NVIDIA Jetson TX2 NX

Thermal Design Guide

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Document History

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Version	Date	Description of Change
1.0	February 22, 2021	Initial Release
1.1	February 26, 2021	Updated parameters in Section 3.1.1
1.2	May 11, 2021	Updated Table 3-1

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

This document is the thermal design guide (TDG) for the NVIDIA® Jetson™ TX2 NX (699-13636-xxxx-xxx) product.

The purpose of this thermal design guide is to provide the system-level thermal, mechanical, and qualification requirements for the Jetson TX2 NX.

Refer to the Jetson TX2 NX module data sheet for detailed drawing and module dimensions.

1.1 Customer Requirements

The customer requirements are as follows:

- Customers are responsible for reading and understanding this entire thermal design guide.
- Customers are responsible for implementing a thermal solution. It maintains the NVIDIA® Tegra® X2 temperatures below the specified temperatures in Table 2-1 under the maximum thermal load and system conditions for their use case.
- Customers are responsible for designing a system that delivers enough power to the Jetson TX2 NX to sustain the maximum thermal load for their use case.
- Customers are responsible for qualification of the Jetson TX2 NX in their system. They are also responsible for any issues related to failure to qualify the product properly.

1.2 Definitions

This section describes terminology that will be referenced throughout this thermal design guide.

1.2.1 Total Module Power

The total module power (TMP) represents the average board power dissipation while the system is running the target workload under the worst-case conditions in steady state. System designs must be capable of providing enough cooling for the Jetson TX2 NX when operating at the TMP level.

1.2.2 Jetson TX2 NX

Figure 1-1 provides a topside view of the Jetson TX2 NX while Figure 1-2 provides the backside view.

Figure 1-1. Jetson TX2 NX–Topside View

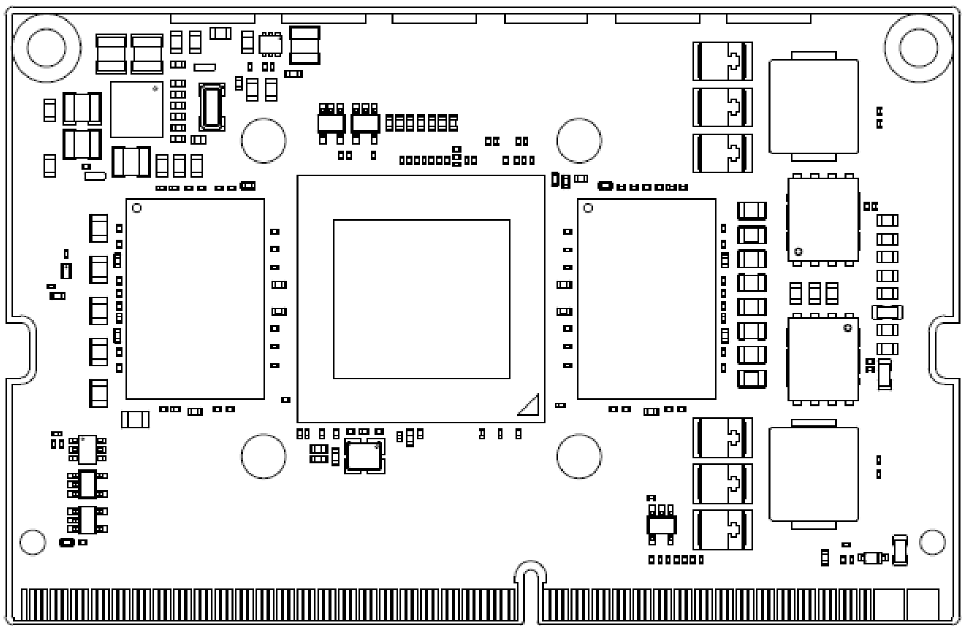
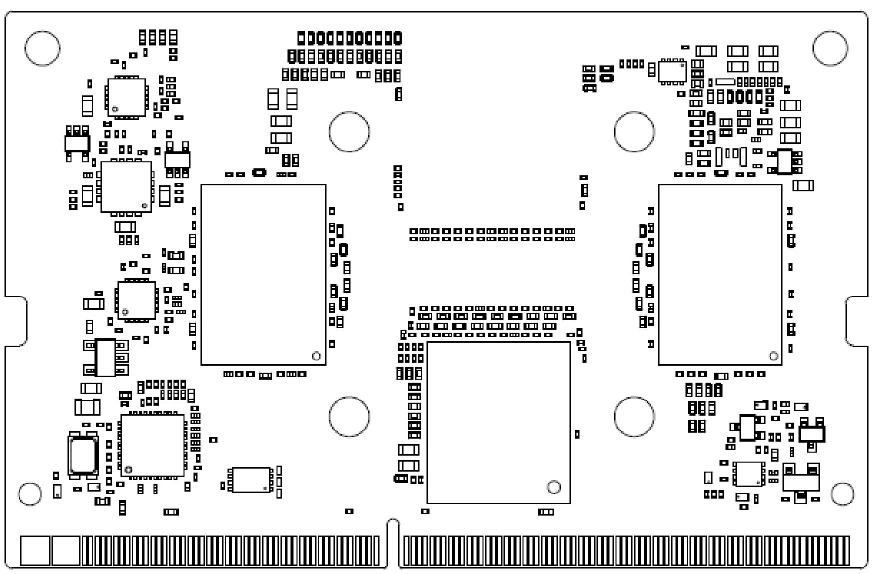


Figure 1-2. Jetson TX2 NX–Backside View



The thermal solution of the customer's system design should attach to the module directly. Mounting holes are provided on the PCB to enable attachment of the customer's thermal solution. More details are provided in Section 3.2 "Mechanical Information." Customer's system thermal solution must provide adequate cooling to maintain all the components on the PCB. This includes the Tegra X2 below the maximum temperature specifications as detailed in Section 2.1 and Section 3.1.

