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Reducing Mutual Coupling in Microstrip Array Antenna Using Metamaterial Spiral Resonator

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Abstract— Utilization of metamaterial structures has been becoming attractive in the community of electromagnetic and antenna. In this paper, a metamaterial spiral resonator (SR) is proposed as an effective solution for reducing mutual coupling in a microstrip array antenna that consists of two elements. Applying the proposed periodic structure in the substrate and between the patches is simulated and studied. Simulation results show the improvement of mutual coupling and return loss by adding spiral resonator structure to the antenna substrate.

Keywords- Microstrip array antenna, Mutual coupling, Metamaterial, Spiral resonator.

I. Introduction

Microstrip array antennas exhibit extensive applications in communication systems due to their unique features and attractive properties such as low profile, light weight, compactness and conformability in structure [1]. For example, they have been applied in smart antenna, scanning radars and pattern beam forming [2]. Because of the important effect of mutual coupling on the antenna results, it is necessary to consider mutual coupling in designing antenna arrays. In [3, 4], errors of beam forming, scanning, input power wastage and degradation of the side lobe level were investigated, especially for the ultra-low side lobe level array antennas, without considering the effect of the mutual coupling. In order to decrease this effect, there are many methods such as loading electromagnetic band-gap (EBG) structures [5], defecting ground structures (DGSs) between elements [6], using concave rectangular patches [7], and grooving the dielectric [8].

Recently, metamaterial has been used widely due to its unique features [9-11]. These structures, which are inherently artificial materials, cannot be found in nature [12]. For the first time, the Russian physicist Victor Veselago presented the properties of metamaterials in the late 1960s. These materials exhibit either negative permeability and/or negative permittivity [13]. Metamaterials can suppress electromagnetic wave propagation in certain frequency band [14]. Therefore, this type of material can reduce the mutual coupling between the elements in the array antenna due to suppressing the surface wave propagation.

In this work, a periodic metamaterial spiral resonator structure is proposed to decrease the mutual coupling of the microstrip antenna arrays. The proposed periodic structure was applied in the substrate and between the patches. The presented simulation results are obtained with the finite element based Ansoft High Frequency Structure Simulator (HFSS). The parametric study is presented on the length, width and SR spacing in the direction of X and Y. The performance comparison of the proposed antenna and reference dielectric show that metamaterial has a good application potential to improve the mutual coupling.

II. Geometry Of The Array Antenna

The microstrip array antenna consists of a FR4 substrate and two patch elements; the distance of the elements is considered 14.1mm. The substrate's dimension and relative permittivity, ε_r, are 70mm×30mm×1.6mm and 4.4, respectively. Fig. 1 illustrates the array antenna structure used in the simulation. The length and width of the feed line is 13.95mm and 1.5mm, respectively. In this research, the length and width of the patches are L=14mm and W=18mm and the antenna resonant at the frequency 4.5GHz**.**

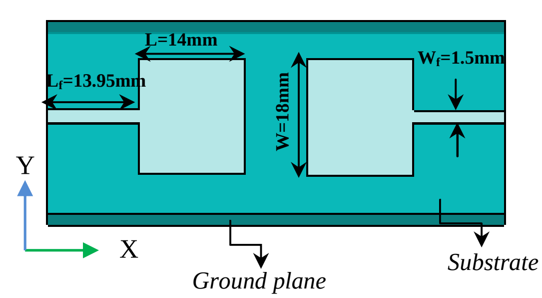


Fig. 1. Top view of two coupled microstrip antenna patches

III. Metamaterial Structure Effect

In this paper, we use a periodic spiral resonator structure, which is depicted a unit cell in Fig. 2. Fig. 3 shows the array antenna loading by 3 rows of SR. Spiral resonator structure is behaved as a MNG metamaterial, which by varying the number of the turns of each spiral; the resonant frequency may be easily tuned to the desired value [15,16]. In this section, the effect of SR's dimensions, different the distances of the SR and variant rows number are analyzed.

