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RCS Reduction of Quasi-Yagi Antenna

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Abstract—A novel Quasi-Yagi antenna with low radar cross section (RCS) is proposed in this paper. By using arrow-shaped Koch dipoles as the driver and director and cutting the ground of the antenna, the RCS can be reduced in the operating band of 5 GHz–8 GHz when the incident wave is perpendicular to the antenna plane. Wideband radar absorbing material (WRAM) with frequency selective surface (FSS) is devised to replace the metallic reflect plate of the antenna to reduce the RCS in the maximum radiation direction. The average RCS reduction of the antenna in the frequency band of 3 GHz–12 GHz is 8.0 dB. The simulated and measured results show that there is a considerable RCS reduction of the Quasi-Yagi antenna with WRAM, and the radiation performance is preserved at the same time.

1. INTRODUCTION

With the development of radar technology, electromagnetic stealth plays an increasingly important role in military competition. Radar cross section (RCS) is an important parameter to describe the stealth ability. The RCS reduction of antenna system is one of the most notable researches because of its significant contribution to scattering on weapons platform. Wideband antenna has been widely used on weapons platform. Therefore, controlling and reduction of the RCS of wideband antenna are necessary.

Quasi-Yagi antenna is widely used for its simple structure, small size, good directionality, high gain, etc. There are many studies about radiation performance of Quasi-Yagi antenna. However, the researches of the RCS reduction of Quasi-Yagi antenna can be seen rarely. In [1], a low RCS bionic Yagi-Uda antenna with oval-shaped radiating elements and feather-shaped directors is proposed. The biological antenna mean that the methods and systems found in the nature are applied to the antenna systems. In [2], arrow-shaped dipoles are used in Quasi-Yagi antenna to enhance the direction and gain. In [3], the Yagi-Uda antenna constructed of three Koch fractal elements is presented. Both arrow-shaped dipoles and Koch ones have the capability of miniaturization which is a traditional way to reduce RCS.

There are many reports on the application of conventional radar absorbing material (RAM) and frequency selective surface (FSS) on RCS reduction [4–7], but the bandwidth is not wide enough when FSS or RAM is used separately. Studies show that the combination of RAM and FSS can expand the bandwidth of RCS reduction effectively [8–10].

The theme of this paper is the RCS reduction of Quasi-Yagi antenna in different states: a planar Quasi-Yagi antenna with and without metallic reflect plate. By designing arrow-shape Koch dipoles as director and driver of the Quasi-Yagi antenna and cutting some area of the reflector ground, the RCS can be reduced as much as 4 dB in the operating band of 5 GHz–8 GHz. Simultaneously, a novel wideband RAM with FSS is designed to replace the metallic reflect plate of Quasi-Yagi antenna. The results show that using of the wideband RAM can obtain a considerable RCS reduction with an average value of 8.0 dB in the frequency band of 3 GHz–12 GHz of the antenna.

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2. RCS REDUCTION OF THE QUASI-YAGI ANTENNA

2.1. Antenna Design

A conventional planar Quasi-Yagi antenna, as shown in Figure 1, consisting of a director, a reflector and a driver, is designed as a reference antenna. The reflector is made by truncated ground plane and the driver is fed by a broadband microstrip and a coplanar strip balun transition. The driver and the director are printed on the top layer of the Rogers substrate which has a thickness of 1 mm and a relative permittivity of 9.8. The reflector is printed on the bottom layer. The specific dimension parameters of the antenna as marked in Figure 1 are stated in Table 1. The simulated result shows that the operating band of the antenna is 5.2 GHz–8.1 GHz. All the simulations in this paper are implemented by using the commercial software Ansoft HFSS 13.

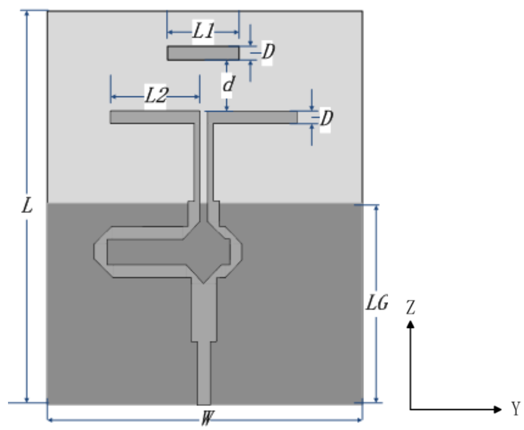


Figure 1. Structure of the reference antenna.

