Mutual Coupling Reduction of Closely Spaced MIMO Antenna Using Frequency Selective Surface based on Metamaterials

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Abstract ─ A new structure for mutual coupling reduction, which is using the application of Frequency Selective Surface (FSS) based on metamaterials is presented in this paper. In this method, first a custom-designed unitcell is presented that provides a proper S_{12} response for the mutual coupling reduction and then, this unitcell is used in a two-element array of wideband dipoles. According to the results, this unitcell provides a maximum reduction of 15dB in the frequency response of the antenna array,while it does not have a considerable effect on the reflection coefficient and radiation pattern of the antenna. To verify the results, the antenna is fabricated and measured and there is a very good agreement between the simulation and measurement.

Index Terms ─ End-fire antenna, frequency selective surfaces, metamaterial, MIMO antenna, mutual coupling.

I. INTRODUCTION

Today, MIMO antennas are the key elements in modern wireless communication systems, because can they minimize the interference, improve the link quality and channel capacity without the need of increasing the bandwidth. One major drawback in designing MIMO antennas is the interactions of electromagnetic wave between the adjacent elements which degrade the antenna parameters such as bandwidth and radiation pattern. To solve this issue, a lot of works have been carried out to decrease the effect of mutual coupling between antennas such as EBG, DGS, as well as metamaterials [1-5]. The abovementioned techniques have been applied for broadside radiation type. For instance, two inverted–L shaped branches and a rectangular slot with one circular end was etched on the ground plane of a folded monopole antenna, which covers different standards suitable for mobile phone applications [6]. With this proposed technique the mutual coupling is better than 15dB and 20dB in the lower and upper band respectively. However, for some applications it is necessary not to modify the ground plane so as to integrate the antenna element to RF front-end systems. Another approach to minimize the effect of mutual coupling is to integrate arrays of split-ring resonators as a metamaterial inclusion between each adjacent element [7]. Recently, the authors in [8] have presented a compact S-shaped EBG structure to reduce the E-plane mutual coupling between two patch antennas by 15 dB at 5.25 GHz. However, the drawback of this configuration is the use of via which adds a complexity to achieve S-shaped configuration.

The authors in [9] have introduced three interdigital lines that excite the orthogonal polarization mode for reducing the mutual coupling between adjacent patch antennas. With this method the isolation corresponds to -20dB. However, using vias in the interdigital lines adds the complexity to the antenna configuration. Applying a T-shaped slot impedance transformer between two-closely spaced PIFA antennas [10] is another approach with isolation of 19.2 and 22.8 for WLAN and WiMAX frequency band respectively. Utilizing the wall loaded by a coplanar strip and defected split-ring resonator is another viable approach to reduce the mutual coupling between closely distanced patch antennas [11]. However, the presence of the wall makes the antenna structure bulky, which is useless for modern wireless communication systems.

In this paper, we propose a simple structure to suppress the effect of mutual coupling between two planar end-fire dipole antennas. The proposed antenna operates in the wide frequency bandwidth of 1.8-4.2 GHz with edge to edge distance of 2mm.To reduce the interaction between antennas, an array of modified FSS metamaterials [12] is integrated on the back side of the dipole antenna. To verify the results, a prototype of the antenna is fabricated indicating there is a good agreement between the simulation and measurement. The measured isolation between antennas is below -40dB over frequency band of 2.15-3.1 GHz, which makes this structure a good candidate for MIMO antenna applications.

II. UNITCELL LAYOUT

Figure 1 shows the schematic view of the proposed design for the FSS metamaterial unitcell. Compared to

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other structures, this unitcell does not have any vias and it is easy to fabricate. This unitcell is implemented on a Rogers RT/5880 substrate with the effective permittivity of 2.2 and the thickness of 1.575mm.

To calculate the frequency response of the unitcell, it is simulated in the HFSS software using the PEC and PMC walls along X and Z directions and two ports located in the Y direction, and the S parameter results are plotted in Fig. 2.

