The Development And Process of A Dual-Band UAV Radar Antenna

Tong Wenqing, Bai Yifeng, Chen Qihai and Huo Shaoxin

1 The 38th Institute of CETC, Hefei 230088, China

Abstract. This In order to meet the design requirements of airborne radar antenna, this article introduces the design and molding process of a dual-band UAV-borne radar composite material antenna. The article proposed a kind of antenna unit which composed of skin, foam and microstrip antennas and carbon fiber, and a reflector with composite structure composed of foam, carbon fiber and stiffeners. The antenna and reflector are designed through an integrated process. A series of measures including the weight reduction and functional design of the antenna unit and reflector, the material performance is analyzed and optimized, and the mold design is adopted. It successfully developed a composite antenna with a size of 6000mm×800mm×20mm. After environmental test verification and a series of performance tests, the product is in good technical condition and meets the design requirements. This kind of composite material antenna has already been used on a type of drone, the drone has gone through flight test and the performance of the antenna is great. The successful development of this product can be used as reference for similar kind of UAV-borne radar antenna.

1. Introduction
Unmanned aerial vehicles (UAV) play an important role in improving battlefield situation awareness, high-risk target penetration capabilities, communication and navigation support capabilities, and the ability to suppress enemy air defense systems. They are in a prominent position in future wars. Airborne radar is a complex electronic device; its reliability level directly affects the success of UAV mission. To improve the performance of the UAV, it is important to control the weight of the airborne equipment without affecting its performance; for the airborne radar composite material antenna [1], it is necessary to integrate the load and platform to make full use of its internal space and reduce tasks load. Based on this, the UAV antenna-radiating unit, reflecting surface, and centimeter network equipment are integrated into the process design, to maximize the equipment capacity of the electronic system.

2. Antenna overview

2.1. Antenna composition
The antenna front is composed of an antenna-radiating unit, reflector, and centimeter network. The antenna unit is arranged on the front of the reflector in the form of N rows * M columns. The centimeter network and other equipment are on the back of the reflector. The centimeter network connector passes through the reflector vertically. The board and the antenna-radiating unit are welded to maintain the signal connection. The antenna-radiating unit is a T-shaped structure with a maximum shape of 395mm×190mm; the reflector is flat shaped, formed by forming the left and right pieces, and then assembled, and its overall outline size is 6000mm ×800mm×20mm, as shown in Figure 1.

2.2. Main technical specifications

![Figure 1. Schematic diagram of the structure of a dual-band antenna.](image1)

The weight requirements meet the relevant requirements of the airborne project

Working temperature: −55°C–+70°C;

The requirements for resistance to damp heat, mold, and salt spray are conducted based on relevant experimental requirements of GJB150A;

Acceleration, vibration, and shock resistance requirements are conducted based on relevant experimental requirements of GJB150A and UAV projects.

3. Antenna weight reduction design

3.1. Weight reduction design of antenna radiation unit

Due to a large number of antennas, to reduce weight, the antenna is designed as a skin/foam/microstrip interlayer composite structure[2]. The antenna element is designed to meet the rigid airborne vibration condition. The antenna unit layer is optimized with lightning holes according to the characteristics of the composite material molding process. ROHACELL foam [3] with excellent dielectric and mechanical properties is selected to reduce the thickness of the skin and foam support. The final weight of the antenna-radiating unit is a P-band antenna single weight of the radiating unit which meets the index requirements. The schematic diagram of the antenna-radiating unit is shown in Figure 2.

![Figure 2. Schematic diagram of an antenna-radiating unit.](image2)
3.2. Weight reduction design of the reflector
Carbon fiber composite material has the characteristics of high strength and rigidity and has the advantages of corrosion resistance and low-temperature deformation. Compared with aluminum alloy components, it can reduce weight by 20%–30%. The reflector of the antenna is made of carbon fiber/epoxy skin. The middle core layer is an interlayer structure with ROHACELL 51HF foam as the core, which greatly reduces the weight of the reflector.

To reduce the weight of the reflector, the thickness of the skin material should be reduced as much as possible on the premise of satisfying the mechanical properties. Due to the long antenna size, the foam core is embedded with reinforced ribs made of mesh carbon fiber/epoxy. The integral molding of skin and foam provides the overall rigidity support of the reflector, which greatly enhances the general strength of the reflector and improves the reliability of the product without affecting its overall weight.

