Mutual Coupling Reduction of Dual Polarized Low Profile MIMO Antenna Using Decoupling Resonators

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Abstract ─ This paper presents a resonator based decoupling structure for 2×2 dual polarized array antenna. The designed structure consists of two decoupling resonators placed between the antenna elements. The proposed decoupling structure can effectively enhance the isolation and has negligible impact on the radiation patterns.

Index Terms ─ Decoupling, dual-polarized array, resonator.

I. INTRODUCTION

Dual polarized and compact array antennas are highly desirable in multiple-input multiple-output (MIMO) systems. However, mutual coupling becomes inevitable in compact MIIMO antennas [1]. A series of mutual coupling reduction techniques have been proposed in the literature. For example, the mutual coupling can be reduced using the defected ground structure (DGS) [2], electromagnetic band gap (EBG) [3], neutralization line [4], parasitic element [5], metamaterial [6]-[8], shorting vias [9], interference cancellation chip [10], hybrid topology optimization [11], decoupling surface [12], decoupling ground [13], dual polarized slot antenna [14]-[17], split ring resonator (SRR) [18], etc. However, the DGS tends to increase the backward radiation; the neutralization line and shorting via methods are mainly suitable for two-element MIMO antenna and are difficult to be extended to MIMO antennas with more than two elements; and most of these techniques works only for single polarized antennas and may distort the radiation pattern, except for [12] and [13], which however inevitably incase the profile of the array.

In this work, we focus on the SRR based decoupling technique for low profile arrays. The SRR decoupling structures have been studied in [18]-[21]. The SRR unit has been used as metasurface element for decoupling [6]. The SRRs presented in [6],[18],[19] are only valid for single-polarized two-port array. The authors in [20] presented a SRR-based superstrate, which works for linear arrays with more than two ports. However, the SRR structure increases the profile. SRR walls were used to decouple a 2×2 array with circular polarization [21]. Moreover, the three-dimensional (3D) SRR structure in [21] dictates a relatively high profile and manufacturing cost.

In this paper, we propose a decoupling resonator (DR) structure to reduce the mutual coupling of a 2×2 dual polarized low profile microstrip array antenna at 3.5 GHz. Two cells of DRs are placed between antennas with an edge-to-edge spacing of $0.14\lambda_0$ (center-to-center spacing of $0.39\lambda_0$). The proposed DR structure can effectively suppress the surface wave in the H-plane, while a small E-plane coupling is achieved by array design itself. Thus, unlike the previous SRR works with single linear polarization, effective mutual coupling is achieved for a dual polarized array. The proposed DR structure effectively reduces the H-plane coupling below -20 dB without degrading either the isolation in the E-plane or the isolation between orthogonal polarizations. Moreover, it is shown that the proposed DR structure does not distort the radiation patterns of the array, which is a highly desirable feature for array decoupling.

II. ANTENNA STRUCTURE AND RESULTS

A dual polarized 2×2 microstrip array antenna with eight SRR decoupling structures is shown in Fig. 1 (a) and Fig. 1 (b) shows the DR unit. A square patch with a

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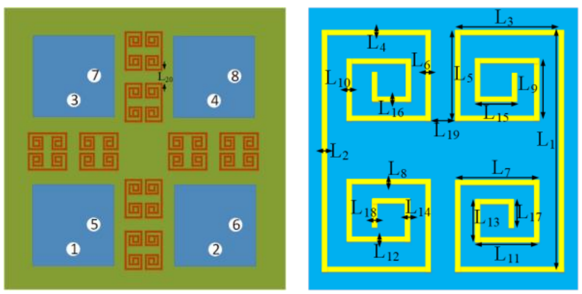
dimension of 21.8 mm is used as the array element. The edge-to-edge spacing between the adjacent elements is 12 mm ($0.14\lambda_0$, where λ_0 denotes the wavelength in free space). The microstrip element is fed by two coaxial ports in the horizontal and vertical directions at a distance of 3.4 mm from the center. The two positions was found to give good impedance matching. The antenna ports are marked as numbers 1-8 in Fig. 1 (a). The substrate is Rogers 4350B with a dielectric constant of 3.48 and a thickness of h = 1.524 mm. The ground has a size of 120 mm × 120 mm. The array has a resonating frequency at 3.5 GHz. The dimensions of proposed DR unit are summarized in Table 1.



(a) (b)

Fig. 1. (a) Dual polarized MIMO antenna with DR decoupling structures; (b) proposed DR unit.

