Conduction Cooling for Stackable SBCs

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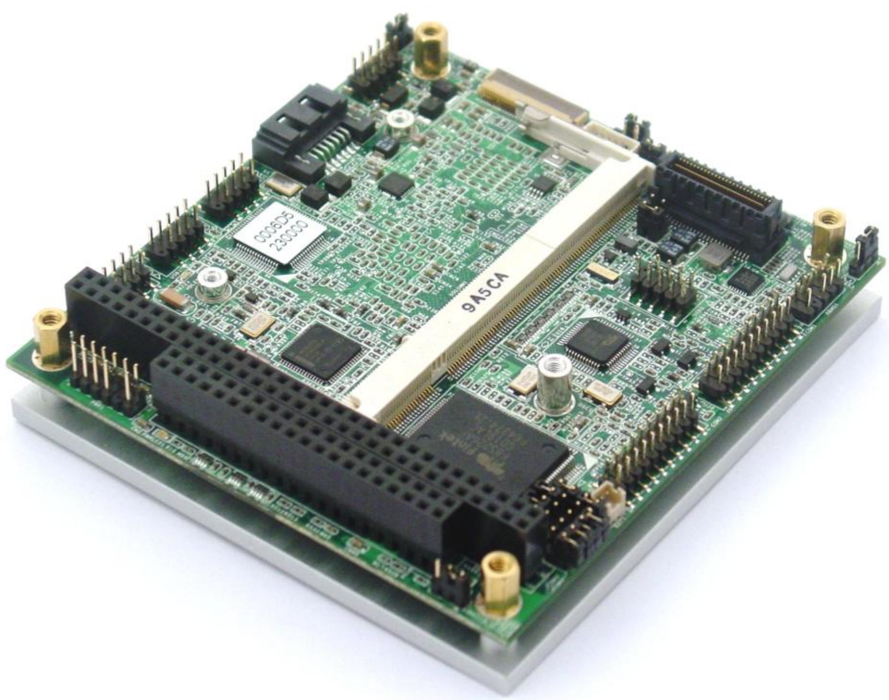
A Diamond Systems White Paper



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1 Background

A significant challenge facing system designers is the removal of heat from high performance processors and chipsets, particularly in the stackable small form factor (SFF) realm.

There is no denying the appeal of the Intel® Atom™ family of processors for new designs and upgrade programs. However, even the 5 to 7 Watts dissipated by the lowest power platform, "Menlow," consisting of Z-series processors and US15W chipset, can wreak havoc on sealed boxes, particularly when I/O cards and other heat generators are in the board stack.

2 Problem Statement

Fanless, sealed enclosures are usually required in harsh environments to maximize reliability and protect electronics from moisture, dust, insects, and corrosive chemicals. Due to the highly insulative nature of air (low thermal conductivity), such enclosures are not a good match for CPUs or other electronics utilizing common board-mounted heat sinks, because the heat must transfer from the heat sink through the air to the enclosure wall. The air acts as an insulator (thermal resistor), causing undesirable temperature build-up. The temperature difference between the outside ambient air and the air next to sensitive electronics can easily reach 15 degrees Celsius or even more. Subjecting SBCs and I/O cards to excessive temperature for extended periods of time can drastically lower MTBF (mean time between failures), an unacceptable situation for mission-critical computers subjected to harsh environments.

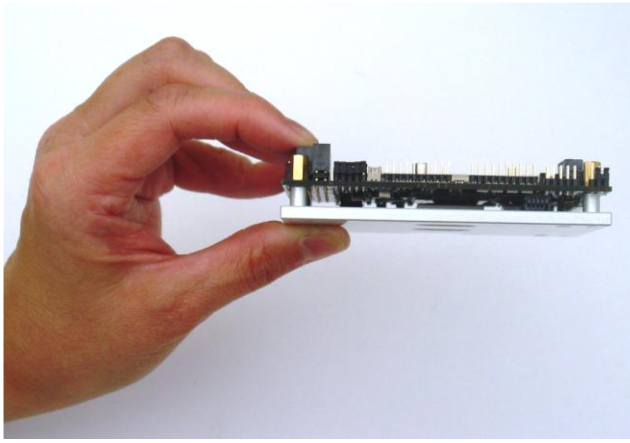
The question becomes: How to optimize the design of Atom- and higher-power CPU-based sealed boxes for effective heat removal, while providing maximum ruggedness and reliability?

