Quectel LTE Module

Thermal Design Guide

September, 2018

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General Overview

Design Guidelines

Test Example

General Overview

This document mainly introduces the thermal considerations for the design of application devices incorporating the following Quectel LTE modules:

- **LTE Module Series**

  ECxx: includes EC25/EC21/EC20 R2.0/EC20 R2.1 modules [NOTE]
  EG9x: includes EG91/EG95 modules
  EM05 module

- **LTE-A Module Series**

  Ex06: includes EP06/EG06/EM06 modules

- **Automotive Module Series**

  AG35 module

NOTE: EC2x includes LCC modules, Mini PCIe modules and Mini PCIe-C modules.

Why Need Thermal Design?

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Proper thermal design significantly extends the high performance operating time without taking the risk of device failure which affects user experience adversely.

- The module's internal electronic circuits will generate more and more heat, due to the increasing demand of high-speed communication and embedded applications.
- Complex workspaces, which is more and more common to see, require modules to have high heat dissipation performance.
- Heat accumulation of modules gives rise to the risk of damage on devices.
  May cause burning sensations on skin/result in high surface temperature.
  Some ICs may not work properly.
- Users may undergo limited device performance due to thermal mitigation algorithms.
- The module will disconnect from network automatically if the device temperature is higher than the absolute maximum temperature.
- The module offers high performance when the internal baseband (BB) chip stays below 105℃. If the peak temperature of the BB chip reaches or exceeds 105℃, the module will not be able to provide high-performance as usual (may offer decreased RF output power, limited data rate, etc.). Therefore, the modules are recommended to optimize thermal design so as to keep the peak temperature of BB chip lower than 105℃. **AT+QTEMP** command can be executed to get the peak temperature of BB chip. The first return value of **AT+QTEMP** indicates the peak temperature of BB chip.

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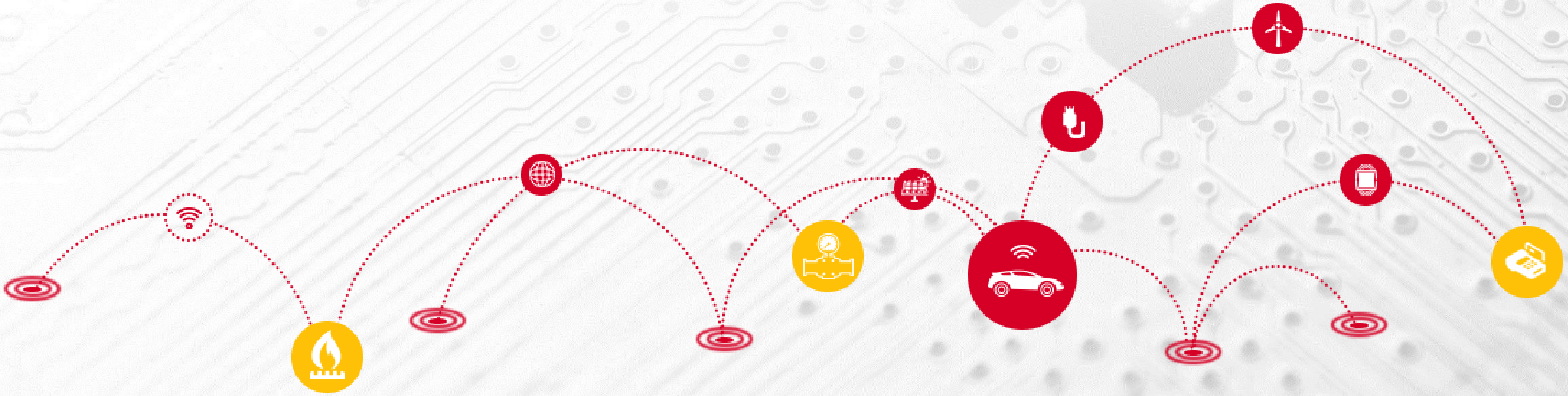
Test Example



Thermal Concept 1

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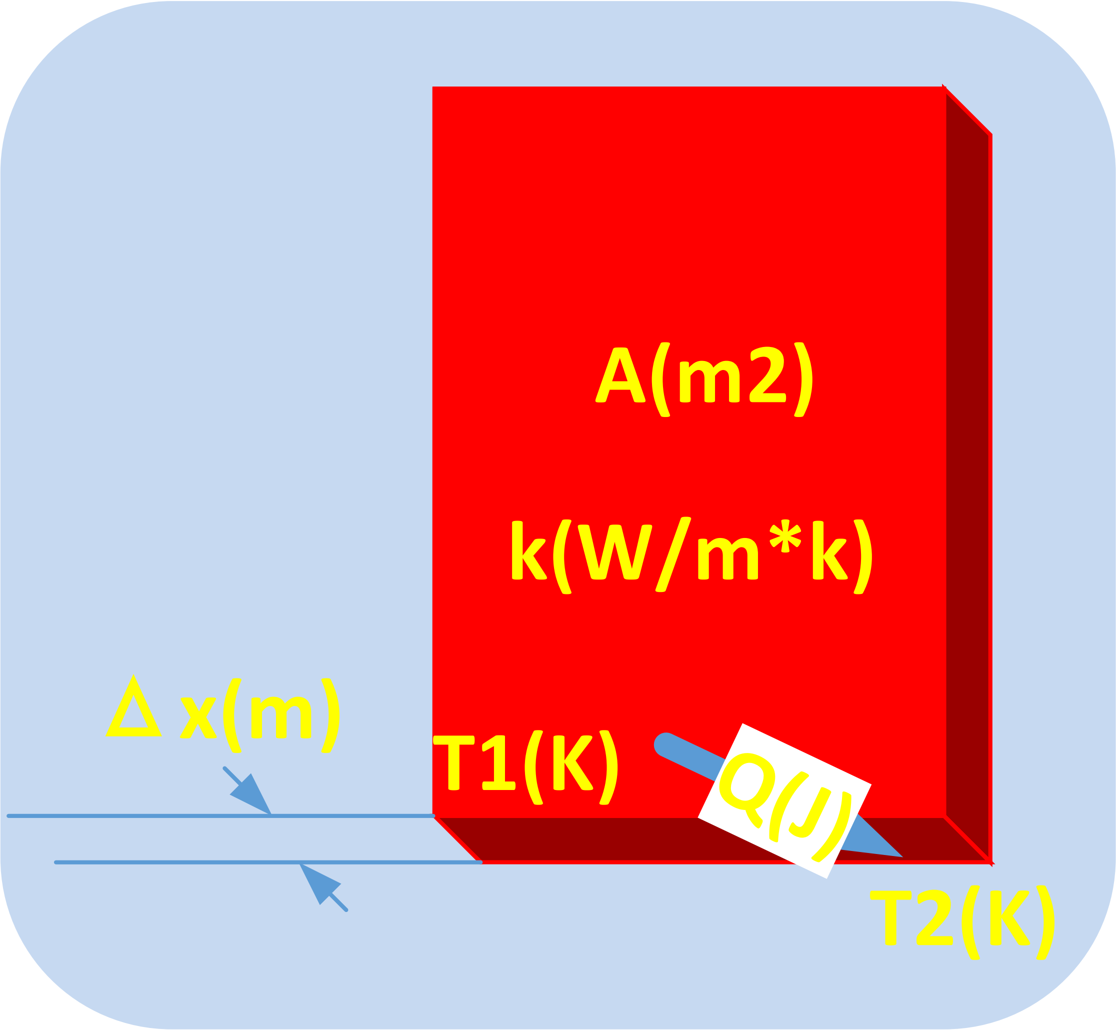


$$\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}$$

- **ΔQ/Δt:** Heat transfer rate, Unit: W
- **k:** Thermal conductivity, Unit: W/m*k
- **A:** Heat conduction area, Unit: m2
- **ΔT:** T1-T2, Surface temperature difference, Unit: K
- **Δx:** Heat conduction length, Unit: m

Thermal Concept 2

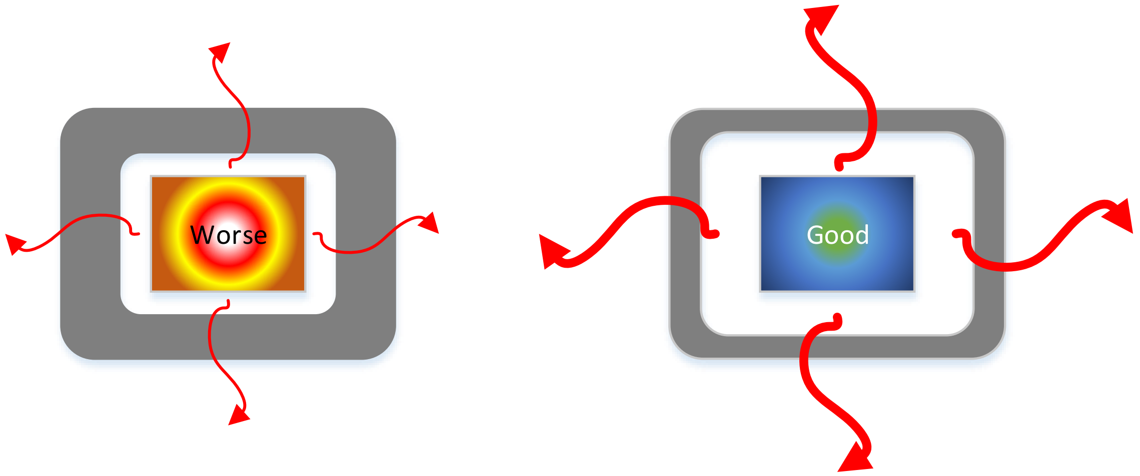
- Materials with higher thermal conductivity (k) transfer heat better.
  - Graphite (in-plane): k > 370 W/m*K
  - Aluminum: k = 205 W/m*K
  - Magnesium: k = 156 W/m*K
  - Plastic: k = 0.2 W/m*K
  - Air: k = 0.024 W/m*K

- Housing/enclosures with larger surface area (A) dissipate heat better.
  - Heat sink dissipates the heat by increasing the surface area in contact with the cooling fluid around the module, such as air.
  - The PCB ground plane's thickness and width (cross-sectional surface area), number of layers, and vias are critical parameters for IC to reduce its peak temperature by spreading heat energy.

