



Jetson AGX Xavier Series

Thermal Design Guide

Document History

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Chapter 1. Introduction

This document is the thermal design guide (TDG) for the NVIDIA® Jetson AGX Xavier™ series modules.

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



Note: References to Jetson AGX Xavier apply to any of the Jetson AGX Xavier series of modules except where explicitly noted.

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 that maintains the NVIDIA® Xavier™ system on chip (SoC) and thermal transfer plate (TTP) 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 sufficient power to the Jetson AGX Xavier to sustain the maximum thermal load for their use case.
- ▶ Customers are responsible for qualification of the Jetson AGX Xavier in their system and are responsible for any issues related to failure to qualify the product properly.
- ▶ The TTP is not designed to be removed by the customer, as the thermal interface material (TIM) cannot be reused. The screws holding the TTP together are marked with tamper evident ink. Removal of the TTP is done solely at the customer's risk.

1.2 Related Documents

The following types of files are associated resources for Jetson AGX Xavier.

- ▶ Jetson AGX Xavier Module 3D CAD STEP Model
A 3D mechanical model of the board is available in the universal .stp file format. The model is provided to enable system level mechanical fit checks, mounting and wiring planning.
- ▶ Jetson AGX Xavier Series Module Data Sheet
The mechanical drawing of the Jetson AGX Xavier module is included in the data sheet.

1.3 Definitions

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

1.3.1 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 sufficient cooling for the Jetson AGX Xavier when operating at the TMP level.

1.3.1.1 TMP Conditions

TMP conditions for this design are defined under the following operating conditions:

- ▶ Worst-case Xavier SoC temperature conditions
- ▶ Maximum power level for the product configuration
 - The TMP power level is based on the target workload
- ▶ Steady state average power

1.3.2 Thermal Transfer Plate

The Jetson AGX Xavier is provided with a thermal transfer plate (TTP) to simplify integration with a system-level thermal solution. The Jetson AGX Xavier is shown in Figure 1-1 (topside view) and Figure 1-2 (backside view).

Figure 1-1. Jetson AGX Xavier – Topside ISO View

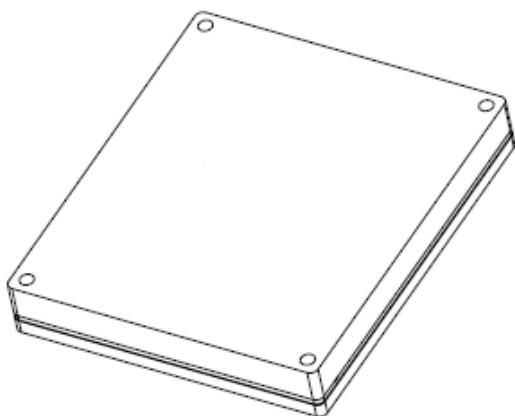
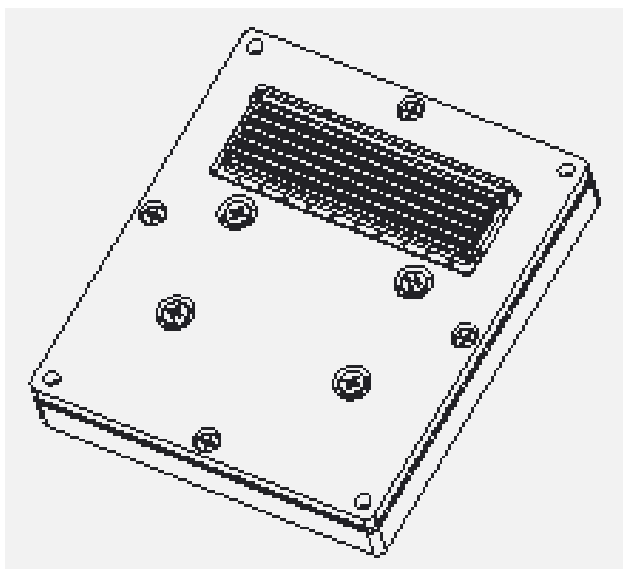


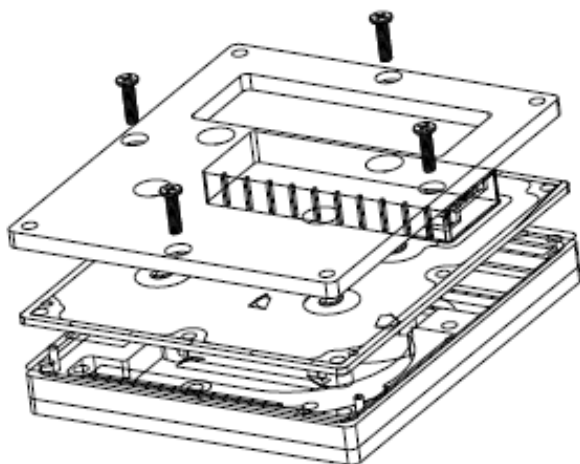
Figure 1-2. Jetson AGX Xavier – Backside ISO View



The thermal solution of the customer's system design should attach to the top surface of the TTP. The thermal solution can be mounted using the main module mounting holes. More details are provided in Section 3.2.

