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Compact Dual-Frequency Microstrip Antenna Array with Increased Isolation Using Neutralization Lines

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Abstract—An effective technique utilizing neutralization lines to increase the isolation of a compact two-element dual-frequency microstrip antenna array is proposed in this paper. Two neutralization lines connect the two elements at the edge of each radiating patch. The positions and lengths of the two neutralization lines are studied to get the best performance of element isolation. A prototype of the proposed design was fabricated to validate the results. The measured results agree well with the simulated ones. It is shown that an increase of about 25 dB at the lower frequency and that of 17 dB at the upper frequency in isolation between the two antennas have been achieved.

1. INTRODUCTION

In recent years, the demand for wireless communication keeps rising, such as high data rate and throughput in a given channel with limited bandwidth and to ensure reliable bit error rate. Multiple-input-multiple-output (MIMO) system can achieve these targets admirably. The MIMO technology can improve the communication quality and raise the system capacity by using multiple antennas at the transmitter and receiver terminals [1]. However, if the antennas are implemented in a size-limited platform, there will be challenges in terms of antenna size and mutual coupling between adjacent radiating elements, which affect the overall diversity performance of the MIMO system [2]. Therefore, how to keep the array size compact and at the same time minimize the effects of strong mutual coupling on the performance degradation of the array is a critical issue to address in the multi-antenna communication systems.

The problem of mutual coupling has attracted intensive studies especially in the past decade. Many techniques to reduce the mutual coupling or to increase the port isolation of antenna arrays have been proposed in literatures [3–12]. The element isolation can be increased by properly arranging the antennas in different orientations, for example, an antenna cube [3]. The parasitic elements can be added into the array to create reverse coupling to reduce the mutual coupling among array elements [4, 5]. The decoupling networks [6, 7] can be designed to increase port isolation. Mutual coupling can also be reduced by introducing defected ground structure (DGS) [8, 9], implementing electromagnetic bandgap structures (EBG) [10] or using neutralization lines [11, 12]. Most of the studies presented in literature reveal a single operating band MIMO antenna system. However, some work shows a dual-band operation [13–15] for two antennas. Inserting two co-centered circular split ring slots between the two elements of a dual-band printed monopole array was proposed in [13]. Although the structure is very simple, it changes the radiation pattern considerably, especially at the rear side. Paper [14] describes a procedure to achieve simultaneous decoupling and matching at two frequencies using decoupling network with series and parallel combination of inductors and capacitors, but the process of calculation is considerably intricate. Utilizing neutralization lines to reduce mutual coupling of a dual-frequency zeroth-order resonance antennas is presented in [15]. Although the isolation performance is achieved by introducing three neutralization lines, there is a considerably complex structure.

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In this paper, a compact and simple structure is proposed to increase the isolation of a compact two-element microstrip antenna array. Two neutralization lines link the two elements, and each of them corresponds to one of the resonant frequencies of the microstrip antennas. The dimensions of the neutralization lines are optimized to achieve high isolation between array elements. A prototype of the proposed microstrip array has been fabricated and tested. The measured results which agree well with the simulated ones show that the element isolation has been obviously increased at the two operating frequencies.

2. DESIGN OF DUAL-FREQUENCY ANTENNA ARRAY

Figure 1 shows the geometry of the proposed array with two neutralization lines. The proposed dual-band antenna array is printed on a 103.2 mm × 60 mm × 1.6 mm FR4 substrate with relative permittivity of 4.4 and loss tangent of 0.02. A pair of microstrip antennas with the edge-to-edge distance of $d = 3.2$ mm is used as the array elements. Firstly, a traditional patch antenna with 50 Ω microstrip inset feed was designed. The size of the patch is 30 mm × 30 mm, and the resonant frequency is about 2.3 GHz. To obtain another resonance, a rectangular slot was etched on the radiating patch. The antenna was simulated and optimized using Ansoft HFSS, and its design parameters are shown in Table 1.

