Electromagnetic Scattering Properties of Cylindrical Frequency Selective Surface

Zhi-Hang Liu[1], Shuang Ma[1], Guo-Hui Yang*[1],Shao-Qing Zhang[2] and Qun Wu[1]
[1] Dept. of Microwave Engineering
Harbin Institute of Technology
Harbin, China
[2] Aviation Key Laboratory of Science and Technology on Electromagnetic Environmental Effects
Shenyang Aircraft Design & Research Institute
Shenyang, China

Abstract-In this paper, the electromagnetic scattering properties of Curved Frequency Selective Surface conformal to a cylinder surface is investigated. Four unit models are used to realize required reflection and transfer characteristics in a wide band range. Simulation shows far field radiation directivity pattern and RCS diagram of cylindrical FSS. The feature influence factors by the structure unit, the curvature of the cylindrical FSS and the dielectric-slab parameters (the thickness of the plate and the dielectric constant)are discussed.

Keywords-Cylindrical Frequency Selective Surface; construction unit; curvature; dielectric-slab

I. INTRODUCTION

Frequency Selective Surface (FSS) is essentially a kind of spatial filter which is usually comprised of periodic arrays of patches or apertures. It is well recognized that the Frequency Selective Surfaces have some good characteristics on filtering electromagnetic wave, and its reflection and transmission properties can be changed along with the frequency, incident angles and polarizations of the incident wave [1-2]. FSSs are widely used in the Information Technology field. Especially in the military communication field, they are generally used in the fighter planes, naval vessels or the missiles as the radome to assist the stealth battle [3]. The great strategic significance has made FSS a research hotspot in every country's military field all the time.

Researches on the FSS have been going on for quite a long time, and many algorithms have been raised to help analysis the properties of FSS, such as Finite Difference in Time Domain (FDTD), Volume-Surface Integral-Equation (VSIE), Method of Moment (MOM) and Characteristic Basis Function (CBF). Until now, the theory researches on FSS are mostly based on the hypothesis that the structure is infinite and planar [4], while in practical applications, FSSs are usually finite and curved, the element currents and the scattering at the edges of a finite plane can be deviated significantly from those of an infinite array for the periodicity and the infinite extent of the surface properties of planar FSSs are lost [5-6]. So, it is necessary to carry out some researches on curved FSS.

It is well known that the cylindrical structure is a kind of typical curved structure, so that the work done in this paper is mainly embodied on the research of the electromagnetic scattering properties of cylindrical FSS. In this paper, the imitation of the circumstance where the plane TM wave from the free space illuminates vertically on the cylindrical FSS is operated. On the other hand, by means of simulation calculation, the condition of electromagnetic scattering, like the distribution of surface current and far field radiation directivity pattern and RCS diagram can be observed intuitively. And the S-Parameters for different cylindrical FSS are obtained. Through comparing the scattering condition, we can further make a research on the influencing factors of cylindrical FSS.

II. MODELLING AND SIMULATION OF CURVED FSS WITH DIFFERENT CONSTRUCTURE UNITS

FSSs with different construction unit types may have different electromagnetic scattering properties. Sometimes, making an appropriate choice of construction unit can bring about a better stability of filtering and reduce the number of grating lobes at the same time. To find out a construction unit with relatively good properties, 4 different aperture unit types are discussed, including circle, circular ring, cross and Y-shape, as shown in Fig. 1.

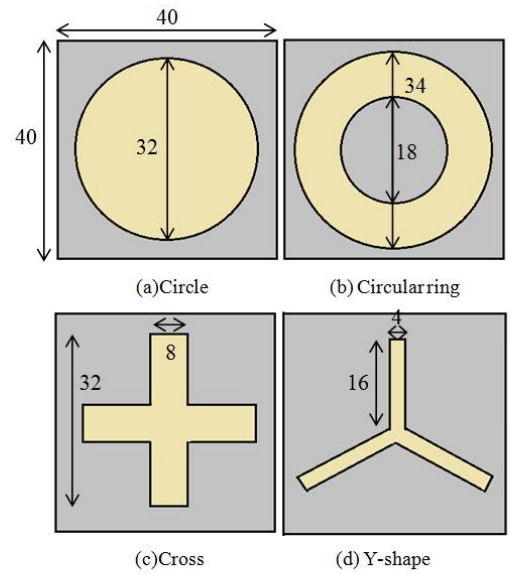
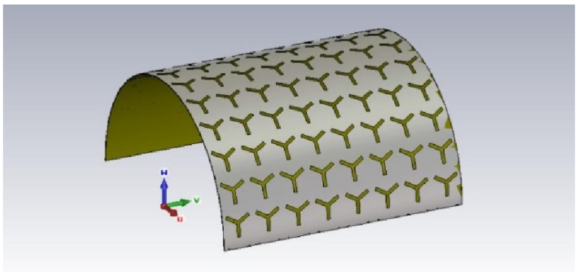


