RRU 4G &5G Heatsink Design and Experimental Evaluation

Minh Dinh Bui
Hanoi University of Science and Technology
No 1, Dai Co Viet street, Hai Ba Trung district, Ha Noi
Dinh.buiminh@hust.edu.vn

Nguyen Chi Cong
IDME Department
VTBR Center, Viettel High Technology -VHT
congnc@viettel.com.vn

Abstract
Active Antenna Unit-RRU 5G 5G/Remote Radio Unit-RRU 4G LTE Heatsink systems are using natural convection cooling due to some outstanding advantages such as low cost, high reliability, noiseless operation, and hard environment operation. However, some main disadvantages such as a relatively low heat transfer and low heat dissipation density are to be solve by optimal heat sink fin design. So an analytic calculation and FEM simulation is required to efficiently design natural convection heat sinks according to the applied design constraints. This paper describes an optimal heatsink fin profile design with V shape angle to maximize natural cooling for Active Antenna Unit-RRU 5G 5G. The proposal design is based from RRU 4G heatsink simulation and experiment results. Several core ICs of RRU 4G with high heat loss sources up to hundred W need to be dissipated by Aluminum heatsink and enclosure or housing. The RRU 4G natural cooling system is composed of parallel-straight plate heat sinks to find an optimum heat sink design based on an analytical calculation of Entropy energy and Heatsink Resistance but the RRU 5G 5G Heatsink system is cooled by V sin plate heat sinks to improve heat exchange. Temperature measurements were carried out to validate the RRU 4G heatsink model and proposal design of RRU 5G 5G heatsink is calculated by an analytical model and FEM simulation. This paper will show an optimal calculation of RRU 5G 5G housing heatsink fin to minimize manufacture and material cost.

Keywords
Remote Radio Unit-RRU, 2 Transmitter/2 Receiver-2T2R, Power Amplifier PA 2x40W and 2X60W.

1. Introduction
Nowadays, RRU 5G 5G applications are driving RF microwave circuit design into high frequencies and high-power levels such as 8T8R, 16T16R, 32T32R and 64T64R with reduction in feature sizes, volumes and increase in complexities. Together with the demand on higher frequencies and higher power levels, the thermal effect can no longer be neglected due to the reduced feature size and the increased power levels [1-4]. Total power of FPGA ICs in RRU 5G 5G is from 800W to 1000W, most of input power will be converted to heating losses [1]. Total heat losses of RRU 4G FPGA and PA is about from 240W to 300W based on operation modes. In order to control overheat temperature of PA transistor, an effective heat sink is design to dissipate the heat loss to air in different cases to avoid overheat. Consequently, a FEM calculation has been applied to optimize thermal distribution of RRU 5G 5G/RRU 4G ICs in PCBs and housing. Thermal dissipation density W/lit is maximized to meet RF/microwave performance and size reduction by different heatsink fin shapes as V wave and V sin.

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This paper describes an optimal heatsink fin profile design with V shape angle to maximize natural cooling for Active Antenna Unit-RRU 5G 5G. The proposal design is based on RRU 4G heatsink simulation and experiment results. Several core ICs of RRU 4G with high heat loss sources up to hundred W need to be dissipated by Aluminum heatsink and enclosure or housing. The RRU 4G natural cooling system is composed of parallel-straight plate heat sinks to find an optimum heat sink design based on an analytical calculation of Entropy energy and Heatsink Resistance but the RRU 5G 5G Heatsink system is cooled by V sin plate heat sinks to improve heat exchange. Temperature measurements were carried out to validate the RRU 4G heatsink model and proposal design of RRU 5G 5G heatsink is calculated by an analytical model and FEM simulation. This paper will show an optimal calculation of RRU 5G 5G housing heatsink fin to minimize manufacture and material cost.

2. Thermal Resistance Calculation

With different geometry parameters of RRU 5G 5G/RRU4G enclosure, they have different heat resistances based on heatsink thickness, material, and heat flow exchange. Analytical model of RRU 5G 5G/RRU4G heatsink under natural convection is applied to Aluminum 6061 and straight heatsink fin which has been investigated by Elenbass [2,3]. This natural convection between isothermal parallel vertical plates and heat losses from FPGA and PA IC inside RRU4G housing.

![Figure 1. Schematic of the natural convection heat sink](image1.png)

As shown in Fig. 1, the 425 x 320 x 140 (mm³) dimension natural convection heat sink for RRU is made by aluminum. The heat sink is set to close to the power amplifier unit. The natural convection heat sink is the cover of RRU. Analytical model of heatsink fins has been programed in MATLAB with input parameter as fig 2.