To ensure the reliability of the connection between the antenna unit and the reflector, the form of pre-embedded parts in the foam interlayer of the reflector is implemented, and the structural form of the embedded parts is optimized and the process design is minimized. Precise positioning not only achieves the goal of weight reduction but also benefits the integration of the reflector later.

During the production process, the weight of part left and right reflector was recorded, and the total weight of various materials was less than 14.2 kg required by the index, which meets the design requirements. The schematic diagram of the antenna reflector is shown in Figure 3.

3.3. Grounding design of the reflector
The reflector is used as an integrated function structural part of the antenna load and the platform. The L+P-band microstrip antenna is installed on the front; the power division network is installed in the back. The communication between the microstrip antennas needs to be designed in the reflector to make all antenna unit forms a connected network, thereby achieve the common ground design between the antenna-radiating unit and power division network.

The P+L band microstrip antenna on the front and power division network on the back is connected with the parts embedded in the foam interlayer of the reflector to achieve connection with the reflector. The embedded parts are all made of aluminum. Therefore, the electrical connection between the microstrip antenna and the power division network can be achieved by connecting the embedded parts. According to the distribution of embedded parts on the reflector, aluminum is processed and turned into aluminum strips of the corresponding size then, embedded in the foam. The aluminum strips and the embedded parts are welded to form an integrated network. The electrical connection and grounding diagram between the reflector and foam are shown in Figure 4.
4. Antenna forming technology

4.1. Material selection

The antenna consists of a radiating element and a reflector. The antenna-radiating element has requirements for wave transparency. Quartz fiber and cyanate ester prepreg are used as skin material. The core material is PMI-51S foam; the reflector is made of carbon fiber and epoxy resin prepreg; as the skin material, and the core material is PMI-51HF foam.

4.1.1. Skin material selection. The composite material has the characteristics of lightweight and high strength, which meets the requirements of the antenna-radiating unit. Reinforced fibers used in composite materials requiring wave transparency include quartz fiber, aramid fiber, and glass fiber series[4]. From Table 1, it can be seen that compared with S glass fiber, the mechanical properties of quartz are slightly lower, but its density and linear expansion coefficient are low, and the moisture absorption rate is also small. In products that require heat and humidity, the low moisture absorption characteristics of the antenna material will greatly help stabilize the dielectric performance, and it is particularly suitable in airborne electronic products; The dielectric properties of D glass fiber are close to that of quartz fiber, but its relatively low tensile strength and elastic modulus cannot meet the vibration and shock requirements of airborne products; for aramid fiber, its moisture absorption characteristics will affect the dielectric of the antenna performance indicators, so quartz fiber has excellent comprehensive performance, which meets the requirements of this project.

| Fiber    | Density (g cm$^{-3}$) | Tensile strength (MPa) | Elasticity modulus (GPa) | Dielectric coefficient | Dielectric loss |
|----------|-----------------------|------------------------|--------------------------|------------------------|----------------|
| E glass  | 2.57                  | 3058                   | 71.5                     | 6.6                    | 0.0011         |
| S$_2$ glass | 2.54              | 4020                   | 83.3                     | 5.6                    | 0.0072         |
| D glass  | 2.14                  | 2000                   | 48.0                     | 3.9                    | 0.0010         |
| Kevelar49| 1.45                  | 3400                   | 130                      | 3.9                    | 0.0010         |
| Quartz   | 2.20                  | 3600                   | 78.0                     | 3.6                    | 0.0002         |

Cyanate ester is a thermosetting resin with excellent comprehensive properties. It has excellent mechanical properties, heat resistance, and damp heat properties. Compared with epoxy resin, its toughness is between the multifunctional epoxy resin and the difunctional epoxy resin. The processing performance is close to or equivalent to epoxy resin. The disadvantage of cyanate resin is that the monomer synthesis process is complicated and the cost is relatively high. The cross-linked structure formed after curing of cyanate ester is highly symmetrical and its polarity is weak. Compared with
other types of thermosetting resins, the structural characteristics of cyanate ester resin ensure that it has good thermal stability and broadband dielectric stability. It is widely used as a temperature-resistant and wave-transparent material. The performance of cyanate ester/quartz cloth prepreg is shown in Table 2, and cyanate ester film is shown in Table 3.

