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Rationale for Choosing Type of Heatsink Profile for New Design of Electronic Module Cooling System

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The reliable operation of complex electronic systems with increased heat generation is ensured by the use of efficient cooling systems, the cost of which is sometimes up to 45% of the cost of electronic modules that are cooled. In this regard, the development of new design solutions aimed at reducing the cost of electronic module cooling systems is an urgent task. In this work, a new design solution to reduce the cost of the basic version of the air cooling system of the transmit/receive (T/R) module is proposed. Instead of the heatsink case of the T/R module made by the method of milling from a solid aluminum plate 53 mm thick, a design is proposed, which consists of two parts: an improved case part, made by the method of milling from an aluminium plate with half the thickness, and a convective heat exchanger attached to it, made from a serial heatsink profile. Active electronic components are in contact with the surface of the heat exchanger through the windows in the case. The main part of this work is devoted to rationale for choosing the most advantageous from a thermal point of view heat sink profile from the existing serial profiles for use in the new cooling system. Using computer simulation, the thermal performance of the proposed cooling system was determined and compared in two versions: based on a serial heatsink profile of type 1 and based on a serial heatsink profile of type 2. Types 1 and 2 of the heatsink profile are similar, but have different geometric characteristics, different number of fins, different fin heights, different base thicknesses and different weights. The purpose of the simulation is to determine the most effective of them for use in the new T/R module cooling system. As a result of simulation, it is shown that the most effective for use in the design of the T/R module air cooling system is a serial type 1 heatsink profile, made of aluminum-magnesium alloy AD 31T. It has a base thickness of 4 mm, a fin height of 21 mm, a fin pitch of 7 mm, a fin thickness at the base of 2.5 mm, and a fin thickness at the top of 1 mm. The maximum temperature at the installation sites of the hottest transistors on a heat exchanger from a type 1 heatsink profile is 8.7–4.9 °C (or 10.0–8.2%) less than on a type 2 heatsink profile heat exchanger (at air velocity from 1 m/s to 5 m/s). The total thermal resistance of the cooling system using a type 1 heatsink profile is 13.5–11.9% less than using a type 2 heatsink profile. Moreover, the mass of the convective heat exchanger based on the type 1 heatsink profile is 367 g (or 8.5%) less.

Keywords: heat exchange; cooling system; thermal performance; convective heat exchanger; heatsink profile

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Introduction. Formulation of the problem

Radar systems are one of the types of complex electronic systems. The construction of modern radar systems is based on highly efficient technologies of active phased antenna arrays (APAA) [1–4]. APAAs must provide a given level of signal output power, be able to work in difficult operating conditions, including at high ambient temperatures.

When developing APAA structures, the main limiting factors for their construction are mass and dimensional characteristics and cost. Typically, APAAs have a complex structure and a dense placement of electronic modules and electronic components [5, 6]. The main electronic module of the APAA is a transmit/receive (T/R) module [7, 8]. Structurally, T/R modules are located on the antenna sheet directly behind the emitters. Modern APAAs can include several thousand T/R modules [9], each of which contains at least one output power amplifier.

Depending on the frequency range in which the T/R module operates, transistors and microwave monolithic integrated circuits (MMIC) of different frequency ranges are used as active electronic components of the output power amplifiers [10, 11, 13], the characteristics of which determine the functionality and capabilities of the whole module. Despite the high efficiency of modern electronic components, a significant share of the electrical energy (70–80%) they consume is converted into heat [14], which causes significant thermal loads on the active element base of output power amplifiers and increases their temperature. The functional characteristics and reliability of transistors and MMIC of output amplifiers, and hence, the T/R module as a whole largely depend on temperature conditions [14–16].

Thus, ensuring normal temperature modes of active electronic components of T/R module output power amplifiers is an urgent problem and requires the creation of highly efficient cooling systems. The cost of cooling systems is sometimes up to 45% of the cost of T/R modules that are cooled [11], which requires the search for constructive and technological ways to make them cheaper.

1 Analysis of research and publications in which the solution of this problem was initiated

To ensure normal thermal regimes of the T/R module APAA, the authors of [9, 14, 17] proposed different options for liquid cooling systems. Despite the high efficiency of liquid systems and their variety, they have such general disadvantages as complexity, high cost, the possibility of leakage of liquid main connections, high energy consumption, etc. Forced air cooling systems are simpler, more reliable and cheaper to manufacture and operate.

The authors of [18] proposed an APAA cooling system with a refrigerating machine. Cooled air is directed to the hottest electronic components owing to which the specified temperature regime of the elements is ensured. However, the presence of a refrigerating machine leads to an increase in the mass-dimensional characteristics of APAA and to significant electricity consumption.

In [19], a forced air cooling system for transmit modules of an antenna array with finned heatsinks was studied. It is shown that the pitch and height of the fins is the main factor affecting the maximum and average temperature of the module case, while the thickness of the heatsink base has little effect on the efficiency of heat dissipation. Compared with the basic design, the optimized heatsink can greatly improve the heat dissipation performance of the transmitting antenna and reduce the maximum and average temperature of the module case by 8°C and 5.9°C, respectively.

The authors of [20] proposed the optimal design of the heatsink of the amplifier block of the active transmitting antenna of the 5G base station, which has a large size and high density of elements, and also operates at a temperature of +40°C. It is shown that the proposed heatsink with V-shaped fins performs better than a conventional heatsink with vertically arranged straight fins. The optimal parameters of the fin orientation angle (54°) and the distance between the fins (16.5 mm) were determined, which significantly improved the performance of the heatsink.

