Axelera Embedded 113m Thermal Design Guide

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Document revision history

Revision	Date	Description
1 – PRELIMINARY	2026-05-05	First issue
2 – PRELIMINARY	2026-08-03	Rebranded product name.

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1 Introduction and scope

This document provides thermal design considerations, specifications, and recommended solutions to optimize heat dissipation for the Axelera Embedded 113m. It outlines key thermal requirements, passive and active cooling approaches, and integration guidelines for different system configurations. The goal is to assist engineers and system integrators in implementing a robust and efficient cooling solution, ensuring sustained and stable high-performance AI inference.

1.1 Recommended reading

The Axelera Embedded 113m has a single Axelera AI Metis AIPU (AI Processing Unit) chip and dedicated LPDDR4X memory. It is designed to provide AI inference acceleration in a system with an M.2 card socket, also known as Next Generation Form Factor (NGFF) socket.

In order to integrate the Axelera Embedded 113m, the following steps are recommended:

- **Review** the *Axelera Embedded 113m Datasheet* and the provided 3D model to verify that your system is compatible with the Axelera Embedded 113m.
- **Read and understand this document**: *Axelera Embedded 113m Thermal Design Guide*.
- **Implement the appropriate thermal solution** based on the information provided in this document to ensure component temperatures remain below the limits in *Table 2: Critical component list for heat generation*.

1.2 Glossary

Term	Definition
AIPU	AI Processing Unit
AL	Aluminum
CFM	Cubic Feet per Minute
FR4	Flame Retardant 4. FR4 is a type of glass epoxy used in the Axelera Embedded 113m PCB
LPDDR	Low Power Double Data Rate. Type of memory used in the Metis AIPU
NGFF	Next Generation Form Factor. Former name for the M.2 expansion card
PC	Polycarbonate, when used in the context of Thermal Interface Materials
PVT	Process, Voltage, Temperature
RP2040	A model of Raspberry Pi microcontroller
SoC	System-on-Chip
TIM	Thermal Interface Materials

2 About the Axelera Embedded 113m

The Axelera Embedded 113m generates heat during operation, necessitating an effective thermal management solution to maintain performance, reliability, and longevity. Proper thermal design is crucial to preventing thermal throttling, performance degradation, or even hardware shutdown under extreme conditions.

Table 1 provides some key thermal and operational specifications of the Axelera Embedded 113m. For full specification details, refer to the *Axelera Embedded 113m Datasheet*.

Table 1: Key thermal and operational specifications of the Axelera Embedded 113m

Specification	Description
Operating Temperature	-20 to 70 °C
Thermal Solution	Options[1]: • **Active cooling** - Axelera supplied heatsink with a blower fan • **Passive cooling, embedded** - fanless system with aluminum heat spreader (not supplied by Axelera)
Typical Power	3.5 – 11.55 W[2]

[1] *Additional options will be proposed in future revisions of this document*
[2] *11 W is the default maximum power setting. The maximum power configuration can be lowered or raised via software commands.*

3 Metis AIPU characteristics and protection

The Axelera Embedded 113m features one Axelera AI Metis AIPU system-on-chip (SoC).

3.1 Metis AIPU characteristics

The Metis AIPU has the following characteristics:

Symbol	Definition	Recommended maximum value	Absolute maximum value
Tj	Junction temperature	105°C[3]	125°C

Symbol	Definition	Value
θjc	Junction-to-case thermal resistance	0.22°C/W

3.2 Thermal throttling and thermal safety

The Metis AIPU has the following features:

- A closed power control loop can be enabled by software to control the maximum average power used by the board. It is configured by default to 11W
- Throttling mechanisms that can be used to reduce power dissipation by controlling peak performance.
- Thermal protection mechanisms to prevent damage to the chip.

These mechanisms include both software and hardware protections and they activate according to temperature thresholds. The mechanisms are triggered based on temperature data read from PVT sensors (process, voltage, and temperature sensors), placed across key areas of the chip as board-level sensors.

Refer to https://docs.axelera.ai/sdk/user-guides/thermal for more details.

[3] *Axelera recommended value to guarantee operating lifetime.*

4 Thermal characteristics of Axelera Embedded 113m

The Axelera Embedded 113m is designed with a system-level thermal solution to efficiently dissipate heat generated during high-performance AI inference workloads. The primary heat dissipation path is through the top surface of the AIPU, where it can be conducted to a heatsink or other cooling solution. Additional heat is also generated and dissipated by other key active components, including the LPDDR, the MPM3896-30 and MP5479 voltage regulators, and the PCB board itself.

While these secondary heat paths contribute to overall thermal management, the majority of heat is dissipated from the AIPU to the top surface. For this reason, an optimized thermal solution must focus on effective heat transfer from the AIPU to ambient air through a properly designed cooling system.

4.1 Power distribution and heat dissipation considerations

The power consumption of the Axelera Embedded 113m varies depending on the workload distribution across the AIPU, LPDDR, and voltage regulators. Efficient thermal management depends on ensuring proper heat spreading across these components to avoid localized hotspots.

