NVIDIA Jetson Xavier NX

Thermal Design Guide

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Document History

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Version	Date	Description of Change
1.0	February 10, 2020	Initial Release
1.1	December 3, 2020	Added Chapter 4 on thermal design guidelines
1.2	May 10, 2021	• Updated thermal performance equations in Section 3.1.1 • Updated Figure 3-2, and Figure 3-4 • Updated Table 3-1
1.3	July 19, 2021	• Updated Figure 3-2 • Updated Table 3-1 • Added thermal performance table for 20 W operational map (Table 3-2)

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Chapter 1. Introduction

This document is the thermal design guide (TDG) for the NVIDIA® Jetson Xavier™ NX product.

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

Refer to the Jetson Xavier 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. The thermal solution maintains the NVIDIA® Xavier™ system on chip (SoC) 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 Xavier NX to sustain the maximum thermal load for their use case.
- Customers are responsible for qualification of the Jetson Xavier NX in their system. Customers 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 Xavier NX when operating at the TMP level.

1.2.2 Jetson Xavier NX

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

Figure 1-1. Jetson Xavier NX–Topside View

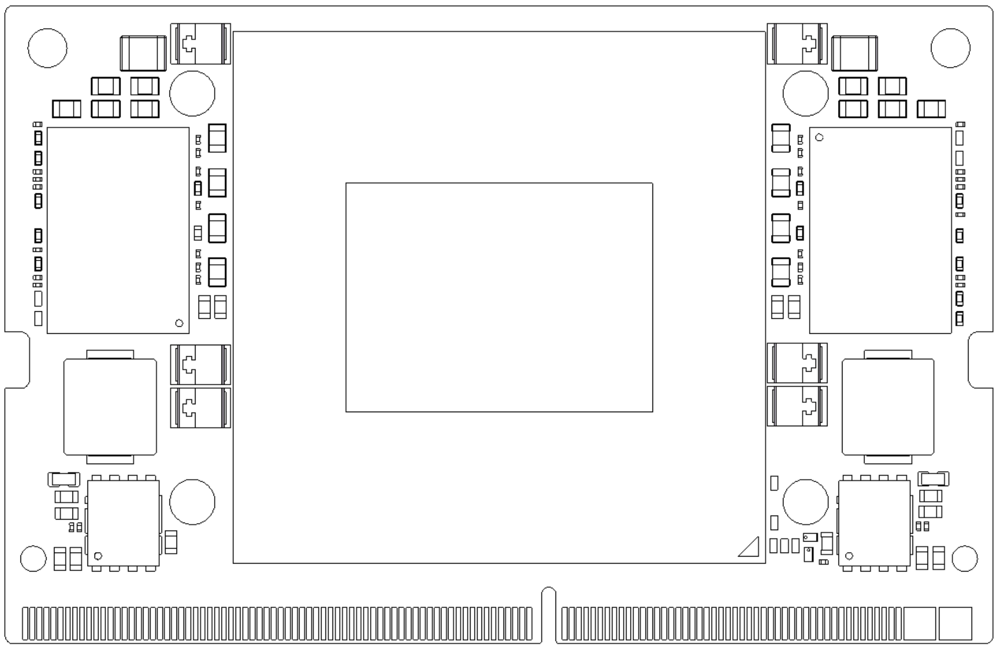
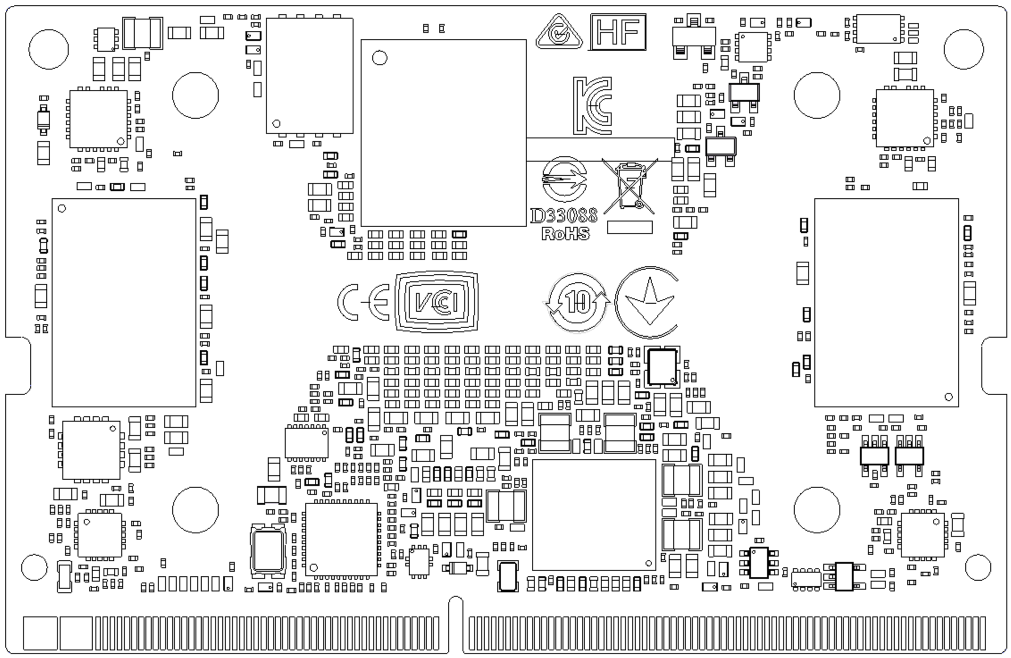


Figure 1-2. Jetson Xavier NX–Backside View



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 Xavier SoC below the maximum temperature specifications as detailed in Section 2.1 and Section 3.1.

