A Highly Directive Slot Antenna with Dielectric Loaded Corrugated Structure

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Abstract: In this paper, we proposed a highly directive slot antenna with dielectric loaded corrugated structure. This antenna is composed of periodic grooves distributed at both sides of the slot feeder source. In order to reduce antenna aperture, medium with high dielectric constant is adopted as the dielectric layer loaded between neighbouring grooves. Based on modulation of surface wave propagation, the antenna performance, especially directivity could be greatly enhanced. We simulated this antenna and found that the antenna gain is largely improved from 6dB to 18.1dB and its half power beamwidth in both E and H plane is also sharply suppressed. The enhancement mechanism is explained, which is due to constructive superposition of secondary source radiated from the dielectric layer region and main source from slot feeder antenna.

Key words: Directivity, Surface wave, Slot antenna, Corrugated structure

1. Introduction

Recently in the microwave domain, two interesting phenomena including extraordinary transmission and beaming effect have been experimentally verified when electromagnetic (EM) wave transmits through a subwavelength aperture surrounded with corrugated structure [1-2]. Spoof surface plasmons are widely accepted to explain the above two unique EM properties [3-4]. In the antenna field, one dimensional surface grooves and "bull's eye" grooves structures have been successfully utilized for realizing high directivity [5-6], based on its beaming effect. However, the grooves period is nearly close to a wavelength and often required 4-6 periodic grooves number to enhance antenna performance, resulting in very large antenna aperture area and low aperture efficiency. So how to reduce the aperture of this kind of the corrugated antenna and meanwhile keep its high performance becomes a very challenging task. In this paper, an effective method for improving the aperture efficiency of this kind of antenna is proposed. In the previous slot antenna with corrugation, the medium with high dielectric constant is introduced between the neighbouring grooves, which can effectively reduce groove period and then numerical simulation shows that utilizing this revised surface corrugation can make the antenna gain sharply increased from about 6dB to 18.3dB. Compared with the conventional corrugated slot antenna, its antenna aperture efficiency is obviously enhanced by about 30%. It is found that the surface EM mode resonance different from that on the conventional corrugated surface plays the great role in the performance enhancement.

2. Antenna Structure

Geometrical model of the proposed antenna with corrugation is shown in Figure 1. The waveguide end slot is utilized as the exciting source, which resonates at 14.5GHz. The surface grooves are symmetrically distributed at both sides of the slot. The medium with dielectric constant of 9.8 and a thickness of 1.5mm is placed between the neighbouring grooves, reducing the groove period. The first groove is located at about $p1$=9.1mm away from the central slot and groove parameters are set as follows: groove width w=2.4mm, groove depth d=2.7mm, groove period

p=11.8mm and groove number n=5. The whole antenna is finally designed to be 125mm×60mm. The numerical simulation is performed to analyze this antenna performance by using CST Microwave studio. It shows that introduction of the corrugation would have negative influence on antenna impedance. However, it can still resonate well with S11 less than -10dB, as seen in Figure 2. Figure 3 depicts the radiation pattern of the antenna, which also includes the result of conventional corrugated slot antenna with the same number of grooves (antenna aperture is 200mm×60mm due to the large groove period), as comparison. It can be seen that the gain of conventional slot antenna is only about 6dB, and its beam width is very broad. After employing the conventional corrugation, the antenna gain is sharply improved by about 9.1dB, reaching 15.1dB, and its half power beamwidth (HPBW) are also suppressed to 8.5 degree in the E plane and 33 degree in the H plane, respectively. While we applied the revised corrugation in the slot antenna, a highly directive beam with HPBW of 12.1 degree is generated in its E plane, and the corresponding angle width in the H plane is largely reduced to 18 degree. So the directivity of this antenna is obviously enhanced. Moreover, the antenna gain is further increased to 18.1dB. It is worthwhile to note that the physical aperture area of the designed antenna is largely reduced by 37.5% in comparison with that of conventional corrugated slot antenna, but reversely its antenna gain is increased to be much larger, indicating the great improvement of its aperture efficiency.