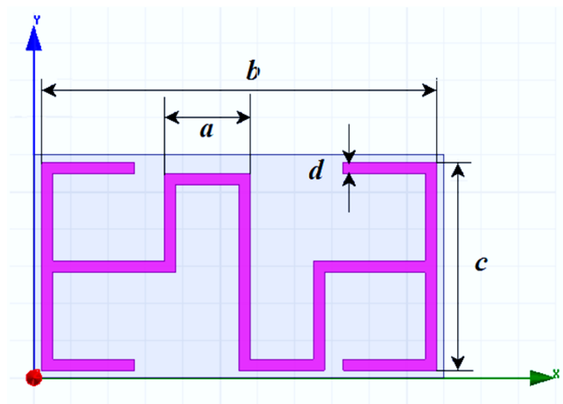
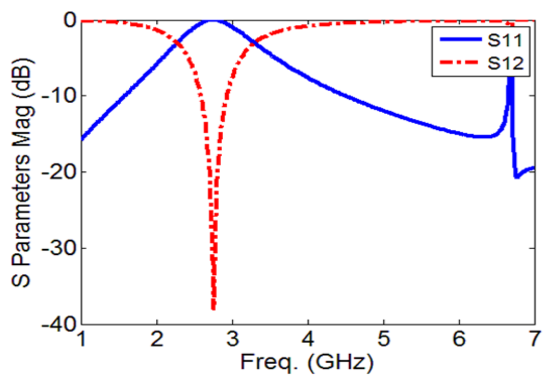
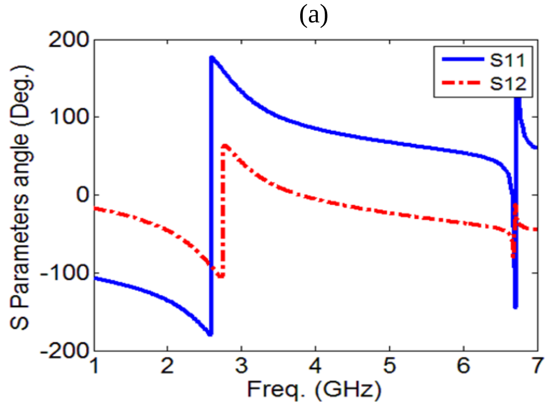


Fig. 1. Schematic view of the unitcell (*a*=2.3, *b*=10.6, *c*=5.6, and *d*=0.3 mm).



(a)



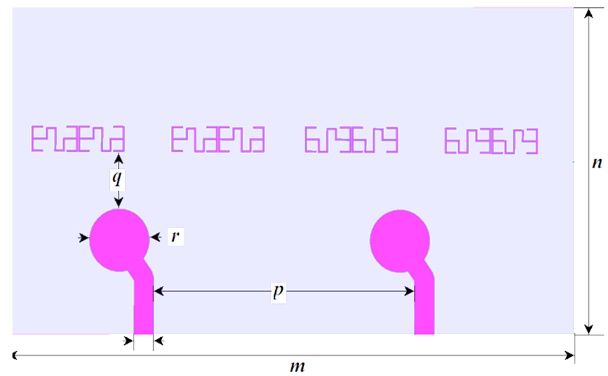
(b)

Fig. 2. Simulated S-parameters of the unitcell: (a) magnitude and (b) phase.

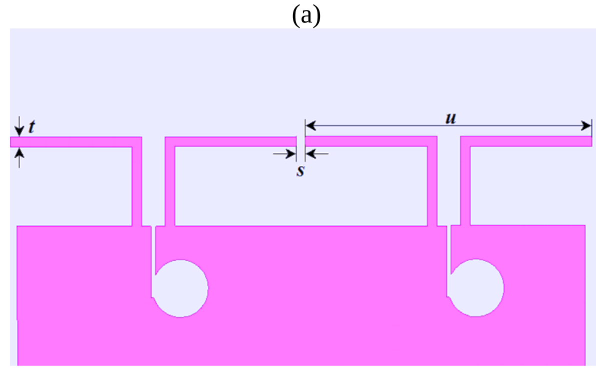
According to the results, there is a very deep fall-off in the S_{12} response of the unitcell from 2.28 to 3.30 GHz. As mentioned in the previous section, the final objective of this paper is to apply this unitcell on a planar antenna array structure and use its sharp fall-off as a mutual coupling reduction mechanism.

