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A Simple Defected Ground Structure (DGS) for Reduction of Mutual Coupling in Closely-Spaced Microstrip Arrays

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Abstract *– A sufficient and simple method to minimize the mutual coupling between closely-spaced microstrip antennas in an H-plane array format, operating at the same frequency is presented. More isolation can be provided through multiple rectangular defected ground structures (DGSs) between the antennas. Inter-element mutual coupling before and after using the proposed DGSs is investigated. The length, width and number of the rectangular DGSs have been optimized for more mitigating the mutual coupling (S12). Position of the DGSs is also the other important factor to have a best performance. By using this technique, more than 31 dB isolation between two patch antennas with a side by side distance of only 1/4 free-space wavelength at resonance frequency of 9.2 GHz can be obtained.*

Keywords*: Mutual coupling reduction, patch antenna array, defected ground structures.*

ORIGINAL ARTICLE

INTRODUCTION

Microstrip patch antennas are inherently low gain antennas and this fact partially offsets the advantages they offer in terms of cost and ease of fabrication [1]. A common disadvantage of microstrip antennas is the reduced radiation efficiency due to excited surface waves through the substrate layer [2]. However, microstrip patch antennas are particularly well suited from a technological point of view to be grouped in large arrays to obtain high gain. An integrated array constructed in this manner is compact, lightweight and reliable [1]. Linear array of microstrip antennas are popular candidates for multiple input multiple output (MIMO) systems and radar applications such as spatial tracking. An important requirement for these applications is high integration densities to utilize available substrate space efficiently [3]. In addition, sufficient isolation between adjacent antenna elements as well as between antennas and other integrated components on the same substrate are desirable. At first glance, approaching the elements of an antenna array to each other is one way to reduce the total size of an array. On the other hand, by reducing the separations of elements, mutual coupling caused by excited surface waves between antennas becomes stronger. Hence inter-element isolation and array performance is degraded. Consequently, introductory of a structure in order to reduce inter-element space while, preserving sufficient isolation seems inevitable.

Several assays to subside the problem of mutual coupling have been recommended in the previous works. All of these studies have some benefits and drawbacks. In [3], 15 dB reduction in mutual coupling is achieved by inserting mushroom-like electromagnetic band gap (EBG) , comprising three rows between patch antennas. However, vias that are used in that structures cause electrical losses and drudgery of fabrication process. In [4], the uniplanar compact electromagnetic band gap (UC-EBG) structure for enhance the isolation between circular metallic patch antennas is introduced. In spite of elimination of vias in this structure, cost and complexity of fabrication make this technique impractical. Nowadays some new forms of EBGs come to solution of their disadvantages. In [5] L-bridge EBG is proposed to reduce electromagnetic interference in high-speed circuits. In [6] a novel structure based on complementary split-ring resonators (SRRs) is introduced to increase isolation between two coplanar microstrip antennas and get 10 dB reduction in mutual coupling.

Furthermore some rudimentary ways to decrease the mutual coupling have been proposed in the literature. For example machining the dielectric below the patch in [7] or using a cored patch and a shorted annular ring design in [8].

Various DGSs have been proposed in different studies for single microstrip antenna but few researches use this applicable structure for antenna arrays. In [9] 12 dB reductions in mutual coupling of microstrip phased array are obtained by use of H-shaped DGS.

In the present work, a simple technique to improve the isolation between microstrip antennas in a linear array format, on a common ground plane, with edge to edge spacing of 0.26λ0 is introduced. We prove that by

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embedding triple rectangular slots in the ground plane 16.5 dB reduction in mutual coupling (31.5 dB isolation) can be achieved. The use of an inexpensive substrate, FR4, makes our design low profile, easy to fabricate and economical.