An exploded view of the Jetson AGX Xavier assembly is shown in Figure 1-3. The PCB is completely covered by the TTP. The TTP design mechanically isolates the Jetson AGX Xavier board and components from external mechanical forces, standardizes the thermal and mechanical interface, and allows for modular system design.

Figure 1-3. Jetson AGX Xavier Design – Exploded View



1.3.3 Xavier SoC Temperature

The Xavier SoC junction temperature (T_j) represents the Xavier SoC die temperature read from the highest 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 4.

Chapter 2. Specifications

2.1 Thermal Specifications

This section provides thermal specifications separately for Jetson AGX Xavier and Jetson AGX Xavier Industrial modules. On Xavier SoC there are multiple on-die temperature sensors that are placed close to dominant hotspots to measure temperature and engage thermal protection mechanisms. Chapter 4 contains the details related to these sensors and their thermal protection mechanisms. The specifications in Table 2-1 and Table 2-2 must be followed to maintain the performance and reliability of the Jetson AGX Xavier series module.

Table 2-1. Jetson AGX Xavier Thermal Specifications

| Parameter | Up to 30 W Mode ⁴ | MaxN Mode ⁵ | Units |
|---|------------------------------|------------------------|-------|
| Maximum TTP operating temperature ¹ | 80.0 | 80.0 | °C |
| Recommended Xavier SoC operating temperature limit ² | T.cpu = 90.0 | T.cpu = 86.0 | °C |
| | T.gpu = 92.5 | T.gpu = 88.0 | °C |
| | T.aux = 89.0 | T.aux = 82.0 | °C |
| Xavier SoC maximum operating temperature limit ³ | T.cpu = 95.5 | T.cpu = 91.5 | °C |
| | T.gpu = 98.0 | T.gpu = 93.5 | °C |
| | T.aux = 94.5 | T.aux = 87.5 | °C |

Notes:

¹The temperature of the TTP must always be kept within this 80 °C limit to maintain the specified performance and reliability. The measurement locations are provided in Figure 3-2.

²These are the temperature thresholds below which the product will operate at the specified clock speeds. Software will apply clock speed reductions once any of these temperature sensors exceed these the specified thresholds. For most workloads, either the CPU temperature or the graphics processing unit (GPU) temperature will reach the temperature limit before the other sensors. It is less common for the AUX sensor to reach its temperature limit. Note that power fluctuations that induce T_j fluctuations above these thresholds will cause temporary clock reductions. See Section 4.3 for details.

³The Xavier SoC will reset the Jetson AGX Xavier module once any of these software-imposed temperature limits are reached to maintain the reliability of the Xavier SoC. See Section 4.5 for details.

⁴The Power Management for Jetson AGX Xavier document describes multiple power modes: a 10 W, a 15 W, and several 30 W modes. The same temperature settings apply to all of these power modes that are within the 30 W module power budget. Even if module power is under 30W, if the use case is significantly unbalanced (i.e., vast majority of power is consumed by one unit), the up to 30W thermal setting cannot be used. Instead, the MaxN thermal settings must be used.

⁵The MaxN power mode allows for higher operating power levels. These higher power modes require lower temperature limits to maintain the reliability of Jetson AGX Xavier.

Table 2-2. Jetson AGX Xavier Industrial Thermal Specifications

| Parameter | Up to 40 W Mode ⁴ | MaxN Mode ⁵ | Units |
|--|------------------------------|------------------------|-------|
| Maximum TTP operating temperature ¹ | 85.0 | 85.0 | °C |
| Recommended Xavier Industrial SoC operating temperature limit ² | T.cpu = 103 | T.cpu = 96.0 | °C |
| | T.gpu = 102 | T.gpu = 98.0 | °C |
| | T.aux = 100.5 | T.aux = 92.5 | °C |
| Xavier Industrial SoC maximum operating temperature limit ³ | T.cpu = 108.5 | T.cpu = 101.5 | °C |
| | T.gpu = 107.5 | T.gpu = 103.5 | °C |
| | T.aux = 106 | T.aux = 98 | °C |

Notes:

¹The temperature of the TTP must always be kept within this 85°C limit to maintain the specified performance and reliability. The measurement locations are provided in Figure 3-2.

²These are the temperature thresholds below which the product will operate at the specified clock speeds. Software will apply clock speed reductions once any of these temperature sensors exceed these the specified thresholds. For most workloads, either the CPU temperature or the graphics processing unit (GPU) temperature will reach the temperature limit before the other sensors. It is less common for the AUX sensor to reach its temperature limit. Note that power fluctuations that induce Tj fluctuations above these thresholds will cause temporary clock reductions. See Section 4.3 for details.

³The Xavier Industrial SoC will reset the Jetson AGX Xavier Industrial module once any of these software-imposed temperature limits are reached to maintain the reliability of the Xavier Industrial SoC. See Section 4.5 for details.

