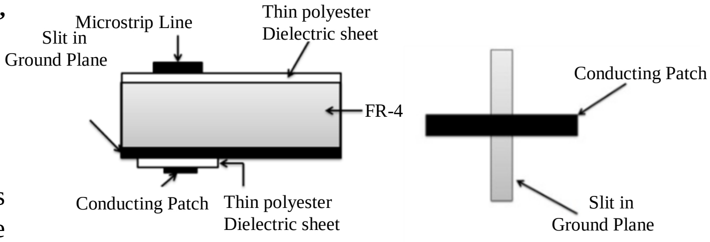
I. INTRODUCTION

Multiple-Input-Multiple-Output (MIMO) technology has been widely used in modern wireless and mobile communications systems. However, when multiple antennas are employed for compact portable devices, the high electromagnetic coupling between antenna elements is a critical factor which affects the performance of the system [1-2]. In recent years, several methods have been presented to reduce high mutual coupling between antenna array elements, such as novel antenna designs [3, 4] and the application of Electromagnetic Band-Gap structures (EBG) [5-7]. The use of single [8-9] and multiple [10] defects (slots or slits) on a ground plane has also attracted significant interest due to the ease of fabrication and applicability with different antenna types. More recently, a new convoluted slit configuration was proposed offering small structural footprint and improved isolation between narrowband printed monopoles [11].

In this paper, novel miniaturized double-layer slit-patch EBG structures are proposed for significantly reducing the mutual coupling between two closely spaced UWB planar monopoles in a compact wireless device. In order to optimize the designs and evaluate the performance of the proposed structures, simulations have been carried out in a commercial software package and measured results of the S-parameters are presented. The proposed slit-patch EBG structures are shown to improve the isolation between the two UWB planar monopoles placed at two different distances, which shows the flexibility in their applicability. Moreover, the proposed structures occupy very little space on the common ground between the antenna elements, allowing for small antenna separation values and increased flexibility in their use with compact ground planes and wireless devices. Fabricated prototypes have been experimentally tested and the measurement results are presented, validating the proposed designs.

II. DOUBLE LAYER SLIT-PATCH DESIGN

The proposed two-layer slit-patch EBG structure is shown in Fig. 1. The key design feature of the double-layer structure is the coupling of the evanescent fields within the dielectric region separating the two arrays of slits and patches respectively [12-13]. The conducting patches and aperture slits are placed on either side of a very thin (55μm) dielectric layer. Strong electric fields appear between the two conducting layers which are equivalent to a high capacitance. The slit apertures are rotated 90^0 with respect to the conducting patches in order to maximize the coupling and hence the equivalent capacitance.



(a) (b)

Fig. 1. (a) Cross-section of the proposed two-layer slit-patch structure used as an EBG ground plane of a microstrip line printed on FR-4, (b) schematic showing the relative orientation of the slit and patch.

The distance d between the two layers remains the same (55μm) for all geometries in this paper and is small enough to produce high values of capacitance. Also, when the width of the conductor patches increases, the overlap area will increase, and the capacitance will assume higher values. As a result, the resonance is expected to move towards lower frequencies. Therefore, it is expected that the band gap could be shifted by changing the width of the conductor patches. Furthermore, when the width of the conducting patches is increased and hence the capacitance is increased, the bandwidth of the band gap is expected to decrease. In order to increase the bandwidth, multiple resonators are employed resulting in a 1-D EBG structure. In order to design the proposed structures and optimise their dimensions for specific operating frequencies, a microstrip line excitation is employed. This type of excitation allows for an efficient design of the proposed structures without the need of incorporating complex antenna geometries.

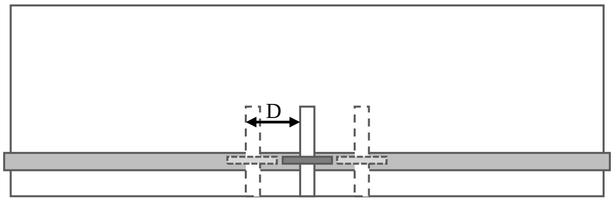


Fig. 2. Geometry of double-layer slit-patch EBG excited by microstip line.

