



Commercial Grade Electronics in Vibration Environments

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ABSTRACT

Electronics reliability in harsh environments has always been difficult because of extremes in power quality, contamination, temperature and vibration. Specifically, temperature and vibration profiles of manned and unmanned vehicles require OEMs and integrators to either isolate or ruggedize sensitive electronics. This paper will address the unique ability of direct spray enclosures to enable a wider variety of less rugged electronics in harsh vibration environments.

Keywords: SprayCool, commercial grade electronics, vibration, direct spray

BACKGROUND

Integrators resist deploying commercial grade electronics in many mobile applications due to vibration. This is because lab grade boards with heat sinks designed only for cooling add too much mass to the board ultimately placing the card natural frequency within the forcing frequency spectrum of mobile platforms that are notorious for high vibration. Ground based vehicle profiles are typically high magnitude and range from 10 Hz to 500 Hz while low magnitude airborne platforms often see vibration up to 2000 Hz. Vibration profiles for every vehicle and mounting location differ greatly. The survivability of Off the Shelf (OTS) commercial grade electronics under vibration is highly dependent on the profile and the card.

The design goal for any card is to be at least 2 octaves above the forcing frequency. This ideal natural frequency for rugged electronics is above 1000 Hz. Few 6U electronics achieve this objective due to physical size of the boards. Furthermore, the mass of the requisite thermal solution drives designers of rugged boards to increase stiffening to avoid natural frequencies that coincide with low frequency, high amplitude inputs.

Vibration requirements rarely exist without the need for extreme temperature ratings, so the thermal and vibration solutions are closely coupled. With the inherent limitation of air-cooling and conduction-cooling to remove heat, OEMs often limit the output of processors, FPGAs and other high heat flux components to balance the heat sink size and weight with what can fit in a standard slot and still reliably withstand vibration. Thus for applications in high ambient temperatures, end-users often sacrifice size, weight and/or performance when purchasing vibration-hardened electronics.

Some commercial board vendors provide configurations of the same functional card for both lab and field environments. The rugged configurations differ from commercial grade boards in four primary ways: Higher natural frequency, industrial grade components with higher operational temperature ratings, longer lead times and higher cost. Still other manufacturers only provide commercial grade cards due to high development costs of multiple configurations. Likewise, OTS boards serving special niche markets have either non-rugged or rugged variants, but not always both.

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COMMERCIAL GRADE ELECTRONICS IN HARSH 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. Direct spray enclosures enable commercial grade electronics even in high vibration applications by providing the option to decouple the cooling solution from the mechanical hardware necessary to meet operational vibration specifications.

SprayCool® direct spray enclosures offer superior cooling performance without the dependence on massive heat sinks; however, the preference is to employ optimized air-cooled heat sinks from the board OEMs that have been designed for harsh vibration profiles so that air-cooled and SprayCool board part numbers are the same. This can often be accomplished by fluid compatible thermal interface materials (TIMs) that board OEMs already employ. Whitepapers are available on the SprayCool website providing more details on [fluid compatibility](#) and [cooling commercial grade electronics at high temperature](#).

