A VITA-Based Framework for Ruggedized COTS Electronics with Emphasis on Liquid Cooling – VITA 48 (REDI)

By Randy Banton and Donald W. Blanchet
Mercury Computer Systems, Inc.

MERCURY WHITE PAPER

Mercury Computer Systems, Inc.

ABSTRACT

Many military and commercial applications share a need to achieve high compute and bandwidth density in the smallest possible volume. In addition, deployed military applications have environmental requirements such as higher levels of shock, vibration, temperature, and altitude. This paper describes activities in the VITA Standards Organization (VSO) related to creation of standards that address the future needs in these applications. Techniques addressing this design trade-space are currently being applied to the VITA 48 "Ruggedized Enhanced Design Implementation" (REDI) draft standard for 3U and 6Ux160mm commercial off-the-shelf (COTS) modules. This standard intends to create a unified mechanical standard for 3U and 6U COTS modules using air-, conduction- or liquid-cooling methods. The REDI mechanical enhancements are independent of electrical standards such as VITA 46 (VPX) or VITA 41 (VXS). The first initiative underway combines VITA 46 and VITA 48 to produce a next-generation platform called VPX-REDI.

It is presumed that the reader is familiar with the extended environmental requirements of many military platforms and applications. Last year's paper by Mercury Computer Systems, Inc. dealt with this. [Ref 1] Familiarity with the power increases in many electronics components at a rate greater than the performance provided is also presumed, and thus the need for enhanced thermal management is not justified in this paper, but taken as a given.

AUTHOR BIOGRAPHIES

Randy Banton (rbanton@mc.com) is responsible for product development and applications insight for the Mercury Computer Systems' defense electronics engineering and applications area. He has more than 20 years of experience in the architecture and development of small to large-scale multiprocessor computer systems focused on applications targeted by the business unit.

He earned a master's degree in computer science from Stevens Institute of Technology and a bachelor's degree in mathematics from Wichita State University. He also earned a certificate in management development from Worcester Polytechnic Institute and has studied at the Massachusetts Institute of Technology and Oregon Institute of Technology. Co-held by Randy are 16 U.S. and international patents in the areas of fault-tolerant computing, switch fabric interconnects, thermal management, and power control.

Donald Blanchet (donbl@mc.com) is a consulting mechanical engineer at Mercury Computer Systems, where he is responsible for the mechanical design, analysis, and testing of packaging and cooling system hardware used in high-density multiprocessor computers. Mr. Blanchet has 35 years experience. He holds bachelor's and master's degrees in mechanical engineering from the University of Massachusetts at Amherst and Northeastern University, respectively. Co-held by Don are 7 U.S. patents in the areas of thermal and structural management.

INTRODUCTION

Mercury Computer Systems, Inc. and other suppliers provide commercial off-the-shelf (COTS) processing equipment to a wide variety of deployed military applications and platforms. These are often described using the term "HPEC" or High-Performance Embedded Computing. A selection of these platforms having HPEC requirements is shown in Figure 1. While there is a wide range of environmental requirements this processing equipment must meet, this paper focuses on the thermal and structural management aspects at the module level. This focus is intersected with the new generation of standards being created that will facilitate new families of COTS products to appear for these HPEC-deployed military applications. This work is being done within the VITA Standards Organization (VSO). [Ref 2] COTS suppliers, prime contractors, and system integrators form the working groups who chair, edit, and achieve approval of these standards.

There have been a number of papers, conferences, and symposiums over the past several years observing the increasing amount of power required for a proportional amount of processing, interconnect or I/O bandwidth, and memory size and performance. As such those issues will not be revisited here. For a good overview see the references [Ref 3], [Ref 4]. As is also well known, the issues around thermally managing this increase in power dissipation is exacerbated by the extended temperature and altitude requirements imposed by many of these military platforms. The temperature requirements often range up to 55°C to 85°C, and this in combination of altitudes requirements up to 10K to 40K feet, and beyond.

Likewise, these platforms also impose higher levels of shock and vibration to this processing equipment, and thus require extended abilities in the assemblies to mitigate the negative effects of this on the processing module designs.

Lastly, one element affecting TCO (Total Cost of Ownership) will be discussed as included in this standards building work, and that is the element of two-level maintenance (2LM).

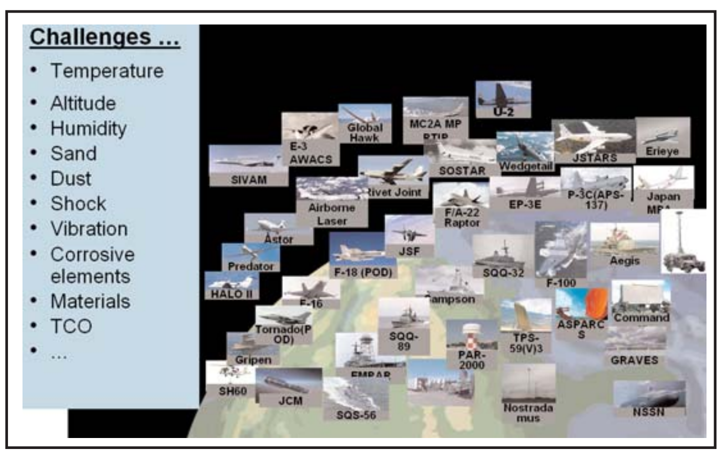

Figure 1. Deployed military platforms using COTS electronics

The VSO has a number of efforts ongoing in the area of next-generation standards for COTS HPEC for use in these military platforms. Figure 2 shows the wide range of these activities, and indicates the close relationship of two of these activities to the VITA 48 "Ruggedized Enhanced Design Implementation" (REDI) effort, which is the focus of this paper.

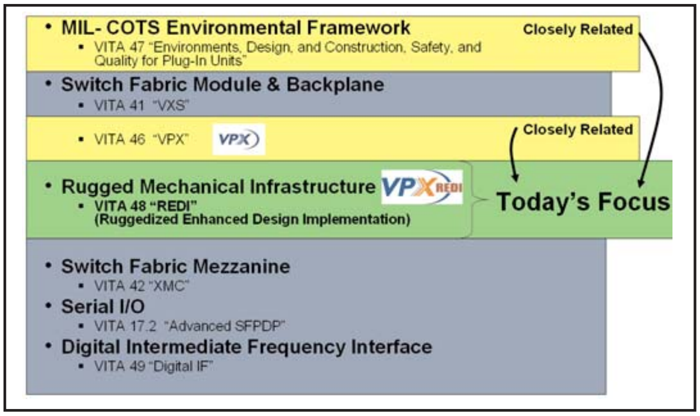

Figure 2. HPEC-Related VITA Standards Activity

VITA 47, "Environments, Design and Construction, Safety and Quality for Plug-in Units," captures in a contemporary standard the environmental requirements of these COTS modules. Aside from specifying shock and vibration in a common format for use by COTS vendors, it also specifies several levels of thermal management requirements, not only covering forced air-convection and conduction-cooling methods, but also liquid cooling. Figure 3 includes an excerpt from the VITA 47 table of contents to illuminate its importance and content.