1.2.3 Xavier SoC Temperature

The Xavier SoC junction temperature (T_j) represents the Xavier SoC die temperature read from any of the internal temperature sensors. The on-die thermal 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 Xavier SoC, there are multiple on-die temperature sensors that are placed close to dominant hotspots for real-time 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 sensor thermal protection mechanisms. The specifications in Table 2-1 must be followed to maintain the performance and reliability of the Jetson Xavier NX module.

Table 2-1. Jetson Xavier NX Thermal Specifications

Parameter	Value	Units
Maximum Xavier SoC operating temperature[1]	T.cpu = 90.5	°C
	T.gpu = 91.5	°C
	T.aux = 90.0	°C
Xavier SoC shutdown temperature[2]	T.cpu = 96.0	°C
	T.gpu = 97.0	°C
	T.aux = 95.5	°C

Notes:

[1]The Xavier SoC maximum operating temperature is the temperature below which the product will operate at the specified clock speeds. Software will apply clock speed reductions after this temperature is reached. 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 Xavier SoC will shut down the Jetson Xavier NX module after any of these software-imposed temperature limits are reached to maintain the reliability of the Xavier SoC. See Section 5.5 for details.

Chapter 3. Design Guidance

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

3.1 Thermal Information

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

3.1.1 Jetson Xavier NX Thermal Performance

The Jetson Xavier 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 Xavier NX PCB as listed in Table 3-1. The thermal resistance network for the system thermal solution can be represented with the following equation:

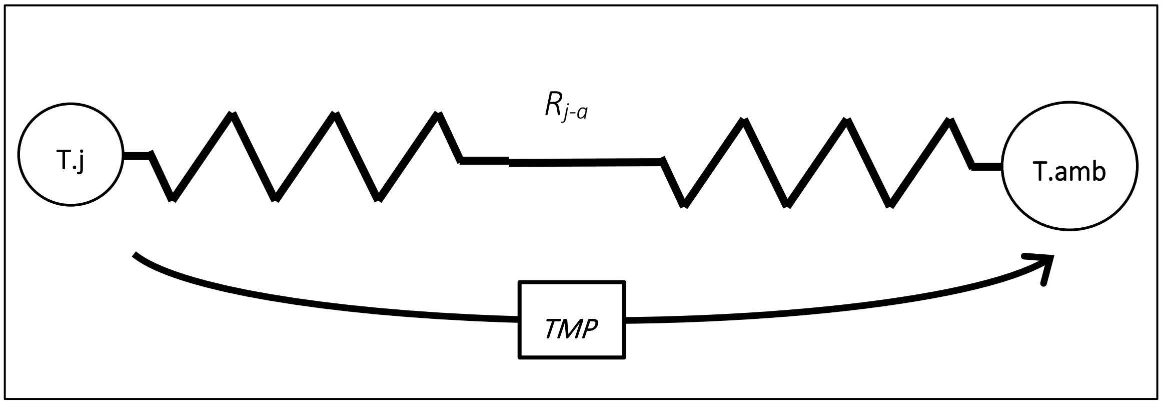
$$R_{1-2} = \frac{T_1 - T_2}{P}$$

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

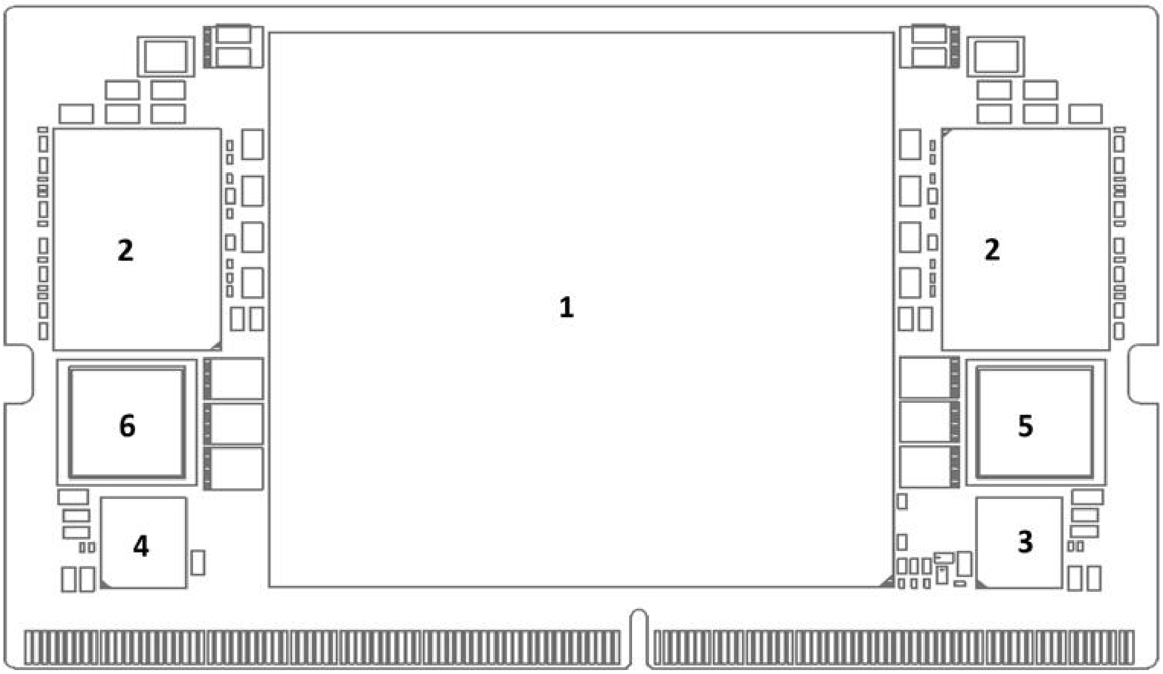


Jetson Xavier NX enables a wide variety of applications that may exercise different components on the module. The variation between applications will cause variation in heat loads on the different components on the Jetson Xavier NX. It will also cause hotspots in different logical partitions of the Xavier SoC.

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 Xavier NX the higher the thermal performance will be.

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

Top Side



Bottom Side

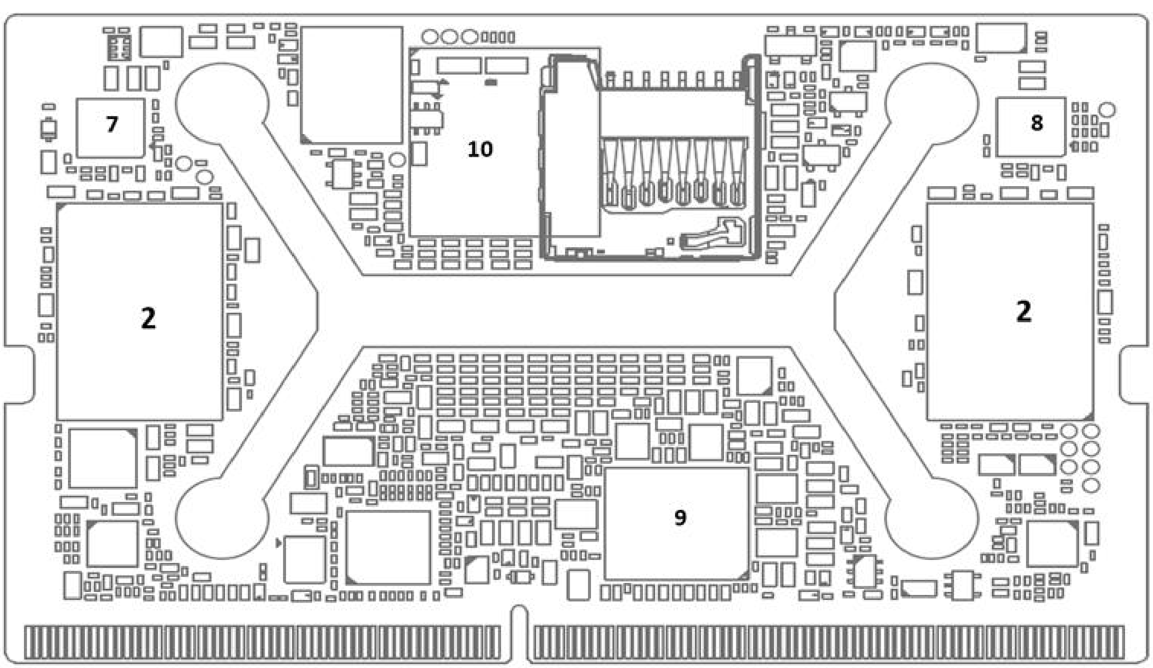


Table 3-1. Jetson Xavier NX Thermal Performance for 15 W Operational Mode

(pink)	Components that will be contacted and need to be monitored
(blue)	Components that must be monitored
(yellow)	Miscellaneous

					Thermal Specifications			
Comp # on Map	**Description**	**Qty**	**Design Power (W)**	**Total Power (W)**	**Rj-c (°C/W)**	**Rj-b (°C/W)**	**Thermal K Value (W/m°C)**	**Tcase (°C)**
1	Xavier SoC	1		9.40	-	-		**Refer to Table 2-1**
2	LPDDR4X Memory	4	0.33	1.32	2.6	12.6	-	85
3	CPU/GPU/CV Dual Package MOSFET	1	0.35	0.35	2.4	12		115
4	SOC Dual Package MOSFET	1	0.09	0.09	2.4	12		115
5	CPU/GPU/CV Inductor	1	0.21	0.21	-	-	4.0	125
6	SOC Inductor	1	0.04	0.04	-	-	4.0	125
7	DDR VDD2 Regulator	1	0.13	0.13	16	48		85
8	DDR VDDQ Regulator	1	0.15	0.15	16	48		85
9	PMIC	1	0.73	0.73	9	27		105
10	eMMC	1	1.1	1.1	8.8	51.5		95
				13.52	= Total Dissipated Power			

Notes:

1. For components which do not show Rj-c and Rj-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. Thermal model for Xavier package is 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.