3. Discussion

Figure 4 depicts the electric field distribution in the E plane of the slot antenna with revised corrugation, which helps to understand its radiation mechanism. We can see that phase of electric field at each groove region is almost the same, while the electric field in central slot region has a reverse phase. So it is not appropriate to consider the surface EM energy at groove regions as the secondary radiation sources, or else the destructive interference would occur, resulting in antenna gain sharply deteriorated. It is worthwhile to note that the dipole-like resonance can be observed between neighbouring two grooves, as shown in Figure 4. Moreover, it is still found that this kind of electric field resonance almost keeps the same phase with that above the central slot. So it is reasonable to regard the whole central region of neighbouring two grooves as the secondary source. In our antenna, it is seen that number of the secondary source is eight. Therefore, it can be concluded that the radiation pattern of our designed antenna is shaped by coherent superposition of the energy from the central slot and eight secondary sources, which well explains why the beamwidth in the E plane is slightly enlarged in terms of the array antenna theory. Moreover, the dielectric loaded grooves' period is smaller than conventional grooves' period, making the modulated surface energy diffracted from a relatively small grooves region, which may be the other reason for the large beamwidth in the E plane.

4. Conclusion

In conclusion, we propose the slot antenna with revised corrugation for increasing antenna aperture efficiency and then discuss the mechanism for performance enhancement. The simulation results show that the gain of slot antenna with conventional grooves is only 15.11dB, while the proposed antenna gain is as high as 18.1dB with reduction of its aperture area, and its half power beamwidth is slightly enlarged to 12.7 degree in the E plane and sharply suppressed to 17degree in the H plane. It is found that another surface electric field resonance mode different from that on the conventional grooves plays the great role in the high directivity, and this kind of resonance mode makes the number of secondary sources reduced, resulting in the slight enlargement of the beamwidth in the E plane.

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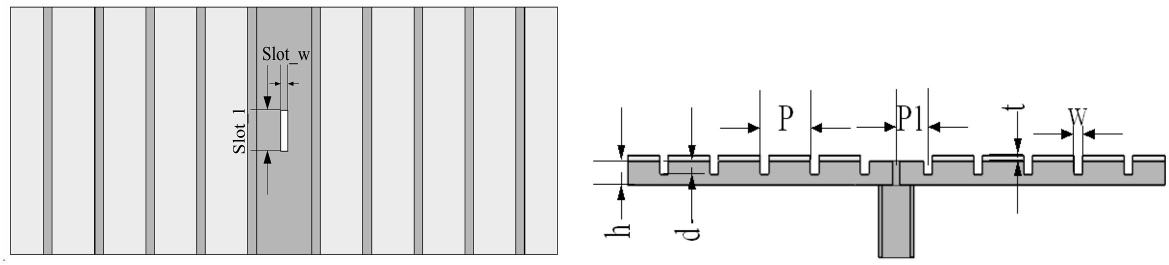


(a) Top view (b) Side view

Figure 1: Geometrical model of the corrugated slot antenna loaded with medium. (a) Top view; (b) Side view.

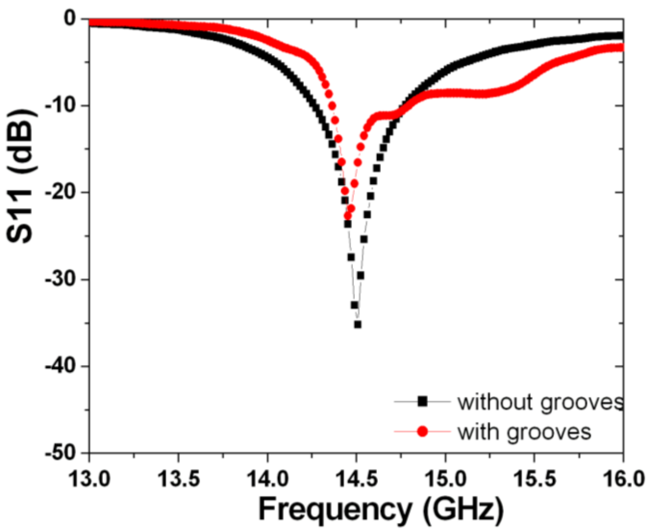
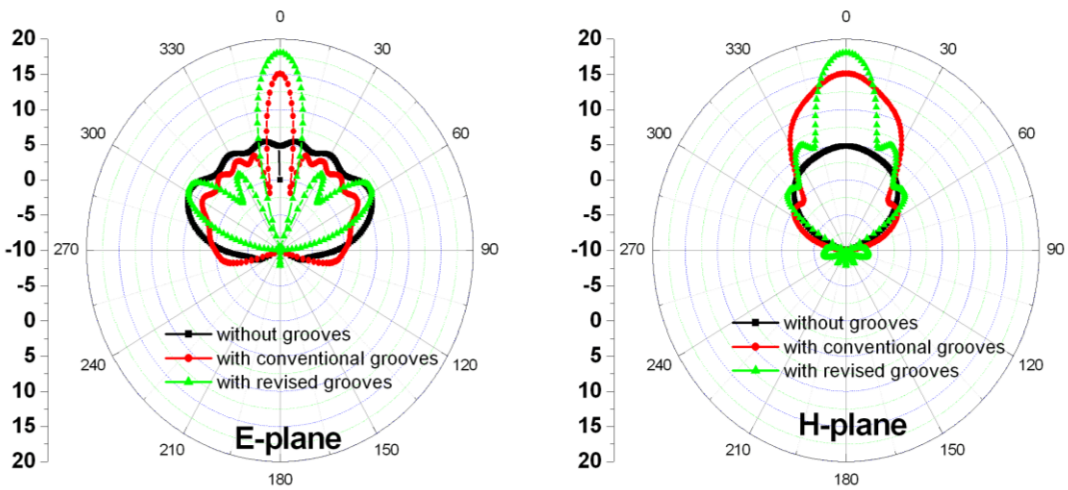


