A Novel Wideband Wide-angle Frequency Selective Surface Composite Structure

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Abstract— A novel wideband FSS composite structure is proposed, Which use modified C-type sandwich cascaded structure and Hexagonal loop element with the characteristics of center symmetry in FSS design resulting in good electrical performance such as high transmission efficiency and stable working frequency band at a wide range of incident angle. The FSS sample is fabricated using low temperature pressing processes and then measured in anechoic chamber, The measured results show relative bandwidth of the FSS composite structure reaches to 45% (Transmission efficiency $> 85\%$) for arbitrary incident angle from 0° to 60° and both polarization. With the increase of the incident angle, the center resonant frequency tends to shift to higher frequency, the maximum offset of which is below 0.5 GHz. Inner envelope relative bandwidth is close to 41% (transmission efficiency $> 85\%$) at a range of $0^\circ \sim 68^\circ$ incident angle of vertical polarization wave and $0^\circ \sim 60^\circ$ incident angle of horizontal polarization wave.

1. INTRODUCTION

Frequency selective surface (FSS) act as space filters to propagating electromagnetic waves. One of the most important applications of FSS is to design the conformal radome with band-pass characteristics [1]. Airborne active phased array radar has become main developing direction of airborne radar in the future for more agile scan and farther detecting-distance. For meeting the stealth demands of active phased array radar with broad bandwidth and wide scan angle, the FSS composite structure mounted on the front of radar antenna also must have characteristics of wideband and wide scan angle correspondingly. The larger bandwidth and better frequency stability with respect to wide incident angle of the FSS composite structure are to a great degree depended on stratified medium structure, FSS element types, and the whole hybrid structure, and so on [2]. A lot of simulations and experiments have shown that wideband FSS structure must be hybrid structure which consists of multilayer medium, multilayer periodic FSS screens, and multilayer foam, as is similar to the design of ultra wide circuit filters.

A Novel Wideband FSS Composite structure which is modified C-type sandwich hybrid structure is provided, which has some advantages of broad bandwidth, unfluctuating passband and excellently stable resonant frequency at a wide range of $0^\circ \sim 68^\circ$ incident angle. As known from the results of experiments about electrical performance of the fabricated FSS sample, it can reduce antenna's RCS greatly on the condition of ensuring the normal work of antenna.

2. DESIGN OF THE FSS COMPOSITE STRUCTURE

The relative bandwidth of the formerly designed C-type sandwich FSS structure (seen in Figure 1) from the reference [3] is around 20% at arbitrary incident angle from 0° to 45°, and that Inner envelope relative bandwidth is about 16% at a range of $0^\circ \sim 45^\circ$ incident angle. This FSS structure may be available in the undemanding circumstance of bandwidth or scan angle. With higher and higher demand of antenna's bandwidth and scan angle, the loaded FSS composite structure also must have the characteristics of wideband and large scan angle. Therefor, a modified C-type sandwich structure is designed as seen in Figure 2. As seen from comparison between the two FSS structures, the modified C-type structure is constructed by mounting lower dielectric constant foam on the both sides and swap outer-layer FSS screen and thin dielectric slab of C-type sandwich. In accordance with FSS design theory [2], the passband resonant frequency of the modified C-type structure mainly depend on the electric and physical parameters of the inner two-layer foam (foam $3b$ and $3c$ in Figure 2). In addition, the accessional foam not only improve the stability of resonant frequency with respect to incident angle and polarization [4], not only strengthen the suppressing effect of stopband and mechanical intensity. Swap of the position of outer-layer FSS screen and thin dielectric slab improve inter-layer matching performance resulting in much more wider bandwidth to a certain extent.

Many simulation results have proven that the larger gaps between the elements will leads to the emergence of resonant peak at higher frequency, which greatly influence the suppressing characteristics in stopband. Therefor, It still use hexagonal loop element which is easy to realize more

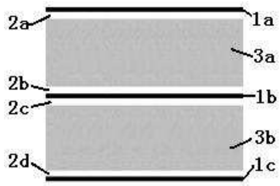

Figure 1: C-type sandwich structure.

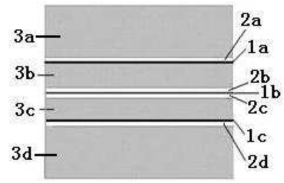

Figure 2: Modified C-type sandwich structure.