To achieve optimal thermal performance, the following considerations must be considered:

- **AIPU (primary heat source)**: Most of the heat is generated by the AIPU and must be dissipated efficiently through a direct heatsink or a passive heat conduction system.
- **LPDDR memory**: Although it generates less heat than the AIPU, the LPDDR memory still contributes to thermal load and should be included in thermal analysis.
- **Voltage regulators (MPM3896-30 and MP5479)**: These components add to the overall power dissipation and should be considered when designing heat dissipation solutions.
- **PCB board heat transfer**: Some heat is transferred through the PCB, this is a secondary path and should not be the sole cooling mechanism.

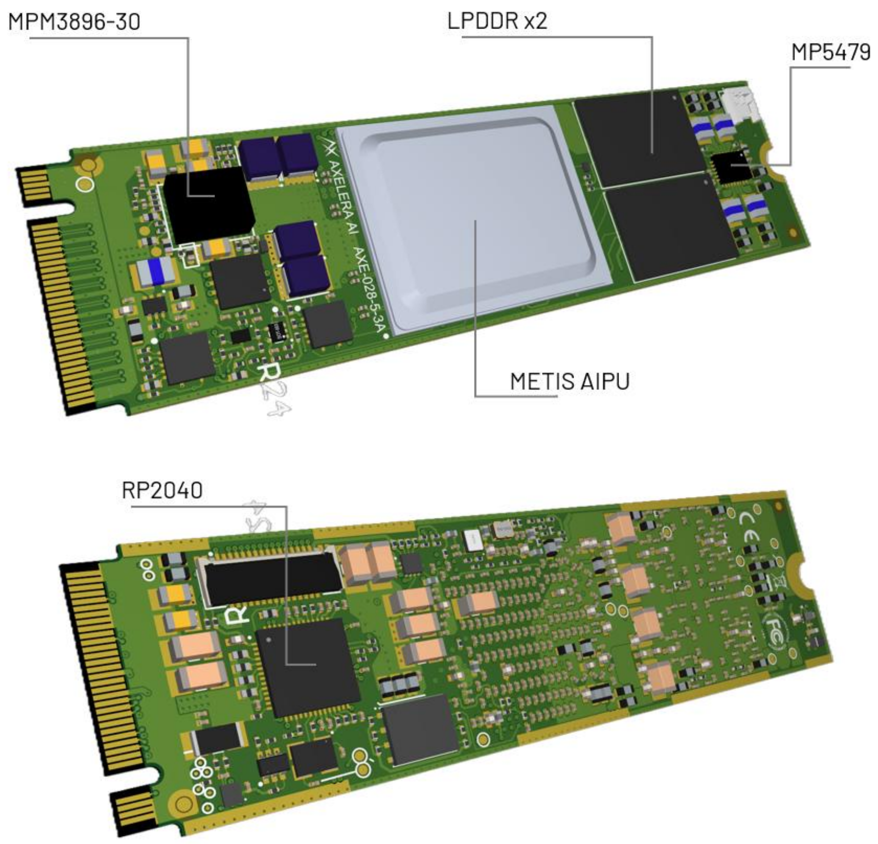


Figure 1: Critical components for heat generation - placement on the Axelera Embedded 113m

Table 2: Critical component list for heat generation

Axelera Embedded 113m: Key components	Power consumption (W)	Thermal resistance value (°C/W)	Allowable max. temperature (°C)
Metis AIPU	1.9-10.30 W[4]	$R_{J\text{-}C}$ =0.22 / $R_{J\text{-}B}$=2.86 / $R_{J\text{-}A}$=8.97	105 (Tj)[5]
LPDDR[6]	1.1 W (0.55Wx2)	$R_{J\text{-}B}$= 7.6 / $R_{J\text{-}A}$= 16.9	95 (Tc)
MPM3896-30	1.32 W	$R_{J\text{-}C}$ =5,4 / $R_{J\text{-}B}$= 31,8	125 (Tj)
MP5479	0.78 W	$R_{J\text{-}A}$ =44 / $R_{C\text{-}B}$= 9	125 (Tj)

NOTE: Tj = junction temperature and Tc = case temperature.

[4] *Power consumption depends on the specific scenario and neural network at different ambient temperatures.*
[5] *This is recommended by Axelera AI as the maximum working temperature to guarantee the operating lifetime.*
[6] *Approximate values for LPDDR.*

4.2 Thermal resistance model

The thermal behavior of the Axelera Embedded 113m can be represented using a thermal resistance network, similar to other electronic systems. The *junction temperature* (Tj) is related to the *ambient temperature* (Ta) through the following equation:

$$T_j = T_A + (R_{Total} \times P)$$

$$R_{Total} = R_{j-c} + R_{TIM} + R_{Heatsink}$$

Parameters:

- **T**j = Metis AIPU junction temperature
- **T**A = Ambient air temperature
- **P** = Power dissipated by the module
- **R** (j-c) = Thermal resistance from junction to AIPU package top surface
- **R** (TIM) = Thermal resistance of TIM (thermal interface materials). This depends on the thermal selection of the material of TIM. For details, see *Table 5: Suggested thermal interface material*.
- **R** (Heatsink) = Thermal resistance of Heatsink (depends on the thermal selection of the material and the heatsink design and the ambient flow rates. For details, see section 5 *Thermal solution options for the Axelera Embedded 113m*.

