RM50xQ Series

Thermal Design Guide

5G Module Series

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About the Document

Revision History

Version	Date	Author	Description
-	2021-08-13	Norton ZHANG	Creation of the document
1.0	2021-08-23	Norton ZHANG	First official release

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1 Introduction

This document introduces the thermal design of the RM50xQ series modules, including general description and power consumption of the modules, thermal simulation in different modes, and heat dissipation solutions based on the simulation result.

1.1. Applicable Modules

Table 1: Applicable Modules

Applicable Modules	
RM50xQ-GL	RM500Q-GL
	RM502Q-GL
RM50xQ-AE	RM500Q-AE
	RM502Q-AE
	RM505Q-AE
RM500Q-CN	

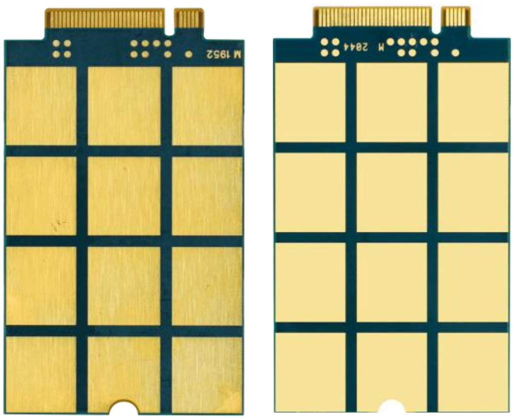
2 Product Concept

2.1. General Introduction

The RM50xQ series comprises the following models: RM500Q-GL, RM502Q-GL, RM500Q-AE, RM502Q-AE, RM505Q-AE and RM500Q-CN. The figure below shows the top view of RM50xQ series modules.

Figure 1: Top Views of RM50xQ Series Modules

The following is the bottom view of RM50xQ series module.



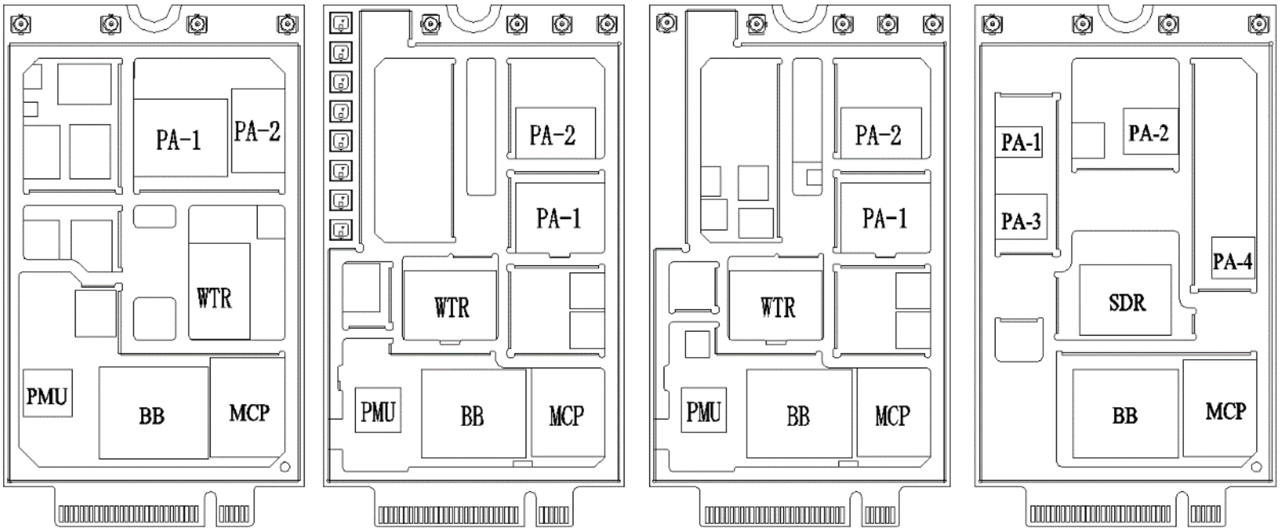
RM50xQ-GL RM50xQ-AE & RM500Q-CN

Figure 2: Bottom Views of RM50xQ Series Modules

NOTE

Images above are for illustration purpose only and may differ from the actual module. For authentic appearance and label, please refer to the module received from Quectel.

The components marked with characters shown below are heat source chips (BB, PMU, MCP, PA, etc.) with thermally conductive adhesive inside the module.



RM500Q-GL & RM502Q-GL RM500Q-AE & RM502Q-AE RM505Q-AE RM500Q-CN

Figure 3: Distribution Diagram of Heat Source Chips Inside the Module

2.2. Key Features

The following table shows the main features of RM50xQ series modules.

Table 2: Key Features of RM50xQ Series Modules

Key Features	Description
Function Interface	● M.2 Kye-B Interface
Power Supply	● Supply Voltage: 3.135–4.4 V ● Typical Supply Voltage: 3.7 V
Shielding Case	● Thermal conductivity: 16.3 W/(m·K) ● Material: SUS304

	● Size: 29.46 × 33.91 mm (T0.15 mm, H1.25 mm)
Shielding Frame	● Thermal conductivity: 25 W/(m·K) ● Material: C7701 ● Size: 29.1 × 33.55 mm (T0.2 mm, H1.25 mm)
Module Size	● (30.0 ±0.15) mm × (52.0 ±0.15) mm × (2.3 ±0.20) mm
Temperature Range	● Operating temperature range: -30 to +75 °C [1] ● Extended temperature range: -40 to +85 °C [2] ● Storage temperature range: -40 to +90 °C

Table 3: Max. Tj of Main Heat Source Chips of the Module (Unit: °C)

BB	PMU	MCP	WTR	PA-1	PA-2
105	115	85	105	115	115

NOTE

Please keep the temperature of BB chip below 105 °C, otherwise, the performance of RM50xQ series modules will be affected, resulting in limited RF output power and data transmission rate. To keep the peak temperature of BB chip below 105 °C, a heat dissipation design is necessary.

[1] For RM502Q-GL, the operating temperature ranges from -30 to +70 °C; Within the operating temperature range, the module meets 3GPP specifications.

