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ACTIVE ANTENNA UNIT - 5G HEATSINK CALCULATION AND EXPERIMENT EVALUATION

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Abstract*: Today, density network deployment is being considered as one of the effective strategies to meet the capacity and connectivity demands of the fifth-generation (5G) cellular system [9]. Active Antenna Unit AAU-5G and Remote Radio Unit RRU 4G LTE Heatsinksare using natural convection cooling due tosome outstanding advantages such aslow cost, high reliability, noiseless operation and positioning independent from other cooling circuits. The main disadvantageis a relatively low heat transfer andan analytic model is requiredto efficiently design natural convection heat sinks accordingtothe applied design constraints. This paper describes a naturalconvection heatsink for electronic circuits of power supplier, PA and FPGA ICs in AAU-5G/RRU 4G. The AAU-5G/RRU-4G natural cooling system is composed parallelplateheat sinks in order to find an optimum heat sink design based on minimum of Entropy energy [1,2] and optimization of V heatsink fin angles.Normally, AAU 4G/RRU 5G efficiency is very low due to transiting/receiving data in high speed of 2,6MHz to 3,8 GHz thus ICs lossesneed to be cooled by natural convection heatsink with Aluminum material such as AluSi10Mg, ALDC-12 or ALHT. The analyticalcalculation was applied to different heat sink profiles with geometry parameters of I and V shape fin angles. Temperature measurements were carried outto validate the FEM model. Then, the achieved thermal performancewas used to the thermal resistance of different RRU heatsinks. This paper will calculate an optimal thickness V shape of heatsink fin profile of AAU 5G/ RRU-4G heatsink to minimum material cost and improving efficient heatsink.*

Index Terms*: Active Antena Unit-AAU 5G, Remote Radio Unit-RRU 4G,2 Transmitter/2 Receiver-2T2R, Power Amplifier PA 2x40W và 2X60W*

I. INTRODUCTION

Nowadays,LTE 4G applications are driving RF/microwave circuit design into high frequencies andhigh power levels [1]. Continuous reduction in feature sizes andincrease in complexities,together with the demand on higherfrequencies 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]. Output of power amplifier in RF/microwave circuits is from 2x40W to 2x60W with efficiency of 30-40%, most of input power will be converted to heating losses [1]. Total heat loss is about from 240W to 300W based on PA operation modes. In order to control overheat temperature of PA transistor, the natural convection heat sink is design to dissipate the heat loss to air in different cases.Consequently, a FEM calculation has been applied to calculate thermal distribution of RRU housing system and hotspot of PA base. Thermal dissipation density W/lit is maximize to meet RF/microwave performance and size reduction.In the past, the importance of the multiphysics analysis has been demonstrated through, for example, the characterization of wirebonding interconnects [2] and the printed circuit board laminatematerials [3]. In thispaper, we introduce an electrical-thermalco-simulation that integrates a full-wave electromagnetic analysis and a transient thermal analysis through an iterative scheme.The co-simulation is based on the finite element method (FEM)[4] owing to its unmatched capabilities in modeling complexgeometries and materials

II. ANALYTICL MODEL

Fig. 1 shows the analytical model of the natural convection heat sink, investigated by Elenbass. This natural convection between isothermal parallel vertical plates.

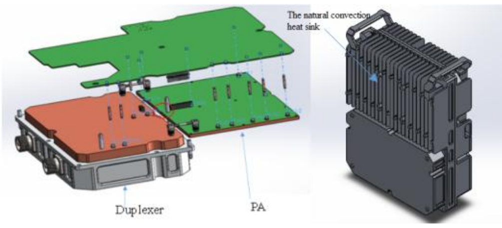


Fig. 1. Schematic of the natural convection heat sink

The natural convection heat sink for RRU is shown in Fig. 1. As shown in Fig. 1, the 425 x 320 x 140 (mm^3) – dimension natural convection heat sink is made by aluminum. The heat sink is set to close to the power amplifier unit in RRU. In addition, the natural convection heat sink is the cover of RRU. Anlytical model of heatsink fins.

