QLS1046-Space - Thermal Management

Revision date :	**17/04/2023**
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Scope :	**BUSINESS UNIT BMS**

Last revision approved by :

Approved by	Approbation Status	Date
PERQUE Vincent	Oui	05/04/2023
LEGENDRE Olivier	Oui	17/04/2023

1. DOCUMENT AMENDMENT RECORD

Author	Issue	Date	Reason for change
Porchez Thomas	A	17/04/2023	First issue

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2. INTRODUCTION

This application note discusses the thermal management aspects for a Space implementation of the Qormino QLS1046-Space module. It provides recommendations for designers to manage the cooling of the QLS1046-Space module.

QLS1046-Space features a LS1046-Space processor, a Space DDR4 memory, and passive components. All the components are installed on a substrate, with a BGA grid underneath. The components that are consuming power and dissipating heat are the processor and the DDR4 memory. The processor is the one exhibiting the highest power consumption by far, and on which the cooling requirement is the strongest.

Prior to size the cooling system, it is first needed to estimate the power consumption of the two active devices:

- For the LS1046-Space processor, the power consumption can be estimated based on the key figures available in the datasheet and the power estimation guide that is available upon request from Teledyne e2v. Power consumption depends mainly upon operating frequency, number of cores used, and operating junction temperature. In typical operating conditions, the power consumption of the processor is expected to be in the 7 to 15W range.
- The power consumption of the DDR4 depends on transfer rate and read/write duty cycle. A power calculation spreadsheet is also available, and the typical power consumption ranges from 1W to 1.5W.

When the power consumption has been evaluated, the sizing of the cooling system can be investigated.

3. COOLING SYSTEM SIZING

The cooling of a Qormino QLS1046-Space is not very different from the cooling of any other component in Space. For both the DDR4 and the processor, thermal models and thermal resistance values are available to perform the thermal analysis. The parameters to simulate the QLS1046-Space substrate are provided in the Table 3-2. In most applications, the memory has a limited power consumption, hence it does not always require a heatsink on top of it. On the contrary, because of the high power density of the LS1046-Space processor, it needs a heatsink most of the time.

In Space applications, the heatsink is usually an aluminum or copper plate placed on top of the components. The heat then needs to be conducted towards the spacecraft mechanical structure, or directly to the cooling panels. Thermal straps are commonly used to conduct the heat since they are reliable and provide mechanical decoupling. Heat pipes can also be considered to improve the cooling efficiency, but they are more complex to implement and less reliable.

This document presents the three general options to cool the module:

- Combined cooling, in that case refer to Section 3.1,
- Separate cooling, in that case refer to Section 3.2,
- Processor cooling only, in that case refer to Section 3.3.

3.1 Combined cooling

3.1.1 Cooling configuration

Combined cooling is the case where a cooling plate covering both devices is used (see Figure 3-1). It is the recommended solution as it is easier to implement and will be more robust from a mechanical standpoint.

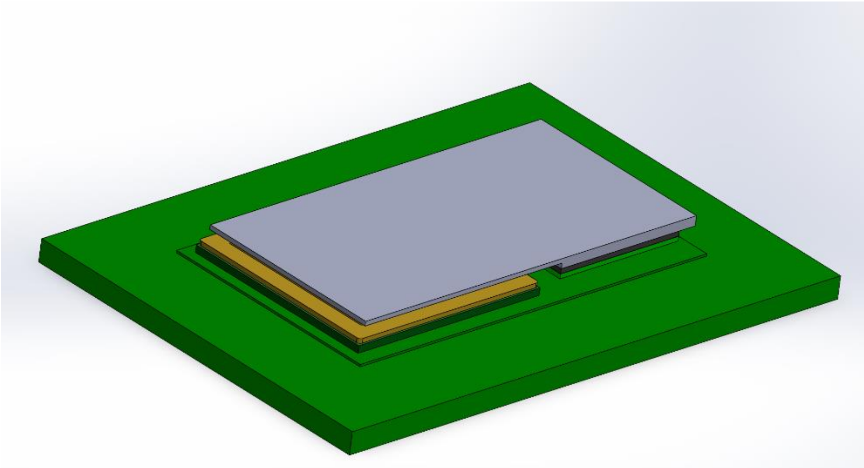

Figure 3-1: Cooling plate covering processor and memory.