[2] Within the extended temperature range, the module remains the ability to establish and maintain functions such as voice, SMS, data transmission, emergency call, etc., without any unrecoverable malfunction. Radio spectrum and radio network are not influenced, while one or more specifications, such as Pout, may exceed the specified tolerances of 3GPP. When the temperature returns to the operating temperature range, the module meets 3GPP specifications again.

3 Thermal Test

3.1. Test Environment

5G M.2 EVB is used as the test carrier of the module. The module's RF antenna interfaces are connected to the test instrument, and the EVB with the module is placed in a thermostat chamber. As shown in the figure below, an external DC power supply shall be connected to the VCC pin of the module through a cable to power the module and to further obtain the total power consumption of the module.

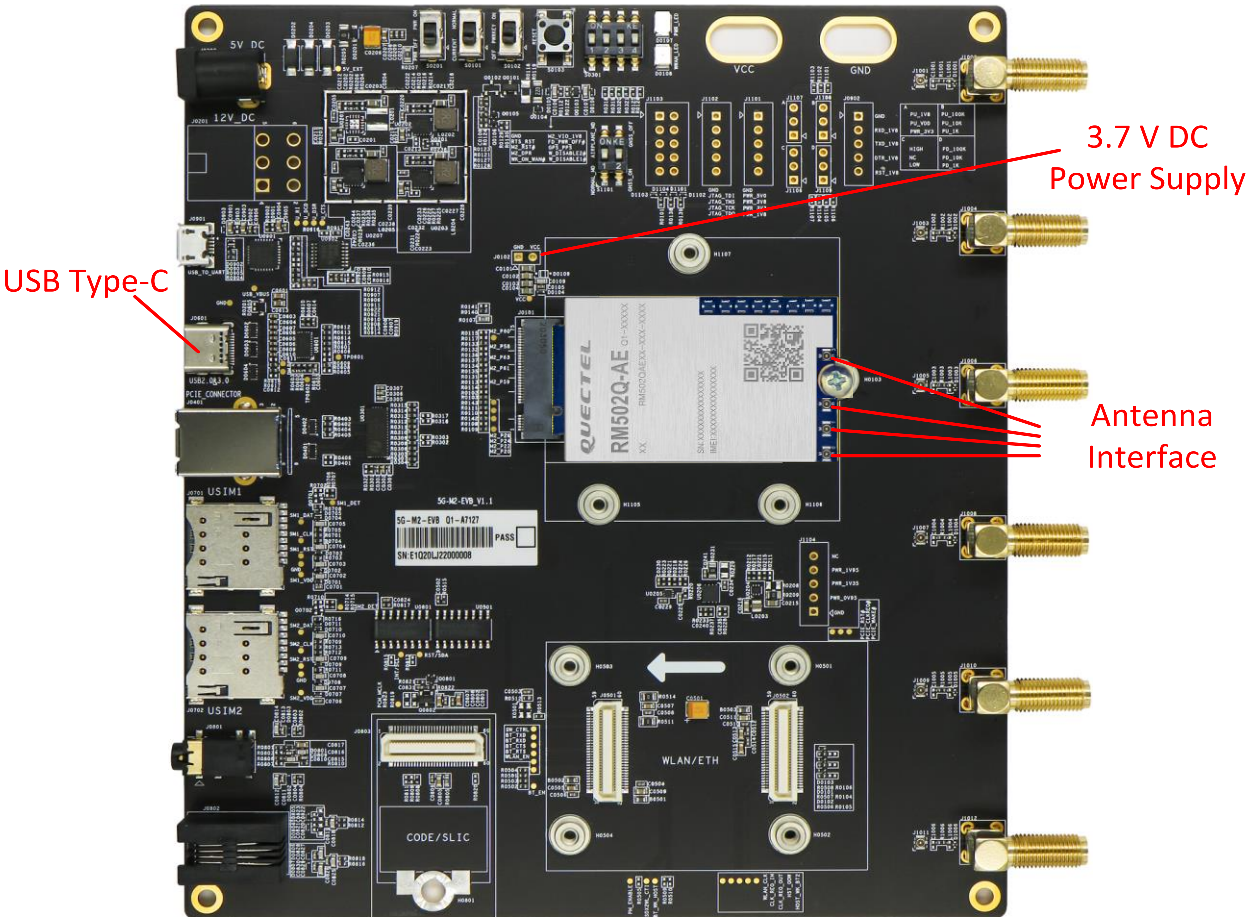


Figure 4: 5G M.2 EVB

The picture below exhibits the thermal power test environment, including computers, UXM 5G wireless test platform, thermostats chamber, EVB and program-controlled power supplies.

Figure 5: Thermal Power Test Environment

3.2. Test Case and Results

For RM50xQ series modules, the main chips that generates heat include the BB, PMU, MCP, and PA, etc. They consumed most power of the module. Based on the test environment shown in ***Chapter 3.1***, the module was tested by KEYSIGHT E7515B UXM 5G wireless test platform (test case: Sub-6 GHz n78 DL 1.75 Gbps + UL 1Tx 22.5 dBm, LTE B3 DL 391 Mbps + UL 22 dBm). Based on this test case, when the ambient temperature is 25 °C, the average current consumption is about 1.4 A in case of 3.8 V supply voltage, and the peak current is about 2.5 A.

The figure below shows main heat chips power consumption data provided by the vendor. Based on this data, the power consumption distribution of each chip in ***Table 4*** can be obtained.

Sub-6/LTE Use Cases

Thermal power use cases and hardware description	SDX55 T_j (C)	Chipset hardware configuration – power in W								
		SDX55	LPDDR4X 512 MB	PMK8002	PMX55	SDR865	SMR526	Sub-6 RFFE [6]	LTE RFFE [6]	Chipset Total
PDCCH 1CC	35	0.44-0.59	0.03	0.01	0.14-0.16	0.19-0.20	0	0.02	0	**0.82-1.00**
DL 1CC + UL 1CC [3]	45	1.18-1.42	0.08	0.01	0.36-0.40	0.48-0.49	0	0.12	0	**2.22-2.51**
Sub-6 DL + Sub-6 UL 1Tx 23dBm + LTE UL 23dBm [5]	85	2.32-3.71	0.10	0.01	0.66-1.05	0.97-1.02	0	1.38	2.58	**8.02-9.85**
LTE FDD 5CA DL 4x4 /2CA UL	65	1.83-2.22	0.08	0.01	0.54-0.64	0.73-0.76	0	0	0.19	**3.38-3.89**