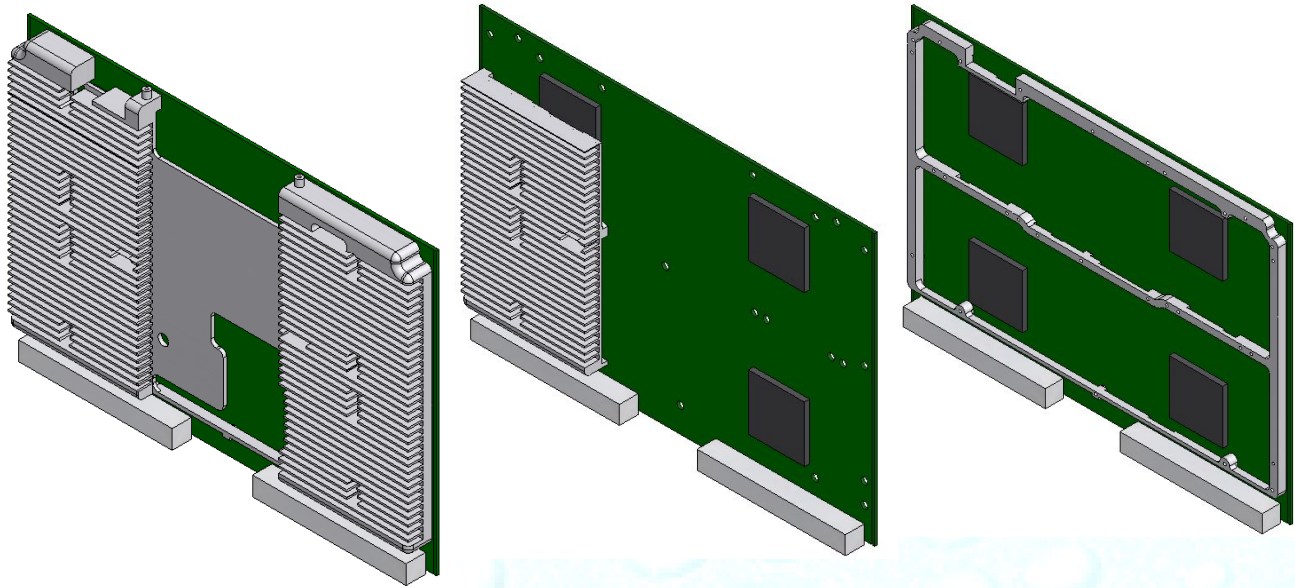
If it is not possible to use the same air-cooled or conduction part number, customers can reduce the size of, or altogether remove heat sinks from the electronics. The natural frequency of a given board is proportional to the ratio of its stiffness to its mass. By removing a heat sink that does not span an entire conduction board, the stiffness is less; however, the mass is also reduced resulting in marginal impact on natural frequency. If additional stiffness is required for commercial cards, localized stiffeners or perimeter rails 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 without modifications for vibration.

VIBRATION ANALYSIS

An analysis on an example commercial grade single board computer was performed to determine the effects of heat sink options on natural frequency. The board selected was an OTS quad processor VME 64x board shown in Figure 1.

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(a)

(b)

(c)

Figure 1 Quad processor 6U VME 64x board with (a) full span heat sink, (b) local heat sink, (c) perimeter rail

Model name: FEA Assembly
Study name: Frame
Plot type: Frequency Displacement1
Mode Shape : 1 Value = 264.71 Hz
Deformation scale: 0.00542493

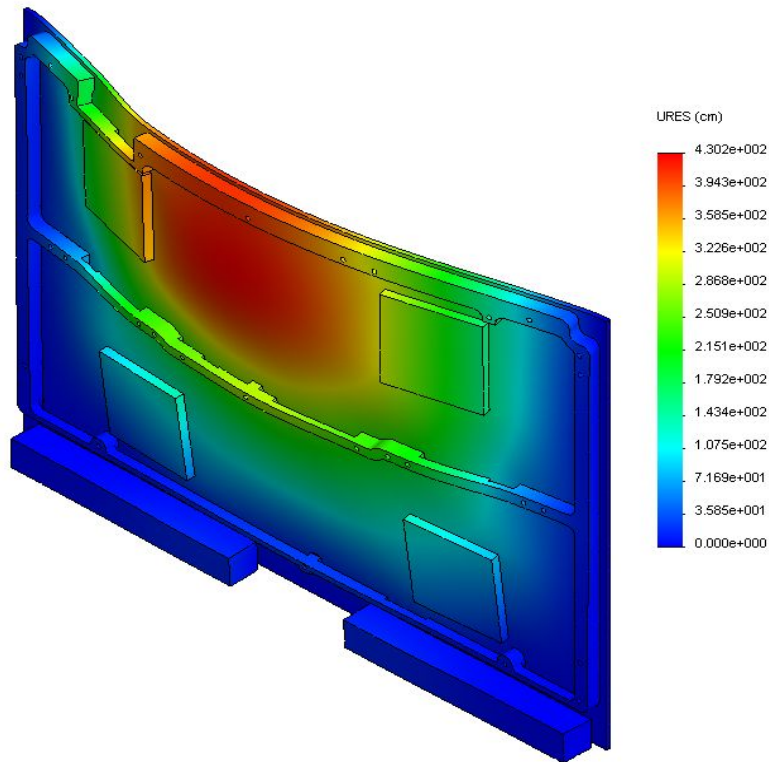


Figure 2 Modal analysis results of Quad processor 6U VME64x board

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A modal analysis (see example in Figure 2) was performed on the board with three configurations: An air-cooled board with heat sink removed, a full heat sink spanning the full length of the board, an OEM perimeter frame and a local heat sink covering ~30% of the board area. Natural frequency results are shown in Table 1.