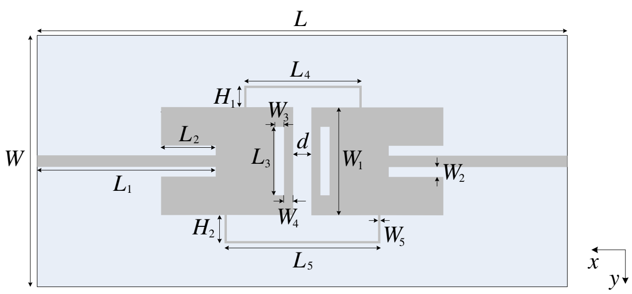

Figure 1. Geometry of the proposed patch antenna array with the neutralization line.

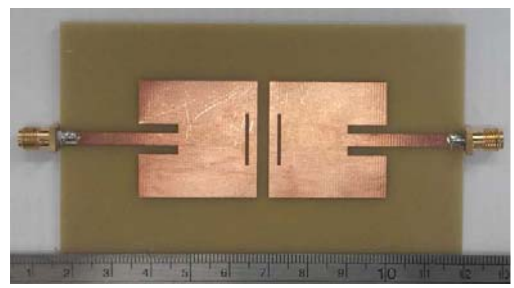

Figure 2. The fabricated dual-frequency microstrip antenna array.

Table 1. Design parameters of the antenna array.

Parameter	W	L	L_1	L_2	L_3	W_1	W_2	W_3	W_4	d
Value (mm)	60	103.2	30	10	13.5	30	2.5	1	2	3.2

Figure 2 shows the fabricated dual-frequency microstrip array. The simulated and measured scattering parameters of the array are shown in Figure 3. The measured and simulated results agree well with each other. It can be seen from the measured results that the array resonates at about 2.3 GHz and 4.2 GHz. It is also noted that the coupling coefficient is −14 dB and −11 dB at the two resonant frequencies, respectively. The two neutralization lines connecting the two patch antennas at each side in Figure 1 are used to increase the isolation at the dual operating frequencies.

3. ISOLATION ENHANCEMENT USING NEUTRALIZATION LINES

Some preliminary study has been done to understand the effect of neutralization line in isolation enhancement. It was found that the connecting position of the neutralization line is closely related to the current distribution on the patch at each resonant frequency. For the higher frequency band, the neutralization line should be attached to the patch around the middle of its side, while for the lower band, the connecting point of the neutralization line is better to be away from the middle of the patch side, as illustrated in Figure 1. Then, the length of a neutralization line can be obtained by parameter study. Firstly, the length of the neutralization line L_5 is considered. The effect of L_5 on the mutual

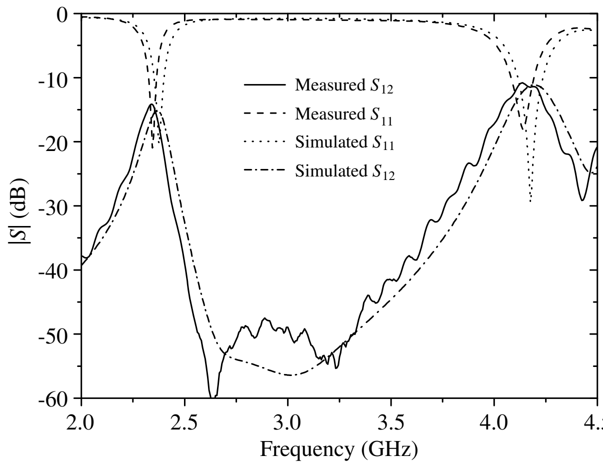

Figure 3. The S-parameters of the designed microstrip antenna array.

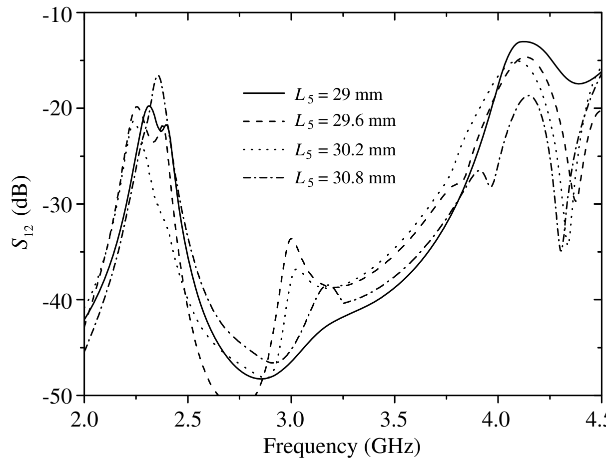

Figure 4. Simulated S_{12} of the first neutralization line for different values of L_5.