Figure 6: Device Power Allocation of Sub-6/LTE Use Cases

Table 4: Power Consumption of the Test on RM50xQ Series Modules

Items \ Module			RM50xQ-GL	RM50xQ-AE	RM500Q-CN
Module Configuration			DL 2000 Mbps; UL 127 Mbps; Bandwidth 100 MHz; NSA (B3 + n79); RX = -65 dBm; TX = 22.5 dBm; 4 × 4 MIMO/DL; 256QAM/LTE DL; QPSK UL/LTE; 256QAM NR DL/UL;	DL 2000 Mbps UL 127 Mbps Bandwidth 100 MHz NSA (B3 + n79), RX = -65 dBm TX = 22.5 dBm 4 × 4 MIMO/DL 256QAM/LTE DL QPSK UL/LTE, 256QAM NR DL/UL	TBD
Power Consumption (Unit: mW)	**Total**		5530	5508	TBD
	Chips	**BB**	1970	1960	TBD
		PMU	560	555	TBD
		MCP	55	52	TBD
		WTR	60	54	TBD
		PA-1	850	834	TBD
		PA-2	635	626	TBD
		Total	4130	4081	TBD

NOTE

The power consumption shows above is calculated based on the measured data and the power consumption ratio provided by the vendor of the main chip.

4 Thermal Simulation

4.1. Thermal Simulation Model Overview

The vendor provided a simulation model of these key components of the modules. During the simulation, power of the heat source chips is set according to the power distribution data. At the same time, a simulation model of other components (such as the shielding frame and the shielding case, etc.) is created based on the 3D model of the module.

The figure below is a simplified diagram of the simulation model:

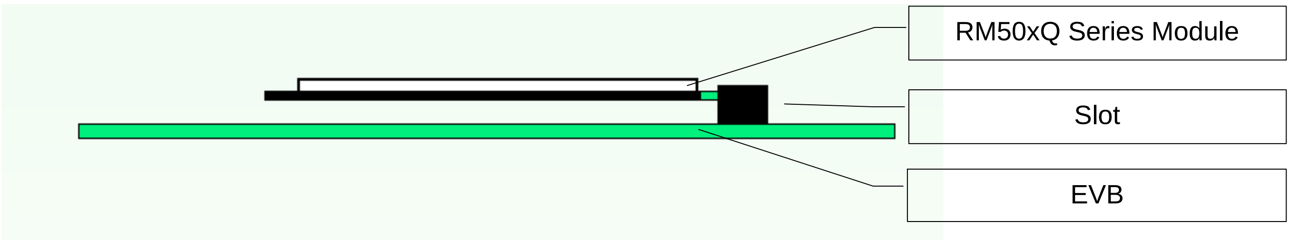


Figure 7: Simulation Model of the Module

The following 7 modes are carried out based on this model.

- Mode 1: Under 25 °C ambient temperature, fill the gaps between the main heat source chips and the shielding case with thermally conductive glue, and cool the module through natural convection and heat radiation.
- Mode 2: Base on Mode 1, install a radiator on the shielding case to cool the module through natural convection and heat radiation.
- Mode 3: Base on Mode 1, place a thermal pad with a thermal conductivity of 6 W/(m·K) to fill the gap between the module and the EVB, and cool the module through natural convection and thermal radiation.
- Mode 4: Base on Mode 1, install a radiator on top of the shielding case, and place a thermal pad with a thermal conductivity of 6 W/(m·K) to fill the gap between the module and the EVB. Cool the entire module through convection and heat radiation.
- Mode 5: Based on Mode 2, change the ambient temperature to 50 °C.
- Mode 6: Based on Mode 3, change the ambient temperature to 50 °C.
- Mode 7: Based on Mode 4, change the ambient temperature to 50 °C.

The figure below is a schematic diagram of the component distribution the RM500Q-GL thermal model. For those models of other RM50xQ series, the thermal model is similar, hence no longer enumerated here.

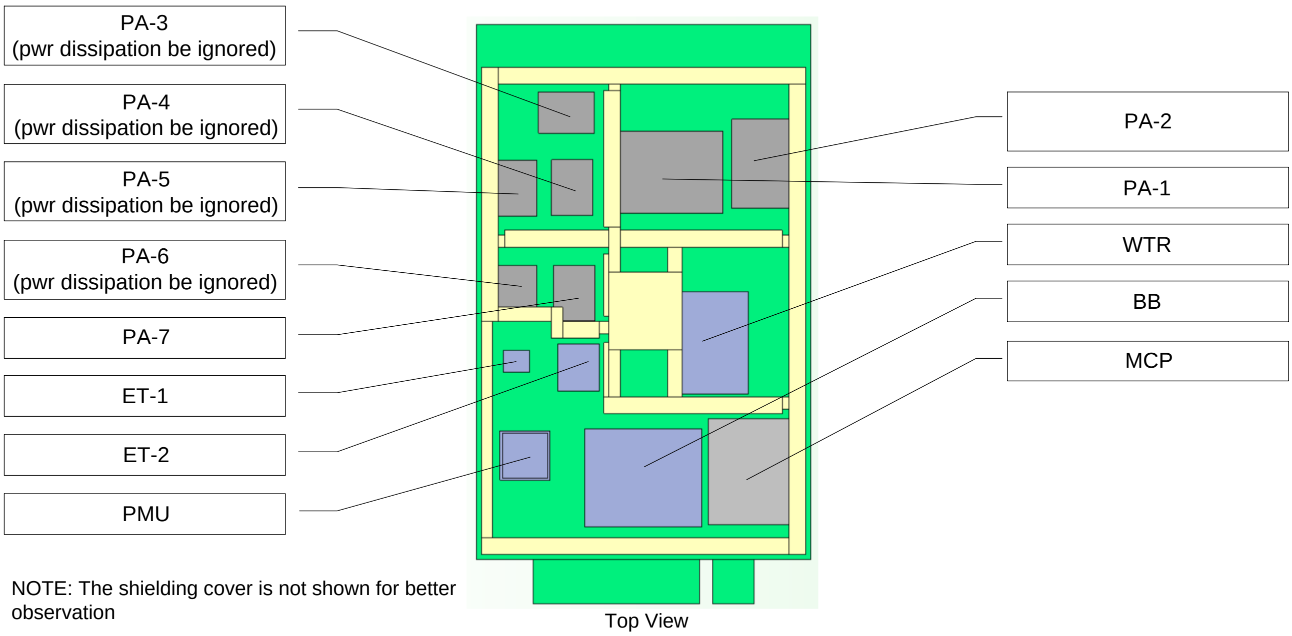


Figure 8: Component Distribution of the RM500Q-GL Thermal Model

4.2. Thermal Simulation Result

This section mainly introduces the simulation results in 4 modes.