Table 3-2. Jetson Xavier NX Thermal Performance for 20 W Operational Mode

(pink)	Components that will be contacted and need to be monitored
(blue)	Components that must be monitored
(yellow)	Miscellaneous

					Thermal Specifications			
Comp # on Map	**Description**	**Qty**	**Design Power (W)**	**Total Power (W)**	**Rj-c (ºC/W)**	**Rj-b (ºC/W)**	**Thermal K Value (W/mºC)**	**Tcase (ºC)**
1	Xavier SoC	1		11.4	0.18	1.62		**Refer to Table 2-1**
2	LPDDR4X Memory	4	0.35	1.4	2.6	12.6	-	85
3	CPU/GPU/CV Dual Package MOSFET	1	0.35	0.35	2.4	12		115
4	SOC Dual Package MOSFET	1	0.21	0.21	2.4	12		115
5	CPU/GPU/CV Inductor	1	0.21	0.21	-	-	4.0	125
6	SOC Inductor	1	0.09	0.09	-	-	4.0	125
7	DDR VDD2 Regulator	1	0.13	0.13	16	48		85
8	DDR VDDQ Regulator	1	0.15	0.15	16	48		85
9	PMIC	1	0.73	0.73	9	27		105
10	eMMC	1	1.10	1.10	8.8	51.5		95
				15.80	= Total Dissipated Power			

Notes:

1. For components which do not show Rj-c and Rj-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. Thermal model for Xavier package is 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.

Note: Table 3-1 and Table 3-2 are subject to change.

The components to be monitored in Table 3-1 and Table 3-2 should be instrumented to measure case temperature while the system is running heavy use caseloads and in the maximum temperature environment the system will have to be operated in. If any component exceeds the specified thermal specifications changes will be required:

- Maximum environmental temperature lowered.
- Maximum use cases reduced to lower device temperatures.
- Thermal solution required for the devices that exceed thermal specification.

WARNING: If devices other than the SoC contact the heat sink (through TIM material), they must still be instrumented to ensure that the case temperature is not higher due to heat from the heat sink due to SoC heat being transferred to the other device.

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:

$T.amb = 55°C$

$T.aux = 86.00°C$ (Targeting $4°C$ T.cpu headroom to account for sensor inaccuracy and possible T_j fluctuations resulting from workload variation)

$P_{TMP} = 15W$

The heat sink thermal performance requirement for the above conditions.

$$\rightarrow Rj - a = \frac{86°C - 55°C}{15W} = 2.06\frac{°C}{W}$$

In this example, a 2.06 °C/W thermal solution is expected to be sufficient to maintain the Xavier SoC within the maximum temperature specification as detailed in Table 2-1. In addition to this, the customer is responsible to verify all other components of the module within their maximum temperature specifications as detailed in Table 3-1 and Table 3-2.

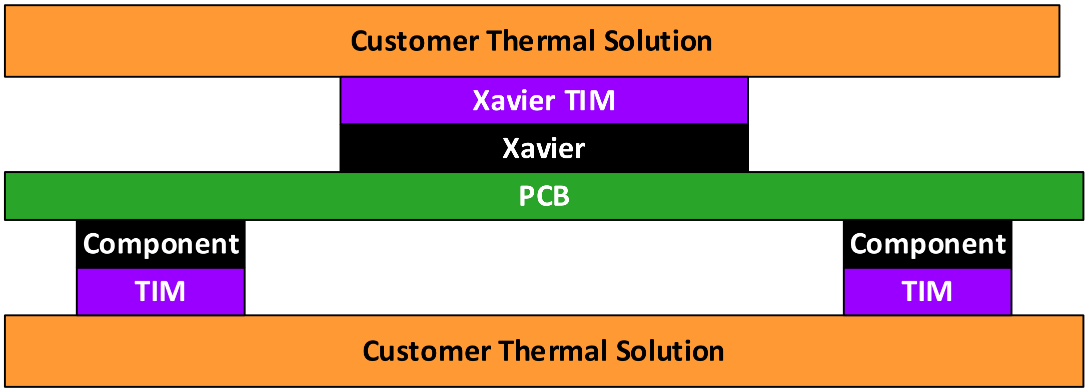
3.1.2 Jetson Xavier NX Thermal Design Details

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 Xavier 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 Xavier SoC 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 and Table 3-2.

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

Figure 3-3. Thermal Stack-up Schematic



3.1.3 Customer Thermal Solution

The customer's thermal solution is the mechanical element that interfaces to the Jetson Xavier 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 Xavier SoC is critical for maximizing the thermal performance of the Jetson Xavier NX. The Xavier SoC consumes the majority of the TMP.
- 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, Table 3-1, and Table 3-2.

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 JESD94B (*Application Specific Qualification Using Knowledge Based Test Methodology*) for more information.