1.2.3 Tegra X2 Temperature

The Tegra X2 junction temperature (T_j) represents the Tegra X2 die temperature read from any of the on-die temperature sensors. The on-die temperature sensors are used for high-temperature T_j management and many other temperature-dependent functions. Details regarding the software thermal mechanisms are described in Chapter 5.

Chapter 2. Specifications

2.1 Thermal Specifications

On Tegra X2, there are multiple on-die temperature sensors that are placed close to dominant hotspots for high accuracy measurements of junction temperature. A built-in hardware controller is used to read the sensors and engage thermal protection mechanisms. Chapter 5 contains the details related to these sensors and the associated thermal protection mechanisms. The specifications in Table 2-1 must be followed to maintain the performance and reliability of the Jetson TX2 NX module.

Table 2-1. Jetson TX2 NX Thermal Specifications

Parameter	Value	Units
Maximum Tegra X2 operating temperature[1]	T.cpu = 95.5	°C
	T.gpu[3] = 95.5	°C
Tegra X2 shutdown temperature[2]	T.cpu = 101	°C
	T.gpu = 101	°C

Notes:

[1]The Tegra X2 recommended that operating temperature limit is the temperature threshold below which the product will operate at the specified clock speeds. Software will apply clock speed reductions once this temperature is reached. These temperature sensors have an accuracy of ±3 °C. Note that power fluctuations that induce T_j fluctuations above these thresholds will cause temporary clock reductions. See Section 5.3 for details.

[2]The Tegra X2 will shut down the Jetson TX2 NX module once any of these software-imposed temperature limits are reached to maintain the reliability of the Tegra X2. See Section 5.5 for details.

[3]The T.gpu temperature is measured by the "ao-therm" sensor.

Chapter 3. Design Guidance

This chapter provides design guidance to meet the Jetson TX2 NX module specifications.

3.1 Thermal Information

The design goal for system thermal management is to keep the Tegra X2 temperature below the limits specified in Section 2.1.

3.1.1 Jetson TX2 NX Thermal Performance

The Jetson TX2 NX module is not equipped with a system level thermal solution to dissipate the TMP thermal load into the ambient environment. It is the customer's responsibility to design an adequate thermal solution to maintain all the component temperatures below the de-rated limits as specified in Table 3-1. Figure 3-2 provides a map of the component placement on the Jetson TX2 NX PCB as listed in Table 3-1. The thermal resistance network for the system thermal solution can be represented with the following equation:

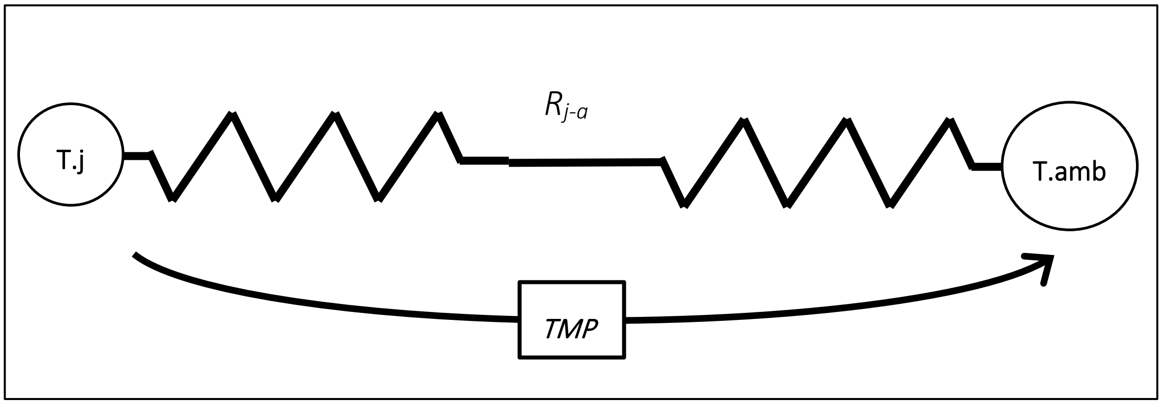
$$R_{1-2} = \frac{T_1 - T_2}{P}$$

Where:

R_{1-2}	The thermal resistance between Point 1 and Point 2
T_n	The temperature at Point *n*
P	The heat load (i.e; dissipated power) transferred between Points 1 and 2

A simple example of a thermal resistance network is shown in Figure 3-1 where R_{j-a} represents the thermal resistance from T_j to the ambient of the system thermal solution. The thermal resistance of the system thermal solution may include multiple components including, but not limited to, thermal interface material (TIM), heat spreaders, and heat sinks.