Table 1. Parameters of the reference antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L	27	W	22.5
L_G	14.4	L_1	5
L_2	6.3	D	0.9
d	3.6		

For reducing the RCS of the reference antenna, arrow-shaped Koch dipoles are investigated as driver and director of the antenna. Compared with straight dipoles, arrow-shaped ones have a less lateral length, therefore we consider making the director and driver of the Quasi-Yagi antenna into arrow shape to reduce the lateral length of the antenna. To achieve this purpose, we rotate back the director and driver dipole with an angle θ.

Space filling characteristics of fractal structure make it have a large electric size, while its surrounding area is very small. Antennas have lower RCS characteristic when their area decreases [11]. Liu introduced the use of fractal in RCS reduction of antenna, the theoretical analysis and experimental results show that, the fractal can realize RCS reduction of antenna and preserve radiation performance at the same time [12]. The arrow-shaped Koch Quasi-Yagi antenna (KQYA) is shown in Figure 2. The parameters k_1, k_2, and k_3 is represented as k_{di1}, k_{di2}, and k_{di3} for the director and k_{dr1}, k_{dr2}, and k_{dr3} for the driver.

To reduce size of the antenna and preserve its radiation performance at the same time, the relative factors are selected as $\theta = 80°$, $\theta_1 = 63.5°$, $k_{di1} = k_{di3} = 0.24$ mm, $k_{di2} = 2$ mm, $k_{dr1} = k_{dr3} = 0.95$ mm, and $k_{dr2} = 4$ mm after optimization. The length of the modified driver and director, got by $k_1 + k_2 + k_3$, is reduced from 5 mm to 2.48 mm and 6.3 mm to 5.9 mm respectively. It is obvious that the length of the arrow-shaped Koch dipole is less than that of the straight ones.

In order to make a further reduction of RCS, we analyzed the current distribution of the Quasi-Yagi antenna. Analyzing the scattering field by current distribution is one of the common ways of studying RCS reduction. Truncated ground plane of the Quasi-Yagi antenna is an important part of radiation as well as a significant cause of RCS. For radiation, the ground plane should make sure that the microstrip line can transmit signal well, while for scattering, the area of the plane should be as small as possible to realize low RCS.

Figure 3 shows the current distributions of radiation and scattering of the reference antenna at

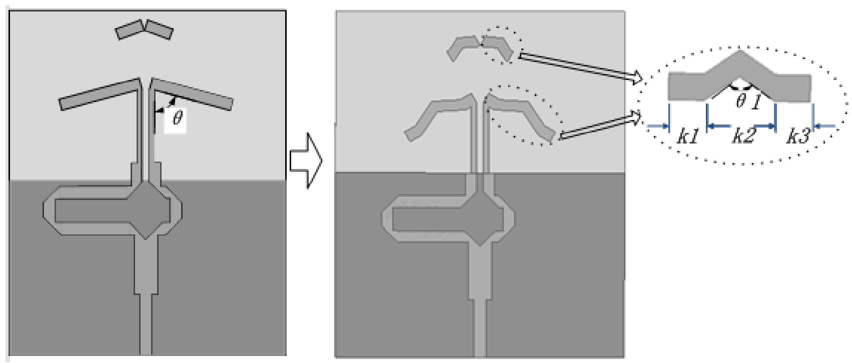


Figure 2. Designing process of the KQYA.