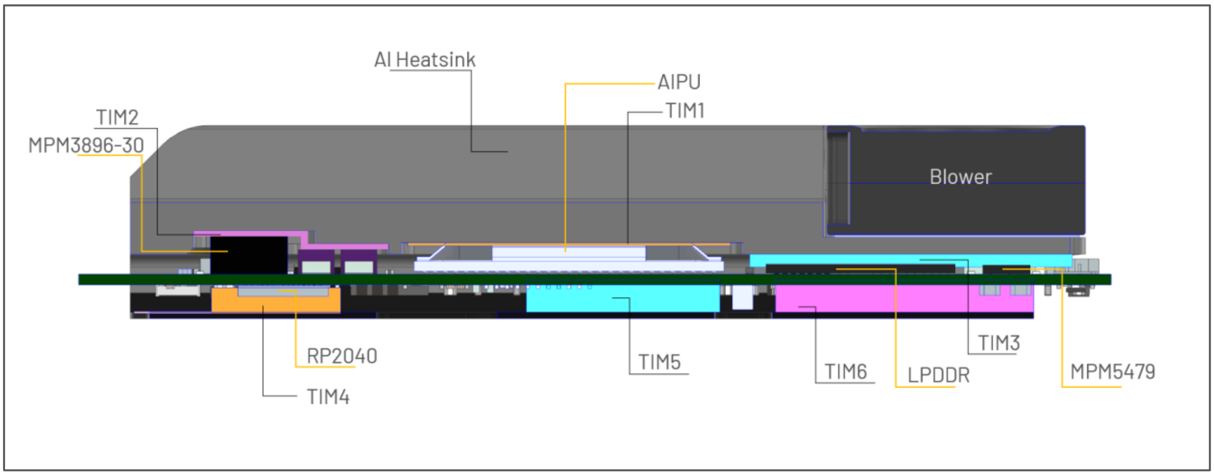


Figure 2: Stack-up of Axelera Embedded 113m (cross-section of Al Heatsink Solution with TIM materials)

The thermal resistance network of the AIPU to ambient is shown in Figure 3. The network diagram is the same as for the other critical heat generated components.

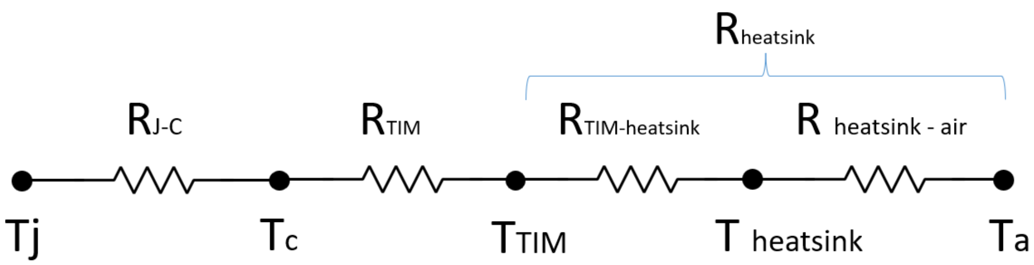


Figure 3: Axelera Embedded 113m thermal resistance network diagram

According to the thermal specifications that are defined in the *Table 2: Critical component list for heat generation*, junction temperatures can be calculated. See the following example.

Example Case: Thermal calculations

This example is for the Metis AIPU chip with the given thermal resistance values.

In this example, using a 0.5 mm-thick thermal pad with a thermal conductivity of 9 W/mK between the chip and an aluminum heatsink, we need to determine the appropriate heatsink selection. Given a power consumption of 6 W and a requirement to keep the junction temperature below 105°C, we must calculate the necessary thermal resistance of the aluminum heatsink to ensure proper cooling. The air flow assumed to be constant as max. 0.5 m/s, such as in a closed system structure.

Parameters:

- $\mathbf{T}_j$ = Junction temperature of the Metis AIPU
- $\mathbf{T}_a$ = Ambient temperature
- **P** = Power dissipation of the AIPU
- $\mathbf{R}_{Heatsink}$ = Thermal resistance from the Heatsink (to be calculated)
- $\mathbf{R}_{j\text{-}c}$ = Thermal resistance of AIPU junction to case
- $\mathbf{k}_{TIM}$ = Thermal Conductivity of TIM
- $\mathbf{R}_{TIM}$ = Thermal Resistance value of the TIM material (to be calculated)
- $\mathbf{t}_{TIM}$ = TIM material thickness
- $\mathbf{A}_{TIM}$ = Area of the Thermal Pad

Example case:

- $\mathbf{T}_a$ = 70°C
- $\mathbf{T}_j$ = 105°C (with reference to allowable AIPU junction temperature)
- **P** = 6 W
- $\mathbf{R}_{j\text{-}c}$ = 0.22°C/W
- $\mathbf{k}_{TIM}$= 9 W/mK
- $\mathbf{t}_{TIM}$ = 0.5 mm = 0.0005 m
- $\mathbf{A}_{TIM}$ = 20x24 mm = 0.00048 m^2

Establish Thermal Resistance Path:

Since we are using an aluminum heatsink on top of the chip with a thermal pad, the primary heat flow path is:

Junction → Case → TIM → Heatsink → Air

The total thermal resistance $\mathbf{R}_{total}$ must satisfy the temperature requirement:

$$R_{total} = \frac{T_j - T_A}{P} \tag{1}$$

To ensure **Tj ≤ 105°C** with **Ta = 70°C**:

$$R_{Total} = \frac{105 - 70}{6} = 5.83\ ℃/W$$

Which means; the total system resistance should not be more than 5.83°C/W to keep the AIPU temperature under 105°C at 70°C ambient.

