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A Low RCS Millimeter-wave Antenna Based on Frequency Selective Absorber

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***Abstract*—In this work, a low RCS millimeter-wave antenna based on FSA is proposed, achieving dual function with wideband radiation and out-of-band absorption. The proposed structure comprises a top-layer of FSA structure and a bottom layer of millimeter-wave antenna. With the addition of the FSA layer, the proposed antenna absorbs incident waves under arbitrary polarizations in the frequency range of 8-21 GHz. Notably, the proposed antenna maintains effective radiation in the frequency range of 21-27 GHz. Consequently, the proposed antenna achieves broadband low out-of-band RCS performance, which exhibit its potential practical utility in millimeter-wave communication and radar safeguard.**

***Index Terms*—Radar cross section (RCS), millimeter-wave antennas, frequency selective absorbers (FSA).**

I. INTRODUCTION

In contemporary communication and radar systems, low radar cross section (RCS) antenna has been a focal point of research [1]. It is owning to influences the system's stealth capability and its effectiveness in target detection. In radar systems, the high frequency of millimeter waves endows them with superior resolution and precise target detection capabilities, gradually establishing them as a critical component in modern military and civilian radar systems[2], [3]. Therefore, investigating the design of low RCS millimeter-wave antennas has become imperative [4].

Various artificial periodic structures [5]-[11], such as frequency selective absorbers (FSA) [7], artificial magnetic conductors (AMC) [8], and polarization conversion metasurfaces (PCM) [9], have been widely applied in antenna for RCS reduction. Generally, FSA, as an effective tool, has been introduced to reduce the out-of-band RCS of antennas. It is a periodic structure with the ability to selectively transmit or reflect electromagnetic waves within specific frequency ranges [10], [11]. In millimeter-wave antenna design, judicious use of FSA can control the propagation of electromagnetic waves on the antenna surface, effectively reducing out-of-band RCS to mitigate electromagnetic interference in complex environments [12]. This method provides a solution that balances the demands for high-performance antennas in millimeter-wave communication and safeguard of radar system security.

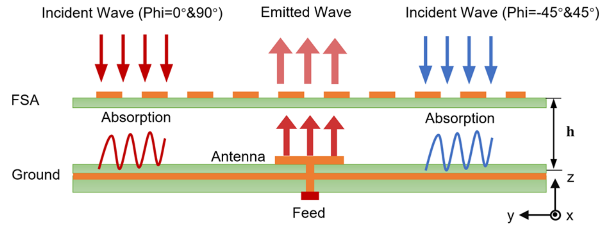
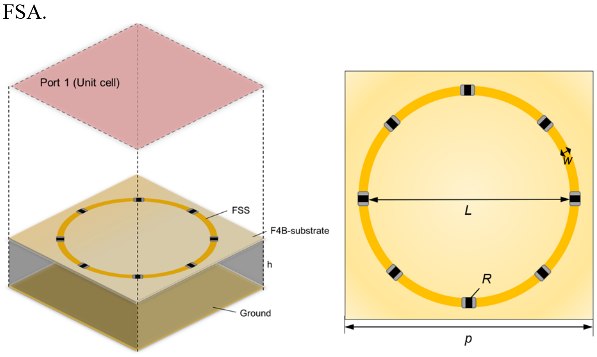


Fig. 1. Working mechanism of the proposed low-RCS antenna with FSA.



(a) (b)

Fig. 2 (a)Unit cell structure of the proposed FSA, (b) top view of the FSA layer (Parameters: ***L***=8.97, ***p***=10.8, ***w***=0.81).

This work proposes a low RCS millimeter-wave antenna based on FSA, achieving dual function with wideband radiation and out-of-band absorption. The proposed structure comprises a top-layer of FSA structure and a bottom layer of millimeter-wave antenna. The proposed antenna is a U-shaped slot microstrip antenna, exhibiting two resonant modes for broadband radiation. The introduced FSA structure, featuring a periodic circular-ring array loaded with resistors, achieves broadband absorption performance without affecting the antenna's radiation outside the absorption band. Therefore, the proposed FSA-based antenna realizes broadband low RCS performance.