Configuration	Fn (Hz)	Weight (Kg)
Bare Card	89	0.23
Card + Full Heat Sink	378	0.55
Card + Perimeter Frame	265	0.28
Card + Local Heat Sink	155	0.33

Table 1 Natural frequency and weight of example board in various configurations

The analysis indicates significant stiffening provided by the full heat sink. The natural frequencies predicted for that configuration are within expected values of typical rugged electronics sold into military and harsh industrial applications ranging from 300-400 Hz for rugged 6U boards. The perimeter frame also offers a light weight alternative for some vibration profiles enabled by a SprayCool enclosure. Many commercial cards with local heat sinks may still be viable for higher frequency or lower magnitude vibration profiles.

LAB TESTING

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 vibration conditions. The card set consisted of two FPGA boards and a single board computer detailed in Table 2. Based on the thermal analysis, the air-cooled heat sinks provided by the card manufactures were deemed sufficient for all testing.

Preparation on each card for vibration testing included Loctite and lock washers to ensure fasteners retained proper torque values. Board modifications consisted of epoxy 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.

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Model #	OEM	Description	Specifications
Thunderbolt V-600	SKY	FPGA	System Processor Intel i960 HD, 40/80 MHz External Memory 2 MB SRAM 16 MB Flash RAM 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)
USPIIe-USB	Themis	SBC	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

Table 2 Demonstration board configuration

An operational, hard-mounted enclosure was exposed to the U-2 vibration profile shown in Table 3 for one hour per axis representing a magnitude of 3.6 Grms. The test was completed without any interruption to scripts continuously exercising the board set. 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.

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 3 Vibration profile for U-2 Dragon Lady

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AIRCRAFT AND VEHICLE FIELD TESTING

Over the past decade, SprayCool enclosures have been tested operationally on many military platforms. First flight testing was done on the EA-6B Prowler that included carrier launch and landing. Additional flight testing was completed on Northrop Grumman's U-2 Dragon Lady high altitude reconnaissance plane culminating in a production contract for the ASIP program (Air Force Signals Intelligence Payload). The same payload on the U-2 was tested on the RQ-4 Global Hawk UAV and is currently in production. Additional flight testing on airborne platforms includes MQ-1 Predator, MQ-1C Warrior, and Little Bird.

Helicopter Autonomous Landing System (HALS) is a sensor used during brown out conditions on the UH-60 Blackhawk. The system, produced by Sierra Nevada Corporation, consists of a 94 GHz radar/sensor and sensor processing units collocated on the exterior nose of the aircraft. The sensor processing unit contains RF cards designed for an air-cooled lab environment. Enabled by the SprayCool enclosure, the same lab assets were successfully proven on the Blackhawk without modification for vibration.

For weight sensitive platforms with lesser vibration profiles such as U-2, Global Hawk, the processor board functions without heat sinks using simple stiffening ribs while RF boards operate successfully without any modification. No modifications to the RF board set for Blackhawk testing was necessary either. By leaving existing heat sinks on air/conduction boards, the survivability of the electronics only improves for hard mount applications.

Testing on ground based vehicles began with General Dynamic's EFV using commercial cards on both water and land. EFV has proven that even with a severe tracked vibration profile, when the enclosure is isolated or mounted in an isolated rack, commercial grade electronics without heat sinks are a viable alternative. HMMWV and military trailer testing for on-the-move command and control applications was performed by the Marine Corp as a result of successful EFV testing.

SUMMARY

The process of employing commercial grade electronics in harsh environments isolated by direct spray enclosures has been successfully repeated on mobile military vehicles for the past decade. Analysis and testing concluded that commercial grade electronics can support a wide spectrum of operational vibration profiles with little or no modifications and without sacrificing performance.

Enclosure flexibility to accept air-cooled and conduction-cooled electronics while providing isolation from mobile environments creates additional options to platform integrators. As trends for enhanced processing for mobile applications continue, alternative methods of environmental isolation for sensitive electronics will include direct spray enclosures.