Thermal Pad Resistance (RTIM):

$$R_{TIM} = \frac{t}{K * A} \tag{2}$$

$$R_{TIM} = \frac{0.0005}{9 \times 0.00048} = 0.116\ ℃/W$$

To choose the correct heatsink, we can calculate the required heatsink thermal resistance:

$$R_{total} = R_{j-c} + R_{TIM} + R_{heatsink} \tag{3}$$

$$5.83 = 0.22 + 0.116 + R_{heatsink}$$

$$R_{heatsink} = 5.83\ - 0.22 - 0.116$$

$$R_{heatsink} = 5.49\ ℃/W$$

If a similar heatsink is used, a thermal resistance **≤ 5.49°C/W** is required to keep the AIPU temperature within safe limits and the system can safely dissipate up to 6 W without exceeding thermal limits at 70°C ambient temperature.

If the power increased to 10 W, then the equation for total system resistance, (1), becomes:

$$R_{Total} = \frac{105 - 70}{10} = 3.5\ ℃/W$$

To choose the correct heatsink, we can calculate the required heatsink thermal resistance, according to equation (3):

$$R_{heatsnk} = 3.5\ - 0.22 - 0.116$$

$$R_{heatsnk} = 3.16\ ℃/W$$

If a heatsink is used with a thermal resistance **≤ 3.16°C/W**, the system can safely dissipate up to 10 W without exceeding thermal limits. In this kind of case, Axelera AI recommends active cooling solutions or an additional cooling plate that is attached to top of the "Axelera Heat Spreader" in the system. For more information please refer to section 5 *Thermal solution options for the Axelera Embedded 113m*.

NOTE: *Heatsink selection must be considered carefully when configuring system power. This example only considers AIPU heat dissipation as the main heat source in the system. Therefore, please also take into account other heat sources in the system to ensure a proper selection. Refer to Table 2: Critical component list for heat generation* to keep the system within safe limits.

5 Thermal solution options for the Axelera Embedded 113m

To prevent the Metis AIPU from reaching critical operating temperatures, several thermal management solutions are proposed to ensure optimal performance and reliability. The design goal of the different solutions is to keep the chip and the critical component's junction temperature within the specified range.

5.1 Axelera Embedded 113m active cooling solution – aluminum heatsink with fan

In this configuration, the Axelera Embedded 113m active cooling solution consists of an aluminum heatsink cooled with forced air from a fan. It is suitable for the following scenarios:

- The M.2 slot area has enough height clearance for proper fan air flow : 50 mm from the board surface to upper surface.
- The host systems may or may not have forced airflow.
- With forced airflow (2 m/s), it is suitable for high-power workloads up to 15 W at 70°C ambient.
- Can tolerate noise level of fan: ≈34.8 dB *(measured at 1 m, fan flow 0.80 CFM).*

Figure 4: Axelera Embedded 113m active cooling solution (heatsink with blower fan forced air)

Table 3: Product specifications for the Axelera Embedded 113m active cooling solution

Part name	Total Length (w-card / Heatsink-only)(mm)	Height to top of the heatsink (mm)	Width (mm)	Weight (g)	Thermal Resistance Values (Under constant air flow ≤0.5 m/s)	Thermal Resistance Values (With additional fan in the system-air flow of 2.0 m/s)	Total Cooling Capacity (W)[7]
Active cooling	80 / 74	15	25	40	~ 3.1(°C/W)	~ 2.1(°C/W)	10.5 to 15.0

For more information on dimensions, please refer to the document *Axelera Embedded 113mDatasheet*.

Parts list for the Axelera Embedded 113m active cooling solution

The Axelera Embedded 113m active cooling solution consists of the following parts, as shown in Table 4.

Table 4: Parts list for the Axelera Embedded 113m active cooling solution

Part name	Material type	Material Info	Quantity
Axelera Embedded 113m	FR4	0.8 mm thickness	1
AL heatsink	Aluminum-Black Anodized RAL9005	AL6000	1
Fan (blower) 3.3 V	PBT (UL94 V0)	0.80 CFM air flow	1
Screw	M2 x 5 mm	n/a	4
Bracket bottom	Sheetmetal SUS301 / Black coating	0.5 mm	1
Thermal pad-TIM	Refer to Table 5	0.5 – 2.5 mm	6
Adhesive tape	Tesa 4965 (adhesive tape)	0.20 mm	1
Isolation Plate-Mylar	PET- Electrical Insulation Layer	0.20 mm	1

For the thermal pads (TIM) in the system, thermal values are as shown in Table 5.

[7] Cooling Capacity defined as to prevent reaching Tj=105℃ (Thermal Throttling limit) at 70℃ ambient temperature.

