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Mutual Coupling Reduction of a Dual-Frequency Microstrip Antenna Array by Using U-Shaped DGS and Inverted U-Shaped Microstrip Resonator

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Abstract—A compact U-shaped defective ground structure (DGS) and an inverted U-shaped resonator are introduced in order to reduce the mutual coupling (MC) between two slotted microstrip antennas at two different resonance frequencies. The proposed DGS and resonator have the same electrical length and both are placed in between two patch antennas, as a technique to suppress the occurrence of MC at two different frequency bands. The DGS and the resonator offer stop bands at 2.45 GHz and 4.5 GHz respectively. Simulated results show a reduction in MC of 20 dB at 2.45 GHz band and 1 dB at 4.5 GHz band. We have developed experimental models that have proved this concept of MC reduction. Finally, the influence of other parameters of the proposed antenna at the presence of the combination of DGS and resonator in the array system has been studied. Prototype antennas for different combinations of DGS and resonator and two-element array integrated with DGS and resonator have been fabricated, measured and the idea has been verified. A good agreement is observed between measured and the simulated results.

1. INTRODUCTION

Microstrip patch antennas have demonstrated to be one of the most versatile antennas in recent years. To obtain compact size a substrate with higher permittivity and a thicker profile has been extensively used in the microstrip antenna design. This substrate results in the increased surface wave excitation in the array structure. In a microstrip array, severe surface waves increase the mutual coupling between array elements, which cause impedance and pattern anomalies associated with the blind angle [1].

The direct MC between two patch elements can be eliminated by properly adding an extra indirect coupling path. A proper design aims at creating an indirect signal transmitting via an extra coupling path that opposes the signal passing directly from element to element. If the two amplitudes are comparable, the two signals add up destructively that results in reduction of MC. MC have a direct impact on the performance of multi-element antenna systems. The interaction between elements degrades S-parameters for the adjacent E-plane coupled elements in the array systems.

The coupling can result in severe degradation to the antenna's radiation characteristics. While surface waves are weakly excited in very thin grounded dielectric substrates, space-waves dominate and show strong coupling when antennas are in close proximity [2–5]. Some of the most referred methods in literature towards the reduction of MC in the array structure are using defected ground structures (DGS) [6–8], electromagnetic band-gap (EBG) structures [9–15] and parasitic elements between the antenna elements [16–20]. DGS, EBG or the parasitic structures created on the substrate between array elements effectively disturbs the distribution of current in the elements and thus introduces high line

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inductance and capacitance of the microstrip line. Therefore, it obtains wide stop band and compact size, which meet emerging application challenges in wireless communication. DGS and EBG structures have been employed for suppressing MC at the cost of high back radiation. A simple structure composed of two parasitic elements is presented in [16]. The difficulty with that scheme is that it needs an additional layer, along with metalized holes for grounding. In [17] MC has been reduced considerably at the cost of some complicated structure at the ground plane and it suffers from radiation pattern degradation. In [18], a simple U-section has been used between two planar microstrip antennas with a separation of 0.6λ (centre to centre distance) and MC has been suppressed by around 16 dB at resonance frequency. In [19], MC of 18 dB has been reduced at the cost of three complicated split-ring resonator structures. In [20], a $\lambda/2$ line resonator has been used between two radiators in such a way that the current vectors flow through the resonator in the opposite direction and cancelled out at the middle of the resonator. As a result, the resonator itself does not radiate and mutual coupling of around 35 dB has been reduced.

In our investigation, a simple and efficient technique is proposed to suppress the effect of MC at two different frequency bands. We have used a simple U-shaped DGS and an inverted U-shaped resonator in between two slotted microstrip antennas and MC of around 20 dB at 2.45 GHz and 10 dB at 4.5 GHz have been successfully reduced. The technique has been experimentally evaluated and the idea has been verified. U-shaped DGS and inverted U-shaped resonator causing suppression of MC do not affect other characteristics like the co-polarized radiation over the principal planes, gain and input impedance. The proposed work presents a novelty in reduction of MC at two different frequency bands simultaneously. Thus, the proposed concept can be employed for achieving improved performances where MC becomes a major limitation in some antennas having some attractive features.

2. ANTENNA DESIGN

A slotted microstrip patch antenna has been designed to operate at 2.45 GHz and 4.5 GHz frequency bands respectively. The characteristic parameters like length (L), width (W) are obtained from standard formulae [21]. The slot dimensions have been optimized by the process of simulation. The schematic diagram of proposed microstrip radiators integrated with DGS and resonator is shown in the Figure 1. FR4 substrate of thickness of 1.580 mm, loss tangent of 0.02 and dielectric constant of 4.4 have been considered for this design.