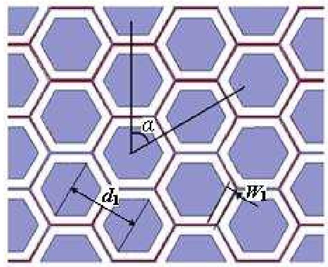

Figure 3: Regular hexagonal loop structure.

compact triangular arrangement resulting in stable and good electrical performance (such as wider bandwidth), with respect to incident angle and polarization.

In Figure 2, $1a$, $1b$, $1c$ are FSS screens. $2a$ and $2d$ are identical thin dielectric slab, the thickness $h1$ and the dielectric constant ε_{r1} of which are 0.127 mm and 2.2 respectively; $2b$ and $2c$ are identical thin dielectric slab, the thickness $h2$ and the dielectric constant ε_{r2} of which are 0.127 mm and 2.5 respectively; foam $3a$ and $3d$ are identical materials, the thickness $h3$ and the dielectric constant ε_{r3} of which are 8 mm and 1.05 respectively; foam $3b$ and $3c$ are identical materials, the thickness $h4$ and the dielectric constant ε_{r4} of which are 4 mm and 1.25 respectively. All FSS screens are made up of regular hexagonal loop Array as shown in Figure 3. but the designing parameters of FSS screen $1a$ and $1c$ are quite identical. For the symmetry of the structure, electrical performance of the designed FSS structure is quite identical regardless of propagating electromagnetic waves from any side of the structure.

As for FSS screen $1a$ and $1c$, the incline angle $\alpha = 60°$, the distance between the center of two adjacent FSS element $d_1 = 8.9$ mm. The width of slot w_1 is close to 1 mm. Design parameters of FSS screen $1b$ are basically identical to FSS screen $1a$ and $1c$.

3. SIMULATED RESULTS

Based on the aboved design parameters, The transmission efficiency curves of FSS composite structure versus frequency for various angle of incidence and both polarization (vertical and horizontal) wave are shown in Figure 4.

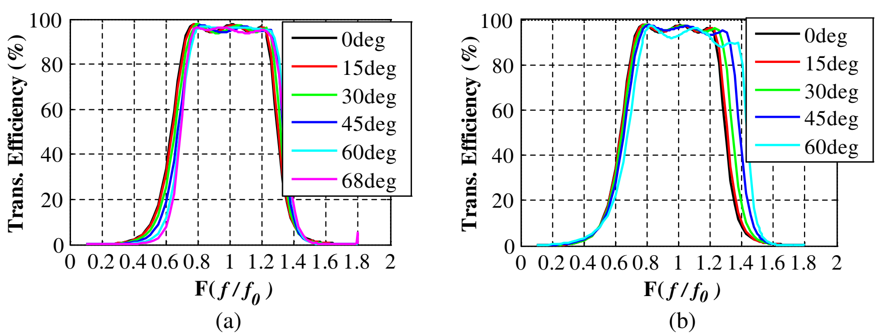

Figure 4: The simulated transmission curves versus frequency for various angle of incidence and both polarization, (a) vertical polarization wave, (b) horizontal polarization wave.

It was seen in Figure 4 that the passband relative bandwidth of the FSS structure exceeds 46% (transmission efficiency > 93%, or transmission coefficient > −0.32 dB) for $0° \sim 68°$ incident angle of vertical polarization wave and $0° \sim 60°$ incident angle of horizontal polarization wave.

Because of passband center frequency's shift with various angle of incidence Inner envelope relative bandwidth reduce to 41% (transmission efficiency > 93%, or transmission coefficient > −0.32 dB) with $0^\circ \sim 68^\circ$ incident angle of vertical polarization wave and $0^\circ \sim 60^\circ$ incident angle of horizontal polarization wave. In addition, the average transmission efficiency in stopband for vertical polarized wave is less than 10.8% (−9.67 dB, $0.1f_0 \sim 0.6f_0$) and 7.6% (−11.9 dB, $1.4f_0 \sim 1.8f_0$); the average transmission efficiency in stopband for horizontal polarized wave is less than 12.4% (−9 dB, 0.1 $f_0 \sim 0.6f_0$) and 8.3% (−8.1 dB, $1.4f_0 \sim 1.8f_0$). Due to the big fall of the transmission efficiency in band at large incident angle of 68° of horizontal polarization wave, its results are not given.

