



Cooling Commercial Grade Electronics For Use in Harsh Military Environments

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ABSTRACT

Within the defense and intelligence community, special applications require purpose-built electronics. A wide variety of less rugged air-cooled, and robust conduction-cooled boards exist in support of both legacy and current application needs. As the adoption of commercial available electronics grows, there is an inevitable need to accommodate a mix of both custom and off the shelf electronics. Furthermore, the trend towards less conditioned air space on manned and unmanned platforms requires improved isolation for critical, sensitive electronics. Few solutions address the need for cost-effective flexibility in electronics selection and integration. The ability to employ commercial grade electronics in harsh environments requires environmental isolation for temperature, vibration and contamination. This white paper will discuss these trends and the process of fielding commercial grade electronics boards in direct spray (SprayCool) enclosures.

Keywords: Commercial grade electronics, direct-spray enclosures, Cooling, Environmental Isolation and Vibration, military vehicle application (with emphasis on aircraft)

APPLICATION BACKGROUND

Military embedded systems have always experienced harsh, rugged environments with extreme environmental conditions. However, the trend for increased computing density utilizing multicore, multiprocessor systems presents integration challenges on military platforms for applications such as radar and image processing, electronic warfare, signal processing, command and control, and mission processing. Electronics continually exceed environmental control system (ECS) capacity as increased performance requirements drive higher heat loads inside pressurized compartments, ultimately forcing electronics out of the conditioned space. UAVs, which are predominately unpressurized, challenge integrators to either ruggedize all electronics, or to otherwise isolate more sensitive electronics from environmental extremes.

Most Intelligence Surveillance and Reconnaissance (ISR) applications today relay critical information from the sensor on an airborne platform to the ground for compilation. Trends to reduce dependence on limited data link rates require more computing in the air. Today more than ever, integrators are asked to provide more performance with less Size, Weight, and Power (SWaP) budget, producing power densities in harsh environments that tax traditional cooling capabilities.

Commercially available electronics are available for many processing applications such as FPGA and DSP boards; however, generally a mix of custom or proprietary as well as commercially

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available boards is requisite to complete an ISR payload. Often, the custom electronics were designed and qualified for conditioned environments.

Likewise, OTS boards serving special niche markets have either an air-cooled or conduction-cooled variant, but not always both. Air-cooled and conduction-cooled enclosures are unable to deal with this inevitable mix of cards. The need for less rugged electronics on unconditioned platforms will require new approaches to environmental isolation.

COMMERCIAL GRADE ELECTRONICS IN HARSH MILITARY ENVIRONMENTS

The desire to deploy commercial grade electronics in harsh environments has merit. Advantages for military integrators include reduced lifecycle costs, use and faster sourcing of readily available technologies, and the reliability achieved through high volume production. Realizing these benefits in military applications is a challenge.

Integrators resist deploying commercial grade electronics in many military applications due to severe environmental requirements such as temperature extremes, high altitude, vibration, shock, humidity, dust/sand, contamination, and EMI. Traditionally, environmental isolation was accomplished via sealed, air conditioned or pressurized compartments. However, the infrastructure required for this approach has SWaP penalties at the platform level negatively impacting useful payload and operational range.

Many military platforms have been unable to provide sufficient conditioned space when upgrading SIGINT payloads. These include the U-2 Dragon Lady (**ASIP** program– Air Force Signals Intelligence Payload) and RQ-4 Global Hawk UAV, both of which had to choose alternative cooling solutions. Other UAV platforms such as the MQ-1 Predator and MQ-9 Reaper do not have any conditioned space, yet had similar requirements for improved sensor capabilities with the intent to leverage *existing air-cooled* board sets.

The UH-60 Blackhawk recently had to place its Helicopter Autonomous Landing System (HALS), consisting of commercial grade cards, on the outside nose of the aircraft so the radar processing could be co-located with the sensors. The recently awarded spiral development of the Broad Area Maritime Surveillance (BAMS) aircraft includes requirements for an Electronic Support Measures (ESM) payload likely employing sensitive RF cards coupled with processing boards that do not have readily available rugged OTS equivalents.

Thus, having an enclosure flexible enough to accept air-cooled and conduction-cooled electronics while providing isolation from military environments creates additional options to platform integrators.

AN ALTERNATIVE APPROACH TO COOLING AND ENVIRONMENTAL ISOLATION

Direct spray enclosures provide a card cage for VME, cPCI, VXS, VPX or cPCIe boards and backplanes compatible with the IEEE 1101.1 Mechanical Core Specifications. Although conduction-cooled boards adhere to IEEE 1101.2, the boards mechanically fit in air-cooled card cages. The primary difference in geometry between the two specifications is the method of cooling that dictates specific hardware such as wedge locks. With fluid as the heat transfer medium, direct spray card cages provide cooling independent of conduction hardware or standard air flow rates typically prescribed.