Since the processor is taller than the memory, the difference can be compensated either by adding a thermal gap filler, or by adjusting the cooling plate thickness. In the following analysis, a Thermal Interface Material (TIM) is used between the top of the components and the cooling plate. The plate is made of aluminum and its thickness is adjusted to match the components height, as shown on the Figure 3-2.

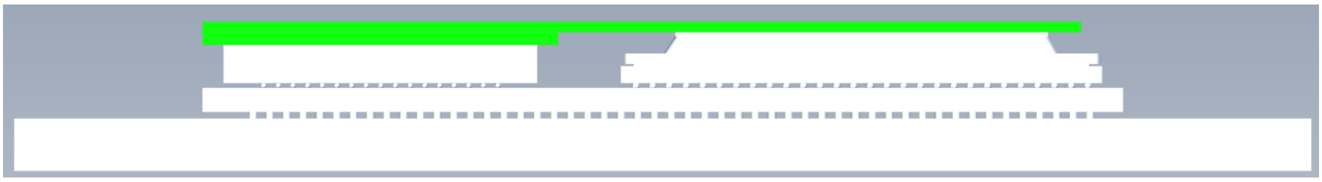

Figure 3-2: Side view of cooling plate to compensate for height difference.

With the cooling plate covering both devices, some thermal simulations have been realized to help customers size their cooling system. Simulations have been performed with a power consumption of 10, 15, and 20W on the LS1046-Space processor. For the DDR4, the simulations were performed for a power consumption of 1.5W. In the simulations, the heat was applied at the dies locations as shown on the figure below:

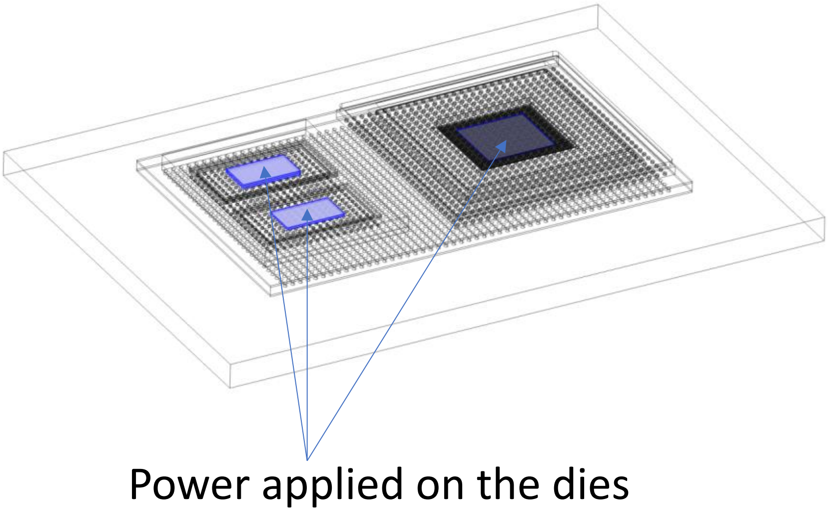

Figure 3-3: Locations where the heat has been applied in simulations.

The operating temperature applied on the PCB on which the QLS1046-Space is installed is set to 60°C or 80°C during the simulations. The operating temperature is set on the edges of the board:

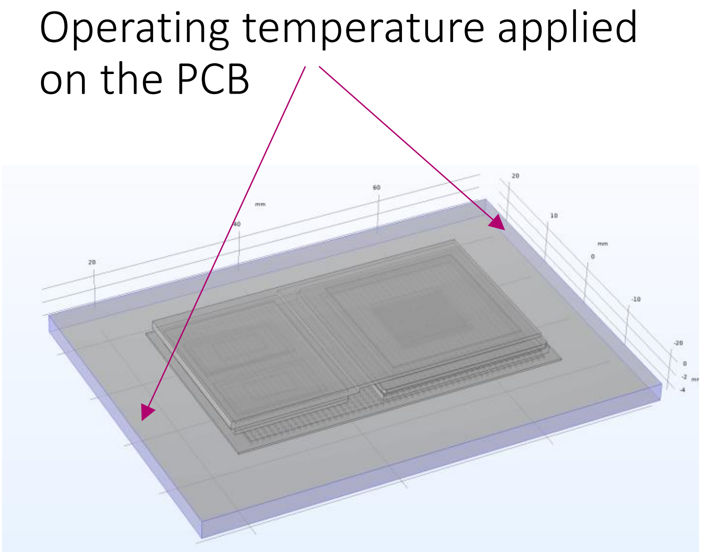

Figure 3-4: Operating temperature is set on the edges of the PCB.