The thermal simulation is performed at an ambient temperature of 25 °C and 1 standard atmospheric pressure, and all components of the module are cooled by natural convection and thermal radiation. During the thermal simulation, the module is inserted in the M.2 slot of the EVB.

The junction temperature of each chip is the measured temperature after the module no longer changes and operates in a steady state during the simulation.

4.2.1. Mode 1

Mode 1: Under 25 °C ambient temperature without cooling measure.

The simulation result is shown below.

Table 5: Tj of RM500Q-GL Main Heat Source Chip in Simulation Mode 1 (Unit: °C)

BB	MCP	PMU	WTR	PA-1	PA-2	ET-1	ET-2
130.4	119.4	127.2	123.5	131.3	116.7	130.9	132.0

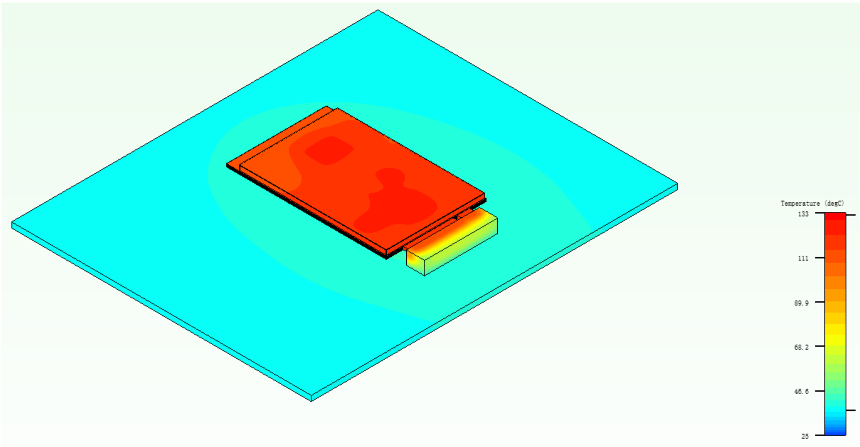


Figure 9: Surface Temperature Contour in Mode 1

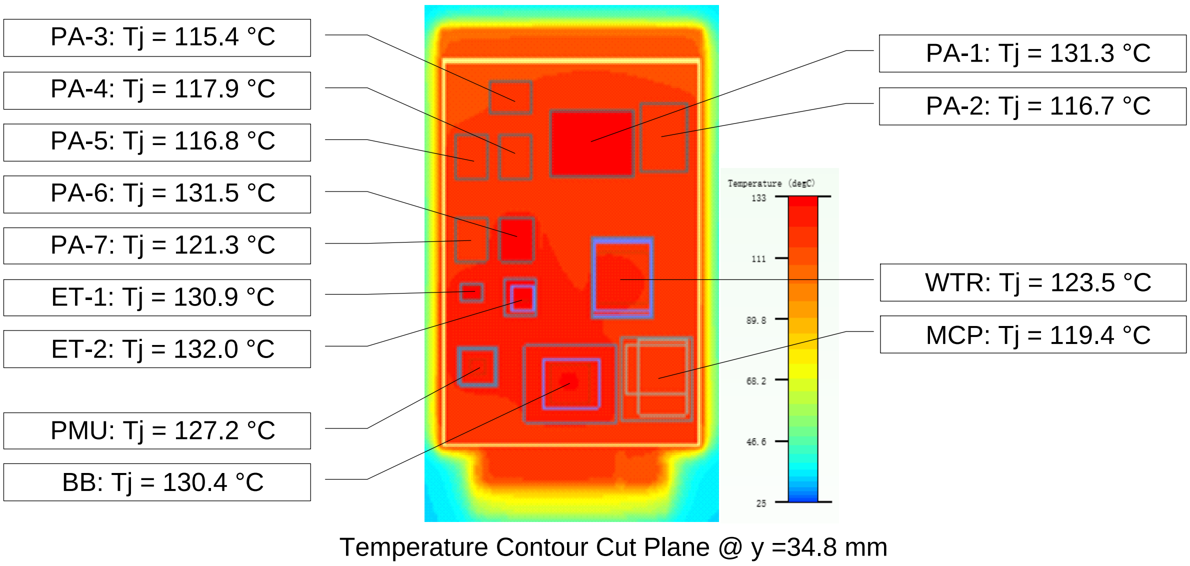


Figure 10: Cut Plane Temperature Contour in Mode 1

4.2.2. Mode 2

Mode 2: 25 °C ambient temperature, the heatsink is attached to top of the shielding case.

The following are the parameters of auxiliary materials during the simulation:

- Heatsink material: aluminum 6063-T5;
- Size:
  - Base size: 40 mm (L) × 61.5 mm (W) × 2.5 mm (T);
  - Heatsink size: 40 mm (L) × 1 mm (T) × 15 mm (H), 10 pcs;
- Thermal conductivity of thermal paste (between the radiator base and the shielding case): 6 W/(m·K);
- Surface treatment: black anodized.

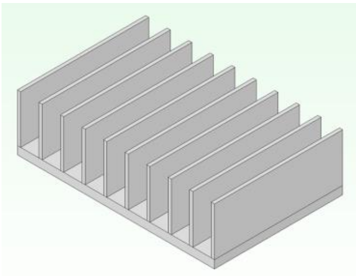


Figure 11: View of the Heatsink

The following table shows the simulation result in mode 2.

