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Novel Decoupling Technique for Enhancing the Mutual Coupling between Printed Antennas

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Abstract—In this work, an E-shape Defected Ground Structure (DGS) is achieved to reduce the mutual coupling between two nearby microstrip antennas up to 47% (from 0.064 to 0.03). Both antennas radiate in the same frequency band of 10 GHz. The technique is based on a wall integrating periodic structure permitting the absorption of the electromagnetic field. By using this structure, it was possible to achieve a 20 dB reduction in the insertion loss S_{21} between the two microstrip patch antennas with center-to-center distance of $0.45\lambda_0$ (λ_0 is the free-space wavelength). The obtained coupling coefficient demonstrates that there is a good isolation between the two antennas. EM solver, simulating the reflection and transmission coefficients of the designed antenna arrays, achieves the reduction of the mutual coupling. The simulated results are verified by measuring the fabricated prototypes.

1. INTRODUCTION

The demand for compact and high performance devices for versatile applications is boosted with the rapid advancement of the wireless technology. Various microwave components such as couplers, dividers, amplifiers, filters, and microstrip antennas have been designed with microstrip technology for high performance applications. Microstrip patch antennas are attractive and economical as a solution for designing compact wireless communication devices.

Planar antennas have several advantages such as low profile, small size, light weight, low cost, and ease of fabrication [1–5]. This kind of antennas is suitable for mobile devices; furthermore, it is easy to integrate with active and passive microwave components. To overcome the individual low gain limitation, especially for the applications that requires high gain and high directivity, antennas array structures are used [6–12]. Yet, the main limitation of these structures is the mutual coupling between elements of an array which adversely affects the radiation characteristics such as antenna gain, radiation efficiency, bandwidth and the overall system performances.

The coupling can arise from the excitation of surface waves, space waves and near-field overlapping of the array elements. Practically, the coupling mechanisms depend on several factors such as permittivity and thickness of substrate material, ground plane size, and type of excited modes [7, 8].

For many years, numerous studies have been conducted to find techniques that reduce the mutual coupling and increase the isolation between antennas. To achieve the reduction of the S_{21} parameter, the main idea consists in introducing some additional coupling path between the radiators. Those techniques include cavity backing, partial substrate removal, corrugations, split ring resonators (SRR), defected ground structures (DGS), periodic structures like high impedance electromagnetic surfaces (HIES) or electromagnetic bandgap structures (EBG), etc. [9–11].

In [12], two symmetric antenna elements and three neutralization lines (NLs) are printed on a printed circuit board (PCB) to reduce the mutual coupling in a wide frequency band. In [13],

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Electromagnetic Band-Gap (EBG) structures are used to adjust and increase the isolation between radiating elements. Additionally, the split ring resonators (CSRRs) are proposed in [14] to improve the isolation between two coplanar microstrip antennas. Moreover, the isolation is improved around approximately 25 dB in [15].

In this article, the technique based on DGS, engraved on a wall placed between the two patch antennas, is used.

2. THEORY

Nowadays, the trend is to multiply the number of the radiating elements on a mobile handset in order to increase the probability of receiving a good signal. However, the proximal placement of the antennas causes an increase of the insertion loss between their feeding ports and consequently degrades the overall diversity performance.

The electromagnetic interaction between the antenna elements in an antenna array is called mutual coupling. The effect of mutual coupling is serious if the element spacing is small [16].

The mutual coupling between two antennas can be calculated by:

$$C = P_L / P_D \tag{1}$$

where P_D is the power radiated by the excited antenna, and P_L is the power delivered to the load of the un-excited antenna.

Various definitions of mutual coupling are presented in the literature. The equivalent network of two antenna array is shown in Fig. 1.