Table 1: Parameters of proposed antenna

Parameters	Values (mm)	Parameters	Values (mm)
L_1	7.90	L_{11}	1.30
L_2	0.25	L_{12}	0.20
L_3	2.40	L_{13}	1.60
L_4	0.25	L_{14}	0.20
L_5	3.00	L_{15}	0.75
L_6	0.20	L_{16}	0.20
L_7	2.00	L_{17}	1.00
L_8	0.30	L_{18}	0.20
L_9	2.60	L_{19}	0.90
L_{10}	0.25	L_{20}	9.00

All simulations are carried out in CST microwave studio in this work. Figure 2 shows the S-parameters of the 2×2 array without DR. As can be seen, given the array design (i.e., element separation, patch size, dielectric, etc.), the H-plane coupling dominates, i.e., the worst mutual coupling of -12 dB occurs in the H-plane (between ports 1 and 2), the mutual coupling in the E-plane (between ports 1 and 3) is below -20 dB, and the mutual coupling between the two polarization in the same patch (between ports 1 and 5) is negligible. Therefore, the effort for mutual coupling reduction is exerted in designing the DR to bring down the H-plane coupling, without degrading either the E-plane coupling or the polarization isolation.

To explain the decoupling mechanism, we analyze the resonator by increasing its number of turns in five steps, see steps a-e in Fig. 3 (a). The corresponding H-plane coupling (S_{21}) is shown in Fig. 3 (b). As can be seen, the initial design (step a) has a resonance at 3.8 GHz. The resonance shifts towards lower frequency as the number of turns increases. The final design (step e) has a resonance at the required frequency of 3.5 GHz.

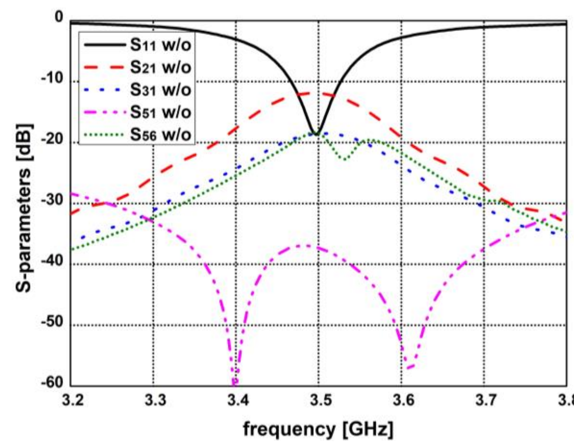
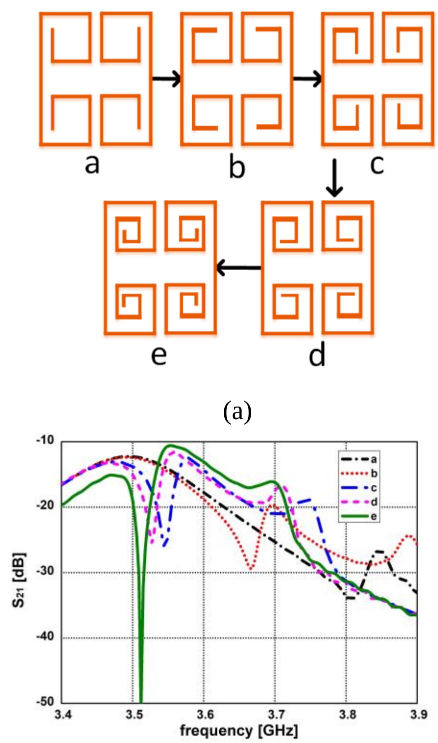


Fig. 2. S-parameters without (w/o) decoupling structure.



(a)

(b)

Fig. 3. (a) Design process of the proposed DR and (b) the corresponding S_{21}.

Figure 4 shows that the mutual impedance of two antennas with and without the DR structure. As can be seen, the DR structure reduces the mutual impedance between antenna ports 1 and 2 to about zero at 3.5 GHz. The surface wave is trapped by the DR units, resulting in low mutual coupling.

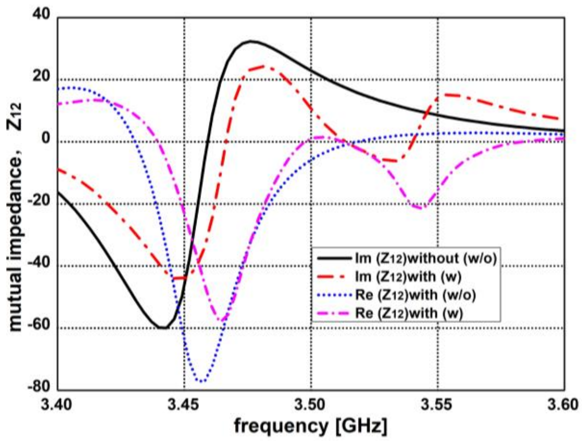


Fig. 4. Mutual impedance Z12 with and without DR structure.