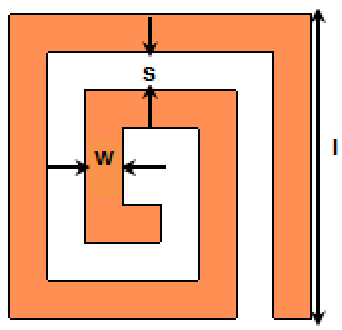


Fig. 2. A unit cell of periodic structure

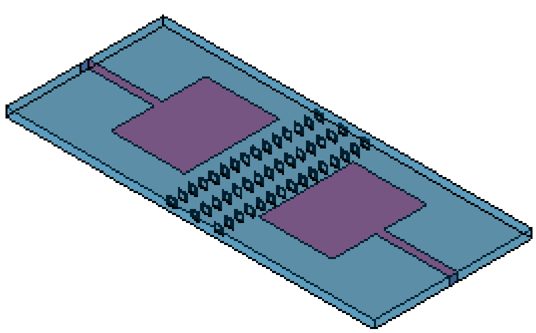
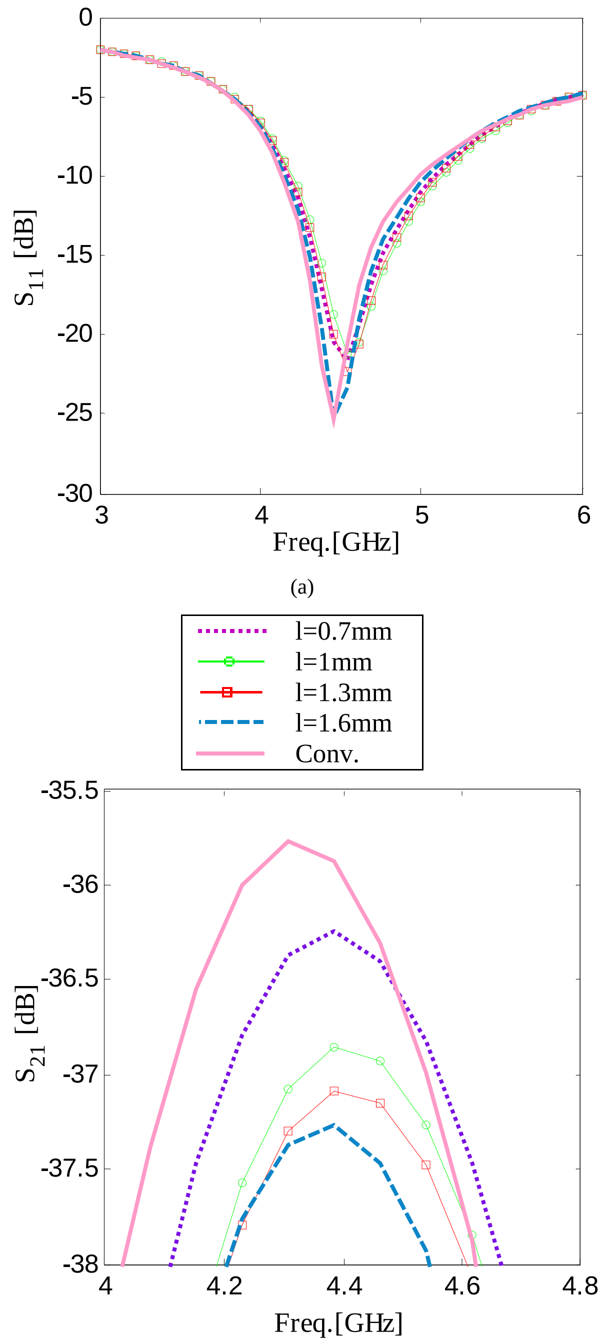


Fig. 3. 3D view of the array antenna with SR structure for 3 rows

A. *Effect of Outer Light of the SR*

In Fig. 2, the side length of the external turn is illustrated by the parameter "l". The effect of the length on the return loss and mutual coupling are shown in Fig. 4. In this case, the amount of the width and spacing in the direction Y of SR structures for 1 row are considered fixed (W=0.05mm and dy=1.5mm). Fig. 4a shows the return loss variation with the frequency for different antenna configurations. It can be observed that all the antennas resonate around 4.5GHz and the return losses are same. Fig. 4b shows that if the SR structures are employed, the mutual coupling level changes. For the different length, the resonant frequency of 4.5GHz falls inside the metamaterial stop band so that the surface waves are suppressed. It is observed that the mutual coupling is decreased by increasing the length so that, the amount of mutual coupling is decreased to around 1.64dB with l=1.6mm.