**Table 2.** Performance of J-284PD cyanate ester/quartz cloth prepreg.

| $\varepsilon$ (9.375GHz) | $\tan\delta$(9.375GHz) | Tensile strength (MPa) | Elasticity modulus (GPa) | Bending strength (MPa) | Bending modulus (GPa) | Interlaminar shear strength (MPa) | Poisson's ratio | Tg (°C) | Curing temperature |
|-------------------------|-------------------------|------------------------|--------------------------|-----------------------|-----------------------|----------------------------------|----------------|--------|------------------|
| 3.3                     | 0.004                   | 657                    | 23                       | 757                   | 23.4                  | 63                               | 0.5            | 236    | 130°C/4h         |

**Table 3.** Performance of J-284F cyanate ester film (with carrier).

| $\varepsilon$ (9.375GHz) | $\tan\delta$(9.375GHz) | Shear strength (MPa) | Board-board peel strength (N/cm) | Board-core peel strength (N/cm) | Roller peel strength (N/mm) | Curing temperature |
|-------------------------|-------------------------|----------------------|----------------------------------|--------------------------------|----------------------------|------------------|
| 3.3                     | 0.004                   | 29.5                 | 65                               | 35                             | 35                         | 130°C/4h         |

As for now, airborne antennas at home and abroad have high specific strength and rigidity because of carbon fiber materials, they mostly use carbon fiber/epoxy composite materials as the skin material. Considering many aspects such as manufacturability and price, the reflector skin material is WP-3021H-6508 carbon fiber prepreg, its performance data are shown in Table 4, the film is J-272 epoxy film, and its performance is shown in Table 5.

**Table 4.** Performance of WP-3021H-6508 carbon fiber prepreg.

| Fiber | Resin | Interlaminar shear strength (MPa) | Bending strength (MPa) | Compressive strength (MPa) | Tensile strength (MPa) | Tensile modulus (GPa) | Curing temperature |
|-------|-------|-----------------------------------|------------------------|---------------------------|-----------------------|----------------------|------------------|
| Toray Company T300-3K | 6508 | 50                               | 610                    | 500                       | 670                   | 50                   | 120°C/2h         |

**Table 5.** Performance of J-272 film.

| Metal | Composite material |
|-------|---------------------|
| Shear strength (MPa) | Shear strength (MPa) |
| $-55^\circ$C | 23°C | 80°C | 120°C | $-55^\circ$C | 23°C | 80°C |
| Honeycomb plane stretch (MPa) | Honeycomb plane stretch (MPa) |
| Roller peeling (Metal-metal) (N/m/m) | Roller peeling (Metal-honeycomb) (N/m/m) |
4.1.2. Core material selection. The commonly used interlayer materials for antenna-radiating elements are Nomex honeycomb and foam. Since the supporting foam of the antenna-radiating element is two layers of upper and lower layers and should be close to the microstrip antenna, there are certain requirements on the shape, which is difficult to achieve with foam honeycomb processing, so the PMI foam 51S integrated molding with excellent dielectric properties are selected [5, 6].

Because the reflector core material needs to be embedded with the ground network and installation of stiffeners, the honeycomb material is difficult to achieve those requirements above. Therefore, the PMI foam material 51HF with the highest strength and rigidity with the same density is selected. The performance of several common foam materials is shown in Figure 5. PMI-51S and PMI-51HF foam performance in Table 6.

Figure 5. Performance comparison of various common foam materials.

