Active Heat Sinks Design and Optimization of RRU 5G Considering Wind Speed Condition

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Abstract

Remote Radio Unit (RRU) is the main part of the 5G base station that has a great size with a high density of chipsets and be operated with significantly high temperature. This paper introduces an optimization protocol of geometric parameters of heat sink on thermal dissipation for RRU 5G 8T8R operation at 2600MHZ. Firstly, the heat sink is calculated by analytical method with minimization of entropy energy. In the next step, two more prototypes of heat sink are proposed to consider their performance on thermal dissipation. The simulation results demonstrated that in general, the heat sink with V-shaped fin has the better performance on thermal dissipation in comparison to conventional models such as in-line arrangement fin heat sinks. An optimal heatsink for RRU 5G have been simulated by FEM method considering different working conditions such as wind speed and high attitudes.

Keywords

Remote Radio Unit-RRU 5G, 8 Transmitter/8 Receiver-2T2R,

1. Introduction

Remote Radio Unit-RRU 5G Heatsink systems are using natural convection cooling due to some outstanding advantages such as low cost, high reliability, noiseless operation, and hard environment operation in S. Shinjo, K 2017. However, some main disadvantages such as a relatively low heat transfer and low heat dissipation density are to be solved by optimal heat sink fin design. The RRU 5G -8T8R, 16T16R, 32T32R, and 64T64R normally have big losses, sizes, volumes, and complexities. Thermal management cannot be neglected due to the reduced feature size and the increased power levels in J. Curtis 2013 The total power of PFGA ICs in RRU 5G is from 800W to 1000W, most of the input power will be converted to heating losses S. Chen 2016. Total heat losses of RRU 4G FPGA and PA is about from 240W to 300W based on operation modes. In order to control the overheat temperature of PA transistors and ICs, a heat pipe and vapor chamber is designed to dissipate the heat loss to air in different cases to avoid overheating. This paper describes an optimal heatsink fin profile design with V shape angle to maximize natural cooling for Active Antenna Unit-RRU 5G. The RRU 5G cooling system is composed vapor chamber and heat plate passive cooling system. Temperature measurement results were carried out to validate the industrial lab experiment. This paper also shows an optimal calculation of RRU 5G housing heatsink fin to minimize manufacturing and material cost of RRU Housing.

2. Assembly Constraints

The 3D model and material parameters have been designed to determine the temperature distribution of the RRU heatsink in figure 1. The hotspot is located in the center of heat sources. The maximum temperature must be lower than the temperature limit of IC PA transistor, modeling steps is shown in Fig 8. The transmit antenna array operates at about 2.6 GHz. The radiating elements, patches, are positioned on a flat surface each one half of a free-space wavelength. The elements are arranged in several layers. An array with up to 6 × 4 elements is possible as well

