Jetson TX2 Series

Thermal Design Guide

TDG-09420-001_v1.1 | March 2020

Document History

TDG-09420-001_v1.1

Version	Date	Description of Change
1.0	March 11, 2019	Initial Release
1.1	March 31, 2020	• Added Jetson TX2 can also use the main mounting holes for mounting the thermal solution (Section 1.3.2) • Updated Figure 1-5 to included arrows and text pointing out threaded holes in TTP on Jetson TX2 • Updated Figure 1-6 to included arrows and text pointing out main mounting holes that must be used for mounting thermal solution for Jetson TX2 4GB and Jetson TX2i • Updated Figure 3-11 to show 3 mm max depth for threaded holes for mounting heat sink.

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 Series modules.

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

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® Tegra® X2 and TTP temperatures below the specified temperatures in 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 Series modules to sustain the maximum thermal load for their use case.
- Customers are responsible for qualification of the Jetson TX2 Series modules in their system and are responsible for any issues related to failure to qualify the product properly.
- The thermal transfer plate (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 TX2 Series modules.

- Jetson TX2 Series Module 3D CAD STEP Model
  A 3D mechanical model of the boards are available in the universal .stp file format. The models are provided to enable system level mechanical fit checks, mounting and wiring planning.
- Jetson TX2 Series Module Data Sheet
  The mechanical drawing of the Jetson TX2 Series modules are 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 enough cooling for the Jetson TX2 Series modules 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 Tegra 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 TX2 Series modules are provided with a thermal transfer plate (TTP) to simplify integration with a system-level thermal solution. The Jetson TX2 is shown in Figure 1-1 and Figure 1-2. The TTP design mechanically isolates the PCB and components from external mechanical forces, standardizes the thermal and mechanical interface, and allows for modular system design.

Figure 1-1. Jetson TX2 – Topside View

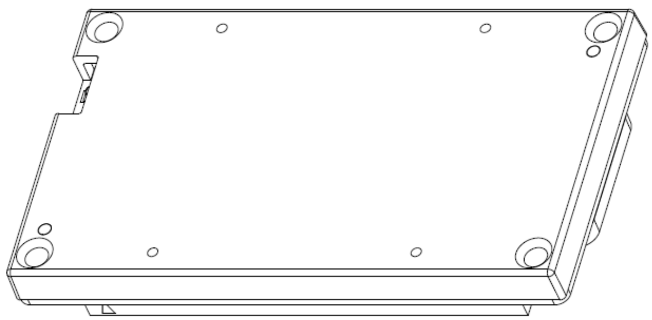
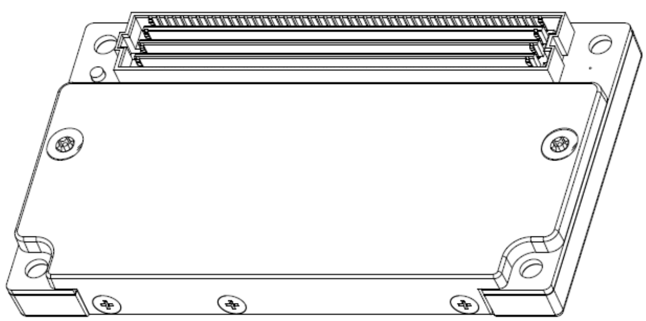


Figure 1-2. Jetson TX2 – Backside View



The Jetson TX2 4GB and Jetson TX2i is shown in Figure 1-3 and Figure 1-4.

Figure 1-3. Jetson TX2 4GB and Jetson TX2i – Topside View

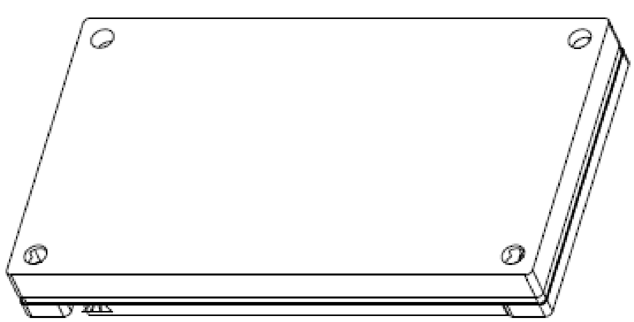
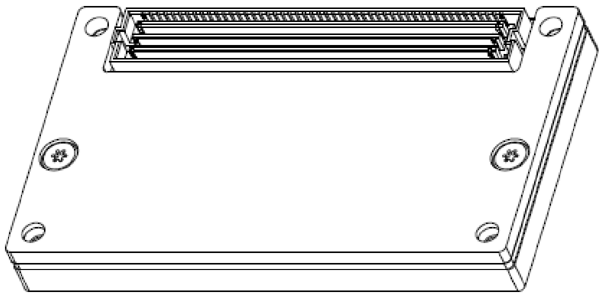


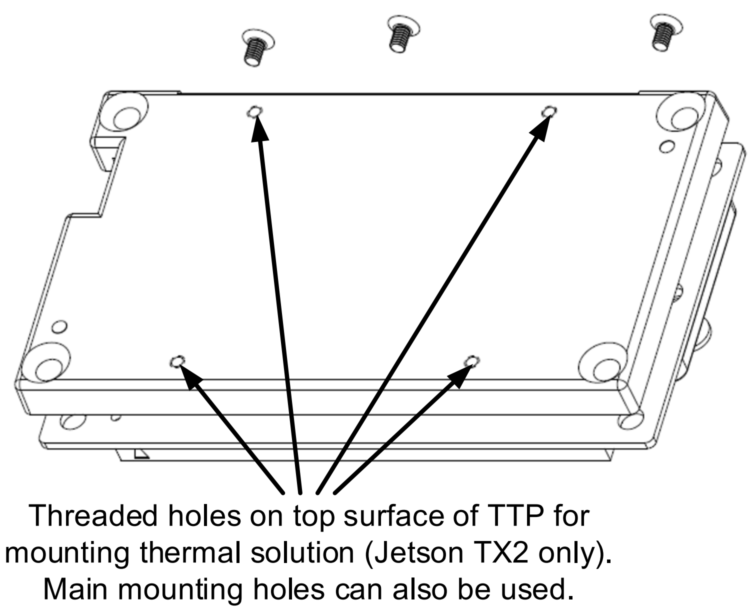
Figure 1-4. Jetson TX2 4GB and Jetson TX2i – Backside View



For Jetson TX2, the thermal solution of the customer's system design should attach to the top surface of the TTP. Mounting holes are provided on the top surface of the TTP to enable attachment of the customer's thermal solution. The thermal solution may also be attached using the main mounting holes as described for Jetson TX2 4GB and Jetson TX2i following. More details are provided for both attachment methods in Section 3.2.

An exploded view of the Jetson TX2 assembly is shown in Figure 1-5. The PCB is completely covered by the TTP (thermal transfer plate), except for the Wi-Fi antenna connectors.