- The smaller distance between the cooling system and heat source is preferred.

Structure Design 1

- Select walls with thinner thickness because of smaller thermal resistance.



- Try to expand the internal space as much as possible for better convection.

Structure Design 2

- Reserve enough space to add a heat sink on the top of the module as well as the opposite side of the PCB area where the module is mounted.
- If the internal space is small, it is recommended to add a thermal pad with high thermal conductivity between the module and the housing/enclosure.
- Do not install any battery or other components that may generate heat both at the top and bottom of the module.

Heat Sink Design

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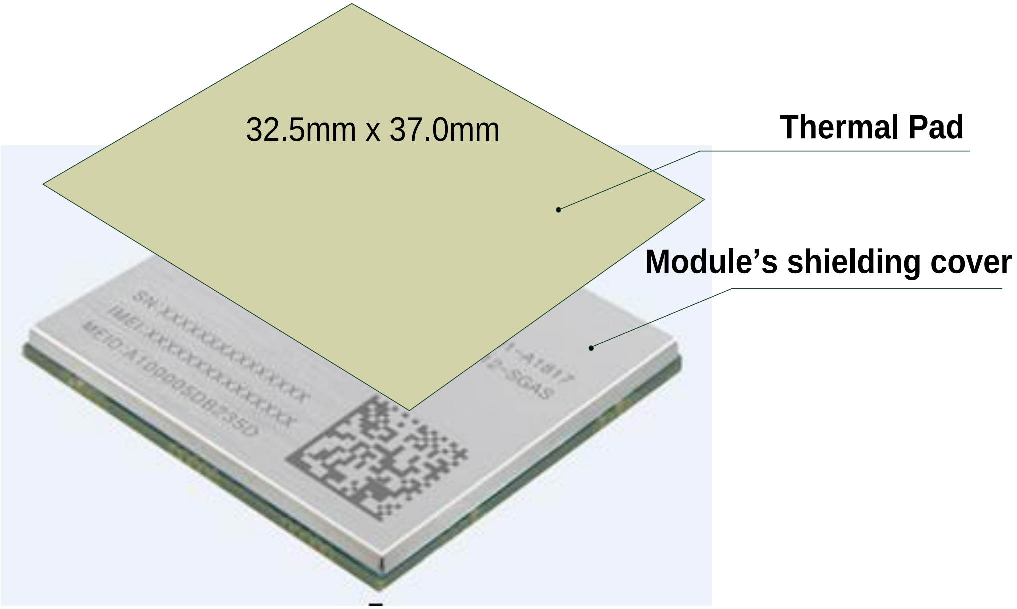
- If the housing/enclosure is made up of aluminum alloy, it is recommended to integrate the heat sink with the housing/enclosure.
- If the housing/enclosure is made up of plastic, it is recommended to design an independent heat sink whose heat dissipation surface should be outside the housing/enclosure.
- Increase the number of heat sink fins as many as possible.

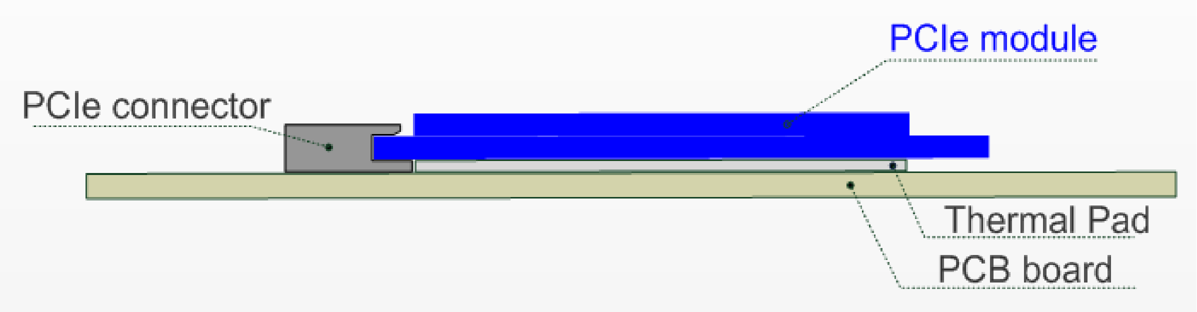
Thermal Pad Design 1

- Selection:
  Select thermal pads with high thermal conductivity (k > 3 W/m*k).
- Heat conduction area:
  It is recommended to select thermal pads with almost the same size with the module's shielding cover. Take AG35 module with size of 32.5mm×37mm as an example, its preferred thermal pad size is about 32.5mm×37.0mm.



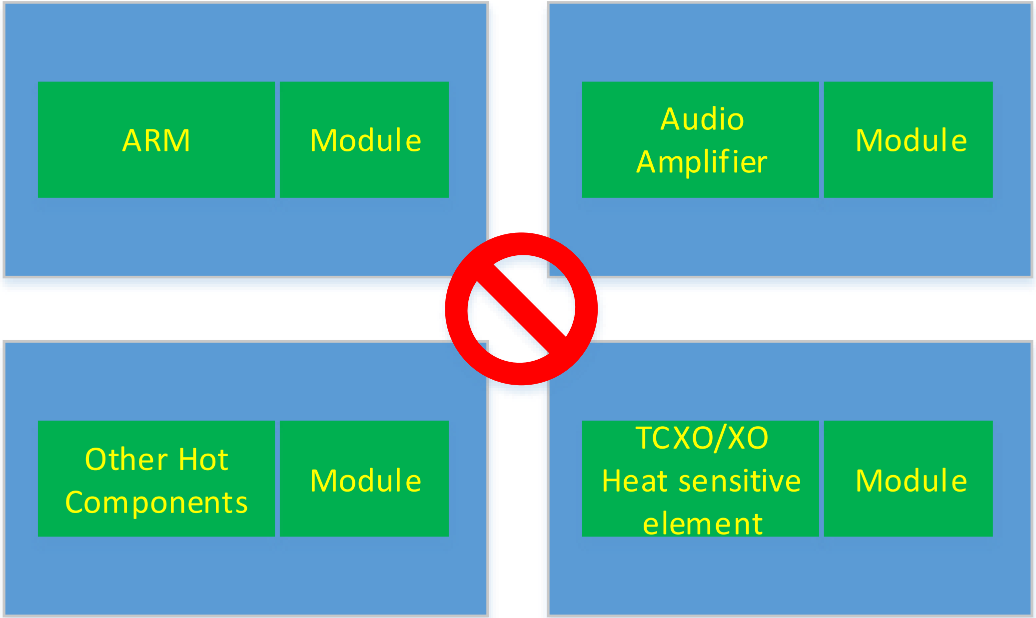
Thermal Pad Design 2

- Thermal pad thickness:
  The thermal pad thickness is recommended to be 0.5mm greater than the distance between the module's top/bottom side and the heat sink (or housing/enclosure). The maximum thickness is recommended to be 3mm.
- Thermal pad position:
  Cooling system on top side of the module: the thermal pad is used between the module's shielding cover and the heat sink (or housing/enclosure).
  Cooling system on bottom side of the module: the thermal pad is used between the PCB area on opposite side of which the module is mounted and the heat sink, or directly between the module's bottom side and the PCB.
- Example:
  Taking Mini PCIe module as an example, the thermal pad is placed between the module's bottom side and the PCB. In such case, please do not apply solder mask on the connection area so as to ensure better heat dissipation performance. The solder mask size should be almost the same as the bottom size of the module.



