

Design of Active Frequency Selective Surfaces for the RCS Reduction

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Abstract

This paper presents a novel three-dimensional active frequency selective surfaces loading a varactor diode to achieve electrically controllable, by loading different values of paranoic voltage to control the variable capacitance diode. Simulation results show that the structure has excellent resonant characteristics in the range of 3.34GHz-1.59GHz, and has certain sensitivity for the change of the capacitance value,so it can achieve electrical controllable in the frequency band. The simulation results also show that this structure can satisfy characteristics for multiple perspectives in the whole plane, and be suitable to reduce radar cross section,when it is used on radomeofweapon systems in practical war.

Keywords-*FSS, diode, electric control, multi-angle incident*

1. Introduction

The application of Electronic surveillance technology of modern warfare in aircraft, missiles and other factors in the air, largely determines the outcome of the war, reduces the radar cross section (RCS) of weapon systems, which is an important mean of anti-reconnaissance to be taken seriously[1]. The overall RCS of aircraft or missile is mainly produced by the head of radar antenna, while the conventional dielectric radome does not reduce the scattering. Application of absorbing material on radar cast is an approach which may be used [2], but this method can reduce the scattering while affecting the sensitivity of the radar unit. The applications of frequency selective surface can overcome this defect.

The frequency selective surface (FSS) is used on the radar cover to form a "magnetic window", so that using the shape of the radome, there is significant RCS reduction out of the antenna operating band, without impacting the performance of its band's work [3]. However, after the array antennas are integrated with FSS, in order to ensure that the antenna works properly, it requires transparent to the operating band of antenna, exposing the problems at the same time that the FSS cannot be stealth in the working band [4]. While it implements stealth out of band of antenna, but in the band it is still exposed to the antenna.

In recent years, using technology to integrate active components such as diodes and FSS, has realized the frequency adjustable characteristics of FSS, switch features of band-pass and band-stop [5]. The emergence of the technology offers hope to solve the in-band stealth problem of antenna. Electrically controlled characteristics of FSS, can be used to control electric controlled band-pass FSS in the antenna transparent for a belt when it works; when the antenna is in a non-working state, through the electric control it will transform from band-pass characteristics to band-rejection characteristics, this solves stealth problems of the antenna both "in-band" and "out-of-band" at the same time [6, 7]. Through good design of electrically controlled FSS, it can completely satisfy the antenna stealth issues over the whole

frequency band, which has strategic significance for the stealth performance of the airborne antenna, and thus achieving a overall performance of the stealth fighter.

For passive FSS research at home and abroad, they mostly focused on the single-layer, double-layer and multi-layer composite structure of FSS [11-8].For active FSS research, they mainly focused on single FSS array loading PIN diodes to switch characteristics of FSS and frequency adjustable features [12-15].

Based on common two-dimensional frequency selective surfaces, this article puts forward a new type of three-dimensional structure of loading PIN diodes to realize electric controllable FSS .Compared with two-dimensional structure, three-dimensional FSS structure will be dispersed in a large solid angle in the space, thereby generating almost isotropic sources.

This structure by loading different values of intolerance voltage to control the variable capacitance of the diode, in order to achieve the electrical controllability of the structure in band, and can be distinguished clearly, for different frequency and incident angle of wave it renders filter characteristics, effective control of reflection and transmission of electromagnetic wave, so as to reduce the RCS of radar systems, and can satisfy the stealth performance of the antenna in broadband segment.

2. Design of New Structure for Active FSS

The FSS in this paper is a three-dimensional structure in space, infinite extension in x-axis and y-axis direction. Each unit consists of three parts, the upper medium plate and the metal layer, the lower medium plate and the metal layer and a varactor diode between the two parts. The unit cell is shown as follows, in which Figure (a) is a unit of the overall configuration, Figure (b) is the bottom view from the bottom upwards looking up the upper board, Figure (c) is the top view from the top down overlooking the lower board:

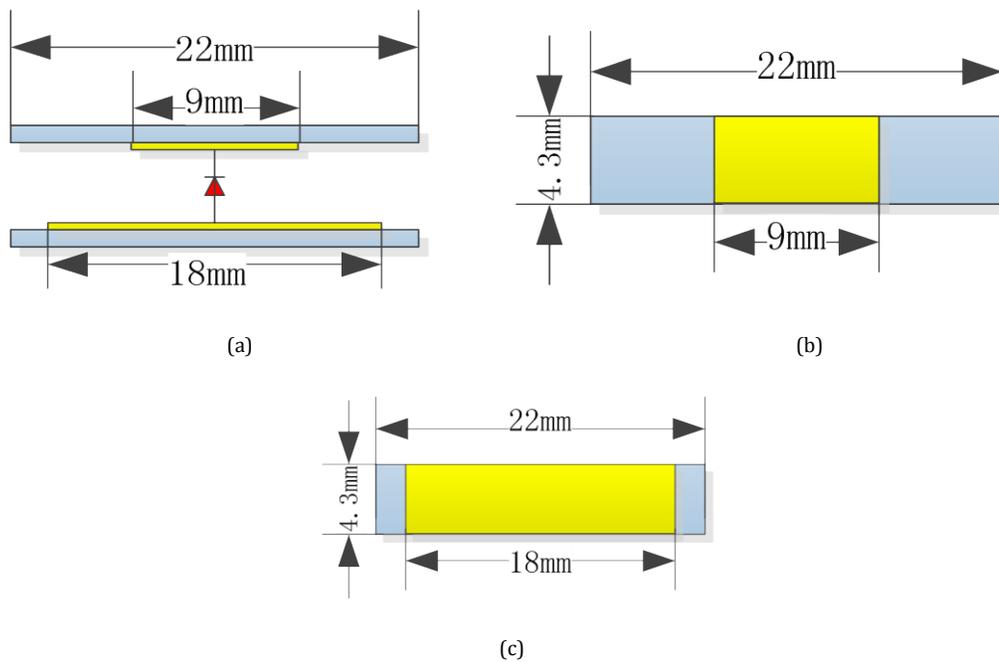


Figure 1. (a) A Unit of the FSS;(b) Bottom View of the Upper Board ;(c) Top View of the Lower Board

The upper medium plate and the lower medium plate is covered with metal copper whose thickness is 0.02 mm, and thickness of the medium plate is 0.5 mm with the dielectric constant 4.2. Length of the dielectric substrate is 22mm, and width is 4.3mm. Length of the upper copper is 9mm, and width is 4.3mm. Length of the lower copper is 18mm, and width is 4.3mm. Two metal layers is put relatively, and spacing of them is 3.5 mm.

Place a varactor diode in the middle of the upper and lower plates, the varactor is produced by Siemens company, a model of BB857. The curve of the capacitance changing with voltage is shown in Figure 2:

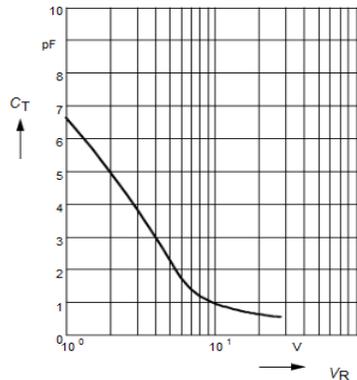


Figure 2. The Curve of the Capacitance Changing with Voltage

Through changing the paranoia of diode voltage its capacitance value will change, the equivalent circuit diagram of varactor diodes in the high frequency is shown in Figure3:

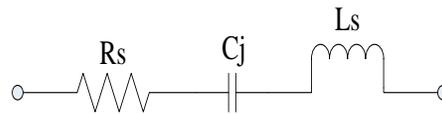


Figure 3. The Equivalent Circuit Diagram of Varactor Diodes

There are a variety of FSS structure analysis methods that are commonly used, such as equivalent circuit method, pattern matching method, finite element method, finite difference time domain method, *etc.* Here we use the most common and most intuitive equivalent circuit method. Two oppositely disposed metallic copper layer represent two strip-line, considering the case of loss of the strip-line, the equivalent circuit of the structure is shown in Figure 4:

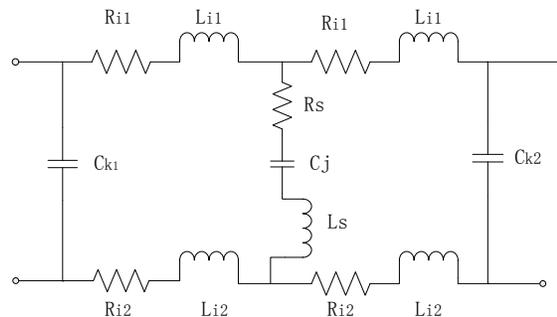


Figure 4. The Equivalent Circuit of the Structure

In Figure 4, R_{i1} , L_{i1} , R_{i2} , L_{i2} is obtained by the equivalent of the copper layer, C_{k1} , C_{k2} is the equivalent capacitance between the two plates, R_s , C_j , L_s is obtained by the equivalent of the varactor diode. As can be seen from the equivalent circuit, changing the length of the copper layer and the distance between the two plates can change the equivalent resistance, inductance and capacitance obtained by the strip line in the equivalent circuit, thereby change the frequency response of the FSS. But this paper only study how the frequency response will change when changing the varactor between the two plates.