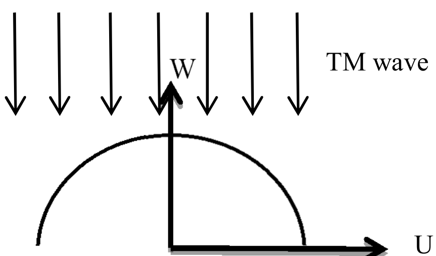
Fig. 1. Different shape of unit model (in millimeter)

As illustrated in Fig. 1, the construction unit is a square with the side length of 40mm, and it is made of thin aperture PEC metal strip and dielectric-slab. The thickness of dielectric-slab is 1mm, and it has a conductivity of 2.2 and permeability of 1.

To fabricate a cylindrical FSS, firstly, thin PEC metal strips are arranged on a plane periodically forming a two-dimension FSS. And then attach the planar FSS to a specific cylindrical dielectric-slab. The final structure model of cylindrical FSS is presented in Fig.2.(a).And Fig. 2.(b)shows the condition that the plane TM wave illuminates vertically on the cylindrical FSS in free space. All the four cylindrical FSSs are in the same simulation condition except that the construction unit is different. The simulation results of electromagnetic scattering characteristics of the four cylindrical FSS are obtained respectively by the use of CST MWS.As shown in Fig. 3, S-Parameter pattern is adopted to represent the transmission and reflection characteristic. From S-Parameter pattern we can see that unlike the planar FSS, each S-Parameter pattern of cylindrical FSSs is not smooth but oscillating through the whole spectrum. That is because the curved surface structure has broken the periodic of two-dimension construction units, as a result, the units coupling condition gets worse. And the existence of curved structure also brings about the edge diffraction effect at the same time. Combining all into consideration, the oscillating in the S-Parameter pattern is inevitable, and in this situation, the analysis for electromagnetic scattering will be quite complicated. We can also find that the cylindrical FSS with Y-shaped unit has an obvious resonance phenomenon at 3.6GHz, in other words, the Y-shaped construction unit has a stronger filtering ability than the other unit types. So, when designing or fabricating a curved FSS, the Y-shaped construction unit should be taken as the first consideration.

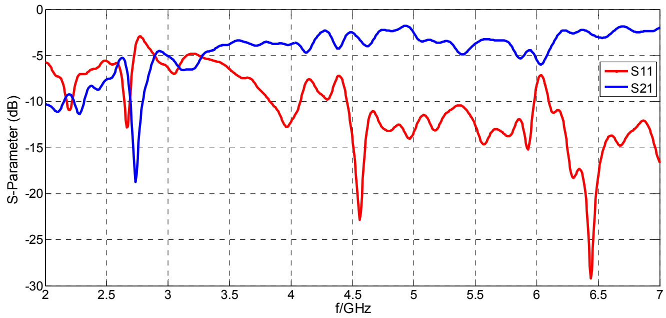


(a)

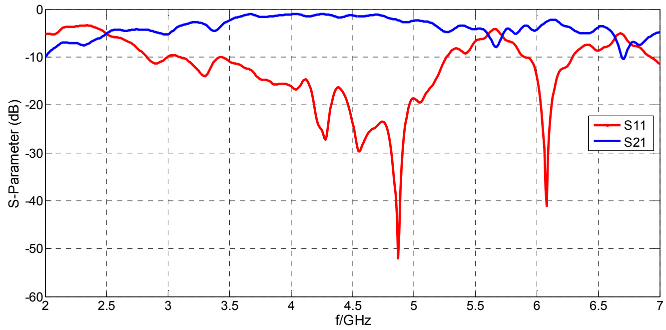


(b)

