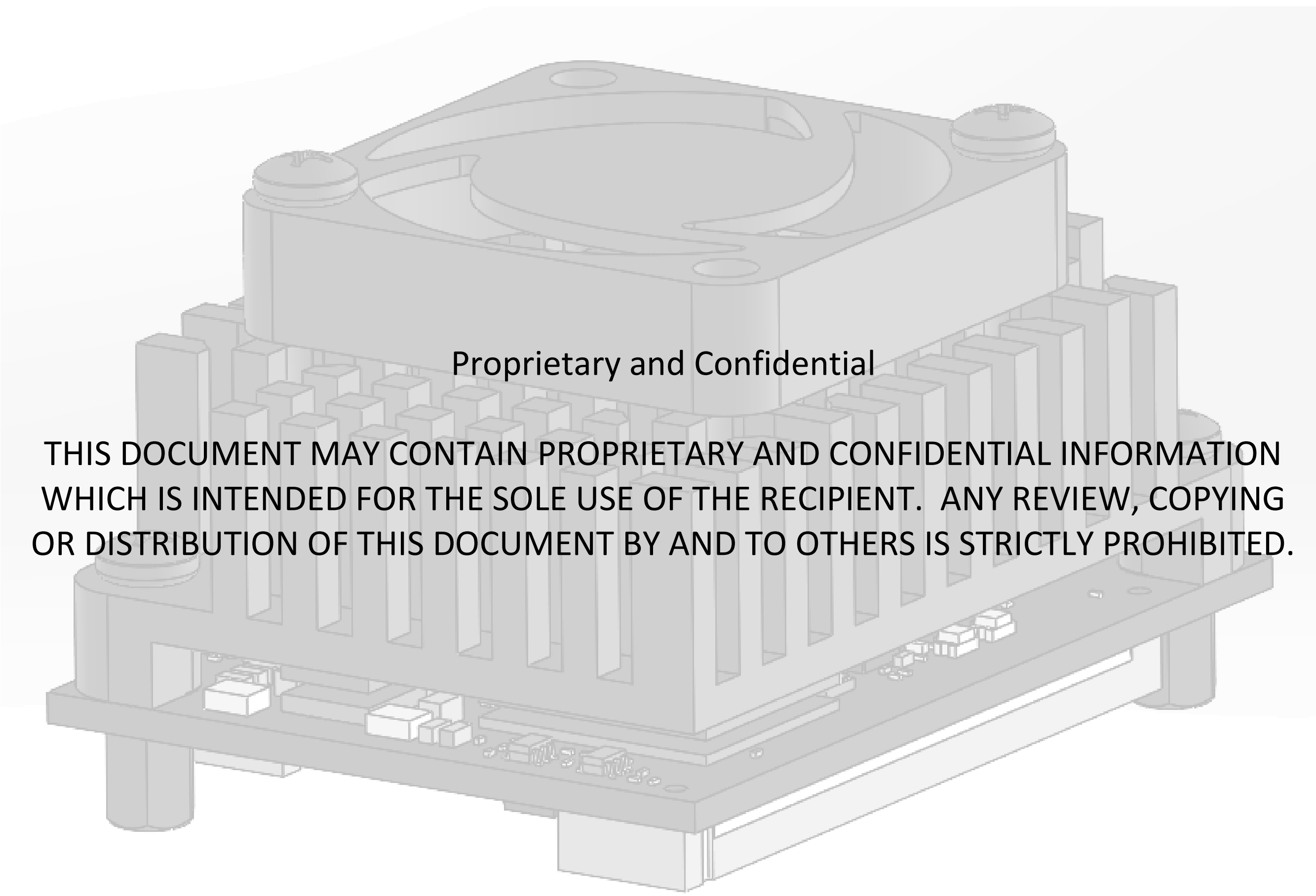
PCM-072/phyCORE-AM64x
Thermal Application Note



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1. Introduction

The SOM has been designed and tested to operate in the -40 to +85C ambient range. All components populated on the board either meet this range or exceed this range. To reach this operating range your system might require a cooling solution available from PHYTEC, or a custom cooling solution unique to your system depending on your use case.

2. Background

2.1. Purpose

This thermal brief is intended to serve as a guide to address the thermal needs of the high performance SoCs we use in advanced embedded systems. **This brief should not be used as a replacement for a thermal model simulation or actual measurements.** The calculations and measurements described in this brief should be used as estimates given many of the parameters used in the calculations are sourced from component datasheets with unclear methods and procedures. The estimates provided in this brief are typically calculated using values and assumptions that overestimate the available thermal margin. If your board operating temperatures have very tight margins to the ambient conditions you require, then a more accurate method will need to be employed.

For these reasons this brief should be used as a reference guide to move you in the right direction with thermal solutions. In the best case, real-world measurements are taken and thermal parameters are calculated for the system the component is used in and cooling solutions are adjusted accordingly. This is sometimes impossible depending on the system and parts used. A thermal simulation combined with system measurements is advised where thermal limits of the parts approach the limits of the required ambient conditions. For many users this is overkill. Most users will not stress the processor and other parts on the SOM under high ambient conditions to reach these limits. In these cases the estimates and solutions provided in this thermal brief may be sufficient.

2.2. Ambient vs. Case vs. Junction Temperature

It is important to understand the difference between ambient operating temperature, case temperature and junction temperature when reviewing temperature data in this brief. We list both ambient operating temperatures, case temperatures and junction temperatures to help you better understand where heat is generated, and which components have temperature limits and what those limits mean. This allows you to modify, augment, or branch from the solutions we have provided in the event your application requires a unique cooling solution.

