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» Whitepaper «

Advanced Thermal Management Solutions Cover Broad Mil-Aero Requirements

Complex and Demanding Military Applications Elevate Thermal Issues for Designers

Part One of Two

Advanced Thermal Management Solutions Cover Broad Mil-Aero Requirements

Complex and Demanding Military Applications Elevate Thermal Issues for Designers

Today's military applications are more demanding than ever, with requirements to push the limits of bandwidth and performance while enduring intense environmental conditions. Survivability is critical, as sophisticated features are only as good as their ability to operate without fail. The rigors of battle in remote locations continue to present an evolving range of unique challenges to military system designers. Everything from severe temperatures, shock and vibration, to explosive decompression, immersion and exposure to sand and dust are variables that must be considered when building rugged, high performance systems for the armed forces. Innovative thermal management techniques have become essential to meeting these requirements for fault-free performance, and military designers are now making it a priority to solve cooling challenges early in the design phase.

By integrating cooling capabilities into the SWaP protocol, packaging engineers have created SWaP-C (Size, Weight, Power and Cooling) as a focus for next-generation solutions. Using COTS solutions as the foundation for semi- and full-custom thermal management, designers are increasing the capabilities of subsystems and enabling new designs that meet or exceed current mil/aero thermal requirements. Thermal options will vary accordingly depending on application, expertise, cost and development time. As a result, it is necessary to have a thorough understanding of how designs generate heat and how design choices reliably dissipate that heat. Knowledge of the primary thermal management methods illustrated in this paper will help designers determine the most appropriate path for their specific design.

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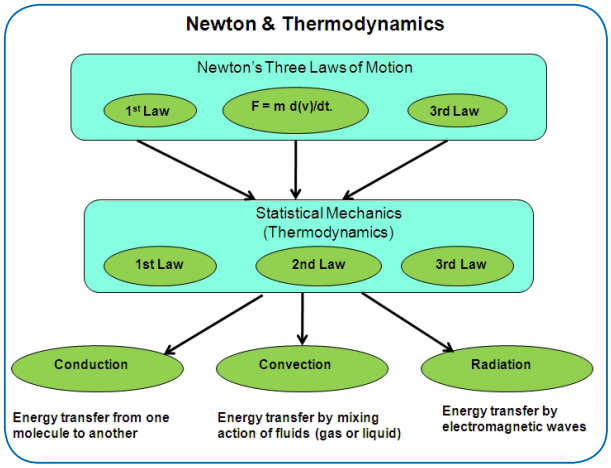
Market Background/Thermal Demands

Rugged design is a mandate warranted by the modern military's more extreme applications and increased performance needs. The most critical and unique design requirements encompass a range of characteristics grounded in ever-increasing computational power and communication bandwidths. Many airborne and ground mobile applications, for instance, operate high definition vision systems with real-time processing. This in turn drives significant power densities at the board, chassis and platform levels. The growing deployment of UAVs combined with current initiatives such as BCT (Brigade Combat Team) modernization has designers dealing with system aggregate power needs of tens of Kilowatts. At the same time, system developers are required to deliver smaller, lighter, faster solutions with effective thermal management ensuring extreme reliability.

Higher temperature decreases overall reliability, and more transistors mean more heat is generated within these systems. Faster, higher density chips equate to higher power densities overall and increased thermal cycling can lead to fatigue failures. Improved cooling has been defined is a priority illustrated by designers embracing the concept of SWaP-C.

Thermal Management Options

Cooling challenges have increased in step with higher performing processors, smaller system footprints and evolving rugged environments. The overall goal for cooling electronic military equipment is to maximize the flow of thermal energy from heat generating equipment to a local heat sink. The heat sink could be ambient air, a cold plate or a liquid exchange system. However, for all the demands of military applications – bandwidth, performance, form factor and more – designers are always bound by the laws of classical physics. Newton's three laws of motion form the foundation of classical physics, which through the application of statistical methods are used to derive the basic laws governing thermodynamics.