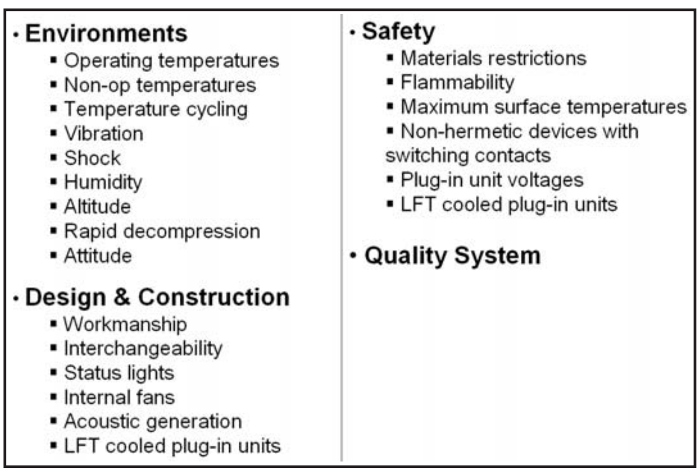

Figure 3. VITA 47 Table of Contents

VITA 46 "VPX" (previously called "AMF" in some past papers and articles) is the complementary electrical standard that defines a new contemporary connector system for use with high-speed serial interconnects and I/O. This connector system achieves high signal density in combination with signaling performance in the 6Gbit/s range. This connector system has also been tested by the working group to assure that it meets the extended requirements around shock and vibration expected in deployed environments.

VITA 48 "RUGGEDIZED ENHANCED DESIGN IMPLEMENTATION" (REDI)

As its name implies, REDI is a standard formed around enhancing the abilities of processing equipment to perform within the harsher military environments.

Figure 4 shows these in the context of cooling methodologies, including forced air convection, conduction, and liquid. The previously standardized 6Ux160mm and 3Ux160mm board formats are used, as these continue to be the format of choice for this style of COTS equipment. With credit to the past VITA 34 standard efforts that have since been shelved, REDI is the first COTS standard to codify the mechanical and thermal interfaces for liquid-cooling methods that are applicable for deployed military platforms. This new aspect of standardized liquid cooling will be discussed in greater detail.

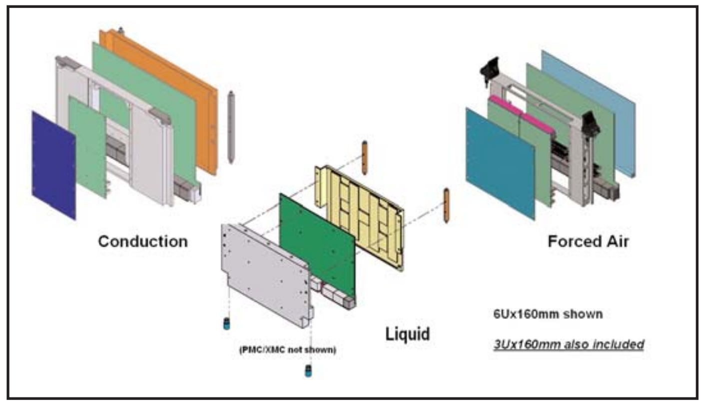

Figure 4. VITA 48 standards coverage

Credit should also be given to the long-lived IEEE 1101.x family of standards that continues to have wide use in these applications. Even with the emergence of REDI, they will continue to be sufficient and widely used in many areas.

As mentioned in the introduction, there are many extended requirements beyond thermal management expected on this type of COTS equipment.

REDI covers four major themes to address this breadth of requirements:

• Board area and module volume

• Structural ruggedization

• Two-level maintenance (2LM)

• Thermal management

Each of these will be discussed in some detail.

BOARD AREA AND MODULE VOLUME

REDI has increased the maximum allowed pitch (or spacing) between modules to 1" from the IEEE 1101 standard of 0.8". Within this 1" pitch, several enhancements are available to a designer.

One is that the secondary side components can now be taller, which allows for not only more physical space and possibilities of what can be on that side, but also the possibility that more "thermally interesting" components can reside on that side.

A greater maximum PWB thickness is also allowed. Whereas IEEE 1101 practice allows for a 0.063" maximum PWB thickness, REDI accounts for up to a 0.120" thickness. This is very relevant to contemporary high-speed, high-density designs that require layer counts ranging upwards of 15 to 24 layers and a stack-up of a variety of materials to meet routing, signaling speed, impedance, capacitance, power distribution, and reliability requirements.

There is a slight increase of 0.050" on the primary side of the PWB that is over IEEE 1101 practice. While this may seem very small, it is sufficient to enable components, such as those associated with memory or on-board power systems, to reside under one of the previous "keep out" areas in IEEE 1386 or VITA 42 XMC mezzanine cards when these are on a 12mm high mezzanine connector option allowed in REDI.

A slightly different theme in increasing available board space comes from the use of an "exoskeleton" for the forced air convection-cooled modules. Using this methodology for stiffening this type of module enables the stiffening to occur in the Z-dimension. Present practice often requires metal rods or bars to be screwed onto the PWB for stiffening, thus taking up precious board area and often with a number of through holes that impeded the routing of the electrical signals.

Figure 5 summarizes the dimensional differences between REDI and IEEE 1101. The top half of the figure is a REDI 1" pitch module, the bottom picture is an IEEE 1101 0.8" module. Highlighted is the 0.150" increase in secondary side dimension, and the 0.120" increase in primary side dimension.

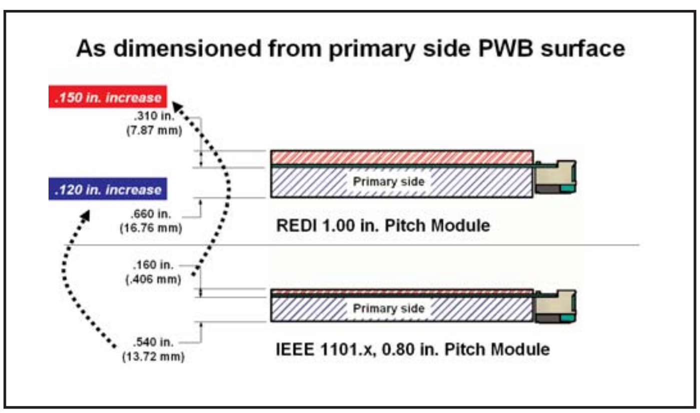

Figure 5. Board area and volume enhancements

STRUCTURAL RUGGEDIZATION

The next of the four themes is structural ruggedization. This theme primarily applies to forced-air convection-cooling modules, because conduction- and liquid-cooled modules already have cold plate entities that make their structure very rugged.