II. DESIGN OF FSA AND ANTENNA

The operational principle of the proposed low RCS millimeter-wave antenna is illustrated in Fig.1. The whole structure consists of a U-shaped slot microstrip antenna supported by the metal plate as the ground, and a top layer

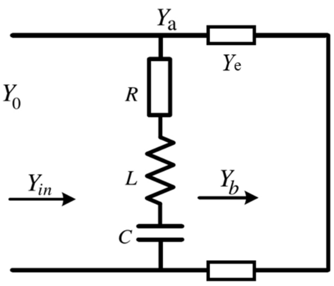
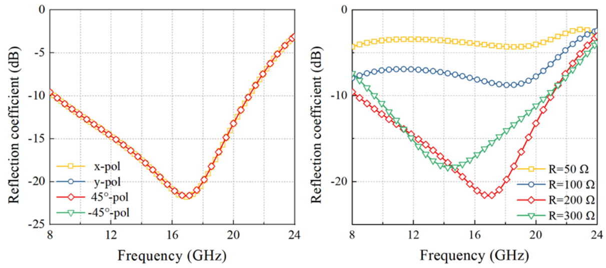
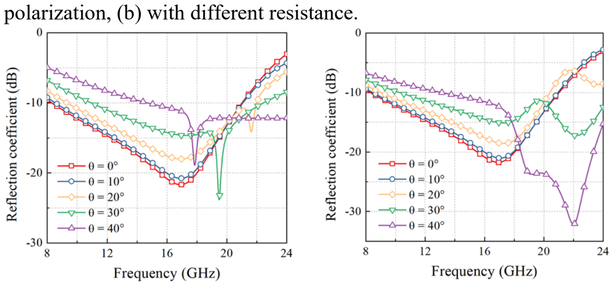


Fig. 3. Equivalent circuit model of FSA.



(a) (b)

Fig. 4. Reflection coefficients of the proposed FSA. (a) For different polarization, (b) with different resistance.



(a) (b)

Fig. 5. Reflection coefficients of the proposed FSA for (a) x- and (b) y-polarization under different oblique incidences.

of FSA. When the antenna serves as a scatter, any polarized incident waves of out-of-band frequencies are absorbed by the FSA. For high-frequency millimeter waves, the FSA can be considered as a transmissive radome, allowing in-band co-polarized incident waves to pass through the FSA layer and received by antenna. Therefore, it exhibits excellent radiation performance in the high-frequency range and maintains low RCS performance in out-of-band frequencies under arbitrary polarization.

The proposed unit cell of FSA is a circular loop loaded with lumped resistors, which is presented in Fig.2. The FSA is printed on a 0.25 mm thick substrate. The height above the ground is h, which is corresponding to $1/4\lambda_f$. As shown in Fig.2(b), the parameters are as follows: P represents the periodic length of the FSA, L is the diameter of the loop, R is the value of the lumped resistance, and W is the width of the loop. To achieve higher performance and a wider absorption bandwidth, resistors must be loaded at positions where the current amplitude is maximal during device resonance. Typically, for horizontally polarized waves, the points where the surface current amplitude is maximal are located at the midpoints of the upper and lower parallel sides. For vertically polarized waves, the

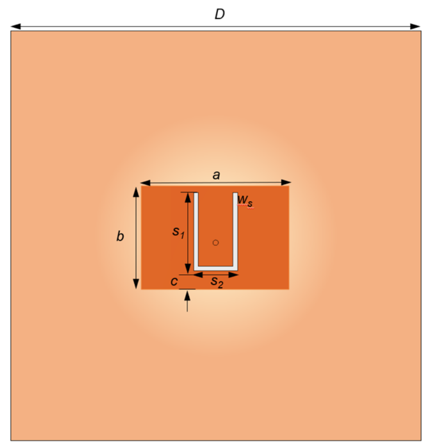


Fig. 6. Structure of the proposed U-shape antenna.(Parameters: ***a***=7.04, ***b***=4.84, ***c***=0.94, *D*=54, ***s₁***=3.52, ***s₂***=1.98, ***wₛ***=0.21, mm)

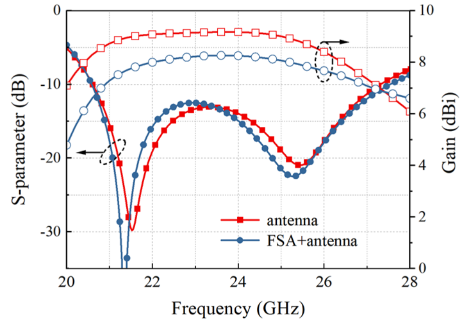


Fig. 7. Comparations of S-parameters and gains for the proposed antenna and the proposed antenna with FSA.

surface current amplitude is maximal at the right and left parallel sides. These holds true for other polarizations as well. Therefore, eight lumped resistances are evenly loaded based on the circular loop unit for stable current distribution under different polarization conditions.