![Figure 2. Input parameters of heatsink](image2.png)

This research is to study the heat transfer performance, thermal resistance, and heat transfer of natural convection cooling with different geometries.

The heat flow by natural convection is given by:

\[
Q_{\text{HS}} = n_{\text{fin}} Q_{\text{fin}} = n_{\text{fin}} (h_p A_p \theta_p + Q_{\text{rad}})
\]  

(1)
With the number of fins \(n_{\text{fin}}\), the heat dissipated from a single fin \(q_{\text{fin}}\), \(h_b\) is heat transfer coefficient for a single fin, the heat sink surface area of a single fin \(A_b\), the differential temperature between fin and ambient temperature \(\theta_b\), the radiation heat transfer \(Q_{\text{rad}}\).

\[
q_{\text{fin}} = h_{\text{fin}} A_b \theta_b
\]

Where \(W\), \(w_c\) and \(w_w\) are geometric parameters according to Fig. 3, and

\[
A_{\text{fin}} = 2(LH_f + H_f w_w + \frac{Lw_c}{2})
\]

Where \(L\), \(H_f\) and \(H_b\) are geometric parameters according to Fig. 3.

The external and internal heat transfer coefficient for a single fin is given by:

\[
h_b = 0.59 Ra_b^{0.25} \frac{k_f}{L}
\]

\[
h_{\text{fin}} = Nu_{\text{fin}} \frac{k_f}{w_c}
\]

Where \(k_f\) represents the thermal conductivity of the air and \(Nu_{\text{fin}}\) is Nusselt standard of the heat sink:

\[
Nu_{\text{fin}} = \left[ \frac{576}{(\eta_{\text{fin}} El)^2} + \frac{2.873}{(\eta_{\text{fin}} El)^{1/2}} \right]^{1/2}
\]

With the Elenbaas number

\[
El = \frac{g \beta \theta_b w_c^4}{\nu_f \alpha_f L}
\]

and the Rayleigh number:

\[
Ra_b = \frac{g \beta \theta_b L^3}{\nu_f \alpha_f}
\]

Where \(\nu_f\) and \(\alpha_f\) represents dynamic viscosity and the thermal conductivity of the cooling medium air.

The radiation heat transfer coefficient is estimated by:

\[
Q_{\text{rad}} = \sigma e_{\text{eff}} LW(T_b^4 - T_\infty^4)
\]

Where the emissivity of the solid (aluminum) \(e_{\text{eff}}\), the Boltzmann constant \(\sigma\) and the heat sink surface \(L.W\), does not account for the shape of the channels. When the surface radiation coefficient is 0.8.

\[
e_{\text{eff}} = \left[ -0.2 - 3.369 \exp\left( -\frac{L}{0.929 H_f} \right) \right] \exp\left( -\frac{H_f}{2s} \right) + 1.12 + 3.004 \exp\left( -\frac{L}{1.526 H_f} \right)
\]

The thermal resistance appears when heat flow transfer from the narrow area to the larger area.

The thermal resistance is given by

\[
R_{\text{fin}} = \frac{\theta_b}{Q_{HS}}
\]
The temperature of every location $\theta(x, y, z)$ of the base plate is calculated as those equations.

$$
\theta(x, y, z) = A_0 + B_0 z + \sum_{m=1}^{\infty} \cos \lambda_m x. [A_m \cosh \lambda_m z + B_m \sinh \lambda_m z] \\
+ \sum_{n=1}^{\infty} \cos \delta_n x. [A_n \cosh \delta_n z + B_n \sinh \delta_n z] \\
+ \sum_{m} \sum_{n} \cos \lambda_m x. \cos \delta_n y[A_{mn} \cosh \beta_{mn} z + B_{mn} \cosh \beta_{mn} z] 
$$

(13)

where

$$
A_m = \frac{2 Q_{HS} \sin \left( \frac{2 x_c + x_s}{2} \right) \lambda_m - \sin \left( \frac{2 x_c - x_s}{2} \right) \lambda_m}{LW_x, k \lambda_m^2 \phi \lambda_m} 
$$

(14)

$$
A_n = \frac{2 Q_{HS} \sin \left( \frac{2 y_c + y_s}{2} \right) \delta_n - \sin \left( \frac{2 y_c - y_s}{2} \right) \delta_n}{LW_y, k \delta_n^2 \phi \delta_n} 
$$