Table 6: Tj of RM500Q-GL Main Heat Source Chip in Simulation Mode 2 (Unit: °C)

BB	MCP	PMU	WTR	PA-1	PA-2	ET-1	ET-2
64.7	56.3	61.5	59.4	68.5	56.4	69.9	70.4

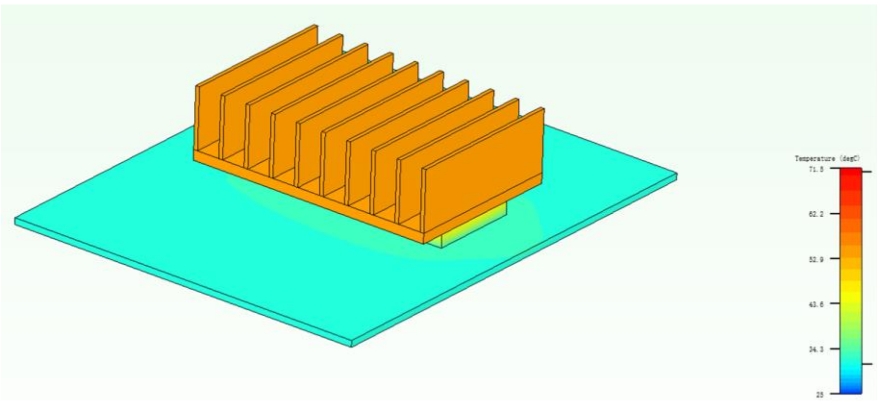


Figure 12: Temperature Contour in Mode 2

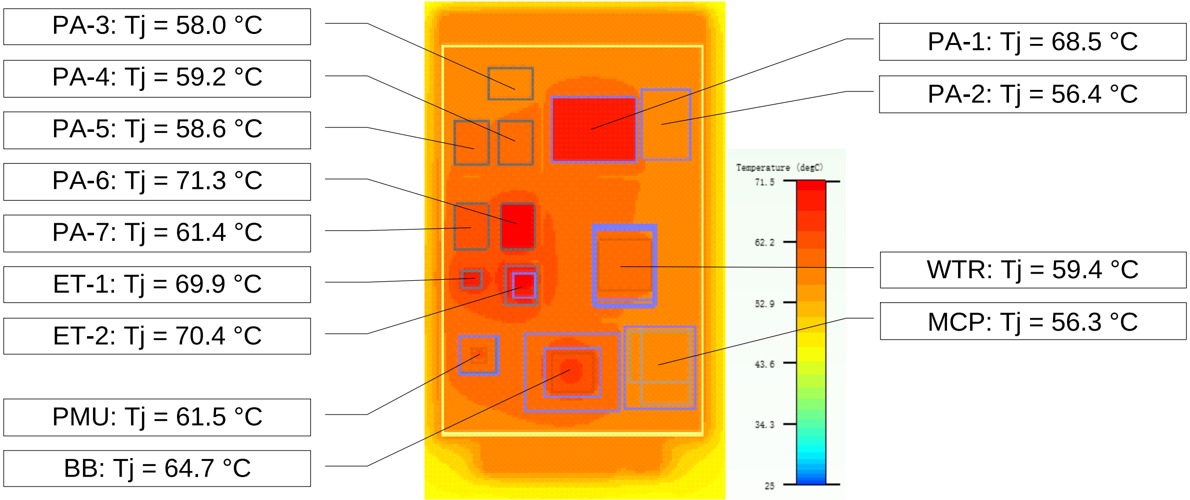


Figure 13: Cut Plane Temperature Contour in Mode 2

4.2.3. Mode 3

Mode 3: A thermal pad with a thermal conductivity of 6 W/(m·K) is used to fill the gap between the RM500Q-GL module and the EVB.

The following table shows the simulation result in mode 3.

Table 7: Tj of RM500Q-GL Main Heat Source Chip in Simulation Mode 3 (Unit: °C)

BB	MCP	PMU	WTR	PA-1	PA-2	ET-1	ET-2
72.1	61.9	68.8	64.7	73.4	59.3	71.7	72.6

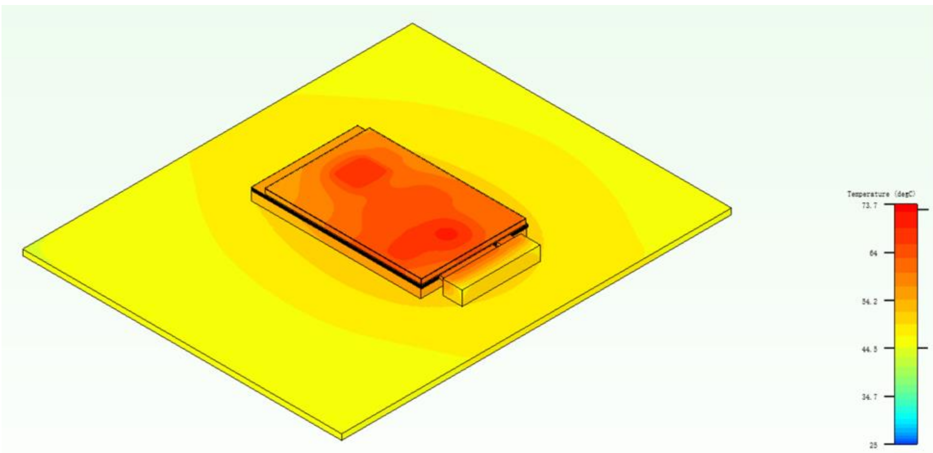
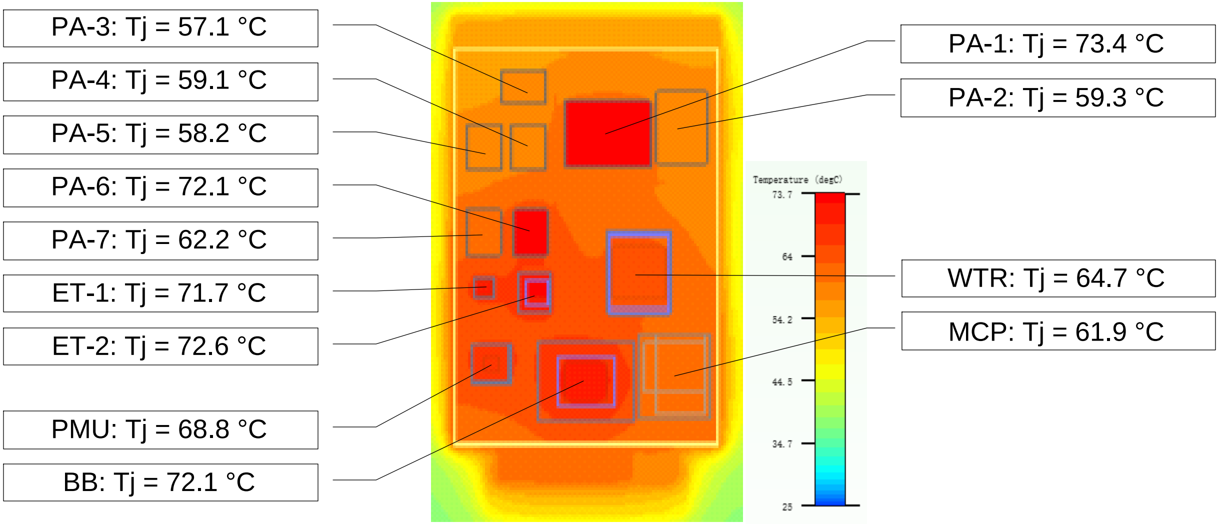


