X-band RCS Reduction of Airborne Antenna Array Using Loaded PIN Diodes

Zijian Wu\textsuperscript{1,a}, Fei Wang\textsuperscript{2,b}, Jianjiang Zhou\textsuperscript{1,c}

\textsuperscript{1}College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China
\textsuperscript{2}College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China
\textsuperscript{3}College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China

\textsuperscript{a} Corresponding author: wzj\_ee@nuaa.edu.cn, \textsuperscript{b}wangxiao\_xian@nuaa.edu.cn, \textsuperscript{c}zjjee@nuaa.edu.cn

Abstract—The paper applies PIN diodes to airborne microstrip antenna array to achieve radar cross section (RCS) reduction while the array is not at work, thus enhance the stealth performance of the aircraft. PIN diode can be regarded as a variable resistance or capacitance when it is forward-biased or reverse-biased, respectively. The equivalent resistance value of PIN diode in the forward-biased state is optimized and the radiation performance of the antenna array is not seriously affected. Simulation results show that the method can dramatically reduce the antenna RCS by disturbing the electric field distribution of current incident wave. The experiment results depict that maximum RCS reduction of aircraft model is more than 25dB, thus validates the proposed method.

1. INTRODUCTION

In the modern warfare, the stealth performance of military aircraft is becoming more and more important. In order to enhance the radio frequency (RF) stealth performance, airborne radar work-hour is always shorter than non-working time. Since the antenna array mounted on the modern aircraft is one of the main scattering sources, it is important to reduce the RCS of the antenna as well as maintaining the radiation performance. The structure of antennas can be modified to achieve RCS reduction \cite{1,2}, which need sophisticate design and trade-off of the parameters. For the advantages of small size, low cost, light weight and easy to conform, microstrip antenna has been widely used in aircrafts. This paper focuses on non-working time RCS reduction of microstrip antenna by changing the bias state of PIN diode determined by the induced electric field distribution\cite{3}, while the radiation performance of the antenna is not seriously affected when it is at work. This paper simulates RCS results of antennas under different frequencies as well as different angles of incident waves. The experiment results of antenna array mounted on a glass fiber aircraft model show that the proposed method can dramatically reduce RCS when antenna is not at work.
2. MODEL OF MICROSTRIP ANTENNA WITH LOADED PIN DIODE

The proposed probe-fed triangular microstrip patch antenna is shown in Fig. 1, which works in X-band. The three-dimensional parameters of the antenna is L×W×h = 10×11×0.813mm, loss tangent tanδ = 0.002, relative dielectric constant εr = 3.55. The patch is an isosceles triangle, Lp×Wp = 9.04×10.44mm.

![Figure 1. Top and side view of the microstrip antenna.](image)

\[
\sigma = \lim_{R \to \infty} \frac{4\pi R^2}{|E_i|^2} \left| \frac{E_s}{E_i} \right|^2
\]

where Es, Ei and R are the scattered electric field at the receiver, the incident electric field at the target, the distance between the target and receiver, respectively. The scattered electric field at the receiver can be changed by modifying the scattering pattern after disturbing the induced electric field under the patch. The PIN diodes are attached to the vertexes of the patch, where the maximum induced electric field occurs.

![Figure 2. The loading circuit model of PIN diode](image)

The loading circuit model of PIN diode is shown in Fig. 2. If the frequency is higher than the cut-off frequency of the PIN diode, then the working state of the PIN diode depends on the magnitude and polarity of the bias voltage loaded at both ends. When the antenna is not at work, the forward bias voltage is applied to both ends of PIN diode to turn it into variable resistance and then suppress the induction resonance mode, thus reducing the RCS of microstrip antenna. By changing the forward bias voltage, the equivalent resistance of PIN diode can be reduced from 10kΩ to several hundred ohms. Therefore, the RCS reduction of microstrip antenna under different incident conditions can be flexibly realized by adjusting the bias voltage.

3. SIMULATION RESULTS OF MICROSTRIP ANTENNA RCS REDUCTION

3.1. RCS reduction for one microstrip antenna

The software FEKO is used to simulate the resistance parameters of PIN diodes at the vertexes of the triangular patch, as well as the RCS simulation of the antenna. In order to study the monostatic RCS reduction, 4 different incident angles are considered, which are (θ=60°,φ=0°), (θ=60°,φ=30°), (θ=60°,φ=60°), (θ=60°,φ=90°), respectively. θ-polarized incident plane wave is considered in the simulation, and the RCS as well as corresponding frequencies are recorded in Table 1.
TABLE I. MAXIMUM RCS OF DIFFERENT INCIDENT ANGLES.

| Angles | φ=0° | φ=30° | φ=60° | φ=90° |
|-------|------|-------|-------|-------|
| Frequency (GHz) | 9.56 | 9.55 | 9.33 | 9.34 |
| RCS (dBsm) | -33.87 | -35.05 | -35.19 | -36.54 |

The RCS of antenna can be reduced after tuning the resistances of the PIN diodes. The maximum RCS reduction (dB) of different frequencies are recorded in Table 2. X represents the frequency corresponding to the maximum RCS, which are shown in Table 1.