3 Executive Summary

Previously, the benefits of conduction cooling in VME markets were not available to users of stackable SFF SBCs. With a new innovative approach, Diamond Systems brings conduction cooling to the PC/104 market so that Atom SBCs and legacy I/O cards can be used in sealed boxes without compromising ambient operating temperature or system reliability. Diamond's approach involves a heatspreader plate on the bottom of the SBC which attaches to the processor and chipset by way of thermal gap pads. The test results show conclusively that the heatspreader keeps the processor well below its maximum temperature rating.

An experiment was conducted to model the expected operating environment of a rugged, sealed system with our Aurora Z530-based single board computer thermally connected to the enclosure wall. The test results below show that the Aurora SBC operates successfully in simulated worst-case conditions of thin aluminum walls (1/16" thick) at 76°C. A 9.6 Watt power resistor load was placed inside the sealed enclosure, raising the inside air temperature to the target value of 89°C, four degrees of margin beyond the 85°C maximum allowable value in the field. The heat spreader plate and the enclosure kept the processor cooler, as expected. The processor case temperature measured 84.45°C, putting the processor transistor thermal junction Tj at 87°C, which is 3°C below Intel's Tj max specification of 90°C.

In practice, thicker aluminum enclosure walls, such as a cast and/or machined enclosure, coupled with a surface temperature at 71°C (160°F) or lower, would reduce Tj further away from the maximum specification.



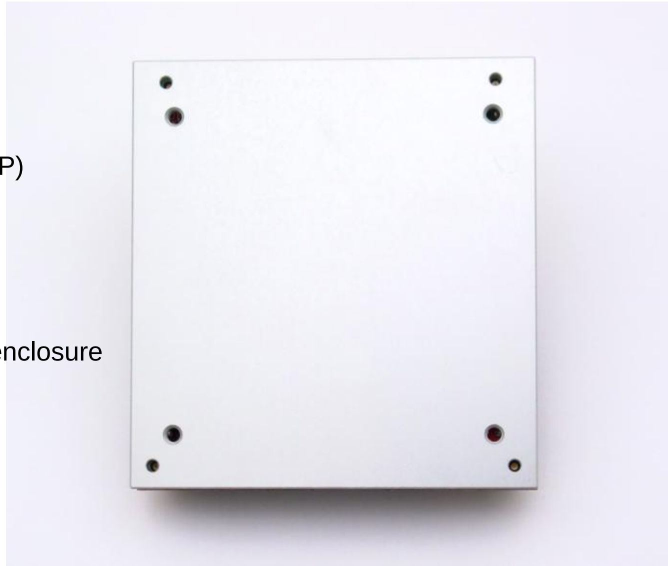
4 Test Description

In this procedure, Diamond's Aurora SBC with 1.6 GHz Z530 Atom CPU was tested under Windows XP SP2 (service pack 2) in order to find the board endurance in special conditions.

5 Test Requirements

Equipment and software used to perform the tests are detailed below.

5.1 HARDWARE USED:



1. Diamond's Pandora PC/104 enclosure
2. Diamond's 9110600 Aurora SBC (1.6GHz Intel Atom Z530P) with 1GB DDR2 SO-DIMM RAM installed
3. Diamond's Aurora heatspreader installed (shown at right)
4. ATX power supply
5. High wattage power resistors to heat up the air inside the enclosure
6. Aluminum plate for heat dissipation and
7. Pico Tech USB temperature data acquisition system with 4 thermocouples
8. Laptop computer to record temperature samples