Table 5: Suggested thermal interface materials (TIM)

Axelera Embedded 113m key thermal components	Material type	Material thickness (mm)	Thermal conductivity coefficient value (k= W/mK)
TIM1 / AIPU	Thermal Grease - PTM7950	0.40 mm (±0.1)	8.5
TIM2 / VRM	Thermal Conductive Silicone	0.50 mm	3.0
TIM3 / LPDDR	Thermal Conductive Silicone	1.00 mm	3.0
TIM4 / RP2040	Thermal Conductive Silicone	2.00 mm	3.0
TIM5 /AIPU(BACK)	Thermal Conductive Silicone	2.50 mm	3.0
TIM6 / LPDDR (BACK)	Thermal Conductive Silicone	2.50 mm	3.0

Refer also to *Figure 2: Stack-up of Axelera Embedded 113m (cross-section of Al Heatsink Solution with TIM materials).*

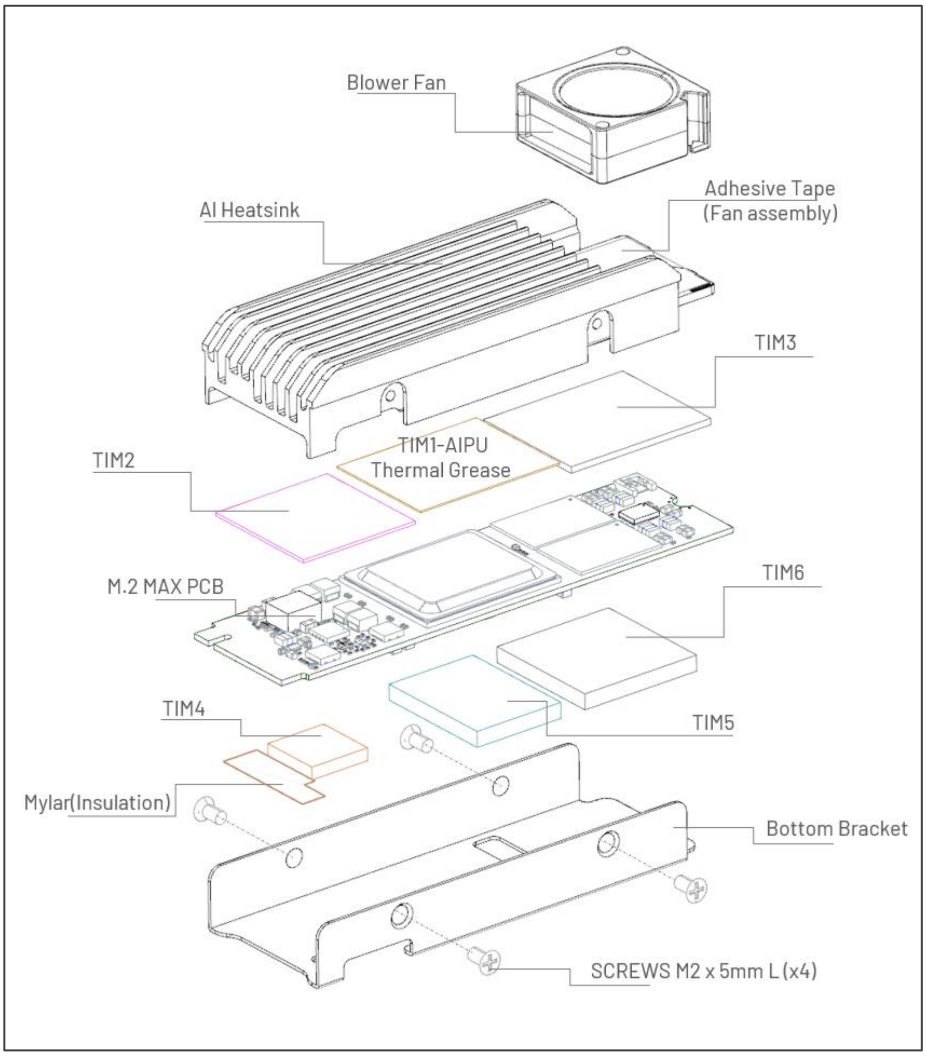
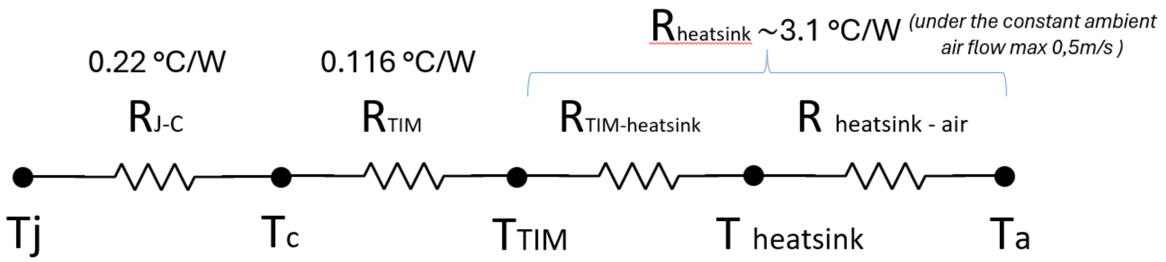