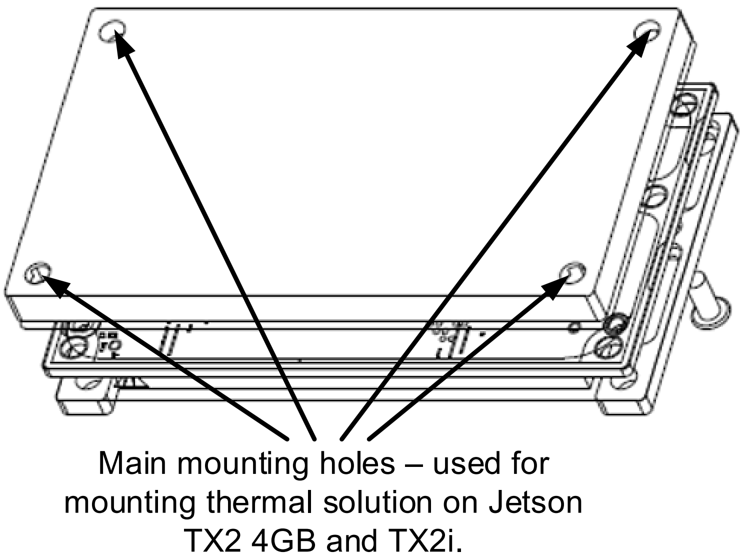
Figure 1-5. Jetson TX2 Design – Exploded View



For Jetson TX2 4GB and Jetson TX2i, 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 TX2 4GB and Jetson TX2i assembly is shown in Figure 1-6. The PCB is completely covered by the TTP. The TTP design mechanically isolates the Jetson TX2 4GB and Jetson TX2i board and components from external mechanical forces, standardizes the thermal and mechanical interface, and allows for modular system design.

Figure 1-6. Jetson TX2 4GB and Jetson TX2i Design – Exploded View



1.3.3 Tegra X2 Temperature

The Tegra X2 junction temperature (T_j) represents the Tegra X2 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. Jetson TX2 Series Specifications

2.1 Thermal Specifications

On Tegra X2 there are multiple on-die temperature sensors that are placed close to dominant hotspots to measure the junction temperature. A built-in hardware controller is used to read the sensors and engage thermal protection mechanisms. Chapter 4 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 Series module.

Table 2-1. Jetson TX2 Series Thermal Specifications

Parameter	Value			Units
	Jetson TX2	Jetson TX2 4GB	Jetson TX2i	
Maximum TTP operating temperature[1]	80	80	85	°C
Recommended Tegra X2 operating temperature limit[2]	T.cpu = 95.5	T.cpu = 95.5	T.cpu = 95.5	°C
	T.gpu[4] = 95.5	T.gpu[4] = 95.5	T.gpu[4] = 95.5	°C
Tegra X2 maximum operating temperature limit[3]	T.cpu = 101	T.cpu = 101	T.cpu = 101	°C
	T.gpu = 101	T.gpu = 101	T.gpu = 101	°C

Notes:

[1]The temperature of the TTP must always be kept under this 80 °C limit to maintain the required performance and reliability. The measurement location is provided in Figure 3-2 (Jetson TX2) or Figure 3-3 (Jetson TX2 4GB/TX2i).

[2]The Tegra X2 recommended 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 4.3 for details.

[3]The Tegra X2 will shut down the Jetson TX2 module or reset the Jetson TX2 4GB/TX2i module once any of these software-imposed temperature limits are reached to maintain the reliability of the Tegra X2. See Section 4.5 for details.

[4]The T.gpu temperature is measured by the “ao-therm” sensor.

Chapter 3. Jetson TX2 Series Design Guidance

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

3.1 Thermal Information

The design goal for system thermal management is to keep the Tegra X2 temperature and TTP temperature below the limits specified in Section 2.1. The TTP temperature limit maintains the component temperatures on Jetson TX2 Series modules within their temperature specifications.

3.1.1 Jetson TX2 Series Thermal Performance

The Jetson TX2 Series modules are 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:

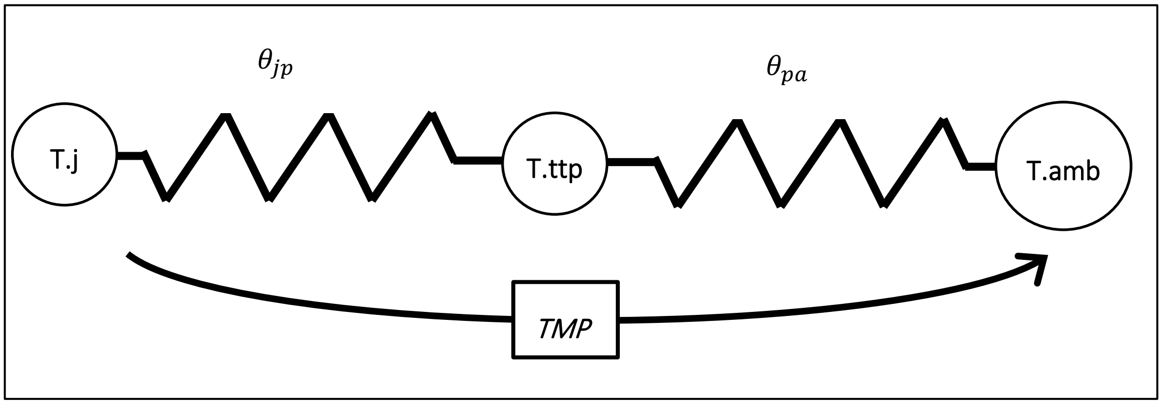
$$\theta_{12} = \frac{T_1 - T_2}{P}$$

Where:

θ_{12}	The thermal resistance between Point 1 and Point 2
T_n	The temperature at Point n
P	The heat load (i.e., 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 TX2 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 and hotspots in different logical partitions of the Tegra X2. While Jetson TX2 is designed to spread the heat and make the thermal performance as consistent as possible, different applications will result in different levels of thermal performance. The more evenly the module power is distributed across the Jetson TX2 the higher the thermal performance will be. A few examples of different workloads are shown in Table 3-1 for reference.

Table 3-1. Jetson TX2 Thermal Performance

	CPU Only Workload[1]		GLBenchmark ManhattanWorkload[2]	
	Jetson TX2	Jetson TX2 4GB and Jetson TX2i	Jetson TX2	Jetson TX2 4GB and Jetson TX2i
θ_{jp}	1.2 °C/W	1.0 °C/W	0.9 °C/W	0.75 °C/W
θ_{jb}	5.5 °C/W			

Notes:

[1]A CPU only workload and is one of the most thermally challenged use cases because the power is concentrated on a small area of the Tegra X2. This is not representative of most use cases.

[2]GLBenchmark Manhattan is a CPU light, GPU heavy, SoC light, DRAM heavy use case which results in power being widely distributed. It is representative of the thermal performance that is obtained with a more balanced workload.

[3]The θ_{jb} value is provided for simulation of the Jetson TX2 Series module as a 2-resistor model in commercial CFD packages. This is the resistance value from the junction temperature of Tegra to the back stiffener of the TTP.