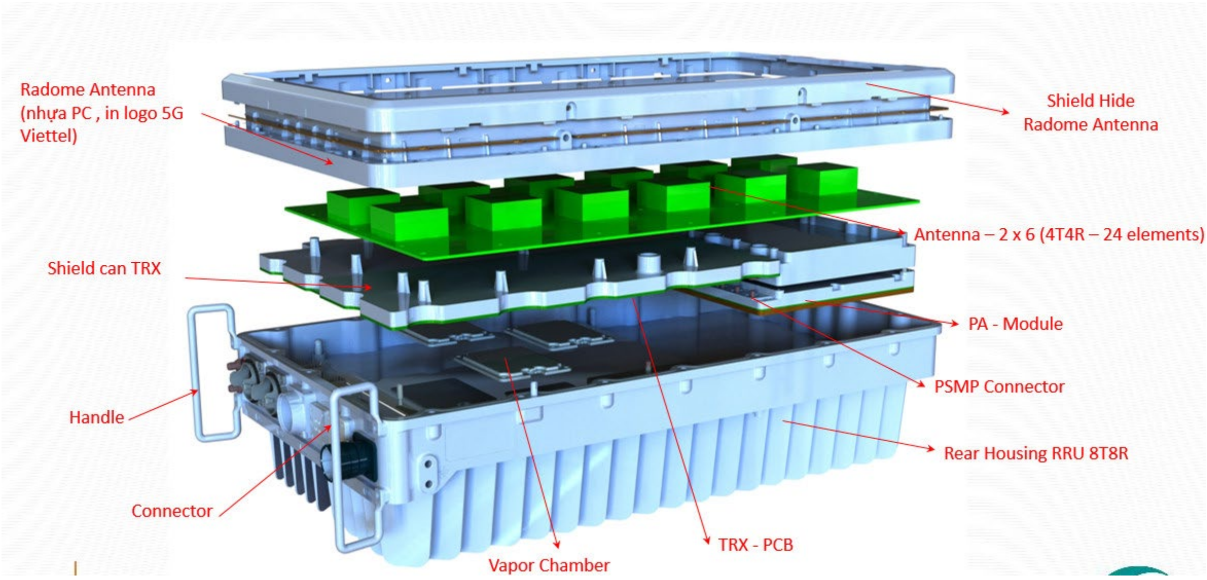


Figure 1. 3D RRU 5G 8T8R Modeling

Due to the small wavelength and a resulting high packaging density, integration of all required parts including the cooling system is a major problem. Figure 1 outlines the principal layer structure of the antenna array, TRX PCB and heatsinks. The topmost layer is radom. It is connected by vias or by means of aperture coupling to a layer featuring a network and the power amplifiers in TRX board. The power amplifiers are directly mounted on a yet to be specified cold plate which are heat pipe and heat plated. The power amplifiers are connected to the feeding network using connectors. Therefore, the cold plate has to incorporate cut outs which will feature the connectors.

3. Analytical Calculation of Thermal Models

With different geometry parameters of RRU 5G enclosure, they have different heat resistances based on heatsink thickness, material, and heat flow exchange. Analytical model of RRU 5G heatsink under natural convection is applied to Aluminum 6061 and straight heatsink fin which has been investigated by John, T.J 2010. This natural convection between isothermal parallel vertical plates and heat losses from FPGA and PA IC inside RRU 5G housing as figure 1. The heat sink sizes for RRU are 425 x 320 x 560 (mm^3) made by aluminum. The heat sink is set to close to the power amplifier unit in RRU as cover of RRU. Analytical model of heatsink resistance has been programed in MATLAB with different shapes as fig 2.

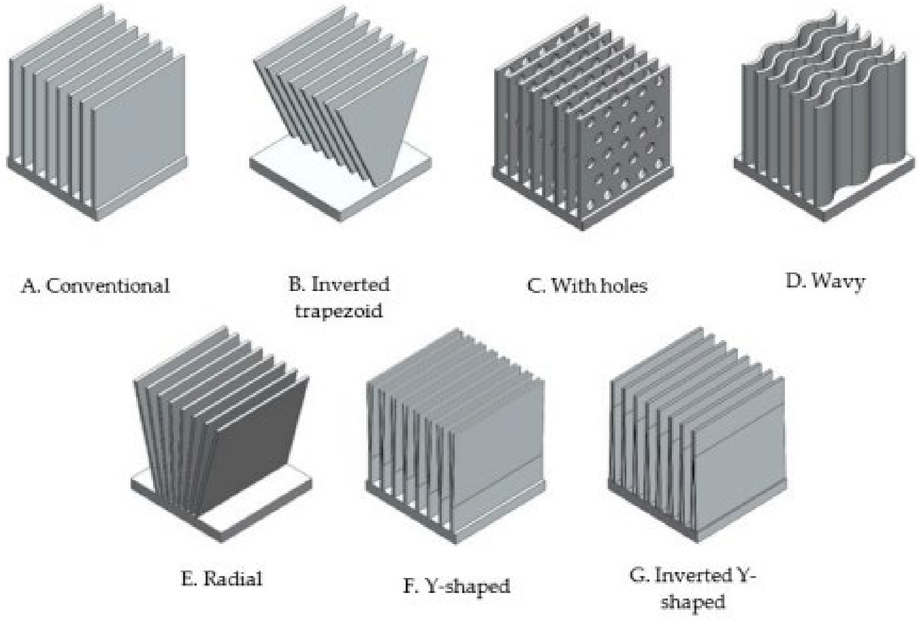


Figure 2. Different fins heat sink model Eva C. Silva 2021

The shape of fins or pins was varied according to some previous studies that showed good results . Zhou, F 2011 Kou, H.S 2008 considering the same boundary parameters.