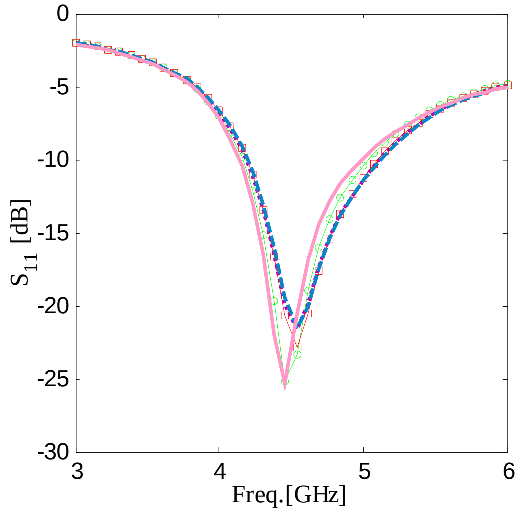
(a)

(b)

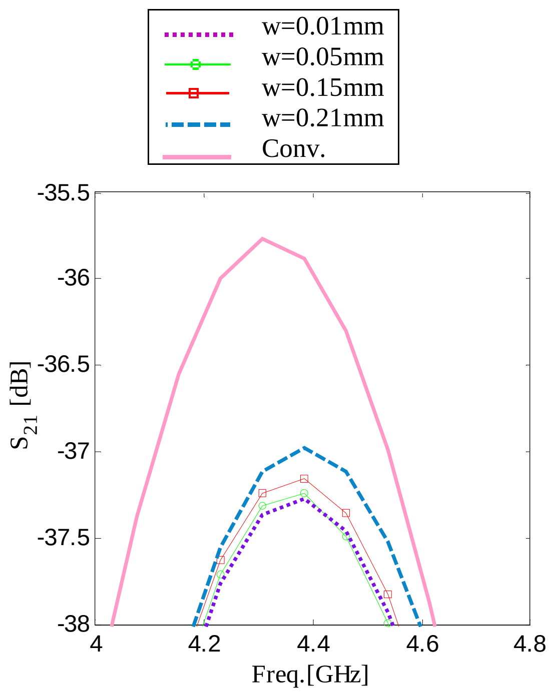
Fig. 4. Return loss (a) and mutual coupling (b) for different length

B. *Effect of Width and the Separation between Rings*

Now, a parametric study is performing on the width and the separation between rings of the SR by keeping the optimal length fixed at 1.6mm. In Fig. 2, the width and the separation between the rings are shown by the parameters "W" and "S", respectively, which are considered at the same amount. The mutual coupling and return loss are calculated for W= 0.01, 0.05, 0.15, 0.21mm. The results illustrated in Fig. 5 depict that lower amount of W can reduce mutual coupling.



(a)

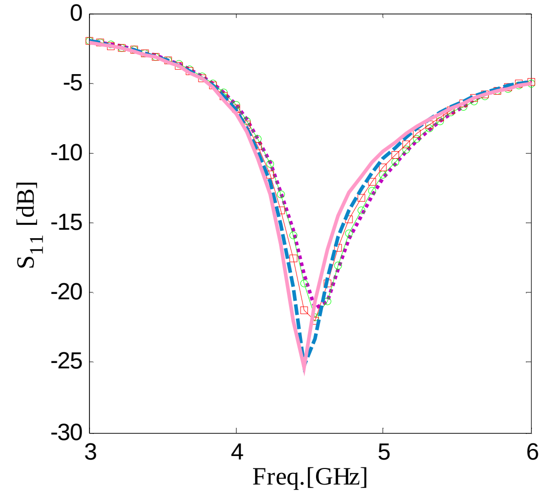


(b)

Fig. 5. Return loss (a) and mutual coupling (b) for different width

C. *The Effect of the Number the SR Rows*

In this section, the effect of the number the SR rows is reported on mutual coupling and return loss. First, the optimal value was achieved spacing in the *Y* direction (dy) for 1 row of the SR structures. Then, by keeping optimal dy fixed at 2mm, the effect of increasing the number of the SR rows to 2, 3 and 5 is studied; the results are shown in Figures 6-9. Notice that, 15 unit cells have been place at every row. The results are exhibited for the various distances in the *X* direction (dx). The lowest mutual coupling is obtained in the 5 rows of the SR structures with dx=1.2mm spacing, in which an approximately 5.5dB reduction is achieved. For this case, the return losses are shown for all the configurations.