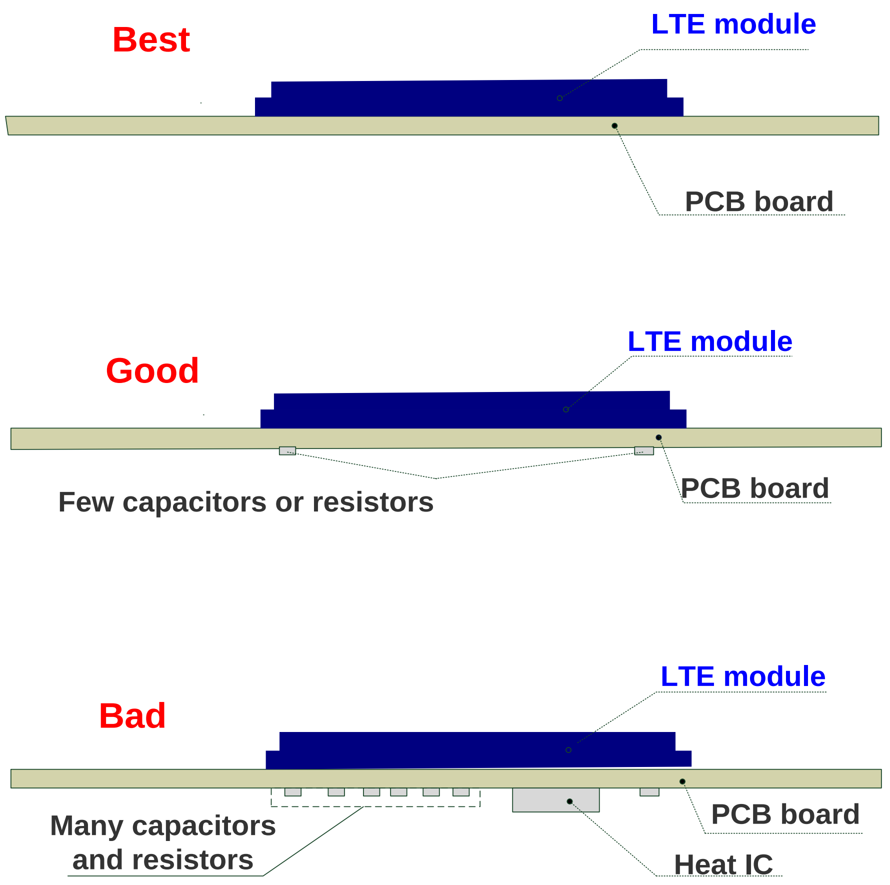
PCB Design 1

- Larger PCB size is beneficial for components placement and has the better performance for heat dissipation
- Keep the module away from the ARM, audio amplifier, and other components that may generate heat.
- Keep the module away from the heat sensitive elements such as the TCXO/XO.



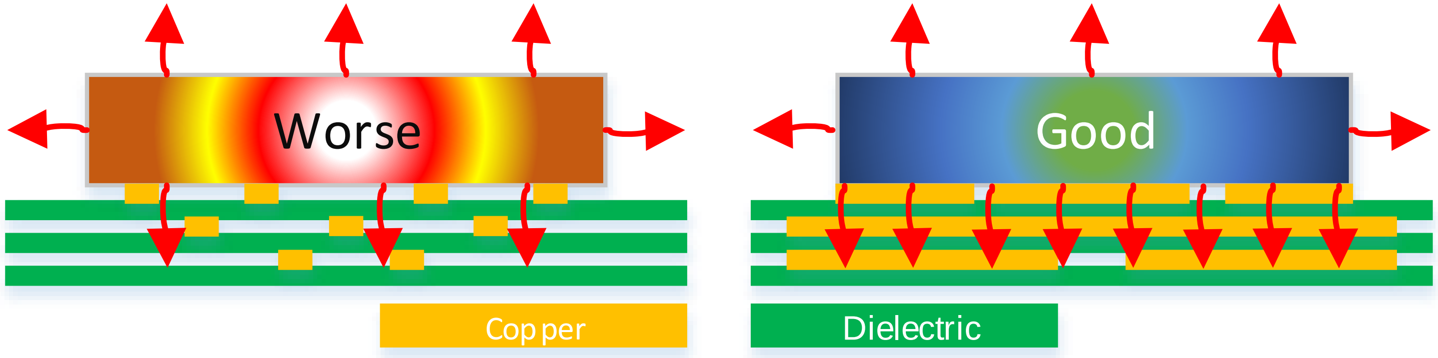
PCB Design 2

- Best design:
  To facilitate adding of the heat sink when necessary, please do not place components on the opposite side of the PCB area where the module is mounted, and do not place components on both the PCB top and bottom areas where the PCIe module is installed.
- Good design:
  Place only some passive components with small packages, such as resistors, capacitors, and inductors, on the opposite side of the PCB area where the module is mounted, and leave a large blank area for adding the cooling system.
- Bad design:
  Placed many components with large packages and even heat sources on the opposite side of the PCB area where the module is mounted.

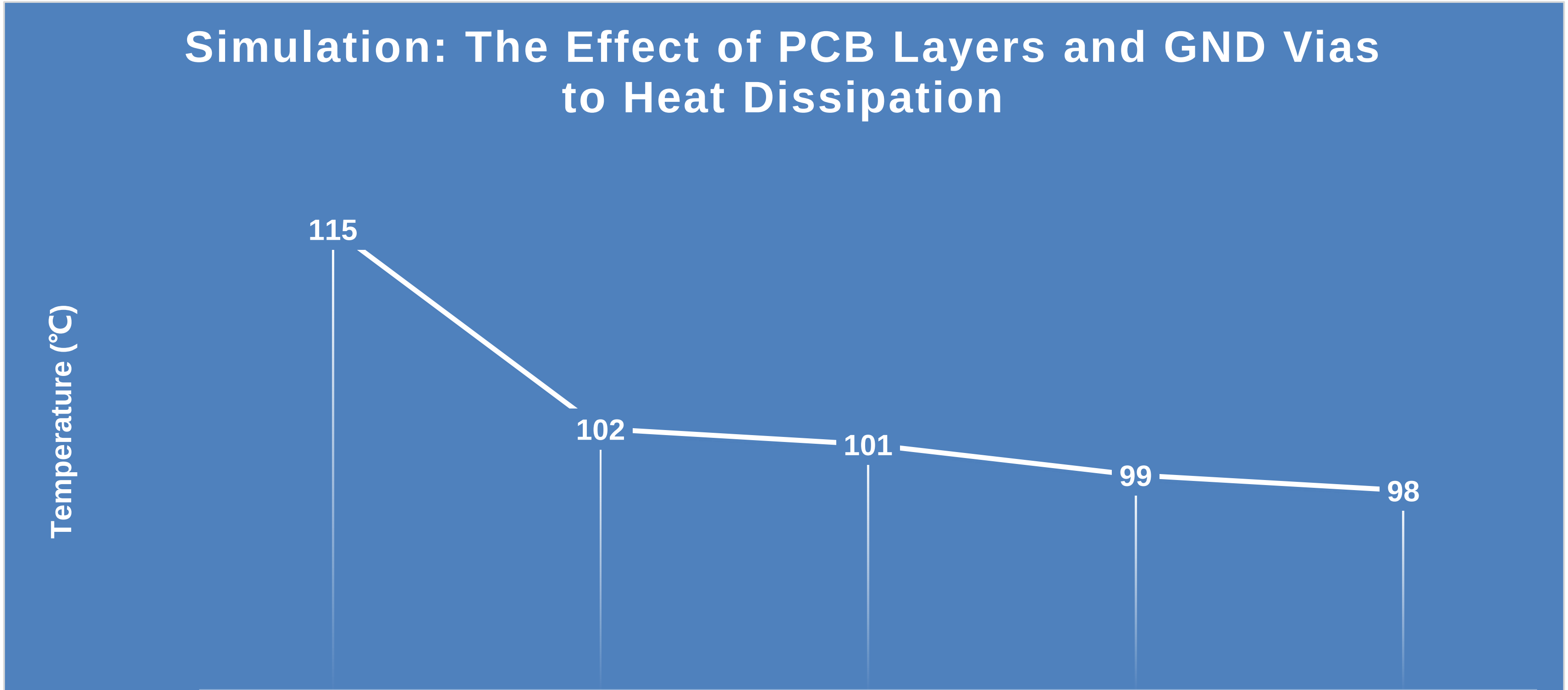


PCB Design 3

- Add layers as many as possible and increase the copper area at each layer.
- Increase the size of the GND plane as much as possible.
- Do not design GND pads of the module into thermal relief pads.
- Fill empty layers with copper wherever possible.
- Increase the power supply plane using thick/wide traces as many as possible.
- Try to keep the copper plane as a whole.



