



OpenVPX Chassis Thermal Management

DANGEROUS MYTHS AND ANALYTICAL TOOLS

DESIGN > DEVELOP > DEPLOY

WHITE PAPER



Flexible D2D Chassis Reduce Costs & Simplify Schedules

Introduction

The Defense and Aerospace rugged systems market demands a wide range of computing capabilities at extreme environmental conditions. Across the board, applications need more processing power and, inevitably, thermal management becomes more challenging as the amount of processing power grows.

The increase in thermal management challenges is also tied to the industry shift from VME implementations to OpenVPX. Certain myths and misconceptions can further complicate the issue for systems designers, while analytic tools exist to help efficiently address thermal management designs. This white paper examines both the myths and the tools, providing a foundation for better understanding and better design decisions.

Designing New Systems with New Standards, New Processors – and a Lot More Heat

New embedded systems designs for Defense and Aerospace have moved to the OpenVPX standard for a variety of reasons, support of high bandwidth fabrics being the main driver. These new OpenVPX systems can be configured with an array of new processing elements, driving huge performance leaps relative to the VME systems of just a few years ago. However, that new performance level brings with it a new design challenge – managing the equally huge leap in power use manifested as heat. 60 Watts was the upper end of power requirements for a 6U VME processing board; 6U OpenVPX processing boards routinely require 125 Watts and the high-performance embedded computing (HPEC) modules are reaching the 180-220W range. To deal with that additional heat, designers need a clear understanding of thermal management using the OpenVPX standard.



Results of inadequate cooling

Myths and Misconceptions on OpenVPX Chassis Thermal Management

Before starting a project, designers need to be aware of common OpenVPX chassis thermal management myths and misconceptions to avoid getting blind-sided by serious thermal problems down the road. Projects can fail qualification and payloads can be damaged if excess heat is not dealt with. The most common myths and misconceptions are:

Myth #1: OpenVPX Thermal Management is really just like VME.

Myth #2: OpenVPX chassis cooling can be addressed later on.

Myth #3: An existing chassis will work just fine.

Myth #4: It is generally possible to cool a chassis with natural convection (no fan), regardless of the ambient environment.

Myth #1: OpenVPX Thermal Management is Really just like VME

Compared to OpenVPX, VME64x modules are relatively low power and require only modest cooling; as a result, thermal management is typically not one of the biggest concerns for a VME system.

Many chassis suppliers and system integrators have successfully developed and deployed VME64x chassis without using sophisticated thermal modeling and simulation tools, because typical VME64x modules don't consume a lot of power. A really hot VME64x module might top out at about 60W. In comparison, for a 6U OpenVPX module, 60W is relatively low power. It's not unusual for hot OpenVPX modules to consume 2 to 3 times as much power. An OpenVPX GPGPU board will typically consume 150W. Dual Intel Xeon boards can reach over 200W!

Because OpenVPX modules consume so much additional power, they operate at much higher temperatures than VME cards. These elevated temperatures require much greater attention to

Thermal Management, so that operating limits are not exceeded. Failure to do so can result in burning up an expensive set of payload modules due to inadequate cooling.

Some families of processors throttle back their clock speed in over-temperature conditions, substantially reducing performance and posing significant problem for real-time applications. In situations like this, an approach that worked for VME is inadequate and the lack of thermal management will put a program's overall success at risk.

Myth #2: **OpenVPX Chassis Cooling can be Addressed Later On**

Often designers don't address OpenVPX chassis cooling during the early stages of a project, thinking that it is a simple problem that can be addressed later on. But because of the typically high power dissipation of OpenVPX modules, if adequate cooling is not a basic part of a design it may be impossible to work it in later without major changes.

Even chassis for lab use can be a problem. General purpose chassis that were designed for VME are often used for OpenVPX lab development without understanding the risk. Beware - the cooling in these chassis is virtually guaranteed to be inadequate, even for lab use. If the development chassis doesn't have cooling per the OpenVPX standard, modules can easily overheat, causing schedule delays while the development team scrambles to solve thermal management issues at the last minute.