⁴The Power Management for Jetson AGX Xavier Industrial module supports multiple power modes. The same temperature settings apply to all of these power modes that are within the 40 W module power budget. Even if module power is under 40W, if the usecase is significantly unbalanced (i.e., vast majority of power is consumed by one unit), the up to 40W thermal setting cannot be used. Instead, the MaxN thermal settings must be used.

⁵The MaxN power mode allows for higher operating power levels. These higher power modes require lower temperature limits to maintain the reliability of Jetson AGX Xavier Industrial module.

Chapter 3. Design Guidance

This chapter provides design guidance in order to meet the Jetson AGX Xavier specifications.

3.1 Thermal Information

The design goal for system thermal management is to keep the TTP temperature and the Xavier SoC temperature below the limits specified in Section 2.1. The TTP temperature limit maintains the component temperatures on Jetson AGX Xavier within their temperature specifications.

Typical workloads that consume less than 30 W module power for Jetson AGX Xavier or less than 40 W for Jetson AGX Xavier Industrial are likely to operate below the T_j temperature limits, so long as the TTP temperature is within the specification. For unbalanced workloads or higher power workloads, more analysis is needed to evaluate the thermal design. This is described in the following section.

3.1.1 Jetson AGX Xavier Thermal Performance

The Jetson AGX Xavier module is designed to have a system level thermal solution attached to the TTP to dissipate the TMP thermal load into the ambient environment. This can be represented with a thermal resistance network where thermal resistance is calculated based on the equation:

$$\theta_{12} = \frac{T_1 - T_2}{P}$$

Where:

θ_{12} The thermal resistance between Point 1 and Point 2

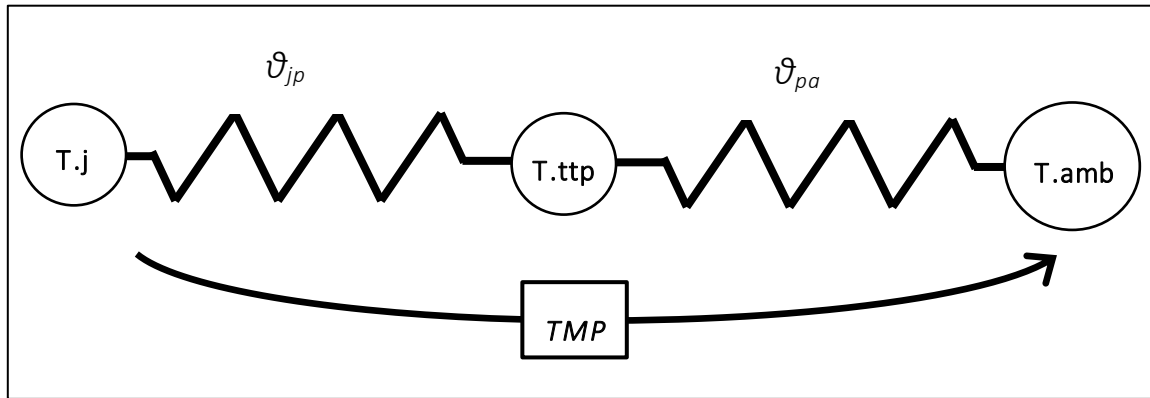
T_n The temperature at Point n

P The heat load (for example, dissipated power) transferred between Point 1 and Point 2

A simple example of a thermal resistance network is shown in Figure 3-1, where θ_{jp} represents the thermal resistance from T_j to the TTP and θ_{pa} represents the thermal resistance 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, heat spreaders, and heat sinks.

Figure 3-1. Thermal Resistance Network



Jetson AGX Xavier 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 AGX Xavier and hotspots in different logical partitions of the Xavier SoC. While Jetson AGX Xavier is designed to spread the heat and make the thermal performance as consistent as possible, different applications have different levels of thermal performance. The more evenly the module power is distributed across the Jetson AGX Xavier the better the thermal performance will be. Typical thermal performance of different workloads is listed in Table 3-1 (Jetson AGX Xavier) and Table 3-2 (Jetson AGX Xavier Industrial) for reference.

Table 3-1. Jetson AGX Xavier Thermal

| | Balanced Workload ¹ | Unbalanced Workload ² |
|---------------|--------------------------------|----------------------------------|
| θ_{jp} | 0.35 °C/W | 0.65 °C/W |
| θ_{jb} | 5.5 °C/W | |

Notes:

¹A balanced workload is well distributed across the CPU, GPU, DLA, PVA, and DRAM. This is expected to be representative of most use cases. The Power Management for Jetson AGX Xavier section of the *NVIDIA Jetson Linux Developer Guide* describes multiple power modes that widely distribute the power across the different partitions of the Xavier SoC.

²In an unbalanced workload, the power is concentrated on a small area of the Xavier SoC. This is not representative of most use cases. An example is a workload that is only running on the CPU partition.

³The θ_{jb} value is provided for simulation of the Jetson AGX Xavier module as a 2-resistor model in commercial CFD packages.