Figure 5: Exploded view of the active cooling solution

5.1.1 *Axelera Embedded 113m active cooling solution – cooling capacity*

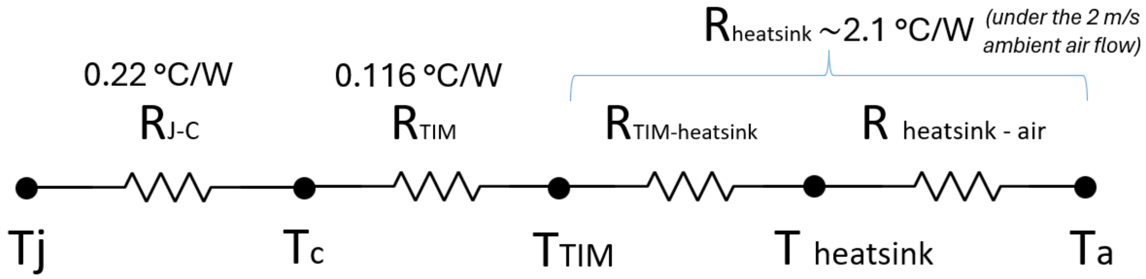
In this configuration, the Axelera Embedded 113m active cooling solution is fixed in a closed structure that allows free air ventilation for the fan to operate effectively. When the inside air flow is less than 0.5 m/s, the heatsink resistance value is assumed to be around 3.1°C/W.

Under these conditions, considering the TIM materials (refer to Table 5: Suggested thermal interface materials) and the Metis junction to case resistance (0.22°C/W) the total resistance is ~3.4°C/W, with the thermal path shown below:



External fan conditions:

If the open frame structure has an internal fan and the air flow rate is a minimum of 2 m/s, it is possible to reduce the heatsink resistance values to around 2.1°C/W. In this case, the total resistance will be 2.4°C/W and the thermal path is given from the following:



According to that configuration, the Axelera Embedded 113m active cooling solution can reach 10.5 W (at 70°C, at 0.5m/s natural air flow) or up to 15.0 W (at 70°C at 2 m/s forced air flow) cooling capacity. See Figure 6.

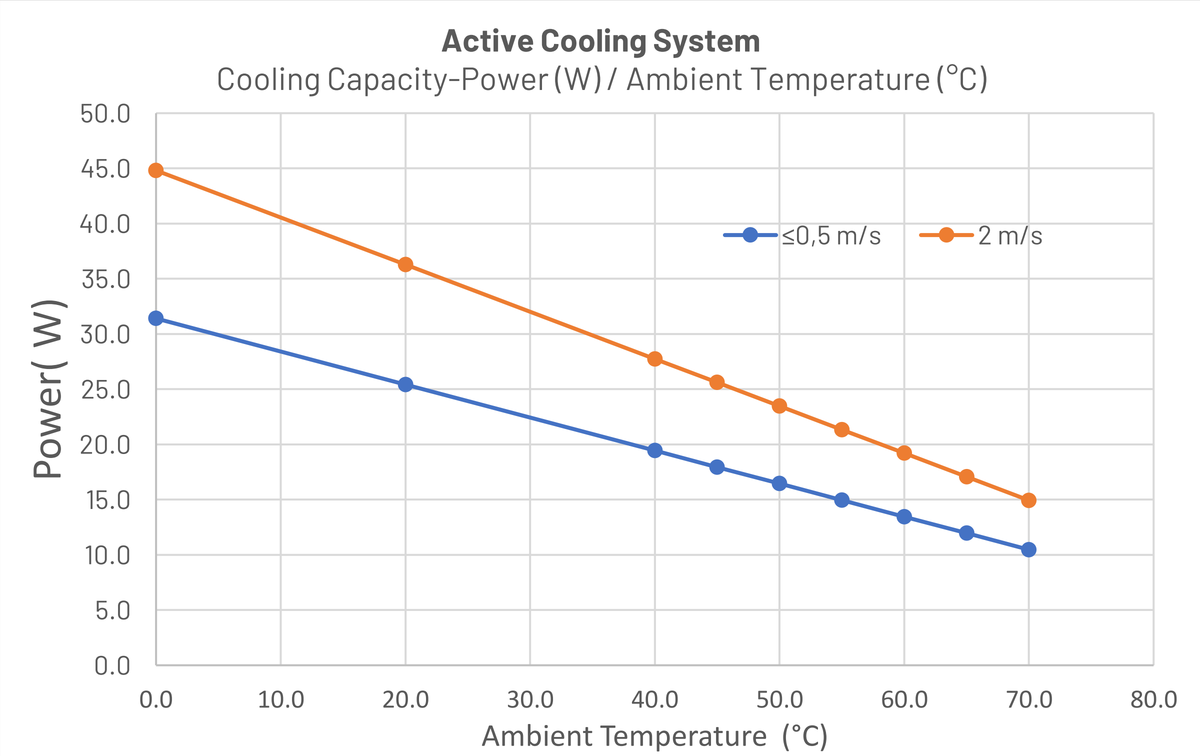


Figure 6: Cooling capacity of active cooling solution in different ambient temperatures and different airflows at ambient airflow rate (max 0.5 m/s) and 2 m/s airflow rate

5.2 Axelera Embedded 113m passive cooling solution - embedded heat spreader

A passive cooling solution with an embedded aluminum heat spreader is recommended for fanless embedded systems with space constraints.

