Numerical simulation and mechanical optimization of power supply assembly for missile-borne radar

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Abstract. The missile phased array radar has the advantages of flexible beam pointing and fast scanning speed. However, the design of missile phased array radar is difficult due to its limited space. The structure and thermal design of array power supply which is a core component of missile phased array radar were studied. The influence of fixed form and other factors on the design strength were analyzed. The design of heat dissipation under different working conditions were explored. The result shows that fixed form has the greatest influence on the design strength. It is necessary to use the form of phase change cooling to solve the heat dissipation problem in the actual working process of array power supply. On this basis, the light quantization, insulation and common design of the array power supply are realized. The design meets the actual requirements. It is a significant reference for following design of electronic equipment for missile-borne radar.

1. Introduction
With the development of military science and technology, the interception technology of missile was becoming more and more mature. The ballistic trajectory of the traditional ballistic missile was relatively easy to be tracked and intercepted. A new type of missile with long range, high strike precision and strong penetration ability to undertake the strategic deterrent task were urgently needed for all governments[1-3]. Phased array radar was the best choice for a new type of missile borne radar due to the advantages of flexible beam pointing, fast scanning speed, strong anti-interference ability and high stability[4-5]. Compared with the original high voltage and high-power transmitter power supply, array power supply which was the main power supply equipment and the main component of the phased array radar had the advantages of light weight, small volume, low energy consumption, high efficiency, high stability and high reliability[6-7]. Because the effective space of the missile borne radar was extremely limited, the array power supply needed to be rationally distributed and was necessary to keep working stability in a bad working environment.

Based on this, the influence factors of fixed form, material and heat dissipation form of the phased array power supply for a missile borne phased array radar were analyzed. The reliability design of the phased array power supply was realized through optimization design, mechanical and thermal simulation.

2. Conceptual design
Due to small size, high heat flux density and complex design of missile borne array power supply, the full process digital prototype technology was applied. Collaborative detailed design based on a unified 3D model was used. Through a variety of simulation analysis methods, such as structural mechanics,
heat and maintenance, the comprehensive optimization of multidisciplinary were realized. The structural performances of the stiffness, strength and cooling of the radar system were completely virtual verified. The array power supply was designed to meet the requirements. During the design process, the concept design was first carried out, and then the rationality of the design was verified. Finally, the structure and performance were improved and optimized.

The key problems such as the size of the power supply, layout of the internal device and heat dissipation of high heat consumption devices were mainly concerned in the process of conceptual design. The design profile of the power supply is shown in Figure 1. The maximum size is 316.05mm × 206.8mm × 51.2 mm, and the main structure size is 238.8mm× 206mm× 39.4 mm. The power supply shell consists mainly of the cold plate, upper and lower cover plates.

High working temperature can reduce the reliability of electronic components, and shorten the service life. So the correct thermal design is very important. At the same time, with the development of the miniaturization and high power of the array power supply, higher requirements for its thermal design are put forward. Because of no cooling resources during working, it is necessary to adopt efficient heat dissipation technology to ensure the safe and reliable operation of missile-borne radar under the envelope of the whole flight. Because regular and reliable operation on the ground joint test was needed for missile borne radar, a set of cooling system suitable must be designed of missile-borne radar for working in the non missile environment. Therefore, cooling system was designed to integrate which combined test and the actual cooling system. In addition, the cold plate was the most critical part for power supply with liquid cooling and filling phase form could be used as fixed and supported components of power supply. According to the design idea of integration of structure heat dissipation, high heating devices were installed on both sides of the cold plate. Other small heat consumption functions were modularized and distributed in three-dimensional layout. Mounting frame and protruding platform were used for conducting heat dissipation. The limited space was used effectively to meet the miniaturization and lightweight requirements.

![Figure 1. Conceptual design of power supply](image)

3. Simulation verification

The finite element software was used to carry out the mechanical and thermal analysis of the foregoing design power supply to verify the rationality and correctness of the design. The array power supply was a complex assembly with independent entities. Electronic components installed with screws on the power supply plate were equivalent to the concentrated mass and handled as a quality point in the ansys module to simplify the calculation. The more the grid means high accurate needing the longer computing time when dividing the grid.

In order to take account of the accuracy and efficiency of the calculation, accurately structural displacement and stress conditions, the automatic grid method was used. Time transition ratio was set to 0.272. The growth rate was set to 1.2. The maximum number of thin layers of thin wall was set to 5. The power supply was composed of 134706 nodes and 81417 units. The finite element model after the grid division was shown in Figure 2.
3.1. Influence of fixed form

The random vibration test conditions were used to verify the design. The power spectrum density of random vibration was 0.04g²/Hz, and the root mean square acceleration was 6.06grms. The structural material was 5A05 aluminum alloy. There are two fixed forms, one is fixed by bending corners and flow flanges (Figure 3 (a)), the other is to add fixedly around the shell on the basis of fixed bending angles and flanges fixed on the flange (Figure 3 (b)).

Through the simulation, it was found that the maximum stress was located at the corner part in the first fixed form, and the maximum stress was about 89MPa, as shown in Figure 3 (c). The result was greater than fatigue limit (85Mpa) of 5A05 aluminum alloy materials (calculated by 1/3 of tensile strength) [8]. Fatigue fracture of material will be caused by long time vibration test. The maximum stress was at the corner part (the maximum stress is only about 7.7Mpa) and the reliability of the design was greatly improved as second kinds of fixed forms were adopted.