5.2 SOFTWARE USED:

1. Windows XP SP2
2. Burnin test pro v5.3
3. Pico Tech control software

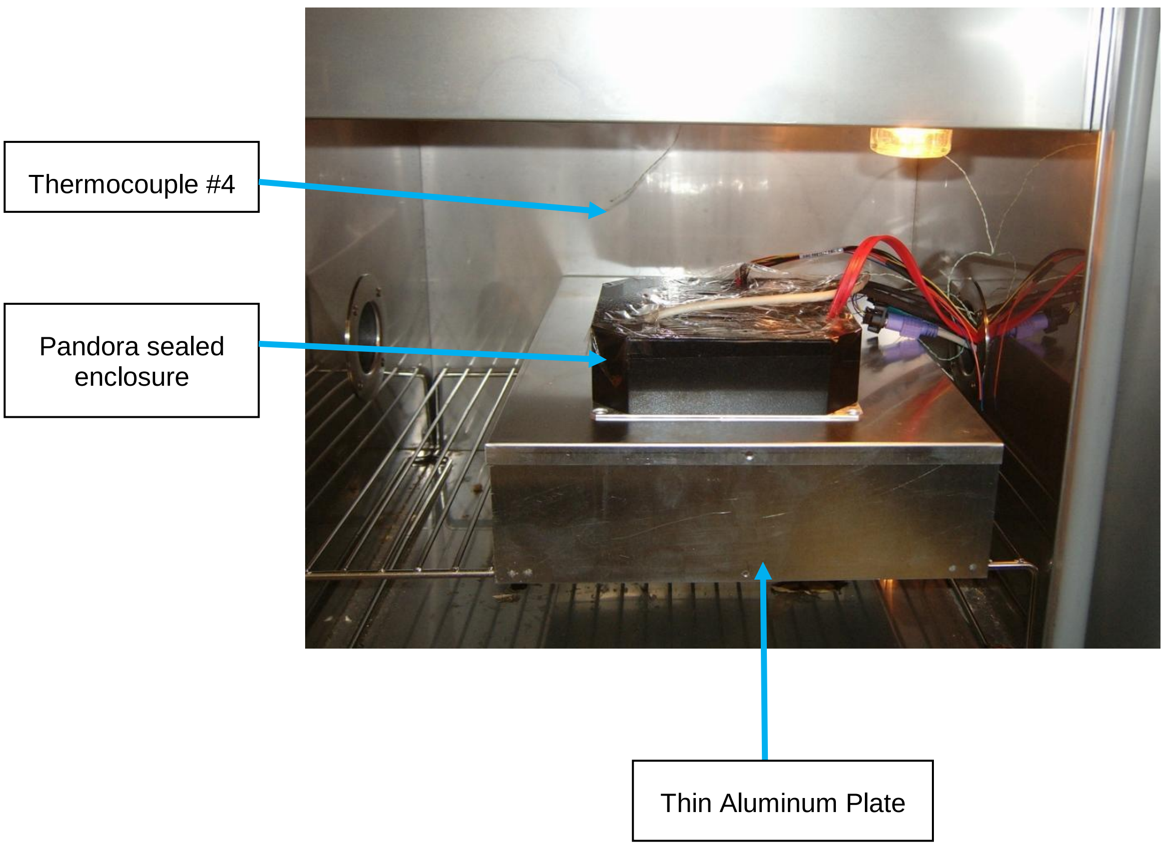
6 Procedure and Results

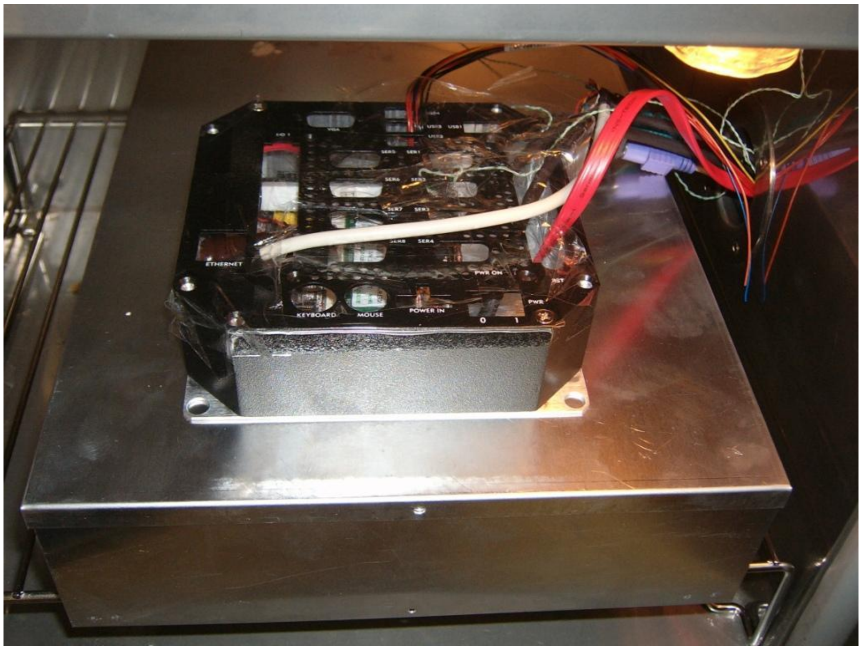
In order to simulate a system manufacturer's environment, it was essential to reach higher temperatures inside the enclosure in contrast with the CPU temperature (Tj), which is specified at a maximum +90^{o}C.