The equivalent circuit model of the FSA is depicted in Fig. 3. According to the theory of circuit-analog absorbers [13], when electromagnetic waves impinge on the metallic unit periodic structure, surface currents are focusing on it. These surface currents circulate around the unit, creating a surrounding magnetic field, resulting in an inductive effect. Numerous positive and negative charges, under the influence of the induced electromotive force, gather at both ends of the unit. Adjacent units along the edge exhibit charges of opposite polarity, generating an equivalent capacitance. In the equivalent circuit model, the equivalent inductance ***L*** on the impedance surface corresponds to the circular loop as illustrated in Fig. 2(b). And the equivalent capacitance ***C*** is generated by the gaps between the unit cells. Additionally, the circuit also includes resistive elements ***R***, leading to the impedance surface being equivalent to a series RLC circuit. By adjusting the parameters of the FSS layer, Y_{in} can be made to closely approximate the free space admittance Y_0 over a wide frequency range. This ensures that the resonant circuit matches well with the spatial electromagnetic waves, and the electromagnetic energy is continually consumed by the resistor.

Fig. 4 shows the reflection coefficients of the proposed FSA at the boundary conditions. It can be seen that the reflection coefficients for different polarizations are less than -10 dB over the frequency range of 8-21 GHz, which maintain stable results. As the surface resistance value increases from 50 to 300 Ω, the reflection coefficient changes greatly due to the change of impedance. The reflection coefficient has a maximum bandwidth with a resistance value of 200 Ω. As shown in Fig.5, the results for both polarization with incidence angles of 0°, 10°, 20°, 30°and 40° are presented. It can be noticed that the proposed antenna shows stable reflection coefficient when the oblique incidence is less than 30° under both x and y-polarization. However, as the angle of incidence increases to 40°, the structure may produce unnecessary resonances at lower frequency, leading to the occurrence of additional null points.

III. Perpormace of the Antenna

As shown in Fig. 6, the proposed millimeter-wave antenna is composed of two sides substrate. The U-shaped small metallic patterns are printed on the center of the top side, exhibiting two resonant modes for wideband radiation. And the bottom side of substrate is the full metal acts as ground, with the antenna fed through a coaxial SMA connector. It is designed as a broadband antenna operated in the frequency range of 21-27 GHz. The parameters are provided in the Fig. 6. To validate whether the antenna can still radiate effectively with the addition of the FSA, the FSA is positioned 5.5 mm above from the propose antenna. In this work, full-wave simulation software (CST Studio Suite) is utilized to simulate the S-parameters and gain of the antenna, as depicted in Fig.7. It can be observed that the reflection coefficient of the antenna undergoes minimal changes with the inclusion of the FSA. The reason why the gain decreases a little may be that a small amount of energy is lost by the surface resistors when the electromagnetic wave passes through the FSA.

Fig. 8 shows the monostatic RCS comparison between the reference antenna and the FSA + antenna for x- and y-polarized normally incident waves. The RCS of the proposed antenna is significantly reduced from 8 to 24 GHz. The maximum reduction values for x- and y-polarized normally incident waves are approximate 35 and 20 dB, respectively. Thus, the effective reductions of out-of-band RCS of the proposed antenna is realized for both polarizations.

IV. Conclusion

In this work, a broadband low RCS millimeter-wave antenna based on FSA is proposed and analyzed. With the addition of the FSA layer, the proposed antenna absorbs incident waves under arbitrary polarizations in the frequency range of 8-21 GHz, which maintains stability under different oblique incident waves. Notably, the poposed antenna maintains effective radiation in the frequency range of 21-27 GHz. Therefore, the proposed antenna achieves broadband low out-of-band RCS performance, without affecting the antenna's radiation. It exhibit its potential practical utility in millimeter-wave communication and radar safeguard.

Acknowledgement

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