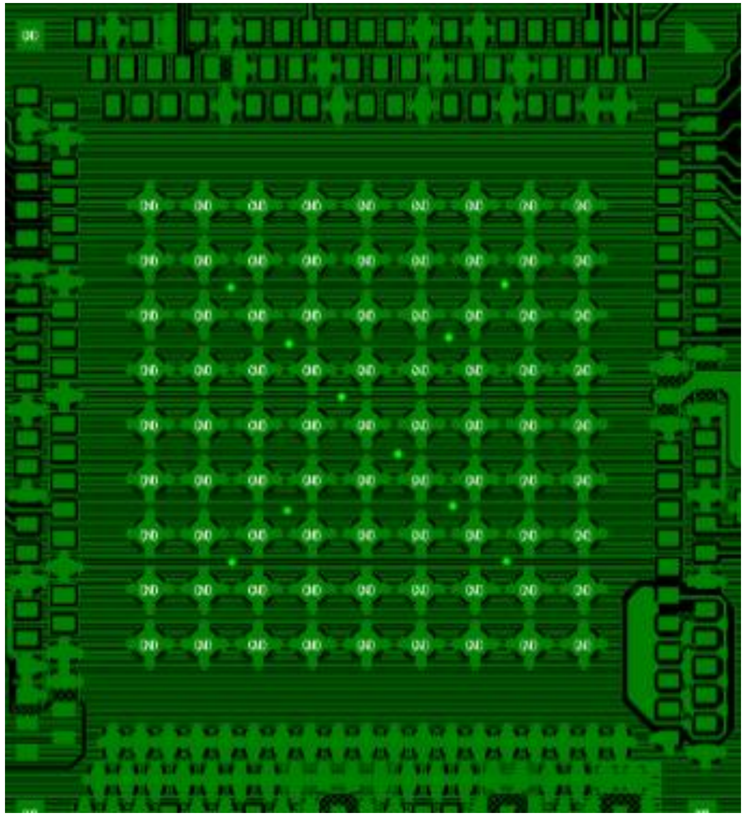
PCB Design 4



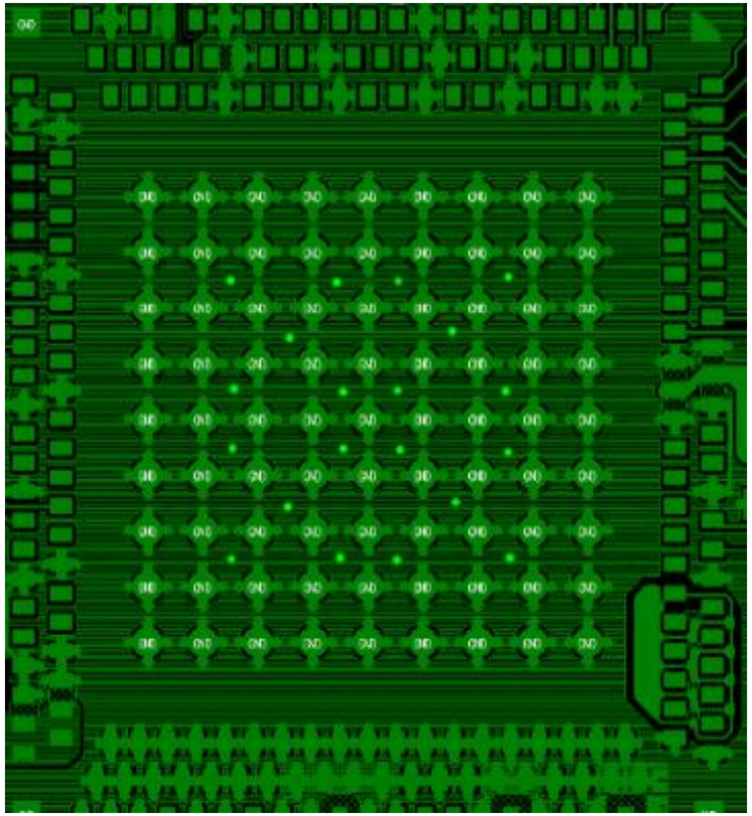
	2 layers PCB, L1 filled with GND	4 layers PCB, L1/L3 filled with GND, and 10 GND vias used.	4 layers PCB, L1/L3 filled with GND, and 20 GND vias used.	6 layers PCB, L1/L3/5 filled with GND, and 5 GND vias used.	6 layers PCB, L1/L3/5 filled with GND, and 10 GND vias used.
BB(℃)	115	102	101	99	98

