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A Simple and Wideband Decoupling Method for Antenna Array Applications

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***Abstract*—In this work, a simple wavetrap-based decoupling method is proposed to suppress the mutual coupling among the antenna elements in a single antenna array. The proposed wavetrap structure consists of a transmission line and a resistor which are in series. By placing two wavetraps between two patch antennas, the isolation between the two corresponding ports can be significantly improved over a wide frequency band. Theoretical analyses and full-wave simulations are carried out to verify the decoupling performance of the proposed method. The results show that the proposed approach features well-designed decoupling characteristics, and can be widely used for large-scale arrays.**

Keywords— Decoupling, wavetrap, large-scale array.

I. INTRODUCTION

It is of great significance to suppress the mutual coupling among the antenna elements in a multiple-input multiple-output (MIMO) antenna array to maintain the stable performance. From the error rate or MIMO capacity point of the view, the isolation between the elements in an antenna array should be better than 17 dB [1]. However, in practical massive MIMO systems, it is very important that the isolation should be better than 25 dB or even higher. Otherwise, a series of negative effects would be generated, such as dramatic deterioration in active impedance matching performance of antenna elements [2], [3], nonlinear distortions on power amplifiers [4], and some other influence [5], [6].

Recently, increasing efforts have been devoted to suppressing the mutual coupling [7]-[9]. In [7], a transmission-line-based decoupling method was synthesized for large-scale arrays. By integrating the decoupling network, the isolation level can be significantly improved. However, the realized bandwidth features a narrow response. On the other hand, using the approaches of near-field resonators and wavetrap structures attracts increasing attentions, where wide decoupling bandwidth can be realized [8], [9]. In [9], a wavetrap-based decoupling approach was proposed. By allocating several groups of shorted stubs serving as wavetrap structures around each antenna elements, multi-resonance decoupling was achieved where a single transmission zero was attributed to a group of wavetraps.

In this work, a very simple decoupling wavetrap structure is presented and studied for antenna arrays. Different from the previous work reported in [9], a transmission zero between the antenna elements can be obtained by using a single proposed wavetrap structure. Furthermore, full-wave simulations are carried out to verify that by just employing two proposed wavetraps, a wide decoupling bandwidth is achieved. The proposed decoupling method is simple and effective, making is valuable for compact and large-scale array applications.

II. ANALYSIS OF THE PROPOSED DECOUPLING STRUCTURE

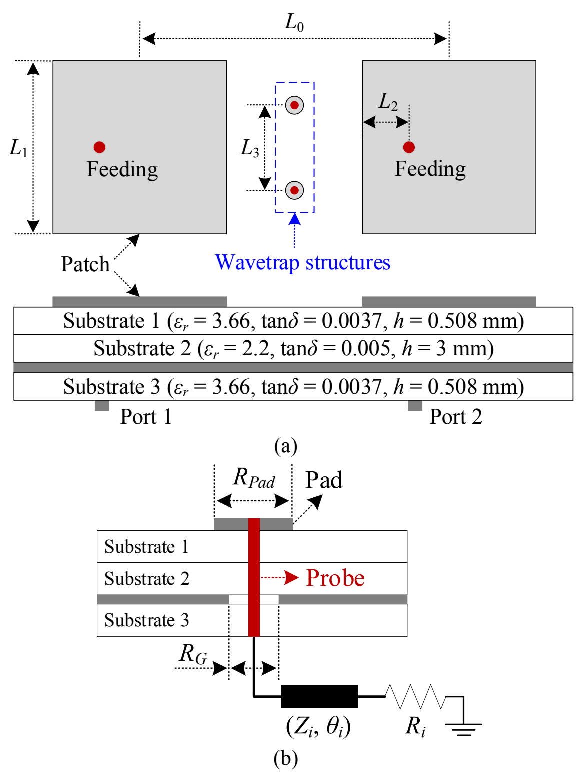
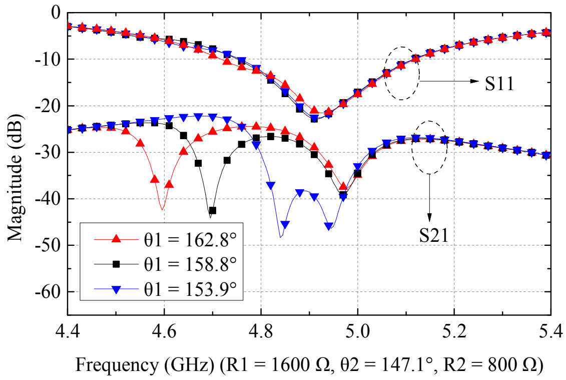
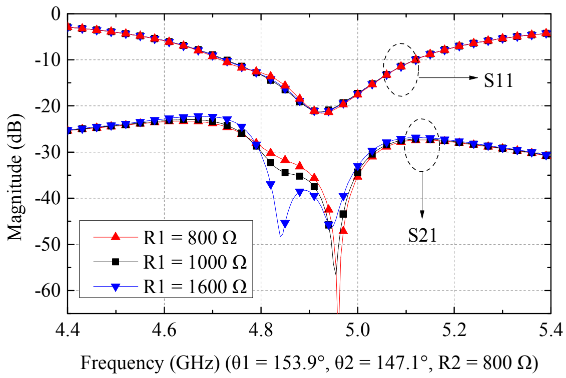