These laws establish that heat will always move from warmer areas to cooler areas through the action of one or more of the following principle modes of heat transfer:

1. Convection - Energy transfer by mixing action of fluids (gas or liquid)
2. Conduction - Energy transfer from one molecule to another
3. Radiation - Energy transfer by electromagnetic waves

Over time, real world requirements have shaped these basic tenets into several principal and proven cooling methodologies summarized below:

» Forced convection
» Conduction paired with forced air or liquid
» Conduction paired with passive convection
» Conduction paired with a cold plate

All of these methodologies benefit from the ever present effects of cooling by radiation, however, the contribution from radiative cooling is usually ignored unless the overall power dissipation is low. In these low power scenarios, the fractional contribution of radiation can be significant and should not be ignored.

The table below offers a general guideline of approximate power dissipation capabilities for various types of cooling. It's important to note that there may be considerable variation in these values depending on environmental conditions.

Power Dissipation VS Cooling Method

Option	Performance (Watts per inch of Pitch)*
Conduction cooled – passive convection (no fan)	25
Conduction cooling – cold plate	50
Conduction cooled – air blown through chassis side walls (Fan or plenum)	75
Convection cooling – air blown (fan or plenum air)	100
Conduction cooled – liquid cooled through chassis side walls	125
Conduction cooled – liquid flow through modules	500
Spray cooling – direct impingement on ICs	700

(*) depending on ambient conditions

Figure: The essentials of thermodynamics are based on Newton's Three Laws of Motion, providing fundamental boundaries for design engineers. Motion and energy behave in specific ways, and manifest as conduction, convection and radiation methods for cooling electronics equipment.

Military applications can vary greatly in their mission objectives. For example the thermal design goals may be quite different for short- and long-range UAVs, man-wearable computers and environments sealed to avoid any number of airborne contaminants. A given thermal solution might need to tolerate the corrosive aspects of naval environments, or dust in the air may limit the design's ability to force ambient air across electronic components. To determine an optimal cooling solution, packaging engineers must fully understand the boundary conditions of the system, form factors and component-level attributes. By analyzing thermal demands of the end-use application, as well as understanding the unique requirements of individual devices designed into the system, designers can determine an optimal cooling scenario.

Forced Convection Cooling

Forced convection cooling applies air in direct contact with boards and system components via the use of chassis fans or a host platform ECU (Environmental Control Unit). Forced air impinging directly on system boards, power supplies and other components, absorbs heat and is then exhausted from the system via exhaust vents.

Forced convection cooling is functionally acceptable if the air is clean and dry, and is ideal for slightly more benign military environments. Power dissipation can be as high as 100 Watts per board, assuming a maximum air temperature of 55°C. An example of a typical forced convection system is the Kontron FS-1290 chassis shown below.

Image: In the Kontron FS-1290, the card cage is cooled by internal fans that draw air through an inlet located on the front door of the chassis. The inlet is routed up through the VME/cPCI card cage, around the power supplies and is exhausted through the upper rear of the enclosure.

To increase thermal dissipation, designers can simply use more or bigger fans to move air through the system enclosure. This assumes that space, cost and noise are not design issues. It is important to note however, that an increase in the number of fans decreases reliability and increases cost and weight. For more sophisticated applications such as unmanned aerial systems, this approach opposes SWaP constraints and forces the designer to explore other means for getting rid of heat.

Conduction Cooling Introduction

Conduction systems differ from forced convection systems by transferring heat energy through direct contact of the heat-generating components to the system enclosure. Thermal energy is then transferred to either a moving air stream or liquid inside hollow side walls, or to external fins for passive convection. In contrast with forced convection solutions, air moving through a conduction design never physically touches system components.

System boards, power supplies and other components are sealed inside an air tight enclosure. Using wedge locks or other mechanical means, the edges of each component within the system are mechanically clamped to the enclosure's structure. As the wedge locks expand when tightened, they create a primary cooling path from the heat-producing elements to the chassis. The wedge locks assure the boards are mechanically secure and offer excellent resistance to shock and vibration. However, conduction designs tend to be more costly than their forced convection-based counterparts.