Table 6. Performance of PMI-51S/51HF foam.

| ROHCELL | Density (Kg/cm³) | Compressive strength (MPa) | Tensile strength (MPa) | Bending strength (MPa) | Shear strength (MPa) | Elastic modulus (MPa) | Shear modulus (MPa) | Breaking elongation ratio (%) | Heat distortion temperature (°C) |
|---------|-----------------|---------------------------|------------------------|------------------------|----------------------|----------------------|----------------------|-------------------------------|-------------------------------|
| 51S     | 52              | 0.7                       | 1.1                    | TBD                    | 0.6                  | 50                   | 20                   | 3.5                           | 190                           |
| 51HF    | 52              | 0.9                       | 1.9                    | TBD                    | 0.8                  | 70                   | 19                   | 4                             | 180                           |

4.2 Mold design

Due to the long size of the reflector, it is designed to be divided into two pieces, and the left and right pieces are spliced together. Therefore, the appearance and plane accuracy of the reflector are required to be high. Consider the use of steel molds when designing the mold. The conventional molding process will due to the lack of filling, there is a hollowing phenomenon on the surroundings, and the defects cause uneven surroundings, which affects the assembly of adjacent reflectors.

To avoid this situation, the surrounding frame needs to be designed to be movable. Therefore, when designing the mold, there should be a four-sided movable enclosure on the mold bottom plate. After the foam board and skin are placed, it can be folded to the middle, and the reflector around the reflector should be pressed tightly (see Figure 6). The four-side frame is equipped with a limit device to make the mold move to the theoretical size of the reflector. The plane accuracy around the reflector and the overall size can be guaranteed in this way.
4.3. Molding process
The antenna-radiating unit and the reflector are formed separately and then assembled through embedded parts. The process flowchart of the antenna radiation unit is shown in Figure 7, and the technical flow process of the reflector is shown in Figure 8.

![Figure 6. Mold of a reflector.](image)

**Figure 6.** Mold of a reflector.

**Figure 7.** Process flow chart of antenna-radiating unit.

**Figure 8.** Process flow chart of a reflector.

5. Experimental verification
To address the characteristics of the UAV’s operating environment, in addition, to consider the impact of environmental factors such as heat and humidity, temperature changes, and salt fog on antenna’s reliability, the impact of vibration in the airborne environment on the antenna is also considered. Through a series of environmental tests such as temperature storage, temperature shock, damp heat, salt spray, and vibration. The environmental resistance characteristic of the prototype antenna meets the product requirements.
Due to a large number of antenna radiation units, we randomly selected a single L and P-band antenna radiation unit for the endurance vibration test. After 9.5 h of endurance vibration test, the antenna is in good condition (see Figure 9) [7]. Simultaneously, the antenna radiation unit still went through tests such as environmental tests such as temperature storage, temperature shock, damp heat, and salt spray following the project test program requirements, and the test results show that the design meets the design requirements.

For the antenna system, we conducted functional vibration and road transportation vibration tests according to the requirements of the airborne products (see Figure 10) [7]. By comparing the standing wave test of the antenna radiation unit before and after vibration, the consistency is good and the index requirements are met.

6. Conclusion
Airborne equipment has high requirements for weight and space. To optimize aircraft performance, airborne equipment must be reduced in size and weight to the utmost extent. Through material optimization, layering weight reduction design and molding process design, the weight of the equipment is greatly reduced and meets the development trend of airborne equipment. The successful development of this product provides new ideas for the design and manufacturing of the UAV radar antenna technology of our institute.

References
[1] Xiaosu Y, Shanyi D and Litong Z 2009 Composite material manual [M], Beijing Chemical Industry Publishing Company.
[2] ShaoxinH, YifengB and Wenqing T 2019 A type of lightweight airborne antenna unit and its preparation method. China national defense invention patent: ZL201618003084.4, 2019.11
[3] Dengcai Z, Yiping Z, Fuqing H and Jie Z 2018 The application of carbon fiber composite material in the structure of satellite antenna. Electronic Mechanical Engineering 352-55.
[4] Liangyuan C, Qinghai W and Qiang Z 2010 Ultra-wideband dome covering X wave point to Ka wave band. Aerospace Material 2 37-40.
[5] Yuexia Z 2010 A PMI brief introduction of the research and application of foam plastics at home and abroad. Aerospace Material 40(2) 13-16.
[6] Pei H 2003 PMI foam: Core material of sandwich structure. Glass fiber reinforced plastics 2 9-17.
[7] Meiyuan W, Chang L and Feng H 2018 A type of lightweight antenna unit structure design. Mechanics and Electronics (1)18-21.