Junction Temperature

The junction temperature is the operating temperature of the semiconductor inside the packaging at the die. This is the most important thermal parameter to pay attention to with any semiconductor but is also the hardest to capture because it is inside the package. Some devices come with an integrated die level temperature sensor (like the processors on PHYTEC SOMs) that allow you to directly measure the junction temperature in software. All other junction temperatures must be estimated and calculated using the thermal parameters provided in the datasheet.

Normally the processors on PHYTEC SOMs are rated with a maximum junction temperature. PHYTEC BSPs are usually configured to read and monitor this internal junction temperature and automatically shut down the system when a maximum value is reached. Thus, the processor has no stated ambient operating temperature, but instead an internal junction temperature maximum. As long as your cooling solution can keep the junction temperature of the processor at or below the maximum, you can operate in any ambient environment you want.

Ambient Temperature

There is seemingly no industry wide accepted definition for ambient temperature. Ambient operating temperature is mostly understood to be the temperature of the air surrounding a device. When ambient temperatures are listed you can be assured that the device will operate correctly with the surrounding air at or below the stated ambient temperature. It is important to note that if there is no air movement around the device that the ambient air will heat up beyond the ambient air just a few centimeters away. Air circulation around the device is critical to keep a constant ambient temperature around the device. This localized heating effect is due to the device generating heat during operation. Therefore, airflow around the device should be carefully considered during any thermal modeling, design, and testing as it can drastically affect the operating limits of the device.

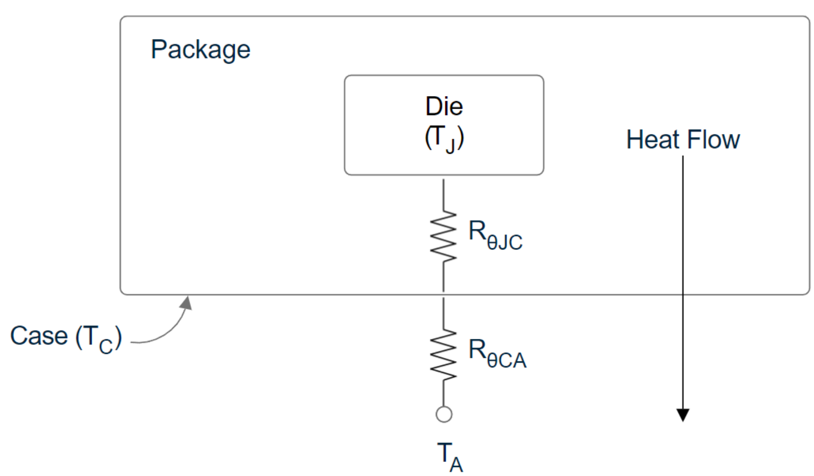
Case Temperature

The case temperature is the operating temperature of the semiconductor when measured at the outside of the casing of the package. The case temperature is normally the temperature of the case “at the outside surface of the package closest to the chip mounting area when that surface is properly heat sunk so as to minimize temperature variations across that surface” (EIA/JESD51-1). For the SMT devices used on our SOMs this case temperature refers to the bottom side of the case where the device is soldered to the PCB. Note that some components will list case temperatures or thermal values for both the top and bottom of the case.

Normally the DRAM on PHYTEC SOMs are rated with a maximum case temperature defined at the top, center of the package. Your cooling solution should ensure that the case temperature is kept at or below the maximum case temperature stated in the datasheet.

Thermal Models and Their Limitations

Thermal circuits are usually modeled using analogous electrical circuit equivalents where temperature is represented by voltage, power is represented by current, and thermal resistance is represented by a resistor. This makes it straightforward for any electrical designer to run the calculations for thermal solutions. Consider the following model for a component where the junction-to-case and case-to-ambient thermal resistances are provided:



Heat flows from the heat generating device (the component) to the ambient air. More precisely the heat (from the power dissipated as heat) flows from the die inside the package to the case and then from the case to the ambient air. The equation for calculating the junction temperature is as follows:

$$T_J = T_A + R_{\theta JC}P_D + R_{\theta CA}P_D$$

Where:

T_J = Junction temperature (hottest point on the die)
T_A = Ambient air temperature around the device
$R_{\theta JC}$ = Junction-to-case thermal resistance (°C/W)
$R_{\theta CA}$ = Case-to-ambient thermal resistance (°C/W)
P_D = Power dissipated by the device

You may already be familiar with the following equation for calculating the junction temperature directly from the ambient air temp and the power dissipation:

$$T_J = T_A + R_{\theta JA}P_D$$

Given the equation(s) above you can calculate the maximum junction temperature from the thermal resistances given in the datasheet for a given ambient temperature you wish to operate in. If the maximum junction you calculate is at or below the stated max in the datasheet, then everything is good, right? Well, not quite. It turns out that the thermal resistance from the case-to-ambient and junction-to-ambient can vary quite differently depending on several factors such as the PCB layout/size, altitude, and external ambient temperature. That means that the case-to-ambient and junction-to-ambient thermal resistances will likely be different in the system the parts are installed in than from what the datasheet says. The parameters in the datasheet are measured under very specific conditions that affect their values greatly. This means that if you were to install a component in your PCB design, hold the ambient air constant, measure the junction temperature (let's pretend you did this with a part like the processor that has an integrated die temp sensor) and calculate the junction-to-ambient thermal resistance like so:

$$R_{\theta JA} = (T_{J\_measured} - T_{A\_held\_value})/P_{D\_measured}$$

You would likely end up with a different number than what the datasheet reports. There are several reasons for this. First, some of the parameters that affect this value, like altitude, are not constant between the test location in the datasheet and your test location. Altitude affects air density which affects the efficiency heat is conducted from the package into the air (more dense air conducting heat better). Second, the equation above does not consider the efficiency that heat is radiated to the ambient. The value we are trying to compute above is a direct measure of how difficult or easy it is for the device to transfer heat from the junction to the ambient air. If you think of it this way it is easy to see that giving the device an efficient mechanism to dissipate heat into the ambient would result in a lower measured junction temperature. Said another way, if the device is attached to a large, copper heavy PCB versus a small, copper light PCB you can imagine how very little heat conducts away from the part in the small PCB (and then into the air) versus the large PCB. This difference in heat transfer through the PCB and then into the ambient directly raises or lowers the junction temperature and therefore directly raises or lowers the junction-to-ambient thermal resistance. This results in a thermal parameter that is only useful to compare the performance of similar packages across manufacturers where the test coupon and other variables are held consistent across manufacturers. Using the junction-to-ambient to calculate the junction temperature of a part in your own system will likely result in erroneous numbers that are sometimes more than 50% off the actual values.