In terms of cooling, a heat transfer coefficient h of 2500 W/m²/K and 3600 W/m²/K, referenced to the ambient temperature, was applied on the thermal plate used as heatsink. This represents the heat dissipation capability of the cooling system, and the equivalent thermal resistances are provided in Table 3-1:

h (W/m²/K)	R_{th} (°C/W)
2500	0.32
3600	0.22

Table 3-1 : Thermal resistance equivalent to the heat transfer coefficient applied in combined cooling.

Figure 3-5 shows where the heat transfer coefficient is applied in the simulations:

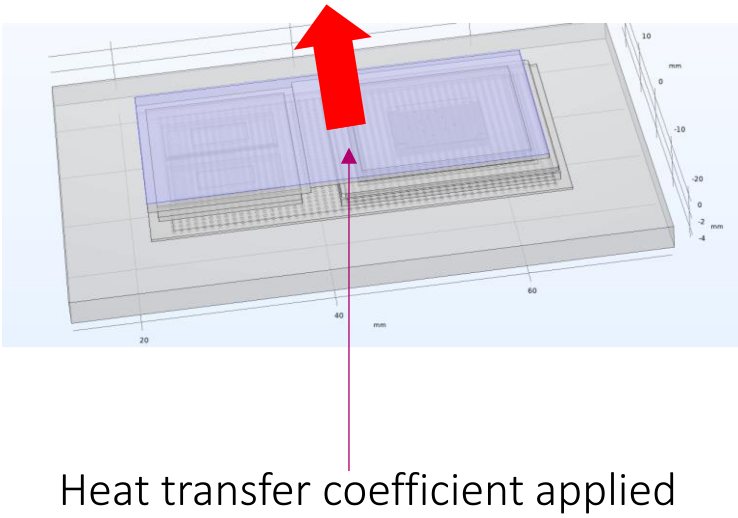

Figure 3-5: Heat transfer coefficient applied on the cooling plate.

The geometrical and thermal parameters used for the analysis are provided in the Table 3-2.

Note: Z axis is perpendicular to the PCB plane, X and Y axis are in the PCB plane.

Material	Thermal conductivity (W/m.K)	Thickness (mm)	Dimensions (mm)
Cooling plate	238	On top of the processor: 1.1mm On top of the DDR4: 0.5mm	42 x 22mm
Thermal Interface Material (Panasonic)	200	0.2mm	Same as the top of the DDR4 and the processor
QLS1046 Substrate	Along X & Y axis: 11 Along Z axis: 5	1.15mm	44 x 26mm
QLS1046 BGA balls	50	0.3mm	1415 x 0.45mm diameter
Simulated PCB	Along X & Y axis: 20 Along Z axis: 3.5	2.5mm	62 x 44mm

Table 3-2: Simulation parameters used in the thermal analysis.

3.1.2 Simulation results

For the combined cooling configuration, twelve thermal simulations were performed to cover the different operating conditions detailed above. The summary of the simulation results is provided in Table 3-3. The simulation N°6 is a worst-case scenario, where the PCB operating temperature is 80°C and the processor consumes 20W of power. The heat transfer coefficient is set to 2500 W/m²/K, to prevent from overheating and keep some safety margin with the maximum junction temperature. In that case, the processor operates at about 110°C, as shown below:

Simulation 6 :