Conduction Paired With Passive Convection

Conduction cooling paired with passive convection offers military designers an alternative ideal for applications which are impractical for fan use. These types of environments may also present a higher MTBF requirement, due to their mission critical aspect and less accessibility for maintenance. As a result, a thermal solution with no moving parts may be required.

Conduction-based passive convection solutions do not use a fan in the system. The boards are confined and completely isolated from the ambient environment. Heat removal is achieved through conduction to a passive cold wall which then convects or radiates the heat away. As the box itself physically heats up, it heats up the air immediately surrounding it. The air's reduced density causes it to rise and pull in cooler air from beneath, achieving passive convection. Conduction-based passive systems are available in either standard ARINC 404A style form factors or custom enclosures. An example of a passive convection design is the Kontron FS-5981 Chassis shown below. Also, shown below is a thermal performance curve for this chassis.

Image: In the Typical Rugged Passive Convection Cooled Enclosure – Kontron FS-5981 Holds Five 3U System Boards

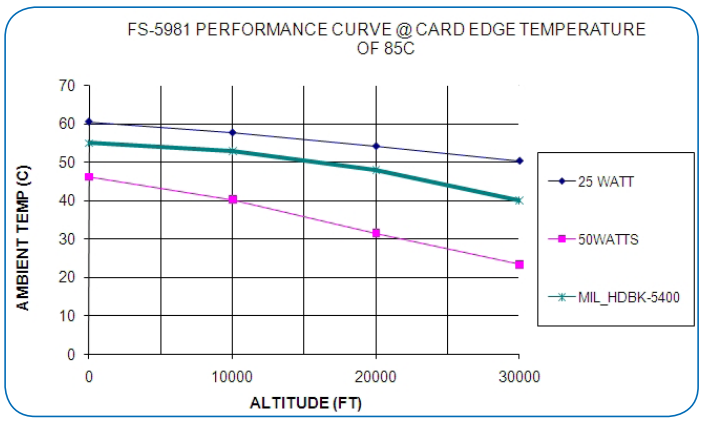


Figure: Thermal Performance Curve for the FS-5981 Chassis

A common myth in systems packaging is that radiation plays a marginal role in cooling electronic equipment. That holds true for higher power systems with high levels of power to be dissipated. However, engineers should pay attention to the effects of radiative cooling in passively cooled convection systems that operate at low power. These smaller, lower power systems are carving a path in military electronics and radiation can play a significant role in their growing applicability. For example, a generic metallic box with dimensions of 8" x 12" x 7" in an environment at 100°F and 0 air pressure (i.e., a perfect vacuum) can dissipate more than 27 Watts by radiation effects alone. This is significant for designers, providing additional cooling for enclosures in unmanned aerial vehicles flying at very high altitudes where the air is thin or where there is a lack of infrastructure to support liquid or air cooling. The Kontron COBALT (Computer Brick Alternative) illustrates a successful passive convection approach, offering scalability and excellent power dissipation in a sealed system.

COBALT is versatile – providing military designers with a small-footprint, low-power and cost-saving alternative to conventional multi-board VME or CompactPCI designs. Efficient thermal design supports fanless operation in severe environments, and computing performance based on specific application requirements , i.e., from very low power Intel Atom processor-based implementations to powerful Intel Core2 Duo processor systems. Handling operating temperatures ranging from -20°C to +55°C (Core2Duo based) and -40°C to +71°C (Atom based), COBALT is compatible with a full range of ground vehicle, UAV, manned airborne or shipborne requirements.

Image: The Kontron COBALT is a fanless, fully enclosed design for efficient thermal management in a small 6.5 x 9.725 x 2.95-inch (165.1 x 247.015 x 25.4 mm) form factor weighing less than 5.5 pounds (2.5 kg). This small, low-profile box-level system meets the military's Size, Weight and Power (SWaP) requirements and features a no-backplane design that is both reliable and cost-effective.