- Flotherm V12.0
- PCB Size: 90mm×150mm×1.6mm

PCB Design 4 – Through Holes

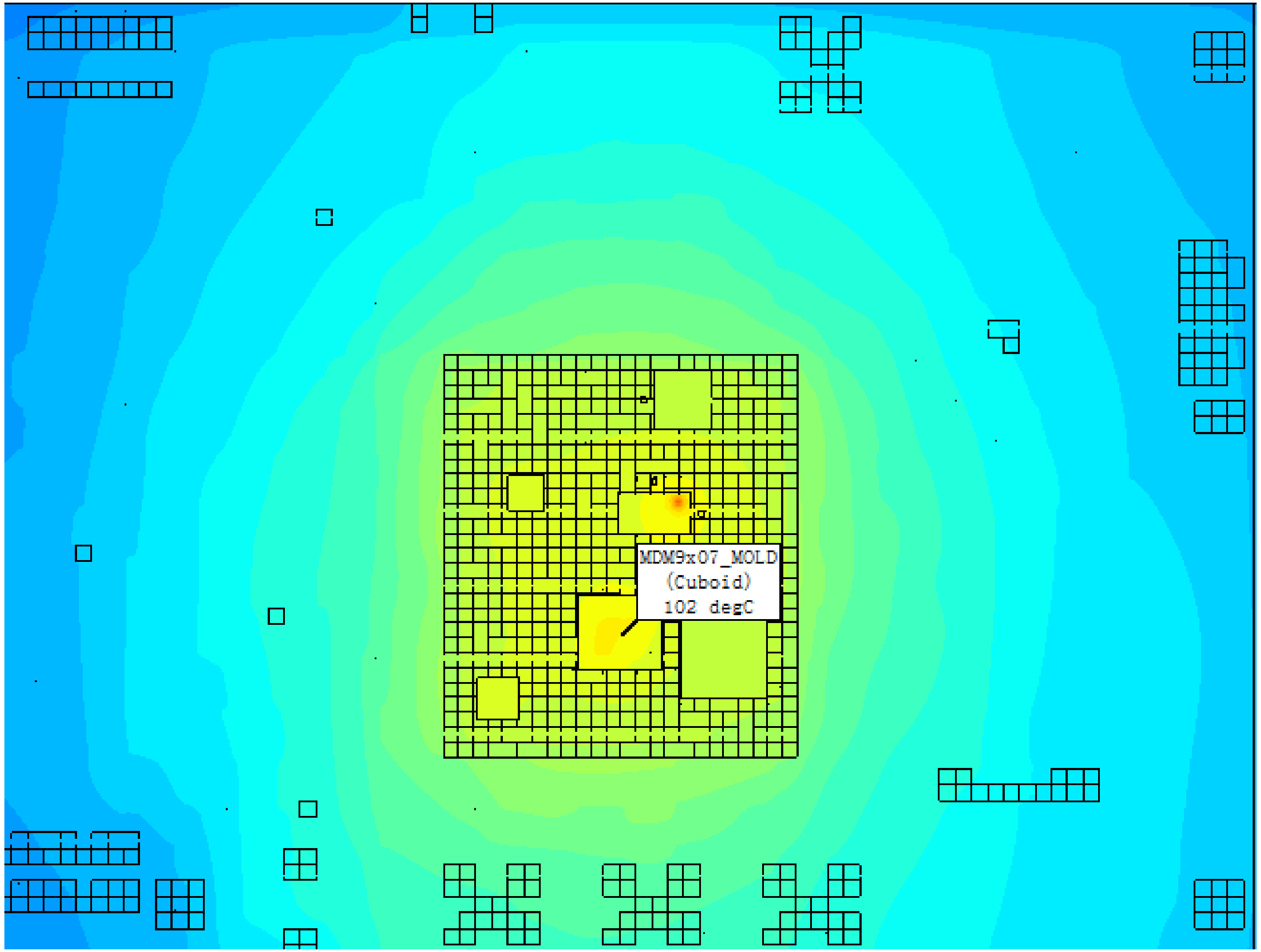


10 Through Holes

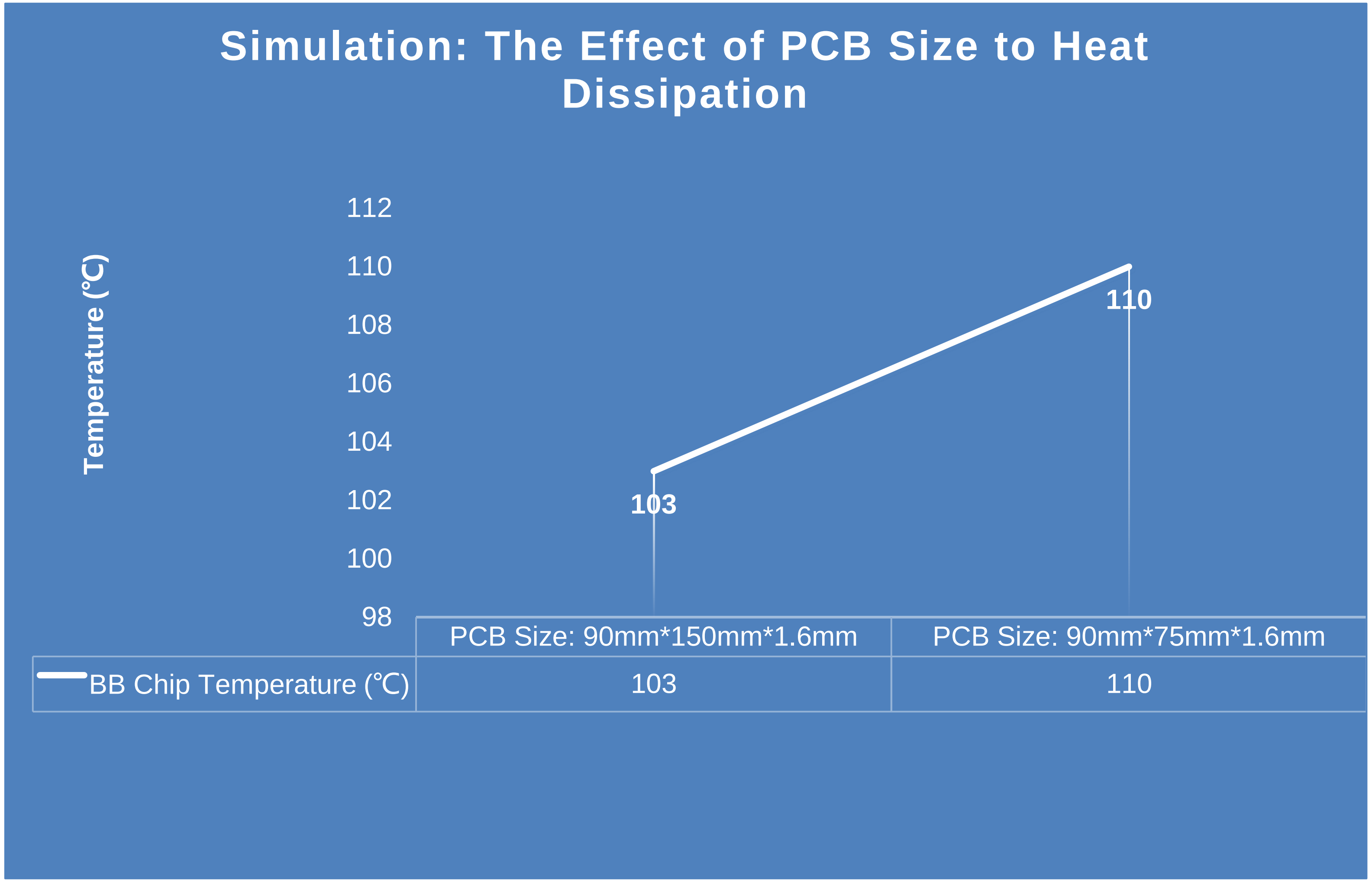


20 Through Holes

PCB Design 4 – Thermal Image



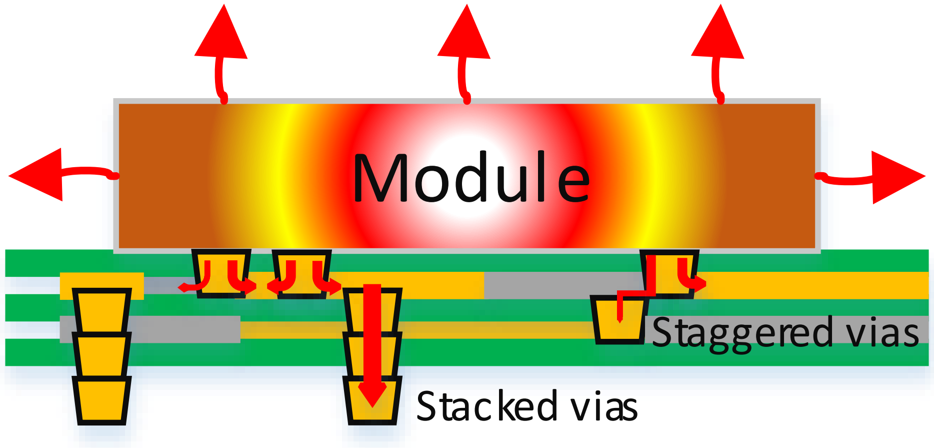
PCB Design 5



- Flotherm V12.0
- PCB:
  90mm×150mm×1.6mm, 6 layers
  90mm×75mm×1.6mm, 6 layers

PCB Design 6

- Vias design:
  a) Add adequate vias under and near the module.
  b) Connect the vias to a large GND plane for better heat dissipation.
  c) Large vias are better than small vias.
  d) Through holes are better than buried vias and blind vias.
  e) Stacked vias are better than staggered vias.

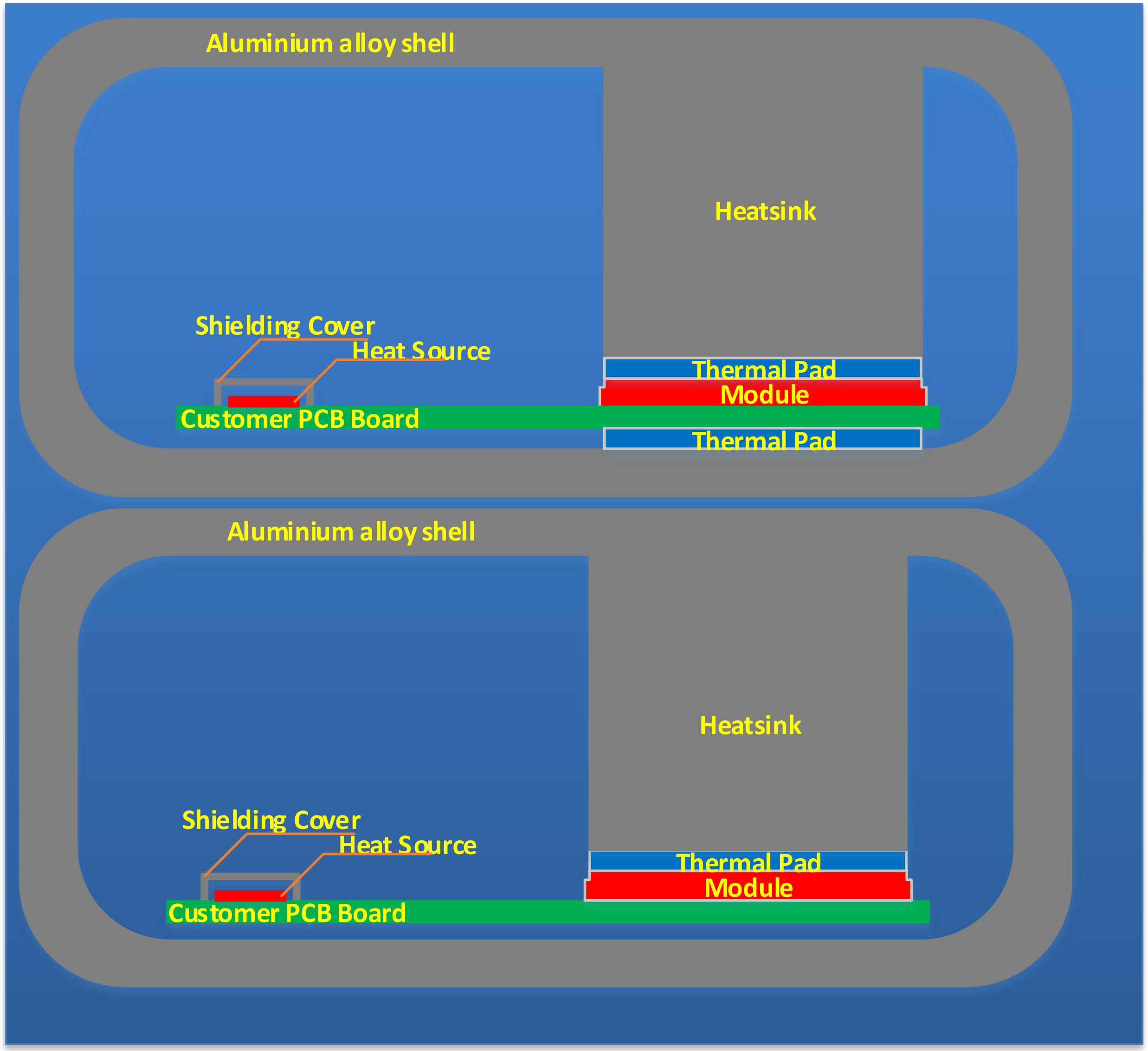


- About solder mask:

  Do not apply solder mask on the PCB area where the module is mounted or installed to provide better heat dissipation performance.