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

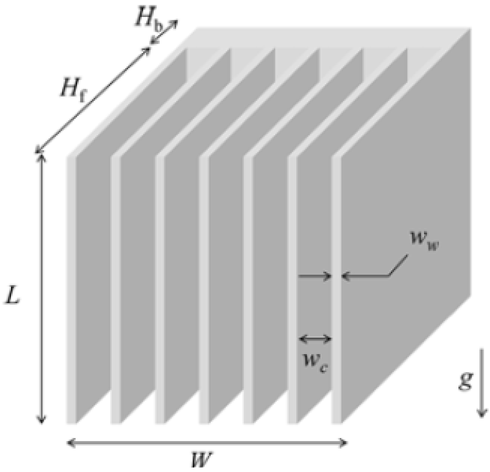


Fig. 2 Inputparaters of Heatsink

The heat flow by natural convection is given by

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

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}.

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

$$A_b = L w_c (n_{fin} - 1) \quad (3)$$

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

where W, w_c and w_w are geometric parameters according to Fig. 3, 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:

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

With the Elenbaas number

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

and the Rayleigh number

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

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

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

Where the emissivity of the solid (aluminium) 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

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

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

The thermal resistance is given by

$$R_{fin} = \frac{\theta_b}{Q_{HS}} \quad (12)$$

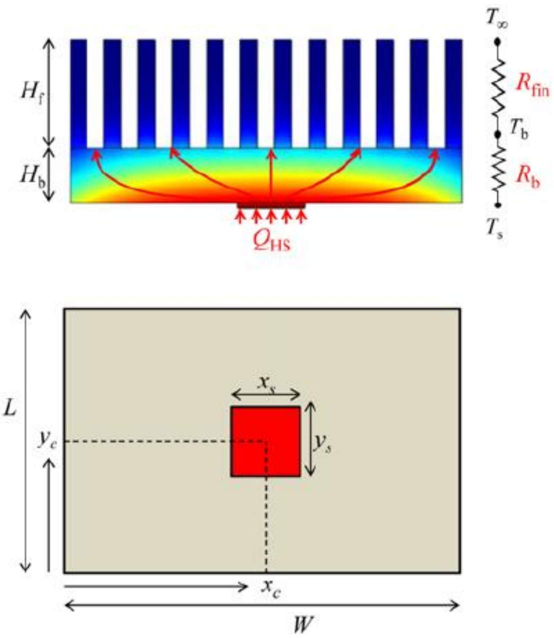


Fig 3 The heat sinks with heat source

The temperature of every location θ(x, y, z) of the base plate can be easily calculated [1-5]. This is done applying

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

(13)

where

$$A_m = \frac{2Q_{HS}\left[\sin\left(\frac{2x_c + x_s}{2}\right)\lambda_m - \sin\left(\frac{2x_c - x_s}{2}\right)\lambda_m\right]}{LWx_s k\lambda_m^2 \phi\lambda_m} \quad (14)$$

$$A_n = \frac{2Q_{HS}\left[\sin\left(\frac{2y_c + y_s}{2}\right)\delta_n - \sin\left(\frac{2y_c - y_s}{2}\right)\delta_n\right]}{LWy_s k\delta_n^2 \phi\delta_n} \quad (15)$$

$$A_{mn} = \frac{16Q_{HS}\cos\lambda_m x_c \sin\left(\frac{1}{2}\lambda_m m_s\right)\cos(\delta_n y_c)\sin\left(\frac{1}{2}\delta_n d\right)}{LWx_x y_s k\beta_{mn}\lambda_m\delta_n\phi(\beta_{mn})} \quad (16)$$

with

$$\lambda = {}^{m\pi}\!/_{W};\ \delta = {}^{n\pi}\!/_{L};\ \beta = (\lambda^2 + \delta^2)^{0.5} \quad (17)$$
$$B_i = -\phi(\zeta)A_i$$

$$\phi(\zeta) = \frac{\zeta\sinh\zeta H_b + {}^{h_{eff}}\!/_{k\cosh\zeta H_b}}{\zeta\cosh\zeta H_b + {}^{h_{eff}}\!/_{k\sinh\zeta H_b}} \quad (18)$$