In [21], 3 variants of the forced air cooling system of the transistors of the amplifier of radio frequency signals of a high-power transmitter were investigated: based on an aluminum heatsink with dimensions of 300 mm × 220 mm × 70 mm, the same heatsink with two copper diffuser plates 6 mm thick at the base of the heatsink and all-copper heatsink. The use of copper diffuser plates made it possible to reduce the thermal resistance of the system up to two times. However, if you use a solid copper heatsink, then the further decrease in thermal resistance will not be significant. So, if an aluminum heatsink with copper diffuser plates leads to a decrease in the temperature of transistors by 9.5°C, then a copper heatsink – by 11.5°C, but this will lead to a significant increase in the mass of the amplifier, which indicates the inexpedience of using a copper heatsink.

In [22], the thermal performance of the APAA T/R module with forced air cooling, which consists of 128 paired T/R modules, structurally made in the form of 8 installation boards, was investigated. 16 T/R modules and one controller board are installed on each installation board. The total power of one installation board is 280 W (16 T/R modules with a power of 14 W each, as well as a controller board with a power of 56 W). It was determined that the required minimum air velocity for cooling was 1.89 m/s for each T/R module. An experimental study showed that at an air flow rate of 1.6 CFM (CFM – cubic foot per minute) for one T/R module, the difference in air inlet and outlet temperatures is 12°C, which corresponds to the numerical calculation. The maximum temperature of the T/R module did not exceed 60°C.

Structurally, T/R module output power suppliers are usually made in the form of an aluminum alloy base, on one side of which recesses with shielding walls are made by milling method for installing active electronic components, and cooling fins are made on the other side [23]. From above, recesses with electronic components are hermetically closed with covers.

The authors of [23] performed a computer simulation of a forced air cooling system for a T/R module with a milled heatsink case (Fig. 1). The total thermal power of active transistors is 224 W. Covers 4, electronic components (except for active transistors), auxiliary structural elements and holes in the base of the heatsink case are not shown in the main view.

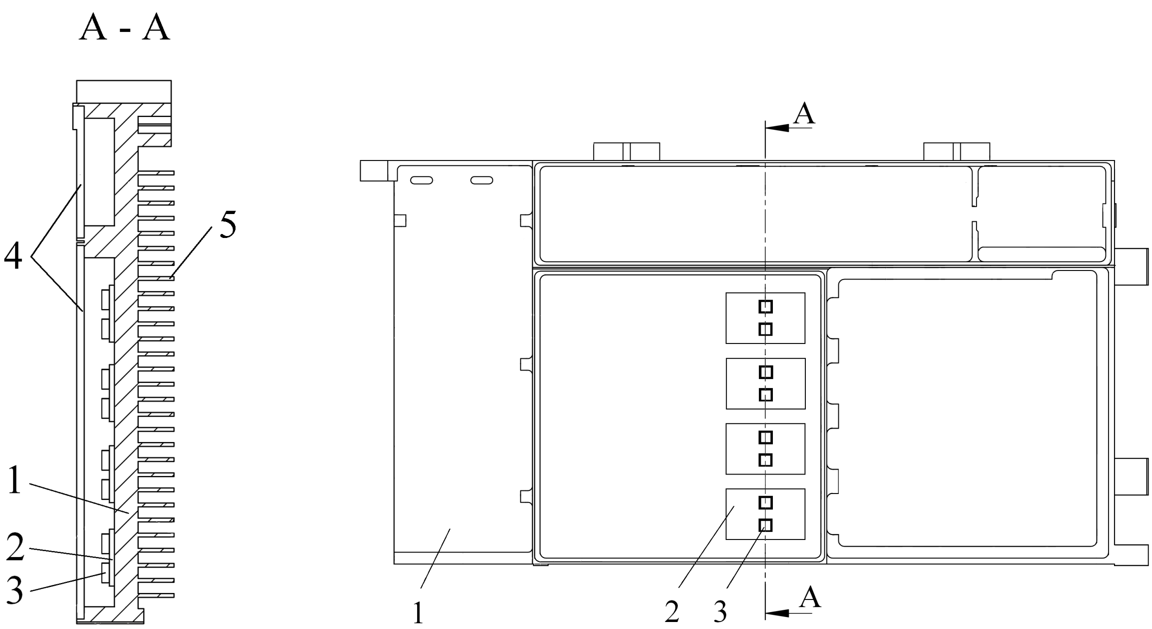


Fig. 1. Structural diagram of the basic version of the T/R module cooling system [23] with a heatsink case made by the milling method: 1 – supporting base; 2 – copper mounting plate (pallet); 3 – active electronic component (transistor); 4 – covers; 5 – cooling fin

The advantage of manufacturing the T/R module heatsink case by the milling method is the possibility of performing the most complex structural elements in the T/R module case, including a wide selection of the type of cooling fins, which are performed on the side of the case opposite to the mounting surface. The thickness of the base of the heatsink case was 12 mm. The number of fins is 29, the length of the fin is 396 mm, the height is 19 mm, the thickness is 2 mm, the distance between the fins is 6 mm. It is shown that at an air flow rate in the cooling channels up to 6 m/s and an inlet air temperature of 40°C, the temperature at the installation site of the hottest transistor is 77.1°C. To increase the efficiency of the T/R module cooling system based on a milled heatsink case, it was proposed in [24] to embed flat heat pipes (HPs) into its base. It was shown by the computer simulation method [24] that the distribution of local heat flows from powerful active transistors to a larger surface of the heatsink with the help of a HP will reduce the temperature of the hottest transistors by 20.3°C. Another work [8] shows that the use of a flat HP in the T/R module design can reduce the temperature of the power amplifier microcircuits by 39°C. Therefore, embedding flat HPs in the T/R module case is a promising way to increase the efficiency of the T/R module cooling system.

