An active frequency selective surface structure with controllable switching characteristics

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Abstract*—This paper designed a double-grid controllable active frequency selective surface structure loading PIN diode based on the mechanism and method of traditional frequency selective surface. This structure can control the switching performance. When the PIN diode is closed, the power transmission efficiency of the FSS structure is greater than 80% in vertical polarization from 0° to 30° angle range in the 8GHz to 18GHz frequency range, and it is greater than 80% from 0° to 60° angle range in the 8GHz to 18GHz frequency range in horizontal polarization. When the PIN diode is leading the way, the power transmission efficiency of the FSS structure is less than 25% from 0° to 60° angle range in the 8GHz to 18GHz frequency range in vertical and horizontal polarization. Controllable active frequency selective surface structure provides a technique solution for the stealth demand of future military development.

***Keywords*—Controllable Active FSS, Equivalent Circuit, PIN diode, Switching Characteristic**

I. INTRODUCTION

The radar only works in a very short time, and the most time is in a non-working state. Because the radome is transparent in the frequency band of radar, which causes the invisibility of radar band, a huge in-band scattering source is formed. With the complexity of the military environment and the improvement of the detection probability of the enemy, the radar stealth gradually develops to the full frequency band stealth direction, only need the radar work to carry on the electromagnetic wave transmission, other time in the full frequency band shielding. The traditional FSS radome cannot meet this requirement. The controllable Active frequency selective surface (CAFSS) is better proposed to adapt to the radar working state.

The resonant characteristics of CAFSS can be changed by adding active elements into the passive FSS structure in the following two ways : (1) the resonant characteristics of FSS can be changed by controlling the active components; (2) the resonant characteristics of FSS can be changed by changing the characteristics of the medium by using the medium with variable electromagnetic characteristics as the substrate. Because the electromagnetic properties of the dielectric are determined by the material characteristics, it is very difficult to design and produce the random variable materials. Therefore, most scholars focus on the way of loading active components.

In this paper, a CAFSS structure loading PIN diode is designed. It can be realized that when the PIN diode is in the non-working state, the structure presents the 8 GHz ~18GHz high transmittance characteristic and the structure presents the 1 GHz ~18GHz fully shielded characteristic when the PIN diode is in the working state.

II. ANALYTICAL METHOD

The equivalent circuit model analysis method (ECM) of FSS is an approximate analysis method, which can be used to analyze FSS with parallel linear units, such as grid unit, square ring element, double rectangular element, and so on. The greatest advantage of ECM is that the algorithm is simple and time-saving. The physical meaning is clear, especially suitable for engineering design.

For the FSS structure, it can be first equivalent to the LC loop, as shown in fig. 1.

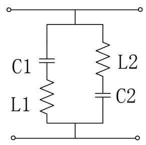


Fig. 1 Equivalent circuit

FSS has the characteristic of band resistance when C1 and L1 series equivalent circuit, that is, C2 is zero and L2 approaches infinity, and when there is C1 and L2 parallel equivalent circuit, that is, when L1 is zero and C2 approaches infinity, FSS has a bandpass transmission characteristic.

III. DESIGN PROCESS

A. Analysis of CAFSS characteristics

CAFSS regulates the structure performance by loading active components. Usually active components show capacitance, inductance, or resistance characteristics. These different characteristics have different effects on the FSS structure. In this paper, a rectangular slot with a passband type FSS is selected as the base unit to load the active components, and the variable capacitance, variable inductance and the variable inductance are loaded respectively. Variable resistance analysis of different characteristics of FSS structure performance, the structure is shown in fig. 2.

(a) unit form (b) equivalent circuit

Fig. 2 Rectangular slot FSS structure loaded with active elements

The ECM shows that the resonant frequency of the FSS structure shown in fig.2 is $f_0 = 1/(2\pi\sqrt{LC})$. After loading the active element, it is equivalent to parallel a variable impedance on the original parallel circuit. When the impedance characteristic is the capacitance, it is equivalent to increase the total capacitance of the circuit, thereby reducing the resonant frequency; when the impedance characteristic is the inductance, it is equivalent to reducing the total inductance of the circuit. So the resonant frequency increases; when the impedance characteristic is small resistance, the incident port is short-circuited, showing the characteristic of total reflection; when the impedance characteristic is high resistance, it is equivalent to the open circuit of the incident port, which makes the structure show the characteristics of conduction.

The full wave simulation method is used to verify the correctness of the conclusion.

As shown in fig.2, the variable capacitance/ inductance/ resistance is symmetrically loaded between rectangular slots, and the performance of the FSS structure changes with the change of capacitance as shown in fig. 3-5..

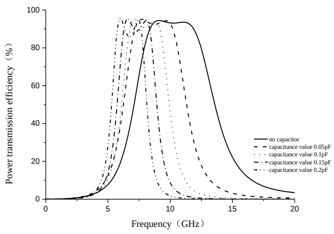


Fig. 3 Performance curve of rectangular slot FSS structure loaded with different capacitors

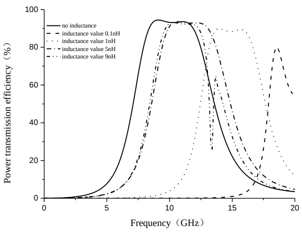


Fig. 4 Performance curve of rectangular slot FSS structure loaded with different inductance

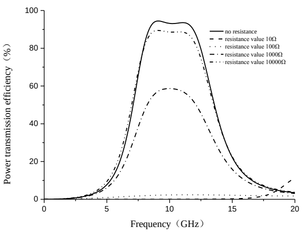


Fig. 5 Performance curve of rectangular slot FSS structure loaded with different resistance

The simulation results show that the resonant frequency of the structure is offset after loading the capacitance, and the resonant frequency of the structure decreases continuously with the increase of the capacitance, and the resonant frequency is also offset after loading the inductance. With the decrease of the inductance, the resonant frequency of the structure increases, and the resonant frequency does not shift obviously after loading resistance, but the transmission performance of the structure decreases with the decrease of the resistance value, and the resistance value increases. The closer it is to the performance of the structure without loading the resistor. The simulation results agree with the conclusion of the equivalent circuit method. When the shunt resistance is switched between the maximum resistance and the minimal resistance in the FSS structure, the switching between the transmission and cut-off performance of the CAFSS structure can be achieved.

