J. Eng. Technol. Sci., Vol. 54, No. 3, 2022, 220309

Optimal Design of V-Shaped Fin Heat Sink for Active Antenna Unit of 5G Base Station

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Highlights:

- Optimal model for a heat sink with a V-shaped fin arrangement.
- Computational fluid dynamics analysis used to calculate the temperature distribution in the heat sink.
- Optimization of V-shaped fin parameters using the Lagrange interpolation method.

Abstract. The active antenna unit (AAU) is one of the main parts of the 5G base station, which has a large size and a high density of chipsets, and operates at a significantly high temperature. This systematic study presents an optimal design for the heat sink of an AAU with a V-shaped fin arrangement. First, a simulation of the heat dissipation was conducted on two designs of the heat sink – in-line and V-shaped fins – which was validated by experimental results. The result shows that the heat sink with V-shaped fins performed better compared to conventional models such as heat sinks with in-line fins. Secondly, computational fluid dynamics (CFD) and the Lagrange interpolation method were applied to find out an optimal set of design parameters for the heat sink. It is worth noting that the optimal parameters of the orientation angle and fin spacing considerably affected the heat sink's performance.

Keywords: *5G station; active antenna unit; CFD; heat sink; optimal design; V-shaped fin.*

1 Introduction

The active antenna unit (AAU) is one of the main part of the 5G base station. In order to increase the bandwidth, beamforming quality, capability of the Internet of Things (IoT), and allowing multiple-input multiple-output (MIMO) [1], AAUs need to operate at high power levels and have a large size. Meanwhile, the performance of the current chipsets is around 40-50% of the power consumption [2], therefore, the heat released from the electric components of the AAU is

Received July 25th, 2021, Revised November 20th, 2021, Accepted for publication January 19th, 2022.
 ISSN: 2337-5779,
DOI: 10.5614/j.eng.technol.sci.2022.54.3.9

extremely high. Alternatively, the chip density of devices like the AAU in a 5G station is very high and they are often arranged along the length of the antenna and concentrated within the PA area, i.e., the upper-half part of the AAU. This is combined with the large height of the AAU, normally around 900-1000 millimeters, as for example in the 32T32R (transmit and receive) AAU, with the negative consequence that the upper half of the AAU will become increasingly hot when the device is operating in inclement weather or under solar radiation. Therefore, it is very important to optimize the heat sink design of the AAU to help dissipate the heat it produces and enable it to operate as efficient as possible.

Several studies have been conducted on improving the efficiency of cooling the electrical components of receiving and transmitting modules of antenna systems by utilizing innovative radiator designs. Both external and internal techniques have been used. For instance, Shih & Liu [3] developed plate-fin heat sinks for electronic cooling by using an entropy generation strategy in calculating and designing this type of heat sink. They demonstrated that the thermal performance could be improved significantly; both the sink size and the structural mass could be reduced through the presented design method and process. Huang, *et al.* [4] introduced a new heat sink design for a high-power LED lamp by combining plate fins with pin fins and oblique fins. They made a comparison between the heat dissipation performance of these designs and that of three conventional fin heat sinks. The result obtained showed that the designed models had lower junction temperatures than the three conventional models by about 6∼12 °C.

Sable, *et al.* [5] introduced a novel type of heat sink with multiple V-fin arrays to enhance the natural convection heat transfer from a vertical heated plate. They showed that the V-type fin array design performed better than a rectangular vertical fin array. This type of heat sink was investigated by Hagote & Dahake [6] through a simulation and experimental work on three geometric orientations: a vertical base with a V-fin array; a horizontal base with a V-fin array; and an inclined base with a V-fin array. They found that the vertical plate gave a greater average heat transfer coefficient compared to the two other designs. Solanki & Vedpathak [7] presented a new heat sink model with V-shaped fin arrays. Likewise, Muhammed & Al-Hamadani [8] evaluated the efficiency of two heat sink designs with V-type and upset V-type fins respectively for the natural heat transfer from a vertical surface. Considering the optimization problem of a heat sink design, Patel & Matawala [9] optimized the parameters of a heat sink with the purpose of minimizing entropy generation.