At the same time, it is practically impossible to implement the design solution proposed in [24] in the existing basic version of the T/R module with a milled radiator case, since flat HPs will overlap many existing mounting holes for various electronic components and auxiliary structural elements at the base of the heatsink case (not shown in Fig. 1), which requires structural improvement of the basic version of the T/R module to avoid this obstacle. In addition, the manufacture of the heatsink case by milling from a solid aluminum plate 53 mm thick leads to an increase in the cost of the basic version of the design of the T/R module air cooling system. All this poses the task of finding new design solutions aimed at reducing the cost of the design of the T/R module air cooling system with a developed heat exchange surface and ensuring the possibility of increasing its efficiency in the future through the use of heat pipes.

The purpose of this work is to develop new design solutions for improving the basic version of the T/R module air cooling system with a developed heat exchange surface by using a cheaper heat exchange surface instead of a milled heat exchange heatsink surface based on a serial heatsink profile existing on the market and substantiating the choice of the best of them.

2 Design features of the new cooling system

In this paper, a new design solution is proposed to reduce the cost of the basic version of the T/R module air cooling system. Instead of the T/R module heatsink case made by milling from a solid aluminium plate 53 mm thick, a new design is proposed (Fig. 2), which consists of two structural parts 1 and 2: improved case part 1, made by milling from an aluminium plate with half the thickness, and the second part attached to it in the form of a convective heat exchanger 2, made of a serial heatsink profile. Active electronic components 5 are installed on copper mounting plates (pallets) 4, which are in contact with the mounting surface of the base of the convective heat exchanger 2 through rectangular windows 3 in the case part 1. The thickness of the heat exchanger base, the parameters of the fins and their number are determined by the selected type of serial heatsink profile.

For the study, the design of a new T/R module cooling system with overall dimensions similar to the basic version of the cooling system was chosen: 490 mm × 324 mm × 53 mm. Similarly, the main active electronic components of the T/R module high-power output amplifiers are also 8 transistors with a thermal power of 28 W each. The total thermal power is 224 W. Transistors are installed on copper pallets with dimensions of 36 mm × 51 mm × 5 mm, 2 transistors on one pallet with a distance between transistors of 6 mm. The area of the contact surface of transistors with copper mounting plates is 100 mm^2. The heat flux density in the contact zone is 28 W/cm^2.

Pallets with transistors are placed along a vertical line on the mounting surface of the base of the convective heat exchanger with a slight offset to the right relative to the central vertical axis. The distance between the copper plates on which powerful transistors are placed is 10 mm, and the distance between the lower edge of the heat exchanger and the first copper plate from the bottom is 16 mm.

Since a heatsink profile with geometric dimensions (especially in width) and characteristics inherent in the basic option of the cooling system with a heatsink case is not widely available, it was proposed as an alternative design and technological solution to manufacture two heat exchangers from different serial heatsink profiles with the closest to the basic option parameters and features. To ensure the specified width of the heat exchanger of 324 mm, each heat exchanger was made of two parts of a serial heatsink profile of the selected type, assembled into a single structure with a width of 324 mm by welding. The existing serial heatsink profiles of two types: 200×25 and 122×26, made of AD31T5 aluminum alloy, which are hereinafter conventionally referred to as heatsink profile of type 1 and heat sink profile of type 2, respectively, were determined to be the closest to the basic version of the cooling system. Convective heat exchangers made of the specified heatsink profiles will be referred to as type 1 heat exchanger and type 2 heat exchanger, respectively. The geometrical parameters of heat exchangers made of different types of heatsink profiles are given in Table 1, and the drawing of their cross-sections is presented in Fig. 3.

Considering the complexity of manufacturing physical models of T/R module cooling system structures with heat exchangers based on different types of heatsink profiles, to determine the nature of the effect of each type of heatsink profile on the main thermal characteristics of the new cooling system, a computer simulation method using the Flow Simulation module of the Solidworks software complex was used.

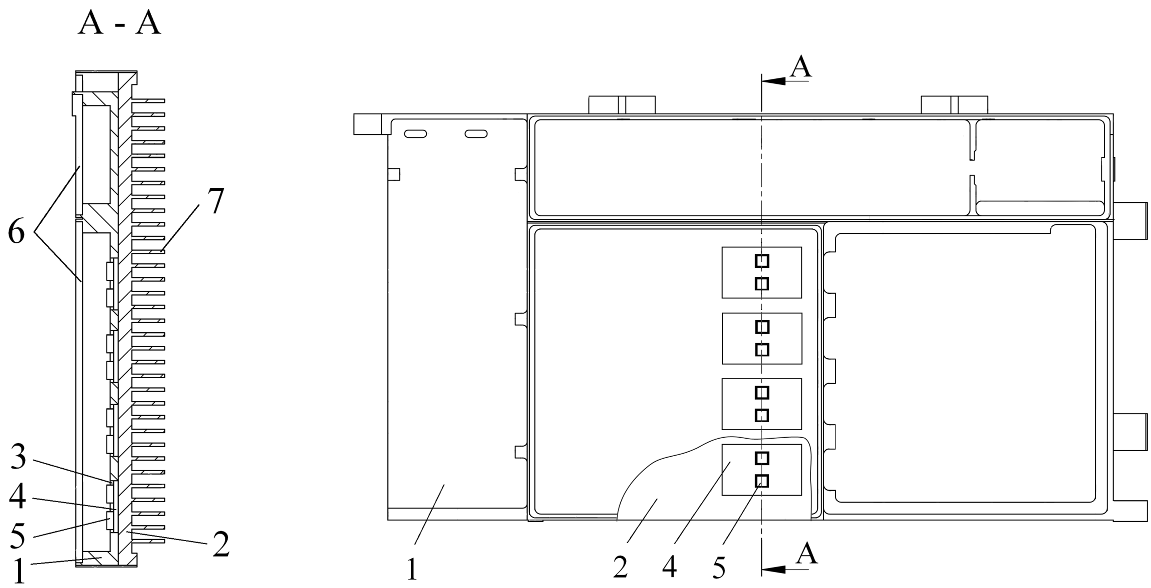
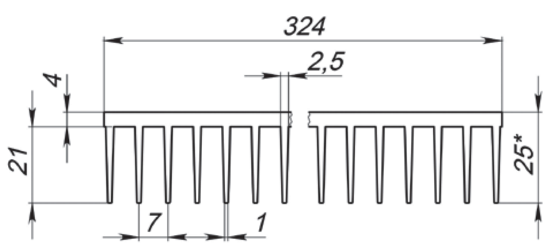