In the case of air-cooled modules, vendors have historically struggled with the fact that with IEEE 1101 methodology the PWB itself is what is captured in the card guide of the card cage, and there's quite a bit of float in that interface. In platforms with extended requirements in the areas of vibration and/or endurance vibration (multi-axis vibration tested over a period of hours), there is often a lot of time-consuming and costly mitigation at the chassis or rack that is required when using these COTS modules.

Another aspect of the IEEE 1101 methodology is that the mass load of the card is actually borne by the PWB edge interfacing into the card cage. Transmitting these forces to the PWB and its mounted components can result in unmanageable or unforeseen stresses fracturing these assemblies, causing premature failure.

By adding an external structure and nesting the PWB inside, an exoskeleton for stiffening the assembly is created. This structure also allows the opportunity to place the load-bearing interface that mates into the card cage on this cover and not the PWB. The tolerances in this module to card-guide interface can be held much tighter, thus reducing the amount of float and mitigating the negative effects of extended vibration or endurance vibration requirements. Figure 6 shows this feature.

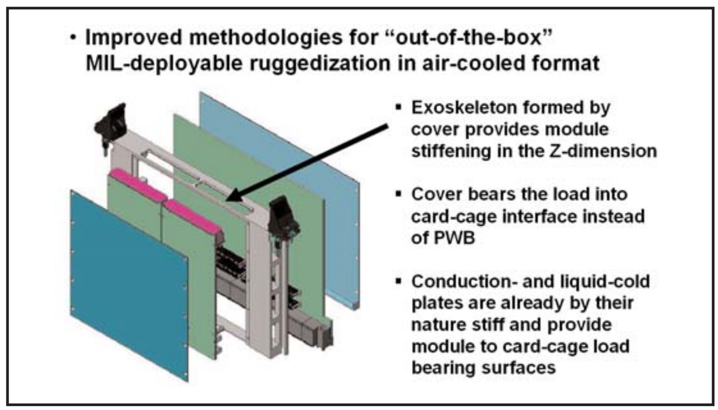

Figure 6. Structural ruggedization enhancements

TWO-LEVEL MAINTENANCE (2LM)

Third in this series of themes is (2LM) support. [Ref 5]

2LM has the potential to significantly improve the TCO associated with maintaining military platforms such as those seen in Figure 1. Simply stated, the process is to gain access to the platform – such as the fighter or the helicopter – pull out a line replaceable unit (LRU), plug in its replacement, and walk away with the original one to return to the vendor via a COTS vendor's RMA process.

The cost savings is that there's no intermediate depot involved, thus no personnel, training, logistics, spares, and such elements to manage. This intermediate depot step is what contrasts 2LM to three-level maintenance (3LM). [Ref 6] An interesting aspect of this maintenance model is that there are not any ESD mitigation methods as found in most commercial computing environments, such as service personal having a grounding strap attached to them that must be grounded to the equipment rack before removing any module. There are logistic, access, and training situations in the deployed military environment that render this impractical. It is known that, while some deployed military programs have desired to use COTS electronics, the lack of 2LM support has restricted their use. The inclusion of this capability in this new standard is expected to open the door to more use of COTS in these areas.

The element within REDI that provides mitigation of this ESD threat to the LRU is the use of covers to encapsulate the module and guidelines as to their appropriate implementation. This protective cover not only covers the main PWB of the module, but also any mezzanine cards that may be attached to that module. These aspects are highlighted in Figure 7.

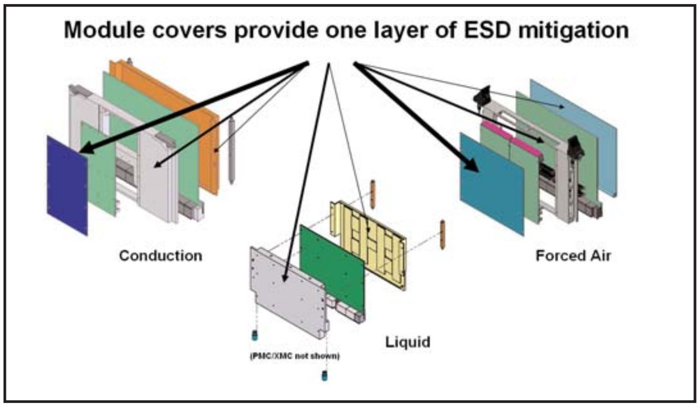

Figure 7. Two-level maintenance (2LM) support

To complement this mechanical ESD protection provided by the mechanical structure in REDI, the VITA 46 connector system has an ESD guard band built into it that shields the signal pins. This is required, since the connectors remain exposed as they are not covered or shuttered in any way. This guard-banding method has been tested and proven workable by the VITA 46 working group.

THERMAL MANAGEMENT

The remaining theme within REDI is that of thermal management.

REDI provides a unification of force air convection, conduction, and liquid cooling, all under the heading of one standard. This allows for defining a methodology that has a high level of commonality in its mechanical design aspects. It also allows for defining the trade-offs that enable a designer to design a common underlying PWB that can be used in any of the cooling methodologies.

This standard is presently the only new standards work that includes the codification of the liquid-cooling infrastructure, and in particular the critical choices and interfaces around the quick-disconnects (QD) used to couple the module's liquid cold plate to the backplane's liquid manifolds.

The air- and conduction-cooling sections of the standard push the ceiling of thermal management to 200W per module. Both the 6U and the 3U formats have this same maximum power level. This is well above the "typical maximum" of 50W in many present 6U modules. It is also above the "extreme maximum" in those stretching to 100-120W using present day standards.

Use of the liquid-cooling methodologies of VITA 48 is intended to allow upwards of 500W in a single module slot.

The heat transfer advantages of liquid-cooling systems are well understood. Take, for instance, the basic differences in the properties of water versus air:

- A 35 times increase in thermal conductivity
- An almost 1000 times increase in density
- A 4 times increase in specific heat storage capacity per pound

Even at modest liquid flow rates of much less than 1 gallon per minute, these combine to produce a significant overall decrease in the local hot spot temperature rise in the cold plate (1-2°C) versus the local temperature rise in a typical air-cooled heatsink (10-20°C or greater). Liquids have a significant "heat capacity" advantage over air. See [Ref 7] for more information on cold-plate characteristics and design.

