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Design of a metamaterial-based high-directivity antenna

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Design of a metamaterial-based high-directivity antenna

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Abstract. Two layer lattice-type metamaterial unit is loaded above a microstrip antenna, gathering electromagnetic wave by using the zero refraction index effect. The π-type metamaterial unit is etched on a substrate, and the band gap is wored out for restraining the backward wave. Simulation tests are carried out to two methods, respectively. Finally two methods are combined for designing a high directivity antenna, and the effeccts of the distance between the covering layer and the antenna are dicusseed. Comparing the simulatted and the real test results, we verified the method and the theory. We can see that the gain of the newly-designed microstrip antenna has achieved by 8.94dB and the directivity factor gained an relative increase of by 49.08%.

1. Introduction

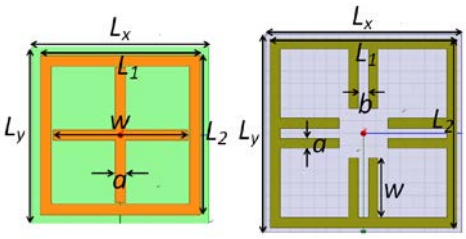
Microstrip antenna, as a typical microwave antenna, has been widely applied in various of elctrical engineering areas because of its merits such as compact size and easiness to assemble. However, its dismerits of disatified directivity and high loss hinde its aplications. With increasing requirements for antenna performance by varied elctrical devices, the demand for high-gain-high-directivity microstrip antenna has attracted the attentions of many reserchers. Traditional optimization methods cannot overcome the interactive restraint among the physical size, bandwidth and gain, etc. Hence, after metamaterials were discovered in 2001, improvement of antenna performance based on metamaterials has become the one of the fashionable topic of studies [1,2,3]. Usually A covering layer with zero refraction index is etched above the antenna to prduce the high gain and high directivity to some extent. Yet, fewer works deal with the use of the combination of two methods above to analyze antenna performance. In this paper, metamaterials are printed in both the covering layer and the base board in a traditional antenna. Detailed analysis is made on the antenna covering layers with influential parameters. The result shows that both the gain and the directivity of this kind of antenna have been obviously inceased in conparison with traditional microstrip antenna.

2. Antenna design

The concrete requirements are set at first, then unit structure is designed and parameters are adjusted to meet the corresponding demands. Through numerical analysis and simulation testing , we choose FR4 with a dielectric constant $\varepsilon_r = 4.4$ and to be the base board of the antenna, seting the thickness h=1.6mm. A type of coaxial feed microstrip antenna with a central working frequency of is designed. The size of the base board is $48\text{mm} \times 40\text{mm}$ and that of the antenna radiation patch is $16\text{mm} \times 10.8\text{mm}$. The coaxial feeding point is 2.7 mm away from the center of the patch ,that is L=2.7mm.We use 50Ω coaxial feed model for the antenna.

2.1. Metamaterial Unit Design

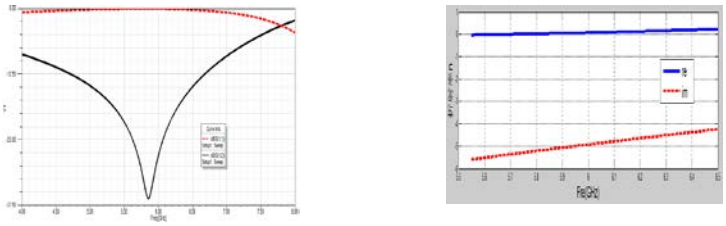
Fig. 1(a) Aand Fig. 1(b) shows the lattice-type (Type Ⅰ)and π -type (Type Ⅱ)metamaterial unit structures, respectively, which are designed in this paper.Their size parameters are : L_x =8mm, L_1=7.5mm,w =6mm, L_y=8mm L_2=7.5mm, a=0.5mm for unit of Type Ⅰand L_x=8mm,L_x=8mm, w =2.8mm,b=0.4mm,L_1=7.5mm,L_2=7.5mm,a=0.4mm for unit of Type Ⅱ.



(a) Unit of Type Ⅰ (b) Unit of Type Ⅱ

Figure 1. Metamaterial unit structures

Six metamaterial units of Type Ⅰare layed and plated on the substrate, with a thickness of 1.6mm as the covering layer of the antenna. HFSS software is used for the simulation analysis . See Fig. 2 (a) for S parameter. Smith method is applied to obtain data showed in Fig. 2 (a) to acquire the effective refraction index of the surface layer in Fig. 2 (b) [4,5]. We can see from Fig. 2 (b) that the refraction rate of the surface layer at the frequency of 6GHz approaches to zero, which conforms to the design requirements.