Heat Dissipation Diagram

- Aluminum alloy shell and recommended cooling system design of LCC/LGA module

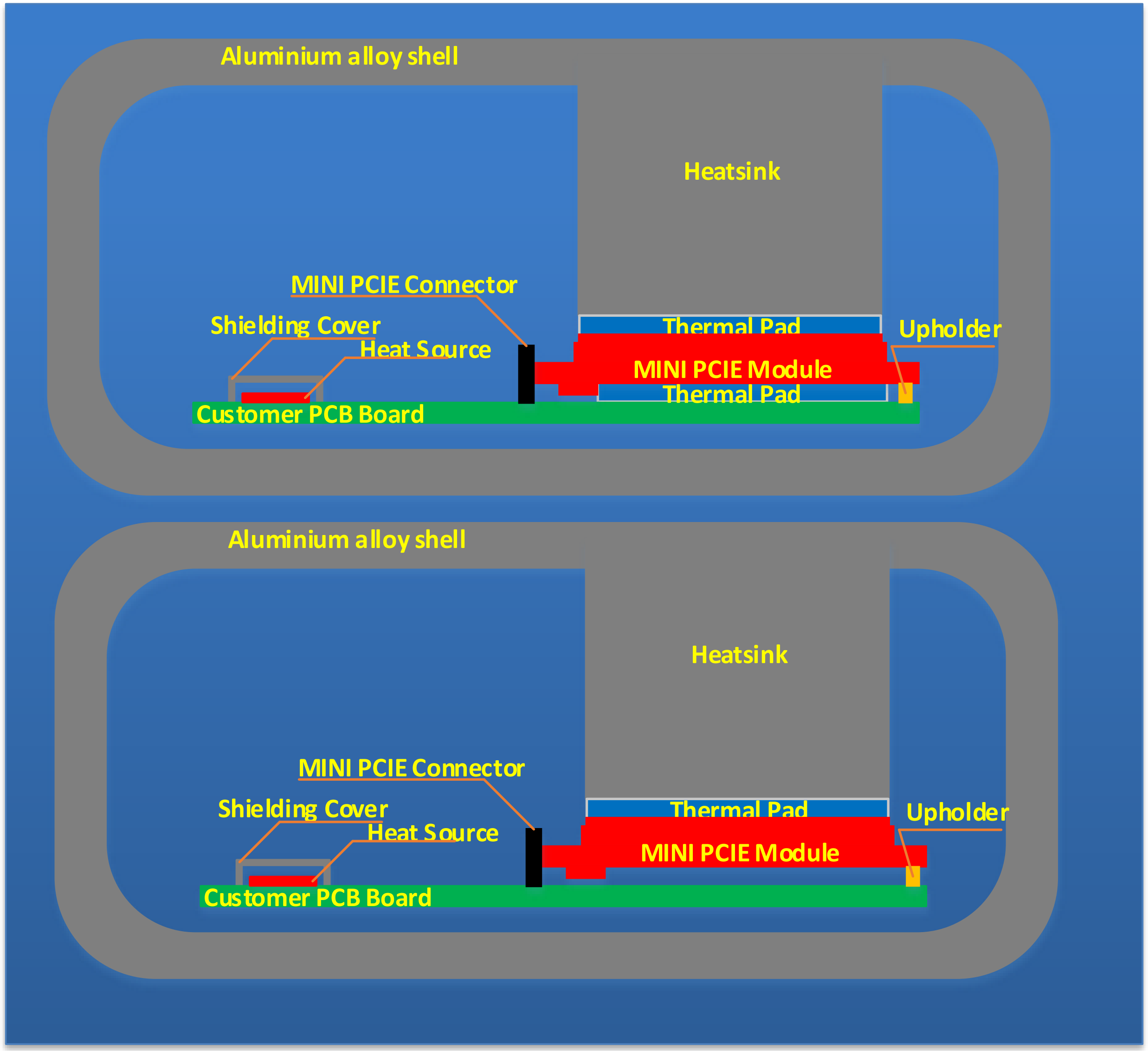


Better

Good

Heat Dissipation Diagram

- Aluminum alloy shell and recommended cooling system design of Mini PCIe module

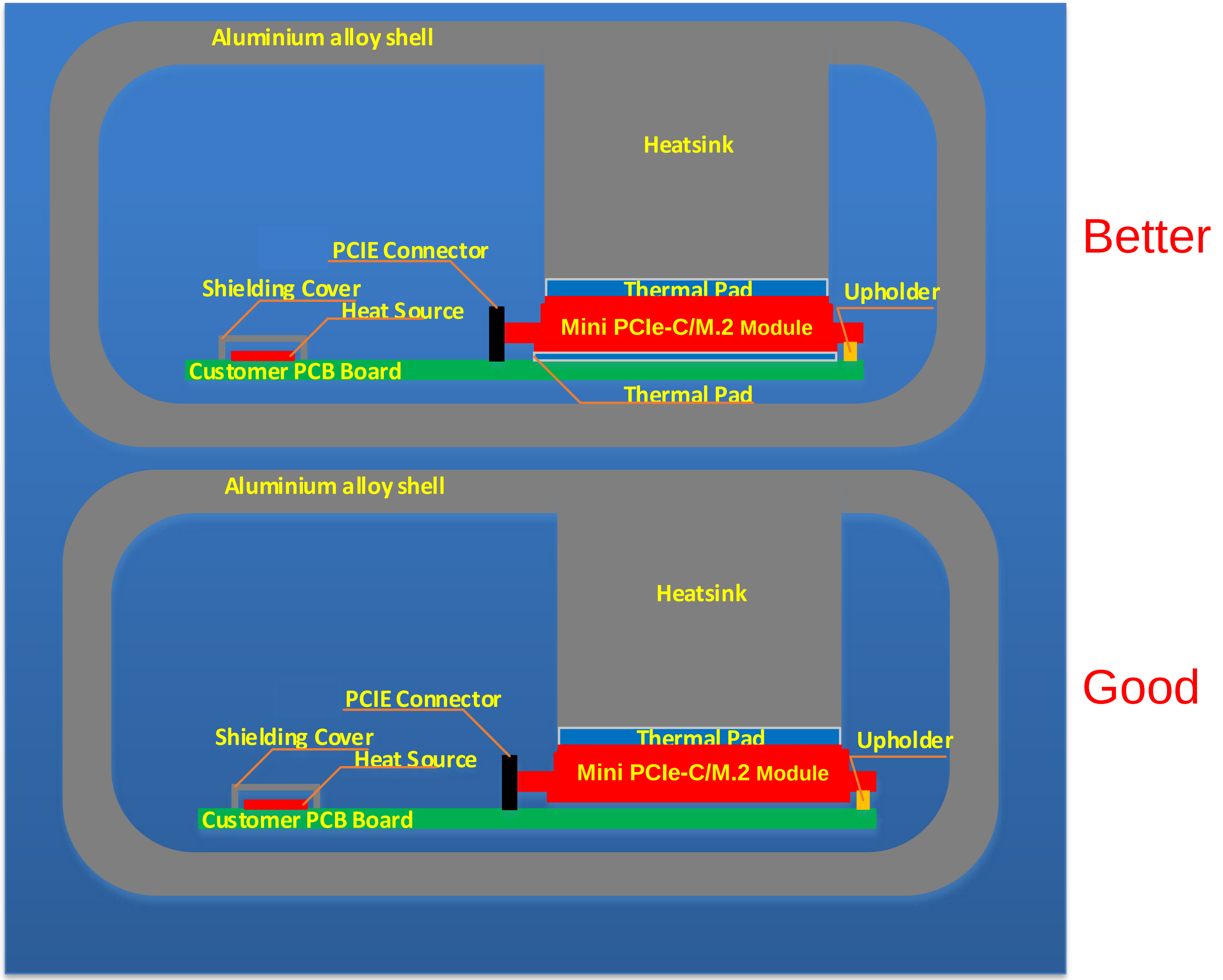


Better

Good

Heat Dissipation Diagram

- Aluminum alloy shell and recommended cooling system design of Mini PCIe-C or M.2 module



Heat Dissipation Diagram

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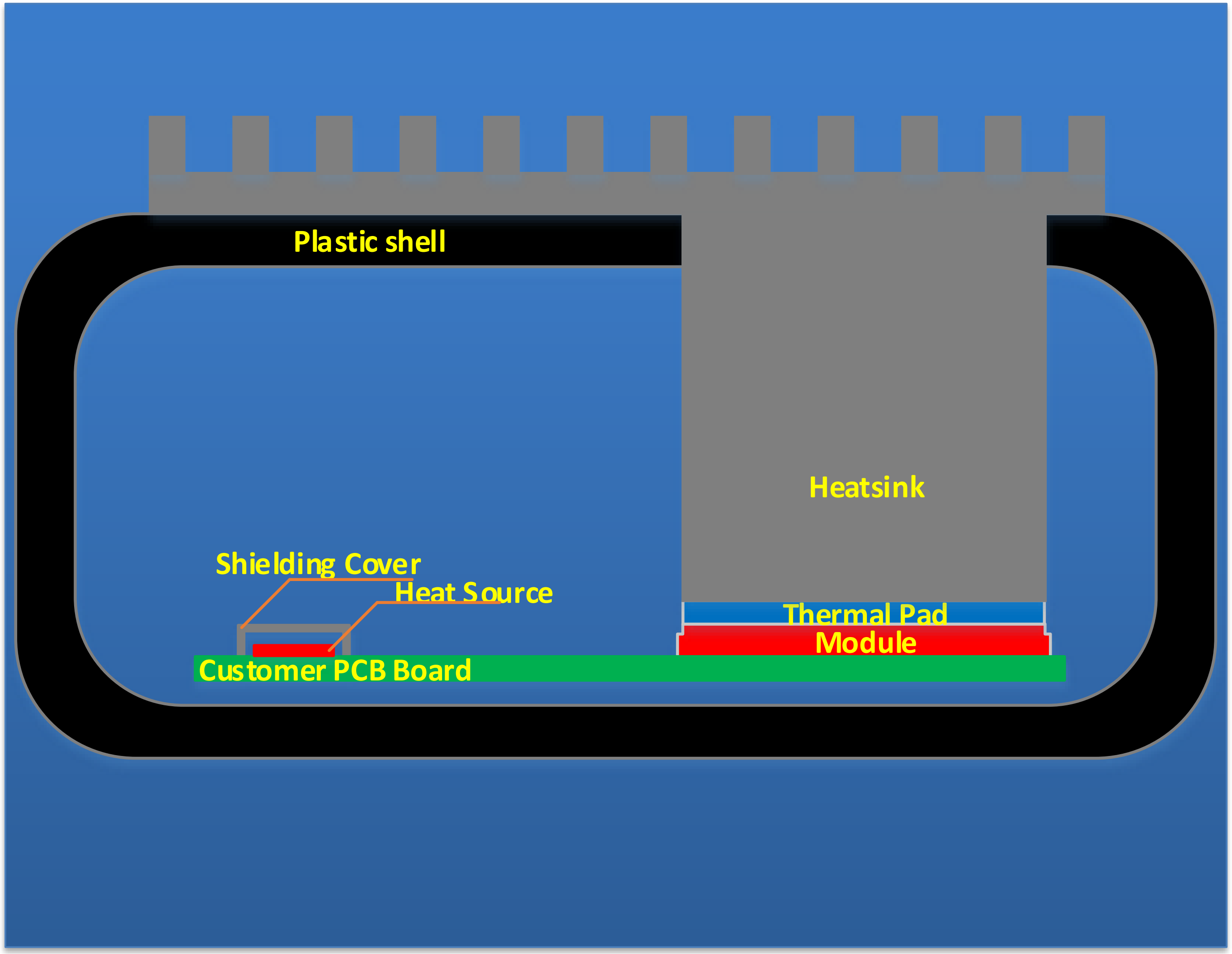
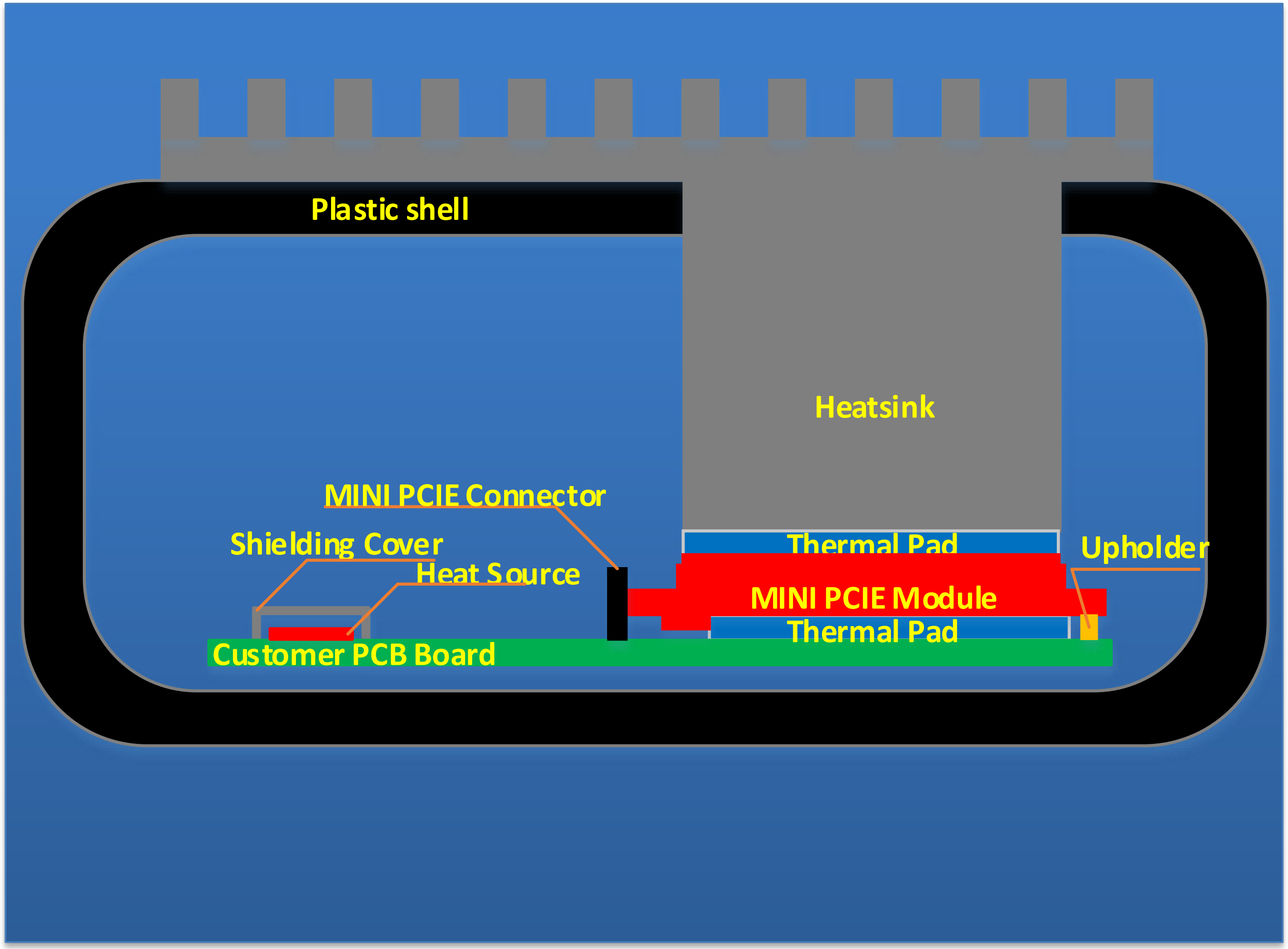
- Plastic shell and recommended cooling system design of LCC/LGA module