Junction-to-Case to Approximate Junction Temperature

A better method to calculate the junction temperature from a measurement you can gather is by using the junction-to-case(top) thermal resistance with the following equation:

$$T_J = T_{C(top)} + R_{\theta JC(top)} P_D$$

Where:

T_J	= Junction temperature (hottest point on the die)
$T_{C(top)}$	= Case temperature at the top side of the case
$R_{\theta JC(top)}$	= Junction-to-case(top side) thermal resistance (°C/W)
P_D	= Power dissipated by the device

The top side case temperature can be measured directly using various methods (including a thermocouple epoxied to the case). The power dissipation in the device can be measured in system or gathered from the datasheet along with the junction-to-case(top) thermal resistance. Combined you can calculate what the expected junction temperature is, right? Well, not quite. What you calculate using this method will be an overestimate of what the actual junction temperature is because the equation above does not consider the amount of heat that transfers through the top case of the package. Instead, it assumes that all the power dissipated as heat in the device is transferred through the top of the case. Intuitively we know that a good portion of the heat will be conducted through the PCB. This translates into the P_D value used above being an overestimate from the power that is really dissipated through the top side of the case. Nonetheless the top side case measurement and calculations are useful for systems that have a wide enough thermal margin.

Putting it All Together

For a given SOM you will have a mix of components that are rated for a maximum ambient temperature, case temperature and junction temperature. Typically, you would specify an ambient operating temperature range for your end system. If this range exceeds the range of the ambient rated parts on the SOM then the SOM is not a good fit and cannot be used in the end system. If your specified ambient range is within the ambient range of the ambient rated components on the SOM, then we can proceed with cooling solutions to ensure the case and junction rated parts are not exceeded for the given ambient range.

2.3. Component Temperature Ranges

Now that you have a good understanding of ambient vs case vs junction temperature, we provide you a short list of how the components on our SOM are categorized so in the event your system requires a custom cooling solution you know which components need active cooling to keep them below their case or junction temperature limit.

Table 1. Component Temperature Ranges

Component	Ambient/Case/Junction	Temp Range
AM64x processor	Junction	-40 to 105 C
Ethernet PHY	Junction	-40 to 105 C
DDR4	Case	-40 to 95 C
eMMC	Ambient	-40 to 85 C
PMIC	Junction	-40 to 150 C
All other components	Ambient Junction[1]	-40 to 85 C, 105 C or 125 C -40 to 125 C or -55 to 150 C

2.4. Power Management

SoC peripheral utilization can have a significant impact on the thermal profile of the SOM. This is why testing your use case is so important when trying to meet desired maximum ambient conditions for your system. In section 4 of this application note you will see that the processor die temperature can vary by 10 degrees or more depending on software and peripheral utilization for a given use case.

A safety mechanism is built into the BSP that will initiate a shutdown of the processor if the thermal maximum of the die is reached (105 C). This safety interlock will prevent the system from exceeding its thermal limits (that could result in damage if exceeded) but it will not prevent the system from ramping up and hitting the limit and causing a shutdown. That is up to the user to verify their use case does not push the system beyond its thermal limits without adequate cooling for the intended maximum ambient conditions.

Lastly, the Linux BSP and carrier board hardware support a 4-wire fan with on/off control. The BSP is configured with a thermal trip point (65 C) that turns the fan on to reduce heat and turns off again after the CPU die temperature has dropped by 2 C below the trip point. The trip point and hysteresis are configurable in the BSP. Using a fan with this capability can reduce your overall power consumption and extend the life of the fan as it is only turned on when necessary for cooling. The testing done in this thermal application note was performed with a fan that is always on as long as power is applied. However, maximum thermal performance does not change with either fan configuration, only overall system power consumption.

[1] These components will remain under their maximum junction temperature for the maximum expected load in an ambient temperature of 85 C by design of the SOM

3. PHYTEC Provided Cooling Solutions

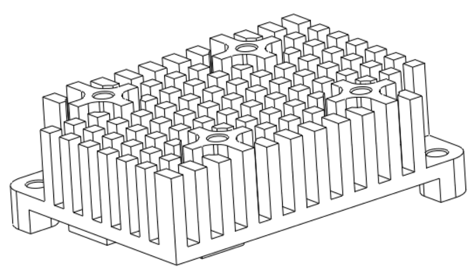
PHYTEC provides custom cooling solutions in the form of a heatsink, a heat spreader, and a fan. These items can be purchased as an accessory to the development kit. The heatsink contacts select components on the SOM to maximize heat transfer from the components to the heatsink. The heatsink has fins or fingers to maximize heat transfer from the heatsink to the ambient air.

The heat spreader also contacts select components on the SOM, however, unlike the heatsink the heat spreader is flat on the top side with no fins or fingers. The heat spreader is meant to be attached to the case of an enclosure to act as a heat transfer mechanism between the board and the enclosure. It is also an option to attach a much larger heatsink to the heat spreader to further improve cooling performance.