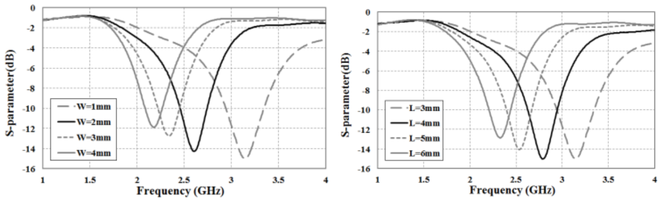


Fig. 3. (a) S21 for length *l*=3mm and different width of patch (b) S21 for width *w*=1mm and different length of patch.

A microstrip line is printed on a 60×15mm², 1.55mm thick grounded FR-4 substrate (ε_r=4.5). A linear shaped slit (9.65mm length and 1mm width) is etched in the ground plane. The configuration of this structure is depicted in Fig. 2. A conducting patch (3mm length and 1mm width) is printed on a very thin dielectric sheet (ε_r=3) of 0.055 mm thickness which is positioned under the linear slit in the ground plane, thereby producing the thin two-layer slit patch structure.

The effect of the length and width of the proposed slit-patch can be evaluated from the S21 response for different patch dimensions. In Fig. 3(a), one slit-patch structure is employed, and the width is changed from 1mm to 4mm, with the length kept *l*=3mm. It can be observed that the resonant frequency of S21 shifts as *w* increases from about 3.2GHz to about 2.2GHz while the bandwidth (-10dB) of slit-patch EBG structure decreases. The effect of the length is similar as it can be derived from Fig. 3(b). The width in this case is kept *w*=1mm and the length varies from 3mm to 6mm. The resonant frequency and the bandwidth decrease, although the length has a smaller impact on the bandwidth than the width.

In order to obtain more bandwidth, multiple slit-patch EBG structures are implemented on the ground plane, as shown in Fig. 3. Two or three identical proposed slit-patch structures are placed on the ground plane. The periodicity of the resulting slit-patch EBG structure D is 2.1mm, and the geometry of each unit cell is the same as before. Fig. 4 illustrates a comparison of simulated data (S21) for one, two and three slit-patch structures respectively. When the number of the slit-patch EBG structures increases, the lower cut-off frequency of the band gap slightly decreases, and the upper band gap is extended to a higher frequency. It is evident that the absolute bandwidth increases considerably with the number of slit-patch unit cells.

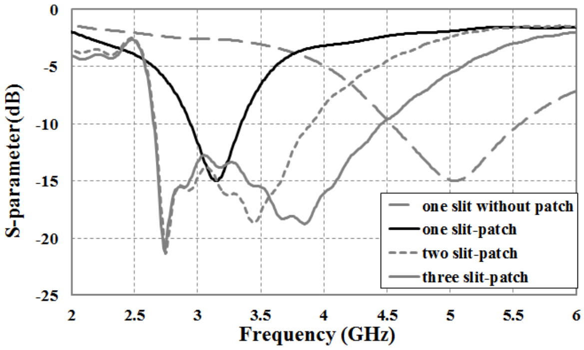
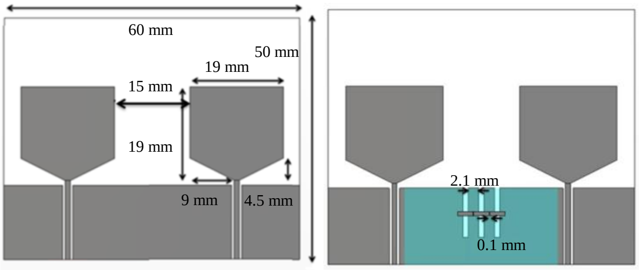


Fig. 4. Simulated (using CST MWS) S21 with one, two and three slit-patch structures.