Also the S-parameters are related to the transmit-mode coupling calculation by:

$$jS_{21}j^2 = (1 - jS_{11}j^2) \cdot C \tag{2}$$

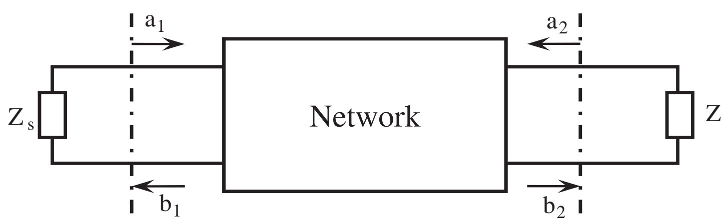


Figure 1. Equivalent network of two antenna array.

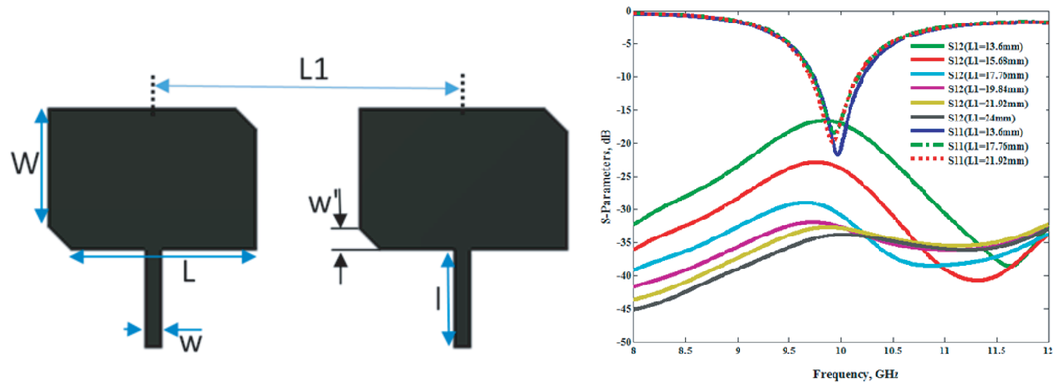
3. COUPLING PROBLEM BETWEEN ANTENNA ARRAY RESONATORS

Let us consider two identical resonators. The geometry of the antenna array, where two microstrip patch antennas having resonance frequency of 10 GHz are shown in Fig. 2(a). The center-to-center inter-patch antenna spacing is $0.45\lambda_0$. The dimensions of our antennas are optimized by using CST Microwave Studio tool with $L = 5$ mm, $W = 8.13$ mm, $l = 4.21$ mm, $w = 0.75$ mm, $w' = 1$ mm. The two antennas are separated (center to center) by a distance L_1. The substrate material type is FR4 and has a relative permittivity of $\varepsilon_r = 4.4$ and loss tangent of $\tan\delta = 0.024$. The thickness of the FR4 substrate is 1.6 mm.

The simulation results obtained for this antenna array are shown in Fig. 2(b). It shows that the array resonates at 10 GHz while the S_{11} parameter is not affected by variation distance L_1; moreover, when the distance L_1 between the two antennas increases, the isolation increases in turn. Therefore, more space is needed.

As a matter of fact, Fig. 3 shows the strength of coupling as described with the coupling coefficient which can be computed according to the following formula [17, 18]:

$$C = \frac{|f_2^2 - f_1^2|}{f_1^2 + f_2^2} \tag{3}$$



(a) (b)

Figure 2. The proposed antenna array, (a) geometry, (b) simulated S-parameters for different L_1.

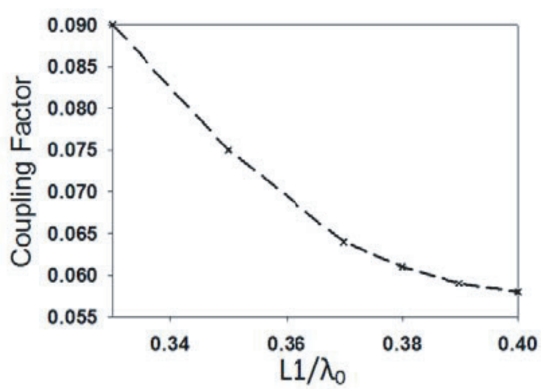


Figure 3. Coupling factor C as a function of normalised distance L_1/λ_0.