This study will estimate thermal resistance, and heat transfer of natural convection cooling with different geometries. The heat flow by natural convection is given by

$$Q_{HS} = n_{fin}.Q_{fin} = n_{fin}(h_b A_b \theta_b + Q_{rad}) \quad (1)$$

with the number of fins n_{fin}, the heat dissipated from a single fin q_{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 θ_b ,the radiation heat transfer Q_{rad}.

$$n_{fin} = \frac{W + w_c}{w_c + w_w} \quad (2)$$

$$A_b = L w_c \quad (3)$$

$$q_{fin} = h_{fin} A_{fin} \theta_b \quad (4)$$

where W, w_c and w_w are geometric parameters according, and

$$A_{fin} = 2(LH_f + H_f w_w + \frac{Lw_w}{2}) \quad (5)$$

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

$$h_b = 0.59 Ra_b^{0.25 \frac{k_f}{L}} \quad (6)$$

$$h_{fin} = Nu_{fin} \frac{k_f}{w_c} \quad (7)$$

Where k_f represents the thermal conductivity of the air and Nu_{fin} is Nusselt standard of the heat sink

$$Nu_{fin} = \left[\frac{576}{\left(\eta_{fin} El\right)^2} + \frac{2.873}{\left(\eta_{fin} El\right)^{1/2}} \right]^{-1/2} \tag{8}$$

With the Elenbaas number

$$El = \frac{g\beta\theta_b w_c^4}{v_f \alpha_f L} \tag{9}$$

and the Rayleigh number

$$Ra_b = \frac{g\beta\theta_b L^3}{v_f \alpha_f} \tag{10}$$

where v_f and α_f represents dynamic viscosity and the thermal conductivity of the cooling medium air.

The radiation heat transfer coefficient is estimated by

$$Q_{rad} = \sigma\varepsilon_{eff} LW(T_b^4 - T_\infty^4) \tag{11}$$

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

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

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

$$R_{fin} = \frac{\theta_b}{Q_{HS}} \tag{12}$$

The temperature should calculate the average value. Finally, the thermal resistance is given by

$$R_{HS} = \frac{\overline{\theta}_{heater}}{Q_{HS}} \tag{13}$$

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

$$h_{eff} = \frac{1}{R_{fin} LW} \tag{14}$$

Thermal calculation follow chart can be shown in Fig 5 from input parameter to results

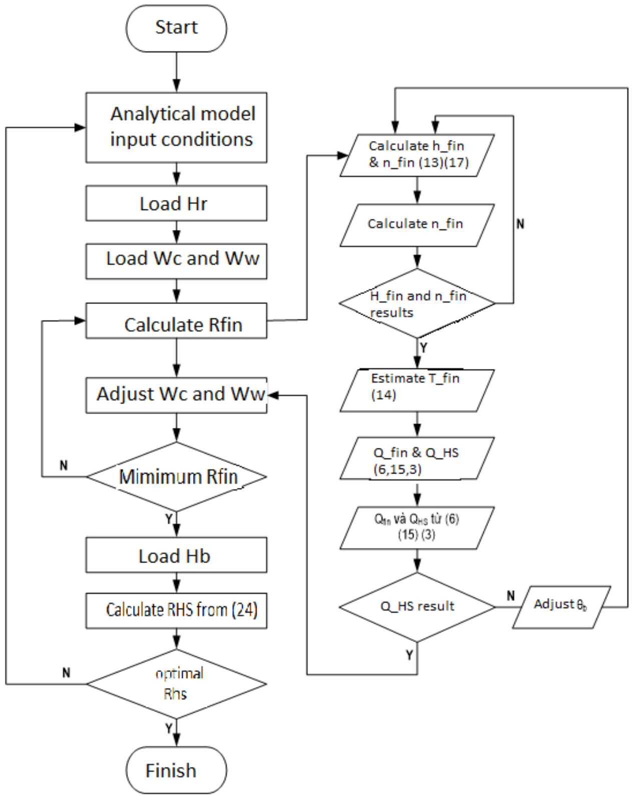
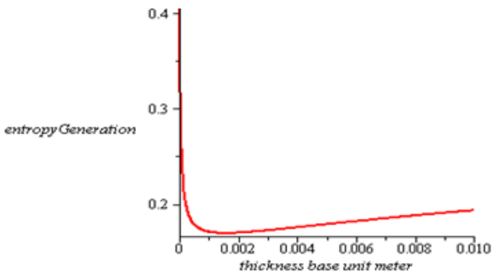
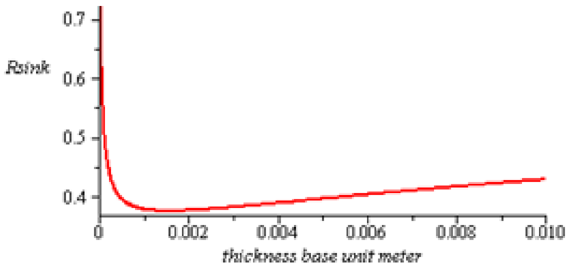