Table 3-2. Jetson AGX Xavier Industrial Thermal

| | Balanced Workload ¹ | Unbalanced Workload ² |
|---------------|--------------------------------|----------------------------------|
| θ_{jp} | 0.45 °C/W | TBD |
| θ_{jb} | 5.5 °C/W | |

Notes:

¹A balanced workload is well distributed across the CPU, GPU, DLA, PVA, and DRAM. This is expected to be representative of most use cases. The Power Management for Jetson AGX Xavier section of the *NVIDIA Jetson Linux Developer Guide* describes multiple power modes that widely distribute the power across the different partitions of the Xavier Industrial SoC.

²In an unbalanced workload, the power is concentrated on a small area of the Xavier Industrial SoC. This is not representative of most use cases. An example is a workload that is only running on the CPU partition.

³The θ_{jb} value is provided for simulation of the Jetson AGX Xavier Industrial module as a 2-resistor model in commercial CFD packages.

The thermal resistance of the module (θ_{jp}) and heat sink (θ_{pa}) sum together for the overall thermal resistance from the Xavier SoC to ambient. The required heat sink thermal performance can be determined based on the ambient temperature conditions, use case, and TMP level required by the customer. Consider the following example (Jetson AGX Xavier Industrial values are used in the example):

$$T_{amb} = 50^{\circ}\text{C}$$

$T_{cpu} = 101.5^{\circ}\text{C}$ (Allowing headroom to account for T_j fluctuations resulting from power fluctuations)

$$\theta_{jp} = 0.45 \frac{^{\circ}\text{C}}{\text{W}} \text{ (Assuming a balanced workload)}$$

$$P_{TMP} = 45\text{W}$$

First, check the heat sink thermal performance requirement for the above conditions.

$$\theta_{ja} = \theta_{jp} + \theta_{pa} \rightarrow \theta_{pa} = \theta_{ja} - \theta_{jp} = \frac{101.5^{\circ}\text{C} - 50^{\circ}\text{C}}{45\text{W}} - \theta_{jp} = 1.14 \frac{^{\circ}\text{C}}{\text{W}} - 0.45 \frac{^{\circ}\text{C}}{\text{W}} = 0.69 \frac{^{\circ}\text{C}}{\text{W}}$$

So, the heat sink's thermal performance (θ_{pa}) must be better than 0.69 °C/W. Next, check that the TTP temperature will be below the 85 °C specification.

$$\theta_{pa} = \frac{T_p - T_a}{P} \rightarrow T_p = \theta_{pa} * P + T_a = 0.69 \frac{^{\circ}\text{C}}{\text{W}} * 45\text{W} + 50^{\circ}\text{C} = 81.0^{\circ}\text{C}$$

So, a 0.69 °C/W or better thermal solution will be sufficient to meet the T_j and TTP temperature specifications.

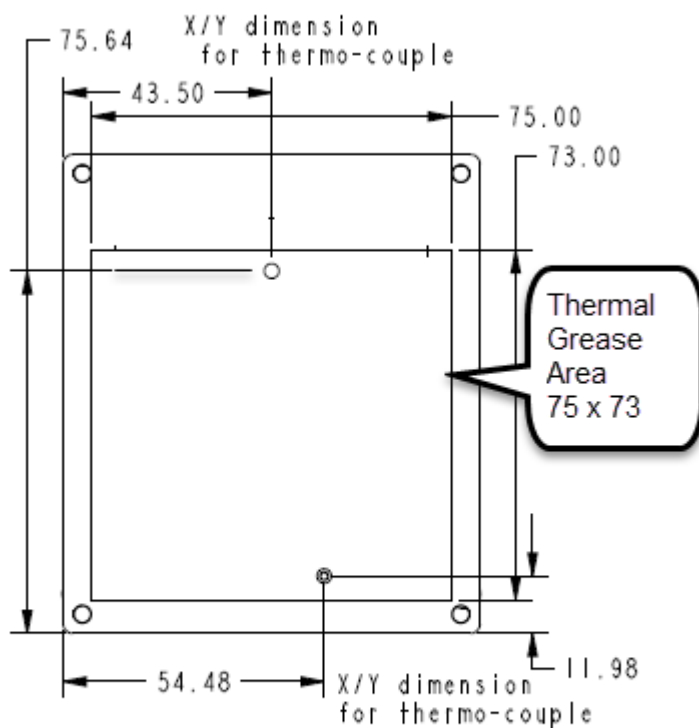
3.1.2 Jetson AGX Xavier Thermal Design Details

The Jetson AGX Xavier product is designed for integration with a product-level thermal solution which could be a passive heat sink, an active heat sink, a cold plate, a chassis mount, etc. The thermal solution must attach to the top surface of the TTP.

The 75 x 73 mm area, as shown in Figure 3-2, is the key contact area for efficient cooling performance. Full contact with the entire top surface of the TTP is suggested for maximum cooling.

The TTP has a maximum operating temperature specified in Table 2-1. If the Jetson AGX Xavier temperature is kept below this limit, then all other critical components on the PCB will be within their temperature limits as well. The TTP temperature is to be measured during qualification testing at the locations indicated by the two circles in Figure 3-2.