The thermal resistance of the module (θ_{jp}) and heat sink (θ_{jp}) sum together for the overall thermal resistance from Tegra X2 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:

$$T.amb \ = \ 55°C$$

$T.gpu \ = \ 89°C$ (Allowing T.cpu headroom to account for sensor inaccuracy and possible Tj fluctuations resulting from workload variation)

$$\theta_{jp} \ = \ 0.90 \ \frac{°C}{W}$$

$P_{TMP} \ = \ 12W$

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

$$\theta_{ja} = \theta_{jp} + \theta_{pa} \rightarrow \theta_{pa} = \theta_{ja} - \theta_{jp} = \frac{89°C - 55°C}{12W} - \theta_{jp} = 2.83\frac{°C}{W} - 0.90\frac{°C}{W} = 1.93\frac{°C}{W}$$

So the heat sink's thermal performance (θ_{pa}) must be better than 1.93 °C/W. Next, check that the TTP temperature will be below the 80 °C specification.

$$\theta_{pa} = \frac{T_p - T_a}{P} \rightarrow \ T_p = \theta_{pa} * P + T_a = 1.93\frac{°C}{W} * 12W + 55°C = 78.2°C$$

So a 1.93 °C/W or better thermal solution will be sufficient to achieve the target use case.

3.1.2 Jetson TX2 Thermal Design Details

The Jetson TX2 Series 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 contact the top surface of the TTP.

For Jetson TX2, the 39 × 45 mm area directly above the Tegra X2, as shown in Figure 3-2, is the key contact area for efficient cooling performance. For Jetson TX2 4GB and Jetson TX2i, the 40 × 45 mm area directly above the Tegra X2, as shown in Figure 3-3, 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 TX2 Series module 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 location indicated by a red cross (+) in Figure 3-2 (Jetson TX2) or Figure 3-3 (Jetson TX2 4GB and Jetson TX2i).

Figure 3-2. Jetson TX2 Location of TTP Thermocouple

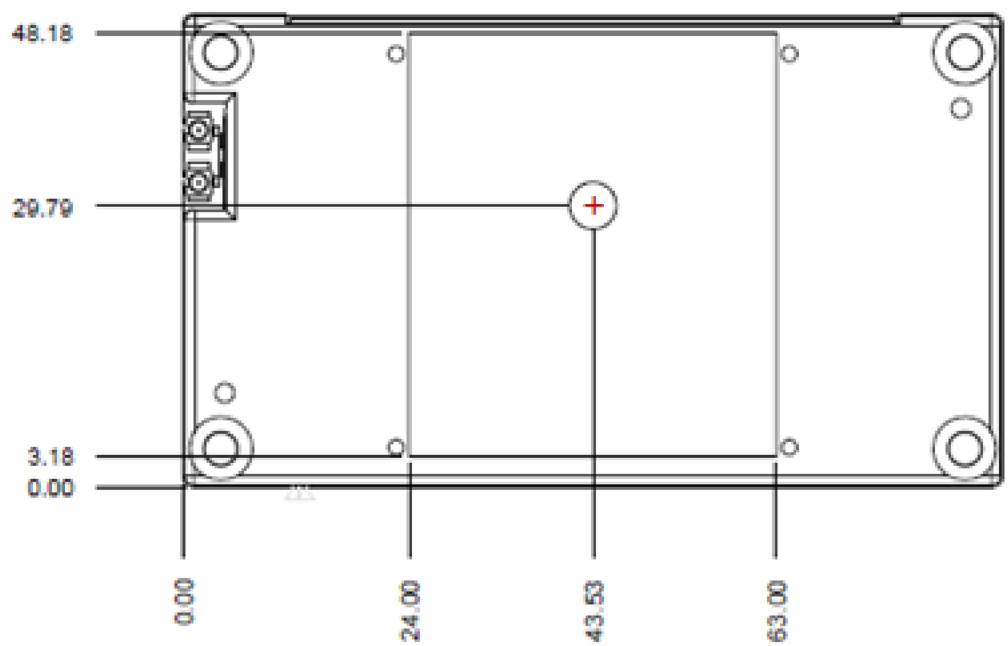
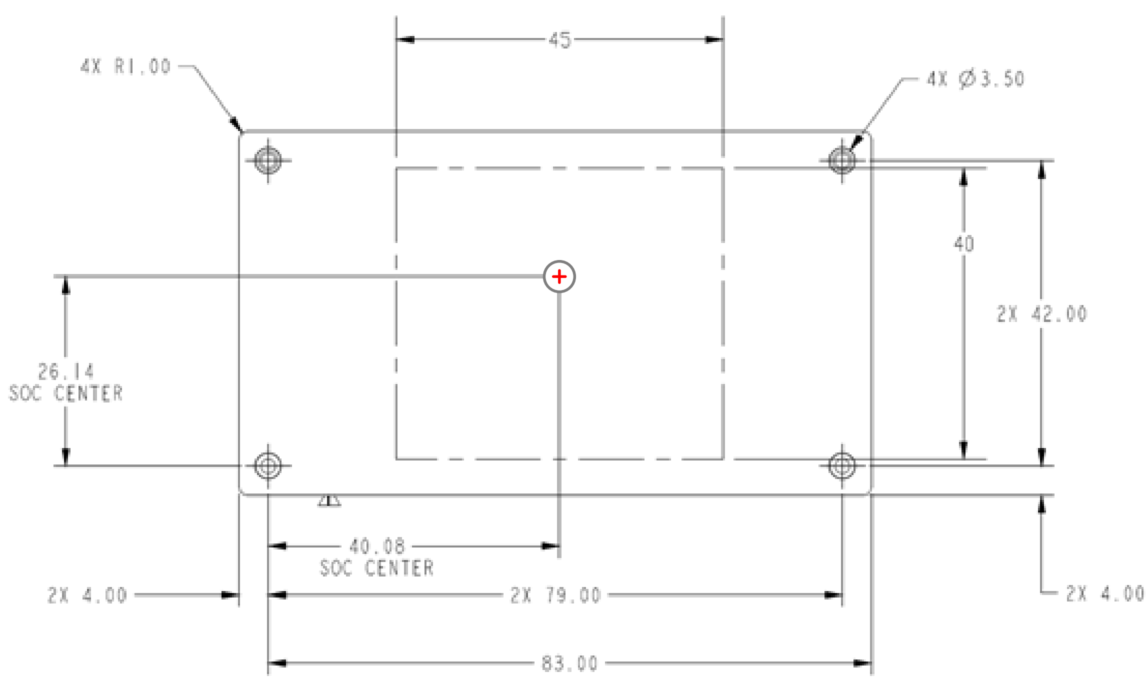


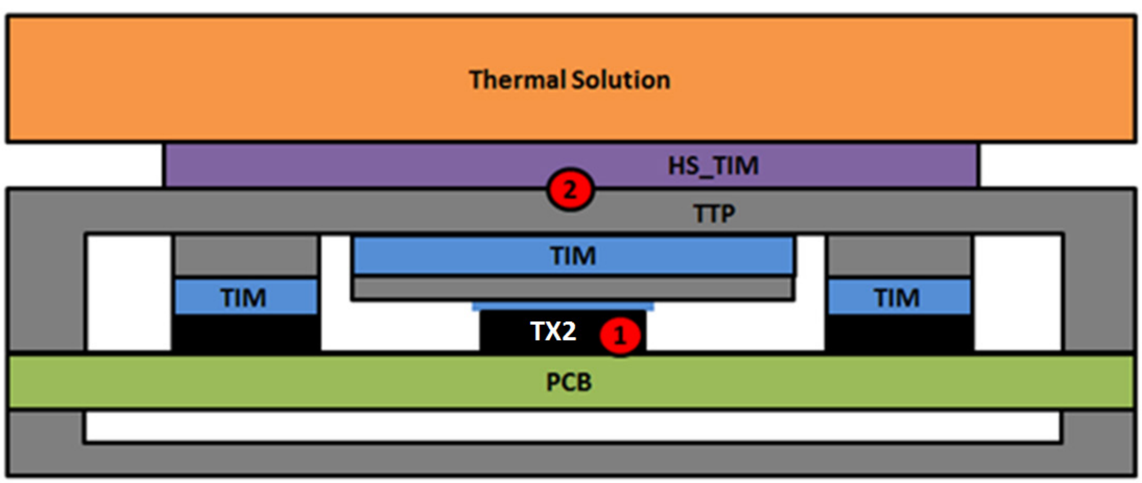
Figure 3-3. Jetson TX2 4GB and Jetson TX2i Location of Thermocouple