Myth #3: **An existing chassis will work just fine**

Be especially concerned about thermal management when a OpenVPX backplane is being installed into a chassis that was originally designed for VME64x, CompactPCI, or VXS. A chassis designed to remove 60W of heat per slot is not going to be able to deal with 150W per slot. As noted above, inadequate thermal management can put your program's overall success at risk.

Myth #4: **It is generally possible to cool a chassis with natural convection (no fan), regardless of the ambient environment**

Because of its simplicity, ease of implementation, high reliability and low-cost, most system designers prefer to use Natural Convection as their cooling method. Unfortunately, natural convection is not able to remove significant levels of heat unless the

ambient environment surrounding the system has a low or moderate temperature. Without relaxed environmental constraints, Natural Convection is not suitable for systems implementing high performance OpenVPX modules.

Cooling Begins With Communication

To identify the appropriate thermal solution for a particular application requires communication and interaction with team members who are knowledgeable about the target environment. Ideally, this communication occurs as early as possible in the system definition process, starting prior to the PDR (preliminary design review) meeting and continuing through the system requirements review.

The first step in the overall system design process is to define the system's required functions or capabilities. The next step is to determine the system's (and platform's) physical constraints, and then, based on those constraints, to select which existing modules can provide the required functions.

At this point a decision might be made as to which module form factor type will suffice, for example 3U or 6U, a decision that is often determined by space constraints. Trade offs in terms of performance, functionality and weight will also be considered. Then a set of system modules will be identified, at least as initial design choices.

Once the module-set is identified, the process of selecting the appropriate cooling solution to match the target deployed environment can begin. While most system integrators have a good general understanding of available cooling options, the rest of this white papers presents a set of questions and tools to help with the this selection process.



Communication is key.

Analytic tools

Determining a System’s Thermal Management Criteria

To avoid cooling issues during a project, some important thermal criteria need to be defined early in a project life cycle. Here are a set of questions to help with that process.

- How much power must be dissipated? Watts per slot? Total watts? Any hot slots?
- How will the payload be cooled? An application may be open to one or more payload cooling approaches, including forced air, conduction cooling, air flow through (AFT) and liquid flow through (LFT).
- If payload cooling will be by forced air: How much cooling air (CFM) does each module require, and at what pressure drop? Can the payload be exposed to the ambient cooling air or is a heat exchanger required?
- If payload cooling will be by conduction: What card edge temperature does each module require? What

- is the thermal resistance of the wedge lock thermal interface to the chassis rail?
- If chassis cooling will be by cold plate/baseplate, where is the conduction plate surface located and what is its operating temperature range?
 - If chassis cooling will be by natural convection or forced air: What is the operating temperature/ altitude envelope?
 - If chassis cooling will be by forced air provided to chassis: What is the cooling air mass flow rate, cooling air operating temperature range, and maximum cooling air pressure drop allowed?
 - If chassis cooling will be by forced liquid provided to chassis: What is the liquid coolant type, coolant flow rate, and coolant operating temperature range? What is the maximum coolant pressure drop?

Cooling Method Details

The commonly used permutations of cooling options available to meet rugged system design requirements are outlined in the table below.

TABLE 1 CHASSIS AND MODULE COOLING METHODS				
Chassis cooling method	Chassis cooling method	Module cooling method	Approximate module power dissipation (W)	Typical limit for chassis power dissipation (W)
Natural convection sealed	Natural convection air cooling (no forced air)	Conduction cooled modules	50	300
Cold plate / baseplate sealed	Conduction cooling - cold plate	Conduction cooled modules	75	500
Forced air conduction cooled (internal fan or externally supplied air)	Forced air conduction cooled (internal fan or externally supplied air)	Conduction cooled modules	150	2000
Liquid conduction cooled	Liquid cooled through chassis side walls	Conduction cooled modules	200	3000
Air Flow Through (AFT) cooled	Air Flow Through (AFT) chassis	Air Flow Through (AFT) modules	200	3000
Liquid Flow through (LFT) cooled	Liquid Flow through (LFT) chassis	Liquid Flow Through modules	600	8000
Forced air cooled	Convection cooling - forced air (internal fan or externally supplied air)	Air cooled modules	150	3000
Air/air heat exchanger cooled	Convection cooling - forced air (internal fan or externally supplied air)	Air cooled modules	100	1000
Liquid/air heat exchanger cooled	Liquid cooled through liquid/air heat exchanger	Air cooled modules	100	1500
Spray cooled with some method of chassis heat removal (typically fan cooled on exterior heat sinks)	Spray cooling - direct impingement on IC's	Air cooled modules (qualified for compatibility with coolant)	700	8000

Key Thermal Management Basic Principles

Thermal management for rugged chassis includes several potential obstacles, so it’s useful to state some basic principles.