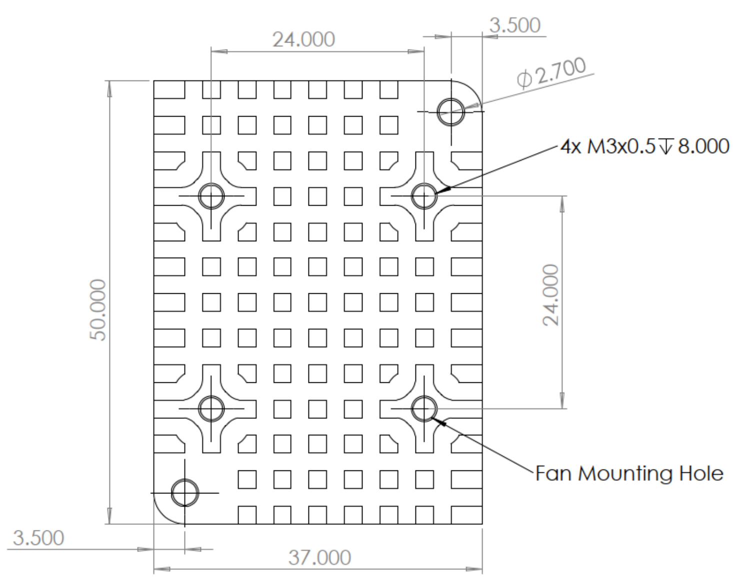
Lastly, the fan attaches to the heatsink to provide a substantial improvement to airflow and cooling. While the heatsink alone provides decent cooling, the addition of a fan to the heatsink provides a significant improvement in the performance of the heatsink and is highly recommended.