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Like conduction enclosures, SprayCool direct spray enclosures protect card cages from EMI, dust, water, humidity, salt fog, etc. The process for integrating boards into a direct spray enclosure involves thermal analysis, fluid compatibility and vibration analysis.

Cooling

With few exceptions, boards are cooled from the card edges with atomizers directing dielectric fluid to heat-generating components. Typical heat transfer coefficients using per fluorocarbon fluids range from 0.1 to 2 W/cm² °C depending on board layout, component proximity to card edge and angle of spray relative to component surface. At the card level, per slot cooling has been proven up to 500 Watts on multiprocessor, multi-core boards. The heat transfer rates of the fluid are not only effective for cooling but for heating the cards at low ambient temperatures. In this way, sensitive boards can be isolated from environmental extremes.

Heat sinks for OEM air-cooled or conduction-cooled boards are designed to address thermal requirements of the card for its intended environment. Whenever possible, direct spray systems make use of the existing heat sinks. There are a number of common Thermal Interface Material (TIM) used between heat sinks and high heat flux components that are fluid compatible. Due to the efficient cooling of direct spray enclosures, the option to use lower profile Integrated Heat Sinks (IHS) can be achieved, enabling a narrower board pitch. Some customers or OEMs may decide to remove heat sinks altogether for weight savings or for vibration requirements.

Mezzanine cards on carriers are common in VME/VPX/VXS and cPCI systems. Narrow gaps between baseboard and peripheral cards can reduce airflow and create challenges for conduction systems. For direct spray systems, narrow gaps enable proper cooling by providing necessary geometries for thin film boiling. Even very small apertures such as 0.01” can enable capillary action generating very good heat transfer coefficients.

Direct Spray - Fluid Compatibility

Perfluorocarbon fluids such as 3M’s Fluorinert have been used in the military for 25+ years for radar cooling on airborne platforms such as E-2C Hawkeye and E-3 Sentry (aka AWACS). By definition, direct spray enclosures involve ‘direct/wet’ fluid contact with electronics. In this instance, compatibility between the fluid and board components is particularly important. In general anything that is gel-like, sticky, stinky, gooey, greasy, or pasty will not be compatible with fluids and can degrade cooling performance. RTV is a good example of materials that should be avoided where possible. All other incompatibilities can be filtered without affecting the electronics or cooling system.

Conformal coating is common on embedded military electronics. Due to the sealed environment of a direct spray enclosure, coating is not requisite during operation. Often customers desire coatings for shipping, handling and storage irrespective of operational use cases. Conformal coatings are compatible in varying degrees with cooling fluids and are generally acceptable for use direct spray systems. Coatings do create a small thermal resistance between fluid and components but do not present an insurmountable cooling problem.

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Label materials vary between boards manufactures. Paper labels will degrade with exposure to fluid over time. More robust materials such as polyemide or vinyl withstand direct spray much better and are becoming more common on today's boards. When conformal coatings are applied, label material becomes irrelevant.

Vibration

Military vehicles are notorious for high vibration. Ground based vehicle profiles commonly range from 10 Hz to 500 Hz while airborne platforms often see vibration up to 2000 Hz. Vibration profiles for every vehicle and mounting location differ greatly. The survivability of OTS commercial grade electronics under vibration and shock is highly dependent on the profile and the card. Designers of rugged boards typically stiffen electronics to avoid natural frequencies that coincide with low frequency, high amplitude inputs.

For sensitive electronics in direct spray enclosures, customers have found advantages to reducing the size or altogether removing heat sinks. The natural frequency of a given board is proportional to the ratio of its stiffness to its mass. By removing a heat sink spanning an entire conduction board the stiffness is less; however, the mass is also reduced resulting in little or no impact on natural frequency. For heat sinks that do not span the length of the board found on air-cooled boards, the net effect can be a higher natural frequency. If additional stiffness is required for commercial cards, stiffeners can be added often without board redesign.

Small surface mount components do very well under vibration while large thru-hole components can create problems. In the event a commercial card has electrolytic capacitors, perpendicular-mounted memory modules or large pin-socket mated components, staking can be used to support the component on the board. As performance density of embedded computing increases, trends toward stacked memory, integrated circuits, tantalum and ceramic capacitors certainly help commercial grade electronics migrate into harsh environments.