In the Z-direction, the cold plate thermocouple should be located on the surface of the TTP as shown in Figure 3-4, indicated by Location 2. During thermal qualification, this is the only temperature that needs to be monitored with a thermocouple. The Tegra X2 temperature (Location 1) is monitored via software. Note the following for Figure 3-4:

- Jetson TX2 Series Contents
  - Thermal transfer plate and backside stiffener - The thermal transfer plate has an internal heat spreader plate connected to Tegra X2 in order to reduce the thermal performance variation between workloads.
  - PCB with components.
  - TIM - Henkel GF3500S35. TIM is applied 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 Tegra X2 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 3-4).

Figure 3-4. 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 recommendation are applicable:

- Good contact of the thermal solution to the TTP is critical for maximizing the thermal performance of the Jetson TX2 Series module. The Tegra X2 is located directly under the TTP and consumes the majority of the TMP. Thus, good thermal contact between the thermal solution and the center of the TTP is crucial.
- NVIDIA thermal testing has demonstrated that if the TTP temperature does not exceed the maximum specified temperature, then the rest of the components will be within their specified operating temperature range.

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 TX2 Series partners should refer to the CAD model referred to 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 of Jetson TX2 are shown in Figure 3-5, Figure 3-6, and Figure 3-7, respectively. The top view, bottom view, and side views of Jetson TX2 4GB and Jetson TX2i are shown in Figure 3-8, Figure 3-9, and Figure 3-10, respectively.

