Modulation Characteristics of Active Frequency Selective Surface Trihedral Corner Reflector

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ABSTRACT

The conventional passive jamming devices such as corner reflectors and chaffs cannot achieve the flexible modulation of radar signal for their fixed scattering cross section. As a passive material, active frequency selective surface (FSS) can dynamically control their electromagnetic characteristics and has been widely applied in the radar target stealth field. In this paper, a radar signal modulation method is proposed based on active FSS trihedral corner reflector. The scattering characteristics and modulation principle of active FSS trihedral corner reflector are analyzed in detail. The effectiveness of the design is demonstrated by simulation results. This design provides a new and efficient method of radar signal modulation.

KEYWORDS

Active Frequency Selective Surface, Modulation Characteristics, Trihedral Corner Reflector.

INTRODUCTION

A corner reflector is a dihedral or trihedral structure composed of two or three mutually perpendicular metal plates. Due to its special geometry, it produces multiple internal reflections on incident electromagnetic waves and has a strong backward radar cross section (RCS). It is often used to constitute a false target for false falsehood. The geometry of the trihedral reflector is stable. When the plates are orthogonal to each other, it can generate strong scattering over a wide-angle range. This means it has a large RCS, so the trihedral corner reflector is used widely. However, the traditional corner reflector has obvious defects. Because its RCS strongly depends on the incident wavelength. In addition, its scattering characteristics is fixed once it is fabricated.

This paper proposes a method of radar signal modulation based on active frequency selective surface (FSS) trihedral corner reflector. The active FSS realizes the dynamic real-time regulation of its electromagnetic scattering characteristics by introducing an external excitation term into the artificial electromagnetic material. The basic design principle is to cover the trihedral reflector with active FSS components and control the scattering characteristics of the trihedral reflector by
adjusting the voltage of the diode to achieve the amplitude modulation effect on the radar signal.

In this paper, a method of radar signal modulation is proposed based on active FSS trihedral corner reflector. In Section II, the active FSS trihedral corner reflector’s structure is analyzed. In Section III, the modulation effect of the active FSS trihedral reflector on the signal is simulated. Finally, conclusions are drawn in Section IV.

ACTIVE FSS AND TRIHEDRAL CORNER REFLECTOR MODEL

Active FSS Unit Cell

The bow-tie dipole is selected as the basic unit cell model of active FSS absorber due to strong absorbing efficiency, wide absorption bandwidth and simple construction. The geometry of the active FSS is illustrated in Figure 1. The active FSS consists of periodic patterns of conducting metal back-plane, dielectric spacer and the active impedance layer. The active impedance layer includes FSS substrate, FSS unit cell and PIN diodes. The PIN diodes act as current controlled variable resistors in the structure.

The planar size of the unit cell of the active FSS is 15×15.5mm². The conducting back-plane is a metal plate. The dielectric spacer has a relative permittivity of $\varepsilon=4.4$ and a thickness of $h_1=4.2$ mm. The thickness of each active impedance layer is $h_2=0.8$ mm and the whole thickness of the active FSS is $H=5.0$ mm. The FSS circuit board was arranged ‘face downwards’ in the assembly and the PIN diode is embedded into the dielectric foam spacer. In this way, the FSS substrate could act as a protective outer skin.

(a) 3D view; (b) top view (unit: mm).
Active FSS Structure

In its basic form an active FSS consists of a two-dimensional, planar periodic grid of conducting patches, or elements, supported on a dielectric substrate. The board measures 236 mm by 236 mm and contains 256 (16 by 16) dipole elements. An active absorber was constructed using the assembly details shown in Figure 2 by mounting the FSS above a conducting back-plane using a 4.2 mm thick, low-loss, foam dielectric spacer (Rhocell 51, $\varepsilon_r = 1.05$, $\tan = 0.0017$).

The principal characteristic of the bow-tie dipole patch is the resonant behavior of its transmission coefficient. To better understand the performance of the proposed bow-tie dipole active FSS, initially full wave electromagnetic simulations were conducted using CST Microwave Studio™. Considering the external excitations mainly affects PIN diode's impedance value, the lumped element can be used to take place of the PIN diode. In the CST simulation, the variation of the voltage applied to the diode is simulated by setting a series of different impedance values of lumped elements. So the dynamic performance of the active FSS absorbing screen can be simulated. The results of the reflection (S11) responses of the active FSS is provided in Figure 3.