Figure 14: Surface Temperature Contour in Mode 3



Temperature Contour Cut Plane @ y =34.8 mm

Figure 15: Cut Plane Temperature Contour in Mode 3

4.2.4. Mode 4

Mode 4: A heatsink is installed on the shielding case of the module, and a thermal pad with a thermal conductivity of 6 W/(m·K) is used to fill the gap between the module and the EVB. The following table shows the junction temperature of the main heat source component simulated in Mode 4.

Table 8: Tj of RM500Q-GL Main Heat Source Chip in Simulation Mode 4 (Unit: °C)

BB	MCP	PMU	WTR	PA-1	PA-2	ET-1	ET-2
55.3	47.6	52.1	49.9	58.6	47.0	58.7	59.3

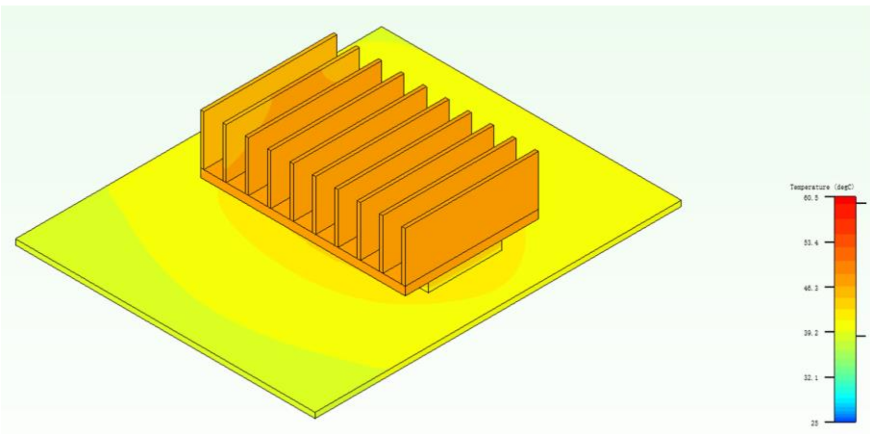


Figure 16: Surface Temperature Contour in Mode 4

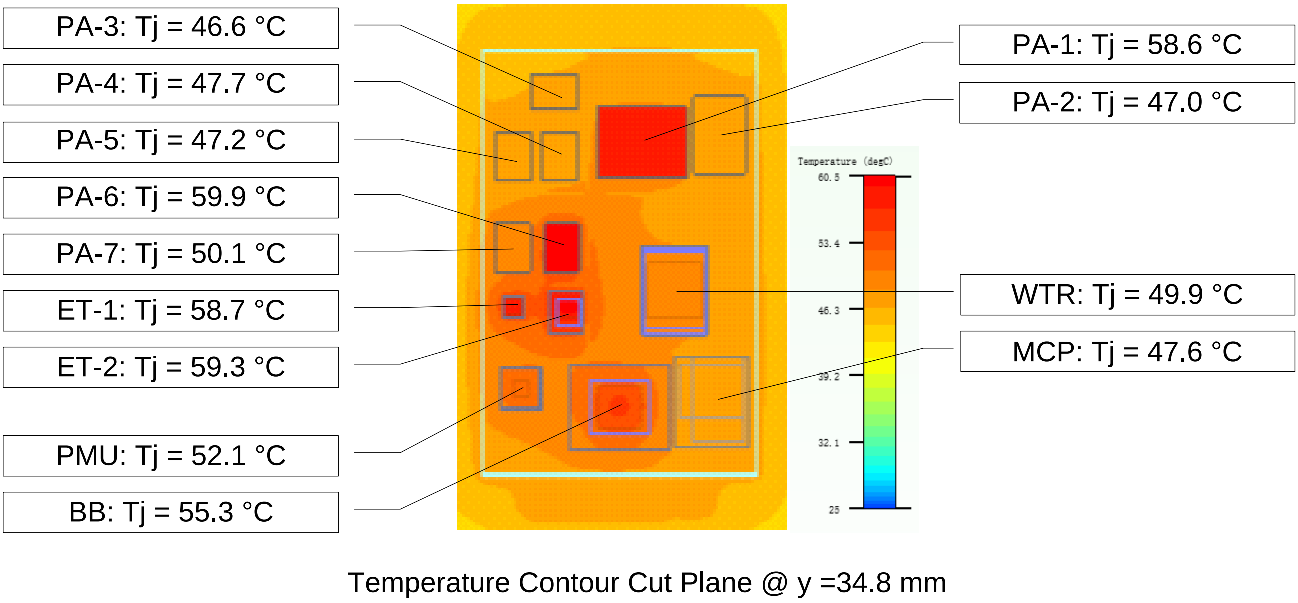


Figure 17: Cut Plane Temperature Contour in Mode 4

4.3. Thermal Simulation Conclusions

According to the four modes listed above, the simulation result is as follows. According to the above simulation scheme, similar data will be obtained when the ambient temperature is 50 °C, therefore the result is not enumerated here furtherly.