Figure 3-2. Location of TTP Thermocouple

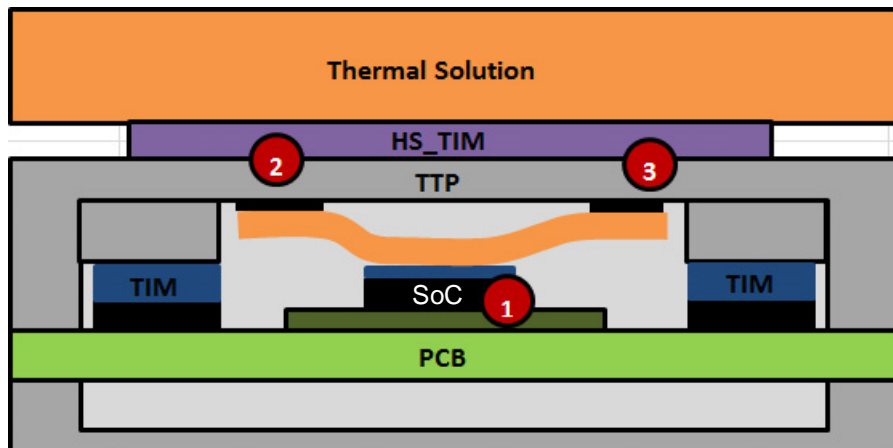


TIM Area for efficient cooling

In the Z-direction, the cold plate thermocouples should be located on the surface of the TTP as shown in Figure 3-2, indicated by Location 2 and Location 3. During thermal qualification, these are the only temperatures that need to be monitored with a thermocouple. The Xavier SoC temperature (Location 1) is monitored via software. Note the following for Figure 3-3:

- ▶ Jetson AGX Xavier Contents
 - Thermal transfer plate and backside stiffener - The thermal transfer plate has an internal heat spreader plate connected to the Xavier SoC in order to reduce the thermal performance variation between workloads.
 - PCB with components.
 - TIM - Henkel GF3500S35. TIM is applied on all components necessary to maintain the component temperatures within their specified limits.
- ▶ Customer Requirements (The customer is responsible for the following items)
 - HS_TIM - The customer is responsible for providing the thermal interface material between the TTP and the 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.
 - Thermal Solution - A thermal solution capable of cooling the appropriate amount of TMP for the target workload.
 - Maximum TTP Temperature - To ensure that the maximum Xavier SoC operating temperature is less than the value specified in Table 2-1 (shown as Location 1 in Figure 3-3), and the maximum TTP temperature must not exceed the value specified in Table 2-1 (shown as Location 2 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 NVIDIA TTP and provides cooling. The thermal solution must attach to the top surface of the TTP, but a variety of 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 TTP is critical for maximizing the thermal performance of the Jetson AGX Xavier. The Xavier SoC is located directly under the TTP and consumes the majority of the TDP. Thus, using a TIM that provides good thermal contact between the thermal solution and the TTP is crucial.
- ▶ NVIDIA thermal testing has demonstrated that as long as the TTP temperature does not exceed the maximum specified temperature, then the rest of the components will be within their specified operating temperature range.
- ▶ The customer thermal solution should include adequate margin to account for module to module variations.

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 to not exceed that which the component is qualified. NVIDIA's 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

Jetson AGX Xavier partners should refer to the CAD model provided in Section 1.2 for the exact product dimensions to determine how to interface the TTP with their thermal solution and ensure mechanical compatibility in their system. The top view, bottom view, and side views are shown in Figure 3-4, Figure 3-5, and Figure 3-6, respectively.