It is found that optimal H-plane decoupling is achieved by inserting two DR units between the adjacent array elements (cf. Fig. 1 (a)). Figure 5 compares the S-parameters of the array antenna with and without the DR based decoupling structure. As can be seen, the DR can greatly reduce the H-plane mutual coupling (S_{21}) by more than 20 dB at the resonating frequency.

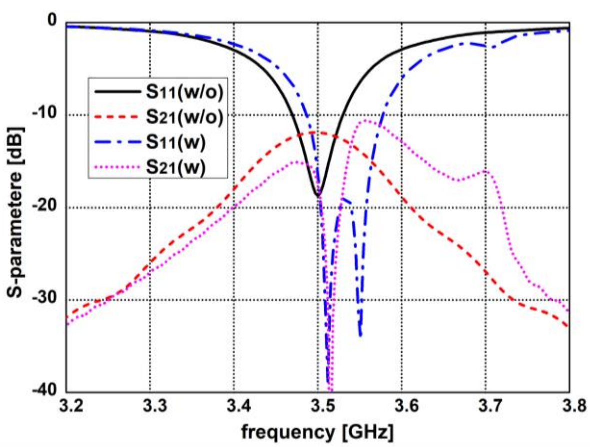


Fig. 5. Comparisons of S-parameters with (w) and without (w/o) DR structure.

Figure 6 shows a photo of the fabricated prototype of the dual polarized 2×2 array with DR based decoupling structure. Figure 7 shows the comparisons of the simulated and measured S-parameters with (w) the DR based decoupling structure. There are in general good agreements between the simulated and measured S-parameters. The small discrepancies are mainly attributed to imperfect soldering and manufacturing tolerance.

Fig. 6. Fabricated prototype of dual polarized antenna with DR structure.

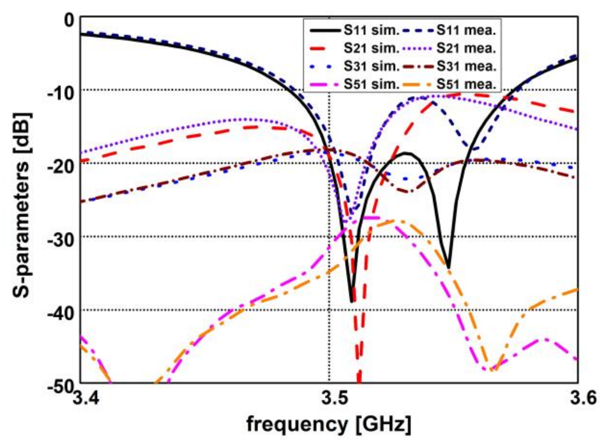
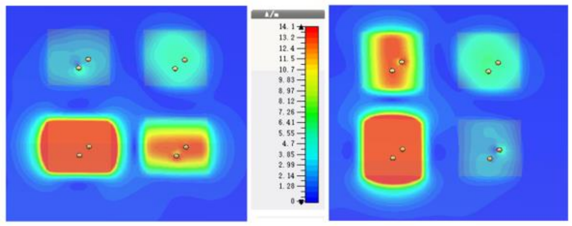
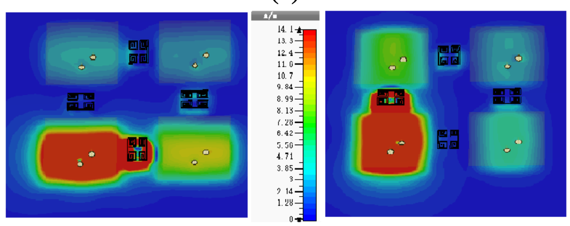


Fig. 7. Comparison of simulated and measured S-parameters with DR structure.