Heat Flux=2500 W/m².K   LS1046 power = 20 W   PCB operating temperature= 80°C

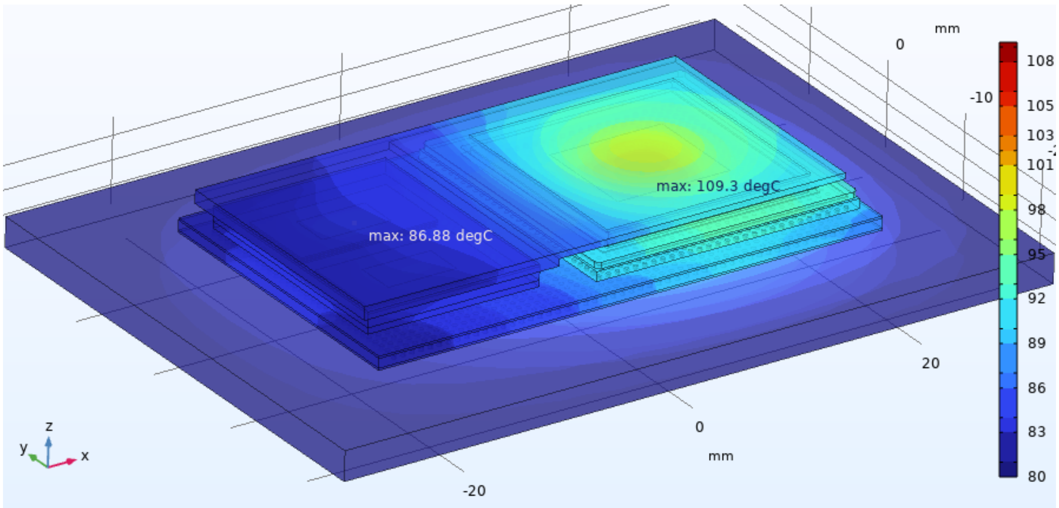

Figure 3-6: Simulation results in worst case scenario.

The summary of all simulations results with combined cooling is provided in the table below:

Case n°	Heat transfer coefficient (W/m²/K)	LS1046 power (W)	PCB operating temperature (°C)	LS1046 junction temperature (°C)	DDR4 junction temperature (°C)
1	2500	10	60	74.7	65.8
2	2500	10	80	94.7	85.7
3	2500	15	60	82.0	66.3
4	2500	15	80	102.0	86.3
5	2500	20	60	89.3	66.9
6	2500	20	80	109.3	86.9
7	3600	10	60	73.2	65.2
8	3600	10	80	93.2	85.1
9	3600	15	60	79.7	65.5
10	3600	15	80	99.7	85.4
11	3600	20	60	86.3	65.8
12	3600	20	80	106.3	85.8

Table 3-3: Results of the thermal simulations in case of combined cooling.

In all simulations performed, the DDR4 junction temperature remains far below the processor junction temperature. This means that in the case of combined cooling, the primary design goal for the heat dissipation is to cool the processor, and consequently the DDR4 will be cooled properly. Simulations also show that a 2500 W/m²/K heat transfer coefficient is sufficient to cool the QLS1046-Space in the worst conditions.

3.2 Separate cooling

3.2.1 Cooling configuration

Separate cooling is the case where a separate cooling plate is used for each device, to cool them independently. For this configuration, the environmental conditions and power consumption taken for the simulations are the same as in the combined cooling configuration. The difference is that the heat transfer coefficient is applied directly on top of each component (see Figure 3-7), without a thermal plate, nor a Thermal Interface Material in between.

