Analysis of the Impact of Airborne Multi-antenna Radar Power Architecture on Weight

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Abstract: Multi-antenna phased array radar is widely used in airborne detection, and the weight of its power system is affected by the number of antenna and power architecture. Based on the morphological differences of secondary power supply, the power architecture is divided into independent unit architecture, independent module architecture and distributed architecture. By analyze the weight composition and characteristics of power system in multi-antenna radar, the applicable scenarios of various architectures are obtained, and the influencing mechanism of antenna number on power weight is demonstrated. Finally, based on typical airborne fire control radar, the specific weight composition of power system of various architectures in single-antenna radar and three-antenna radar is compared, and the specific effect of antenna number on power weight is obtained.

Keywords: Multi-antenna Radar, Power Architecture, Weight

1. Introduction

Phased array radar is a detective system with multiple functions, such as rapid scanning of antenna beam, rapid changing of antenna beam shape, spatial orientation and spatial domain filtering, spatial power combining, conformal with platform and multi-beam forming. It has been widely used in space-object detection, advanced air defense systems, airborne early warning, airborne fire control, multi-target precision tracking and measurement [1].

Static single-antenna array cannot achieve omnidirectional scanning. There are two methods to realize omnidirectional beam scanning, one is the traditional mechanical scanning radar, and the other one is multi-antenna phased array radar, which arranging multiple phase arrays in different directions statically to cover all airspace. Multi-antenna phased array radar has many advantages, such as no transmission system, high reliability, strong adaptive ability and high scanning speed [2].

Different from single-antenna phase radar, the power system of multi-antenna phase radar is more complex, which needs to meet the power supply requirements of each antenna array at the same time. Based on the comprehensive consideration of the overall combat performance, the evaluation indexes of the power system are not only limited to the power supply capacity, conversion efficiency, power supply quality and other technical indexes of power supply, but also including the system weight, which is the key mechanical index of airborne equipment. Aiming at the airborne multi-antenna phase array radar, this article analyzes the weight composition and influence factors of power systems in different architectures.
2. Power system of multi-antenna radar

a) Main form and typical power supply mode of multi-antenna phased array radar

Airborne multi-antenna phased array radar is commonly used in early warning aircraft (AEW). There are many types of AEW equipping with multi-antenna phased array radar, such as A-50 AEW (Russia), ZDK-03 AEW (China), Phalcon AEW (Israel), S100B AEW (Sweden), etc. The appearance of each AEW is shown in Fig. 1. In order to expand the azimuth of sight and improve the survivability in battlefield, some types of fighter aircraft have equipped with multi-antenna phased array radar in recent years, such as Sukhoi Su-57 (Russia) shown in Fig. 2.

![Figure 1. Typical AEW equipping with multi-antenna radar](image1)

![Figure 2. Typical fighter aircraft equipping with multi-antenna radar](image2)

The object of this article is the multi-antenna phase array radar with a moderate distance between each antenna and a common power system, excluding the situation that the antennas are too discrete and completely independent.

The power consumption of the antenna array unit is not always divided equally, and needs to be adjusted according to the operational requirements of the mission system in different spatial domain. Especially in the single target tracking mode, the radar needs to concentrate power supply on a certain antenna array unit. Therefore, the power system must have the ability to meet the full power supply of all antenna array units.

b) Composition of power system

Phased array radar uses transceiver modules widely, which requires a power supply with high current, high reliability and high stability characteristics. The power system generally adopts a three-level conversion architecture (shown in Fig. 3): the primary power component converts the AC power provided by the aircraft into a DC high-voltage power; the secondary power component converts the DC high-voltage power into various types of DC low-voltage power; the tertiary power component converts the DC low-voltage power into various voltages for specific RF module. The tertiary power component is installed in the transceiver and RF module, and will not be analyzed in this article.
It can reduce the inputing (shown in Fig. stem). Therefore, it adopts the form of “chassis-blind plug module” (shown in Fig. 5), resulting in more and heavier structural parts of the power supply unit. However, the antenna array unit is light because it does not need to install secondary power component.

The secondary power component is lighter. Due to the centralized layout of the secondary power supply, the entire system only needs to equip one set of full-power secondary power devices to meet the full power supply needs of all antenna array units. Therefore, it can reduce the redundancy of the secondary power devices effectively.

The interconnecting cables are relatively heavier. First, after primary and secondary conversions, the interconnecting cables between the power unit and antenna array unit are low-voltage high-current...
c) System weight analysis of independent module architecture
In this architecture, the power system consists of one primary power unit and several secondary power modules (shown in Fig 5). Since the primary power unit has a more single function and a smaller volume, a box structure is generally used. There are no components such as the chassis and interconnecting backplane, so that the weight of primary power is lighter.

The secondary power component is heavier. First, in order to improve the maintainability, the secondary power module is mostly connected with the antenna array unit by blind plugging. Therefore, it is necessary to add structures such as guide rails and blind plug connectors. Second, each antenna array unit needs a full-power secondary power module, which causes the secondary power to double.

The interconnecting cables are relatively lighter. After primary conversion, the interconnecting cables between the power unit and antenna array unit are high-voltage low-current cables, so that the weight per unit length of the cable is lighter. Furthermore, there is only one pair of cables usually.

Base on a single perspective of system weight reduction, this architecture is suitable for radars with less antenna arrays and a longer distance between the power unit and the antenna array unit.

d) System weight analysis of distributed architecture
In this architecture, the secondary power is changed to several distributed parallel module based on the independent module architecture. This architecture has the advantages of simple thermal design, easy modularization and standardization, high redundancy and reliability, high accuracy of load voltage regulation, and easy expansion [4-6].

