Structural Design and Thermodynamic Analysis of a Missile Borne RF Module

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Abstract. The volume, weight and heat dissipation resources of missile borne SAR seeker are seriously limited, and the working environment is extremely harsh. Therefore, more stringent requirements are put forward on the structural design and thermal design of the electronic module on the missile borne SAR seeker. In this paper, the modular structure design and passive thermal control of a missile borne RF module are studied. In order to improve the interchangeability of products and simplify the design, a universal RF module based on JVPX connector is designed in this paper. In view of the high-speed and high-temperature physical working environment of the SAR seeker, the structure of phase-change heat sink is adopted in the module, which solves the thermal control problem of short-term reliable operation of the heating chip on the module. Finally, the effectiveness of the passive heat dissipation is verified by simulation analysis.

1. Introduction
With the development and improvement of SAR imaging technology, the application of SAR technology to missile seekers [1-2] can not only improve their all-weather and all-day detection capability, but also improve their accuracy of locating targets and identification probability, along with the operational effectiveness of the missiles [3].

In view of the requirements of the missile borne platform for the compound of seeker functions as well as the development cycle and cost, modular structural design is often adopted for RF functional components. The same structure of RF modules with different technical indexes and functions can not only simplify the design, shorten the development cycle and improve the development efficiency, but also realize the economic benefits of mass production and save costs. When the functional requirements change, it can also realize the general interchangeability at the component level and reduce unnecessary repetitive development work.

As for the thermal design difficulties of missile borne SAR seekers, such as the volume, weight, heat dissipation resources and so on, and the extremely tough working conditions, it is particularly urgent to carry out the research on instantaneous high-efficient thermal control technology in this field. In recent years, the application of phase change materials to the passive cooling of intermittently working electronic equipment has attracted researchers’ wide attention. Its advantages lie in small volume change and large latent heat of phase change, which can reduce the restriction of working conditions on chip thermal control [4-5].
This paper centers around the research on modular structural design and passive thermal control of RF functional module of the back end of a missile borne SAR seeker. By classifying modules based on functional independence, a universal RF functional module based on JVPX connector is designed. The external interface of the module is unified and the connection is reliable. The RF functional module adopts the structure of phase change heat sink to realize the passive heat dissipation of the heating chip on the module, and carries out the relevant thermal design research through simulation analysis.

2. Structural design
The classification of the back end RF functional module of a missile borne SAR seeker is conducted according to functional independence and on the basis of the signal interconnection and installation structure, the modular structural design is carried out. This paper will take a typical universal RF functional module as an example to introduce its structure in detail.

2.1. Structural composition
As shown in Fig. 1, the RF functional module designed in this paper is mainly composed of a phase change heat sink shell, a JVPX digital circuit board and a locking mechanism, etc. The back end of the module is blind inserted into the back panel of the rack through the JVPX connector to realize the effective transmission of various signals (light, RF, low-frequency signals, etc.).

![Figure 1. Structure of the RF module.](image)

The RF functional module is mainly used for missile borne seekers with relatively severe external conditions such as vibration and impact. The random vibration spectrum is shown in Fig. 2, with the magnitude of 0.16 g²/Hz and the total root-mean-square value of 18g. In order to improve its environmental adaptability, two loose fastening screws are added in the front of the module to strengthen the connection and fixation between the module and the rack, compared with other traditional modules which only use the locking mechanism on both sides to immobilize the module and the rack.

![Figure 2. Random vibration spectrum.](image)
In order to realize the structural design of the lightweight module, the RF functional module removes the extractor used for traditional module insertion and extraction, and uses two round holes with diameter of 3mm on the front panel with special tools to realize the module disassembly, as shown in Fig. 3.

![Figure 3. Comparison with traditional modules.](image)

The JVPX digital circuit board is fixed on the phase change heat sink shell, and a heat conduction gasket is installed between the heat chip and the phase change heat sink shell, which ensures the effective contact between the chip and the phase change heat sink, so as to reduce the contact thermal resistance.

2.2. **Structural design of the locking mechanism**

The locking mechanism of the traditional module is shown in Fig. 4. When the locking mechanism is loosened, the wedge block at the end will rotate accordingly, causing the wedge block and the guide groove to be stuck, so that the module cannot be pulled out.

![Figure 4. Comparison of the locking mechanism.](image)

The RF module designed in this paper adopts a new type of locking mechanism. The inner guide rail of the locking mechanism uses a solid guide rail instead of a locking screw, which not only plays a guiding role, but also prevents the outer guide rail from rotating, and avoids the jam of the outer slide when being tightened.

2.3. **Structural design of the phase change heat sink shell**

In this paper, the RF function module adopts the phase change heat sink shell, which makes use of the high-efficient heat storage performance of the phase change materials to realize passive thermal control. According to the specific layout of the digital circuit board, the phase change heat sink shell has different specific structures, but they all have the same basic structure, as shown in Fig. 5.
The basic structure of the phase change heat sink shell is a heat dissipation baseplate plus a phase change cavity along with a cover plate, in which the phase change cavity is a closed cavity formed by welding the heat dissipation baseplate and the cover plate, and filled with phase change materials inside.

Considering the thermal performance index and machining performance, the Aluminum Alloy 6063 with good heat conduction capacity is selected as the heat dissipation baseplate and cover plate in this paper. Vacuum brazing is used between them to form the phase change cavity. In order to realize the filling of phase change materials, charging ports are reserved on the cover plate, which are located on the diagonal sides of the phase change cavity.

