Thermal Efficiency for Conduction Cooled MIL-Spec Enclosures

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Conduction cooled enclosures are often the most practical embedded packaging choice for thermal management in extremely rugged and demanding military and aerospace applications. Military specifications detailing the essential technical requirements for compliance must be met or exceeded.

Conduction cooled systems enable full environmental sealing for "all-conditions" operation, and can be fully ruggedized for Unmanned Aerial Vehicle (UAV) and other mission-critical conditions where system size, weight and power are crucial, and high performance capability is required. By optimizing the cooling path, efficient thermal conductivity can provide for robust cooling performance and maximum power dissipation.

Today's embedded systems consume more power and generate more heat than ever before, and though the military tries to follow the "COTS directive," many of the applications are so specialized that no present packaging product meets the project's requirements, and a specialized unit must be built. In addition, deployment cycles are becoming shorter.

Both factors mean that a completely new design must work right the first time. Through experience, calculation and the use of sophisticated tools such as FloWorks, highly efficient conduction cooled enclosure solutions that meet military thermal management challenges can be validated before the application-specific design is completed.

MIL-Spec Enclosure Cooling Conundrums

Modern defense electronic systems, especially new high performance processor modular boards and power supplies, generate considerably more heat than their predecessors. These systems have more components running at increased speeds, making it more difficult to get that heat out. Also, more systems are moving to the 3U form factor. This requires component densities to increase still further.

In some circumstances ambient air cannot be circulated since it may be nonexistent, such as in space or at high altitudes. Often, the system must operate in desert, salt spray or other extremely harsh environments. These enclosures must be fully sealed to prevent contamination.

Every military system requires heat management beyond natural convection or radiation at the board level. While fans are still used in many systems, the military recognizes the advantages of systems with fewer moving parts and that are completely sealed against any possible environmental factor.

Air cooling can be very effective, but has its limitations. Military systems are often expected to have a MTBF of 200,000 hours or more. The use of fans can severely impact MTBF.

Fans that can produce very high velocities are often expensive and noisy. Since the cooling effect of air increases in proportion to the square root of the velocity, the gains achieved by moving air faster than 1,000 LFM (linear feet per minute) become small.

Conduction Cooled Enclosure Solutions

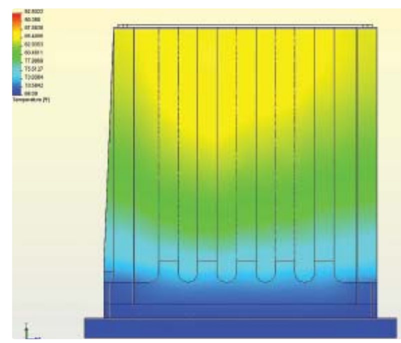
Properly designed conduction cooled enclosure systems can provide improved performance over forced convection cooled systems and reduce size 25 percent to 50 percent because no space is needed for airflow. In conduction cooled systems, boards are designed to conduct heat from hot components to wedge mounts at the edges of the card.

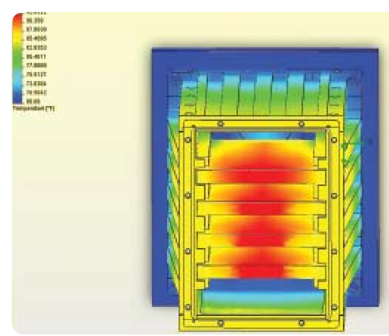
Cards fit into channels machined into the sides of the enclosure. Metal screw-driven wedge segments expand against one side of the channel, forcing the heat conducting material on the edges of the PCB against the opposite side with high pressure, thereby optimizing the conductivity of the thermal path between the edge of the board and the chassis. In addition, these wedge mounts secure the module in the chassis, preventing any movement.

In many cases, it is impossible to conduct all of the heat through the PCB substrate. In these cases, it is necessary to add an aluminum or copper "hat" on the PCB, providing heat generating components another path to get the heat to the board edges.

Conduction cooled board form factors and wedge mounts are standardized by IEEE 1101.2. Also, ANSI/VITA 47 and 48 normalize the different severity levels for conduction cooled modular boards. These standards assure that boards from different vendors will work together.

When designing systems, physical models are created by 3-D mechanical software such as SolidWorks and thermal conductivity is simulated by using these models with thermal analysis software such as FloWorks. Designers must know the quirks of design and simulation software to get results faster. Example: A screw holding a metal plate with a different thermal conductivity may cause the software to spend excessive time over the insignificant thermal conductivity effects of the screw. Keep models simple.





Aluminum has good thermal conductivity for its weight, but if weight is not critical copper can be used. Copper has a thermal conductivity 1.8 times greater than aluminum. Heat pipes have an effective thermal conductivity tens-of-times greater than copper, and can provide solutions to what seem like insurmountable problems. Their use will likely increase over time as engineers become familiar with their application and develop effective simulation techniques.