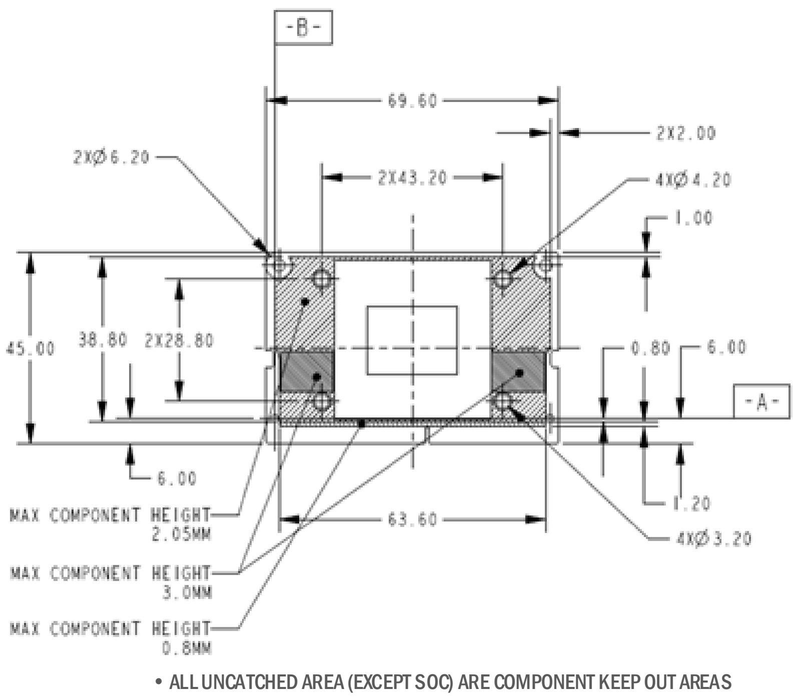
3.2 Mechanical Information

Refer to the Jetson Xavier NX module mechanical drawing for the exact module dimensions. This will 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, Xavier SoC, and the module board. The module board is provided with mounting holes to accommodate mounting options for a suitable heat sink.

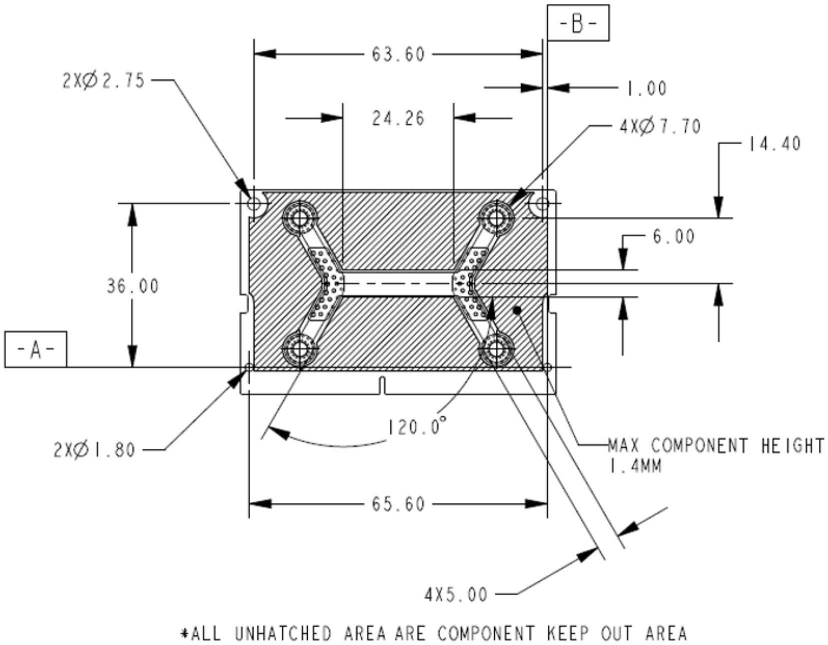
Figure 3-4. Module Board with Mounting Features



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 Xavier SoC (Shown in Figure 3-4) and two holes (Ø 2.75 mm) on the edge opposite to edge connector (Shown in Figure 3-5).
- All holes are NPTH 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 mounting force for the thermal solution is 4 kgf.
- There is a keepout area behind the module board to allow for backplate to support the board while the heat sink is mounted from top side.
- Figure 3-5 illustrates where the module provides room for the backplate should the design require a backplate to assist in stiffening the board and for mounting and locking features. The outline shows the keepout area for the backplate on backside of the module.

Figure 3-5. Module Board PCB Back Support Keepout Area



3.2.2 Assembly Guidelines

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

Orientation of the unit is to be aligned with the connector and secured to the baseboard. Suggested hardware for mounting the module to the baseboard is use of standoff between the two board, anchored with screw on 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 Xavier NX module.
   a). Baseboard with suitable standoff based on SODIMM connector height.
   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 SODMM connector.
   d). Secure the Jetson Xavier NX module to the baseboard with screws onto the standoff/spacer.

Chapter 4. Thermal Design Guidelines

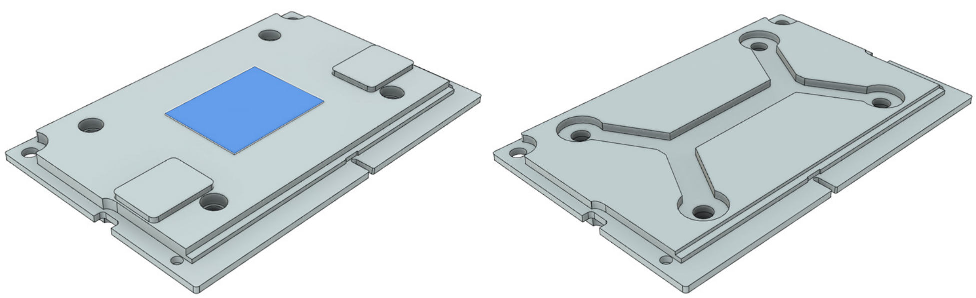
4.1 3D Component Envelope

NVIDIA provides a 3D CAD file (STP format) of the Jetson Xavier NX module on the downloads section of the "NVIDIA Developers Website."