Figure 3-5. Jetson TX2 Top View

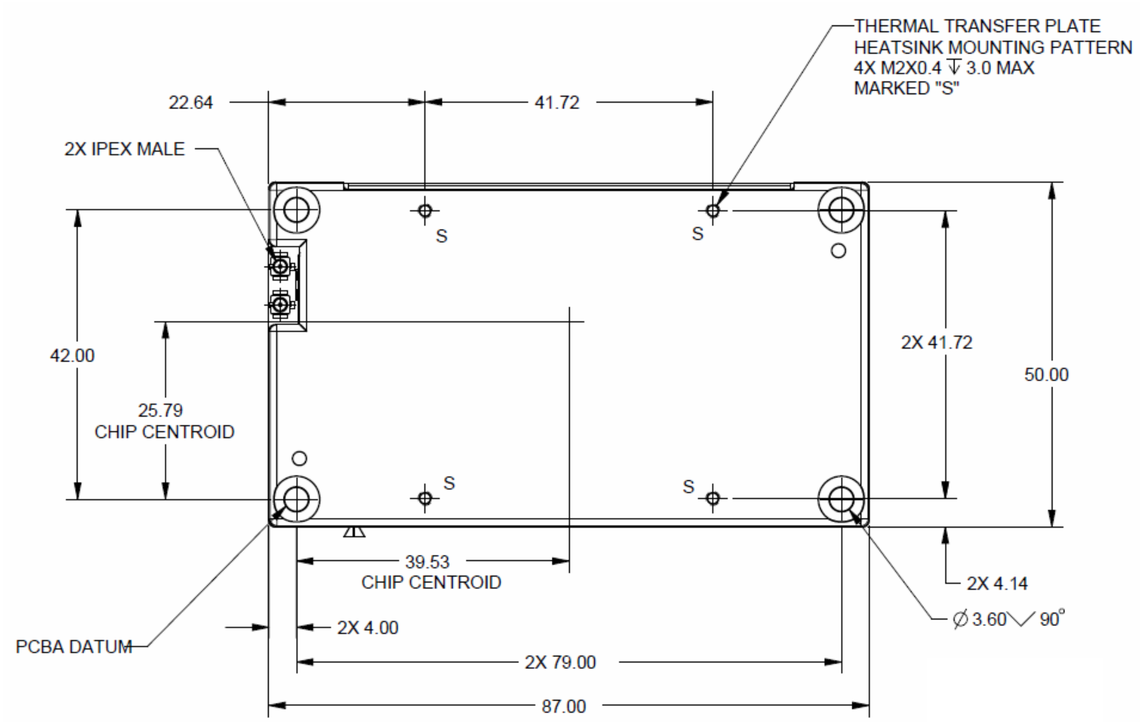


Figure 3-6. Jetson TX2 Bottom View

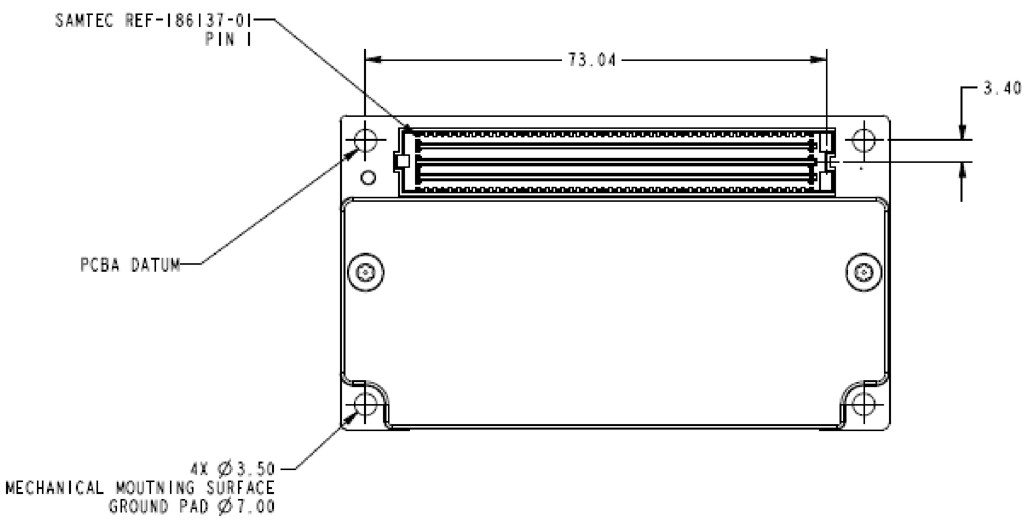


Figure 3-7. Jetson TX2 Side View

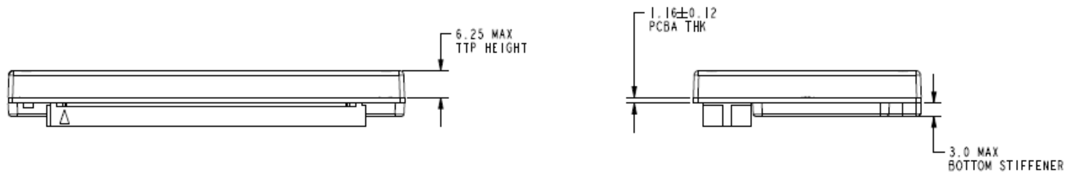


Figure 3-8. Jetson TX2 4GB and Jetson TX2i Top View

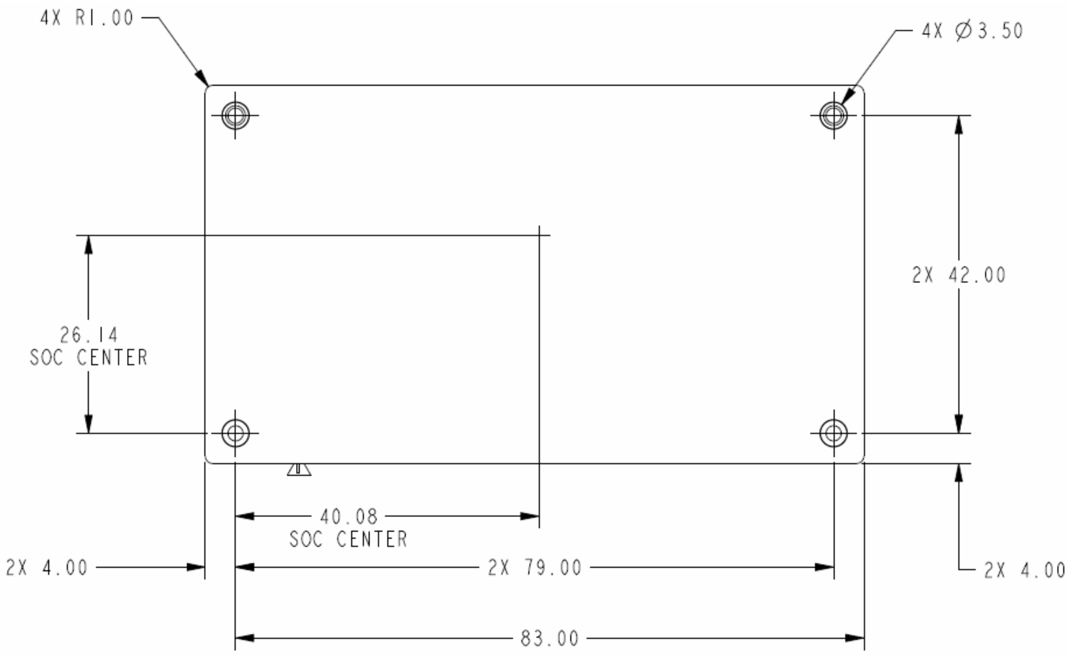


Figure 3-9. Jetson TX2 4GB and Jetson TX2i Bottom View

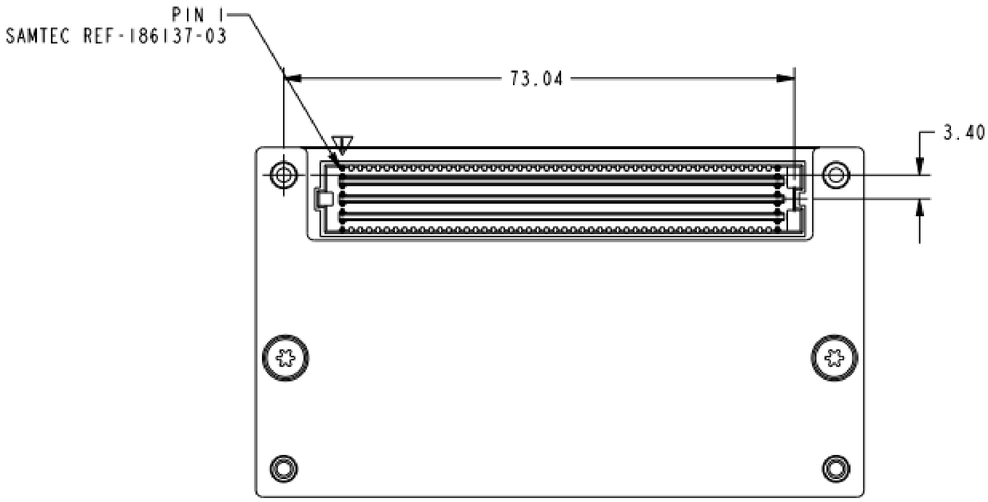
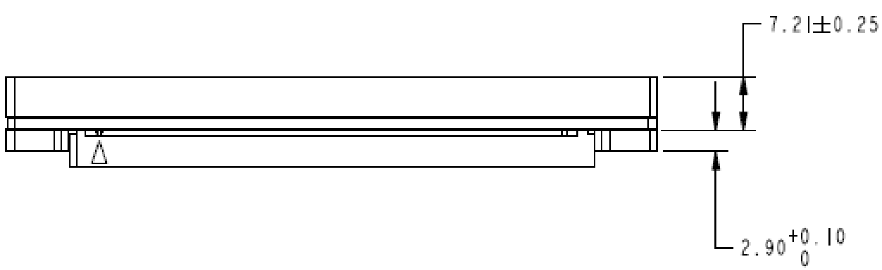


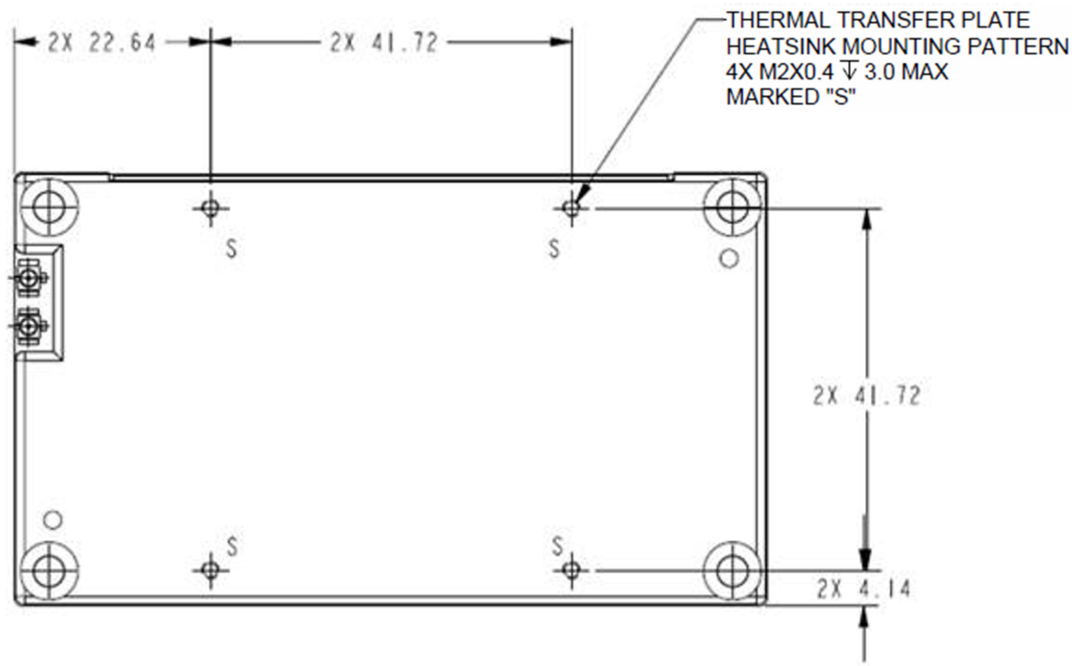
Figure 3-10. Jetson TX2 4GB and Jetson TX2i Side View



3.2.1 Jetson TX2 Heat Sink Mounting Guidelines

As noted in the thermal section, the mechanical design of the system must ensure good contact between the thermal solution and the TTP. The TTP is provided with mounting holes to accommodate mounting options for a heat sink. M2 screws should be used for mounting customer's heat sink. The depth of the M2 threaded hole on the TTP is 2.5 mm maximum as shown in Figure 3-11. Hardware threaded beyond the 2.5 mm depth could lead to permanent damage.