Fig. 1. (a) Configuration of a 1×2 patch array integrated with the proposed decoupling structures. L_0 = 30.6 mm, L_1 = 17 mm, L_2 = 4.5 mm. (b) Configuration of the single wavetrap structure. R_{pad} = 3 mm, R_g = 2 mm.

Fig. 1 shows a 1×2 patch antenna array centered at 4.9 GHz with the proposed wavetrap-based decoupling structures. For the antenna element, two stacked substrates are utilized to realize a wide impedance bandwidth. The patch is printed on the top of substrate 1, and the ground plane is inserted between substrates 2 and 3. Two wavetraps are positioned between the two elements. The center distance between the two elements is $0.5\lambda_0$, where λ_0 is the free-space wavelength at the center frequency. As illustrated in Fig. 1(b), a single wavetrap consists of a small metal pad printed on the top of substrate 1, a transmission line placed on the bottom of substrate 3, a probe through the three substrates as the connection between the pad and the transmission line, and a resistor loaded at the other side of the transmission line. The characteristic impedance and electrical lengths of the transmission lines are Z_1 and θ_1, Z_2 and θ_2, for the two wavetraps, correspondingly. For the arrays composed of the proposed structure shown in Fig.1, the mutual coupling among the antenna elements can be well suppressed by selecting the parameters of the transmission lines and the loaded resistors.



(a)



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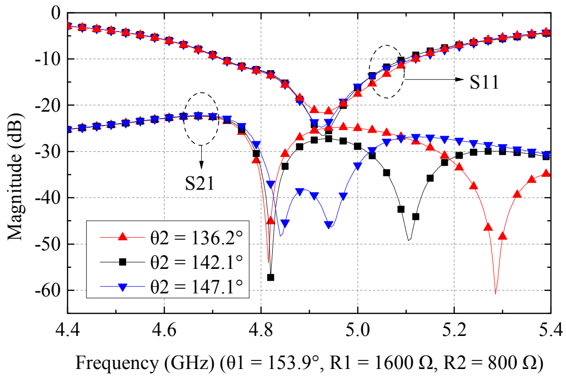
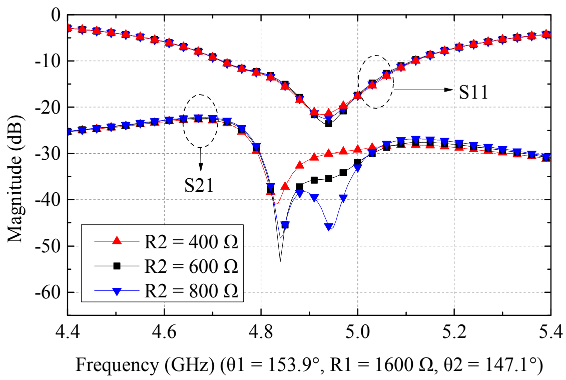


(c)



(d)

Fig. 2. Full-wave simulated results of the 1×2 array integrated with the proposed wavetraps versus different parameter values.

Here, a series of graphical studies are carried out to give further investigations on the decoupling performance of the 1×2 patch array. Fig. 2 illustrates the full-wave simulated transmission responses between ports 1 and 2 versus different R_i and θ_i, where the characteristic impedance Z_i = 50 Ω. It is observed that two transmission zeros can be realized at certain frequencies with specified parameters. Since two transmission zeros of S_{21} are observed at the desired frequencies after decoupling, the significantly enhanced isolation performance is achieved. The result also verifies that the decoupling performance of the two wavetraps are independent of each other, making the design and the realization to be very simple and effective.