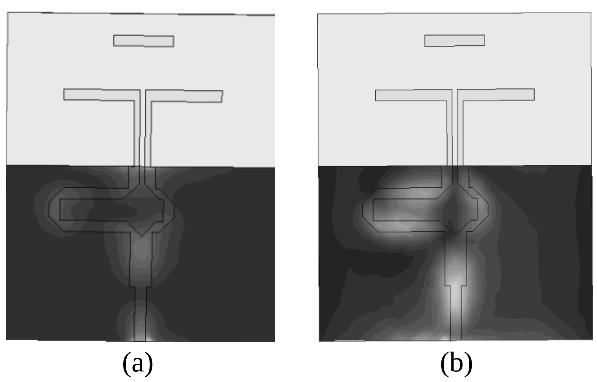


Figure 3. Currents distribution on the reference antenna. (a) Radiation. (b) Scattering.

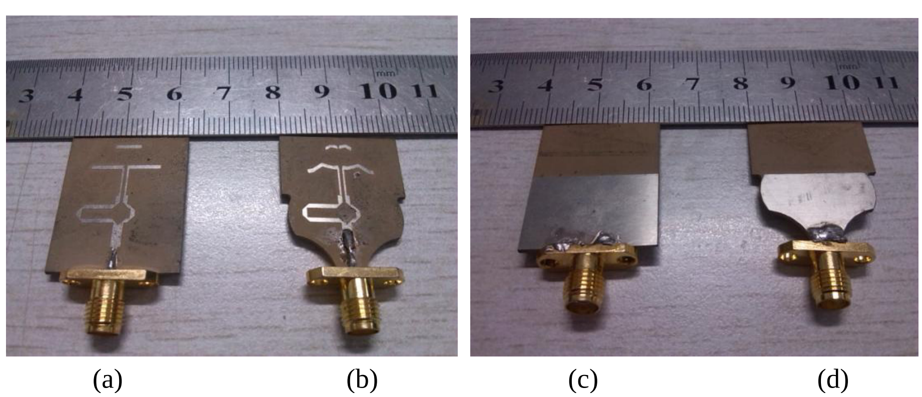


Figure 4. (b), (d) Photographs of the MQYA and (a), (c) the RQYA. (a), (b) Top view. (c), (d) Bottom view.

6.6 GHz. Form the figure we can see that some areas of the ground plane contribute a lot to the scattering field but little to radiation. For this reason we can cut these areas to reduce RCS. Photographs of the finally modified Quasi-Yagi antenna (MQYA) and the reference Quasi-Yagi antenna (RQYA) are shown in Figure 4.

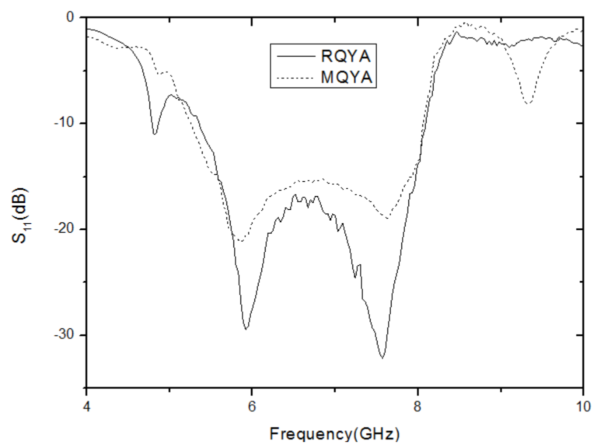


Figure 5. S_{11} of the two antennas.