3.1. Drawings and Dimensions

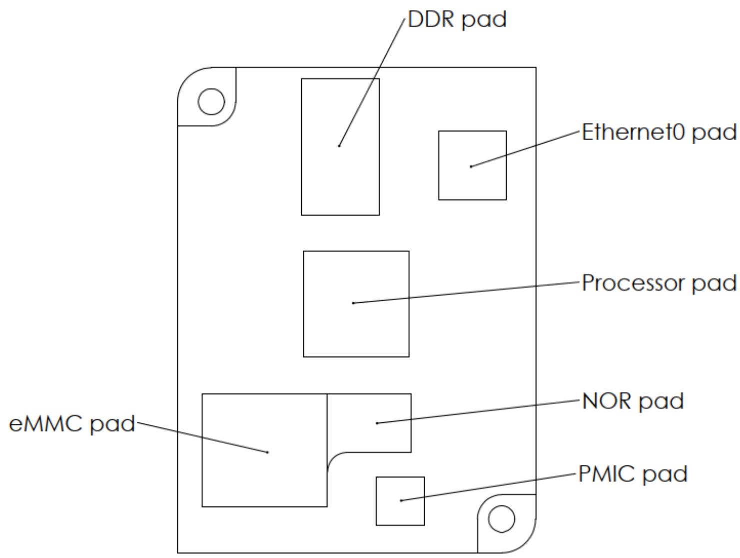
3.1.1. Heatsink



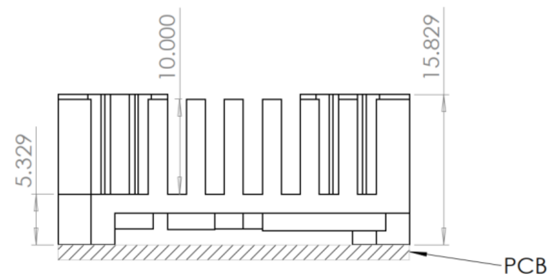
OVERVIEW



TOP VIEW

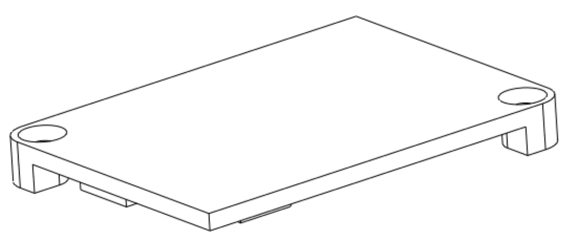


BOTTOM VIEW

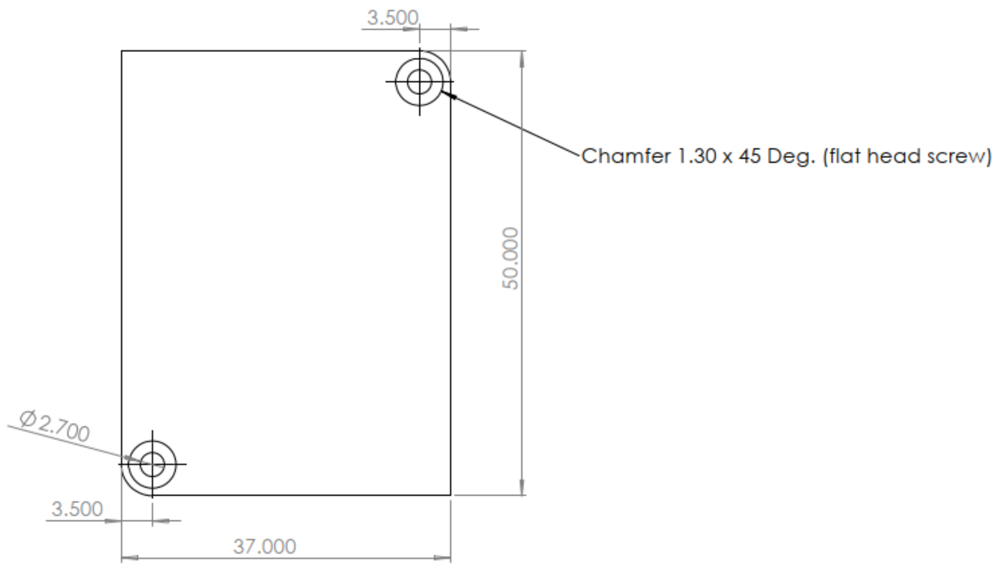


END VIEW

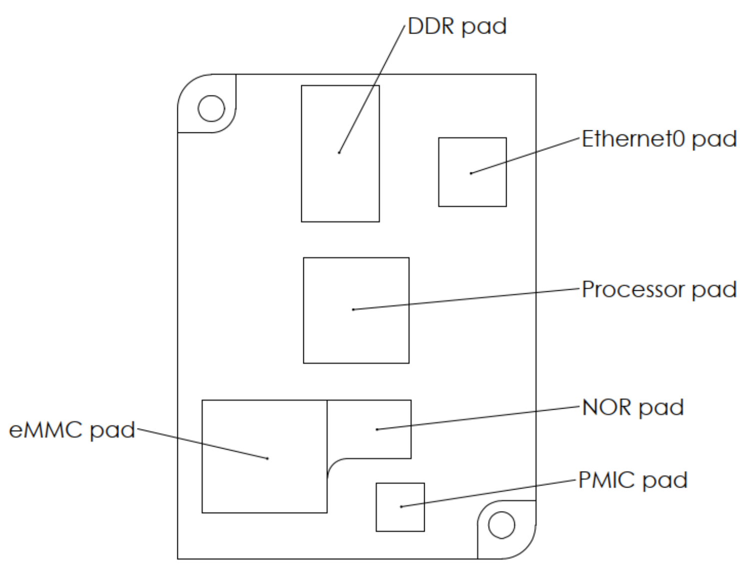
3.1.2. Heat Spreader



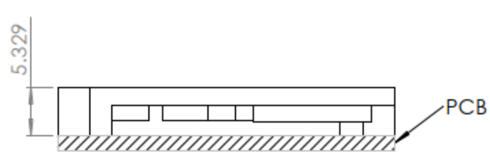
OVERVIEW



TOP VIEW

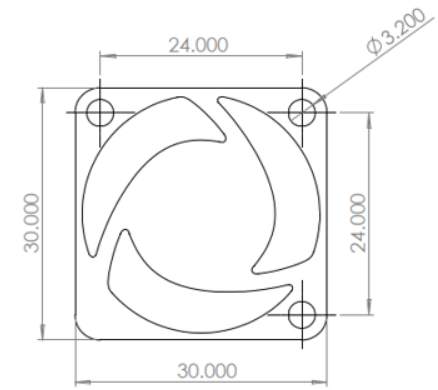


BOTTOM VIEW

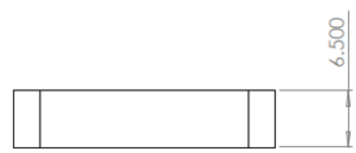


END VIEW

3.1.3. Fan



TOP VIEW



SIDE VIEW

3.2. Fasteners

The SOM is fastened to the carrier board using screws through the top of the SOM mounting holes into standoffs on the carrier board. Attaching a heatsink or heat spreader only requires the length of the screws to be extended to pass through the corner mounting holes of the heatsink/heat spreader, down through the SOM PCB, and into the carrier board standoffs. The fan is attached directly to the heatsink using M3 fasteners. The SOM and heatsink/heat spreader mounting holes are sized for M2.5 fasteners. The following fasteners are recommended:

Table 2. Required Fasteners

Part	Fasteners	Notes
Heatsink	2 @ M2.5 x 8-10mm pan head screws 2 @ M2.5 split lock washer (optional)	Length depends on standoff used on carrier board.
Heat Spreader	2 @ M2.5 x 8-10mm flathead screws	Length depends on standoff used on carrier board.
Fan	2-3 @ M3 x 10-12mm pan head screws 2-3 @ M3 split lock washer (optional)	The recommended fan only has three mounting holes. At least two screws should be used to secure the fan, but up to three can be used if desired.

3.3. CAD Data

A 3D STEP model of the heatsink, heat spreader, and fan are provided for you to incorporate into your mechanical design or to modify as you see fit for your custom application.

Table 3. CAD Data

Part	Model	Version
Heatsink	https://fileshare.phytec.com/index.php/s/eWrec3iocnJa6aj	1.0
Heat Spreader	https://fileshare.phytec.com/index.php/s/eKjMDyisQPMZ5DK	1.0
Fan	https://fileshare.phytec.com/index.php/s/DRn8cFPQRfYQ2Mg	-

3.4. Thermal Foam

The manufacturing tolerances of the heatsink, heat spreader, and SOM result in a slight variance of part heights and heatsink pad heights across different SOMs and heatsinks/heat spreaders. To account for this mechanical variance a 0.7mm gap between the top of the SOM components (processor, DDR, eMMC, PMIC, Ethernet PHY, NOR) is employed in the design. This requires a thermally conductive foam to be installed as a gap filler and will allow for efficient transfer of heat from the components on the SOM to the heatsink/heat spreader.

We recommend using Würth Elektronik WE-TGF thermal gap filler pad (P/N: 40102010) with a thermal conductivity of 2W/(m*K) and a thickness of 1mm. Other thermal gap filler foams/pads can also be used but should be tested to ensure that the thermal conductivity is good enough to keep the components under their maximum temperature operating limits. You should avoid using foams that are too thick that might result in high compression forces to the tops of the components when the heatsink/heat spreader is fastened down to the top of the SOM with the corner mounting screws.

3.5. Ordering Information

PHYTEC provides a thermal management kit that contains the heatsink, heat spreader, fan, thermal foam, and applicable fasteners to get you started.

Table 4. Ordering Information (Thermal Kit)

Part	Vendor	MFG	MFG P/N	Orderable Part Number
Thermal Management Kit	PHYTEC	PHYTEC	KZUB-072-T01.A0	KZUB-072-T01.A0

The individual pieces can be ordered separately. The heatsink, heat spreader, and fan can be ordered from PHYTEC directly. The fan is also optionally sourced from component vendors like Mouser, or Digikey. Note that you will need to order the appropriate fasteners from somewhere like McMaster-Carr if you are ordering the heatsink or heat spreader as standalone items from the table below.