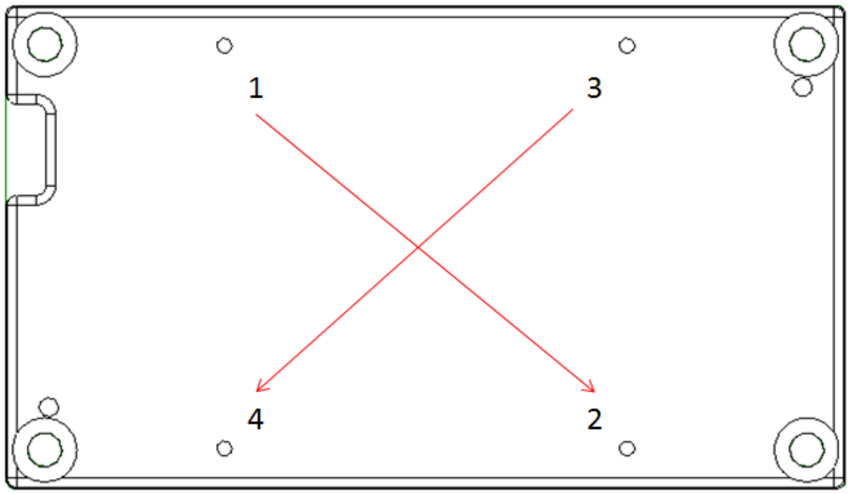
Figure 3-11. Heat Sink Mounting Pattern



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

- M2X0.4 screws should be used for all mounting holes locations.
- For all mounting screws, a maximum torque of 0.1 N-m is recommended. The tightening sequence shown in Figure 3-12 should be done in two cycles with the last one as maximum torques recommended.
- M2 screw depth requirements - Refer to Figure 3-11.
  - Item 1: The four mounting holes in the TTP area should not exceed a depth of 3.0 mm as measured from the surface of the TTP.
  - Item 2: Follow the torque pattern sequence as shown in Figure 3-12.

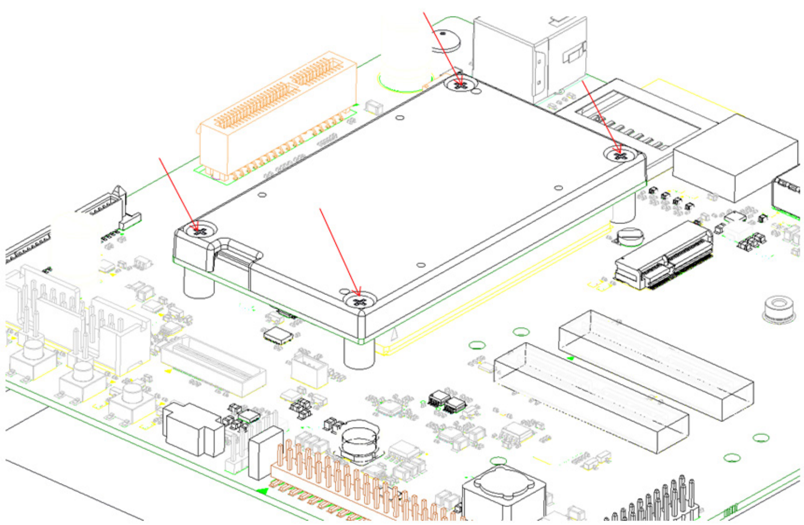
Figure 3-12. Torque Pattern Sequence



3.2.2 Jetson TX2 Assembly Guidelines

The Jetson TX2 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 3-13. Suggested hardware for mounting is four M3X0.5X7 mm long female-female standoffs.

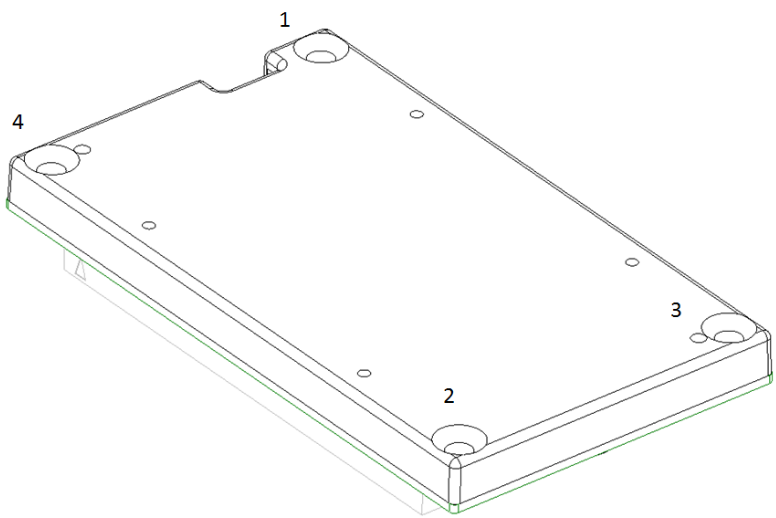
Figure 3-13. Jetson TX2 System Assembly Example



Here are some suggested assembly guidelines.

1. Assemble the heat sink and fan combination.
2. Install the Jetson TX2 by the carefully aligning the connector.
   Each mounting M3 screw should be attached loosely in the sequence shown in Figure 3-14. The tightening sequence should be followed for two cycles. On the last tightening sequence, the screws should be fully torqued.

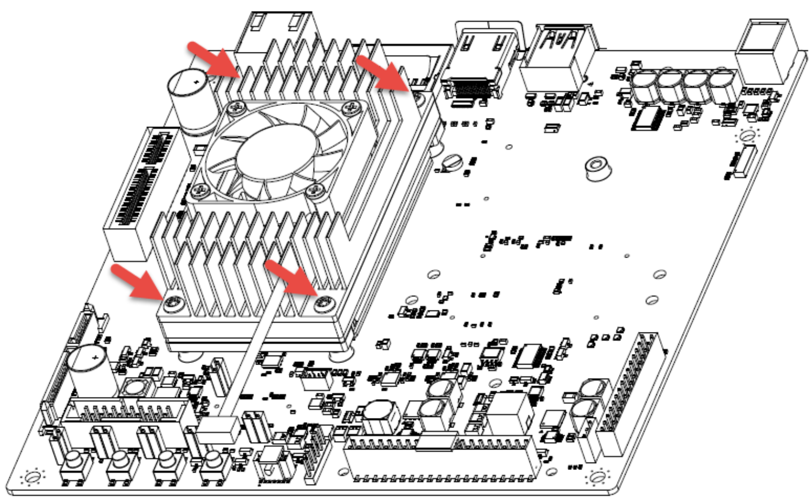
Figure 3-14. Mounting Screw Sequence



3.2.3 Jetson TX2 4GB and Jetson TX2i Assembly Guidelines

The Jetson TX2 4GB and Jetson TX2i 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 3-15. 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.