Another example of a passively cooled system is Kontron's VETRONICS enclosure. VETRONICS has been designed for ground mobile applications and integrates three single board computers based on Computer-on-Modules into a fanless system. This enclosure can dissipate up to 85 Watts of power via passive convection through external fins on the side of the box. Designed for rugged military environments with extreme shock and vibration, this enclosure is a good example of a high reliability, fanless solution with no moving parts.

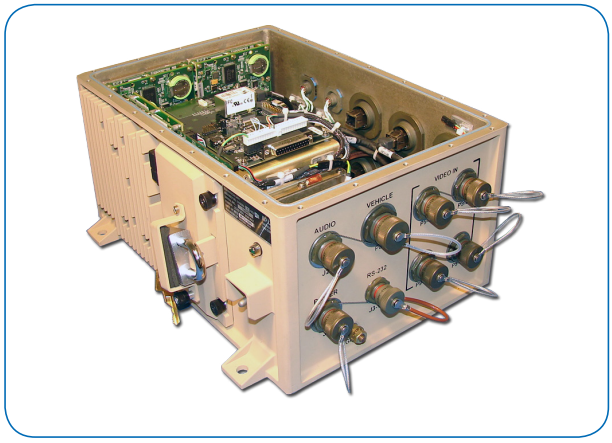


Image: With three SBCs, removable solid state drives, and Ethernet switch, Kontron's fanless VETRONICS system is thermally efficient and functional for a range of rugged mil/ aero applications.

Image: Kontron FS-5985 Holds Five 3U System Boards

Conduction Paired With Forced Air

In using conduction cooling methods with a fan, the boards are again sealed off from environmental elements. The types of seals employed in conduction cooling offer not only protection from environmental contaminants but also protection from EMI effects for conducted, radiated and emitted electric fields. A rear mounted fan pulls air through hollow side walls and exhausts it out of the enclosure. The reason air is pulled rather than pushed is to prevent fan-generated heat from being introduced into the air stream and subtracting from the system's overall thermal efficiency. Similar to passive convection enclosures discussed earlier, these systems are available in either standard ARINC 404A styles or custom form factors.

The Kontron FS-5985 shown below is an example of this type of enclosure. This system houses five 3U CompactPCI or VPX system boards and a 200 Watt AC or DC power supply. The I/O is easily customizable and offers a versatile wiring scheme via internal Meritec, 2 mm hard metric, and five wire wafers. A rigid-flex circuit can also be utilized for higher volume applications for increased reliability and reduced cost.

A thermal performance curve for the FS-5985 chassis is shown below. For power dissipations of 100 Watts or less, it meets the requirements of MIL-HDBK-5400.

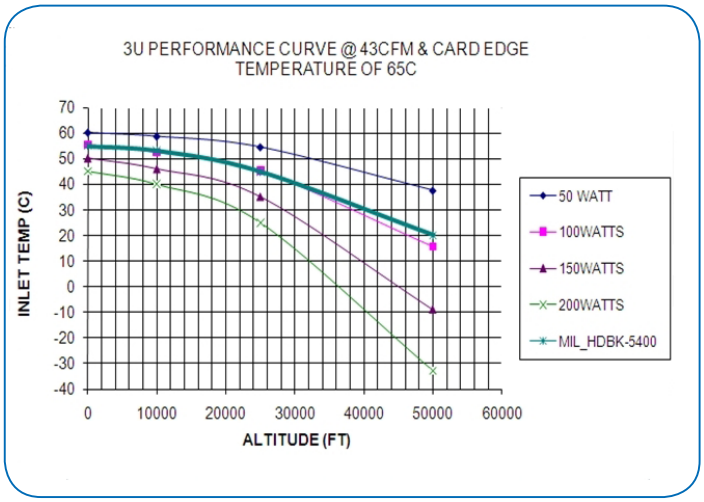


Figure: Thermal Performance Curve for the FS-5985 Chassis

Conduction Paired With a Cold Plate

Some applications cannot afford access to a replenishable air supply for either forced convection or passive convection cooling. In these cases, a conduction chassis paired with a cold plate may be the optimal thermal configuration. As with any conduction cooled chassis, heat is conducted to the chassis side walls, but in this case the heat is directed to a bottom- or side-mounted cold plate. The cold plate itself can be either actively or passively cooled. The Kontron FS-5977 chassis is a bottom-mounted cold plate design and is shown in the illustration below, along with its thermal performance curve.