NOTE: Axelera does not supply this heat spreader - system integrators design and build their own, using the material list, thermal specifications, and cooling capacity data in this section as reference.

The solution has the following characteristics:

- In embedded systems, if there is a space between the main heatsink and the M.2 board, an aluminum heat spreader solution can be used as a heat transfer component from the M.2 board to the external enclosure.
- Provides efficient heat dissipation for compact and fanless designs.
- Suitable for lower-power applications in space-constrained designs - overall height as low as 12 mm (the total module height of 6 mm from top of the Metis AIPU).

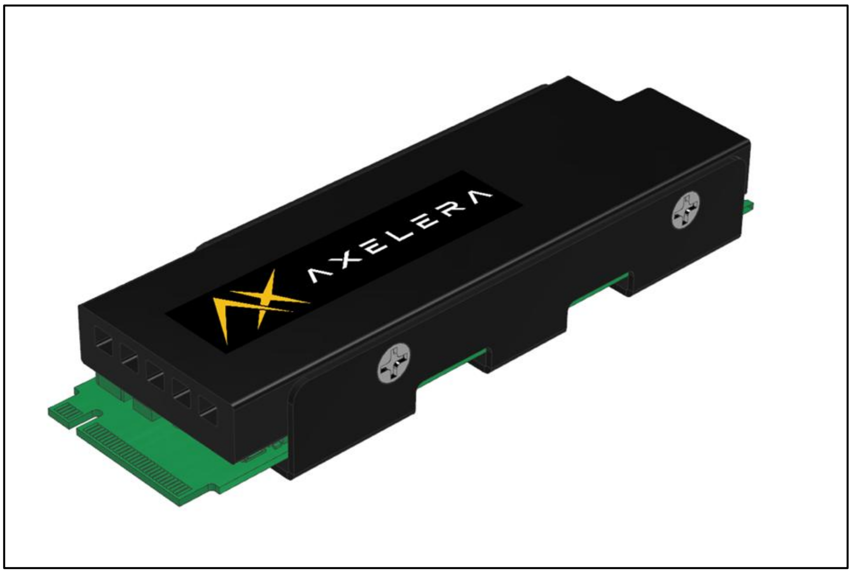


Figure 7: Rendering of the Axelera Embedded 113m with an example heat spreader. Heat spreader not supplied by Axelera.

Figure 8: Example of a fanless embedded system

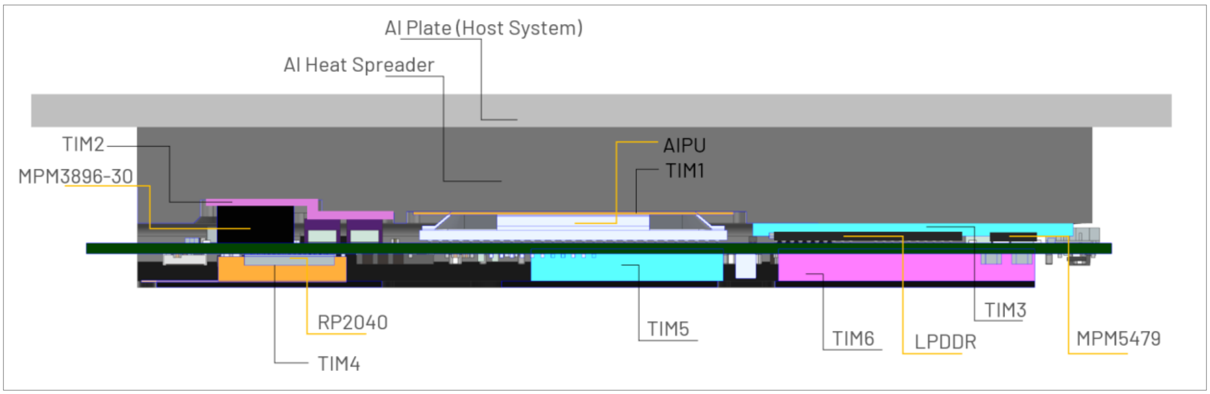


Figure 9: Stack-up of the Axelera Embedded 113m passive cooling solution showing the heat spreader in an Embedded System

The thermal values for the standalone configuration and for use with an additional cooling plate are shown below.

Table 6: Product specifications of M.2 passive cooling solution with embedded heat spreader

Part name	Total Length (w-card/ Heatsink-only) (mm)	Height to top of the heatsink (mm)	Width (mm)	Weight (g)	Thermal Resistance Values		Total Cooling Capacity (W)
					Standalone	With 250x250 mm, 2 mm thick Al Cooling Plate [8]	
Heat spreader / Passive cooling	80 / 72.5	10	25	25	~ 13.5 (°C/W) (under forced air flow of 3 m/s)	~ 3.0 (°C/W) (constant Air flow of max 0.5 m/s)	2.5 to 10.5

Parts List for the Axelera Embedded 113m passive-embedded cooling solution

A reference parts list for designing the passive cooling solution is shown in Table 7.