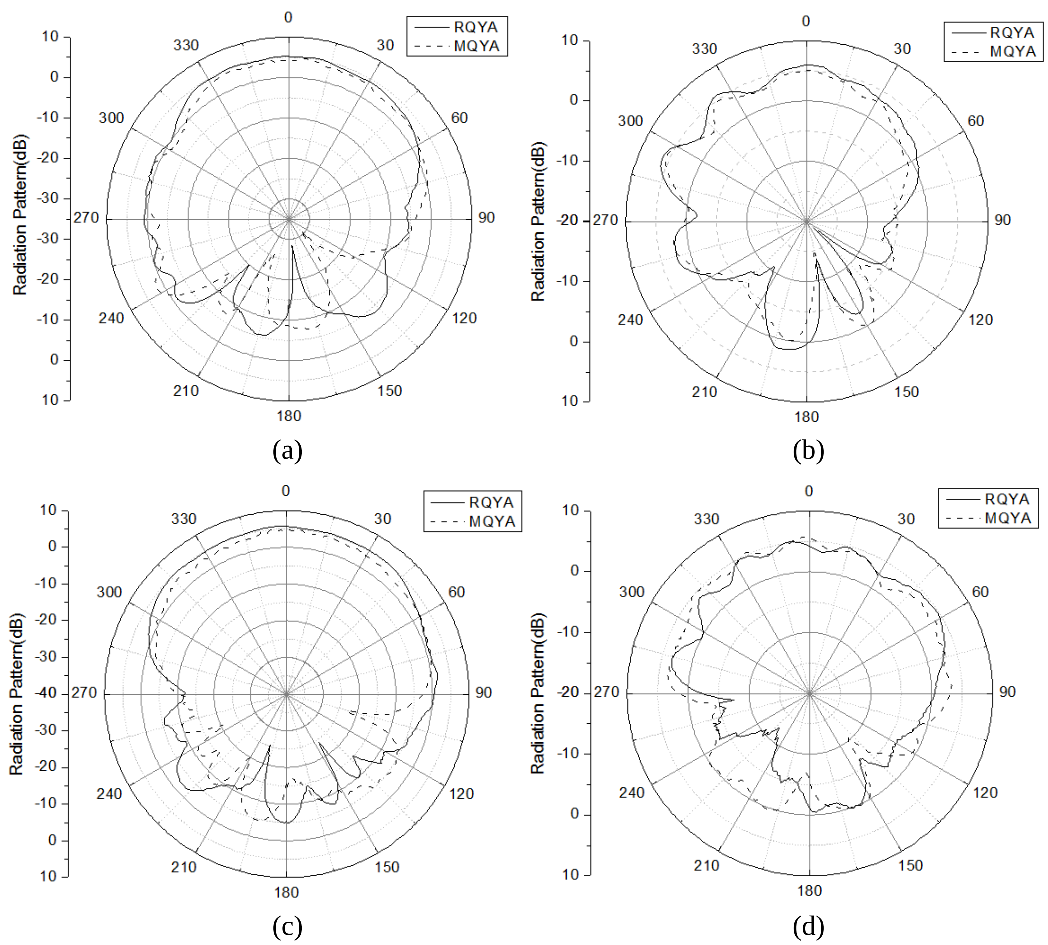


Figure 6. Radiation patterns of the two antennas at (a) 5.5 GHz in YoZ plane, (b) 5.5 GHz in XoZ plane, (c) 7.5 GHz in YoZ plane, and (d) 7.5 GHz in XoZ plane.

2.2. Results and Analysis

The measured comparisons of the radiation characteristics between RQYA and MQYA are shown in Figure 5 and Figure 6. The comparisons of the simulated radiation efficiency and gain in the operating band of the two antennas are respectively shown in Figure 7 and Figure 8. From the results we can see that the radiation performance of the antenna is preserved well. Figure 9 gives the simulated comparison of the monostatic RCS among the RQYA, KQYA and MQYA. Here the incident wave is perpendicular to the antenna plane. From Figure 9 it can be seen that the KQYA has a lower RCS than the RQYA, and the MQYA can realize better RCS reduction effect in the frequency band of 4 GHz–10 GHz. So the methods proposed above are proved to be useful for RCS reduction.

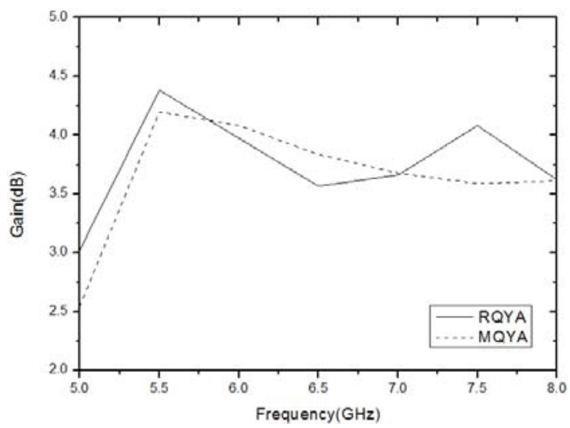


Figure 7. Radiation efficiencies of the two antennas.