4. MEASURED RESULTS

To demonstrate the accuracy of simulation results, experiment sample is fabricated by photo-etch and low temperature bonding process between various medium layer and FSS screens (shown in Figure 5). The impact of fabricating tolerance on the transmission performance of sample is firstly analyzed to ensure good agreement between measured and simulation results. The results of analysis has shown that when fabricating tolerance of thin dielectric slab and foam are less than 0.005 mm and 0.1 mm respectively, the better approximate results can be obtained. The measured results about transmission curves for various incident angle and both polarization are shown in Figure 6.

It is shown from the measured curves of Figure 6 that inner envelope passband bandwidth with $0^\circ \sim 68^\circ$ angle of incidence for vertical polarized wave is around 40% ($0.8f_0 \sim 1.2f_0$, transmission efficiency > 90%); The inner envelope passband bandwidth with $0^\circ \sim 60^\circ$ angle of incidence for horizontal polarized wave is also around 40% ($0.8f_0 \sim 1.2f_0$, transmission efficiency > 90%). In addition, the average transmission efficiency in stopband for vertical polarized wave is less than 4.17% (−13.8 dB, $0.1f_0 \sim 0.6f_0$) and 3.86% (−14.1 dB, $1.4f_0 \sim 1.8f_0$); the average transmission efficiency in stopband for horizontal polarized wave is less than 5.58% (−12.36 dB, $0.1f_0 \sim 0.6f_0$) and 4.3% (−13.66 dB, $1.4f_0 \sim 1.8f_0$).

As can be known from comparison of above simulation and measured curves, the measured bandwidth is less than the simulation bandwidth, transmission efficiency in band reduce. The reason is that The simulated FSS composite structure is seen as infinite periodic structure in an ideal environment, however, The fabricated FSS sample is finite size (when the size is greater than 10 wavelengths, It's electric performance close to infinite structure), and the measured results is easy to suffer interference brought by environmental factors. However, stopband suppression performance become better because of the fall of transmission efficiency in the whole frequency band and other factors such as environment, finite size of the FSS structure etc..

In order to validate the effect of the FSS sample on radiation and scattering performance of

Figure 5: FSS composite structure sample.

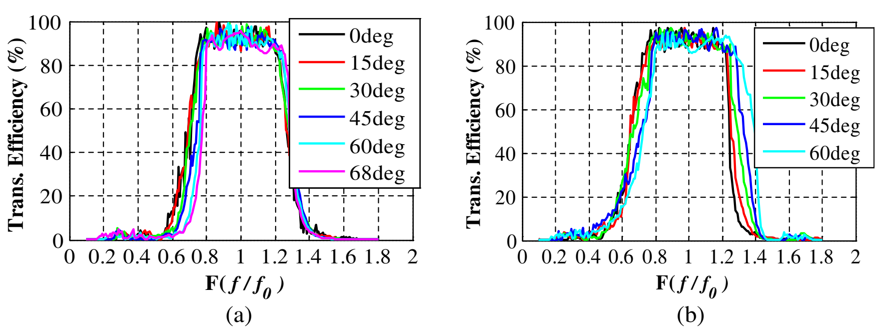

Figure 6: The measured transmission curves versus frequency for various angle of incidence and both polarization, (a) vertical polarization wave, (b) horizontal polarization wave.

antenna, the radiation and scattering experiment on antenna loaded with FSS sample or without is made. The measured results to a certain extent demonstrate the good ability of the newly designed FSS sample on reducing antenna's RCS. For some reasons, the measured results are not provided.

5. CONCLUSION

The FSS composite structure designed in the paper has the advantage of wideband, good transmission efficiency in band, low frequency shift with various angle of incidence and polarization etc.. Many experiments have proven that after it is mounted on the front of the phased array antenna or other types of antenna, the RCS of the corresponding antenna is reduced greatly on the condition of ensuring radiation performance of antenna. The developed FSS sample must will provide technological help for the development of various types of stealth fighter in future.

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