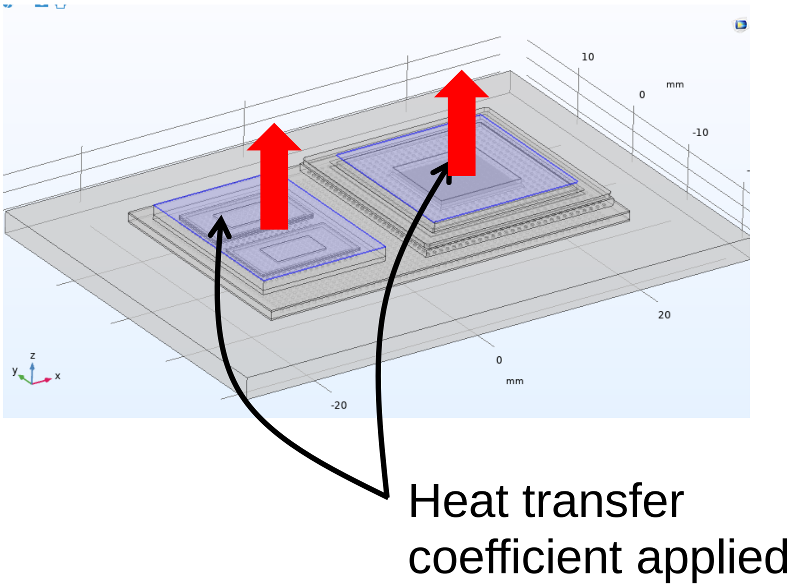

Figure 3-7: Heat transfer coefficient applied on the devices.

In the case of the separate cooling configuration, the equivalent thermal resistances for each device are provided in Table 3-4:

DDR4	
h (W/m²/K)	R_{th} (°C/W)
2500	1.35
3600	0.93
LS1046	
h (W/m²/K)	R_{th} (°C/W)
2500	1.26
3600	0.88

Table 3-4 : Thermal resistance equivalent to the heat transfer coefficient applied in separate cooling.

3.2.2 Simulation results

For the separate cooling configuration, the twelve thermal simulations were also performed to cover the different operating conditions. The summary of the simulation results is provided in Table 3-5. The simulation N°6 is a worst-case scenario, where the PCB operating temperature is 80°C and the processor consumes 20W of power. The heat transfer coefficient is set to 2500 W/m²/K, to prevent from overheating and keep some safety margin with the maximum junction temperature. In that case, the processor operates at about 115°C, as shown below:

Simulation 6 :

Heat Flux=2500 W/m².K   LS1046 power = 20 W   PCB operating temperature= 80°C

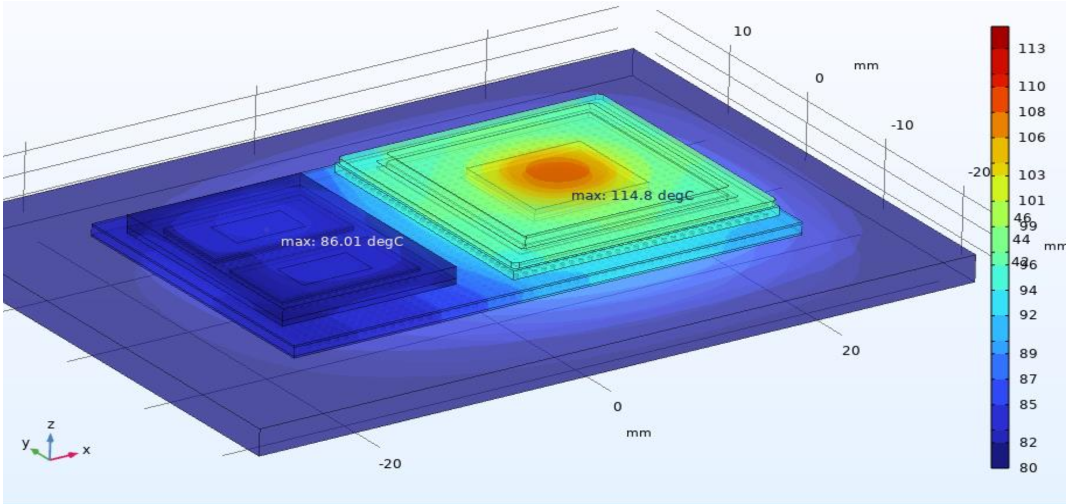

Figure 3-8: Simulation results in worst case scenario.

The summary of all simulations results with separate cooling is provided in the table below:

Case n°	Heat transfer coefficient (W/m²/K)	LS1046 power (W)	PCB operating temperature (°C)	LS1046 junction temperature (°C)	DDR4 junction temperature (°C)
1	2500	10	60	77.4	65.3
2	2500	10	80	97.4	85.3
3	2500	15	60	86.1	65.6
4	2500	15	80	106.1	85.6
5	2500	20	60	94.8	66.0
6	2500	20	80	114.8	86.0
7	3600	10	60	74.8	64.6
8	3600	10	80	94.8	84.6
9	3600	15	60	82.2	64.9
10	3600	15	80	102.2	84.9
11	3600	20	60	89.6	65.1
12	3600	20	80	109.6	85.1

Table 3-5: Results of the thermal simulations in case of separate cooling.