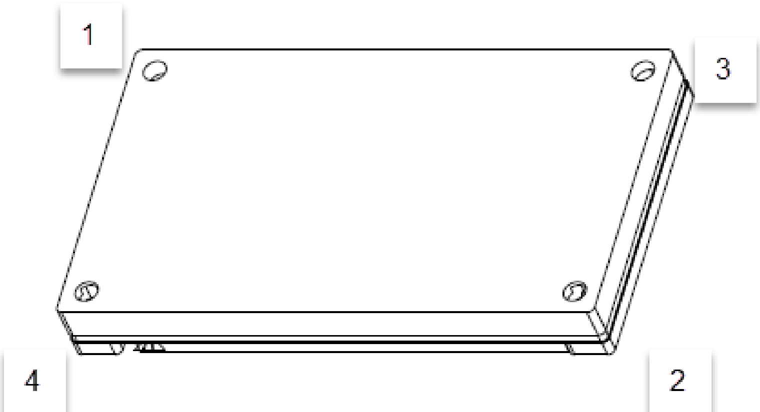
Figure 3-15. Jetson TX2i System Assembly Example



The following are suggested assembly guidelines.

1. Install the Jetson TX2 4GB and Jetson TX2i 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 3-16.
4. Align the heat sink with the module.
5. Each mounting M3 screw should be attached loosely in the sequence shown in Figure 3-16. The tightening sequence should be followed for two cycles. On the last tightening sequence, the screws should be fully torqued.

Figure 3-16. Jetson TX2 4GB and Jetson TX2i Mounting Screw Sequence



Chapter 4. Software Thermal Management

4.1 Temperature Monitoring

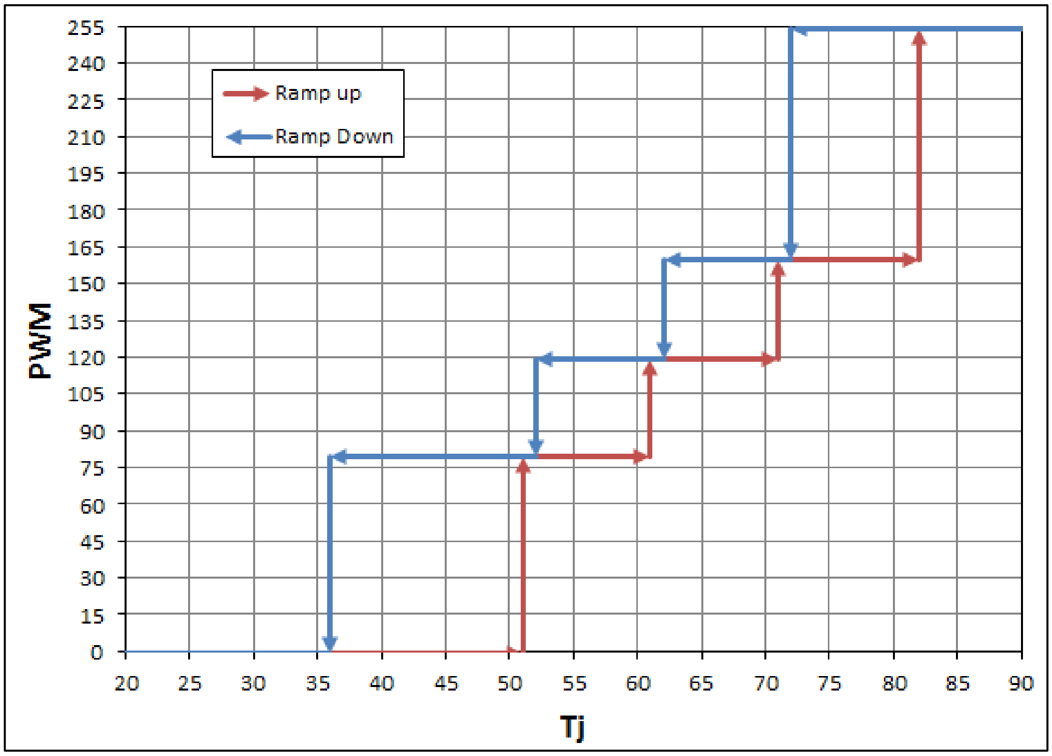
The Tegra X2 junction temperature can be directly read from sysfs nodes, as shown in the following example. Note that the name of each temperature zone is noted in the type node and that the temperature values are reported in units of m °C.

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

4.2 Fan Control

The Jetson TX2 Series modules can be configured to control a system fan. Pulse width modulation (PWM) output and tachometer input are supported. Jetson TX2 Series modules have configurable fan control of step-based speed control with hysteresis, 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 2^8 scale, with 255 being equivalent to 100% duty cycle.

Table 4-1. Jetson TX2 Series Default Fan

"thermal-fan-est" Thermal Zone Temperature[1]	PWM	Hysteresis[2] (°C)
51	80	15
61	120	9
71	160	9
82	255	10

Notes:

[1]Fan speed is controlled by thermal-fan-est thermal zone, which is the average of BCPU-therm, MCPU-therm, and GPU-therm.

[2]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.

4.3 Tegra X2 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 4-1 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 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 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.

4.4 Tegra X2 Hardware Thermal Throttling

If the software thermal management is not able to maintain the Tegra X2 temperature, then the hardware thermal throttling will engage to prevent an over-temperature thermal trip. Thermal trips on Jetson TX2 Series modules cause the system to reset. To avoid thermal trip conditions without being overly conservative, Tegra X2 has hardware-engaged clock throttling mechanisms that are used as a last resort to prevent thermal trip 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 product safety and reliability standards.

4.5 Tegra X2 Thermal Trip Temperature

Tegra X2 is rated to operate at a junction temperature not-to-exceed 105 °C.

On Jetson TX2 4GB and Jetson TX2i, the hardware shutdown mechanism enforces this limit by automatically performing a system reset when this temperature is exceeded.

On Jetson TX2, the hardware shutdown mechanism enforces this limit by automatically halting the system 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 Tegra X2 under worst-case conditions. If a thermal trip event is triggered, then a major fault in the Jetson TX2 Series module 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 in Jetson TX2 4GB and Jetson TX2i:

- Internal sensor-based thermal trip - Failsafe thermal trip is guaranteed by using the thermal trip signal directly from Tegra 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 following thermal trip mechanisms have been implemented on Jetson:

- Internal sensor-based shutdown- Failsafe thermal shutdown is guaranteed by using the SHUTDOWN signal directly from Tegra 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.
- T.diode/temperature-monitor-based shutdown- When the external temperature monitor detects that the T.diode temperature is above a pre-programmed T.shutdown, the monitor's THERM output signals the PMIC to shut down the system without any software control. This is a back-up mechanism to the internal sensor based shutdown, so its T.shutdown is intentionally margined to a higher temperature to avoid contention with internal sensor-based shutdown.