In the formula (17), ζ is replaced by correlated λ, δ, β

$$\to \theta_h = \frac{Q}{LW}\left(\frac{H_b}{k} + \frac{1}{h_{eff}}\right) + 2\sum_{m=1}^{\infty} A_m \frac{\cos\lambda_m x_c \sin\left(\frac{1}{2}\lambda_m x_s\right)}{\lambda_m x_s} +$$
$$+2\sum_{n=1}^{\infty} A_n \frac{\cos\delta_n y_c \sin\left(\frac{1}{2}\delta_n y_s\right)}{\delta_n y_s} + \quad (19)$$
$$+4\sum_{m=1}^{\infty}\sum_{n=1}^{\infty} A_{mn} \frac{\cos\lambda_m x_c \sin\left(\frac{1}{2}\lambda_m x_s\right)\cos\delta_n y_c \sin\left(\frac{1}{2}\delta_n x_s\right)}{\lambda_m \delta_n x_s y_s}$$

If have many the heat source, should calculate the average value. Finally, the thermal resistance is given by

$$R_{HS} = \frac{\bar{\theta}_{heater}}{Q_{HS}} \quad (20)$$

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

$$h_{eff} = \frac{1}{R_{fin} LW} \quad (21)$$

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

The input parameter for optimal fins are Q = 300W, L = 174 mm, W = 380 mm, t_b = 5 mm, b = 12 mm, H = 55 mm. The entropy $\dot{S}_{gen}$ is a function of fin thickness.

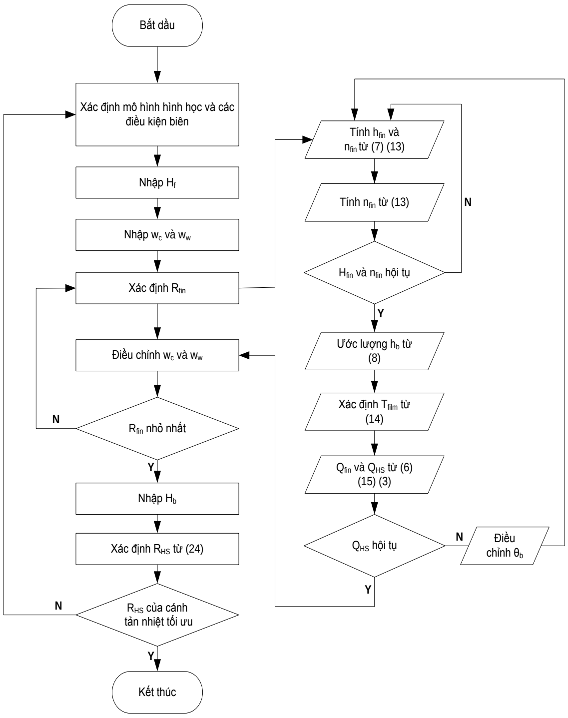


Fig 4. Optimal heatsink fins calculation

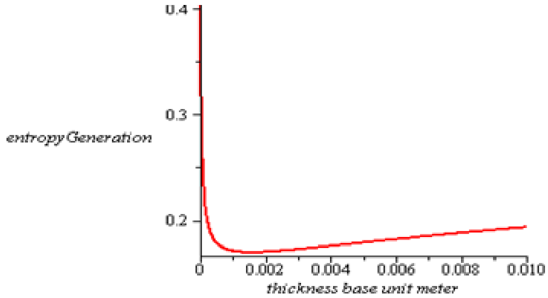


Fig 5. Entropy vs fin thickness

The entropy generation is minimum with thickness t = 0.0015m (1.5mm).

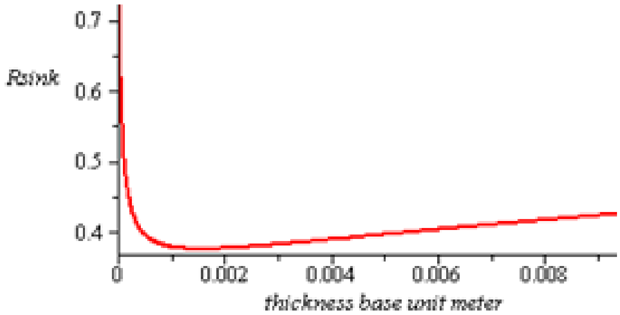


Fig 6. Heatsink resistance vs fin thickness

The Entropy and Resistance is minimum with heatsink thickness of 1.5 mm, 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 Solidwork and NX software.