**Figure 3.** Influence of fixed support on the design strength: (a) local fixed, (b) fully fixed, (c) strength with local fixed, (d) strength with fully fixed
3.2. Influence of ear form and material

Under the first fixed form, the bending corner had the stress concentration. The maximum stress of the power supply with the first fixed form (Figure 3 (a)) was about 89MPa which was beyond the fatigue limit of the aluminum alloy.

The stress concentration still occurred at the corner. The maximum stress was increased to 137.38MPa when the ear material was changed from 5A05 aluminum alloy to 06Cr19Ni10 stainless steel. However, the fatigue strength was below 173MPa of the stainless steel (calculated according to the tensile strength of 1/3)[8]. It met the design requirements, but the reliability was not high. In order to avoid stress concentration, the influence of different bending angle forms on the stress was studied, as shown in Figure 4. The maximum stress in the stress concentration can be reduced from 89MPa to 69MPa when the power module was fixed and the material remained unchanged which can further reduce the stress concentration.

![Figure 4. The influence of structural style and materials on the design strength: (a) structural style I, (b) structural style II, (c) strength with stainless steel for structural style I, (d) strength with aluminium alloy for structural style II](image)

3.3. Influence of heat dissipation

Combined with the characteristics of this array power supply, it is necessary to carry out a variety of integrated design of heat dissipation. There are many internal heating devices in the array power supply. The high heating device was placed at the short time of the heat transfer path, and the small heating device was placed at the far end of the heat transfer path which caused the dispersing of the arrangement of the heat dissipation components. It was not suitable for the cold plate with deep hole drilling. So the conventional rectangular channel type cold plate was adopted.

In addition, high heat conduction, high heat capacity and low thermal resistance design at the contact surface should be taken full consideration during the materials selection and structural design. Heat capacity consumption cooling should be carried and the working time was short due to without or limited resources. The temperature index of the power pipe should be calculated according to the maximum temperature resistance index, and the tolerance of the capacitor should be considered. The thermal design should take into account the initial working temperature and the state of the heat consumption before the radar was launched. There was no coolant in the cold plate of the array power supply.
supply in actual work. Only the heat capacity and conduction of the cold plate could be used for heat dissipation. The simulation results (Figure 5 (a)) showed that the maximum shell temperature of the chip was 118.7 °C. The thermal resistance of the shell was 1.3 /W, and the highest temperature was 118.7+1.3 ×20=144.7°C. The highest temperature was higher than 125 °C which did not meet the requirements of actual work. During the commissioning phase, the power needed to work for a long time with liquid cooling. The simulation results showed that the highest shell temperature of the chip on the power module was 79.9 °C. The thermal resistance of the shell was 1.3 /W, and the highest junction temperature was 79.9+1.3× 20=105.9 ℃ which was smaller than its permitted temperature of 125 ℃.

Figure 5. Influence of heat dissipation for power supply: (a) natural heat dissipation(working at 70℃), (b) liquid cooling at debugging phase

4. Optimal design
Based on the impact analysis of the influence factors on the structure design of array power supply, the optimal design of the power supply was carried out. First, all round fixed form was used for structural design. Then, aluminum alloy was still used in the ear with the strengthened in order to ensure the light weight. The end, the common design concept was adopted to further realize the light weight. The results of the specific design was shown in Figure 6. The maximum stress was about 7.4Mpa which was far less than the fatigue strength of the aluminum alloy and satisfied the design requirements.

Figure 6. Design strength of power supply after mechanical optimization: (a) optimization result, (b) simulation result

Because multi-module parallel output was needed for the array power supply, a long confluence bar was required for the traditional form which was easy to cause damage to the printed board and solder joints. Based on this, a piecewise form confluence was presented, as shown in Figure 7.

First, the required connection circuit was to connect by copper clad form. The layout of the bus bar was segmented in the external way when the current was large which could increase the current capacity. There was little distance between this form of segmentation. The small gap resistance for this
form which had little impact on the overall current shelter. It reduced the deformation which caused by the welding stress.

In addition, how to carry out effective insulation was essential because of the extremely limited power space and a large number of collected inside confluence. The powder spraying process of the confluence strip was studied, and the epoxy resin powder coating was used. The results were well displayed. The specific physical drawings were shown in Figure 8.

In conclusion, power supply by liquid cooling can satisfy the heat dissipation requirement during debugging, as shown in Figure 9. But it does not meet the requirements in the actual work. So the heat dissipation of the actual work of the array power supply was optimized. First, the high thermal conductivity material was used between the device and the cold plat. The contact thermal resistance was reduced. The cooling plate and the cold plate frame fitted together to increase the heat dissipation capacity. The three was adding phase change material in the cold plate to increase the heat capacity.

A way of heat of aluminum material and latent heat of phase change was used for heat capacity when heat capacity consumption type was for heat dissipation of radar. Combined with the use of the environment and other physical parameters, such as the latent heat and the thermal conductivity of phase change materials, a kind of graphite paraffin composite phase change material with better parameters(The phase transition temperature was about 74℃) was selected. The simulation results showed that the highest shell temperature of the chip on the power module was 85℃(Fig.10). The thermal resistance of the shell was 1.3 °C/W, and the highest junction temperature was 85+1.3 × 20=111℃ which was smaller than its permitted temperature of 125 ℃.
5. Conclusion

(1) The fixed form, the form of the ear and the material had different influence on the design strength of the array power supply. The influence of the fixed form was the most, the form of the ear and the influence of the material were small.

(2) The liquid form could effectively meet the requirements of array power supply debugging. Phase change materials were used to solve the heat dissipation problem in actual work.

(3) Through conceptual design, simulation test and optimization design, the whole process design concept could effectively save design time and avoid design errors.

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