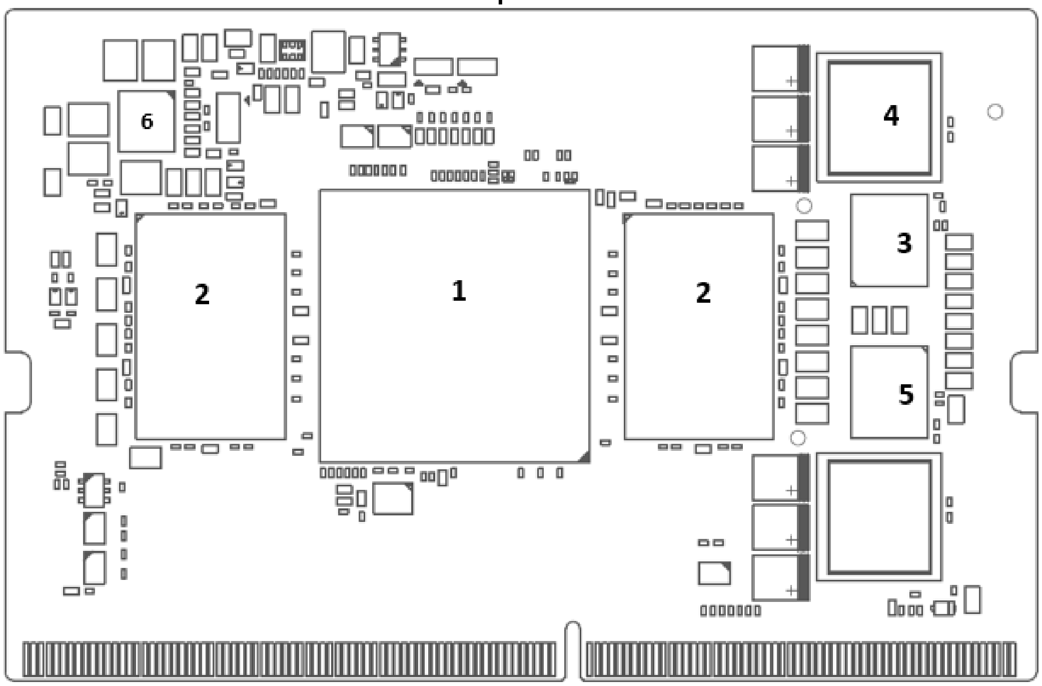
Figure 3-1. Thermal Resistance Network



Jetson TX2 NX enables a wide variety of applications that may exercise different components on the module. The variation between applications will cause variation in heat loads on the different components on the Jetson TX2 NX and hotspots in different logical partitions of the Tegra X2. While the system thermal solution will help to spread the heat and make the thermal performance as consistent as possible, different applications will have different levels of thermal performance. The more evenly the module power is distributed across the Jetson TX2 NX the higher the thermal performance will be.

Figure 3-2. Component Placement Map for Jetson TX2 NX

Top Side



Bottom Side

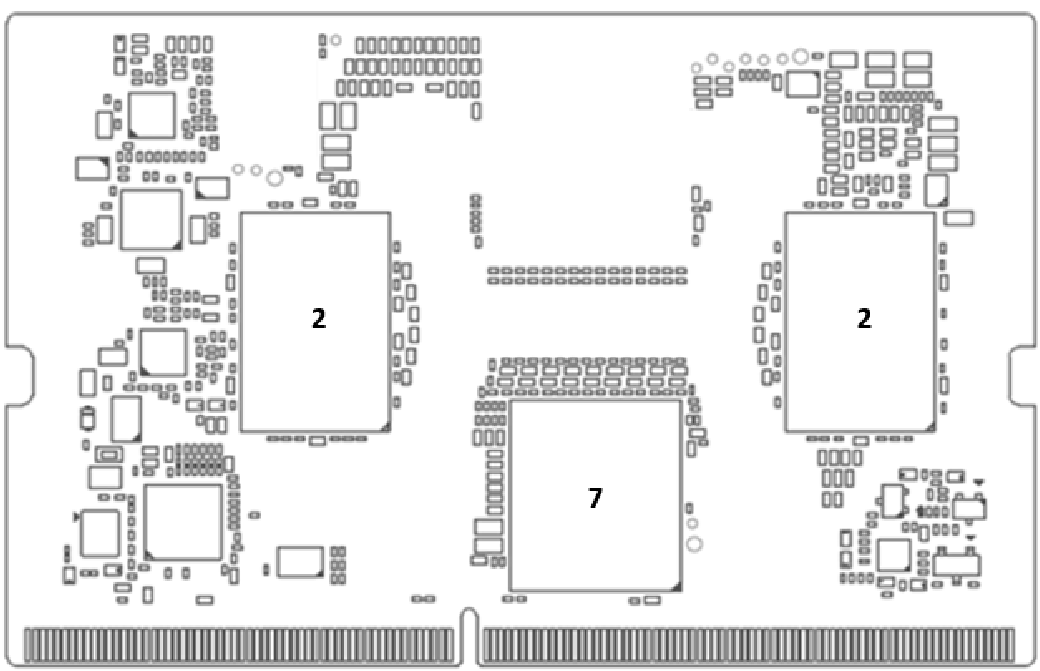


Table 3-1. Jetson TX2 NX Thermal Performance

	Components that will be contacted with thermal solution and need to be monitored
	Components that must be monitored (and can be contacted by thermal solution if required)
	Miscellaneous (can be contacted by thermal solution if required)

					Thermal Specifications			
Comp # on Map	Description	Qty	Design Power (W)	Total Power (W)	R_{j-c} (°C/W)	R_{j-b} (°C/W)	Thermal K Value (W/m°C)	Tcase (°C)
1	TEGRA X2	1		11.00	0.04	1.82		Refer to Table 2-1
2	LPDDR4 Memory	4	0.50	2.00	2.7	12.6		85
3	CPU/GPU/SRAM Dual Package MOSFET	1	0.55	0.55	10.5	6.5		115
4	CPU/GPU/SRAM Inductor	1	0.24	0.24		-	4.5	125
5	SOC Dual Package MOSFET	1	0.17	0.17	10.5	6.5		115
6	PMIC	1	0.48	0.48	2.5	7.0		105
7	eMMC	1	0.64	0.64			0.3	95
				15.08	= Total Dissipated Power			