(a)S parameter (b) Refraction rate

Figure2. unit parameter of Type Ⅰ

Type Ⅱmetamaterial is layed around the antenna substrate. Fig. 3 shows the S parameter after simulation. It can be seen from the figure that the peak value of the transmission curve of the baseboard is $-24.5dB$ at the fequency of 6GHz. It can be seen that this kind of structure can be used to restrain the backward wave of the antenna and it meets the needs of the designed antenna.

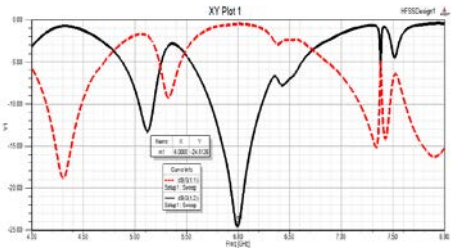
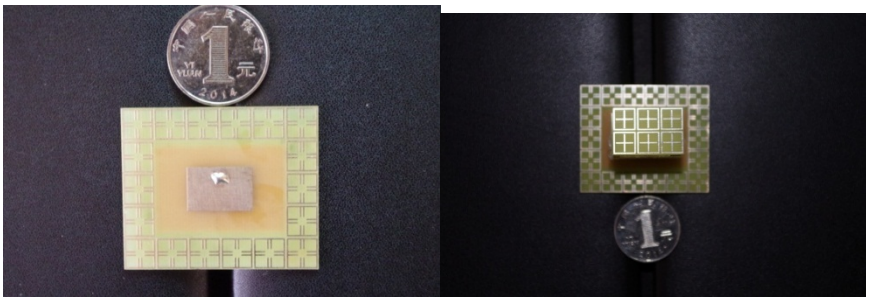


Figure 3. Transmission curve of metamaterial substrate

2.2. Metamaterial-based Antenna Design

Type Ⅱ metamaterials unit is periodically plated on the antenna baseboard around the patch to obtain the antenna showed in Fig. 4 (a), while the . Then covering layer of Type Ⅰ is supported by foam and put right above the microstrip antenna. The distance between the lower layer and the antenna is equal to half of the wavelength. The distance between the two layers is set to b=5mm. The designed antenna structure is shown in Fig. 4 (b).



(a) Antenna with metamaterial substrate (b) real antenna

Figure 4. High-directivity antenna prototype

The return loss of the original antenna, the metamaterial-based antenna with and the antenna designed by simulation and real antenna experiments are shown in Fig. 5. From the the figure, compared with the original antenna, we can see that the return loss of the antenna deteriorates after metamaterials is loaded. The reason is that weak loss of the metamterial itself occurs at the central frequency.

Fig. 6 and Fig. 7 show the gain of the antenna. It can be seen from the gain of the figures that metamaterials-loaded antenna get an obvious increase at angle of about $\pm 100^{0}$, infering that the metamaterials substrate can effectively suppress the backward wave. Due to the incompletely covering of metamaterials sidelobe appears in antenna directivity figure. The antenna gain reaches $8.94dB$, appearing an increase of over $3dB$ compared with the original antenna..

Fig. 8 shows the antenna ‘s directivity factor. From the figure we can see that the directivity factor of the antenna with metamaterials appears an increase of 49.08% compared with the traditional antenna.