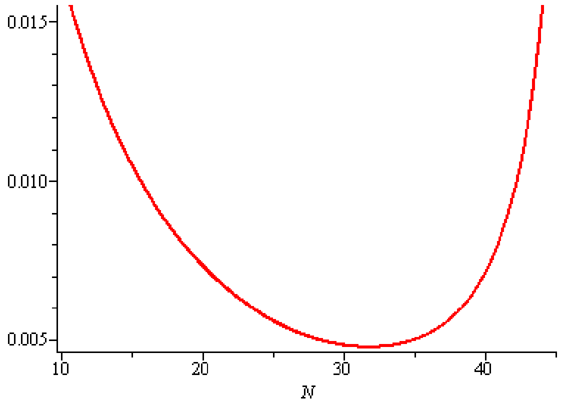


Fig 7. Optimal number of fins

III. THERMAL SIMULATION

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 heats sources. The maximum temperature must be lower than temperature limit of IC PA transistor, modeling steps is shown in Fig 8.

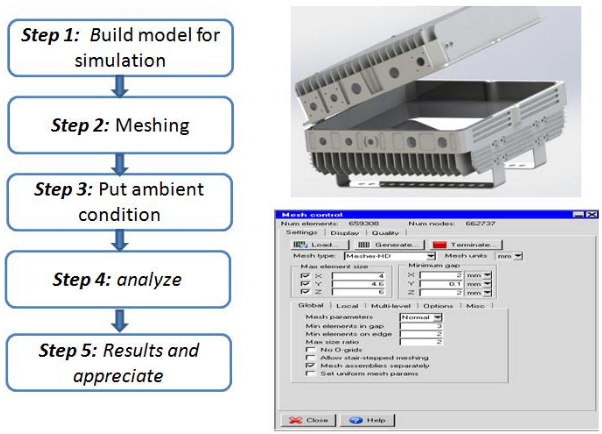


Fig 8. Modeling steps

Material properties of thermal conduction and heat losses are inputs of FEM model.

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 97 C lower than temperature capacity of ICs inside RRU housing. To evaluate the simulation results, a hardware setup has built.

Blocks : (18)							
Object			Material		No. of Sides	Power	
Name	Shape	Block type	Surface	Solid	Num Sides Added	Total	Type
Cir_L.1	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	6.0 W	constant
Cir_L.2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	6.0 W	constant
Cover	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2		
Cover_Dup_Band3	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2		
Cover_Dup_Band3_No2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2		
Driver.1	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	7.0 W	constant
Driver.2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	7.0 W	constant
FPGA	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	8.5 W	constant
Housing_4G_Band3_20180416	Bsplines	Solid	{Paint-Al surface}	{Aluminum 6061-T6}	2	24.0 W	constant
Other_IC.1	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	2.0 W	constant
Other_IC.2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	2.0 W	constant
PW_IC.1	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	3.0 W	constant
PW_IC.2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	3.0 W	constant
PW_IC.3	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	3.0 W	constant
PW_Module	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	25.0 W	constant
RAM	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	2.0 W	constant
TR1	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	70.0 W	constant
TR2	Bsplines	Solid	Steel-Oxidised-surface	Al-Extruded	2	70.0 W	constant