Notes:

1. For components which do not show R_{j-c} and R_{j-b} values in the table. It should be modeled as a single block with bulk thermal conductivity specified in the table.
2. For PCB thermal properties, use orthogonal thermal conductivity kX=45 W/mK, kY = 45 W/mK and kZ = 1 W/mK.
3. R_{j-c} and R_{j-b} values for TEGRA X2 are based on "Uniform heat loading of die". In practice, the die will be non-uniformly loaded depending on the type of workload running on the die. Designers need to account for adequate margin when designing a thermal solution.
4. For 2R model - Use Die Size = 16 mm × 16 mm × 1.3 mm

The required system thermal performance can be determined based on the ambient temperature conditions and TMP level required by the customer. Consider the following example:

$$T.amb \ = \ 55°C$$

$T.cpu \ = \ 91.5°C$ (Targeting $4°C$ T.cpu headroom to account for sensor inaccuracy and possible T_j fluctuations resulting from workload variation)

$$P_{TMP} \ = \ 10W$$

The heat sink thermal performance requirement for the above conditions.

$$\rightarrow Rj - a \quad = \frac{91.5°C - 55°C}{10W} = 3.65\frac{°C}{W}$$

So, in this example, a 3.65 °C/W thermal solution is expected to be sufficient to maintain the Tegra X2 within the maximum temperature specification as detailed in Table 2-1. In addition to this, the customer is responsible to verify that this thermal solution can maintain all other components of the module within their maximum temperature specifications as detailed in Table 3-1.

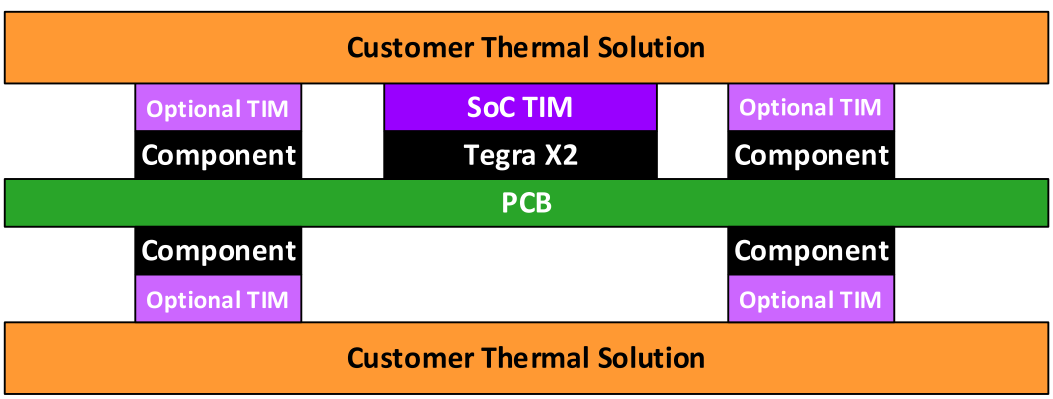
3.1.2 Jetson TX2 NX Thermal Design Details

The customer is responsible for the following items:

- Thermal Solution: A system thermal solution capable of cooling the appropriate amount of TMP for the target workload.
- TIM: The customer is responsible for providing the TIM between the Jetson TX2 NX module and customer's system level thermal solution. For best thermal performance, the TIM should provide low thermal impedance within the mechanical, reliability, and cost constraints of the customer's product.
- Maximum Temperature: To ensure that the maximum Tegra X2 operating temperature is less than the value specified in Table 2-1, and the maximum component temperatures on the PCB must not exceed the value specified in Table 3-1.

Example thermal stack up is shown in Figure 3-3.

Figure 3-3. Thermal Stack-Up Schematic



Note: Components other than the SoC may need to contact the thermal solution. See Section 3.1.3 and Chapter 4 for detailed guidelines and recommended solution.

3.1.3 Customer Thermal Solution

The customer's thermal solution is the mechanical element that interfaces to the Jetson TX2 NX module and provides cooling. A variety of thermal solution configurations are possible depending on the customer's chassis design. In all cases, however, the following recommendations are applicable:

- Good contact of the thermal solution to the Tegra X2 is critical for maximizing the thermal performance of the Jetson TX2 NX. The Tegra X2 consumes the majority of the TMP. The TIM should contact the full SoC surface area that is 12.8 mm × 11.5 mm.
- Customer must determine if system thermal solution needs to contact all or select components on the PCB to make sure that they are maintained within the maximum temperature specifications listed in Table 2-1 and Table 3-1.

3.1.4 Temperature Cycling

Long-term reliability of all solder interconnects is negatively impacted by temperature cycling. It is the customer's responsibility to minimize the component's exposure to temperature cycling and not to exceed what the component is qualified for. The NVIDIA graphics and core logic components are qualified to JEDEC standard JESD47.

> **Note**: NVIDIA recommends that customers refer to JESD94.01 (*Application Specific Qualification Using Knowledge Based Test Methodology*) for more information.

3.2 Mechanical Information

Refer to the *Jetson TX2 NX Module Datasheet* for the exact module dimensions to determine how to interface the module board with the system thermal solution and ensure mechanical compatibility.