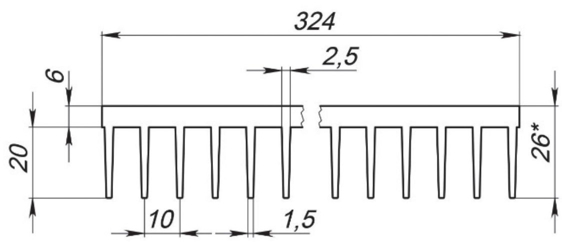
Fig. 2. Structural diagram of the new T/R module cooling system with a heat exchanger based on a serial heatsink profile: 1 – the first milled part of the T/R module case; 2 – convective heat exchanger made of heatsink profile; 3 – rectangular window in the base of the first part of the case; 4 – copper mounting plate (pallet); 5 – active electronic component (transistor); 6 – covers; 7 – cooling fin of heatsink profile

Табл. 1 Geometrical parameters of heatsink profiles and convective heat exchangers on their basis

Parameters	Values	
	Type 1	Type 2
Dimensions of the cross section of the heatsink profile, mm	200 × 25	122 × 26
Cross-sectional dimensions of the heat exchange surface, mm	324 × 25	324 × 26
Base thickness, mm	4	6
Fin height, mm	21	20
Fin pitch, mm	7	10
Fin thickness at the base, mm	2.5	2.5
Fin thickness at the top, mm	1	1.5
Number of fins, pcs	46	33
The number of inter-fin channels, pcs.	45	32
Cross sectional area of 1 cooling channel $\times 10^{-4}$, m^2	1.1	1.6
Cross sectional area of all cooling channels $\times 10^{-4}$, m^2	49.6	51.2
The area of the heat exchange surface at heatsink length 0.49 m, m^2	1.090	0.805
Volume of material used $\times 10^{-3}$, m^3	1.463	1.599
Heatsink weight, kg	3.951	4.318



(a)



(b)

Fig. 3. Geometrical characteristics of convective heat exchangers based on type 1 (a) and type 2 (b) heatsink profiles; $*$ – size for reference

3 Computer simulation of cooling system

3.1 Computer simulation method

Two variants of the T/R module forced air cooling system based on type 1 and type 2 heatsink profiles were chosen as the object of computer simulation.

Models of active transistors with a power of 28 W each were used as heat load sources, which were placed 2 transistors on a copper mounting plate. Four copper mounting plates with installed heat load sources were placed on the mounting surface of the convective heat exchanger made of the selected type of heatsink profile.

Based on the geometrical parameters of the new cooling system, a computer model was created in the Solidworks software package. For numerical simulation, the Solidworks Flow Simulation module was chosen, the use of which made it possible to numerically simulate the temperature distribution in the cooling system at the thermal power of 8 transistors of 224 W for discrete system parameters.

The main advantage of using the Solidworks Flow Simulation module of the Solidworks software package is that due to its full integration into Solidworks, it becomes possible to simulate geometry and perform all calculations in one program, as well as flexibly change geometry and add new elements to increase the accuracy of simulation. SolidWorks allows us to arbitrarily select arrays of simulation results of a significant number of properties of used computer models both for objects made of solid materials and moving media for their export in numerical form.

This makes it possible to analyze the results graphically and numerically. Problems related to heat transfer in SolidWorks Flow Simulation are solved using the Navier-Stokes, energy and discontinuity equations. The used dependences describe the laws of conservation of mass, momentum and energy of the cooling liquid or air, as well as empirical dependences of viscosity and thermal conductivity of the medium components on temperature. It should be noted that the analytical solution of such problems is quite difficult and, usually impractical.

The preparatory stage of modelling in SolidWorks Flow Simulation includes, in addition to the direct development of a 3D computer model of the cooling system, the imposition of simulation conditions (selection of medium and material properties, determination of thermal load, as well as selection of the area and discretization of the calculation grid for simulation). As a result, the simulation allows us to obtain a visualization of the temperature fields as models of solid bodies and determine the temperature field of heat exchange surfaces (heat exchangers, mounting plates and transistors), and air properties (temperatures, speeds, etc.).

3.2 Initial and boundary conditions

General simulation conditions for the design of the cooling system: thermal radiation is neglected; environment is air; air inlet temperature is +20°C, atmospheric pressure is 101.325 кPa.

The developed computer models of the cooling system based on the selected heatsink profile fit into a calculation area of 494 mm × 330 mm × 35 mm or 494 mm × 330 mm × 36 mm for the type 1 and type 2 heatsink options, respectively.