Table 9: RM500Q-GL Thermal Simulation Tj Summary (Unit: ºC)

Main Chip	Without Any Cooling Measure	A Heatsink is Added	A Thermal Pad Is Added	Both Heatsink & Thermal Pad Are Added
BB	130.4	64.7	72.1	55.3
PMU	127.2	61.5	68.8	52.1
MCP	119.4	56.3	61.9	47.6
WTR	123.5	59.4	64.7	49.9
PA-1	131.3	68.5	73.4	58.6
PA-2	116.7	56.4	59.3	47.0
Shielding Case	Tc = 110.9	Tc = 55.3	Tc = 57.2	Tc = 45.1

Four conclusions based on the above simulation results are listed below:

1. Since the heat dissipation conditions and performance of the RM50xQ series vary in different terminal products, the above simulation results shall be considered for reference only. It is recommended to simulate according to actual application scenarios for specific data.
2. Through comparison of these simulation results, additional heat dissipation measures (e.g. an external heatsink) are requisite to facilitate heat dissipation besides the thermally conductive glue filled in the gap between the heat source chip and the shielding case.
3. It is recommended to apply forced convection to effectively reduce the temperature rise of the module and keep all components work within their maximum junction temperature ranges.
4. To reduce the temperature of the module and guarantee sufficient thermal margin of all main components, please choose a larger heatsink when there is enough space.

5 Thermal Design Scheme

To ensure the module works as long as possible under high temperature or extreme conditions (such as maximum power or maximum data transmission rate, etc.), while to guarantee the overall performance, the following heat dissipation measures are recommended.

5.1. Product Housing Design

1. Under the premise of a guaranteed mechanical reliability, choose a thinner housing to reduce the thermal resistance.
2. Enlarge the internal space as much as possible to improve air convection.
3. Reserve sufficient space inside the device for the radiator to facilitate heat dissipation capacity.
4. Use metal enclosures for the device to the greatest extent.

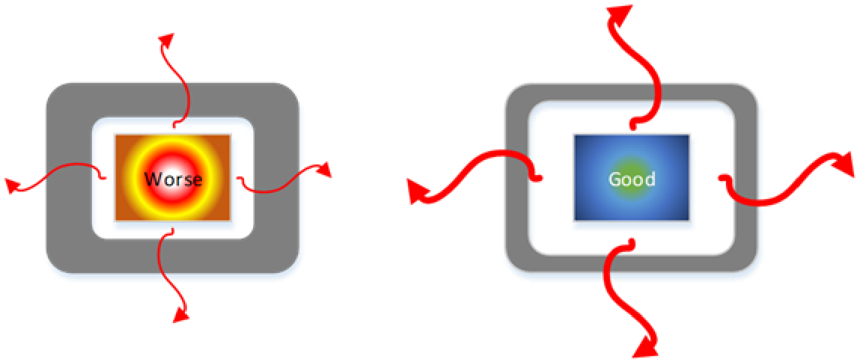


Figure 18: Thinner Housing to Reduce Thermal Resistance

Figure 19: Enlarge Internal Space for Better Air Convection

5.2. Cooling Measures Outside the Module

5.2.1. Cooling Measure 1

Place the heatsink on top of the shielding case. Fill the gap between the module shielding case and the heatsink with TIM (thermal interface material) so that they are completely contacted, and please use TIM with higher thermal conductivity. It is recommended to choose 6063-T5 aluminium heatsink. The surface of it can be black anodized and nano-carbon coated to enhance the heat dissipation capability. Additionally, add heat dissipation holes to the greatest extent in the motherboard where the module is installed to facilitate heat dissipation. The measure is shown by the following figure.

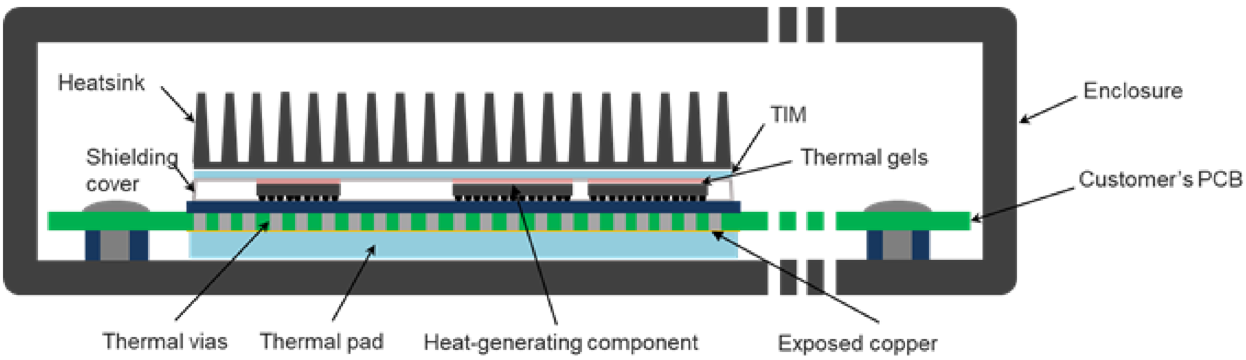


Figure 20: Cooling Measure 1

NOTE

The TIM and radiator specifications mentioned in the following chapters are consistent with this Cooling Measure 1, and it is a general measure to add as much heat dissipation vias as possible in the motherboard on which the module is mounted. Therefore, they will not be repeated in the following chapters.

5.2.2. Cooling Measure 2

Two radiators are applied. One is placed on the top of the module's shielding case, and the other is placed on the back of the motherboard. Fill the gaps between the shielding case/motherboard and the heatsink with TIM to make them fully contacted.

Remove the solder mask on both sides of the motherboard and expose as much copper as possible to reduce thermal resistance and facilitate heat dissipation.