Fig 9. Material properties

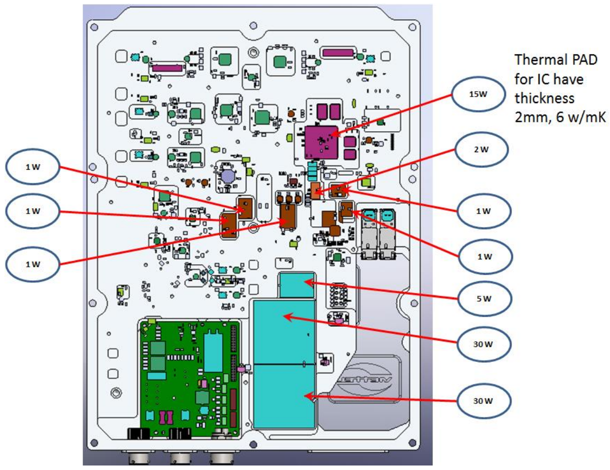


Figure 10. Power losses of RRU

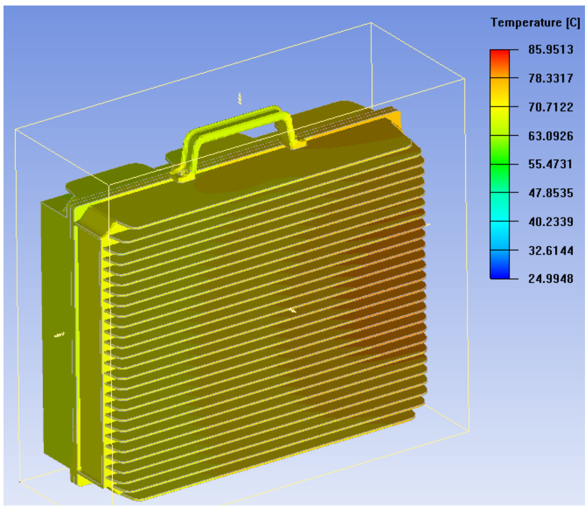


Fig 11. Thermal simulation results

IV. CALCULATION EFFICIENCY OF RUU AND PA:

In order to calculate efficiency of power amplifier-PA of RRU, an indirect method has been applied to obtain losses from RF duplexer losses and Electric power inverter of RRU from 48V and 28V are applied to PA, DUP and All Ics in hardware PCBs.

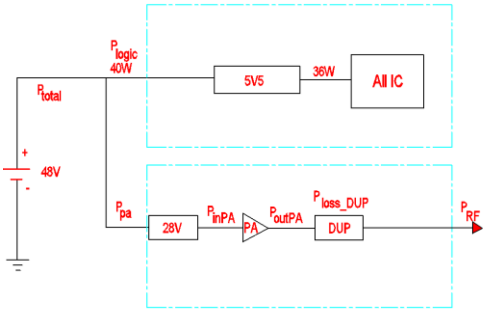


Fig. 12. Electric circuit of RRU devices

To calculate efficiency of power amplifier of RRU, flow chart of calculation shows in figure below:

$$P_{total} = P_{logic} + P_{PA} \qquad P_{PA} = P_{total} - P_{logic}$$

$$P_{logic} = 40\text{ W.} \qquad \Rightarrow P_{inPA} = \eta_{Power\_PA}.\,P_{PA} = \eta_{Power\_PA}.\,(P_{total} - P_{logic})$$

$$\Rightarrow P_{outPA} = \eta_{PA}.\,P_{inPA} = \eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic})$$

$$\Rightarrow \boxed{\begin{array}{l} P_{outPA} = \eta_{PA}.\,P_{inPA} = \eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic}) \\ P_{RF} = \dfrac{P_{outPA}}{10^{0,06}} \qquad \text{Add loss Duplexer (0.6 dBm)} \end{array}}$$

$$\Rightarrow \boxed{\begin{array}{l} P_{outPA} = \eta_{PA}.\,P_{inPA} = \eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic}) \\ P_{RF} = \dfrac{P_{outPA}}{10^{0,06}} \qquad \text{Add loss Duplexer} \\ \eta_{RRU} = \dfrac{P_{RF}}{P_{total}} = \dfrac{\eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic})}{10^{0,06}.\,P_{total}} \end{array}}$$

