Mutual Coupling Reduction in Patch Antenna Arrays Using Corrugated Structure

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1. Introduction

Microstrip antennas are widely used in a broad range of military and commercial applications due to its low cost, low profile, easy fabrication and light weight. But this kind of antenna also has some drawbacks. For example, the diffraction of surface waves at the edge of finite grounded substrate decreases the antenna efficiency and degrades the antenna pattern [1]. In the phased array antenna, serious surface wave would produce strong mutual coupling between elements, which may cause scan blindness and reduces the scan range [2]. So far, some effective technologies have been intensively investigated for suppressing the surface wave propagation, such as electromagnetic band gap material [3], defected ground structure [4], choke grooves [5] and metal fences [2]. Our latest work has proposed a new method to reduce mutual coupling between elements, which is to introduce surface corrugation in the waveguide-end slots array for modulating the propagation of surface wave instead of suppression [6]. This kind of surface corrugation was firstly reported in the optical region [7] and then scaled into microwave region [8-9], which both can realize extraordinary transmission and a highly directive beam. Based on the above two unique properties, this surface corrugated structure has been applied in the antenna field for improving radiation performance [10-12]. The surface wave in this corrugated structure is excited, modulated and reradiated. Obviously, its work mechanism is different from that of the choke grooves which is well known to have the main ability to suppress surface wave propagation due to its surface impedance characteristics. The groove depth of the choke grooves is often required to be a quarter of the resonance wavelength ($\lambda/4$) for forming high surface impedance, while in our corrugated structure, the groove depth is not limited to $\lambda/4$, and the groove cavity resonance and coupling between grooves and array element can determine the distribution of surface electromagnetic (EM) resonance mode [13]. In this paper, this kind of corrugated structure is loaded on the ground plane of patch antenna array for reducing mutual coupling between elements. Simulation results show that employment of the grooves can effectively reduce the mutual coupling to less than -40dB. Moreover, when the elements space is reduced to about 0.5λ, the corrugated structure can be still utilized in the patch array to perform its effective performance in the mutual coupling reduction.

2. Antenna Structure

Geometrical model of the patch antenna array loaded with grooves is shown in Fig. 1. The dielectric substrate is with a relative permittivity ε_r of 2.2 and a thickness of 1.575mm. The spacing *dx* between two patch elements is 15.5mm (0.75λ). The coax driven element is adopted to excite patch antenna array and make it work at f=14.5GHz. The corrugated structure is loaded on its ground plane, as shown in Fig. 1(b). The grooves are placed at both sides of each patch element. The grooves parameters are optimized as follows: groove depth d=3.8mm, groove width w=1.1mm, distance between groove centre and patch element centre *p*=5.45mm. The whole ground plane size is $Sub\_l \times Sub\_w \times h = 40 \times 25 \times 5\text{mm}^3$. Numerical simulation was carried out by using finite difference time domain method for demonstrating surface grooves' effectiveness on the mutual coupling reduction. In this patch antenna array, one patch element is excited and its S parameters are presented in Fig. 2, which also includes the simulation results of the patch antenna array on the flat ground plane. It can be seen that the conventional patch antenna resonates well at 14.5GHz, and mutual coupling between patch1 and patch2 is very serious, and its coupling coefficient is about -27dB. When the corrugated structure is loaded on the ground plane, the mutual coupling between patch elements is sharply suppressed and S21 is only about -48dB, demonstrating effectiveness of the loaded grooves on the mutual coupling reduction. In addition, the corrugated structure has some negative influence on the impedance matching of the patch antenna, but still make S11 less than -10dB around 14.5GHz.

Figure 3 shows the mutual coupling level between patch elements as a function of groove depth *d*. It is observed that the central frequency for the minimum mutual coupling level is shifted towards low frequency, as the groove depth *d* is increased. This obvious resonance characteristic in the corrugated structure originates from the groove cavity resonance controlled by value of *d* [13]. Moreover, we can still note that once groove depth *d* deviates from the optimized value, the effectiveness of suppressing mutual coupling is degraded, which indicate that other groove parameters also influence the surface wave propagation. However, the groove depth may be only one important parameter in the choke grooves, and its value controls the surface impedance characteristic. So the designed grooves structure has the different working mechanism from that of choke grooves, although they seem similar in shape.

