Research on the RCS of Serrate Gap in Real Aircraft State

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***Abstract*—Serrate gaps, as weak scattering sources, are distributed on the surface of aircrafts to affect their stealth performance. Therefore, to obtain the accurate RCS of such gaps in the real aircraft state is of great significance. This study proposes a carrier cancellation method to obtain the RCS scattering characteristics of serrate gaps under the real state of the aircrafts. Commercial software such as FEKO and MATLAB are utilized to implement the ISAR imaging validation of the method. The simulation results show that the gap self-scattering can be obtained accurately by the proposed method. Using this technique, the RCS of serrate gaps are computed under electromagnetic wave irradiation under different frequencies and polarizations.**

Keywords-serrate gap; carrier cancellation; microwave imaging; RCS

I. INTRODUCTION

As one of the important discontinuous characteristics of the aircraft surface, a large number of gaps exist on the butt surface of the aircraft body, such as the cover and active surface, which is hard to avoid. The flight height of the aircraft is negligible compared with the conventional detection radar detection distance, and the radar detection wave can be approximated as a horizontal incidence illuminating onto the fuselage and wing, as shown in Fig. 1, which is defined as the real state of the aircraft. Effective reduction method is adopted by stealth aircraft adopts on the main scattering sources, such as smooth metal mirror and cavity, and its overall radar scattering cross section can be reduced by dozens of decibels than conventional aircraft. At the moment, the proportion of weak scattering sources such as gaps and steps increase greatly. Thus, it is very important to obtain the scattering characteristics of weak scattering sources such as aircraft gap in the real state. Weak scattering sources such as gap affect the stealth performance of aircraft greatly but are limited by the processing and manufacturing process and cost. Some researchers have studied weak scattering sources by using numerical computational method in the real state of aircraft [1-2]. Compared to straight gap, serrate gap has lower RCS. Therefore, the amount of coated absorbing material can be greatly reduced, and the aircraft's guarantee and maintenance performance will also be greatly improved [3]. However, direct measurement methods have not been able to eliminate the interference of the carrier, and the actual calculation is affected by the shape of the specific carrier. In [4] the straight gap during the small angle domain in conditions of vertical incidence is studied and a carrier cancellation measuring method is proposed. But it does not extract the scattering characteristics of the serrate gap in the real state of the aircraft. In this paper, the scattering characteristics of the serrate gap on the aircraft are studied by means of carrier cancellation.

Based on the above background, this paper firstly introduces the serrate gap and application scenarios of aircraft. Then, the carrier cancellation theory is illustrated. FEKO and MATLAB are used to conduct 2D ISAR image of serrate gap to test the applicability of carrier cancellation algorithm. Finally, numerical simulation is used to study the real state of RCS simulation.

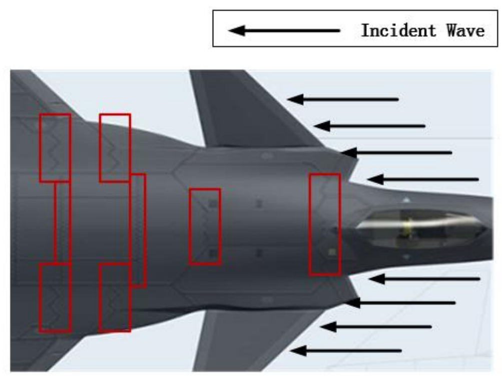

Figure 1. Serrate gaps and radar wave incidence of aircraft

II. CALCULATE METHOD

A. *Carrier Cancellation Theory*

Radar scattering cross section commonly shows the stealth characteristics of targets and is defined as,

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{|\vec{E}_r|^2}{|\vec{E}_i|^2} = \lim_{R\to\infty} 4\pi R^2 \frac{|\vec{H}_r|^2}{|\vec{H}_i|^2} \tag{1}$$

$\vec{E}_i$ and $\vec{H}_i$ denotes the intensity of electric field and the intensity of magnetic field of radar incident wave at the target position respectively. $\vec{E}_r$ and $\vec{H}_r$ denotes the intensity of electric field and magnetic field of the radar reflected wave at the target position respectively. R denotes the distance between the target and the radar. $R\to\infty$ means that both the incident and reflected radar waves have the properties of plane waves at the target position in the far field.