Recently, Nikolaenko, *et al.* [10] gave another option to increase the T/R module's air-cooling efficiency, i.e., by incorporating internal heat pipes into the design. This novel technological solution consists of attaching flat heat pipes to the heat sink casing of the T/R module's supporting base. This allows local heat fluxes from the microwave transistors to be dispersed across the entire heat-removing surface of the fins, regardless of their distance from the heat source, lowering the maximum temperature of the microwave transistors' semiconductor crystals and increasing the uniformity of the temperature field of the module case's mounting surface. Baranyuk, *et al.* looked at three different types of radiators for cooling electrical equipment from the outside: solid lamellar fins, split lamellar fins sliced in half, and split portions rotated at an angle of 30° [11]. They showed that cutting the petals in half and turning them led to an intensification of the heat transfer by 35% but increased the aerodynamic drag by 80%. However, the authors did not test their enhanced radiator under natural convection settings.

The previous works focused mainly on the geometry of the fins and concluded that 35-45 mm V-shaped fins provide the maximum heat transfer coefficient. Regarding the heat sink design for a radio remote unit (RRU), Dinh & Vuong [12] recently introduced the optimal calculation of plate-fin heat sinks for RRUs. The heat sink model was optimized to improve the power loss and the heat transfer rate. However, the RRU for a 4G base station has a small size and the power consumption is not too high in comparison with an AAU.

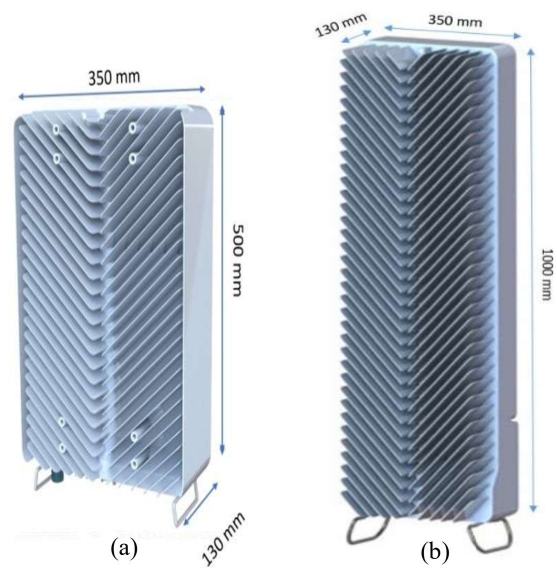


Figure 1 (a) 8T8R AAU and (b) 32T32R AAU with V-shaped fins.

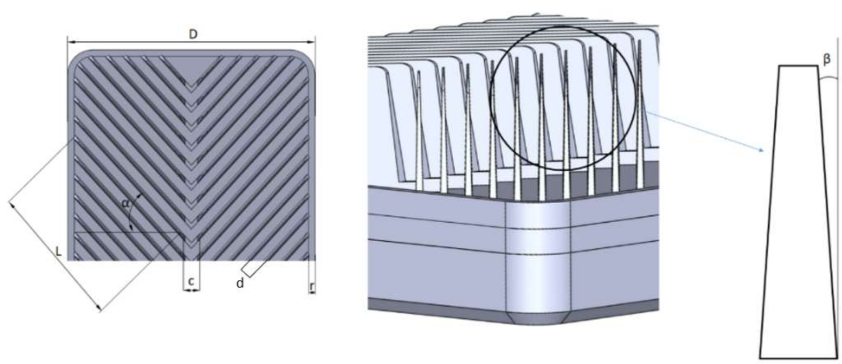
The present paper addresses an optimal design of a heat sink model with a V-shaped fin arrangement for the AAU of a 5G base station to enhance the heat removal performance. Two AAU product lines, an 8T8R AAU and a 32T32R AAU, were used, with increasing size and power consumption. The larger the size, the higher the efficiency achieved when using a V-shaped fin arrangement heat sink, which is demonstrated in detail in this paper. Figure 1 depicts the 8T8R AAU and the 32T32R AAU with the V-shaped fin arrangement heat sink integrated in the housing of the devices, with dimensions 500 x 350 x 130 mm and 1000 x 350 x 130 mm, respectively, and an average fin height of 70 mm.

The next section of this paper shows the systematic design method, which consisted of addressing the heat sink model parameters, a CFD analysis, and applying the Lagrange interpolation method. Specific case studies will be discussed in the third section, followed by a comprehensive conclusion in the final section.

2 Designing Method

2.1 Model Parameters

Following the growing trend of 5G technology, related products should be designed towards mass production. Therefore, the research and development process hinges on many technological factors. The manufacturing technology readiness level for AAU is especially important. As such, AAU heat sink models are built based on the technical parameters. However, not all of the geometric parameters in Figure 2 will have a significant effect on the performance of the model. To determine the most influential parameters, we conducted a CFD analysis.