The problem posed was solved in a stationary formulation in compliance with the requirement that solutions are independent on the discreteness of the computational grid. The boundaries of the computational domain were taken to be adiabatic.

Thermal contacts between transistors and pallets and heat exchangers were assumed to be ideal. It was taken into account that the pallets are made of M1 copper with a thermal conductivity coefficient of 406 W/(m·°C), and the heatsink profiles are made of AD31T5 aluminum alloy with a thermal conductivity coefficient of 183 W/(m·°C).

The simulation was carried out for two versions of the heat exchanger of the cooling system at the given velocities of air movement in the channels of the cooling system: 1 m/s, 3 m/s, 5 m/s, 7 m/s, 9 m/s and 15 m/s.

3.3 Calculation grid

The simulation procedure involves the discretization of the elements of the solid body of the model and the gaseous medium of the calculation area with the aid of non-uniform calculation grids.

To carry out 3D simulation, solid body and gaseous medium models in the computational domain are discretized into elements using non-uniform grids, the density of which automatically increases in regions with higher heat flows or surface curvature. The use of calculation grids allows us to describe the flow of thermal processes occurring in cooling systems.

For the selected types of cooling systems, computer models were used with a total number of elements from 2.3 million to 3.2 million, with automatic setting of the mesh density depending on the complexity of the geometry, and the dimensions of the smallest element were assumed to be 0.25 mm × 0.25 mm × 0.25 mm. For the selected models of cooling systems, the number of elements that were used in the models is given in Table 2.

Табл. 2 The number of elements of calculation grids for models of cooling systems based on type 1 and type 2 heatsink profiles

Element parameters	Type of heatsink profile	
	Type 1	Type 2
Total elements	3 176 989	2 298 105
Elements in moving environment	1 603 428	1 277 923
Elements in a solid body	1 573 561	1 020 182
Elements at the interface between a solid body and a gaseous medium	954 271	724 626

Convergence and discretization error control was based on the simulation procedure for models with different levels of discretization (from 80.000 to 3.2 million elements). As a control parameter, the maximum temperature at the place of installation of the transistor at different velocities of air movement was chosen. Based on the calculations, the simulation error was determined, which is less than 4% of the weighted average, which indicates the convergence of the results and the reliability of the used computer models.

4 Results and discussion

4.1 Comparison of the results of numerical simulation of temperature distribution and non-uniformity on the mounting surface of type 1 and type 2 heat exchangers

For a more visual comparison of temperature distributions on the mounting surface of heat exchangers based on type 1 and type 2 heatsink profiles, they are shown in the general figure (Fig. 4) for both options at an air velocity in the cooling channels from 1 m/s to 15 m/s. In these images, areas of the surface with the same temperature are highlighted in a certain colour and united by isotherms indicating the correspondence of the colour. The scales show the temperature value t, °C.