In this architecture, the state of the independent power unit (primary power) and the interconnecting cables are consistent with the independent module architecture. In AEW radars operating in lower frequency bands, due to the higher power and electromagnetic compatibility requirements, the secondary power devices are larger in size, and generally installed in the surrounding area of the functional module with independent structural shells or incorporated into the functional module without independent structural shells. In fighter aircraft radars operating in higher frequency bands, due to the high degree of system integration, secondary power devices can be stacked and installed into the overall structure of the antenna array unit as a profile, and a sandwich structure needs to be added.

Base on a single perspective of system weight reduction, the applicable situation of this architecture is the same as that of the independent module, but the weight of the two architectures needs to be evaluated according to the specific situation.

![Image](image_url)

**Figure 5.** The typical form of power component in different architecture

e) Impact of antenna array quantity on power system weight
The number of antenna array affects the weight composition of different power architectures directly. Under the same total power consumption conditions, when the number of antenna array is small, the independent unit architecture power system is heavier because of heavier unit chassis and
interconnection cables; when the number of antenna array is large, the remaining two architectures power systems are heavier because of the doubling of secondary power devices.

4. Example analysis

a) Analysis Overview
In the actual engineering design, the choice of power architecture needs to conduct overall evaluation from multiple perspectives, such as electrical performance, structural performance, technological feasibility, quality characteristics, and cost. This example is based on some typical fighter aircraft fire control radar. Under the same total power consumption, the power system weight composition under different antenna array quantity is analyzed.

In the analysis, the weight of the power system is divided into six parts: the primary power device (recorded as PPD), the secondary power device (recorded as SPD), the primary power structure (recorded as PPS), the secondary power structure (recorded as SPS), the antenna array unit frame weight gain (recorded as AFG), and the interconnection cable (recorded as IC).

In the independent unit architecture, the primary power and the secondary power are combined into a chassis unit. The weight of the structural components of the entire chassis is divided into the PPS and SPS in proportion to the ratio between the PPD and SPD. In the independent module architecture, the SPS refers to the blind plug module structure of the secondary power, and the AFG refers to subsidiary structure added to support the installation of the secondary power module in antenna array unit, such as the directional guides, pins and blind plug connectors. In the distributed architecture, the SPS refers to the sandwich structure required for distributed installation, and the AFG refers to the mounting blocks and rigidity strengthening structures required to match the power sandwich structure.

b) Analysis example simplification
Simplify the analysis example as follows:
- Does not consider the situation that the arrays are too discrete and completely independent.
- Assume that the dimensions of each array are the same, and all arrays have full power mode.
- Assume that the total input power of the system is constant, so that the PPD is constant in various architectures and various antenna array quantities.
- Set the PPD to one unit weight, and the weight of each part is measured by the ratio of its actual weight to the PPD.

c) Power weight composition of single-antenna array radar
The power weight composition of three architectures in single-antenna array radar is shown in Fig.6. The weights of three architectures are roughly the same. The distributed architecture is the lightest and the independent unit architecture is the heaviest.

Fig.7 is a pie chart of weight composition. It can be seen that in the independent unit architecture, the chassis weight (PPS + SPS) and IC are the components that make it heaviest; In the independent module architecture, the secondary power is installed on the antenna as a module, without the need for a separate chassis and a sandwich structure, so that the SPS is reduced significantly; In distributed architecture, although the SPS in the form of sandwich has increased significantly, but the SPD has also decreased significantly.
Figure 6. Power weight composition of single-antenna array radar

1) Independent unit  2) Independent module  3) Distributed (7)

Figure 7. Weight composition pie chart of single-antenna array radar

d) Power weight composition of three-antenna array radar

The power weight composition of three architectures in three-antenna array radar is shown in Fig.8. The weights of three architectures vary widely. The independent unit architecture is the lightest and the independent module architecture is the heaviest.

Fig.9 is a pie chart of weight composition. It can be seen that in the independent unit architecture, the total weight does not increase much compared to the single-antenna array radar, which is mainly reflected in the increase of the IC; in the other two architectures, the SPD and SPS have doubled, resulting in significant weight gain.

e) Correlation between the array quantity and the power weight

After analyzing the situation of the two-antenna array and the four-antenna array similarly, the total weight of the power system under different numbers of arrays is summarized and compared in Fig.10.
When the number of antenna arrays is small, the power weights of three architectures are close, and the distributed architecture has a slight advantage; as the number increases, the power weight of the independent module architecture and the distributed architecture increases significantly. Due to higher device integration, the weight of the distributed architecture is slightly better than the independent module architecture.

In the independent unit architecture, the secondary power supply device is shared by multiple arrays, so the weight is not sensitive to changes of array quantity. In the other two architectures, each antenna array is equipped with a secondary power separately, so the weight is sensitive to changes of array quantity.

Figure 10. Comparison chart of power weight under different antenna quantity

5. Conclusion
Based on the analysis and example comparison of the weight composition of different power architecture in the multi-antenna array radar, the following conclusions are formed:

1) The antenna array quantity has different effects on the power weight of different architecture. In independent unit architecture, power weight is not sensitive to the change of array quantity; in the independent module architecture and distributed architecture, power weight is sensitive to changes of array quantity;

2) When the antenna array quantity is large, the independent unit architecture is lighter; when the antenna array quantity is small, the other two architectures are lighter;

3) The independent module architecture and the distributed architecture are very close in weight, but the distributed architecture with a higher integration has a slight advantage.

This article demonstrates the impact of the antenna array quantity and power architecture on the weight of the radar power system, and provides a theoretical reference for the overall demonstration and design of the power system of multi-antenna phase array radar.

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