Figure 3-4. Jetson AGX Xavier Top View

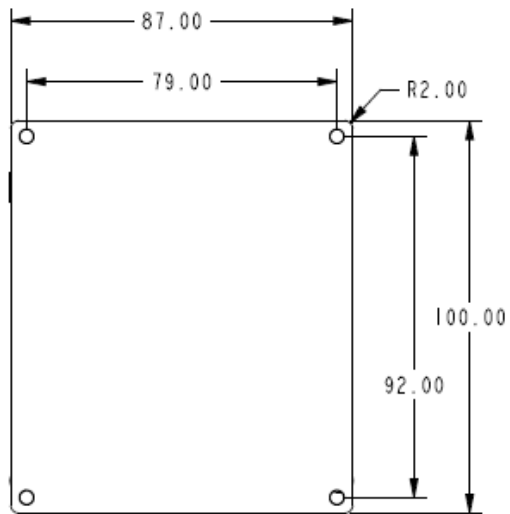


Figure 3-5. Jetson AGX Xavier Bottom View

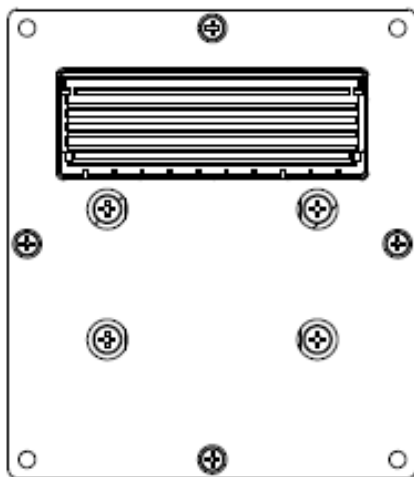


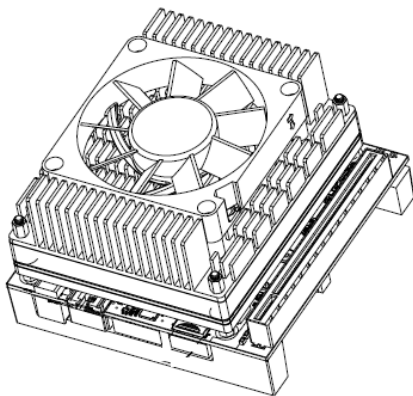
Figure 3-6. Jetson AGX Xavier Side View



3.2.1 Assembly Guidelines

The Jetson AGX Xavier and TTP are provided as a complete unit. Orientation of the unit is to be aligned with the board-to-board connector and secured to the baseboard as shown in Figure 3-7. Care should be taken to make sure that the mounting screws are not inserted at an angle and that they go through the thermal solution, the TTP, and the backside stiffener. The mounting screws must thread into standoffs that contact the backside stiffener to support the module. Note that the connector alone cannot be used to support the module.

Figure 3-7. Jetson AGX Xavier System Assembly Example

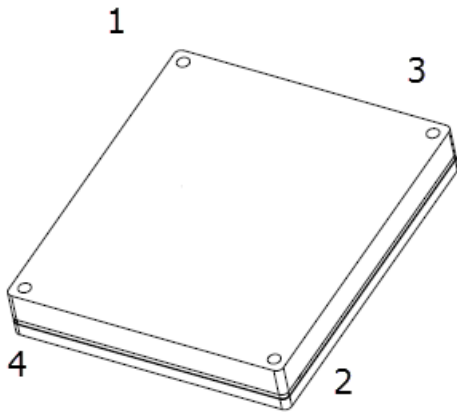


The following are suggested assembly guidelines.

1. Install the Jetson AGX Xavier by the carefully aligning the module connector with the base board connector.
2. Insert the module connector into the base board connector.

3. Install each mounting M3 screw into the heat sink.
 - a). If the TIM has been pre-applied to the heat sink, make sure to remove the protective cap covering the TIM.
 - b). If the TIM was not pre-applied to the heat sink, apply the TIM to the center of the module as shown in Figure 3-2.
4. Align the heat sink with the module.
5. Each mounting M3 screw should be attached loosely in the sequence shown in Figure 3-8. The tightening sequence should be followed for two cycles. On the last tightening sequence, the screws should be fully torqued.

Figure 3-8. Mounting Screw Sequence



Chapter 4. Software Thermal Management

4.1 Temperature Monitoring

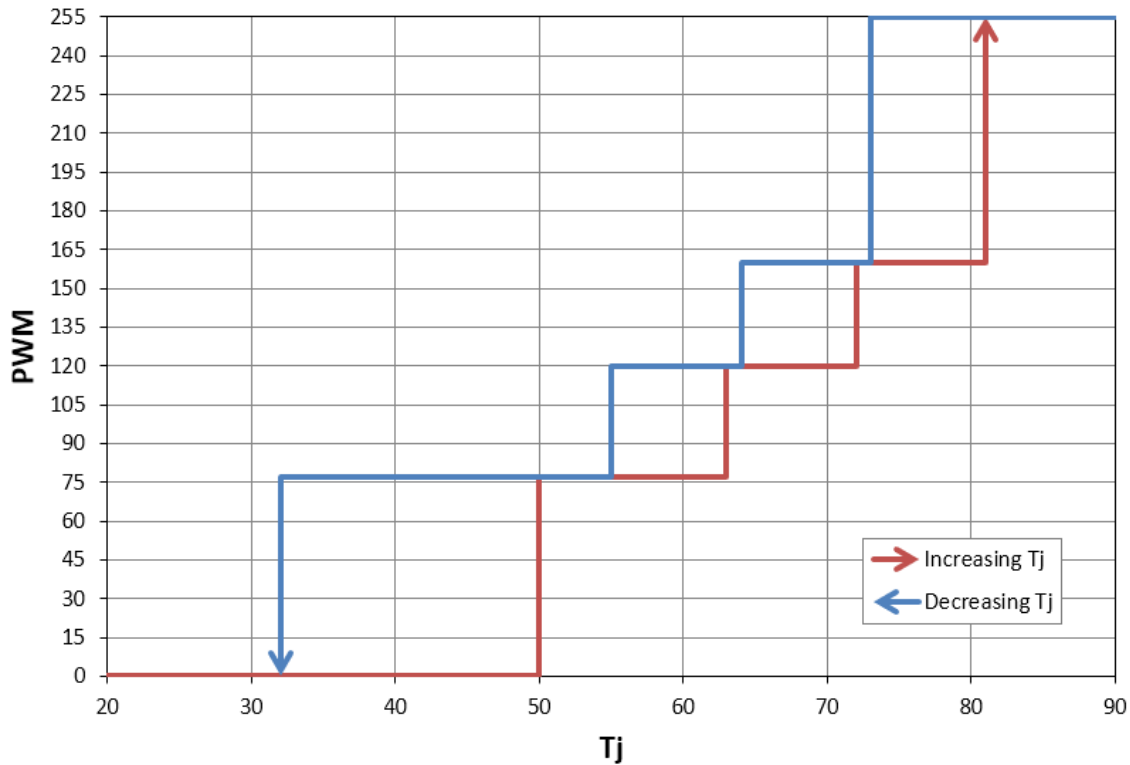
The Xavier SoC junction temperature can be directly read from sysfs nodes, as shown in the following example. Note that the name of each temperature zone is noted in the type node and that the temperature values are reported in units of m °C.

```
# cat /sys/devices/virtual/thermal/thermal_zone0/type
bcpu-therm
# cat /sys/devices/virtual/thermal/thermal_zone0/temp
35000
```