III. UWB PLANAR MONOPOLE WITH THE SLIT-PATCH

A dual-element UWB (Ultra Wide Band) planar monopole array is printed on a 60x50mm², 1.5mm thick, FR-4 substrate (ε_r=4.5). The geometry of the proposed antenna array, designed to operate from 3 to 6 GHz, is depicted in Fig. 5(a). The separation between the two radiating elements is only 15mm. The simulated and measured S-parameters of the dual-element antenna array are shown in Fig. 6(a). Due to the two antennas being completely symmetrical on the substrate, the simulated S11 and S22 are identical within the operating frequency band of UWB monopoles. The measured S11 is slightly different to the simulated results in some frequencies. Nevertheless, the simulated and measured S11 is less than -10dB across the operating frequency band (3-6GHz). The discrepancies between simulation and measurement are attributed to dimensional fabrication tolerances and the effect of soldering the connectors on the compact ground.

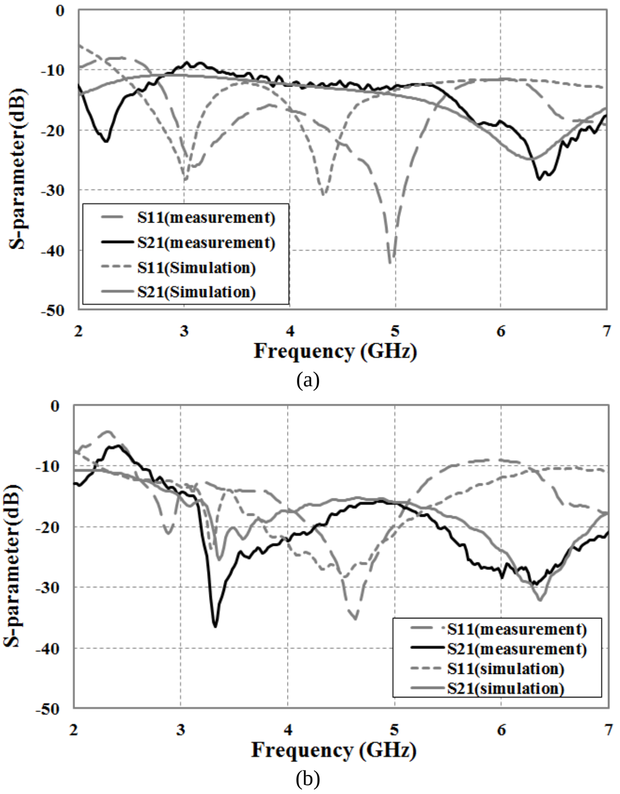
The simulated and measured mutual coupling between two antenna elements is more than -13dB across the operating frequency band when the two antenna elements are 15mm apart on the substrate. The slit-patch EBG structure described in section II is inserted in the compact ground plane between the two planar monopoles (Fig. 5(b)). The slit and the conducting patch elements have the dimensions that were chosen before.



(a) (b)

Fig. 5. Two-element UWB planar monopole array with (a) a conventional ground plane (b) three slit-patch structure.

Three slit-patch structures are inserted in the ground plane between two UWB monopoles, as shown in Fig. 5(b). The separation between each slit is 2.1mm. The distance between two conducting patch edges is 0.1mm. Fig. 6(b) shows the simulated and measured S-parameters of the UWB planar monopole array with the three slit-patch structures. The S21 in both simulation and measurement is less than -15dB across the whole operation frequency band.



(a)

(b)

Fig. 6. Simulated and measured S-parameters of UWB antenna array with (a) a conventional ground plane structure (b) three slit-patch structure.