Simulation data is exported from FEKO in the form of complex vector. Here $\vec{E}_{\theta}$, $\vec{E}_{\Phi}$ denote the electric field of the board with serrate gap and $\vec{E}_{\theta 1}$ and $\vec{E}_{\Phi 1}$ denote the electric field of the board without serrate gap. According to reference [5], the scattering relation between the serrate gap and the carrier conforms to the calculation relation of vector addition:

$$\vec{E}_{\theta,ff}=\vec{E}_{\theta}-\vec{E}_{\theta 1} \tag{2}$$

$$\vec{E}_{\Phi,ff}=\vec{E}_{\Phi}-\vec{E}_{\Phi 1} \tag{3}$$

where $\vec{E}_{\theta,ff}$ and $\vec{E}_{\Phi,ff}$ denotes the electric field vector after carrier cancellation, which can calculate the RCS of the serrate gap after carrier cancellation.

$$\sigma=\lim_{R\to\infty} 4\pi\frac{|R\vec{E}_{\theta}|^2+|R\vec{E}_{\Phi}|^2}{|\vec{E}_i|^2}=\lim_{R\to\infty} 4\pi\frac{|\vec{E}_{\theta,ff}|^2+|\vec{E}_{\Phi,ff}|^2}{|\vec{H}_i|^2} \tag{4}$$

B. *Microwave Imaging Verification*

When the incident electric field is perpendicular to the serrate gap plate, we denote it as vertical polarization (VV) in this paper. When the incident electric field is parallel to the serrate gap plate we denote it as horizonal polarization (HH) in this paper. According to reference [6], 2D ISAR imaging can be used to test the validity of carrier cancellation method.

The size of metal board is 200mm*200mm*5mm. The single length of serrate gap is 40 mm the width of serrate is 2mm. Incident angle is 0°~180°. The increment angle of incident is 2°, which is shown in Fig. 2 and Fig. 3.

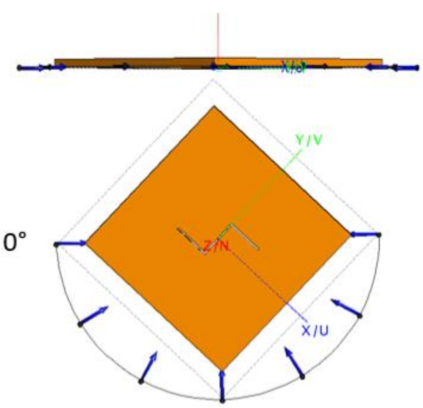

Figure 2. Serrate gaps imaging calculation model

According to the comparison between the serrate gap board and smooth board which is shown in Fig. 4, there is a good match between the board with gap and the smooth board when the incident angle is 85°, which means the scattering of gap is not buried by the scattering of board. So the incident angle center of imaging is 85°. Imaging range is 44° (63°~107°) and its single increment is 2.2°. The frequency of incident wave is 8~18GHz and single increment is 125MHz in conditions of vertical polarization. The imaging model is shown in Fig. 5 and Fig. 6.

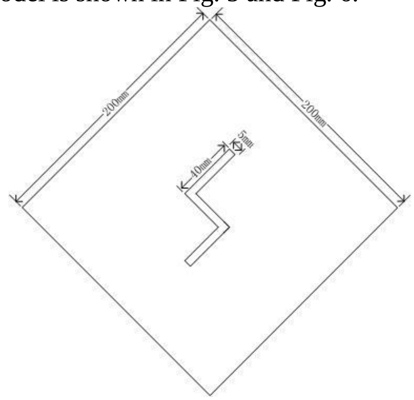

Figure 3. Geometric dimension of serrate gaps plate

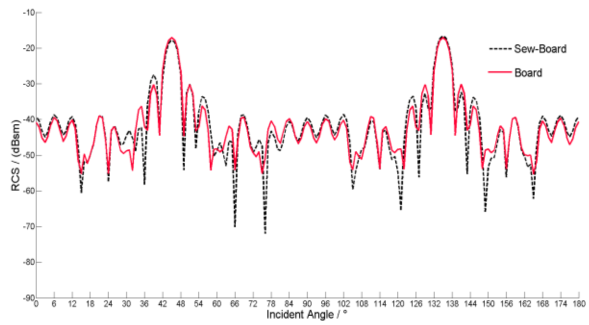

Figure 4. The RCS of serrate gap board and smooth board in different incident angles

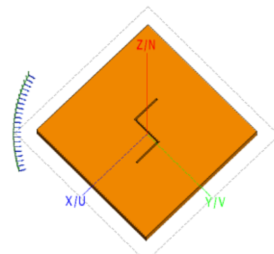

Figure 5. Serrate gap board model

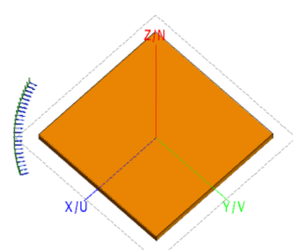

Figure 6. Smooth gap board model

According to the electric field data exported from FEKO, the electric field after carrier cancellation can be calculated using Equations (2-3). The 2D ISAR image is as shown in Fig. 7-Fig. 9. There are two phenomena observed from the images after 2D ISAR imaging verification within the range of error ($\Delta Y=\Delta X=\frac{C}{2B}$):