4.2 Fan Control

The Jetson AGX Xavier can be configured to control a system fan. Pulse width modulation (PWM) output and tachometer input are supported. Jetson AGX Xavier has configurable fan control of step-based speed control with hysteresis, example as shown in Figure 4-1.

Figure 4-1. Fan Control Behavior



The default fan table is listed in Table 4-1. Note that PWM is configured on a 2⁸ scale, with 255 being equivalent to 100% duty cycle.

Table 4-1. Jetson AGX Xavier Default Fan

| "thermal fan-est" Thermal Zone Temperature ¹ | PWM | Hysteresis ² (°C) |
|---|-----|------------------------------|
| 50 | 77 | 18 |
| 63 | 120 | 8 |
| 72 | 160 | 8 |
| 81 | 255 | 8 |

Notes:

¹Fan 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.

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

For example, 81 °C – 8 °C = 73 °C, which is greater than the 160 PWM trip point at 72 °C.

4.3 Xavier SoC Recommended Operating Temperature Limit

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 uncertainty of $\pm 4^\circ\text{C}$.

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 by the DVFS algorithm.
- ▶ 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 time period.
 - Throttle 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 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.

4.4 Xavier SoC Hardware Thermal Throttling

If the software thermal management is not able to maintain the Xavier SoC temperature, then the hardware thermal throttling will engage in an attempt to prevent an over-temperature thermal trip. Thermal trips on Jetson AGX Xavier cause the system to reset. To avoid thermal trip conditions without being overly conservative, Xavier SoC has hardware-engaged clock throttling mechanisms that are used as a last resort to prevent thermal trip 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 product safety and reliability standards.

4.5 Xavier SoC Thermal Trip Temperature

The Xavier SoC is rated to operate at a junction temperature not-to-exceed 105 °C for Jetson AGX Xavier or 125 °C for Jetson AGX Xavier Industrial. Jetson AGX Xavier has hardware thermal trip mechanisms that enforce this limit by automatically performing a system reset when this temperature is exceeded.

The thermal trip 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 Xavier SoC under worst-case conditions. If a thermal trip event is triggered, then a major fault in the Jetson AGX Xavier or system cooling solution has occurred. Thermal trip 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 trip mechanisms have been implemented:

- ▶ Internal sensor-based thermal trip - Failsafe thermal trip is guaranteed by using the thermal trip signal directly from the SoC to the PMIC. After the failsafe thermal trip, the system will reset without the user pressing the power button or equivalent input.
- ▶ T.diode/temperature-monitor-based thermal trip - When the external temperature monitor detects that the T.diode temperature is above a pre-programmed thermal trip, the monitor's THERM output signals the PMIC to reset the system without any software control. This is a back-up mechanism to the internal sensor-based thermal trip, so it is intentionally margined to a higher temperature to avoid contention with internal sensor-based thermal trip.

The Xavier SoC thermal trip settings cannot be altered. These settings are implemented by NVIDIA to meet product safety and reliability standard.