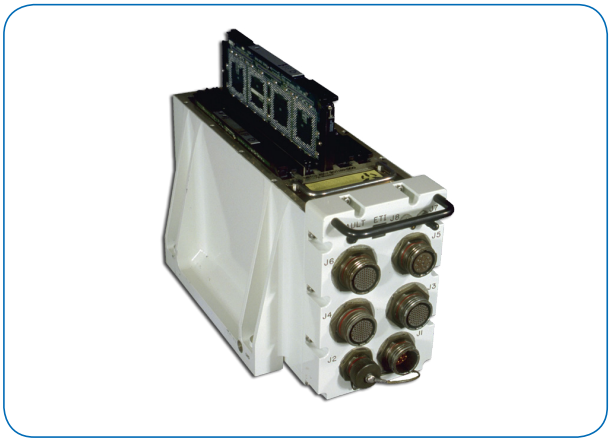


Image: Kontron FS-5977
Holds Five 6U System Boards

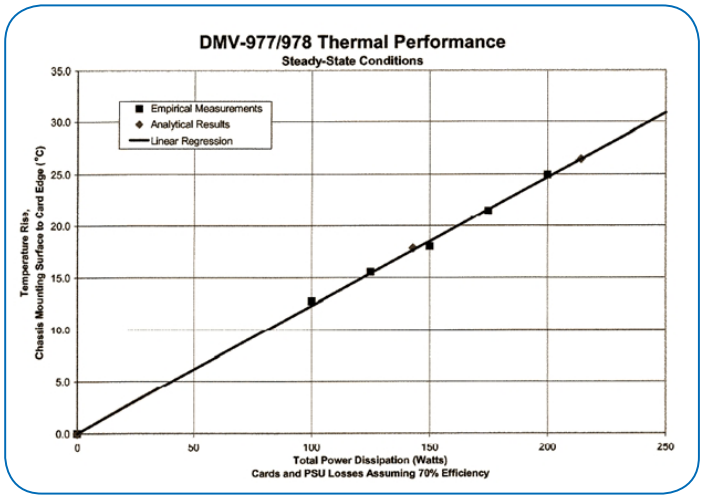


Figure: Thermal Performance for FS-5977

Conduction Cooling Paired With a Liquid

When power dissipation demands exceed the thermal capabilities of forced air or passive convection systems, designers can consider liquid cooled conduction systems. The liquid typically used to move heat is a water/glycol mixture or non-conducting fluid such as Fluorinert, an inert fluorocarbon fluid. Design options include liquid flowing through hollow side walls of the chassis or direct impingement of a dielectric (non-conducting) fluid on the system components known as "Spray Cooling." In both methods, the liquid requires a separate heat exchanger, which can be within the enclosure itself or external to it. The need for a heat exchanger is a disadvantage to liquid cooling, adding weight, cost and complexity to the system that ultimately decreases overall MTBF. However, for enclosures generating power in excess of 1 Kilowatt, liquid cooling may be the only option.
An example of a liquid cooled chassis is shown below. This enclosure uses a high performance, blind mate style connector to enable rear I/O including copper and fiber optic signaling. Fluid is introduced through quick disconnect style connectors that are designed with automatic shut-off poppet valves.

It is a common misconception that liquid cooling is required for systems dissipating power in the range of 500 Watts to 1 Kilowatt. These systems can be cooled using conduction paired with forced air; however, they do require multiple high performance fans and careful design modeling. The advantage to using conduction with forced air in these applications is the absence of the heat exchanger, which requires a costly and heavy infrastructure for support. This is an especially important consideration for airborne or ground mobile combat applications where reliability and reduced weight is a premium.