Figure 2 Simulated S11 of the slot antenna with and without grooves



(a) (b)

Figure 3 Comparison of radiation pattern for three kinds of the slot antenna, which are the slot antenna without grooves, the slot antenna with conventional grooves and the slot antenna with revised grooves, respectively. (a) E-plane; (b) H-plane.

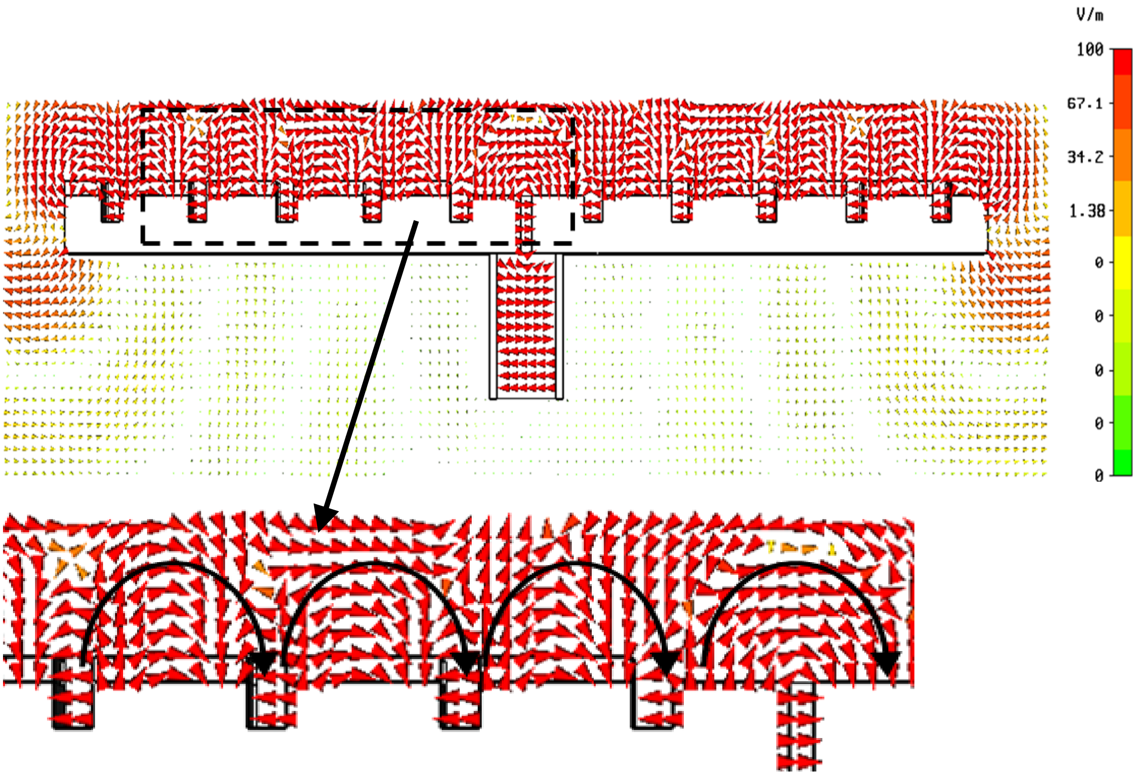


Figure 4 Electric field distribution of the slot antenna with revised corrugation.

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