Chapter 5. Optimizing Jetson AGX Xavier for Power and Performance

5.1 Power Supply

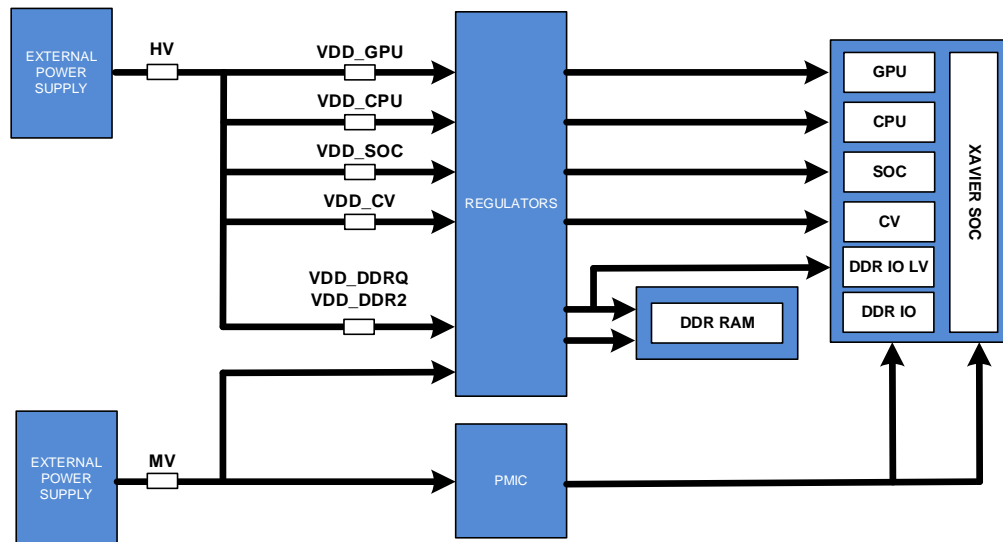
The choice of voltage for the input power supply to the Jetson AGX Xavier has an impact on the overall power efficiency. There are two input voltage rails for Jetson AGX Xavier: `sys_vin_hv` and `sys_vin_mv`. The input voltage for `sys_vin_hv` can range from 9V to 19V while `sys_vin_mv` requires 5V. For optimal efficiency, a lower voltage power supply should be used. For example, a standard 9V power supply provides better efficiency over a 19V one. As the input voltage increases from 9V up to 19V the module operating efficiency will drop off.

5.2 Power Measurement Hardware

The Jetson AGX Xavier module has 2 power monitors on board for measuring power consumption of the total module power. `VDD_GPU`, `VDD_CPU`, and `VDD_SOC` are measured by one of the power monitors. `VDD_CV`, `VDDQ`, and `SYS5V` are measured by the other power monitor.

Figure 5-1 shows the block diagram of the power supply and the rails that can be measured with built-in power monitors. The built-in power monitor has a range up to 26 V, which makes it possible to measure all the ranges that are supported on Jetson AGX Xavier. The location of the measurement points is shown in Figure 5-1. Note that the SOC, CPU, GPU, CV, and DDR power rails are sampled BEFORE the voltage regulator, so any measurements include the voltage regulator losses.

Figure 5-1. Jetson AGX Xavier Module Power Rails



Upon system power up, the 2 power monitors report voltage and current values of the 6 power rails by averaging the last 512 samples from the continuously probed data. Power is calculated from these averaged samples (TBD).

The data is easily accessed by reading the corresponding sysfs nodes of the power monitors. It provides the data for measuring voltage, current, and power without the need for any additional instruments. The measurements reported by the power monitors are accurate within 5% (TBD).

5.3 Power Measurement Software Usage

The Jetson AGX Xavier module has 3-channel INA3221 monitors at I2C addresses 0x40 and 0x41. The sysfs nodes to read rail name, voltage, current, and power can be found under the INA3221 driver's directory:

```
/sys/bus/i2c/drivers/ina3221x
```

Among the listed addresses under the sysfs directory, 0-0040 and 0-0041 are the power monitors for supply rails on Jetson AGX Xavier module:

The following data can be obtained from the Sysfs:

```
Rail Name:      ../<address>/iio_device/rail_name_<Channel>
Current (mA) :  ../<address>/iio_device/in_current<Channel>_input
Voltage (mV) :   ../<address>/iio_device/in_voltage<Channel>_input
Power (mW) :     ../<address>/iio_device/in_power<Channel>_input
```

The address and channel allocations are given in Table 5-1.

Table 5-1. Address and Channel Allocation

| Power Rail | <Address> | Channel | Power Rail | <Address> | Channel |
|------------|-----------|---------|------------|-----------|---------|
| VDD_GPU | 0-0040 | 0 | VDD_CV | 0-0041 | 0 |
| VDD_CPU | 0-0040 | 1 | VDD_VDDRQ | 0-0041 | 1 |
| VDD_SOC | 0-0040 | 2 | VDD_SYS5V | 0-0041 | 2 |

Use the CAT commands to display each power rail's name along with voltage, current, and power consumption.

To display the name of the GPU rail:

```
$ cat /sys/bus/i2c/devices/1-0040/iio_device/rail_name_0
GPU
```

To display the current (in mA) of GPU rail:

```
$ cat /sys/bus/i2c/devices/1-0040/iio_device/in_current0_input
24
```

To display the voltage (in mV) of GPU rail:

```
$ cat /sys/bus/i2c/drivers/ina3221x/0-0040/iio_device/in_voltage0_input
19520
```

To display the power (in mW) of GPU rail:

```
$ cat /sys/bus/i2c/drivers/ina3221x/0-0040/iio_device/in_power0_input
468
```

Note that reading internal nodes utilizes internal CPU resources. Thus, accessing the nodes too frequently will incur excessive amount of power consumption due to this reading task.

It is recommended to set the sample interval to 1 second or longer.

Since the power consumption of the system can change with temperature, it is also recommended that the power measurements be performed after the system has warmed up to a steady state and is running the application at target ambient temperature.

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