› **Jetson Xavier NX 3D CAD STEP Model (P3668)**	A01	2020/05/28

It provides a 3D CAD model that shows an envelope that the board components will not exceed. Any heat sink should be designed to not intrude into the envelope. The heat sink should be referenced to the SoC die area (Highlighted).

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



4.2 Heat Sink Design

There are typically two types of heat sink attachments:

- Die referenced.
- PCB referenced.

The following sections show the differences between the two types. Jetson Xavier 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 and Table 3-2.

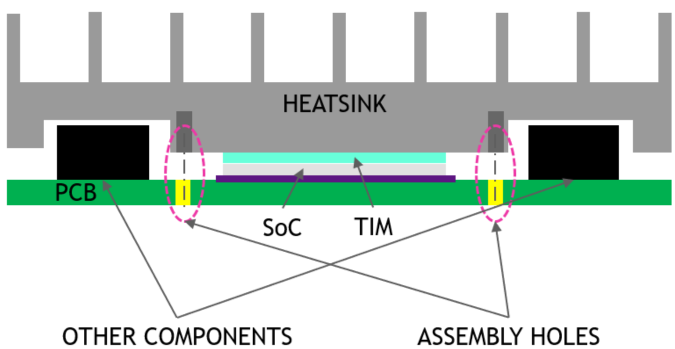
WARNING: Adding thermal material to components other than the SoC may increase their case temperature due to heat transfer from the SoC and they may exceed their maximum limits.

4.2.1 Die Referenced

The die referenced heat sink attachment is the preferred design for Jetson Xavier 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. Preferred Die Referenced Heat Sink Example

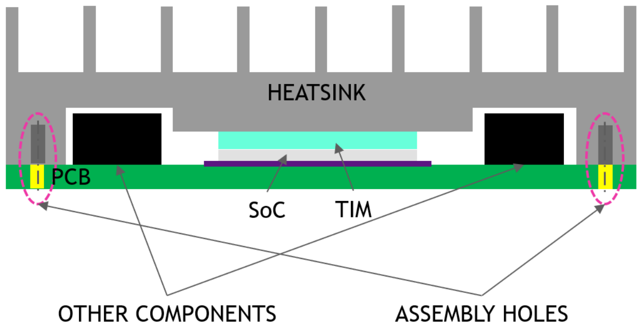


4.2.2 PCB Referenced

The PCB referenced heat sink attachment is not the preferred design for Jetson Xavier NX.

- 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 bondline thickness of a die-refenced design.
- May cause PCB warpage due to tolerance deltas.

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



4.3 Heat Sink Assembly Guidelines

This section discusses the heat sink assembly guidelines for Jetson Xavier 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.

> ! CAUTION: 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 Xavier NX, the maximum pressure that can be applied to the Xavier SoC die is 60 PSI.

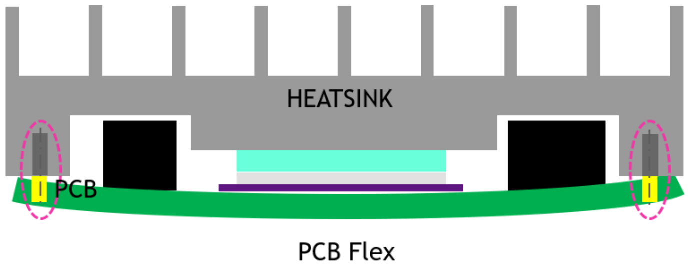
4.3.2 PCB Flex

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 and pin cracks

For Jetson Xavier NX, the amount of flex (bow or bend) of the PCB should cause more than 500 micro-strain within 5 mm of the Xavier 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.
- Jetson Xavier NX Developers 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 Force vs Deflection curves from gap filler vendors of their choice based on their design requirements and use adequate compression force.

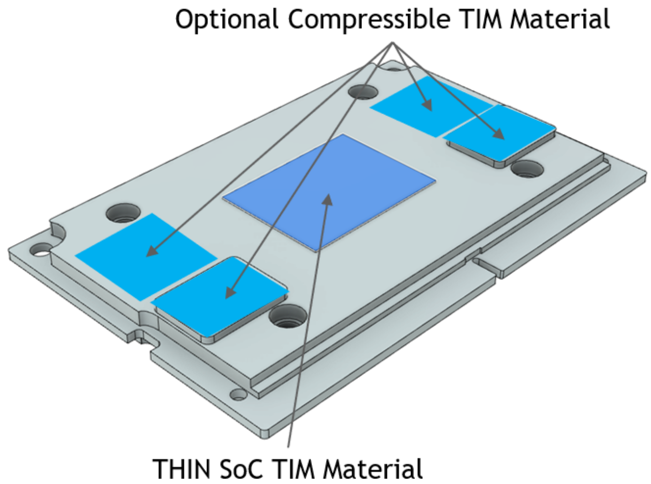
If used, ensure that compression force does not create pressure greater than recommended on the SoC die or cause PCB warpage beyond the allowable limit.