3. Discussion

Figure 4 shows average electric field distribution in the side view of the patch antenna array with corrugated structure, which includes the case of the standard patch antenna array as comparison. It can be seen that strong energy is excited from the patch1 and then coupled to the coax driven port of the patch2 on the flat ground plane, as seen in Fig. 4(a). However, the introduction of grooves changes the electric field distribution. When the surface wave propagates from patch1 to patch2, it will encounter surface defect and be modulated by the designed grooves. The production of groove cavity resonance makes strong electric field energy exist inside the groove. Therefore, the energy coupled to patch2 is sharply reduced, achieving the reduction of the mutual coupling between elements.

When elements space is further reduced to about 0.5λ, there is rather limited room to place two grooves between patch elements. At this case, we would make these two grooves overlapped and form only one groove, as seen in Fig. 5(a). The size of the patch antenna is kept fixed and the groove parameters are changed as follows: groove depth d=4.3mm, groove width w=0.85mm, distance between groove centre and patch element centre $p=dx/2$=5.17mm. The simulated S parameters are shown in Fig 5(b). We can see that loading only one groove between elements also can suppress mutual coupling by about 20dB, in comparison with the case of patch antenna array with flat ground plane. In addition, it is worthwhile to point out that the groove parameters and distribution need a new optimization routine, once the patch elements space is changed.

4. Conclusion

In conclusion, we have adopted the corrugated ground plane to reduce mutual coupling between elements in the patch antenna array. This corrugated structure has the ability of modulating surface wave propagation through groove cavity resonance and coupling between patch element and grooves, which is obviously different from the conventional choke grooves. Simulation results have demonstrated that the employment of the corrugated ground plane can effectively suppress mutual coupling by about 20dB, even though the elements space is very small.

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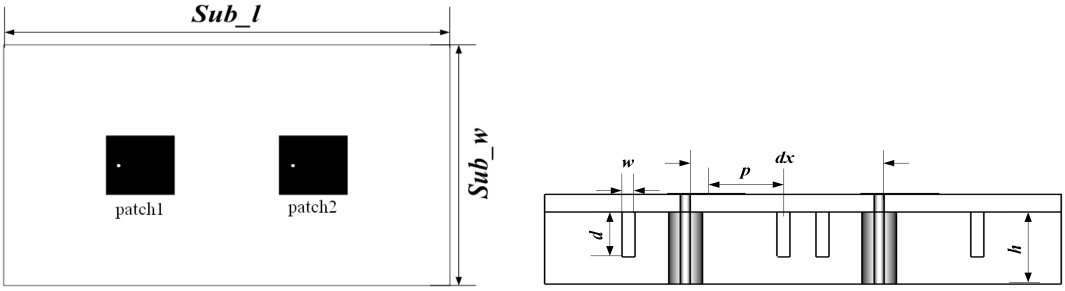


(a) Top view (b) Side view

Figure 1: Geometrical model of the patch antenna array with corrugated structure (elements space *dx*=0.75*λ*). (a) Top view; (b) Side view.

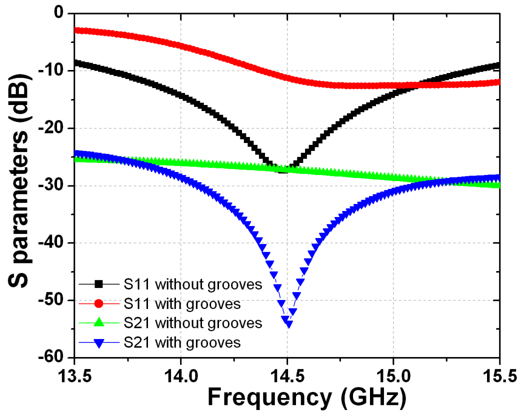


Figure 2: Simulated S parameters of the patch antenna array with corrugated structure (elements space *dx*=0.75*λ*).