In a bid to adapt to the volume expansion when the phase change material state changes, the cavity must be in a vacuum environment after the phase change material is charged. Therefore, in order to ensure the vacuum environment in the cavity, the structure of electron beam welding plug is adopted at the charging port with 5A05 as the plug material, as shown in the Fig. 6.

![Figure 5](image)

**Figure 5.** Basic structure of phase change heat sink shell.

![Figure 6](image)

**Figure 6.** Structure of the charging port.

![Figure 7](image)

**Figure 7.** Structure of phase change heat sink shell.
Although the phase change material has the advantages of high heat capacity and high phase change enthalpy, its thermal conductivity is relatively low, making it unable to quickly transmit the heat emitted from the chip while working to the whole paraffin-filled area. Thus, the phase change zone only appears near the heat source, which affects the heat dissipation efficiency of the whole module [6].

To improve the thermal conductivity of the phase change heat sink shell, the heat conduction reinforced structure — fin, is designed on the heat dissipation baseplate. Through the fin structure, the heat near the power consumption chip can be rapidly diffused to other areas to ensure that the phase change material in the phase change heat sink can absorb the heat relatively evenly. The typical structure of the phase change heat sink shell is shown in Fig. 7.

3. Thermodynamic analysis and design

When the missile borne SAR seeker works, the surface and its vicinity are in a physical environment with high-speed and high-temperature, and there is no active heat dissipation resource in the heat dissipation system of the missile borne electronic equipment, so the back end RF functional module can only use passive mode to achieve heat dissipation.

3.1. Thermodynamic design

The RF function module designed in this paper adopts the structure of combining conduction and phase change material heat storage, which solves the thermal control problem of the short-term reliable operation of the heating chip in the module, and realizes passive heat dissipation.

The traditional metal cold plate only uses the sensible heat capacity of its own structural material to achieve heat storage, and its heat capacity is small with its weight easily limited. The phase change materials with suitable phase transition point, high latent heat, low density, low cost and mature application can achieve both high heat storage performance and sharp weight reduction design in the meantime.

According to the characteristics of the products, the low-temperature phase change material with phase transition temperature between 60℃ and 90℃ are given priority to. The RF module designed in this paper selects 75# paraffin as the phase change material, and its typical parameters are shown Table 1.

| Table 1. Typical parameters of 75# paraffin. |
|---------------------------------------------|
| peak phase change temperature (℃) | 75±3 |
| phase change enthalpy (kJ/kg)            | 190  |
| solid density (kg/cm³)                  | 928  |
| liquid density (kg/cm³)                 | 770  |

When the RF functional module is working, the board heating chip in the module contacts with the boss on the phase change heat sink shell, transmitting the heat to the phase change heat sink through conduction. The phase change material absorbs a large amount of heat in the phase change process, which increases the temperature in a small range, and ensures the chip to work reliably in a controllable temperature environment. In order to reduce the contact thermal resistance between the chip and the boss, a heat conductive gasket is filled in the contact interface, and the overall heat transmission path is shown in Fig. 8.
Figure 8. Heat transmission path of the module.

The key point of the thermal design of the RF functional module is the design of the phase change heat sink shell. When the working time of the module or the heat output of the chip changes, it is necessary to adjust the volume of the phase change cavity in the phase change heat sink shell, so as to adjust the charge amount of the phase change material. When designing the phase change heat sink, it is usually required that the charge amount of the phase change material can completely absorb the total heat generated by the module chip, namely:

\[ V = \frac{P \cdot t}{\rho \cdot \Delta H} \]  

Among this: \( V \) is the filling amount of the phase change material, \( \rho \) is the density of the phase change material, \( \Delta H \) is the phase change enthalpy of the phase change material, \( P \) is the total heat consumption of the module, and \( t \) is the total working time of the module.

3.2. Thermodynamic analysis

In this paper, according to the characteristics of the special working environment of the missile, a typical RF functional module is taken as an example to carry out thermodynamic simulation analysis. The total heat consumption of the RF module is about 80W, in which the heat consumption of FPGA chip is 45W and the thermal resistance of crust is 0.15℃/W.

Based on its working characteristics, the thermodynamic simulation analysis is carried out by using the finite meta-simulation software. The transient simulation results of the functional module are shown in Fig. 9.
It can be seen from the figure that at the end of the operation, the maximum shell temperature of the module FPGA chip is about 99°C, which is less than the chip temperature resistance index of 125°C. It meets the heat dissipation design requirements of each heating chip in the module.

4. Conclusions
In this paper, a universal RF functional module based on a JVPX connector is designed, which realizes the efficient development and design of different functional modules, improving the technical maturity and shortening the product development cycle. Aiming at the special physical working conditions of the missile borne SAR seeker, the RF functional module adopts the structure of the phase change heat sink to realize passive heat dissipation.

A typical universal RF functional module is taken as an example to elaborate its specific structure, and corresponding thermodynamic design and analysis is carried out according to its working characteristics. The RF functional module is reliable in connection and easy to plug in and out, which
can ensure the blind insertion accuracy between the JVPX connector and backplane. The structure of the phase change heat sink is used to solve the thermal control problem of short-term reliable operation of the heating chip in the module, and the passive heat dissipation of the module is realized. In order to improve the thermal conductivity of the phase change material — paraffin, the heat conduction fin is added in the phase change cavity, and the effectiveness of the heat dissipation form is verified by simulation analysis.

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