Often these high power levels come with a presumption of it being due to a few high-power flux components such as microprocessors. Related to this, there is often a discussion of "hot-spot cooling" methods. However, for most COTS modules today, the thermal management issue is with all components, not just a few hot spots of concentrated power and heat.

Whether it is devices such as DDR2, XDR, or QDR memory, or those associated with FPGAs, DSPs, high-speed serial interconnect, or on-board power systems – thermal management today must encompass all of the components. Even these listed elements have experienced significant power flux increases in the past few years, requiring care to meet their stated case or junction temperatures in the extended environments required for some deployed military applications. As such, a new standard must allow for techniques to thermally manage all these types of devices – in the face of the extended deployed military temperature and altitude requirements – whether on the primary or secondary side of the PWB.

While the methods around extending air and conduction cooling to these levels are not covered in detail in this paper, a brief summary of enhancements is provided below.

Forced-air convection-cooling enhancements summary:

- Wider slot pitch allows for taller heatsinks and heat spreaders on the primary or the secondary side of the PWB.

• Use of the exoskeleton-type structural cover removes stiffening ribs from the PWB that are often 90 degrees to the airflow and often impede or block the flow.

• The cover also defines a controlled plenum within the slot and card cage that has sides on it and in which more precise, or finely managed air flow can be achieved by adding air shaping features on the cover's surface.

Conduction-cooling enhancements summary:

• Allowance for the primary side cold plate to make direct contact with the conductive side-rail of the card cage. In present IEEE 1101.2 practice, the primary side cold plate is conducted to the secondary side side-rail making a circuitous path for the heat to flow at these high power levels.

• Ability to have a full-fledge cold plate on the secondary side of the PWB, which is not possible in IEEE 1101.2. This can be conductively coupled to the side-rails.

• The option for large wedge clamps – often called "jumbo" wedge clamps. These jumbo wedge clamps exert more pressure on the cold plate to side-rail interface, and it has long been shown that the thermal resistance and thus heat transfer through this imperfect metal-to-metal interface is proportional to the pressure being applied. Use of the jumbo wedge clamp does change the dimension of the card-cage interface.

In addition to these enhancements, all cooling methods now have the ability to include improved cooling to the secondary side of the PWB. This is particularly important since, as covered in the previous theme of increasing PWB area, larger components and those with higher power can be placed on the secondary side. Figure 8 highlights this area.

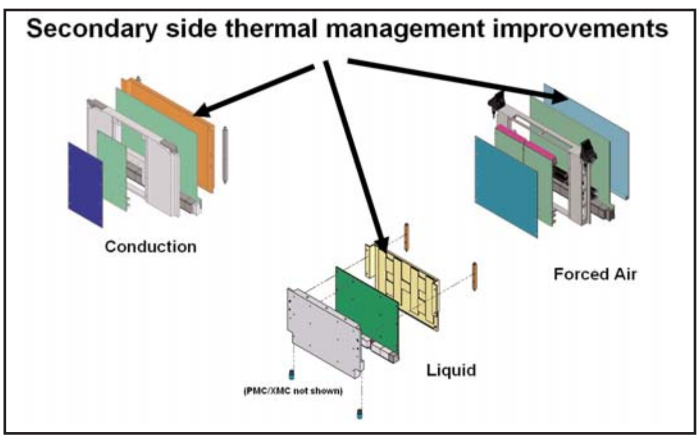

Figure 8. Secondary side thermal management

For air cooling, the secondary side cover provides the plenum wall for the module into which a proportioned amount of airflow can be managed. This cover can also be thermally coupled to select devices to provide a heat-spreading function.

In conduction and liquid cooling, this secondary side plate creates a direct conductive path from devices to the plate that does not exist in present conduction-cooling standards such as IEEE 1101.2. The increased secondary side dimensions in VITA 48 not only allow for taller, higher-powered components, but also space to use reasonable thermal interface material and cold-plate designs.

Variants on the secondary side cold plate for liquid cooling will be explored further as the discussion of liquid cooling develops in the next section.

STANDARDIZED LIQUID COOLING

REDI is presently the only on-going standards formation that includes the codification of the liquid-cooling infrastructure and in particular the critical choices and interfaces around the quick-disconnects (QD). The QD is the critical element used to couple the module's liquid cold plate to the backplane's liquid manifolds in a way that allows the modules to be readily inserted and removed. Distinct differences between past liquid-cooling methods and the need for a contemporary standard dealing with contemporary devices and their heat flow will be covered.

These features, coupled with the performance-rich processing and I/O elements that will be available – albeit at high absolute power levels – will bring a new level of performance and functional density to a single 1" pitch slot. Figure 9 shows the basic structure of the liquid-cooled VITA 48 module.

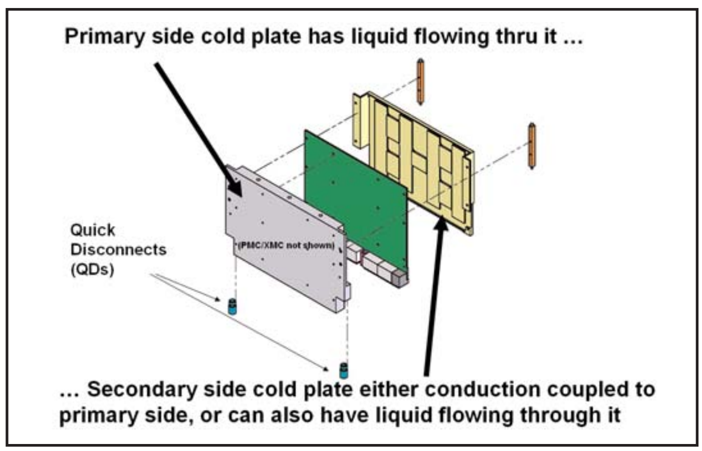

Figure 9. Basic liquid-cooled REDI module

The primary side cold plate contains the liquid interfaces to the backplane in the form of QDs. Quick disconnects have been in use in the deployed military platforms for several decades and are a very well-understood technology. An informative public reference in this area was a study by The Boeing Company [Ref 8].

In addition, Parker Hannifin and Eaton Aerospace are long-time vendors of this technology, both to military and commercial markets. Both of these companies are members of VSO and are participating in this standards development activity.

Since this basic liquid-carrying interface is well understood and proven, the standards working group did not have to carry out the arduous task of developing and proving fundamental technology in this area. In addition, the IP (Intellectual Property) ownership and rights have a long history of vetting and understanding.