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

Chapter 5. Optimizing Jetson TX2 Series Modules for Power and Performance

5.1 Power Supply

The choice of voltage for the input power supply to the Jetson TX2 Series modules has an impact on the overall power efficiency. The input voltage can range from 5.5V to 19V for Jetson TX2 or 9V to 19V for Jetson TX2 4GB and Jetson TX2i. 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.

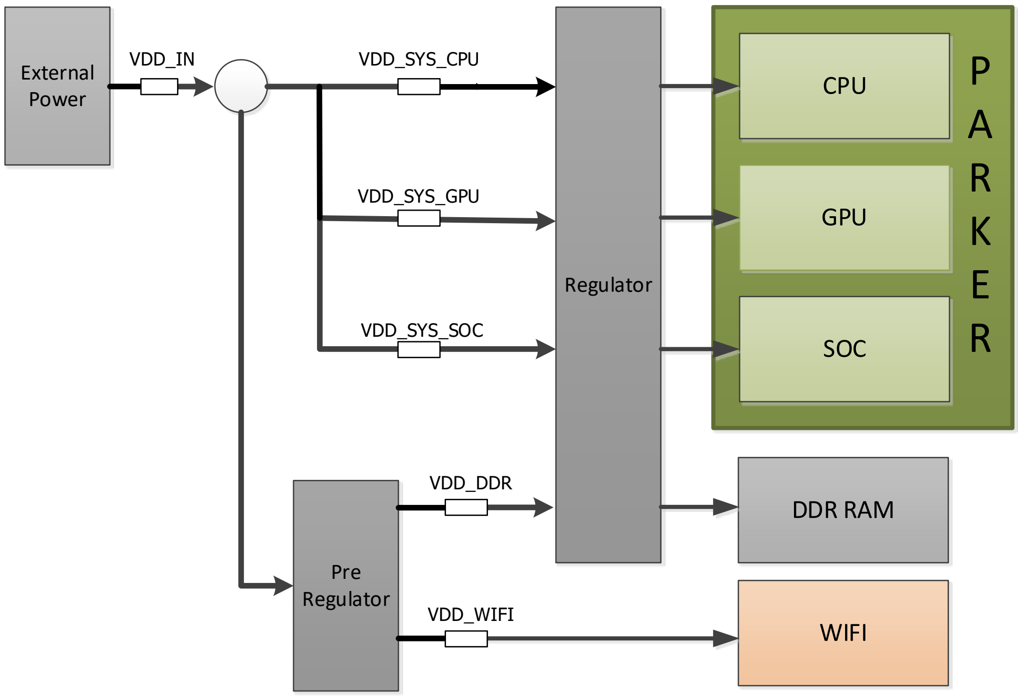
5.2 Power Measurement Hardware

The Jetson TX2 Series modules have 2 power monitors on board for measuring power consumption of the primary supply rails.

- For Jetson TX2, VDD_IN, VDD_DDR and VDD_WIFI are all measured by one of the power monitors. VDD_SYS_CPU, VDD_SYS_GPU and VDD_SYS_SOC are measured by the other power monitor.
- For Jetson TX2 4GB and Jetson TX2i, VDD_IN, VDD_SYS_CPU, and VDD_DDR are measured by one of the power monitors. VDD_SYS_GPU, and VDD_SYS_SOC 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. VDD_IN, VDD_SYS_CPU, VDD_SYS_GPU, VDD_SYS_SOC, and VDD_WIFI (Jetson TX2 only) voltage levels depend on external power source voltage level while VDD_DDR is supplied by a pre-regulator. 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 TX2 Series modules. The location of the measurement points is shown in Figure 5-1. Note that the SOC, CPU, GPU, and DDR power rails are sampled BEFORE the voltage regulator, so any measurements include the voltage regulator losses. VDD_IN shows the actual power values.

Figure 5-1. Jetson TX2 Series Module Power Rails



Note: Wi-Fi is only supported on Jetson TX2.

Upon system power up, the 2 power monitors report voltage and current values of the power rails by averaging the last 512 samples from the continuously probed data. Power is calculated from these averaged samples. The VDD_SYS_GPU, VDD_SYS_SOC, and VDD_WIFI (Jetson TX2 only) rails are probed in a round robin sequence. Similarly, VDD_IN, VDD_SYS_CPU, and VDD_DDR rails are also probed in a round robin manner.

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%.

5.3 Power Measurement Software Usage

The Jetson TX2 Series modules have 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 above sysfs directory, 0-0040 and 0-0041 are the power monitors for supply rails on Jetson TX2 Series 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_IN	0-0041	0
VDD_SOC	0-0040	1	VDD_CPU	0-0041	1
VDD_WIFI (Jetson TX2 only)	0-0040	2	VDD_DDR	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/drivers/ina3221x/0-0040/iio_device/rail_name_0
VDD_SYS_GPU
```

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

```
$ cat /sys/bus/i2c/drivers/ina3221x/0-0040/iio_device/in_current0_input
      8
```

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

```
$ cat /sys/bus/i2c/drivers/ina3221x/0-0040/iio_device/in_voltage0_input
      1909
```

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

```
$ cat /sys/bus/i2c/drivers/ina3221x/0-0040/iio_device/in_power0_input
      152
```

This is an example script that can report the average power consumed by each of the 6 rails (5 for Jetson TX2 4GB and Jetson TX2i – **VDD_4V0_WIFI** is only on Jetson TX2):

```
#!/bin/bash
```

```
# to measure average power consumed in 30sec with 1sec sampling interval
duration=30
interval=1

RAILS=("VDD_IN /sys/bus/i2c/drivers/ina3221x/0-0041/iio:device1/in_power0_input")
  "VDD_SYS_GPU /sys/bus/i2c/drivers/ina3221x/0-0040/iio:device0/in_power0_input"
  "VDD_SYS_CPU /sys/bus/i2c/drivers/ina3221x/0-0041/iio:device1/in_power1_input"
  "VDD_SYS_SOC /sys/bus/i2c/drivers/ina3221x/0-0040/iio:device0/in_power1_input"
  "VDD_SYS_DDR /sys/bus/i2c/drivers/ina3221x/0-0041/iio:device1/in_power2_input"
"VDD_4V0_WIFI /sys/bus/i2c/drivers/ina3221x/0-0040/iio:device0/in_power2_input")

for ((i = 0; i < ${#RAILS[@]}; i++)); do
  read name[$i] node[$i] pwr_sum[$i] pwr_count[$i] <<<$(echo "${RAILS[$i]} 0 0")
done

end_time=$(($(date '+%s') + duration))
while [ $(date '+%s') -le $end_time ]; do
  for ((i = 0; i < ${#RAILS[@]}; i++)); do
    pwr_sum[$i]=$((${pwr_sum[$i]} + $(cat ${node[$i]}))) &&
      pwr_count[$i]=$((${pwr_count[$i]} + 1))
  done
  sleep $interval
done

echo "RAIL,POWER_AVG"
for ((i = 0; i < ${#RAILS[@]}; i++)); do
  pwr_avg=$((${pwr_sum[$i]} / ${pwr_count[$i]}))
  echo "${name[$i]},$pwr_avg"
done
```

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.