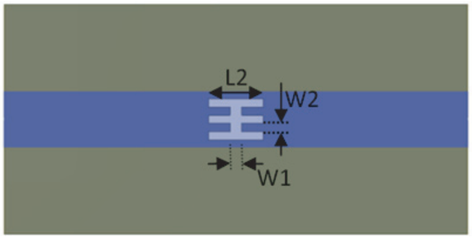
where f_1 and f_2 are resonant frequencies of coupled resonators. The resonant frequencies can be precisely found from electromagnetic simulations. However, when the coupling is small, the resonant frequencies are close to the resonant frequency of uncoupled resonators. When the strength of coupling increases, the difference between two resonant frequencies of coupled resonators increases as well. Hence, this article will approach the DGS technique to leave the distance between the two patches intact and improve the isolation by engraving the DGS structure on a vertical wall between the two patches.

In the next section, the article will shed light on the DGS that will be etched on the wall between the two patches.

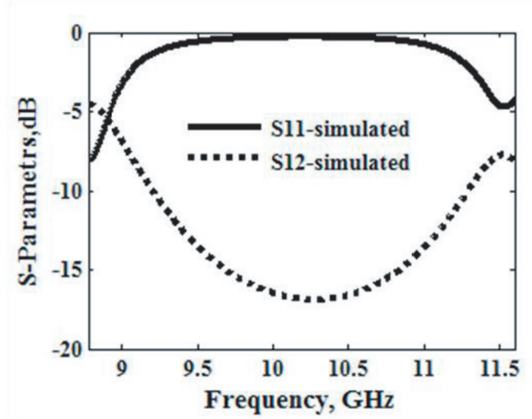
4. EBG CONFIGURATION AND CHARACTERISTICS

In Fig. 4(a), the proposed E-shaped DGS geometry is shown. The reference characteristic impedance of the transmission line is $50\,\Omega$. Therefore, the transmission line is simulated with the E-shaped DGS. The S-parameter obtained for the given structure is shown in Fig. 4(b). It should be noted that this is a band-stop filter around 10 GHz.

After showing the proposed E-shaped DGS, it will be engraved on a wall between the two patch antennas as shown in Fig. 5.



(a)



(b)

Figure 4. E-shaped DGS unit: $L_2 = 3.3\,\text{mm}$, $W_1 = 0.7\,\text{mm}$, $W_2 = 0.5\,\text{mm}$, (a) structure; (b) S-parameters.

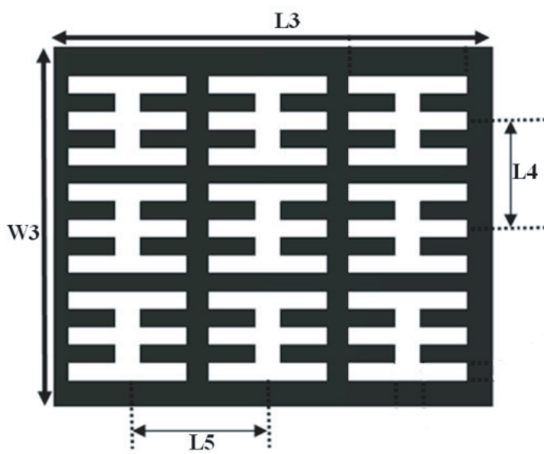


Figure 5. The proposed structure of DGS wall ($L_3 = 12.21\,\text{mm}$, $L_4 = 3\,\text{mm}$, $L_5 = 3.9\,\text{mm}$, $W_3 = 10\,\text{mm}$).

5. MUTUAL COUPLING REDUCTION OF MICROSTRIP ANTENNA ARRAY AND RESULTS.

Microstrip patch antennas are often arranged in array for high gain, beam forming or diversity purposes [19]. However, the spread of surface waves and the duplication of fields close to the array elements lead to a strong mutual coupling which severely reduces the performance of the antenna. Fig. 6 shows the implementation of the E-shaped DGS between two adjacent elements of an array. The distance between the two adjacent patch elements is $0.45\lambda_0$, and the wall with DGS is located exactly in the middle of them.