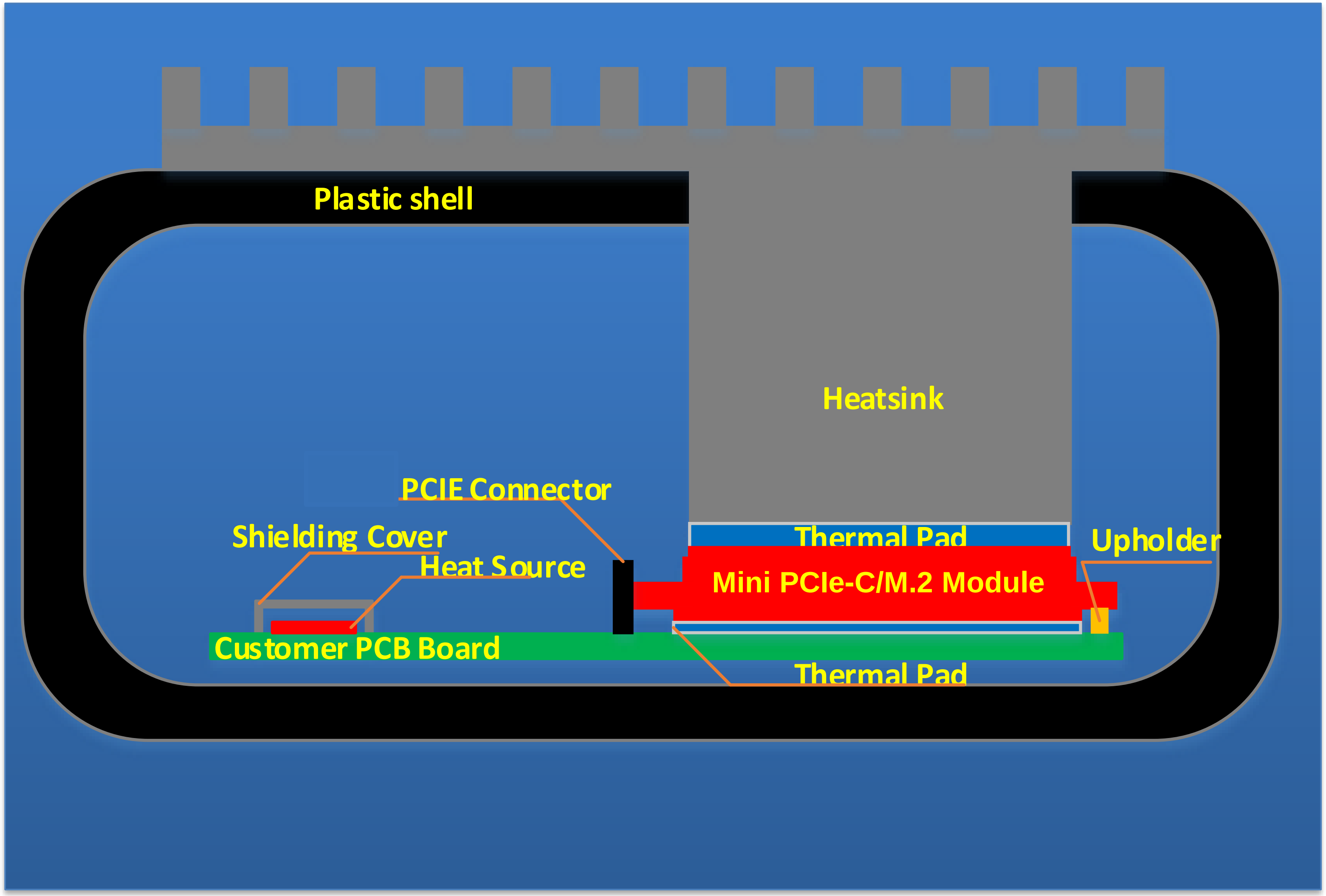
Heat Dissipation Diagram

- Plastic shell and recommended cooling system design of Mini PCIe module



Heat Dissipation Diagram

- Plastic shell and recommended cooling system design of Mini PCIe-C or M.2 module