Table 5. Ordering Information (Individual Parts)

Part	Vendor	MFG	MFG P/N	Orderable Part Number
Heatsink	PHYTEC	PHYTEC	XK072	XK071
Heat Spreader	PHYTEC	PHYTEC	XK072	XK072
Fan	Mouser	Sunon	MF30060V1-1000U-A99	369-MF30060V11UA99
Thermal Foam	Mouser	Wurth	40102010	710-40102010

4. Thermal Performance

The major thermal limit in the system is the processor. It is the device that generates the most heat and is the component that will likely reach its junction temperature limit when pushing the processing load before any other component in the system. In general, you need to pay close attention to the temperature of the processor when considering your ambient operating environment. All other components will normally operate within their limits as long as the maximum rated ambient conditions for the SOM are not exceeded.

In this section we summarize various processor operating loads, ambient temperatures, and cooling solutions and how they perform so you can confidently decide if no cooling is required in your end system, if the PHYTEC provided solutions are sufficient, or if something custom will be necessary.

4.1. Performance at Room Temp

A baseline performance is established in this section at room temperature so you can get a feel for how the SOM performs with no cooling solution at various processor loads running at 1.0GHz.

Ambient Temperature: ~22.0 – 23.0 C

Table 6. Performance at Room Temperature

Component	Measurement Location	Idle Temp	Typical Load	Heavy Load
AM64x processor	Junction (on-chip die sensor)	~51.2	~59.3	~61.8
Ethernet PHY	Center top of case (thermocouple)	~49.2	~59.4	~59.6
DDR4	Center top of case (thermocouple)	~45.9	~52.9	~56.6
eMMC	Center top of case (thermocouple)	~45.0	~49.2	~50.9
PMIC	Center top of case (thermocouple)	~48.4	~54.7	~55.8

A thermal image of the SOM running a heavy load with no heatsink is presented below. The temperatures marked match the right most column of the table above. Pay special attention to junction temperatures vs case temperatures when reviewing these numbers.

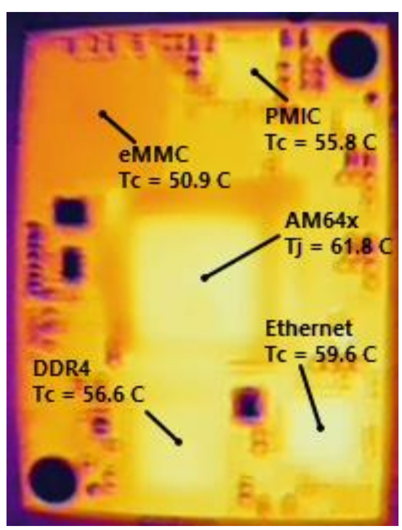


Figure 4-1. SOM Thermal Image under Heavy Load, no Heatsink

4.2. Temperature vs Operating Points and Cooling Configurations

Now that baseline has been established across various operating points with no cooling solution, we present a graph of the AM64x die temperature and DDR4 case temperature (along with ambient) during various operating points (idle and heavy load) and cooling configurations (no heatsink, heatsink set on top of the SOM, heatsink securely screwed down to the SOM, heatsink secured + fan). This graph provides a good visual to further understand how the SOM performs and how much difference the heatsink makes to extending the maximum operating temperature. Note the significant difference between the AM64x die temperature before and after the heatsink is screwed down to the SOM. Making good solid contact between the heatsink and the components on the board is vital to ensuring good heat conduction.