In Fig. 7, the current distribution of two patch antennas before engraving the wall is shown. The flow of the current, from one antenna to the other, means that there exists a strong mutual coupling between the two patches at the resonant frequency.

After the implementation of the DGS wall, as show in Fig. 8, the current is blocked, and the mutual coupling is significantly reduced. The simulated current distribution is at 10 GHz when the right antenna element is triggered and vice versa.

From Table 1, one can see that if the wall is introduced between the two resonators, the coupling

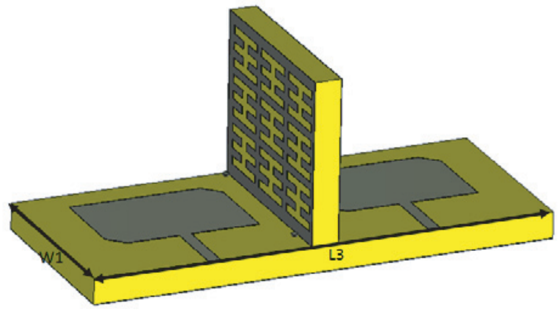


Figure 6. The proposed 3D structure of the vertical wall integrated in antenna array ($L_3 = 28.38$ mm, $W_1 = 12.21$ mm).

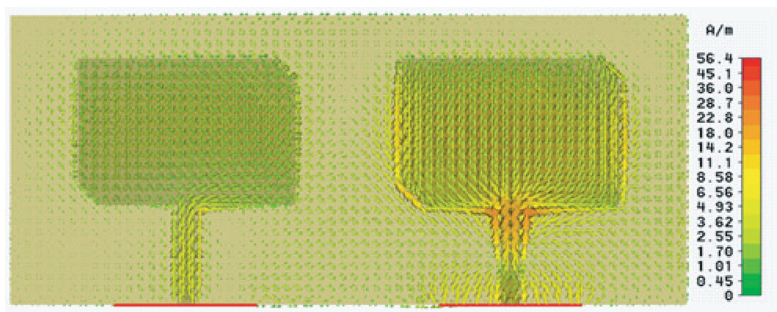


Figure 7. Current distribution of patch antennas without DGS wall.

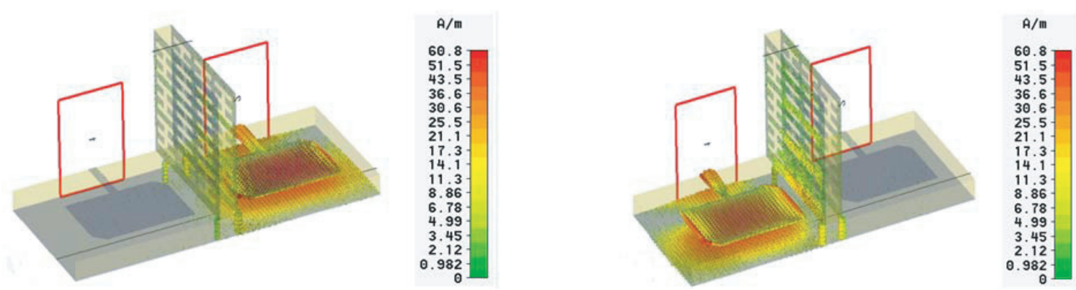


Figure 8. The 3D current distribution at 10 GHz for the two patches with DGS wall.

Table 1. Comparison of coupling factor with and without wall.

Distance L_1	Coupling Factor without wall	Coupling Factor with wall
$0.37\lambda_0$	0.064	0.03

factor is reduced from 0.064 to 0.03. This means that the overall surface is decreased to a great amount.

Figure 9 illustrates the comparison of S_{21} parameter of the two adjacent patches with E-shaped DGS and without DGS. The insertion loss S_{21} between the two adjacent patch elements is reduced by about 20 dB with respect to the non-DGS patches.