Liquid-cooling cold plates function much like those for conduction cooling, where the underlying components on the PWB are coupled to the cold plate through an appropriate thermal interface material. In the case of conduction cooling, the heat is transferred from the component to the cold plate and then to the side rail of the chassis. Liquid cooling at the module level has the advantage of transferring the component heat to the cold plate, then directly to the liquid flowing through the cold plate.

There is, however, a very significant distinction between the relationship of the PWB and cold plates in REDI and those of past implementations. The relationship of the cold plate and PWB is turned "inside out" from most past implementations as compared with the liquid-cooling method contained in REDI.

Figure 10 shows a Mercury Computer Systems liquid-cooled module from the mid-1990s and done under contract for a military program. On first glance, one might wonder where the liquid cold plate is; it is between the two PWBs, much different from REDI practice. It is not unlike those done in this same era by primes and system integrators. The liquid cooling option of SEM-E (Standard Electronic Module – Format E) is also similar.

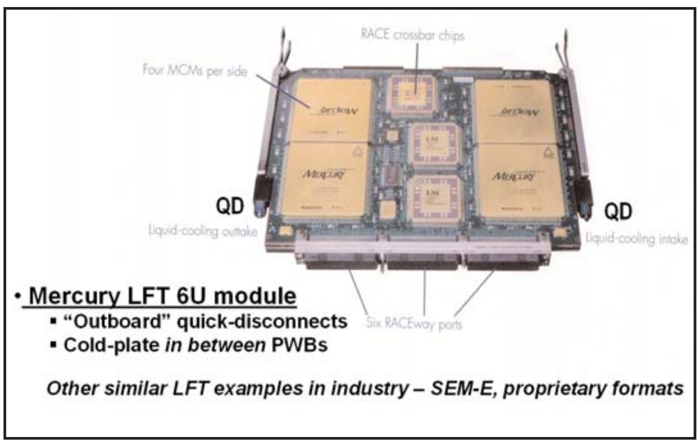

Figure 10. Prior practice in liquid-cooled modules

In the 1970s and into the early 1990s, many higher-powered integrated circuits were constructed such that heat flowed "down," or in other words, through the base of the chip, through its connection to the PWB, and into the PWB itself. Given this reality, the cold plate was placed on the secondary side of the PWB, so the heat being transferred to the PWB from the components was carried away in the liquid flowing in the cold plate.

During the 1990s, this characteristic of component heat flow changed radically. Component packaging began to reverse the direction of this flow and channel the majority of the heat "up," or through the top of the component. This remains the majority practice now and for the foreseeable future.

This reversal in heat flow from "into the PWB" to "away from the PWB" has made thermal management in liquid cooling (and conduction cooling) progressively harder when using past standard or proprietary methods such as shown in Figure 10.

By turning the PWB and cold plate relationship "inside out" as REDI has done, the PWB containing these components transferring heat away from the PWB is now surrounded by cold plates to which the components interface.

Whereas the primary side cold plate always has liquid flowing in it, the secondary side thermal transfer can be done in a couple of ways.

One way is for the secondary side to be conductively coupled to the primary side. In other words, the heat from components on the secondary side can be managed much like a standard conduction module – the difference being that the conductive path is to the primary side liquid cold plate rather than to the side-rail of the card cage. A secondary side cold plate used in this manner can not only couple to the primary side at the top and bottom of the plate, but also have thermal transfer through posts or some other shape of metal or heatpipe going through the PWB and making contact with the primary side plate.

A second method that can be used for the secondary side cold plate is to have liquid also flowing through it. While the complexity of the design does increase, this will increase the heat-carrying capacity of the secondary side. As with the majority of standards covering the mechanical aspects of the system, REDI does not specify how to do things such as this. It only strives to allow for them to be done in a reasonable way using foreseeable and cost-efficient techniques.

The module made up of these cold plates and PWB is done in such a way as to adhere to the standard 6U or 3U x 160mm formats used in many areas of the COTS market. To achieve this, QDs are located within the envelope of this module outline, adjacent to the backplane connectors. These dimensions and details are shown in Figures 11 and 12.

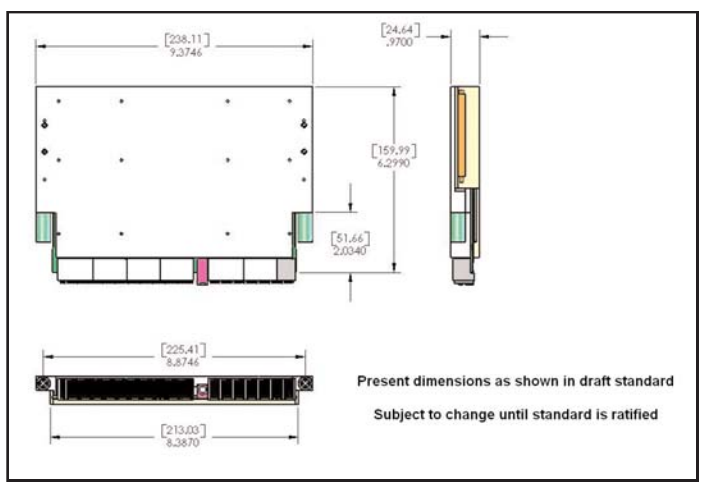

Figure 11. REDI 6U liquid-module envelope

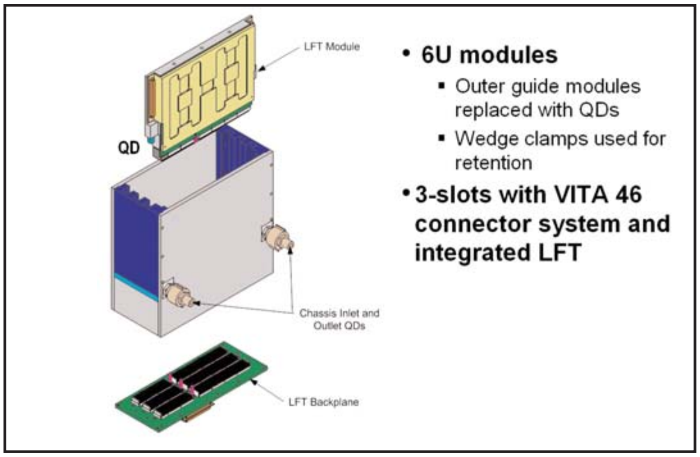

Figure 12. Liquid module and card cage

Captured in the REDI standard are all the details related to this QD interface, because location, alignment, and tolerances are critical to achieving the performance of this interface as required by deployed military platforms. [Ref 8]

The working group is carefully addressing these critical areas through analysis and prototyping:

- Controlling the location of QDs to minimize accumulating tolerances.
- Limiting the amount of float required in the QDs so that connectors can mate without issues.
- Duplicating the guiding function in the QD assembly while at the same time providing enough float.
- Insertion features that won't allow the connectors to be "overwhelmed" and subsequently damaged.
- Cost issues: Care not to over-specify tolerances on piece parts.
- Interchangeability: Tolerances need to be controlled to assure mix and match over production runs.