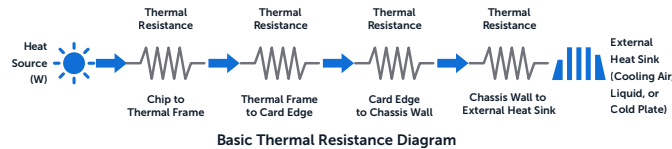
- In rugged chassis the Heat Sources are typically chips on embedded modules and power supplies
- In rugged chassis the External Heat Sink is typically ambient air, ducted cooling air, a liquid coolant, or a cold plate.
- Heat flows from the Heat Sources to the External

- Heat Sink, from higher to lower temperature
- This heat flows through various Thermal Resistances to the External Heat Sink, which means that (except in the case of refrigeration) the Heat Source will be at a Higher Temperature than the External Heat Sink.
 - If the Heat Source is not at a sufficiently Higher Temperature than the External Heat Sink, then Refrigeration is needed.
 - All of the Thermal Resistances must be taken into account.

The Heat Transfer Equation

Many cooling methods are via air or other fluids to transfer heat away from the system. The temperature of the cooling fluid (air or liquid) increases when it absorbs heat from the heat source. The mass flow heat transfer equation is shown in the figure below.

- The temperature rise is proportional to the total heat (W)
- The temperature rise is inversely proportional to the specific heat of the fluid
- The temperature rise is inversely proportional to the mass flow rate of the fluid.
- Note that the mass flow rate of air at a given volumetric flow rate (e.g. cubic feet per minute (CFM)) decreases rapidly with altitude.



Density of Air vs. Altitude

Figure 1 shows the density of air vs. altitude. At even a modest altitude of 10,000 ft, the air density is reduced to 75% of its value at mean sea level (MSL); at 60,000 feet it is less than 10% of its value at MSL; ergo the mass flow of cooling air at a given number of CFM is also less than 10% of its value at MSL, dramatically altering the cooling performance. That's why it is critical to understand the combined temperature-altitude envelope for operating conditions.

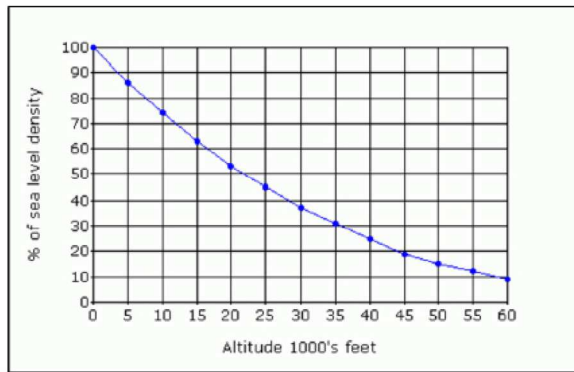


Figure 1: Density of Air vs. Altitude

- $Q = c_p \cdot dm/dt \cdot \Delta T$
 - Q = Total Heat in Watts
 - (Specified by Hardware Implementation)
 - c_p = specific heat of fluid (Fixed Fluid Property)
 - dm/dt = mass flow rate of fluid
 - $dm/dt = \rho \cdot dV/dt$
 - dV/dt = Flow rate in Cubic Feet per Minute
 - ρ = density of fluid
 - (note: density of air varies strongly with altitude)
 - ΔT = Allowed change in Temperature
 - (Driven by Customer Thermal Boundary Conditions)

Watts per cubic inch

Figure 3 below quantifies cooling performance of different cooling methods in terms of Watts per cubic inch, which provides a rough figure of merit for these different cooling methods. Different cooling approaches have vastly different performance.