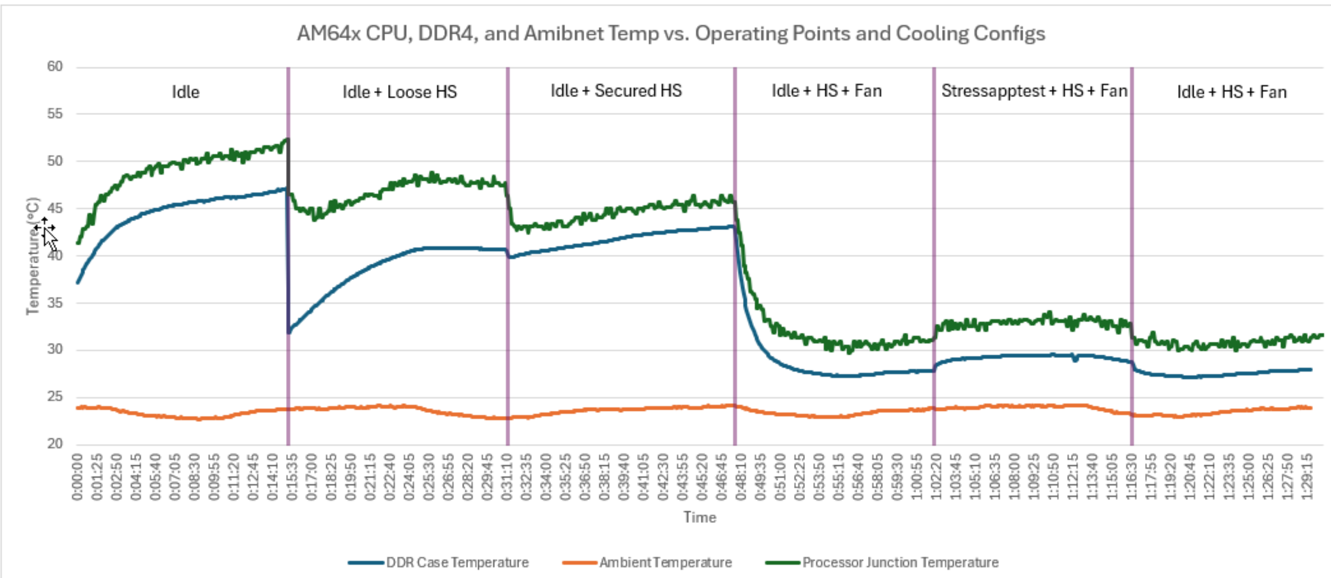


Figure 4-2. CPU, DDR4, and Ambient Temp vs Operating Points and Cooling Configs

4.3. Maximum Ambient at Idle, Typical Load, and Heavy Load

The table below is a summary of the maximum ambient temperatures the SOM is able to reach under various processor loads and with various cooling solutions both inside of an enclosure (vented) and without an enclosure running at 1.0GHz. These maximum temperatures listed below ensure that all components on the SOM are within their maximum temperature operating limits.

Table 7. Maximum Ambient at Idle, Typical, and Heavy Load with and without Cooling

	No Enclosure				Inside Enclosure		
	No Heatsink	Heatsink	Heatsink with Fan		No Heatsink	Heatsink	Heatsink with Fan
Idle	~85 C	85 C	85 C		~81 C	85 C	85 C
Typical Load	~85 C	85 C	85 C		~77 C	~85 C	85 C
Heavy Load	~83 C	85 C	85 C		~73 C	~84 C	85 C

There are two important things to note from the data above:

1. The contrast between the maximum ambient the SOM can run in when it’s inside an enclosure vs. when it is sitting in the temperature chamber can be quite big. The reason for this is the temperature chamber has very high air movement/circulation inside the chamber. This guarantees that the localized ambient air that immediately surrounds the SOM is replaced with new ambient air that the chamber is constantly trying to hold at a given temperature. This might be what you would see if you were to operate the SOM in the open air outside on a breezy day. When the SOM is placed in an enclosure the localized ambient air around the SOM is not immediately replaced by new ambient air held at a constant temperature because the enclosure blocks this action. The excess heat generated by the SOM must conduct through the walls of the enclosure or escape through the vented slots in the enclosure through convection.
2. The data marked with approximates (the numbers with a ~ in front) is the average of what 4 systems were able to reach before shutting down. This means the CPU’s maximum die temperature of 105C was being hit around these temperatures. Since this testing was carried out with just 4 units and the results are an average, it effectively means you should expect your upper maximum for your system to be somewhere below these limits to give some headroom to account for variances across different SOMs/systems. Of course, the actual maximum should be something you carry out with controlled testing in your system. The numbers in the tables above are meant as a guide to give you a rough idea of how the system might perform under various cooling solutions and operating points.

4.4. Achieving Maximum Ambient Range

The PHYTEC provided cooling solutions may not always be sufficient to achieve the maximum ambient temperature rating of the SOM under all use cases. We attempt to provide a cooling solution that is compact and will work for a large majority of customer use cases. However, your use case and system may push the SOM beyond the limits that our cooling solutions can handle. In this case special cooling is required and you will need to design and test a solution that works for your use case.

For the PCM-072/phyCORE-AM64x SOM the recommended fan and heatsink combination listed in this document are sufficient to run the processor under heavy loads at 85 C ambient at 1.0GHz. However, it may be that the PHYTEC provided fan and heatsink combo do not fit in your enclosure form factor, do not meet budget requirements, or other limitations that prevent you from using our solution. If you fall in this category then the following section will be useful to help you find an alternative solution that works in your system.

5. Testing Your System

To determine your cooling needs you will need to test your system and monitor/measure several components for temperature. To do this you will need the following equipment:

1. Several prototypes of your system with our SOM installed.
2. A climate chamber to precisely hold the system at your desired ambient temperature.
3. A temperature data logger with several thermocouples to monitor the case temperature of any components that are case temperature rated.
4. A PC with a serial port to control and monitor the system while it runs in the climate chamber.

Note that the list above omits a cooling solution attached to the SOM. To determine if you need a cooling solution you should first test your system without any cooling at all. If die or case temperatures exceed their limits for your specified ambient maximum, then you will need to run these tests again with a cooling solution attached to the SOM.

5.1. Operating Conditions

It is important that you run your system under the worst-case power dissipating/heat generating conditions you expect to encounter under all system configurations and operating points during climate chamber testing.

5.2. Translating Junction to Case

Ensuring all the components on the board remain within their operating limits is easy for some and difficult for others. In the case of the ambient rated components it is easy because the ambient is a parameter you control in the climate chamber. The case rated components are a little more difficult, but a temperature data logger with a thermocouple attached to the case can measure this. The junction rated components are the trickiest parts to monitor because it requires knowing the maximum power dissipation in the part which can often be hard or impossible to measure. While the processor is a junction rated component, it is easy to handle because a temp sensor is integrated directly into the die, allowing direct measurement of the junction temperature. To handle junction rated components that do not have an integrated temp sensor on the die we can do the calculations to translate to a temperature we can measure: the case temperature.