Figure 3 Optimal heatsink fins follow chart

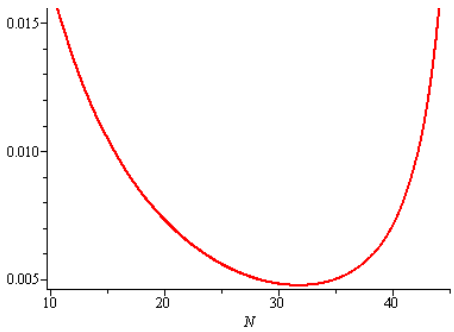
The input parameter for optimal fins are Q = 450W, L = 560 mm, W = 380 mm, t_b = 5 mm, b = 12 mm, H = 55 mm and wind speed v=0.5-3m/s. The entropy $\dot{S}_{gen}$ is a function of fin thickness from Matlab program.



a. Entropy vs fin thickness



b. Heatsink resistance vs fin thickness



c. Optimal number of fins

Figure 4. Entropy, thermal resistance, and number of heat sink fin calculation results

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. Air cooling by means of forced convection is realized by air moving devices like fans and blowers. Forced air cooling is a very common choice for many applications since a cooling system is often low-cost and can comparably easily be build. In a BST pole, basically two environments for forced air cooling are conceivable: the pressurized and controlled temperature zone and the non-pressurized and non-controlled temperature zone. Altitude significantly affects the second environment. The first scenario, a temperature and pressure-controlled location for the heat sink, simplifies overall design since different ambientconditions do not have to be considered. Since the final location of the heat sink in the aircraft has notbeen decided yet at this stage of the project, the more general second scenario will be characterized in the following.

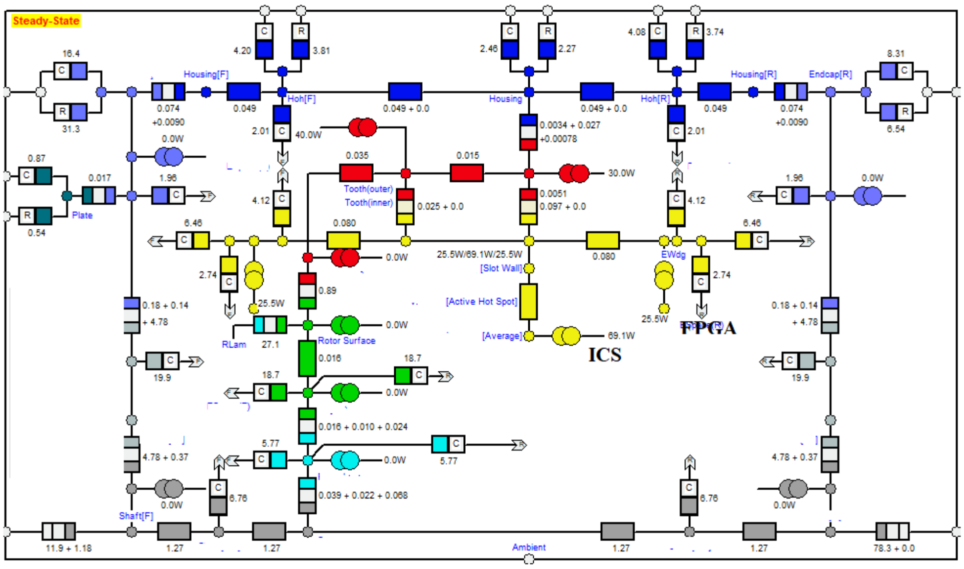


Figure 5. Heat loss and resistance circuit of RRU 5G

3. Thermal Simulation and Experimental Result Analysis

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 figure 6.