4.5 Recommended Solution

Design a die referenced thermal solution based on the 3D CAD model provided. Jetson Xavier NX Developers 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. Ensuring other components do not exceed their rated specification.

Figure 4-5. Recommended TIM Placement



Chapter 5. Thermal Management

5.1 Temperature Monitoring

The Xavier SoC 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_zone0/type
cpu-therm
# cat /sys/devices/virtual/thermal/thermal_zone0/temp
35000
```

5.2 Fan Control

The Jetson Xavier NX can be configured to control a system fan. Pulse width modulation (PWM) output and tachometer input are supported. Jetson Xavier NX has configurable fan control of step-based speed control with hysteresis, as shown in Figure 5-1 and Figure 5-2.

Two different fan mode settings are available for better user experience. The two fan modes are "Quiet Mode" and "Cool Mode" respectively. The default fan mode is set to "Quiet Mode." The default fan curve settings for the "Quiet Mode" are listed in Table 5-1. The default fan curve settings for the "Cool Mode" are listed in Table 5-2. Note that PWM is configured on a 2^8 scale, with 255 being equivalent to 100% duty cycle.

Figure 5-1. Fan Control Algorithm for "Quiet Mode"

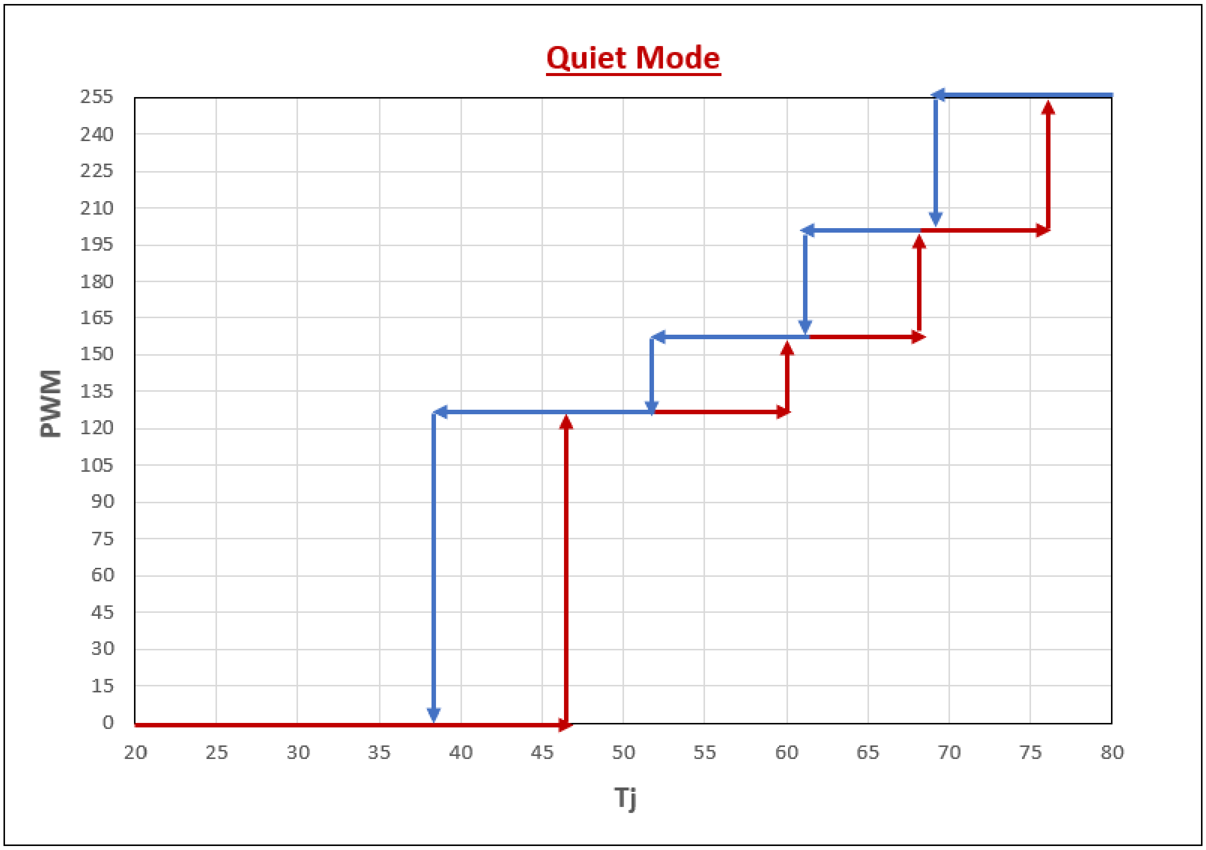


Table 5-1. Default Fan Control Parameters for "Quiet Mode"

"thermal fan-est" Thermal Zone Temperature[1]	PWM	Hysteresis[2] (°C)
46	130	8
60	160	8
68	200	7
76	255	7

Notes:

[1]Fan speed is controlled by the thermal-fan-est sensor, which reports the weighted average of the CPU, GPU, and AUX sensors at a 3:3:4 ratio.

[2]The hysteresis set for each trip point must be greater than the previous trip point.

Figure 5-2. Fan Control Algorithm for "Cool Mode"

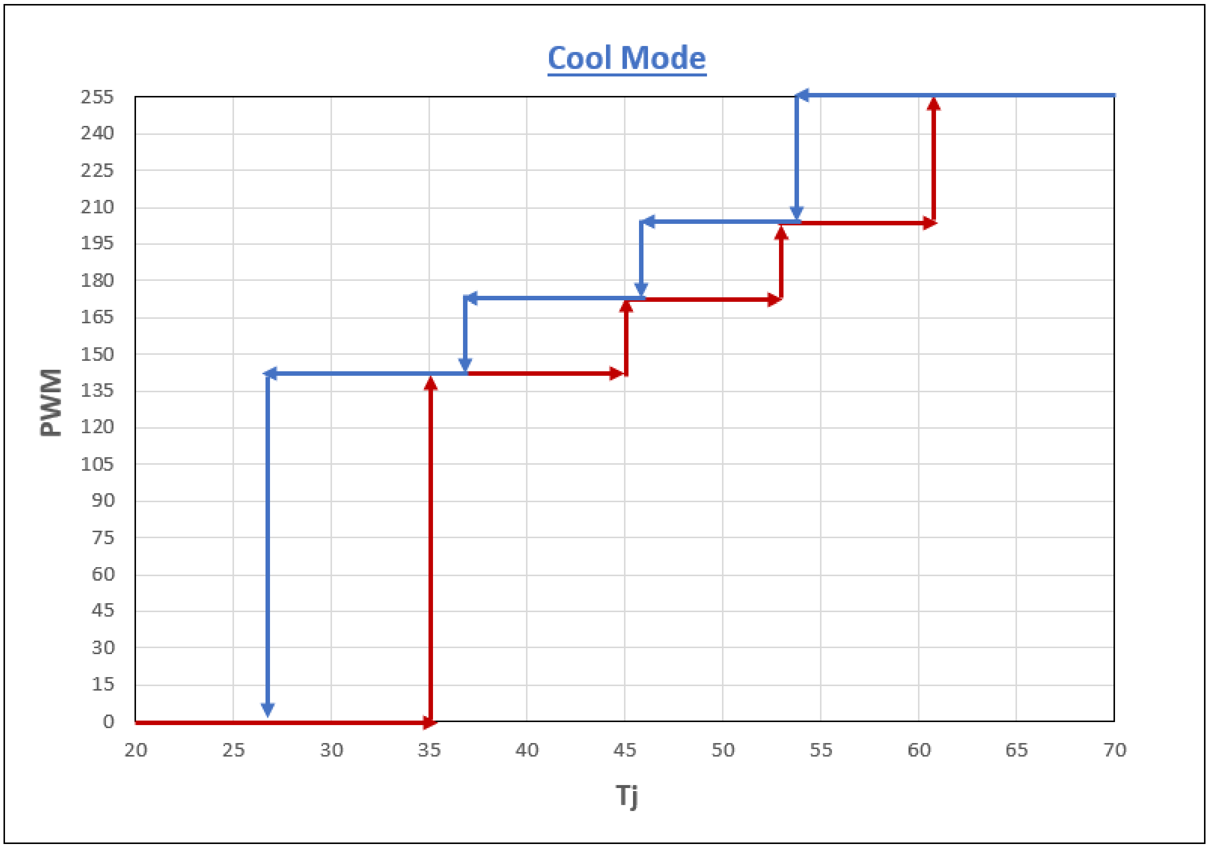


Table 5-2. Default Fan Control Parameters for "Cool Mode"

"thermal fan-est" Thermal Zone Temperature[1]	PWM	Hysteresis[2] (°C)
35	140	8
45	170	8
53	200	7
61	255	7

Notes:

[1]Fan speed is controlled by the thermal-fan-est sensor, which reports the weighted average of the CPU, GPU, and AUX sensors at a 3:3:4 ratio.