6.1 TEST SETUP

Four thermocouples were used in this test:

- One thermocouple channel on the CPU chip, one channel in the middle of the Pandora enclosure 1.5cm above the board, one on the plate 20cm from the Pandora enclosure, and the last one suspended in the chamber itself.
- The Pandora enclosure holes were covered to allow for no convection (no chance for heat to escape, simulating a perfectly sealed box).


Thermocouple #4
Pandora sealed enclosure
Thin Aluminum Plate



6.2 PROCEDURE

6.2.1 First test: no thermal connection between Aurora SBC and Pandora bottom plate (supported by insulators), plus 2 watt load resistors

- The purpose was to find out how hot the CPU got without dissipation and inside a sealed box, as shown in Figure 1 from time t=0 to point B. This simulates the operation of a conventional heat sink in a sealed box without air flow.

6.2.2 Second test: with Aurora SBC on the Pandora plate and large aluminium plate and 2 watt load resistors

- The assembly has been set on the plate with two watt resistors inside the box, as shown in Figure 1 points B to C. Aurora's heatspreader is resting on the bottom plate of Pandora, which in turn is resting on the external aluminum plate. No thermal paste is used between metal surfaces for this test.

6.2.3 Third test: with Aurora SBC on the Pandora bottom plate and the large aluminum plate and 9.6 watt load resistors

This test is the same as the second test with these additions / changes:

- 9.6 Watt resistor load on 12 volts (2x30 Ohm, 10 Watts) to heat up inside the enclosure
- Added thermal paste between Aurora heat spreader and Pandora bottom plate and then aluminum plate respectively, for better thermal dissipation, leading to the results shown in Figure 2.

The graphs below show that the chamber temperature was applied manually to the assembly which soaked until steady state was reached. The CPU temperature in the graphs and the following tables are 2-3 degrees lower than the actual junction temperature displayed in the BIOS setup screen (which reads a CPU register). To approximate the junction temperature, 2 degrees was added to the case temperatures measured by thermocouples since the BIOS setup screen is not accessible while running the burn-in test Win32 application.