TABLE II. RCS REDUCTIONS OF DIFFERENT INCIDENT ANGLES AND FREQUENCIES.

| Frequency (GHz) | φ=0° | φ=30° | φ=60° | φ=90° |
|-----------------|------|-------|-------|-------|
| 9               | 4.73 | 8.15  | 9.84  | 9.55  |
| 10              | 6.04 | 6.16  | 8.43  | 4.94  |
| 11              | 2.66 | 2.85  | 6.17  | 3.19  |
| X               | 25.41 | 23.34 | 18.72 | 22.81 |

As is shown in Table 2, the microstrip antenna can achieve significant RCS reduction by attaching and tuning PIN diodes to the vertexes of the patch.

3.2. Radiation of one loaded microstrip antenna

In order to study the influence on the radiation performance of the proposed loaded antenna, the radiation parameters of the antenna is simulated. Fig. 3 shows the S11 curves of the antenna with and without loaded PIN diodes. Fig. 4 depicts the radiation pattern in E-plane and H-plane.

Figure 3. 

![Figure 3](image-url)  

(a)E-plane
The relative bandwidth with $S_{11}$ less than -10 dB of the loaded antenna is almost the same as before. The gain of the antenna is only reduced by 0.1 dB and the back lobe of the antenna increases about 0.2 dB. The radiation performance is not seriously affected and there is no need to redesign the antenna.

3.3. RCS reduction for microstrip antenna array
In this part, we apply the RCS reduction method to a ten-element linear microstrip antenna array. The repetitive period of antennas is 15mm and PIN diodes are attached between vertexes of each adjacent antenna. The equivalent resistance of PIN diode has been tuned to $670\,\Omega$, and the RCS curves of antenna array with and without the loaded PIN diodes of different incident plane wave angle at 10GHz are shown in Fig. 5. The red dotted line and the black solid line represent the RCS of antenna with and without loaded PIN diodes, respectively.

Curves in Fig. 5 show that up to 4dB reduction of RCS can be achieved between -15° and 15°. The maximum RCS reductions appears at azimuth angle 0°, where the incident wave direction is normal.

4. Antenna array placement and RCS measurement
In order to check the effect of proposed method on airborne antenna array, two 3*50 microstrip antenna arrays are mounted on two wings of a glass fiber aircraft model, which is measured in microwave darkroom. The photo in Fig. 6 shows the aircraft model mounted with antenna arrays. Resistors are used in the experiment to represent PIN diodes for simplification of the model.
Figure 6. Glass fiber aircraft model and antenna array.

The repetitive period of antennas is 15mm, and the angle of pitch of the 10GHz incident plane wave is set to 45°, which ensures that the incident wave can illuminate the array near normal angle. RCS curves of the glass fiber aircraft model are shown in Fig. 7.

Figure 7. RCS of the aircraft at angle 45°.

In Fig. 7, the red dotted line and the blue solid line represent the RCS of antenna with and without loaded PIN diodes, respectively. The RCS can be reduced up to 25dB at azimuth between -20° and 20°. Considering that scattering angle near the nose direction of the aircraft is important to the stealth performance, the result of RCS reduction is inspiring.

5. CONCLUSION
In order to enhance the stealth performance of aircraft mounted with antenna array, the paper applies PIN diodes to microstrip antenna array to realize radar cross section reduction while the array is not at work. The equivalent resistance value of PIN diode is optimized in the forward-biased state and the induction resonance mode can be suppressed. Simulated results illustrate that optimization of PIN diode state based on the electric field distribution of current incident wave can dramatically reduce the antenna RCS while the radiation performance of the antenna array is not dramatically affected. The proposed antenna arrays are tested on a glass fiber aircraft model and the maximum RCS reduction is more than 25dB, which means the stealth performance of the aircraft can be well maintained.

ACKNOWLEDGMENT
This research was supported by the Aeronautics Science Foundation of China (Grant No. 2017ZC52036, No. 20172752019), National Natural Science Foundation of China under Grant 61801212, and Natural Science Foundation of Jiangsu Province under Grant BK20180423.

REFERENCES
[1] N. Rajesh, K. Malathi, S. Raju, et al, “Design of Vivaldi Antenna With Wideband Radar Cross Section Reduction,” IEEE Trans. Antennas Propag. vol. 65, no. 4, pp. 2102-2105, April 2017.
[2] M. Zahir Joozdani, M. Khalaj Amirhosseini and A. Abdolali, “Wideband radar cross-section reduction of patch array antenna with miniaturised hexagonal loop frequency selective surface,” Electron. Lett. vol. 52, no. 9, pp. 767-768, April 2016.

[3] Y. Liu, H. Wang, K. Li and S. Gong, “RCS Reduction of a Patch Array Antenna Based on Microstrip Resonators,” IEEE Trans. Antennas Propag. Lett. vol. 14, pp. 4-7, 2015.

[4] Y. Shang, S. Xiao, M. C. Tang, Y. Y. Bai and B. Wang, “Radar cross-section reduction for a microstrip patch antenna using PIN diodes,” IET Microw. Antennas Propag. vol. 6, no. 6, pp. 670-679, 24 April 2012.

[5] S. Wang, J. Gao, X. Cao, Y. Zheng and J. Lan, “Design of Wideband Patch Antenna Array with Low RCS Performance Based on Metasurface,” J Electron. Inform. Technol. vol. 40, no. 9, pp. 2273-2280, 2018.