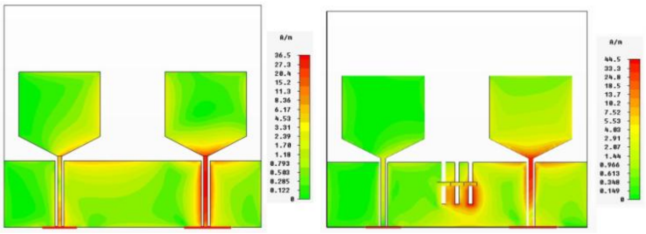
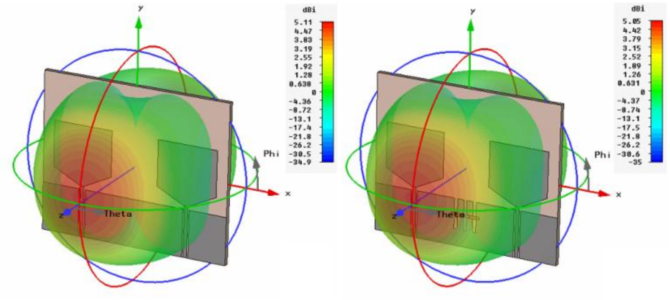

(a) (b)

Fig. 7. Simulated current flow and distribution of (a) the original UWB antenna array configuration when antenna1 is excited and (b) the array with 3 slit-patch structures when antenna1 is excited, on the ground plane at 3.5GHz.

The current distribution on the UWB monopoles as well as on the ground plane is shown in Fig. 7. When the UWB array is built on a compact conventional ground plane, a large current is induced on the monopole on the left when the monopole on the right is excited, thus producing a high mutual coupling between the antenna elements. After the proposed slit-patch unit cells are inserted on the ground plane between the two antennas, the current induced on the passive monopole (left) is significantly reduced. This is attributed to the proposed slit-patch EBG structure which, due to its stopband characteristics, significantly disturbs the fields and induced currents between the two monopoles and reduces their mutual coupling.

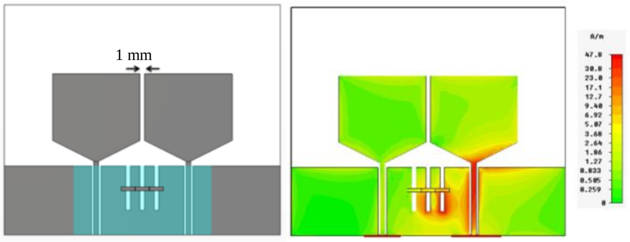
The radiation patterns of the proposed UWB antenna array for the two cases are presented in Fig. 8. The radiation patterns in the presence of the proposed slit-patch structures are only slightly different than the antenna system without the structure.



(a) (b)

Fig. 8. Simulated radiation patterns of (a) the original UWB antenna array configuration and (b) the array with 3 slit-patch structures.

In order to further investigate the use of the proposed slit-patch EBG structures and to produce the maximum reduction of the area of antenna array, the separation between the two antenna elements is reduced to 1mm resulting in the configuration of Fig. 9(a). When the two UWB monopoles are very close to each other with a convetional ground plane, as shown in Fig. 10, the measured S21 is over -10dB from 3.37GHz to 4.35 GHz. The insertion of the three slit-patch EBG structures introduces a transmission zero in the coupling coefficient between the antennas, reducing the measured S21 to values lower than -20dB across most of the operating frequency band of the UWB monopoles from 3.44GHz to 6.13GHz. By employing the proposed slit-patch EBG structures, the area of antenna array has been reduced significantly whilst maintaining the performance of the antenna system. The surface current on the ground plane of the proposed slits is presented in Fig 9(b). In comparison to the case shown in Fig.7(a), without the proposed slit-patch structure, a stronger current is induced on the neighbor radiating element because of the small separation between the two UWB monopoles. By employing the three slit-patch structures, most of the current on the ground plane has been trapped around the slit-patch structure even when the separation between the two antenna elements is 1mm.



(a) (b)

Fig. 9. (a)The configuration and (b) Simulated current flow and distribution the dual element antenna array when the interelement distance is 1mm.