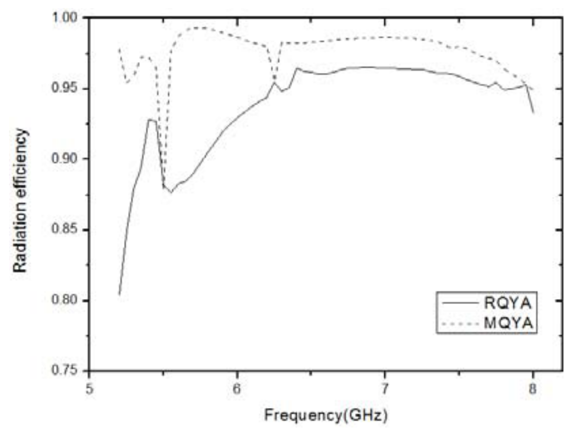


Figure 8. Gains of the two antennas.

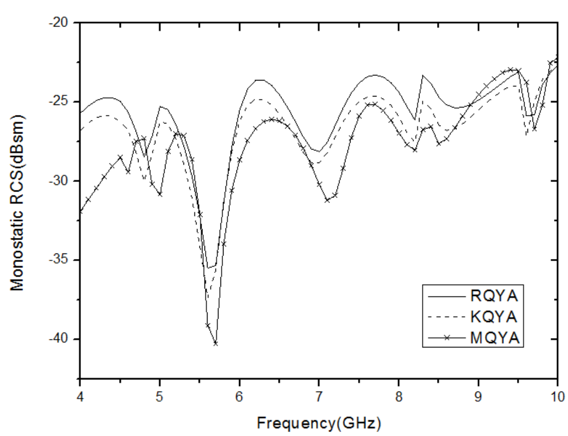


Figure 9. The monostatic RCS of RQYA,KQYA and MQYA.

3. DESIGN OF WIDEBAND RADAR ABSORBING MATERIAL

The operating band of FSS or RAM is not wide enough when they are used separately. Impedance adjusting with great freedom of FSS makes it easier for RAM to match with free space when the FSS is loaded on it, so as to make RAM achieve better absorbing effect. In the meantime, the resonant frequency of FSS can be adjusted to be closed to that of the RAM hence to form a broader absorbing band [10]. Inspired by which a novel wideband RAM (WRAM) with FSS is proposed here. The structure of the WRAM is shown in Figure 10 and the unit form of the loaded FSS is in Figure 11. The FSS is milled on top layer of the substrate FR4 with a relative permittivity as $\varepsilon_r = 4.4$ and the metal ground

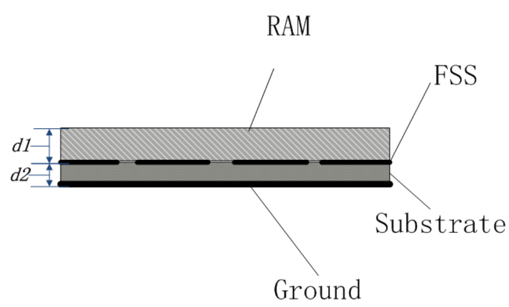


Figure 10. Structure of the WRAM.

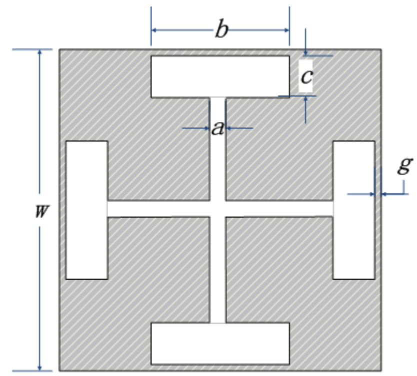


Figure 11. Unit of the FSS.