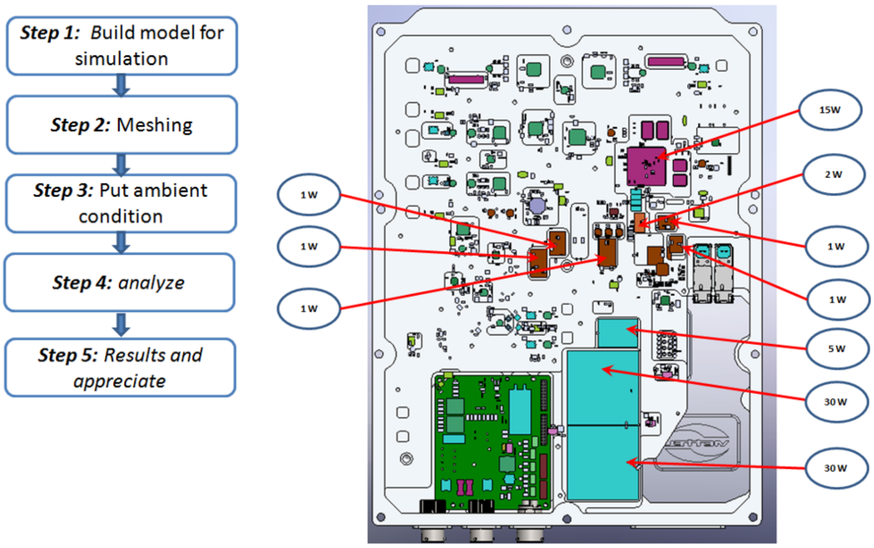
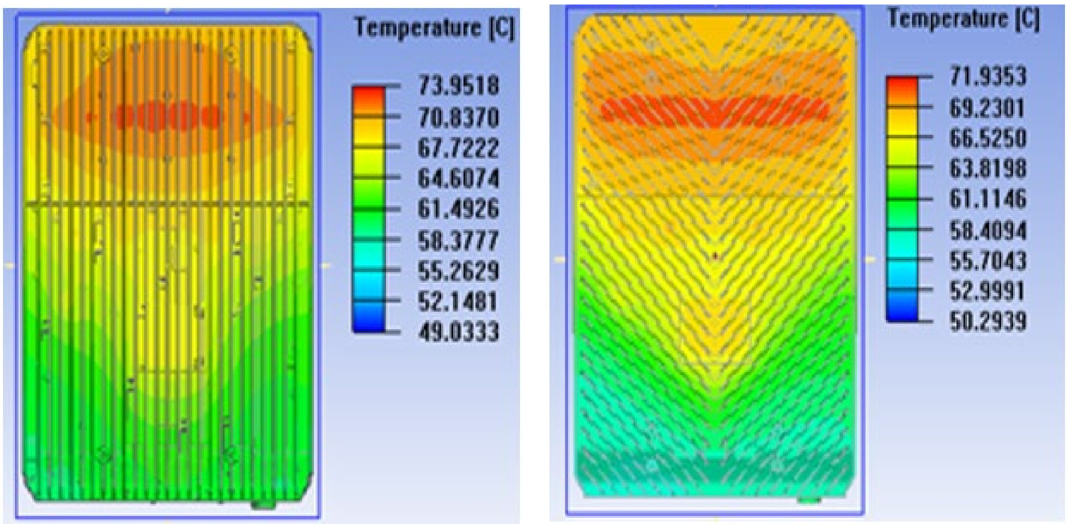


Fig 6. Heat loss distribution

The total heat source is 350-400W at ambient temperature of 25^0C and natural convection, Aluminum conduction AL6061 of 171 W/m.K has setup and applied for thermal model. The simulation results are shown in figure 6, in general, the performance of the design with V-shaped fins is better than vertical fins. For instance, the maximum temperature on 8T8R AAU with V-shaped fins arrangement was declined slightly by 2.73% in comparison to the model with vertical fin. Next stage is a validation of the simulation results, we applied the parameters of the simulation to fabricate 8T8R heat sink with V-shaped fins. The experimental system consists of an environment cabinet, 8T8R active antenna unit and an infrared thermometer. The environment cabinet is to generate working environment as reality with the temperature of 40°C, an infrared thermometer named Fluke Ti27 is used to capture thermal image on the surface of the heat sink. The experimental result is shown in Fig. 5, as can be seen that the maximum temperature on surface of heat sink approximates 73°C at the picked point in Fig. 5. The heat pattern of Fig. 5 is as similar as the simulation results in Fig. 3b. An error of 1.4% between the simulation and experimental result is acceptable for this research. To witness the significant improvement of the heat sink with V-shaped fins, in the next section, we will research on version 32T32R, and 64T64R which is bigger than 8T8R.



a) 8T8R AAU vertical fins heat sink; b) 8T8R AAU V-shaped fins arrangement heat sink

Figure 6. Thermal simulation result

The maximum temperature of RRU heatsink is 72^0 C in the front side with V heatsink fins and 74 ^{0} C rear side with a straight fin. To evaluate the simulation results, a hardware setup has been built by a temperature sensor, power losses, and PC-data acquisition. The experimental setup includes heatsink, heat source and Data acquisition to record temperature values with a time sample of 30 seconds and total test duration of 3 hours.