1. Strong scattering points appear in four corners of smooth board; compared with smooth board, the strong scattering points of serrate gap board appear in four corners and four peaks of serrate gaps.
2. The RCS of serrate gaps is extracted by carrier cancellation method. The effect of the carrier scattering is basically eliminated, which demonstrates the feasibility of carrier cancellation method.

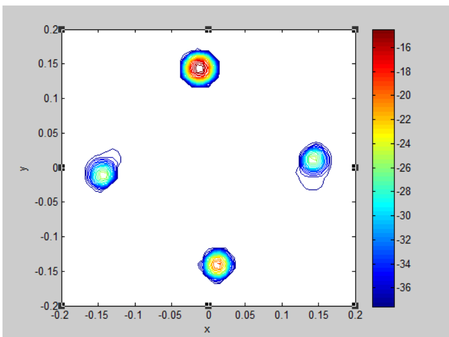

Figure 7. The 2D ISAR imaging of smooth board

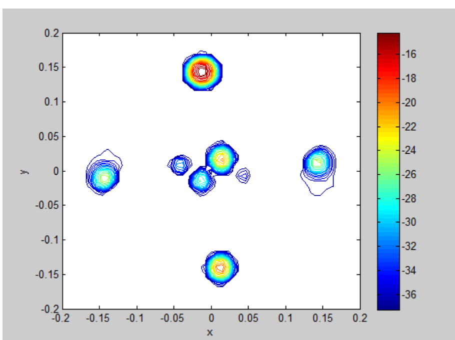

Figure 8. The 2D ISAR imaging of serrate gap board without cancellation

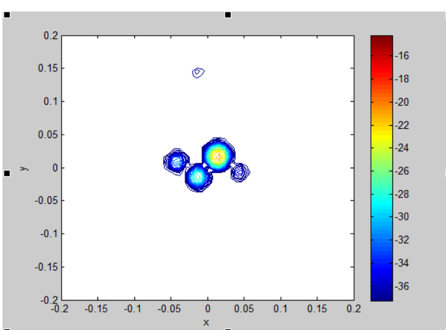

Figure 9. The 2D ISAR imaging of serrate gap board with cancellation

III. Calculation of Serrate Gap Scattering

A. Serrate Gap Model

According to reference [6-7], as shown in Fig. 10, ideal metal conductor with serrate gap is defined as model in this paper to simulate the real state of aircraft. The frequency of incident wave is 6~15GHz, with single increment frequency as 3GHz.

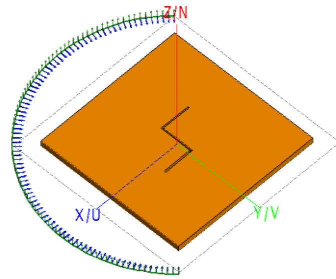

Figure 10. The RCS calculation model of serrate gap

B. Simulation Results

The RCS of serrate gap board and serrate gap in conditions of different polarization (HH and VV) is shown in Fig. 11-Fig. 14.

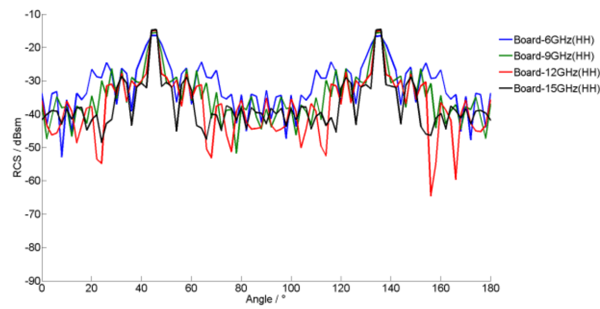

Figure 11. The RCS of serrate gap without cancellation (HH)

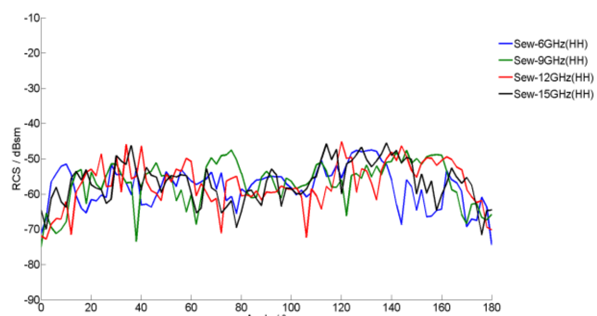

Figure 12. The RCS of serrate gap with cancellation (HH)

