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Military EMBEDDED SYSTEMS

AFT cools high-power COTS modules for military applications

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Open-standard Air Flow Through (AFT) cooling technology is a welcome addition to the options available to designers of rugged COTS systems for defense and aerospace applications. Northrop Grumman's AFT technology, incorporated in the ANSI/VITA 48.5-2010 standard, provides a cost-effective way to cool high-performance VPX boards used in C4ISR applications.

Successfully addressing the thermal management requirements of high-power, high-density COTS systems calls for a full range of cooling approaches, ranging from air and conduction cooling to spray and liquid flow through cooling technologies, as well as the requisite experience and expertise to implement them.

The power density of many VPX systems today precludes use of standard conduction-cooled cards. As cards reach up to 170 W densities, they are exceeding the single-slot capability that a conduction -cooled card can handle, especially when several of these high-powered cards are used in adjacent slots in a system (depending on components and environmental constraints). Northrop Grumman’s Air Flow Through (AFT) cooling technology for VPX cards, defined in the ANSI/VITA 48.5-2010 standard, provides an additional weapon for defense and aerospace integrators to use in their fight against excessive heat in high-power-density cards and systems. AFT hits the "sweet spot" for today's high-performance modules, enabling reliable cooling of 120 to 200 W cards within the boundaries of +55 °C air. Consideration of alternative approaches such as conduction cooling, air cooling, spray cooling, and LFT serves to highlight the benefits of AFT.

Goal: Cooling close to the component

Conduction cooling

Standard conduction-cooled cards have difficulty handling the temperature rise across a 170 W card. Adding to the challenge is the additional thermal resistance of transferring the heat to the enclosure, then rejecting to the surrounding air plus the adjacent cards' power dissipation. Regardless of which medium is used to reject heat, the solution becomes impractical for a typical +55 °C ambient air environment. This means that the familiar cooling methods – such as external forced convection (air blown over the outside of the chassis' surfaces to draw heat from the system) and baseplate cooled (heat conducted to the mounting surface and rejected into the mounting plate) – are insufficient.

A typical conduction-cooled card has too large of a thermal resistance to cool today's highest-performance modules. In some cases, heat pipes or copper inserts have been utilized to handle power densities too high for a typical aluminum conduction heat sink, to move heat to the card edge. The thermal transport capability of heat pipes can provide a significant benefit to solving the aforementioned issues. Unfortunately, when taking into consideration the total power of the system, the temperature range, and attitude dependencies of the heat pipes, the solution can become a significant cost driver and still does not effectively handle large power densities in the enclosure.

Air cooling

A better solution requires a shorter thermal path from the heat-generating component to the cooling medium. This means the cooling medium must be brought as close to the component as possible. The simplest, most reliable, and most economical approach is to simply blow air across the cards. This brings the cooling medium (air) right to the component, removing a huge amount of conduction resistance. But ambient air can be contaminated with dust, humidity, salt fog, and so on, which pose concerns such as electrical short circuits for the electronics, for example. So a sealed enclosure is needed to keep the ambient air from coming into contact with the cards. This eliminates the feasibility of ambient air-cooled cards and chassis for many rugged environments.

Theoretically, it would be possible to use air-cooled cards if they were in a sealed chassis that had internal fans to pull heat out of the cards, internal high-density fins to pull heat out of the internal air and push it into the chassis' exterior, and external high-density fins to push heat into the external ambient air. Unfortunately, this approach would double the fan count, double the fan power, and, unfortunately, still might not provide a low enough thermal resistance. (Air-to-air heat exchangers are very inefficient.)

Spray cooling and Liquid Flow Through (LFT)

Other options for bringing a cooling medium close to the component are spray cooling or Liquid Flow Through (LFT) heat frames. Spray cooling could remove heat from the cards by spraying the cooling medium directly on the card, but it involves nontrivial modifications to the cards, corrosion/erosion concerns for the coolant on the cards, and complexity associated with the spray nozzles, pumps, accumulators, valves, coolant, liquid-to-air heat exchanger, and so on. This solution requires higher-frequency maintenance with some real reliability concerns, and makes it more difficult to meet weight requirements in SWaP-constrained environments.

With LFT heat frames, liquid is passed through the metal frame that mounts to the circuit card. The liquid removes the heat in the high-power components and alleviates erosion concerns – the fluid never contacts the components – but it's costly to manufacture and includes a fair amount of complexity in valves, pumps, bladders, and so on. And like spray cooling, there are weight concerns because of the required chassis, coolant, hoses, valves, and a liquid-to-air heat exchanger. LFT has some very attractive qualities because the cooling medium is right over the component but not in contact, but the impact of weight and complexity limits its use.