Fig 13. Logic calculation of power losses

When the analytical calculation is applied for different loads of power amplifier and RRU 4G, some basic parameterswere pre-determined by firmware or software such as radio frequency power (P_RF), duplexer loss (0.06dB) and energy consumption P_total from power supply driver

$$\begin{array}{l} P_{RF} = 2x39{,}5 = 79\ W \\ P_{total} = 48{,}4\ (V)x10{,}6\ (A) = 513\ W \\ \eta_{Power\_PA} = 0.9\ \ (90\%) \end{array} \Rightarrow \boxed{\begin{array}{l} \eta_{RRU} = \dfrac{79}{513} = 15{,}4\ (\%) \\ \eta_{PA} = \dfrac{P_{RF}.\,10^{0.06}}{\eta_{Power\_PA}.\,(P_{total} - P_{logic})} = 21{,}3\ (\%) \end{array}}$$

$$\boxed{\begin{array}{l} P_{outPA} = \eta_{PA}.\,P_{inPA} = \eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic}) \\ P_{RF} = \dfrac{P_{outPA}}{10^{0,06}} \qquad \text{Add loss Duplexer} \\ \eta_{RRU} = \dfrac{P_{RF}}{P_{total}} = \dfrac{\eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic})}{10^{0,06}.\,P_{total}} \end{array}}$$

Fig 14. Detail calculation result of 2x39W

Energy consumption of RRU 4G can be changed from 400W to 600W with different capacity or loading level. The efficiency of power amplifier circuit and RRU.

$$\begin{array}{l} P_{RF} = 2x39 = 78\ W \\ P_{total} = 48{,}4\ (V)x9.1\ (A) = 440{,}4\ W \\ \eta_{Power\_PA} = 0.9\ \ (90\%) \end{array} \Rightarrow \boxed{\begin{array}{l} \eta_{RRU} = \dfrac{78}{440{,}4} = 17{,}7\ (\%) \\ \eta_{PA} = \dfrac{P_{RF}.\,10^{0.06}}{\eta_{Power\_PA}.\,(P_{total} - P_{logic})} = 24{,}9\ (\%) \end{array}}$$

$$\boxed{\begin{array}{l} P_{outPA} = \eta_{PA}.\,P_{inPA} = \eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic}) \\ P_{RF} = \dfrac{P_{outPA}}{10^{0,06}} \qquad \text{Add loss Duplexer} \\ \eta_{RRU} = \dfrac{P_{RF}}{P_{total}} = \dfrac{\eta_{PA}.\,\eta_{Power\_PA}.\,(P_{total} - P_{logic})}{10^{0,06}.\,P_{total}} \end{array}}$$

Fig 15. Detail calculation result of 2x39W

V. EXEPERIMENTAL RESULTS

The experimental setup includes heatsink, heatsource and Data acquisition to record temperature values with time sample of 30 second.

Fig. 16 shows the schematic of experimental setup, which includes the power amplifier of RRU heatsink of 240-300W (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.

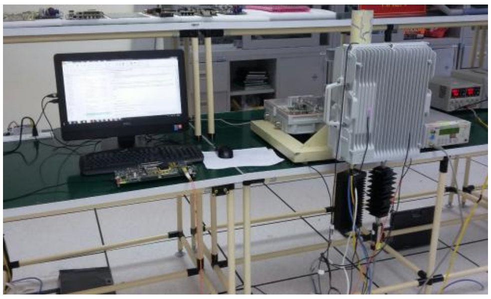


Fig. 16. Schematic of experimental setup

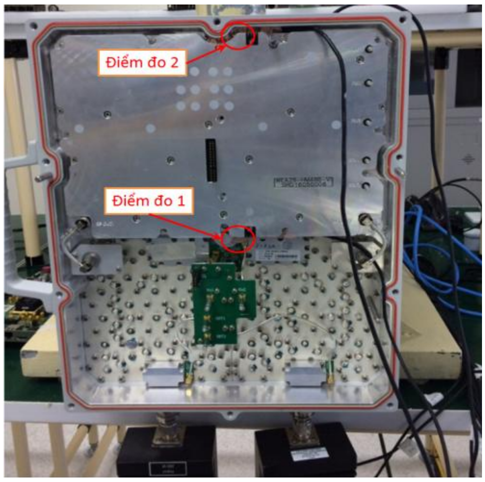
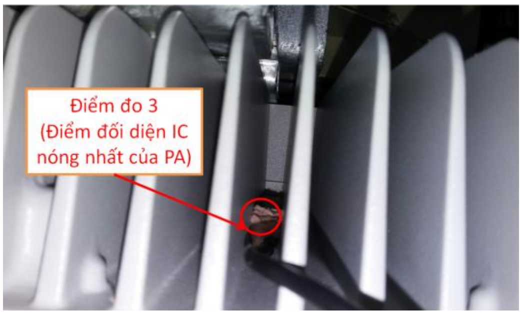