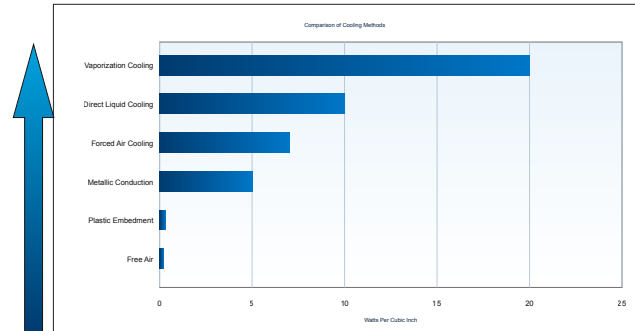


Figure 3: Cooling Methods by Watts per Cubic Inch

For design implementation, we offer the industry's most comprehensive range of rugged module, chassis, and subsystem solutions, with the broadest mix of chassis and cooling technologies available, to meet the demands of any defense and aerospace environment.

Platform Suitability

For rugged applications, cooling performance is just one dimension. Figure 4 maps the suitability of a number of chassis-module cooling methods to different applications.

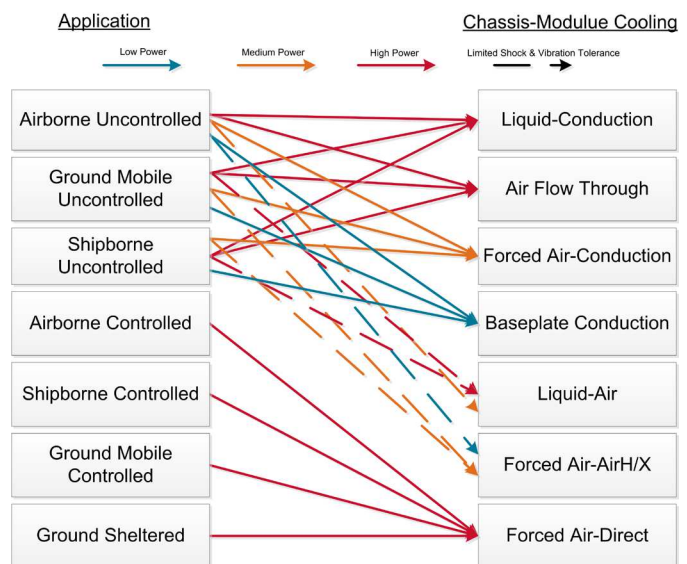


Figure 4: Applications and Cooling Methods

Primary Cooling Mechanism	Typical Heat Transfer Coefficient (W/m ² K)	Relative Effectiveness	Achievable Density	Complexity
Natural Convection (air)	10	.01	Low	Very Low
Forced Convection (air)	100	1.0	Medium	Low
Natural Convection (liquid)	100	1.0	Medium	Medium
Forced Convection (liquid)	1000	10.0	High	High
Phase Change (liquid)	8000	50.0	High	High

Heat Transfer Coefficients

The Table below shows typical Heat Transfer Coefficients for different cooling mechanisms. Different cooling mechanisms have intrinsically different levels of performance which can determine suitability for a given application.

Summary

OpenVPX systems offer a huge performance leap over VME systems but there is also a significant increase in the complexity of the thermal management; design approaches used with VME are no longer viable. To avoid cooling issues during an OpenVPX chassis project, thermal criteria need to be defined early in the life cycle. Fortunately, there are several viable cooling methods as well as analytic tools to evaluate these methods based on system configurations and application requirements.

Engaging with Atrenne for OpenVPX Chassis Thermal Analysis and Design

Atrenne, has extensive experience with chassis thermal analysis and design that has been earned and proven over decades through the successful deployment of chassis and backplanes with COTS modules in hundreds of programs. By engaging with us, system integrators can access that expertise to avoid thermal management issues, optimize designs and stay on schedule.

For design implementation, we offer the industry's most comprehensive range of rugged module, chassis, and subsystem solutions, with the broadest mix of chassis and cooling technologies available, to meet the demands of any defense and aerospace environment.

Learn More

Chassis Solutions Guide
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