Examples of available QDs are shown in Figure 13.

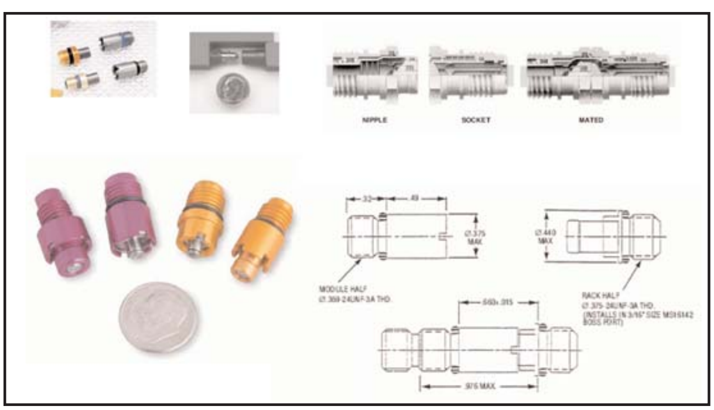

Figure 13. Typical liquid quick-disconnects

LIQUID COOLING – THE REST OF THE SOLUTION

Often there is surprise when one looks at the rest of the solution for liquid cooling and its required infrastructure at the system level. Many times these surprises come in two areas:

- Lack of understanding about the nature of the system to which the heat from the previously described modules and card cages are move into, and its path to being dissipated to the external environment at some point. Or, in other words, the basic thermodynamics are still in play for a liquid-cooling system, thus the heat being removed from the electronics is ultimately dissipated from the platform into the surrounding atmosphere at some point.
- Total size, weight, and power (SWaP) allocations that are typically given to the total processing system being wholly or partly provided by the COTS supplier. In other words, the processing system's size, weight, and input power allocations are often inclusive of the cooling apparatus. This is often not clearly communicated or appreciated.

This section seeks to provide a basic grounding in these areas to reduce or remove this element of surprise.

Figure 14 shows a general diagram of a closed-loop, liquid-cooling system. The zones of "SWaP surprise" are shown to be:

1. Air-to-liquid heat exchanger

2. Liquid reservoir

3. Pump (and associated piping, valves, and closed-loop control)

All of these have size and weight associated with them, often in surprising amounts. Pumping infrastructures including the closed-loop control also can have a non-trivial power input requirement.

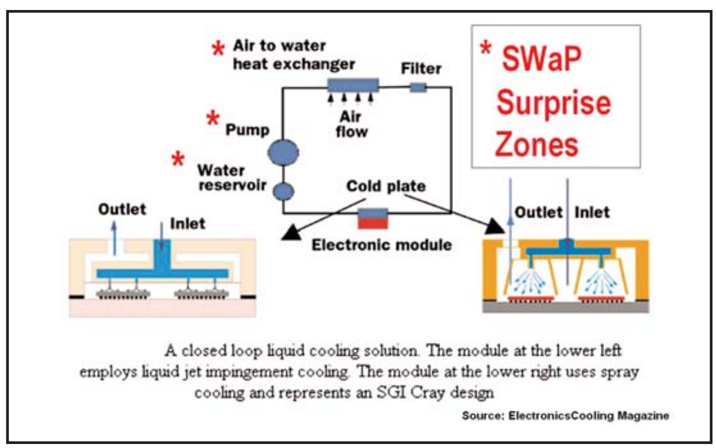

Figure 14. SWaP surprise zones

An example of a self-contained system from Parker Hannifin is shown in Figure 15. Parker Hannifin calls this a "heat rejection unit" (HRU) [Ref 9], which is of the general class known as environmental control units (ECUs). This HRU, like ECUs in general, connects to the liquid inlet and outlet of the liquid-cooled card cage. It circulates liquid at the appropriate volume and pressure to remove the heat load at the rate required to keep the electronics within their specifications. The HRU-1000 is compatible with a number of liquids:

- Polyalphaolefin (PAO) per MIL-PRF-87252C or NATO S-1748
- Ethylene glycol/water (EGW) mixture
- Propylene glycol/water (PGW) mixture
- 3M Fluorinert™ fluids FC-77, FC-104, FC-75

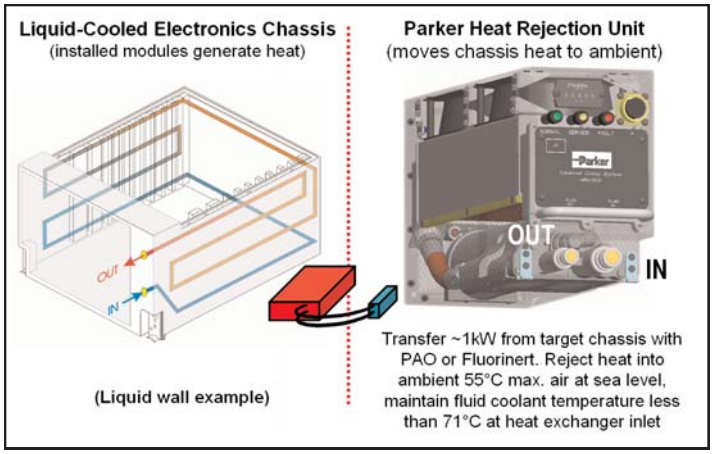

Figure 15. Liquid chassis and Parker Hannifin HRU-1000

Each of these has very different thermal and environmental properties that the system design must take into account. They also have MSDS (Material Safety Data Sheets) that the design and maintenance provider must be aware of.

This is a useful example, because it is a self-contained unit including the heat exchanger, pump, reservoir, and associated control circuitry. This unit is a ½ ATR (Air Transport Rack) short size, similar in size to a Size 14 men's shoebox. It measures 7.62" H x 4.88" W x 15.19" L - 565 cubic inches. It weighs 23 pounds (with some configuration dependencies), with an input power of 28VDC at 200W maximum.