3.2.1 Heat Sink Mounting Guidelines

As noted in the thermal section, the mechanical design of the system must ensure good contact between the thermal solution, Tegra X2, and the module board. The module board is provided with mounting holes to accommodate mounting options for a suitable heat sink.

The following guidelines should be followed to ensure good mechanical and thermal contact between the chassis thermal solution and the module board.

- Four holes (Ø 3.2 mm) are provided near the Tegra X2, and two holes (Ø 2.75 mm) on the edge opposite to edge connector.
- All holes are PTH with annular ground pads. These holes can be used for system mount as well as heat sink mount based on individual customer design intents.
- Shoulder screws can be used for all mounting hole locations to prevent thread damaging the board.
- Maximum Pressure on Tegra X2 should not exceed 413 kPa (60 psi).
- Recommended total spring force: 3.63 Kgf (8.0 lbs). Pressure: 241 kPa (35 psi)
- Module board should not bow or bend to cause more than 500 micro-strain within 5mm of the Tegra X2.
- There is a keepout area behind the module board to allow for backplate to support the board while heat sink is mounted from top side.

3.2.2 Assembly Guidelines

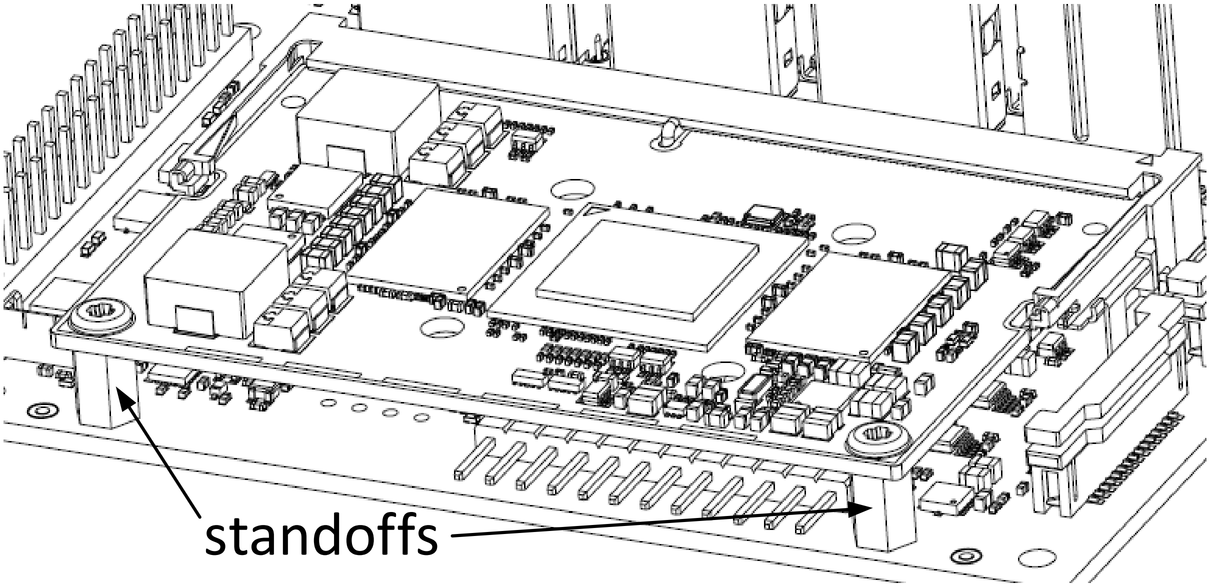
The Jetson TX2 NX comes with JEDEC standard 260 DDR4 SODIMM 0.5MM pitch edge connector and is provided to interface with 260 PIN DDR SODIMM SOCKET WITH 0.5MM PICTH, based on SO-018.

Orient the unit as shown in Figure 3-4. The suggested hardware for mounting the module to the baseboard is two threaded standoffs between the baseboard and module, anchored with screws to each board.

Here are some suggested assembly guidelines.

1. Assemble the heat sink and fan if needed on the module board.
2. Install the Jetson TX2 NX module.
   a). Baseboard with suitable standoffs suitable for the SODIMM connector height selected.
   b). Insert module at an angle of 25 to 35 degrees into the SODIMM connector.
   c). Arc down the module board until it latches to the SODIMM connector.
   d). Secure the Jetson TX2 NX module to the baseboard with screws into the standoffs. Figure 3-4 shows use of two standoffs and screws to secure the module to the system/base- board.

Figure 3-4. Jetson TX2 NX System Assembly Example on System Board

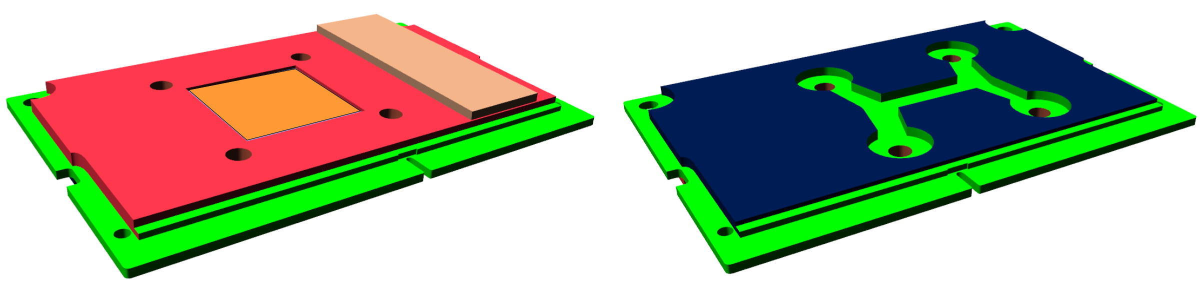


Chapter 4. Thermal Design Guidelines

4.1 3D Component Envelope STP file

NVIDIA provides a 3D CAD file (STP file) of the Jetson TX2 NX module on the "Downloads" section of the NVIDIA Developers website. It provides a 3D CAD model that shows an envelope that the board components will not exceed into. Any heat sink should be designed to not intrude into the envelope. The heat sink should be referenced to the SoC die area (highlighted in orange).