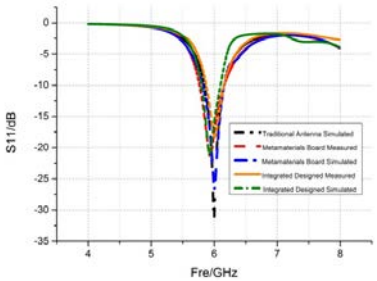


Figure 5. Return loss of the antenna

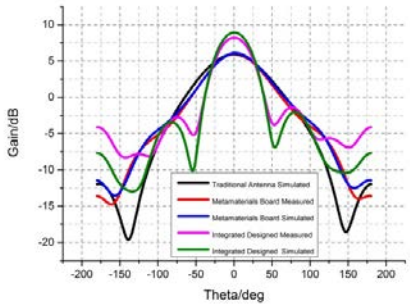


Figure 6. Antenna gain chart

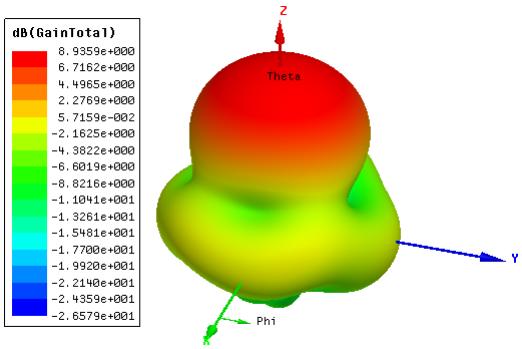


Figure 7. Three-dimensional radiation pattern

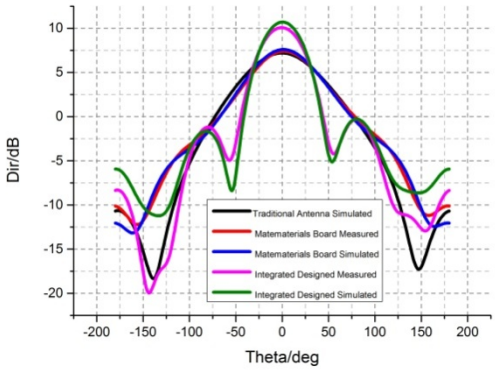


Figure 8. Directivity factor of the designed antenna

2.3. Discussion of Parameters of the Covering Layer

In the design process, we need to adjust the geometric size of the metamaterials unit so that it matches the central working frequency of the antenna. Besides, the loading of the covering layer above the antenna, space between the covering layer and the antenna and space between covering layers are all important parameters affecting the antenna performance.

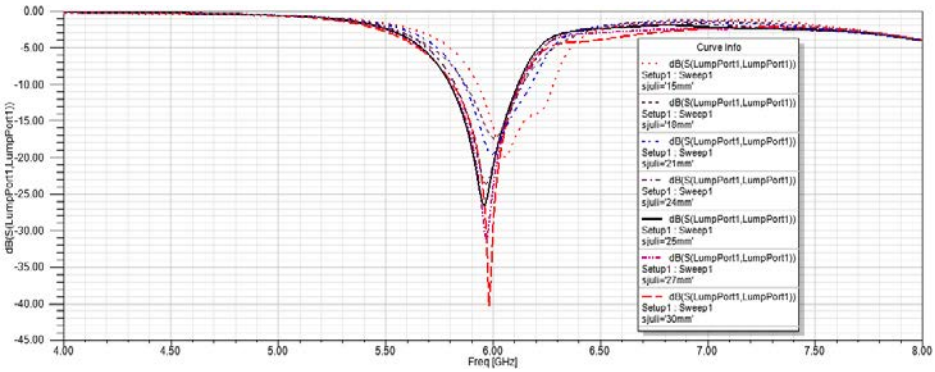
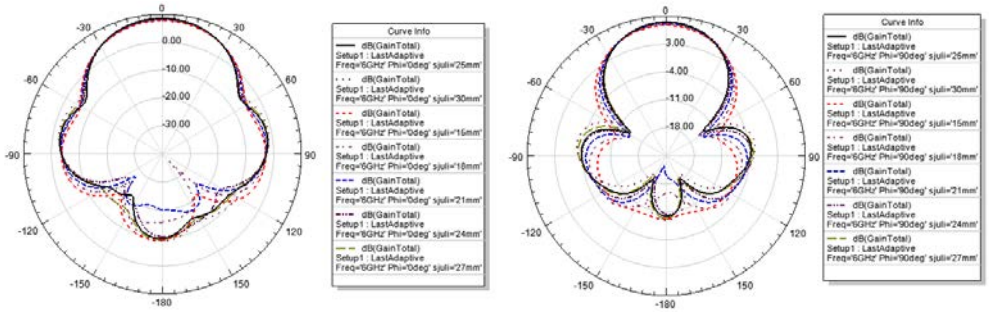


Fig. 9 Influences of changes in the distance between the covering Layer and antenna over return loss of the Antenna



E Plane (b) H Plane

Fig. 10 Influences of changes in the distance between the covering layer and antenna over radiation direction of the antenna

According to Fig. 9, changes in the distance between the antenna covering layer and the antenna bring about small deviation in the central frequency of the antenna; the greater the distance between the covering layer and the antenna, the weaker the near field impact on the antenna. Accordingly, the return loss of the antenna decreases as the distance between the covering layer and the antenna increases. It can be known from Fig. 10 that the distance between the antenna covering layer and the antenna doesn't have great impact on the radiation main lobe of the antenna. While the total radiation energy of the antenna is fixed, changes in the distance between the antenna covering layer and the antenna influence the energy distribution on the back lobe and sidelobe because the electromagnetic wave of the antenna radiation produces certain reflection when it meets the covering layer. The reflection waves form a looping-in between the space between the antenna covering layer and the substrate, which leads to amplified back lobe of the antenna.

3. Conclusion

Two different metamateiral units, the lattice-type and π-type metamaterials units, are loaded on the same microstrip antenna. The typical feature of zero refraction index of metamaterials and the band gap feature are applied to design the antenna covering layer, which suppress the surface wave of the sustrate from the direct radiation of electromagnetic wave and reduce the back wave energy loss of the antenna. It is realized that both the antenna directivity factor and the gain are increased, with the antenna performance being significantly enhanced.

Acknowledgments

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