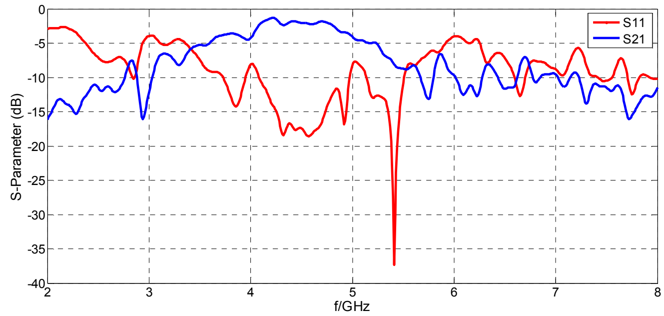
Fig. 2. Model of cylindrical FSS with Y-shaped unit



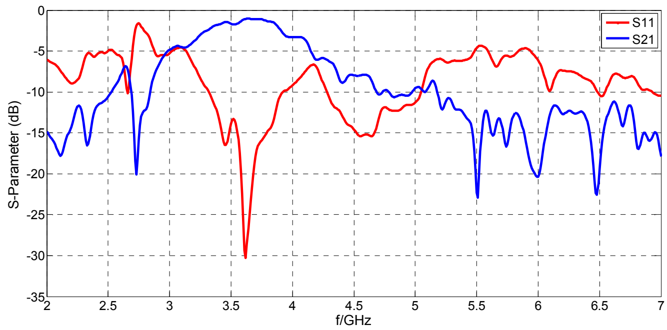
(a)



(b)



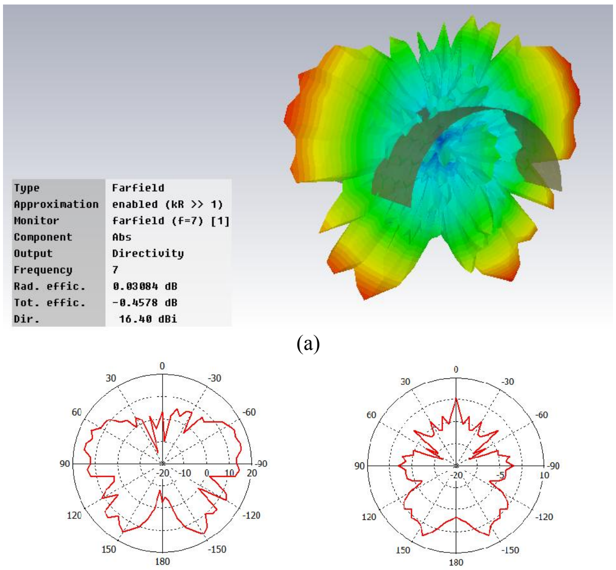
(c)



(d)

Fig. 3. S-Parameter Pattern of cylindrical FSS with different construction unit, (a) with circle unit, (b) with circular ring unit, (c) with cross unit, (d) with Y-shaped unit.

Fig. 4 shows the far field radiation condition and RCS diagram when plane TM wave illuminates vertically on the cylindrical FSS. When the incident wave works at 7 GHz, Fig. 4 (a) shows the three-dimensional far field radiation directivity pattern. Through this figure, the distribution of the radiation field intensity is presented intuitively. From the directivity pattern it can be seen that the electromagnetic scattering field in the space distributes mainly in the axial direction and circumferential direction. Axial direction is in the VOW plane while circumferential direction is in the UOW plane. In order to better describe the electromagnetic radiation condition, Fig. 4 (b) and (c) introduce the RCS diagram in the two directions. Due to the different distance between adjacent units on cylindrical FSS, there are grating lobes in both of the two RCS diagrams. Furthermore, the circumferential RCS diagram is relatively uniform, while in the axial RCS diagram, energy is mainly concentrated on the top of cylindrical structure.



(a)

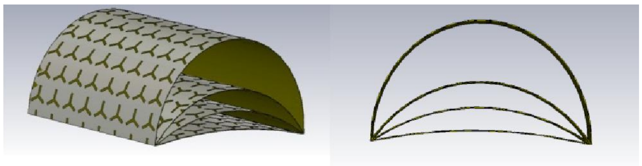
(b) (c)

Fig. 4. (a) Three-dimensional far field radiation directivitional pattern, (b) Circumferential direction RCS diagram, (c) Axial direction RCS diagram

III. Influence of Different Curvature Radius of Cylindrical FSS

The curvature is another primary influencing factor of the curved FSS. Cylinder structures with different radius of curvature may have different electromagnetic scattering abilities and center resonance frequency. So, when designing a curved FSS, besides the conformal processing, the effects of the curvature should also be taken into consideration. From the above analysis, it can come to the conclusion that the Y-shaped cylindrical FSS has a better filtering property and an obvious resonance band. So, Y-shaped unit is applied in the following research.