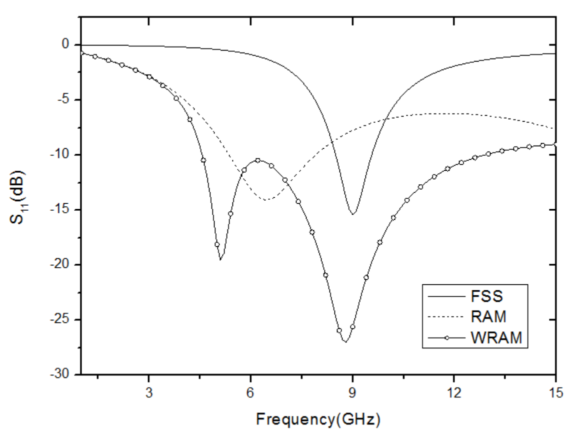


Figure 12. Comparison of the S_{11} of WRAM, RAM and FSS.

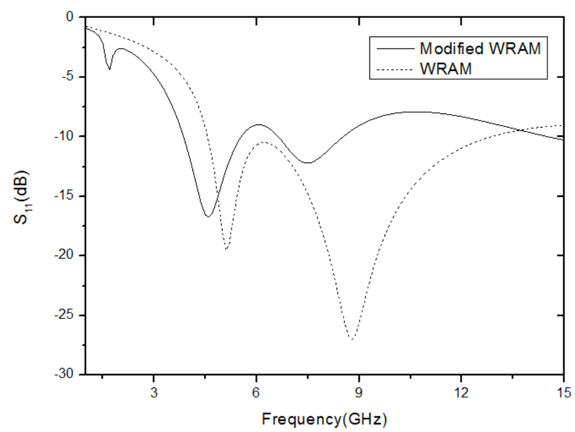


Figure 13. S_{11} of the two WRAM.

Table 2. Parameters of the novel WRAM.

parameter	Value (mm)	parameter	Value (mm)
d_1	1.2	d_2	1.5
a	0.14	b	2
c	0.4	g	0.04
w	4		

is on the bottom layer, and then the RAM is on the FSS. The related parameters are optimized to make the WRAM exhibit good performance over a wideband. The optimizing result is given in Table 2.

The comparison of the reflection coefficient between WRAM and the separate RAM and FSS is given in Figure 12. The bandwidth of the RAM without FSS is 36.4%, within which S_{11} is below than -10 dB. The minimum value is -14 dB at 6.5 GHz. When FSS is loaded on the RAM, the bandwidth is broadened to 94.3% with two valleys of -19.5 dB at 5.1 GHz and -27 dB at 8.8 GHz.

4. MQYA WITH WRAM PLANE

Generally a metallic reflect plate is added to an end-fire antenna to enhance the gain and reduce the backward radiation, and the price to pay for which is the deterioration of RCS. The operating band of the proposed WRAM is wide enough to cover that of the antenna, so the metallic reflect plate is replaced by the WRAM. In the designing it is found that serious absorbing depth of the WRAM may cause too much gain loss, because RCS reduction of antenna always implies a tradeoff between the radiation performance and scattering characteristic. Therefore, RCS reduction of antenna will generally result in gain loss. The WRAM with a large absorbing rate can realize good RCS reduction but the gain loss of the antenna is also large. The parameters of the WRAM is adjusted to ameliorate the situation. The modified WRAM with a proper absorbing rate can reduce the RCS of the antenna and the radiation performance of the proposed antenna is also preserved at the same time. The parameters of the modified WRAM are listed in Table 3 and the S_{11} is shown in Figure 13. In the operating band of the antenna, S_{11} of the modified WRAM is in the range of -16 dB to -9 dB, which is satisfactory in terms of RCS reduction and radiation conservation.

A photograph of the MQYA with WRAM is shown in Figure 14. The measured S_{11} of the two antennas given in Figure 15 shows that the operating band of the two antennas are almost consistent.

Table 3. Modified parameters of the novel WRAM.

parameter	Value (mm)	parameter	Value (mm)
d_1	1.8	d_2	1.5
a	0.3	b	2
c	0.4	g	0
w	4		

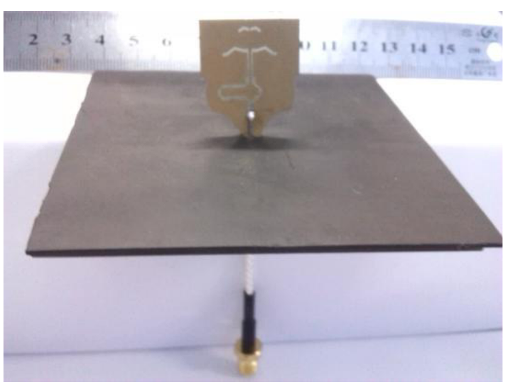


Figure 14. Photograph of the MQYA with WRAM plane.