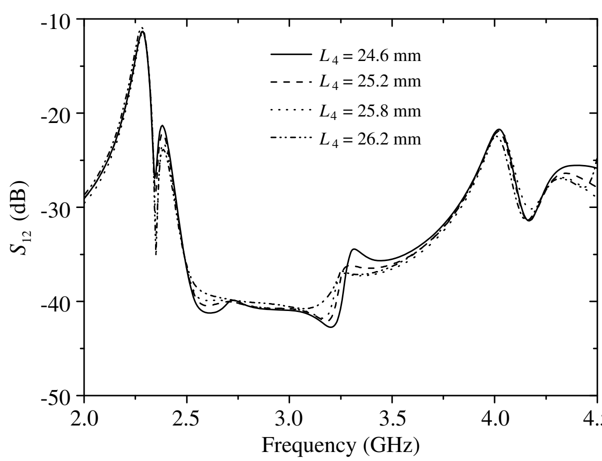

Figure 5. Simulated S_{12} of the second neutralization line for different values of L_4.

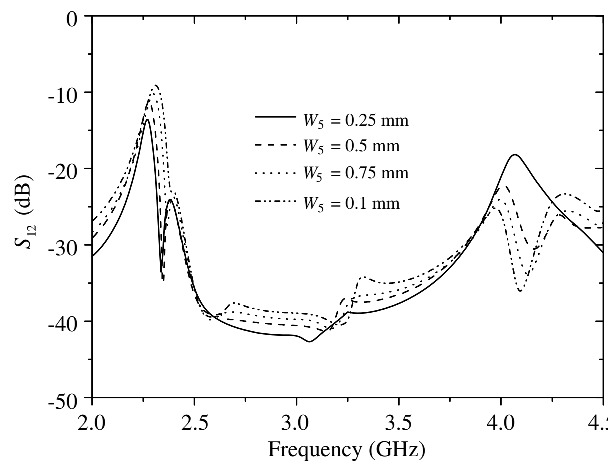

Figure 6. Simulated S_{12} of the proposed array for different values of W_5.

coupling of the array is discussed in Figure 4 with H_2 equal to 4 mm. As shown in Figure 4, the coupling coefficient of the array with the neutralization line changes much more at the upper frequency band than at the lower frequency band with the variation of L_5. It is also noted that the frequency shifts downwards at the upper band as L_5 increases.

Similarly, the second neutralization line connecting the two elements is added and located at the other side of the array, as shown in Figure 1. With H_1 equal to 3 mm, the effect of the variation of L_4 on the mutual coupling of the array is shown in Figure 5. It can be seen that as L_4 increases the frequency in the lower band also increases. Next, the width of the neutralization lines, W_5, is considered, as in Figure 6. It is obvious that the variation of W_5 affects the coupling coefficient at both frequency bands. When $W_5 = 0.5$ mm, significant reduction in mutual coupling can be achieved at both the lower and upper bands.

According to the above study, the dimensions of the neutralization lines can be optimized. With $L_4 = 26.5$ mm and $L_5 = 31.6$ mm, the simulated S-parameters of the designed antenna array are depicted in Figure 7. As can be seen, the bandwidth of the proposed array almost remains unchanged in spite of a slight frequency shift. However, the coupling coefficient has been reduced to -35 dB at 2.3 GHz and -31 dB at 4.2 GHz, respectively. That is, the element isolation has been significantly increased with the inclusion of the neutralization lines.