Case study: A PROCESS DEMONSTRATION

Recently, a board set from SKY Computers was integrated in a direct spray enclosure provided by SprayCool to illustrate the process of taking commercial grade cards into extreme ambient conditions. The card set consisted of two FPGA boards and a single board computer detailed in Table 1. Based on the thermal analysis, the air-cooled heat sinks provided by the card manufacturers were deemed sufficient for all testing. The fluid compatibility assessment identified thermal grease on the Themis SBC processor heat sink that was not an ideal material, but was used with adequate system-level filtration capacity. No other components or materials were identified for incompatibility.

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Preparation on each card for vibration testing included Loctite and lock washers to ensure fasteners retained proper torque values. Board modifications consisted of staking several electrolytic capacitors to the baseboard of the SBC for reinforcement. The FPGA cards had heat sinks on the PowerPC processors held on by tape. The heat sinks were also staked to the baseboard. No other modifications were made to test the commercial grade cards exposed to vibration. With so few alterations to the electronics, integration and testing began just one week after identification of the board set.

Model #	OEM	Description	Specifications
Thunderbolt V-600	SKY	FPGA	<p>System Processor Intel i960 HD, 40/80 MHz External Memory 2 MB SRAM 16 MB Flash RAM</p> <p>Compute Module Processors: (4) MPC7410 Performance: 16 GFLOPS per module (peak) Clock Frequency: 500 MHz L1 Cache: 32k instruction, 32k data L2 Cache: 2 MB Backside, 64-bits wide @ 250 MHz Floating Point Unit IEEE 754: single and scalar Fixed Point Units: Dual 32-bit Integer Units Vector Instructions: Full 128 bit AltiVec implementation 8, 16, 32 bit integer, single precision floating point Memory: 256 or 512 MB SDRAM per processor, 64-bits wide @ 125 MHz Module Interface: SKYchannel Packet Bus (ANSI/VITA 10-1995) Power: 65 Watts (baseboard and compute module)</p>
USPIIe-USB	Themis	SBC	<p>Processor: (64-bit) – 650-MHz UltraSPARC IIe Performance: 25/28 SPECint95/fp Memory: 128-MB to 4-GB SDRAM???? On-chip L1 Cache: 16-KB Instr / 16KB Data On-chip L2 Cache: 4-way associative 512-KB Flash Memory: 2-MB system, 8-MB user OS: 64-bit Solaris 8, 9 and 10 Power: 36 Watts</p>

Table 1 Demonstration board configuration

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Heat Rejection: On airborne platforms, the cooling fluid has many options for heat rejection: Ram air, ambient air, Ethylene Glycol and Water (EGW), fuel, aircraft skin, hull, PAO, etc. The heat exchanger would be sized based on the board set, ambient conditions and ultimate heat sink. For the purposes of this test, a heat exchanger was located outside the chamber and was used to reject heat from the enclosure as the fluid was taken to a common high operational temperature of 70C. The enclosure was held for (4) hours at this high temperature while SKY successfully ran a high performance application on both boards. The boards were monitored for continuous operation to ensure full functionality.

Vibration: An operational, hard-mounted enclosure was exposed to the U-2 vibration profile shown in Table 2 for one hour per axis representing a magnitude of 3.6 Grms. To give some perspective, a typical electronics bay for UH-60 Blackhawk helicopter profile is 1.89 Grms. The worst case wheeled vehicles from MIL-STD-810 is the trailer (vertical) at 3.86 Grms while the general tracked vehicle profile is up to 5.93 Grms. Without spectral information Grms values are not equivalent, so only order-of-magnitude conclusions can be drawn between random or random-on-random profiles.

U-2 Aircraft Operating Spectrum	
Frequency (Hz)	Power Spectral Density (G ² /Hz)
10	0.01
29	0.01
40	0.02
57.5	0.02
61	0.01
500	0.01
800	0.01
2000	0.0016

Table 2 Vibration profile for U-2 Dragon Lady

SUMMARY

The process of employing commercial grade electronics in harsh environments, using direct spray enclosures has been successfully repeated on mobile military vehicles for the past decade, by SprayCool. SKY Computer's testing concluded that their particular board set comprised of commercial grade electronics were able to fully operate at extreme temperatures and under vibration. As trends for enhanced processing on airborne and mobile ground platforms continue, alternative methods of cooling and environmental isolation for sensitive electronics will undoubtedly have to include direct spray enclosures.

For more details on life cycle cost and speed of deployment benefits, please see companion white papers titled:

- *Flexibility in Electronics Selection and Deployment for Airborne Platforms (Life cycle Cost Analysis and Deployment comparisons)*
- *Comparing Platform Level Electronics Cooling Approaches at the Systems Level*