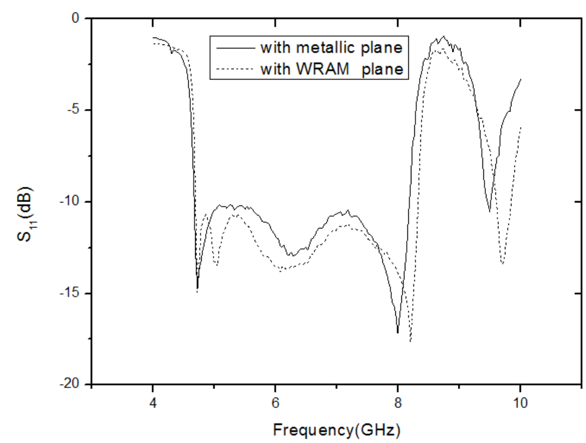
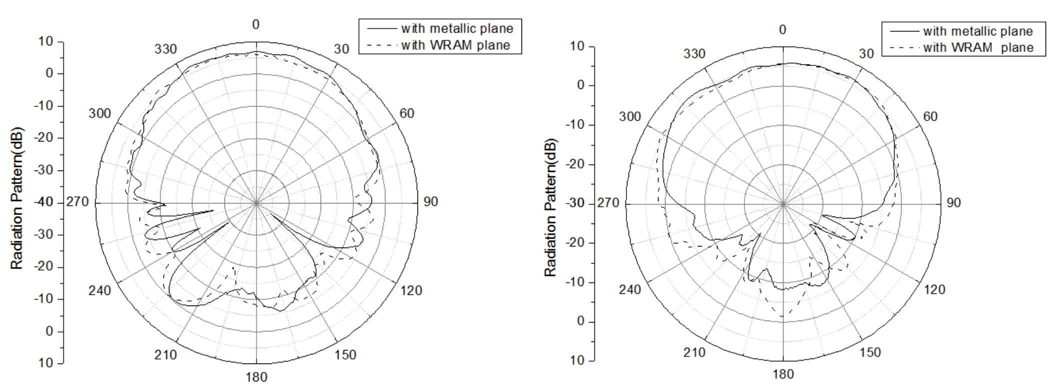
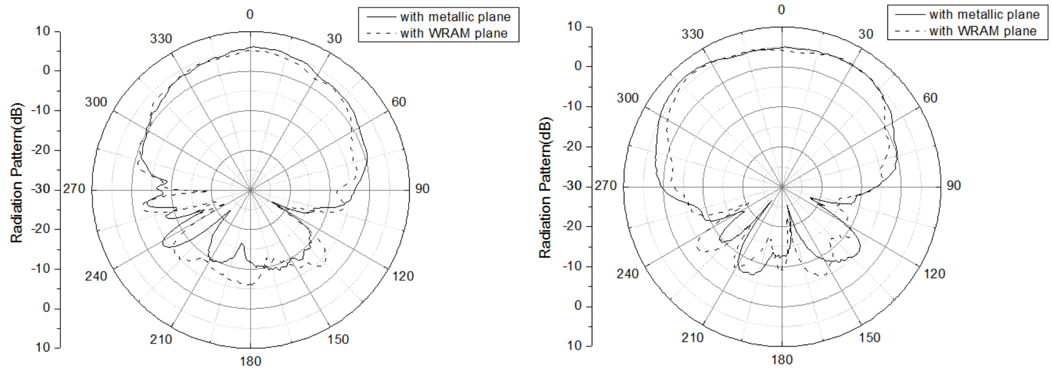


Figure 15. S_{11} of the MQYA with two different reflect plate.