ANTENNA CONFIGURATION AND DESIGN

The configuration of the designed array is illustrated in Fig.1. It consists of a pair of adjacent microstrip patch antennas that are fed by 50 Ω microstrip line feeds with length and width of 10 mm and 1.9 mm, respectively. The proposed structure is printed on FR4 substrate with relative permittivity of 4.4, loss tangent of 0.02 and thickness of 1 mm. Both radiated elements have equal dimension as mentioned in Fig.1. Based on the previous studies, a strong surface wave can be excited in the selected substrate because the condition h > o.3λ0/2π√εr [10]. In order to decrease the mutual coupling three rectangular slots [see Fig.1] are inserted on the array ground plane with dimension of 63.5×40 mm2. These filtering slots with the proper position and dimension exhibit rejection band at 9.2 GHz. A defected ground structure presents a bandstop effect because of the combination of equivalent inductance and capacitance. The inductance and capacitance level can be independently controlled by the aperture area and the gap width, respectively [2]. Surface currents on the ground plane which have the impedance matching with equivalent impedance of slots, can radiate from these apertures.

PARAMETRIC STUDY

The proposed array structure is simulated using a High Frequency Structure Simulator (HFSS, ver. 11) [11]. Fig.2 shows the mutual coupling between the conventional two patch antennas without the triple slots. About -15 dB mutual coupling (S_{12}) between the antennas at 9.1 GHz is observed. As revealed in Fig.3, when three rectangular slots are etched on the ground plane a further 16.5 dB reduction in mutual coupling occurs.

To perceive the design process of the proposed triple DGS, parametric study has been done. We illustrate that, four important parameters: the number of slots (*N*), length (*L*), width (*W*) and position (*D*) of them influence the performance of the array and the mutual coupling between its elements.

The first parameter that must be considered is the number of slots, *N*. The results which are obtained by use of different number of slots are shown in Fig.4. In this case, the other dimensions are fixed as mentioned in Table I. It is observed that by increasing the number of slots more mitigation is achieved. Because of more interaction between antennas and slots in case of four slots, which

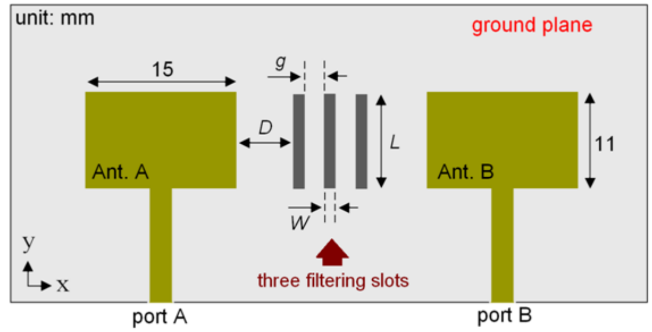

Fig. 1. Geometry of the proposed antenna array structure

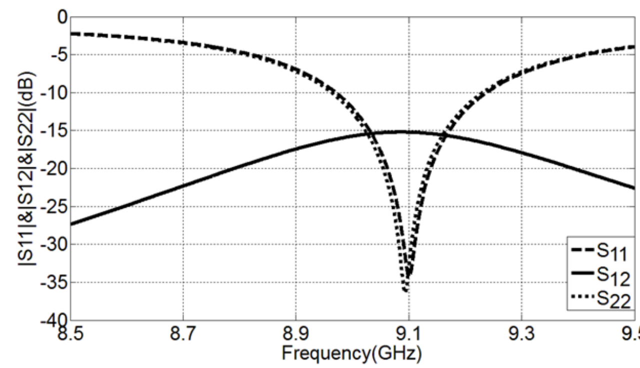

Fig. 2. Simulated S parameters of conventional microstrip antenna array without triple DGS.