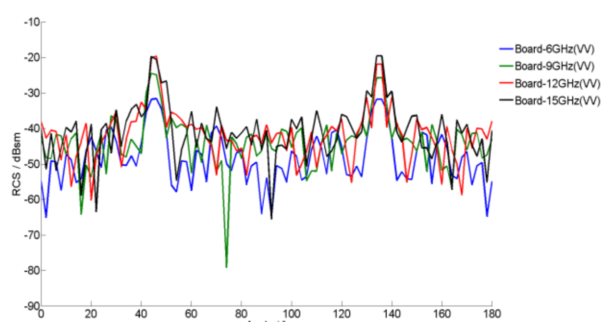

Figure 13. The RCS of serrate gap without cancellation (VV)

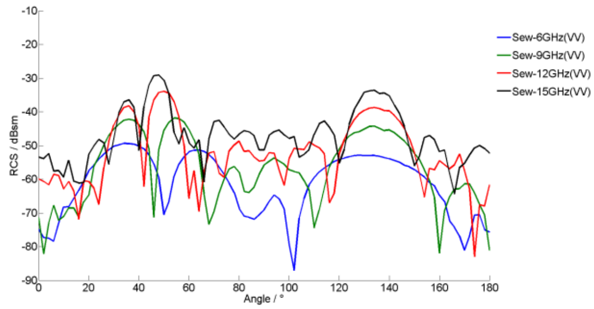

Figure 14. The RCS of serrate gap with cancellation (VV)

TABLE I. AVERAGE RCS AT DIFFERENT FREQUENCIES AND POLARZATIONS

Frequency	Average RCS			
	Without cancellation (HH)	With cancellation (HH)	Without cancellation (VV)	With cancellation (VV)
6GHz	-31.55dBsm	-57.98dBsm	-48.32dBsm	-61.59dBsm
9GHz	-34.59dBsm	-56.96dBsm	-43.89dBsm	-57.18dBsm
12GHz	-37.61dBsm	-57.19dBsm	-41.88dBsm	-52.67dBsm
15GHz	-37.50dBsm	-56.77dBsm	-40.88dBsm	-47.23dBsm

Some phenomenon (HH) are observed in Fig. 11: The RCS reaches the peak value at the incident angles of 45 °and 135 °without carrier cancellation and the peak RCS reaches -16.4dBsm, -15.6dBsm, -14.9dBsm, -14.7dBsm at different frequencies (6GHz, 9GHz, 12GHz, 15GHz). The peak RCS increases with the increment of frequency. The RCS of serrate gap maintains around -57dBsm with carrier cancellation in conditions of HH polarization as in TABLE I.

Compared with the phenomenon for HH polarization, the RCS of VV polarization reaches the peak value at the incident angles of 45 °and 135 °without carrier cancellation; The peak RCS reaches -31.8dBsm, -25.7dBsm, -21.9dBsm, and -19.5dBsm at different frequencies (6GHz, 9GHz, 12GHz, 15GHz) in Fig. 13. The peak RCS (VV) of serrate gap with carrier cancellation reaches -49.47dBsm, -42.2dBsm, -38.2dBsm, -36.4dBsm at different frequencies (6GHz, 9GHz, 12GHz, 15GHz) in Fig. 14 and TABLE I.

IV. CONCLUSION

In this paper, the RCS of serrate gap in the real state of aircraft is calculated, and the scattering characteristic of serrate gap is analyzed [8]. The following conclusions can be drawn: Two serrate gaps are simulated and computed, whose average RCS is around -56 dBsm. In the real case, however, the length of aircraft serrate gaps may increase to ten times the simulated length, and the average RCS may increase to around -46dBsm. As is shown in reference [9-11], forward scattering comes into being the peak value (about -23dBsm) when the incident wave is parallel to the serrate gap board with 0 intersection angle. The RCS of serrate in this paper can maintain around a stable value (about -33dBsm) in the same case, which demonstrates that serrate gap has a lower scattering characteristic. Using the carrier cancellation method, the RCS of carrier and serrate gap can be separated and it conforms to electric field vector superposition, which denotes that it takes less time and money to construct the gap board model. And It can be extended to the calculation and measurement of other weak scattering sources.

ACKNOWLEDGMENT

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