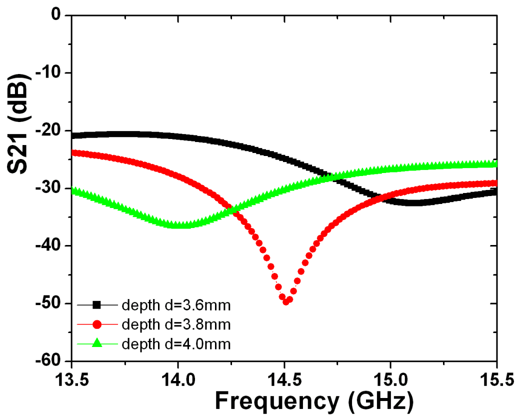


Figure 3: Response of the mutual coupling level to the variation of groove depth *d*.

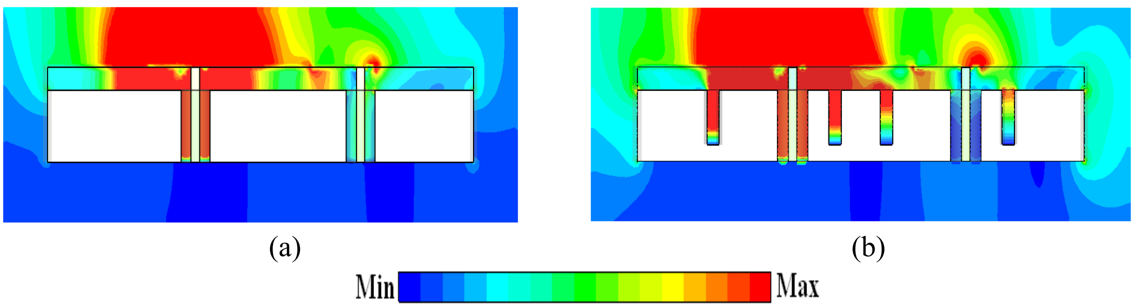
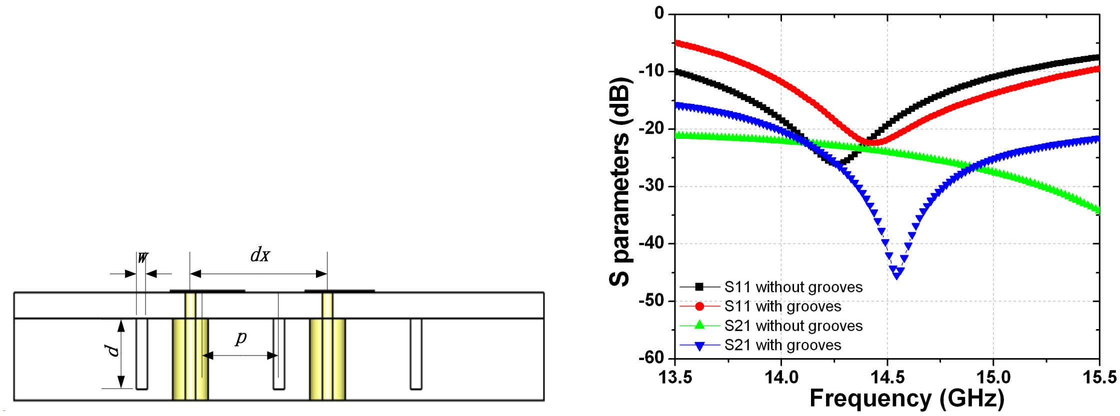


Figure 4: Comparison of average electric field distribution in the side view of the patch antenna array with and without corrugated structure. (a) Flat ground plane; (b) corrugated ground plane.



(a) (b)

Figure5: (a) Side view of geometrical model of the patch antenna array with corrugated grooves (elements space dx=0.5λ) and (b) its simulated S parameters.

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