![Figure 2. The the details of the active FSS topology.](image-url)
Active FSS Trihedral Corner Reflector Model

As shown in Figure 4, the active FSS trihedral corner reflector is mounted orthogonally by three standard active FSS screens. As the conventional trihedral corner reflector, the active FSS trihedral corner reflector does not emit electromagnetic waves actively, but scatters the electromagnetic wave after receiving the incident electromagnetic wave. The direction of the reflected wave is parallel and opposite to the direction of the incident wave. The PIN diodes are periodically arranged on the active FSS screen. The impedance value of the PIN diode changes with its voltage, affecting the RCS peak value. The thickness of the dielectric spacer determines the peak position of the RCS. These two factors cause changes in the overall periodic structure, dynamically affecting the scattering strength of the active FSS screen, realizing the effect of radar signal amplitude modulation.
SIMULATION AND RESULTS

The foregoing analysis shows that the active FSS trihedral corner reflector can realize the radar signal amplitude modulation. Since PIN diodes can work as variable resistors at microwave frequencies, the dynamic performance of the active FSS absorbing screen can be simulated by setting a series of different impedance values of lumped elements in the CST simulation.

The modulation properties of the bow-tie shaped active FSS trihedral corner reflector are simulated by CST over the frequency range from 8 to 12 GHz. It was excited by a uniform plane wave for the incident angle: $\theta=45^\circ$, $\varphi=45^\circ$. The background material is vacuum. All the boundaries are set to be open boundaries. Resistors are loaded into the FSS unit cell to model the variation in PIN diode resistance, and its value varies from 100 to 3100 $\Omega$.

![Figure 5. The RCS of the active FSS trihedral corner reflector.](image)

Figure 5 demonstrates the RCS of the active FSS trihedral corner reflector. It has an absorption peak appear at 8.5 GHz. The bandwidth of the absorption peak can reach 400 MHz. The RCS is approximately -20 dBsm, when the resistance value is 1300 $\Omega$, showing a low-scattering state. While the RCS is approximately -1 dBsm when the resistance value is 100 $\Omega$, showing a high-scattering state. Therefore, this frequency band can be defined as a tunable area between the high-scattering state and low-scattering state. When the band of radar transmitting signal is within the tunable area of the active FSS trihedral corner reflector, the active FSS trihedral corner reflector can realize the modulation switching between high-scattering and low-scattering to the transmitting signal by regulating the impedance values of lumped elements, and the absorption attenuation can reach 20 dBsm.

When the radar transmits the LFM signal to the active FSS absorption screen, the spectrum of the echo signal $R(f)$ can be expressed as

$$R(f) = S(f) \times A(f)$$ (a)

S(f) represents the spectrum of the incident LFM signal. A(f) represents the frequency response of the active FSS absorbing screen. $L_A$ represents the degree of amplitude modulation of the LFM signal in the low scattering state. $B_A$ represents
the bandwidth of the absorption peak. $f_A$ represents the center frequency of absorption peak.

When the active FSS is controlled by a fixed bias current, its frequency response $A(f)$ remains the same, and the signal characteristics of the intermittent modulation by the active FSS absorbing screen can be simply obtained by the formula (a). Assuming that the active FSS exhibits a maximum absorption amplitude, the control bias current is $I_{\text{max}}$. As shown in Figure 7, when the bias current is continuously switched between the zero and $I_{\text{max}}$ states throughout the incident pulse time, the active FSS absorber screen operates in an intermittent scattering state. The frequency response function of the active FSS absorbing screen $A(f)$ changes continuously with the change of the control current during the pulse irradiation, and the effect on the reflected signal appears as the effect of the amplitude modulation. A variety of modulation patterns can be realized based on the principle of intermittent sampling.

After the incident signal is intermittently scattered by active FSS trihedral corner reflector, the frequency spectrum is shifted in frequency and the energy is redistributed into a larger bandwidth, achieving the amplitude modulation effect on the radar signal.
CONCLUSION

The main novelty of this paper is to propose a radar signal modulation method based on the active frequency selective surface trihedral corner reflector. In this paper, the active FSS trihedral corner reflector is modeled and its scattering properties are simulated. The result shows that the active FSS trihedral corner reflector can obtain the flexible switching between high-scattering and low-scattering states by adjusting the voltage of the bias circuit, and it can also achieve wave beam backtracking, demonstrating that the active FSS trihedral reflector could achieve dynamically adjustable amplitude modulation.

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