B. Unit design

In this paper, we propose to design a FSS structure with both wide-band transmission and full-band shielding. Therefore, this design is based on a typical bandpass FSS element-slot element. From the analysis of the characteristics of the loaded active components, it is shown that when the small resistance is loaded, the incident port of the band-pass FSS equivalent circuit is shorted, so that the structure presents the characteristic of total reflection, while the loading of the large resistance characteristic is equivalent to the open circuit of the incident port. Make the structure take on the character of conduction. Based on this feature, PIN diode elements are selected. Considering the machining mode of the components, it is necessary to set the welding joint of the components in the unit. The solder joints show metal properties which will affect the performance of the structure. So the small rectangular patch in the slot element is used as the joint of the element and it is regarded as a part of the structural design directly without any additional influence on the structure performance. In the same way, the electrical connection between the element and the element needs the feeder to be a whole connected power supply, which can be controlled by the voltage change. In the design, it is found that the feed network of the slot type FSS element loaded with the active element is overlapped with the element itself, as shown in fig. 6.

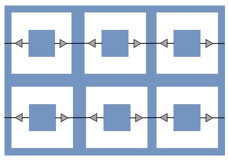
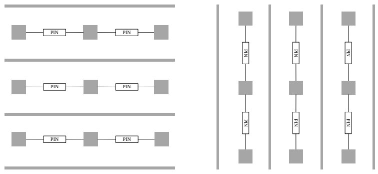


Fig. 6 Slot FSS loaded active element feeder

The PIN diode feeder control network is complex, in order to reduce the circuit complexity and realize the convenient control of the diode, at the same time, it eliminates the performance influence caused by the overlapping of the feeder network and the FSS cell, and deforms the rectangular slot cell structure. The PIN diode is symmetrically loaded on both sides of the composite dielectric structure using the inner rectangular patch of the slot as the processing connection point. The FSS unit structure is located between the bars of the gate as shown in fig. 7.

The FSS metal screen needs to be loaded on the medium and is split into two parts of the FSS element on both sides of the medium structure. The structure of the composite medium is matched and optimized to achieve the impedance matching of the structure so as to obtain excellent structural performance.

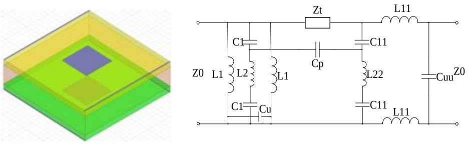


(a) unit 1 (b) unit 2

Fig. 7 Schematic diagram of CAFSS unit structure

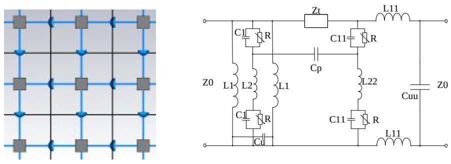
IV. SIMULATED ANALYSIS

The deformed structure of grid and slot FSS element is modeled. The schematic diagram and equivalent circuit are shown in fig. 8. The structure diagram and equivalent circuit after loading PIN diode are shown in fig. 9.



(a) structure (b) equivalent circuit

Fig. 8 Schematic diagram of grid FSS cell structure



(a) vertical view (b)equivalent circuit

Fig. 9 Schematic diagram of CAFSS cell structure modeling

Two kinds of ON/OFF states of CAFSS diodes are simulated and analyzed, and the structure performance curves are shown in figs. 10~ 11.

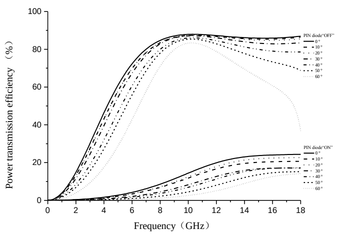


Fig. 10 Transport performance Curve of CAFSS structure (vertical polarization)

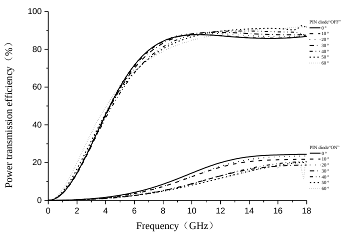


Fig. 11 Transport performance Curve of CAFSS structure (horizontal polarization)

V. CONCLUSION

The gate strip FSS cell structure loaded with PIN diode is designed in this paper. The switching between high transmittance and cutoff of CAFSS structure is realized effectively by using the low resistance / high resistance switching characteristics of PIN diode in "through" / "off" state. This is reflected in: (1) when the PIN diode is closed, the power transmission efficiency of the FSS structure is greater than 80% in vertical polarization from 0 ° to 30 ° angle range in the 8GHz to 18GHz frequency range, and it is greater than 80% from 0 ° to 60 °angle range in the 8GHz to 18GHz frequency range in horizontal polarization; (2)when the PIN diode is leading the way, the power transmission efficiency of the FSS structure is less than 25% from 0 ° to 60 °angle range in the 8GHz to 18GHz frequency range in vertical and horizontal polarization.

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