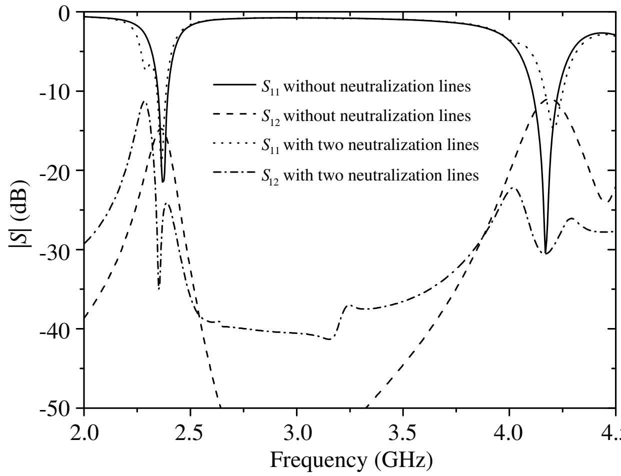

Figure 7. Simulated S-parameters with the two neutralization lines integrated on array structure.

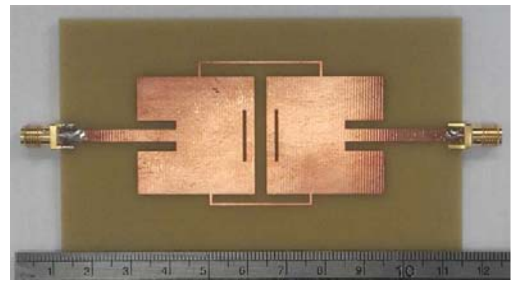

Figure 8. The fabricated dual-frequency microstrip antenna array with neutralization lines.

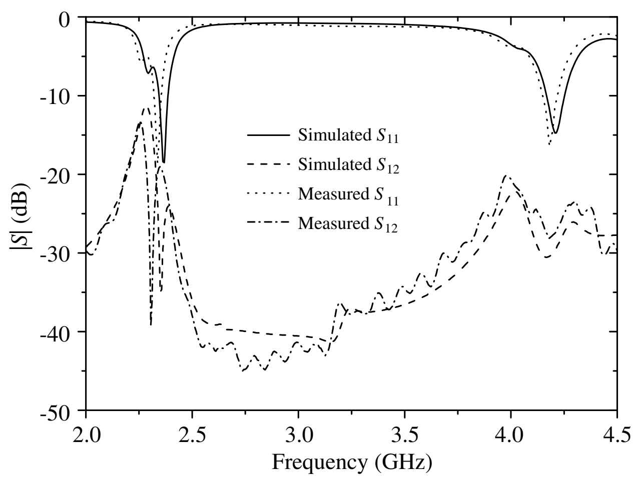

Figure 9. The measured and simulated S-parameters of the array with neutralization lines.

A prototype of the proposed array, as shown in Figure 8, has been fabricated to validate the results. The measured results are illustrated in Figure 9 with comparison of the simulated ones. It can be seen that the measurement agrees well with the simulation, in spite of a slight frequency shift. According to the measured results, an increase of 25 dB at 2.3 GHz and an increase of 17 dB at 4.2 GHz in the element isolation have been achieved, respectively. The simulated normalized radiation patterns of the microstrip antenna array with and without the neutralization lines are shown in Figure 10. It is noted that the patterns keep their general shapes when the neutralization lines are added to the microstrip array.

By assuming uniform external signal source distribution, the envelope correlation coefficient (ECC) between the two antenna ports based on the S-parameters can be calculated by [16]

$$\rho_e = \frac{|S_{11}^* S_{21} + S_{12}^* S_{22}|^2}{-\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)}. \tag{1}$$

The ECC results of the proposed MIMO array with and without neutralization lines are shown in Figure 11. It is shown that the ECC is lower than 0.02 in both of the operating bands, which is as good as the results in [11, 15]. Therefore, the proposed array has good spatial diversity and may be suitable for MIMO systems.