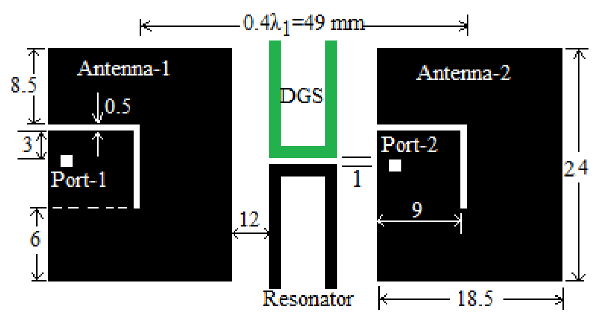


Figure 1. Antenna structure integrated with DGS and resonator (dimensions are in mm, $\lambda_1 = 122.5$ mm at 2.45 GHz).

By the introduction of U-shaped DGS and a similar shaped microstrip section, an extra coupling path can be created with proper adjustment of width and length of the DGS and resonator. Both are involved in the coupling at two different resonant frequencies. The DGS reduces MC at 2.45 GHz and the resonator does it at 4.5 GHz frequency bands. The schematic diagram of the proposed DGS and its return loss (RL) characteristic are shown in the Figure 2(a)–Figure 2(c).

From Figure 2(c), it is observed that DGS offers a stop band from 2.45 GHz to 2.70 GHz and as a result the MC is suppressed at 2.45 GHz when DGS is integrated with the antenna structure (as shown in the Figure 1). Similarly resonator integrated antenna structure reduces MC at 4.5 GHz frequency band. The RL characteristic of antenna-1 without the presence of DGS, resonator and antenna-2 is shown in the Figure 3.

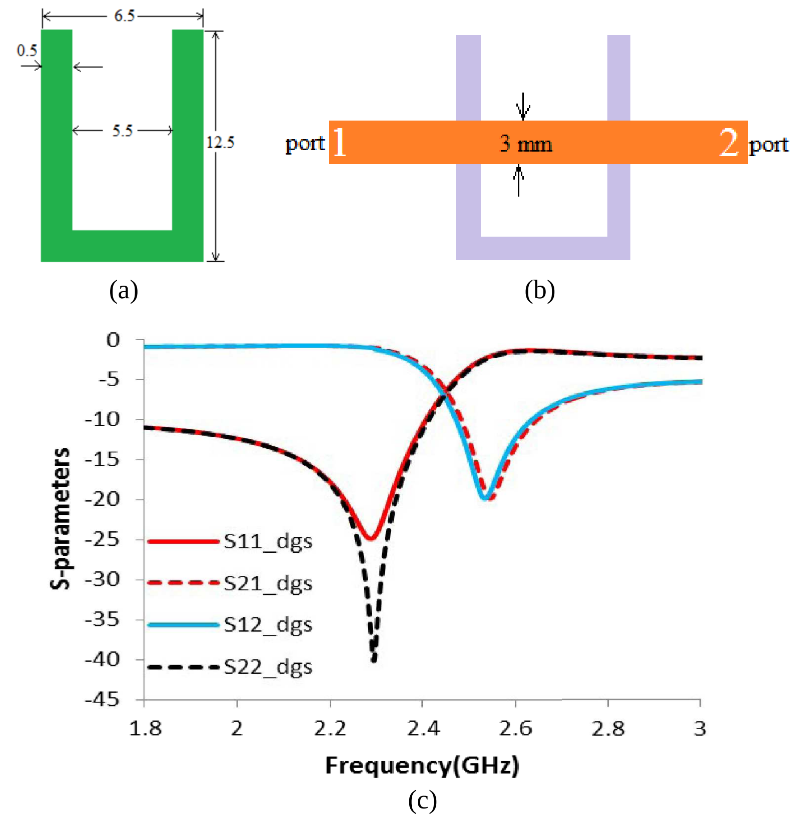


Figure 2. Schematic diagram of proposed DGS/resonator (dimensions are in mm), (b) DGS with 50 Ohms line, and (c) simulated S-parameters characteristics.