AFT cooling

This leads us to the next approach, which replaces LFT's cooling fluid with utilization of air. This delivers the same benefit of having the cooling medium very close to the component without direct contact. This also provides a very significant reduction of weight and complexity from the designs that utilize liquid. And air is cheap. A proven AFT method – which combines the simplicity of forced-air cooling and the extreme reduction of thermal resistance to the cooling medium offered by LFT – is Northrop Grumman's

AFT cooling technology, an open-standard defined in ANSI/VITA 48.5-2010. With AFT, air passes through the heat frame, preventing the ambient air from contacting the electronics but dramatically decreasing the thermal path to the cooling air.

Given the benefits of AFT in simplicity of design, weight efficiency, and low thermal resistance, Curtiss-Wright is utilizing this approach as a preferred solution for its highest-power-density systems. These AFT modules achieve reliable operation over an inlet ambient air temperature of -40 °C to +55 °C. The modules are enclosed in a thermal frame with openings for inlet and outlet air. AFT heat sinks provide maximum cooling over a large surface area for the system modules. On both the inlet and the exhaust sides of the card, a gasket mounted inside the chassis seals the card's internal air passage to the chassis' sidewalls. These seals prevent air from being blown into the chassis and protect the internal electronics from the harsh external environment. A comparison of the aforementioned cooling methods is presented in Table 1.

Cooling technology	Application ruggedization level	Power "sweet spot"	Subsystem complexity	Subsystem cost	System cost/ Impact
Air cooling	Benign or moderate	< 200 W/slot	Low	Low	Low
Forced air conduction cooling	High	< 80 W/slot	Low	Low	Low
Forced liquid conduction cooling	High	80-200 W/slot	Medium	Medium	High
Air Flow Through (AFT) cooling	High	80-200 W/slot	Medium	Medium	Low
Liquid Flow Through (LFT) cooling	High	> 200 W/slot	High	High	High

Table 1: A side-by-side comparison of the cooling methods discussed.

(Click graphic to zoom by 1.9x)

Thermal analysis

As an example of the cooling benefits of AFT, we conducted a detailed thermal analysis of a variety of cases (results available upon request). The results of a typical VPX SBC thermal analysis indicated that with input air of +55 °C, the system can be adequately cooled with margin. One of AFT's benefits is that cooling air is brought in very close proximity to the high -power components; this is true not only for components on the base card, but also for the components on the XMC cards. Providing a short-circuit path to the cooling ambient air from the high-power components on the XMC enables the highest performance possible for even the XMC cards. Each high-power component interfaces to the AFT heat frame through a conductive, flexible gap pad.

Isolation of thermal paths

Another extremely valuable benefit of AFT is the isolation of the thermal path of each card in the system. With AFT, cards don't share cooling air or the thermal interface into which they conduct heat. Each AFT card has its own inlet of +55 °C air and its own exhaust. There is no other cooling path other than the cooling air. From a thermal standpoint, this enables each card to be viewed in isolation. By ensuring balanced airflow through all of the cards in the system, each card receives the amount of cooling air required to keep components at their appropriate temperature. To highlight the capability of the approach, a thermal analysis was performed assuming a combination of a high-power base card and daughtercards. The results are shown here:

Thermal results: SBC with two XMCs thermal results

This generic card was assumed to have the following heat loads: SBC: 90 W XMC: 40 W

Total power = 170 W in a single slot

Thermal analysis summary

The thermal analysis is consistent with the performance and findings of the previously developed systems that utilize AFT for their cooling solution. The analysis overall shows a large amount of margin if it is assumed that case temperatures can be +100 °C or higher. As Curtiss-Wright performs these analyses very frequently, it is understood that the real application might have worse power density issues than described here, as the high-power components in many cases are “flip-chip” designs with the die mounted on the top of the BGA substrate. With the die generating all of the heat, the high power being dissipated is through a smaller area than allocated in this analysis.

Several techniques can be employed to combat the high-power-density challenges of these high-performance components – including higher-performance/thinner gap pads, use of copper heat spreaders, and use of adjustable-height copper heat spreaders to minimize gap pad thickness. Given this understanding and the results of the aforementioned analysis, AFT is a great solution for cooling the "sweet spot" 120 to 200 W high-power and high-performance SBCs and DSP modules.

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