(15)

$$
A_{mn} = \frac{16 Q_{HS} \cos \lambda_x x_s \sin \left( \frac{1}{2} \lambda_m m_n \right) \cos (\delta_n y_s) \sin \left( \frac{1}{2} \delta_n d \right)}{LW_x, y_s k \beta_{mn} \lambda_m \delta_n \phi (\beta_{mn})} 
$$

(16)

with

$$
\lambda = \frac{m \pi}{W} ; \delta = \frac{n \pi}{L} ; \beta = (\lambda^2 + \delta^2)^{0.5} \\
B_i = -\phi(\zeta) A_i \\
\phi(\zeta) = \frac{\zeta \sinh \zeta H_b + \frac{h_{eff}}{k \cosh \zeta H_b}}{\zeta \cosh \zeta H_b + \frac{h_{eff}}{k \sinh \zeta H_b}} 
$$

(18)

In the equation (17), $\zeta$ is replaced by correlated $\lambda, \delta, \beta$
\[ \theta_h = \frac{Q}{LW} \left( \frac{H_h}{k} + \frac{1}{h_{eff}} \right) + 2 \sum_{m=1}^{\infty} A_m \frac{\cos \lambda_m x_c \sin \left( \frac{1}{2} \lambda_m x_s \right)}{\lambda_m x_s} + \\
+ 2 \sum_{n=1}^{\infty} A_n \frac{\cos \delta_n y_c \sin \left( \frac{1}{2} \delta_n y_s \right)}{\delta_n y_s} + \\
+ 4 \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn} \frac{\cos \lambda_m x_c \sin \left( \frac{1}{2} \lambda_m x_s \right) \cos \delta_n y_c \sin \left( \frac{1}{2} \delta_n y_s \right)}{\lambda_m \delta_n x_c y_s} \tag{19} \]

If there are many heat sources, the temperature should calculate the average value. Finally, the thermal resistance is given by:

\[ R_{HS} = \frac{\bar{\overline{\theta}}}{Q_{HS}} \tag{20} \]

The thermal conductivity coefficient \( k \) and \( h_{eff} \) in the formula (17), (18) are the effective thermal conductivity coefficients.

\[ h_{eff} = \frac{1}{R_{m} LW} \tag{21} \]

Thermal calculation follow chart can be shown in Fig 4 from input parameter to results.

![Diagram](image)

**Figure 4. Optimal heatsink fins follow chart.**

The input parameter for optimal fins is \( Q = 300W, L = 174 \text{ mm}, W = 380 \text{ mm}, t_b = 5 \text{ mm}, b = 12 \text{ mm}, H=55\text{mm}. \) The entropy \( S_{cw} \) is a function of fin thickness from MATLAB program.
The entropy generation is minimum with thickness \( t = 0.0015 \text{m} \) (1.5mm) MATLAB program.

The Entropy and Resistance is minimum with heatsink thickness of 1.5mm, however CNC machines can manufacture the heatsink fin from 2mm because of deformation.

The number fins \( n = 32 \) and thickness of 2mm are optimal parameters of RRU heatsinks. Those parameters will apply for 3D design by Solid work and NX software.

3. Thermal simulation and experimental result

The 3D model and material parameters have been loaded in Ansys-Icepack model to determine temperature distribution of RRU heatsink. The hotspot is located in center of heat sources. The maximum temperature must be lower than temperature limit of IC PA transistor, modeling steps is shown in Fig 8.
Material properties of thermal conduction and heat losses are inputs of FEM model and losses were applied to ICs and electronic devices as in Fig 9.

The total heat source is 260-300W at ambient temperature of 25°C and natural convection, Aluminum conduction AL6061 of 171 W/m.K has setup and applied for thermal model.

The maximum temperature of RRU heatsink is 85°C lower than temperature capacity of ICs inside RRU housing. To evaluate the simulation results, a hardware setup has built.
4. Loss analysis

Electronic devices PA, DUP and ICs in hardware PCBs is quite big because of high frequency from 1800 MHz to 2600 MHz in RRU 4G. To calculate losses of power amplifier-PA of RRU, an indirect method has been applied to obtain losses from RF duplexer, PA, and All ICs as Fig 11.