Heat Pipes, Cold Plates and Liquid Cooling

Heat pipes combine thermal conductivity and liquid vapor phase transition to transfer heat. Heat pipes are passive devices without any moving parts. The hot end of the heat pipe contains a liquid that turns into a vapor, absorbing the heat of vaporization. At the cold end, the vapor condenses and releases its latent heat. Usually in electronic applications, capillary action through a sintered powder metal that lines the tube returns the liquid to the hot end.

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Heat pipes have a sharp threshold at the boiling point of their transport liquid at the pressure of the partial vacuum inside the pipe. Below this threshold, only the heat conducted by the walls of the pipe is significant. At or above this threshold, the heat pipe becomes a very effective thermal conductor.

The heat pipe's threshold temperature can be engineered and incorporated into thermal management design. Using current heat flow simulation tools requires some ingenuity in this regard. Below its threshold temperature the heat pipe must be simulated as a metal pipe, above the threshold the heat pipe is an extremely high conductance path. Since the emphasis is on cooling hot components, the simulation can often be simplified.

The heat pipe manufacturer sets the threshold by selecting the liquid and the partial vacuum pressure. In systems that may be subjected to an ultra-cold environment, this threshold can be selected to allow a board to warm up and stabilize to the threshold temperature before transferring heat to the ambient. Care must be taken in the design and manufacture of the enclosure so that the heat pipe bends are never less than the minimum radius of curvature specified by the manufacturer, plus a safety factor.

An example of a conduction cooled enclosure.

A properly designed heat pipe, when used within its limits, can carry 150 times the equivalent volume heat of aluminum. It should be noted that because heat pipes have a working liquid, their actual conductivity varies according to attitude (gravitational effects), and their heat transfer rate has a power curve and a maximum limit.

Conduction cooled enclosure systems are generally heat managed by one of three methods: by cold plate, by air over conduction or by liquid cooling.

A cold plate is used where it is convenient to have one surface cool many different electronic enclosures. The cold plate is kept cool by a circulating refrigerant or some other pumped liquid, such as water cooled by a heat exchanger in sea water.

Air over conduction cooling can be used when air is available, but is unsuitable for passing through electronic assemblies. Fins are machined or attached to the outside of the conduction cooled enclosure, and fans are used to blow cooling air over the fins.

Liquid cooled systems are often used in aircraft where neither air nor a cold plate is available. Cool liquid is circulated through the walls of the enclosure with a pump.

Conduction Cooled MIL-Spec Enclosure Design

Design-phase contact with the conduction cooled MIL-Spec enclosure manufacturer should not happen before functionality is defined and a block diagram is created modularizing this functionality into boards. The experience and expertise of the enclosure manufacturer is essential to anticipating potential heat management problems and to verify that the backplane has the required connectors to bring the board signals to front panel. This is especially important with conduction cooled systems, since the backplane is mounted against one side of the chassis and there is seldom room for any rear I/O.

With the advent of standards-based systems, such as VME, cPCI and VPX, many engineers pick their CPU and I/O boards and assume that something just must exist that will perfectly meet their needs. As a result, the chassis and cooling design of a system is often an afterthought.

The enclosure manufacturer can help evaluate overall system cost and time to market or delivery, and can also help determine if a COTS enclosure, a semi- or complete custom system will best achieve the desired functionality in a harsh environment.

The enclosure manufacturer's design engineers can make predictions on heat management in the final design, which is more important than ever since there's seldom any budget or time for prototyping.

Thermal models are generally unavailable from board vendors. There are few clues given by standards such as IEEE 1101.2 or ANSI/VITA 47 and 48 on how to design an enclosed system with effective thermal management. These standards only specify construction details such as for backplanes, connectors and form factors.

MIL-STD-810F specifies tests for ruggedized systems, which the design must meet or exceed. Other than maintenance access, removal and insertion force of boards, MIL-STD-810F views the system as a black box. The standard's various tests increase the confidence level that the system will perform in a mission-critical environment successfully.

Today's design cycles are so short that chassis, backplane and software must be developed in parallel. While software lends itself to tweaks in the field, it is usually difficult and very expensive to modify a conduction cooled chassis that doesn't perform to expectations. These shortcomings may only be discovered during system qualification, which usually occurs only weeks before scheduled system delivery, and far too late to allow a redesign. The system must meet specifications the first time.

Working closely with an enclosure and backplane manufacturer and utilizing their expertise in powering, packaging, connectorization, ruggedization and cooling is essential. In times like these, good testing and simulation tools are essential to any successful product delivery.

Charles Linquist is director of Engineering at Dawn VME Products. He has 30 years experience in mechanical, electrical and software design with telecom, commercial and military OEMs.

Dawn VME Products designs and manufactures MIL-Spec compliant enclosure, backplane, and thermal management systems to enable military rugged, high performance computing applications. For more information visit www.dawnvme.com.