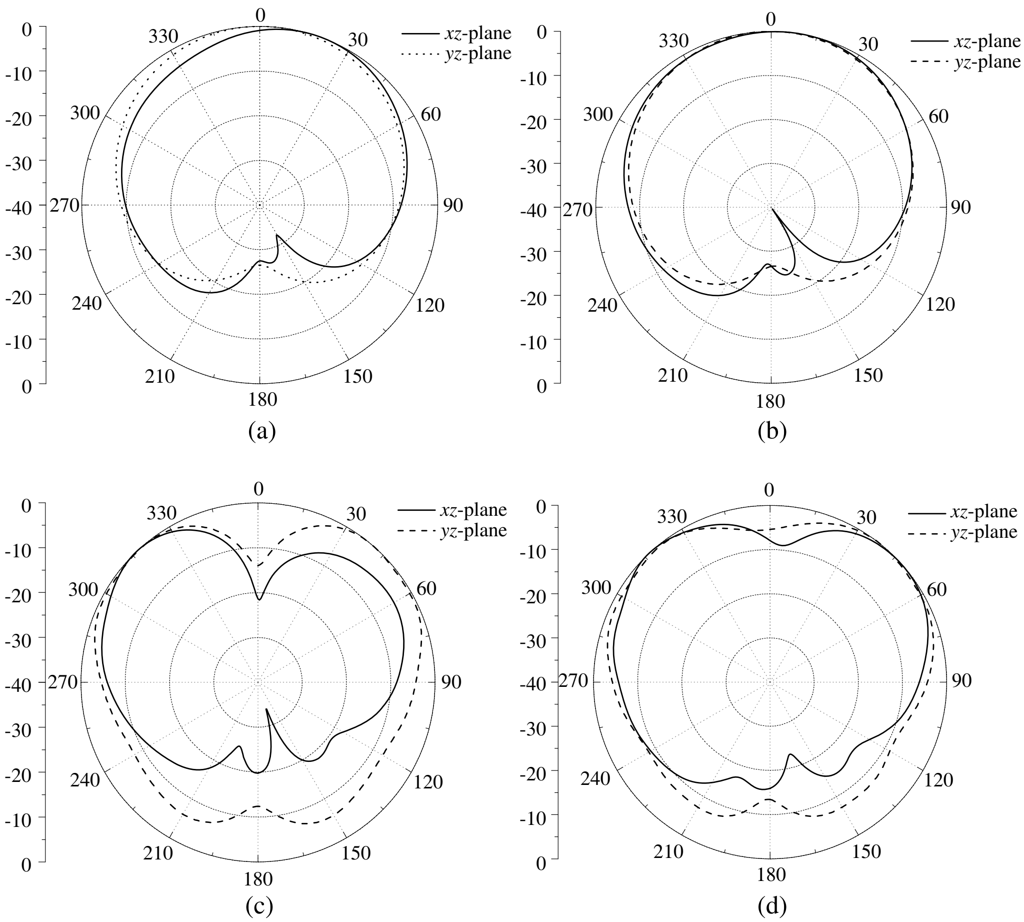

Figure 10. The normalized radiation patterns of the array: (a) 2.3 GHz without neutralization lines (NL); (b) 2.3 GHz with NL; (c) 4.2 GHz without NL; (d) 4.2 GHz with NL.

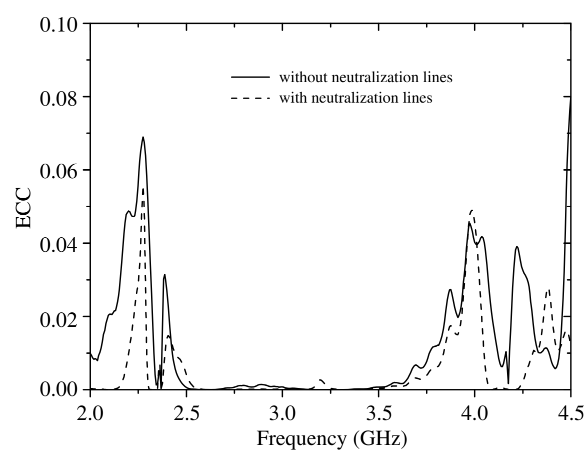

Figure 11. The measured envelope correlations of the proposed array.

4. CONCLUSIONS

This paper proposes a simple yet highly efficient technique to reduce the mutual coupling at dual operating frequencies of a microstrip antenna array by utilizing two neutralization lines linking two edges of the array. The isolation increment of 25 dB is obtained at the lower band, and that of 17 dB is achieved at the higher band. Both the simulated and measured results show that the neutralization lines can be used to enhance the element isolation of a compact microstrip antenna array, even for dual frequency bands.

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