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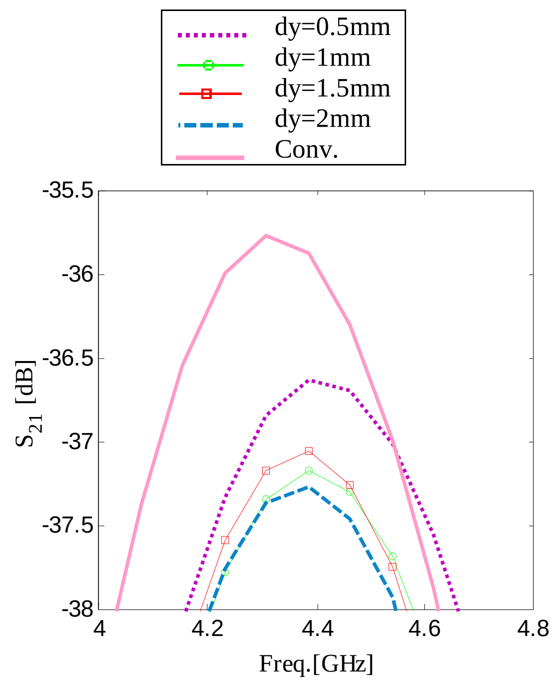
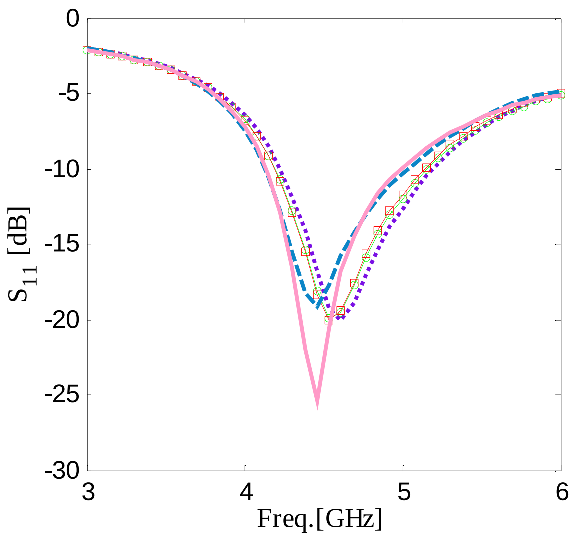
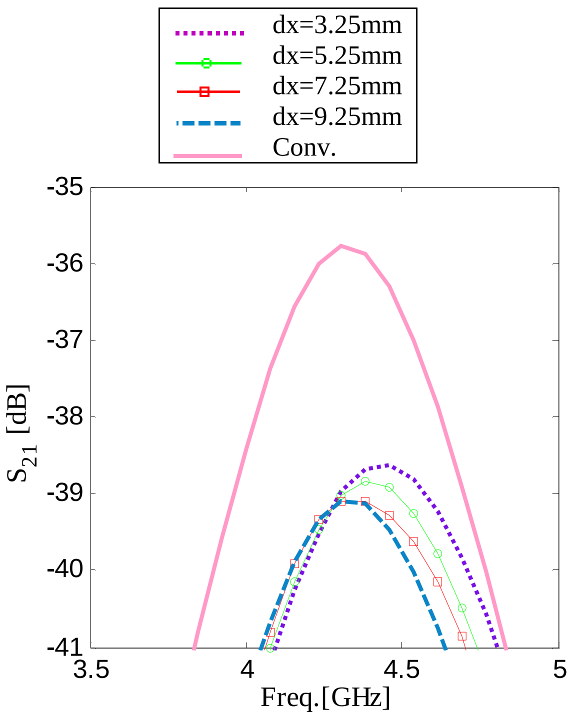


(b)

Fig. 6. Return loss (a) and mutual coupling (b) for different spacing in the Y direction for 1 row

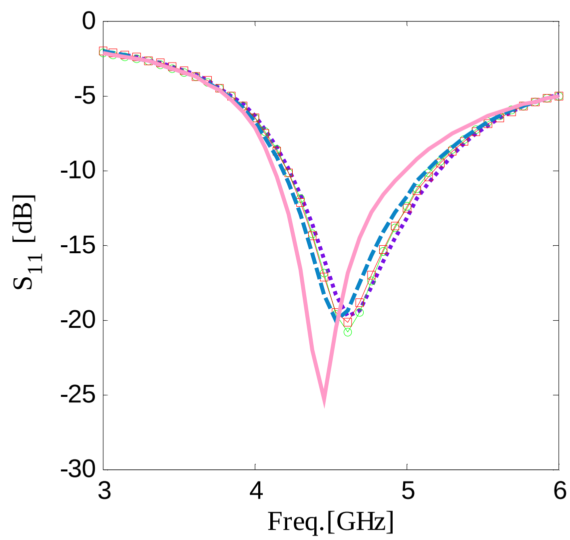


(a)