Fig.5 presents a contrasting pattern of a cylindrical FSS structure with the radius of curvature of 160 mm, 200 mm, 300 mm and 800 mm respectively, and each of the cylindrical FSS covers an area of 320×320mm^2 square. Fig.6 shows the simulation results of the cylindrical FSS with different curvature radius. With the radius of curvature of cylindrical FSS changed from 160 mm to a planar FSS, the center resonance frequency shifts around 3.7 GHz. From 160 mm to 300 mm, the center resonance frequency shifts to lower frequency. While the radius of curvature is over 300 mm, it leaps to higher frequency. The resonance frequency of planar FSS is 3.8 GHz. At the same time, as the FSS structure becomes flat, the S-Parameter pattern gets smoother, the jittering phenomenon beyond the resonance band is improved, and the transmission coefficient of incident wave is increased as well.



(a) (b)

Fig.5 Contrasting pattern of a cylindrical FSS with different curvature radius, (a) a general view, (b) a side view

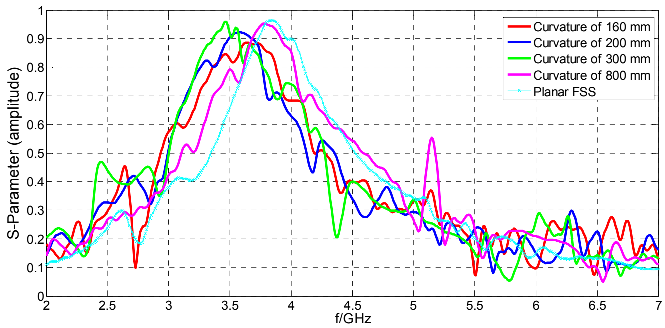


Fig. 6. S-Parameter contrasing pattern of cylindrical FSS with different radius of curvature

IV. Influence of Different Dielectric-Slab

If a FSS structure is loaded with a dielectric layer, the mechanical properties will be improved to some extent, and the sensitivity to the incident wave will be reduced as well. That is to say, it can keep a good stability of performance when the incident wave's polarization mode and incident angle change. But the introduction of dielectric-slab will also bring about the Wood Anomaly phenomenon inevitably [7]. So, if taking the use of the dielectric-slab properly, it will be very convenient when designing a FSS. Next, it will be discussed in this paper that how the thickness and dielectric constant of the dielectric-slab affect the electromagnetic scattering properties.

A. The Thickness of Dielectric-slab

Firstly, choose a FSS structure from Fig. 5 which has a radius of curvature of 200mm. Then change the thickness of the dielectric-slab from 1mm to 5mm in five steps. Make a simulation calculation of the 5 cylindrical FSSs with different thickness of dielectric-slab respectively, and then put five S-Parameter results into a pattern. As presented in Fig.7, the S21 parameter is adopted to represent the electromagnetic transmission characteristic of cylindrical FSS, and the letter “d” presents the value of thickness.

From the results we can see that with the increase of thickness of dielectric-slab, the center resonance frequency drifts to the lower frequency. When the operating frequency is over 3.1GHz, the rate of frequency drifting tends to be at a low level. And it seems that the center resonance frequency finally reach a fixed value. In the process of the drifting of center resonance frequency, the resonance zone keeps unchanged all along, that is to say, the change of thickness nearly has no effects on the transmission capacity of the cylindrical FSS.

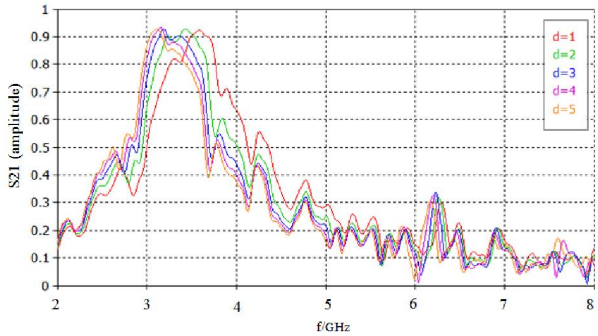


Fig. 7. S21 parameter pattern of cylindrical FSS with different thickness of dielectric-slab