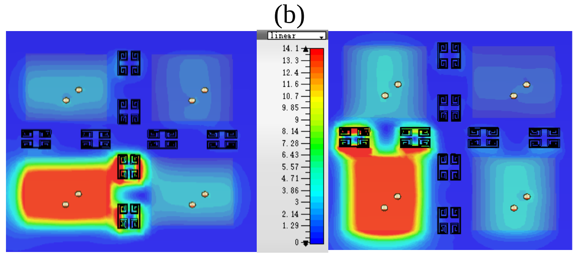
To further illustrate the decoupling property of the DR structure, the absolute surface currents with and without the DR decoupling structure are plotted in Fig. 8. Specifically, Fig. 8 (a) shows the surface current distribution of the 2×2 array without the DR decoupling structure; Fig. 8 (b) shows the surface current distribution of the 2×2 array with a single DR unit between the adjacent array elements; Fig. 8 (c) shows the surface current distribution of the 2×2 array with the proposed decoupling structure (i.e., two DR units between adjacent array elements). As can be seen, the with one DR unit between the adjacent array elements, the coupling is reduced. Yet there is still noticeable amount of coupling left. By inserting two DR units between adjacent array elements, the coupling is reduced significantly.



(a)



(b)



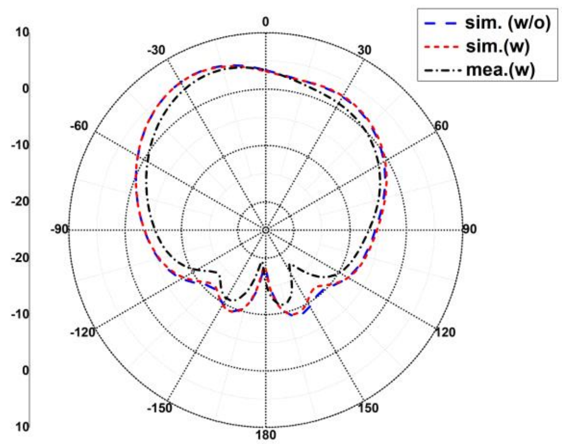
(c)

Fig. 8. Surface current distribution at 3.5 GHz: (a) without DR, (b) with a single DR between adjacent array elements, and (c) with two DRs between adjacent array elements.

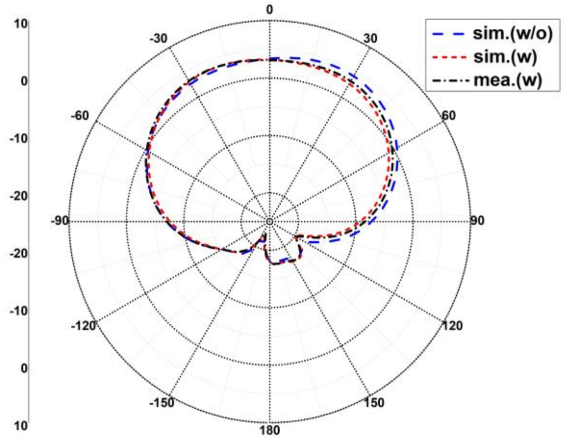
Figure 9 shows the comparisons of simulated radiation patterns with and without decoupling structure. In addition, the measured radiation pattern of the prototype (with decoupling structure) is plotted in the same figure. As can be seen, due to antenna misalignment, imperfect soldering, and manufacturing tolerance, small discrepancy exists between the simulated and measured radiation patterns. Nevertheless, there is still reasonable agreement between them. The slight tilt in the radiation pattern is probably due to the asymmetrical location of the antenna in the finite ground plane. More importantly, the good agreement between the simulated radiation patterns with and without the decoupling structure indicate that the DR has little effect on the radiation pattern. Note that the total radiation efficiency of the proposed antenna with the DR structure is about 66%, where the total radiation efficiency of the antenna without the DR structure is about 73%. So the DR structure introduced some losses. But the losses are not significant.

III. CONCLUSION

In this paper, a DR structure for dual polarized 2×2 array antenna was proposed. By designing the array antenna itself, small E-plane coupling was achieved, while the severe H-plane coupling could be reduced by more than 20 dB at the resonating frequency using the proposed DR decoupling structure. In this way, DR based mutual coupling reduction was achieved for dual polarized low profile array. Moreover, the DR decoupling structure does not distort the radiation pattern of the array, which is a highly desirable feature of the decoupling technique.



(a)



(b)

Fig. 9. Radiation patterns of simulated (sim.) without (w/o), simulated (sim.) and measured (mea.) with (w) DR decoupling structure: (a) vertical polarization; (b) horizontal polarization.

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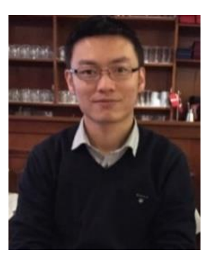

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