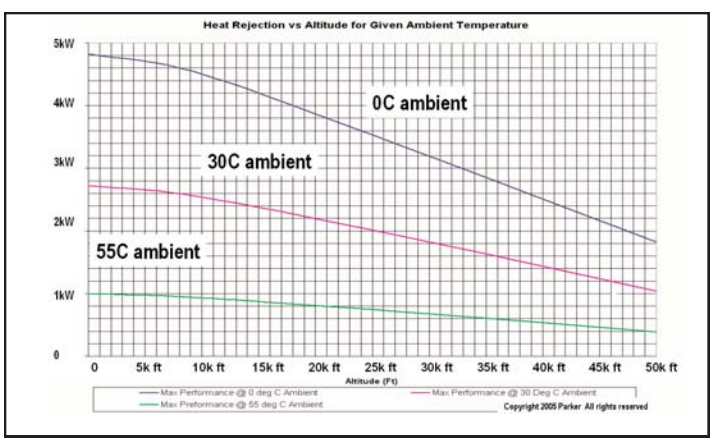

Figure 16. HRU-1000 performance curves for PAO

As shown by its performance curves in Figure 16, it is specified to include deployed military-like temperatures and altitudes. Furthermore, it is built to comply with the shock and vibration specifications one would expect in those applications, thus its weight accounts for the needed structure. The performance curves shown are for PAO. For EGW mixture, the heat rejection performance is 1.9x that shown. [Ref 10]

To further quantify this in SWaP terms, this unit can be viewed as managing 950W in a surrounding air temperature of 55°C at a concurrent altitude of 10K feet – a common specification. This would yield 41W/lb and 1.7W/cu.in of thermal management capacity.

If the altitude requirement was 40K feet at a 55°C ambient, still a common requirement in a semi-closed electronics bay, the heat rejection performance is reduced to approximately 550W. This would yield 24W/lb and 1W/cu.in of thermal-management capacity, a significant decrease from the 55°C, 10K feet case.

This type of degradation is not specific to the Parker Hannifin HRU, but, in general, the case for any heat exchanger design. While specific degradation at altitude will vary from design to design, from this it is easy to see that taking altitude into account for heat exchanger performance is critical. Also, the choice of liquid used and the requirements on maximum temperature rise of liquid can have positive or negative effects on performance.

As also shown by these performance curves, if the system designer can take advantage of lower operating temperatures – which are sometimes available in flying platforms – there can be a significant increase in thermal management capacity.

Recalling that the REDI standard is targeting liquid cooling for modules in the 500W range, one can see how this infrastructure can add up, given a collection of these modules in a card cage.

Another vendor - Meggitt Defense Systems, Western Design - also provides excellent examples of several ECUs developed for deployed military platforms. One of several solutions they have is shown in Figure 17.

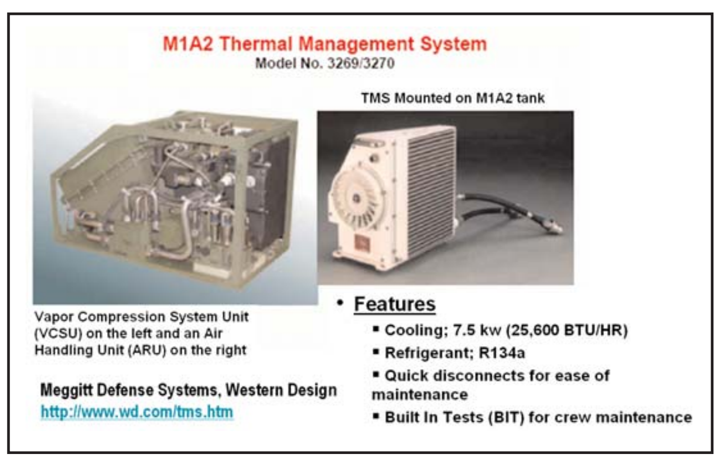

Figure 17. Meggitt Defense Systems C-130 TMS

These examples are shown and references made so the reader has pointers to real examples of the size, weight, and power required while managing the heat rejection from liquid-cooled electronics.

None of this overview is meant to at all question the use of liquid cooling in the appropriate situations – recall its use has a long history in the military – and its time has come for COTS solutions. However, this short overview has been intended to alert module, chassis, and system designers to make sure to analyze and size the whole system in an effort to mitigate the element of surprise early in the design cycle.

The final example of this liquid-cooling infrastructure is the ultimate – the liquid-cooling infrastructure is integrated directly into the platform. In this case, it's into a next-generation fighter aircraft. Shown in Figure 18 is the F/A-22. The F-35 Joint Strike Fighter (JSF) is another example. Some numbers of older fighter aircraft are also receiving various upgrades to include more liquid cooling in the processing sections. At this writing, the public information regarding this is unclear, thus nothing further is included here.

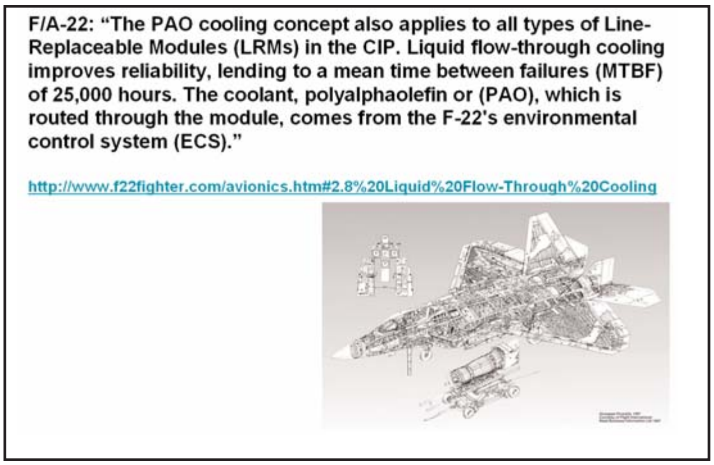

Figure 18. Platform-integrated "plumbing" - F/A-22 fighter aircraft

REDI STATUS

At this writing, the REDI standard is in draft form and being finalized in the VSO working groups. Below is the present structuring of the draft standard and its status.

The VITA 48 REDI standard is structured into four elements:

- 48.0 - Mechanical Specifications for Microcomputers Using Ruggedized Enhanced Design Implementation (REDI)
- 48.1 - Mechanical Specifications for Microcomputers REDI Air Cooling Applied to VITA 46
- 48.2 - Mechanical Specifications for Microcomputers REDI Conduction Cooling Applied to VITA 46
- 48.3 - Mechanical Specifications for Microcomputers REDI Liquid Cooling Applied to VITA 46

VITA 48.0, .1, and .2 have been through initial working group balloting and comments are being folded back into the drafts. The VITA 48.3 draft is in review and preparing to go to first working group ballot. It is expected that these all will be approved in accordance with the VSO procedures in 1H 2006.