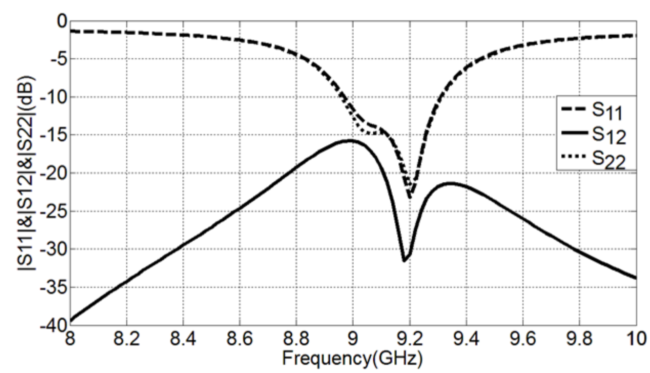

Fig. 3. Simulated S parameters of the proposed array in Fig. 1 with triple DGS

disturb all of the S parameters (S_{11}, S_{22} and S_{12}) the optimal number of slots is chosen to be three (*N* = 3).

The other parameter is width of the slots. During the simulation of different widths, Fig.5 discloses that if we adjust the width of each slot in 1 mm or *W* = 1 mm, the best result at the operation frequency will be get. The other prominent parameter is the position of the slots. As shown in Fig. 6, the most appropriate position is exactly the middle of the ground plane. Therefore, the value of *D* must be chosen about 2.25 mm. In this case, as shown in Fig.6, the value of S_{12} is decreased from 15 [see Fig.2] to

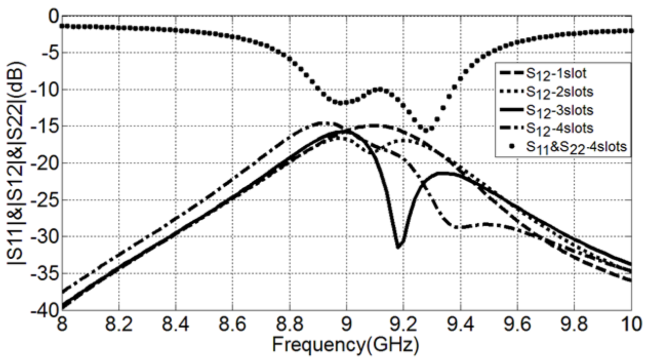

Fig. 4. Simulated S parameters for different number of the slots (*N*)

31.5 dB. Then, a mutual coupling reduction of about 16.5 dB is obtained. It would be better to mention that we can get about 40 dB reduction in mutual coupling if we chose the case of D = 1.125mm. But in this case the S_{11} and S_{22} values around resonant frequency are damaged. Hence as each technical work, we have to use trade-off between isolation and impedance matching.

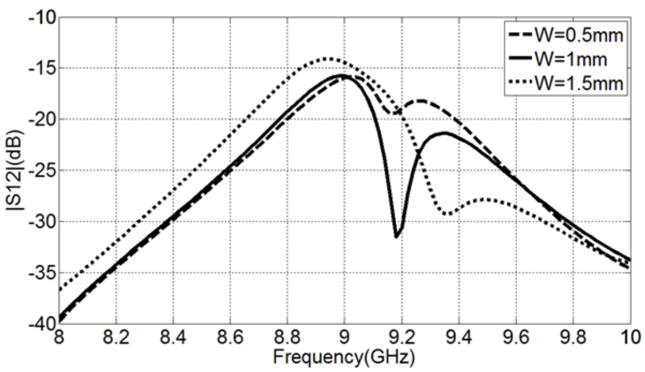

Fig. 5. Simulated S_{12} for different values of *W*.