Figure 4-1. Jetson TX2 NX System 3D CAD Envelope View



4.2 Heat Sink Design

There are typically two types of heat sink attachments (Die referenced, and PCB referenced). The following sections show the differences between the two types. Jetson TX2 NX should use a die referenced design. The SoC is the main component that should be contacted and provided with a thermal solution. Other components should not require any thermal solution but can be provided if necessary.

For components other than SoC, customers should make sure that they do not exceed the maximum temperature limit specification provided in Table 3-1.

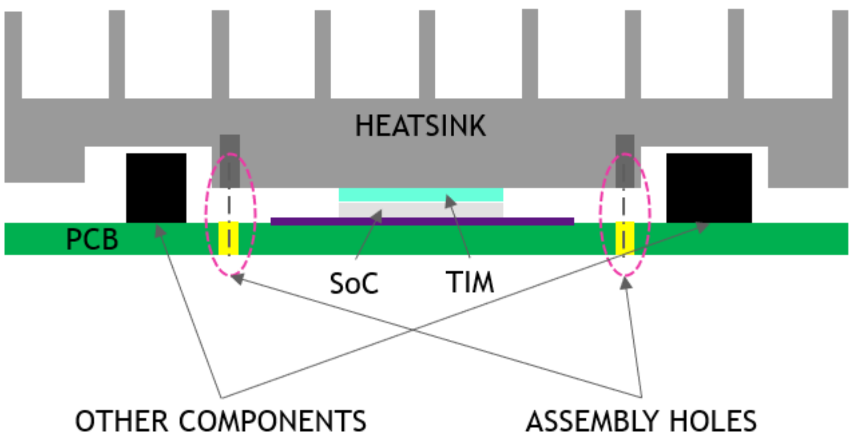
WARNING: Adding thermal material to components other than the SoC may increase their case temperature due to heat transfer from the SoC and they may exceed their max limits.

4.2.1 Die Referenced

The die referenced design is preferred for Jetson TX2 NX.

- Heat sink contact is referenced to TOP of SoC die
- Use nearby mounting holes to minimize board flex
- Springs (if used - not shown) may be located either above the heat sink or below the PCB
- Bondline typically controlled by achievable pressure, TIM compressibility and TIM filler particle size
- Better control of pressure applied at the die

Figure 4-2. Die Reference Heat Sink Example–Preferred

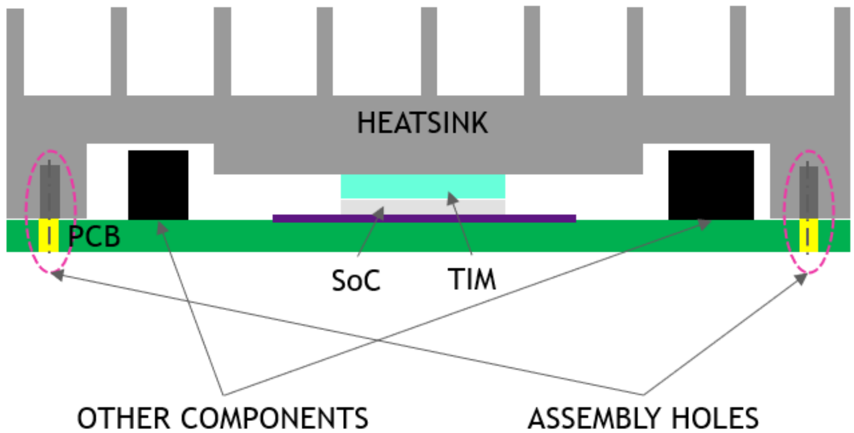


4.2.2 PCB Referenced

The PCB referenced design is NOT preferred for Jetson TX2 NX but can be used if necessary.

- Tolerance loop includes (at least) the package height and heat sink base height
- TIM thickness determined by tolerance stack up
- Optionally uses corner mounting holes in PCB
- Up to 10x the TIM bond line thickness of a Die-refenced design
- May cause PCB warpage due to tolerance deltas

Figure 4-3. PCB Referenced Heat Sink Example–Not Preferred



4.3 Heat Sink Assembly Guidelines

This section details the heat sink assembly guidelines for Jetson TX2 NX.

4.3.1 Die Pressure

For all types of heat sinks, the amount of pressure applied to the SoC die is critical. If too much pressure is applied the die may crack. The pressure must be applied evenly across the die.

> ! IMPORTANT: During assembly to maintain a constant pressure, do not completely tighten the heat sink mounting screws on one corner at a time. Instead do small adjustments on each screw in a round robin manner.

For Jetson TX2 NX, the maximum pressure that can be applied to the Tegra X2 SoC die is 60 psi.