In parallel with this activity, non-operational proof-of-concept designs were developed to enable hands-on mechanical form and fit review for feedback into the standard ahead of its approval.

January 2005 saw the first introduction of the air- and conduction-cooled proof-of-concept chassis and modules. This is shown in Figure 19.

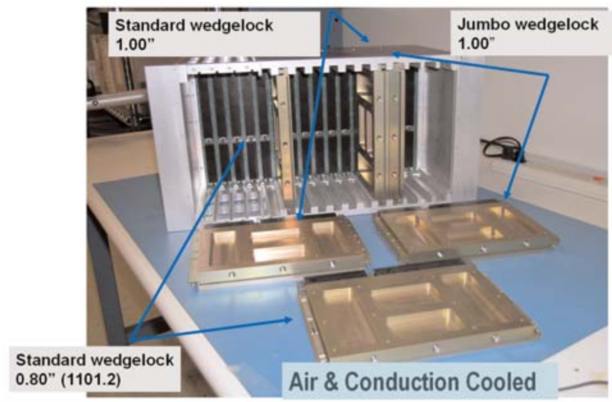

Figure 19. VITA 48 air- and conduction-cooled proof-of-concept

May 2005 saw the first introduction of a liquid-cooled proof-of-concept. This is a three-slot card cage with representative liquid-cooled modules. This is shown in Figure 20.

In the second half of 2005, these non-operational versions evolved into operational proof-of-concept vehicles. Thermal load cards with programmable heat sources with monitoring via a LabVIEW interface were constructed for all cooling methods. In particular, the liquid-cooling proof-of-concept design shown at the November VITA face-to-face meeting has an HRU-1000 attached to the card cage, liquid flowing through modules, and the ability to control and monitor the amount of heat load being removed using this new standardized method of construction.

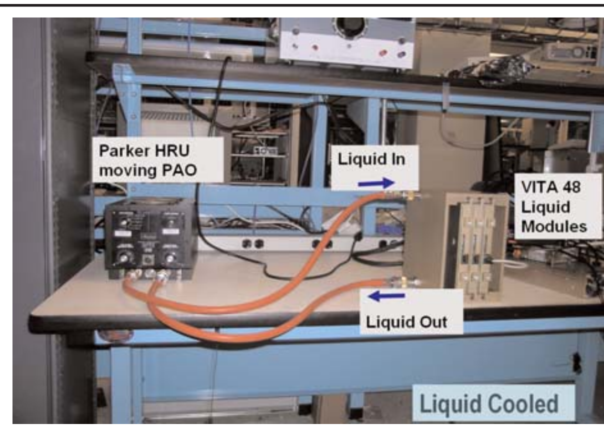

Figure 20. VITA 48 Liquid-cooled proof-of-concept

CONCLUSION

In this paper, we have observed that many deployed military systems and applications have a need to achieve high compute and bandwidth density in the smallest possible physical size, weight, and power input while using COTS electronics. In addition, deployed military applications continue to have extended environmental requirements such as higher levels of shock, vibration, temperature, and altitude.

This paper has described a unified approach to gaining not only enhanced thermal performance in VITA standards-based modules, but also enhancements to increase available board space and volume, structural ruggedness, and support for 2LM – the latter being an important theme for reducing the TCO of these COTS-based military systems.

In addition, the inclusion of a standardized method of liquid cooling for COTS modules has been disclosed. Details have been shown that convey the working group's attention to detail and guiding principals that revolve around creation of a standard that can in fact be implemented - and standardized in a way that allows the designer freedom of flexibility as to their implementation.

This activity is under the auspices of the VITA Standards Organization (VSO) and specifically managed in the VITA 48 "Ruggedized Enhanced Design Implementation" (REDI) working group.

ACKNOWLEDGEMENTS

The authors would like to acknowledge several individuals key to the preparation of this paper, the creation of the VITA 48 REDI draft standards, and engineering assessment of the underlying design and implementation trade-space:

Mike Gust, Manager, Mechanical Engineering, Mercury Computer Systems, Inc.

(Draft editor – VITA 48 REDI)

Paul Zuidema, Principal Mechanical Engineer, Mercury Computer Systems, Inc.

The VSO and the sponsors, chairs, editors, and participants in these standards formation activities

REFERENCES

Ref 1: Blanchet, Don W., "Utilizing Advanced Thermal Management for the Optimization of System Compute and Bandwidth Density," DesignCon East 2004, http://www.iec.org/events/2005/designcon_east/conference/2004/4ta2.html.

Ref 2: VITA Standards Organization (VSO), http://www.vita.com/vso-stds.html.

Ref 3: Banton, Randy, Jaenicke, Richard, "New Cooling Infrastructures for Deployed Military Environments," VMEbus Systems, August 2004, http://www.mc.com/literature/literature_files/VMEbusSys_ManagedAir8-04.pdf.

Ref 4: Zuo, Dr. Jon, "Integrated Thermal Architecture for Thermal Management of High Power Electronics," Intel Technology Symposium, September 2001.

Ref 5: Robles, James A., "Reflections on COTS in Avionics/Vetronics," MEECC, May 12, 2005, http://www.meecc.com/presentations/robles.pdf .

Ref 6: Robles, James, Straznicky, Ivan, "A System Level View of Avionics/Vetronics Cooling Options for Harsh Environment Two-Level Maintenance Systems," 20th IEEE SEMI-THERM Symposium, March 9, 2004.

Ref 7: Whitenack, Kathryn, "Cold Plate Analysis," MEECC, May 17, 2005, http://www.meecc.com/presentations/Whitenack-cold-plate.pdf.

Ref 8: Robles, James; L-8265-JAR00-004, Rev A, "A Report on a Quick Disconnect Designed Experiment," The Boeing Company, September 21, 2000.

Ref 9: Parker Hannifin, "Rugged Computer Cooling HRU-1000," http://www.parker.com/advancedcooling/parkerHRU1000.pdf.

Ref 10: Parker Hannifin, "Advanced Heat Rejection Unit for Electronics Datasheet," http://www.parker.com/advancedcooling/20050609ParkerHRU1000.pdf.

447-01E-0106-v48_wp

Mercury Computer Systems, Inc.

Challenges Drive Innovation™

Corporate Headquarters
199 Riverneck Road
Chelmsford, MA 01824-2820 USA
+1 (978) 967-1401 • +1 (866) 627-6951
Fax +1 (978) 256-3599
www.mc.com

Worldwide Locations
Mercury Computer Systems has R&D, support and sales locations in France, Germany, Japan, the United Kingdom and the United States.

For office locations and contact information, please call the corporate headquarters or visit our Web site at **www.mc.com**.