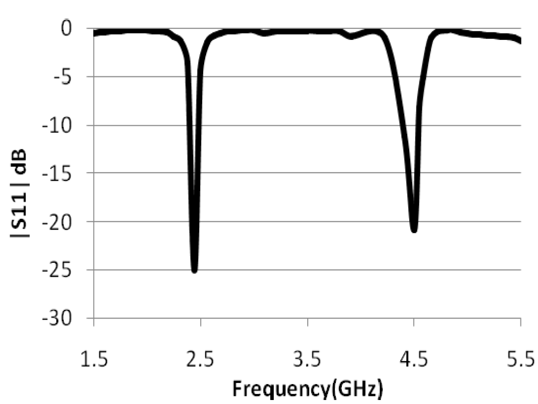


Figure 3. Simulated RL curve of antenna-1 without DGS, resonator and antenna-2.

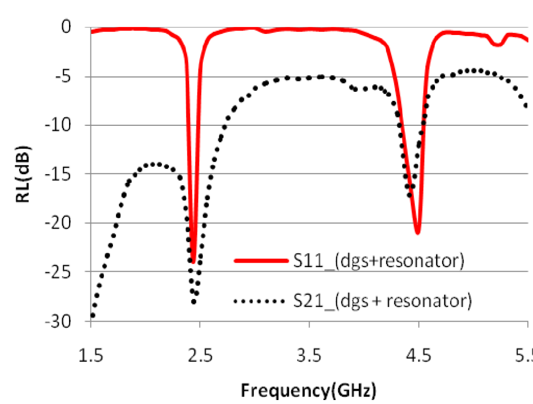
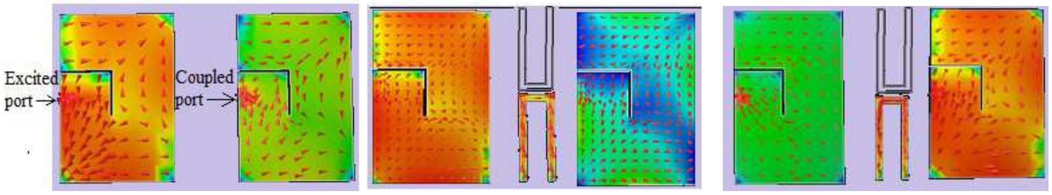


Figure 4. Simulated S-parameters of Figure 1 (antenna-1 is excited).

From Figure 4, it is revealed that the MC of 20 dB at 2.45 GHz and 10 dB at 4.5 GHz has been achieved. Simulated current distributions for different configurations are shown in Figures 5(a)–5(c). The simulation process has been done by using IE3D Electromagnetic simulator based on the method of moment (MoM).

From Figure 5(a) it is observe that without the presence of DGS and resonator, a strong coupling exists between excited port and coupled port. There is a little coupling observed between two adjacent patch elements in presence of DGS/resonator as shown in the Figure 5(b) and Figure 5(c). The simulated



(a) (b) (c)

Figure 5. Simulated current distributions at 2.45 GHz, (a) antenna-1 is excited without resonator and DGS, (b) antenna-1 is excited with resonator and DGS, and (c) antenna-2 is excited with resonator and DGS.

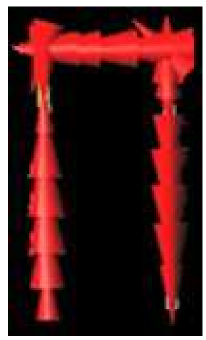


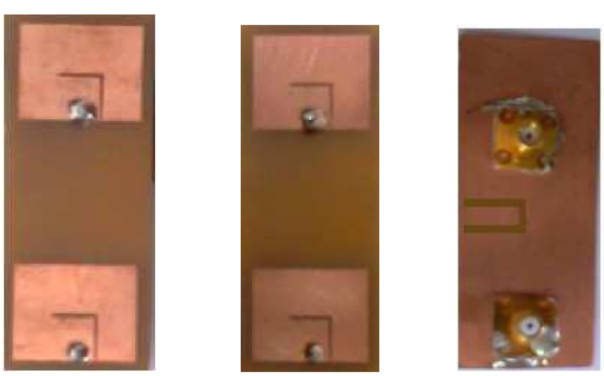
Figure 6. Current distribution of inverted U-shaped resonator at 4.5 GHz.

current distributions of inverted U-shaped resonator are shown in the Figure 6.

From current distribution characteristics of Figure 6, it is observed that the directions of current vector are such that they cancelled each other at 4.5 GHz. As a result the resonator itself does not radiate and reduces the MC at the designed frequency.