(a) (b) (c)

Figure 2 Geometry parameters of the V-shaped fin arrangement heat sink model: a) back view of AAU; b) 3D view of AAU; c) fin section.

2.2 CFD Analysis

CFD is a well-known method that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. In this paper, CFD was applied in two phases, 1) model meshing, and 2) fluent dynamics solving. In the first step, the whole AAU model with a V-shaped heat sink was simplified to eliminate small components that do not significantly affect the analysis results. In the next stage, the hexahedral-dominant meshing approach [13] was used to transform the model into countable nodes and elements. The meshing model was then imported into the FLUENT software to run a simulation. In FLUENT, the governing equations were solved using the finite volume approach. From [7], we got the following governing equations from Eqs. (1) to (3):

Conversation of mass:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

Conversation of momentum:

$$\begin{aligned}
&\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}\\
&= -\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)\frac{\partial(\rho vu)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}\\
&= -\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+g(\rho-\rho_\infty)\frac{\partial(\rho wu)}{\partial x}+\frac{\partial(\rho wv)}{\partial y}\\
&\qquad +w\frac{\partial(\rho w^2)}{\partial z}\\
&= -\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)
\end{aligned} \tag{2}$$

Conversation of energy:

$$\frac{\partial(\rho uT)}{\partial x}+\frac{\partial(\rho vT)}{\partial y}+w\frac{\partial(\rho wT)}{\partial z}=\frac{\mu}{Pr}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \tag{3}$$

When the simulation was finished, the temperature contour result plots could easily be taken from the CFD software for making comparisons. In this way, the parameters that had the most considerable effect on the heat sink model were obtained. These are important for the design process in terms of improving the heat sink performance.

2.3 Lagrange Interpolation Method

The Lagrange interpolation method is a good method for constructing an approximating polynomial function from given nodes or points. In general, if there are $N+1$ distinct points $a \leq x_0 < x_1 < x_2 < x_3 < \cdots < x_n \leq b$. Then the problem of interpolation is to obtain *p(x)*, satisfying the conditions [14]:

$$p(x_i) = f(x_i), i = 1,2, \ldots, n \tag{4}$$

There exists only an N^{th} degree polynomial that passes through a given set of $N+1$ points. Its form is expressed as a power series:

$$g(x) = a_0 + a_1 x + a_2 x^2 + \cdots + a_N x^N \tag{5}$$

This study applied the Lagrange interpolation method to find the functions of the relationships between the geometry parameters and the operating temperatures of the AAU, by which the optimal parameters were obtained.

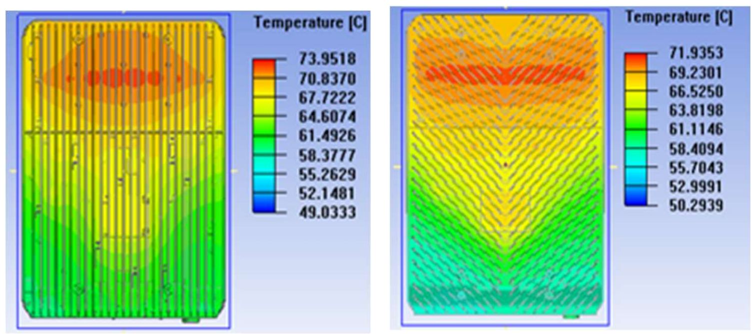
3 Results and Discussions

3.1 Simulation and Experimental Results

In the first experiment, this study used two AAU models for making comparisons, i.e., the 8T8R AAU with a vertical fin heat sink and the 8T8R AAU with a V-shaped fin arrangement heat sink. The parameters of the design were as follows: $h = 70$ mm, $D = 350$; $c = 22$ mm; $r = 6.7$ mm; $\beta = 1.5°$; $\alpha = 54°$; $d = 16.5$ mm; $t = 2$ mm, materials: AL6061 with thermal conductivity 200 w/mk. Technically, the layouts and wattages of the chipsets for each AAU product line are the same. The simulation process was set up as follows: environment temperature: 40 °C; number of iterations: 100; convergence criteria: 0.001 - energy: 10^{-7}. The number of meshing elements was 9,230,402 and the number of nodes was 10,041,750.

The simulation results are shown in Figure 3. In general, the performance of the design with V-shaped fins performed better than the design with vertical fins. For instance, the maximum temperature on the surface of the 8T8R AAU with a V-shaped fin arrangement was slightly lower (2.73%) in comparison to the model with a vertical fin arrangement.