Another example of liquid cooling is the use of liquid flow-through modules. These designs provide superior thermal performance by delivering coolant closer to the sources of heat within the system, in turn enabling higher power densities. In these designs, liquid, in addition to flowing through the chassis side walls, also flows through special channels on the system boards themselves. An example of this type of cooling module is illustrated by the Kontron 6U VPX chassis shown below.

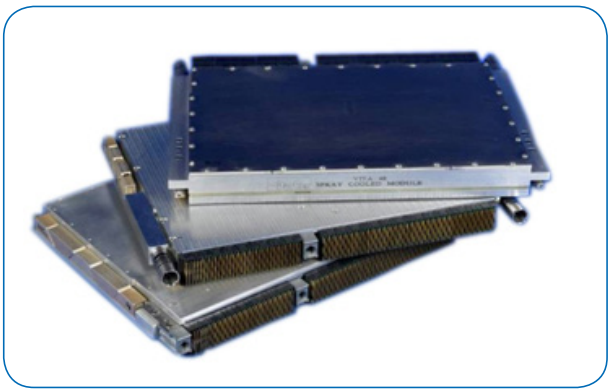


Image: 6U VPX Liquid Flow-Through Modules

Semi- and Full-Custom Thermal Solutions

To adequately cover the range of functionality in today's military mobile device applications, attention to heat, dust and other airborne contaminants is essential. Some of these added requirements can further constrict system airflow, and demand customized attention to thermal management.

Due to the diversity of requirements, the most optimally designed systems are customized appropriately – addressing performance, cost, reliability needs and development timelines. Therefore, thermal management in particular must be dealt with head-on. Packaging designers first need to determine a system's thermal calculations and make design decisions accordingly. Selection of the appropriate thermal solution also hinges on selecting a manufacturing partner that is experienced across the range of platforms and form factors who can serve as advisor. Kontron's full range of thermal management methodologies, supported by a long history of effective and innovative military designs, matches complex needs of designers and applications. Ideally this type of manufacturing partnership provides a significant competitive advantage to designers, where all critical levels of expertise are combined into a single engineering resource.

Military OEMs further benefit from the breadth of Kontron's own product offerings ; customized support and expertise is available regardless of form factor, platform or rugged application. By maintaining a flexible production mix, Kontron incorporates its own manufacturing along with contracted manufacturing to ensure business continuity through custom design, thermal modeling and product development processes.

Thermal Management Moving Forward

Increasingly complex military systems are driving increased challenges in integrating effective thermal management methodologies. Designers are learning that making early choices about power dissipations, design layouts, paths for air flow and overall thermal performance has become essential to developing rugged systems suitable for mission-critical military environments. On the positive side, advancements and the broad scope of thermal methodologies are benefitting packaging engineers who have developed a deep understanding of each type of available solution.

Higher performance (with higher speed and density components), coupled with smaller form factor boards and reduced system footprints are frequent demands of rugged military applications. As designers continue to push the envelope with increased functionality, new thermal management options will continue to evolve to satisfy next-generation application requirements for more efficient cooling solutions to match new standards specifications or increased ruggedness. Managing the complex cooling issues associated with many of these unique or extreme environments requires broad thermal expertise, and a thorough understanding of supporting design choices including working with a strong partner that can provide extensive expertise in how and when to provide proven semi- and full-custom solutions.

About Kontron

Kontron is a global leader in embedded computing technology. With more than 30% of its employees in Research and Development, Kontron creates many of the standards that drive the world's embedded computing platforms. Kontron's product longevity, local engineering and support, and value-added services, helps create a sustainable and viable embedded solution for OEMs and system integrators. Kontron works closely with its customers on their embedded application-ready platforms and custom solutions, enabling them to focus on their core competencies. The result is an accelerated time-to-market, reduced total-cost-of-ownership and an improved overall application with leading-edge, highly-reliable embedded technology.

Kontron is listed on the German TecDAX stock exchange under the symbol "KBC".
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