III. ANTENNA DESIGN

Figure 3 depicts the schematic view of the presented antenna array with the unitcells printed as the mutual coupling reduction elements. The reference antenna is derived from [11] where a special balun structure is used to obtain a wideband result.



(a)



(b)

Fig. 3. Schematic view of the antenna with unitcells: (a) top, (b) bottom (dimensions in millimeters are: *m*=130, *n*=71.7, *p*=60.5, *q*=12.7, *r*=13.5, *s*=1.9, *t*=2, *u*=63.1).

This two-element antenna array is also implemented on the Rogers RT/5880 substrate with the thickness of 1.575mm. The effect of FSS metamaterial unitcells on the mutual coupling of the antenna is demonstrated in Fig. 4.

According to Fig. 4, a reduction in the S_{12} parameter of the antenna is observed from 1.7 to 3 GHz, the maximum amount of mutual coupling reduction is 15dB, which is achieved at the frequency of 2.45 GHz. The other important feature of the metamaterial inclusions in front of antenna is their negligible effect on the antenna matching as demonstrated in Fig. 5.

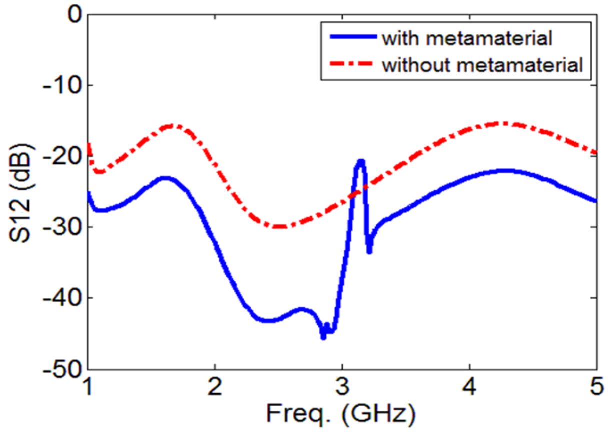


Fig. 4. Simulated S_{12} of the antenna with and without FSS metamaterial.

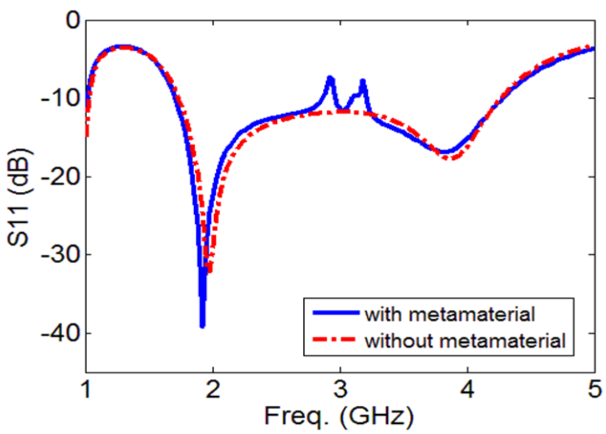


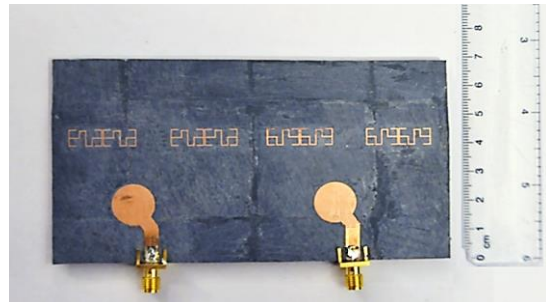
Fig. 5. Reflection coefficient of antenna with and without FSS metamaterial.

According to Fig. 5, the FSS metamaterial loading has no effect on antenna reflection coefficient and the S_{11} parameter is almost the same with and without FSS metamaterial. The antenna gain is 6dB when the unitcells are used which is the same as the antenna with no unitcells.