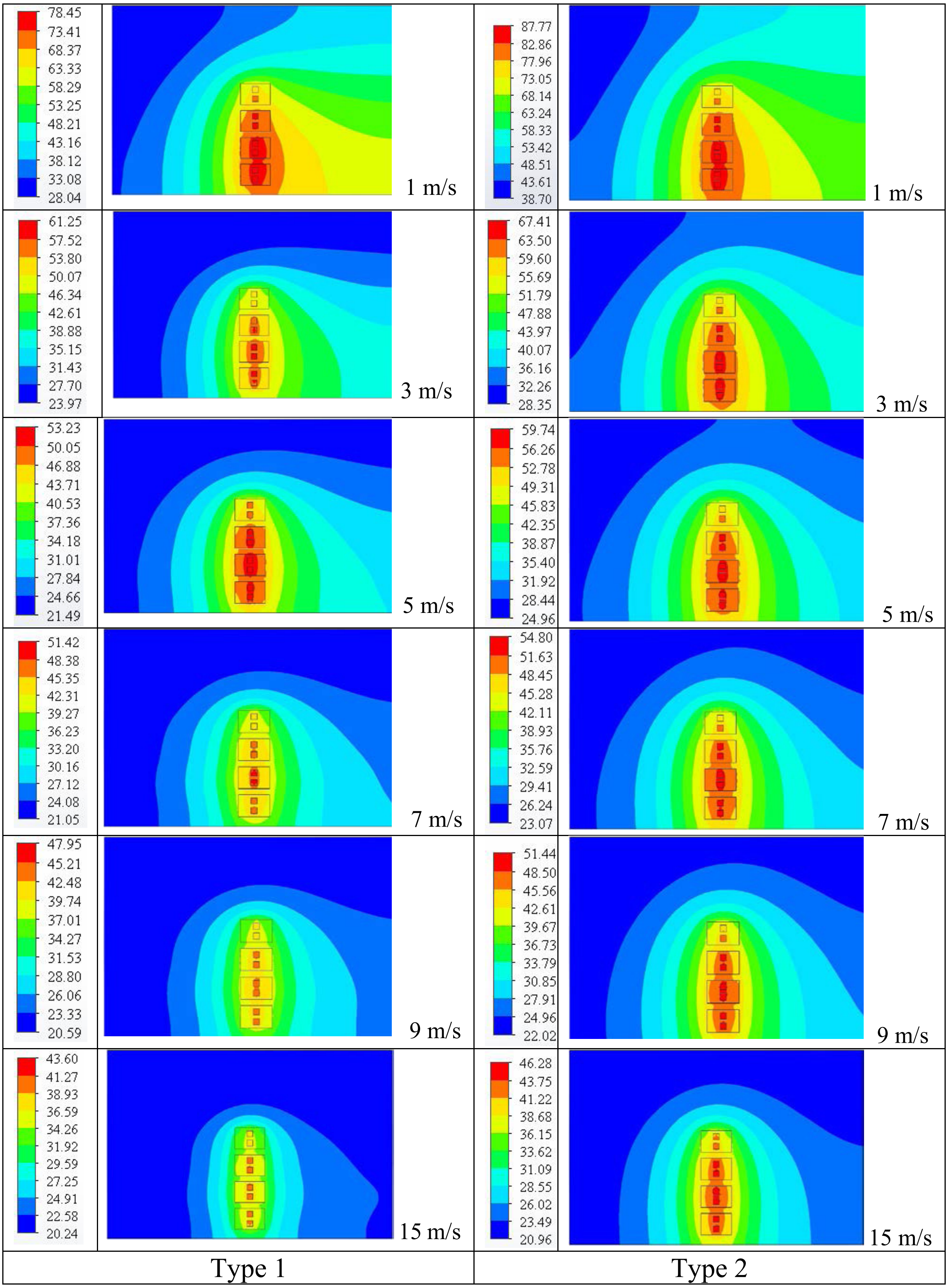


Fig. 4. Temperature field of the cooling system with type 1 and type 2 heat exchangers at air velocity in the cooling channels from 1 m/s to 15 m/s

From Fig. 4, it can be seen that the hottest areas on the mounting surface of the heat exchangers are the areas near the installation of the mounting copper plates, on which the powerful transistors are placed, and the part of the heat exchanger through which air is blown, and the coldest are the areas near the air inlet to the cooling channels.

Table 3 shows the temperature non-uniformity of the mounting surface of two types of heat exchangers at different air velocity values in cooling channels. It can be seen that the difference between the maximum and minimum values of the temperature of the mounting surface in both heat exchangers is quite significant. The maximum temperature non-uniformity on the mounting surface is observed at an air velocity of 1 m/s and is 50.41°C when using a type 1 heatsink profile and 49.07°C – when using a type 2 heatsink profile. As the air velocity increases to 15 m/s, the temperature non-uniformity decreases to 23.36°C and 29.42°C for heat exchangers of type 1 and 2, respectively. Only at an air velocity of 1 m/s, the temperature uniformity of type 2 heat exchanger is better by 1.34°C, and at all other velocities it is worse by 1.36–3.04°C, than that of type 1 heat exchanger.

From the point of view of ensuring the reliable operation of the T/R module with the specified cooling systems, it is important to know the temperature values in the places where the transistors are installed on the mounting surface of the heat exchangers, since the reliability of the operation of the transistors depends on the level of this temperature.

Табл. 3 Temperature field non-uniformity on the mounting surface of heat exchangers of the cooling system with type1 and type 2 heatsink profiles

Air velocity, m/s	The difference between the maximum and minimum temperatures of the mounting surface, °C		
	Type 1 heat exchanger	Type 2 heat exchanger	Increasing temperature non-uniformity, °C
1	50.41	49.07	–1.34
3	37.28	39.06	1.78
5	31.74	34.78	3.04
7	30.37	31.73	1.36
9	27.36	29.42	2.06
15	23.36	25.32	1.96

4.2 Comparison of the temperature in the places of installation of transistors on the mounting surface of type 1 and type 2 heat exchangers

According to the results of computer simulation, the maximum values of the temperature of the mounting surface of both types of heat exchangers were found at the installation locations of each transistor at different values of the air velocity in the cooling channels (Fig. 5).

As can be seen from Fig. 5, when using a type 1 heatsink profile in the cooling system, regardless of the air velocity in the cooling channels, the places where transistors T3 and T4 are installed have the highest temperature, whereas when using a type 2 heatsink profile with wider cooling channels at an air velocity in the channels from 1 m/s to 3 m/s inclusive, the place where transistor T2 is installed is the most heated. In the range of relatively low air velocity values in the cooling channels from 1 m/s to 3 m/s, the maximum temperature value in the places of installation of the hottest transistors on the type 1 heat exchanger is significantly (by 10.0–11.9%) less than on the type 2 heat exchanger. Thus, at an air velocity of 1 m/s in the cooling channels, the highest temperature on the surface of the heat exchanger of type 1 is 78.6°C, while on the surface of the heat exchanger of type 2 it is 87.3°C. Thus, at low values of cooling air velocity in the channels of heat exchangers, the design and type of heatsink profile of which the heat exchanger is made have a significant effect on the thermal regime of transistors. With a further increase in the air velocity (from 5 m/s to 15 m/s), the effect of the type of heatsink profile on the temperature in the places where the transistors are installed is significantly reduced. For example, at an air velocity of 5 m/s, the reduction of the maximum temperature at the place of installation of the hottest transistor T3 when using a type1 heatsink profile instead of type 2 is 4.9°C (or 8.2%), at a velocity of 15 m/s 2. 7°C (or 5.9%).