![Figure 11. Electric power circuit of RRU 4G](image)

To calculate efficiency of power amplifier of RRU, flow chart of calculation shows in Fig 11.

\[
\begin{align*}
P_{\text{total}} &= P_{\text{logic}} + P_{\text{PA}} \\
P_{\text{logic}} &= 49 \text{ W} \\
P_{\text{PA}} &= P_{\text{total}} - P_{\text{logic}} \\
P_{\text{inPA}} &= \eta_{\text{power,PA}} \cdot P_{\text{PA}} = \eta_{\text{power,PA}} \cdot (P_{\text{total}} - P_{\text{logic}}) \\
P_{\text{outPA}} &= \eta_{\text{PA}} \cdot P_{\text{inPA}} = \eta_{\text{PA}} \cdot \eta_{\text{power,PA}} \cdot (P_{\text{total}} - P_{\text{logic}}) \\
P_{\text{RF}} &= \frac{P_{\text{outRF}}}{10^{\text{dBm}}} \text{ Add loss Duplexer (0.6 dBm)}
\end{align*}
\]

![Figure 12. Electric power and efficiency calculation of RRU4G](image)

Normally, the power RRU 4G 2 (Transmitter and 2 Receiver 2T2R) is operated in two modes 2x40W and 2x60W, it depends on user number and uplink/downlink speed. Power losses are from P_RF, duplexer and power supply board (P_total). A detail case of 2x39W was addressed in Fig 12. Electric consumption is from 400W to 500W based on loading rate or operation modes. Efficiency of whole system is quite low from 20% to 35% because of PA, DUP and FPGA circuit losses.

![Figure 13. Efficiency calculation of RRU 4G 2T2R 2x40W](image)

Efficiency of PA board is about 24.9%, it is quite low in comparison with other vendors such as Nokia and Ericson. Because this PA circuit is not yet optimized.
The experimental setup includes heatsink, heat source and Data acquisition to record temperature values with time sample of 30 second and total test duration of 3 hours.

Fig.14 shows the schematic of experimental setup, which includes the power amplifier of RRU heat sink of 300W (heat source), data acquisition with 6 channels for 6 measure points, and desktop PC. The heat transfer surface of the heat source is attached to the sidewall of heating block, and value of the input power is controlled by the power meter.

Input power for RRU heat source is 48V*9.2A=440W and the temperature in PCB and ICs base and heatsink fin are record by data acquisition and PC in fig 15. According to IEC experimental test, the maximum temperature is kept in 3 hours.
Temperature results are recorded by data acquisition in Lab. After three hours for heat run test, the maximum temperature in electronic power transistor is 79\(^\circ\)C degree and temperature base is 68\(^\circ\)C degree. Each power amplifier circuit has an Aluminum plate coating Ag to improve grounding and heat transfer and two IC transistors 2x40W@2600MHz were welding in this base plate. Temperatures of IC transistor, base and ambient are shown as Fig 18.

![Temperature sensor in FPGA](image)

**Figure 17. Temperature sensor in FPGA**

5. Novel Design of V Shape heatsink fins

To optimize temperature distribution, the RRU 5G heat sink system is design with V shape fins as Fig 19. The V fin can increase total heat exchange areas and heat flows are from in centre to both sides. This proposal will be new design for long RRU 5G with 64T64R about 1300x400mm.

![V shape in RRU 5G 8T8R heatsink](image)

**Figure 19. V shape in RRU 5G 8T8R heatsink.**

V fin heatsink have been designed for RRU 5G 8T8R to improve natural heatsink efficiency in Fig.20.

![Temperature curves of PA base](image)

**Figure 18. Temperature curves of PA base**
Figure 20. Thermal simulation of I shape and V shape RRU 5G 8T8R heatsink.

The Fluke temperature measurement device has been installed to compare temperature distribution in RRU 5G as Figure 22. The temperature difference is from 2 to 3 °C degree. It is acceptable.

Figure 21. Thermal simulation of I shape and V shape RRU 5G 5G 8T8R heatsink.

In comparison with I shape heatsink fin, new V shape heatsink design is reduced about 2 °C degree and temperature distribution is not so big different from hotspot center point to outside. The temperature improvement will be significant with longer RRU 5G -32T32R and 64T64R (1300x500x200) in comparison The RRU 5G 8T8R 600x400x140mm. The RRU 5G with V and I form of heatsink fins have simulated with the same electronic power losses and resulted in Fig 22.
6. Conclusion

This paper has implemented analytical and FEM simulation methods for optimizing two parameters of heatsink fin distance and skew angle to find out minimum temperature or increase heat transfer factors. The described analytical thermal model reveals good results compared to thermal measurements over a wide range of power losses. Therefore, an easy to apply design method is given to efficiently design natural convection heat sinks of RRU 4G&5G. The analytical optimum design shows the potential of carefully designed heat sinks compared to commercially available profiles. Furthermore, the optimization is more efficient the better the base plate area is utilized. Thus, power modules might not be the preferred choice, but discrete semiconductors, where the power circuit might adopt an optimal shape of the base plate area.

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