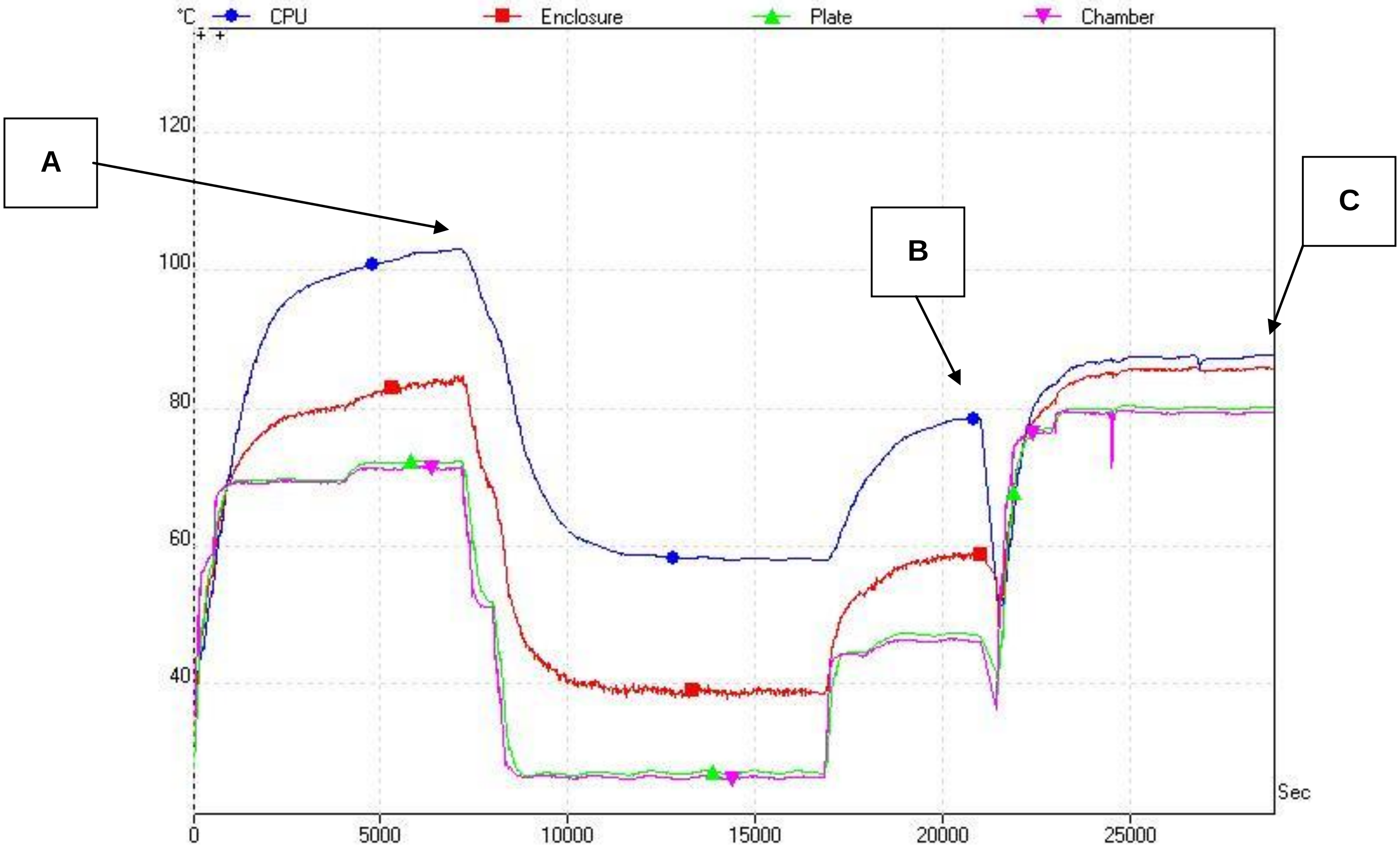


Figure 1

Note: The thermocouple called “Enclosure” measures the air inside the Pandora enclosure, 1.5cm above the Aurora SBC. The thermocouple called “Plate” measures the temperature of the plate Pandora sits on.