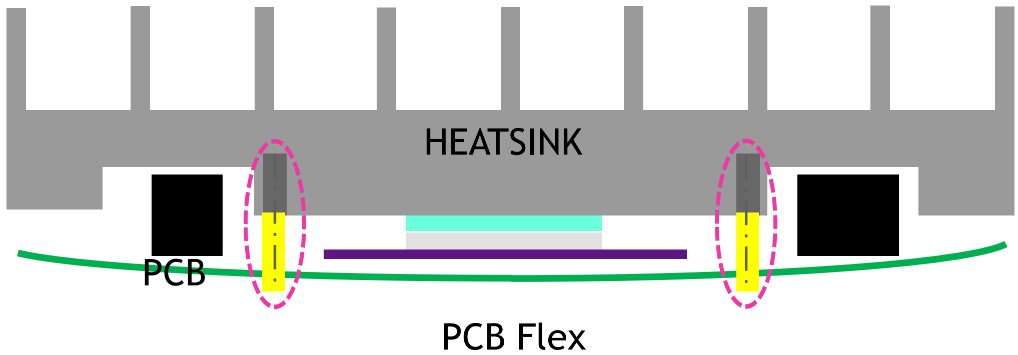
4.3.2 PCB Flex

The amount of die pressure combined with the heat sink attachment may cause the PCB to flex in some circumstances. If the board flexes too much, this may cause a variety of issues.

- PCB failure
- Component Ball/Pin cracks

For Jetson TX2 NX, the amount of PCB should not bow or bend to cause more than 500 micro-strain within 5 mm of the Tegra X2 SoC.

Figure 4-4. PCB Flex



4.4 Thermal Material

For best thermal transfer, a thin bondline TIM material should be used between the SoC die and the thermal solution.

- Uniform thickness of this TIM material is required to provide consistent thermal results
- Die referenced design will help enable a thin bondline between SoC and heat sink
- For reference, the NVIDIA® Jetson™ Xavier™ NX Developer Kit uses a 50 um thick layer of thermal grease

For other components (if needed), a compressible TIM material (Gap pads) can be used between the thermal solution and other components. Customers should request for Force vs Deflection curves from gap filler vendors of their choice based on their design requirements and use adequate compression force.

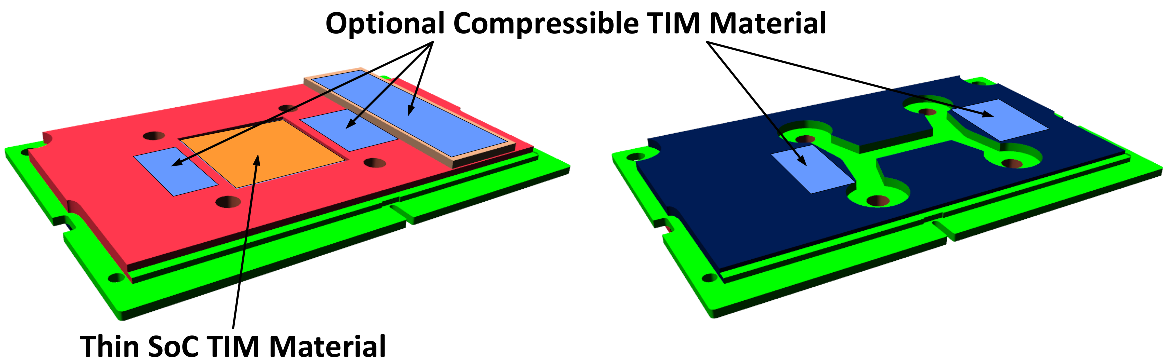
- If TIM is used, ensure that compression force does not create pressure greater than recommended on the SoC die or cause PCB warpage beyond the allowable limit.

4.5 Recommended Solution

Design a die referenced thermal solution based on the 3D CAD model provided. For reference, the Jetson Xavier NX Developer Kit uses a 50 um thick layer of thermal grease with thermal conductivity of 6.0 W/m °K.

Do not exceed the maximum supported pressure on the SoC die. If absolutely required, use compressible TIM material (gap fillers) for other component contact to fill the gap between the heat sink and the component. Ensure other components do not exceed their rated specification.

Figure 4-5. Recommended TIM Placement



Chapter 5. Thermal Management

5.1 Temperature Monitoring

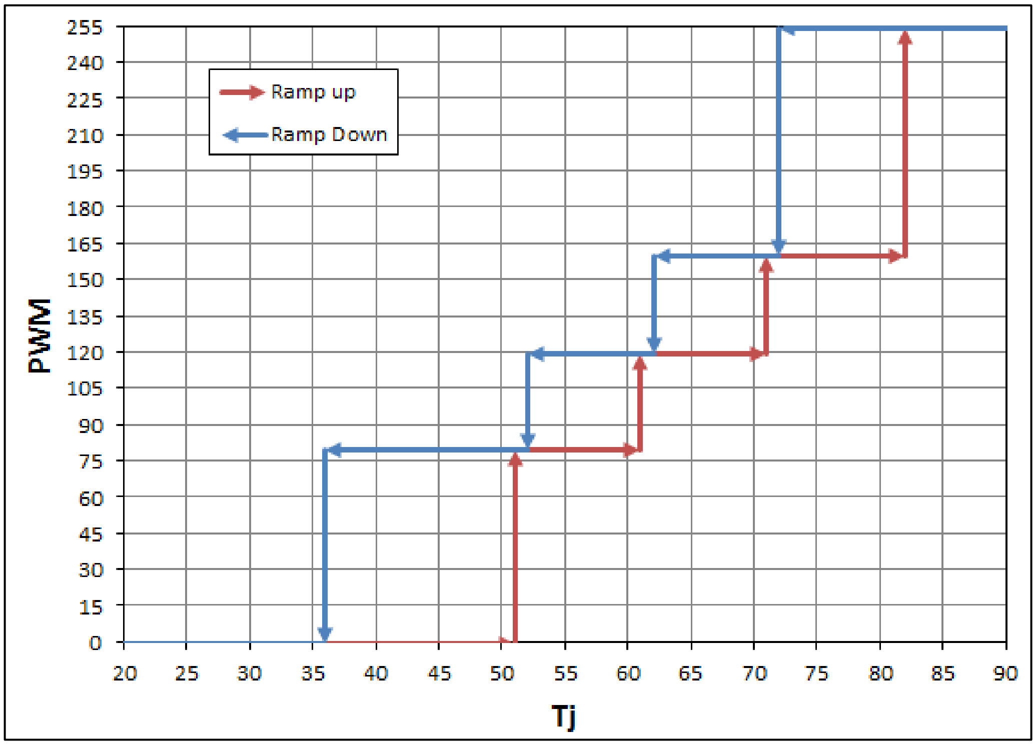
The Tegra X2 junction temperature can be directly read from sysfs nodes, as shown in the following example. Note that the name of each temperature zone is noted in the type node and that the temperature values are reported in units of m °C.

```
cat /sys/devices/virtual/thermal/thermal_zone1/type
cpu-therm
# cat /sys/devices/virtual/thermal/thermal_zone1/temp
35000
```