The next step was the validation of the simulation results. We applied the parameters of the simulation to fabricate an 8T8R heat sink with V-shaped fins. The experimental system consisted of an environment cabinet, an 8T8R AAU, and an infrared thermometer, as displayed in Figure 4. The environment cabinet was used to generate a working environment as occurs in reality, with a temperature of 40 °C. An infrared thermometer (Fluke Ti27) was used to capture thermal images of the surface of the heat sink. The experimental result is shown in Figure 5, from which it can be seen that the maximum temperature on the surface of the heat sink approximated 73 °C at the picked point in Figure 5. The heat pattern in Figure 5 is similar to the simulation results in Figure 3(b). The error of 1.4% between the simulation and the experimental result is acceptable for this research.



(a) (b)

Figure 3 CFD thermal contour plots: (a) 8T8R AAU vertical fin heat sink; (b) 8T8R AAU V-shaped fin heat sink.

To test the significance of the improvement of the heat sink with V-shaped fins, we compared its performance with the 32T32R AAU, which is two times longer than 8T8R, while the other dimensions (width and depth) are exactly same. The simulation results are shown in Figure 6.

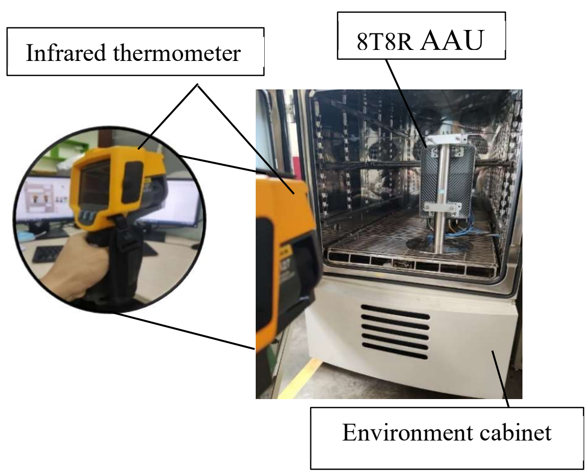
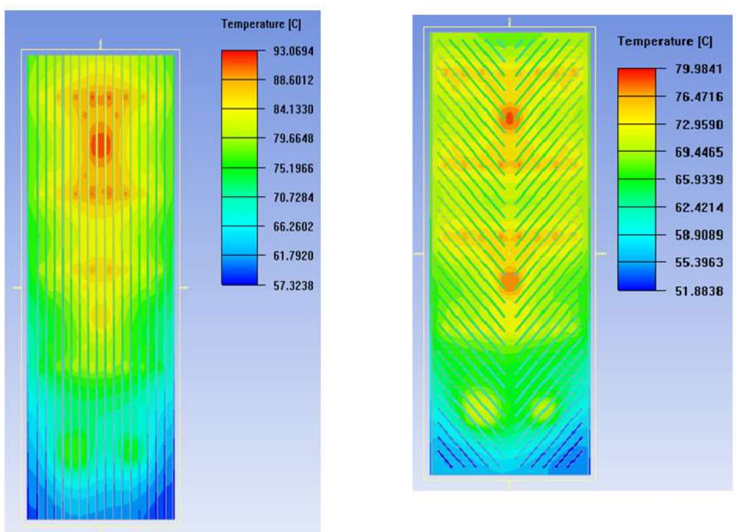


Figure 4 Experimental system.

Figure 5 Experimental result.

As can be seen in Figure 6, the maximum temperature of 32T32R AAU with V-shaped fins showed a significant drop of 14.06% in comparison with using vertical fins. This demonstrated the positive effect of the V-shaped fins on thermal dissipation.



(a) (b)

Figure 6 CFD thermal contour plots: a) 32T32R AAU vertical fin heat sink; b) 32T32R AAU V-shaped fin heat sink.

In the next section, we attempt to optimize the parameters for the 32T32R AAU model. As the CFD analysis showed, orientation angle α and fin spacing d have the largest effect on the operating temperature of the AAU. Their values are listed in Tables 1 and 2.