III. Full-Wave Simulations

In this section, two design examples are developed and simulated. The first one is a 1×2 array with the decoupling structures, and the second is a 1×8 array extended from the two-element array. Next, the performance of the two arrays will be given and discussed.

A. 1×2 patch array

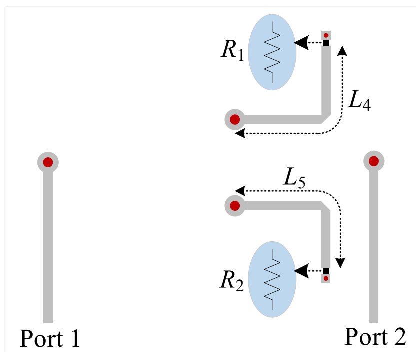


Fig. 3. Physical dimensions of the feeding layer of the decoupled 1×2 patch array. L_4 = 15.65 mm, L_5 = 14.95 mm, R_1 = 1600 Ω, R_2 = 800 Ω.

According to the graphical studies operated in Section II, the optimized dimensions of the decoupling wavetraps are determined, as shown in Fig. 3. The wavetraps with different electrical lengths and loaded resistances represent two transmission zeros between the two antenna elements, leading to a wide decoupling bandwidth. The full-wave simulated *S* parameters of the two-element array are illustrated in Fig. 4. It is observed that the isolation between the two elements is enhanced to over 38 dB after decoupling, which is significantly enhanced compared with the one before decoupling. Since there is no additional structure connected to the antennas directly, the impedance matching performance of the array is not affected, as plotted in Fig. 4. The simulated radiation patterns when port 1 is excited, are provided in Fig. 5. It can be seen that the employed wavetraps have nearly no influence on the radiation patterns of the array. Fig. 6 depictes the radiation efficiency of the array when port 1 is excited. Due to the ohmic and conductivity losses introduced by the wavetraps, the radiation efficiency is degraded. Despite that, the radiation efficiency is still higher than 80% within the frequency band from 4.8 to 5.0 GHz.

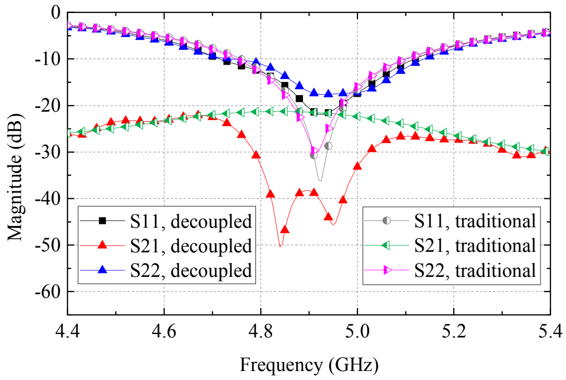
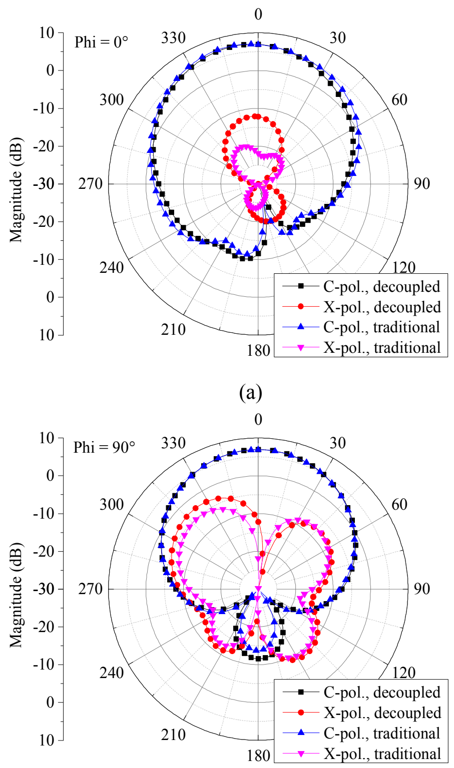


Fig. 4. Full-wave simulated *S* parameters of the 1×2 array with/without the decoupling structures.



(a)

(b)

Fig. 5. Full-wave simulated radiation patterns of the array with/without decoupling, when port 1 is excited. (a) Phi = 0°. (b) Phi = 90°.