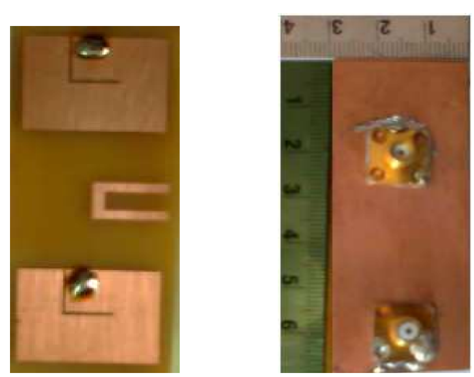
3. PROTOTYPE ANTENNAS AND EXPERIMENTAL RESULTS

A finite ground plane of $70 \times 29\,\text{mm}^2$ for DGS/resonator integrated antenna structure and $74 \times 34\,\text{mm}^2$ for two-element array have been taken. This antenna structures are fabricated on FR4 substrate to validate the concept of MC between two adjacent antenna elements. The photograph of the prototype antennas are shown in the Figure 7 and Figure 8. The antennas are tested and compared with the simulated results.



(a) (b) (c)

Figure 7. Fabricated antennas, (a) front view without DGS & resonator, (b) front view with DGS only, and (c) back view with DGS.



(a) (b)

Figure 8. Fabricated antennas, (a) front view with resonator only and (b) back view with resonator.

The experimental results of fabricated antennas are illustrated in the Figure 9, Figure 10 and Figure 11.

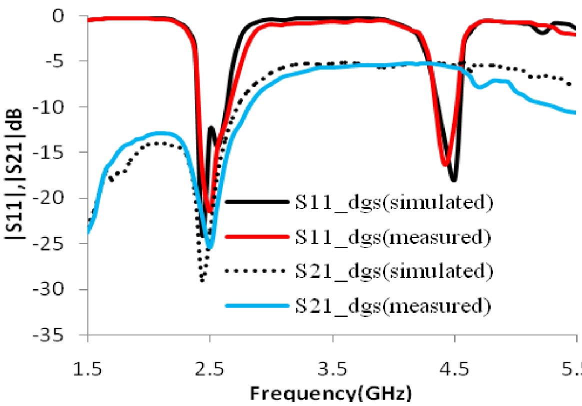


Figure 9. Measured and simulated S-parameters with DGS integrated antenna structure.

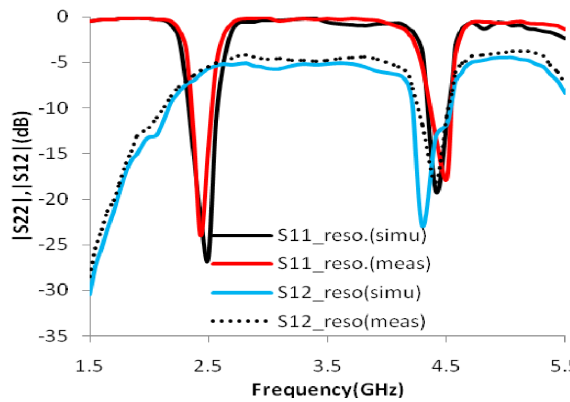


Figure 10. Measured and simulated S-parameters with resonator integrated antenna structure.

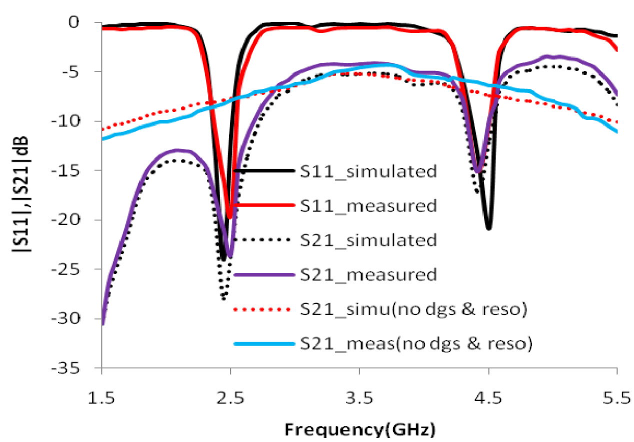


Figure 11. Measured and simulated S-parameters with DGS and resonator integrated antenna structure.

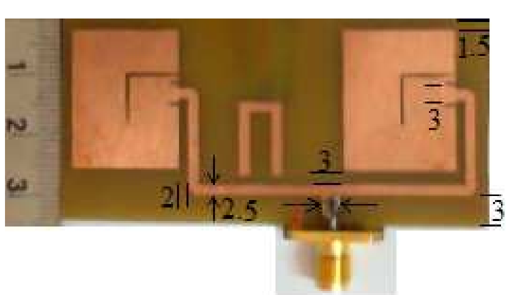


Figure 12. Two element array with DGS and resonator (dimensions are in mm).