Table 7: Reference parts list for a passive cooling solution with embedded aluminum heat spreader

Part name	Material type	Material Info	Quantity
Axelera Embedded 113m	FR4	0.8 mm thickness	1
AL heatsink	Aluminum-Black Anodized RAL9005	AL6000	1
Screw	M2 x 5 mm	n/a	4
Bracket bottom	Sheetmetal SUS301 / Black coating	0,5 mm	1
Thermal pad-TIM	Refer to Table 5.	0.5 - 2.5 mm	6
Isolation Plate-Mylar	PET-Electrical Insulation Layer	0.20 mm	1

5.2.1 *Passive-embedded solution - cooling capacity reference*

If the embedded structure has an internal fan and the air flow rate is a minimum of 3 m/s, a heat spreader solution is usable under the following ambient temperature. Under these conditions, the total system thermal resistance value will be 13.5°C/W.

To increase power-handling capability, Axelera AI recommends using the heat spreader with an additional aluminum plate (for example an aluminum plate 250x250 mm 2 mm-thick) and fixed with a 1 mm thick, 1.8 W/mK thermal pad. In this assembly configuration, the total resistance

[8] *For the attached cooling plate, a TIM material (1 mm thick, 3 W/mK thermal conductivity) between aluminum heat spreader and cooling plate is considered.*

will be 3.0°C/W under the natural convection conditions (natural convection - maximum air flow 0.5 m/s).

According to test results, an embedded aluminum heat spreader solution can reach 10.5 W (at 70°C) cooling capacity with an additional cooling plate in the embedded system.

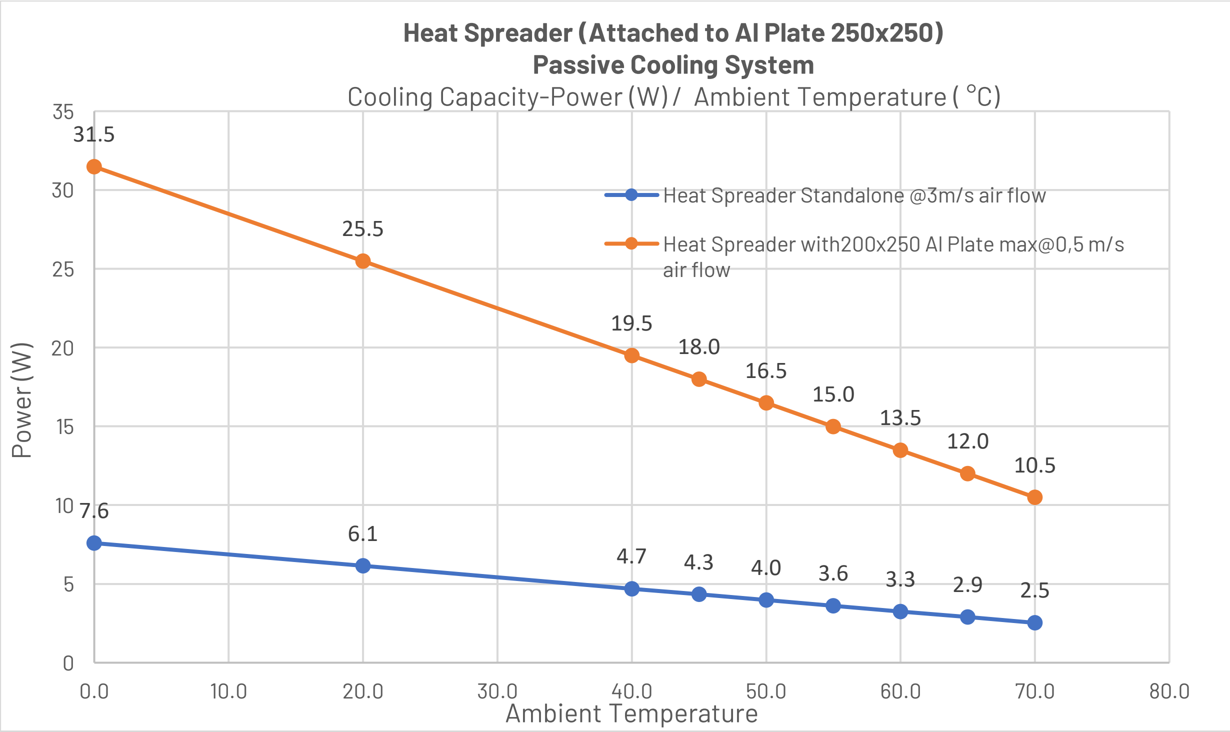


Figure 10: Cooling capacity of heat spreader solution-embedded system solutions in different ambient temperatures

6 Appendix

6.1 3D model documents

Information is provided in the following IGS documents:

- **Axelera Embedded 113m board standalone (no cooling)**
  - Axelera Embedded 113m – no cooling solution
- **Axelera Embedded 113m active cooling solution**
  - Axelera Embedded 113m - active cooling solution

6.2 2D drawings

Please refer to the *Axelera Embedded 113mDatasheet* for 2D drawings of the Axelera Embedded 113m.

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