In 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. According to obtain constant temperature values, the experimental test is running in 3 hours. There are five temperature sensors is inserted in several points as vapor chamber, copper plate, housing, front and rear sides.

Temperature results are recorded by data acquisition in Lab. After three hours for heat run test, the maximum temperature in the electronic power transistor is 74^0 C degrees and the temperature base is 68^0C degrees. Each power amplifier circuit has an Aluminum plate coating Ag to improve grounding and heat transfer and two IC transistors were welded in this base plate. Temperatures of IC transistor, base, and ambient are shown in figure 7.

The Fluke temperature measurement device has been installed to compare temperature distribution in RRU 5G as figure 8. The temperature in pick point is 67.8 ^{0}C degrees and this point is very close to the vapor chamber plate. It is clear that heat loss was dissipated and the temperature difference between the vapor chamber and heatsink is small. Thus, the vapor chamber and heat pipe embedded is a significant effect.

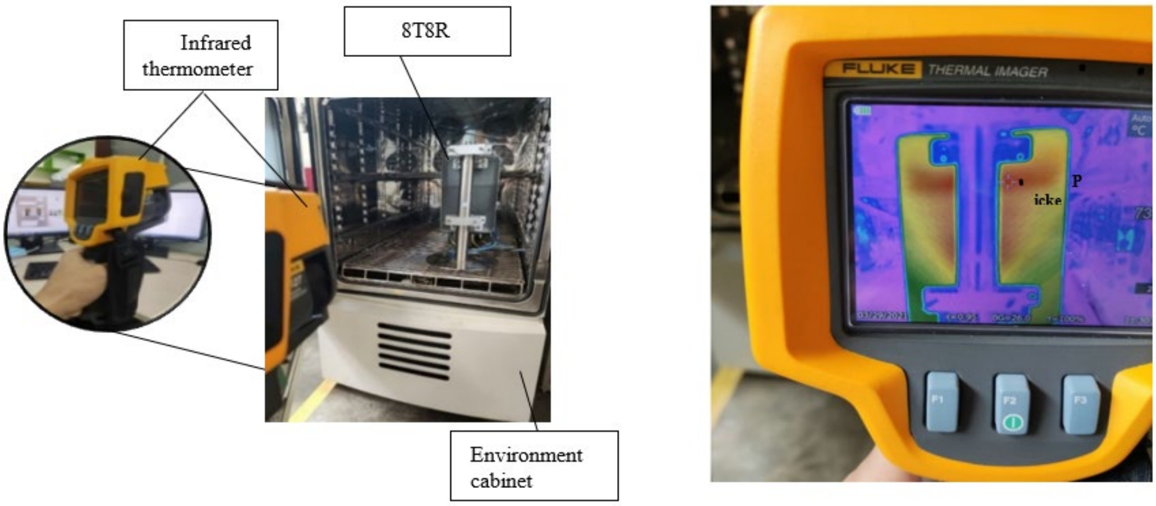


Figure 10. Thermal distribution of RRU 5G 8T8R V heatsink fin

The temperatures in simulation results (figure 6) and temperature image (figure 10) are good agreement and acceptable.

6. Conclusion

This paper has implemented FEM simulation and experiment methods for RRU 5G heatsink embedded vapor chamber and heat pipe to improve heat transfer efficiency. This research illustrated that V shape heatsink fin with vapor chamber and assemblies is potentially applied for the industry. 3D Thermal simulations have been carried out to find out the best V shape angle. The thermal performance of heat sinks design under forced convection, varying geometric and boundary parameters (inlet velocity and heat source temperature), was conducted by computational fluid dynamics simulation with ANSYS ICE park. Considering heat sinks with fins configuration, it was found out that the thickness of the fins should be as thin as possible and widely spaced. The optimal design is obtained by an agreement between both parameters. The wind speed has a greater impact on the pressure drop, the bigger fins spacing (2.5 mm) was considered for studies related to the wind speed of 1.5m/s. For this last iteration on the shape configuration, all geometric and boundary parameters were kept constant, varying only in heat sinks design. It was found that radial fins designed with V shape have great advantages and the design was the one with better performance. Finally, the RRU 5G heat sink with V-shaped fins was applied to fabricate and measure temperatures in the lab by supporting Viettel High Technology Industries Corporation, Vietnam

Acknowledgment: *This work was supported by project "Viettel Remote Radio Unit 5G", Viettel High Technology-VHT, Viettel Military Industry and Telecoms Group, Vietnam)*

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