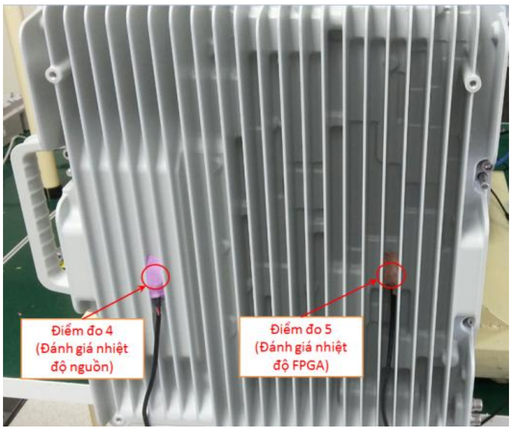
Fig 17. Temperature sensors inside RRU housing.



Hình 18. Temperature sensor in ICs

Input power for RRU heat soure is 48V*9.18A=440W and the temperature in PCB and IC base and heatsink fin are record by data acquisition and PC in fig 19.According to IEC experimental test, the maximum temperature is kept in 3 hours.

Temperature results are recorded by data acquisition in thermal lab. After 3 hour heat run, the maximum temperature is 79^{0}C degree and PA base temperature is 70^{0}C.



Hình 19. Temperature sensor in FPGA

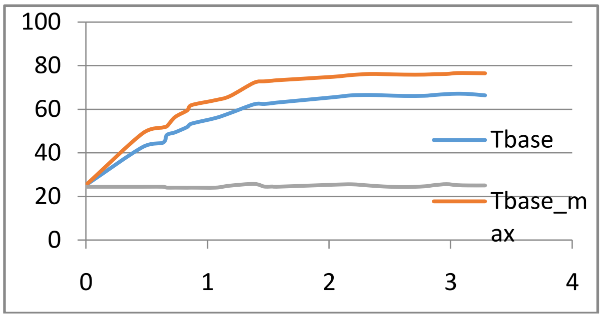
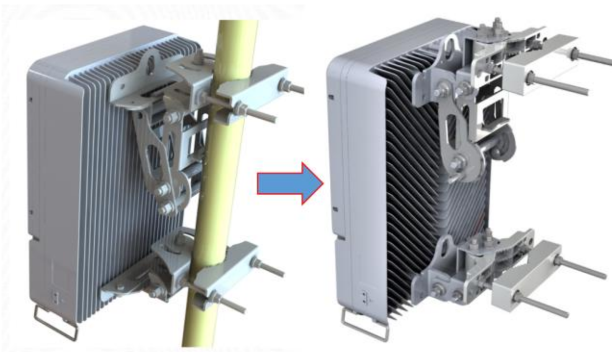


Fig 20. Temperature curves of PA base

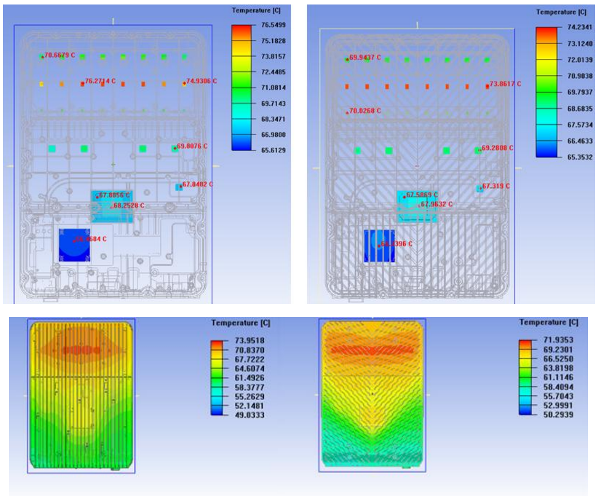
Maximum thermal resistance is calculated from results measure temperature and losses, maximum thermal resistance is obtained:

$$R = \frac{T_{base} - T_{ambient}}{Q_{loss}} = \frac{76 - 25}{279} = 0.184$$



(a) *(b)*

Hình 21. I shape (a) and V shape (b) in AAU 5G 8T8R heatsink



Hình 22. Thermal simulation of I shape (a) and V shape (b)AAU 5G 8T8R heatsink

VI. NOVEL DESIGN OF V SHAPE HEATSINK FINS

A new idea for improving heat transfer efficient is change heatsink fin from straight from to V form with different angle. This paper will also give out a analytic model for optimal angle calculation.

In order to increase to heatsink efficient, V shape heatsink fins have been designed to improve natural heatsink efficiency in figure 16.

In comparison with I shape heatsink fin, new V shape heatsink design is reduced about 2^{o}C degree.

VII. CONCLUSION

The described analytical thermal model reveals good resultscompared to thermal measurements over a wide range ofpower losses. Therefore, an easy to apply design methodis given to efficiently design natural convection heat sinks of RRU heatsink. The analytical optimaldesign shows the potentialof carefully designed heat sinks compared to commercially available profiles. Furthermore, the optimizationis more efficient the better the base plate area is utilized.Thus, power modules might not be the preferred choice, butdiscrete semiconductors, where the power circuit might adoptan optimal shape of the base plate area.

ACKNOWLEDGMENT

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TÍNH TOÁN VÀ THỬ NGHIỆM ĐÁNH GIÁ BỘ TẢN NHIỆT THIẾT BỊ PHU PHÁT SÓNG 5G

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Tóm tắt: *Ngày nay việc phát triển mật độ mạng lưới đang là một trong những chiến lược để giải quyết bài toán công suất và điểm nối của thiết bị thu pháp song 5G. Hệ thống tản nhiệt thiết bị thu phát viễn thông AAU 5G/ 4G RRU làm việc dựa trên mô hình tản nhiệt đối lưu tự nhiên thường việc ngoài trời điều kiện khắc nghiệt về nhiệt độ, độ ẩm, sương muối tuy nhiên thiết bị có nhiều ưu điểm như giá thành gia công sản xuất thấp và độ tin cậy cao, nhược điểm duy nhất là khả năng truyền nhiệt thấp, để tăng cường khả năng truyên nhiệt thì việc tính toán tối ưu kích thước gân cánh tản nhiệt đóng vai trò quan trọng trong việc tối ưu kích thước trọng lượng tuy nhiên vẫn đảm bảo tiêu tán công suất tản nhiệt ra ngoài môi trường. Bái báo này sẽ giới thiệu phương pháp thiết kế gân tản nhiệt dạng thẳng cho thiết bị RRU 4G và gân chéo hình chữ V với các góc nghiêng khác nhau để tối ưu khả năng tản nhiệt cho bộ thu phát sóng ăng ten chủ động 5G dựa vào giảm thiểu entropy. Thông thường các thiết bị thu phát song 4G/5G có hiệu suất điện thấp vì hoạt động ở tần số cao 2,6GHz và 3,8MHz do vậy các tiinr hao công trên ICs là rất lớn và được tản nhiệt bằng vỏ nhôm hợp kim AluSi10Mg. ALDC12 hoặc AlHT. Mô dình giải tích tính toán gân cánh tản nhiệt sẽ dựa trên tiêu trí tối thiểu năng lương entropy trong vùng không khí giữa 2 gân cánh tản nhiệt và tối thiểu hóa nhiệt trở Heatsink (W/C). Nội dung chính của bài báo sẽ tập trung phân tích phương pháp tính chiều dày gân tối ưu nhắm giảm thiểu chi phí vật liệu và kích thước vỏ hộp tản nhiệt thiết bị viến thông 4G RRU.*