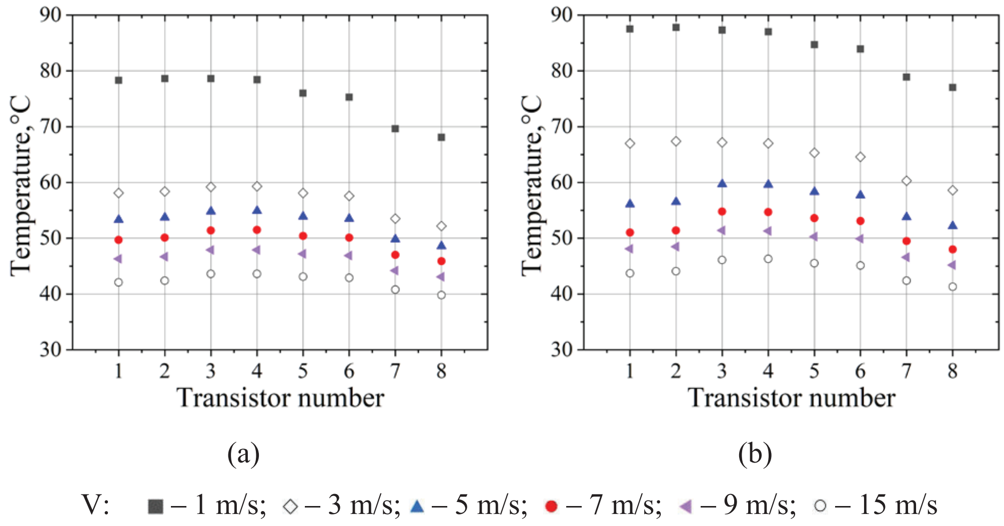


Fig. 5. The temperature in the places of installation of transistors at different velocities V of air movement in the cooling channels of heat exchangers based on type 1 (a) and type 2 (b) heatsink profiles

Table 4 shows the temperature values in the places where the hottest transistor T3 is installed on type 1 and type 2 heat exchangers at different air velocity values in the cooling channels, and Fig. 6 shows their comparison.

Табл. 4 Temperature in the places where T3 transistor is installed on heat exchangers made of type 1 and type 2 heatsink profiles, at an air velocity in the cooling channels from 1 m/s to 15 m/s

Air velocity, m/s	From type 1 heatsink profile	From type 2 heatsink profile
1	78.6	87.3
3	59.2	67.2
5	54.8	59.7
7	51.4	54.8
9	47.9	51.4
15	43.6	46.1

As can be seen from Fig. 6, installing the transistor T3 on a type 1 heat exchanger, compared to installing it on a type 2 heat exchanger, allows reducing the maximum temperature at the place of installation of the hottest transistor T3 by 8.7°C (or by 10%) at an air velocity of 1 m/s and by only 2.5°C (or by 5.4%) at an air velocity of 15 m/s.

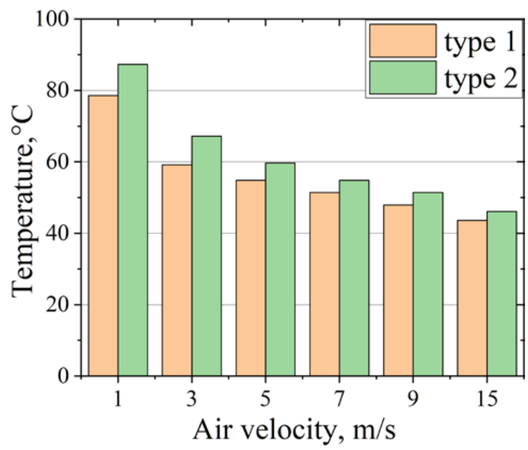


Fig. 6. Comparison of the temperature at the installation locations of the hottest transistor T3 on heat exchangers made of type 1 and type 2 heatsink profiles

4.3 Comparison of the total thermal resistance of a cooling system based on type 1 and type 2 heatsink profiles

An important parameter of the cooling system is its total thermal resistance R, which is determined according to the dependence:

$$R = \frac{t_{\max} - t_a}{P},$$

where: t_{max} is the maximum temperature of the mounting surface of the heat exchanger in the places where the transistors are installed, °C; t_a is the temperature of the cooling air at the inlet to the heat exchanger channels, °C; P is the thermal power of all 8 transistors (224 W).

Based on the results of computer simulation of the thermal performance of the cooling system, the calculation of the total thermal resistance was performed when the air velocity changes in the selected range (from 1 m/s to 15 m/s). Table 5 shows the calculated values of the total thermal resistance of the proposed cooling systems with heat exchangers based on heatsink profiles of two types (type 1 and type 2) at an inlet air temperature of 20°C.

According to the data in Table 5, plots (Fig. 7), are constructed which show the dynamics of changes in the thermal resistance of the cooling system depending on the air velocity in the heat exchanger channels.

Табл. 5 Thermal resistance of cooling systems at the air velocity in heat exchanger channels from 1 m/s to 15 m/s

Air velocity, m/s	Based on type 1 heatsink profile	Based on type 2 heatsink profile
1	0.262	0.303
3	0.175	0.212
5	0.156	0.177
7	0.140	0.155
9	0.125	0.140
15	0.105	0.117

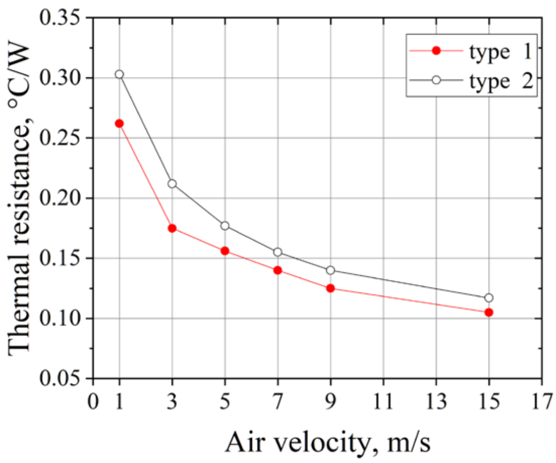


Fig. 7. Comparison of the dependences of the total thermal resistance of cooling systems with type 1 and type 2 heat exchangers on the velocity of air movement in the cooling channels

As can be seen from Fig. 7, the dependence of the total thermal resistance of the cooling system on the air velocity in the channels of heat exchangers of both types has a monotonically decreasing pattern. As the velocity of air movement increases, the thermal resistance of the cooling system decreases, because the intensity of heat exchange between the air and the fins of the heat exchanger increases when the velocity of air movement in the heat exchanger channels increases. More intensive air movement increases the heat transfer coefficient of the surface, as a result of which the efficiency of the cooling system increases.