(a) (b)



(c) (d)

Figure 16. Radiation patterns of the MQYA with two different reflect plates at (a) 6.5 GHz in YoZ plane, (b) 6.5 GHz in XoZ plane, (c) 7.5 GHz in YoZ plane, and (d) 7.5 GHz in XoZ plane.

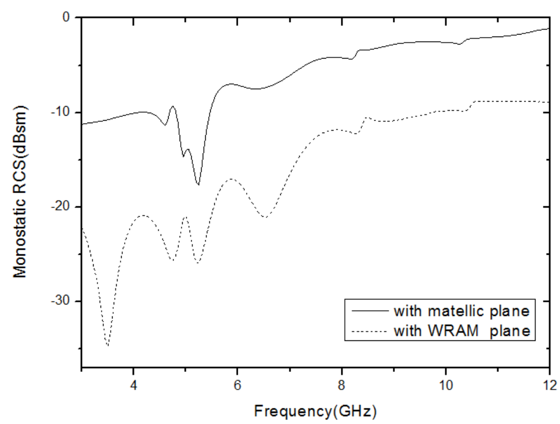
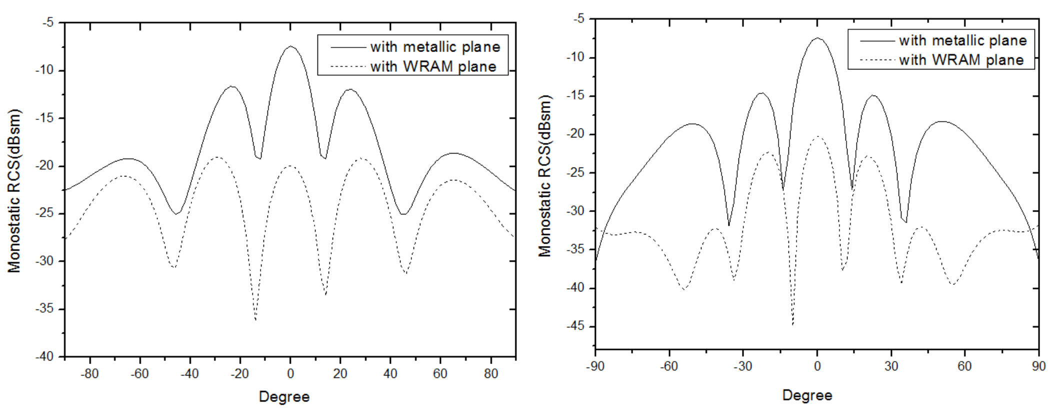


Figure 17. Comparison of the monostatic RCS of MQYA with two different reflect plates.



(a) (b)

Figure 18. Monostatic RCS of the MQYA with two different reflect plates under different incident wave at 6.5 GHz. (a) YoZ plane. (b) XoZ plane.

The measured radiation patterns of the two antennas at 6.5 GHz and 7.5 GHz are given in Figure 16, which indicate that the radiation performances of the two antennas are similar. At 6.5 GHz, the largest gain degradation is 0.5 dB, which is an acceptable sacrifice for the RCS reduction purpose.

Figure 17 shows comparison of the monostatic RCS between the two antennas. The incident wave is in the direction of $\theta = 0°$. The comparison shows that there is a substantial RCS reduction of MQYA with WRAM in the frequency band of 3 GHz–12 GHz, as much as 16.9 dB at 4.8 GHz.

Figure 18 gives the monostatic RCS of MQYA with two different reflect plates under different incident angles. The simulation is taken at 6.5 GHz. From the figure we can see that there is an considerable RCS reduction of the MQYA with WRAM reflect plate in the whole angular region in both the XoZ plane and the YoZ plane.

5. CONCLUSION

This paper introduces the RCS reduction of Quasi-Yagi antenna. Arrow-shaped Koch dipoles and reduction of the ground area are operated to reduce the RCS of the antenna. A novel wideband RAM with FSS is designed to replace the metallic reflect plate of the antenna, and the WRAM can absorb the incident wave and keep the performance of the antenna at the same time. RCS of the MQYA with WRAM can be reduced as much as 16.9 dB. The experimental results show that all the methods proposed in this paper are useful for RCS reduction of Quasi-Yagi antenna.

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