Simulated radiation patterns of two-element arrays with and without DGS at 10 GHz are shown in Fig. 10. In the case with DGS, the gain is increased to more than 1 dB due to the slow waves of DGS.

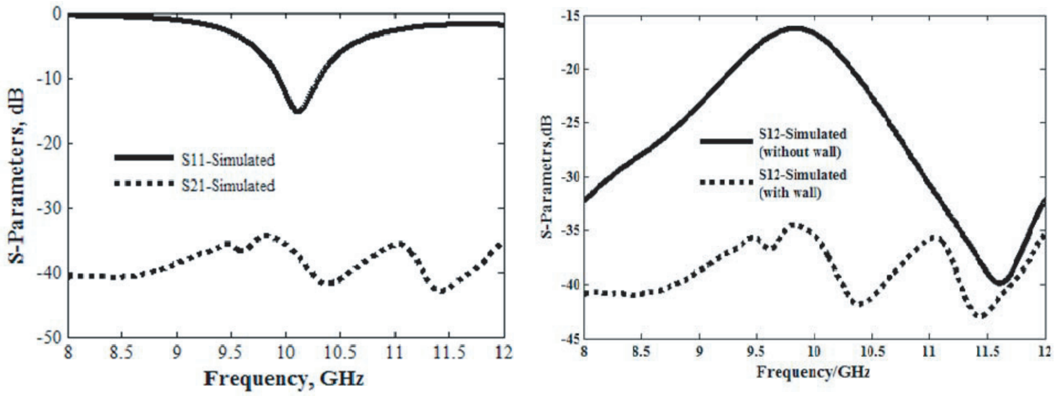
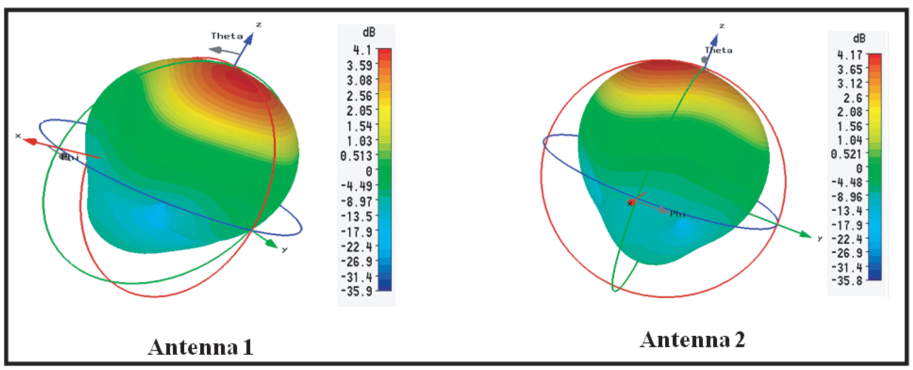
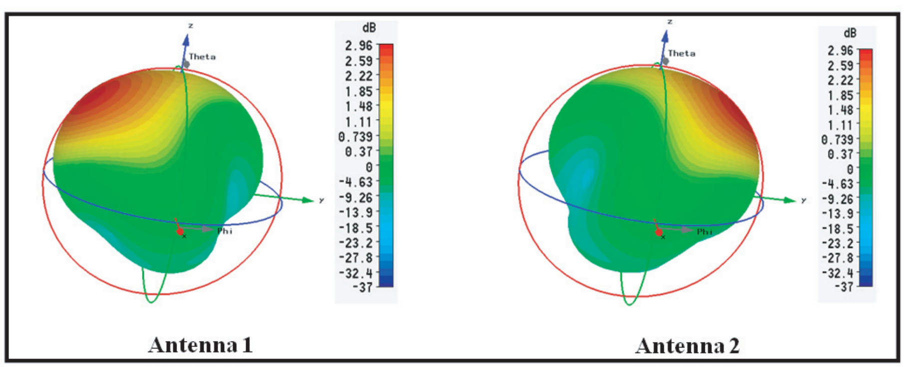


Figure 9. The simulated S parameters of the proposed antenna array with and without DGS wall.