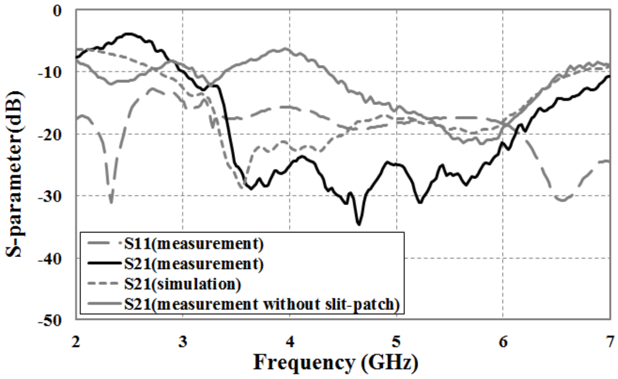


Fig. 10. The simulated and measured S-parameters of printed monopole array with three slit-patch structure when D is 1mm.

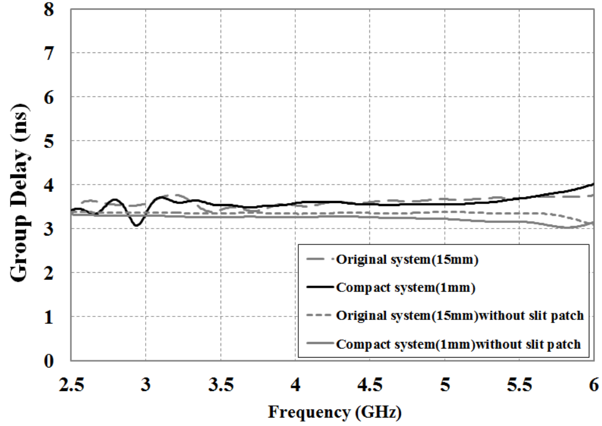


Fig. 11. Group Delay of the UWB antenna array configuration with and without slit-patch structures when the separation between the antenna elements is 15mm and when the separation is 1mm.

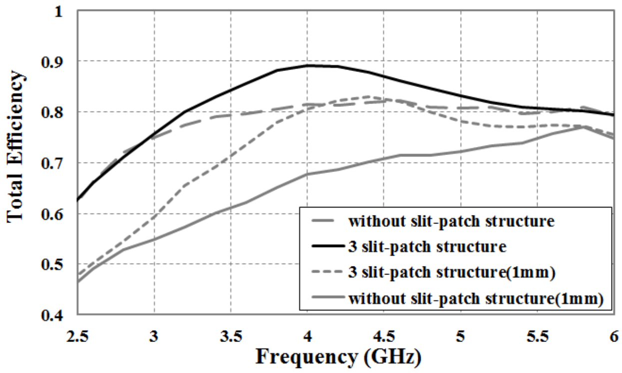


Fig. 12. The simulated total efficiency of whole antenna system in the presence of the proposed slit-patch structures.

The group delay of the antenna system has been calculated and presented in Fig. 11. Whether the separation is 15mm or 1mm, the group delay is slightly affected by the slit-patch structures. The antenna system is characterized by a relatively constant group delay in the operating frequency range from 3 to 6 GHz. The total efficiency has also been calculated from the simulated results: $\eta_{tot} = \eta_{rad}(1 - |S_{21}|^2 - |S_{11}|^2)$. Fig. 12 illustrates the simulated total efficiency of the antenna with and without slit-patch EBG structures. It is evident that the total efficiency exhibits an improvement across the operating frequency band of the antennas in the presence of the proposed slit-patch EBG structures. When the separation between the two planar monopoles is reduced to 1mm, the total efficiency of the antenna with a conventional ground plane has a significant reduction due to higher mutual coupling between the antenna elements. However, the efficiency in the presence of the proposed EBG structure is clearly improved.

IV. CONCLUSIONS

A novel approach for reducing the electromagnetic coupling between closely spaced UWB monopole antennas has been presented. The proposed technique is based on the insertion of miniaturized slit-patch EBG structures on the common ground plane. Simulation results have been validated with measurements.

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