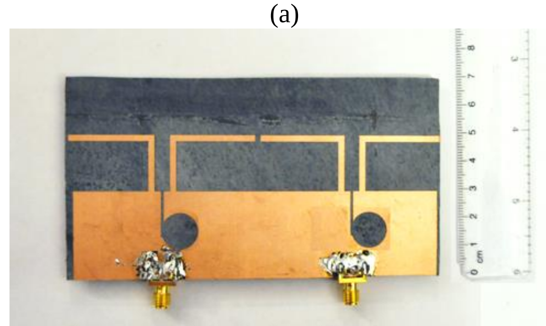
IV. EXPERIMENTAL RESULTS

To verify the simulation results, the antenna is fabricated and measured. A photograph of the fabricated prototype is shown in Fig. 6.

The measured reflection coefficient of the antenna with the decoupling elements is plotted in Fig. 7, which is in a very close agreement with the simulation results. Moreover, the measured radiation pattern of the fabricated prototype totally complies with the simulation in both E- and H-planes as depicted in Fig. 8.

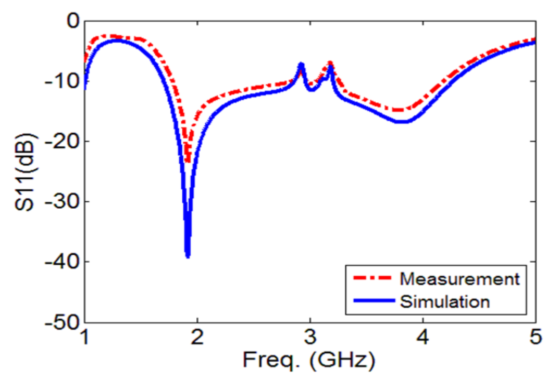


(a)

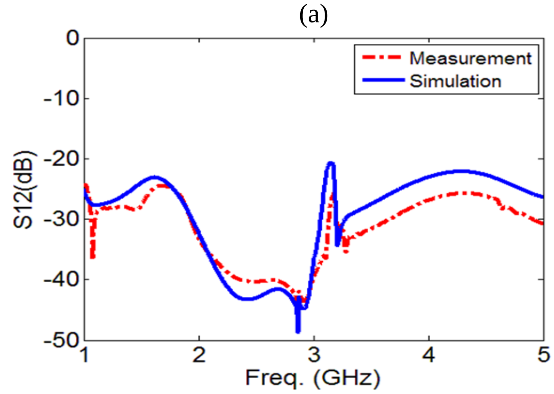


(b)

Fig. 6. The fabricated prototype: (a) top and (b) bottom.



(a)



(b)

Fig. 7. Measured S-parameters of the antenna: (a) S_{11} and (b) S_{12}.

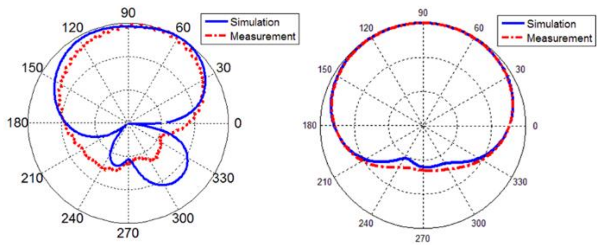


Fig. 8. Measured radiation pattern at 2.45 GHz: (a) E-plane and (b) H-plane.

V. CONCLUSION

In this paper, a new structure for mutual coupling reduction has been introduced. In this structure, a special FSS metamaterial unitcell has been designed to produce a deep fall-off in the desired frequency range and then the presented unitcell is used in the structure of a planar two-element antenna array. According to the results, the presented technique leads to a reduction of 15dB in the S12 parameter of the antenna array while not affecting the antenna matching and radiation pattern. A prototype of the antenna array with the embedded unitcells is fabricated and the measurement results are very close to the simulation. The presented unitcell provides a simple, low-profile and effective method for mutual coupling reduction of antenna arrays and can be used in modern MIMO applications.

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