(a)



(b)

Figure 10. Simulated radiation pattern of two-element array: (a) with and (b) without DGS wall.

6. FABRICATION AND MEASUREMENT

The designed antenna structure is fabricated and tested in the lab, and the practical results are found to be well consistent with the simulated ones. Shown in Fig. 11 is a photograph of the fabricated prototype antenna array. In this design, an FR4 substrate is used due to its low cost and easy fabrication. The substrate height is 1.6 mm, dielectric constant 4.4, and loss tangent 0.024.

Finally, the array design is measured by using a Rohde and Schwarz ZVB 20 vector network analyzer. As shown in Fig. 12, the insertion loss S_{21} level is nearly -35 dB at 10 GHz with the vertical

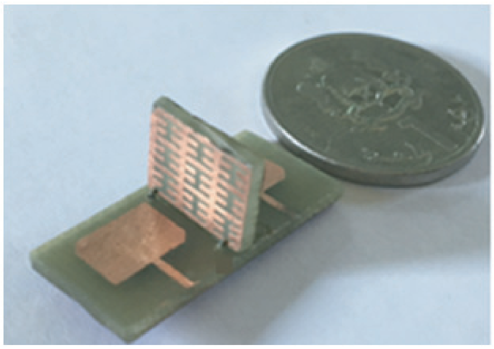


Figure 11. Photographic views of proposed antenna array with DGS wall.

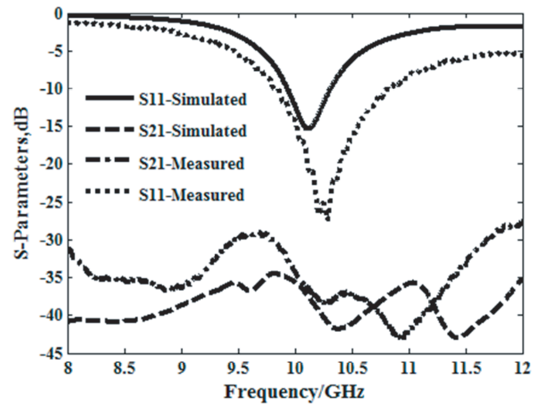


Figure 12. EM simulation and measurement results.

DGS wall by an enhancing of −20 dB in comparison with the structure without vertical DGS wall.

The measured results show very good agreement with the simulated ones, except slight discrepancies, which can be attributed to the fabrication and soldering imperfection.

Table 2 below presents a comparison between the proposed structure study and other configurations in literature.

Table 2. Performance of the proposed approach and other structures.

Ref.	Approach	Size in mm^2	Freq (f_0) in GHz	Center to Center Spacing	Improvement in S_{21} (dB)
[20]	Multilayer Dielectric Substrate	130 ∗ 130	3	$0.75\lambda_0$ (75 mm)	10.00
[21]	Slotted CSRR	78 ∗ 60	5	$0.50\lambda_0$ (30 mm)	10.00
[22]	DGS	63.5 ∗ 40	9.2	$0.70\lambda_0$ (23.6 mm)	16.50
[23]	EBG	Not reported	8	$0.60\lambda_0$ (22.5 mm)	5.00
The Proposed Approach	Vertical DGS wall	22.73 ∗ 10.41	10	$0.45\lambda_0$ (13.6 mm)	20.00

As mentioned in Table 2, the proposed approach has the advantage of minimizing the coupling in comparison with other approaches in the literature with a minimum size.

7. CONCLUSION

The mutual coupling between the microstrip antenna array elements is investigated for cases with and without DGSs. It has been demonstrated that when DGS wall is placed in between the patch antennas, the suppression of surface waves leads to reduced mutual coupling, and therefore a significant reduction in size can be achieved.

However, the isolations between antennas are greatly improved from 15 dB to more than 35 dB at the center frequency. This concept is validated by the experimental results, and the measurement results match quite well with the simulation ones.

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