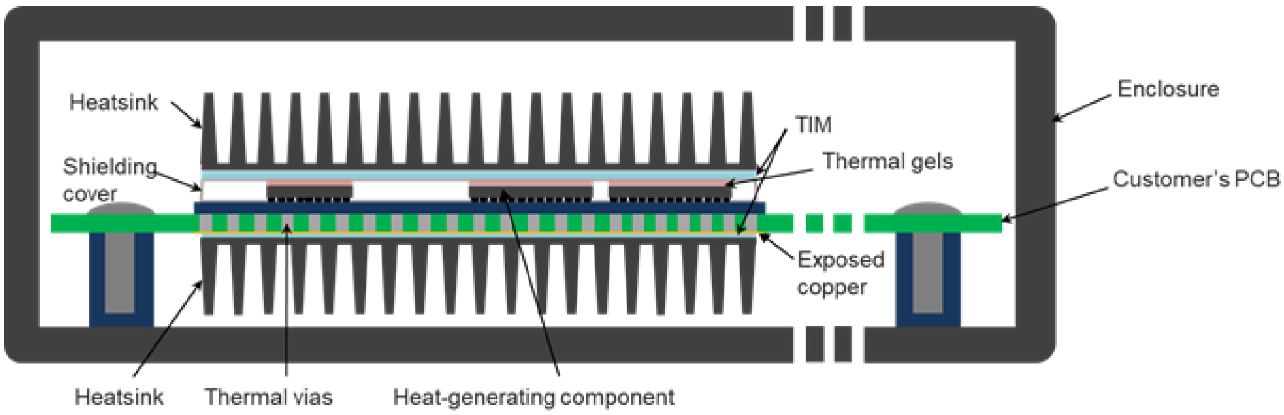


Figure 21: Cooling Measure 2

5.2.3. Cooling Measure 3

Use a metal housing with heatsinks, and fill the gap between the module's shielding case and the device housing with TIM to guarantee full contact between the module and the housing with heatsink.

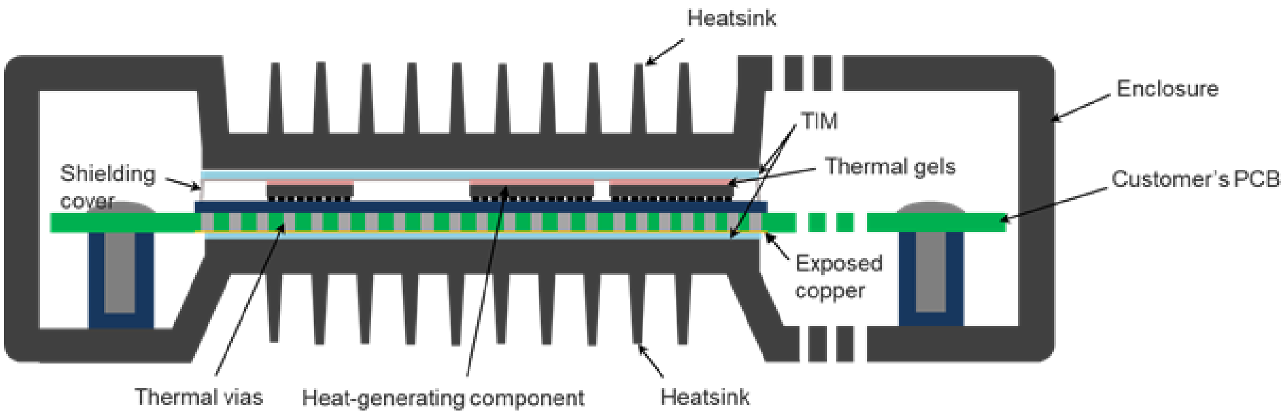


Figure 22: Cooling Measure 3

5.2.4. Cooling Measure 4

Add a heatsink on the back of the motherboard, and fill the gap between the motherboard and the heatsink with TIM for full contact. Besides, for the area on which the module is mounted, remove the solder mask on both sides of the motherboard to reduce thermal resistance and facilitate heat dissipation. Additionally, add a thermal pad between the module's shielding case and the device enclosure.

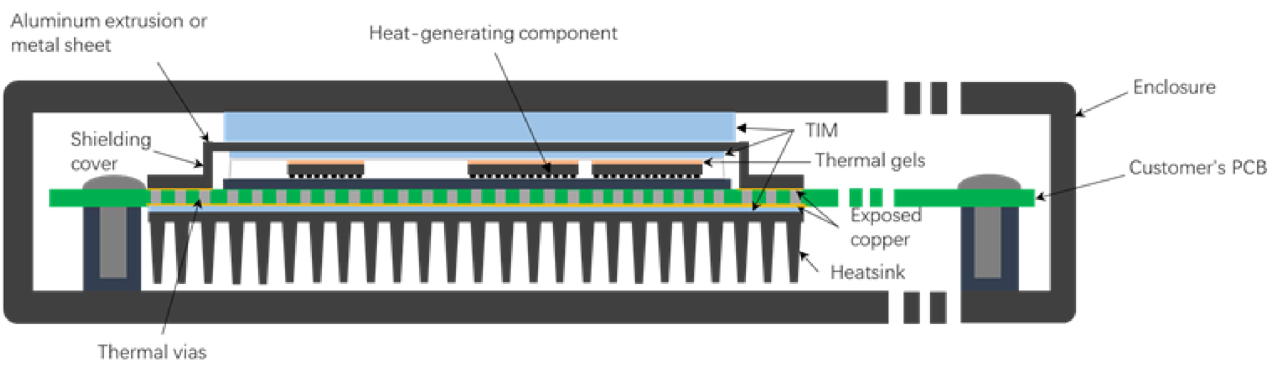


Figure 23: Cooling Measure 4

6 Summary

In view of the above thermal test, thermal simulation and cooling measures for the module, the following principles are concluded:

- Due to the size limitation, the temperature rise problem cannot be solved completely from the module’s side, an effective and reliable system-level cooling solution is necessary.
- For better thermal dissipation, thermal vias should be added to the motherboard on which the module is mounted, solder mask openings shall be reserved for the mounting area, and a radiator should be used. Meanwhile, select an appropriate radiator and a suitable housing according to the product structure, and try to conduct the heat generated by the module directly to the device housing.
- Choose suitable thermal pads, thermal adhesive and thermal paste, and avoid using thicker thermal pads.
- For products whose thermal dissipation relies on natural convection, it is necessary to facilitate heat transfer performance from structural parts and housings to air.

7 Appendix References

Table 10: Terms and Abbreviations

Abbreviation	Description
BB	Baseband
CPU	Central Processing Unit
EVB	Evaluation Board
MCP	Multiple Chip Package
PA	Power Amplifier
PCB	Printed Circuit Board
TIM	Thermal Interface Materials
Ta	Ambient Temperature
Tc	Case Temperature
Tj	Junction Temperature
UL	Uplink
XO	Crystal Oscillator