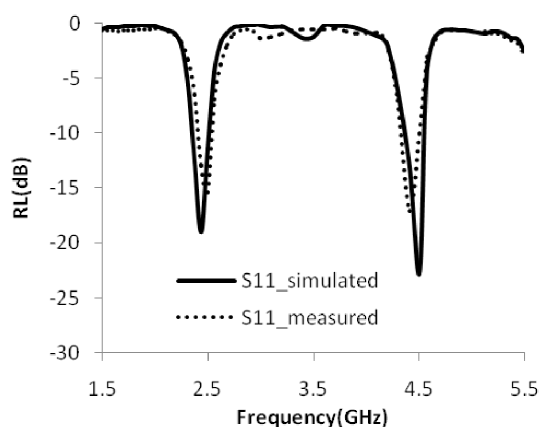


Figure 13. Measured and simulated S_{11} of the two element array of Figure 12.

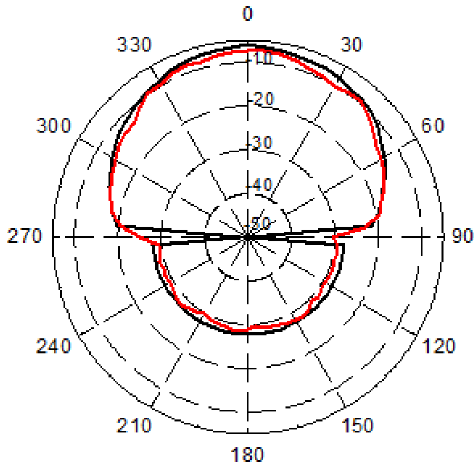


Figure 14. Measured (red) and simulated (black) E-plane pattern of the two element array at 2.45 GHz.

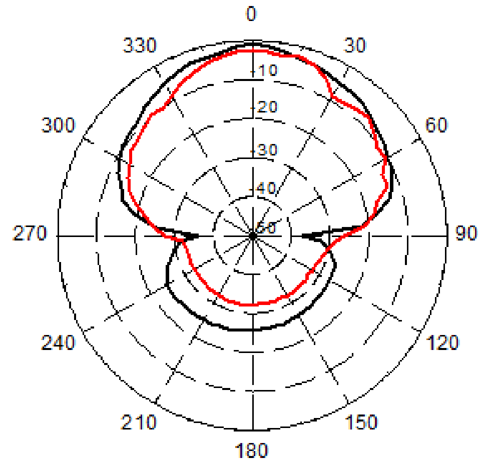


Figure 15. Measured (red) and simulated (black) E-plane pattern of the two element array at 4.5 GHz.

From Figure 11, it is observed that the MCs have been suppressed by 15.7 dB and 8 dB at 2.45 GHz and 4.5 GHz respectively at the presence of DGS and resonator. A prototype of two element array is shown in the Figure 12.

Figure 13 shows that the presence of DGS and resonator causing suppression in MC does not affect RL characteristics.

From RL curve, it is also observed that there is a good agreement between simulated and measured results. Simulated and measured radiation patterns at two different frequencies of two-element dual-frequency array are shown in the Figure 14 and Figure 15.

Radiation curves of Figure 14 and Figure 15 show that the presence of DGS and resonator do not degrade the patterns in the principal plane. One can observe a small difference between measured and simulated data of S-parameter curves and radiation patterns at resonant frequencies. This might be due to other unknown parasitic effects which are not considered in the simulation process. Since the soldering is not done with a machine on the PCB, positional errors might give rise to the discrepancy.

4. CONCLUSION

A dual-frequency two-element microstrip antenna array with suppressed MC at two different frequency bands is proposed. The aim of this work is to maintain the MC with the designed structure as simple as possible while having a high amount of MC reduction. This paper presents a novel structure suppressing the MC between nearby patches. U-shaped DGS and inverted U-shaped resonator have been introduced as a technique of suppressing the occurrence of MC in the two-element microstrip antenna array. A slotted dual-frequency patch array with and without DGS/resonator are examined using simulation and experimental results and the idea has been verified. Furthermore, the introduction of resonator and DGS causing suppression in MC at two different frequencies does not affect other characteristics like the co-polarized radiation over the principal planes, gain, and input impedance compared to those with conventional microstrip patch. Thus, the proposed concept can be employed for achieving improved gain and radiation pattern with reduced MC where high MC becomes a major limitation in the array of antennas.

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