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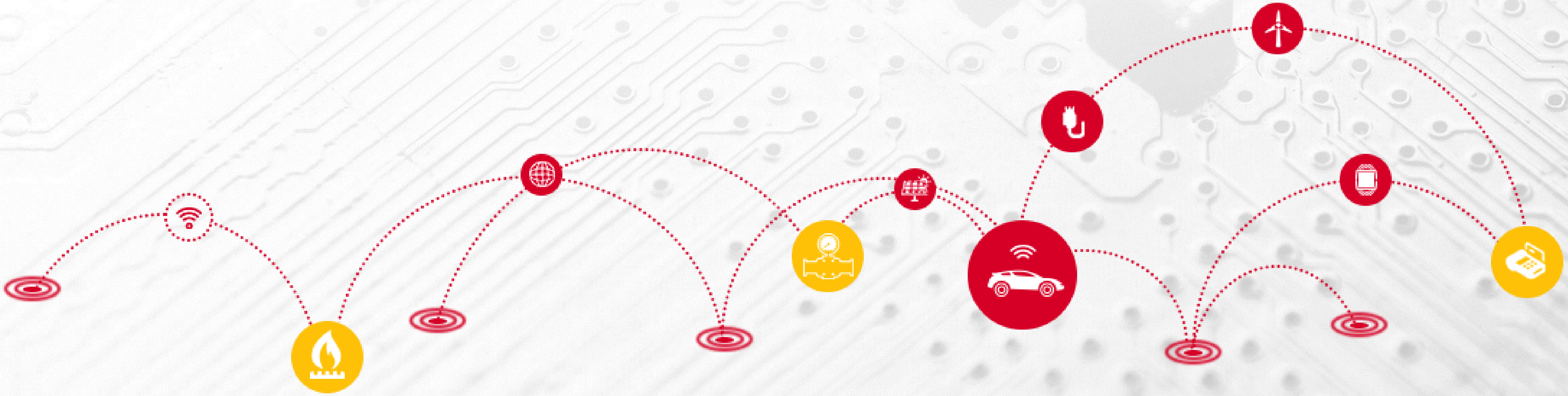
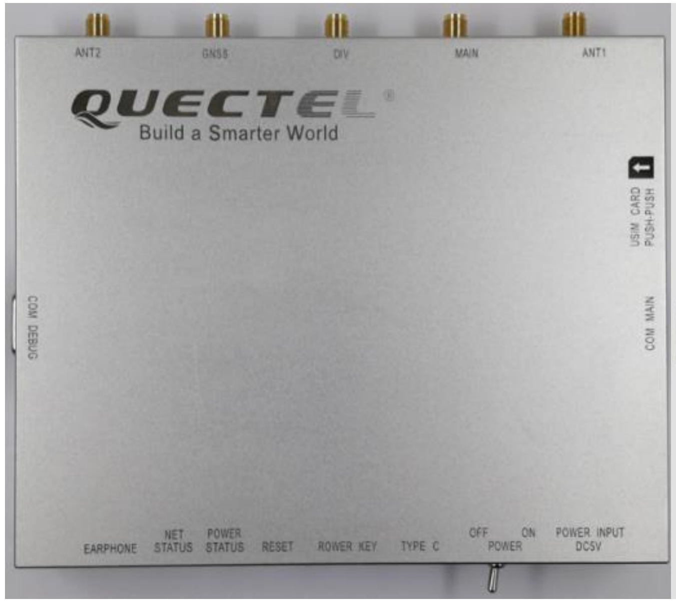
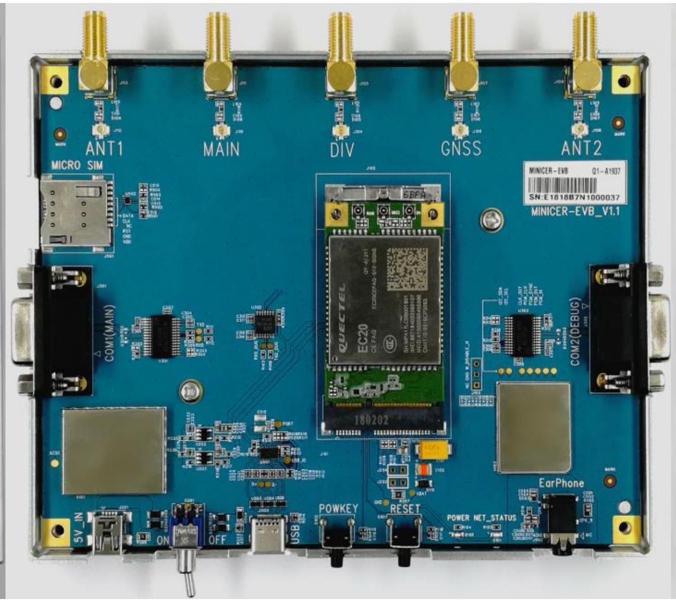


Test Environment

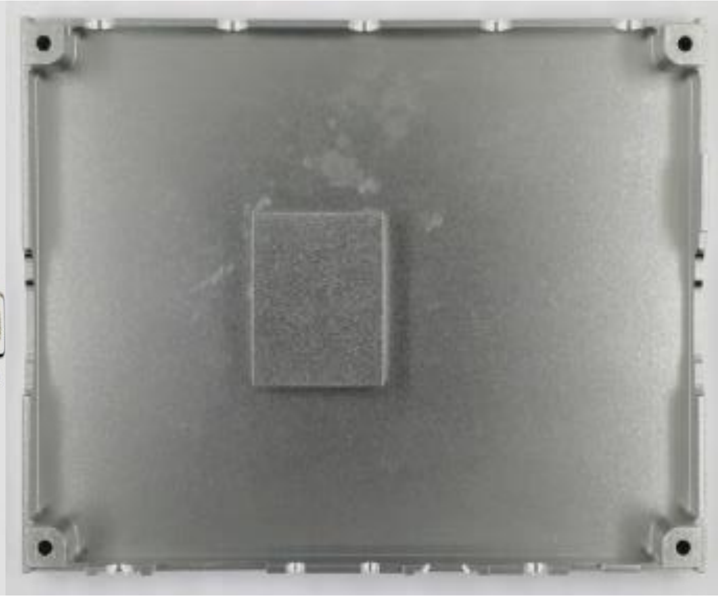
Aluminum Alloy Shell



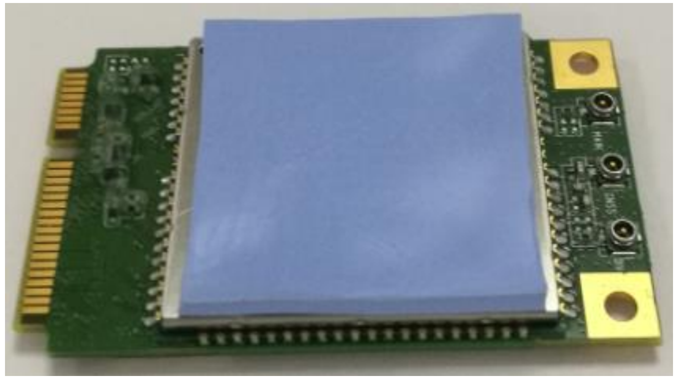
Mini PCIe Module



Heat Sink



Thermal Pad on the Top Side



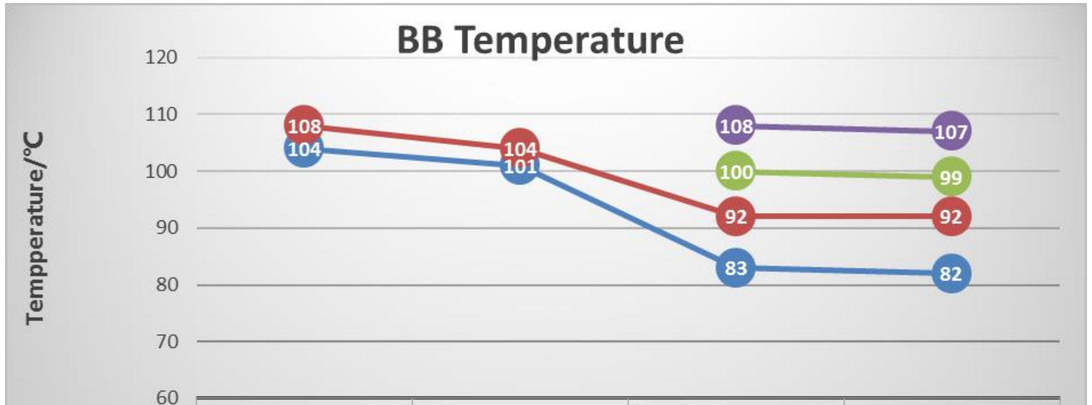
Thermal Pad on the Bottom Side

Test Condition

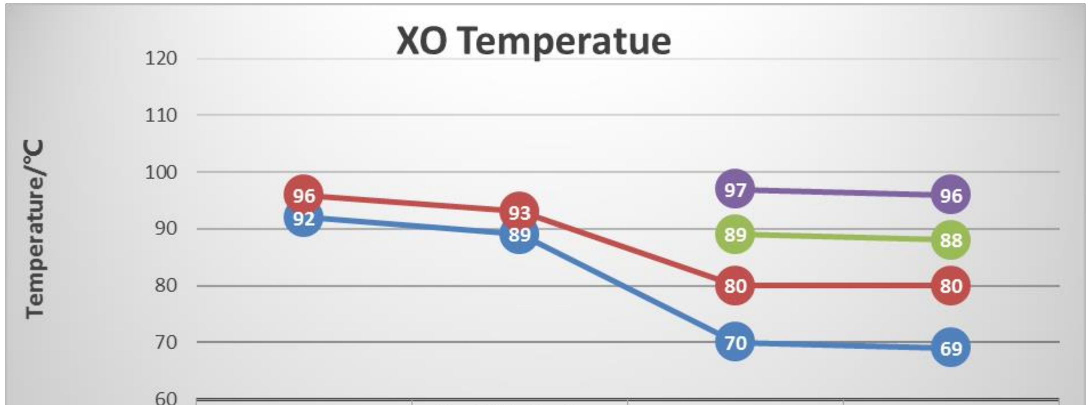
- Power the EVB by 5V DC power supply
- Connect the main antenna of the Mini PCIe module to CMW500 through RF cable
- Set the max power, max data rate, and UDP transfer mode
- Set different test temperatures, such as 55℃, 65℃, 75℃, and 85℃
- Use **AT+QTEMP** command to get the current temperature every 10s

Test Results

- **The Best Solution**: Cooling system available on both sides of Mini PCIe module
  It can lower the BB temperature by 8℃ @T=85℃, and lower the XO temperature by 9℃ @T=85℃.
- **Good Solution**: Cooling system on the top side of Mini PCIe module
  It can lower the BB temperature by 7℃ @T=85℃, and lower the XO temperature by 8℃ @T=85℃.



	No heat dissipation	Heat Dissipation on the bottom side	Heat Dissipation on the top side	Heat Dissipation on the both side
T=55℃	104	101	83	82
T=65℃	108	104	92	92
T=75℃			100	99
T=85℃			108	107



	No heat dissipation	Heat Dissipation on the bottom side	Heat Dissipation on the top side	Heat Dissipation on the both side
T=55℃	92	89	70	69
T=65℃	96	93	80	80
T=75℃			89	88
T=85℃			97	96

Thank you!

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