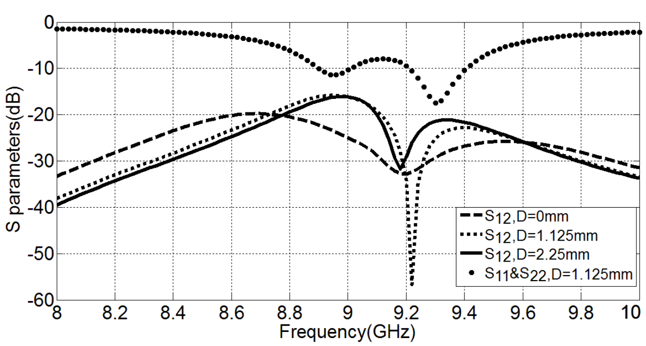

Fig. 6. Simulated S parameters for different values of *D*

TABLE 1
OPTIMAL DIMENSION OF STRUCTURE

L	*W*	*g*	*D*	*N*
9.75mm	1mm	0.5mm	2.25mm	3

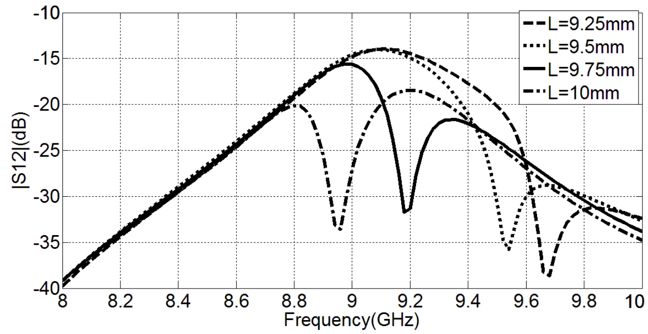

Fig. 7. Simulated S12 for different values of *L*

The last but not least factor in the proposed structure is the length of slots, *L*. The proper value for this parameter is fixed at 9.75 mm, which is about $\lambda_g/2$ at resonance frequency of 9.2 GHz [see Fig.7].

Fig. 3 shows a considerable shift in the main frequency of the patches with a maximum value of 100 MHz and sensible degradation of quality and bandwidth of $S_{11}$and S_{22} because of the substrate losses and effects of the DGS on the electrical length. It is worth noting to say that, increasing the area of slots due to expanding the length or width of the slots or increasing number of them, cause larger aperture of slots. Thus, by using the proposed slots in our design, the values of the gain and radiation efficiency are nearly degraded. Moreover, because of the increasing level of the backward radiation, the values of the front-to-back ratio of the total 3-D radiation characteristic are also decreased. These problems can be considerably solved by using the various techniques such as a proper EBG high-impedance surface structure in the bottom side of the ground plane [12].

The surface current distribution on the common ground plane at the operation frequency of 9.2 GHz is shown in Fig.8. It is observed that the great amount of surface currents which are excited by first antenna, are circulate around the slots and do not affect the second antenna.

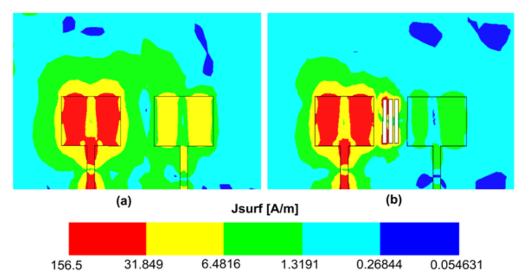

Fig. 8. Surface current distribution on the ground plane, (a) without triple DGS and (b) with DGS

Table II
Various comparisons between proposed DGSs and filtering structures in [4] and [6]

Parameters ↓	Rectangular DGSs	[6]	[4]
The depth of $\|S_{21}\|$	high	Moderate	Low
Occupied area	Low	Moderate	High
Design complexity	Very low	Low	High

Ultimately, for suitable performance of suggested design, the optimal dimensions of structure are identified in Table I. The results of the comparison between the proposed structure and the other good designs are summarized in Table 2. As a result, the proposed design has better performance than [6] and [4]. The proposed structure in [6] is a good design with a low design complexity, but with a low reduction in the mutual coupling. It is also interesting to note that the occupied area of the proposed design on the ground plane is only 39 mm^2. This value is very suitable, especially for the high frequency designs.

CONCLUSION

This manuscript presented an effective technique for diminishing the mutual coupling of closely spaced microstrip array elements. By suppressing surface waves through a triple rectangular DGS about 16.5 dB further reductions as compared to conventional array in mutual coupling was achieved. Simplicity of the design and its good performance made our proposed structure practical and reliable. The technique is useful for MIMO antennas and RADAR arrays.

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