3. Simulations and Results Analysis

3.1. Simulation Results of Different Capacitance Values

Using software CST, set the boundary condition in the x and y directions being periodic structure, and z direction being free space. In the frequency range 0-6GHz, the incident wave is perpendicularly incident along the z axis. The diode capacitance variation range from 0.5pF to 6.5pF, by the curves of the bias voltage changing with the diode capacitance variation, select the capacitor values 0.5 pF, 1.0 pF, 1.5 pF, 3 pF, and 6.5pF, the corresponding bias voltages of 12V, 10V, 6.5V, 3V and 1V. Using the frequency-domain simulation, the comparison curve of the frequency response is shown in Figure 5:

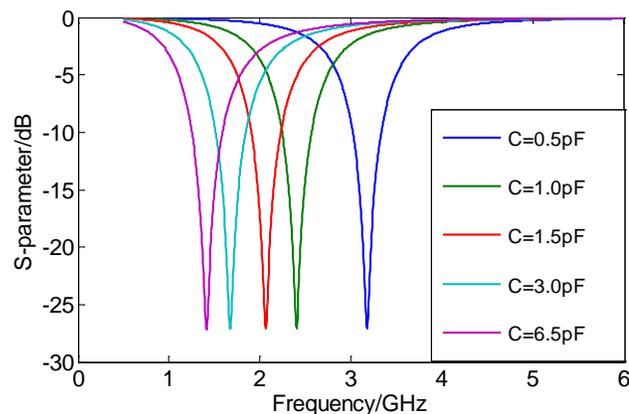


Figure 5. Different Capacitance Values of the Frequency Response of the FSS

It can be seen from the above, when the capacitance of the varactor diode is 0.5pF, its center resonant frequency is 3.18GHz, the depth of the resonance is -27.042dB, bandwidth is from 3.02GHz to 3.34GHz, and relative bandwidth is 10.19%. When the capacitance of the variable varactor is 1.0pF, its center resonant frequency is 2.40GHz, depth of the resonance is -27.097dB, bandwidth is from 2.24GHz to 2.57GHz, and relative bandwidth is 13.75%. When the capacitance of the varactor diode is 1.5pF, its central resonance frequency is 2.07GHz, depth of the resonance is -27.108dB, bandwidth is from 1.91GHz to 2.23GHz, and relative bandwidth is 15.94%. When the capacitance of the varactor diode is 3.0pF, its center resonant frequency is 1.66GHz, depth of the resonance is -27.113dB, bandwidth is from 1.51GHz to 1.85GHz, and relative bandwidth is 20.48%. When the capacitance of the varactor diode is 6.5pF, its center resonant frequency is 1.41GHz, its depth of the resonance is -27.16dB, bandwidth is from 1.25GHz to 1.59GHz, and relative bandwidth is 24.11%.

Seen from the above data, the structure of the FSS has a good resonance characteristics, a deeper depth of the resonance and wider resonance bandwidth.

This article selects five different capacitance values for comparison when paranoid voltage changes linearly. By the results, when select capacitance variation values dense enough, the FSS structure can meet requests at 3.34GHz-1.59GHz, and within each frequency band, radar system can achieve lower scattering cross section, while meeting the antenna stealth performance.

3.2. Analysis of Simulation Results for Different Incidence Angles

Next, study the resonance characteristics of the FSS for different incident angles.

First, study the frequency response of incident wave in the x-z plane at different incident angles, that is the frequency response of different θ values. Select the capacitance value of 0.5pF and $\phi = 0^\circ$. Since it is a symmetrical structure, select $\theta = 0^\circ, 30^\circ, 60^\circ$, which vary within the half plane, then it can understand the frequency response changing in the whole plane. Still use the frequency-domain simulation, the simulation results is shown in figure 6:

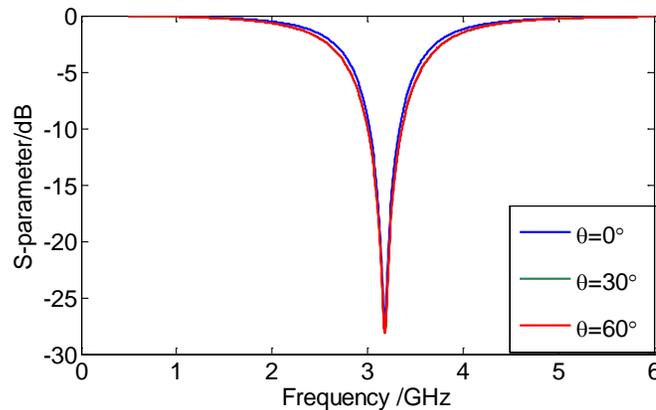


Figure 1. Different θ Values of the Frequency Response of the FSS

As is shown in Figure 6, when the incident angle is $\theta = 0^\circ$, the center resonant frequency is 3.18GHz, its resonance depth is -27.042dB, bandwidth is from 3.02GHz to 3.34GHz, relative bandwidth is 10.19%. When the incident angle is $\theta = 30^\circ$, the center resonant frequency is 3.18GHz, its resonant depth is -28.14dB, bandwidth is from 3.0GHz to 3.36GHz, relative bandwidth is 11.32%. When the incident angle is $\theta = 60^\circ$, the center resonant frequency is 3.2GHz, its resonant depth is -32.632dB, bandwidth is from 2.85GHz to 3.45GHz, relative bandwidth is 18.75%.

It can be seen, the changes of the incident direction of the electromagnetic wave in θ has not much effect with the frequency response, and can achieve perfect wideband characteristics of the band-pass, and when $\theta = 60^\circ$, the resonance effect obtains optimum.

Next, study the frequency response of incident wave in the x-y plane at different incident angles. That is the frequency response of different ϕ values. Select the capacitance value of 0.5pF, and $\theta = 0^\circ$, also because it is a symmetrical structure, select $\phi = 0^\circ, 30^\circ, 60^\circ$, which vary within the half plane, then it can understand the frequency response changing in the whole plane. Still use the frequency-domain simulation, the simulation results is shown in Figure 7:

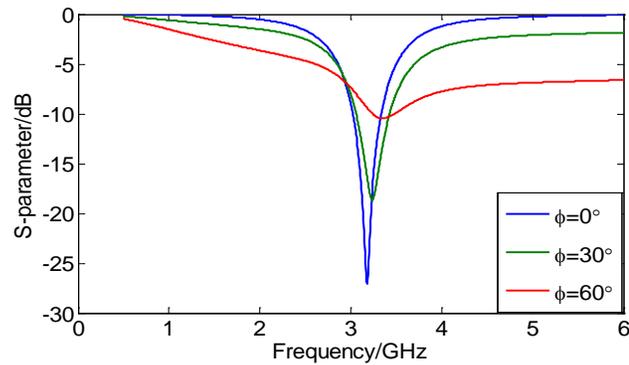


Figure 2. Different ϕ Values of the Frequency Response of the FSS

As is shown in Figure 7, when the incident angle is $\phi = 0^\circ$, the center resonant frequency is 3.18GHz, its depth of the resonance is -27.042dB, bandwidth is from 3.02GHz to 3.34GHz, relative bandwidth is 10.19%. When the incident angle is $\phi = 30^\circ$, the center frequency of the resonant is 3.22GHz, its resonant depth is -18.69dB, bandwidth is from 3.05GHz to 3.42GHz, relative bandwidth is 11.49%. When the incident angle is $\phi = 60^\circ$, the center resonant frequency is 3.35GHz, resonant depth is -10.452dB, bandwidth is from 3.24GHz to 3.48GHz, relative bandwidth is 7.16%.

It can be seen, the changes of the incident direction of the electromagnetic wave in θ has a greater impact on the frequency response, the greater the deviation of angle is, the greater impact on the frequency response is. But when it change from $\phi = 0^\circ$ to $\phi = 60^\circ$, it still meet the requirements.

4. Conclusion

This paper presents a novel three-dimensional structure of loading PIN diode to achieve electrical controllable FSS. According to the characteristics of the diode model, by loading different values paranoid voltage to control a variable capacitance diode, the simulation results show that when the diode capacitance values are 0.5 pF, 1.0 pF, 1.5 pF, 3 pF, and 6.5pF, the structure has excellent resonant characteristics within the range of 3.34GHz-1.59GHz. It has a certain sensitivity for a changing in capacitance diode, and it can achieve electrical controllability in the band, thereby reducing scattering cross section of the radar system. The simulation results of different incident angles in the x-z plane and x-y plane also show this structure can achieve incident characteristics of multi-angle range in the whole plane, and be used on radomes in an actual war to reduce radar cross section of weapon systems.

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