From Fig. 7 it is obvious that the use of a convective heat exchanger made of a type 1 heatsink profile in the new T/R module cooling system, from the point of view of reducing the total thermal resistance is more beneficial than the use of a heat exchanger made of a type 2 heatsink profile. For instance, in the most acceptable range of air velocities in the cooling channels from 1 m/s to 5 m/s, the total thermal resistance of the cooling system based on a type 1 convective heat exchanger is 13.5–11.9% lower than that based on a type 2 convective heat exchanger.

Conclusions

1. A new design solution to reduce the cost of the basic version of the forced air cooling system of T/R module is proposed. Instead of using a T/R module heatsink case milled from a solid 53 mm aluminum plate, the new cooling system consists of two parts: an improved case part milled from half the thickness of an aluminum plate, and an attached convective heat exchanger made of serial heatsink profile. Copper mounting plates with active electronic components contact the surface of the attached heat exchanger through rectangular windows in the improved case part.

2. Computer simulation of two versions of the new T/R module air cooling system based on convective heat exchangers made of serial heatsink profiles of different types made it possible to evaluate the influence of the type of heatsink profile on the thermal performance of the cooling system without making expensive experimental samples and to choose the most effective of them.

3. The most effective for use in the new T/R module air cooling system is a serial type 1 heatsink profile made of aluminum-magnesium alloy AD 31T, which has: base thickness 4 m, fin height 21 mm, fin pitch 7 mm, fin thickness at the base 2.5 mm, fin thickness at the top 1 mm. The maximum temperature in the places of installation of the hottest transistors on a heat exchanger of type 1 heatsink profile is 8.7–4.9°C (or by 10.0–8.2%) lower than on the heat exchanger of type 2 heatsink profile (at the air velocity from 1 m/s to 5 m/s). The total thermal resistance of the cooling system using the type 1 heatsink profile is 13.5–11.9% lower than using the type 2 heatsink profile. Moreover, the mass of the convective heat exchanger is 367 g (or 8.5%) less than the type 2 heat exchanger.

4. The proposed new T/R module air cooling system provides the possibility of further increasing its efficiency by embedding heat pipes into the base of convective heat exchanger. Due to the higher (several times) effective thermal conductivity of heat pipes compared to the thermal conductivity of aluminum

alloy, they allow us with minimal thermal resistance to disperse the local heat flow from active transistors to a larger surface area of the convective heat exchanger and reduce the maximum temperature in the places where the transistors are installed.

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Обгрунтування вибору типу радіаторного профілю для нової конструкції системи охолодження електронного модуля

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Надійна робота складних електронних систем з підвищеним тепловиділенням забезпечується застосуванням ефективних систем охолодження, вартість яких іноді становить до 45% від вартості електронних модулів, які охолоджуються. У зв'язку з цим, розробка нових конструктивних рішень, спрямованих на здешевлення систем охолодження електронних модулів, є актуальною задачею. В даній роботі запропоновано нове конструктивне рішення здешевлення базового варіанта повітряної системи охолодження приймально-передавального модуля (ППМ). Замість корпуса-радіатора приймально-передавального модуля, виконаного методом фрезерування з суцільної алюмінієвої плити завтовшки 53 мм, запропонована конструкція, яка складається з двох частин: удосконаленої корпусної частини, виготовленої методом фрезерування з алюмінієвої плити з удвічі меншою товщиною, та приєднаного до неї конвективного теплообмінника, виготовленого з серійного радіаторного профілю. Активні електронні компоненти крізь вікна в корпусній частині контактують з поверхнею теплообмінника. Обгрунтуванню вибора найбільш вигідного з теплової точки зору радіаторного профілю з існуючих серійних профілів для використання в новій системі охолодження присвячена більша частина даної роботи. Методом комп'ютерного моделювання визначено та порівняно теплові характеристики запропонованої системи охолодження з конвективним теплообмінником в двох варіантах виконання: на основі серійного радіаторного профілю типу 1 та на основі серійного радіаторного профілю типу 2. Типи 1 і 2 радіаторного профілю мають близькі, але різні геометричні характеристики, різну кількість ребер, різну висоту ребер, різну товщину основи і різну масу. Метою моделювання є визначення найбільш ефективного з них для використання в новій системі охолодження ППМ. В результаті моделювання показано, що найбільш ефективним для застосування в конструкції повітряної системи охолодження ППМ є серійний радіаторний профіль типу 1, виготовлений з алюмінієво-магнієвого сплаву АД 31Т, який має: товщину основи 4 мм, висоту ребер 21 мм, крок ребер 7 мм, товщину ребра біля основи 2,5 мм, товщину ребра біля вершини 1 мм. Максимальна температура в місцях встановлення найбільш нагрітих транзисторів на теплообміннику з радіаторного профілю типу 1 на 8,7–4,9°C (або на 10,0–8,2%) менша, ніж на теплообміннику з радіаторного профілю типу 2 (при швидкості повітря від 1 м/с до 5 м/с). Загальний тепловий опір системи охолодження з використанням радіаторного профілю типу 1 на 13,5–11,9% менший, ніж з використанням радіаторного профілю типу 2. Крім того, маса конвективного теплообмінника на основі радіаторного профілю типу 1 менша на 367 г (або на 8,5%).

Ключові слова: теплообмін; система охолодження; теплові характеристики; конвективний теплообмінник; радіаторний профиль