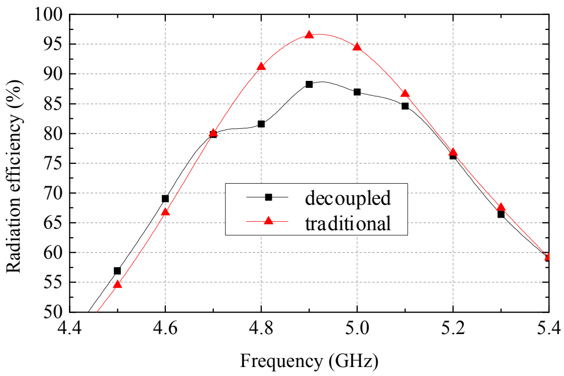


Fig. 6. Full-wave simulated radiation efficiencies of the 1×2 array with/without the decoupling structures when port 1 is excited.

B. 1×8 patch array

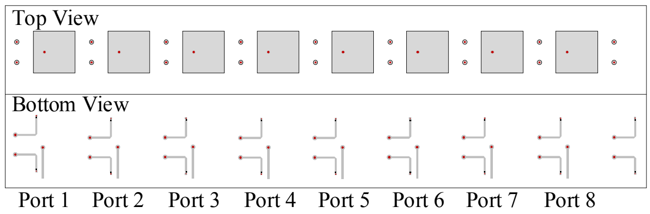
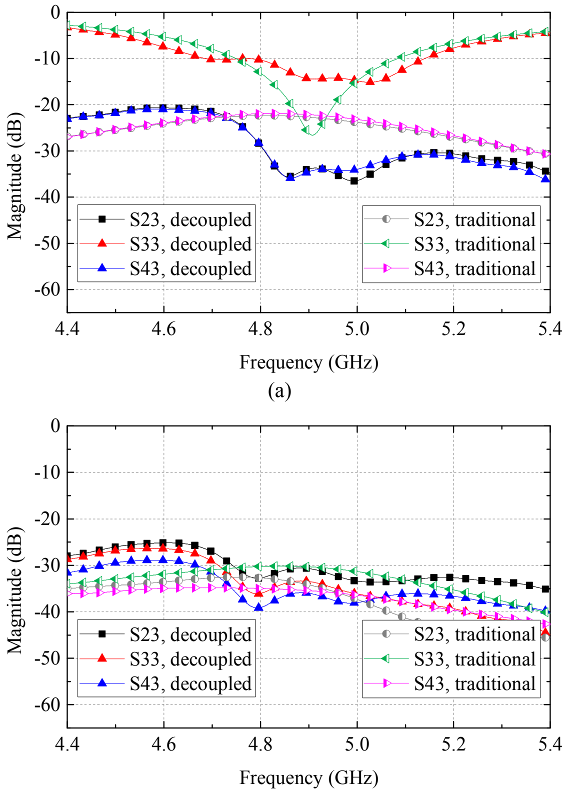


Fig. 7. Configuration of the 1×8 antenna array with the proposed decoupling structures.



(a)

(b)

Fig. 8. Full-wave simulated *S* parameters of the 1×8 array with/without the decoupling structures.

To further show the performance of the proposed decoupling method, a 1×8 patch antenna array integrated with the proposed wavetraps are developed, as illustrated in Fig. 7. Please note that all the parameters of the proposed wavetraps and the antenna elements are identical with those of the decoupled 1×2 array. Full-wave simulations are operated. Part of the *S* parameters of the eight-port array is plotted in Fig. 8, where the results of the traditional array without the decoupling structures are also given for comparison purposes. Here, port 3 is selected as the representative one.

It is clearly seen from Fig. 8(a) that the isolation between adjacent antenna elements has been highly improved from 22.5 dB to over 30 dB among a wide frequency band (4.81 to over 5.4 GHz). Moreover, the impedance bandwidth is also extended after decoupling. For the isolation among nonadjacent elements, they are still kept at a high level of over 30 dB or even further improved, as described in Fig. 8(b). The far-field radiation performance is not significantly influenced after decoupling, similar to the 1×2 array and not given for brevity.

IV. CONCLUSION

To suppress the mutual coupling among the elements in a MIMO antenna array, a simple but powerful decoupling method is proposed and studied. By integrating two decoupling wavetraps between every pair of adjacent elements, the isolation performance between the two corresponding ports can be significantly enhanced. Full-wave simulation is carried out to verify the performance of the proposed structure. The results indicate that the proposed decoupling method is with nearly no influence on the radiation performance of the antennas, and can be widely used for large-scale antenna array applications such as phased array and massive MIMO arrays.

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