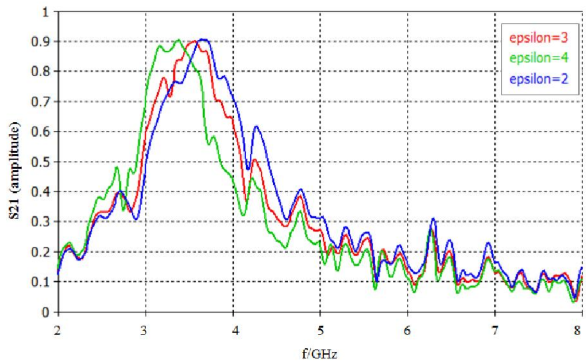


Fig. 8. S21 parameter pattern of cylindrical FSS with different dielctric constant of dielectric-slab

B. Dielectric Constant of Dielectric-slab

Dielectric constant is an important parameter of the dielectric-slab. It decides on the material which is adopted in designing. With the same method as above, we choose three groups of cylindrical FSS that has a curvature radius of 200mm with the permeability of *1* and conductivity of *2， 3, 4* respectively, and then have the simulation computation of the three cylindrical FSSs, finally put the S21 parameter results into a pattern.

As illustrated in Fig. 8, epsilon is the value of dielectric constant of dielectric-slab. As the value increases from 2 to 3, the S21 parameter curve will drift to the low frequency direction while the shape of curve keeps almost unchanged. It means that on the one hand within a certain range, the center resonance frequency will decrease with the increase of value of dielectric constant, and on the other hand, the dielectric constant has little effects on the electromagnetic transmission capacity of cylindrical FSS.

To sum up, the impact of dielectric-slab on the cylindrical FSS is mainly embodied in the deviation of the center resonance frequency, while the impact on the electromagnetic transmission capacity is tiny.

V. CONCLUSION

In this paper, the electromagnetic scattering properties of cylindrical FSS are studied, and the impact factors on electromagnetic scattering properties, including structure unit, curvature and dielectric-slab, have been discussed successively. The simulation result shows that the Y-shaped unit cylindrical FSS has a better filtering property and an obvious wide resonance band from 3.2GHz to 4.2GHz. The far field radiation directional pattern and RCS diagram of cylindrical FSS with Y-shaped unit are observed as well. The curvature of cylindrical FSS has the ability to change the resonance property, and a flatter curved FSS has a smoother S-Parameter curve. The change of the parameter of dielectric-slab can cause the drift of the center resonance frequency but the electromagnetic scattering capacity is almost not affected. The work that has been done in this paper has some value for reference in the engineering field. Through the regularity summarizations, it will be helpful to the design or fabrication of curved FSS application.

ACKNOWLEDGMENT

This work is supported by National Natural Science Foundation of China(No.61571155, No.61371044) and Aeronautical Science Foundation of China (No.20142677011). In addition, the authors would like to thank the Aviation Key Laboratory of Science and Technology on Electromagnetic Environmental Effects in Shenyang Aircraft Design & Research Institute for additional support to this project.

REFERENCES

[1] Raj Mittra, Chi H.Chan, Tom Cwik. Techniques for analyzing frequency Selective Surfaces—A review [C].Proceedings of the IEEE, 1988.76(12): 1953-1615.

[2] B. A. Munk. Frequency Selective Surfaces: Theory and Design. New York: Wiley,2000.

[3] Lu Jiange, Zhang Jian, Yang Jieying, “The research status and trend of development of Frequency Selective Surfaces radome,” Acta Phys Sinica 2013,28(5)

[4] Hou Xinyu, Wan Wei, Tong Mingan, Wan Guobin, “Analysis of Transmission Properties of A Symmetric Double-Layer FSS,” Journal of Electronics,1999, 21(4):569-572.

[5] Ben A. Munk. Finite Antenna Arrays and FSS. New York: Wiley, 2003.

[6] Sinisa Skokic, Zvonimir Sipus, “Moment Method Analysis of a Spherical FSS in Free Space,” Applied Electromagnetics and Communications, 2005, ICEC 2005. 18th International Conference on Dubrovnik: IEEE Press.2005, 1-4.

[7] A.Hessel, A.A.Oliner. A New Theory of Wood’S Anomalies on optical Gratings[J]. Applied optics，1965，4(10)：1297.