3.2 Optimal Design of V-shaped Fins

The Lagrange interpolation method was applied to the data from Tables 1 and 2. Two interpolation functions were obtained. The interpolation function of temperature depends on orientation angle α as described in Eq. (6), with R^2 = 0.9998. A graph of this function is shown in Figure 7.

$$T_\alpha = 4.7e^{-9}\alpha^6 - 1.48e^{-6}\alpha^5 + 1.82e^{-4}\alpha^4 - 0.01\alpha^3 + 0.35\alpha^2 - 6.12\alpha + 138.61 \quad (6)$$

From Eq. (6), the lowest temperature was found: $T_{\alpha\_min} = 79.85$ °C at α = 53.90°. The interpolation function of temperature depends on fin spacing d as described in Eq. (7), with R^2 = 0.9993. A graph of this function is shown in Fig. 8.

$$T = 1.07e^{-4}d^6 - 1.05e^{-2}d^5 + 0.42d^4 - 8.77d^3 + 100.27d^2 - 597.53d + 1537.9 \quad (7)$$

From Eq. (7), the lowest temperature was found: $T_{d\_min} = 80.74$ °C at d = 16.1 mm. With these optimal parameters, the designed heat sink's performance is guaranteed at the highest level.

Table 1 Orientation angle α and maximum temperatures.

α(°)	Maximum temperature on chipsets (°C)	Maximum temperature on heat sink (°C)
20	92.9813	92.1598
40	83.1440	82.3282
60	80.6151	80.4713
80	87.6845	87.5477
90	93.5973	93.0694

Table 2 Fins spacing d and maximum temperatures.

d (mm)	Maximum temperature on chipsets (°C)	Maximum temperature on heat sink (°C)
8	92.3632	91.4863
12	83.5774	82.7140
16	80.8448	80.0068
20	84.0101	83.7780
22	84.8488	84.2746
24	86.8396	85.9752

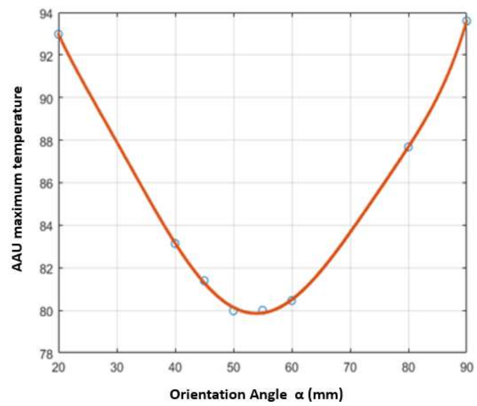


Figure 7 Diagram of temperature depending on orientation angle α.

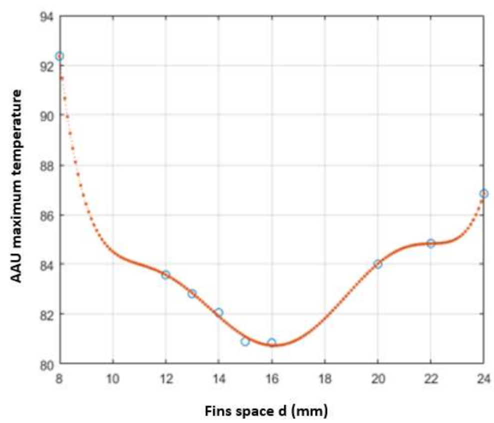


Figure 8 Diagram of temperature depending on fin spacing d.

4 Conclusions

This paper addressed an optimal design of the heat sink for an AAU of a 5G base station. A systematic design method for AAU heat sinks was deployed through a CFD analysis and the Lagrange interpolation method. The results demonstrated that using a V-shaped fin arrangement was better than a vertical fin arrangement for the heat sink in terms of cooling performance. The larger the size of the AAU, the more pronounced the effect. Also, this research illustrates that the orientation angle and fin spacing parameters have a significant effect on heat sink performance. The optimal parameters were computed by solving the optimization problem based on considering the interpolation function of temperature as an objective function. Finally, the optimal design of a heat sink with V-shaped fins was applied to fabricate the heat sink for the AAU of the 5G base station in Viettel High Technology Industries Corporation, Vietnam.

Nomenclature

L	=	Fin length, geometrically calculated by: $L = \frac{D-c-2r}{2cos\alpha}$ (mm)
h	=	Fin height (mm)
t	=	Fin thickness (mm)
α	=	Orientation angle (degree)
c	=	Bottom spacing (mm)
d	=	Fin spacing (mm)
β	=	Technology tilt angle (the angle used in die-casting technology, β ϵ (1.2°; 1.5°)
(x, y, z)	=	Coordinates
(u, v, w)	=	Velocity components
ρ	=	Density
T	=	Total energy
D	=	AAU width
r	=	AAU edge width

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