3.3 Processor cooling only

This is the case where the DDR4 doesn't require a heatsink on top of it, meaning that its heat can be dissipated through the PCB. In that case, the heatsink is only required for the processor. It can be verified if the DDR4 requires additional cooling based on the power estimation performed previously and thermal resistance value of the DDR4 package (or thermal model if a finer analysis is preferred). The parameters that can be used to simulate the QLS1046-Space substrate are provided in the Table 3-2.

In that case, the heatsink is sized as if the processor was used in standalone, i.e. the cooling doesn't differ from a regular component in Space.

3.3.1 Cooling configuration

For this configuration, the environmental conditions and power consumption taken for the simulations are the same as in the combined cooling configuration. The difference is that the heat transfer coefficient is applied only on top of the processor (see Figure 3-9), without a thermal plate, nor a Thermal Interface Material in between.

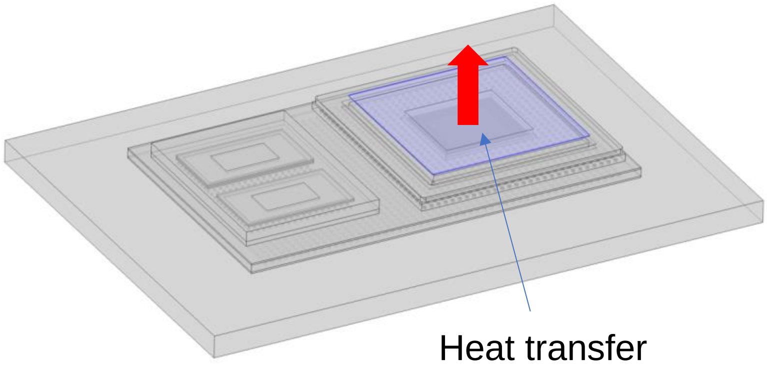

Figure 3-9: Heat transfer coefficient applied on the processor.

3.3.2 Simulation results

For this configuration, the twelve thermal simulations were also performed to cover the different operating conditions. The summary of the simulation results is provided in Table 3-6.

Case n°	Heat transfer coefficient (W/m²/K)	LS1046 power (W)	PCB operating temperature (°C)	LS1046 junction temperature (°C)	DDR4 junction temperature (°C)
1	2500	10	60	77.766	76.6
2	2500	10	80	97.773	96.5
3	2500	15	60	86.464	77.9
4	2500	15	80	106.47	97.7
5	2500	20	60	95.161	79.1
6	2500	20	80	115.17	99.0
7	3600	10	60	75.07	76.0
8	3600	10	80	95.076	95.8
9	3600	15	60	82.467	76.9
10	3600	15	80	102.47	96.8
11	3600	20	60	89.863	77.8
12	3600	20	80	109.87	97.7

Table 3-6: Results of the thermal simulations in case of processor cooling only.

In that configuration, the LS1046 junction temperature is very similar to the separate cooling configuration. The operating junction temperature of the DDR4 memory is significantly higher than in other cases due to the lack of specific cooling, but it remains below 100°C in all cases. It means that for a power consumption of up to 1.5W on the DDR4, it is expected that the heat can be dissipated through the PCB, and no specific cooling is required on top of it.

4. SUMMARY

The different steps to apply for sizing the cooling system for the QLS1046-Space are summarized below:

1) The first step is to estimate the power consumption of the QLS1046-Space, consisting in the power consumption of the DDR4 and of the processor.
2) Based on the power consumption and the environmental conditions, the nearest operating point in the sets of simulations can be found.
3) Then, depending on the maximum desired operating temperature of the device, the required heat transfer coefficient can be determined from:
    a. Table 3-3, if combined cooling is selected,
    b. Table 3-5, if separate cooling is implemented,
    c. Table 3-6, if the DDR4 doesn’t require cooling.
4) Finally, the cooling system should be sized to reach the required heat transfer coefficient, and thermal simulations can be run to validate the design.