5.2 Fan Control

The Jetson TX2 NX can be configured to control a system fan. Pulse width modulation (PWM) output and tachometer input are supported. Jetson TX2 NX has configurable fan control of step-based speed control with hysteresis, as shown in Figure 5-1.

Figure 5-1. Fan Control Algorithm



The default fan curve settings are listed in Table 5-1. Note that PWM is configured on a 2^8 scale, with 255 being equivalent to 100% duty cycle.

Table 5-1. Default Fan Control Parameters

CPU Temperature (°C)	PWM	Hysteresis[1] (°C)
51	80	15
61	120	9
71	160	9
82	255	10

Note:

[1]The hysteresis set for each trip point must be greater than the previous trip point. For example, 82 °C – 10 °C = 72 °C, which is greater than the 160 PWM trip point at 71 °C.

Custom fan settings can be implemented if needed. Refer to the *Platform Adaptation and Bring-up Guide* for details.

5.3 Tegra X2 SoC Maximum Operating Temperature

The recommended operating temperature limit is the threshold at which the module will operate without performance reduction. These temperatures are listed in Table 2-1 and cannot be adjusted. The customer's tolerance for performance reduction should determine the amount of T_j operating headroom in the thermal solution design to accommodate the temperature sensor accuracy of ± 3 °C.

Software thermal management operates as follows:

- When the measured temperature is at or below the operating temperature threshold, software T_j thermal management is not engaged. The system is free to vary the system frequencies and voltages.
- When the measured temperature reaches the thermal management threshold, the internal temperature sensors generate an interrupt to software. At this point, the software thermal management algorithm engages and begins periodically performing the following operations:
  - Polling temperature.
  - Running a thermal management control algorithm to calculate the throttle degree, that indicates the amount of throttling to apply during the next time period.
  - Throttling the system to the level of throttling indicated by the throttling control algorithm. Throttling is applied through limits on the clock frequency of high-power units. Such as the CPU and graphics processing unit (GPU). Higher throttling degree results in lower frequency limits. DVFS policies operate within these frequency limits.
- Software thermal management remains in operation until the Tegra X2 temperature has returned to a value below the throttling threshold, and throttling degree has returned to zero.

> **Note**: Power fluctuations that induce T_j fluctuations above the software thermal management thresholds will cause temporary clock reductions. Power fluctuations in the target workload should be evaluated for their potential to cause temperature to fluctuate above the software threshold.

5.4 Tegra X2 Hardware Thermal Throttling

In the event that software thermal management is not able to maintain the Tegra X2 temperature, then hardware thermal throttling will engage in an attempt to prevent thermal shutdown. To help avoid thermal shutdown conditions without being overly conservative, Tegra X2 has hardware-engaged clock throttling mechanisms that are used as a last resort to prevent shutdown conditions. This will lower the Tegra X2 temperature, but it will also significantly reduce the overall Tegra X2 performance. The Tegra X2 throttle settings cannot be altered. These settings are implemented by NVIDIA to meet safety and reliability standards.

5.5 Tegra X2 Shutdown Temperature

Tegra X2 is rated to operate at a junction temperature not-to-exceed 105 °C. Tegra X2 has hardware shutdown mechanisms that enforce this limit by automatically halting the system when this temperature is exceeded.

The shutdown temperature should not be reached at any time during normal operation. But it may occur if cooling system components are broken, jammed, or otherwise unable to cool the Tegra X2 under worst-case conditions. If a thermal shutdown event is triggered, then a major fault in the Jetson TX2 NX or system cooling solution has occurred. Thermal shutdown can be initiated by any of the sensors. Using multiple sensors enables operation closer to the temperature limit without compromising reliability by reducing the uncertainty associated with the hotspot location.

The following thermal shutdown mechanism has been implemented:

- On-die sensor-based shutdown. Failsafe thermal shutdown is guaranteed by using the SHUTDOWN signal directly from Tegra X2 to the PMIC. After the failsafe shutdown the user will have to manually turn the system on by pressing the power button or equivalent input.

The Tegra X2 shutdown settings cannot be altered. These settings are implemented by NVIDIA to meet safety and reliability standards.

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