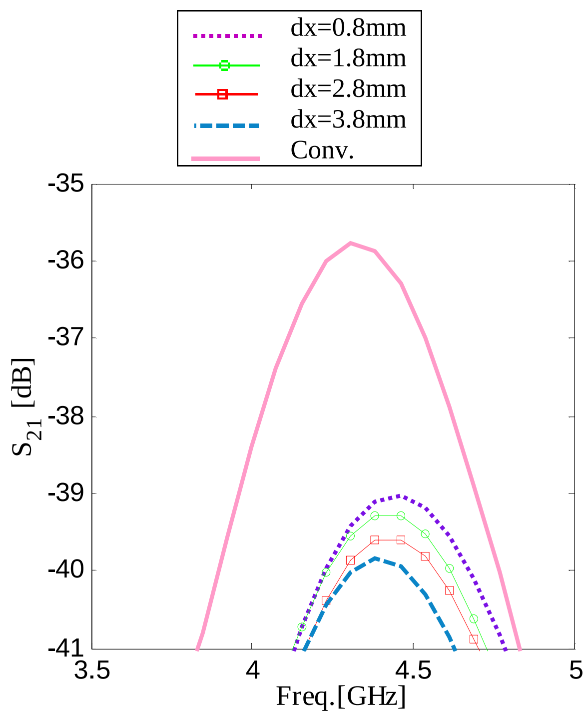


(b)

Fig. 7. Return loss (a) and mutual coupling (b) for different spacing in the X direction with 2 rows

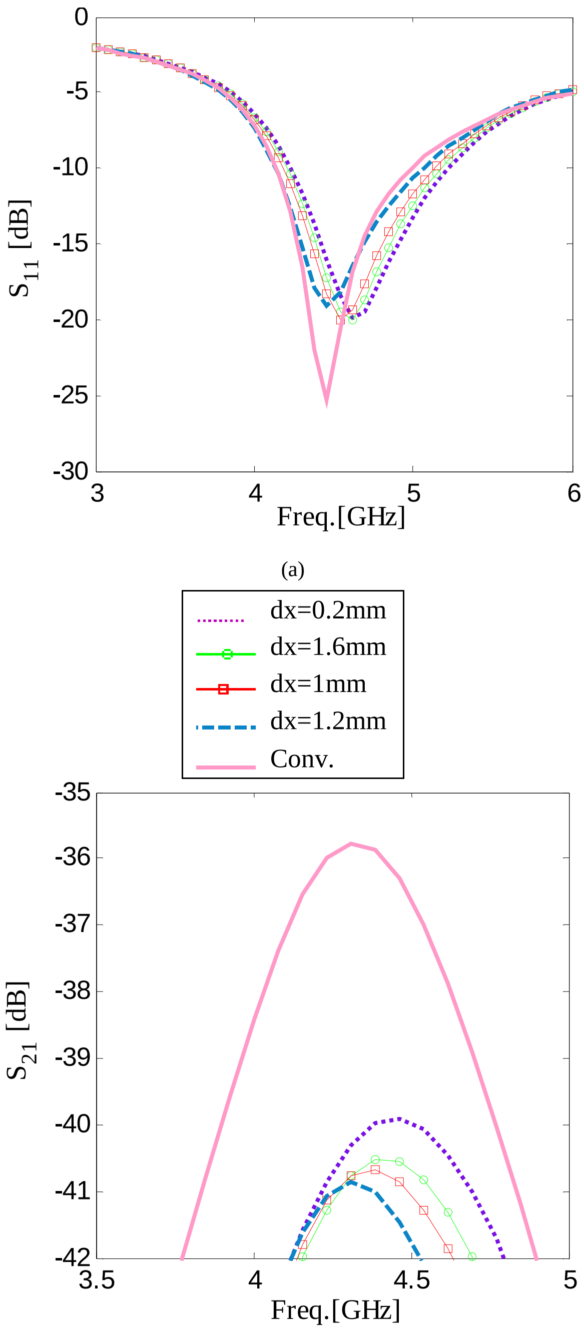


(a)



(b)

Fig. 8. Return loss (a) and mutual coupling (b) for different spacing in the X direction with 3 rows



(a)

(b)

Fig. 9. Return loss (a) and mutual coupling (b) for different spacing in the X direction with 5 rows

IV. CONCLUSION

In this paper, a metamaterial spiral resonator structure was used for reducing the mutual coupling between the elements of the microstrip array antenna. The parameters of the structure (length, width, spacing and the number of the rows) were studied. The proposed antenna with SR had the 5.5dB reduction of mutual coupling in comparison with the microstrip array antenna used alone. This comparison demonstrated that the unique capability of the metamaterial structure reduced mutual coupling by suppressing surface waves.

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