[2]The hysteresis set for each trip point must be greater than the previous trip point.

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

5.3 Xavier 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, and the system is free to vary the system frequencies and voltages.
- When the measured temperature reaches the thermal management threshold, the internal thermal 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, indicating the amount of throttling to apply during the next 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 Xavier SoC 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 Xavier SoC Hardware Thermal Throttling

If software thermal management is not able to maintain the Xavier SoC temperature, then hardware thermal throttling will engage to prevent thermal shutdown. To help avoid thermal shutdown conditions without being overly conservative, Xavier SoC has hardware-engaged clock throttling mechanisms that are used as a last resort to prevent shutdown conditions. This will lower the Xavier SoC temperature, but it will also significantly reduce the overall

Xavier SoC performance. The Xavier SoC throttle settings cannot be altered. These settings are implemented by NVIDIA to meet safety and reliability standards.

5.5 Xavier SoC Shutdown Temperature

Xavier SoC is rated to operate at a junction temperature not-to-exceed 105 °C. Xavier SoC 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. It may occur if cooling system components are broken, jammed, or otherwise unable to cool the Xavier SoC under worst-case conditions. If a thermal shutdown event is triggered, then a major fault in the Jetson Xavier NX or system cooling solution has occurred. Thermal shutdown can be initiated by any of the sensors listed in Table 2-1. 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:

- Internal sensor-based shutdown. Failsafe thermal shutdown is guaranteed by using the SHUTDOWN signal directly from Xavier SoC 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 Xavier SoC shutdown settings cannot be altered. These settings are implemented by NVIDIA to meet safety and reliability standards.

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