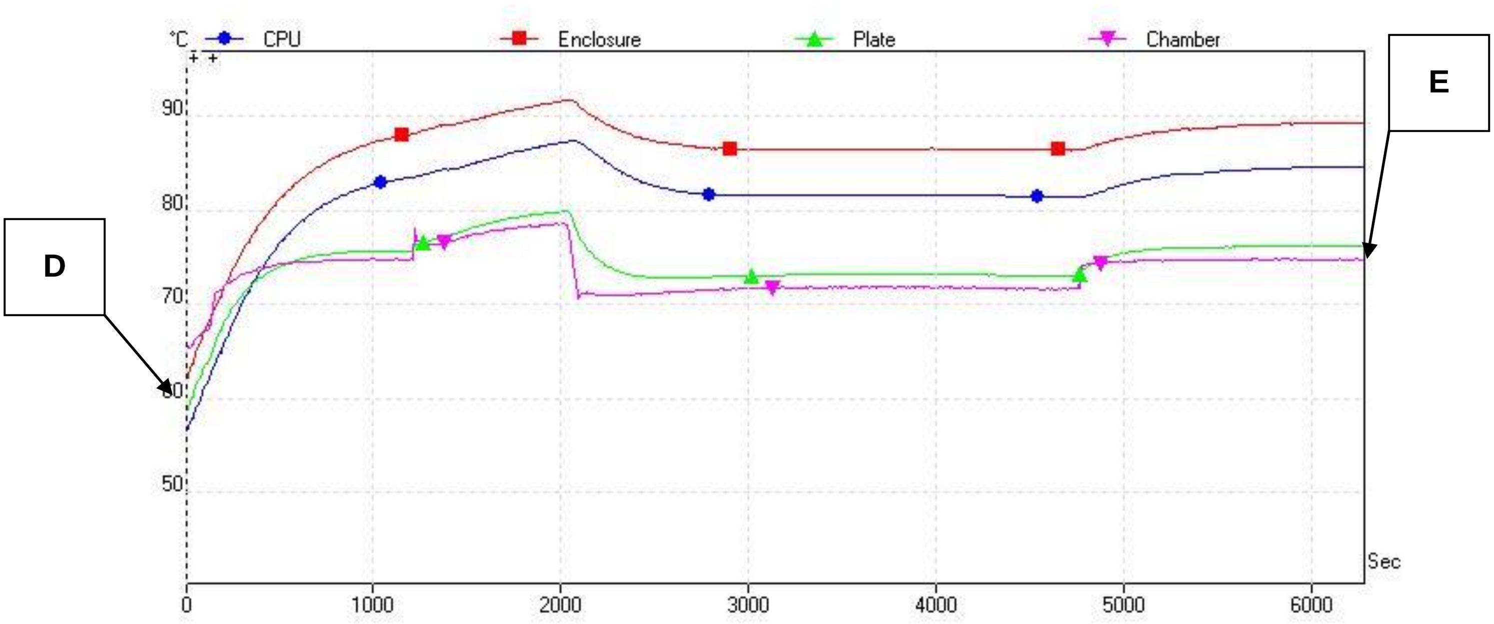


Figure 2

7 <u>Results</u>

7.1 FIRST TEST

Aurora SBC raised up and no thermal conductive contact to the bottom of Pandora box, with 2 watts resistor load

Spot	Time	CPU	Estimated CPU temp	Enclosure (Inside Air)	Plate	Chamber
	Seconds	°C	°C	°C	°C	°C
A	7000	103.0	105	84	73	72
B	21071	78.5	81	58.5	47.0	46.0

➔ 81-47=34°C rise (no conduction)

7.2 SECOND TEST

Aurora SBC on the plate (thermal conductive path) with 2 watts resistor load

Spot	Time	CPU	Estimated CPU temp	Enclosure (Inside Air)	Plate	Chamber
	Seconds	°C	°C	°C	°C	°C
C	29146	87.5	90	86.0	80.0	79.0

➔ 90-80=10°C rise (conduction cooling with 2W additional load)

7.3 THIRD TEST

Aurora SBC with thermal paste between plates and 9.6 Watts resistor load

Spot	Time	CPU	Estimated CPU temp	Enclosure (Inside Air)	Plate	Chamber
	Seconds	°C	°C	°C	°C	°C
D	0	56.0	59	61.5	58.0	65.0
E	6360	84.5	87	89.0	76.0	75.0

➔ 87-76=11°C rise (conduction cooling with 9.6W additional load)

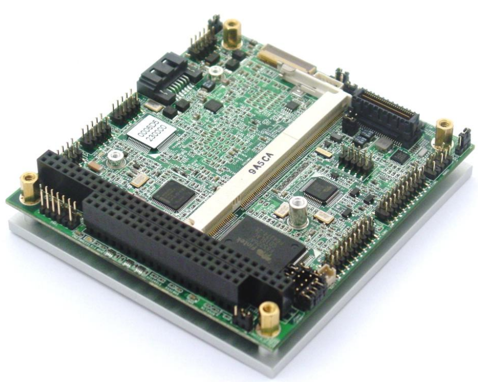
8 Conclusion

The heatspreader plate is effective in providing a thermal conductive path from the hot processor and chipset (6W total) to the enclosure surface which in turn dissipates the heat to the outer environment (temperature chamber).

The thermal junction rating is satisfied when conductive cooling is used, even in the presence of nearly 10W of additional thermal loads inside the enclosure (power resistors).

However, the maximum thermal junction specification is violated when there is no conductive path for the heat to the outer enclosure. This is because the 6W from the CPU is dumped into the inside air along with the 10W thermal load. Traditional heatsinks are effective in systems with vents and cooling fans where forced air actively removes heat. The test results show that Atom SBCs with traditional CPU and chipset heatsinks cannot be used in sealed enclosures that reach 70°C in the presence of other internal heat sources, since the internal temperature rise is nearly unbounded (thermal runaway). In Section 7.1 above, the thermal junction rose +34°C above the enclosure temperature *even with only 2W of additional thermal load*. Result A in the above charts shows the thermal runaway condition where the Tj maximum specification was violated. The thermal junction temperature exceeded 100°C without having a thermal conductive path to the plate. Missions cannot be put in jeopardy due to inadequate thermal design.

Diamond's Aurora SBC is the first conduction cooled PC/104 single board computer (PC/104 size with PCI Express and ISA expansion), which greatly simplifies sealed box designs and enhances the functionality and processor speed possible within small enclosures without risking reliability.



Resources: Conduction Cooled SBCs presentation

Diamond Systems website

Aurora SBC webpage