For the PCM-072 SOM the ethernet PHY requires this calculation to be done. From the DP83867IRRGZ datasheet we know the following:

Max junction temperature	= 105 C
Junction-to-ambient thermal resistance	= 30.8 C/W
Junction-to-case(top) thermal resistance	= 18.7 C/W
Typical power consumption	= 495 mW

From these numbers we can use the following equation to calculate what the maximum case temperature (at the top of the case) can be:

$$T_C = T_{Jmax} - R_{\theta JC} P_D \;\; \rightarrow \;\; 105\ C - \left(\frac{18.7\ C}{W}\right)(0.495\ W) = 95.7435\ C$$

The PMIC also requires this calculation:

Max junction temperature	= 150 C
Junction-to-ambient thermal resistance	= 36.7 C/W
Junction-to-case(top) thermal resistance	= 26.6 C/W
Estimated power consumption	= 625mW

From these numbers we can use the following equation to calculate what the maximum case temperature (at the top of the case) can be:

$$T_C = T_{Jmax} - R_{\theta JC} P_D \;\; \rightarrow \;\; 150\ C - \left(\frac{26.6\ C}{W}\right)(0.625\ W) = 133.375\ C$$

The calculation above assumes that 25% (625mW) of the maximum power (2.5W) drawn by the SOM is consumed by the PMIC. This is an overestimate as most of the power delivered by the PMIC is from highly efficient switching regulators. This calculation also assumes that 100% of the 625mW consumed by the PMIC is conducted through the top surface of the PMIC to the ambient. In reality the majority of the power converted to heat is conducted through the bottom of the PMIC into the PCB. Thus the ~133 C number above is really lower than what the real case temperature could be for a 150 C junction temperature. Nonetheless let’s use this overestimate and charge forward with our calculations.

From Table 6 we can see that the differential between the maximum PMIC case temperature and the ambient is about 34 C. Put another way, the PMIC case temperature under a heavy load will be about 34 C above the surrounding ambient with no cooling solution attached to the SOM. At 85 C ambient we would expect the case temperature to be 85 C + 34 C = 119 C. From our calculation above 119 C is well below the maximum of 133.375 C the case is allowed to reach when the junction is at 150 C. We can conclude that the PMIC has sufficient thermal margin that we do not need to worry about it overheating. The processor will overheat and shut the system down before the PMIC reaches anywhere near its maximum junction temperature.

5.3. What to Monitor

When monitoring the temperature of the components of the SOM in the temperature chamber it is important to do so while running your system under all expected operating points/load conditions. This ensures that the system will generate its maximum temperatures during testing. Table 8 below is a concise summary of which components to monitor and how to make the measurement. Figure 5-1 shows where the components are located and where to measure on the package.

Table 8. What to Monitor and How to Measure

Component	Measurement Location	Measurement Method	Max Temperature
AM64x processor	Junction	Polled via software	105 C
Ethernet PHY	Case	Thermocouple to top, center of the case[2]	95.7435 C
DDR4	Case	Thermocouple to top, center of the case	95 C
All others	Ambient	Thermocouple or other temp probe measuring the ambient air around the device	85 C

[2] When using a thermocouple it is recommended to use a small dab of thermal epoxy to secure the thermocouple to the top of the case.

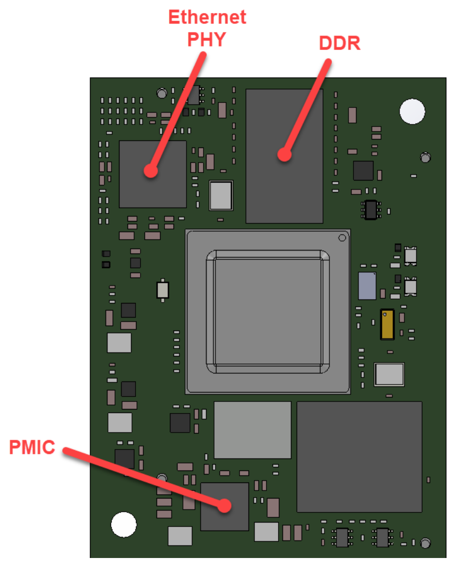


Figure 5-1. Component Measurement Locations

You should allow sufficient time in the climate chamber for the systems to reach maximum heat and exercise all operating points. If you find that your measured temperatures are very close to the maximum you should consider increasing the number of systems you test to account for hot and cold silicon.[3]

[3] Dies coming from a silicon wafer will vary in power dissipation across the wafer. This natural variance translates into some semiconductors operating hotter than others.

6. Custom Cooling Solutions

If the PHYTEC provided cooling solutions do not work for your use case to achieve the ambient environment you wish to operate in then you will need to find a custom cooling solution. While many cooling options exist, a list of ideas is presented below to get you started:

1. Modifying the PHYTEC provided heatsink to increase its size, providing more surface area for heat to dissipate into the surrounding air.
2. Modifying the PHYTEC provided heatsink to use a larger fan that is capable of moving heat away from the SOM more effectively.
3. A combination of #1 and #2 above to increase heatsink and fan size.
4. Designing a custom heatsink that includes a liquid cooled solution.
5. Attaching a large, off-the-shelf heatsink to the PHYTEC provided heat spreader.
6. Attaching an off-the-shelf liquid cooled heatsink to the PHYTEC provided heat spreader.

When modifying the PHYTEC provided heatsink or heat spreader it is important to maintain the geometry on the bottom side of the heatsink/heat spreader for proper contact to the components on the SOM.

7. FAQ

Q: How do I know if I need a cooling solution?

A: You should run your system in its worst-case power dissipation configuration inside a climate chamber held at the ambient temperature you wish to operate in while monitoring the components in **Table 8** to ensure they do not exceed the limits specified in the table. If any of the components exceed the limits in the table then you will need a cooling solution. A good estimate to figure out if you need a cooling solution is to refer to column 1 and 4 in **Table 7**. You can refer to the other columns in the table to determine if the PHYTEC provided cooling solution will be sufficient. If not, a custom solution will be required.

8. Definitions

Term	Definition
Idle	System booted into Linux and sitting at a prompt running a minimal bash script to log CPU die temperature. Only USB C power cable and serial cable connected.
Typical Load	stress-ng running on 1 CPU core with a cable plugged into ethernet 0. USB C power cable and serial cable also connected.
Heavy Load	stressapptest running on 2 cores over 800MB of DDR. Ethernet 0 plugged in running an iperf3 bandwidth test. USB C power cable and serial cable also connected.

9. Revision History

Date	Version	Changes
2024/07/31	LAN-117e.A0	Initial release